The Northern Eurasia Earth Science Partnership Initiative (NEESPI) Executive Overview (*December 2004)*

<u>Version 2.1</u>

Preface

The following overview of the NEESPI Science Plan is intended to provide a concise summary of the NEESPI rationale, the science priorities and general strategies for conducting a large-scale, integrated, regional program of research focusing on the area of Northern Eurasia as it exists in its current phase of development.

Version 2.1 of the full NEESPI Science Plan has been completed after two major Science Plan workshops held in Russia and the Ukraine during 2003, which also included an independent science panel review of a first draft science plan. Responses to the review panel suggestions as well as to additional agreements with the Russian leadership concerning the form and content of the Science Plan have been incorporated into the Science Plan*. However, being a project open to other national and international agencies, the present NEESPI Science Plan has been drafted to be sufficiently flexible to accommodate needs and incorporate contributions from other sides who may express their interest to participate in the Initiative. As such, the NEESPI Science Plan and this overview can be considered to be only preliminary.*

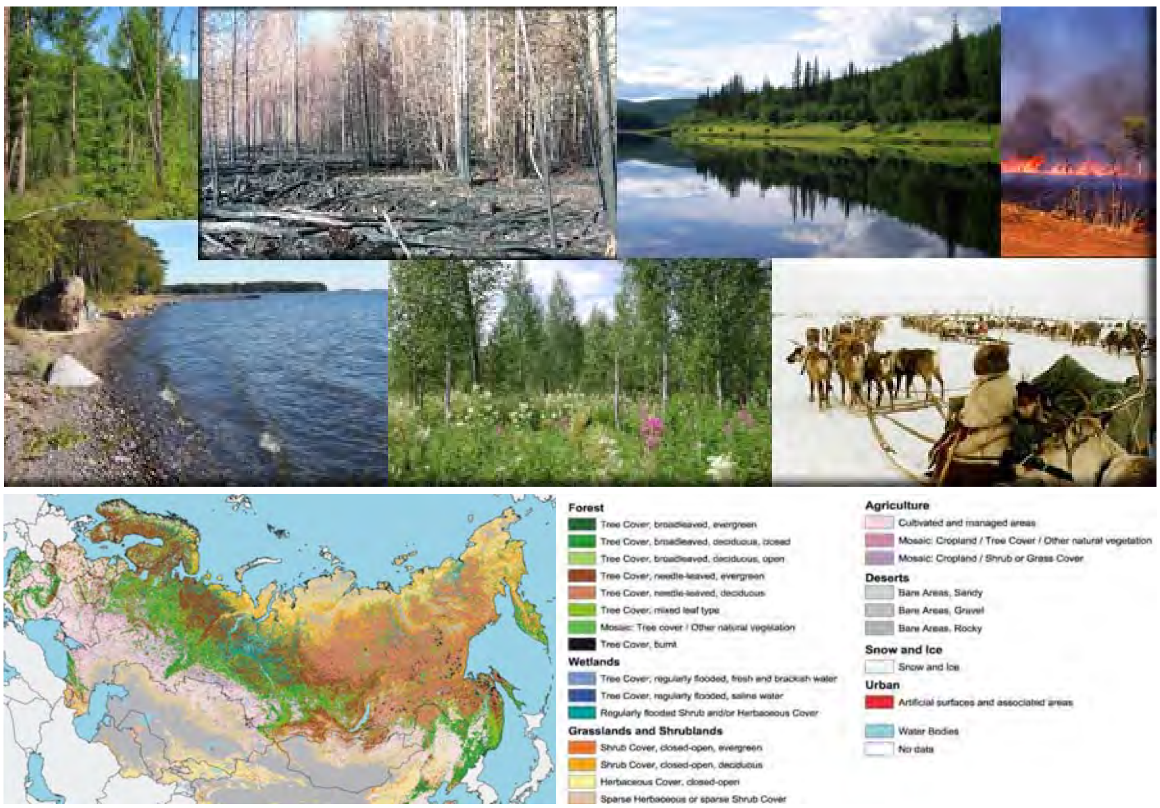
This overview is an attempt to represent the key elements of the Science Plan as can be elaborated at the time of this writing of the overview document in December 2004. The focus of this document is the scientific rationale and science questions. It is hoped that distribution of this overview document can yield additional feedback into the programmatic priorities of interested government agencies and international science programs such that possible adjustment can be made to better reflect those priorities and lead to eventual sponsorship of some elements of the research of the NEESPI. At its full maturity, the NEESPI is intended to be a broad-based international program in scientific participation, project sponsorship, and organizational leadership. It will draw upon and complement existing and planned national and international research programs with the goal of developing a multi-disciplinary, integrated understanding of this important region of the globe and how it relates to the functioning of the global Earth system.

Additional details about the NEESPI can be found at the NEESPI Web site at http://neespi.org/. The full NEESPI Science Plan, an updated Executive Overview of the Science Plan and associated documents and information will be posted on the Web site as they are completed.

The NEESPI Science Plan Development Team

1. INTRODUCTION

Northern Eurasia embodies 19% of the Earth's land surface and 59% of the terrestrial land cover north of 40°N. It is a diverse region. Although covered by tundra in the North and semi-deserts and deserts in the South, Northern Eurasia contains a substantial fraction of the Earth's boreal forests (about 70%) and more than two-thirds of the Earth's land that is underlain by permanent soil ice or permafrost. Thus, Northern Eurasia must be regarded as a key region for studying global change processes for these two biomes and their interactions with the Global Earth System.



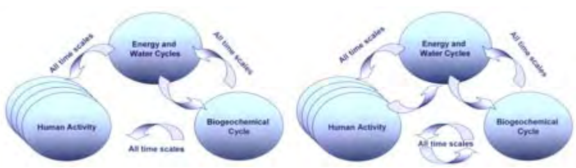
NEESPI study area includes Former Soviet Union, Northern China, Mongolia, Fennoscandia, Eastern Europe and the coastal zone of these countries. Inserted map shows land cover for the region. Source: European Commission, Joint Research Center (Bartalev et al. 2003; Bartholomé and Belward 2005).

Over the past 5,000 years, climatic changes in Northern Eurasia were among the most dramatic in the world. Surface air temperature increases reported by instrumental observations during the past century were the greatest for the interior parts of Northern Eurasia; and model simulations of future climate changes show that this region will have the most substantial changes in the future. Current evidence strongly suggests significant and rapid changes in the atmosphere, hydrosphere, cryosphere, and land cover in Northern Eurasia, but it is important to accurately quantify these changes and the particular processes that caused them. Taking into account the geographic scale and rate of change, the current lack of process understanding must be viewed as unacceptable. It is critical to develop the ability to measure, monitor, and model the processes that will provide accurate future projections of climatic and environmental changes in this region because these changes have the potential to impact the Global Earth System and the human society.

The functioning of the Global Earth System can be considered as an interaction of three major types of processes (cycles):

- Biogeochemical Cycles, which affect the composition of the atmosphere and ocean, the formation of soils, and the evolution of biomes.
- Energy and Water Cycles, which affect the transfer of energy, water, aerosols, and trace gases between the atmosphere, land surface, hydrosphere, and cryosphere.
- Human Activity, which began to strongly affect the planetary system on the regional level with the establishment of the first agricultural civilizations, now includes effects on the Global Earth System.

Studying any one of these cycles or activities often requires analyses of its interaction with the other two and of the transitional (non-equilibrium) character of these interactions.



Pre-industrial (up to circa mid 19th century) and present interactions in the Earth Global System.

The science plan is focused on surface and near-surface processes in the Northern Eurasian region and addresses the overarching theme of the Northern Eurasia Earth System Partnership Initiative (NEESPI), which is **Terrestrial Ecosystem Dynamics and its Interactions with the Global Earth System.** This executive overview first presents the overarching NEESPI science questions and elaborates on the science themes through developing science questions relevant to each of the topical areas. Next follows a brief discussion of the unique and important aspects of the study region that warrant the focus of research attention here. The final major section looks at process studies, modeling, remote sensing and other "tools" needed to address these science questions and outlines elements of the proposed research strategy, which also includes an education component in anticipation that a considerable network of students will gain expertise in this area while working on the Initiative. We conclude by outlining the next decade's goals for the NEESPI.

2. SCIENCE THEMES AND KEY SCIENCE QUESTIONS

The major scientific areas, or science themes, to be addressed in the NEESPI include terrestrial ecosystem dynamics, biogeochemical cycles, surface energy and water cycles, land use interactions: societal-ecosystem linkages, ecosystems and climate interactions, and topics of special interest, which include cold land region processes, coastal zone processes, and atmospheric aerosol and pollution.

The overarching NEESPI science question is:

How do Northern Eurasia's terrestrial ecosystems dynamics interact with and alter the biosphere, atmosphere, hydrosphere, and cryosphere of the Earth?

This question can be reformulated in a pragmatic way as:

How do we develop our predictive capability of terrestrial ecosystems dynamics over Northern Eurasia for the 21st century to support global projections as well as informed decision making and numerous practical applications in the region?

While seemingly different, the two questions converge because, to answer them, the same scientific investigations are required. Specifically, the following questions must be addressed:

- How does the Northern Eurasia ecosystem function and how and why has it been changing during the past centuries?
- What are the linkages between the Northern Eurasia ecosystem, atmosphere, and the World Ocean?

- What has been the role of anthropogenic impacts on producing the current status of the ecosystem, both through local land use/land cover modifications and through global gas and aerosol inputs? What are the hemispheric scale interactions, and what are the regional and local effects?
- How will future human actions affect the Northern Eurasia ecosystems? And, how will changes in these ecosystems feed back to society? How can we describe these processes using a suite of local, regional, and global models?
- What will be the consequences of global changes for the regional environment, the economy, and the quality of life in Northern Eurasia? How can science contribute to decision making on *environmental issues* in the region?

> NEESPI studies will secure improved interpretation of current and future remote sensing information in Northern Eurasia and provide the bridge between this information and historical in-situ observations.

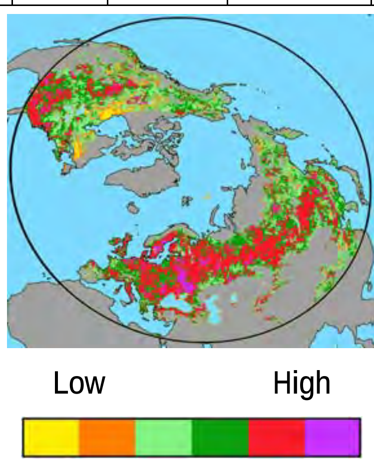
Information on the status and dynamics of terrestrial ecosystems, the understanding of the main driving forces, and prediction of the future consequences are essential for global change science, implementation of environmental treaties, development programs, natural resource management, environmental protection, and human health and well-being. Therefore, we need to establish (restore, develop, utilize) a modern observational system capable to retrieve and properly interpret information about the current state and changes of the environment of Northern Eurasia. Thereafter, we need to develop ecosystem level and regional input (data flux, model blocks, and missing parameter values) to contemporary Regional and Global Earth System models, thus merging terrestrial ecosystems dynamics studies in the region with the global change science. Other NEESPI science questions related to the key science themes are presented and discussed below.

Biogeochemical Cycles

- What are the current geographical and temporal distributions of the major stores and fluxes of carbon and other elements in Northern Eurasia?
- What are the major drivers and feedback mechanisms that control the dynamics of the biogeochemical cycles at local, regional, and continental scales?
- What are the likely future dynamics of biogeochemical cycles that are important to the functioning of the Earth system and the human society?
- What points of intervention and windows of opportunity exist for society to manage biogeochemical cycles in order to mitigate adverse consequences?

Understanding the role and projecting the future dynamics of biogeochemical cycles in Northern Eurasia is critically important for comprehensive, *policy-relevant* knowledge of the global carbon cycle, and for welfare of the populations inhabiting the region. Proposed *diagnostic* analyses include distributed terrestrial measurements, detailed description of the properties and dynamics of individual landscapes and ecosystems, monitoring of disturbance regimes, and studies of hydrologic transfers of carbon and other elements and their sequestration in sediments. These activities will be organized into process-based models, inversion and tracer transport models, and data assimilation schemes; all three supported by interdisciplinary intensive field campaigns. Proposed *process-oriented research* activities will be based on process-oriented models at a regional scale, which would accumulate and explicitly use knowledge on individual landscapes, land use systems, and ecosystems and include studies of responses and feedbacks of terrestrial biogeochemistry to internally-caused perturbations and external forcing. Modeling is the only viable approach to generate predictive capabilities of biogeochemical cycles. Research related to *management of biogeochemical cycles* will include analyses of economics, land use, and energy policy options for this management, analyses of vulnerability of carbon pools, development of scenarios for incorporation into global Earth models, assessment of sequestration options, and development of anticipatory strategies of adaptation of the NEESPI region's terrestrial ecosystems to environmental changes.

Forest	Area 10^6 ha	Soil Carbon Pg	Plant Biomass Carbon, Pg	Total Carbon, Pg
Boreal	1509	624	51	675
Tropical	1756	216	159	375
Temperate	1040	100	21	121

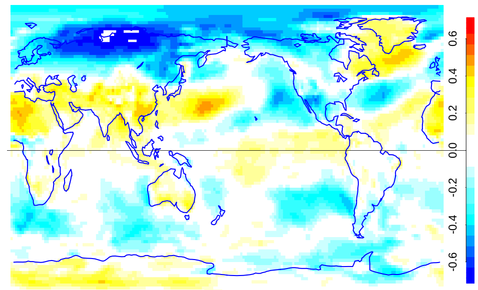


Persistence of greening

NASA's data on spatial patterns in persistence of normalized difference vegetation index (NDVI) increase: 1981-1999 (Zhou et al 2003). According to the interpretation of NDVI data by Myneni et al (2001), boreal forest might provide the net sink of 0.68 $\pm$ 0.34 Gt of C yr^{-1} of which nearly 70% is in Northern Eurasia.

Surface Energy and Water Cycles

- What is the relative importance of the major drivers and feedback mechanisms that control the variability and changes of the surface energy and water cycles at local, regional, and continental scales?
- What are the details of surface energy and water cycle dynamics in Northern Eurasia, and how do they improve our understanding of how this region interacts with global cycles?



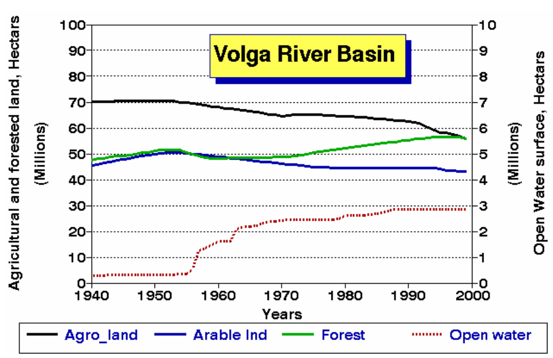
Correlations of the surface air temperature data with northern hemispheric meridional temperature gradient (zone 0-30ºN minus zone 60º-90ºN) for the winter season (Gershunov 2003). The gradient defines the intensity of zonal circulation in the extratropics.

Priorities in surface energy and water cycle studies were set according to two criteria. ***First, attention must be paid to the processes that directly feed back to the global Earth system.*** This justifies the interest of the international community in environmental changes in Northern Eurasia. These processes (listed in Section 3 of this Overview) are also very important on regional and larger scales. In most cases, the feedbacks to the Global Earth System are only feeble manifestations of enormous changes within the subcontinent that "spill out" across the regional borders. Furthermore, by affecting the Global Earth System, they, by definition, affect Northern Eurasia. The fundamental study of land-atmosphere exchange in this region incorporates the need to evaluate the natural dynamics in contrast to large scale land use changes affecting the land-atmosphere exchanges. ***Second, the processes of major societal importance must be addressed.*** They may or may not affect the Global Earth System, but for the region's population, they are of pivotal importance. These include extreme weather events, water supply, thaw of permafrost, desertification, and impacts on agriculture and air and water quality. Major deficiencies in surface energy and water cycle knowledge and observing systems will be addressed by (a) using modern tools of environmental monitoring, (b) integration the results from historical data sets, present observational systems, and process studies into a unified knowledge base, (c) development of an interactive suite of the land surface models that can account for major land surface process dynamics in Northern Eurasia and interactively feed back to regional and global climate, environmental, and economic models, and (d) performing all necessary studies to make this suite of models a viable working tool.

Land Use Interactions: Societal-Ecosystem Linkages

The central set of land use and society, or "societal feedback," questions to be addressed in the NEESPI are:

- What land use changes are taking place in Northern Eurasia and what are their impacts on the environment and society?



Land use dynamics over the Volga River Basin during the past 60 years (Golubev et al. 2003, updated).

- What lessons can be learned from the responses to dramatic land-use modifications during the "planned" economy period for future sustainable natural resource management?

The Aral Sea from an "in-situ" observation.

- What will be the consequences of socio-economic changes in Northern Eurasia on the environment?
- How can science contribute to development of environmental and economic strategies for society (societies)?

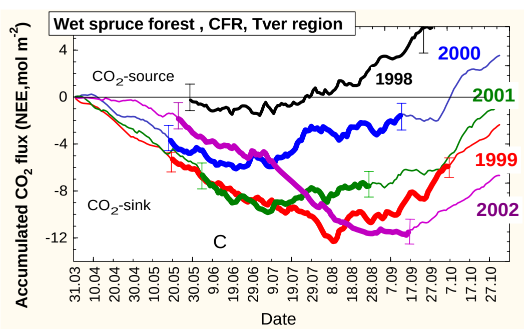
The vast regions of Northern Eurasia and the broad range of lands, ecosystems, and peoples that characterize them – have undergone major fundamental changes resulting from the unprecedented and dramatic transformations of the social, economic, political, environmental, and technological systems in the countries of the region. The changes in land use have altered a number of ecosystem processes (including carbon and water dynamics, greenhouse gas emissions, biodiversity) and land-atmosphere interactions. Current understanding of the linkages and changes in the coupled human, environmental, and climatic systems associated with land sustainability in the region is inadequate. The development of NEESPI research studies related to this topic will focus on: human health and well-being, impact of fires and pollution on humans and ecosystems, biodiversity, agricultural and forestry productivity, water management and quality, and natural hazards. Advances in studies addressing these issues, will provide a direct support to the informed decision making and numerous practical applications in the region. Much of this region is continuing to undergo transformation on a large scale and thus the timing of NEESPI is at the same time both critical and potentially highly rewarding.

Ecosystems and Climate Interactions

Northern Eurasia is one of the regions where ecosystem and climate interactions play a critical role, and a topical question for the NEESPI is:

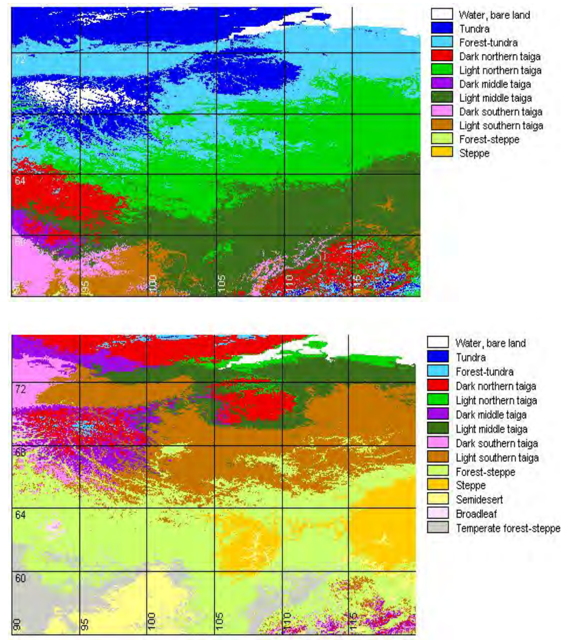
- How do we account for the synergy of feedbacks among major processes within the regional terrestrial ecosystems, climate, cryosphere, and hydrosphere of Northern Eurasia and their interactions with society?

An extensive overview of studies in Northern Eurasia shows that a combination of factors, conditions, and links makes it very difficult to answer the question about even the sign, let alone the magnitude of the terrestrial ecosystems - climate interactions that are loosely named “biogeochemical and biogeophysical feedbacks”. Understanding these feedbacks and their description within a viable blend of models is essential for predicting their future behavior. The main attention should be focused on the most vulnerable ecosystems, “hot” positive feedbacks, or feedbacks which, when initiated, may cause run-away processes in the Earth system, and the key regions. In particular, larger changes in ecosystem-climate interactions across North Eurasia should be expected in the taiga (watch for hydrology-vegetation feedbacks), in the coastal zone (watch for permafrost thaw-greenhouse gases release feedbacks), and at borders of major vegetation zones like forest-tundra (watch for albedo-vegetation feedbacks), forest-steppe (watch for albedo-vegetation and hydrology-vegetation feedbacks), steppe-desert (watch for desertification processes), and in mountains.



Net Ecosystem Exchange (NEE) for 1998-2002 [positive CO_2 flux stands for source to the atmosphere; archive of the Eurosiberian Carbonflux Project]. Sign of annual NEE depends upon weather conditions.

It is concluded that for a reliable regional pattern of environmental changes in Northern Eurasia, which is prone to very strong ecosystem variability and powerful feedbacks, the simultaneous interactive models’ runs should be conducted[1]. Thus, a synergetic approach and knowing all substantial climate-ecosystem interactions in Northern Eurasia are a prerequisite to the future projections and/or scenario simulations for the region and for the globe.



Major ecosystems distribution in central and eastern Siberia (top) in the current climate and (bottom) the warmed climate that would be by 2090 derived from the HADCM3GGa1 run (Tchebakova et al. 2003). According to this scenario, the tundra and forest-tundra zones (currently ~ one third of the area) practically disappear while taiga zones (currently about two thirds of Siberia) move northward and reduce to ~40% of the area.

Topics of Special Interest

Cold Regions, Coastal Zone, and Atmospheric Aerosols and Pollution were identified as cross-cutting topics of special interest with the following topical scientific question for each of them:

- How do their changes (or changes in these regions and/or zone) affect regional and global biogeochemical, surface energy and water cycles, and human society?

Cold land region processes. The changing properties of permafrost and glaciers play an important role in driving the ecosystem balance and

[1] Otherwise (e.g., in the GCM simulation of the greenhouse gases increase scenario), large-scale changes in land cover would generate additional regional forcing (actually, biogeophysical feedbacks), and, thus, compromising the GCM run assumptions. Furthermore, the changes in biomass, soil and wetlands carbon, and permafrost thawing (that inevitably must accompany such changes) would generate additional and substantial forcings (actually, both biogeophysical *and* biogeochemical feedbacks) on both the GCM forcing *and* the greenhouse scenario itself.

effecting the carbon, energy, and water cycles in the Cold Land Regions. Presence of large amounts of ice on and below the ground surface makes northern and high elevation ecosystems and infrastructure very vulnerable to present and future climate warming.

The stability of the ecosystems in the Cold Land Regions relies on the stability of ice that, so far, holds these systems together. In losing the glacier ice and permafrost, we are losing the stability of the systems.

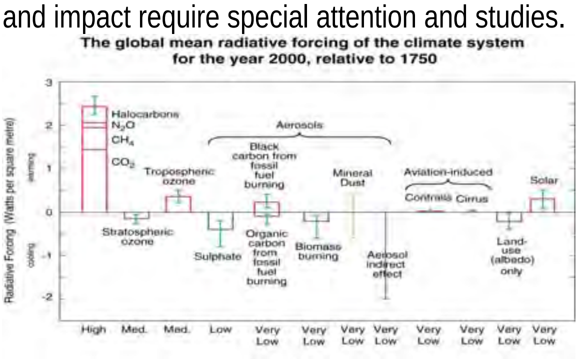
The major threshold occurs when permafrost starts to thaw from its top down and when glaciers start to retreat intensively. At this point, many processes (some of them very destructive) will be triggered or intensified. Even if some ecosystems and infrastructure could avoid complete disintegration, their characteristics will be changed dramatically. Therefore, coordinated efforts are urgently needed to (a) establish and support comprehensive permafrost and glaciers monitoring systems; (b) build reliable models accounting for changes in land ice and its interactions with terrestrial ecosystems, hydrology, atmosphere, and society in the framework of integrated change assessment; and (c) develop mitigation strategies for the regions negatively affected by the permafrost thaw and glaciers retreat.

(Top) Present boreal forest over permafrost and (bottom) two scenarios of its changes when permafrost will thaw: wetlands (under poor drainage conditions) and steppe.

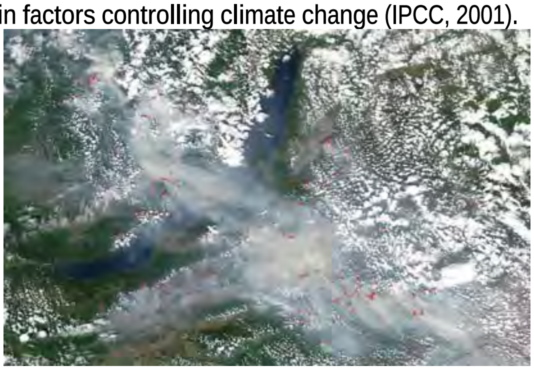
Coastal zone. Several areas of concentrated economic development, large populations, and intensive present and future coastal zone changes require special attention because of *the extreme risk of degradation in the coming decades*. The major issues are: possible intensified erosion of coastal escarpments and depositional bodies, degradation of unique natural coastal and marine ecosystems, damage to local and regional infrastructure affecting quality of life, and change of bottom topography due to coastal and bottom erosion of permafrost rocks that may be significant for future use of the Northern Sea Route and the global biogeochemical cycle. Reasonable, regionally oriented strategies of development in the coastal zone should be introduced. In particular, balances should be found between environmentally sound future development, the necessity to preserve unique ecosystems, and economically advantageous further development.

Top. Endangered oil tanks at the coast of Pechora Sea (20 years ago they were 60 m from the coast; Ogorodov 2003). Bottom. Phytoplankton distribution in Dnepr Estuary demonstrates eutrophication processes in the area. Landsat7. August 10, 1999 (Bands ETM+: 3,2,1)

Atmospheric Aerosols and Pollution. In Northern Eurasia, additional aerosol particles and gaseous pollutants come from emissions from fossil fuel combustion and other industrial processes, anthropogenic enhancements of fires, and increases in atmospheric dust due to human-induced land use changes. The direct and indirect effects of aerosol particles on surface energy and water cycles are currently the most uncertain of the known climate forcings. Atmospheric aerosols and gaseous pollutants can affect terrestrial and marine ecosystems and agricultural production, pose a health threat, and cause property damage. Climate change and population development in the 21st century are expected to cause increases in atmospheric aerosol concentrations. *Therefore, there is a clear need for improved knowledge of interactions between changing atmospheric aerosols and the Earth System to increase confidence in our understanding of how and why the climate and environment have changed.* NEESPI will provide a strong scientific underpinning to address this complex problem focusing on Northern Eurasia where pollution levels and several unique features of aerosol production and impact require special attention and studies.



Main factors controlling climate change (IPCC, 2001).



Forest fires and smoke across the Baykal Lake on July 6, 2003 (MODIS image).

Tools: Remote Sensing, Data, Information Technology, and Modeling

Remote Sensing, Data, Information Technology, and Modeling are among the major tools for the NEESPI studies and the topical scientific questions for these areas of endeavor are:

- How can we characterize and improve the accuracy and availability of current remotely sensed data products to meet the needs of the NEESPI science community and resource managers?
- How do we improve the capability of present and future observation systems as well to capture climatic and environmental characteristics and change in the unique conditions of Northern Eurasia?
- How do we reduce the uncertainty of regional and global Earth System modeling related to poor knowledge of major processes and feedbacks in Northern Eurasia?
- How do we secure a societal feedback loop in our models that allows simulation of various scenarios of human activity and, in particular, land use in the region?

3. THE IMPORTANCE OF STUDYING NORTHERN EURASIA

Given that many of the above scientific questions involve the Global Earth System, the question naturally arises as to why we should focus on Northern Eurasia. In brief, the answers are:

- Changes in this region have the potential to affect the global climate and environment and may already be doing so.
- The region has unique features that need to be better understood, parameterized, and accounted for. Without clear understanding of these features, adequate description and modeling of the entire Earth system is not possible.
- The study will have benefits to the societies of the region.

- Northern Eurasia possesses a wealth of scientific talent that can be utilized in this study. It has been studied in detail for more than a century, yet the abundance of data that has been collected (particularly, by Soviet and Russian research projects) has not been utilized enough to study these problems and is in danger of being lost.

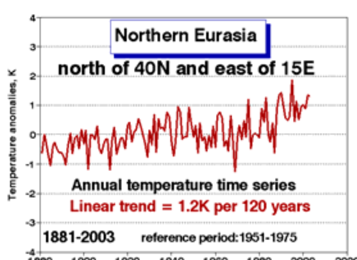
The first two of these points are further elaborated below.

Current and Future Changes and Global Impacts

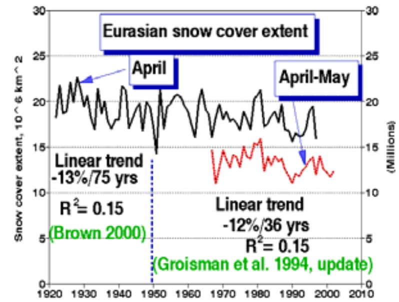
Being the largest land mass in the extratropics, the largest terrestrial reservoir of carbon in the biosphere, one of the regions with the largest observed and predicted climatic variations, and an area of active land use changes during the past century (and possibly in the future), Northern Eurasia has a unique capacity to generate non-linear, large-scale, and sometimes abrupt changes in regional carbon, surface energy, and water balances. These changes may feed back to the global climate, biosphere, and society. Specifically,

- If we are to understand the global carbon cycle and other biogeochemical cycles, we must know how they function in the NEESPI region which holds more than half of the total pool of terrestrial carbon.

- Accelerated climatic changes across Northern Eurasia may cause changes in global atmospheric circulation and meridional heat transfer.



- Changes in surface albedo (snow/ice cover, shifts in vegetation, land use change) and atmospheric humidity may change the Earth' heat and water balances.

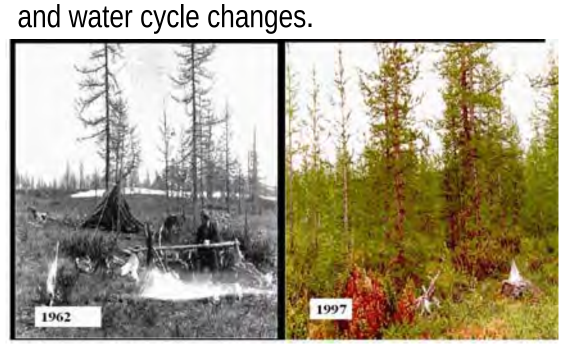


Eurasian snow cover extent in spring (April, April-May; Brown 2000, Groisman et al. 1994, updated).

- About half of the Northern Eurasian terrain has permafrost that controls the hydrosphere and biosphere of the eastern half of the continent. Thawing of permafrost may change the soil carbon cycle and the entire ecosystem above it and, thus, the concentration of greenhouse gases in the atmosphere. It also would produce major changes in land cover and hydrology.

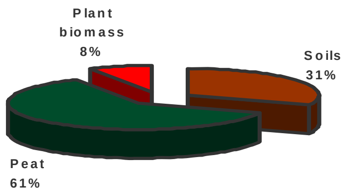
Circumpolar permafrost extent (Brown et al. 1997). Glaciers (dark blue) and areas of continuous, discontinuous, sporadic, isolated, and relict permafrost are shown. Shelf permafrost limit is depicted by the red line.

- Advance/retreat of the forest line, increase/decrease of conditions conducive for forest fires, wind-throw, bogging, and logging may lead to global biogeochemical, energy, and water cycle changes.



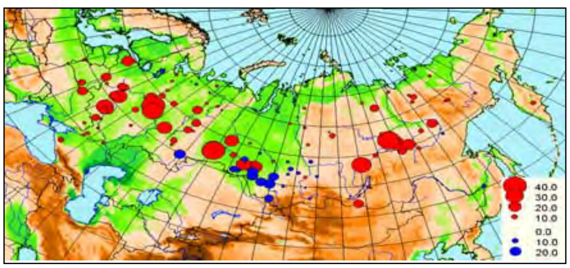
Tree line shift.

- Drying of bogs over expansive areas in West Siberia and the Great Russian Plain may result in their degradation as well as affect the global carbon cycle and runoff formation.



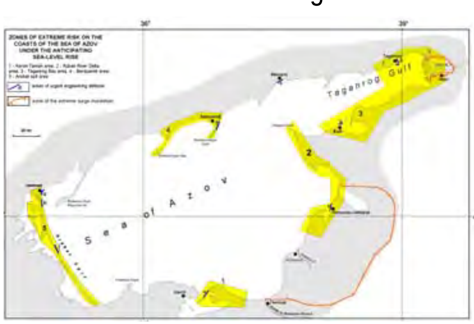
Role of bogs in the carbon storage distribution in boreal ecosystems.

- Changes in the hydrological cycle over the continent control the fresh water transport to the World Ocean and interior lakes. Changes in the fresh water transport to the Arctic Ocean may affect the World Ocean thermohaline circulation.



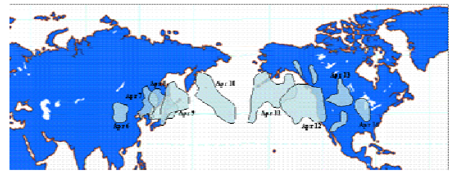
Resent changes in North Eurasian annual runoff. Deviations (%) of runoff for 1978-2000 compared to the long-term mean for ~ previous 55 years. Georgievsky et al. (2002). Runoff increase may affect the World Ocean thermohaline circulation.

- Boundary exchange of fresh water, organic and inorganic matter may affect biochemical processes in the shelf seas and interior lakes. Intensive erosion (currently up to 10 m yr^{-1} in some areas) and other coastal line changes may affect life conditions and cause enormous economic damage.



Sea of Azov coastal zones at extreme risk.

- Ongoing aridization of the continental interior may cause a massive aeolian aerosol input into the troposphere that can affect the Earth's heat balance and generate direct biospheric and societal impacts thousands of kilometers away from the origin of these dust storms.

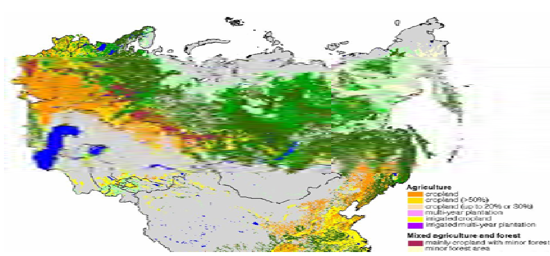


Long-range transport of the dust storm originated over the Gobi desert on April 6th, 2001 (Darmenova et al. 2005).

- Deglaciation in the mountain systems of Central Asia and the Caucasus, increasing water withdrawal, and increasing dryness of steppe and semi-arid zones will affect surface albedo and water resources and their quality of the interior areas of the continent and, thus, the global climate and society.

Example of a central Tien Shan glacier recession. Petrova Glacier in the Akshiyrak area (Kuzmichonok et al. 2004).

- Human activity has changed ecosystem types over most of the steppe and forest-steppe zones and over part of the forest zone causing numerous biogeochemical and biogeophysical feedbacks, near-global environmental changes, and affecting environmental health and quality of life.

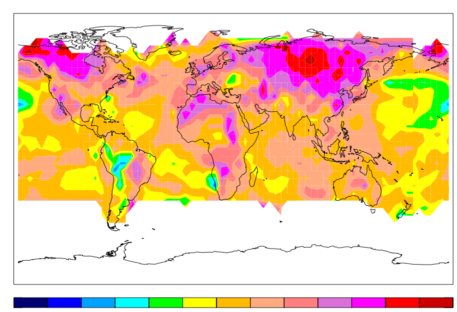


Cropland (orange areas) occupies currently more than 90% of steppe and forest-steppe zones of Northern Eurasia (Fischer et al. 2001b).

Unique Features

Northern Eurasia is the largest contiguous land region in the extratropics. Several unique features of this part of the world are predefined by its location:

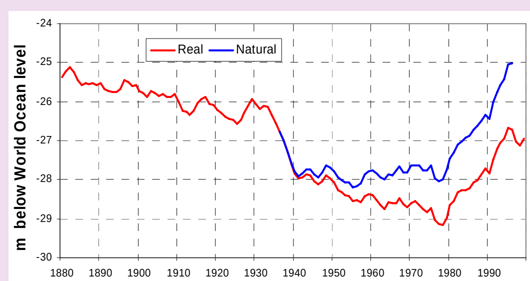
- Northern Eurasia is a major host of the boreal forest and bog ecosystems, which may exercise control over the global biogeochemical cycle affecting the atmospheric composition of such greenhouse gases as methane and carbon dioxide.
- This is the world's largest cold region with two thirds of the permafrost area, two thirds of the area with seasonal snow cover, and more than a third of the mountain glaciers in the Northern Hemisphere. Cold land processes define, control, and put a unique signature on the Northern Eurasian climate, hydrology, and environment.
- This is the region where the most continental climate is observed that affects the intensity of the Eurasian monsoon circulation, which is vital for the densely populated southern half of Eurasia.
- This is the region with the largest river, lake, and reservoir systems on Earth, the largest closed drainage basins, and the most extensive coastal zone exposed to permafrost thaw.



Mean annual temperature change 1965 to 2004 over the globe. Data source: Jones and Moberg 2003.

- In Northern Eurasia, the major ecosystems are frequently under heat and/or moisture stress. Over most of the continent there is a heat deficit and in the regions where the heat is sufficient, the water is typically not. The region is mostly cut off from the humid tropical air masses. Consequently, this region has the highest levels of observed climate and weather variability. The Northern Eurasian surface has modulated, and probably will continue to modulate, any external forcing imposed on the Global Earth System.

The Caspian Sea is the world's largest lake. It does not have outflow and thus is salty. Most of its influx (~80%) comes from the Volga River that has been covered by a set of reservoirs during the 20th century. These reservoirs and water withdrawal for irrigation and other types of water consumption caused a systematic decrease in the River streamflow that affected the Sea level, and thus the coastal zone, fisheries, urban development, and transportation. During the past sixty years, Figure below shows a relatively stable Sea level up to the late 1970s and then an increase in the Sea level that would have happened without the anthropogenic impact. However during the 1950-1980 period, this natural process had been temporarily reversed by the regional anthropogenic impact misguiding the water managers. The misjudgment caused enormous economic and environmental losses when protective measures "to save the Sea" (the dam construction to separate the Kara-Bogaz-Gol Bay from the Sea) were implemented and finally failed.



Observed and "natural" changes of the Caspian Sea level (Shiklomanov 1976; Shiklomanov and Georgievsky 2003). "Natural" changes are the changes that would have happened if there were no anthropogenic impacts on the river inflow into the Sea.

- Extensive variable dry land areas in Northern Eurasia host highly vulnerable natural and agricultural ecosystems that depend upon scarce and highly variable water resources and are the largest source of dust in the extratropics, polluting areas far away from the source.

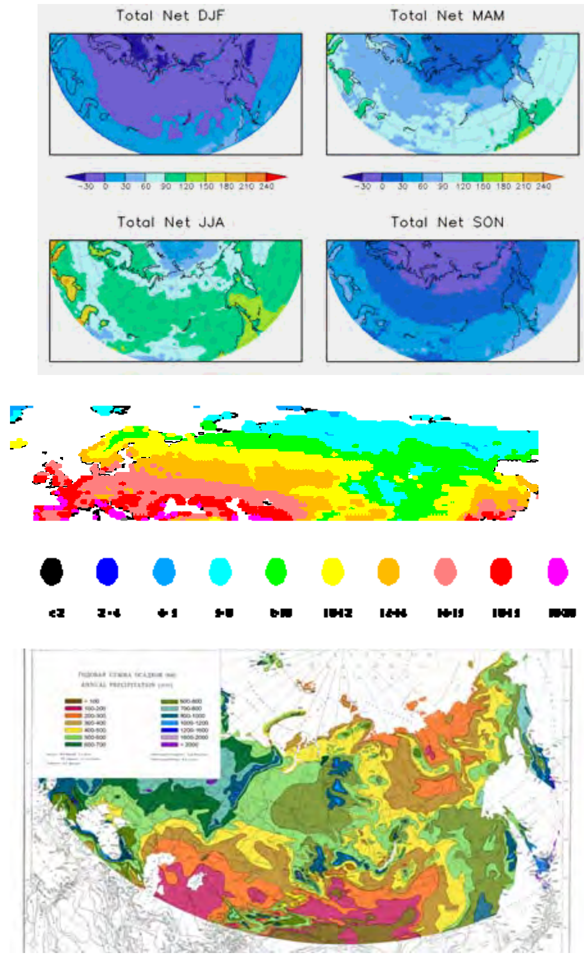
In addition, the regional land use history and social forces that underlie this history are unique within the global environmental science framework and present challenges to social and ecosystem scientists assessing the human dimensions of land cover and land use change.

Comparison with North America

These two major continents in the north, in many respects, complement each other rather than express similarities. Major factors that cause differences are geographical: the size of the Eurasian continent that prevents atmospheric circulation systems from crossing the continent; mountain ranges and plateaus that isolate its northern part from the tropics; and different roles of oceans in the formation of climates of both continents. The geographical differences produce unique ecosystems with different reactions to external forcing and unique controls that vary differently with global Earth system changes. Human activity has added a new and distinctively different feature to each of the continents. Synergy of all the above has generated, and will generate, different feedbacks and patterns of environmental changes. Therefore, to be able to know the processes that define environmental change in the extratropics, comprehensive studies of both continents are required.

Intensity of processes.

Compared to the tropics, the absolute values of the surface energy and water cycle in Northern Eurasia are relatively low and variations in the cycles do not need to be huge to cause significant perturbations. The low intensity but high variability of processes makes it difficult to monitor and study them. Therefore, if we intend to monitor changes in Northern Eurasia with the same precision as in other regions (e.g., remotely), we need more than the usual amount of information about processes causing these changes.



The mean seasonal total net surface radiation budget, W m^{-2} (Stackhouse et al., 2004; top). Annual water vapor content in the atmosphere (surface to 300 hPa; Randel et al. 1996, middle), and precipitation, mm, over Northern Eurasia (Korzun et al. 1974; bottom).

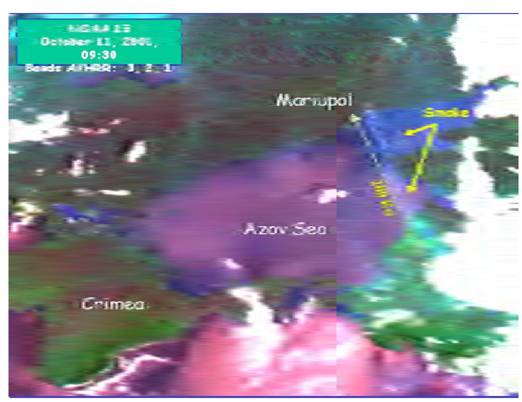
4. RESEARCH STRATEGY AND TOOLS TO ADDRESS NEESPI SCIENCE QUESTIONS

Terrestrial ecosystems, being an integrating component at the land surface and, in some sense, one of the major components of the biogeochemical cycle, absorb, control, transform, react to, and, to some extent, generate the changes in all these cycles. Human activity exercises controls on all these cycles, depends upon them, and reacts to their changes. *Therefore, in Northern Eurasia all components, climatic processes, environmental changes, and* *societal sustainability are closely and substantially interconnected to each other and should be studied together in an interdisciplinary fashion.* Moreover, many of the important processes that define the environmental role of Northern Eurasia occur at the boundary between zones and ecosystems. Interdisciplinary studies are critical for understanding these changes. Within the integrative framework of the Northern Eurasian partnership, the NEESPI studies are expected to include learning from and contributing to other relevant regional and global programs.

Research strategies for the science plan include: extraction and preservation of past observations, satellite assessments and monitoring, process studies, studies of impacts of environmental changes on society and the societal feedback, and modeling. The education component is an important, intrinsic part of each component of the research strategy. These research directions are closely linked and overlap one another.

To answer the major science questions of the Science Plan it is necessary to *better understand the processes and interactions within the regional ecosystems.* Therefore, process studies will be a key research element of the NEESPI Program. These studies include: (a) biogeochemical cycling in terrestrial ecosystems in Northern Eurasia studies; (b) recovery of the information accumulated during century-long process studies of the past and blending it with a new generation of environmental studies; and (c) new field and process-oriented studies that focus on processes critical to Northern Eurasia (cold land processes, large scale interaction with boreal and tundra ecosystems, sustainable agriculture in zones with high risk of incremented weather). At the plant, patch, and micro-meteorological levels, as well as at the ecosystem, watershed, and regional scales, a set of research questions should be addressed in order to develop model representations of processes and feedbacks associated with the land-surface, terrestrial hydrology, cryosphere, and vegetation and their validation with observations.

Focused societal studies are common in global change assessments. The unique objective of the NEESP Initiative (or at least one that is rarely met) is to elevate these studies to the level of investigation of an equally important *interactive* process that shapes (in substantial manner) the present and future global and regional changes. Therefore, impact of environmental changes on society and the feedback loop will be an important part of the NEESPI research program. Studies that address these societal issues are clustered into the following five major groups. Studies of human health and well-being shall analyze the interconnections between environment, climate, urban and industrial development, pollution, land use, and social/political changes and human health. This includes studies of the vulnerabilities and capacities of humans and



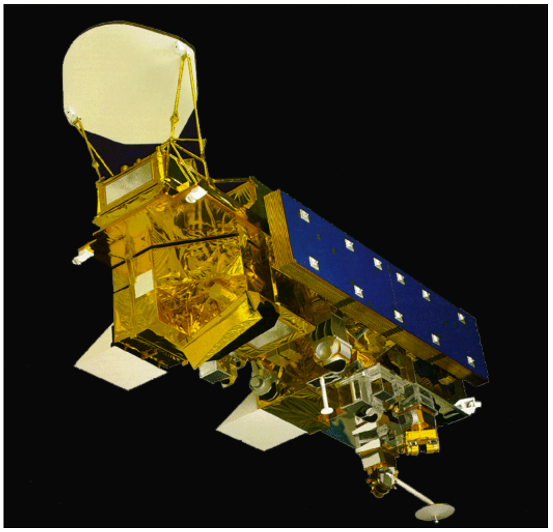
Top. Scorched land around the Norilsk Industrial region. Bottom. Smoke distribution from Mariupol Metallurgical Factory (Donbass) , October 11, 2001.

ecosystems to adapt to these changes, possible mitigation actions, and improved decisions and policies for future actions proposed. Ecosystem health studies will focus on the effects of global and regional changes, in particular pollution, on biodiversity, productivity, and sustainability. Research to improve the quantification of the impacts of climate and environmental variability and change on agricultural and forestry productivity, shall include a feedback loop in consideration and into models that accounts for social, economic, political and governmental policies, practices, and management. Water management and quality studies shall assess past, present and potential impacts of anthropogenic influences and climate change on quality and quantity of the water supply. Implications of this assessment should be analyzed and possible mitigation measures suggested when and where needed. Natural hazards and disturbance studies shall assess the frequency and intensity of extreme events, extensive fires, and other natural disasters in the region, the vulnerabilities of the people to these events, and their capability to cope with disasters. The contribution of regional fires to trace gas emissions and long range transport of particulates outside the region will be also examined. These studies should include improved efforts to monitor, predict, and to feed back that information to people for emergency preparedness and assessment of anticipated additional effects that could result from environmental changes of different origin.

Inherent in the NEESPI research strategy is the incorporation of a variety of "tools" that will be required or helpful in conducting the scientific investigations. These tools include remote sensing, modeling, and data and associated technologies.

Remote Sensing

One of the goals of NEESPI is to involve scientists in the development and testing of the integrated global observing systems (IGOS). Such systems would provide monitoring of Northern Eurasia using satellite facilities and information technologies that include data collection and management, image processing/analysis, spatial data analysis and modeling, data distribution, and users interface. There is a wide range of existing satellite instruments that will cover needs of various applications within Northern Eurasia to study and monitor vegetation status, land use, coastal zone, inland waters (lakes, reservoirs, and rivers), snow cover, ground ice (glaciers) and permafrost characteristics, components of surface energy and carbon budget, precipitation, evapotranspiration, and atmospheric water vapor. The use of remote sensing, however, is hampered by inadequate in situ information needed for validation of the remote sensing products and by lack of understanding of the regional processes required for reliable implementation of the retrieval algorithms. Therefore, validation studies and regional retrieval algorithms development will be an important component of NEESPI.



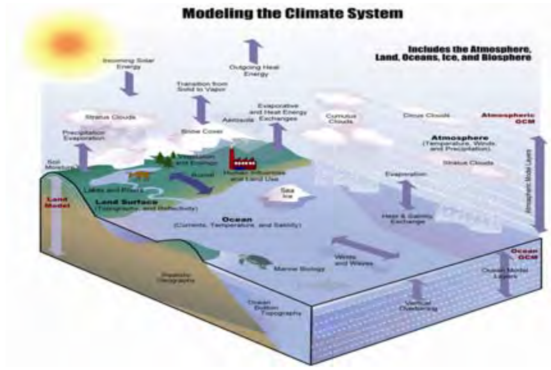
Aqua Satellite, NASA

Observations from space allow accurate and comprehensive quantification of many otherwise unavailable characteristics of ecosystems. The accuracy of these products, however, still has to be improved with the help of information from in-situ observations and/or regional model data assimilation. Expanding the modern in-situ environmental networks into Northern Eurasia and strengthening the existing operational and science oriented systems may substantially improve the situation. An investment to properly validate remote sensing algorithms for Northern Eurasia is required. Satellite remote sensing will also provide an input to early warning systems and timely information for improved resource management.

Remote sensing in Northern Eurasia is of particular importance because vast areas of the region are not well covered by in-situ observations. Currently, NASA, NOAA, NASDA, ESA, and Rosaviakosmos satellites conduct monitoring of various characteristics of the Earth climate, environment and land use. New launches will occur in the years to come. Sensors on board these satellites and techniques for data interpretation rely on understanding of the processes of interaction among radiation, the Earth surface, and the atmosphere. NEESPI studies will secure improved interpretation of current and future remote sensing information in Northern Eurasia and provide the bridge between this information and historical in-situ observations.

Modeling

The triad of the primary functions of modeling (i.e., studying processes, filling gaps in observations, and projecting the future) will be represented in NEESPI. Local, regional, and global scale models are all important, as well as integrated assessment modeling and modeling strategies for prediction (e.g., environmental and societal issues). The overarching, complementary scientific topics for the NEESPI modeling component are processes that control energy, water, and carbon fluxes over Northern Eurasia, direct and feedback effects of environmental changes in Northern Eurasia on the Global Earth System and their evolution, capability of the models to simulate observed environmental changes in Northern Eurasia, and capability of the models to provide an operational interface between on-ground and remote sensing data for data assimilation. The NEESPI modeling efforts will focus on models' improvements to address the above topics, enhancements of the models' capability to simulate the past and to estimate the spectrum of possible future environmental and societal changes both in Northern Eurasia and globally, and assessments the vulnerability of the regional ecosystems and societies to future environmental conditions.

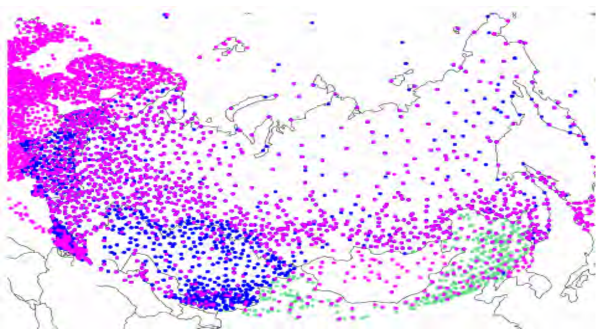


Components of the climate system and the interactions among them (including the human component). All these components have to be modeled as a coupled system including the oceans, atmosphere, land, cryosphere, and biosphere (Karl and Trenberth 2003).

The NEESPI modeling efforts will be organized on three scales: local, regional, and global. The three-scale approach implies using or developing a wide range of models, including atmospheric boundary layer models, soil-vegetation-atmosphere transfer models of different levels of complexity, permafrost models, air pollution models, data assimilation schemes, regional 3-D atmospheric models coupled to comprehensive land surface components, regional high-resolution hydrologic models, models of primary and secondary successions in vegetation and soils, dynamic general vegetation models, global climate models, including, general circulation models and Earth system models of intermediate complexity, socio-economic models, and integrated assessment models. The modeling activity is to be supplemented with developing model diagnosis and inter-comparison tools, data assimilation, and down- and up-scaling techniques. Finally, in the framework of the integrated assessment modeling, a systematic, integrated environmental change assessment study is to be conducted within the framework of a quasi-closed system with an explicit mechanism for incorporating and addressing stakeholders' (decision-makers) questions and concerns regarding global change as applied to Northern Eurasia and for the interests of the major societal and economic activities.

Data and Information and Associated Technologies

Each of the science foci of NEESPI has unique requirements for data. A brief assessment indicates that there is a wealth of information from various sources, but mechanisms to discover, identify and share datasets, and to integrate them into a multi-lateral research program such as NEESPI are lacking. While the first step to remedy this deficiency will be the creation of a metadata archive (i.e., a catalog of existing datasets within NEESPI countries in standard form), significant efforts will also be devoted to preservation and dissemination of past and current observations and organization of an open exchange of data and information among project participants, to the greatest extent allowable by institutional, national, and international regulations. Preservation of existing unique observational programs and stabilization of the density of standard meteorological, hydrological, and environmental observations is a critical task for Northern Eurasia.



Meteorological stations in Northern Eurasia. Stations depicted in pink color are those included in the WMO-A list.

Educational Component

NEESPI needs an increase in the availability of trained scientists working on critical Earth-science issues in the region, the fostering of good international relations through increased cross-cultural and collaborative opportunities, an increase in research and study opportunities for talented students, a broader exposure (access) of scientists in the region to modern technologies and methods of environmental studies, and an avenue for continuing education and re-training of experienced scientists who may have recently faced significant institutional changes. While the presence of an education component will be among the funding requirements of *successful* NEESPI projects, several stages of education and training will be additionally implemented at the following levels: elementary and secondary school, undergraduate education, graduate professional education, graduate Ph.D. education, and continuing education and re-training.

It is coming!

In summary, the NEESPI research strategy plans to capitalize on a variety of remote sensing and other tools and implement a general modeling framework linking socio-economic factors, crop, pollution, land use, ecosystem, and climate models with observational data to address key research questions within Northern Eurasia. As an integral part of these activities, a set of educational activities for students, educators, and the general public is needed as well as interaction with appropriate components of the related ongoing scientific and operational programs. A major objective of NEESPI will be to provide information, which empowers society and decision-makers to plan and react wisely, to mitigate the negative and to benefit from the positive consequences of environmental changes.

5. GOALS AND DELIVERABLES

Through conducting the scientific research during the next decade as addressed in the NEESPI Science Plan the following products are expected:

- *An integrated observational knowledge data base for environmental studies in Northern Eurasia that includes validated remote sensing products*
- *A suite of process-oriented models for each major terrestrial process in all its interactions (including those with the society)*
- *Prototypes for a suite of global and regional models that seamlessly incorporate all regionally specific feedbacks associated with terrestrial processes in Northern Eurasia and which could serve to improve scientific understanding that would enable future environmental change projections and provide input to informed decision-making for land use and environmental protection policies.*
- *Systems demonstrated in the research domain in collaboration with operational partners that can serve the emergency needs of society (early warning / management / mitigation of floods, fire, droughts, and other natural hazards)*

List of contributors and Chapter authors

In bold font are the lead chapter authors
(except the lead authors, all other contributors are listed in alphabetic order)

Chapters 1 and ,2. **H.H. Shugart, P.Ya. Groisman, S.A. Bartalev, A.S. Isaev, A.V. Mestcherskaya, A. Robock**, V.Yu. Georgievsky, A.G. Georgiadi, L.D. Hinzman, A.D. McGuire, A.G. Lapenis, R.A. Pielke, Sr., V.E.Romanovsky, A.I. Shiklomanov, N.M. Tchebakova, N.N. Vygodskaya, M.S. Zalogin

Chapter 3.1. **S.A. Bartalev, A.S. Isaev, H.H. Shugart**, A.G. Georgiadi, P.Ya. Groisman, , G.N. Koptsik, S.V. Koptsik, N.I. Koronkevich, O.N. Krankina, G.S. Kust, N.V. Lukina, A.D. McGuire, A.A. Sirin, V.S. Stolbovoi, S.E. Vompersky, and D.G. Zamolodchikov

Chapter 3.2. **A.D. McGuire, N.V. Lukina**, A.G. Georgiadi, M.E. Harmon, O.N. Krankina, A.G. Lapenis, Sh. Maksyutov, D.S. Ojima, K.J. Ranson, A.V. Oltchev , A.Z. Shvidenko, N.N. Vygodskaya, D.G. Zamolodchikov

Chapter 3.3. **P.Ya. Groisman, A.G. Georgiadi**, G.V. Alekseev, V.B. Aizen, E.M. Aizen, R.G. Barry, S.G. Conard, V.Yu. Georgievsky, A. Gershunov, V. I. Gorny, L.D. Hinzman, G. Inoue, A.V. Kislov, L.M. Kitaev, A.N. Krenke, A.D. McGuire, A.V. Mestcherskaya, G.N. Panin, V.N. Razuvaev, V.E. Romanovsky, A.V. Oltchev , T. Ohta, A.A. Onuchin, B.G. Sherstyukov, A.I. Shiklomanov, I.A. Shiklomanov, A. B. Shmakin, S.A. Sokratov , A.J. Soya, P.W. Stackhouse, N.A. Speranskaya, N.N. Vygodskaya, W. Wagner, M.S. Zalogin, S.A. Zhuravin, A.N. Zolotokrylin

Chapter 3.4. **N.F. Glazovsky, D.S. Ojima, N. G. Maynard**, K.M. Bergen, N. Chubarova, N. Davaasuren, G. Fisher, E. L. Genikhovich, P.Ya. Groisman, G.V. Kalabin, V.M. Kotlyakov, G.S. Kust, V. Osipov, V.E. Romanovsky, C. Rosenzweig, K. Seto, A.A. Chibilev, F. Tubiello, N.M. Vandysheva, R. Walker

Chapter 3.5. **N.N. Vygodskaya, P.Ya. Groisman, N.M. Tchebakova**, V.B. Aizen, E.M. Aizen, V.Yu. Georgievsky, L.O. Karpachevsky, N.K. Kiseleva , A.V. Kozharinov, Yu.A.Kurbatova, Sh. Maksyutov, A.V. Meshcherskaya, T. Nilson, R.A. Pielke, Sr., V.N. Razuvaev, A.B. Savinetsky, A.O. Selivanov, A.I. Shiklomanov, N.A. Speranskaya, Yu.L.Tselniker, A.V.Varlagin, A.N. Zolotokrylin

Chapter 3.6.1. **V.E. Romanovsky, T. E. Khromova**, O. A. Anisimov, V.B. Aizen, E.M. Aizen, R.G. Barry, M.B. Dyurgerov, A. G. Georgiadi, L.D. Hinzman, O.N.Krankina, S.S. Marchenko, T.S. Sazonova

Chapter 3.6.2. **A.O. Selivanov, I.P. Semiletov, S. V. Victorov**, A.G. Georgiadi, V. Yu. Georgievsky, P. Ya. Groisman, Yu.L. Obyedkov, V. E. Romanovsky, S. Shaporenko, A. I. Shiklomanov, F. A. Surkov, M. S. Zalogin

Chapter 3.6.3. **I. N. Sokolik, E.L. Genikhovich**, M.S. Zalogin

Chapter 4. **S.A. Bartalev, V.G. Bondur, A.A. Gitelson, C. Justice, E.A.Loupian**, J. Bates, **D. Cline**, G. Fisher, **V.I. Gorny**, P.Ya. Groisman, G. Henebry , **T.E. Khromova**, C. Prigent, J. Roads, W. Rossow, A.J. Soya, **P.W. Stackhouse, S.V. Victorov**, L.A. Vedeshin, W. Wagner

Chapter 5. **V.M. Kattsov, I.I. Mokhov, R.A. Pielke, Sr., S.V. Venevsky**, O. A. Anisimov, E.L. Genikhovich, A.G. Georgiadi, P.Ya. Groisman, A.S. Komarov, V.V. Kozoderov, D.O. Logofet, V.M. Lykosov, Yu.G. Motovilov, A.V. Oltchev, V.E. Romanovsky, M.E. Schlesinger, A.I. Shiklomanov, N.I. Shiklomanov, A.B. Shmakin, N.N. Vygodskaya

Chapter 6. **J. G. Masek, V.N. Razuvaev**, V.E. Gershenzon, P.Ya. Groisman

Chapter 7. **V.G. Bondur, K.M. Bergen**, R. Heino, V.V. Kozoderov, R.G. Mamin, F.A. Surkov

Chapter 8. **P.Ya. Groisman, S.A. Bartalev**, L.D. Hinzman, R.G. Barry, A. Robock, N. G. Maynard

Contributors from Austria, Estonia, Finland, France, Germany, Japan, Kazakhstan, Mongolia, Russia, Ukraine, and the United States participated in the Science Plan preparation.

Editors of the Science Plan are the NEESPI Project Scientists:
Pavel Ya. Groisman (USA) and Sergey A. Bartalev (Russia)

1. INTRODUCTION

Because it is so vast, the scale of Northern Eurasia is difficult to express without superlatives. It covers eleven time zones and an area of about 28,600,000 km^2. This is slightly more than the sum of the areas of the United States, Canada and Europe, or 19% of the land surface of the Earth. From the point of view of understanding the dynamics of the earth system, the Northern Eurasian Earth Science Partnership Initiative (NEESPI) study region is about 60% of the terrestrial land cover north of 40°N and about 35% of the Earth outside of the tropics and subtropics. It is a diverse region. Covered by tundra in the North and semi-deserts and deserts in the South (Figure 1.1), Northern Eurasia holds a substantial fraction of the Earth's boreal forest (about 70%) and more than two-thirds of the land on Earth that is underlain by permanent soil ice or permafrost (Zhang et al., 1999, 2000). Thus, when global change processes involve these two biomes, Northern Eurasia is a key region for studying these processes and their impact on the global Earth system.

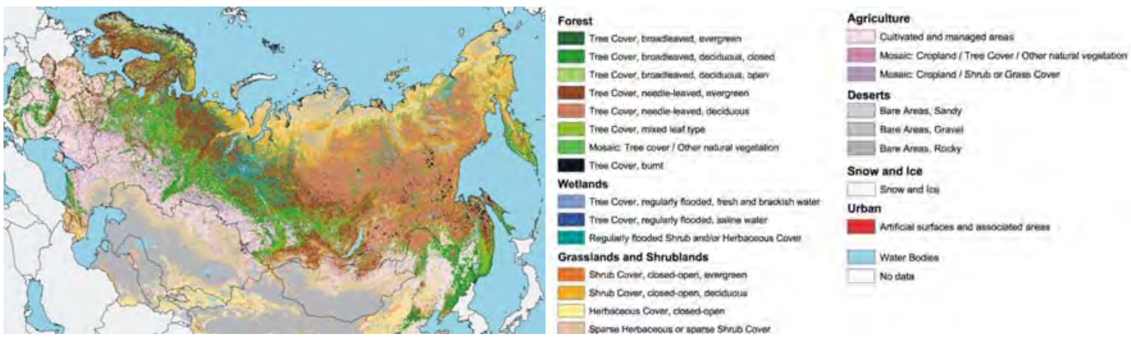


Figure 1.1. NEESPI study area includes Former Soviet Union, Northern China, Mongolia, Fennoscandia, Eastern Europe and the coastal zone of these countries. Inserted map shows land cover for the region. Source: European Commission, Joint Research Center (Bartalev et al. 2003; Bartholomé and Belward 2005).

We see the functioning of the global Earth system as an interaction of three major types of processes (cycles):

- ***Biogeochemical Cycles*** (BC) is defined as processes which affect the composition of the atmosphere and ocean, the formation of soils and the evolution of biomes. Global changes in this cycle can be slow, such as in forest succession, with typical time scales of multiple years and longer. Under this situation, the state of the BC could be considered as the initial condition when changes in processes of shorter time scales are considered. Processes involved in the BC can be also quite rapid (e.g., grassland vegetation dynamics, fires) or instantaneous (e.g., carbon assimilation in the photosynthesis process).
- ***Energy and Water Cycles*** (EWC) are defined as the processes which affect the transfer of energy, water, aerosols, and trace gases between the atmosphere, land surface, hydrosphere, and cryosphere on all time scales.
- ***Human Activity*** (HA), which began to strongly affect the planetary system on the regional level (land use, water withdrawal) with the establishment of the first agricultural civilizations, and now includes effects on the global climate system.

These processes are interrelated and their joint study addresses the overarching theme of the NEESPI, Terrestrial Ecosystem Dynamics. When described in a suite of reliable

models, these dynamics can be comprehensively simulated and projection estimates (scenarios) can be made.

With the industrial revolution, and increasingly since the end of the 19th century, human activity is more and more evident at the global scale with observed changes of the chemical composition of the atmosphere, with air and water pollution, and with large-scale changes in land cover. At present, humankind has become an essential part of the functioning of the dynamics of the planetary system, capable of globally altering the biogeochemical, energy and water cycles and thus changing terrestrial and oceanic ecosystems. We need to know how this will affect our planet and our species' future.

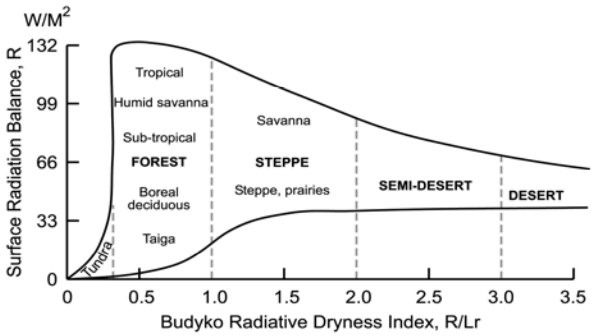


Figure 1.2. Geobotanical zones as functions of the annual surface radiation balance, R, and Budyko radiative dryness index (R/Lr), where r is annual precipitation and L is specific latent heat of vaporization.

EWC largely defined the state of the landscape up to as late as the beginning of the past century. The Law of Geographical Zonality (Grigoriev 1954, Budyko, 1971; Figure 1.2) describes the general relationship between major ecosystems and climate conditions. In the past, ecosystems have gradually adjusted themselves to slowly changing climate conditions, even in Northern Eurasia, which was historically more sensitive to climate variations and changes than most of the globe (Vinnikov 1986). This adjustment has always been interactive, because changes in terrestrial ecosystems feed back causing appropriate changes in EWC affecting the physical properties of the landscape (surface roughness, soil water holding capacity, river routing), as well as heat and water fluxes themselves (e.g., by controlling physical evaporation and transpiration). Thus the movement towards a new equilibrium occurs. When HA became a substantial factor, the time scale of changes in both EWC and BC shifted to shorter time scales with added forcings. Many of these changes (e.g., emission of greenhouse gases, deforestation, agricultural land use) have been one-directional and introduced trends that we now observe in meteorological and environmental records (IPCC 2001a,b). Figure 1.3 schematically shows the difference between the pre-industrial and present relationships among these three types of the processes. ***Studying any one of these cycles or activities often requires analyses of its interaction with the other two and of the transitional (non-equilibrium) character of these interactions.***

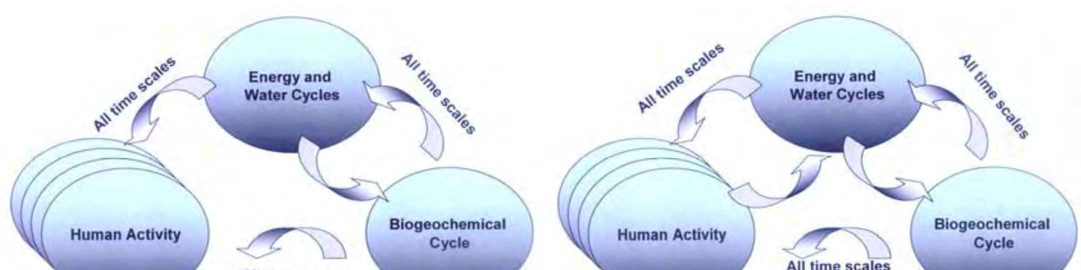


Figure 1.3. Pre-industrial (up to circa mid 19th century) and present interactions in the Earth Global System

Most of the energy that arrives at the Earth is first absorbed by the surface and only then is transferred to the atmosphere, cryosphere, biosphere, and into the deep ocean. Therefore, the energy exchange properties at the surface have a strong direct influence on all major processes of the global earth system, namely, on the biogeochemical, energy and water cycles, and on human activity. This includes the climate system. This science plan is focused on surface and near-surface processes in the Northern Eurasian region for three fundamental reasons:

- The changes in this region have the potential to affect the entire Earth system and may already be doing so.
- The processes in this region and their effects on the Earth system are so important and powerful that without clear understanding of them, the description/modeling of the entire Earth system is not possible.
- The study will have benefits to the societies in the region, helping to alleviate the negative aspects of environmental change and to respond to the positive aspects of these changes. This has special importance in this region with fast demographic trends, abrupt social changes, and a weak infrastructure.

These fundamental reasons will be discussed in greater detail in the "Major Scientific Topics" sections of the plan (Chapter 3). Tools to address these topics are described in Chapters 4 through 6. Our plan of action includes an education component (Chapter 7).The last chapter (Chapter 8) outlines the key elements of the NEESPI research strategy.

Most of factual information (physico-geographical description, climatology, state of the environment and society, as well as description of the observed changes, etc.) from all Chapters has been moved to ***Scientific Background Appendix***. This information as well as list of cited references is too volumetric to be presented in the Science Plan.

2. SCIENTIFIC QUESTIONS AND MOTIVATION

This chapter is addresses two major topics. First, the scientific questions are presented. Next we explain why studying Northern Eurasia is a crucial opportunity to help answer these questions.

2.1. Scientific Questions

The overarching NEESPI science question is:

How do Northern Eurasia's terrestrial ecosystems dynamics interact with and alter the biosphere, atmosphere, and hydrosphere of the Earth?

This question can be reformulated in a more pragmatic way as:

How do we develop our predictive capability of terrestrial ecosystems dynamics over Northern Eurasia for the 21st century to support global projections as well as informed decision making and numerous practical applications in the region?

While seemingly different, the two questions converge, because to answer them, we must conduct the same scientific investigations. We need to specifically answer the following questions:

- *How does the Northern Eurasia ecosystem function and how and why has it been changing during the past centuries?*
- *What are the linkages between the Northern Eurasia ecosystem, atmospheric composition and circulation, and Arctic Ocean and sea ice dynamics? For example, do the properties of the land system affect the Arctic Oscillation, and how does the Arctic Oscillation affect the patterns of the Northern Eurasia ecosystem? How do the changing precipitation, land use, forest cover, and permafrost affect runoff into the Arctic Ocean, and subsequent salinity and ocean circulation?*
- *What has been the role of anthropogenic impacts on producing the current status of the ecosystem, both through local land use/land cover modifications and through global gas and aerosol inputs? What are the hemispheric scale interactions, and what are the regional and local effects?*
- *How will future human actions affect the Northern Eurasia and global ecosystems? For example, for different scenarios of future greenhouse gas and aerosol inputs, and for different forest clearing, water and agricultural land management, urban, industrial, and oil development projects, how will the ecosystem be changed? And how will changes in these ecosystems feed back to society? How can we describe these processes using a suite of local, regional, and global models?*
- *What will be the consequences of global changes for regional environment, the economy, and the quality of life in Northern Eurasia? And how can science contribute to decision making on environmental issues in the region?*

The last question above, while addressing local regional problems, is in fact the most important for the nations of Northern Eurasia. This part of the world has proven to be prone to extraordinary climatic and environmental changes in the past. Sometimes, only the remnants of these changes impact the outside world. The possible consequences of global changes in Northern Eurasia are many and we can expect others will arise as we learn more about the system.

The major uncertainty which justifies our science questions is that during the past, we have evidence of significant and rapid changes in the atmosphere, hydrosphere, cryosphere, and land cover in Northern Eurasia, but still need to accurately quantify these changes and the particular processes that caused them. Taking into account the scale and rate of changes, this situation is unacceptable. We need to develop the ability to measure, monitor, and model the processes that will provide for us future projections of climatic and environmental changes in the region because these changes may impact the Global Earth System and the human society.

Topical scientific questions that are further elaborated in Chapters 3 to 5 are structured differently for several reasons. These are briefly explained here.

Study of **Biogeochemical Cycles** is relatively young and our topical scientific questions start from climatology:

- What are the current geographical and temporal distributions of the major stores and fluxes of carbon and other elements in Northern Eurasia?

Thereafter we want to know their major processes and impacts. This leads to the next two questions.

- What are the major drivers and feedback mechanisms that control the dynamics of the biogeochemical cycles at local, regional, and continental scales?
- What are the likely future dynamics of biogeochemical cycles that are important to the functioning of the climate system and human societies?

The answer to the second of these questions already assumes the ability to model the major processes that define the dynamics of biogeochemical cycles. Finally, we need to know our ability to control the situation. This requirement leads to the last question:

- What points of intervention and windows of opportunity exist for society to manage biogeochemical cycles in order to mitigate adverse effects in them?

For the **Surface Energy and Water Cycles** the major topical scientific question is:

- What are the details of surface energy and water cycle dynamics in Northern Eurasia, and how do they improve our understanding of how this region interacts with global cycles?

The scientific community is already at work on this question. We need a suite of calibrated land surface models that are well fed by in-situ and remote sensing observations and seamlessly interact with regional and global earth system models. But, this does not mean that this question is already answered (3.3, 3.5, 3.6, 4, and 5). In fact, the rich set of observational data available in this region (e.g., Robock et al. 2000, Schlosser et al. 2000) will go a long way toward helping us to understand these processes on a global basis). A significant part of the NEESPI Research Strategy (8) is devoted to working on this problem. We still may need to clarify the answer on another topical question for the Surface Energy and Water Cycles:

- What is the relative importance of the major drivers and feedback mechanisms that control the variability and changes of the surface energy and water cycles at local, regional, and continental scales?

Land Use and Society. Society affects and is being affected by the environment. Its wellbeing has been affected and will be affected by environmental changes. Thus, it can now be considered as an active and conscious part of the Earth environment. This generates a set of "societal feedback" questions that will also be a focus of the NEESPI studies**:**

- What land use changes are taking place in Northern Eurasia and what are their impacts on the environment and society?
- What lessons can be learned from the responses to dramatic land-use modifications during the "planned" economy period for future sustainable natural resource management?
- What will be the consequences of socio-economic changes in Northern Eurasia on the environment?
- How can science contribute to development of environmental strategies for society (societies)?

We have emphasized these questions separately because the ability to answer them intelligently provides the best and likely the only chance for correct future policy decisions related to environmental issues in the region.

Northern Eurasia is one of the regions where **Ecosystem and Climate Interactions** play a particular role. These interactions strongly control the state of the Earth system in the region and must be understood first, if we plan to properly describe and model both these components of the global Earth system. This requirement leads to a topical question:

- How do we account for the synergy of feedbacks of major processes within the regional terrestrial ecosystems, climate, cryosphere, and hydrosphere of Northern Eurasia and their interactions with society?

Cold Regions, Coastal Zone, and Atmospheric Aerosols and Pollution were identified as cross-cutting topics of special interest. In 2.2 below, the reasons for this special interest are spelled out and the topical scientific questions are:

- **Cold Regions and Coastal Zone:** How do the changes here affect regional and global biogeochemical, surface energy and water cycles, and human society?
- **Atmospheric Aerosols and Pollution:** How do their changes affect regional and global biogeochemical, surface energy and water cycles, and human society?

Remote Sensing, Data, Information Technology, and Modeling are among the major tools of the future NEESPI studies and the topical scientific questions are:

- How can we characterize and improve the accuracy and availability of current remotely sensed data products to meet the needs of the NEESPI science community and resource managers
- How do we improve the capability of present and future remote sensing systems as well as in-situ observations to capture climatic and environmental characteristics and change in the unique conditions of Northern Eurasia?

- How do we reduce the uncertainty of regional and global Earth System modeling related to poor knowledge of major processes and feedbacks in Northern Eurasia?
- How do we secure a societal feedback loop in our models that allows simulation of various scenarios of human activity and, in particular, land use in the region?

2.2. Why Northern Eurasia?

Given that many of the above scientific questions involve the Global Earth System, the question naturally arises as to why we should focus on Northern Eurasia. In a nutshell, the answers are:

- The changes in this region have the potential to affect the entire Earth System and may already be doing so.
- The region has unique features that need to be better understood, parameterized, and accounted for. Without clear understanding of them, description and modeling of the entire Earth system is not possible.
- The study will have benefits to the societies of the region.
- This region possesses a wealth of scientific talent that can be utilized in this study.
- This region has been studied in detail for more than a century by Soviet and Russian research projects, yet the abundance of data that has been collected has not been utilized enough to study these problems and is in danger of being lost.

2.2.1. The Role of Changes in Northern Eurasia in the Global Earth System

Climate changes will affect Northern Eurasia to a greater degree than the rest of the planet, and this has been shown in studies of past climate change and virtually all of the simulation models of the Earth's climate system under global warming scenarios. These changes will cause and interact with changes in terrestrial ecosystems that, in turn, will feed back to regional and global climate. Society will continue changing the environment, be affected by these changes, and react to them. Therefore, it is crucial to understand Northern Eurasia as a fundamental component of the global climate and ecological system.

Being the largest land mass in the extratropics, the largest terrestrial reservoir of carbon in the biosphere, one of the regions with the largest climatic variations, and an area of active land use changes during the past century (and possibly in the future), Northern Eurasia has a unique capacity to generate non-linear, large-scale, and sometimes abrupt changes in regional carbon, surface energy, and water balances. These changes may feed back to the global climate, biosphere, and society. Specifically,

- If we are to understand the global carbon cycle and other biogeochemical cycles, we must know how they function in the NEESPI region[1].

[1] At present, Northern Eurasia accounts for more than half of the total pool of terrestrial carbon in soil, wetlands, and above-the-ground biomass. A single country in Eurasia, Russia, holds most of the Eurasian forest resources. At present, it appears that during the last decade of the 20th century, boreal forests were a net sink of atmospheric carbon, with most (around 70%) of this sink (0.4 Gt of carbon per year) located in Siberian taiga (Figure 2.1). Whether or not this region will continue to remain a carbon sink in the future is not known (3.1, 3.2, 3.5, 3.6.1).

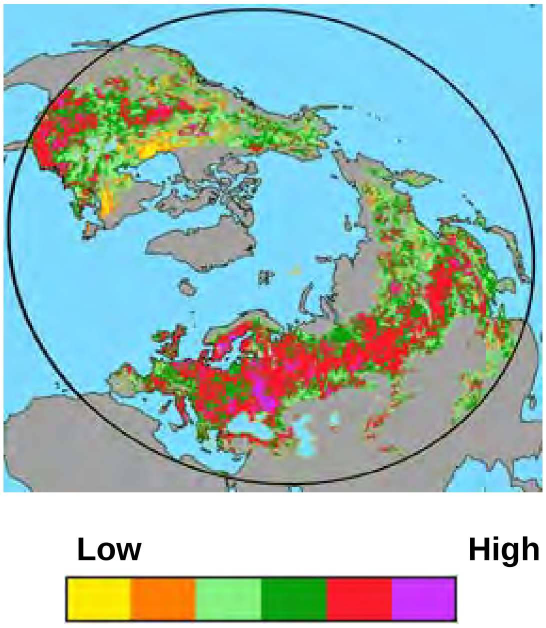


Figure 2.1a. NASA's data on spatial patterns in persistence of normalized difference vegetation index (NDVI) increase: 1981-1999 (Zhou et al 2003). According to the interpretation of NDVI data by Myneni et al (2001), boreal forest might provide the net sink of 0.68 ± 0.34 Gt of C yr^{-1} of which nearly 70% is in Northern Eurasia.

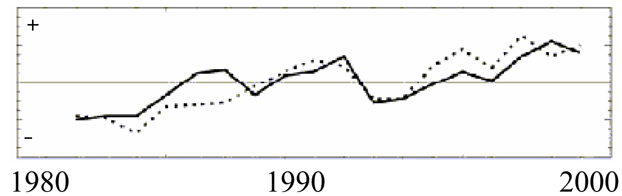


Figure 2.1b. Spatial average of NDVI from the Global Inventory Monitoring and Modeling Studies for vegetated pixels between 40ºN and 70ºN from 1982 to 1999 in North America (solid line) and Eurasia (dashed line). The scale of NDVI changes is from –0.04 to + 0.04. It was suggested that observed trends in NDVI reflect on trends in atmospheric temperature, precipitation or atmospheric concentration of carbon dioxide. According to Zhou et al. (2003), air temperature changes between the early 1980s and the late 1990s were responsible for much of the observed increase in satellite measures of northern forest greenness.

- Accelerated climatic changes across Northern Eurasia may cause changes in global atmospheric circulation and meridional heat transfer (3.3; Figure 2.2).

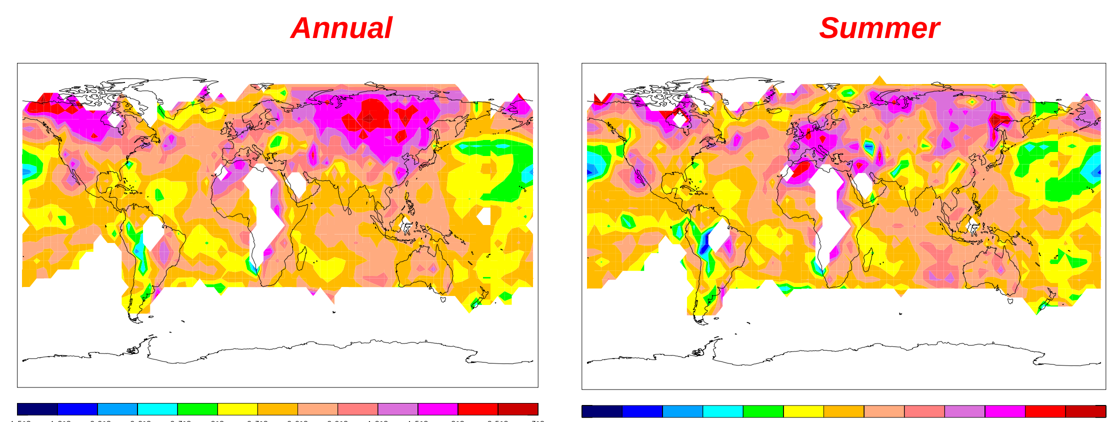


Figure 2.2. Mean Temperature Change 1965 to 2003 over the globe. Data source: http://www.cru.uea.ac.uk/cru/data/temperature/ (Jones and Moberg 2003). Processed by the U.S. NCDC Global Climate at the Glance Mapping System.

- Changes in surface albedo (snow/ice cover, shifts in vegetation, land use change) and atmospheric humidity may change the Earth heat and water balances (3.3, 3.4, 3.5).

About half of the Northern Eurasian terrain has permafrost (Figure 2.3). Its presence controls the hydrosphere and biosphere of the eastern half of the continent. Thawing of permafrost may change the soil carbon cycle and the entire ecosystem above it and, thus, the concentration of greenhouse gases in the atmosphere. It also will produce major changes in land cover and in surface and subsurface hydrology[2] (3.6.1).

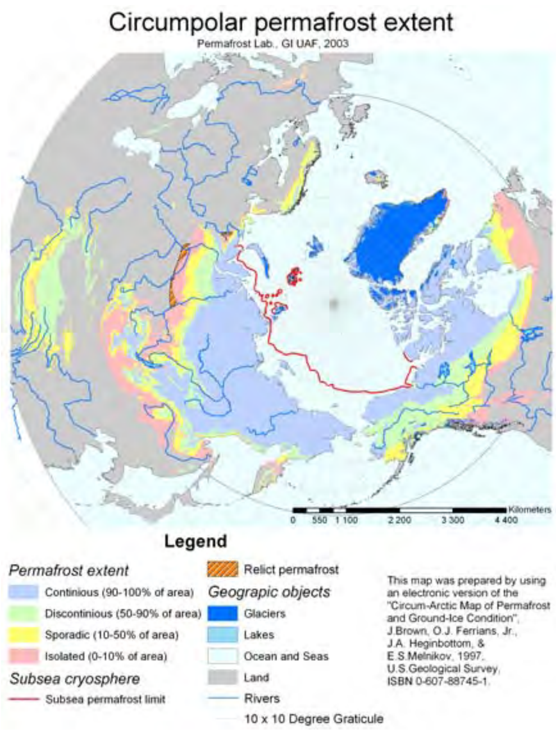


Figure 2.3. Circumpolar permafrost extent map based on the electronic version of the "Circum-Arctic Map of Permafrost and Ground-Ice Condition", J. Brown, O. J. Ferrains, Jr., J. A. Heginbottom, and E. S. Melnikov, 1997, U.S. Geological Survey. In the continuous permafrost zone, permafrost occupies the entire area (except beneath large rivers and deep lakes). In the discontinuous permafrost zone, including the sporadic zone, anywhere from 10 to 90 percent of the surface is underlain by permafrost. In the southernmost isolated permafrost zone, permafrost occupies less than 10% in a form of isolated masses within the generally permafrost-free area.

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[2] A significant amount of potentially decomposable organic material, methane (CH_4), and carbon dioxide (CO_2) are now sequestered in permafrost and ground ice. Climate warming can potentially thaw the permafrost and greatly enhance the microbial activities in the formerly frozen soils. Thawing permafrost and melting ground ice would release the greenhouse gases into the atmosphere. If this occurs, the vast storage in the arctic and sub-arctic ecosystems of Northern Eurasia could become strong sources of CO_2. Also, in the areas of the active thermokarst lakes development, new and significant production of CH_4 will occur. Permafrost is already thawing in many areas and its degradation is expected to accelerate with future climate warming. This can significantly affect the biogeochemical cycle in the cold regions of Northern Eurasia and may create an amplifying feedback loop in the greenhouse gases composition in the atmosphere and, thus, cause a further warming. Dramatic damage to the infrastructure and changes in vegetation cab be also associated with the permafrost degradation. Precipitation on a large part of permafrost area corresponds to semi-desert, however permafrost results in a perched water table and keeps the water in the root zone. Loss of permafrost is expected to increase soil drainage and may result in desertification in these areas. This also would affect, and even reverse, the tendency of increased carbon sequestration in the taiga regions of Northern Eurasia observed in the last decade (3.6.1).

- Changes in the hydrological cycle over the continent will affect the fresh water transport to the Arctic Ocean and, thus, may influence the shelf seas and the ocean thermohaline circulation (3.3).
- Deglaciation in the mountain systems of Central Asia, increasing water withdrawal, and increasing dryness of steppe and semi-arid zones will affect surface albedo, water resources, and their quality of the interior areas of the continent and, thus, the global climate and society (3.3, 3.4, 3.6.1).
- Advance/retreat of the forest line[3], increase/decrease of conditions conducive for forest fires, wind-throw, and logging may lead to global biogeochemical, energy and water cycle changes (3.2, 3.3, 3.5).
- Drying of bogs over expansive areas in West Siberia and the Great Russian Plain may result in their degradation, will affect the global carbon cycle[4], and runoff formation.

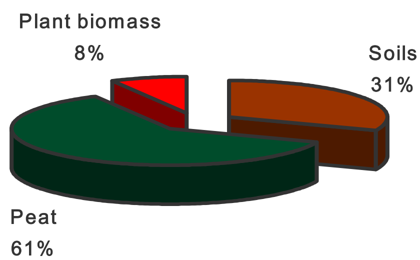

Figure 2.4. Peat is responsible for 61% of carbon storage in boreal ecosystems. Estimates of peat stores in Russia range from 45 to 138 PgC.

- Boundary exchange of fresh water, organic and non-organic matter across the extensive coastal zone may affect the world ocean circulation (3.3) and biochemical processes in the shelf seas and interior lakes (3.6.2). Intensive erosion (up to 10 m yr^{-1} in some areas) and other coastal line changes may affect life conditions and cause enormous economic damage[5] (3.6.2).
- Ongoing aridization of the continental interior may cause a massive aeolian aerosol input into the troposphere[6] that can affect the Earth's heat balance and generate direct

[3] The northward expansion of the forest line into the tundra zone will cause a decrease in surface albedo. However, if at the same time the southern border of the forest zone shifts northward, giving the room for forest-steppe and steppe environment, the increase in surface albedo will occur in the south. Furthermore, the surface albedo is affected by interactions in the forest - snow cover – thaw – soil and vegetation wetness system. This makes definite projections of its changes very difficult (3.5).

[4] Much of the soil carbon in the region is stored in peatlands (Figure 2.4), which occupy an estimated 273 million ha and contain about 118 PgC in Russia alone (Vompersky et al. 1994, Alexeyev and Birdsey 1998), out of the total estimate for Northern peatlands of 358 million ha and 455 PgC (Gorham, 1991).

[5] The coastal zone in Northern Eurasia is extensive (Figure 2.5). It contains over 40% of the entire population of Northern Eurasia and more than half of its economic resources. Capitals of several countries of the region and major industrial centers are also located in this zone. In the coastal zone, tendencies of increasing population, economic activity (especially prospecting and exploitation of oil and gas fields), sea level rise, degradation of sea coast due to wave and thermal erosion, denudation, slope processes, and pollution of the coastal bays (especially in the river deltas near large cities) are intensifying.

[6] Atmospheric aerosols have several direct and indirect impacts on the environment and climate. Changes in the emission of these aerosols can trigger several complex feedbacks in the Earth System that are poorly quantified (IPCC 2001; 3.6.3). Atmospheric aerosols come from a wide variety of natural and anthropogenic sources and are produced via direct emission of particles (e.g., wind-blown dust from natural deserts and carbonaceous particles from natural fires) or formed via chemical reactions of gaseous precursors emitted into the atmosphere

biospheric and societal impacts thousands of kilometers away from the origin of these dust storms (3.3, 3.6.3).

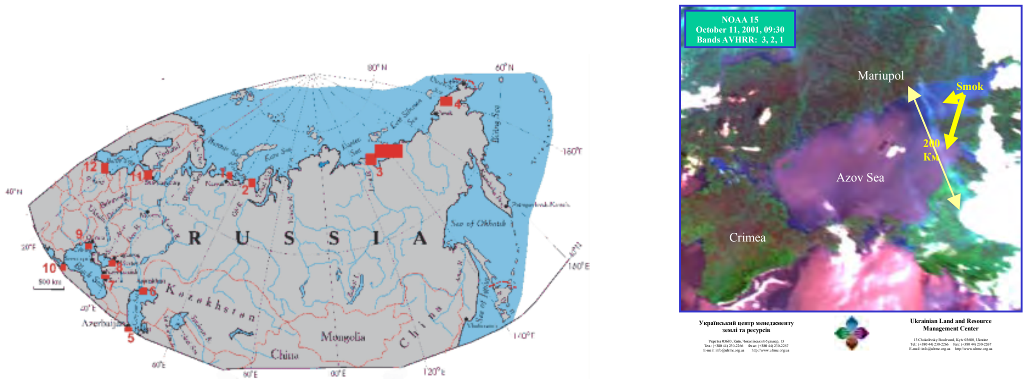

Figure 2.5. (Left) Coastal zone of Northern Eurasia with the regions most affected by past, present and projected changes (Right) Example of pollution in the coastal zone of the Sea of Azov: Smoke distribution from Mariupol Metallurgical Factory (Donbass), October 11, 2001 (09:30).

- Human activity has changed ecosystem types over most of the steppe and forest-steppe zones and over part of the forest zone (3.1, 3.4) causing numerous biogeochemical and biogeophysical feedbacks (3.5), near-global environmental changes (box inserts A.1 and A.2 cf. Scientific Background Appendix), and affecting environmental health and quality of life[6] (Figure 2.6; 3.4, 3.6.3).

Each of these aspects of global impact of Northern Eurasia will be discussed in Chapter 3 and in Chapters 4 through 8, where major directions of the proposed initiative are outlined.

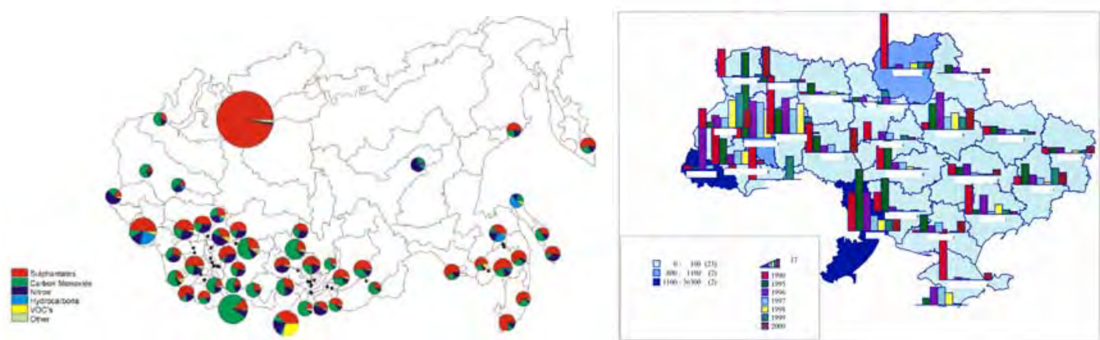

Figure 2.6. Examples that characterize the environmental health in two regions of Northern Eurasia, Siberia and The Ukraine: (Left) Volume emissions of gaseous and particulate air pollutants in Siberia (IIASA, 2003) and (Right) Emergency Contamination of Environment and Hazardous Situations in the Ukraine (Environment of Ukraine, 2001)

2.2.2 Unique features of Northern Eurasia

(e.g., sulfates formed by gas-to-particle conversion of SO_2). There is a compelling body of evidence that human activities result in increasing concentrations of lower atmospheric (tropospheric) aerosols. The lifecycle of all aerosols is closely related to the cycles of energy and water, including biogeochemical cycles. Aerosols constitute an important component of air and water pollution. For example, currently, deserts in Northern Eurasia are the second largest in the world. Varying desert area (now affected also by human activity) controls the lower tropospheric aerosol loading because deserts are the main natural source of mineral dust in the atmosphere. This loading, in turn, affects climate, environment, and human health.

Northern Eurasia is the largest contiguous land region in the extratropics. Several unique features of this part of the world are predefined by its location:

- Northern Eurasia is a major host of the boreal forest and bog ecosystems, which may exercise control of the global biogeochemical cycle. One of the largest storages of organic carbon is located here, which indicates that for a long period of time the region was a carbon sink, thus affecting the atmospheric composition of such greenhouse gases as methane and carbon dioxide. (3.1, 3.2, and 3.5).
- This is the world's largest cold region (more than twice as large as Antarctica) where the coldest recorded temperature has been reported in human settlement (Verhoyansk, -71°C). Two thirds of the permafrost area, two thirds of the area with seasonal snow cover, and more than a third of the mountain glaciers in the Northern Hemisphere are in Northern Eurasia. This is the region the most extensive coastal zone exposed to the permafrost thaw. Snow cover variations, effects of permafrost, and seasonal freeze/thaw/refreeze processes define, control, and put a unique signature on the Northern Eurasian climate, hydrology, and environment during most of the year (and in the permafrost areas, year round).
- This is the region where the most continental climate is observed with seasonal temperature amplitudes of ~60°C. In winter, this is a heat sink and in summer (although short in the far north), it is a source of heat for the regions east-, west-, and northward. This peculiarity of the continental surface heat balance affects the intensity of the Eurasian monsoon circulation, which is vital for the densely populated southern half of Eurasia.
- In Northern Eurasia, the major ecosystems are frequently under heat and/or moisture stress. Over most of the continent there is a heat deficit and in the regions where the heat is sufficient, the water is not. Northern Eurasia is relatively dry, being mostly cut off from the humid tropical air masses. This is the area of the western air transfer contrary to monsoon Asia. It receives most of its moisture from extratropical cyclones coming from the west (Kuznetsova 1983), and its interiors heavily depend upon the intensity of zonal water vapor transport. Thus, the precipitation here comes with extratropical cyclones that by no means can be considered a stable source. Consequently, this is the region where the highest levels of climate and weather variability are observed and the Northern Eurasian surface modulated and probably will modulate any future external forcing imposed on the Earth Global System.
- Extensive variable dry land areas in Northern Eurasia are the largest source of dust in the extratropics due to a predominantly zonal circulation spread over mid- and high latitudes polluting areas far away from the source (Darmeneva and Sokolik 2002). Furthermore, these regions host highly vulnerable natural and man-made (e.g., agricultural) ecosystems that depend upon scarce and highly variable water resources (Vörösmarty et al. 2000).
- This is the region with the largest river, lake, and reservoir systems on the Earth. Furthermore, Northern Eurasia hosts the largest closed drainage basins on Earth (the largest of them are the Aral, Caspian, and Tarim River basins) with a total area of more than $5x10^6$ km^2. These basins have been trapping atmospheric moisture for a long period of time (Aizen and Aizen, 1998).

Comparison with North America. There are two major continents in the northern extratropics. Thus a legitimate question is: Why would it not be enough to study environmental processes in one of them and just extrapolate the findings to the second one? The answer to this question is because in many aspects North America and Northern Eurasia complement each other rather than express similarities. Major factors that cause differences are geographical: the size of the Eurasian continent that prevents atmospheric circulation systems from crossing the continent while they commonly do this in North America; mountain ranges and plateaus that isolate its northern part from the tropics; and different roles of extratropical oceans (Atlantic and Pacific) in the formation of climates of both continents. Furthermore, the major part of the freshwater runoff into the Arctic Ocean comes from Northern Eurasia. The geographical differences produce unique ecosystems with different reactions to external forcing and different history throughout the geological past, and unique combinations of atmospheric circulation conditions and controls that vary differently with global Earth system changes. Human activity added a new and distinctively different feature to each of the continents. Finally, synergy of all the above generated, and will generate in the future, different feedbacks and patterns of environmental changes. The bottom line here is: To be able to know the processes that define environmental change in the extratropics, comprehensive studies of both continents are required.

Intensity of processes. Compared to the tropics, the absolute values of the surface energy and water cycle in Northern Eurasia are relatively low. The annual surface radiative balance is usually a positive value and, in Northern Eurasia, these values are lower than in the southern regions. Low air temperatures and soil moisture deficit are associated with low values of latent heat fluxes and low precipitation. This together with a long cold season and extensive desert areas suppress the intensity of the water cycle in Northern Eurasia. At the same time, variations in the energy budget (e.g., disturbances due to greenhouse gases increase or vary meridional heat transport controlled by the North Atlantic Oscillation) or in the water cycle (e.g., reduction in storm activity or depletion of the water storage due to deglaciation) do not need to be huge to cause significant relative perturbations in the regional weather conditions and terrestrial hydrology. This low intensity but high variability of processes in Northern Eurasia creates a twofold problem. It is difficult both to monitor these processes and to study them. On the other hand, this raises the importance of information about energy and water cycles in Northern Eurasia. If we intend to monitor changes in Northern Eurasia with the same precision as in other regions (e.g., remotely), we need more than the usual amount of information about processes causing these changes. Numerous unresolved problems are listed at the end of Sections 3.2, 3.3, and 3.5.

Box insert. Some historical considerations that separate the Northern Eurasia.

"Northern Eurasia" with its suggested borders (Figure 1.1) is very close to the "Eurasian geographical world" of Eurasists – political and scientific school in the first ("white") Russian emigration (Savitsky, 1927). The school considered most of old Russia as a specific geographical world, "Eurasia", which together with two others worlds - "Europe" (Western Europe in common use) and "Asia" (the rest of common Asia) form the Eurasian continent. Savitsky insisted that these geographical features determine the past and future history, economy, culture, etc. Just follow his predictions we associate now with Northern Eurasia "regions in transition", i.e., those with societal, land use, and economic changes.

According to the Eurasists' school, the first unique peculiarity of Northern Eurasia is the broad geographical horizontal zonality. From the coast of the Arctic Ocean to the coast of the Black Sea, not only the climate changes in the direction of increasing aridity, but even the water table has a single slope from near the surface in tundra to around or above 50 meters at the Black Sea shores. The second unique peculiarity is the existence of the Central Latitudinal Axis along the border of the forest and forest – steppe zones or inside the latter zone. Along the Axis, the soils are most fertile and the biodiversity reaches its maximum. The third unique peculiarity is the north-south symmetry on both sides of this Axis – many features are changing to the north and south of it in a similar manner – the biodiversity and bio-productivity diminish, the color of soils (and animals!) becomes whiter (e.g., white wolves in tundra and deserts), the soil became thinner, there are many analogues in the soil chemistry between swamps in the north and solonchaks in the south. We observe a cycle of biomes: desert, tundra, forest, steppe, desert (special case: Far East). This gave Savitzky the reason to formulate the periodical low of zonality –the term that 20 years later was developed further by Grigoriev (1954). Finally, the fourth peculiarity is the two possible ways of evolution – expansion or thinning the central zones in both directions from the Axis simultaneously. The details of geology and topography too may cause the Axis-ward and Axis-away processes. Savitzky stressed that biota not only depends on soils and climate but also feed back to them, just like we all believe now (e.g., Kabat et al. 2004).

2.3. Goals and deliverables

Through conducting the scientific research during the next decade as addressed in the NEESPI Science Plan the following products are expected:

- ***An integrated observational knowledge data base for environmental studies in Northern Eurasia that includes validated remote sensing products***
- ***A suite of process-oriented models for each major terrestrial process in all its interactions (including those with the society)***
- ***Prototypes for a suite of global and regional models that seamlessly incorporate all regionally specific feedbacks associated with terrestrial processes in Northern Eurasia and which could serve to improve scientific understanding that would enable future environmental change projections and provide input to informed decision-making for land use and environmental protection policies***
- ***Systems demonstrated in the research domain in collaboration with operational partners that can serve the emergency needs of the society (early warning / management / mitigation of floods, fire, droughts, and other natural disasters)***

2.4. Specific objective for remote sensing in Northern Eurasia

Currently, NASA, NOAA, NASDA, ESA, and Rosaviakosmos satellites conduct monitoring of various characteristics of the Earth climate, environment, and land use. New launches will occur in the years to come. Sensors on board these satellites and techniques for data interpretation rely on understanding of the processes of interaction among radiation, the Earth surface, and the atmosphere. When these processes are poorly understood or they change, remote sensing is difficult. Avoiding this situation is a key objective of world space agencies. *NEESPI studies will secure improved interpretation of current and future remote sensing information in Northern Eurasia and provide the bridge between this information and historical in-situ observations.* Chapter 4 specifically addresses the tools available and research objectives of remote sensing for Northern Eurasia.

Remote sensing in Northern Eurasia is of particular importance, because vast areas of the region (e.g., Arctic, Siberia, and Central Asia) are not well covered by in-situ observations. Therefore, reliable assessment of the state of present climate and environment and their changes is not doable without integration of high-quality remote sensing products and in situ observations within a suite of global, regional, and process-based models. However, some of present and planned remote sensing products in the region (e.g., precipitation, net ecosystem exchange, surface energy budget, cloudiness, and water vapor) need substantial improvements. Efforts to provide these improvements by *development of better regional retrieval algorithms and establishment of a network for their validation will be one of important objectives of the NEESPI studies.*

2.5. Rationale for the synthesis approach and linkages

Terrestrial ecosystems, being an integrating component at the land surface and, in some sense, one of the major forms of the biogeochemical cycle, absorb, control, transform, react to, and, to some extent, generate the changes in all these cycles. Human activity exercises controls on all these cycles, depends upon them, and reacts to their changes. Therefore, in Northern Eurasia all components, climatic processes, environmental changes, and the societal sustainability, are closely and substantially interconnected to each other and should be studied together in an interdisciplinary fashion. This approach is further justified in Chapter 3.5. The global role of Northern Eurasia and its response to global change are shaped by complex interactions among many processes, including climatic change, land cover and land use change, ecophysiological and successional processes in ecosystems, wildfire and other disturbances, changes in permafrost, snow, and ice, hydrologic processes in rivers and wetlands, social, and technological changes. Traditionally, studies of these processes were segregated by discipline and geographic zone or ecosystem type. However, many of the important processes that define the environmental role of Northern Eurasia occur at the boundary between zones and ecosystems as the balance between forest and tundra, wetlands and agriculture, forest and wetland, in the coastal zone, shifts with changing climate and land use. *Interdisciplinary studies are critical for understanding these changes.*

The NEESPI science plan includes **education, satellite monitoring, data acquisition and information technology, and modeling components**. The rationale for the education component is the anticipation that a network of students will gain expertise in this area while working on the Initiative. This is especially important for the newly independent countries of the Commonwealth of Independent States and Mongolia, where a significant reduction of investment in environmental sciences has been observed in the past decade. By outlining the modeling, monitoring, and information technology aspects of the study, we want to emphasize the role of new tools (primarily remote sensing, new modern field observation techniques, and modeling) that will be widely employed while working on the Initiative. Four core countries involved in the Initiative (Russia, China, Japan, and the United States), as well as the European Union, have space study capabilities that can be further developed, enhanced, and employed for the Initiative objectives. Within the integrative framework of the Northern Eurasian partnership, the NEESPI studies will include learning from and contribute to other relevant regional and global programs existing and/or projected under umbrella of the World Climate Research Programme (***WCRP***), International Geosphere-Biosphere Programme (***IGBP***), and others. In particular, close collaboration and intertwining of efforts are anticipated with two integrated regional projects ***NORTH*** (NORTHern Latitudes Observing System that is currently under development by the European Union Research Community) and ***SEARCH*** (Study of Environmental ARctic CHange, a U.S. Interagency Research Program; http://psc.apl.washington.edu/search/).

3. MAJOR SCIENTIFIC TOPICS

3.1. Terrestrial Ecosystem Dynamics

Contributors: **S.A. Bartalev, A.S. Isaev, H.H. Shugart,** A.G. Georgiadi, P.Ya. Groisman, G.N. Koptsik, S.V. Koptsik, N.I. Koronkevich, O.N. Krankina, G.S. Kust, N.V. Lukina, A.D. McGuire, A.A. Sirin, V.S. Stolbovoi, S.E. Vompersky, and D.G. Zamolodchikov

3.1.1, Introduction

Information on the status and dynamics of terrestrial ecosystems, the understanding of main driving forces, and prediction of future consequences is essential for global change science, implementation of environmental treaties, development programs, natural resource management, and environmental protection. Terrestrial ecosystems are primary components within the Earth system and strongly interact with other fundamental components of the planet such as the atmosphere, ocean, and human society (Figure 3.1). The mechanism of their interactions is based on the matter and energy exchange processes. In spite of complexity of these interactions, they can be quantified through the appropriate measurement and modeling of water/energy exchanges and biogeochemical cycles.

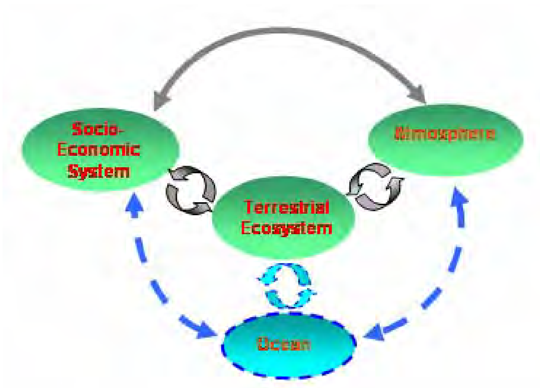

Figure 3.1. Primary interacting components within Earth system.

Terrestrial ecosystems are a source of goods of vital importance for the human society (agricultural production, timber, fuel, and etc). The production of these goods produces significant changes in the landscape pattern and dynamics. Nonetheless, climate is the dominant factor controlling the geographic distribution of the biomes. Climate also drives the phenological dynamics of land cover through seasonal changes in temperature, light, and moisture availability. The vegetation of the northern territories is sensitive to climate change due to the importance of temperature as the main limiting factor for plant growth and succession. Such change in vegetation and land cover characteristics will be a particular focus of the NEESPI terrestrial ecosystem dynamics component. Plans for study of the interactions between terrestrial ecosystems and climate are laid out in Chapter 3.5.

Northern Eurasia is the world's largest terrestrial reservoir of carbon and a region over which climatic variations already appeared, but it is also a region of abrupt, recent changes in the Socio-Economic System that drives anthropogenic land cover change. The collapse of the USSR in the beginning of the 1990's and the subsequent formation of several new independent states have produced profound changes to land-use over much of Northern Eurasia. A focus on these human-induced changes is also a topic of this chapter. Plans to study the feedback changes in human society and corresponding societal-ecosystem linkages are laid out in Chapter 3.4. Changes in Northern Eurasia that affect terrestrial ecosystems and the global climate system are addressed in a set of Chapters (3.3, 3.5, and 3.6).

3.1.2. Ecosystem pattern and key features.

Most of the section has been moved to the Scientific Background Appendix

Northern Eurasia embraces conditions ranging from the arctic deserts and tundra of the north down to some of our planet's oldest forests at the borders of the southern dry steppes, to the arid deserts that span the southern region (Figure 3.2). Northern Eurasia's land cover map for the year 2000 (Figure 1.1) derived from SPOT-Vegetation satellite data gives the most up-to-date and accurate geographical description of the terrestrial ecosystems of the sub-continent. The ecosystems overlap and grade one into another over extensive transition zones, such as forest-tundra, forest-steppe, or semiarid ecosystems. While the role of the climatic factors is important, the distribution of ecosystems also strongly depends on soil forming rocks, relief, and on land-use history and disturbance regimes. The actual composition and geographic distribution of ecosystem types are a result of complex interactions of biota with climate, as well as with other natural and human induced factors (Figure 3.3; Stolbovoi and McCallum, 2002).

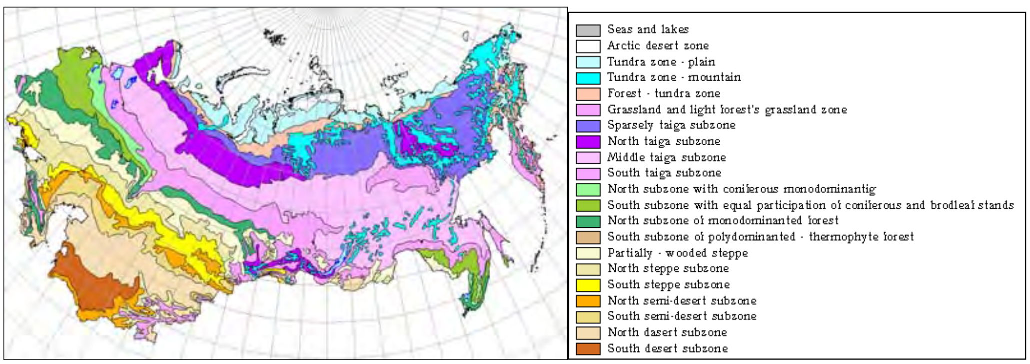

Figure 3.2. Main natural terrestrial biomes of former USSR (Kurnaev, 1973)

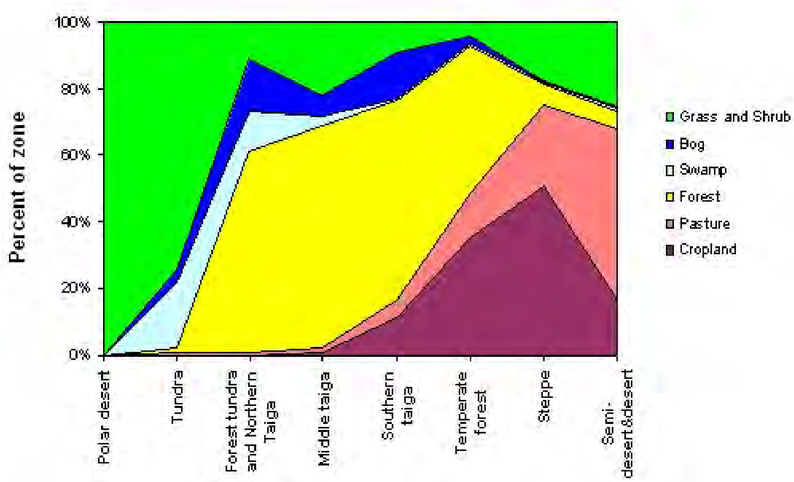

Figure 3.3. Land cover / land use mosaic by natural biomes of Russia

Vegetated lands. In Russia alone, the area of vegetated lands is assessed to be 1630 million ha and the living vegetation biomass of terrestrial ecosystems is estimated as 81.8 Pg of dry matter, including 59.47 Pg accounted for by above-ground phytomass (Morozova, 2002). The aboveground phytomass is highly variable over Northern Eurasia. The lowest aboveground phytomass, about 1 t/ha, is typical for Arctic tundra and desert communities. This amount increases in open woodlands up to 20-40 t/ha, and reaches values of 110-230 t/ha in the forest ecosystems of northern and southern taiga. For some southern broad-leaved forests, aboveground phytomass may reach values of up to 310 t/ha. Although the general pattern of geographical distribution of aboveground phytomass in Northern Eurasia is known and ranges of its variability are quantified, the spatial resolution and accuracy of existing data is far from what is required by global change science and sustainable natural resources management. Biophysical characteristics of Northern Eurasia's vegetation cover, such as Leaf Area Index (LAI) and Fraction of Photosynthetically Absorbed Radiation (fPAR), are imperative for estimation of ecosystem productivity, but still require improvements of their estimations, including geographical distribution and seasonal changes. The status and dynamics of vegetation composition at the level of plants' life forms and/or species and its structure may serve as an important indicator of climate change. They must also be taken into account for biodiversity assessment and as a basis for a wide range of socially important human activities, e.g. forestry and agriculture. The regularly updated data on structural properties of the vegetation cover (vertical and horizontal), such as the presence of vegetation layers and height and density of vegetation cover may serve as important indicators of climate change. They are also needed as input variables into models of energy and water cycles and are essential for land use management. The data on the structural properties of the stands over a significant part of Northern Eurasia is routinely collected by national forest services but, the use of these data at the sub-continental level has come with some difficulties - particularly its lack of accuracy and reliability and, in many cases, its limited accessibility for the research community. For the non-forest natural ecosystems, such as tundra and grasslands, the descriptions of vegetation composition is mainly obtained by dissociated research groups on the test sites with unknown accuracy resulting in non-uniform data sets for the sub-continent. The conclusion can be made that, at *the sub-continental level of Northern Eurasia, there is a lack of uniform data with known accuracy of composition and structural properties of vegetation cover*.

Peatlands. The world's largest peatland territories are found in the West Siberian mire massif while The Polistovo–Lovatsky mires are the biggest in Europe. Russian peatlands support globally significant biodiversity and provide a variety of hydrological and biogeochemical functions valuable to people throughout Eurasia. Peatlands are characterized by the unique ability to accumulate and store dead plant material originating from mosses, sedges, reeds, shrubs, and trees as peat, under waterlogged conditions It is difficult to determine whether a mire/peatland ecosystem works as a sink or source of carbon at a given moment. This source/sink function can change from year to year with long- or short-term climatic changes working as a triggering mechanism. Paludified lands and forests having a thin peat layer (<30 cm) are especially sensitive to such functional changes. There is a strong need to improve data on the peat-covered area over Northern Eurasia considering nature diversity of the regions, peatland/mire typology, and peat depth. Remote sensing data could make a valuable contribution to peatland inventory and hard-to-reach northern and eastern regions may have no alternative. Peatlands provide a wide range of wildlife habitats supporting important biological diversity. They play an important role in maintaining freshwater quality and hydrological integrity and carbon stores and sequestration. Peatlands contain one-third of the world's soil carbon and 10 % of the global freshwater volume (Wise …, 2002). Only in Russia can peatlands store from 113.5 (Vompersky et al., 1996) to 210 Gt C (from the data for the USSR obtained by Botch et al., 1995), which makes up 20–50 % of the world's peatland carbon. Peatlands present a high variety of natural conditions and, thus, have quite a different peat accumulation rate, contribution to the other components of the carbon balance, GHG emission, etc. (Vompersky et al., 1998; Vasiliev et al. 1999; etc.). *The accurate data on carbon and water storage, carbon accumulation rate, and GHG emission for Russian peatlands must be developed* using adequate methodological approach to be work properly. From a conservation point of view, it is important that most of the peatlands are relatively intact and offer a rare opportunity for conserving areas large enough to allow natural hydrological and ecological processes to occur.

Fresh water systems. Besides socio-economic functions, fresh water systems (rivers, interior lakes, and reservoirs) play a very important role as a factor of environmental sustainability as well as important link between global and regional cycles of carbon and other biogenic elements (3.2). Because of low water temperatures, the processes of self-purification in the majority of rivers and water bodies of Northern Eurasia go on slowly and that is why the fresh water systems are especially vulnerable. The biotic component of fresh water systems is also very vulnerable to external impacts, including anthropogenic ones. At the same time, it fulfils extremely important functions of the regulation of the fresh water systems state, their self-purification, and self-recovering. Fresh water systems fulfil their regulating optimally when values of their parameters are close to the natural ones.

The important task is to identify optimum balance between economic demands in water and biological resources and their possibilities for themselves preservation. The important index of fresh water ecosystem change is the degree of transformation of structure and metabolism of biocenosis or their ecological modifications (Izrael and Abakumov, 1991). In populated regions of Northern Eurasia, many rivers and water bodies are in a state of anthropogenic ecological tension and ecological and metabolic regress by hydrobiological indices.

Problems. The information on actual the geographical pattern and characteristics of the terrestrial ecosystems need to be improved in order to provide better understanding of land cover distribution over all of Northern Eurasia for better understanding of the main driving forces of the ecosystem dynamics and their links with the fundamental physical, biogeochemical, and socio-economic processes within the Earth system. A particularly advanced land cover database for Northern Eurasia has to be developed with the use of elaborated classification approach for tundra, forest, and peatland ecosystem components. The vegetation cover component of the NEESPI land cover database need to be linked with biophysical (LAI, fPAR, NPP, above- and below-ground biomasses, etc) and structural (plant composition, height and density of the cover, presents of the layers, etc.) properties, which may provide essential input into appropriate global and regional models and serve as indicators of climate change. The complementary database with information on soil and permafrost formations has to be developed in order to compensate the lack of accurate and uniform data related to these important issues. The dramatic scale by which anthropogenic changes happened during the last century, such as conversion of the forests and steppe into agriculture lands and replacement of taiga by secondary broadleaf forest formations as a result of intensive timber harvesting, drying-out of wetlands, and peatland exploitation, are not well documented. Changes also include land cover, vegetation composition and structure induced by fires, insect outbreaks, timber harvest, agricultural establishment and abandonment, overgrazing, air pollution, etc. A multidimensional time series (magnitude and geographical pattern) of the ecosystem changes resulting from these disturbances may provide essential input for the theoretical assessment of the biogeochemical, water, and energy cycles. This can lead to understanding of the climate-ecosystem interactions as well as to the identification of critical regions where the ecosystem changes may lead to environmental degradation or social conflicts. *Reconstruction of the land cover changes over the entire Northern Eurasian territory over the last century in order to estimate their scale and geographical pattern has to be considered among priority scientific tasks of the NEESPI.* This includes the collection of data on responses of the ecosystems, in particular, changes of the phenological rhythms of the vegetation, biophysical properties of the plants, frequency and severity of climate dependent (fires, insects, plant epidemics) disturbances, structure of the vegetation and species composition, as well as changes in the geographical distribution of biomes. *The task performance will require intensive involvement of the historical data records and maps, air photographs, and available satellite images.* The satellite images date back to the early 1960s. Starting from this time, the spatial and temporal resolution of land cover change products may be increasingly improved.

3.1.3. Soils. Most of this section has been moved to the Scientific Background Appendix

Soils act as a reservoir for carbon in the form of soil humus. In this case, any type of soil degradation, as a rule, leads to disengagement of soil carbon to the atmosphere and the lack of such data provides mistakes in the modeling of the global carbon cycle and global climate. The second point is that soils are home to more than 80% of terrestrial animals and act, in this case, as the necessary element for biodiversity conservation issues. Lastly, soils act as a "shield" for litho- and hydro- spheres preventing their destruction and pollution and providing the sustainability of their chemical composition (Dobrovolskiy and Kust, 2003). Unfortunately, the understanding of the role of soils in the biosphere is a very new scientific concept and there are almost no data on soils on this issue. Most soil data have been collected only for agricultural and (much less) for forestry purposes; they were presented in the forms of land inventories and not renewed for the past 20 years. Moreover, most of these data were not published and are stored in "hard copies" in the archives of different organizations (Kust and Kutuzova, 2003). The conclusion can be made that *there is a lack of present uniform soil data available to use for the adequate assessment of the real role of soil cover in the environmental changes of Northern Eurasia*

3.1.4. Driving forces of the large-scale ecosystem dynamics

Terrestrial ecosystems are highly dynamic due to both natural forces and anthropogenic actions. An important objective of NEESPI is to improve our knowledge on large-scale dynamics of terrestrial ecosystems over all of Northern Eurasia (including past and immediate changes), to gain a comprehensive understanding of the main driving forces of these dynamics and scientific explanation of their links with the fundamental physical, biogeochemical, and socio-economic processes in the Earth system. This knowledge may also serve for better prediction of possible future changes in the geographical pattern of the land cover, structure, and productivity of the terrestrial ecosystem (the magnitude and spatial variability of the main dynamic factors under various scenarios of climate change and social development). There are evidences of dramatic changes of Northern Eurasia's land cover during last few centuries resulting from land-use change and natural disturbances.

Anthoropogenic factor. Considering the most recent history among the most profound human induced changes of 20th century are the conversion of steppe ecosystems in to agricultural lands in Southwestern Siberia and Kazakhstan through extensive logging of taiga forests in the European North of Russia, drying-out of wetlands mainly for peat extraction and agriculture, development of oil and gas production industry in Siberia. Only in Kazakhstan, during the period of years 1954-1960, 25.5 million ha of virgin steppe was newly ploughed and converted to croplands (http://kazakhstan.awd.kz). Broadleaf trees now occupy the vast area of former dark coniferous forests in the taiga belt of European Russia. This conversion happened mainly during the last century and resulted from extensive forest logging in USSR and which had two peaks of activity: at the industrialization time in the 1920s and after the second Word War. As reported by The State Committee on Land Resources of Russia, the annual area of wetlands dried-out during 1991-98 was about 5 millions ha (http://www.aris.ru/MSHP/DEMELIO/hist.html). Certainly, many other examples of land cover change of less impressive scale, but spread almost everywhere over Northern Eurasia, can be given to illustrate the statement. The environmental changes during last century are not well documented and quantified, although such data are needed in order to estimate environmental consequences and mitigate them if they are of negative character. They are also necessary for better understanding of actual ecosystem evolution and prediction of future status and feedbacks. The immediate changes of the terrestrial ecosystems, to a great extent, resulted from natural and human caused disturbances. Post-disturbance dynamics, such as natural regeneration and consequent successions of the vegetation cover within disturbed landscape, is an important component of the terrestrial ecosystem sustainability. Both, the disturbance and post-disturbance dynamics strongly depend on the functioning of the Socio-Economic System, which includes industry, forestry, agriculture, grazing, water management, and other human activities which influence both the terrestrial ecosystem and climate. The well being of the Socio-Economic System, including human health, also strongly depends on the ecosystem status.

Tundra ecosystem. The dynamics of the tundra ecosystem caused by the past climate change considerably vary between different Arctic regions (Serrese et al., 2000) and result in both positive and negative feedbacks in "permafrost – active-layer – vegetation – atmosphere – climate" interactions (Chapin et al, 2000). *The situation stresses the necessity of the development of an adequate methodological base to generalize known effects on permafrost areas of Northern Eurasia.* The system of climate-tundra feedbacks includes more than just the carbon dioxide balance. The lakes and over-humidified tundra soils are important sources of methane fluxes (Zimov et al., 1997). The climate changes can lead to increased unfrozen periods and stimulate methane emissions. On the contrary, a drying climate results in the restriction of tundra wetlands and a corresponding decrease in methane emissions.

Additional problems in the prediction of tundra biome dynamics are created by changes in the feedback hierarchy under long-term climate influence with stimulation of negative feedbacks (Camill and Clark, 2000; Oechel et al., 2000b). *To improve conclusions of climate change effects on tundra ecosystems, it is necessary to have more observations on the system functioning in different regimes over long-term scales.* The specific question is the current destruction of shores of Arctic seas (3.6.2). During this process, the terrestrial substances enter the seawater, affecting the biogeochemical cycles in marine ecosystems. *The scales of coast destruction and ecosystem effects need to be investigated.* The frequency of tundra fires was expected to increase during global warming (Oechel, 1993). The recent catastrophic fire events in the Far-East region of the Eurasian tundra confirm that prediction. Tundra fires often lead to complete destruction of aboveground vegetation cover and up to 15 cm of top organic soil horizons. The direct CO_2 emissions from tundra fires constitute up to 50 tC ha^{-1}. The majority of tundra territories in Russia are not fire protected, which is leading to the absence of data on fire events and burned areas. The period of post fire regeneration of the carbon pool in vegetation is nearly 10 years and, in soil, nearly 100 years (Zamolodchikov et al., 1998). *The up-to-date and accurate data on tundra fires, including burned areas and fire severity, have to be collected on a regular basics.* The important part of the tundra ecosystem is the reindeer populations, as they are a major consumer of the net primary production. The reindeer husbandry presents the basis of life for many native people such as the Nenets, Evenks, Chukchi, and others. *The system approach to the study of tundra biome demands the consideration of reindeer population dynamics as a possible object for optimization* (3.4). The industrial influence on the tundra biome is expressed mainly in resource exploration and pollution (3.4). Any types of building and transportation activity in tundra lead to disturbances of vegetation cover and hydrological regimes, changing the soil heat conductivity and permafrost degradation. The similar processes are observed in polluted zones in The Cola Peninsula and the southern part of The Taymyr Peninsula. *The remote sensing technique is considered as most appropriate to estimate the impact of human caused disturbances on the regional scale* (Virtanen et al., 2002).

The following specific scientific questions may form a basis for tundra ecosystem research activity of the NEESPI science plan:

- *What are regional and zonal trends in permafrost dynamics and related changes in biogeochemical cycles?*
- *What is the climate influence on long-term dynamics of tundra ecosystems?*
- *What are inputs of tundra wetlands and lakes in regional biogeochemical cycling?*
- *What are the scales and biogeochemical impacts of the destruction of sea costs?*
- *What are the scales and ecosystem effects of tundra fires?*
- *What is the role of reindeer populations in biogeochemical cycling of tundra ecosystems?*
- *What is the environmental impact of resource exploration in the Arctic on the regional and zonal scale?*

Forest ecosystem. The current pattern of forest vegetation reflects the combined effects of anthropogenic and natural disturbances over a range of time scales. Nowadays, the growth of forest trees and the functioning of the forest ecosystems are affected by multiple stresses as a combination of climate change and disturbances. Forest ecosystems of Northern Eurasia are subjected to climate changes that may result in changes in length of the growing period and snow cover period, production and vegetation carbon storage enhancement, replacement of tundra with boreal forest, warming permafrost, and fire frequency increase. But some observations in the northern regions were already said to contradict the general predictions on global warming (Normile, 1995; Polyakov et al. 2003)

Thus, there still exist major uncertainties in prediction of the length of the growing season changes. The accuracy of predictions can be increased by the coordinated investigations of past changes in both biotic and abiotic environments (Houghton et al, 1996), taking into account regional variations.

Analyses based on satellite data suggest that both production and vegetation carbon storage have generally been enhanced across the boreal forests in recent decades (Myneni et al, 1997; 2001; Randerson et al, 1999; Zhou et al, 2001), an observation that is consistent with climate warming. One hypothesis for the mechanism of increased production is that warming increases decomposition of soil organic matter to release nitrogen in forms that can be taken up by plants. Since production is often limited by plant nitrogen supply in boreal forests (Van Cleve and Zasada, 1976; Van Cleve et al., 1981; Chapin et al., 1986; Vitousek and Howarth, 1991), an increase in nitrogen availability to plants should increase production. Several boreal warming experiments and modeling studies have provided support for this mechanism (Van Cleve et al., 1990; Bonan and Van Cleve, 1992; Bergh et al., 1998; Stromgrem and Linder, 2002; Clein et al., 2002). Increased N deposition, management changes, and increased CO_2 are also possible explanations for these records (Erisman and de Vries, 2000). Increased accumulation of soil organic matter in European forests has also been observed. One of hypothesis is that increased N deposition causes an increased rate of soil organic matter accumulation due to an increased biomass of assimilative organs, litter production, and a reduced decomposition of organic matter (Berg and Matzner, 1997).

The hypotheses explaining production and carbon storage enhancement across the boreal forests in recent decades have not been critically evaluated for ecosystems in northern Eurasia.

The replacement of tundra with boreal forest occurred in earlier warm periods of the Holocene in Northern Eurasia (MacDonald et al., 2000). Over the last half-century, treeline advances into tundra have been documented in Alaska. There are also some evidences of this phenomenon in Russia (Gorchakovsky and Shiyatov, 1978). Because a significant part of Russian forests (41 %) is categorized as mountain forests, investigation of tree line variations in mountains is of great importance. Permafrost maintains a perched water table that keeps moisture in the root zone and maintains forest cover. Loss of permafrost is expected to increase soil drainage and may result in aridization in these areas and loss of forest cover (3.6.1).

While treeline advance and warming permafrost may affect climate change, investigations of temporal and spatial variations of these phenomena are challenging.

Vegetation type and distribution have large impacts on regional and global climate through effects on terrestrial carbon storage (Smith and Shugart, 1993) and on water and energy exchange (Charney et al., 1977; Shukla et al., 1990; Bonan et al., 1992). Forest ecosystems, through water/energy and radioactively active gases, have an exchange with the atmosphere and may respond to climate change in ways that tend to enhance warming (positive feedbacks) and through effects that tend to mitigate warming (negative feedbacks) (3.2, 3.5). *The present and future role of Northern Eurasia cannot be adequately understood without better knowledge of response of forest ecosystems to climate change. Of particular concern is the likelihood of amplifying a feedback loop that can cause a further warming (3.5).*

Disturbances. Human influences on the disturbance regime include both direct effects, such as harvesting or inducing and/or suppressing natural disturbances (fires, insects, flooding, etc.), and indirect effects from altering the forest environment. Indirect influences include both climate change and atmospheric pollution and their effects on tree health and survival.

Because of natural and human- induced disturbances, forest area in Northern Eurasia is a gigantic mosaic of successions (Smirnova, 2004). The most important disturbance factor in the forests of Northern Eurasia is ***fire***. In northern Eurasia, most of the fires occur east of the Ural Mountains. It is estimated that large fires account for 90% of the area burned in central Siberia (Ivanova et al., 2002). Official fire statistics available from Russia suggest that area burned in Russia is much less, with only approximately 1 million ha burning annually, and that the maximum annual area burned is less than 3 million ha (Kasischke et al., 2003). However, analyses based on satellite data estimate that 11.7 million ha burned in 1987 and that 13.3 million ha burned in 1998 (Conard et al., 2002; Kasischke et al., 2003). More careful analyses of fire frequency in Russia suggests that fire frequency in Siberia is higher than in Alaska and Canada (Shvidenko and Nilsson, 2000; Shvidenko and Goldhammer, 2001; McGuire et al., 2002). Thus, for boreal forests outside of Europe and European Russia, official statistics of fire in Russia represent a significant underestimation of burned area and available data suggest that between 0.5 and 1% of boreal forest burns annually with the highest rates in Siberia along the Yenisey River (McGuire et al., 2002). The degree to which increased fire frequency has the potential to release carbon in the boreal forest depends, in part, on fire severity. Fires in central Russia, which is dominated by Scots pine, tend to be surface fires in which trees survive because of thick bark. In contrast, fires in far eastern Russia tend to be stand-replacing fires. Analyses of the effects of climate change projections on fire weather suggest that climate change has the potential to increase fire frequency in northern Eurasia (Csiszar et al., 2003). *A major challenge is to understand how the extent, timing, and severity of fires in northern Eurasia change in response to climate and other factors.* Periodically Northern Eurasian forests are subject to massive ***insect infestations*** that occur on millions of hectares, causing forest dieback or damage. These outbreaks are induced by a combination of favorable weather conditions (optimal temperature, low levels of precipitation and humidity) and occur with a periodicity of 15 to 25 years. Harsh climatic conditions have, thus far, limited the outbreaks to areas below 60^{o} north latitude. However, with increased warming, outbreaks may occur in the forests north of this line since desirable food species are available. *Adequate detection and mapping of insect outbreaks is essential for understanding of their impacts and the assessment of potential for northward expansion*. The forests of northern Eurasia represent a wood resource of global significance. Forests are heavily managed for wood production and harvest resulting in losses of the organic matter and nutrients. In general, ***forest harvest and management*** results in lower vegetation and soil carbon stocks than equivalent unmanaged forests. Wood harvest could reduce carbon storage in Siberia's boreal forest (Rosencranz and Scott, 1992) and may have already done so. Agricultural activities in Northern Eurasia have also been changing rapidly over the last decade. According to official statistics, 29 million ha of arable lands were lost in Russia from 1990 to 1999 (Russian Statistical Yearbook, M., Goscomstat RF, 642 pp). Ongoing analyses of satellite data indicate that most of the abandoned agricultural land is converted to young forest regrowth (Bergen and Zhao, 2003; Utkin and Zukert, 2003). While the ***abandonment of agricultural lands*** is likely increasing carbon storage in Northern Eurasia, the increase has not been well quantified. *Because of the changing dynamics of logging and agriculture in northern Eurasia, it is important to understand how these disturbance regimes are changing throughout Northern Eurasia to better understand net changes in carbon storage associated with these activities.* Nowadays, ***air pollution*** is an important driving factor of forest dynamics. According to modern hypotheses, the growth of forest trees and the functioning of the forest ecosystems are affected by a combination of direct air pollution, indirect soil-mediated acidifying impacts of S, N deposition and eutrophication, and changes in weather conditions, either acting directly via drought or indirectly via pest infestation or fungi attack (Erisman and de Vries, 2000). In Russia, monitoring and investigations of pollutant effects on forests are rather scarce and a critical load of these pollutant maps are based on a limited amount of data (see Downing et al, 1993; Posch et al., 1995, 1997; Koptsik and Koptsik, 1995; Koptsik et al., 1996; Semenov et al., 2001). Application of dynamic models is much more limited (Koptsik and Koptsik, 2001). In recent years, concerns about the large-scale dispersion of heavy metals that may regulate the C cycle through impacts on microorganisms have arisen. That is why quantitative analyses and predictions are important for non-acidifying atmospheric pollutants, as well. Results showed that the uncertainties in the calculated critical load values are considerable. Important sources of possible error include variations in soil properties over Russia, the restrictions of the methods used, and the application of the effect-based threshold levels. Thus, *at present, there are no systematic assessments concerning critical loads of S, N, and heavy metals on Northern Eurasia's forests. Critical load maps should be revised as new experimental input data become available and as assessment methods will be improved. To gain insight into damage delay or recovery time, application of dynamic models is needed.* Obviously, due to a lack of data and other resources, it would be impossible to run dynamic models on all sites in Russia for which critical loads can be calculated. However, the assessment of short and long-term environmental risk of excess sulfur, nitrogen, and heavy metal inputs on forests with a dynamic biogeochemical model seems to be reasonable for a few (key) intensively monitored sites in Russia.

The different types of disturbances are often linked. For example, in some forest types the probability and intensity of fire may increase following insect outbreaks because of increases in available fuel. In other cases, salvage logging (recovering the usable timber following a disturbance) can reduce the total area of living forest that is disturbed in a given year by all agents combined. It is common to try to replace natural disturbances (such as wildfires) with commercial harvesting using a combination of protection and scheduled logging. The interactive effects of disturbances and climate change need to be studied. Fire, insect outbreaks, timber harvest, agricultural establishment and abandonment, and air pollution fall within the disturbances resulting in large-scale changes in forest biome that may affect climate. The major challenges are:

- *to critically evaluate the hypotheses explaining production and carbon storage enhancement across the boreal forests of Northern Eurasia in recent decades*
- *to assess temporal and spatial variations in tree line advance and warming permafrost phenomena in Northern Eurasia*
- *to understand how the extent, timing, and severity of fires in Northern Eurasia change in response to climate and other factors*
- *to detect and map insect outbreaks and to assess the potential for northward expansion*
- *to understand how logging and agricultural establishment and abandonment regimes are changing throughout Northern Eurasia*
- *to assess critical loads of S, N, and heavy metals on Russian forests with application of dynamic models to gain insight into damage delay or recovery time.*
- *to assess the balance between positive and negative feedbacks (net effect) that can generate climate change.*

Grasslands and arid ecosystems. Grasslands, and especially semi-desert and desert ecosystems, are very fragile. At the same time, grasslands are the main regions for the primary agricultural activity. Now, despite the big area occupied by grasslands and arid ecosystems in Northern Eurasia, one can find here very few plots of natural grasslands (that are substituted mostly by arable lands) as well as a great areas of degraded ecosystems in arid and semi-arid conditions (usually used for grazing). The natural biomes remain only on the territories of protected areas (natural reserves and parks, military polygons) or in remote, unsettled regions. Desertification is determined by the UNCCD (1992) as land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities. Principal factors of desertification in the region are connected with pasture degradation (overgrazing) and cause unfavorable changes in the species composition of pastures (decrease in grass yield in the hayfields and rangelands). The second main cause is the unjustified tillage of soils that leads to wind and water erosion, causing the development of dust-storms and an increase in the mobile sand area. Improper (especially drainless) irrigation, such as abuse of irrigation technology during drought conditions, usually causes secondary salinization and alkalinization. These causes, as well as felling of trees and shrubs for fuel in economically weak developed regions separately or in synergetic ways, result in the increase of the surface albedo, loss of biological diversity, depletion and pollution of local water resources, increase in climate aridity manifested in the increased occurrence, intensity, and duration of soil and atmospheric draughts. A lot of local causes being replicated are comparable with regional and global effects, and manifested in the following degradation trends: water erosion of soils, formation of sands that are subjected to deflation, salinization and/or alkalinization of soils and ecosystems, soil compaction, and soil dehumidification. The desertification phenomena does not take place everywhere in the area, but the potential risk of various desertification trends occur in 90-95% of the whole grassland territory (Andreeva and Kust, 1999). The following specific scientific questions may form a basis for grassland, arid and semi-arid ecosystems research activity of the NEESPI science plan:

Assessment of the past, present and future dynamics of ecosystems

- *What were the initial pre-industrial conditions in drought affected ecosystems in the past (natural trends, human induced trends)?*
- *What are the observed trends? Have they changed during the last decade?*
- *What changes are predictable?*

Land-use and natural land resources

- *What were the effects of the land uses and land-use changes on the Earth system function (e.g. regional climatology, water resources, carbon and surface energy balance, biogeochemistry, biodiversity)?*
- *What lessons can be learned from system responses of dramatic land-use modifications for sustainable natural resource management?*
- *How do human modifications of land cover affect regional Northern Eurasian and global ecosystem functions and ecosystems feedbacks?*
- *What is the vulnerability of grasslands, semi-arid, and arid ecosystems (incl. agricultural lands) to expected climate and socio-economical trends?*

Peatlands. Human activities continue to be the most important factors affecting peatlands. Vast peatland areas in Russia are being traditionally used in a broad range of activities. Human pressures on peatlands are both direct, through drainage, land conversion, excavation, inundation and visitor pressure, and indirect, as a result of air pollution, water contamination, water removal, and infrastructure development. The key management issues related to peatlands in Russia are peat extraction for different purposes (fuel, cattle breading, horticulture, fertilizers, chemistry, medicine, etc.) and drainage for agriculture and forestry. The main indirect threats to peatlands in Russia are peat fires, road and pipeline construction, contamination in oil and gas mining regions, air pollution, and recreation activities within populated regions. The vast territory, different traditions, and social-economic background lead to geographical and spatial uncertainty of peatland use and threats to them in Northern Eurasia. Many important sites have been destroyed and degraded throughout most of the industrial and agricultural regions. A few data available demonstrated a high variety of peatlands' reactions to paleoclimate change (Klimanov and Sirin, 1997; etc.). Dry/wet and cold/warm periods in the past were marked by changes in vegetation species compositions, in carbon accumulation values, but sometimes no reaction could be found. Mires worked out several specific mechanisms to survive during unfriendly periods and we could not expect an equal response of peatlands, having a different origin and geographical location, to future climatic changes. The following specific scientific questions may form a basis for peatland ecosystem research activity of the NEESPI science plan:

- *What is the present day paludification? What approach and methods should be worked out and used to study it on a local and regional level?*
- *What was the reaction of peatlands and paludified forests of different origins to paleoclimate changes, especially during last Millennium, and what we could expect under various climate change scenarios?*
- *What are inputs of peatlands in regional biogeochemical cycling?*
- *What are the environmental effects today of peatland exploitation under different land use practice, peatland nature origin, and geographical conditions?*
- *What are the scales, ecosystems' and environmental effects of peatland fires?*
- *What changes could be expected under climate change scenarios concerning peatland regulation functions (watershed hydrology, carbon sequestration, GHG emission, etc.), their resources, and biological diversity?*

Fresh Water Systems. Climatic short-term and long-term dynamics is one of the main forces of hydrological changes (Belyaev and Georgiadi, 1992; Klige et al., 1998). From the beginning of 20th century, and especially since 1930s, the increasing role begins to play the anthropogenic factor, which is imposed on natural variability, increasing during the whole 20th century, till the 1980-1990s (Koronkevich, 1990). The fresh water systems of the central and southern parts of the Russian plain, (the southern and western parts of Siberia) were characterized by an extraordinarily high intensity of river runoff resource use (Voronkov, 1970; L'vovich, 1974; Water Resources…, 1987; Shiklomanov, 1989, 2002; Koronkevich, 1990; etc.). The following specific scientific questions may form a basis for water system research activity of the NEESPI science plan:

- *How do fresh water systems, including their biota, respond to changing conditions of climate and economic activity? What is the contribution of each of them to the change of the amount and quality of water resources (state of water ecosystems)? What is the hydrological role of human activity on river watersheds, which affects fresh water systems indirectly through soils, surface biota, and the atmosphere?*
- *Which hydrological changes have taken place in the contemporary period (since the beginning of the 1990s) in fresh water system functioning due to a specific combination of natural and anthropogenic factors of water resources formation?*
- *What are the maximum permissible anthropogenic loads upon fresh water systems, both on quality of water in them and on its volume?*
- *What is the contemporary state of fresh water systems in the main regions and river basins of Northern Eurasia and what is their contribution to sustaining the equilibrium in the biosphere of the Earth?*
- *What will the future state be for the fresh water system as a result of the possible climate change and economic activity?*
- *What should be done in order to optimize the contemporary and expected unfavorable changes of fresh water systems?*

3.2. Biogeochemical Cycles

Chapter lead authors: A.D. McGuire and N.V. Lukina

Contributing authors: A. G. Georgiadi, M.E. Harmon, O.N. Krankina, A.G. Lapenis, Sh. Maksyutov, D.S. Ojima, A.V. Oltchev, K.J. Ranson, A.Z. Shvidenko, N.N. Vygodskaya, and D.G. Zamolodchikov

3.2.1.1. Why is it Important to Understand the Biogeochemical Cycles of Northern Eurasia?

Terrestrial ecosystems are an important component of the dynamics of the biogeochemical cycles of the Earth system. Biogeochemical cycles are important to understand because they play a key role in the functioning of the climate system and because they are responsible for providing goods like food and fiber for use by human societies. Because Northern Eurasia represents a substantial proportion of the vegetated surface of the Earth that is currently undergoing dramatic changes in climate and land use, the response of terrestrial ecosystems of Northern Eurasia to global change have the potential to influence biogeochemical dynamics of the region in a way that has implications for the climate system and for the regional and global welfare of human societies. The carbon cycle of Northern Eurasia is important to understand because it is directly relevant to the concentrations of radiatively active gases in the atmosphere and the yields and harvests from agriculture and forestry.

3.2.1.1. The Regional and Global Context of the Carbon Cycle in Northern Eurasia

The carbon cycle of terrestrial ecosystems in Northern Eurasia has the potential to influence the climate system primarily through affecting the atmospheric concentrations of the radiatively active gases carbon dioxide (CO_2) and methane (CH_4). These radiatively active gases are of concern globally because CO_2 is currently increasing by 0.4% per decade and CH_4 is increasing 0.6% per decade. Since 1750, increases in atmospheric CO_2 and CH_4 are estimated to be responsible for trapping 1.46 W m^{-2} and 0.48 W m^{-2}, respectively, which is about 80% of the estimated radiative forcing of 2.43 W m^{-2} that has been attributed to greenhouse gases since 1750 (Ramanswamy et al. 2001). A number of recent analyses based on atmospheric inversion models have identified that the exchange of CO_2 between northern ecosystems and the atmosphere is characterized by substantial spatial and temporal variability. Atmospheric analyses generally agree that high latitudes were a modest sink of carbon during the 1980s and early 1990s (Rayner et al. 1999; Bousquet et al. 1999, Dargaville et al. 2000), and that a majority of the sink was in Eurasia (Schimel et al. 2001). These analyses suggest that ecosystems of Eurasia may be mitigating the increase in atmospheric CO_2 caused by the burning of fossil fuels.

While CO_2 has been responsible for a majority of the radiative forcing associated with greenhouse gases, the increase in atmospheric CH_4 is of concern because CH_4 is 23 times more effective per molecule than CO_2 in absorbing long-wave radiation on a 100-year time scale (Ramanswamy et al. 2001); on a 20 year time scale CH_4 is 62 times more effective. In recent decades, it has been estimated that 270 Tg CH_4 yr^{-1} are emitted from natural sources (Prather et al. 2001), of which 65 Tg CH_4 yr^{-1} are emitted from northern wetlands (Walter et al. 2001a). Peatlands are estimated to be responsible for 60% of CH_4 emissions between 50^o N and 70^o N (Matthews and Fung, 1987). The exchanges of CO_2 and CH_4 between Northern Eurasia and the atmosphere are particularly relevant to the climate system because ecosystems of this region are one of the world's largest organic carbon stores in vegetation and soils. Of the nearly 700 Pg C contained in tundra and boreal biomes (nearly 30% of global terrestrial carbon storage), approximately half this storage occurs in Russian ecosystems alone (Nilsson et al. 2000, Shvidenko et al. 2000). Much of the soil carbon storage in the region is stored in peatlands, which occupy about 20% of Russia's land cover and contain about 120 Pg C (Vompersky et al. 1994, Alexeyev and Birdsey 1998). Riverine export of terrestrial ecosystem carbon to coastal and ocean ecosystems, which is estimated to be about 60 Tg C yr^{-1} from Russian rivers (Nilsson et al. 2003), is another important link in the global carbon cycle that is controlled by terrestrial ecosystem processes and hydrologic linkages with freshwater aquatic ecosystems.

The carbon cycle of terrestrial ecosystems in Northern Eurasia has come under direct human management through agriculture (including grazing of domestic livestock) and forestry activities. Human use of plant biomass in these activities uses approximately 15% of the net primary production of Northern Eurasia (Nilsson et al. 2003). The flux of harvestable products that contain carbon not only provide food, but also compete in the market place with fossil fuels, and with other materials for construction (such as cement) and other purposes (such as plastics), and have implications for the global carbon cycle (Kauppi et al. 2001).

3.2.1.2. Interactions of Other Element Cycles with the Carbon Cycle in Northern Eurasia

While the direct effects of biogeochemical cycles on the climate system and human societies can generally be elucidated in terms of the carbon cycle, cycles of other elements interact with the dynamics of the carbon cycle and are also important to understand. Nitrogen is an important element in the chemical structure of enzymatic proteins, which are responsible for catalyzing biochemical reactions in organisms. Interactions between carbon and nitrogen dynamics are particularly important to understand because the production of plant biomass in northern ecosystems is generally limited by the availability of nitrogen to plants (Vitousek and Howarth, 1991). Human activity has modified the global nitrogen cycle in several ways (Vitousek et al. 1997) that may be influencing plant growth in Northern Eurasia. In particular, fossil fuel burning has released nitrogen- and sulfur-based trace gases into the atmosphere, which are being deposited into terrestrial ecosystems. Increased N availability associated with N deposition may cause an increased rate of soil organic matter accumulation due to an increased biomass and litter production combined with reduced decomposition of organic matter (Berg and Matzner, 1997). However, N fertilization in the N deficient northern forests delays the hardening-off process, resulting in increased winter damage, and thus negating some of the growth enhancement (Makipaa et al. 1999). Increasing CO_2 levels may also be affecting the interactions between carbon and nitrogen as N concentration in hardwood leaf litter is reduced when plants are raised in an elevated CO_2 atmosphere (Cotrufo et al. 1998). Interactions of the carbon cycle with other elements are also important to understand. Atmospheric pollution can have impacts on plant productivity (Roose et al., 1982; Scholz et al., 1989; Tingey and Andersen, 1991; Gravenhorst et al., 2000), for example, through the effects of elevated levels of tropospheric ozone and sulfur dioxides in decreasing photosynthesis. Also, the deposition of heavy metals has had dramatic impacts on vegetation downwind from smelters (Johansson et al. 2001).

3.2.1.3. Responses of Biogeochemical Cycles in Northern Eurasia to Global Change

The biogeochemical cycles of terrestrial ecosystems in Northern Eurasia may respond to global change in ways that tend to enhance warming (positive feedbacks) and through effects that tend to mitigate warming (negative feedbacks) (Smith and Shugart, 1993; McGuire and Hobbie, 1997; McGuire et al. 2000a; Chapin et al. 2000; Clein et al. 2002). The net effect will depend on the balance between the two and positive feedbacks to warming are of imminent concern. To predict the effects of climate and land cover change on the future dynamics of CO_2 and CH_4 exchange in northern Eurasia, it is important to understand the processes involved and their spatial and temporal dynamics. Predicting the long-term influence of elevated CO_2 concentrations on the carbon stocks of forest ecosystems remains a research challenge (Bolin et al. 2000; Prentice et al. 2001, Arneth et al. 2002). Ecosystems that initially absorb C in response to higher atmospheric CO_2 will become 'saturated' or even later release CO_2 if increasing temperatures lead to enhanced decomposition and respiration (Cao and Woodward, 1998; Scholes et al. 1999). Fires and other disturbances could increase in frequency and intensity if temperatures increase and precipitation patterns change. The net impact of these, and other global changes, is an area of active research (e.g., Woodwell et al. 1998). Changes in land use also affect the biogeochemical cycles in forest, grassland, and other ecosystems. The dynamics of land use, which are driven by different socio-economic factors in China, Mongolia, Russia and the other former Soviet Union Republics, have implications for biogeochemistry (e.g., the stability of permafrost has been affected in areas disturbed by resource extraction activities; Ivanov 2003). However, how these changes have affected biogeochemical cycles in not well documented and is not well understood. The future trends of land use are uncertain and will likely affect the future storage of carbon and the dynamics of other biogeochemical cycles in the region.

3.2.2. Science Questions

Because Northern Eurasia plays a major role in the global carbon cycle, understanding this role and projecting the future dynamics of biogeochemical cycles in Northern Eurasia is critically important to understanding and projecting the future dynamics of the climate system. Furthermore, an improved understanding of the biogeochemical cycles in Northern Eurasia is important for developing comprehensive, policy-relevant knowledge of the global carbon cycle. A major objective of the UN Framework Convention on Climate Change (FCCC) is decreasing concentration of radiatively active gases in the atmosphere, which requires a full accounting of the dynamics of these gases (Steffen et al. 1998). Thus, the NEESPI science questions that we define for biogeochemical cycles are designed to be parallel with the major themes of the Global Carbon Project (2003), which has developed an international framework for understanding the dynamics of the global carbon cycle in a manner that develops knowledge relevant to predicting responses of the carbon cycle and for supporting policy decisions to manage the carbon cycle. Thus, the NEESPI program addresses the following broad themes with special focus on issues relevant to the Northern Eurasia region:

- **Patterns and Variability:** What are the current geographical and temporal distributions of the major stores and fluxes of carbon and other elements in Northern Eurasia that are important to the functioning of the climate system and human societies?
- **Processes and Interactions:** What are the major drivers and feedback mechanisms – both anthropogenic and non-anthropogenic – that control the dynamics of the carbon and other important biogeochemical cycles at local, regional, and continental scales in Northern Eurasia?
- **Responses of Biogeochemical Cycles:** What are the likely future dynamics of biogeochemical cycles in Northern Eurasia that are important to the functioning of the climate system and human societies?
- **Management of Biogeochemical Cycles:** What points of intervention and windows of opportunity exist for human societies to manage biogeochemical cycles in Northern Eurasia in a way that mitigates the effects of global change on the climate system and human societies?

3.2.3. Patterns and Variability

An understanding of the patterns and variability in biogeochemical cycles is important for developing hypotheses about processes and interactions responsible for patterns and variability, for improving prognostic capabilities to predictively model the responses of biogeochemical cycles to global change, and for providing information relevant policies and management of biogeochemical cycles. Atmospheric, terrestrial, and coastal/oceanic observations are important to developing a better understanding of the temporal dynamics and spatial variability of the carbon and other biogeochemical cycles in Northern Eurasia. Because it is not possible to measure everything, everywhere, and all of the time, patterns and variability must be diagnosed with approaches that involve the use of both observations and models. The approaches to diagnosis in this science plan are similar to those of the North America Carbon Program (NACP). Major elements of the ***diagnostic*** analyses of carbon and other biogeochemical cycles of Northern Eurasia should include:

- A hierarchical approach for large-scale, distributed terrestrial measurements, including improved estimates of patterns of disturbance that are resolved in time and space.
- Systematic compilation and analysis of new and existing remotely sensed imagery for use in models of carbon exchange;
- Comprehensive description of properties of individual landscapes and ecosystems into spatially explicit data layers;
- An atmospheric observing system consisting of ground stations, aircraft and measurements from towers;
- Improved fossil fuel emissions inventories with high resolution in time and space, and methods for evaluating these inventories using atmospheric measurements;
- Improved estimates of nitrogen, sulfur, and heavy metal deposition that are resolved in time and space.
- Hydrologic transfers of carbon over land, and sequestration in sediments;
- Ocean measurements and modeling, both in the coastal zone and the open ocean.
- Synthesis and integration activities organized into three interlocking strategies: Spatially-distributed modeling of carbon cycle processes using process-based models driven by many kinds of observations; top-down synthesis using inversion of variations in atmospheric trace gas composition and tracer transport models; and model-data fusion and data assimilation to produce optimal estimates of spatial and temporal variations that are consistent with observations and process understanding;
- Interdisciplinary intensive field campaigns designed to evaluate major components of the model-data fusion framework in limited domains in space and time for which all major fluxes can be measured by multiple techniques.

3.2.4. Processes and Interactions

It is important to develop an understanding of the processes and interactions responsible for patterns and variability of biogeochemical cycles because this understanding is necessary for being able to diagnose, predict and manage the responses of biogeochemistry to global change. The processes responsible for the responses of biogeochemical dynamics in monitoring studies and manipulation experiments need to be elucidated at a range of temporal and spatial scales. Major elements of the ***process-oriented research*** activities on biogeochemical cycles in NEESPI should include:

- Responses of terrestrial biogeochemistry to changes in atmospheric CO_2, climate, nitrogen/sulfur deposition, atmospheric pollution (tropospheric O_3 and sulfur oxides), and heavy metal contamination;
- Responses of terrestrial biogeochemistry to changes in disturbance regimes, forest management, and land use;
- Responses of terrestrial biogeochemistry to agricultural and range management;
- The impacts of lateral flows of carbon in surface water from land to fresh water and to coastal ocean environments

3.2.5. Responses of Biogeochemical Cycles

An important goal of research on biogeochemical cycles is to improve prognostic models of the carbon cycle that includes interactions with other biogeochemical cycles. This is important for being able to predict the responses of these cycles, which is information necessary for informing policy. Research to improve prognostic models require the synthesis of information from observations and process studies, retrospective analyses to evaluate model performance, and comparisons with diagnostic models. Predictive models of biogeochemical are also important tools that can be used in scenario research to examine potential sensitivity of biogeochemical cycles to projected changes. Finally, research leading to improved prognostic biogeochemical models will allow the develop of coupled climate-social-ecological models that can be used for purposes of integrated assessment of responses of the NEESPI region to global change. Major elements of the ***predictive modeling*** activities on biogeochemical cycles supported under NEESPI should include:

- Transfer of synthesized information from process studies into prognostic models of the carbon-cycle models that include interactions with other biogeochemical cycles;
- Retrospective analyses to evaluate the spatial and temporal dynamics of disturbance regimes simulated by prognostic models;
- Evaluation of temporal and spatial variability simulated by prognostic models with estimates of variability based on continued monitoring using legacy observational networks and diagnostic model-data fusion systems;
- Development of scenarios of future changes in driving variables of prognostic models;
- Application and comparison of prognostic models to evaluate the sensitivity of carbon storage and the dynamics of other biogeochemical cycles into the future;
- Consideration of ecosystems as ecological-social systems and development of corresponding coupled models; and
- Incorporation of prognostic biogeochemical models into coupled models of the climate system.

3.2.6. Management of Biogeochemical Cycles

Research on diagnosis, understanding, and prediction should translate into an ability to better inform policy decisions that involve the management of carbon and other biogeochemical cycles in Northern Eurasia. Coupled models that integrate physical, ecological, and social processes are important tools that can examine vulnerabilities to future change, and identify options for mitigating vulnerabilities. Major elements of the research related to management of biogeochemical cycles to be provided by NEESPI should include analyses of:

- Economics and energy policy options for management of the carbon and other biogeochemical cycles given improved diagnosis, understanding, and prediction;
- Analyses of the permanence of sinks and vulnerability of carbon pools and methane exchange;
- Scenario development for incorporation into coupled models of the climate system so that future climate can be simulated;
- Assessment of sequestration options given the best scientific evaluation of present and future behavior of biogeochemical cycles.

3.3. Surface Energy and Water Cycles

Chapter lead authors: P.Ya. Groisman and A.G. Georgiadi

Contributing authors: G.V. Alekseev, V.B. Aizen, E.M. Aizen, R.G. Barry, S.G. Conard, V.Yu. Georgievsky, V. I. Gorny, L.D. Hinzman, G. Inoue, A.V. Kislov, L.M. Kitaev, A.N. Krenke, A.D. McGuire, A.V. Mestcherskaya, G.N. Panin, V.N. Razuvaev, V. E. Romanovsky, A.V. Oltchev, T. Ohta, A.A. Onuchin, B.G. Sherstyukov, A.I. Shiklomanov, I.A. Shiklomanov, A. B. Shmakin, A.J. Soya, P.W. Stackhouse, N.A. Speranskaya, N.N. Vygodskaya,W. Wagner, M.S. Zalogin, S.A. Zhuravin, A.N. Zolotokrylin

Introduction. The Surface Energy and Water Cycles (SEWC) are the two major cycles that largely defined the state of the environment in Northern Eurasia. A proper description of these processes in a Global Earth System model is a crucial prerequisite to successfully model the observed climate and its variations, including climate projections on the decadal to century time scales. To accurately simulate the complex interactions that define the Earth System, it is now necessary to correctly characterize these processes, and (a) *project/account for society's continued development and potential influence on future climate and environment dynamics* and (b) to *account for change in the rate of changes* (i.e., the acceleration in such processes as accumulation of CO_2 or degradation of land and sea ice) *that forces the slow-changing components of the Earth System (such as biosphere and cryosphere) to react and feed back to the contemporary and near future climate and the hydrological changes (3.1, 3.2, 3.4, and 3.5).* Now, with an increasing rate of current and projected global changes, Northern Eurasia is a "frontrunner" in these changes (Figures 2.1, 2.2, and 2.7[7] through 2.17). Box inserts A2.1 and A2.2 give vivid examples of large-scale regional changes in terrestrial hydrology that appear to be caused by both global climate changes and regional human impact. These examples (among many others) show that without a proper understanding of processes that control the contemporary climate and terrestrial hydrology and their drivers, society is helpless in addressing the future problems in a harsh and quickly changing environment. In Northern Eurasia, the scale of these problems is among the largest in the world. Thus, knowledge and ability to project the underlying processes that cause these problems is a necessity. In the diagnostic mode of weather modeling (the re-analysis mode) any erroneous parameterizations or misinterpretations of the processes that define the behavior of the system are corrected by the data. There is no such helping hand when we are trying to project future climate and state of environment or assess their vulnerability. All basic processes must be described as accurately and completely as possible within the model because the quality of this description becomes the only guiding light. This again leads us to the need to study processes. *At the land surface, these major processes together with the biogeochemical cycle are surface energy and water cycles.*

3.3.1. Major processes responsible for the maintenance and variability of the surface energy and water cycles in Northern Eurasia

The primary processes controlling the SEWC at the land surface are listed below with a short annotation.

[7] Figures 2.7 through 2.18 and Box Inserts A2.1 and A2.2 can be found in Scientific Background Appendix.

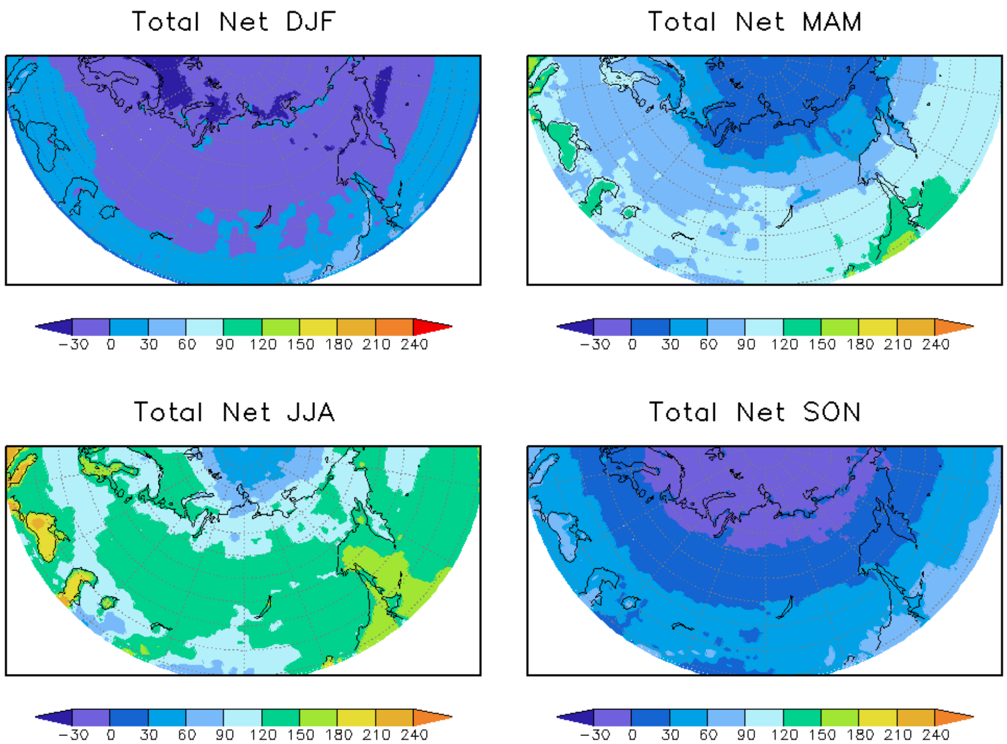

Figure 3.3.1. The mean total net surface radiation budget over Northern Eurasia on a seasonal basis from July 1983 through October 1995 as determined by the GEWEX SRB project (Stackhouse et al., 2004).

- ***Surface heat exchange.*** The surface is a focal area where (a) most of the solar energy absorption and a significant fraction of reflection occur, (b) a significant fraction of the outgoing long wave radiation forms, and (c) atmospheric warming by turbulent and long wave radiation fluxes is generated. The surface heat exchange defines temperatures at the surface and above and below ground, and changes the surface substance by snowmelt and evaporation as well as by providing the energy for the functioning of the biosphere. While at the top of the atmosphere above Northern Eurasia, the annual radiative budget is negative, the surface is a heat sink only in the winter season (Figure 3.3.1). The negative heat balance in Northern Eurasia is compensated by transport of latent heat from more temperate regions, a considerable part of which comes from Northern Atlantic region via the westerly atmospheric circulation.
- ***Atmospheric circulation.*** Advective processes (mostly westerlies, but Arctic and monsoon effects are also present) modify the climate of Northern Eurasia, reduce its continentality, and are the source of water for interiors of the continent. Weather conditions favorable for cloud formation and precipitation are highly variable in time and space. Thus, atmospheric circulation is a major source of the variability in land surface processes.
- ***Water exchange processes.*** Heat advection modifies regional climate while water vapor advection and precipitation *actually define it.* Most of the precipitable water that initially comes from outside the region may recycle several times in precipitation/evaporation processes (Drozdov and Grigorieva, 1963; Trenberth, 1999) until it leaves by runoff or via atmospheric flow. Generally, water resources are scarce over most of Northern Eurasia, but both the water deficit and the water abundance affect terrestrial ecosystem functioning and human activity and are a cause of numerous feedbacks associated with environmental and climate change (3.5).

- ***Role of land cover in the surface processes.*** Land cover (natural vegetation or disturbed conditions) modifies surface heat and water exchanges depending upon its physical (albedo, heat conductivity), mechanical (roughness, plant surface area density), and biological (leaf area index (LAI), stomatal conductance, photosynthesis, root system depth, etc.) properties. Some types of land cover (vegetation, snow, ice, frozen soil, and soil itself) are changing during surface heat and water exchanges, feed back to them and, therefore, have become integral components of the surface processes (3.5).
- ***Anthropogenic impact.*** Human activities cause direct (by land cover changes and water withdrawal and diversion) and indirect (by changing atmospheric composition and water quality) impacts on numerous processes in the biosphere, hydrosphere, cryosphere, and atmosphere. The impact of such disturbance on the land surface processes is the most direct and among the strongest (3.4).

Which Processes to study? Each of the above topics is important and should be investigated to achieve the NEESPI objectives. Priorities, however, should be set according to two criteria. *First, attention must be paid to the processes that directly feed back to the Global Earth System.* This justifies the interest of the International Community in the environmental changes in Northern Eurasia. These processes are also very important on the regional and larger scales. In most cases, the feedbacks to the global Earth System are only feeble manifestations of enormous changes within the subcontinent that “spill out” across the regional borders. Furthermore, by affecting the Global Earth System, they by definition affect Northern Eurasia. *Second, the processes of major societal importance must be addressed.* They may or may not affect the Global Earth System but for the region’s population they are of pivotal importance.

3.3.2. Processes that directly feed back to the Global Earth System

Processes in Northern Eurasia that have the capacity to feed back to the Global Earth System have been listed in 2.1. Below we provide a rationale for this listing.

Accelerated climatic changes across Northern Eurasia. y large perturbation of the global climate manifests itself most prominently in the cold and transition seasons in high latitudes over land areas and sea ice (Shnitnikov 1975; Vinnikov 1986; Figure 2.7). While the thermal inertia of the oceans is a major cause of its relative resilience to disturbance compared to the land areas, there are several reasons for a higher sensitivity of high latitudes to external forcing compared to low latitudes. First, if the external radiative forcing (ΔQ) is uniformly distributed along the longitude, its relative contribution to the surface radiation balance in the high latitudes will be more significant than in the tropics. Furthermore, several positive feedbacks (snow-ice and water vapor feedbacks being the most significant) are more prominent in high latitudes than in low latitudes. Finally, because the high latitudes are an energy sink, some proportion of tropical ΔQ from the tropics inevitably ends up in mid- and high latitudes. Thus, the pattern of the recent observed changes is a logical expectation of the progression of apparent impacts of a warming climate (Figure 2.2). These changes (if continued) may in turn further affect the global climate by:

- Changes in atmospheric blocking over the continents (Semiletov et al. 2000);
- An increase in the water holding capacity of the atmosphere[8];
- Systematic changes in the regional surface heat balance (Zolotokrylin 2002, 2003);
- Changes in meridional heat transfer in the atmosphere and thus the entire large-scale circulation pattern (Figure 3.3.2);

[8] Budyko and Drozdov 1976; Allen and Ingram 2002; Trenberth et al. 2003, Yang et al. 2003.

- Non-linear (and not well understood) changes in land surface hydrology and land cover (2.8, 3.1, 3.5, 3.6.1, and 3.6.2), and
- Interaction of all of the above that, combined, will yield non-zero feedbacks to the heat and water balance of the continent and, therefore, to the Global Climate System.

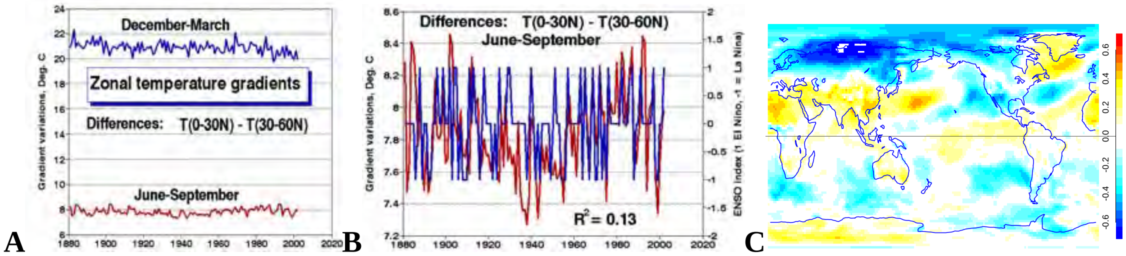

Figure 3.3.2. A. During the 20th century, systematic changes have occurred in the temperature gradient between the tropics and mid- and high latitudes affecting the meridional heat exchange. Changes in the warm season, while of a lesser magnitude, were (a) higher in relative terms and (b) of opposite sign to those in the cold season. (derived from data of Lugina et al. 2003, and Spirina 1970). B. A match of the ENSO occurrence (blue) and changes in the previous summer (June-September) temperature gradient. For the ENSO characteristic, the JMA ENSO index time series were used: (+1 for warm phase, 0 for neutral, -1 for cold). C. Correlations of the surface air temperature data with northern hemispheric meridional temperature gradient (zone 0-30ºN minus zone 60º-90ºN) for the winter season (Gershunov 2003). Note a significant reduction of Dec-Mar temperature gradients in the past three decades (A) due to a disproportional warming of Northern Eurasia (C).

Changes related to snow cover changes. Every year during the cold season, up to ~ 55% of the landmass of the Northern Hemisphere is covered by seasonal snow for a period of one week to 10 months. This is a major factor of the Northern Eurasian climate that affects (a) both shortwave and long wave components of the surface radiative balance (although cooling due to the high albedo of snow cover is the most prominent factor); (b) the shape of the hydrological cycle by accumulating the cold season precipitation and then releasing it during the snowmelt period into the soils and runoff; (c) the soil temperature profile by insulating the surface from cold winter air, (d) the energy losses associated with snowmelt, (e) the surface air temperature growth above the melting point, and (f) large-scale atmospheric circulation (including monsoon circulation) by controlling land-ocean temperature gradients. All of the above, in turn, feedback to the biosphere (cf., Jones et al. 2000) and shape many aspects of human activity (winter crops, reservoir management, transportation, construction industry, etc.). n all seasons when snow is present on the ground, it feeds back to ecology, weather, and society. But, its effect on the surface radiative balance is the highest in spring (Groisman et al. 1994). This is a season when most systematic changes in snow cover have been observed during the past century (Figure 2.12). For the former USSR territory, the snowmelt runoff is about 2600 km^3 and 70% of it returns annually to the Arctic Ocean (Krenke et al. 2004). The changes in this amount are critically important for the North Atlantic thermohaline circulation that maintains the global heat distribution (Broecker 1987).

The fresh water transport through the Arctic Ocean. Thermohaline circulation is a global-scale overturning in the ocean that transports significant heat via a poleward flow of warm surface water and an equator-ward return of cold, less saline water at depth. The overturning, crucial to this transport in the Northern Hemisphere, occurs in the Greenland, Irminger and Labrador Seas (Broecker 1997, 2000). The overturning also moderates anthropogenic impact on climate because it removes atmospheric CO_2 to the deep ocean. The occurrence and intensity of overturning is sensitive to the density of water at the surface in these convective gyres, which, in turn, is sensitive to the outflow of low-salinity water from the Arctic Ocean. This outflow from the Arctic basin is subject to significant interannual oscillations. About 10% of the global river runoff is discharged to the Arctic Ocean, which is only 5% of the global ocean area and 1.5% of its volume (WCRP-72 1992). About three-quarters of the inflow come from the six largest rivers, the Yenisey, the Lena, the Ob, the Mackenzie, the Pechora and the Kolyma (Vuglinsky, 1997; Forman et al. 2000). Five of them are in Northern Eurasia. The effect of global change on hydrology in Northern Eurasia has been estimated for various future projections[9]. These results showed a possibility of extremely serious changes in hydrological regime of the North Eurasian rivers in the 21st century. In particular, *an increase in Arctic outflow (if the current trends will continue, e.g., Peterson et al. 2002, Figures 2.14 and 2.15) could reduce the overturning and, therefore, the oceanic flux of heat to northern high latitudes*.

Changes in surface albedo related to vegetation changes, shift of ecological zones, and land use changes. These changes directly affect the surface heat and water balance and are discussed in 3.4 and 3.5 in detail. While it is possible to reconstruct some of these changes over time[10], large-scale environmental monitoring became a reality only in the era of remote sensing. During the last two decades, the area of forested land, green vegetation (NDVI), forest fire scares, agricultural fields, and their changes with time are objectively monitored and documented from satellites (4.1). The period of this monitoring is still too short to permit confident conclusions about a shift of ecological zones, but pilot estimates (e.g., Figure 2.1) have already indicated large-scale changes in the biogeochemical cycle over Northern Eurasia with global implications (3.2). There is substantial spatial variability in winter albedo within the boreal forest due to the spatial mosaic of coniferous forests, deciduous forests, and non-forested wetlands and burn scars. The latter have a higher albedo of ~ 0.6 in the cold season when the short-statured vegetation is snow covered. Thus, it is important to know the proportion of the landscape occupied by short-statured ecosystems within boreal forest. During summer, the albedo of deciduous stands and boreal non-forested wetlands is higher than the albedo of coniferous forests (Rauner 1972; Chapin et al. 2000a). Therefore, changes in the land cover composition directly affect surface heat balance.

Thawing of permafrost. Degradation of permafrost and changes in the soil carbon cycle in Northern Eurasia have the potential to noticeably affect the atmospheric CO_2 and CH_4 concentrations and, therefore, global climate, ecosystems, infrastructure, and hydrology. Section 3.6.1 specifically addresses all issues related to this process.

Changes in the boreal forest ecosystem. A description of the interaction of Surface Energy and Water Cycles with the forest ecosystems and feedbacks to the regional climate is provided in Section 3.5.1. Additionally, changes in energy and water balances in this zone may directly affect sinks and sources of carbon (3.1, 3.2) and runoff of major rivers of Northern Eurasia. Considering the large area occupied by this ecosystem in Northern Eurasia (~50%), these changes feed back to the global climate.

Ongoing aridization of the continental interior and dust storms. Temperature rise without appreciable changes in precipitation (or even its decrease) can lead to aridization in steppe, semi-arid and arid climatic zones of Northern and Central Eurasia. Additional causes for aridization could be of anthropogenic origin (water withdrawal and/or intense agricultural use) and glaciers and permafrost degradation. Whatever the causes may be, an increase of the dust load in the troposphere may be a result. With an average transport time of up to

[9] Georgievsky, et. al., 1996; Shiklomanov and Georgievsky, 2001; Shiklomanov and Shiklomanov 2001, Georgiadi and Milyukova, 2002, Mokhov et al. 2003.

[10] e.g., the lake levels, changes in the area of agricultural land (3.4; Golubev et al. 2003), and reports of the forest harvest and inventories (Shvidenko and Nilsson 2002).

several weeks, mineral particles can be transported great distances downwind from the source, causing diverse effects on health, environment, and climate (Figure 3.3.3). *Once lifted into the atmosphere, both anthropogenic and natural components of mineral aerosols play an important role in air quality, atmospheric chemistry, ecology, biogeochemical cycles, cloud formation, rainfall, agriculture, Earth's radiation budget, and, hence, climate change.* Since Central and East Asia is the second largest source of atmospheric dust in the world, a quantitative understanding of Eurasian dust sources, transport routes, and effects on the climate system on regional and global scales is urgently needed. Section 3.6.3 addresses these issues in detail.

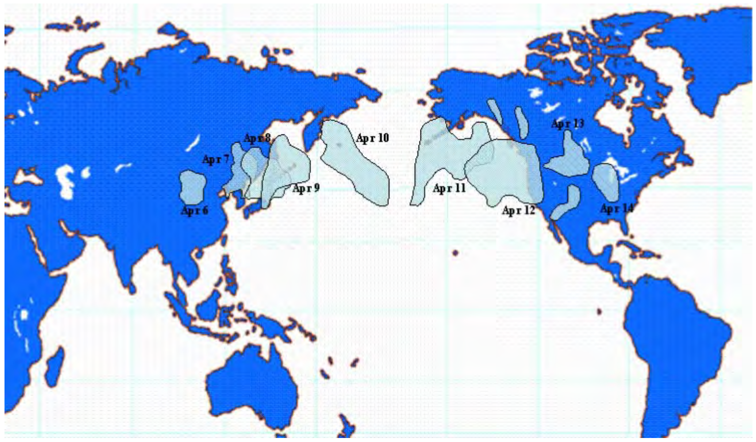

Figure 3.3.3. Long-range transport of the dust storm originated over the Gobi desert on April 6th, 2001 (based on TOMS aerosol index; Darmenova and Sokolik, 2002).

Deglaciation in the mountain systems of Central Asia and Caucasus, increasing water withdrawal, and increasing dryness of steppe and semi-arid zones. Climate variations at high altitudes (similarly to high latitudes) may have larger amplitudes compared to lowlands[11]. Thus, the changes over the greatest highlands in the world, a group of mountainous systems and plateau of Central Asia that are spread from the Himalayas in the south to Tien Shan, Junggar, and Altai-Sayani, in the North, have been historically and are anticipated to be large. In Northern Eurasia, the Tien Shan, Junggar, and Altai-Sayani mountains hold one of the greatest concentrations of perennial snow and ice in the mid latitudes and constitute a vital source of water for Kazakhstan, Kyrgyzstan, Uzbekistan, Tajikistan, and Xinziang (West China), where the total population reached 100 million by the end of the 1990s. In Central Asia, there are approximately 30,000 glaciers with a total area of about 25,000 km^2. Eighty percent of these glaciers have been retreating since the 1950s (Haeberli, 1990) with a recent acceleration (Khromova et al. 2003). Managing water resources in these hugely populated areas is a complex problem because changes in the hydrological regime (in addition to natural forcing) have strong anthropogenic components. It makes a difference for global climate, biosphere, and human society if (a) cold snow/ice covered mountains and plateaus in the center of Eurasia feed surrounding areas with water via lengthy rivers or (b) the same areas become heat islands of dry deserts that duly evaporate atmospheric precipitation and provide an ample source for dust storms over the hemisphere (Middleton et al., 1986). Observations indicate that the Caucasus Mountains and some regions in the Central Asian Mountains are in transition from the former to the latter types of landscape (Aizen et al. 2003, Figures 2.13 and 3.6.5; Table 3.6.1[12]).

[11] Vygodskaya 1982; Polikarpov et al. 1986; Barry 1992; Oerlemans 2001.
[12] Figures 3.6.1 through 3.6.5, and Table 3.6.1 can be found in Scientific Background Appendix.

3.3.3. Processes of major societal importance

- ***Extremes.*** Normal functioning of society assumes "average" climate/weather conditions. Extremes usually negatively affect this functioning (droughts and low levels in rivers, lakes, and ponds, fires, floods [in particular catastrophic ice-jam floods on large Siberian rivers or floods in densely populated areas], landslides, and soil erosion after heavy rains and/or unusually intensive snowmelt, cold and hot spells) and affect various aspects of societal activities, health, and even human lives. Numerous changes in frequencies of extreme events in Northern Eurasia have been reported[13] and and projected (Mokhov et al. 2003; Shmakin and Popova 2003; Hegerl et al. 2004).
- ***Terrestrial hydrology and water supply.*** Industry, agriculture, human sustenance and health, recreation fisheries, and environmental health depend upon sufficient and timely fresh water supply. Water quality is an issue for many of these needs. According to forecasts by the WorldWatch Institute, two-thirds of the world's people will be suffering water shortages by 2025, including those in the southern half of Northern Eurasia (ICCP, II, 2001). Probable runoff decrease of the rivers of southern slope (Don, Dnieper) and subsequent deficit of water resources in the steppe regions of Russia and Ukraine, the ongoing and worsening water deficit in Central Asia, and changes in the hydrological regime of the Arctic are the major areas of concern (Vörösmarty et al. 2000; Peterson et al. 2002).
- ***Soil / freeze/ refreeze/ thaw of permafrost interaction with hydrological processes.*** Thawing of permafrost causes numerous structural damages to the infrastructure, shifts and/or replacement of the ecosystems, and changes in the coastal zone of the Arctic Ocean and hydrograph of Siberian rivers. With projected increases in surface temperature and decreases in surface moisture levels, the active layer thickness will probably increase, permafrost area extent will decrease and permafrost will become thinner, leading to subtle but predictable ecosystem responses such as vegetation changes. Permafrost in arctic regions exerts a significant influence upon hydrologic and ecosystem dynamics through controls on vegetation and drainage. In relatively flat areas where the frozen layer is near the surface, the soil moisture contents are usually quite high. These areas have relatively high evapotranspiration and sensible heat transfer, and a low conductive heat transfer due to the insulative properties of thick organic soils. The climax vegetative species and soil forming processes are dominantly controlled by the closely coupled permafrost and hydrologic conditions. As permafrost degrades, the soil moisture holding capacity increases, soil drainage improves and moisture is no longer held near the surface but percolates to deeper reservoirs. Thermokarst lakes are formed on flat terrain. As permafrost becomes thinner or absent, groundwater contributions from springs become more important (Vörösmarti et al. 2001a).
- ***Snow cover (impact on flooding, interaction with ecosystems and agriculture).*** Snowmelt is a major cause of flooding in most of Northern Eurasia. Projected intensification of winter precipitation, shortening of snow cover season, changes in spring freshet, and dependence of agriculture (winter crops) and wild life on snow are focal points of concern.
- ***Glaciers (changes, impact on hydrology).*** The current retreat of mountainous glaciers, while initially considered as a factor that was increasing the streamflow, will eventually yield decreasing river discharge. There are indications that in the Caucasus and mountains of Central Asia, the degradation of glaciers has already advanced to the state of decreasing rates of runoff from melting ice. Currently, glacier melting is increasing

[13] Mestcherskaya and Blazhevich 1997; Georgievsky et al., 1999; Heino et al. 1999; Groisman et al. 1999, 2003, 2004; Georgiadi 1993; Milly 2002; Zolotokrylin 2003.

only in the heads of river basins with large-scale glaciation. In the river basins with relatively small-glacierized areas, the increase of the glaciers' melt has already led to a decline in the glaciers' area and has thus reduced their contribution to river runoff (Aizen et al., 1997, 2003). This can explain, at least partly, the wastage of large Central Asian lakes, such as Balkhash, Lobnor, and Aral (Figures 2.8, 2.9a, and 2.16).

- ***Surface-atmosphere interactions in changing climate and land use.*** Some of these interactions along with certain changes can be dangerous (e.g., dust storms and landslides). Others may gradually lead to harmful (and sometimes irreversible) negative changes in soil (salinization, inundation, and desertification) and biosphere (replacement of species with others "less useful" for society) (3.1, 3.4).

3.3.4. Surface Energy and Water Balance: Quantifying the Components and their Interactions

3.3.4.1. Climatology

Surface radiation balance. A climatology of the Surface Energy Balance was first constructed in the early 1960s from the data of a relatively sparse network of in-situ observations by Budyko (1963). In the maps that comprise the Atlas of the Earth Heat Balance (Budyko 1963), smooth and sparse isolines are justified by the accuracy of the information available at that time for monthly and annual time scales (Figure 3.3.4a). After

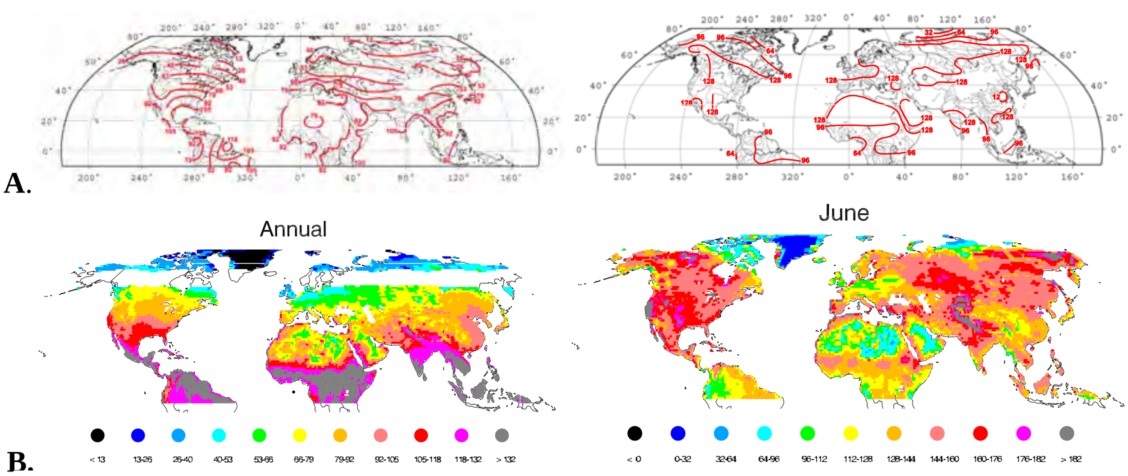

Figure 3.3.4. Mean annual and June surface radiation budget (W m^{-2}) of northern hemispheric land areas (a) according to Budyko (1963) and (b) Stackhouse et al (2004). The authors of Atlas of Heat Balance (Budyko 1963) skipped mountainous regions in their analyses due to insufficient information available at that time. Their maps were originally prepared in different units, which explains the unusual choice of isolines presented in this figure after conversion to Wm^{-2}. In the "twilight" zone (57°N-65°N) in winter months, calculations of shortwave surface radiation fluxes are not provided by the NASA satellite product.

launching a sequence of the Earth-observing satellites by NOAA and NASA, a new epoch of the Earth Energy Budget studies started (Barkstrom 1984; Barkstrom et al. 1989; Kyle et al. 1993). In particular, in the framework of the International Satellite Cloud Climatology Project (ISCCP, Rossow and Schiffer 1999), time series of major components of the surface radiation budget have been constructed from July 1983 to October 1995 (and will be updated to present) with a 3-hourly time- and 1-degree spatial resolutions. All observations for this budget are made from space and thus a special system of radiation-transfer models is used to calculate fluxes at the surface[14]. A comparison of climatology based on ISCCP and Budyko

[14] Gupta et al 1992, 2001; Darnell et al. 1988, 1992; Wilber et al. 1999; Stackhouse et al. 2004.

(1963) is shown in Figure 3.3.4. There are many reasons for these estimates to be different, including different definitions of "surface" in forested areas (cf., Figure 3.5.2) and a 40-year-long advance in understanding of radiation processes that came with remote sensing. But, discrepancies in high latitudes (that emerge only when all radiation fluxes are low and disappear in the summer time) may also be a manifestation of an accuracy problem in the remote sensing product (4.4). *The need of a higher accuracy in quantification of surface radiation components in high latitudes is especially acute, particularly in the cold season, and must be addressed in the NEESPI studies.*

Other components of the surface heat balance. The positive surface radiation balance is partitioned into heat flux into the ground and turbulent heat fluxes back into the atmosphere through sensible and latent heat flux. If snow and/or ice are on the ground, energy is also utilized in snow/ice melt. Qualitative evidence that all four of these processes took place everywhere is overwhelming, but the information on how they are interacting and what quantitatively is going on at a given point and at a given time is sparse. The most critical situation arises from the lack of information on turbulent heat fluxes. When partitioning of the surface radiation balance is made by various land surface schemes, it is usually assumed that (a) heat flux into the surface is relatively small[15] and (b) that melting and evaporation are dominant if snow and/or soil moisture are available. But, there are constraints on these assumptions: (a) Snow may be shaded by vegetation and thus melt may be delayed by several weeks; (b) Even in the cases of bare soil, the uppermost soil level can create a crust that prevents/reduces further evaporation; (c) Various types of vegetation have developed different adaptations to control the transpiration process, regulating their stomatal conductance; (d) In dense forest stands, surface energy storage (which is spent on changes of biomass temperature and photosynthesis carbon gain) can account for 10-12% of daily net radiation; and (e) Mosaic composition of vegetation species and terrain elements, make it difficult to quantify the turbulent heat processes theoretically while tower observations over forested land show very different partitioning of turbulent heat fluxes depending upon the forest type[16]. A reliable and representative observational base to test the performance of the currently available land surface schemes over the entire variety of typical landscapes in Northern Eurasia is virtually absent. Use of the modern generation of tower flux observations is quite rare over the region. Moreover, it is difficult to extrapolate the results of these observations over the regions beyond the point of measurement (e.g., Sogachev et al. 2002). Therefore, *a new modern observational base for surface flux measurements in the NEESPI region and new scaling-up schemes are desperately needed.* ring comprehensive field experiments in the past ten years[17] when all components of the surface energy balance were directly measured, the observed surface energy balance often did not close (R_n - G > LE+H; where R_n is the net radiation flux, G is the heat flux into ground, and LE+H is the sum of the surface vertical turbulent fluxes). The main cause of this systematic imbalance is not the experimental methodology but a conceptual deficiency. It is related to the fact that the

[15] This is generally true for most soils and wetting conditions. However, there are indications that in some areas of Northern Eurasia the terrestrial endogenic energy discharge by the convection in the Earth's crust is much higher than the background level thus contributing to biodiversity (Gorny 1998; Gorny and Teplyakova 2001). Beyond obvious evidence (areas around hot springs), observations of this effect are virtually absent.

[16] E.g., Rauner 1972; Chapin et al. 2000a; Tchebakova et al. 2002; Chapin and Chambers 2003.

[17] Bernhofer, 1992; Foken et al. 1993; Lee and Black, 1993; Fitzjarrald and Moore, 1994; Barr et al. 1994; Panin and Nasonov, 1995; Baldocchi et al. 1997; Blanken et al. 1997; Goulden et al. 1997; Lafleur et al. 1997; McCaughey et al., 1997; Pattey et. al. 1997; Panin et al. 1998; Laubach and Teichmann, 1999; Polonio and Soler, 2000; Kim et al. 2001 ; Wang, 2001; Huizhi et al. 2001; Sakai et al. 2001 ; Turnipseed et al. 2002; Beyrich et al. 2002; Wilson et al. 2002; Gustafsson et al. 2003; http://www.ihas.nagoya-u.ac.jp/game/GAME-Siberia.html).

energy-mass exchange between the land surface and the atmosphere is determined by applying theories that are based on the hypothesis of stationarity and horizontal homogeneity (SHH) neglecting the advection terms. In SHH conditions the cospectral form derived by Kaimal et al (1972), Kaimal and Finnigan (1994) have been taken as the archetype of surface-layer turbulence spectra. It works over flat homogeneous surface but fails over complex horizontally inhomogeneous terrain. *Currently, better estimations of surface sensible and latent heat fluxes over Northern Eurasia are needed to fill the large gaps in measurements over this area. Theoretical basis for new approaches*[18] *does exist but it still has to be implemented.*

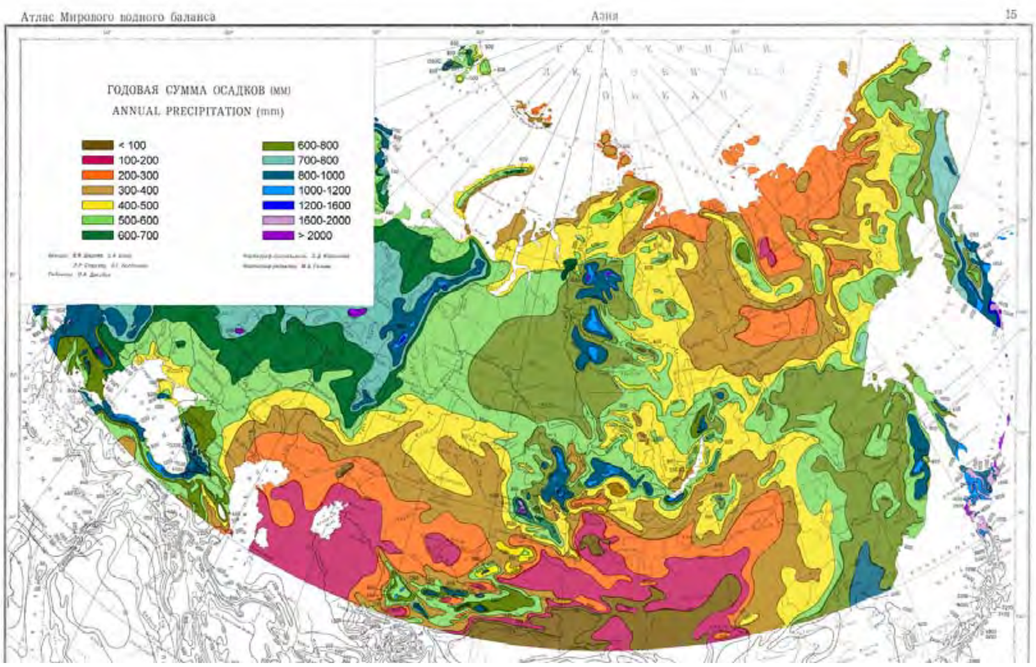

Figure 3.3.5. Annual precipitation (in mm) over Northern Eurasia (adapted from Korzun et al. 1974).

Surface water balance. Among the five major components that define the surface water budget, precipitation, snow accumulation and melt, runoff, evaporation and soil moisture, only the first three components are observed at relatively dense meteorological and hydrological networks (at about 10^5 sites throughout Northern Eurasia; although in northern sparsely populated parts of the continent the density of this network is insufficient; Chapter 6). The meteorological network delivers information for the controlled environment of standardized meteorological sites, while natural ecosystems (e.g., forest) and agricultural fields are covered by a fewer number of stations. Evaporation has been observed at about 100 sites in the former Soviet Union (Golubev and Kuznetsov 1980) and soil moisture measurements are made at agrometeorological stations along the narrow belt, mostly in forest-steppe and steppe climatic zones at about 10^4 sites (Vinnikov and Eserkepova 1991; Robock et al. 2000). Therefore, when rigorous water balance studies were conducted in the former Soviet Union in the 1960s and 1970s (Korzun et al. 1974), however, evaporation was a calculated variable. Quantitative maps of the precipitation pattern for Northern Eurasia utilizing this thirty-year-old research (Figure 3.3.5) have been recently improved for mountainous (Kotlyakov et al 1997) and Polar Regions (Bogdanova et al. 2002) but, nevertheless, to date, they represent the most comprehensive precipitation climatology in

[18] E.g.,Kazanskiy and Zolotokrylin, 1994; Panin et al. 1998; Finnigan et al. 2003; Avissar et al. 2004.

Northern Eurasia for the mid-20th century. Measurements of each component of the surface water balance have deficiencies. Some of them are due to the extreme paucity of observations (evaporation, soil moisture, all components north of 60°N). There is a major deficiency (bias) in precipitation measurements, especially for solid and mixed precipitation (Groisman et al. 1991; Goodison et al. 1998; Bogdanova et al. 2002). Peak runoff measurements are hampered by the over-bank flow that is difficult to account on level terrain. Failure to close surface heat balance (cf., previous sub-section) creates further difficulties in use of the MODIS-E (evapotranspiration) algorithm (Running et al. 1994). Low intensity of the water cycle in Northern Eurasia increases the relative errors of its estimation by remote sensing and makes useless some of the methods of its evaluation, e.g., microwave soundings of precipitation (4.4; Huffman 1997). All the above severely constrain water cycle studies in Northern Eurasia, particularly those when the goals of the study are the cycle changes and their interpretation. The *projected Global Precipitation Mission (GPM) may be of a major help in this regard. Therefore, preparations for a best possible calibration of the GPM instrumentation to account for specific conditions in Northern Eurasia are among the NEESPI objectives.* ***Soil moisture*** is the most critical element in the surface processes analyses. Soil moisture has a spatial mosaic distribution that is difficult to model and monitor and is poorly observed[19]. But, it controls evaporation, runoff, and vegetation and is a focal point of essential process studies at the land surface[20]. Furthermore, soil moisture measurements are virtually absent in the forest and it is impossible to estimate it there using the observations at the neaby agriculture field sites. The underground zone especially in the boreal forest is a strong regulator that smoothes seasonal and long-term variability of river runoff (Wood, 1999; Oltchev et al. 2002). Processes that define the base flow in the permafrost zone (about 30% of annual runoff) are insufficiently investigated. Terrestrial hydrological changes are now a focal application point of several processes that feed back to environment, society (3.3.3, 3.4, 3.5, 3.6.2), and even to global climate (3.3.2). *Their study should be based on a reliable observational data base and description of the major processes that are, at least, inadequate.*

Atmospheric transport of water vapor. A relatively dense spatially distributed network of aerological stations has allowed for early estimation of major characteristics of the water vapor distribution in the atmosphere and its transport over most of Northern Eurasia within the former Soviet Union boundaries (Kuznetsova 1978, 1983; IWP 1984). It appears, that while the atmosphere over the western half of Northern Eurasia is more humid, most of the water vapor (~88%) passes over it (or recirculates) and the "utilization" of the water vapor in Siberia is more effective. About half of the water vapor is converted to soil moisture and eventually streamflow. One of the semi-closed branches of the water cycle originates in the Northern Atlantic: evaporation from the ocean, atmospheric moisture transfer to Eurasia by westerlies, precipitation, runoff into the Arctic Ocean, and return to the Northern Atlantic via oceanic currents. *At present, there is no clear understanding of the characteristics of these highly variable processes that control the energy and water budgets of Northern Eurasia. This problem can be addressed with a focused regional modeling effort and a multi-facet observational program.* Modern estimates based on satellite observations (Randel et al. 1996) show similar results for total water content of the atmosphere (Figure 3.3.6). Assessment of the results of Figure 3.3.6 indicates the total water content of the atmosphere

[19] Actually, the same spatial heterogeneity problem, which makes it difficult to evaluate turbulent heat fluxes over complex horizontally inhomogeneous terrain, affects hydrological and land surface – atmosphere interaction studies in the region and requires a thorough study (Avissar et al. 2004).

[20] Shukla and Mintz, 1982; Georgiadi et al. 1998; Rodrigues-Iturbe, 1999; Hinzman et al. 2004; Vygodskaya et al. 2004.

has significantly increased since the 1960s, especially over Kazakhstan. To date, the aerological network remains the single source of information about the water vapor transport over Northern Eurasia because the radar network does not yet cover the entire continent. Interannual variability of this transport is poorly known. *Modern satellite measurements of the water vapor in the atmosphere of Northern Eurasia (including microwave and spectrally-resolved infrared water vapor sounders would improve quantitative assessment of temporal variations in climatic and hydrological processes on regional scales.*

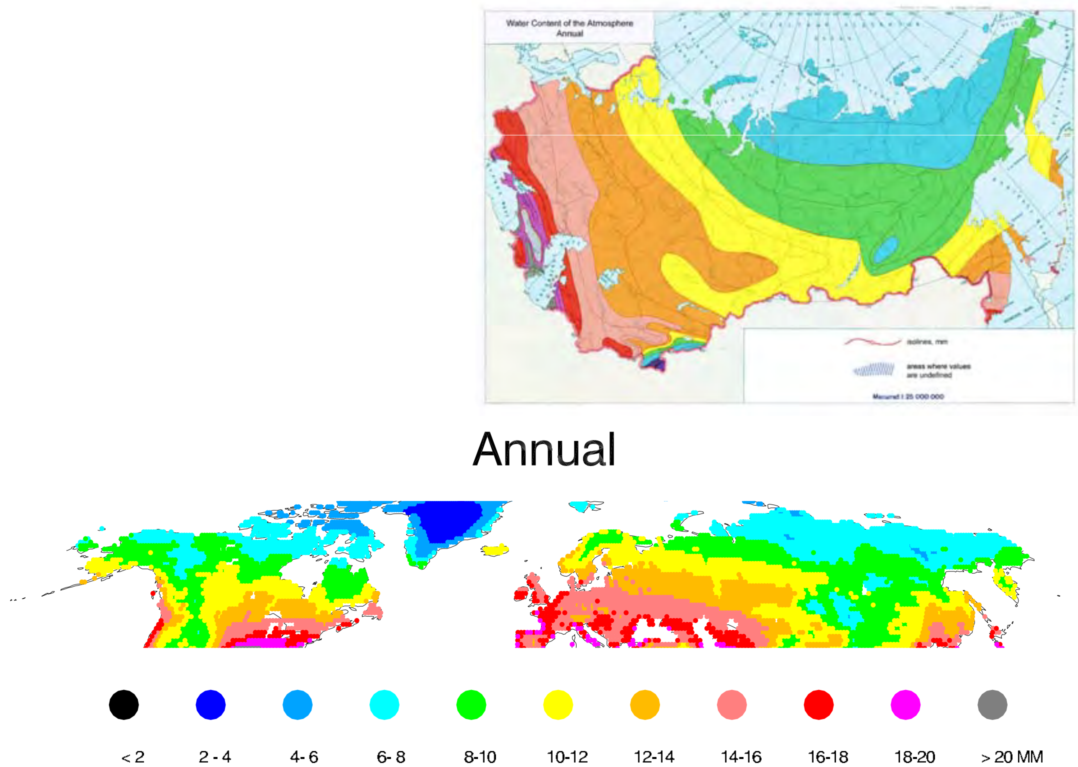

Figure 3.3.6. (a) Annual water vapor distribution in the atmosphere over the former USSR in the [surface to 300 hPa] atmospheric layer based on rawinsonde network for the 1961-1970 period (IWP 1984) and (b) the same quantity over the land areas north of 40º N constructed from satellite (TOVS) and rawinsonde data for the 1988-1999 period (Randel et al. 1996).

3.3.4.2. Changes

To trace the changes in surface energy and water cycles during the past century, we must rely upon the most frequently observed climatic and hydrological variables that directly or indirectly characterize these changes[21]. The time series for surface air temperature, precipitation, snow cover extent, and streamflow are the most commonly available. Figures 2.2, 2.7 through 2.17 show several major features of these changes.

> *The surface air temperature is a function of both short- and long-wave radiation budgets, heat advection, and turbulent heat flux and has significantly increased during the past century (IPCC 2001; Razuvaev 2003; Lugina et al. 2001; Figure 2.2). Snow cover has retreated throughout the century in the spring season (Brown 2000; Figure 2.12). The volume and areal extent of mountain glaciers has decreased markedly (Khromova et al.,*

[21] Radiation measurements are sparse (in situ network) or short (remote sensing) to make reliable conclusions about these changes in Northern Eurasia. Although attempts to make such conclusions on a global and continental spatial scales have been made (Pivovarova 1977, Bryson and Goodman 1980; Vinnikov and Groisman 1982).

2003; 3.6.1). Precipitation and streamflow along the arctic slope of Northern Eurasia have increased[22] *while in internal regions of Central Eurasia dryer conditions have been gradually established during the past several decades*[23]*. In Northern Eurasia, the pattern of runoff changes became much more complicated during the past 50 years due to large-scale direct human intervention (reservoirs' construction, water withdrawal and diversion) and natural and man-induced landscape changes (Figures 2.9, 2.15; and Box insert A3.6.1). In some regions, the natural component (that itself may be a manifestation of global change) prevails while in others, anthropogenic factors dominate.*

3.3.4.3. Major unresolved issues

Critical research tasks include:

- develop, corroborate, and establish modern tools of comprehensive monitoring of the contemporary state of the climate, landscape, and terrestrial hydrology of Northern Eurasia, especially in high latitude and mountain regions.
- integrate results from historical data sets and present observational systems and process studies into a unified knowledge base (a) to better understand the contemporary changes and (b) to capitalize on the past knowledge of the major processes that control surface energy and water cycles in Northern Eurasia[24]. *A concise effort to deliver these results to the research community will ascertain the role of Northern Eurasia in the global SEWC and facilitate all ongoing experiments and studies.*
- create, test, and apply an interactive suite of the land surface models that can account for major land surface process dynamics in Northern Eurasia and interactively feed back to regional and global climate, environmental, and economic models thus closing an

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[22] Vinnikov et al. 1990; Groisman, 1991; Groisman et al. 1991, 2003; Georgievsky et al. 1996; Groisman and Rankova 2001; Peterson et al. 2002; Shiklomanov et al. 2002; Yang et al. 2002; Figures 2.14 and 2.15.

[23] Kira 1995; Vaganov 1997;Aizen et al. 1997; Glantz, 1999, Figures 2.11 and 2.12.

[24] An enormous amount of effort has been made during the past decades to allow reliable description of the processes of the heat and water exchange at the surface and to parameterize them for the typical landscapes around the world, including Northern Eurasia (Budyko 1963; Rauner 1972; Korzun et al. 1974; Fedorov 1977; The Study…, 1984; Krenke et al. 1990; KUREX-91, 1998; ISLCSP, Sellers et al. 1995; Global Energy and Water Cycle Experiment and its sub-projects in North America (GCIP, MACS) and Northern Eurasia (BALTEX, GAME) [Lawford 1999; Stewart et al. 1998; Raschke et al. 1998, Kotlyakov and Georgiadi, 1998]; Project for Intercomparison of Landsurface Parameterization Schemes (PILPS; Luo et al. 2003; Bowling et al. 2003); and many others). A network of heat-balance stations deployed since the mid-20th century over the former USSR covers fallow and bare soil types of landscape, but not the forested land. There were ~100 of these stations in the peak of their deployment in the 1970s. A network of research stations (including water balance stations that represent a set of 22 experimental watersheds filled with meteorological and hydrological instrumentation) up to recent time covered all major biomes of the former USSR. Methodology to estimate the surface sensible heat flux from routine in-situ synoptic observations is representative only for bare soil and snow covered landscapes (Groisman and Genikhovich 1997). This methodology can be used at approximately 4,000 locations in Northern Eurasia in the former USSR, Mongolia, China and Romania. The "complex" method of relating surface energy and water balance (Budyko 1971) provides an approximation for climatology of sensible and latent heat fluxes. Long-term field studies of heat energy balance within vegetation cover in European forests were summarized by Rauner (1972). In this study, adjustments have been developed to account for radiation and turbulent flux enhancements over various types of forest compared to the forest-free sites where most of meteorological and all heat balance and actinometrical networks are located. A network of flux measurements (FLUXNET), similar to those that cover some regions of North America, Asia, and Europe (Wofsy and Hollinger 1997), Schulze, 2000; Valentini 2003) is not yet fully deployed across Northern Eurasia. Several international projects have recently been launched to mitigate the lack of vital information on these fluxes. They include field studies in Eastern Siberia (Holllinger et al. 1995; Kelliher et al. 1997, including those in the framework of the GAME (http://www.ihas.nagoya-u.ac.jp/game/GAME-Siberia.html), the Euro-Siberian CARBONFLUX, and TCOS-Siberia projects (set of publications in *Tellus* **54B**, 2002) and the joint Japanese-Russian effort to monitor heat, water vapor, methane, and CO_2 fluxes at a 500 km spatial resolution over Western Siberia (Inoue, 2003).

important loop critical for future climate and environmental change projections and enhancing the society wellbeing.

- address the following issues critical for understanding of surface and energy cycles in the region;

  (a) process studies:

  - Surface heat fluxes should be parameterized within scalable land surface models. These parameterizations should account for landscape heterogeneity.
  - Precipitation (especially convective precipitation) should be realistically described at the storm event level.
  - Hydrological flow-formation models should be enhanced to incorporate anthropogenic impact, glaciers and permafrost dynamics on the background of global warming.
  - Land surface water cycle closely interacts with land cover. It includes the pathways and fluxes of water among snow, glaciers, rivers, lakes, permafrost, ground aquifer, and flow within soils. Contemporary land surface models should reproduce (estimate and project) the variability of the land surface water cycle (including the water composition) and provide a summarized feed back to the atmospheric and riverine branches of the water cycle and to the major biogeochemical cycles. Anthropogenic impact on runoff and its interactions with climatic changes and natural variability should be thoroughly studied and incorporated into the land surface models.
  - A network of research field stations, including Water Balance Stations (WBS), within major biomes of Northern Eurasia has to be re-vitalized and re-equipped with modern instrumentation. Direct measurements of all components of surface energy and water balance should be conducted at most of these the sites. Keeping in mind a significant uncertainty of our understanding the hydrological processes in the permafrost zone, continuity and enhancement of the observational program at the research stations in this zone is a high priority.
  - Permafrost thawing processes should be properly described including interactions with vegetation and soil moisture.
  - The role of blowing snow and sublimation in the distribution of snow cover and seasonal snowpack (SWE) needs to be determined.
  - Advance extreme events modeling (floods, droughts, heat, cold, wet, and dry spells, fire weather, early/late frost, damaging thunderstorms, glacier lake outburst floods, etc.) should lead to an early warning system of natural hazards (cf., (c)); In particular, techniques of forecasting the ice-jam flooding on the Siberian rivers and recommendations on reduction of their catastrophic consequences should be developed.
  - New scaling techniques should be developed to transfer changes and feedbacks among processes of different spatial and time scales (e.g., Randall et al. 2004; Sogachev et al. 2002, 2004). Sub-grid heterogeneities and their impact on heat and moisture fluxes as well as on hydrological processes should be assessed.
  - Controls on the water chemistry processes associated with changes in cryosphere (glacier, snow, and permafrost), biosphere (bogs, soil, vegetation), as well as anthropogenic impacts (pollution, land use, water withdrawal) should be quantified.
  - Understanding ongoing aridization of continental interior, the chemical composition and volumes of primary and secondary aerosols in Northern Eurasian deserts and semi-deserts is important for projecting the global radiative forcing.
  - Estimation of geocryological consequences of global warming should be assessed.

  (b) climate modeling studies:

- How can we improve parameterization of convective precipitation?
- Snow under a canopy is poorly represented in GCMs, how can we improve this situation with physically-correct parameterization (e.g., Onuchin 2001)?
- How can we include the proper representation of permafrost and seasonally frozen ground dynamics into GCMs?
- How can we organize an interactive feedback of impact models to GCMs?
- Do we need river routing to properly force the terrestrial hydrological cycle (or is instant integrated discharge with sharpened seasonality, as in current GCMs, sufficient)?
- It now becoming clear that biogeochemical and land biospheric (dynamic vegetation) components should be an indispensable part of global projections based on GCMs. How can we effectively incorporate them in these GCMs?
- Future projections require estimates of probability distributions changes rather than changes in means; thus a chain of consequences evolves
    - ⇨ massive ensembles rather than single deterministic simulations are needed
    - ⇨ how many members in projection ensembles will be sufficient?

(c) from the point of view of observers and users:

- A representative network of major environmental and hydrometeorological fields should be established (selected) and a homogeneous time series at this network should be collected, maintained, and disseminated to the broader scientific community. Each major biome must be well covered by this network. Furthermore, the observations at this network should be linked with modern remote sensing observation systems (Alsdorf et al. 2003; Wagner et al. 2003), complement them, and provide a much needed third-dimension (time) to assessments of contemporary changes of the Global Earth System.
- Reliable water demand projections should be conducted. These include development of new irrigation practices and new water consumption standards.
- A system of natural hazards' early warning should be developed.
- Historical geochemistry records on major, minor, and trace elements should be collected and assessed. This will allow establishment of a long-term monitoring of the biogeochemical cycle dynamics over the continent. In particular, the measurements of insoluble mineral material deposited on glacier surfaces in Northern Eurasia should be organized and assessed. They may provide a better understanding of aerosol production and transport in the Northern Hemisphere.
- The most recent hybrid observational system of the surface energy and water cycles is a real-time, distributed, uncoupled land surface simulation system (Land Data Assimilation System, LDAS) is a combination of fine resolution (1 km and less) land surface vegetation information, in-situ and satellite observations of precipitation, radiation, and snow cover, and land surface and regional circulation models[25]. *We propose that a system similar to LDAS for North America (NLDAS) would greatly advance scientific analyses in the NEESPI region.*

[25] Developed by NASA in cooperation with NOAA and several U.S. universities, LDAS delivers a spatial resolution of 0.125º for North America and 0.25º for the globe and its performance is now extensively tested for North America (Meng et al. 2003; Rodell et al. 2003; Cosgrove et al. 2003; Pinker et al. 2003; Lohmann et al. 2003; Robock et al. 2003). While LDAS includes sophisticated models to describe the processes at the surface, they all are diagnostic models that work well when quality input information is supplied to them.

3.4. Land Use Interactions: Societal-Ecosystem Linkages

Lead Chapter Authors: N.F. Glazovsky, D.S. Ojima, and N. G. Maynard

Contributing authors: K.M. Bergen, N. Chubarova, N. Davaasuren, G. Fisher, E. L. Genikhovich, P.Ya. Groisman, G.V. Kalabin, V.M. Kotlyakov, G.S. Kust, V. Osipov, V.E. Romanovsky, C. Rosenzweig, K. Seto, A.A. Chibilev, F. Tubiello, N.M. Vandysheva, R. Walker, M. Zalogin

3.4.1 Background

Northern Eurasia has a diverse land cover and land use with over 20% of the world's arable lands and 24% of the world forests. The Eurasian grasslands constitute the largest contiguous grasslands in the world. The region also has a large extent of rich soils to support productive agricultural systems. However, the semiarid agriculture, both croplands and pastoral systems, are limited by availability of reliable water resources. The sustainable land use is dependent on the appropriate water and land resource management. Pastoral systems in the region can account for as much as 30 to 40% of the GDP in certain regions of the countries. Forestry is a major employer in the region. In much of the region, the rural service economy is poorly developed, has greatly eroded during the past decade, and are only slowing recovering (IBRD 2002). Northern Eurasian ecosystems present challenges to social and ecosystem scientists assessing the human dimensions of land cover and land use change. The social forces that underlay these complex vegetative changes are also unique to the region, which has experienced profound institutional change and an abrupt insertion into a globalized economy over the past decade. The emergence of a market system, changes in governance and property regimes, the onset of international capital flows, and accelerating population movements have all impacted the region's resources and land use. Developing models to explain and predict land cover change in Northern Eurasia will require new approaches that allow for complex interactions of social processes.

Some of the key characteristics of the NEESPI region related to land use are:

- Change in land use intensification related to water use, nitrogen fertilization rates, and grazing affecting agricultural production, and forest and crop management systems;
- Change in economic policy and land-use; and
- Degradation of land productivity, including loss of soil fertility, increase wind and water erosion.

The NEESPI Human Activities science strategy represented in the following sections of this chapter is consistent with the focus of the IGBP and IHDP Global Land Science joint research agenda for land-centric research – people, biota, and natural resources (cf., NRC 1998; Box insert 3.4.1). The focus in all programs is the emphasis on the linkages and changes in the coupled human and environmental system associated with land sustainability.

Box insert 3.4.1. Human Dimensions Imperatives from: "Human Dimensions of Global Change" prepared by the U.S. NRC Committee on Global Change, Board on Sustainable Development (NRC 1998).

- Understand the major human causes of changes in the global environment and how they vary over time, across space and between economic sectors and social groups.
- Determine the human consequences of global environmental change on key life support systems, such as water, health, energy, natural ecosystems, and agriculture, and determine the impacts on economic and social systems.
- Develop a scientific foundation for evaluating the potential human responses to global change, their effectiveness and cost, and the basis for deciding among the range of options

▪ Understand the underlying social processes or driving forces behind the human relationship to the global environment, such as human attitudes and behavior, population dynamics, and institutions and economic and technological transformations.

3.4.2. Land Use in Transition

The Eurasian region consists of a broad range of ecosystems and associated land uses. During the past decade, most of the land use management in these countries has changed and are transitional economies. These countries are among the most vulnerable in terms of their economic, political, and environmental systems. Interactions between and among policies, human responses, and Earth system function cannot be decoupled. Transition economies are characterized by a combination of a) volatile markets, b) policy reforms, and c) unclear and uncertain land tenure systems. It is not any single factor, but rather the combination of all three, that makes these systems and peoples vulnerable in a number of different capacities.

The past two centuries have seen the world's largest decline of forests and grassland areas from the Eurasia region (Grubler 1994). Croplands have increased in the region with the peak land area occurring in the late 1980s. In the northern regions of Eurasia, a decrease in the agricultural land areas started after World War II (Golubev et al. 2003). Land degradation has become a serious environmental concern in the region due to overgrazing, cropping marginal lands, and increased frequency of fires resulting in desertification, increased dust storms and erosion soil losses, salinization, and increased aerosol loading due to burning. Liberalization has eroded the state institutions through which the socio-economic system was organized and in the absence of alternative social and market-based institutions households have been left to face the risk of a natural calamity alone. As a result, the effects of natural disasters upon the pastoral economy are likely to be far more severe than they have been.

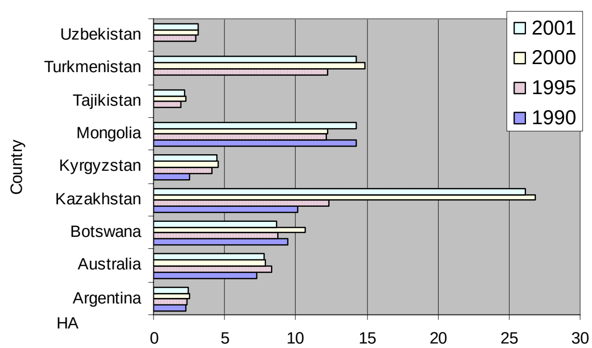

Figure 3.4.1. Permanent pasture per livestock unit (FAO data). For Kazakhstan, a twofold increase in this parameter during the 1990s means (unfortunately) not an increase in the pasture area but a collapse of large collective farms and decrease in livestock.

Transition from centrally governed pastoral systems to free market economy brought very different consequences for livestock industry in countries of east and central Asia during the last decades. While the switch to the market economy was relatively successful in China and Mongolia, it had a detrimental affect in Central Asian states such as Kazakhstan, Tajikistan, and Kyrgyzstan (Kerven and Lunch 1999; Behnke 2001; Kerven 2001). The Institute of Geography of the Russian Academy of Sciences estimates that these ecological problems characterize nearly 16 % of the territory of the former Soviet Union. The human-environmental system in these regions is under greater stress, since over 48% of the former Soviet Union population lives within the region of affected lands. This disproportionate reliance on these lands will further stress the land resources given the concentration of human population around these ecologically fragile lands.

Studies are needed to analyze the nature and extent of the impacts of the varied and different governmental policies, politics, markets, and changes in governance in addition to climate change on nomadic pastoral and sedentary systems, livestock management, grazing patterns, cropping systems, large-scale conversion of natural lands to crop lands, and, *especially, the indigenous peoples of the Russian North. Studies should be done to determine ways to reduce the vulnerability of target populations against these forces.*

Studies are needed to analyze the interconnections between the impacts of climate and social/political changes and their combined effects on land use land cover change and on the productivity of the land as well as effects on ecosystem services.

Studies are needed to determine the impacts of the post-Soviet reduction in basic social services (e.g., health care, education, drought mitigation) on human populations and the impacts of the resulting poverty and abandonment of agriculture on the different ecosystems. Studies should be done to determine ways to compensate for loss of these basic social services.

3.4.3 Land Conversion and Driving Forces

Land conversion has taken place throughout the region from northern areas where forestry, mining, and oil and gas development have significantly altered the landscape in these regions to more temperate regions where agricultural development has been extensive during the past century. The agricultural output of Eurasia has been one of the most productive in the world. High soil fertility, good, but variable climatic conditions, and an industrious human resource base have all contributed to the rich agricultural production. Contributing to this increased productivity of croplands is the increased use of synthetic fertilizers, intensification of agricultural practices as evidenced by the number of tractors being used today, and increased number of livestock produced. The human activities, which have significantly altered the environment and, in turn, impacted the people of each region, are described in the following section by ecosystem type.

Far East Asia

Due to an increasing population, industrialization, and urbanization, the demand for land resources has been growing in Far East Asia. During the past century, natural ecosystems such as forest, grasslands, and wetlands have been encroached by farmland and other man-made ecosystems on a very large scale. Estimates of Chinese land cover for 1992 indicate that farmland; forest, grasslands, and desert comprise 0.96, 1.33, and 3.19 million km^2, respectively. During the same period, land degradation has also been very serious, resulting in a shortage of land resources, leading to environmental problems such as desertification, deforestation, and soil and water erosion affecting the sustainable economic and social development of the region. Rapid development of industrial economy and expansion of urbanization in the North China Plain have reduced cropland areas. This has also generated a tremendous demand on water resources, which has caused a further shortage for agricultural irrigation, resulting in a decline of irrigated land since the late 1970s (Xu 1996, Zuo and Xu 1996).

Studies are needed to assess the relationships between climate variations and climate changes - including, natural disasters such as floods, droughts - and rapid development, population growth, urbanization, industrialization, and government policies as well as their combined resultant impacts on agriculture, livestock management, and water availability.

Studies are needed to assess results of the policy decisions to move large populations of non-indigenous peoples into the lands formerly inhabited by indigenous peoples, including loss / change of indigenous culture, traditional land use practices, and subsequent impacts on the land.

Far North (Arctic coastal zone, tundra)

Climate changes in the Far North are the largest and most rapid since the beginning of civilization and are dramatically impacting humans, societies, infrastructure, and ecosystems. Indigenous peoples are especially vulnerable to climate change due to dependence upon subsistence hunting, herding, and fishing as well as often isolated existence in small rural communities with little infrastructure support (Box insert 3.4.2). Climate change is accompanied by other environmental and social changes including pollution, increased UV radiation, habitat destruction, urbanization, development, and tourism (Corell 2004). The ecosystems at the northern extreme of the continent have been already quite vulnerable due to the extreme weather conditions. Now many oblast'[26] are affected by industrial development. The extraction of minerals in the North has the greatest impact on the environment and human health and of all of the mining enterprises, the coal industry has the most negative ecological and economic impact[27].

A comprehensive scientific assessment of the impacts and consequences of environmental changes across the Arctic region is presented in The Arctic Climate Impact Assessment (ACIA 2004). Coordination with the ACIA recommendations will be important for NEESPI program development. *Taking into account the ACIA Assessment findings, studies are needed on the impacts of climate variability and change and increased UV radiation on the people and ecosystems of the NEESPI region; and studies are needed on the vulnerabilities and capacities of human and ecosystems to adapt to these changes.*

The Arctic Monitoring and Assessment Program (AMAP) in assessing the Arctic pollution issues, concluded that there is a general lack of specific data about contaminant levels in the Russian Arctic and initiated a special project "Persistent Toxic Substances, Food Security and Indigenous Peoples of the Russian North" (AMAP 2002). Further studies are needed to better define the sources, fate, and effects of the contaminants from the different sources of contamination – both in ecosystems as well as human populations. Health effects on local populations, including indigenous peoples, is a high priority research area. The effects of climate change on the sources, fate, and effects of these contaminants should be also investigated.

Box insert 3.4.2. Reindeer in Russia: An Example of Social-Ecosystem-Climate Linkages and the Impacts of Land Use Transitions. Reindeer husbandry in Northern Russia is an economic activity with a special cultural dimension of utmost importance to the indigenous peoples (AMAP 2003). Approximately 60,000 people, including 20-25 different groups of indigenous peoples, are employed in reindeer husbandry that is very sensitive to changes in the environment (Jernsletten and Klokov 2002). Climate changes with warmer temperature are creating significant problems now in the Arctic for the reindeer herds (Anisimov and Fitzharris, 2001; Fancy and White 1985; Cameron et al. 1992; Malcolm 1996). In addition to the impacts from climate change, industrial development (e.g., mining, pipelines, oil and gas infrastructure) has increased across reindeer migratory routes in Northern Russia, blocking pathways to summer pasturelands and reducing usable pasturelands (Forbes, 2000). The recent transition of Russia to a market economy has resulted in complete disorder in most parts of the supply and transport systems in remote northern areas. This has resulted in nearly complete disruption of any system of supply of goods, services and health care to northern Russian indigenous peoples. As a result of these factors combined, there are rapidly deteriorating health and living conditions in the reindeer herder communities, with growing death rates and serious health impacts (Jernsletten and Klokov 2002).

Boreal Forest Zone

The boreal forest ecosystems have come under extensive fire threat in the past decades with catastrophic fires covering approximately 200,000 hectares annually in Russia alone (3.1; Korovin and Zukkert 2003). In addition to the more natural disturbances, timber cutting

[26] Oblast' = province; Krai = large boundary provice in Russia that may include some "oblast'" as its part.
[27] For example, the mining of 1 million tons of coal is accompanied by a discharge to the open water reservoirs of 3.22 million cubic m of polluted industrial waters, removal and dislocation of 1.5 million m^3 of stripped and enclosing rocks, disturbance of 10.2 hectares of land plots, and emission of about 3.0 thousand tons of harmful substances to the atmosphere.

(over 1 million hectares of forest lands annually) continues to be active in these ecosystems. The quality of forest resource products have declined and the area of high-grade timber has declined markedly, though pressure for wood products does not seem to be declining. Another impact associated with indirect effects of mining and industrial activities is the decline in forest productivity due to increased pollution levels (hundreds of thousands of hectares on the Kola Peninsula, Urals, southern Siberia, Norilsk and other). At the same time, during the last several years, agricultural lands were overgrown with forests – the area covered with forest increased by 36.2 million hectares.

Studies are needed on the effects of the extensive fires, which have taken place over the past decade across Northern Eurasia on the area's ecosystems, human health and well-being, and forest-related products and services. Studies should include the effects of climate change on the frequency and intensity of fires in forests, peat, and other ecosystems.

Studies are needed on the effects of pollution from mining, oil and gas development, and other industrial activities on forest productivity, the forest ecosystem, and the human populations that depend upon the forest environment, including health effects.

Studies are needed to assess the rate and specific features of forest restoration after felling and the relationship to human activities.

Areas of intensive agriculture development (steppe, forest, steppe, and forest zones)

Agricultural development is located at a key intersection between industrial modernization and preservation of natural resources (Fuelner 2001). On the one hand, ever-increasing needs of humans put pressure on the quantity and rate of food production, while on the other hand, food production itself depends largely on healthy ecosystems. Because agriculture is a major land use/change activity in Northern Eurasia, it is important to increase awareness of the consequences of associated desertification, deforestation, reduced biological diversity, limitations of fresh water, and degradation of lands (Fuelner 2001). Climate change and elevated CO_2 will affect agro-forestry systems, productivity, altering local food and fiber supply, thus affecting the magnitude of land carbon fluxes and their spatial distributions. Impacts will depend on the severity of climate change as well as on the adaptation capacity of regional systems (Rosensweig and Tubiello, 2004). All of these forces must be part of any research program for assessing the success, impacts, and future sustainability of agriculture in the Northern Eurasian region.

One of the main factors affecting the state of the environment in Northern Eurasia is the change of area and structure of agricultural lands. Highly cultivated regions have tended to grow except for the cultivated chernosem areas. Thus, levels of agricultural cultivation attained by 1980-90 had reached their maximum extent for practically all areas of the European territory (Table 3.4.1). During 1990-2001, in all the oblasts of the European territory, a reduction of agricultural lands took place.

Existence of fertile soils in Northern Eurasia (e.g., in many regions of chernozem – one of the most fertile soils in the world) has historically predetermined the development of agriculture. Located in these zones is the main grain belt of Ukraine, Russia, and Kazakhstan. Thus, steppes and forest steppes of the Russian plain, occupying 6% of the Russian territory, give 40% of its agricultural productivity (Steppes…, 1994). Droughts and soil erosion are the most powerful factor of crop capacity formation in all grain- producing oblasts of the former USSR[28]. Decrease of soil fertility and soil erosion have led to reduction

[28] For example, oblasts with a possibility of drought of over 25% along with dry and arid regions include a significant part of Moldova and Ukraine south of Russia and Trans-Caucasus, whereas oblasts with a possibility of drought of less than 25% include the more northern territory, up to the latitude of Saint Petersburg in the European part of the Region (60° N), part of south of Siberia, and even Central Yakutia. Agricultural lands in

of productivity of arable land by 30-40%. Deficiencies in projects, construction, and exploitation of irrigating systems led to the fact that, out of 5 million hectares of irrigated lands in Russia, 739 thousand hectares (or 15%) are in an unsatisfactory state. The present sowing area over these regions amounts to 1.028 million hectares which is 5.3 million hectares less than at the time of maximum cultivation (1990).

Table 3.4.1. Land Use Characteristics for Russia, Belarus, and Ukraine (IBRD 2002)

Indicator \ Country	Russia	Belarus	Ukraine
Land Area (10^6 ha)	1690	20.7	57.9
	Land Use (%)		
Arable Land	7	30	57
Permanent Pasture	5	14	13
Other Agricultural	0.1	0.6	1.7
Forest and Woodland	45	35	16
Other	42	20	12
Irrigated Cropland (%)	3.9	1.8	7.2
Fertilizer Use (kg/ha)	13	119	27
Agricultural % of GDP	7	13	14

Research work is needed to improve the description and quantification of the impacts of climate variability and change on agricultural and forestry productivity, as well as to describe how management and land use changes feed back on the regional climate and carbon cycle, and, in turn, how feedbacks with social, economic, political and governmental policies affect practices, management, and land use changes.

It is necessary to improve current biophysical descriptions of agricultural and managed forestry systems within existing ecosystem models, focusing on plant growth and yield as a function not only of climate, but also as a function of genetic and management factors such as crop and cultivar characteristics, irrigation and fertilization schedules, rotation types, soil management, as well as influences of policies and social factors.

There is need to close the gap among site-level crop modeling studies, land use dynamic, and terrestrial carbon modeling, including critical linkages with climate modeling. *Strong interdisciplinary collaborations should be developed among researchers with expertise covering crop, ecosystem modeling and carbon cycle, as well as climate change impacts land and water resources, adaptation and management strategies, social and economic forcing, and vegetation-climate interactions within regional and general circulation models*. Such expertise should include ground-truthing of data, models, and scenarios using field, statistical, and satellite data. Integration of research and education at the local to international level needs to be an essential component of this effort.

Pronounced observed and projected patterns of warming in the Eurasian region over the coming decades may be associated with high impacts on ecosystems, land use and management, greatly affecting carbon cycle dynamics and the sustainability of societies. *Therefore, a general modeling framework linking crop, land use and ecosystem models, socio-economic factors, and climate, to investigate key research questions within the areas of intensive agriculture development of Northern Eurasia is a must.*

Arid and semiarid zones

Arid semi-arid and dry sub-humid regions occupy a considerable part of the CIS countries (Table 3.4.2) China and Mongolia. The area of dry arid regions with a ratio of

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Russia impacted by water erosion equal an area of 300,000 km^2 and lands damaged by wind erosion equal 79,000 km^2. The area of eroded lands grows by 4-5 thousand km^2 each year and lands impacted by secondary salinization of irrigated lands grows by about 7.7 thousand square km a year.

precipitation to potential evapotranspiration of less than 0.65 amounts here to over 4.6 million km (Glazovsky and Orlovsky, 1966; Glazovsky 1997). Over 70 million people live in this territory within the CIS and more than 100 millions in Northernmost China and Mongolia. In semi-deserts and deserts, only 15-20% of the pastures are in satisfactory condition, 30-40% are moderately worn out pastures, 30-40% are strongly worn out, and 15-20% are withdrawn from agricultural use and transformed into worn out sands and bad lands. Within the limits of sand pastures, the area of open and mobile sands increased from 5-10% to 20-30%. In these semiarid and arid regions of Eurasia, drought and desertification affected areas are widespread. The increase in drought and desertification has caused an important new source and mechanism for potential health problems as well as ecosystem impacts – the transport of airborne desert soil dust (often in large amounts) that is lifted and carried by the winds over significant distances. Dust and dust storms from the arid areas have been increasing due to drought, agricultural and other land activities, and population growth. Recent studies have shown that dust in the atmosphere may present a serious set of health issues. Dust events can cause significant impacts from the dust itself, as well as accompanying contaminants, salt, and other inorganic and organic materials, including pathogenic microorganisms (Maynard 2004; 3.6.3). The damage to humans and ecosystems from desertification and dust storms is exemplified by the Aral Sea story, a combination of human and natural forces working together to create a dramatic ecological disaster.

Table 3.4.2. Area of dry and arid regions, thousand square km (with the ratio of precipitation to evapotranspiration less than 0.65)

COUNTRY	AREA	COUNTRY	AREA
Azerbaijan	40	Russia	610
Armenia	12	Tajikistan	95
Georgia	6	Turkmenistan	488
Kazakhstan	2627	Uzbekistan	440
Kyrgyzstan	145	Ukraine	136
Moldova	13		

Studies are needed to assess the present state of impact of human activity on ecosystems and human societies in arid and semi-arid regions and projected future trends given current social, economic, climatic and developmental projections. Studies are needed on the relationships between human activities, ecosystem changes, climate changes, and the initiation of the large dust storms in Northern Eurasia.

Studies are needed to determine lessons learned from past land use practices and ecosystem responses in arid and semi-arid regions and to develop more sustainable natural resource management practices.

Studies are needed to assess the impacts of extreme desertification and dust events on human and ecosystem health, including the effects of the dust and contaminants, salt, and microbes on downwind populations, livelihoods (e.g., agriculture), and ecosystems. Related studies are needed on possible ways to mitigate these effects and improve land management practices.

Urban and industrial development

Rapid urban growth and industrial development stemming from the promise of perceived improvement in economic opportunity and quality of life have resulted in often extreme concentrations of people accompanied by significant impacts on surrounding ecosystems as well as adverse feedbacks to the urban dwellers themselves and populations nearby. Factors such as poor sanitation, congestion, lack of social and physical infrastructure, poverty, pollution of the air and water by municipal and industrial waste, and imprudent use of water combine to contribute to degradation of the environment and to health problems in local populations. Demands on the surrounding regions are large so the linkages between urban/industrialized areas, local ecosystems and humans are increasingly important. Human interactions with hydrological and biogeochemical cycles and geological processes are especially strong in urban areas. This may create serious problems[29].

Studies are needed on the effects of urban and industrial development on global and local land use and change patterns in Northern Eurasian regions, especially, as they reflect the changing policies, governance, and economic realities of the post-Soviet era. These studies must take into account the effects of climate and environmental changes.

Studies are needed to devise tools to detect the effects of human-related structural changes to land surface characteristics and ecosystem properties in urban and industrial areas in Northern Eurasia and the ramifications for human and ecosystem health.

Studies are needed to document lessons learned in current industrialized regions and urban areas and to devise more sustainable strategies for future development practices.

3.4.4. Natural and Anthropogenic Hazards

The Northern Eurasian region is subject to a complex mix of serious hazards from both natural environmental forces (including climate change) as well as anthropogenic causes. In the first place, the region is characterized by extreme weather-related events such as strong winter storms, high winds, low temperatures, floods, landslides, snow, sleet, ice and heavy rain storms, severe thunderstorms, avalanches, landslides, drought, massive dust storms, and coastal erosion, all of which may have enhanced effects from climate and environmental changes in the future. Climate change is already creating unprecedented changes in Northern Eurasia (3.3.4.2). In addition, there are a number of growing, serious anthropogenic influences making dramatic changes to the environment, such as pollution from persistent organic pollutants, heavy metals, radioactivity, munitions waste, hazardous materials dumping, and acidification as a result of mining, oil and gas development, building of infrastructure, road construction, and other forms of industrial development in the Northern Eurasian region – accompanied by infrastructure, additional pollution, congestion and other manifestations of human presence.

Studies are needed to more clearly define the frequency and intensity of extreme events and natural disasters in the different regions of Northern Eurasia as well as the vulnerabilities of the population to these events. In particular, the capability of the peoples to cope with natural as well as anthropogenic disasters should be studied and measures to enhance this capability should be suggested.

Studies are needed to define the additional effect anticipated that could result from climate changes in the region on the severity and nature of the extreme events and natural disasters (e.g., sea level rise, permafrost thaw, ice melt, thunderstorm activity) and their impacts on people of the region. This should include improved efforts to monitor and predict

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[29] Examples of these problems are, in Russia, 725 cities (66% of the cities) are subjected to landslides, 301 (28%) to karst, 958 (88%) to suffusion, 563 (52%) to subsidence of loess rocks, 442 (40%) to soil erosion, 734 (67%) to surface and gully erosion, 50 (5%) to reworking of sea shores and water reservoirs, 960 (88%) to floods from beneath, 72 (7%) to cryogenic processes, 103 (9%) to earthquakes, and 746 (68%) to floods. The amount of waste from urbanization and industrial development, production, and consumption, including the toxic waste, is gradually growing. There are already 1.8 billion t. of toxic waste accumulated, their annual increment being 108 million t. Only 15% are rendered harmless. Of the burial sites of the most dangerous toxic waste, 70% do not meet sanitary requirements.

climate conditions and changes – and to feed back that information to people in the region for emergency preparedness.

3.4.5. Impacts on Ecosystem Services

Land use impacts in the region have affected ecosystem services. Ecosystem services, such as, water quality and quantity, air quality, and biodiversity have been greatly affected. The net result has been a lessening of the quality of life in the region with implications on declining human well-being and health in the region. The following sections discuss some of these concerns.

Impact on water quality and quantity

The use of natural waters is one of the most important problems in arid and sub-arid regions of northern Eurasia. The problem is aggravated by the fact that the geographic distribution of water resources is extremely irregular and all the largest river basins are located within the territories of several states. Water issues are also affected by the rapid increase of irrigation development and the water quality changes associated with drainage runoff from these irrigation projects. The Aral Sea as a Case Study for Water Issues is described in (2, 3.3; Box insert A2.1).

Studies are needed to analyze lessons learned from previous water management projects in Northern Eurasia and elsewhere and to find methodologies for integrating these lessons into future planning efforts on water management projects in the region.

Studies are needed to assess the proposed plans to transfer river waters from Siberian rivers to Central Asia, and to assess the impacts of those actions on the ecosystems and people of all effected regions.

Studies are needed to assess the magnitude and impacts of pollutants from both localized sources in specific regions (e.g., industrial development) as well as long-range transport of pollutants from distant sources on quality of water supplies in Northern Eurasia.

Studies are needed on the present and potential impacts of anthropogenic influences and climate change on the sources and pathways of key water supplies of Northern Eurasia which are a resource to major population centers. Studies are also needed on the implications of these changes in supply and quality of water to receiving populations as well as an analysis of possible mitigation measures.

Studies are needed to better understand the societal, governmental, and political/economic factors which cause adverse effects on water supplies.

Impact on air quality

Air pollution from both natural and anthropogenic causes is considered to be one of the most serious world-wide environmental-related health problems, and is expected to become worse with changes in the global climate ((Piver et al. 1999; McMichael et al. 2000; Patz et al. 2000). Populations in large urban settlements are expected to be exposed to increased air pollutants, where health effects could be exacerbated by increases in weather-induced heat waves (McCarthy et al. 2001). This is a particular concern because of the dramatic migration of populations from rural to urban centers and the associated rapid expansion of cities (Parris and Kates 2003). Contaminants, smoke, and pollutants from fires, stoves, motor vehicles, industrial development, and other sources can create significant problems for both city and rural settlement populations. Some of the pollutants of greatest concern are ozone, nitrogen dioxide, sulfur dioxide, acid aerosols, carbon monoxide, lead, and particles (Bernard, Samet et al. 2001). Recent studies have demonstrated an important new source for potential health impacts in airborne desert soil dust that is lifted and carried by the winds over significant distances. Although atmospheric transport of large amounts of dust has taken place throughout geologic time, dust amounts have been increasing in Asia since the 1950s (Kebin et al. 2002; 3.6.3) due to drought, agricultural and other land activities, and population growth. In addition, air pollution from forest fires is a growing issue due to the increase in the occurrence of fires of both natural and human-caused origin (Korovin and Zukkert 2003). Of special concern are "dirty fires", in which radioactive or other toxic material burns, converting the smoke into an especially serious air pollution problem.

Studies are needed to determine the sources, fates, and effects of emissions of the different kinds of urban, mining, and industrial activities on human health and ecosystems, and their interactions with the water and land ecosystems. In particular, studies should be done to locate, map, and prioritize nuclear and toxic test sites, dumps, spills, and accident sites and then provide environmental, hydrological, and climatological expertise and information to help guide the clean up process.

Studies are needed to better understand the relationships between the social/political forces in Northern Eurasia and the pollution from cities and industrial development. This problem may be divided into three objectives: The inventory of air pollutants emission data over Northern Eurasia, that has a lot of gaps; Qualification of emission rates and total concentration in troposphere of the most important optically active gases (CO_2, NO_2, N_2O, O_3, etc); and finally studies should be conducted to determine mitigating actions might be taken to reduce pollution levels that are harmful for human health.

Studies are needed to better understand the causes (social, political, economic as well as natural), nature, and magnitude of the occurrence of fires including health impacts on populations. This should include the risks associated with "dirty fires" which involve radioactive and toxic materials.

3.4.6. NEESPI Contributions to Biodiversity Science in Northern Eurasia

In terms of practical actions to preserve biodiversity, reasonably anthropocentric approach was recommended (Zagorodniuk, 2000). It includes completion of red lists of endangering species, combined with urgent designing of quasi-natural ecosystems and protection of functionally steady aggregations of species rather than species as such. In scope of this and other approaches following priorities could be proposed:

- *Zoning of the protected territories the most threatened by global climate changes*
- *Management of transboundary protected areas and territories, development of the Northern Eurasian Protected Areas network*
- *Biodiversity and sustainable agriculture*
- *Enhance the application of IT (RS, GIS and Internet)*
- *Migratory species monitoring and conservation.*

The NEESPI expects to contribute to the updating the global biodiversity model (GLOBIO) as well as to the improving scenarios "2010" and "2100" related to biodiversity and support projects that seek to use modern technologies and modeling to better understand and quantify the relationship between biodiversity and land-cover/use change and climate change and their interactions in Northern Eurasia. There are a number of national and international groups (e.g., the Biodiversity Program within NASA, World Resources Institute, Conservation International, World Wildlife Fund, Greenpeace Russia, and other groups in United States, Northern Eurasia, and Europe) whose contribution to the NEESP initiative is highly desirable.

3.4.7. Consequences of land use change for society: Human Health and well-being

To evaluate the health and well-being of humans in the Russian Arctic, it is necessary to address the complex mix of factors which make up the human environment, including physical, chemical, biological, social, and cultural factors - all of which affect people's health and well-being (AMAP 2002). Currently, a significant number of people in the Arctic are exposed to high level of environmental pollutants. Of particular concern, persistent contaminants, from both local and long distance sources, were found to magnify in animals that are used a traditional foods by the indigenous peoples, thus providing a direct pathway for pollutants to human (AMAP 2003). In general, indigenous peoples of the Russian Arctic reflect a poor health status relative to the general population of Russia as well as to other Arctic indigenous peoples, with life expectancies 10-20 years lower than the average Russian population.

In Northern Eurasian cities, atmospheric pollution is an important health factor, especially in the Siberian and Ural regions. In many cities where the level of pollution is extremely high, it is reflected in high levels of morbidity and mortality. The most recent information about air pollution in Russia was presented in the national report, published by Izrael et al. (2002). Materials of this report list the most polluted Russian cities where short-term (20 min averaged) concentrations of one of the pollutants, monitored in 2001, were higher than the <u>tenfold</u> value of the corresponding Maximum Permissible Concentration (the Russian National Ambient Air Quality Standard) at least once. The values of MPC (usually both, short- and long-term) are established in Russia for more than 2000 species. In 2002, the list of the most polluted Russian cities based on this API sorting included 31 cities with a total population of over 15 million. The impact of high levels of pollution on human health is detrimental, in particular, proven correlation with cancer in polluted regions was documented (cf., Box Insert A3.4.3 in Scientific Background Appendix).

Atmospheric, water, and soil pollution are important health factor in several rural regions in Northern Eurasia. First of all, these are the regions windward and downstream of major industrial areas and regions of ecological and technogenic catastrophes (e.g., areas around Chernobyl, Chelyabinsk, Semipalatinsk, and Aral Sea).

Studies are needed to better understand the links between environment, weather, climate and health problems in Northern Eurasia including factors such as urban, regional, and global air and water pollution; contaminant transport and deposition – through oceans, atmosphere, and ice; UV radiation, water-borne-diseases, thermal stress; and infectious and vector-borne diseases.

Studies are needed to identify relative vulnerabilities of different populations (urban, rural, close proximity to mining and industrial operations) to health impacts from environmental, weather, pollution, and climate factors, and to identify mitigation actions to reduce risk.

Studies are needed to define the governance, social, economic, and policy drivers which have created the sources and pathways of pollutants which are affecting human health, and to find methodologies for feedback of this information to policy-makers and decision-makers for improved policies and actions for the future.

Studies are needed to better define the health impacts of POPs, heavy metals, radioactivity, and acidification on Northern Eurasian peoples, the variations within different settlement types (urban, rural), and possible mitigation actions.

3.4.8. Major Science Questions are grouped in four categories according to *Human Dimensions Imperatives* (cf., Box insert 3.4.1, NRC 1998).

Understand the major human causes of changes in the global environment and how they vary over time, across space and between economic sectors and social groups.

- What is impact of land use structure changes on biogeochemical cycles?
- What is the state of impact of human activity on ecosystems and human societies in arid and semi-arid regions and projected future trends given current social, economic, climatic and developmental projections? What are the relationships between human activities,

ecosystem changes, climate changes, and the initiation of the large dust storms in Northern Eurasia.

- What are the effects of urban and industrial development on global and local land use and change patterns in Northern Eurasian regions, especially, as they reflect the changing policies, governance, and economic realities of the post-Soviet era?
- What are the present and potential impacts of anthropogenic influences on the sources and pathways of key water supplies of Northern Eurasia which are a resource to major population centers? Studies are also needed on the implications of these changes in supply and quality of water to receiving populations as well as an analysis of possible mitigation measures. How can we better understand the societal, governmental, and political/economic factors which cause adverse effects on water supplies?
- What are the vulnerabilities of agricultural, grasslands, and managed forest ecosystems to expected climate and socio-economical trends?
- What is the role of aerosol and gas air pollutants from the industrial centers in Northern Eurasia to climate change processes? From the point of view of air pollution over Northern Eurasia, will the future climate be more favorable or not (increased occurrence of temperature inversion, low wind speed, etc)?

Determine the human consequences of global environmental change on key life support systems, such as water, health, energy, natural ecosystems, and agriculture, and determine the impacts on economic and social systems.

- How will population numbers and density in various regions of Eurasia affect the land use?
- How do human modifications of land cover affect regional Northern Eurasian and global ecosystem functions and ecosystems feedbacks?
- What are the effects of the land uses and land-use changes during the planned economy on Earth system functions (e.g., regional climatology, water resources, carbon and surface energy balance, biogeochemistry, biodiversity)?
- What are the impacts of extreme desertification and dust events on human and ecosystem health, including the effects of the dust and contaminants, salt, and microbes on downwind populations, livelihoods (e.g., agriculture), and ecosystems.
- How do we identify relative vulnerabilities of different populations (urban, rural, close proximity to mining and industrial operations) to health impacts from environmental, weather, pollution, and climate factors and how do we identify mitigation actions to reduce risk?
- How can we better define the health impacts of POPs, heavy metals, radioactivity, and acidification on Northern Eurasian peoples, the variations within different settlement types (urban, rural), and possible mitigation actions (especially, indigenous people)?

Develop a scientific foundation for evaluating the potential human responses to global change, their effectiveness and cost, and the basis for deciding among the range of options.

- What lessons can be learned from past land use practices and system responses of dramatic land-use modifications for sustainable natural resource management?
- What are the lessons learned in current industrialized and urban regions to devise more sustainable strategies for future development practices?
- What are the lessons learned from previous water management practices which could help define improved methodologies for sustainable water management in Northern Eurasia?

Understand the underlying social processes or driving forces behind the human relationship to the global environment, such as human attitudes and behavior, population dynamics, and institutions and economic and technological transformations.

- How will global economic processes affect the land use in Northern Eurasia?
- What are the relationships between climate changes and social, economic, and political drivers of land use change?
- What is the nature and extent of the impacts of the varied and different governmental policies, politics, markets, and changes in governance on nomadic pastoral and sedentary systems, livestock management, grazing patterns, cropping systems, large-scale conversion of natural lands to crop lands. How can the vulnerability of target populations against these forces be reduced? How will climate variability and change affect these systems and interactions?
- What are the best means of quantifying the impacts of climate variability and change on agricultural and forestry productivity, as well as the description of how management and land use changes feed back on the regional climate and carbon cycle, and, in turn, how feedbacks with social, economic, political and governmental policies affect practices, management, and land use change?
- How can we better define the governance, social, economic, and policy drivers which have created the sources and pathways of pollutants which are affecting human health, and to find methodologies for feedback of this information to policy-makers and decision-makers for improved policies and actions for the future?

A separate question is: *What were the initial pre-industrial conditions in Northern Eurasian ecosystems in the past?* If we know the answer on this question, we can try separating (at some extent) natural trends from human induced trends.

In summary, the vast regions of Northern Eurasia – and the broad range of lands, ecosystems and peoples that characterize them - have undergone major fundamental changes resulting from the unprecedented and dramatic transformations of the social, economic, political and technological systems in the countries of the region. There are many questions regarding the complexities of the social-ecosystem linkages and their impacts on land and resource use and management, and, ultimately, the consequences for basic sustainability of the regions. This chapter has provided a brief summary of the state of knowledge of the understanding of the linkages and changes in the coupled human and environmental systems associated with land sustainability in the region as well as a list of research gaps that should be resolved to fully address the following NEESPI questions, which are of special relevant to the Societal-Ecosystem Linkages of Land Use Interactions:

- *What has been the role of anthropogenic impacts on producing the current status of the ecosystem, both through local land use/land cover modifications and through global gas and aerosol inputs? What are the hemispheric scale interactions, and what are the regional and local effects?*
- *How will future human actions affect the Northern Eurasia and global ecosystems? For example, for different scenarios of future greenhouse gas and aerosol inputs, and for different forest clearing, water and agricultural land management, urban, industrial, and oil development projects, how will the ecosystem be changed? And how will changes in these ecosystems feed back to society? How can we describe these processes using a suite of local, regional, and global models?*
- *What will be the consequences of global changes for regional environment, the economy, and the quality of life in Northern Eurasia? And how can science contribute to decision making on environmental issues in the region?*

And to answer the overarching NEESPI science question:

How do we develop our predictive capability of terrestrial ecosystems dynamics over Northern Eurasia for the 21st century to support global projections as well as informed decision making and numerous practical applications in the region?

3.5. Ecosystems and climate interactions

Chapter lead authors: N.N. Vygodskaya, P.Ya. Groisman, N.M. Tchebakova

Contributing authors:
V.B. Aizen, E.M. Aizen, V.Yu. Georgievsky, L.O. Karpachevsky, N.K. Kiseleva , A.V. Kozharinov, Yu.A.Kurbatova, Sh. Maksyutov, A.V. Meshcherskaya, R.A. Pielke, Sr., V.N. Razuvaev, A.B. Savinetsky, A.O. Selivanov, A.I. Shiklomanov, N.A. Speranskaya, Yu.L.Tselniker, A.V.Varlagin, A.N. Zolotokrylin

Introduction. The climate system and terrestrial ecosystems interact as they change. The interactions enhance and/or moderate the changes making these changes non-lineary. There are theoretical indications that the particular state of the ecosystem may make the history of the global climatic changes intransitive[30]. Gradually, Human Activity (HA) has become a part of these interactions by affecting the atmosphere, hydrosphere, cryosphere, and biosphere. As a working hypothesis we can assume that, in the past, ecosystems were in dynamic equilibrium with climate at the 10^2 –10^3 year time scales (Figures 1.2 and 1.3)[31]. The present situation, however, requires new approaches as the equilibrium has been disrupted and a mounting body of evidence shows changes in the states of both the ecosystem and climate with human impact/reactions contributing to the swiftest of these changes (Figures 2.1, 2.2, and 2.7 through 2.17[32], AGU 2003). Thus, HA have introduced significant transient forcing and feedback to a dynamic nonlinear system, which already has natural thresholds[31]. Contemporary climatic changes in Northern Eurasia are among the largest in the world, are projected to remain so, and may affect the global climate system (2.2.1, 3.3.4.2, and Figures 2.2 and 3.3.2). Ecosystems here are vulnerable to external forcing, especially along their boundaries (in transient zones), and when affected may exercise important controls on the global Earth system (3.1, 3.2). In many parts of Northern Eurasia, the present state of the ecosystems has been sharply affected by HA and is already far from equilibrium (3.1, and 3.4). Thus, it can change without further external impact with unprecedented rates and even in a direction opposite to the climate-induced tendency[33]. Interpretation of the observed

[30] I.e., a possibility of the multiple long-term equilibriums of the Global Earth System exists under the same external conditions (Pielke 1998). One of the regions of the possible intransitivity is in the Central East Asia desert area (Claussen 1998). Another example is in the boreal forest zone of Northern Eurasia, where a millennium-scale process of paludification, i.e., gradual moss coverage of the surface and mire development could be an autogenous process (Pajula 2000). For example, the surface air temperature and precipitation conditions ~10,000 years ago may be approximately the same as the present at certain locations. But, now we have there a well developed moss cover that insulates the ground while10 to 6,000 years ago the moss cover was absent (or undeveloped) and the entire regional ecosystem (first of all, the soil temperature regime) was different.

[31] There are always ecosystems that are not exactly in equilibrium with the current climate state due to their slow response times. Furthermore, due to a non-linearity of the Global Earth System some of its components (ecosystems, cryospheric and/or hydrological states, ocean and/or atmospheric circulation modes, etc.) may be close to critical thresholds. When these thresholds are crossed during the "linear" way of changes or just by chance, abrupt shifts and trends follow (Rial et al. 2004). The paleoevidence shows that Northern Eurasia experienced such shifts and trends in the past (Neishtadt 1957; Khotinsky 1977; Klige et al. 1998; Kobak et al. 2002; Kozharinov and Puzachenko 2004; Figure 2.18).

[32] Figures 2.7 through 2.18 as well as figures 3.5.4 and 3.5.5 can be found in Scientific Background Appendix.

[33] For example, "greening" of abandoned farmland and pastures in Russia and Kazakhstan in the 1990s (Robinson et al. 2003) occurred while the climate became drier (Figure 2.11).

changes became a more difficult problem, though[34]. Finally, the observed environmental changes affect human society and forces it to react to changes, thus creating the human feedback to ecosystems and climate. This situation raises stakes in our quest for understanding of multifaceted processes that control natural interactions (feedbacks) and forced impacts and systems' responses in Northern Eurasia. The unique features of the region (2.2.2), important controls that it exercises over the global climate and environment (3.2, 3.3, 3.6.1, and 3.6.3), and the scale of observed climatic and environmental changes make the need of this understanding urgent. We must understand them to properly interpret the observations and generate projections of the most plausible scenarios of future changes.

Disclaimer: Direct anthropogenic effect of the fossil fuel burning on climate is not considered in this Chapter. It is sufficiently covered by IPCC (2001). Uncertainties associated with changing the chemical composition of the atmosphere are discussed in 3.2 and 3.6.3. Possible societal reactions to this change are addressed in 3.4. The focus of this chapter is on the feedbacks that emerge when climate and terrestrial ecosystems interact whatever other "external" forcing may be.

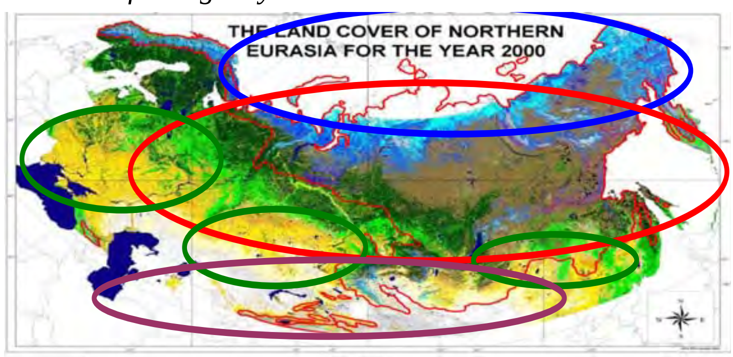

Figure 3.5.1. Present land cover of Northern Eurasia (Figure 1.1), boundaries of Cold Land Regions (thin red line; Figure 3.6.1), and schematic outline of four major ecosystems that will be discussed in this chapter: Arctic desert and tundra (blue), boreal forest (red), steppe/forest steppe/agricultural land (green) and desert and semidesert environment (brown).

3.5.1. Major relationships that define interaction of climate and ecosystems in Northern Eurasia

3.5.1.1 Major feedbacks

Statement of the problem. Terrestrial ecosystem-weather/climate interactions can be interpreted in terms of natural biogeochemical and biogeophysical feedbacks (Claussen et al., 2004). The biogeochemical feedbacks are associated with changes of terrestrial biomass, soil chemical properties, and microbiology and, thus, with changes of the chemical composition of the atmosphere. The biogeophysical feedbacks directly affect surface and near-surface energy, water, and momentum fluxes via changes in surface albedo, roughness, moisture availability for evapotranspiration, etc. More frequently, the biogeophysical feedbacks are the primary processes and are more "visible", while the biogeochemical feedbacks are secondary ones, being the function of biogeophysical processes. This partition is rather conditional: (a) The same process can control different feedback mechanisms[35] and (b) a non-

[34] We observe a summarizing effect, let's say, a decrease of wind over European Russia (Belokrylova 1989; Starkov et al. 2000), but cannot explain whether this is a result of weakening westerlies (cf. Figure 3.3.2) or of changes in landscape (e.g., reforestation). Furthermore, this reforestation in European Russia appears to be anthropogenically forced (abandoned agriculture lands as it is clear from the same figure) instead of a natural forest regeneration.

[35] e.g., the Leaf Area Index (LAI) change or stomatal conductance control both CO_2 exchange and transpiration (Monteith, 1975, 1976; Bihele et al., 1980; Mooney et al., 1999; Baldochii et al., 1996).

linear character of the ecosystem-climate interactions frequently manifests itself as a synergetic effect of all factors and individual feedbacks thus making partition meaningless (Berger, 1999, Ganopolski et al, 1998). But, while biogeochemical and biogeophysical feedbacks could be closely related, their direct interactions could be quite minor (Claussen et al. 2001; Claussen, 2001). There are still a lot of uncertainties in efforts to reveal the synergetic and resonance effects of various feedbacks, the major non-linearities, and areas of local equilibrium in the ecosystem-climate relationships. In different geographical regions, seasons, and times of day, different feedbacks may dominate and the same feedback may be of opposite sign and varying strength. Feedbacks and their dynamics may manifest differently on different spatial and temporal scales and thus determine the long-term climate (ecosystem and biome levels) change and short-time weather (ecosystems) variability in different ways[36]. Short-term variability of ecosystem responses to weather/climate variability (including extremes) is caused by physiological processes in the plant component of the ecosystem[37] and by reversible changes in physical and chemical soil processes. The long-term variability and changes in ecosystem responses to climatic changes are caused by biological processes (growth and loss of above- and below-ground biomass), by decomposition processes within the ecosystem, by stable changes of species composition and vegetation cover structure, and by changes in soil properties. It is clear *a priori* that large scale and long-term changes in climate (biome) should impact biome (climate) (Botkin et al., 1992; Gutman, 1995; Claussen et al., 1998). But, these impacts frequently reveal themselves in short-term events such as fires, dust storms, floods, windthrow, landslides, droughts, excessive soil moisture, thaws, ice jams, etc. Imperceptible accumulation of quantity (e.g., gradual drying or temperature rise) then qualitatively manifests itself in an extreme event (that old-time residents cannot recall) or in a changing frequency of such events. An opposite scenario may also occur. A sequence of strong regional feedbacks during short periods of time (e.g., high vegetation mortality during droughts) may then (a) determine the multi-seasonal and inter-annual variability of both the ecosystem *and* climatic system, (b) enhance spatial gradients and instability of the atmosphere boundary layer, (c) affect the ecosystem stability and its immediate and delayed responses to the climate impact, and finally (d) the changed ecosystem feeds back to the climatic system. Furthermore, feedbacks manifest themselves in interactions of vegetation, atmosphere, hydrosphere, cryosphere, and soil, each having very different inertia (response times to forcing). Thus, the total ecosystem response to climatic changes becomes non-linear and can be unexpected. This volatility makes the study and projections of ecosystem-climate interactions extremely difficult.

Biogeochemical feedbacks. At present, using models and experiments in controlled environmental laboratory chambers, the direct and indirect effects of CO_2 increase on photosynthesis, vegetation growth, transpiration, and mineralization of soil organic matter are sufficiently studied. However, the long-term effects of the CO_2 enrichment at the ecosystem level are still unclear[38]. We still have insufficient information about the synergistic effects of changes in atmospheric CO_2 concentration, temperature, and nitrogen deposition on the ecosystem- and biome-scale responses[39]. According to Claussen (2004), classical biogeochemical feedbacks are based on an assumption that, in a warmer climate, there will be an intensification of bioproductivity, $B+\Delta B$, and thus a sequestration of some fraction of the anthropogenic CO_2 will occur. For example, boreal forest located in the regions of greatest

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[36] E.g., Braswell et al., 1997; Pielke et al., 1998; Raupach, 1998; Loehle, 2000.

[37] E.g., Irvine et al., 1998; Maercker-Maier 1998; Varlagin and Vygodskaya 1993.

[38] Schlesinger, 1988; Schlesinger, 1997; Schulze and Mooney, 1992; Hättenschwiler and Körner, 1996; Norby et al., 1999, Mooney et al., 1999; Ellsworth, 1999; Arneth et al., 2002.

[39] Aber and Driscoll, 1997; Churkina and Running, 1998; Lloyd, 1999; Mund et al., 2002.

warming *and* a general surface heat deficit is a primary candidate for this *negative* feedback. But, several constrains (unresolved questions) are attached to this assumption:

- What if the area of the boreal forests changes with climatic change? If the answer to this question is positive, the product of the area of this change, ΔS, and $(B+\Delta B)$ can then be *positive or negative* and will oppose or enhance the effect of ΔB. This alone makes the summarized sign of this particular feedback undefined.
- What if, with the temperature increase, the rates of respiration, transpiration, decomposition of dead biomass and soil organic material, and the rate of release of methane and CO_2 from soil increase (especially from the thawing permafrost, 3.6.1)[40]? Northern Eurasia, and particularly its boreal forest zone, tundra, and wetlands have the largest carbon soil pool in the world (3.1.2, 3.1.3, and 3.2). The changes in these rates may generate a potential runaway scenario of a strong positive biogeochemical feedback[41].
- What if, with time, the influence of some of these factors saturate (e.g., bioproductivity growth), and exhaust (e.g., carbon-rich layers decompose), while others enhance (e.g., changes in forest fire and windthrow areas, thawing of new areas with permafrost)? This raises the temporal factors (dynamics) as a critical issue of actual changes in this feedback.
- What if the forthcoming changes affect biomass and biodiversity of microbiota that control the biogeochemical cycle on various spatial and temporal scales[42]? Not much is known about the consequences of these changes especially for the ecosystems in Northern Eurasia.
- What if the changes in biodiversity associated with changes in both climate and land use affect trophic links within the ecosystems and thus interfere with the major biogeochemical feedback[43]?

And, finally,

- What if other changes in the ecosystems of Northern Eurasia associated with climate change, HA, and biogeophysical feedbacks interfere? For example, a changing rate of disturbances (e.g., forest fires, Figures 2.17 and 3.5.5) and changes in the water cycle (Figures 2.9 through 2.16) directly affect bioproductivity, soil and the wetland carbon pool.

Other substantial biogeochemical feedbacks in Northern Eurasia are related to changes in soil acidity and nitrogen deposition due to industrial pollution[44]. Anthropogenic impact may substantially enhance or weaken the major biogeochemical feedbacks. It may affect N pools and stimulate accumulation in the biomass and soil of phosphorus, sulfur, and heavy metals (3.2 and 3.4). For example, acidification of soils due to a long-term biogenic and microelement pollution at some types of soils can stimulate tree growth (Mund et al. 2002),

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[40] Dadykin, 1952; Grier, 1988; Dyer et al., 1990; Gorhman, 1991; Tzelniker et al., 1993; Inoe et al., 1995; Christensen et al., 1995, 1999; Kirschbaum, 1995; Krankina and Vinson, 1995; Borman et al., 1995; Hobbie, 1996; Ryan et al., 1997; Goulden et al., 1998; Vedrova and Mindeeva, 1998; Liski et al., 1999; Panikov and Dedish , 2000; Janssens et al., 2001; Bird et al., 2002; Buchman, 2000; Valentini et al., 2000; Vygodskaya et al., 2002.

[41] E.g., Moore and Roulet 1993; Schulze et al. 2001; Friborg et al. 2003.

[42] Finlay et al. 1997; Schiemel and Gulledge, 1998; Schiemel and Clien, 1999; Buchman,2000; Santruckova et al., 2000, Wardle 1998, Chernov 1980; Warde 1998.

[43] 3.2, 3.4; Archer et al., 1995; Archer et al., 2001; Baranchikov et al., 2002; Chapin et al., 1996; Collatz et al., 1998; Heywood and Watson, 1995; Hooper and Vitousek, 1997; Lovelock, 1994; Krivoluzky and Pokarzhevsky, 1986; Naeem et al., 1994.

[44] 3.4; Karpov, 1983; Schulze, 1989a; Schulze et al., 1989b; Kuhlusch et al., 1991; Berendse et al., 1993; Godbold and Hutterman, 1994; Kaipiainen et al., 1995; Holland et al., 1997; Berg et al., 1999; Schulze et al., 2000a, 2000b; ; Renn et al., 2001; Gravenhorst et al., 2002; Mund et al., 2002.

but negatively affect lichen and mosses. The anthropogenic impact upon the ecosystems can have cumulative features and reveal itself (and feed back) with a prolonged delay due to biochemical and phitocenogenic structural changes in the ecosystems. Furthermore, changes in the biogenic non-methane hydrocarbons in the atmosphere have an anthropogenic origin (Fexsenfeld et al., 1992; Guentther, 1997). Non-methane hydrocarbons play an important role in catalyzing the formation of tropospheric ozone and photochemical smog and indirectly (via various chemical reactions) influence the resident time of the greenhouse gases in the atmosphere (3.2). *A combination of factors, conditions, and links makes it very difficult to answer the question about the final sign and the magnitude of the terrestrial ecosystems - climate interactions that are loosely named "biogeochemical feedbacks".*

Biogeophysical feedbacks. Vegetation is the most variable component of each terrestrial ecosystem, except deserts. Effects of vegetation and soil changes on the surface energy and water cycles are named "biogeophysical" feedbacks. There are general effects of vegetation on albedo (usually, the presence of vegetation decreases it)[45] and on surface roughness (usually, the presence of vegetation increases it). Vegetation may generate meso-scale effects of advection and turbulence due to spatial heterogeneity[46]. It enhances regional precipitation and evaporation (Rauner 1972; Pielke 2001). It controls the land structure, preventing erosion as well as affects smoothing of the near-surface temperature gradients. Vegetation provides shade, affects surface energy balance (Figure 3.5.2), controls evaporation, runoff, soil

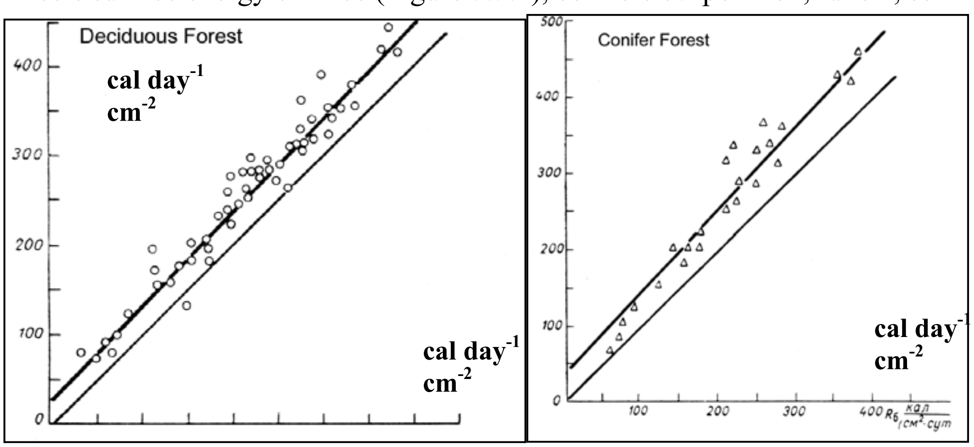

Figure 3.5.2. Radiation balance of forested (RB_f) versus nearby forest-free (RB_0) sites (Rauner 1972). Original units in this graph (cal day^{-1} cm^{-2} = 0.48 W m^{-2}). After conversion in Si units in the regression approximation, $RB_f = a\ RB_0 + b$, parameter values are:
for conifer forest: a = 1.10; b = 20 W m^{-2} and for deciduous forest: a = 1.05; b = 15 W m^{-2}.

moisture, snowmelt, and a partition between sensible and latent heat losses. Vegetation of different species composition, age, and density exercise these effects differently in different parts of the year and different times of the day[47]. The direct effects of changing land cover and spatial mosaic then manifest themselves in temperature, the hydrological cycle, and atmospheric circulation, thus extending the impacts beyond the region where vegetation is

[45] Vegetation decreases albedo of most surfaces except dark wet soil (Ross 1975; Vygodskaya and Gorshkova 1987), but this decrease is the most spectacular for snow-covered surfaces. This feedback is positive: the more vegetation => the more absorbed solar radiation => the further vegetation growth/advance can be expected along the border between tundra and taiga if water and nutrients supply is sufficient (Berger 2001).

[46] Jacobs and Bruin, 1992; Pielke and Avissar, 1990; Fitzjarrald and Moore, 1992,1994; Raupach, 1991,1998; Sogachev et al. 2002.

[47] Geyer and Jarvis, 1991; Galenko 1983; Hollinger et al. 2002; Baldocchi et al. 2001; Kelliher et al 2004; Valentini 2003b; Vygodskaya 1981.

changed[48]. These changes in turn may feed back to vegetation. On a global scale, the biophysical land atmosphere coupling due to (a) interactions between vegetation and snow[49], (b) desertification process (Zolotokrylin 2003), (c) interactions between vegetation and bare soil or between different vegetation types (Charney, 1975; Chase et al. 2000, 2001; Narisma et al. 2003), and (d) variation of sensible and latent heat fluxes (Chapin et al. 2000) are the primary paths of interaction between land surface and the atmosphere in Northern Eurasia. Variable non-linear interactions in the system weather-vegetation-soil moisture cause major feedbacks on a global scale that may contribute to intransitivity of the climatic states (Claussen et al. 2004).

Hydrology-vegetation feedbacks constitute a special subclass because it is impossible to allocate these interactions *a priori* to one of two feedback classes. Water deficit controls the vegetation growth and can completely suppress it causing numerous feedbacks to the surface energy and water cycles (SEWC) and the biogeochemical cycle (BC). The abundance of water above the normal vegetation needs can also be harmful and cause a different set of feedbacks to both SEWC and BC. These feedbacks may be considered as principal ("hot spots"), determining chains of specific biogeochemical and biogeophysical processes depending on regional climate and ecosystem type. A few examples in Box insert 3.5.1 illustrate the volatility and complex character of these feedbacks for the forested land in Northern Eurasia. In the semi-desert, steppe, and forest-steppe zones, the water availability is a major factor that restricts vegetation growth. Thus, hydrology-vegetation feedbacks in these zones are more predictable, although can be non-linear and/or generate an intransitive chain of changes (Claussen 1998; Zolotokrylin 2003). In different ecosystems/climatic zones and under different scenarios of external forcing, these feedbacks manifest themselves with varying strength and sometimes even with an opposite sign. The final consequences (changes) resulting from the climate and ecosystems interactions depend upon all factors and processes involved in the interactions. These processes are interrelated, overlap, may generate similar consequences *initially* and then split off, or may prevent each other from occurring for a while and then may enhance each other. Observations will report the summarized changes, but in order to *explain them,* assess their predictability, *and (if possible) project* into the future we need to have reliable, process-oriented models of each of these feedbacks. Figure 3.5.3 provides an example of when an expected sign of summarized effect due to one feedback changes due to a synergetic impact of another feedback.

Box insert 3.5.1. Hydrology-vegetation feedbacks in forests of Northern Eurasia.

1. In the dry climate of central Siberia, there is a high probability of fire and forest post-fire successions (Stocks and Jynham 1996; Furyaev et al. 2002). If summer temperatures increase here *without an adequate increase in precipitation*, these probabilities would further increase and fire would be the major vegetation feedback to the increasing water deficit. Among the anticipated changes, there will be accumulation of black carbon borrowed temporarily from phytomass and yet, N-pool changes (3.2, 3.6.3; Kuhlbush and Crutzen, 1995; Wirth et al., 2002; Schulze et al., 1999). Thus, hydrology-vegetation feedbacks in this region would cause increased atmospheric levels of aerosols and additional CO_2, biomass reduction in soils and the ground layer (thus, biogeochemical feedbacks to both climate and future vegetation growth), changes in albedo (mostly increase but could also be a decrease in summer, after a strong fire), increase in sensible heat fluxes and reduction in latent heat fluxes, reduction of local surface roughness, and increase the spatial inhomogeneity and thus the regional surface roughness (i.e., biogeophysical feedbacks) [Claussen 2004; Avissar et al. 2004]. It is worth noting that (a) during the past century regional changes followed this scenario (3.5.2) and (b) an adequate increase in precipitation and thus, the reduction of the probability of fire would cause an opposite sequence of feedbacks *and* a set of

[48] Pavlov 1984; Jarvis 1995; Sellers et al. 1997; Baldocchi et al. 2000.
[49] Otterman et al. 1984; Harvet 1988,1989; Bonan et al. 1995; Lynch et al. 1998; Sturm et al. 2001.

new feedbacks would emerge (e.g., changes in decomposition rates of dead above- and below-ground biomass, new successions, and new black carbon pool; 3.1, 3.2, Inoue et al. 1995; Panikov and Dedish 2000; see also item 4 below).

2. In relatively humid West Siberia, which contains the major areas of peat bogs, the same hydrology-vegetation feedback *in the case of the drying climate* would likely reveal themselves in an increase of evaporation (biogeophysical feedback) and the bog water table dropping. These processes would be followed by decreases in biomass, LAI, photosynthesis, and the water use efficiency. The large areas of drying bogs in the boreal forest zone would cause an albedo increase (biogeophysical feedback). Consequently, an increase in albedo and total ecosystem respiration would promote bog transformation from a CO_2 sink into a CO_2 source, a decrease of peat accumulation, and an additional methane release into the atmosphere (thus, biogeochemical feedbacks, 3.2).
3. In the forest zone of European Russia, *in the case of the drying climate*, responses of both forest and bog ecosystems similar to the above may be anticipated (Figure 3.5.3). An increased probability of forest fires could occur here, although, on moist soils of a heavy clay structure, a probability of ignition and fire distribution is low compared to that in Siberia (Korovin and Zukert 2003). Moreover, the non-linear responses of CO_2 exchange in moist boreal forests to droughts may be surprising, going from a CO_2-source to a CO_2-sink (Figure 3.5.4c).

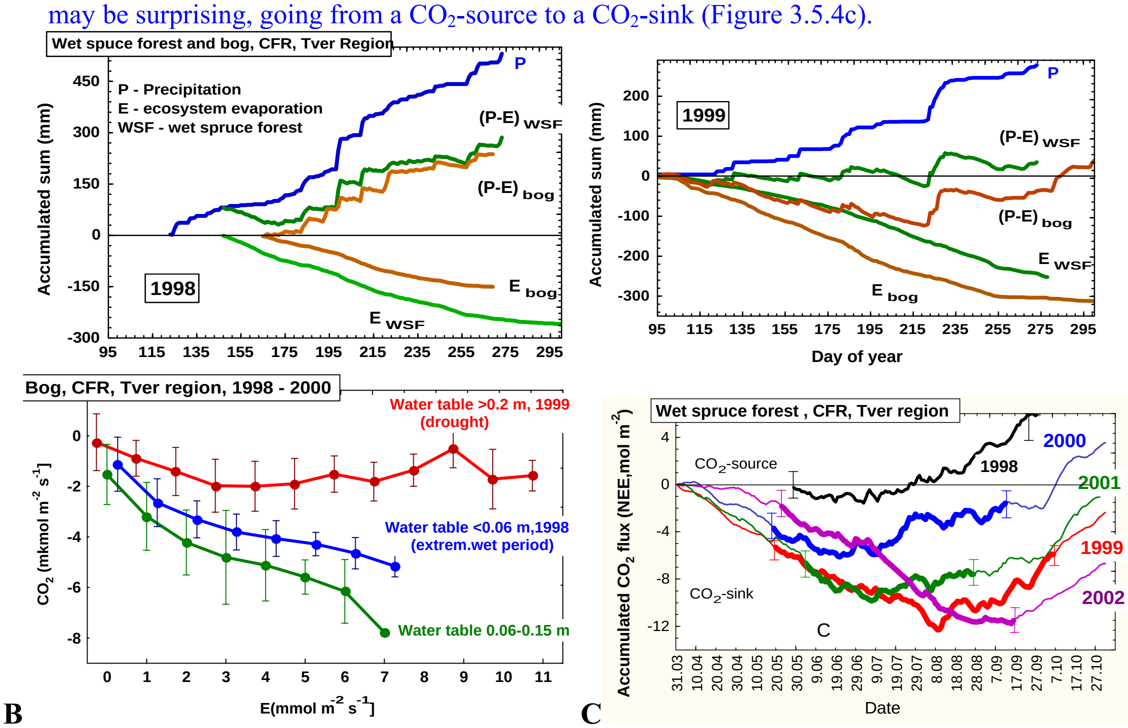

Figure 3.5.3. Two typical boreal ecosystems in wet European southern taiga, unmanaged wet spruce forest (WSF) and bog, during dry (e.g., 1999, 2002) and wet (e.g., 1998) years (Tver', 56^0N, 33^0E, Russia). Interannual variability of ecosystem water balance and evaporation (a), CO_2-fluxes and evaporation rate (b), and Net Ecosystem Exchange (NEE) (c) for 1998-2002; positive CO_2 flux stands for source to the atmosphere (archive of the Eurosiberian Carbonflux Project). In (b) vertical lines depict standard deviations while in (c) periods of active spruce vegetation. Water balance (P-E) is very different in dry and wet years and in dry years evaporation from bog is higher than from WSF while usually the opposite is true. In dry years on bog [P-E < 0; water table is above 0.2 m, red line in (b)], E is high (up to 10-11 mmol m^{-2} s^{-1}), but transpiration and CO_2 assimilation are suppressed. Thus, bog has practically neutral daytime carbon balance and become a CO_2-source due to positive nocturnal CO_2-fluxes. When P-E > 0 and water table is high or average [blue and green lines in (b)] bog is a CO_2-sink. Surprising is the influence of dry conditions on the NEE of the wet spruce forest (c). Opposite to bog, WSF is a CO_2 sink during dry growing seasons (1999 and 2002) when soil water content in the upper 20 cm (root zone) is below 0.4 m^3/m^3 . The different reactions to drought for bog

and WSF are because the lead change in dry conditions on bog is a decrease of the CO_2 assimilation while in WSF with dry soils respiration goes down. During the wet years (soil water content in the upper 20 cm above 0.75 m^3/m^3), forest is a CO_2 source. This result shows that during the growing season overmature spruce forests may act in both ways as CO_2 source and sink.

4. When *weather conditions become wetter*, soil moisture increases and the water table rise causes the bogging of large areas of boreal forests that are on heavy clay soils or on permafrost (Rode 1964). However, ecosystem resistance to heat and water supply alterations depends, to a great extent, on a root system type of dominant species. So, the spruce forests with surface root systems are potentially most vulnerable to soil moisture changes. Bogging combined with local storm winds cause stand destruction (windthrows) followed by secondary successions (Vygodskaya et al. 2002, 2004). Windthrows followed by decomposition of dead wood generate an additional CO_2-source for the atmosphere (Knohl et al. 2002). Therefore, for the regions where the wetter conditions prevail, soil moisture-vegetation interactions become a key feedback. Moreover, the role of these interactions as a potential destructive factor may considerably increase here if the probability of extreme weather conditions increases (Vygodskaya et al. 2002).

3.5.1.2. Areas of sustainable development of ecosystems

A general ecosystems' impact on climate looks like a buffering factor. In high latitudes, vegetation serves as an additional blanket (Figure 3.5.2) that warms the surface. In arid regions, vegetation cools the surface, promotes nocturnal condensation, increases air humidity, and makes life conditions there more tolerable. Autocatalytic effects (positive feedbacks) related to vegetation include wetland and black and podsol soil development, while regulatory effects (negative feedbacks) are observed in the system vegetation-permafrost. Like living creatures, ecosystems generate resilience to extremes or even use them to their advantage in the long run. But, this resilience is not unlimited. When forced, changes in a sequence of successions occur along the following scheme:

> *First, quantitative changes start due to climatic change or changes in the disturbance regime. They affect functional plant ecophysiology and major functional relationships and, thus, the structure of vegetation cover. The species' reaction to the changing environment is defined by their physiological lability. At that time, a replacement of less competitive species by more competitive species occurs under new environmental conditions. Then, finally, stable changes of species compositions and formation of a new ecosystem occur. This looks like a "vegetation shift" because seeds of plants typical of other ecosystems gradually "invade" the area.*

Spatial distribution of ecosystems and their composition is defined by the ability of species to adapt to the environment and to tolerate possible disturbances/extremes. An example of climatic limits of the major boreal ecosystems in Siberia is provided in Table 3.5.1. These types of tables exist for each large region and show typical plant requirements for the main ecological resources - warmth, water, and cold tolerance within each ecosystem. In addition to these basic climate requirements for the ecosystems' survival, bounds for weather variability (its level should be tolerable), air quality (some levels of air pollution are deadly), nutrient availability (3.2), and water supply quality (e.g., level of mineralization) restrict the wellbeing of the ecosystems (3.1). When external forcing and/or feedbacks move a particular ecosystem close to these bounds, they are in danger. If and when one of these limits is crossed, the ecosystem starts degrading and a process of its replacement with a new one accelerates. The follow up changes may have precipitous and, frequently, intransitive character: mountain deglaciation, desertification, forest retreat in refuges, and soil erosion and deflation (Zolotokrylin 2003; Kozharinov and Puzachenko 2002, 2004; Vinogradov et al. 1996; Jaskovski, 2002). In addition to slow changes caused by climate trends, the shift may happen quite swift as a result of disturbances (extreme weather event, prolonged drought or surplus wet conditions, fire, permafrost degradation, windthrow, and/or insect infestation) or anthropogenic impact (logging, ploughing up), after which the old ecosystem does not recover, ceases to exist, and gives way to a new ecosystem.

Models of terrestrial ecosystem dynamics[50] do include these boundaries explicitly. Therefore, the correct input information is a prerequisite for these models. This information will allow tuning models of terrestrial ecosystem dynamics for the region. Then these models can be used for reproduction of the past and present ecosystem dynamics and biome shifts in Northern Eurasia, for assessment of their predictability, and for projections into the future. ***The major task for the future, though, is (a) to collect the necessary input information and (b) to make a viable blend of these models with contemporary global change models that allow all major feedbacks to manifest themselves simultaneously and provide a required synergy of all kinds of interactions.***

Table 3.5.1. Climatic limits for major Siberian ecosystems (Tchebakova et al. 2003). Three basic characteristics: – needs for heat resource expressed in positive degree-days above 5°C (GDD_5), drought resistance characterized by the annual moisture index (AMI, a ratio of GDD_5 to annual precipitation), and cold tolerance characterized by negative degree-days below 0 °C (NDD_0) are presented. The "undefined" limits mean the current absence of climatic conditions in Siberia that draw the ecosystem to the appropriate limit.

Vegetation type	Heat resource, GDD_5		Drought resistance, AMI		Cold tolerance, NDD_0	
	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Tundra	0	<300				
Forest-tundra and sparse taiga	300	500				
Northern dark-needled taiga	500	800		<1.5	>-4500	
Northern light-needled taiga	500	800	>1.5			<-4500
Middle dark-needled taiga	800	1050		<1.5	>-3500	
Middle light-needled taiga	800	1050	>1.5			<-3500
Southern dark-needled taiga and birch sub-taiga	1050	1250		<2.25		
Southern light-needled taiga and sub-taiga	1050	1250	>2.25			
Forest-steppe	1250	1650		<3.25		
Steppe	1250	1650	>3.25			
Broadleaf forest	1250	1650		<1.5		
Temperate forest-steppe	>1650		1.5	3.25		

3.5.1.3. Key regions.

In the context of global climate changes, the main attention should be focused on the most vulnerable ecosystems and to "hot" positive feedbacks, or feedbacks which, when initiated, may cause non-linear run-away processes in the climatic system and the biosphere. Larger changes in ecosystem-climate interactions across North Eurasia should be expected at borders of major vegetation zones (in transient zones) like forest-tundra, forest-steppe, and steppe-desert and in mountains where strong altitudinal contrasts allow the presence of a variety of ecosystems at short distances from each other. Historically, the changes along these borders were very substantial (Figure 2.18). The changes in these most vulnerable ecosystems can be better appreciated and understood when compared with "etalon ecosystems" located in the

[50] E.g., Shugart et al. 1992; Kellomaki et al. 1993; Solomon and Kirilenko, 1997; Kirilenko and Solomon, 1998; Kirilenko, 2001; Bonan 2002; Chapter 5.

"center" of biomes where the climate-ecosystem interactions are closest to the equilibrium state.

Tundra-forest. Under climate changes along the boundary of these two zones, *permafrost-vegetation* and *albedo-vegetation* feedbacks will be among the most prominent interactions. Their potential strengths will be different over Siberia and northern European Russia, depending on present-day climate and its trends, and within different regions, depending on moisture conditions, vegetation types, forest tree species compositions, and LAI[51]. In particular, in western Eurasia, temperature does not restrict the northward forest propagation, but excessive precipitation does. In continental Siberia, the tundra-forest boundary is controlled by temperature. Along the Pacific coast, excessive air humidity restricts the forest growth (Puzachenko, 1982). This is one of the reasons why climate impacts and feedbacks along the tundra-forest boundary in Northern Eurasia are regionally specific and asynchronous (Tanfil'ev, 1896). Active layer depth increase that follows the permafrost thaw along the tundra-forest boundary (as well as right in the middle of these zones) may cause various biogeochemical and biogeophysical feedbacks[52] and vegetation shifts in a chain of interrelated processes (Shugart et al. 1992; Tchebakova et al., 2003; 3.6.1). However, the synergism of these processes is still not well studied and, therefore, the resulting changes in the ecosystem-climate system are not yet clear. The most probable change here predicted by the GCMs simulations is a regional albedo decrease when a low tundra vegetation cover is replaced by a higher shrub and forest vegetation (Bonan et al. 1995; Lynch et al. 2003). This increases a regional warming, i.e., provides a positive (biogeophysical) feedback. When forest and forest-tundra vegetation are replaced by tundra vegetation, the same positive feedback accelerates the regional cooling.

Forest-steppe. In southern Northern Eurasia, along the border of steppes and forest, *hydrology-vegetation feedbacks* dominate under the insufficient moisture conditions (Girs and Stakanov, 1986; Zherbatiyk et al. 1996; Khmelev et al, 2002). The forest-steppe transition zone moved depending on both moisture conditions[53]. Leaving the HA aside, a decrease in soil moisture causes forest decline. First, deciduous shrub communities replace temperate deciduous forest. Then, the area of grassland within shrubs increases and, finally, grass communities are established (Archer et al. 1995). These successions are followed by a leaf longevity decrease, decrease in LAI and in the total above- and below-ground biomass (Titlianova and Tisarzhova, 1991; Karpachevsky et al. 1994a; Utehin, 1997). Finally, typical forest soils are replaced by typical steppe soils, with decreased carbon and nitrogen pools and lower evapotranspiration (Bihele et al. 1980). A negative vegetation-albedo feedback (conversion of lower forest albedo to higher steppe albedo followed by a further albedo increase in dry steppes on dry soils; e.g., Ross 1975) should slow this transition down mostly in the cold season. The regional albedo may also decrease due to the ravine development and surface roughness increase under soil erosion. A positive hydrology-vegetation feedback, mostly in the warm season associated with additional precipitation decrease (Rauner 1972) and additional surface warming due to an evapotranspiration decrease with decreasing soil moisture, should enhance the ecosystem changes. The total result of all feedbacks may be different if an increased probability of dust storms will be taken into account (3.6.3). Historical and paleoclimatic records indicate a high variability of this specific transitional zone, thus witnessing a prevailing of the positive feedbacks in the zone (3.5.2). While the

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[51] Dadykin,1952; Targulian, 1971; Skatveit et al., 1975; Parmuzin, 1979; Bliss et al. 1981; Puzachenko, 1982; Chapin, 1988; Alekseev,1994; Chapin et al., 1996; Vaganov et al., 1999.

[52] Parton et al. 1981; Lefleur 1992; Pavlov 1994; Christensen et al. 1995, 1999; Zamolodchikov and Karelin 1999; Zamolodchikov at al. 1998; McGuire et al. 2002; Chernov 1980.

[53] Tanfil'ev 1896; Krylova, 1915; Berg, 1947; Piavchenko, 1950; Mil'kov, 1952; Dinesman, 1977) and HA (Kirikov 1979; Osipov and Gavrilova 1983; Vinogradov et al. 1996; Serebryannaya 1982.

mechanisms causing the biogeophysical feedbacks in the forest-steppe zone are quite clear (except, probably, the local water cycle processes along the forest – steppe border line), those causing the biogeochemical feedbacks are not. It is unclear how steppe ecosystem production would change, how the C and N pools would change, how the CO_2 absorption from the atmosphere and ecosystem respiration would change, and how the NO and non-methane hydrocarbons emissions would change (Collatz et al. 1998; Fexsenfeld et al. 1992; Guentther 1997). It is currently unknown how all these processes would manifest themselves at regional and global levels.

Steppe-desert, desertification. Interior regions of Central Asia receive most of their water from remote sources via the atmospheric circulation. Variations of the westerlies and the amount of moisture that they are bringing affect the steppe-desert boundary and initiate its movement (3.3.2, Gumilev 1990). Several important biogeophysical feedbacks enhance and/or prevent this process. Advance of the desert (desertification or increased aridity) is a result of interaction between regional processes of degradation of dry lands with positive and negative feedbacks related to albedo and precipitation changes. The analysis of surface heat balance observations in Northern Eurasia reveals a negative correlation between albedo and surface temperature in arid areas where the radiative mechanism of surface energy exchange is dominating (Zolotokrylin 2002, 2003). Semi-arid areas differ from the neighboring territories by increased variability of energy fluxes and a decrease in correlation between albedo and surface temperature. There is a threshold albedo determined by vegetation of semi-arid areas. If the albedo is above the threshold value, the evapotranspiration regulation of surface temperature is changed into a radiative one, which increases aridity and is a precursor for desertification. This threshold is close to "a point of no return" when desertification begins. Variations of precipitation distribution also control the desertification process, but high boundary layer temperatures make precipitation less probable. Thus, both the decrease of total precipitation and the frequency of low intensity precipitation events predetermine the desertification process. Aeolian erosion of the fertile upper soil accompanies the final stage of desertification causing both biogeophysical (aerosols, albedo) and biogeochemical (e.g., pollution of downwind areas) feedbacks. While steppe areas are a weak carbon sink (Titlyanova and Tesarzhova, 1991), NPP in desert and semi-desert areas is negligible (Bazilevich 1993). While the desertification can occur in a few years, the rates of the reversal of deserts into steppe are unclear. Historical evidence and the past decade in the Near-Caspian lowlands show that grassland advance into desert, when the climate conditions become favorable (i.e., more precipitation), could also be quite quick.

Forest zone. The forest zone is the largest within Northern Eurasia. Its impacts on the global carbon balance (3.2) and on surface water and energy cycles (3.3; Figure 3.5.2) are very strong. The zone occupies several climatic zones: from moderate and moist in Europe, to extreme-continental in Siberia, to monsoon in the Far East. Over the forest zone in Northern Eurasia, seasonal and annual climatic changes were, are, and will probably be of different magnitudes and signs. Numbers of dominant tree and ground plant species in the forest zone are limited. But these species have large ecological niches (habitats) and their distributions overlap each other. As a result of the overlapping of different climates, landscapes, and distances from refuges (Kozharinov and Puzachenko 2002, 2004), a great variety of ecosystem types are found in the forest zone which may be doubled, tripled, etc. by their secondary successions after logging, fires, windthrows, and insect outbreaks. From a global viewpoint, the forest zone may be considered as a powerful terrestrial buffer that stabilizes global biosphere-climate interactions. Its buffer role is in preserving a great amount of carbon in forest above- and below the ground biomass, soils, and peat (Karpachevsky, 1981; Karpov, 1983). Therefore, states of forest soil and bog carbon pools are most critical for global carbon cycles. Hydrology-vegetation feedbacks are among the most prominent here. They are region-specific, though, and controlled by nitrogen deposition (Popova, 1983; Berg et al., 1999). It is problematic to find individual ecosystems that are vulnerable to climate changes and thus to find "hot" feedbacks within the forest and wetland ecosystems. This search should be conducted for large regions within the forest zone, varying by current climate and climate trends and variability (cf., Box Insert 3.5.1). One exception, however, exists: in the forest zone with permafrost (i.e., over more than a half of Northern Eurasia and about 65% of Russia, Pozdnyakov, 1986), the *permafrost-vegetation* feedback is of critical importance (3.6.1).

For the forest zone of Northern Eurasia in the framework of ecosystem-climate interactions and biogeochemical feedbacks, the questions connected to causes and effects of forest fires are currently the most investigated (Korovin and Zuckert 2003). Two less understood topics here require special attention:

- Estimates of black carbon pool and its turnover time and
- The possibility that HA can influence the probability of natural fires caused by lightning from convective cloudiness by changing the spatial-non-uniform mosaic of vegetation cover with timber harvest.

For ecosystem-climate interactions in the forest zone, the following questions are among the least investigated:

- *Reactions of water and carbon balance of the wetland ecosystems to changes of climate, possible area changes, and their dynamics*.
- *Process of bogging in the wet areas of the forest zone*. This process is difficult to reverse (Sjors 1961, Pajula 2000) and it leads to cardinal changes in soil properties, development and growth of plants, and in the carbon, water, and energy balances in general. Depending on prevalence of bogging, this process can cause changing the regional albedo. However, the areas of boggy forests across the territory of Northern Eurasia and their dynamics are poorly studied.
- *The changes connected to change of the dominant species after logging and natural succession of the large areas in European southern and middle taiga*. The replacement of coniferous forest with secondary deciduous stands should lead to podsol soil development, to changes of the components of the water, energy, and carbon balances, and to an increase of regional albedo. The question is closely connected to the problem of the overgrowth of the abandoned agriculture land by shrubs and forest.
- *Forest susceptibility to the windthrow*. We have a few data on the areas with windthrow and their dynamics. A time-lag is not clear of when the windthrow areas turn from a source of CO_2 to the atmosphere (due to a decomposition of the dead biomass) into a sink (when, in the course of succession, the photosynthesis rate exceeds the rate of decomposition). Besides, windthrow areas are problematic for the current remote sensing algorithms of the NPP evaluation due to peculiarities of albedo changes.
- *Influence of the soil eutrophication (nutrient pollution) as a result of technogenic pollution on the growth and development of vegetation* in different areas of the forest zone.

Clearly, the importance of all the above processes and phenomena for regional and global climate changes depends on the size of the areas covered with these processes. These areas, although, are not well known, except the notion that each of them can be quite large.

Besides, for biogeochemical feedbacks and carbon balance in the forest zone, one must pay attention to the large areas (more than half of the State Forest Fund area in Russia) occupied currently by mature and overmature stands. Usually, in calculations of the regional carbon budget, their mean annual net ecosystem exchange (NEE) is assumed to be zero (Isaev and Korovin 1997). In fact, the resulting sign of the annual NEE within this large fraction of the forest zone varies from year to year (Milyukova et al. 2002; Vygodskaya et al.

2004; Knoll et al. 2004). Therefore, this sign will depend on the *future* rates of assimilation and total ecosystem respiration and balance between them as well as on *future* ecosystem-climate interactions.

Managed ecosystems. Managed (agrofields, urban environment) and/or maintained (pasture, fallow, managed forest) ecosystems are created by humans. Sustainability of these systems depends on the ability of the society to preserve these ecosystems in a changing world. Large-scale changes in species distribution have occurred under the HA influence in steppe, forest-steppe (3.1), and even over forested lands (e.g., west of the Ural Mountains as a result of secondary successions after massive logging; 3.1). Most managed ecosystems are on a "slope" and would gradually restore their "pre-anthropogenic" status when the human impact is finished. But, the area of these ecosystems in Northern Eurasia is large, they occupy the most fertile land, and have become part of the landscape. Their properties, including numerous feedbacks to climate, differ from those for "natural" ecosystems and thus, are to be studied separately (3.4).

3.5.1.4. Key question

In 3.5.1.1, we summarized the most prominent feedbacks that affect Northern Eurasia and their most obvious direct consequences. Indirect impacts of these feedbacks, by changing regional and global climate and synergetic effects, are too numerous to list. All of the above clearly indicate that, without synergy of all factors and their interactions, it is impossible to estimate *a priori* the actual strength *and sign* of most of the biogeochemical and biogeophysical feedbacks in Northern Eurasia. The corollary is that a thorough parameterization (process-oriented model) of each process involved in these feedbacks should be conducted, tested, and incorporated into a comprehensive suite of physical and numerical models (Chapter 5). Thus, a major **Question arose:** ***What relationships and/or their parameters that describe the above mentioned feedbacks are not yet well understood, are critical, and should be investigated first of all for Northern Eurasia?***

Empirical parameters of dominant plant species habitats and biome-specific parameterizations are the basis for modeling terrestrial ecosystems dynamics (e.g., 5; Shugart et al. 1992; Kellomaki et al. 1993; Kirilenko 2001). The feedbacks listed in 3.5.1.1 and 3.3.2 have a more "globalized" nature and may affect the Earth system far from the "source" and then return the impact to the ecosystem that caused them in a very different way (e.g., as a changed precipitation pattern). Obviously, palaeo-vegetation and palaeo-climate reconstructions coupled with comprehensive models provide the only possible ways of validation of these global long-term feedbacks. Using ecological limits of modern plant species distribution, spore-pollen analyses, ^{14}C-dating, palaeo-vegetation and palaeo-climate reconstructions, archeological artifacts and other methods provide test samples for validating the modern (and future) models with all their complexity and feedbacks. The richer the palaeo and present evidence is about the environmental and climatic changes and the better the models reproduce these dynamics, the more trust can be placed on these models. Then they can be used for assessment of the predictability of the future, then, hopefully, for its reliable projections and for credible assessing of the possible variants of HA to reveal its future harm as well as for testing the adaptation strategies.

3.5.2. Observed impacts of *changes* in ecosystems and climate on each other

[Section was transferred to the Scientific Background Appendix]

3.5.3. Role of the biosphere-climate systems interaction in the projections of the future changes in Northern Eurasia.

3.5.3.1. Future land cover projections based on contemporary GCM projections. What is missing?

The interactions (feedbacks) between the biosphere and global climatic system play a specific role in Northern Eurasia (3.3.2; 3.5.1) that can substantially change the regional environment and global climate. In the two previous sections, evidence on present and past manifestations of these interactions is given. Here we show what may happen in a changing future.

In Figure 3.5.6, which illustrates one of the climate projections, estimates of the future climate conditions were constructed using one of the IPCC greenhouse gas increase scenarios (a1, see more about these scenarios in IPCC 2001) and the output of the Hadley Centre HADCM3GGa1 run (Gordon et al. 2000). They were used as input to the Siberian bioclimatic model (Tchebakova et al. 1993) to generate a pattern of ecosystem distribution corresponding to a new state of the 2090 climate (Tchebakova et al. 2003). All three, the a1-scenario of increase in the greenhouse gases, the GCM run, and the bioclimatic model do not account for many of the feedbacks discussed in 3.5.1.1. Specifically, a team of specialists in radiative forcing had generated scenarios of its changes due to industrial pollution and its sequestration /decomposition with time (Ramaswamy et al. 2001) (a1 is one of them), then climate modelers used it in their transient runs as an input, and, finally, a carefully regionalized bioclimatic model produced the most probable changes in land cover that would be the result of this scenario and the simulated climatic changes. In Figure 3.5.6, the output of one of the GCMs was used, but the use of several other models gave qualitatively similar results (e.g., Monserud et al. 1996). A brief look in Figure 3.5.6 shows sweeping changes in land cover with the warming anticipated in the last decade of the 21st century:

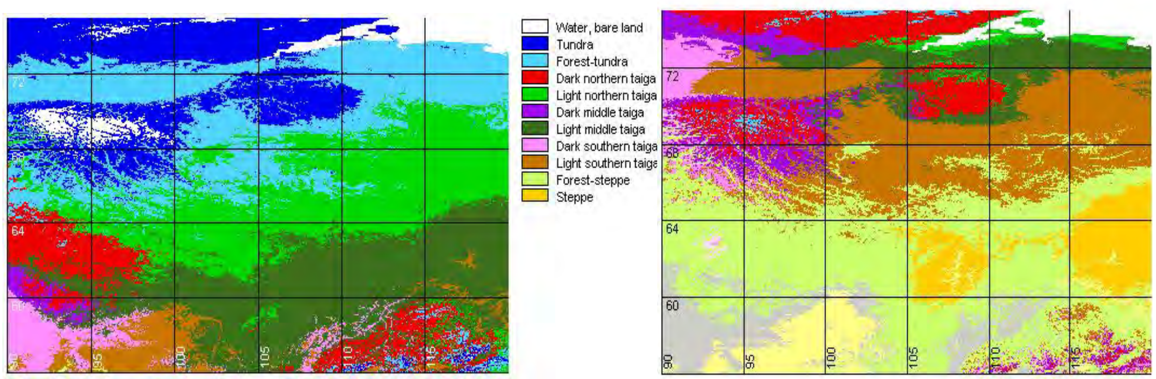


Figure 3.5.6. Major ecosystems distribution in central and eastern Siberia (a) in the current climate and (b) the warmed climate by 2090 derived from the HADCM3GGa1 run (Tchebakova et al. 2004).

- The tundra and forest-tundra zones (currently ~ one third of the Siberian area) practically disappear;
- Taiga zones (currently about two thirds of Siberia) move northward and reduce to ~40% of the area;
- Steppe, forest-steppe, semi-desert, and desert areas (practically absent now) are projected to occupy up to 45% (forest-steppe) and up to 15% (steppe, desert, and semi-desert) of the area; [large areas of steppe should cover the central Yakutian Plain and the Tungus Plateau, and semi-desert zone would cover a significant area of the Angara Plain].

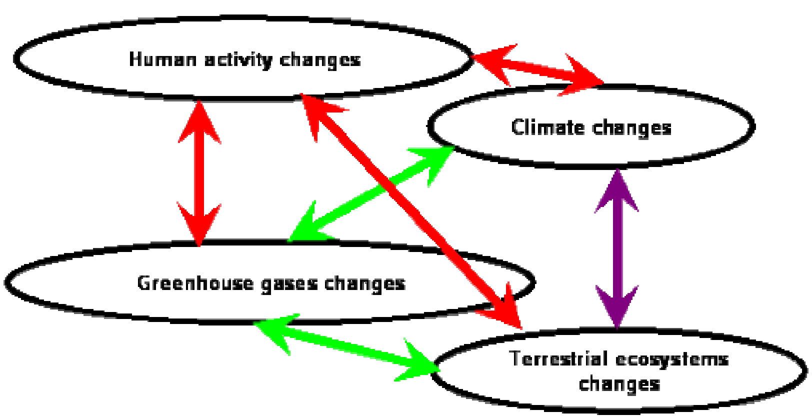
These estimates broadly correspond to palaeoclimatic reconstructions of two warmer climate epochs of the past: the Mickulin interglacial epoch (122-125K years BP), that was approximately 2°C warmer, and the "climatic optimum of Holocene" (6K years BP), that was approximately 1°C warmer than the present climate (Kobak et al. 2002; the authors suggested that changes in biomes, their areas, and major carbon pools associated with climate warming have occurred quite rapidly as a result of secondary allogene successions). It is unclear if the ecosystem shifts can indeed be as rapid as projected. Probably, the estimates in this figure give us an equilibrium state that would be established if the climatic changes projected by the GCM would be steady. But, it is also clear that there is no such luxury as equilibrium for environmental changes in the 21st century. The climatic system will be on the move, creating instability to the ecosystems' functioning, pushing them toward the other states.

In these projections (and we realize that it is only one of the scenarios that may emerge), it is not clear which effect of land cover changes over the entire Northern Eurasia (tundra-forest transition or forest-steppe transition) will prevail and be more significant for the global albedo. So far, two scenarios may be suggested: (i) higher albedo in southern arid regions would prevail over lower albedo in northern forest-tundra regions with resulting higher global albedo and (ii) global albedo may insignificantly change, compared to current values, if changes in forest-steppe regions will be balanced by changes in forest-tundra. In both scenarios, however, the regional climate conditions should be very different from those generated by the GCM simulation and used to produce Figure 3.5.6. Indeed, a more thorough analysis of this projection clearly indicates that ***for a reliable regional and, probably, global pattern of climate and ecosystem changes, the simultaneous interactive models' runs should be conducted instead of a sequential approach.*** Large-scale changes in land cover (cf., Figure 3.5.6) would generate additional regional forcing (actually, biogeophysical feedbacks), and thus compromising the GCM run assumptions. Furthermore, the changes in biomass, soil and wetlands carbon, and permafrost thawing (that inevitably must accompany such changes) would generate additional and substantial forcings (actually, both biogeophysical *and* biogeochemical feedbacks) on both the GCM forcing *and* the greenhouse scenario itself. In other words, the presently prevailing quasi-linear approach[54] in assessing the future Global Earth System changes:

Human activity changes => Greenhouse gases changes < = > Global Climate System changes => Biosphere changes

should be replaced by a synergic approach (shown in the scheme below) that allows and accounts for numerous feedbacks that modify (and may even reverse) the final state of the Global Earth System as well as affect the modes of HA. The recent attempts to regulate the

A synergetic approach to study and develop scenarios of future changes



This schematic illustrates interactions between components of the Earth system. In this figure, "climate" refers to physical components of the Earth system.

[54] It would be unfair to say that the current approach, including that used in the latest IPCC assessment (2001), is linear. For example, substantial efforts were made to account for the major biochemical feedbacks due to changing climate when terrestrial and ocean sequestration of CO_2 was projected (Prentice et al. 2001, Chapter 3 of IPCC 2001). However, all these estimates were made in an off-line mode with a prescribed climate change "forcing".

greenhouse gases, to control over pollution, changes in agriculture and irrigation practices, and forest management are vivid examples of the changing HA *in response* to the Global Climate System changes. For several reasons outlined above, the amplitudes of the changes in Northern Eurasia in all components of the Global Earth System have been and are anticipated to be among the greatest. ***Thus, a synergic approach for their projections is a must.*** A detailed strategy of this approach is presented in Chapter 5.

3.5.3.2. Transient responses as a new feature of the present century.

When studying the short-term climate- ecosystem interactions, the ecosystem level is appropriate, but for the long-term interactions, scaling-up should be conducted to switch to regional and to global (biome) levels. However, the link between the ecosystem responses to the variability of different time scales is not well understood. It is uncertain how long and intensive the extreme situation or systematic weather/climate anomaly should be in order to influence the inter-seasonal and inter-annual variability of carbon, energy, and water balances. In the changing climate and its future interactions with the biosphere, the conversion of short-term ecosystem reactions into long-term biome responses is among the critical problems[55].

Time is a critical issue while assessing all feedbacks and (in general) the future of ecosystems in the contemporary changing climate. Many of the climate-ecosystem interactions are expanded in time (e.g., slowly developing drought, desertification, growing "new" and old species and their competition, advance/retreat of vegetation). Other interactions occur very quickly (dust storm, fire, windthrow, and flash flood). Some changes are accumulated with time (e.g., lake level and water table, release of methane, thawing of permafrost), while other changes (especially, those associated with HA) follow a step function behavior. Most feedbacks act differently depending on the present state of the ecosystem and the present weather conditions. Timing defines our perspective of future changes (i.e., societal response). For example, one can be pleased to foresee more favorable climate conditions at the end of the 21st century for agriculture. But, if between today and this shining future, the ecosystems (including agricultural fields) would be being non-reparably harmed by soil erosion, industrial pollution, dust storms, forest fires, droughts, surplus wet periods, and floods for several decades, then these conditions will probably be non-beneficial.

Generally, the society should be served by reasonable projections of the future climatic and ecosystem changes decade by decade. Then potentially dangerous consequences of these changes can be mitigated and/or even prevented. Knowing all substantial feedbacks and climate-ecosystem interactions in Northern Eurasia is a prerequisite to these projections for the region and (as it has been already stated in 3.3.2) for the globe. ***Among the major objectives of this Science Plan is a requirement to develop predictive capabilities in order to support informed decision-making and numerous practical applications in the region and thus for the globe. This justifies the major tasks towards this objective outlined below.***

3.5.3.3 Major tasks for studying of the terrestrial ecosystems and climate interactions

These tasks are quite general and seem to not be regional specific. They are, however**,** pressing specifically for Northern Eurasia and important for both the globe and the region, and all five parts of Chapter 3 confirm this (as well as the following part, 3.6, that outlines three more specific areas of research and societal concerns). **These tasks are:**

[55] Continuous long-term direct measurements of energy, heat, water and CO_2 fluxes for major ecosystems (3.2; 3.3; Baldocchi et al., 1996; Lindorth at al., 1998; Joiner at al., 1999; Vygodskaya et al. 2002; McGuire et al. 2002) are required for the realistic solution of this problem. The follow up research should combine these continuous surface flux measurements, the long-term synoptic time series, local process studies, and process-oriented modeling.

- ***To develop an understanding of all major processes and their interrelationship within regional terrestrial ecosystems, climate, cryosphere, and hydrosphere of Northern Eurasia and their interaction with society.*** Particular attention should be paid to the synergy and resonance processes that make this interrelationship non-linear, producing positive feedbacks and run-away scenarios affecting both the region and the globe.

Only having models that reasonably describe and reproduce these processes during the past centuries, we can move forward in the next two tasks.

- ***To establish (restore, develop, utilize) a modern observational system potentially capable to retrieve and properly interpret information about the current state and changes of the environment (ecosystems and climate) of Northern Eurasia.***

Realistically, nobody will substantially change existing in-situ networks and remotely sensed observations. But, the time for simplistic interpretations (such as more precipitation => more runoff; or higher NDVI => carbon sink is occurring) is gone. This system should be based on the understanding of underlying processes with their full complexity. This will show actual gaps in observations and our knowledge and then steps to fill in these gaps should follow.

- ***To develop a regional input (data flux, model blocks, missing parameter values) to contemporary Global and Regional Earth System models, thus allowing for reliable assessment of past and present environmental changes as well as future projections of these changes, and analyses of their impact/interference with society development in Northern Eurasia.***

A particular attention should be paid to areas and ecosystems that are vulnerable and are currently close to the thresholds of their sustainability (e.g., transient zones and most of the man-made systems), as well as to the regions where ecosystem-climate interactions and feedbacks may generate non-linear run-away processes in the climatic system and the biosphere.

3.6. *Topics of Special Interest*

3.6.1. COLD LAND REGION PROCESSES

Chapter lead authors: V.E. Romanovsky, T.E. Khromova

Contributing authors:

O. A. Anisimov, V.B. Aizen, E.M. Aizen, R.G. Barry, M.B. Dyurgerov, A. G. Georgiadi, L.D. Hinzman, O. N. Krankina, S.S. Marchenko, T.S. Sazonova

3.6.1.1. Introduction

Some definitions

There is no single definition of "Cold Land Regions". Climate classifications, such as Köppen's, identify tundra and polar climates as well as highlands that are cold land regions. Additional criteria might include the presence of permanent ice above, on or below the ground surface i.e. regions with permafrost, glaciers, ice caps, and long-term snowfields. We will not directly include in our assessment sea ice, although interactions in the coastal zone must take account of land-fast ice. The major thresholds affecting the development of ecosystem infrastructure are related to decadal and century time scale degradation of permafrost and glaciers, not to changes in the seasonally frozen layer. Furthermore, the degradation of ice-rich permafrost and glaciers are accompanied by distinct land surface changes that can be detected using remote sensing, whereas changes in the seasonally frozen layer do not have such a clear signature, except for changes in area and frequency of occurrence. Therefore, seasonally frozen ground processes while also relevant to "cold lands" will not be covered in this Section. Actually, all Eurasia north of Himalayas is the region where seasonally frozen ground occurs.

The discussion in this section will be on processes specific to the permafrost zone (continuous, discontinuous and sporadic permafrost), both "latitudinal" and "altitudinal" (mountain), and processes in the glacial and periglacial environments.

Geography of the Cold Regions in Northern Eurasia

[Sub-section was transferred to the Scientific Background Appendix]

Focus of this Section

Most of the physical and biochemical processes were discussed in sections 3.1, 3.2, and 3.5. From this discussion it became clear that the physical and biological systems are closely interrelated. Here we emphasize physical processes directly related to observed and predicted changes in permafrost and glaciers and the consequences of these changes that are important for ecosystems and infrastructure in the Cold Land regions. Also, we will emphasize the interrelations between changes in permafrost and glaciers, on the one hand, and in biota and disturbance regimes (both natural and human-made) on the other, as well as feedbacks between them.

The most important changes that affect permafrost and glaciers result from increases in air temperatures and intensification in the hydrological cycle that augments summer and winter precipitation, snow cover depth, runoff, and summer evaporation from the land surface. Changes in snow duration, soil moisture, and vegetation are among other important climate-related changes (Groisman et al. 1994; IPCC 2001, p. 124; see also Chapters 2, 3.3, and 3.5).

The large observed and predicted future climatic changes will inevitably change the energy and mass fluxes at the land surface and, as a result, the near-surface and subsurface physical conditions in northern Eurasia (soil temperature and moisture, availability of energy and moisture for vegetation, snow line elevation, mass and energy balance and thermal state of glaciers, freshwater ice and so on). This will trigger changes in ecosystems that will be largest in the Cold Land Regions because of

- the immense changes here in the atmosphere and soil climate, and
- the extreme sensitivity of the natural systems in these regions, making them highly vulnerable to rapid natural and anthropogenic changes because of presence of ice near the ground surface with temperatures close to its melting point.

This is especially evident in the mountain areas of central Asia where rapid glacier recession is underway over the last 30 years (Khromova et al. 2003). In the arctic tundra biome, the ground temperatures are generally low and any widespread permafrost degradation in natural condition is not expected in this area during the current century (with possible exception for the European tundra). However, the close to the ground surface location of the exceptionally icy soil horizons, that are very typical for the arctic tundra biome, makes tundra surfaces extremely sensitive to the natural and human-made changes. Any increase in the active layer depth can lead to development of superficial processes that are dangerous for ecosystems and infrastructure. In the boreal forest biome with permafrost, the ground ice horizons typically locate at some depth below the permafrost table. Because of that, the increase in the active layer depth will not lead to immediate development of destructive processes. However, because the temperature of permafrost in this biome is so close to the melting point of ice, warming of permafrost induced by the climate warming or surface disturbances will soon lead to the crossing of the 0°C threshold at the permafrost surface resulting in extensive permafrost degradation. Permafrost degradation will soon affect the deeper icy horizons and trigger numerous destructive processes.

The stability of the ecosystems in the Cold Land Regions relies on the stability of ice that so far holds these systems together. In losing the glacier ice and permafrost we are losing the stability of the systems. Thus, even if some ecosystems could avoid disintegration, their characteristics will be changed dramatically.

3.6.1.2. Contemporary and predicted permafrost changes in the Cold Land Regions

[Section was transferred to the Scientific Background Appendix]

3.6.1.3. Past changes in North Eurasian glaciers and future predictions of their dynamics

[Section was transferred to the Scientific Background Appendix]

3.6.1.4. Major Scientific questions and Their Rationale

Seasonal and long-term changes in ground temperature and depth of the active layer in Northern Eurasia occur under influence of complex hydrometeorological and landscape factors, which are extremely changeable both in time and in space (Water … 1999). Data on permafrost temperature and dynamics are still sporadic and with poor spatial and temporal coverage. Very often, these data were obtained in northern Eurasia by individual science enthusiasts, often without adequate financial support (especially during the last decade). Some sites don't show permafrost temperature increase even with warming air temperatures (Zheleznyak 1998; Skryabin et al. 2003). More studies are needed to explain these data. Orchestrated and coordinated efforts are urgently needed to establish and support comprehensive permafrost monitoring system in northern Eurasia. The emerging Global Terrestrial Network for Permafrost (GTN-P) program can help to address these problems. In 1997, the Global Climate Monitoring System (GCOS) and the Global Terrestrial Observation System (GTOS) identified the active layer and permafrost thermal state as two key cryospheric variables for monitoring in permafrost regions (WMO 1997). In 1999, the Global Terrestrial Network for Permafrost (GTN-P) was established under the GCOS/GTOS.

Following the international workshop on permafrost monitoring held at IARC in Fairbanks, Alaska in 2000, the International Permafrost Association's ad hoc GTN-P group has made considerable progress in organizing and implementing the GTN-P (Burgess et al. 2000; Burgess et al. 2001; Romanovsky et al. 2002). During the last five years, some Russian and international programs were established that could also provide some important information (Georgiadi et al. 2001; Georgiadi and Onishchenko 1998; Fedorov and Konstantinov 2003).

Significant uncertainties still exist in predictions of future changes in permafrost and the active layer. Most of these uncertainties reflect diversity in climate change projections provided by different GCMs and by scenarios of the build up of different greenhouse gases. Especially significant uncertainties exist in future snow cover change scenarios. Also, there is still no convincing evidence of the increase of the active layer depth in the polar and sub-polar regions (Pavlov 1994; Pavlov et al. 2002; Romanovsky et al. 2003; Skryabin et al. 2003). Much longer time series of the active layer measurements are needed. The Circumpolar Active Layer Monitoring (CALM) network was established ten years ago (Brown et al. 2000). This program, assuming it receives continued support, can provide these time series. There are compelling data on an increase in the active layer depth in the mountain permafrost zone (Brown 2000; Marchenko 2002; Sharkhuu 2003).

A more comprehensive evaluation of glacier changes is imperative to assess ice contributions to global sea level rise and the future of water resources from glacierized basins. For different regions, the available estimations of mass balance of glaciers based on different observational periods and have used different methods. The number of direct mass balance measurements is limited. All available long-term reconstructions of mass balance time series indicate negative values almost for all northen Eurasia glaciers during the 20th century. However, the sparse mass balance data need much more input form remote modem techniques studies to be robust in spatial and temporal coverage. The recent availability of high-resolution Landsat-7 ETM+ and ASTER images, together with new digital inventories of glaciers in the former Soviet Union, in combination with GIS techniques, affords one avenue to a practical solution of these problems. The Second Adequacy Report on the Global Observing Systems for Climate has reaffirmed the importance of glacier observations (GCOS, 2003; see also http://www.wmo.ch/web/gcos/networks.htm). The study have been planned under the umbrella of the evolving World Climate Research Programme (WCRP) Climate and Cryosphere (CliC) project (http://clic.npo-lar.no) and will also provide a contribution to the forthcoming 2005/06 assessments of the Inter-governmental Panel on Climate Change (IPCC).

Changes in the physical environment will force the Cold Land Region ecosystems to cross several very important thresholds. These are: (1) times and locations where an increase in thickness of the active layer reaches the upper surface of massive ground ice bodies or extremely ice-rich soil horizons, (2) mean annual temperature at the base of the active layer exceeds 0°C and permafrost starts to thaw from the surface downwards, (3) the complete, or practically complete, disappearance of glaciers from the mountain watersheds.
The scientific questions here are:

- ***How well do we know these thresholds? Do we know all of them?***
- ***How well we can predict the moment in time and the spatial location of the regions when and where these thresholds will be crossed?***
- ***What should be done to improve our prediction capabilities?***

The crossing of these thresholds will unleash many natural processes that will enhance changes in the Cold Land Regions of Northern Eurasia and subsequently affect the entire Earth System. Some of these processes may be quickly developing and very destructive for the northern and high-altitude ecosystems and infrastructure. Examples of these processes are: 1) surface settlement, 2) thermokarst formation, 3) swamping, 4) talik development, 5) landslides and slope failures, 6) activization of movement of the rock glaciers and rock fields; 7) thermal erosion of the river banks and deep gullies formation, 8) dramatic increase in river sediment loads, 9) desertification, 10) increase in glacier surges with increase of probability of floods and mud-flows, 11) decrease of volume of melt-water production, river runoff, drooping water level of lakes, loosing high-altitude pasture, 12) loosing attractiveness of mountains for recreation and sport.

- ***How well do we know the physical and biophysical drivers of these processes?***
- ***How well we can predict them and their ecological and societal consequences?***

The principal processes in the Cold Land Regions that affect regional and global systems are: 1) changes in hydrology, 2) changes in vegetation, 3) changes in energy and water fluxes between the land surface, Arctic Ocean, and the atmosphere, 4) changes in CO_2 and CH_4 cycles.

- ***What are the special problems of global change in permafrost and mountain regions given the close proximity of biotic zones, biodiversity, heterogeneous terrain (water cycle and extreme events)?***
- ***How will the local and regional changes in hydrology and vegetation feed back to the permafrost and glacier degradation?***

3.6.1.5. Impact of permafrost degradation on surface hydrology

Permafrost degradation can substantially change the surface hydrology in many ways. Within the area with ice-rich permafrost and poor drainage conditions permafrost degradation will lead to significant ground surface subsidence and pounding (“wet thermokarst”). The ground will become over-saturated, which could cause trees to die (Osterkamp et al. 2000; Jorgenson et al. 2001). Standing water covers a large portion of these areas, which changes surface albedo, evapotranspiration and heat exchange conditions. This kind of terrain will be developing within some portions of floodplains, low terraces and at some places within the highlands and plateaus. Permafrost degradation on well-drained portions of slopes and highlands will proceed in a form of “dry thermokarst”. This process will further improve the drainage conditions and lead to a decrease in the ground water content (Hinzman et al. 2003; Hinzman et al. 2004).

Changes in the active layer thickness and permafrost continuity will affect ground water and river runoffs. Since permafrost is the single most dominant control on arctic terrestrial hydrological processes, it is important to achieve a better understanding of how permafrost will change with changing climate and how these changes in permafrost will affect the arctic and sub-arctic hydrology. In time, the Arctic Ocean watershed will change from the recent condition, when the continuous permafrost is typical for most of the area, to a watershed less and less affected by permafrost. In the future, the larger portion of the watershed will be covered by discontinuous permafrost and this portion will be expanding. Changes in river runoff (both the total discharge and the seasonality) will be different for different parts of Northern Eurasia due to differences in permafrost, hydrological and geomorphologic conditions and vegetation (Georgiadi 1997; Water … 1999). The major question is how Northern Eurasia river discharge will be affected by these changes and what changes in discharge will be observed during the current and the following centuries. Changes in permafrost continuity and in seasonally thawed/frozen layer characteristics will affect the conditions of the groundwater recharge. Furthermore, permafrost degradation will affect ground water flow and storage, significantly changing the portioning of water between evapotranspiration, surface runoff, and ground water flow. However, the changes in ground water storage and discharge (hydrogeology) related to permafrost degradation are not very well understood and much more research is needed.

Current climate warming as well as anthropogenic impacts on river channels are the main reasons of recent catastrophic floods in Eastern Siberia caused by ice dams (Lobanova 2000; Lenskie waters 2003). Their frequency during last decade increased in comparison with previous long-term period. These events led to a significant damage and loss of human lives. Mechanism of such phenomenon is not clear yet. It is not clear now how the frequency and size of catastrophic ice dams and related floods could change under future climate conditions.

3.6.1.6. Impact of glaciers and mountain permafrost degradation on surface hydrology

Glaciers provide from 20 to 45% of total river runoff in alpine central Asia (Aizen et al. 1995b; 1996; Aizen and Aizen 1998). In the Northern Tien Shan, the volume of stored ground ice, both seasonal and perennial is comparable with that of modern glaciers. Melting of this ice accounts for up to 20% of the total runoff (Gorbunov et al. 1997). The recent decrease in the volume of glaciers in this region is equivalent to the mean annual runoff of the Sir-Darya River nourishing the Aral Sea. Glacier melt and permafrost thaw are increasing only in the heads of the river basins of large-scale glaciation or extensive permafrost presence. In the river basins with relatively small glacial coverage, the increase in glacier melt has led to a decline in the area covered by glaciers and has thus reduced the contribution of glacier melt to river runoff. At the same time, the permafrost thaw causes the development of large aquifers that may absorb and store large volumes of water. Therefore, assessment of the decadal changes in glaciers and mountain permafrost in this the world largest closed drainage basin (Aralo-Caspian and Tarim) could help to elucidate some hydro-climatic questions in this region and improve our knowledge of other environmental problems such as drought in the Aral Sea region and Lobnor lakes, and the Caspian Sea and Issyk Kul lakes rise.

Combined changes in glaciers and permafrost share in river runoff modify water cycling and storage in terrestrial reservoirs affecting water supply, flood magnitude and frequency, stream chemistry, impact on chemical species, nutrients in lakes, streams, and soils. Forecasted increase in evaporation and liquid precipitation, degradation of glaciers and permafrost should change the moisture exchange between external and internal water cycles and water resource redistribution in the central Asian lakes and watersheds. Disappearance of glaciers collapses the natural storages of solid precipitation and intensive permafrost thaw increases water seepage to the deep ground systems destroying the surface runoff.

Runoff from the glaciers and thawing permafrost at the northern edge of Central Asia in the Altai-Sayni Mountains has a significant influence on the hydrological regime of the large Siberian rivers such as the Ob', Yenisey and Amur Rivers and plays a part in regulating the global thermohaline circulation through the hydrological cycle of the Arctic Ocean (Wang and Cho 1997). According to Barry et al. (1993), the continental runoff amounts account for about 53.9% of the total freshwater inflow into the Arctic Ocean, and the water flowing from the Ob and Yenisey rivers accounts for 40% of the total river inflow into the Arctic (Aagaard 1980). We expect that modern climate change that impacts runoff in the headwaters of these rivers have a considerable influence on the freshwater budget of Arctic Ocean. However, the scale of this influence is unknown and the specific physical processes involved are very poorly understood.

3.6.1.7. Impact of permafrost degradation on ecosystems

Northern ecological systems depend on permafrost conditions. Permafrost controls plant communities and biomass production by soil temperature, active layer thickness, moisture content, presence of unfrozen water, and surface hydrology. The changes in the permafrost thermal regime and active layer thickness can affect plant diversity and biomass (Walker et al., 2003). There is some available data showing that various changes have already occurred to the vegetation in the recent past (Silapaswan et al. 2001; Sturm et al. 2001a; Zamolodchikov et al. 1998). Degradation of permafrost in the southern tundra zone often creates local well-drained microsites favorable for the establishment of tree and tall shrub species at the arctic treeline (Lloyd et al. 2003).

The thawing of the ice-rich permafrost within the boreal forest biome can lead to destruction of the substrate and major changes in ecosystems. In case of the "wet thermokarst" scenario of permafrost degradation, changes can result in replacement of the boreal forest with wetlands (Figure 3.6.6)[56], and changes in wildlife habitats (Osterkamp et al. 2000; Jorgenson et al. 2001; Zamolodchikov and Karelin 1999). In case of "dry thermokarst", the boreal forest ecosystems may be replaced by steppe-like habitats (Figure 3.6.7). As a result of these changes, the area of boreal forest can be reduced; the habitat area for caribou and other terrestrial mammals and terrestrial birds will be shrinking, while the area favorable for aquatic birds and mammals will be increasing.

Figure 3.6.6. Thawing of permafrost in poor drainage conditions converts boreal forest into wetlands in the Tanana Flats, Fairbanks, Alaska (photo by T. Jorgenson).

Figure 3.6.7. Thawing of ice-rich permafrost, triggered by the forest fire in Central Yakutia, transforms boreal forest into steppe-like habitats (photo by V. Romanovsky).

Long-term permafrost degradation (even without active thermokarst processes) will continuously improve conditions for the subsurface water drainage (especially in sandy soils) that will lead to increased dryness of soils, putting significant stress on vegetation. Improved drainage conditions will also lead to shrinkage of numerous ponds within the degrading permafrost area dramatically affecting aquatic ecosystems (Yoshikawa and Hinzman 2003; Hinzman et al., 2004). Increased thermal erosion of slopes and riverbanks will increase flux of sediments into the river systems affecting the riverain aquatic ecosystems and clogging the salmon spawning streams with sediment and debris.

[56] Figures 3.6.1 through 3.6.5, 3.6.11 through 3.6.15, and Table 3.6.1 are in Scientific Background Appendix.

3.6.1.8. Impact of glaciers and mountain permafrost degradation on ecosystems

Climate warming and glaciers and permafrost degradation will change the mountain and foothill ecosystem dramatically. Landscape and morphology in postglacial environments will be dominated by the eroded landforms (e.g., such as eroded bedrocks, rock knobs, striated rock surfaces, roches mountonees, cirques and troughs), creating some of the most spectacular landscapes on the Earth. Large and small lakes are and will be developing in deglaciated valleys. A current and further expected drop in the water resources of the Central Asian Mountains, such as degradation of glaciers and alpine permafrost, and an increase in seasonal soil thawing will promote development of adverse cryogenic processes (thermokarst and thermal erosion) and entail catastrophic phenomena (landslides and glacial mudflows). The changes in precipitation partitioning among land surface storages with different residence times, evaporation fluxes, and subsurface storage and flow significantly affect mountain river runoff, lake water stores and ground water reservoirs in the Aral-Caspian, Balkhash, Issyk Kul and Tarim basins. The water resources in mountains are the main source of water and are especially important now, when severe drought in Central Asia has persisted for several years (Agrawala et al., 2001). The ice loss will also open up new terrain lead to plant and animal migrations and expose new mineral resources (gold mining in the Tien Shan).

3.6.1.9. Impact of permafrost degradation on carbon cycle

Significant amounts of carbon are now sequestered in perennially frozen soils (permafrost) and within the active layer, which thaw every summer but completely re-freeze during the following winter, where the organic matter decomposition is slow. This may lead to additional carbon accumulation (Michaelson 1996; Bockheim et al. 1999). That is why the majority of northern ecosystems are apparently carbon sinks at present time. Climate warming and caused by this warming permafrost degradation will change this situation. A thicker, warmer and dryer active layer will be much friendlier for microbial activities during the summer. Significantly later freeze-up of this layer in winter and warmer winter temperatures (that means much more unfrozen water in it) will considerably enhance the microbial activities during the winter. So, the arctic and sub-arctic ecosystems could turn into a source of CO_2 (especially on an annual basis) very soon. Actually, this is already happening (Oechel et al. 1993 and 1995). Further permafrost degradation and formation of taliks will amplify these changes because a layer that will not freeze during the entire winter (talik) will appear above the permafrost, where microbial activities will not cease during the winter. In the area of “wet thermokarst” formation, new and significant sources of CH_4 will be developing. There will be a considerable difference in greenhouse gas production from degrading permafrost depending on a different type of substrate and soil carbon quantity and quality. This point is very well appreciated. However, there will also be a substantial difference, depending on the age of thawing permafrost. Many areas of present-day permafrost degradation involve permafrost that was formed during the Little Ice Age. This permafrost was in existence only for the last 200-300 years. During the previous several thousand years this material was not frozen. In this case, we should not expect any significant changes in carbon fluxes from these areas upon thawing. Much more dramatic changes in the emission of greenhouse gasses will be observed when old syngenetic permafrost (e.g. “Ice Complex”) would start to thaw (Zimov et al. 1993, 1996 and 1997).

The local and regional changes in hydrology and vegetation will strongly feed back to the permafrost and glacier degradation, significantly increasing nonlinearity of the major ecological and societal processes in the Cold Land Regions of Northern Eurasia. It was well established in permafrost science that vegetation (especially ground surface vegetative layer) plays one of the most important roles in forming permafrost characteristics (permafrost temperature and the active layer thickness) and in determining permafrost stability

(Kudryavtsev et al. 1974; Luthin and Guymon 1974; Brown et al. 2000; Sturm at al. 2001b; Walker et al. 2003; Sazonova and Romanovsky 2003). The major effect that vegetation change inserts on permafrost manifests through changes in insulative properties of the ground vegetation. Another important outcome of changes in vegetation is the alternations in winter snow cover depth and its thermal properties. However, very limited data are available on thermal properties of the ground vegetation cover (Feldman et al. 1988; Gavriliev 1998; Beringer et al. 2001). Also, there are many uncertainties in the future projections of the ground vegetation evolution in response to changing climate.

Even more uncertain is the feedback effect of changes in surface and subsurface hydrology on permafrost. There are some data available that the development of both "wet" and "dry" thermokarst creates a positive feedback in the process of permafrost degradation (Kudryavtsev et al. 1974; Yershov 1998; Fedorov and Konstantinov 2003). However, the dryness of the active layer can trigger some negative feedbacks to the permafrost temperature and, under some conditions, can increase the permafrost stability. Much more research on this topic is needed.

NEESPI program can contribute significantly in resolving these uncertainties by development a truly integrated study that will include remote sensing, field and laboratory experiments and physical and ecological modeling.

3.6.1.10. Impact of permafrost and glaciers' degradation on infrastructure

Thaw settlement related to permafrost degradation is presently responsible for damage to houses, roads, airports, military installations, pipelines, and other facilities founded on ice-rich permafrost (Osterkamp et al. 1997). Any natural increase in the mean annual surface temperature of permafrost and subsequent thaw settlement would create severe maintenance problems for facilities in the Arctic and Sub-Arctic, adding to effects already being observed. Some structures, airports, and roads might have to be abandoned if funds are not adequate to continue repairs (Esch and Osterkamp 1990). The physical and mechanical properties of permafrost are generally temperature dependent and, for warm permafrost (permafrost within one or two degrees of thawing), dependent strongly on temperature. Most of the engineering concerns related to a climatic warming can be classified into those related to an increase in permafrost temperatures, those related to increases in the active layer thickness, and those related to the degradation of the permafrost.

Engineering concerns related to a general warming of the permafrost result primarily from the decrease in mechanical strength, especially compressive and shear strengths, and the increase in creep rates of frozen ice-rich soils. Systematic increases in the thickness of the active layer may be expected to lead to thaw settlement. Increased frost heaving during winter may also be expected. Continued climatic warming and increases in the depth of the snow cover will eventually cause much of the discontinuous permafrost to thaw. Continued thawing at the permafrost table results in progressing thaw settlement in ice-rich permafrost. Thermokarst terrain, increased downslope soil movement and landslides, and other terrain features common to degrading permafrost may be expected to appear. Roads, airfields, railway embankments and other foundations on degrading permafrost may be subject to continuing deformations as a result of the thaw settlement. Accurate predictions of the climate-permafrost response at a regional level are needed to assess the timing, duration, and severity of these problems. New and innovative engineering design will be required to solve them.

In mountainous regions of Central Asia and Caucuses, the warming climate caused activization of slope instability processes including solifluction, landslides, debris flows, catastrophic rock glaciers moving, catastrophic events, such as the rock-ice avalanche at Kolka Glacier, northern Ossetia, Russia, in September 2002 (Institute of Geography 2002; Kääb et al. 2003), and development of thermokarst depressions. Development of thermokarst lakes on moraines can lead to mudflows, which a hazard to ecosystem, population and infrastructure of high mountain regions. The development and growth of dangerous glacier-dammed lakes, due to the progressive disintegration of debris-covered glacier tongues pose major societal and economic hazards. In the mountains where gravitational processes play a decisive role in mobilizing the material, the differences in the physical and mechanical properties between frozen and thawed soils control the susceptibility of slopes to natural and man-made impacts. Anthropogenic modification of the landscapes in the permafrost areas together with recent warming often triggers destructive natural processes.

The impact of glacier runoff changes for streamflow, stream chemistry, and soil moisture may be severe in the productive yield-growing regions and quality water supply in down-river villages and towns. The air masses polluted over the Central Asia are the source of thousands of tons of toxic chemicals and radionuclides in snow/ice accumulation areas poisoning glacier water resources for several generations. Decrease in glacier river runoff has a formidable impact on hydropower, melioration system, lake level and water supply in alpine villages and down-river towns. The consequences could be so sever that it will require removing existing settlements or search for other sources of water.

Protection of the quality and supply of Freshwater resources is the issues in disputes concerning trans-boundary water resources. The water-issued problems are extremely important for Kyrgyzstan and its neighboring countries because Kyrgyzstan has key geographic position in water sources and water distribution. Although small, land-locked, and bereft of major resources, Kyrgyzstan has an important location at the headwaters of major river systems in Central Asia, streamed from high mountain cold regions of the Tien Shan and Pamiro-Alay mountain ranges, which enables it to affect critical and sensitive issues such as agriculture, electricity generation, and the environment in the down-river countries of Kazakhstan, Uzbekistan, and Turkmenistan. Kyrgyzstan's neighboring countries depend upon water resources originating in Kyrgyzstan to meet their agricultural and domestic water supply needs. Furthermore, Kyrgyzstan depends on its water resources for a large portion of its electricity requirements. Consequently it is important that Kyrgyzstan, in cooperation with its neighbors, manage its water resources in the most sustainable manner possible.

Socio-economic consequences of the ongoing changes in permafrost and glaciers in the Cold Land Regions of Northern Eurasia are paramount and are further discussed in Section 3.6.2 and, mostly, in Section 3.4.

3.6.2. COASTAL ZONE PROCESSES

Chapter lead authors: A.O. Selivanov, I. P. Semiletov, S.V. Victorov

Contributing authors:

C.S. O'Connor, A.G. Georgiadi, V. Yu. Georgievsky, P. Ya. Groisman, V. E. Romanovsky, S. Shaporenko, A. I. Shiklomanov, F. A. Surkov, M. S. Zalogin

3.6.2.1. Definition of Coastal Zone

The coastal zone can be defined in many ways depending upon the perspective of the individual. In this plan, the coastal zone is defined as the area near the shore that experiences the interaction of land and sea, both during the past several millennia (4-5,000 yrs) and during the next century. This zone extends seaward and inland, due to the interaction of waves, tides, sediment erosion and deposition, and freshwater flux from rivers and groundwater. In the ocean, the limit of the coastal zone is arbitrarily specified as the point where riverine effects are only 10% of similar marine processes. In the Arctic, this boundary frequently coincides with the 20 pro mille isohaline in the sea surface layer. Landward, the zone is limited by the extent of extreme storms, wave and wind surges, saline groundwater intrusion and other related processes. Practically speaking, the coastal zone may stretch from 5 to 200 km seaward and from 10 to 100 km landward from the shoreline (Figure 2.5a).

3.6.2.2. Importance of coastal zones of Northern Eurasia

Presently, coastal zones of Northern Eurasia include over 40% of the population and more than half of the area's economic resources. The recent trends of increasing population and economic activity accompany degradation of the coast due to erosion, denudation, and slope processes. Prospecting and exploitation of oil and gas fields, both onshore and offshore, also affect this zone.

In the whole coastal zone of Northern Eurasia, economic development and natural processes have already resulted in dramatic conflicts between various economic and environmental interests. Industrial, port, and oil and gas field development may conflict with recreational use and the necessity to conserve unique ecosystems; living conditions for local people may be enhanced, or degraded. Due to all these factors, the risk of catastrophic events in the coastal zone of Northern Eurasia has increased and will inevitably increase further. Under present and anticipated future levels of anthropogenic impact, the major regions at risk are coastal zones of the Pechora, Kara, Laptev, East-Siberian, and western Chukchi Seas in the Arctic Ocean, the northeastern Black Sea, the Sea of Azov, the north Caspian Sea, and the Sea of Japan in the south of the region. Furthermore, protection of the Baltic Sea coastal zone is a matter of great concern to all the Baltic Sea states.

3.6.2.3. Past and present changes in the coastal zones of Northern Eurasia

Coastal zones of Northern Eurasia underwent drastic changes during the last millennia. The shoreline of several coastal areas migrated landward by 300-400 km (especially in low-lying Arctic areas and on the North Caspian) during the past 10,000 years after the continental glaciation in the Northern Hemisphere had totally disappeared. This landward migration was a result not only of sea-level rise but also, even more importantly, of coastal processes

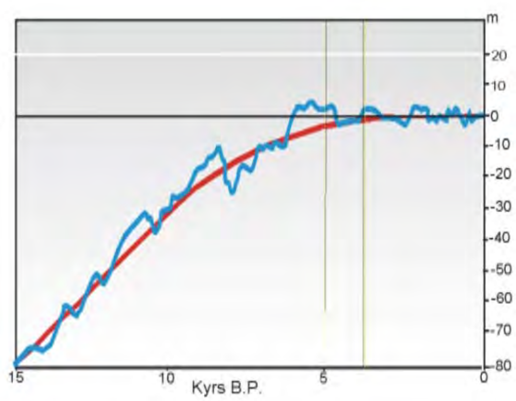


Figure 3.6.8. Global mean sea-level rise during the past 10,000 yrs. The general trend (red line) and fluctuations are shown. The period of sea-level rise deceleration indicating the beginning of the present period of coastal zone evolution (nearly 5-4,000 yrs B.P.) is shown by vertical bars (adapted from Selivanov 1996; Kaplin and Selivanov 1999).

(erosion, denudation, slope processes). Specific coastal segments, such as river deltas, advanced seaward by several dozen kilometers due to heavy sedimentary inflow. During the past 4-5,000 years, the rate of sea-level rise slowed (Figure 3.6.8) and sea coasts reached some sort of equilibrium. This situation was disturbed during the 20th century primarily by anthropogenic activity. By the end of the 20th century, over 70 percent of the Northern Eurasian coasts had undergone erosion and degradation (Bird 1993; Pirazzoli 1996; Kaplin and Selivanov 1999).

The increasing depth of coastal waters, and changes in their salinity and chemical composition already has resulted in significant coastal ecosystem changes. Presently and in the decades to come, Northern Eurasia is/will be one of the most important natural systems to study because of the area's widely increasing economic development and high sensitivity to anthropogenic impact from local, regional and global sources. Furthermore, in the next few decades, the Eurasian Arctic coastal zone will be a critical natural system to monitor because of polar amplification of projected climatic changes (IPCC 2001), and the possibility that changes in the highly sensitive Arctic coastal zone may feed back to the global oceanic ecosystem (ACIA Report 2004).

The extremely high vulnerability of the Arctic coastal zone is determined by the following factors:

- intensive prospecting for, developing, and exploiting oil and gas fields, both offshore and onshore, and accompanying pipelines, refineries, infrastructural and other engineering development in the coastal zone;
- high natural sensitivity of seacoasts due to intensive retreat of sea coasts (in some places over 10 m yr^{-1}) as frozen ground warms and is lost, and the resulting degradation of unique ecosystems and lower living conditions for the local population.

Recent changes in Arctic climate are leading to increased frequency of cyclones, warming, melting of permafrost, and increased river runoff that can lead to environmental changes in the Arctic seas. Increased atmospheric forcing and runoff have caused an increase in the flux of dissolved and solid terrestrial material to the Arctic Seas, especially the Laptev and East-Siberian Seas. Increased offshore transport of terrestrial material is expected to contribute significantly to sediment accumulation and carbon, nitrogen and phosphorus (CNP) cycling in the Arctic Ocean (Semiletov et al. 2000; Peterson et al. 2002).

Other areas of risk are the northern Black Sea, the Sea of Azov and the Baltic Sea coastal zones with their very high level of economic development and coastal materials composed primarily of loose sediments. Economic development includes port facilities, heavy industry, recreation and also, during the past decade, oil and gas pipelines crossing the coastal zone. Various types of economic activities and specific hydrographic characteristics of the Baltic Sea determine the high vulnerability of the Baltic Sea coastal zone. In the Caspian Sea, the problems are aggravated by oil prospecting and development immediately in the coastal zone (Kaplin and Selivanov 1999).

The northern Black Sea and the Sea of Azov also need immediate attention because of their high vulnerability to changes in biogeochemical processes and water salinity. Anoxic water horizons in the Black Sea episodically influence coastal waters and this effect may increase in the future. In the Sea of Azov, bioproductivity of "beach-builder" mollusks and their shells, which depends upon water salinity, affects the rate of coastal erosion (see **Box insert A3.6.1**).

3.6.2.4. Major research problems:

What were the changes in coastline position, environment, and population migration and adaptation strategies in Northern Eurasia during the past 5,000 yrs? Proper consideration will be given to the following:

- estimation of changes in shoreline position during this period in the coastal zones of Northern Eurasia, especially in highly climate-dependent areas such as the low-lying Arctic and north Caspian Sea.. The intensively eroding northeastern Black Sea, the southern coast of the Baltic Sea, and the eastern Sea of Azov should be closely monitored.
- application of important lessons learned from our experiences with population migration, ethnic evolution and past cultural adaptation strategies in order to create successful strategies for future coastal development during the present century.

How do human modifications of land use and land cover during the last 50-100 years affect the state of the inland waters, marine and coastal environments, ecosystem functions and ecosystem feedback, and to what extent can anthropogenic impacts influence these processes in the upcoming decades?

What is and will be the impact of climate change on the quality and supply of freshwater, and on coastal saline water quality? Answering this question requires determination of:

- the initial conditions (i.e., the "quasi" equilibrium state of the coastline),
- the present trends,
- the connection between atmospheric processes, river discharge (liquid and solid), transport and fate of fluvial and particle transport to the marine coastal zone, and
- projection of future changes.

What is and will be the effect of climate, sea-level and related changes on biogeochemical cycles in semi-enclosed seas like the Black Sea and the Sea of Azov and enclosed lakes like the Caspian Sea?

It is of particular importance in Global Biogeochemical Cycle studies to include the coastal zone of the Arctic Ocean. This ocean accounts for 20% of the world's continental shelves. The amount of terrestrial organic carbon stored in the wide circum-Arctic shelf and slope areas is certainly of importance for calculation of organic carbon budgets on a global scale (Macdonald et al. 1998; Aagaard et el. 1999; Gobeil et al. 2001). More than 90% of all organic carbon burial occurs via sediment deposition on deltas, continental shelves, and upper continental slopes (Hedges et al*.* 1999), and a significant portion of organic carbon withdrawal occurs over the Siberian shelf (Fahl and Stein 1999; Bauch et al. 2000). Determining the magnitude of particulate and dissolved fluxes of organic carbon and other terrestrial material from land is critical to constraining a range of issues in the Arctic shelf-basin system, including carbon cycling, the health of the ecosystem, and interpretation of sediment records**.** The role of the coastal zone in the transport and fate of terrestrial organic carbon has not been discussed sufficiently, although it has been stated that coastal erosion plays an important role in the dynamics of coastal permafrost, bathymetry, and transport of terrestrial material (Reimnitz et al. 1988; Are 1999). Studies conducted along the North American shelf (Schell 1983; Reimnitz et al. 1988; MacDonald et al. 1998) indicate large volumes of, and significant variability in sediment contribution by coastal erosion, riverine runoff, and *in situ* primary production within 10 km offshore. Biogeochemical consequences of coastal erosion play a significant role in the formation of a net primary production, (NPP) with a terrestrial signature that has been found in the food web over the narrow North American shelf (Schell et al. 1983). This terrestrial signal should be most pronounced in the near-shore zone of the Eurasian Arctic where rates of coastal erosion are highest and the shelf is the widest and most shallow (Semiletov 2003). However, biogeochemical consequences of coastal erosion may be more pronounced over the wide, shallow East Siberian shelves in comparison with the narrow Arctic Alaskan and Canadian shelves, because distribution of the stable carbon isotope data shows a westward increase in "light" terrestrial organic carbon from the Beaufort shelf to the East Siberian and Laptev Sea shelves (Semiletov 1999a,b; Naidu et al. 2000). The above indicates that the coastal zone plays a significant role in the regional budget of carbon: transport, accumulation, transformations, seaward export, and atmospheric carbon dioxide (CO_2) emission. Therefore, ***biogeochemical consequences of changing coastal erosion and fresh water input in the Arctic coastal zone need to be investigated on a priority basis.***

What is and will be the effect and intensity of coastal inundation, erosion and related processes in the terrestrial part of the coastal zone? Proper consideration should be given to the following major issues:

- possible intensified erosion of coastal escarpments and depositional bodies (barriers, spits, etc.);
- degradation of unique natural coastal ecosystems;

- damage to local and regional infrastructure (ports, industrial structures, shelf and coastal oil and gas fields and respective pipelines, transport, and utilities);
- possible decrease in the quality of life for local populations due to inundation, erosion, salinization, and contamination of underground and coastal waters; and
- change of bottom topography due to coastal and bottom erosion of permafrost rocks that may be significant for the future use of the Northern Sea Route.

What are the reasonable, regionally oriented strategies of (economic) development in the coastal zone of Northern Eurasia? This problem includes the following aspects:

- a preference for environmentally sound future development within the key study areas (see 3.6.2.5 below), including the necessity to preserve unique ecosystems;
- economically advantageous further development of agriculture, heavy and light industry, port facilities, infrastructure, oil and gas extraction, etc.

3.6.2.5. Key study areas

Several areas of high intensive economic development and/or heavy population and intensive present and anticipated future coastal zone deformations require special attention because of the extreme risk of their degradation in the following decades. These key coastal areas recommended for detailed studies (Figure 2.5a) include in clockwise order:

(1) **The southern Pechora Sea (literally, the southeastern part of the Barents Sea) near Naryan Mar.** This area is extremely important for its ice-rich coastal scarps which are highly vulnerable to global/regional warming (annual retreat by over 15 m in some coastal areas) and its intensively exploited and developed oil and gas fields, with their respective infrastructure and pipelines which extend across the coastal zone (see **Box Insert A3.6.2**).

(2) **The south-western Kara Sea west of the Yamal Peninsula.** As the ice-rich coast rapidly retreats (by over 10 m/yr), the Ob River delta degrades both morphologically (literally, loses its area) and environmentally (as habitat for unique fish and bird communities is degraded and lost). Developing the oil and gas fields in the shelf area near the Ob River delta will inevitably contribute significantly to decreased water quality, shore retreat and accompanying processes.

(3) **The Laptev Sea, especially the area adjoining the Lena River delta, and the western East Siberian Sea, especially the Dmitry Laptev Strait and Sannikov Strait**. The area is characterized by the very high ice content in coastal sediments, and it is therefore intensely dynamic. An entire archipelago disappeared in this area due to climate changes and wave/surge action during the past century. The highest rates of coastal erosion in the Arctic region (Figure 3.6.14) were observed in the western East Siberian Sea. Unique ecosystems within the presently established state coastal reserve encompassing the Lena River delta already suffer from sea-level changes and economic development and could totally degrade in the next few decades if we do not take protective measures. Dynamics of the bottom topography in the Seas already affects the transportation between the Lena, Kolyma, and Indigirka Rivers, the most active portion of the Northern Sea Route in Eastern Siberia.

(4) **The western Chuckchi Sea between Pevek and Uelen.** This area is generally economically undeveloped at present but is extremely vulnerable because of its specific geomorphological structure (intensively degrading gravel barriers that separate extensive lagoons). Settlements are generally situated on capes composed of ice-rich sediments where the shoreline retreats very fast. Entire blocks of houses were destroyed during recent decades. Sea-level rise and related processes will inevitably bring catastrophic consequences for these areas, which are favorable for oil and gas prospecting.

(5) **Apsheron Peninsula near Baku in the south-western Caspian Sea faces problems similar to those discussed for the previous area.** Here, high population density, extreme

water and air pollution and fast retreat of coastal scarps and beaches composed of sand and sandstone aggravate the problems.

(6) **The Volga River deltaic area and adjacent areas in the northern part of the Caspian Sea.** Drastic (and unpredictable) water-level change in the Caspian Sea exceeded a rate of 15 cm/yr (100 times more than global sea-level changes) during recent decades. The low-lying areas in the Volga River delta and adjacent areas, including unique ecosystems, human communities, industrial structures, oil and gas fields, refineries and pipelines, all suffer greatly from these changes.

(7) **The northeastern Black Sea between Novorossiisk and Sochi.** This area represents the most important sea resort in modern Russia. A strong conflict between recreational use and industrial development, including development of port facilities and the creation of pipelines across the coastal zone, exists presently against a background of swiftly retreating coastal scarps and damage to unique ecosystems.

(8) T**he Taganrog Gulf, Sea of Azov** suffers much from coastal erosion of high scarps on which the most important industrial, living and recreational facilities are situated, from contamination of coastal waters, industrial pollution (Figure 2.5b), and damage to one of the richest bio-resources in the world (**see: Box insert A3.6.1**). These processes have already, or will soon cause a "coastal disaster" across many stretches of this coastline (Selivanov 2001).

(9) **The Odessa Gulf, north-western Black Sea**. This area is traditionally highly developed (heavy industry, port facilities, shipping, sand extraction, agriculture, recreation) and suffers from coastal erosion, lack of freshwater supply, atmospheric pollution, sea water contamination from big rivers such as the Danube, the Dnepr, the Dniester, and the Southern Bug, eutrophication processes in the coastal zone, etc. The respective problems were aggravated during recent decades due to intensive economic growth of the area (Figure 3.6.10).

(10) **The Bosporus Strait connecting the Black Sea and the Sea of Marmara, near Istanbul,** is an overpopulated area of extreme economic activity (sea traffic, industry). Changes in the coastal zone in this part of the world will affect water quality, cause damage to ecosystems, degrade living conditions, and may affect one of the most important regional sea traffic routes.

(11) **The Finnish Gulf near St. Petersburg, Baltic Sea.** This heavily populated and highly economically developed shallow area suffers from water contamination (due to insufficient waste water treatment capacity for the city of 5 million inhabitants), coastal erosion, rise of the groundwater table, salinization of underground waters and related processes. Current construction of new ports potentially increases the risk of coastal zone oil slick pollution (**see Box Insert A3.6.3**).

(12) **The southern Baltic Sea between Kaliningrad and Kiel.** This heavily populated and industrially developed area of a very shallow sea is subject to coastal erosion, water and air pollution, and related processes. These processes are/will be additionally aggravated by increased erosion of coasts composed of loose sediments (high sandy scarps alternating with beaches, barriers and spits) due to the decrease of sediment supply both from rivers and from offshore(**see Box Insert A3.6.3**).

3.6.2.6. Future changes in the coastal zones of Northern Eurasia in the 21st century.

Based on long-term assessment of future changes in the coastal zone of Northern Eurasia, predictive estimates of coastal zone changes in the area by 2050 and 2100 are selected as benchmarks for projections. The latest internationally approved estimates for 2050 vary from 0.08 to 0.24 m of the sea level rise with a central value of 0.17 m and for 2100, from 0.11 to 0.77 m with a central value of 0.48 m, which corresponds to an average rate of about two to four times the rate that occurred during the 20th century (IPCC 2001; Figure 3.6.9). The respective rise in globally averaged surface air temperature is projected to increase by 1.0 to

5.8°C by 2100 with a high probability of twice as much warming in the most sensitive Arctic areas (ibid.). Of greatest importance will be the inevitable amplification of extreme events, such as “passive” inundation of low-lying coastal lands, storm surges, and river floods, with resulting excessive input of water and sediments into the coastal zone.

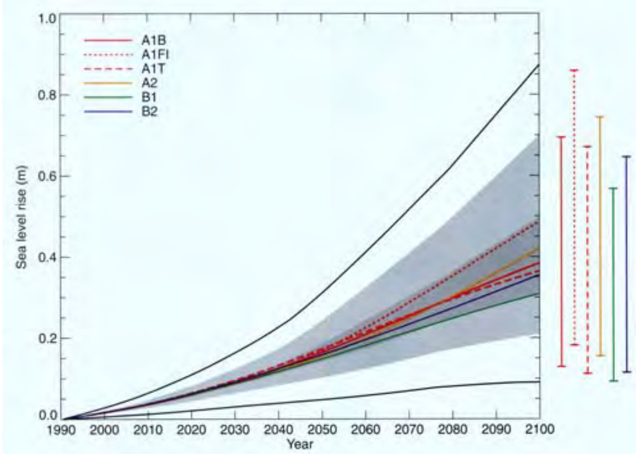


Figure 3.6.9. Shaded area shows global average sea level rise simulated by a global climate model (GCM) according to several climate change scenarios for the 1990-2100 period (a total of 35 scenarios were employed). Range of uncertainty in 2100 for six selected scenarios is shown by vertical bars on the right. (Figure 11.12 from IPCC 2001).

Some negative effects on the coastal zone could be significantly reduced if countermeasures are implemented. Preliminary estimates for the Sea of Azov and some other areas clearly demonstrate that direct economic losses can be significantly reduced (Selivanov 2001). If indirect effects are included, even more resources can be saved.

Arctic coast of Northern Eurasia

Under these conditions, catastrophic changes are likely to occur during the present century in most Arctic coastal zones of Northern Eurasia. The most prominent and dramatic changes include:

- drastic retreat of ice-rich coasts caused by thermoerosion, thermodenudation, influence of waves, tide surges, and sea level rise. By 2100, this retreat could exceed 200-300 m in several coastal sectors (e.g. Pechora Sea, southwestern Kara Sea, Laptev Sea, and East-Siberian Sea)
- intensive inundation of low-lying coasts, especially tidal flats, river deltas and estuaries, under accelerated long-term sea-level rise and higher risk of extreme events. The shoreline retreat by 2100 could be as much as 800-1500 m over several coastal stretches of the White, Barents, Pechora, Kara, Laptev, and East-Siberian seas. River deltas (Pechora, Ob, Yenisey, Lena, Indigirka, and Kolyma rivers) will suffer from these processes to the greatest extent
- intensive movement and general destruction of coastal depositional bodies, such as barriers and spits (especially in the White Sea, Pechora Sea and Chuckchi Sea). Due to the lack of sediment supply, important barriers and spits where several economically important structures are situated or planned will be partially or totally destroyed
- degradation of unique ecosystems (primarily fish and bird habitats)
- bearing in mind that most economic activity occurs near the present shoreline, a direct loss of economic and living structures in populated areas as well as damage to pipelines and other engineering structures is anticipated
- indirect decrease in the quality of living conditions for local populations
- increasing offshore transport of fluvial and eroded material, causing changes in food webs and formation of net primary production with a “terrestrial signature”
- extensive erosion of coastal and bottom permafrost along the Arctic Eurasian coast changes the bottom topography which must therefore be surveyed again and again to

plan Northern Sea Route activity (both transportation routes and mining and oil exploration over the shallow shelf).

Densely populated and economically developed areas of coastal zones

Densely populated and economically developed coastal areas in various parts of Northern Eurasia, namely in the south (the Black Sea, north Caspian Sea and the Sea of Azov), the west (Baltic Sea) and, partially, in the eastern sector (the Vladivostok and Nakhodka areas in the Sea of Japan) will inevitably suffer from climate changes, sea-level rise and related environmental processes. The principal negative processes include:

- erosion of high coastal slopes comprised of rocks of varying hardness under conditions of sea-level rise and increasing storm activity. This is especially important on the northeastern (Novorossiisk-Sochi) and northwestern (Odessa Gulf) Black Sea, and in the eastern and northern parts of the Sea of Azov, especially in the heavily economically developed Taganrog Gulf. The shoreline retreat might exceed 300-400 m by 2100 in several coastal areas
- biogeochemical instability in the Black Sea (Figure 3.6.10) and the Sea of Azov resulting from the possible rise of an anoxic water horizon in the former, and lower bioproductivity of "beach-builder" mollusks in the latter

Figure 3.6.10. Phytoplankton distribution in Dnepr Estuary, retrieved from a Landsat 7 image, demonstrates eutrophication processes in the area. August 10, 1999 (Bands ETM+: 3,2,1)

- inundation of low-lying areas, including deltaic and estuarine parts of the northern Caspian Sea (the Volga River delta and adjacent areas) and the Gulf of Finland near St. Petersburg
- degradation of beaches and other depositional coastal features that are extremely important for recreational and other uses (the northern Black Sea, Sea of Azov, Baltic Sea). Some of these areas, especially in the Sea of Azov and in the eastern Baltic Sea (Kaliningrad area, Lithuania, Latvia) may be totally destroyed during the next few decades
- degradation of unique ecosystems, including those in the protected areas (reserves)
- highest population density and most economic activity exist near the present shoreline and a direct loss of economic viability and structures in densely populated and economically developed areas is inevitable

* general decrease of living conditions for the local population due to coastal erosion and direct loss of property; decreasing quality of potable water and other factors due to the rise of the underground water table, increasing industrial activity, and higher population density.

3.6.2.7. Unresolved issues that should be addressed during the NEESPI implementation

Arctic coast of Northern Eurasia

* Dependence of coastal dynamics, including retreat of coastal scarps in thawing ice-rich loose permafrost sediments (ice complexes or yedoma) and destruction of depositional features (including sea bottom erosion), upon present and possible future climate, sea-level, and related changes has not yet been adequately studied. An "ice-complex" is Pleistocene permafrost soil enriched by organic carbon (usually between 1 and 20% by weight) that contains huge ice wedges (up to 60-80 % by volume) (3.6.1; Tomirdiaro 1974; Are 1999; Romanovsky et al. 2000; Semiletov 1999b). The methodology of these studies has been developed (Selivanov 1996; Kaplin and Selivanov 1999), but the necessary data base describing coastal changes in the past using instrumental, historical and other documentary information has yet to be compiled.
* Connections among atmospheric forcing (air temperature, major circulation patterns), oceanographic regime (sea ice, sea level, water mass, hydrochemistry), and the food web in the near-shore zone are not well understood. The fieldwork to extend the existing data sets for assessment of this relationship (ACIA Report 2004) would be a prospective research area within the framework of NEESPI.
* The coastal zones of the eastern Laptev and East Siberian Seas correspond to a number of geographically critical contrasts in the Arctic system. The highest rates of coastal erosion (Tomirdiaro 1990; Romanovsky et al. 2000) and most pronounced biogeochemical consequences (Semiletov 1999a) have been found there. This area remains largely understudied and provides an excellent natural laboratory that can be used to achieve an improved understanding of the interactions across the atmosphere-land-ocean system and the impacts of those interactions on freshwater dynamics and biogeochemistry.

Densely populated areas of coastal zone and estuaries

In most cases, it is not known whether changes in coastal morphology, water salinity and quality, and related environmental processes observed during the past decades were connected with natural changes or with economic development and urbanization of these coasts. This lack of understanding prevents us from predicting environmental changes in these coastal zones under anticipated climate, sea level, and related changes. Changes in water salinity and its chemical composition, due to both natural and anthropogenic processes, and the effect of those changes on coastal biogeochemistry and dynamics have not been adequately analyzed. This is especially true for semi-enclosed and enclosed seas such as the Sea of Azov, the Baltic Sea, and the Caspian Sea. Historical aspects of the influence of environmental change upon economic strategies have not been analyzed. ***These studies, carried out under the NEESPI umbrella, will help in the establishment of sustainable development strategies for these areas.***

[All Box Inserts of this Section were transferred to the Scientific Background Appendix]

3.6.3. ATMOSPHERIC AEROSOLS AND POLLUTION

Chapter lead authors: I. N. Sokolik and E.L. Genikhovich

Contributing author: M. S. Zalogin

Atmospheric aerosols, or fine particles in solid, liquid or mixed phase, come from a wide variety of natural and anthropogenic sources. Primary aerosols are produced via direct emission of particles (e.g., wind-blown dust from arid and semi-arid regions, carbonaceous particles from fires), whereas so-called secondary aerosols are formed via the chemical reactions of gaseous precursors emitted into the atmosphere (e.g., sulfates formed by gas-to-particle conversion of SO_2). The lifecycle of natural aerosols is closely related to the cycles of energy and water, and main biogeochemical cycles of the Earth's climate system, whereas anthropogenic aerosols are associated with various human activities, ranging from industrial processes to human-induced land-use changes. Once lifted into the atmosphere, both anthropogenic and natural aerosols play an important role in the Earth's energy balance, major biogeochemical cycles, cloud formation and precipitation, ecology, air quality and human welfare. Given the high abundance of atmospheric aerosols and air pollutants in Northern Eurasia, a better understanding of climate change in this region will require the understanding of adverse effects of aerosols in connection with other climatic factors.

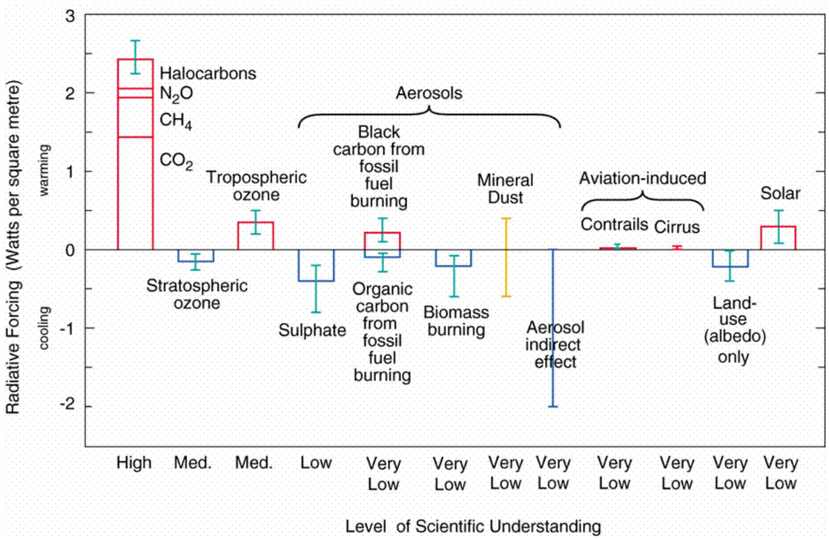


Figure 3.6.16. Main factors controlling climate change (IPCC, 2001). The global mean radiative forcing of the climate system for the year 2000, relative to 1750.

Atmospheric aerosols may affect the Earth's energy balance directly by scattering and absorbing solar and terrestrial radiation, or indirectly by affecting other radiatively important atmospheric constituents (e.g., affecting the properties and amount of clouds). Recent assessments of the radiative forcing of the climate system carried out by the Intergovernmental Panel on Climate Change (IPCC, 2001) reveal that anthropogenic aerosols are a significant radiative-forcing agent. Figure 3.6.16 shows the range of the global mean radiative forcing for the direct and indirect radiative effects of five distinct aerosol types. Anthropogenic aerosols can cause either a positive or negative direct radiative forcing. Comparing to other climatic factors, it becomes clear that the radiative forcing of anthropogenic aerosols represents one of the largest uncertainties in the prediction of climate change. The uncertainty is related to the great variability and complex nature of aerosols which make it difficult to accurately characterize aerosol properties and predict their impacts. Because aerosol distribution and effects are heterogeneous, both spatially and temporally, the radiative forcing due to anthropogenic aerosols has a complex geographical distribution. To illustrate, Figure 3.6.17 shows the examples of the spatial distribution of the direct radiative forcing due to several types of tropospheric aerosols. Although different modeling studies predict somewhat different spatial patterns, they all agree that climate change in Northern Eurasia could be strongly affected by the aerosol radiative forcing. In turn, climate change in this region would lead to changes in the sources, properties and loadings of atmospheric aerosols. Thus, there is a clear need for an integrated study of aerosol-climate interactions in Northern Eurasia to improve our understanding of current and future climate, not only in this region, but also on the global scale.

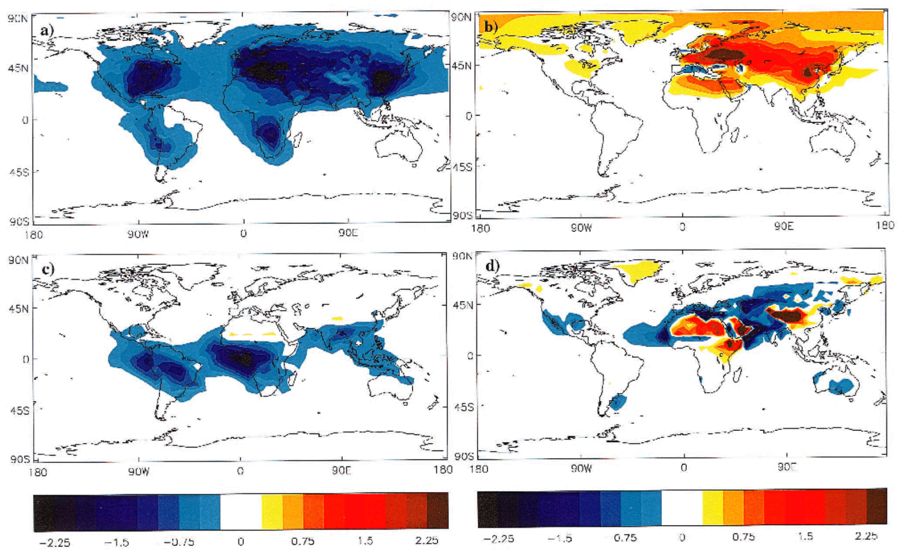


Figure 3.6.17. Model predicted direct radiative forcing (W/m^2) due to (a) sulfates, (b) organic and black carbon from fossil fuel burning, (c) organic and black carbon from biomass burning and (d) mineral dust (Haywood and Boucher, 2000).

Table 3.6.2. Major radiative effects caused by atmospheric aerosols and their importance (modified from Sokolik, 2003)

Impacts	***Importance***
Direct radiative impacts	
Cause the radiative forcing at the top of the atmosphere	Affect energy balance of the Earth's climate system by causing either a warming or cooling (depending on the aerosol types and environmental conditions)
Alter the energy balance at the surface	Affect surface temperature and surface-air exchange processes
Cause radiative heating or cooling within an aerosol layer in the atmosphere	Affect temperature profile and atmospheric dynamics and thermodynamics
Alter photosynthetically active radiation (PAR)	Affect net ecosystem productivity of the terrestrial biosphere and CO2 concentration, and, hence, Earth's climate
Affect visibility	Decrease visibility and degrade air quality
Indirect radiative impacts	
Serve as ice nuclei	Affect the properties and amount of ice and water clouds and hence their radiative effects
Serve as cloud condensation nuclei	
Promote or suppress precipitation	Affect the lifetime of clouds and hence their radiative effects
Alter actinic flux	Alter the abundance of radiatively important atmospheric gases
Absorb chemically important gases	
Provides particle surfaces for heterogeneous chemical reactions	

In addition to the radiative forcing at the top-of-the-atmosphere analyzed in the IPCC report, atmospheric aerosols cause other important radiative effects summarized in Table 3.6.2**.** The presence of aerosols alters the surface radiation budget, affecting surface temperature and various surface-air exchange processes (e.g., evaporation). By altering the amount of light reaching the surface, aerosols can significantly affect the ability of plants to undergo photosynthetic reactions and absorb CO_2. Radiative heating or cooling occurring within the aerosol layer itself affects the temperature profile and, hence, atmospheric dynamics and thermodynamics. The direct radiative impact of aerosols is augmented by indirect radiative effects such as aerosol-induced variations in clouds and radiatively active atmospheric gases. Some aerosol particles result in brighter clouds that may produce less precipitation.

Furthermore, atmospheric aerosols can cause various adverse impacts: pose a health threat, affect biogeochemical processes in the oceans, affect terrestrial systems, cause property damage, affect agricultural production, etc. Traditionally, these issues are studied by scientists from very different and poorly-connected fields. *It becomes apparent that improvements in the quantification of overall aerosol impacts on the climate system will require joint efforts from the interdisciplinary scientific community.*

The magnitude of the aerosol impacts is controlled by the type and amount of aerosols, as well as environmental conditions. Complex spatial and temporal dynamics of atmospheric aerosols in Northern Eurasia render predictions of aerosol impacts particularly difficult. Assessment of aerosol-climate interaction in this region will require an understanding of the factors that determine the abundance and properties of anthropogenic sulfates, black and organic carbon, and mineral dust, as well as gaseous air pollutants. Potentially important effects caused by these aerosols and gaseous air pollutants in Northern Eurasia are discussed below.

Anthropogenic sulfates are formed mainly from SO_2 emission from fossil fuel combustion, though SO_2 has several other sources (e.g., biomass burning). In contrast to greenhouses gases, sulfates cause a negative radiative forcing by reflecting a portion of incident solar energy back to space. Sulfates also cool the climate system indirectly through their role in cloud formation. Emissions of anthropogenic sulfur compounds not only compensate for some fraction of warming associated with greenhouse gases, but also contribute to air quality problems along with other air pollutants (such as O_3, CO, NO_x, carbonaceous particles, trace metals and hydrocarbons, including toxic organic compounds).

The spatial distribution of the emission of SO_2 and air pollutants varies significantly across Northern Eurasia. To illustrate, Figure 2.6a shows the emissions (by volume) of some major air pollutants in Siberia. Air pollution emissions in Siberia tend to be higher in the vicinity of the major industrial centers (Irkutsk, Krasnoyarsk, and Novosibirsk). The most polluted areas are Tyumen oblast and Krasnoyarsk Kray. Based on volume-based emissions data for 1992-1993, Warner-Merl (1998) estimated that anthropogenic activities in these regions contributed over two times the volume of pollution as any other area in Siberia. The next high polluted areas are Irkutsk oblast and Kemerovo oblast. This map shows that sulfur-containing air pollutants are the most serious threat in many regions of Northern Eurasia. Recent estimates show that Siberia accounts for about 30% of SO_2 release from the FSU territory or about 10% of overall anthropogenic sulfur emission (Koutsenogii and Koutsenogii, 1997).

Emissions of anthropogenic sulfur compounds also contribute to the so-called acid rain problem, causing harmful effects on human health, plant growth, and corrosion of building material. Nilsson and Shvidenko (1999) estimated that there are about 230 million ha of forested areas at risk from sulfur depositions, which is 30% of the total forested area of

Russia. Table 3.6.3 shows that the problem of sulfur and nitrogen depositions is greatest in Asian Russia, mainly due to the higher sensitivity of ecosystems in this region.

Table 3.6.3 Forest area and growing stock at risk from sulfur and nitrogen depositions in Russia (Nilsson and Shvidenko, 1999)

	Forested area (in million ha)	Growing stock (in billion m^3)
Sulfur		
European Russia	21.5	2.8
Asian Russia	210.0	24.5
Total	231.5	27.3
Nitrogen		
European Russia	1	0.2
Asian Russia	87	11.4
Total	88	11.6

Two other important types of aerosols in Northern Eurasia are black and organic carbon. The main sources of these carbonaceous particles are fossil fuel and biomass burning. Black carbon, produced from incomplete combustion, is a key aerosol type which strongly absorbs solar radiation, contributing to climate warming. In addition, black carbon (soot) may warm the climate via so-called "semi-direct effects" in which the absorption of solar radiation by soot-containing aerosols heats the atmosphere layer and thereby suppresses cloud formation. This effect is also important for the hydrological cycle because it presumably decreases cloud cover and hence precipitation. Given a high frequency of forest burning and wide spread industrial combustion in Northern Eurasia, the role of black carbon in climate change processes in this region is of special importance.

Natural fire (caused by lightning), being the main source of natural black carbon, is an important ecological factor in the boreal forest system. Fires play a crucial role in determining the distribution of boreal species and improve forest vitality by removing old trees weakened by drought, storm, insect infestation or extreme cold. However, only 15% of the recorded fires in the Russian Federation are caused by lightning. Thus, a large fraction of black carbon emitted from the forest fires has anthropogenic origin. Also, increased temperatures caused by climate change could lead to fires occurring considerably more than past and present natural frequencies (2.8, 3.5.2). Satellite remote sensing provides a valuable tool in detecting fires. To illustrate, Figure 3.6.18 shows a MODIS image of thick smoke from fires near Lake Baikal on July 6, 2003. Smoke from fires in Northern Eurasia can be transported over large distances as confirmed by satellite observations. It will be critical to identify the area affected by long-range transport of smoke from Northern Eurasia and quantify the associated effects on air quality and climate.

The recent study by Menon et al. (2002) of climate effects of black carbon in China and India showed that black carbon absorbing aerosols heat the air, alter regional atmospheric stability and vertical motions, as well as affect the large-scale circulation and hydrological cycle with significant regional climate effects. It will be important to perform a similar study over Northern Eurasia to quantify the effects of black carbon on the environmental systems and climate in this region. Such an analysis would require the data on temporal variations of black carbon and organic carbon from both natural and anthropogenic sources. The fraction of black carbon from fossil fuel burning was estimated recently by Novakov et al. (2003) (see Figure 3.6.19). The trends of black carbon show the rapid increase in the 1800s, the leveling off in the first half of the 1900s, and the increase during the past 50 years as China and India developed. The recent decrease of black carbon emissions from fossil fuel burning in FSU is associated with a slow-down of the economy. It is likely that sulfur emission has similar temporal dynamics. It will be important to reconstruct the historical trends of total black carbon emissions due to both fossil and anthropogenic biomass burning in Northern Eurasia to evaluate the role of black carbon in climate change and constrain the warming associated with black carbon and greenhouse gases (Hansen et al. 2004).

Figure 3.6.18. The MODIS image of smoke near Lake Baikal on July 6, 2003.

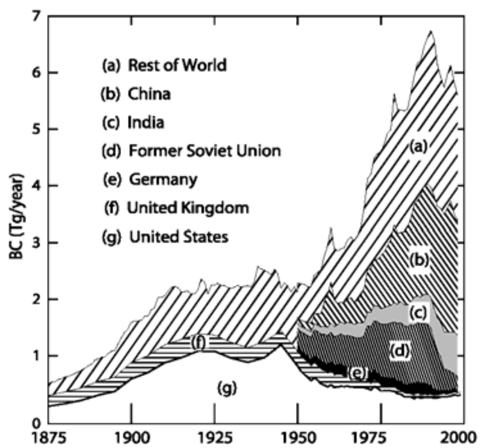


Figure 3.6.19. Estimated regional emissions of black carbon from fossil fuel burning (Novakov et al., 2003).

Another anthropogenic source of carbonaceous aerosols and gaseous air pollutants (especially, hydrocarbons) is petroleum gas flares in the oil fields. Oil industry is a key component of Northern Eurasia's economy. Several recent studies addressed the ecological impact of these pollutants on the forests and wetlands in Western Siberia (Bulgakova et al., 2003) and on the coastal zone of the Russian Arctic (3.6.2; Kaplin and Selivanov 2003). Figure 3.6.20 shows the relative forest and wetlands area affected by air pollutants from burning flares in oil fields of the Vasyugan group and the Igolsko-Talovoe oil field. The planned increase in oil production in the Igolsko-Talovoe oil field, reaching the level of 1,850,000 ton per year by 2005, will affect the large area of forest ecosystem in the Tomsk Region.

In addition to sulfate and carbonaceous aerosols, aeolian (wind-blown) mineral dust plays an important role in controlling climate change in Northern Eurasia. The vast arid and semi-arid regions of Central Asia (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan), Mongolia and Northern China are a prodigious source of mineral dust. Although it has long been recognized that Central and East Asia are the world's second largest source of atmospheric dust, emissions of dust and its diverse impacts on the environmental systems and climate in this region remain highly uncertain.

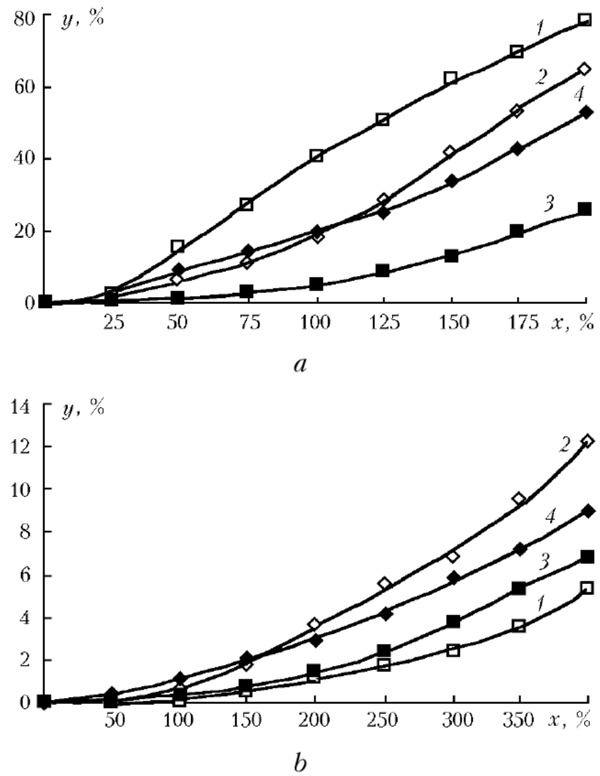


Figure 3.6.20. Relative area of the forests and wetlands contaminated by air pollutants as a function of oil production volume for (a) oil fields of the Vasyugan group and (b) the Igolsko-Talovoe oil field: (1) dark coniferous forest, (2) pine forest, (3) small-leaved forest and (4) wetlands (Bulgakova et al., 2003).

Dust particles are not only natural phenomena, but they are also produced as a result of various human activities. Over-cultivation of poor soils, inappropriate irrigation practices, human-induced wind erosion, severe trampling and heavy grazing, deforestation, urbanization, building and road construction, mining and industry, off-road vehicle use, and tourism are among the major factors which contribute to anthropogenic dust loading. Recent estimates show that the anthropogenic fraction of dust could be as much as 20% to 50% of total dust production, but this remains uncertain. The dependence of dust emissions on climatic parameters, such as wind speed and precipitation, strongly suggests that the atmospheric dust load could be significantly affected by any climatic change that may result from human activities. This fraction of the dust particles is considered as anthropogenic dust too, but it is largely unquantified.

The striking example of a human-made source of dust in Northern Eurasia is the drying up of the Aral Sea, one of the most staggering environmental disasters of the 20th century (Box insert A2.1). Due to improper irrigation practices, by 1999 the sea level dropped more than 18 m and the width of dried seabed reached 120 km, having a total dry area of about 40,300 km^2. The seabed has become the world's newest sandy-solonchak desert, emitting tremendous amounts of salt and dust into the atmosphere. Salt and dust from the Aral Sea cause not only local problems, but affects the large geographical region. The traces of pesticides carried by dust particles from the Aral region were found in the blood of penguins in the Antarctic, and typical Aral dust has been found on Greenland's glaciers and in Norway's forests, thousands of kilometers from Central Asia. A new qualitative phase of desertification is now occurring in the Near-Aral ecosystem. Degradation takes place that affects regional climate, mountainous flow-forming systems, and water quality in the densely populated agricultural zone of Central Asia (Zolotokrylin 2003, Kust 1999, Aizen et al. 2003).

In recent years, severe dust storms in Central and East Asia have intensified in frequency, duration, and area of occurrence (Sun et al. 2001). It is unclear, however, whether the increase is driven by land surface degradation, drought or by changes in atmospheric circulation or a combination of the above. Rapid desertification in this region is also a plausible factor. It will be critical to establish how the sources and transport routes of Asian dust are affected by climatic changes taking place in Northern Eurasia. In turn, the diverse impacts of dust on regional and global climate must be quantified to provide an improved understanding of the main mechanisms controlling climate change in the region.

Mineral particles exert more complex impacts on the environment and climate than those caused by sulfate and carbonaceous aerosols. Dust can cause either positive or negative radiative forcing at the top of the atmosphere, leading to a warming or a cooling of the climate system. The sign of the direct radiative forcing is determined by the optical properties of the dust as well as atmospheric conditions and surface reflectance. For instance, dust plumes over dark surfaces such as the ocean result in negative forcing (contributing to a cooling), while their radiative forcing is positive over bright surfaces such as bright deserts, snow and ice. The land use practices of converting the darker vegetation areas to brighter lands may also change the sign of direct radiative forcing of dust. In addition, the presence of dust strongly alters the surface radiation budget, affecting the surface temperature and water cycle among other important surface-air exchange processes. Overall, the radiative impact of dust is important relative to that of other types of aerosols, such as sulfates and carbonaceous particles, due to its widespread distribution and large optical depth.

Recently, considerable progress has been made in utilizing satellite observations to characterize dust transport on a global scale. As an example, Figure 3.3.3 shows the transport route of Asian dust in April of 2001 reconstructed from satellite data. Each year, large quantities of dust, originating in Asia, are carried out over the North Pacific to the west coast of the United States. Given that the dust plumes are readily observed by satellite sensors operating in the UV, visible and IR spectral regions, satellite imagery can be used to guide the development of the model of dust sources, transport and deposition.

Of special importance is deposition of atmospheric dust to the ocean that plays a key role in several major biogeochemical cycles (such as the C and S cycles). In the 1930s it has been suggested that deposited dust affect the phytoplankton growth in the so-called high nutrient, low chlorophyll (HNLC) areas of the oceans, whose concentrations of dissolved iron, an essential micronutrient, are much lower than in other regions. By dissolving carbon in seawater and by fixing it as biomass or inorganic particulate matter, phytoplankton regulates carbon dioxide in the atmosphere and thus helps regulate global climate. With the ocean currently consuming 25-35% of the CO_2 emitted into the atmosphere, there clearly is a strong need to quantify the iron supply to the oceans associated with Asian dust transport.

Modeling studies suggested that the diverse effects of dust may trigger various feedbacks on the climate system. Several competitive feedbacks were proposed. For example, a reduction of the surface winds likely has a negative feedback, whereas a decrease in precipitation may lead to a positive feedback. It will be important to explore how climate change in Northern Eurasia might be affected by these and other aerosol feedbacks to better understand the overall impacts of tropospheric aerosols on the environment and climate.

In addition to tropospheric aerosols, Northern Eurasia is affected by a large-scale aerosol perturbation such as stratospheric aerosols from volcanic eruptions. Major volcanic eruptions increase the stratospheric aerosols mass loading by tenfold or more background levels, the three most recent events of this magnitude being the eruptions of Agung in 1963, El Chichon in 1982 and Pinatubo in 1991. An increase in the aerosol optical depth following a volcanic eruption recorded by ground-based monitoring stations in Russia is illustrated in Figure

3.6.21. It has been demonstrated that volcanic aerosols have important impacts on both solar and thermal radiation, affecting surface temperature and atmospheric circulation (Robock, 2002).

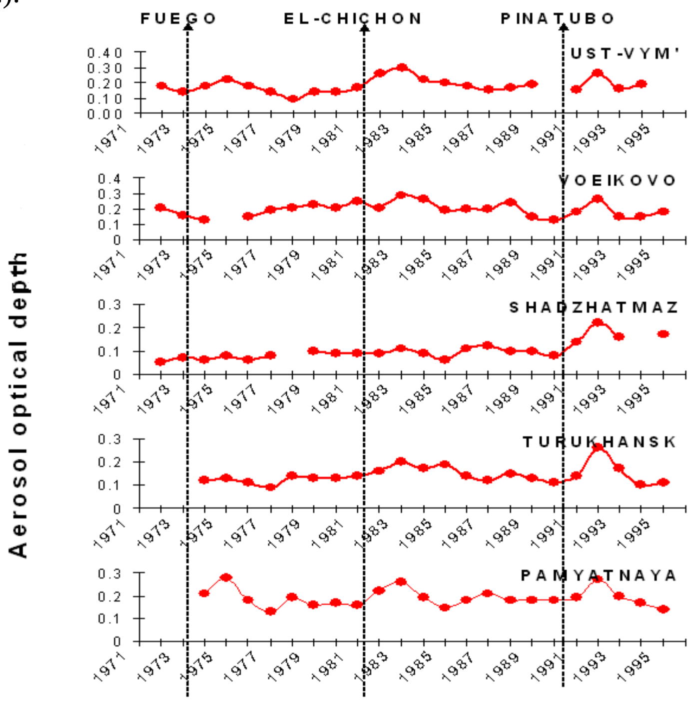


Figure 3.6.21. Long-term time series of the aerosol optical depth at the 500 nm wavelength observed at Russian mid-latitude monitoring stations (Rusina et al. 2001).

The above discussion demonstrates the importance and complexity of the effects caused by aerosols in Northern Eurasia. This complexity underlies several important research questions that need to be addressed to quantify the impacts of the specific aerosol types, as well as their net effect on the environment and climate:

- *How have the sources, distributions and properties of aerosols in Northern Eurasia changed in recent years, and to what extent are these changes attributable to natural variability and human causes?*
- *How will the future land-use and land cover changes, industry development and other human-induced changes affect emissions of different aerosol types in Northern Eurasia?*
- *What are the magnitude and spatial/temporal distribution of the radiative forcing caused by atmospheric aerosols over Northern Eurasia?*
- *To what extent do atmospheric aerosols affect the surface radiation balance in Northern Eurasia?*
- *What are the effects of changes of aerosol concentrations and properties on the formation of clouds, precipitation, and the overall hydrological cycle in Northern Eurasia?*
- *How do atmospheric aerosols affect the terrestrial and aquatic ecosystems in Northern Eurasia?*
- *How do atmospheric aerosols affect air quality and human health?*
- *What are the main feedback mechanisms among climate change, aerosol and air pollutions, and the environmental systems in Northern Eurasia?*

Climate change and population development in the 21st century are expected to cause increases in atmospheric aerosol concentrations. Greenhouse gases and atmospheric aerosols cause competing effects on climate and hydrological cycles. There is a clear need for improved knowledge of interactions of atmospheric aerosols with the climate system to increase confidence in the understanding of how and why climate and environmental systems have changed.

4. REMOTE SENSING

Chapter lead authors: S.A. Bartalev, V.G. Bondur, A.A. Gitelson, C. Justice, E.A. Loupian, D. Cline, V.I. Gorny, T.E. Khromova, P.W. Stackhouse, and S.V. Victorov

Contributing authors: J. Bates, P.Ya. Groisman, G. Henebry, C. Prigent, J. Roads, W. Rossow, A.J. Soya, W. Wagner

Introduction

Remote sensing has an important role in the NEESPI science program, providing up to date and historical, spatially explicit information to inventory and quantify changes in the land surface and in the coastal zone for use in process and modeling studies. Priority within the NEESPI remote sensing research community is to provide quality, validated data products to enable the science goals to be met. In addition, remote sensing will continue to play a role in monitoring the resources of the region. NEESPI science and observations will provide the opportunity for improved resource management and decision-making.

The following characteristics of the Northern Eurasia region place the research and development of satellite remote sensing capabilities among the key elements of the NEESPI Science Plan:

- Extensive and remote territories, large areas of land which are poorly inventoried and monitored
- Lack of uniform data sets across the region and restricted access to the existing more traditional data sets
- Rapid recent socio-economic change coupled with climate variability and change increases the variability of observed environmental conditions and natural hazards
- Science and resource management requirements for uniform and comprehensive data sets and integrated databases gives increasing emphasis on the generation of new data products

Satellite remote sensing provides a unique opportunity to obtain up-to-date information for global change science, natural resources management, and early warning for disaster management in the NEESPI region. Recent advances in satellite monitoring, provide a number of new data sets and tools for researchers and resource managers alike. Demonstrating current satellite monitoring capabilities and transitioning them from research to the operational domain within the region will be an important goal for NEESPI. A primary NEESPI program objective is to integrate satellite and in-situ observations and information technologies to obtain up-to-date information on the status and dynamics of the region and make it available to a wide range of public entities.

The functional structure of such an integrated observing system will consist of the following components:

- Satellite and in-situ data collection and management
- Geospatial data processing and analysis
- Spatial analysis and modeling (including GIS tools)
- Data distribution, user interfaces, and data archives

In addition to the provision and dissemination of satellite data from outside the region by satellite data providers, e.g., NASA, NOAA, ESA, and NASDA, the NEESPI satellite data collection module should help establish a network of satellite receiving stations, dedicated data processing and distribution centers within the region to provide customized products and near real-time data to meet regional needs (Loupian et al., 1999). Generation, processing and archiving of data will need to be undertaken in a distributed way, taking advantage of the expertise of various NEESPI participants within and outside the region. It will be important to maintain an open dialogue between data providers and data users, particularly from the modeling and monitoring communities, to ensure that priority data requirements are met. A culture of open data sharing will need to be fostered amongst the NEESPI scientists and an acceptable data policy established at the outset of the program.

The following satellite instruments will contribute to the NEESPI research and applications goals:

- Coarse to moderate spatial resolution data (8km-250m), e.g., NOAA-AVHRR, SPOT-Vegetation, Terra and Aqua MODIS, Envisat-MERIS, SeaWiFS. These data will provide daily observations and temporally composited products
- High spatial resolution data (c. 30m), e.g., SPOT, Landsat-ETM, ASTER, Meteor-3M, EO-1, and IRS high-resolution.
- Very high spatial resolution data (<1-4 m), e.g., IKONOS, Quick-Bird. These commercial products will be subject to copyright restrictions.
- Multi-view angle optical data, e.g., from Terra-MISR
- Moderate to high spatial resolution (500m-15m) Synthetic Aperture Radar data and products, e.g. Envisat-ASAR, ERS-1+2, JERS, Radarsat, SIR-C, SRTM
- Very coarse spatial resolution (25km) microwave radiometer data, e.g., Aqua-AMSR-E, DMSP-SSM/I, DMSP-SMMR
- Historical optical data, e.g. MSU-SK/RESURS-O1, KFA-1000, DISP-CORONA

In addition, opportunities will be sought for ad-hoc targeting of high-resolution observations from manned spacecrafts e.g. in framework of "Uragan" program on the board of International Space Station.

The following sections outline priorities for research and development of various aspects of remote sensing techniques, methods and applications in order to provide observations and products in response to the needs of the main scientific goals of the NEESPI. The sections are divided into remote sensing of terrestrial systems, remote sensing of coastal zones and inland waters, remote sensing of the cryosphere, remote sensing of energy and water balance.

4.1. Remote Sensing of Terrestrial Ecosystems

Section lead authors: **S. Bartalev, A. Gitelson, and C. Justice**

In general terms we can distinguish four focus areas when developing and applying remote sensing to northern Eurasian terrestrial ecosystems: land cover mapping and characterization; large-scale vegetation dynamic processes; biophysical properties of the vegetation; and forest and rangeland management.

4.1.1. Land cover mapping and characterization

Northern Eurasia includes a wide range of ecosystem types, e.g., tundra, forest, steppe, wetlands, and agricultural lands, and their status and dynamics play profoundly significant roles in environmental and economic processes. A number of existing terrestrial products derived from coarse to moderate resolution satellite data (8km – 250m) have been developed including the NOAA-AVHRR land cover (Loveland et al., 1999), MODIS land cover and percent tree cover (Friedl et al., 2002; DeFries et al., 2002) and the SPOT-Vegetation data GLC 2000 land cover map (Bartalev et al., 2003). These products provide a description of the current pattern of terrestrial ecosystems for Northern Eurasia. Future land cover mapping efforts will be focused on the production of regional higher spatial resolution land cover datasets from optical sensors, e.g., MODIS 500m and 250m, Landsat-TM/ETM+, SPOT-HRV (30m). The SIBERIA-I project has generated a Central Siberia Forest Cover Map using ERS and JERS-1 radar satellite data at a scale of 1:200 000 (Schmullius et al., 2001: Balzter et al., 2002). New MODIS products for detecting land cover change are also under development for this region (e.g., Zhang et al., 2003). However, for quantifying land cover change and, in particular, for measuring land use related change, high spatial resolution data is needed. Future land cover products for Northern Eurasia would benefit from the application of a common approach to classification system, e.g. the FAO Land Cover Classification System (Di Gregorio and Jansen, 2000).

Remote sensing of vegetation cover and structure provides information on lifeform/species composition, age/successional status, phenology, and characteristics of 3D structure of trees, such as cover/crown density and forest stand height. Such parameters are used in ecosystem and biogeochemical process models. Optical satellite sensors currently provide the primary source for these parameters. Development of improved moderate resolution vegetation cover products at the regional scale should continue to exploit multi-spectral and multi-temporal data to provide direct parameterization and classification of vegetation types. This characterization should take into account lifeform (e.g. trees, shrubs, grasses, mosses and lichens), leaf types (broadleaf and needleleaf) and phenological attributes (deciduous/evergreen, annual/biennial/perennial, moisture-limited/temperature-limited). The composition of vegetation types at the sub-pixel level can be characterized using advanced algorithms, based on spectral unmixing (Adams and Smith, 1986). Multi-angular satellite observation, for example from Terra-MISR, combined with BRDF models provides a unique opportunity to develop methods to characterize 3D structure of the forest cover (Widlowski et al., 2001; Pinty et al., 2002).

4.1.2. Large Scale Vegetation Dynamics

Vegetation is dynamic, experiencing changes in the phenological tempo, species composition, biophysical and structural characteristics that are driven by successional and anthropogenic processes as well as by variation in climatic regimes as a variety of time scales. The large-scale vegetation dynamics focus includes the study of rapid vegetation changes including extensive forest clearcutting, conversion of forest or grasslands to agriculture, land abandonment following institutional changes, or short term disturbances to vegetation condition from drought, flood, fire, or pests, as well as longer term interannual and decadal trends in vegetation cover, including forest and grassland degradation, desertification, and changes in phenology or biome distribution resulting from regional climate change.

Large forest clear-cuts, which is the main type of forest logging in Russia, can be identified using 250 m resolution satellite data from Terra-MODIS (Chan et al., 2002). Whereas more fine scale clearance and selective logging can be quantified by applying change detection methods to Landsat-TM imagery (Bartalev et al., 1997).

For the last few decades, time series of NDVI derived from NOAA AVHRR sensors have been widely used to investigate vegetation phenology in response to interannual climate variability (Justice et al., 1985; Myneni et al., 2001) and to the collapse of the Soviet Union (de Beurs and Henebry, 2004). For deciduous forest, time-series of NDVI reflects largely leaf-on and leaf-off phases and, to a lesser extent, leaf area index. Recently, some progress has been made in using the MODIS Enhanced Vegetation Index (Zhang et al., 2003) and LSWI (Boles et al., 2004; Xiao et al., 2002). Alternative vegetation indices provide an opportunity for improved characterization of the seasonal dynamics of vegetation phenology and structure, particularly in croplands and grasslands (e.g., Gitelson et al., 2003; Viña et al., 2004).

4.1.3. Vegetation biophysical characteristics

Research is being undertaken to provide satellite estimates of leaf area index (LAI), the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) and Net Primary Production (NPP) (e.g., Myneni et al., 2002). These products are important variables for biogeochemical cycle and energy flux modeling. The LAI and NPP products generated from MODIS are currently being validated using ground based measurements independent ground based measurements including data from flux towers (Cohen et al. 2003; Morisette et al. 2004). As these new products are being used in quantitative models, it is critical that their precision, accuracy, and uncertainty be determined for the NEESPI region. New indices from vegetation monitoring and new methods for satellite estimation of primary production are being adapted for assessing semi-arid land degradation (De Beurs and Henebry, 2004).

As the science community develops an improved understanding of land - atmosphere interactions, advances are being made in the area of weather and climate modeling and land data assimilation (Dickinson et al., 1998). Improving the mesoscale climate modeling for northern Eurasia will be important for science goals of NEESPI and which will have a number of practical applications as well, viz., in terms of the impact on vegetation distribution, disturbance regimes, and agricultural production. Monitoring and modeling of agricultural production is improving with the wider availability of computational resources and improved moderate resolution satellite monitoring. Satellite methods are also available for early warning of droughts and agricultural blights. These tools, although tested in various locations, have yet to be evaluated over large regions and transitioned to operational datastreams for use by agricultural agencies.

4.1.4. Forest and Rangeland Management

Forests, which cover a large part of the Northern Eurasian region, are under varying degrees of management. Up to date information on the state and extent of forest cover and improved forest inventories are necessary components for effective management (Isaev and Sukhikh, 1991). Satellite remote sensing has a role to play in keeping information on forest extent and change current.

Industrial pollution is having a serious impact on forest productivity in European parts of the region and the extent of these effects and effectiveness of legislation aimed at reducing this impact and various mitigation efforts will need to be monitored (Butusov et al., 1996). Illegal logging is purported to be extensive and is proving to be a large forest management problem. The location and extent of logging is poorly quantified but can be monitored by a combination of satellite and ground based monitoring (Breido and Sukhikh, 1995). Insect infestations are extensive, covering millions of hectares and requiring early warning, if they are to be managed effectively (Isaev et al. 1991). Eurasian forests provide a large carbon sink and an opportunity for carbon management and accounting (Isaev et al., 1995), though independent verification will be necessary for carbon accounting.

Monitoring of rangeland (steppes and semi-deserts) is essential part of NEESPI program. The importance of studying vegetation dynamics of rangeland has been recognized for decades. A key driver has been the interest in understanding the patterns of rangeland productivity and its relationships with global biogeochemical cycles of carbon and nitrogen (e.g. Cao and Woodward, 1998). The main challenges for remote sensing of regional rangelands are (1) characterization of vegetation dynamics in ecosystems with high spatio-temporal variation in aboveground biomass, and (2) estimation of range condition (available forage) by synoptic sensors at scales relevant to animal use. Development of techniques for accurate estimation of vegetation dynamics would be a focus of NEESPI program.

Moderate-resolution data from optical satellite sensors, such as NOAA-AVHRR (Grégoire and Pinnock, 2000) and Terra-MODIS (Justice et al., 2002), provide an opportunity to collect information about active vegetation fires on the global scale with daily time frequency. The possibility to map vegetation burned area at the global scale from the SPOT-VEGETATION satellite data has been recently demonstrated by GBA 2000 project (Grégoire et al., 2003). High spatial resolution imagery (20-30 m) can be effectively applied at local scale to estimate burn severity in forests, which is essential for assessment of carbon emissions caused by fires (Isaev et al., 2002). Emphasis is needed on the validation of these new data products (Justice et al., 2003). Wildfires and insect infestations are natural disturbances in the boreal forests that have important economic implications for forest management. Where fires intersect with human population, anthropogenic ignitions augment lightning ignitions requiring more active management of fires and fuels. New and improved methods for fire danger rating and early detection of fires have been developed by the science community and are being made available for the fire management community (Ahern et al. 2001: Korovin et al., 1998). Similarly, methods are being developed by the research community for automated mapping of burned area, providing annual measures of the area burned, allowing monitoring of trends in fire extent and providing an input to national annual emission inventories (e.g., Roy et al., 2002). Smoke from extensive fires cause regional air pollution and smoke palls are lofted and transported great distances from their source. Direct measurement of the energy released from fires is being explored in the NEESPI region using data from the BIRD and MODIS satellites (Wooster et al. 2003) The trace gas emissions from the extensive forest, peat and grassland fires in the region are poorly quantified for Eurasia, but initial estimates indicate that they are globally significant (Kasischke and Stocks, 2000). The impacts of projected climate change on fire regimes and future forest and fire management in the region have yet to be assessed, although regional climate modeling for the boreal regions of Canada would suggest increasing frequency of fire and an associated increase in emissions (Stocks et al., 1998). Potential linkages of disturbance regimes with climate modes (Wang and Schimel, 2003) need to be evaluated within Eurasia.

Improved climate modeling will enable study of the linkages between climate and human health. Satellite monitoring of land cover change and vegetation condition are being used to identify insect breeding sites and study disease vectors. A combination of ground sampling and remote sensing of water bodies could be used for early warning of the potential for diseases such as cholera. Climate and land cover predictions can be used to study the potential spread of diseases.

Integrated Terrestrial Observing System. While most current research projects use one particular sensor system for land cover and vegetation monitoring, it is recognized that a more integrated approach is needed. To meet the NEESPI science objectives, a multi-sensor approach based on the best combination of available satellite data will be pursued. The move towards integrated observing systems is being promoted by the international community (Justice et al., 2003). To ensure continuous vegetation change detection using coarse and moderate spatial resolution satellite data, new approaches to the analysis of image time series will be investigated to provide a common methodological framework to detect a wide range of change types, including rapid changes in the vegetation, and trends in the status of vegetation. These new methods for deriving quantitative information regarding the vegetation changes have to be investigated and developed. In particular the following approaches may be considered:

i. Multi-resolution validation of measurements derived from the sequentially sampled satellite data along with coarser to finer spatial resolution imagery (e.g., ranging from <4m to 1000m);
ii. Model-based approach (spectral mixing, BRDF and light-canopy interaction models) to estimate structural changes in the vegetation cover based on measured changes in spatio-spectral heterogeneity;

In addition to multi-source data fusion, world space agencies are currently exploring sensor web technology using high frequency satellite observations to direct sampling with higher spatial resolution systems.

4.2. Remote Sensing of Coastal Zone and Inland Water Bodies

Section lead authors: S. Victorov and A. Gitelson

Remote sensing in this area include the study of estuarine and coastal phytoplankton and dissolved organic matter for atmospheric carbon dioxide estimation; water quality, geomorphology and sedimentology, and coast evolution among others. To address these areas of study, comprehensive data on water quality are required. *In situ* measurements of water constituents provide accurate information for a point in time and space, but these measurements are difficult, expensive, and often inaccurate for understanding either the spatial or temporal patterns of optically active constituents needed for accurate assessment of their distributions (e.g. Curran and Novo, 1988). Assessment of the magnitude of these problems and the formulation of effective monitoring strategies require more reliable data, an improved understanding of the spatial and temporal patterns involved, and faster retrieval of information. Remote sensing techniques provide spatial and temporal data on water parameters, thus making it possible to monitor the landscape effectively and efficiently by identifying and quantifying distributions of optically active constituents such as phytoplankton, dissolved organic matter and suspended matter (e.g., Cracknell, 1999). New satellites and sensors (SeaWiFS, MODIS, MERIS, HYPERION) provide the improved spectral and spatial resolution needed to monitor coastal and inland water quality parameters from space platforms. However, there may be, in many cases, a requirement of the use of airborne or even hand held sensors to thematic calibration of algorithms.

There has been considerable success in optical remote sensing of chlorophyll concentrations (Chl) in ocean waters where the variation of optical properties is dominated by phytoplankton and associated material, and some consensus is emerging with regard to appropriate algorithms (http://seawifs.gsfc.nasa.gov/SEAWIFS.html). In contrast, Chl retrieval in turbid productive waters is still a matter of intense research activity and few convincing examples are available of satellite-derived Chl concentrations for such waters. However, the demand for detailed monitoring of Chl in such waters is very high because of the importance of estuarine and coastal phytoplankton in the balance of atmospheric carbon dioxide (Frankignoulle et al., 1998) and hence, possible climate change. It is also important due to the need to manage inland and coastal eutrophication.

Constituent concentrations in turbid productive waters are independent, thus, the blue-green two-band ratio algorithm (Gordon and Morel, 1983) used for ocean waters is not appropriate and alternative approaches must be sought. The data of the Coastal Zone Colour Scanner (CZCS), operated from 1978 to 1986, and the Sea-viewing Wide Field of View Sensor (SeaWiFS), which was launched in 1997 and is still operational, should be analysed to retrieve Chl and CDOM. CZCS did not have the ability to separate CDOM from phytoplankton. New algorithms are able to distinguish between these constituents (Carder et al., 1999) and have to be tested.

In the case of Northern Asian lakes, in reservoirs and rivers in the 400-500 nm spectral range, the absorption by tripton (particulate matter after removal of phytoplankton pigments) is generally greater than phytoplankton absorption. Considering that the satellite-based sensor sees only the effect of the total absorption coefficient (particulate plus dissolved matter plus pure water), it is clearly important to at least be able to distinguish phytoplankton related features in the total particulate absorption spectrum. A number of analytical algorithms have been developed for case 2 waters (e.g., Doerffer and Fischer, 1994; Vasilkov, 1997) that should be tested using satellite data.

For assessment of Chl*a* concentration, a specific Chl spectral feature (peak near 700 nm) has been used (e.g., Gitelson 1992; Gons, 1999; Dall'Olmo et al., 2003). There are numerous successful examples of chlorophyll retrieval using these algorithms in productive turbid water using hand held and aircraft sensors. Now, when MERIS data (channels around 670 and 6700 nm - http://wdc.dlr.de/sensors/meris/main.html), are available, these algorithms will play a significant role in estimation of Chl distributions. However, accuracy and robustness of chlorophyll retrieval, as well as a range of conditions in which concentration retrievals are reliable, have to be the main focus of NEESPI research.

One of the most exciting advances in recent remote sensing is estimation of chlorophyll *a* fluorescence from space using MODIS and MERIS systems (http://picasso.oce.orst.edu/ and http://wdc.dlr.de/sensors/meris/main.html). This is the first time scientists have been able to measure physiological changes in phytoplankton communities rather than just population increases. It can help to accurately estimate the primary productivity (the amount of organic carbon phytoplankton produces). However, only the first steps have been done in MODIS and MERIS data interpretation. Future research of the effect of constituents other than chlorophyll fluorescence on reflectance around 685 nm is required. It is especially important in turbid productive waters where scattering by suspended material, as well as absorption by chlorophyll, can greatly affect the reflectance signal in this spectral range.

4.3. Remote Sensing of the Cryosphere

Section lead authors: T. Khromova T. and D. Cline

Remote sensing provides the spatial and temporal observing capabilities needed to investigate and understand cryospheric processes over Northern Eurasia.

4.3.1. Remote Sensing of Glaciers

NEESPI glacier investigations will include studies of glacier/ice cap mass change, 2D and 3D glacier geometry, glacier velocity fields, monitoring of transient snow lines, radio-echo sounding studies, deep ice-core drilling, ground truth observations, and special studies in poorly known regions. Remote sensing will play an important role in these studies. Remote sensing technologies such as GPS, geodetic airborne or satellite laser altimetry/LIDAR, high-resolution imagery, and InSAR are revolutionizing the observation of glacier mass balance. Geodetic and photogrammetric measurements are also being improved. The current and emerging methods will facilitate repeated observations of glacier volume changes over larger spatial scales and for longer observational periods while index-stake measurements will provide high temporal resolution and allow calibration of remotely sensed data. New technologies are also enabling the production of digital-based inventories over large glacierized areas. In NEESPI, these global and continental level inventories will further benefit from continuing acquisition of Landsat ETM+ and ASTER data, ASTER stereo capabilities, and data products from missions such as ICESat and data products from CryoSat. The use of a combination or of separate spectral bands of ASTER images allows for investigation of accumulation and ablation areas of the glaciers, which have different reflective characteristics. For open ice surfaces, the range 0.78-0.86 μm works more effectively, and for debris surfaces, the range 0.52-0.60 μm is more informative. The geometrical resolution of space images determines opportunities for the studying of morphology elements of a surface and glacier boundaries extraction. These opportunities also depend on the glacier size and morphological type of glacier. Radar images, despite a number of obvious advantages, are less effective for studying montane glaciation because of topography, which produces significant noise. The high-resolution optical remote sensing data from a number of space platforms can be used for assessment of modern Northern Eurasia glaciation. The following data can be used for studying individual glaciers: the PAN and LISS-3 (the I R S- 1C, the I R S - 1D), the ASTER (Terra), ETM + (Landsat7), and the MSU-A (Meteor - 3M). For retrospective analysis, it is necessary to use comparisons of the resolution of historical images: KFS-1000 (Resource - F1), MK-4 (Resource - F2), TK-350 (Comet). For study proxies and mechanisms of catastrophic glacier processes (such as Karmadon Ice-rock avalanche) images of more detail resolution provided by IKONOS (0.61

m) are required. Additionally, the RADARSAT images can be used for studying physical characteristics of glaciers.

4.3.2. Remote Sensing of Snow

DEM of the region can be used to define the altitude of glacier boundaries, which are important characteristics for glacio-hydrological calculations. For example, the position of a glacier's equilibrium line is a very informative index which could then be approximately recalculated in the solid and total precipitation (Krenke, 1982). This method is used in the World Atlas of Snow and Ice Resources (1997) created in Russia that is now available in digital form (Kotlyakov and Khromova 2002). The use of satellite images in the visual band for snow, firn, and superimposed ice lines on the glaciers at the end of ablation season together with air temperature data of the same year summer would permit evaluation of precipitation of the given year or even organization of the alpine zone precipitation monitoring.

Remote sensing will be essential for investigation of the hydrological properties of snow within the NEESPI study area because traditional in situ data collection in this region is both sparse and non-uniform, depends heavily on human observers, and data verification is almost impossible. Snow remote sensing efforts will focus on developing, validating, and refining empirical and theoretical algorithms for snow cover properties (extent, water equivalent, wet/dry state) in varying climatic regions and landscapes using passive and active microwave data. Optical (visible and near-infrared) remote sensing data will also be used, but their use is constrained by cloud cover and darkness, which is common in the study area during winter. Data from passive microwave sensors (including SSM/I and AMSR-E) allow daily coverage through thick clouds and during darkness (Armstrong et al., 1997; Krenke et al., 1997). Automated algorithms permit objective observations that are important for the development of modeling and data assimilation capabilities. The spatial resolution of these data varies from 12.5 - 25 km for SSM/I and MTVZA-OK to 5 km for AMSR-E. Of particular importance would be regular remotely sensed observation of snow water equivalent (SWE). The product of snow depth (or snow cover height) and snow density, SWE is fundamentally important to the terrestrial hydrology and ecosystem dynamics of the region. Passive microwave radiometry (e.g. SSM/I and AMSR) is the only remote sensing method available today for retrieving estimates of SWE, but with mixed results. Further, studies are needed to address well-known limitations of this approach to improve the estimation of SWE for NEESPI (Armstrong and Brodzik, 2001). All SSM/I algorithms tend to underestimate SWE and snow extent, especially during early winter and in forested areas. SWE cannot be determined when the snow pack is wet, although the presence of wet snow can be detected.

Remote sensing science goals for NEESPI include development and validation of new regional SWE algorithms for passive microwave data in the NEESPI study area and the development of multi-sensor (e.g. combined with optical and in situ data) and modelling approaches to overcome problems in shallow-snow and forested areas. The relatively low resolution of passive microwave sensors is inadequate for many regional hydrological studies. The use of active microwave sensors (radars) is emerging as the cutting edge of snow remote sensing. Radars have strong capabilities to measure snow properties, including wet-snow (complimenting passive radiometry, which typically only measures dry snow), and provide excellent resolution for hydrological studies. The major limitation to progress in this area has been the radar frequencies available on past and current satellites – primarily L- and C-band. Higher frequencies (e.g. Ku-band) are needed to measure SWE using polarimetric methods. There has been recent progress in using L-band interferometry to determine SWE. Development of improved radar remote sensing techniques for snow properties will be an important task for NEESPI. Studies using ground-based and airborne instruments under different conditions in NEESPI will be essential for advancing snow remote sensing capabilities. Finally, there are modeling approaches that combine land cover and meteorological data, digital cartographic information, and remote sensing data both in optical and microwave bands with regional algorithms for snow characteristics retrieval and techniques for joint processing of various space- and time-distributed data.

4.3.3. Remote Sensing of Frozen Ground and Permafrost

NEESPI cryosphere remote sensing efforts will include development of methods for mapping seasonally and perennially frozen ground and associated features, thereby facilitating the assessment of its changes. Supporting ground truth data collection programs need to be established at a number of locations. The programs will provide baseline data for developing satellite-based mapping methods and for validating and improving spatially distributed heat transfer models that are needed to investigate the effect of changes in air temperature and surface conditions on the active layer and permafrost. Multidimensional SAR configurations (i.e. multi-frequency, -temporal, -polarization, -incidence angle) also need to be investigated to improve the present approaches so that permafrost maps can be produced in the discontinuous and continuous permafrost zones. The multi-temporal SAR data (ERS-1/2 and RADARSAT) for monitoring the seasonal freeze/thaw cycle of sub arctic tundra and forest are available. For mapping the surface heat balance in permafrost terrain, NOAA AVHRR data can be used. Many important landscape features in permafrost regions are small in scale, but provide important indication of changes occurring to the permafrost in the region, e.g. pingos and ice-wedge polygons. Very-high-resolution IKONOS and high-resolution Landsat satellite data will be used to map and analyze these changes in selected parts of the NEESPI study area. Ground-based remote sensing methods, including ground-penetrating radars, will also be used to help evaluate permafrost conditions within the study area (e.g., Liu, 2000; Yakurov and Yakurov, 2003).

Remote sensing will be used to map the seasonal and interannual variations of seasonally frozen soils. Recent progress in using passive microwave data together with a simple numerical heat transfer model to distinguish near-surface soil freeze/thaw status over snow-free land (Zhang and Armstrong, 2001) allow a preliminary determination of frozen ground extent and variability within the NEESPI study area. Further development of this capability will be one of the foci of the NEESPI remote sensing development.

4.4. Remote Sensing of Surface Energy and Water Balance Components

Section lead authors: P. Stackhouse and V. Gorny

Contributing authors: J. Bates, P. Groisman, C. Prigent, J. Roads, and W. Rossow

Estimates of radiative, turbulent heat fluxes, precipitation, and soil moisture are required to describe the water and energy budgets over the NEESPI region. Satellite remote sensing provides the only way to observe some of these variables and operational weather forecast models, as well as climatic and ecological models, are dependent on the large-scale satellite-based datasets that are currently available. These data sets provide cloud forcing, longwave radiation, short-wave radiation, radiative flux, solar irradiance, solar radiation, photosynthetically active radiation, direct and diffuse solar radiation, albedo, ice, ozone, precipitable water, pressure, reflectance, snow, and temperature.

4.4.1. Radiative components of the surface energy balance

The radiative components most important for climate and climate processes involve the fluxes of radiative energy exchange between space, the atmosphere, and the surface in the short-wave (SW) (direct and diffuse) and long-wave (LW) (emitted and reflected) wavelengths. The exchange of this radiative energy at the surface constitutes a significant portion of the surface energy balance. The WCRP GEWEX Surface Radiation Budget (SRB) project has produced a long-term surface radiative energy dataset containing SW and LW fluxes (Stackhouse et al. 2000; 2002; 2004). The dataset uses the GEWEX International Satellite Cloud Climatology Project (ISCCP) (Rossow and Schiffer, 1999) as input to produce a 3-hourly, ~100-km resolution time series of radiative fluxes. Other data sets covering Northern Eurasia over parts of the last 20 years include the SW and LW ISCCP Flux Data (Zhang et al., 2004) and The University of Maryland SW only (Laszlo and Pinker, 2001) datasets. These data sets have a nominal 280-km resolution. Other radiative flux data sets exist at higher resolution but for shorted time periods, including the SW and LW fluxes from the European ERS satellite (ATSR data are used), retrieving with the resolution of ~ 1km (Xue et al., 1998, Xue et al., 2000a). Despite the successes of these projects, large uncertainties in the derivation of the surface radiative fluxes remain due to complexities of the Northern Eurasia region. These include uncertainties due to (a) nonuniform temporal sampling of the entire region by polar orbiting and geosynchronous satellites, (b) the retrieval of solar fluxes at very low sun angles and high viewing angles, (c) difficulties in distinguishing cloud over snow and ice surfaces, (d) the retrieval of the spectra surface albedo due to terrain complexity, varying snow cover, and atmospheric constituents such as aerosols, (e) the retrieval LW fluxes during times of a cold inversion over ice surfaces, and (f) the determination of surface emissivity in time. These and other uncertainties remain an impetus for study of radiation balance with the NEESPI region.

4.4.2. Turbulent heat fluxes and water balance components

There are no reliable methods for the direct remote measurements of these heat and mass fluxes over the land areas, but there are numerous efforts to address the problem. The most promising are those that use information on the rate of changes in brightness temperatures within the diurnal cycle to infer the thermal inertia of the surface that can be linked to the fraction of the available surface radiation budget released in the form of the latent heat flux (Watson et al., 1971; Watson, 1974; Miller and Watson, 1977; Ho, 1986; Moran et al., 1989; Vidal and Perrier, 1989; Thunnissen and Nieuwenhuis, 1990; Caselles et al., 1992; Cracknell and Xue, 1996a.,b; Xue et al, 2000b; Diak et al., 2004).

Some of the surface water balance components could be determined remotely with the different confidence level. These include evapotranspiration (latent heat flux), precipitation, and soil moisture. Several techniques are used to determine precipitation rates over land from space. They are based on passive microwave, active microwave (precipitation radar), infrared, outgoing longwave radiation (OLR) measurements, and TIROS Operational Vertical Sounder (TOVS) data. In practice, the measurements from different platforms are combined, used jointly, and frequently calibrated and re-adjusted with the help of in-situ gauge measurements (Kummerow et al., 1998, 2000, 2001; Ferraro et al., 1996; Ferraro, 1997; Hou et al., 2001; Adler et al., 2001, 2003; Huffman et al., 1997, 2001; Joyce et al., 2003; Hsu et al., 2003). The retrieving algorithms have two different objectives. The first objective is to have the most reliable near – real time product linked to an operational weather forecast scheme (Hou et al., 2001; Janowiak et al., 2000). The second objective is a construction of long-term homogeneous, "combined" time series with near-global coverage for global climate change studies (e.g., Global Precipitation Climatology Project, GPCP[57], Adler et al.

[57] The GPCP dataset contains the monthly precipitation data since 1979 at the 2.5° x 2.5° grid cell resolution with a global coverage. For Northern Eurasia, the "blended remote" GPCP product heavily relies on the monthly rain gauge data that have a preference versus the remote sensing information. Generally, in the GPCP product over land, the scaled-down pattern derived from the remote sensing data, is used to fill in gaps in the

2003). The quality of all satellite retrievals is better when they are a part of the data assimilation scheme in a regional atmospheric model with sophisticated land surface block (Susskind et al., 1997; Kummerow et al., 1998; Hou et al., 2001; Mitchell et al., 2000; 2003). That is why this approach may be recommended for the NEESPI project. Because of a long period of snow cover in the NEESPI region, the radar method of snow equivalent determination in the boreal forest using active and passive microwave methods (Goita et al., 2003) seems to potentially be quite operationally accurate.

The use of microwave sensors (both passive and active techniques) for soil moisture retrieval have been investigated since the 1970s (Ulaby et al., 1982; 1986) and now practical methods for mapping soil moisture from local to global scales are emerging. The first global, multi-year (1992-2000) has been derived from ERS scatterometer data (C-band, 50 km spatial resolution) and is available from http://www.ipf.tuwien.ac.at/radar/ers-home.htm (Wagner et al., 1999; Scipal et al., 2002). Global passive microwave data in C-band (AMSR-E) is currently available and L-band (SMOS) will become available in the near future (Jackson et al., 2002; Kerr et al., 2004). For local scale mapping, Synthetic Aperture Radar (SAR) data, as well as passive microwave multichannel survey, are used with increasing success (Jackson et al., 2002; Wickel et al., 2001). All of these microwave techniques have been best tested for agricultural and grassland regions of temperate, tropical, and arid zones. Very little work in the area has yet been carried out over cold regions (e.g. French et al., 1995; Kasischke et al. 1995), which constitute the major part of the NEESPI area of interest. A much better understanding of the impact of wetlands, peat, humus, freeze-thaw, active layer depth, and shallow surface water on passive and active microwave data needs to be obtained before reliable soil moisture data can be obtained over boreal forest and tundra regions.

Accuracy of the retrieval of characteristics is the main problem of the remote sensing observations of the surface energy and water cycles. Comparisons to surface radiative measurements available from in the Northern Eurasia region give seasonally averaged mean bias that varies from 0.2 to 4.4 W m^{-2} and route mean square difference that varies from 8.2 to 17.7 W m^{-2} for the LW and SW fluxes respectively. Accuracy of the turbulent heat flux estimates is comparable with the natural variability, i.e., it is unacceptably high. The relative errors (or biases) for *strictly satellite* precipitation products in the tropics are on the order of 30% in terms of the annual mean (Kummerow et al. 2000). The estimates of relative random errors of similar products should be expected to be higher in the regions with predominantly light precipitation, i.e., in Northern Eurasia. These problems could be addressed by (a) using an additional number of observations, i.e., new satellite launches; (b) more thorough validation routines with the help of the in situ observations inside each ecosystem; and (c) combination of different remote sensing methodologies even with the help of in situ observations.

4.4.3. New satellite systems.

The Clouds and Earth's Radiant Energy System (CERES) instrument on board several Earth Observing System (EOS) satellites from NASA's Earth Science Enterprise (ESE) program provides a direct measurement of TOA broadband reflectance and convolves this measurement with higher resolution retrievals of atmospheric, cloud, and aerosol properties from the MODIS instrument to estimate radiative fluxes. The Surface and Atmospheric Radiation Budget (SARB) component of CERES computes the surface and atmospheric fluxes by iterating retrieved atmospheric properties with the measured TOA fluxes. Surface and atmospheric fluxes are available at the footprint level with a nominal resolution of 20 km. Time and space averaged data products are being produced with ~100-km resolution. Two

gauge data. Re-adjustment to the monthly rain gauge totals is also used in several other retrieval algorithms (e.g., Xie et al. 2003).

CERES instruments were launched aboard the EOS Terra satellite in December 1999 and on the EOS Aqua spacecraft in 2002. SARB data after July 2002 will include fluxes from both Aqua and Terra polar orbiters to improve sampling. Equatorward of 60°N, CERES SARB also uses geosynchronous data for time interpolation, improving the time and space averages of fluxes at these latitudes. Other proposed satellite systems that will effect the retrieval and inference of surface radiative fluxes by improving the retrieval of cloud and atmospheric properties. The Clouds-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) and the CloudSat missions will provide cloud and aerosol information from active lidar and cloud radar systems. These and other measurements from both microwave, visible, and infrared remote sensing platforms will provide new opportunities to improve the understanding of temperature, water vapor, clouds, aerosol, and surface properties of the Northern Eurasia region.

5. MODELING

Lead Authors: V.M. Kattsov, I.I. Mokhov, R.A. Pielke, Sr., S.V. Venevsky

Contributors: O.A. Anisimov, E.L. Genikhovich, A.G. Georgiadi, P.Ya. Groisman, A.S. Komarov, V.V. Kozoderov, D.O. Logofet, V.M. Lykosov, Yu.G. Motovilov, A.V. Oltchev, V.E. Romanovsky, M.E. Schlesinger, A.I. Shiklomanov, N.I. Shiklomanov, A.B. Shmakin, N.N. Vygodskaya

5.1. Introduction

The triad of major aspects of modeling as such (studying processes, filling gaps in observations, and projecting the future) will be represented in full measure in NEESPI. The overarching, complementary scientific questions for the NEESPI modeling component are:

- What processes control energy, water, and carbon fluxes over Northern Eurasia (NEA) and how do the fluxes vary in space and time?
- What are the direct and feedback effects of environmental changes in NEA on the global Earth System (in particular, how do global climate changes impact NEA ecosystems and society)?
- How have these feedbacks evolved during the instrumentally recorded period and in the geological past?
- Are our models capable of simulating observed environmental changes?
- Can we correlate data obtained from different fields (e.g., parameters of biological turnover of carbon between forest and soil and their dependencies on climate changes) for initialization of model runs?
- Can our models provide an operational interface between on-ground and remote sensing data for data assimilation?

If the answers to the above questions are uncertain, then how our models must be improved to address them? And especially, how do we enhance the capability of our models to simulate the past and to estimate the spectrum of possible future environmental (and societal) changes both in NEA and globally? And, finally, can we assess the vulnerability of NEA to future environmental conditions, even if skilful projections are not possible? These questions are of vital importance to assist policymakers to formulate robust decisions about future human perturbations to the regional and global environment, including atmospheric composition changes (emissions of greenhouse gases (GHG) and aerosols) and land-use changes.

5.2. Background

A key feature of NEA climate projected for the 21st century by state-of-the-art global coupled Atmosphere-Ocean General Circulation Models (AOGCM) is a strong surface air temperature increase (compared to most of the Earth), especially in the second half of the century (e.g. Meleshko et al., 2004). Most of the AOGCMs also project an overall precipitation increase in the north and northeast, but a decrease of soil water content in the interior regions of NEA (already arid) during the summer. The high-latitude (including northern NEA) amplification of global warming due to atmospheric GHG increase is a well-known feature of AOGCM projections (IPCC, 2001). The amplification is attributed to positive feedbacks in the climate system. An important feature of those simulations is a large across-model scatter.

To what extent the projected changes are a result of real processes and feedbacks, rather than to model imperfections? Some presumably crucial processes (e.g. possible changes in vegetation, soil, and permafrost and the effects that these changes will have on future climate) are not adequately taken into account in the state-of-the-art climate change projections. The role of the biosphere, specifically the role of the terrestrial ecosystems dynamics, in the contemporary and projected climatic changes is not yet well understood (3.1, 3.2, 3.5) and was not accounted for on a full extent during the past cycle of the IPCC Assessments (IPCC, 2001). There are indications, including the palaeo-evidence, that, over NEA, this role has been (and very likely will be) especially pronounced (3.5). Clearly, all important processes operating in the NEA environmental systems must be properly represented and successfully simulated by AOGCMs as a necessary condition to provide credible projections of future changes. Our insufficient understanding of the processes and associated feedbacks seriously hampers model skill. The inherent nonlinearity of the climate system also limits the projection skill of the models (Rial et al., 2004).

5.3. Research approach

The NEESPI modeling component will consist of developing and validating models of different systems and scales, scaling model descriptions of different processes, reproducing NEA natural system states and evolution observed in past and present, and, finally, assessing the predictability and projecting future changes. The main foci are processes and feedbacks within the NEA socio-environmental system, and between the NEA system and the global Earth system.

The proposed modeling efforts are to be organized on three scales: local, regional, and global. Such structuring in particular determines clear links between observational and modeling components of NEESPI. Local studies will be mostly process-oriented and connected with *in situ* observational data sets and the most advanced fine-resolution remote sensing information. Regional studies (most naturally – river-basins, administrative regions, major forest tracts, etc.) heavily depend on fine- and moderate-resolution remote sensing information. The global scale studies presume employment of existing global reanalyses and objective analyses of observational data.

The approach implies using (developing) a wide range of models, including atmospheric boundary layer models, soil-vegetation-atmosphere transfer (SVAT) models of different levels of complexity, permafrost models, air pollution models, models of coastal zone evolution, data assimilation schemes, regional 3D atmospheric models coupled to comprehensive land surface components, regional high-resolution hydrologic models (including river routing), dynamic general vegetation models (DGVM), global models, particularly, GCMs, comprehensive Global Earth system Models (GEM, based on AOGCMs with advanced biospheric components), Earth system Models of Intermediate Complexity (EMIC), and Integrated Assessment Models (IAM).

The modeling activity will be supplemented with developing model diagnosis and intercomparison tools, data assimilation, as well as down- and up-scaling techniques.

5.3.1 Local scale modeling

A local scale signifies a scale finer than 10 km^2. It is the scale of single experimental point sites at which individual fluxes or cycle components can be measured directly and individual processes can be modeled explicitly. In forested areas it corresponds to elementary inventory unit (stand). Such studies are crucial before integrating the processes at regional or global scales.

5.3.1.1 Energy and water cycles

For parameterization of the vertical energy/water fluxes at the land surface, so-called SVAT (Soil-Vegetation-Atmosphere Transfer) models of different levels of complexity (single-layer and vertically/spatially structured models) have been developed (reviewed by e.g. Sellers et al., 1997). SVATs reproduce the entire cycles of energy and water transformations at the land surface and within the soil, snow, and vegetation cover. The processes are regulated by both physical and biological mechanisms and their interaction, so the models have to parameterize all of them. To do this, SVATs evaluate the state variables such as temperature and water content of the soil/snow/vegetation. Also, some additional fluxes/parameters (runoff, melting/thawing intensity, etc.) are calculated. Some current SVATs include not only energy/water exchange, but also carbon budget in vegetation and soil and transfer of different atmospheric pollutants (gases, aerosols) between land surface and the atmosphere (including the methane cycle in soil). It should be noted, however, that SVATs only represent biophysical effects such as transpiration as related to carbon assimilation, but not plant growth. There is work to blend SVATs into dynamic vegetation models, but almost all SVATs are still limited to the time scales that they are appropriate.

Accuracy of flux estimates with SVATs depends on (1) model complexity and assumptions used, and (2) precision in estimations of both landscape (biological, hydrophysical, etc.) and atmospheric (downward radiation, precipitation, etc.) parameters.

In most of the available 1D SVATs, horizontal homogeneity of the vegetation canopy is assumed. Internal variability of biophysical properties of vegetation and morphological properties of soils in such models are usually not directly considered. This assumption can be successfully applied to a mono-specific uniform forest plantation. However, accuracy of flux estimates with such models, e.g., for mixed uneven-aged forest stands can be significantly decreased through a variation of biological, morphological and optical properties of individual tree species (Oltchev et al. 2002; Avissar et al. 2004). Such forms of heterogeneity can be accounted by simulation models (Chertov et al., 1999).

Certain difficulties are associated with modeling water fluxes in cold regions and alpine watersheds. The control of extreme seasonal runoff by snowmelt and ice-break-up, large-scale redistribution of snow and the effects of seasonally and perennially frozen soils, water retention by the snow pack, freeze/refreeze of the melt water, glacier runoff, and ice melt under glacial moraines are the processes that need to be better studied (Bowling et al., 2000; Aizen et al., 2000; Rawlins et al., 2003). In recent PILPS (Project for Intercomparison of Land Surface Parameterization Schemes; Henderson-Sellers et al., 1995) and SnowMIP (Snow Model Intercomparison Project; Etchevers et al., 2003) experiments, special attention was paid to modeling cold season processes, and SVATs were tested against observations at NEA sites: boreal forest and grassland (Slater et al., 2001; Luo et al., 2003); boreal forest, swamps, and mountain tundra (Bowling et al., 2003; Nijssen et al., 2003); and permafrost (Gusev and Nasonova, 2004; Machul'skaya and Lykosov, 2002; Shmakin, 1999, 2003).

Shallow lakes (and wetlands) significantly affect the structure of the atmospheric surface layer and, therefore, the surface fluxes of heat, water vapor, and momentum (e.g., Vidale et al., 1997). Furthermore, wetlands are a significant source of methane for the atmosphere (3.1, 3.2). Their role in land-atmosphere interactions and gas exchange is still poorly understood. In most numerical models for environmental applications, most notably numerical weather prediction and climate models, the effects of lakes and wetlands are either entirely ignored or is parameterized very crudely. The problem calls for further investigation, in particular, due to the envisaged increase in horizontal resolution of future numerical modelling systems.

5.3.1.2. Vegetation.

Among approaches which try to model realistic mechanisms of vegetation dynamics, the most popular are perhaps the so-called 'gap'-models formalizing the major mechanism of forest dynamics, namely, formation and subsequent overgrowing of a gap in the closed forest canopy (see reviews in Shugart, 1992 and Shugart et al., 1992). During the past decade gap modeling developed from individual tree-based models to space/height-distributed ones (Smith et al., 1995; Lischke et al., 1999). Long-term dynamics, such as the vegetation succession, depend strongly on whether seeds of successive species are available at the current stage of succession (Lischke et al., 2003). Gap simulation models of forest stand dynamics with fine resolution (typically a patch of 100 m^2) can be applied at local scales. The minimum unit of vegetation can vary from different plant species (e.g. Gignoux et al., 1998) to biomes (Haxeltine and Prentice, 1996). Vegetation objects can have explicit locations or can be placed implicitly in a grid cell with the uncertainty determined by the size of the cell.

There is an understanding that creation of “hybrid” forest ecosystem models with a simultaneous simulation of tree growth, stand development, understorey and ground vegetation, and soil dynamics is a necessary approach to unite description of elements' biological turnover in the forest-soil system and biodiversity dynamics (e.g. Chertov et al., 1999). These models allow for the transition from “turbid layer” models of vegetation to individual-based models linking population and balance approaches (Komarov et al., 2003). Such an approach enables description of heterogeneity of vegetation and soils and joins models of weather and water regime with models of ecosystem dynamics.

The concept of primary succession may be taken as a theoretical basis for calibration of the simulation models for prediction of main tendencies of forest-soil dynamics. This approach allows for the accounting of prehistory and the position of forest site in relation to the climax state. Forest site classification is very useful for distinguishing limits of changing variables, and Monte Carlo procedure allows for diminishing uncertainties in initial data.
Simulation models must account for different climate change scenarios, different levels of nitrogen deposition, changes in water regimes and consequences of different silvicultural operations (cuttings, plantings, etc.), as well as natural and human induced forest fires of different types, which are very important driving processes in vegetation and soil dynamics in NEA. Simulation models, being basic at the local scale, can help in evaluating parameters of the models at the regional and global scales.

5.3.1.3 Permafrost

Despite rapid growth in the permafrost observation network in NEA (e.g., Global Terrestrial Network-Permafrost, GTN-P, and Circumpolar Active Layer Monitoring, CALM, programs, see Section 3.6.1), geocryology remains a data-limited science. This necessitates development of methods for processing and interpreting data obtained from different sources over a range of geographical scales and combining them with mathematical modeling to make the best use of limited empirical information. The important application of numerical simulations is temporal reanalysis of usually short and sporadic observational records of permafrost parameters (e.g., permafrost temperature, thickness of the active layer) to evaluate long-term trends. At the local scale, permafrost models are also necessary to analyze physical processes responsible for spatial and temporal regularities in the permafrost conditions and their relationship to variables dominant over larger areas.

Modeling of permafrost is usually based on employing numerical multi-layer 1D models of ground heat transfer, accounting for phase transitions of moisture as well as snow and vegetation covers. A wide range of numerical simulators has been developed (Goodrich, 1978; Guymon et al., 1984; Romanovsky et al., 1997; Romanovsky and Osterkamp, 2000; Malevsky-Malevich et al., 2001; Machul'skaya and Lykosov, 2002; Ling and Zhang, 2003; Molkentin et al., 2003; Sergueev et al., 2003). Input parameters of the permafrost model include skin temperature at the upper boundary of snow or vegetation cover; the thickness of snow and vegetation covers, and physical properties of soils. At the lower boundary of the domain, the geothermal heat flux is prescribed.

At present, several well-developed 1D heat transfer numerical models are available. However, many permafrost-related processes are 2- or 3D in nature (complex geometry taliks formation, soil settlement upon thawing, thermokarst development, differential frost heave, etc). Therefore, even on the local scale, 2- and 3D permafrost models need to be developed to represent the crucial features of permafrost dynamics.

Pronounced variability of permafrost properties, even within relatively small areas, raises concerns about the ability of deterministic models, either 1D or 3D, to make accurate regional estimates of the volume of thawed soil, which are necessary to estimate trace-gas emissions in high-latitude regions. A more appropriate approach is to consider near-surface permafrost parameters as randomly, spatially distributed variables consisting of both deterministic and stochastic components and to use their probability distribution functions (PDFs) as the metric for evaluation (Anisimov et al., 2002). Within the framework of this method the divide between deterministic and stochastic components is flexible, and depends on the availability and resolution of data required to drive the models. As long as the high resolution data are available, deterministic models can be used to distinguish between permafrost sites with explicitly different soil, vegetation, and snow properties, while the "nested" stochastic models can provide insight into the sub-grid variability of the permafrost parameters. Such an approach based on combination of deterministic and stochastic modeling is yet to be developed.

5.3.1.4 Biogeochemistry (carbon fluxes)

A high resolution soil-vegetation model should provide respiration, net primary productivity, and soil decomposition carbon fluxes. It is rather important to concentrate, not only on carbon dioxide, but methane and water vapor fluxes as well, which are products of microorganism activity in permafrost soils of NEA. Soil temperature and moisture strongly affect the rate of CO_2 emission from soil and methanogenesis and can change the total methane emission to the atmosphere and, therefore, modify the GHG forcing (3.2, 3.5, 3.6.1). It is still unclear how these emissions would respond to climate change and, thus, the methanogenesis should be properly parameterized in models. These local scale biogeochemistry models should capture non-homogeneities of landscapes and incorporate outputs of SVAT models for assessment of drainage and soil moisture conditions. Local resolution biogeochemistry models can be validated against tower flux observations and compared with high resolution atmospheric inverse models.

5.3.1.5 Priorities

Priorities for local-scale modeling include recognizing the most important processes specific for different NEA regions, as well as those affecting the regional and global climate and environment, e.g. biogeochemical feedbacks that change the gas composition and aerosol loading of the atmosphere (3.5, 3.6.1, 3.6.3) and landscape change (Eugster et al., 2000) – to be modeled in more detail. NEESPI local-scale modeling is focused on developing:

- detailed parameterization of the SVAT processes crucial for different NEA regions (e.g. non-uniform vegetation and soil, swamps, lakes and wetlands, high level of ground water, insufficient soil water content, permafrost, complex relief, etc.);
- advanced algorithms to describe impacts of anomalous weather and climate events (e.g. droughts, floods, etc.) on water and carbon cycles of different vegetation types;
- sophisticated approaches (1- and 3D) to describe energy, water, and carbon exchanges between soils, mixed (e.g. coniferous and broadleaf species) forest stands, and the atmospheric boundary layer;
- parameterizations to describe exchange of atmospheric pollutants (GHG, aerosols) between land surface and the atmosphere;
- 2- and 3D permafrost models that will include the thermal effect of changing vegetation, moving ground waters, and changing ground surface geometry;
- models of coastal zone evolution under climate and sea-level changes;

- new methods to describe spatial heterogeneity of the land cover and meteorological input parameters that allow up-scaling heterogeneity effects to the regional scale.

5.3.2. Regional scale modeling

A regional scale signifies a range 10-10^6 km^2. At this scale, local-scale processes are integrated over heterogeneous land surfaces. Interactions in the horizontal between the local scale processes come to a focus. The horizontal interactions can be either direct (e.g. horizontal flows within river catchments), or indirect (e.g. between land surface points via atmospheric circulation). Regional scale modeling provides a bridge between local ecosystem behavior and sub-continental through global-scale phenomena. The finer spatial scales are particularly important for assessing extreme events.

5.3.2.1 Atmospheric regional modeling

Three-dimensional regional atmospheric models, or Regional Climate Models (RCMs), are supposed to have a resolution on the order of 10^1 km and domains of up to a sub-continental size. Depending on the problem to be solved at their lateral boundaries, RCMs can be driven by (or, in other words, downscale) either GCM outputs or global atmospheric reanalyses. Finer scale RCMs can be nested into coarser scale RCMs. Though dependent on the quality of driving GCMs, RCMs allow for meaningful utilization in a broad spectrum of applications, particularly in climate change projections. Usually, an RCM will undergo a complex procedure of calibration and testing before it can be used for a certain region (i.e. it is "customized" to the region). If compared to other parts of the world, NEA (especially its northeastern part) is a region for which few RCMs exist (e.g. Shkolnik et al., 2001).

Among the most evident applications of RCMs within NEESPI are studies of deforestation and forest succession, forest fires, land use changes, climatic zone shift effects on atmospheric general circulation, and chemical composition. RCMs are a valuable tool in air pollution studies. In the framework of NEESPI, RCMs will be used both as drivers of and in a coupled mode with SVAT models, hydrological models, dynamic vegetation models, models of joint forest-soil and biodiversity dynamics, permafrost models, etc.

5.3.2.2. Catchment modeling

A significant part of the NEA drainage area is ungauged, and the temporal and spatial variability of runoff there is not known. The most feasible option for estimating runoff in the ungauged areas, as well as to increase our understanding of different processes, is hydrologic modeling. Current hydrological models demonstrate a skill in replicating timing and variability of terrestrial freshwater fluxes from large river systems. However, there are problems in capturing spatial variability of surface water impoundment by lakes and wetlands and frozen soil by parameterizations that represent spatially averaged processes at the resolution of the model grid cell. Regional hydrological models of varying complexity are used to estimate the projected impact of climate change on runoff characteristics. A number of such models have been developed and adopted for NEA (e.g., Georgievsky et al., 1999; Aurora and Boer, 2001; Georgiadi and Milyukova, 2002).

Accurate estimation of energy and water fluxes demands the precise extrapolation of meteorological parameters within the catchment from data available either from RCMs or from meteorological stations. Spatial patterns of temperature, solar radiation, and precipitation depend on many factors such as regional atmospheric circulation, surrounding relief, and land properties (Oltchev et al., 2002). Thus, development of adequate algorithms for downscaling and extrapolation of meteorological information based on both statistical approaches and process-oriented (e.g., large-eddy simulation) models is required.

Local soil properties are crucial for spatial distribution of ground water flows and infiltration rate within catchments. In many models, the infiltration rate is used for calibrating parameters which is estimated from a water balance equation using results of field measurements of precipitation, physical evaporation, transpiration, soil water content and runoff, and assumption of ideal closure of the annual catchment water budget.

Developing and employing comprehensive river routing models combined with SVATs and comprehensive permafrost models for NEA sub-regions will allow for linking hydrology at the regional scale directly to ecological concerns about the role of water in ecosystem functioning, spatial patterns of habitat condition, and the effects of land-use and climate change on nutrient cycling and water stress in NEA.

5.3.2.3 Dynamic vegetation

Many important processes that control the water exchange between forest ecosystems, rivers, and the atmosphere and feedback effects of changes of moisture conditions on forest functioning are poorly understood. Studies are mostly focused on individual experimental sites and on individual components of the hydrological balance without integrating the processes into a system approach on a regional scale. Moreover, it is still not clear how significantly various factors influence the water budget of forest areas (e.g. deforestation, forest succession, and environmental changes). The latter is particularly important with respect to climate change and variability as well as for planning rational forest management regionally. It is necessary to understand the features of water-regulating and water-protecting functions of forests under climatic changes.

Dynamic general vegetation (or ecosystem) models (DGVM, or DGEM, Woodward et al., 2000; Kucharik et al., 2000) are designed in a modular framework in which different ecological and physical processes, depending on weather conditions and previous stages of soil and vegetation, interact with each other. The main DGVM components include canopy physiology, vegetation phenology, population dynamics and competition, terrestrial carbon balance, soil hydrology, and soil biogeochemistry. Vegetation cover is described in a grid cell as a set of plant functional types (PFTs) (Smith et al., 1997). The definition of plant functional types is based on a few important characteristics of vegetation morphology and ecology: physiognomy (trees and grasses), leaf habitat (evergreen and deciduous), photosynthetic pathway (C_3 and C_4), and leaf form (broad-leaf and needle-leaf) (Haxeltine and Prentice, 1996). Variation in composition of PFTs and associated variation in water, carbon, and energy fluxes provide important input to climate and impact models.

A regional DGVM model for NEA should describe important feedbacks between soil-vegetation and the atmosphere and provide a basis for an improved land surface scheme in RCM. In order to make a synergetic assessment of environmental status of NEA and provide the land surface-atmosphere feedbacks for RCM, the following important ecosystem components are necessary:

- vegetation, particularly larch forest, with competition and population dynamic processes;
- organic floor with different types of lichen, moss, and grass layer communities, providing a regulating role for population dynamics and fire disturbance;
- forest and tundra fires with associated changes in vegetation dynamics, biogeochemical, water, and energy fluxes;
- permafrost, seasonally frozen soils, and wetlands with adjacent heat and mass transfer processes, as well as microorganism communities driving aerobic and anaerobic decomposition and regulating the trace gas fluxes;
- snow with accumulation, melting, and thermophysical regulating.

5.3.2.4. Air pollution

One possible regional impact of projected environmental changes is related to changing the pattern of the wind flows and, therefore, the atmospheric transport and dispersion of natural and anthropogenic air pollutants. It could result in changing the loadings on the ecosystems, including forests and surface waters, risks of morbidity and mortality for humans, and so on. Corresponding assessments can be done using dispersion modelling.

Existing models of atmospheric thermodynamics include advection-diffusion equations (ADEs) that describe transport and dispersion as well as physical and chemical transformations of gases and aerosols influencing the atmospheric temperature distributions, dynamics, and, finally, climate. Corresponding effects are especially important on the global scale. On smaller scales, the feedbacks are frequently neglected and ADE is considered as a client of the numerical weather prediction or climate GCM (RCM). In such a case, output of GCMs is considered as an ADE input. The input, however, should satisfy certain requirements (see Genikhovich and Sofiev, 2003). Specific features of the dispersion model as a client of a GCM/RCM are: (i) variable filtering of turbulence, (ii) variable spatial resolution, and (iii) Lagrangean process modeled, even when using an Eulerean description.

Input fields from GCM/RCM drivers are: 3D wind velocity field, precipitation (type and intensity), surface conditions (land use, snow cover), clouds (type, water content), solar radiation, temperature, and humidity. ADEs need additional input fields, like the eddy diffusivity, mixing height, surface fluxes, and surface conditions (wetness, vegetation), that should be reconstructed from available input data and/or physical parameterizations.

Monitoring networks existing in NEA, especially in its Asian part, are too sparse to provide reliable estimates of anthropogenic and natural pressure of the atmospheric pollution on the environment and human health, both on the impact and background levels. Even less are the monitoring data applicable for estimating possible changes in this pressure due to projected climate changes. In the NEESPI framework, local- and regional-scale dispersion models should be used for generating the state-of-the-art estimates and providing this information for environmental authorities and scientific communities. For the past and present conditions in the European part of NEA, this work will overlap with activities going on in the framework of EMEP (see 3.6.3).

5.3.2.5. Permafrost

Investigation of the temperature and spatial distribution of permafrost is an important problem, assuming a particular significance under the conditions of a warming climate. When setting a problem related to changes of permafrost parameters due to climate change, it should be taken into account that continental permafrost boundaries are rather conventional. When speaking about a shift in permafrost boundaries, a total disappearance of relict permafrost is not implied, but rather a detachment of the permafrost “table” from the bottom of the active layer and a transition from the regime of seasonal thawing to the regime of seasonal freezing in a region between the two conventional boundaries.

As a first approximation, impact of climatic changes on permafrost can be estimated using diagnostic indices based on surface air temperature and/or precipitation. Such approach allows for projection of permafrost evolution under specified scenarios of anthropogenic climate change and compares them with the palaeoclimatic warm epochs (Demchenko et al., 2002; Anisimov et al., 2002b).

Within the general framework of global-change studies, permafrost models currently used for regional, continental, and circumpolar calculations are the most appropriate tools for providing realistic description of climate-permafrost interactions over NEA. Currently available techniques for spatial permafrost modeling, however, rely on regular grids with a cell size comparable with GCM resolution or resolution of fields of required input parameters and an assumption of homogeneity of all geosystem components within each grid cell (e.g., Sazonova and Romanovsky, 2003). This assumption results in uniformly distributed estimates of permafrost parameters within each grid cell, regardless of the level of natural variability. A challenging task would be to account for such variability by means of stochastic modeling. This newer approach has been successfully implemented to a regional study of permafrost in the Valley of Kuparuk River in Alaska (Anisimov et al., 2002a) and will be adjusted to NEA.

At present, very little is known about the spatial heterogeneity of thaw depth at scales beyond those that can be explicitly resolved by existing spatially distributed permafrost models. General hierarchical modeling principles adopted by NEESPI should employ a multiscale permafrost modeling approach to provide transitions between spatial scales at which major geocryological processes operate, data are available, and models are formulated. The linkages between observational data and continental-scale permafrost models should be provided by a series of high-resolution meso-scale regional models. The selection of modeling approach and modeling domain is likely to depend on availability of spatially distributed information required to characterize environmental conditions of the area. Such information includes landscape characteristics derived from remote sensing images and spatial fields of climatic and subsurface variables. Output generated by regional models can be used to characterize sub-grid spatial variability of models operating on a continental scale. They can also be used to provide necessary input parameters for watershed-scale hydrologic and regional atmospheric and ecosystem models.

5.3.2.6. Priorities

Within NEESPI, priorities for regional-scale modeling include direct incorporation of improved parameterizations approbated in local-scale studies and developing different types of models and techniques:

- atmospheric regional models customized to NEA sub-regions (including assessment of RCM skill at improving simulations for NEA that are obtained from GCMs);
- comprehensive river routing models combined with SVAT and permafrost models;
- dynamic general vegetation models;
- comprehensive air pollution models;
- newer permafrost modeling approach that accounts for both deterministic and stochastic (sub-grid) variability of sub-surface, vegetation, and snow properties;
- advanced one-way and two-way nesting techniques for nesting hydrological, permafrost, dynamic general vegetation, and other environment component models into RCMs;
- data assimilation schemes that seamlessly incorporate modern satellite products and ground-based observations.

5.3.3. Global scale modeling

Direct and feedback effects of NEA environmental system within the global Earth system are the main foci of the NEESPI modeling component at the global scale. The relevant studies require employing comprehensive Global Earth system Models (GEMs, based on AOGCMs with advanced biospheric components) and those of intermediate complexity (EMICs, Claussen et al., 2002, 2004). These studies are closely connected with simulating observed and projecting future climates. A major emphasis within the NEESPI modeling component is given to developing and improving global climate model representations of land surface including terrestrial cryosphere, aerosols, carbon cycle, dynamic vegetation, and atmospheric chemistry. Progress in improving the corresponding model components is heavily dependent on the progress in local and regional modeling described above.

5.3.3.1 Effects of vegetation dynamics and interaction with land-surface on NEA energy and water cycles

Climate changes can impact rapidly (through changes of heat and water budgets, air and water pollution) to the intensity at which forest species reproduce. Many studies of forest dynamics showed that boreal forests would be more strongly affected by climate changes than forests in other latitudinal zones (IPCC, 2001). In the view of studies of the response of boreal forest ecosystems to global changes, it is necessary to understand how terrestrial water balances of NEA sub-regions change with time as a function of external factors, such as climatic and land-use influences, and what the effects are of these changes on forest ecosystem functioning.

Representation of the boreal forest and tundra land surfaces within AOGCMs has been, at best, incomplete and, at worst, incorrect (Harding et al., 2001). This is particularly true for wintertime conditions where the snow distribution and its interaction with vegetation are poorly understood and modeled. DGVMs are supposed to be applicable for investigation of the time-dependent behavior of vegetation in NEA affecting Earth system dynamics when climate and land use are changing rapidly. This is because only DGVMs are designed to describe transient (and not equilibrium) changes in vegetation cover and soil in response to changing environmental conditions. Indeed, a number of field observations show that the response of fragile northern ecosystems (tundra, taiga) to possible climate changes may be highly variable and have a multidirectional character. The incorporation of DGVMs into AOGCMs has only recently started. However, even early experiments with the sophisticated land-surface schemes interacting with AOGCMs demonstrated importance of representing feedbacks between boreal vegetation and the atmosphere (Betts, 2000).

The insulating effects and change of surface albedo due to terrestrial snow cover are of particular importance for climate change projections. Current AOGCMs demonstrate varying degrees of sophistication in their snow parameterization schemes (IPCC, 2001). Advanced albedo schemes incorporate dependences on snow age and temperature. However, a major uncertainty exists in the ability of current AOGCMs to simulate terrestrial snow cover, particularly its albedo effects and the masking effects of vegetation that are potentially important for the surface energy budget (e.g., Strack et al., 2004).

5.3.3.2. Effects of cryospheric and vegetation changes on the chemical composition of the atmosphere.

It has been estimated that the ***boreal forest*** regions may currently sequester a substantial amount of carbon, but the non-forest regions may be losing carbon due to the effect of warming in these regions (Apps et al., 1993; Oechel et al., 1993; 3.2). It is not yet clear whether long term increased carbon dioxide levels and associated global warming will increase carbon dioxide release due to increased soil decomposition or increase its uptake due to increased plant growth (Oechel et al., 2000; 3.5.1). The timing of spring ***snow*** melt may be crucial, because in the most northerly sites this can change the length of the active growing season by as much as 50% (Lloyd, 2001). Further south, the variation in the date of snowmelt can change the active season carbon accumulation by more than 100% (Aurela et al., 2001). The processes determining the summer exchanges of carbon are comparatively well understood. On the contrary, the winter carbon exchanges are poorly described. However, they might be important, owing to the 8 to 9 month winter duration in the north of NEA.

An effect of climate change on *forest fires* needs to be studied. On one hand, fires result in additional emission of carbon dioxide whose quantities remain to be evaluated. On the other hand, black carbon released during these fires may have an important additional effect on the atmospheric energy budget. Interaction of fire regimes and thaw/freeze processes are very important for vegetation structure in the permafrost zone and should be directly implemented into a land-surface scheme when making any integrated climate change projections/climate variability simulations.

Permafrost changes may have an effect on the atmospheric chemical composition, particularly GHG concentrations such as CO_2 and CH_4. While some climate models do now incorporate explicit parameterizations of permafrost processes (Volodin and Lykosov, 1998;

Alexeev et al., 1998), the feedback between thawing permafrost and warming climate through released GHG is currently not taken into account in climate simulations.

5.3.3.3. Effect of changes in NEA river runoff on the thermohaline circulation of the North Atlantic Ocean.

The freshwater budget of the Arctic Ocean (and its possible link to the intermittence of the North Atlantic deep water formation) integrates the hydrological cycle modeling problems not only in the Arctic, but also far beyond it – over the vast terrestrial watersheds of the Arctic Ocean (3.3.2). The river discharge into the Arctic Ocean must be properly represented in the AOGCMs in order to maintain its observed stratification and sea-ice distribution and transport. Land surface components of AOGCMs are now including simple river routing schemes able to provide reasonable yearly means of discharge, but not its seasonal cycle. This is particularly the case for the Arctic Ocean terrestrial watersheds where the discharge is highly seasonal (Kattsov et al., 2000). It is not clear, however, whether incorporating more comprehensive river routing schemes, ensuring proper seasonality of the discharge, would result in a significant improvement of the Arctic Ocean general circulation simulated by AOGCMs. A more intriguing question is how terrestrial hydrology-vegetation and hydrology-permafrost feedbacks, particularly in NEA, will affect river water inflow into the Arctic Ocean in the changing climate, and how this, in turn, will influence the global THC.

5.3.3.4. Other effects

Effects of changes in NEA (e.g., land use/albedo) on climate in other regions (teleconnections) should receive particular consideration in the framework of NEESPI (e.g., monsoons, changes in macrocirculation characteristics, such as Arctic Oscillation, North Atlantic Oscillation, Pacific Decadal Oscillation, El Niño/Southern Oscillation). Significant energy and water cycle changes over NEA become part of the global Earth System change and, therefore, their effect is global by definition. Such teleconnections could permit large changes in climate remotely from the study area. Whether this is true or not (and the magnitude of any effect) is a critical research topic (e.g., Arpe et al. 2000; Mokhov et al. 2003).

5.3.3.5. Priorities

Within NEESPI, foci of global-scale modeling should be:

- incorporation of improvements in process understanding at local and regional levels into comprehensive hydrological, vegetation, cryospheric components of GEMs;
- studying effects and feedbacks of environmental changes in NEA in the global context at the decadal, centennial, and millennial time scales and comparison with instrumental, historical, and palaeo data;
- estimates of extreme ranges in climate change impacts in past and in present for the entire NEA;
- assessing the predictive skill of GEMs and projecting the future.

5.3.4. Integrated assessment modeling

Nowadays, environmental policy is internationally and intra-nationally negotiated and climate impact assessments are part of political processes. From this perspective, the future of ecosystems in the NEA in conditions of the changing environment should be accurately investigated and adaptation and/or mitigation options should be elaborated.

The ultimate goal of an Integrated Assessment (IA) study is to represent the environmental change problem within the framework of a quasi-closed system such that the social and environmental consequences of policies to adapt to or to limit environmental change are seen in their totality. The need to include a variety of biophysical process characteristic to cold and dry continental regions in global integrated assessment studies is well recognized. However, a systematic, environmental change IA study has never been conducted for the whole circumpolar zone, or any of its continental parts (like NEA). Furthermore, an explicit mechanism for incorporating and addressing stakeholders' (decision-makers) questions and concerns regarding global change is required to carry out an IA. In application to NEA, such a mechanism should provide, first at all, for the interests of the major industry/agricultural sectors (oil and gas industries, energy production, forestry, and agriculture) and related societal and economic activities.

There are three categories of challenges for IA efforts to actively incorporate stakeholders in application to NEA: (1) an institutional fit problem – matching the scales of the biogeographical systems and the management system; (2) a scale discordance problem – matching the scales of the assessment and the management system; (3) a cross-scale dynamics problem – understanding the linkages between scales and how they affect decision-making, information flows, and the integration of information into the decision making process. A resolution of the problems may suggest substitution of the unidirectional flow of information from research to management (the pipeline model) to boundary organization of IA, which facilitates the multidirectional flow (needs, output formats) between science and decision-making and across scales.

In order to conduct an environment impact assessment, it is necessary to satisfy a strong desire among stakeholders for a qualitative explanation of the various forms that a future world may look like. To provide a framework for the policy makers to respond, the identification of vulnerabilities of key resources to environmental change and variability needs to be developed. Such a framework has been proposed in Pielke and Bravo de Guenni (2004), which includes examples from high latitude regions.

Climate, landscape, and ecosystem changes and variability can be described as a set of several world views, representing the societal values (ranging from consumerist to conservationist) and level of governance (ranging from local to global) in terms of climatic and impact variables. Finally, the world views and their consequences should be presented to locally important stakeholders in more than 20 countries of NEA via a series of individual interviews and group discussions for further corrections of assessment studies (see example of boundary integrated climate impact assessment study in the UK; Lorenzoni et al., 2000). These vulnerabilities should be identified and prioritized.

An IA study should not only present spatial and temporal dynamics of a metric representative for NEA, but also estimate uncertainties related to negligence of some environmental impacts, various aggregation schemes, and explicit or implicit assumptions on methods including possible specifications of non-linearity and synergy effects. The recommended modeling paradigm for an IA study in NEA can be 'strategic cyclical scaling' (Easterling, 1997) which demands the sequential pairing of bottom-up and top-down models over a set of common attributes/metrics determined in collaboration with stakeholders.

5.3.5. Developing strategy for environmental prediction in the framework of NEESPI

In the NEESPI modeling component, a general approach to environmental prediction is synergy that allows and accouts for numerous feedbacks that modify (and may even reverse) the state of the global Earth system. Recent attempts to regulate GHG emissions, to control pollution, changes in agriculture and irrigation practices, and forest management are vivid examples of the changing human activity *in response* to the global climate changes.

The NEESPI strategy for research of impacts of the 21st century environmental changes on ecosystems (e.g., forests, tundra, aquatic systems, agriculture, fire) and the resulting impacts of the changes in ecosystems on the global Earth system (i.e., feedbacks in the coupled Earth system) implies using and including: (a) selected use of GEMs (AOGCMs) and other models (e.g., RCMs, EMICs, nested high-resolution hydrological models, DGVMs, permafrost models, etc.), (b) integrated assessment models, (c) uncertainty (probability) analysis, (d) concentration on extremes such as droughts, floods and heat waves, (e) organization of a seamless observational data flow via data assimilation schemes, and (f) working toward upscaling and downscaling of model outputs to assess the value added and skill of their performance. At the moment it is not clear e.g. how AOGCM projections of future climates can skillfully account for local and regional feedbacks simulated by RCMs or impact models. This problem should be considered in the framework of NEESPI.

There is a large, natural variability in the NEA climate system and this part of the uncertainty cannot be eliminated simply by model development. Instead, one needs to focus on the climate predictability problem and probe the inevitable natural uncertainty through a systematic search in probability space. To do this we need to make ***ensemble simulations*** where both initial states and uncertain model parameters are varied within a realistic range associated with a probability distribution.

5.4. Observational needs of NEESPI modeling component

GEM-based scenarios of the Earth system evolution in the future can only be credible if the models simulate the present and past states and evolution of the system realistically – globally and in the region of interest. While an accurate simulation of the present-day state of the Earth system does not guarantee a realistic sensitivity to an external forcing (e.g. higher GHG and aerosol concentrations, land use change, etc.), a grossly biased present-day simulation may lead to weakening or elimination of key feedbacks from the simulation of change, or an exaggeration of them.

To validate coupled high-resolution models in NEA we need improved and extended ***observational data sets***. *In situ* observations are publicly available for a few locations and restricted time periods and more such data sets (including palaeo-data) are needed. There is an urgent need for a better historical database, especially for the low-populated areas (e.g., Siberia). A link is needed for modern monitoring tools to the historical databases.

A high priority is development of data sets of input landscape, atmospheric, vegetation, and other characteristics with enough temporal and spatial resolution for NEA. To obtain a better coverage in space and time the remote sensing products (6.2) should be utilized in full strength. For the NEA region, gaps exist in the present remote sensing instrumentation capabilities (Chapter 4). They should be recognized (e.g., the absence of reliable precipitation information) and remedies should be researched.

A good opportunity for validating RCMs and driving other types of models (hydrological, permafrost, ecosystem) is provided by reanalyses, employing numerical weather prediction models to convert irregularly spaced observational data into complete global gridded temporally homogeneous data (currently – for periods of several decades). Reanalysis data include both observed (assimilated) variables (e.g. temperature, geopotential height) and derived fields (e.g. precipitation, cloudiness), for some of which direct observations are almost non-existent (e.g. evaporation). Reanalyses have a potential to provide high-resolution validation data, which are not available from the raw observations, as well as provide an effective tool to monitor long term weather changes globally and regionally (e.g. Chase et al., 2000). Reanalyses at a fine scale resolution for the study area seem to have no alternatives in RCM validation. Within NEESPI, a possibility should be investigated of undertaking a ***Regional Reanalysis*** of NEA, similar to North American Regional Reanalysis (Cosgrove et al. 2004), conducted by NCEP and the Arctic System Reanalysis, planned by SEARCH (Overland et al., 2003). This activity could capitalize upon existing global and regional reanalyses and employ a regional NWP model incorporating advanced terrestrial, river-routing, etc. modules customized to the NEA region.

Finally, employing models in planning and directing observational campaigns and experiments and optimizing observational networks should be considered as promising and potentially important interaction between modeling and observational components of NEESPI.

5.5. Links with other programs

NEESPI modeling activity inevitably overlaps with modeling components of a number of already existing programs and, thus, should include learning from them. Evidently, links should be established between the NEESPI modeling component and modeling groups of the World Climate Research Programme (WCRP), Working Group on Numerical Experimentation (WGNE), and Working Group on Coupled Modeling (WGCM), as well as modeling groups and panels of major WCRP programs such as Climate Variability and Predictability (CLIVAR), Climate and Cryosphere (CliC), Global Energy and Water Experiment (GEWEX), and, probably, SPARC. Water fluxes between forest ecosystems and the atmosphere, the interactions of water resources of the land surface with the forest canopy for different spatial and temporal scales, and responses of water-regulating functions of forests on the global climate change are key topics of several major international programs and projects, e.g., International Geosphere-Biosphere Programme (IGBP), International Hydrological Programme (IHP), Global Change and Terrestrial Ecosystems (GCTE) (IGBP Core Project), recently completed Biospherical Aspects of Hydrological Cycle (BAHC), and Boreal Ecosystems Atmosphere Study (BOREAS). The NEESPI modeling component could capitalize upon the knowledge and experience of some national (regional) programs, researching the same or different regions than NEA, but having similar objectives and approaches: Community-wide Hydrological Analysis and Monitoring Program (CHAMP), Study of Environmental Arctic Change (SEARCH), Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA), etc. Expectations of model improvement should be associated with the increasing international activity in the field of model intercomparison exercises helping to identify model errors, their causes, and how they may be reduced. NEESPI-oriented diagnostic subprojects should be initiated (if not already) in major on-going Model Intercomparison Projects (MIP), e.g. Atmospheric MIP (AMIP, Gates, 1992), Coupled MIP (CMIP, Meehl et al., 2000), Paleo MIP (PMIP, Braconnot, 2002), PILPS (Henderson-Sellers et al., 1995), SnowMIP (Etchevers et al., 2003), and similar international efforts, e.g. the Climate of the 20th Century (C20C) experiment (Folland et al., 2002).

6. DATA AND INFORMATION TECHNOLOGY

Lead authors: J.G. Masek and V. N. Razuvaev

Contributing authors: V. Gershenzon and P. Ya. Groisman

6.1. NEESPI Data Requirements

Observations are an important component of the regional science program and are essential for environmental monitoring. Fortunately, there is a large overlap between the observations needed to support global change research and the observations needed for environmental and natural resource management. The operational monitoring systems necessary to provide the systematic observations are expensive to maintain and hard to justify based on science inquiry alone. No single country can provide the requisite observing systems for regional and global monitoring: international coordination is essential. The observational needs for global change research and resource management are being promoted and coordinated under the international Integrated Global Observing System (IGOS) program[58].

In general, NEESPI seeks to address the interactions between Northern Eurasian ecosystems, climate, and human activity, using a combined framework of predictive models, long-term in-situ and spatially complete modern remote-sensing observations, and process studies. Ultimately, by developing mature, tested models specific to Northern Eurasia, we hope to develop realistic predictions of how global and regional climate will respond to ecological changes during the next several centuries. In this context, NEESPI observational datasets will be used to:

- parameterize and validate predictive models of ecosystem dynamics and ecosystem-climate interactions;
- provide evidence for long-term trends in Northern Eurasian climate and ecosystems, in response to human and global climate forcing;
- generate new understanding of ecosystem processes that can be incorporated into model physics.

The last point is particularly important, in that existing models used for European or North American ecosystems may neglect processes important in the Northern Eurasian region (e.g. thermokarst activation, forest stand replacement, detailed albedo/snow-cover feedbacks). Thus, identifying and/or creating relevant observational datasets is a vital aspect of the NEESPI science program.

The NEESPI science themes drive specific data requirements. The initiative is formed from three major research thrusts: (1) understanding the biogeochemical cycling, natural and man-induced dynamics, and changes to Northern Eurasian ecosystems, (2) understanding the interactions between the land surface (including terrestrial ecosystems and hydrology) and climate systems, and (3) understanding the linkages between human activities and environmental change. Each of these thrusts has unique requirements for data. Tables 6.1-6.3 present the types of data products of importance to NEESPI; these are discussed in more detail in the sections below.

6.1.1. Terrestrial Ecosystems and Biogeochemical Cycles

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[58] For the terrestrial component, the Global Observation of Forest Cover and Land Cover Dynamics (GOFC/GOLD) program, which is part of the Global Terrestrial Observing System (GTOS) is developing regional networks of scientists and data users to articulate the observational needs (Townshend et al. 2004).

Of paramount importance are datasets that map the distribution of vegetation composition, structure, dynamics, and biochemistry. These data are essential for parameterizing photosynthetic models of primary productivity. In the forest zone, long-term measurements of forest age and disturbance rate (e.g. forest fire, insect defoliation) will allow the calculation of net ecosystem and biome productivity and the land-atmosphere carbon flux. Observed standing biomass can be used to validate ecosystem productivity models, and to assess the loss of carbon stocks following disturbance. For these purposes, forest inventory data are essential to the NEESPI enterprise. Although access to such inventory data is not uniform across the NEESPI region, the program accepts as a goal the dissemination of sufficient forest ecosystem data to allow parameterization of continental-scale biogeochemical models. Given the importance of methane balance in Northern wetlands, detailed maps of wetland extent and vegetation composition are also important. In the steppe, semi-desert, and desert zones, the primary scientific questions revolve around land degradation, susceptibility of agriculture and pasture land use to changes in climate, and changing land use in response to shifting socio-economic conditions. Addressing these issue require datasets on agricultural extent and land management, as well as socio-economic time series. The potential activation of below-ground carbon in Northern Eurasia necessitates measurements of soil carbon concentration, accumulation, and respiration rate. In tundra and forest-tundra regions, these data can be supplemented with observations of permafrost extent and thermokarst formation in response to measured energy balance.

Table 6. 1. Biogeochemical Cycling Data Requirements

Vegetation Dynamics	Land-cover type Disturbance history Land-cover change Phenology
Vegetation composition/structure	tree types stand height stand age biomass LAI
Vegetation biochemistry	fAPAR light use efficiency water use efficiency nutrient limitations CO2, methane fluxes
Soils	soil type soil carbon soil hydrology
Hydrology	Carbon export forest ET fluxes
Ecosystem health	stand replacement history fragmentation biodiversity metrics

Models of carbon exchange fed by observational inputs may be complemented by direct observations of CO_2 and methane fluxes using eddy covariance techniques. There is currently a significant gap in the global FluxNet network within northern Eurasia, and NEESPI should help to coordinate filling this gap. Ideally, such FluxNet observations would be spread across multiple ecosystems (forest, grassland, tundra, etc), and incorporate observations from chronosequences of known age and disturbance history, and sample a variety of land management regimes. In addition, the emplacement of a small number of "tall" flux towers (100-500m height) would allow validation of regional and continental-scale carbon fluxes.

In addition to understanding land-atmosphere fluxes of carbon, long-term changes in Northern Eurasian ecosystems are of interest for predicting biodiversity and understanding the impacts of regional climate change. Long-term observations of stand replacement, grassland/woodland dynamics, plant and animal inventories, and habitat fragmentation may provide information on ecosystem health in response to changing climate, land use change, and a general anthropogenic load (pollution, water withdrawal, urbanization, timber harvesting, various industrial and agriculture activities).

6.1.2. Surface Energy and Water Cycles

The Surface Energy and Water Cycles research element seeks to understand how changes in global climate propagate to Northern Eurasian ecosystems, and, in turn, how ecosystem changes feed back to affect regional and global climate. Observational data are required to parameterize regional and global climate models, to analyze historical trends in surface hydrometeorology, and to evaluate the linkages between terrestrial ecosystems and climate. Meteorological variables are required to determine the transfer of energy and water between the land surface and atmosphere. Surface temperature, air temperature, wind speed, radiation balance, cloudiness, and surface albedo help constrain the sensible and radiative energy balance. Observations of precipitation, relative humidity, and water vapor, combined with temperature and wind speed as a well as direct measurements of evapotranspiration in selected locations help constrain the transfers of water and latent heat.

Table 6.2. Energy-Water Cycling Data Requirements

Energy balance	Cloud fraction, type Surface albedo Surface, air temperature Longwave fluxes Wind speed, direction
Water balance	Relative humidity ET fluxes Precipitation Snowcover, depth River runoff Soil moisture
Atmospheric Dynamics	Barometric pressure Large-scale circulation Topography Aerosol, dust loading

Hydrologic observations are critical to understanding how water availability varies through time, and how it affects terrestrial ecosystems. Surface and subsurface hydrology measurements (runoff, soil moisture, soil permeability, etc) can be combined with meteorological observations (evapotranspiration[59], precipitation) to constrain the regional water balance. Fluctuations in water availability can be related to observations of ecosystem health and productivity, and to regional climate patterns. The importance of cryospheric processes to the energy and water balance in the region requires measurements of glacier dynamics, snow cover extent, depth, water equivalent, and albedo.

6.1.3. Land use and socio-economic information

[59] Evapotranspiration is a calculated variable in most hydrological studies. But, unique observational programs that exist in Northern Eurasia (heat balance and lysimeter networks) allow direct measurements of this variable that may then be used to validate/calibrate the calculations.

One of the most important components of NEESPI is the inclusion of data on socio-economic resources of the region. Changes in the environment, climate, and social systems are closely linked and, in many cases, the wellbeing of regional cultures depend on the provision of natural resources from the environment. Therefore, the NEESPI implementation should provide and use comprehensive information on the state and dynamics of the socio-economic system. This includes:

Table 6.3. Socio-economic Data Requirements

Social Information	Population and Demographics
	Health and Life Expectancy
	Work Activity
	Education
	Migration Patterns
	Income and Wealth
	Land Tenure
Economic Infrastructure and Technology	Employment
	Industrial Production by Sector
	Economic Indicators (GDP, etc)
	Trade Balance
	Productivity
	Energy Consumption
Natural Resources	Water Resources
	Agricultural Resources
	Timber Volume
	Energy Resources

In addition to the present state of resources, we also need to have historical information in order to estimate socio-economic trends and the depletion of resources, key aspects for the decision making process. Using this information in conjunction with data on the environment and climate will allow a comprehensive approach to studying processes that are occurring in the region in all their complexity and feedbacks. Information on resources and socio-economics can be obtained from the reference documents that are routinely prepared by the government institutions of Russia, PRC, The Ukraine, Kazakhstan, and other countries of the region (as well as by the former USSR prior to 1991). Considerable information is currently available via the Internet (e.g., http://old.priroda.ru; http://www.sci.aha.ru/RUS/wab_.htm; http://www.eurasianet.org/eurasianet/resource/; and others).

6. 2. Satellite and In-Situ Data Availability

6.2.1. Satellite Data

As noted in Chapter 4 of the Science Plan, given the geographic expanse of Northern Eurasia and the relative paucity of certain types of in-situ measurements, much of NEESPI research will rely on satellite remote sensing. The use of remote sensing technologies, carefully calibrated by direct station measurements, may offer a more robust approach for providing this information and filling in the gaps in the in-situ data. Here we review issues related to the availability of various satellite data sets.

Table 6.4: Satellite Remote Sensing systems relevant for NEESPI science activities. Italics represent future missions. Resolution in meters unless otherwise specified

Coarse Resolution Passive Optical	Resolution	Operations Dates	Spectral Range	Applications	Data Availability
NOAA AVHRR	1100	1978 -	VNIR-TIR	global vegetation, surface temperature, cloud cover, fire	Derived products from USGS EDC, NASA GSFC, UMD
RESURS-01 MSU-SK	150	1994 -	VNIR-TIR	global vegetation, surface temperature	TransparentWorld
Terra MODIS, Aqua MODIS	250-1000	2000 -	VNIR-SWIR-TIR	global vegetation, surface temperature, water vapor, clouds, aerosol, fire, snowcover	EOSDIS
SPOT Vegetation	1200	1998-	VNIR-SWR	global vegetation	CNES
Hi-Res Optical					
Landsat	30-90	1972 -	VNIR-SWIR-TIR	land-cover/ change, coastal environment	USGS EDC (paid), UMD Global Land Cover Facility, MSU Landsat.org, Transparent World
SPOT XS/Pan	20	1986-	VNIR	land-cover/ change, coastal environment	SPOT Image (paid)
Terra ASTER	30	2000 -	VNIR-SWIR-TIR	Land-cover, surface temperature, fire	EOSDIS
RESURS-01 MSU-E	30	1994 -	VNIR	land-cover/change	Transparent World
IRS LISS	25	1988 -	VNIR	land-cover/ change	Transparent World
SpaceImaging IKONOS	<4	1999 -	VNIR	urban, land-cover, validation	SpaceImaging (paid)
DigitalGlobe Quickbird	<4	2000-	VNIR	urban, land-cover, validation	DigitalGlobe (paid)
Active Microwave					
RadarSat	8-100	1995-	C band		commercial distribution
ERS	25	1991-	C band	land-cover, sea ice, vegetation structure	ESA (limited, paid)
JERS	18	1994-1998	L band	vegetation structure, sea ice	JAXA, JRC
PALSAR	*10-100*	*2004 -*	*L band*	*vegetation structure, sea ice*	*JAXA (limited)*
Envisat ASAR	30-75	2002 -	C band	land-cover, sea ice, vegetation structure	ESA (limited, paid)
Passive Microwave					
Aqua AMSR-E	5-50km	2001 -	Passive microwave	Soil moisture, sea ice, snow hydrology	EOSDIS
NOAA AMSU	50-150km	1998-	Passive microwave	Soil moisture, sea ice, snow hydrology	NOAA SAA
DMSP SSM/I	15-60km	1987-	Passive microwave	Soil moisture, sea ice, snow hydrology	NOAA SAA
Other					
ICESAT GLAS	~100	2003-	Lidar	vegetation structure, topography	EOSDIS
Terra MISR	275	2000 -	VNIR	multi-angle vegetation, clouds, aerosol	EOSDIS
SRTM	30-90	2000	Radar	global topography	USGS EDC
ENVISAT MERIS	300	2002-	Hyperspectral	global vegetation, clouds, aerosol, snowcover	ESA (limited)
EO-1 Hyperion	30	1999-	Hyperspectral	vegetation composition, land-cover	USGS EDC (paid)
Terra MOPPIT	22km	2000-	Spectrometer	CO, CH4 concentrations	EOSDIS
Terra/Aqua CERES	20km	2000-	Radiometer	Albedo, clouds, radiation budget	EOSDIS

Table 6.4 provides a brief description of relevant satellite data streams, together with the typical geophysical parameters derived from them. Note that in some cases data

availability may limit the utility of these data streams. For example, very high-resolution optical imagery (IKONOS, Quickbird, air photos) may also be useful for certain ecological applications (tree counts, crown closure estimates, forest migration studies, etc). However, obtaining these data can be costly, and we anticipate that only a limited amount of high-resolution imagery may be purchased for specific NEESPI projects through individual grants.

It should be noted that long-wavelength Active Radar (L-band SAR) data may be extremely important for mapping wetlands, vegetation biomass, and for land-cover in conditions of low solar elevation or high cloud cover. At present, there is no U.S. or Russian source for L-band SAR data. However, archived JERS-1 data and the upcoming PALSAR mission from JAXA may offer an approach to filling this need. For example, the Siberia-2 project has recently released a mosaic of JERS-1 imagery from the late 1990's across Siberia. Passive microwave datasets can be used to examine snow cover and soil moisture, two critical parameters within the study region. These datasets are widely available through European, Japanese, and U.S. research missions (e.g. NASA Aqua, Envisat, etc).

Coarse-resolution optical remote sensing data (e.g. spatial resolution > 100m) is relatively easy to access from NASA, NOAA, ESA, and RKA. Within the United States, MODIS and MISR reflectance data and geophysical products may be downloaded at no cost from Distributed Active Archive Centers (DAACS) or from sites hosted by academic institutions. Similarly, SPOT Vegetation products may be obtained for no cost for research purposes. Archival AVHRR reflectance and NDVI data are also available from 1981 to the present. Thus, there is a ready supply of coarse-resolution optical data for the last twenty years, with more detailed geophysical products available since 1998.

Table 6.5. Moderate-Resolution Optical Data Sources

Dataset	Description	Source
GeoCover 1975-2000	Decadal (1975, 1990, and 2000) global cloud-free coverage from Landsat MSS, TM, and ETM+	UMD Global Land Cover Facility; USGS EDC, MSU Landsat.org
NASA LCLUC Archive	370+ Landsat TM and ETM+ images purchased by NASA PI's	NEESPI Project Office
Transparent World Archive	530 Landsat-7 images, as well as extensive archives of Landsat-5, IRS, and ASTER	R&D Center ScanEx , Moscow
USDA Foreign Agricultural Service (FAS)	360+ Landsat-5 and Landsat-7 images (since 1989)	USDA FAS
EO-1 Archive	400+ EO-1 ALI and Hyperion images over Northern Eurasia	USGS EDC
Terra ASTER archive	TBD ASTER granules over Northern Eurasia	EDC DAAC

Access to moderate-resolution imagery (Landsat, SPOT XS, ASTER, IRS, MSU-E, etc) is more problematic. Unlike coarse-resolution sensors that always gather data, moderate-resolution sensors are typically tasked to acquire particular images of interest. Thus, depending on acquisition priorities, data gaps may occur. Furthermore, most of these sensors are partly commercial (SPOT, IRS) or charge for data distribution (Landsat). As a result, it can be difficult to assemble comprehensive, interannual, continental datasets for research purposes. For example, analysis of existing image databases indicates a persistent gap in coverage for the late 1980's and early 1990's throughout the Russian Far East for both Landsat and SPOT systems. Nevertheless, large archives of free or inexpensive Landsat-type images do exist (Table 6.5). For example, the Global Land Cover Facility (GLCF) at the University of Maryland distributes, free of charge, the GeoCover datasets produced by the

Earth Satellite Corporation. These datasets include cloud-free imagery for most of Northern Eurasia centered on 1975, 1990, and 2000, providing decadal views of land-cover across the region. ScanEx Corporation in Moscow also hosts archives of Landsat, IRS, and RESURS imagery available at low cost through the TransparentWorld interface.

6.2.2. In-Situ Data

Reflecting the long history of ecological and geophysical research in the region, there are numerous archival geophysical datasets that have been collected for routine monitoring or for special studies. In many cases, these data have little distribution or visibility outside of the host country or institution. One of the priorities of NEESPI is to identify these datasets and promote their distribution to address the science goals of the NEESPI project.

Table 6.6. List of meteorological elements observed at the standard meteorological station within the former USSR.

3-HOURLY DATA SET	DAILY DATA SET
Air temperature Water vapor pressure Dew-point temperature Relative humidity Sea level pressure Station level pressure Air pressure tendency Visibility Total cloud amount Lower cloud amount Cloud genera Height of cloud base Wind speed Wind direction Precipitation Present weather Past weather Surface skin temperature Ground state Atmospheric phenomena	Mean daily air temperature Maximum air temperature Minimum air temperature Daily precipitation Snow depth Snow coverage Characteristics of site Minimum of relative humidity Minimum of surface temperature Wind speed maximum Atmospheric phenomena Atmospheric phenomena duration Daily total and low cloud amount Sunshine duration

During the NEESPI implementation, different types of in-situ information will be used: hydrometeorological, socio-economic, land-cover, and land-use data. Each data type has particular attributes with regard to collection, archiving, and pre-processing. For example, the system of hydrometeorological observations in within the former Russian Empire and USSR has been established over a lengthy period of time. At the end of the 19th century (1891 is considered as the year when the major types of regular observations were finally established; Vannari 1911), the system had already satisfied major needs in the data on environment in he densely populated parts of the continent. Since that time an enormous volume of observations has been accumulated and, relatively recently, most of it was digitized. Table 6.6 shows major meteorological elements that have been observed at the meteorological network within the former USSR (up to 1936 three times per day, then four times per day, and since 1966, 3-hourly). In addition to standard meteorological elements listed in Table 6.6, special networks observe runoff characteristics, soil moisture, and atmospheric radiation. Frequently, these stations are co-located.

The number of the major operational stations over Russia and the former USSR varied from ~100 in the past decade of the 19th century to maximum of ~ 3500 in 1985. At that time, however, precipitation was measured at ~11,000 locations. Presently, at the Russian territory there are ~1900 operational stations. The information from these stations is routinely archived at the State Data Fund in several special “archive” formats. However, this information is not used for research purposed directly, but serves as a baseline source for specialized sub-arrays to address particular tasks (e.g., such WMO programs like GEWEX-GAME-Siberia or ACSYS). It is expected that funded NEESPI activities will take the form of joint research projects, with formal collaboration of the relevant State Data Fund data managers and scientists involved in organization, maintenance, and quality assurance of pertinent observation programs. Such a partnership will ensure the integrity of data used for investigations.

In addition to data available via the State Fund, there are a lot of data arrays accumulated during various research projects, field expeditions/experiments, etc. Many of these datasets are referenced in Section 3.3. These data are a property of Institutions, private firms, but very infrequently the "Principal Investigators". Access to these data can be very different. As it can be seen from Table 6.6, the scientific potential of the baseline archive is significant and should be utilized. In addition to the direct data flow from meterological stations to the State Fund, an operational ("real-time") data flow exists through the Global Telecommunication System (GTS) mostly for weather forecasting needs. These data also can be used for NEESPI purposes but only as "near-real time data", i.e. in a quality-controlled form. The "near-real time" data flow is, nevertheless, less reliable (also it is available within a month or so) and should be later be replaced.

Ecological datasets from Northern Eurasia include forest inventories and ecological research networks, documenting vegetation structure, species composition, and biomass. For example, within China, the Chinese Ecological Research Network (CERN) consists of 33 research stations covering major vegetation biomes. CERN stations started collecting data in 1988, and include datasets on soil ecology, photosynthetic productivity, biodiversity, and carbon cycling. Another example, the forest inventory of Russia, has long collected regional data on timber resources and forest types across the country. These inventory datasets have very different rules and methods of collection, archiving, and dissemination that also must be accounted for realistic estimates of their availability for the NEESPI needs. Hydrological datasets of interest include river runoff and soil moisture observations. In some cases the geographic scope of the datasets is limited (i.e., soil moisture was primarily monitored in agricultural regions), or the data have not been widely available outside the host country. In some cases, these station observations have been compiled and gridded to create maps of regional climate, hydrological, and ecological patterns. An example of this is the IIASA Land Resources of Russia dataset, which features numerous maps of socio-economic variables, natural resources and climate, and land use compiled from various primary data sources. In cases where original plot-level field data are not available, NEESPI researchers can utilize these existing gridded data products for model inputs.

6.2.3. Known Data Gaps

Several gaps in data coverage have been identified during the NEESPI planning process. These include:

- moderate/high-resolution optical remote sensing coverage for northeast Siberia during the 1980's and early 1990's.
- meteorological, hydrological, forest and ecological inventory data from Northern Eurasia, which exist but (a) not in digital form; (b) are not available for scientific purposes; and (c) have not been widely distributed ;
- direct measurements of atmospheric CO_2 and water fluxes from a permanent flux-tower network;
- socio-economic datasets that provide coherent views of population, demographics, and land-use patterns and their changes.

Where possible, NEESPI will attempt to fill these gaps through the collection of new datasets, or through improved dissemination of existing datasets.

6. 3. Data Policy and Management

The success of the NEESPI project requires the open exchange of data and information among project participants, to the greatest extent allowable by institutional, national, and international regulations. For addressing issues related to data management and policy, a special working group should be created under the NEESPI Project auspices. The group should coordinate the conditions of dissemination of the information products prepared through NEESPI, select the team responsible for update and creation of derived products, and resolve publication policies for use of those products. The end result of this process should be a NEESPI Data Policy NEESPI, to be included with the overall project Implementation Plan.

The first and crucial step in the information policy will be a creation of a comprehensive metadata archive: information about base datasets, information products, and their derivatives. History of stations and their observation practice should be a subject of another metadata archive that will facilitate the quality assessment of the scientific results and secure the NEESPI scientist from "discoveries" that thereafter will be discarded as artifacts due to the inhomogeneities in the data.

To facilitate the exchange of information, a NEESPI Information System should be implemented. NERIN, the Northern Eurasian Regional Information Network, has been proposed as an umbrella network for the exchange of data and information among NEESPI participants. As a forum for data producers and data users, NERIN is helping to formulate, prioritize, and articulate the requirements for satellite and in situ monitoring of the region. The regional network is currently involved in engaging regional scientists and resource managers in the evaluation and validation of new satellite products. The NEESPI Implementation Plan should finalize recommendations for the full NERIN system. In doing so, various factors need to be considered. First, a great many historical datasets exist throughout the region, and care must be taken to ensure that the dataset producer alone is responsible for changes to the data, releasing official versions, and distributing the appropriate version to users. Also, many datasets are not currently available in electronic format, and some institutions across the region do not have reliable access to the internet. To speed access throughout the region, an information architecture should be considered that relies on "mirrored" sites within the United States, Europe, Japan, and countries of Northern Eurasia. Some consideration should be given to partnering arrangements, so that institutions with poor electronic capabilities can collaborate with larger institutions that have good connectivity. Given the importance of Geographic Information Systems (GIS) in allowing data sources to be integrated to further scientific discovery, some emphasis should be directed toward ensuring that NEESPI electronic datasets are available in GIS-compatible formats.

Long-term archiving of datasets is another priority for the NEESPI project. We anticipate that, following the conclusion of the formal NEESPI activities, new NEESPI datasets will still have significant scientific value for the research and applications communities. Datasets created or substantially modified through NEESPI will be permanently archived at appropriate long-term data centers within the host countries. Provisions for this should be documented within both the NEESPI Implementation Plan and Data Policy.

6. 4. Data and Information Technology Priorities

While overall priorities for the NEESPI Research Strategy are given in Chapter 8, the preceding discussion suggests some particular priorities with respect to Data and Technology:

1. ***Creation of a Metadata Archive***: The first priority for NEESPI should be to catalog existing datasets within NEESPI countries, and gather the metadata from these datasets into a standard form. These metadata may then be used as the basis for an electronic

information system (see item 2 below). Particularly important is to understand the distribution (temporally, geographically) of in-situ monitoring networks, and how the characteristics of those networks have changed through time.

2. ***Implementation of a NERIN Information System***: A significant contribution of NERIN would be to allow Earth Scientists to locate diverse data pertaining to Northern Eurasia, to establish a fruitful collaboration with the specialists who have the first hand experience in the observational programs , and, consequently, to promote the open exchange of data products among researchers. A full NERIN Information System would meet these goals. Such an information system should be distributed, to take advantage of existing institutional data warehouses, and should allow for retrieval of various data types and formats (e.g. in-situ plot and station data, national inventories, satellite data and products, etc.)
3. ***Creation of a Northern Eurasia Ecological Network***: Given the difficulty in accessing plot-level inventory data from all NEESPI countries, NEESPI should consider supporting a unified ecological network across the region to make independent measurements of vegetation characteristics, soil conditions, and atmospheric fluxes. This approach could merge systematic ecological measurements (e.g. the Chinese CERN approach, long-term biospheric observational stationars in Russia, and the international FLUXNET program), new flux tower locations, and validation of satellite data products (e.g. extending the NASA EOS Core Sites). The International Long-Term Ecological Research (ILTER) network could provide a framework for this activity.
4. ***Generation of gridded modeling product suites for Northern Eurasia***. While it may not be possible to distribute all national inventories, it may be possible to coordinate the release of coarsely gridded summaries. These summaries, including data on forests, crops, land-cover, water resources, and socio-economics, would be extremely useful for Earth Science modeling, and could obviate the need for release of plot-level data. A model for this activity is the IIASA Land Resources of Russia dataset. However, the NEESPI study area is larger than Russia, and NEESPI should support the harmonization of inventory datasets from across the region.

7. EDUCATION

Chapter lead authors: V. G. Bondur and K. Bergen

Contributing authors: R. Heino, V.V. Kozoderov, R.G. Mamin, F.A. Surkov

7.1. Goals and Objectives

The framework of the Northern Eurasia Earth Science Partnership Initiative (NEESPI) will create opportunities for essential education and training of scientists working in the broad and dynamic arena of earth science in Northern Eurasia. Equally importantly, educational activities encompassing preparation of new scientists and continuing education and re-training of experienced scientists will be essential for meeting NEESPI scientific objectives. Education is defined broadly to include aspects such as: formal curricula, practical training and seminars; involvement of students in NEESPI research projects, development of educational and scientific materials; participation in educational expeditions, implementation of educational exchange programs and partnership programs, creation and maintenance of Internet sites, and other integrative activities. More specifically benefits include: an increase in the availability of trained scientists working on critical earth-science issues in the region; the fostering of good international relations through increased cross-cultural and collaborative opportunities; an increase in research and study opportunities for talented students; and an avenue for continuing education and re-training of experienced scientists who may have recently faced significant institutional changes. ***Therefore, NEESPI is committed to incorporating a strong education and training component into this science plan***.

The main purpose and content of this chapter is to outline how the educational component will be designed and will support NEESPI at the following levels: a) elementary and secondary school, b) undergraduate education, c) graduate professional education, d) graduate Ph.D. research and teaching education, and e) continuing education and re-training. This chapter will also discuss important programmatic aspects including a) financing, and b) administrative issues.

7.2. Financing

Core NEESPI educational activities should be financed by allocating not less than 15 % from the budget of each scientific project carried out within the framework of NEESPI. These can include (similar to the LBA program) support such as: stipend/tuition for graduate students working on NEESPI research projects to complete NEESPI-related thesis' or dissertations, individual undergraduate research involvement support, development of formal courses/curricula, development and implementation of workshops for students and/or continuing professionals, development of curricular materials for dissemination; field experiences for students; opportunities to present research results at meetings, and other educational opportunities directly related to NEESPI project goals. These should be outlined in each NEESPI project proposal and their presence and quality should be ranked as part of the review process. At the same time NEESPI should consider that an open competition specifically for financial support of student scientific research projects be organized within the NEESPI framework.

In addition to educational components funded under NEESPI auspices, other sources of financing should also be sought and used at the implementation stage of the educational activities. These sources could be 1) existing funding opportunities for students at universities and scientific institutions participating in NEESPI; each institution participating in the NEESPI program can use its own specific educational programs and procedures for implementation of an educational part of NEESPI. Scientific problems of the Research

Sections of NEESPI are already and/or can be included in curriculums of participating universities and can subsequently to become a subject of research works of teachers and students; 2) in-kind contributions such as use of laboratories, equipment, and communication facilities; 3) other existing programs of a federal level in each of the countries (for example, in the U.S., National Science Foundation (NSF) International Programs Directorate, the START Program, and private foundations with international science and cooperation programs).

7.3. Implementation of the Education Component

The purpose of the education component of NEESPI is to create opportunities for training new scientists and re-training existing scientists. These scientists should represent a diversity of international countries, of geographic regions within Northern Eurasia, of scientific interests, and of ages and genders. In developing this, quality and focus of the program are important – key organizations with existing strengths should exhibit leadership roles in their own organizations and in fostering growth in other and new organizations, and opportunities should be available for motivated new entrants in the NEESPI education program.

In Russia, the educational component will be implemented primarily by the Scientific and Educational Center of Aerospace Environmental Monitoring Problems “Aerocosmos” and Moscow State University of Geodesy and Cartography (major organizations experienced in realization of various stages of aerospace education) with the participation of Moscow State University, St. Petersburg State University, and other universities (e.g., in Rostov-on-Don, Nizhnii Novgorod, Novosibirsk, Krasnoyarsk, Irkutsk) that can demonstrate innovative educational programs which have potential for realization under NEESPI. Significant regional expertise has been accumulated in The People Republic of China (Lanchzhow Desert Institute), Uzbekistan (Uzbek State University, Tashkent), Kazakhstan (Kazhakh State University, Almaaty), The Ukraine (Kiev State University), Estonia (Tarawere Observatory, Tartu), and Finland (Helsinki University, Finnish Meteorological and Finnish Forest Research Institutes). Having important regional expertise, these Universities and Institutes will be an important part of the NEESPI educational network.

In the United States, strengths in NEESPI Education will be distributed in a diversity of universities and research organizations that demonstrate dynamic programs and an interest in NEESPI research and education activities. A number of universities and organizations currently participating in NASA-Russia research grants may be expected to contribute to planning (for example the LCLUC PI institutions). Other universities with researchers in the NASA programs interested in Northern Eurasia should be encouraged to participate in new research and educational activities. Currently NASA also supports universities to manage data and data archiving programs and these should be encouraged to participate in educational activities. Linkages to agencies and organizations with a more applied emphasis will also be fruitful. There is a considerable amount of work to be done to meet NEESPI goals, and open competitions for involvement in NEESPI education should be encouraged.

7.4. The Education Programs

As mentioned above, several stages of education and training will be implemented within the framework of NEESPI. These are outlined below at the following levels: a) elementary and secondary school, b) undergraduate education, c) graduate professional education, d) graduate Ph.D. education, and e) continuing education and re-training.

7.4.1. Elementary and Secondary School Education.

Here we include all students in school programs (in the U.S. K-12, in Russia high schools), up to their entry into a college degree program or directly into the workforce. Students not going on to college could be prepared to work in entry level jobs in a variety of agencies and organizations related to earth sciences. Students immediately desiring to further their education would enter college or technical school undergraduate degree programs.

This elementary-secondary school level presents the ideal opportunity to link with existing NASA education programs. As an example of the international program of training and supervision over quality of environment it is feasible to adopt starting points of program GLOBE. GLOBE started in 1996 and since 2002 is carried out under NASA administration. GLOBE's international plan represents the program of partnership between the USA and more than 100 other countries. More than one million children of elementary and middle schools at more than 12000 schools take part in this program. It has more than 20000 teachers who passed training and certified under GLOBE program rules. Their numbers continue to grow. For the areas of research, procedures of gathering of the scientific data have been developed and successfully adopted on the international basis into practical activities of schoolchildren. Studies include learning about terrestrial cover, ozone, aerosols, and meteorological characteristics, characteristics of soil and many others. Data collected and accumulated by schoolchildren of GLOBE program (on the territory of NEESPI research) is the important source of in situ measurements of the NEESPI research program. These measurements include data for studying processes in ecosystems; data for identification of the Earth's surface that are frequently necessary for the analysis of pictures from the artificial satellites. The increase in number of schools actively participating in the GLOBE program on the territory of NEESPI studies is the important part of the educational unit.

7.4.2. College education

Here the students will achieve a basic college (undergraduate or Associates) degree at 2- and 4- year colleges, universities and/or professional technical schools. Graduates would expect to attain good entry level positions in agencies, science institutions, primary/secondary school teaching, other organizations and/or be prepared to go on to graduate degree programs.

Key subjects for students to concentrate on may include: geography, ecology, biology, physics, computer science, mathematics, astronomy, natural sciences. At carrying out of the basic college education stage attention should be given to the use of remote sensing, GIS, and other spatial data and methods. Introduction to such data can be established on the basis of the Internet, or with use of the basic stations of reception of the space information such as « the Earth from space » (that could be created in school laboratories).

At this stage of training a practice of performing individual tasks, course works and work contests should be employed. Thus, except the traditional forms of training a various electronic courses on remote sensing education can be adopted. For implementation of this stage of training some methodical materials, tutorials, scientific literature for teachers, working writing-books, complete sets of games and etc. should be developed. The main attention should be given to:

- Basic studies of the aerospace data processing in relation to different thematic directions: pollution (land, rivers, seas, oceans and atmosphere); detection of forest fires; studying of dynamics of a snow cover, etc.
- Bases of map creation using aerospace data.
- Development of Internet search skills of the accessible aerospace information.
- Development of skills of work with the operative aerospace information received by simple ground stations of reception.

7.4.3. Graduate Professional Education.

Here the graduate education has a strong professional and applications orientation. Graduates would expect to go on to work in agencies, institutes, and organizations, emphasizing both research and applications of the earth sciences. With their advanced training, graduates may eventually take leadership roles in these organizations. This stage prepares experts with the profound knowledge of the following subjects:

- Bases of aerospace monitoring of an environment,
- Theoretical and practical studies of aerospace information processing on various thematic directions,
- Theory and practice of modeling processes of various natural ecosystem function,
- Modeling fields of the radiation registered by systems of remote sensing,
- Theory and practice of applications of aerospace methods and technologies in for monitoring various natural ecosystems, Studying methods of reception, processing, archiving and use of the aerospace data,
- Applications of geographical information systems data received from aerospace monitoring
- Bases of remote sensing of the Earth,
- Mechanisms of regional nature management and eco-economic regulation of economic activities,
- Applications of the newest aerospace and information technologies for regional management, quality of regional environment and bases for nature conservation decisions,
- Application of aerospace methods and technologies in forestry,
- Regional-based decisions of nature related subjects implemented by means of aerospace monitoring.

The list of guidelines for the professional training can be specified during the implementation process of NEESPI.

7.4.4. Graduate Education (Ph.D. Level)

Here the graduate education has a strong research emphasis. Graduates would expect to go on to teaching and research careers at universities and other scientific research institutes, agencies, and organizations. They should become strong international leaders in their field in terms of theory, research, and teaching. These stages will be implemented the following way:

- Professional training of the high-skilled researchers and university teachers by means of postgraduate studies and doctoral studies
- Preparation of courses and seminars to improve professional skill of the these experts

The greatest effect of a high skilled professional training will be achieved with a direct participation of aspirants in scientific researches and the projects, which are carried out with use of aerospace methods and technologies, within the framework of various thematic directions of NEESPI. At implementation stage of personnel training a special attention should be given to development of methods of remote sensing, technologies of reception, processing and storage of the aerospace information, monitoring of an environment and studying GIS technologies, etc.

These stages of educational program can be implemented on the basis of the specialized scientific-educational facilities equipped with modern means of reception, processing and long-term storage of the aerospace data.

7.4.5 Continuing Education and Re-Training

Here the participants are “students” who have been working at jobs for several to many years that have some connection to the NEESPI goals, and desire to update their skills and/or move into a new area of competence, but without pursuing further formal university degree programs. These participants will be more diverse than the above categories - they may have no college degree – or may have up to a Ph.D. This category may also include visiting scholar programs – opportunities for scholars to both learn and share their expertise in a new international environment.

Content may include:
- New or updated skills in remote sensing data analysis and new remote sensing data,
- New or updated skills in GIS technology and methods of analysis,
- Special themes in NEESPI research: landscape ecology, land-cover change, global change, carbon cycle science, forestry, and many others

Methods and Venues may include:
- Independent short courses for professionals with continuing education credit
- Training workshops/courses associated with major conferences
- Opportunities to spend a semester at a NEESPI affiliated university participating in courses and/or research
- Internships in agencies and organizations
- Online courses for credit or updating of skills
- Opportunities to be visiting scholars – learn (sit in on workshops, courses) and share expertise (lectures)

7.5. Administrative Component

7.5.1. Applied technologies

At the preparation of curriculums the modern information technologies should be applied. They should include means of reception of the space information, technical and software methods of the satellite data processing and storage. Apart from the traditional forms of educational process Internets-technologies of online (remote) training and other modern opportunities should be used. The important place in implementation of various stages of education program is participation in the process of scientific researches and projects within the framework of NEESPI with use of space methods and technologies.

7.5.2. Grants

The list of student stipends/grants and also conditions of participation in competitions should be published and be maintained on the NEESPI website. Grant recipients should exchange ideas and present their scientific results to the leading scientists and managers of NEESPI at annual conferences.

7.5.3. Educational field trips

Educational field trips have very influential factor for increase in number and degree of interest between pupils, students, scientists and administrators of the various levels, participating in NEESPI. The main summer field trips can be organized, for example, by a means of crossing routes with NEESPI researches – the first from northwest on a southeast and the second from northeast on a southwest. Details of those trips can be subject to annual updating according to the NEESPI curriculum. Linkages to already established frameworks should be made. For example, the EarthWatch program regularly provides some funding to researchers to organize field expeditions in which students can participate (students typically pay a fee, however there are also some scholarships).

7.5.4. The Internet websites

NASA Internet Site (http: // www.nasa.gov) is a magnificent example of use of new information technologies for attraction of attention and informing of the public through World Wide Web. The NEESPI web site should become a center of achievements of high technologies. For example, with the use of geographical information system (GIS) accessible through the Internet, it will be possible in the interactive mode to model and predict dynamics of quality of environment of the Northern Eurasia at various scenarios of anthropological activities. Links can be made to GOFC networks and websites in Northern Eurasia.

7.5.5. Partnership

Additional opportunity to increase the involvement and interest of NEESPI program among the local population is organization and support of several new programs of partnership between similar territories in the different countries. For example, Tagus-Baikal Institute (http: // www.tahoebaikal.org/projects/) include programs of educational exchange visits. Programs of exchanges play a main role in increase in a level of mutual understanding and increase of efficiency of the international projects of a similar level.

7.5.6. International Coperation

Co-operation with other international ecological educational projects will give an educational part of NEESPI program an additional impulse. Attraction in educational programs of projects of sustainable development (http: // www.unesco.org/education/tlsf/, http: // www.esdtoolkit.org/authnote.htm) is a good example of possible co-operation.

8. RESEARCH STRATEGY

A survey of the science community represented by an interdisciplinary workshop convened by NEESPI in April 2003 and summarized in the remainder of this chapter revealed several notable gaps in our current level of understanding of Northern Eurasian biospheric, climatological, and hydrological systems. At the same time, rapidly emerging data sets, technologies, and modeling resources provide an unprecedented opportunity to move substantially forward. Six major research and synthesis challenges with accompanying recommendations for strategic investments in the science of the North Eurasian system are given below. Furthermore, five major directions of the NEESPI studies are formulated.

8.1. Research challenges

Understanding, simulating, and predicting (or assessing the predictability of) contemporary and future biosphere, climate, and hydrological system dynamics and interaction with human activity are greatly limited by the following:

1. There is a sparse observational network for routine monitoring and an absence of integrated data sets of spatial and temporally harmonized biogeophysical information over the Northern Eurasian domain. The variety of biomes from tundra in the North to semi-deserts and deserts in the South amplifies the problem with observations. The situation is far from optimal, and is deteriorating rapidly over much of Northern Eurasia, especially in Central Asia, Mongolia, and Kazakhstan. The Eurasian Arctic has a scarcity of meteorological and hydrological data. This reinforces the need for reliance on historical data, but also shows the necessity of improved data collection.

<u>*Recommendation:*</u> **A substantial commitment should be made to rescue, maintain, and expand current environmental, meteorological, and hydrological data collection efforts.** Establishing high-resolution gridded maps of climatic, hydrologic, topographic, vegetation, and soil temperatures and property attributes for Northern Eurasia is strongly advised. Additional resources must be invested in scaling techniques, including the expanded use of a combination of modeling and remote sensing. Support for free and open access to the Northern Eurasian environmental data sets is essential to future progress. Coordination with existing national and international monitoring programs is critical.

2. There are numerous gaps in our current understanding of basic scientific principles and processes regarding the interdisciplinary issues of the energy, biogeochemical, and water cycles over the entire Northern Eurasian domain. There is a lack of cross-disciplinary synthesis research and modeling to decipher feedbacks arising from changes in Northern Eurasian climate, land cover, ecosystem, hydrological processes, and cryosphere on the entire Earth system and on society.

<u>*Recommendation:*</u> **Support should be given to integrative research that identifies the unique role of Northern Eurasian hydrological systems and ecosystems in the broader Earth system.** An assessment of the feedback mechanisms through which progressive environmental change influences both natural and human systems is urgently needed. New research devoted to establishing quantitative linkages between the biogeophysical and socioeconomic research communities is strongly advised. We must develop a better physical understanding of processes controlling feedbacks; meaning we must develop better models to assess the vulnerability of society to changes in climate, fresh water/sea-ice, vegetation, dust production, seasonal snow and other parameters of the natural systems. Integrated models of atmospheric, environmental, hydrological and cryospheric processes, nutrient transport, the ecosystem and societal dynamics must be developed and

verified within the major river basins of Northern Eurasia and eventually around the entire continent.

3. We must link terrestrial processes with riverine and coastal responses. We must also quantify how each of these processes has changed over the recent past (50-100 years) and project how they will continue to change in the next 100 years. Changes in soil moisture are an important factor affecting the local, regional and global climate and environment. We must characterize how land use changes (naturally occurring disturbances and anthropogenic perturbations, including afforestation and deforestation) and changes in permafrost extent affect surface soil moisture with subsequent impacts on energy and water balances, and carbon accumulation as well as losses in bogs and forest that grow on peatland.

Recommendation: **Intensive study of soil moisture should be continued and enhanced.** Tools to aid in soil moisture change assessment include: (a) Extensive soil moisture and temperature monitoring at established meteorological stations as well as in other terrain types for target key ecosystems and landscapes, to include different soil types and texture; (b) Development of field techniques to quantify soil moisture levels over spatial areas that would represent a pixel size in a satellite image; (c) Development of remote sensing methods to accurately measure soil moisture levels over large areas; (d) Development of methods to quantify historic levels of soil moisture; (e) Quantifying historic and future changes in precipitation patterns and amounts; (f) Improving understanding of the relationship of soil moisture to other processes; (g) Determining if widespread drying/inundation of soils is occurring and if so, determine the subsequent climatic and ecosystem impacts; (h) Improving our spatial database and distributed modeling expertise on snow cover distribution and re-distribution, changes in forested area, permafrost and active layer dynamics and river discharge; (i) Synthesizing Northern Eurasian water balance studies from around the entire continent; and (j) Development of reliable databases and climatology are required for driving distributed, biospheric, hydrological, and permafrost models, for calibration of remote sensing data/products and for validation of model outputs. Given the scarcity of observational networks in the high latitudes, Siberia, and desert areas of Central Asia, remote sensing and model simulation will play a major role in Northern Eurasia hydrology, atmosphere, ecosystems, and cryosphere studies.

4. Drastic aridization and deglaciation are occurring in the interior of the continent due to an aggregation of global and local anthropogenic causes.

Recommendation: **Extensive monitoring and mitigation strategies should be developed for the Central Asian region.** The current situation in the Central Asian region must be recognized as a complex societal and environmental problem. Studies should include implementation of water and upper soil preserving technologies, modifications of land use, and improved crop management.

5. The coastal zone encompasses the most densely populated and economically developed areas in Northern Eurasia. Unfortunately, it also includes the most vulnerable regions in the current climate and in the forthcoming climate.

Recommendation: **The coastal zone should be explored in detail to quantify its sensitivity to climatic and environmental changes and to the sea level rise.** Estimates of possible damage to the environment, economy and infrastructure should be done on a regional level. The most vulnerable areas must be identified and mitigation strategies proposed for their further development.

6. Society will be affected by anthropogenic and naturally caused environmental changes and react to them. These responses must be guided by an understanding of both the anthropogenic and natural systems, so as to optimally mitigate negative impacts.

<u>*Recommendation:*</u> **Assessments of the consequences and feedbacks of societal actions in response to environmental change (mitigation strategies) should be carried out.** These assessments must be based on comprehensive models of environmental change that include human actions as an indispensable component of simulations and allow feedback loops of societal reactions to the change. A suite of societal actions (e.g., in the areas of agriculture, water resources, forest management practices, environment protection actions, economy development plans, demography planning) should be among the internal blocks of the models of environmental change.

8.2. Major Assumptions

- **Human-caused global and regional climate change will continue for decades to come.** Changes of greenhouse gases and aerosols in the atmosphere, along with land use change will continue to have a global anthropogenic impact. The global consequences of these anthropogenic climate forcings will continue through the 21st century.
- **Numerous feedbacks within the Biosphere-Global Climate-Human Society system have been and probably will be amplified over Northern Eurasia**. Some of these feedbacks are significant and yet are not well understood.
- **Regional anthropogenic environmental impact in Northern Eurasia has been and probably will be non-linear**. In some fragile ecosystems (e.g., in tundra, semi-deserts, and alpine mountains), this impact has been (and is projected to be) especially strong. Potentially, this impact will increase with time and affect all ecosystems in Northern Eurasia.
- **A responsible society empowered by knowledge of climatic and environmental processes can foresee major consequences of anthropogenic environmental impact**. Thus this impact may be mitigated to some extent.

8.3. Five suggested research directions

A. EXTRACTION AND PRESERVATION OF PAST OBSERVATIONS

<u>Unique observational programs</u>. Several sets of environmental data made during the past 60 years in the former USSR are unique. Among them is a set of water and heat balance observations from agrometeorological stations and soil temperature and soil moisture networks; pan-evaporation and actual evapotranspiration measured at the lysimeter network; and lidar monitoring of tropospheric and stratospheric aerosols (baseline atmospheric quality monitoring) (Chapter 5). These networks were established at co-located meteorological and agro-meteorological stations and, therefore, are accompanied by a suite of standard and auxiliary meteorological data. Many of these unique environmental data are stored only in manuscripts or publications (reference books). Therefore, these observational data still need to be digitized, quality controlled, and organized on computer media in a database. These data sets will then be available for use with standard meteorological and present environmental observations and the next generation of observations (e.g., vertical turbulent heat and water vapor flux measurements made by the eddy-covariance flux method and satellite-borne radiation, soil moisture and temperature, and surface heat flux measurements).

<u>Routine observations</u>. Standard meteorological observations in Northern Eurasia have been carried out at more than 15,000 locations. At its peak, the hydrological network included 8,000 river gauges. During the past century, observational programs in Eastern Europe, Nordic countries, the former USSR, Mongolia, and (during the past 50 years) in China have been traditionally rich and include (in addition to standard observations), a set of special observations (Chapter 5). Environmental monitoring included air and water quality control, crop monitoring, and agricultural land and forest inventories. However, during the past 15 years, the in-situ network in Northern Eurasia has substantially deteriorated. To

stabilize and (if possible) restore the density of standard meteorological, hydrological, and environmental observations in the regions of the most prominent contemporary and simulated future changes to climate and land surface in Northern Eurasia is a requirement of highest priority to implement NEESPI science. We have to ensure an adequate representative network for each biome affected by these changes.

B. MONITORING.

Modern observations from space allow accurate and comprehensive quantification of many otherwise unavailable characteristics of ecosystems. Among them are snow cover, glacier area and denudation, soil moisture, forest cover and its attributes, bog area, forest fire area (including past forest fire scars), a host of other land-cover types and, the condition of major agricultural crops. It is also possible to link these characteristics and to estimate, for example, the area of forest located on wet bog and what is still covered by snow.

Since the mid-1960s, international and national satellites have carried various suites of instrumentation that monitor and estimate important parameters of the Earth climate system. Now and in the nearest future, a new generation of satellites (Terra, Aqua, and those to come thereafter) allow enhanced observations of the Earth's energy, water, and biogeochemical cycles (Chapter 5). Generally, satellite measurements that target the surface are more challenging over the land than over the ocean due to heterogeneous terrain with changing properties (vegetation, soil moisture, and seasonal snow cover). It is still difficult to distinguish from space low stratiform cloudiness from snow cover, to "see" snow cover under the canopy, and to assign the "surface" layer to skin temperature measurements over forested areas. Nevertheless, many land surface properties are currently monitored from space and detailed digital elevation data allow fine spatial downscaling of numerous remote, in-situ, and blended land surface observational products.

The accuracy of these products, however, still has to be improved. This can be done with the help of information from in-situ observations and/or regional model data assimilation. The better this information is, the more reliable the monitoring can be. Some algorithms used in interpretation of remote sensing products exist only because of a lack of a choice or no validation data available to properly re-calibrate (or even to discard) these algorithms. For example, the latest intercomparison with in situ observations shows that for North America, using the regional weather forecast ETA model with a 12 km horizontal grid interval, daily surface radiation fluxes at the 0.5° x 0.5° grid can be estimated with the accuracy of 25 W m^{-2} and hourly fluxes with an accuracy of 90 W m^{-2} (Pinker et al. 2003). Similar estimates for Northern Eurasia have been made only up to 1997 with a 2.5° horizontal grid interval. But, these estimates (a) can be easily continued up to date with the same 2.5° spatial resolution (Rachel Pinker, University of Maryland, personal communication, 2003) and (b) if augmented with an appropriate regional hydro-dynamic model and land surface information, can be done with the same spatial and temporal resolution and accuracy as for North America. Expanding the modern in-situ network (FLUXNET) into Northern Eurasia may substantially improve the situation. A large scale investment to properly calibrate the remote sensing algorithms for the Northern Eurasia region is required.

There is the risk that future climatic and environmental changes in Northern Eurasia could negatively affect human society (e.g., aridization, inundation, thunderstorm activity, forest fires, water deficit). Given this background, the risk of extreme events will be more frequent, including catastrophic floods, droughts, fires, forest wind-throw, and landslides. In this situation, the need for comprehensive monitoring with the ability of short-term prediction of detrimental events cannot be underestimated.

C. PROCESS STUDIES

Carbon cycling in terrestrial ecosystems in Northern Eurasia. This is one of the major processes in Northern Eurasia of global importance that require thorough study. The region is the largest terrestrial reservoir of organic carbon where significant past and future changes in climate, cryosphere, disturbance regime, and land use combined with ongoing socio-economic transformation are expected to cause large but very uncertain changes in the magnitude and distribution of carbon sources and sinks. Even the sign of the resulting changes in this distribution is uncertain because several competing factors have affected (and probably will affect) the dynamics of the terrestrial ecosystems in Northern Eurasia. The major threats include (a) intensification of naturally occurring disturbances and anthropogenic perturbations including forest and bog fires, wind-throw, and insect outbreaks; (b) thawing of permafrost (leading to changes in land cover, carbon cycling in vegetation and soils, and changes in surface and subsurface hydrology); (c) changes in land use associated with rapid socio-economic change; (d) changes in ecophysiological processes of vegetation, plant mortality and organic matter decomposition; (e) change in anthropogenic nitrogen deposition; and (f) redistribution of species, changes in successional processes, and shifts of vegetation zones.

Special field campaigns of the past. Northern Eurasia is actually a well-studied region. Numerous seasonal and long-term field campaigns have covered the region during the past century. All environmental topics had been covered in these studies from topographical, geological, and geophysical to biological. It would be a massive effort to repeat many of these surveys instead of collection of all these research materials accumulated in archives of Institutions of the National Academies of Sciences, Hydrometeorological, Forest, and Agricultural Services. Many of these studies can shed light on the past state and historical evidence of dynamics of processes within the Northern Eurasian environment (atmosphere, biosphere, hydrosphere, and cryosphere) that otherwise cannot be acquired. Others can provide clues to a new generation of researchers. Thus, an important task within NEESPI will be to collect the past research data, append and blend them with a new generation of environmental field studies.

Modern field and process-oriented studies. We need a general advance in process-oriented studies specific to Northern Eurasia (cold land processes, large scale interaction with boreal and tundra ecosystems, sustainable agriculture in zones with high risk of incremented weather). To evaluate climate change and variability and land use impacts on the ecosystems' well-being, the following questions need to be solved at the plant and micro-meteorological levels: (a) to determine inter and intra-species variability of stomata resistance/conductance and to organize their databases for the dominant tree species for each ecosystem; (b) to determine transpiration rates and their variability in relation to climate and soil moisture (sap flow method), and pre-dawn water potential for the dominant tree species in the key ecosystems; (c) to determine the boundaries of the ecosystem sustainability; and (d) to determine the thresholds when the structural changes will occur (permafrost thaw, desertification, inundation, swamps advance or degradation, forest degradation, massive insect infestation, soil erosion, and irreversible changes in soil fertility). At the ecosystem and regional scales the following questions should be addressed: (a) What are the major factors of climatic change and human activity that affect seasonal, annual, and interannual variability of key components of energy, water, and biogeochemical cycles within the ecosystem at regional scales? (b) What are the risks of bogging and droughts under various climate change scenarios? (c) How will variability and changes in the cycling of water through the ecosystems be linked to variability and changes in the cycling of carbon and nitrogen within the ecosystems and regional scales? (d) How will changes in the water balance and its components influence the regional climate?

Developing model representations of processes and feedbacks. State-of-the-art climate models suffer from inadequate representation of some physical, chemical and biological processes presumably playing crucial roles in the response of the climate system to changes in forcing. This is associated with insufficient understanding of these processes and limits the models' ability both to simulate natural variability and to simulate realistic scenarios of future changes of the climate system. Model representations of individual processes are to be developed on the basis of and validated against observational data. Within NEESPI, developing of model representations of processes and feedbacks associated with the land-surface, terrestrial hydrology, cryosphere, and vegetation, and their testing of skill using observations, should receive high priority.

Block insert 8.1. Paleoclimatological studies.

Glaciers, frozen ground, swamps, peat, buried soils and wood, tree rings, and lake sediments provide a unique opportunity to unlock many clues about the recent past and present climates, and their system responses, due to the memory stored in them. Integrating process data with paleoclimate data should provide a more powerful basis upon which we can verify simulations of climate states and system responses to climate change. For example, impacts of soil moisture and trace gas feedbacks from the tundra and boreal forest regions, and ice sheet instabilities are critical for accurate model simulations of potential future climates. These analyses are possible due to a unique combination of events and processes that exist nowhere else on Earth. Glaciers in the Arctic and in the high mountains are extremely sensitive to subtle changes in climate and display the effects of long-term trends through their impacts upon surface features. They may provide unique climatic information that can be linked to changes in atmospheric circulation, temperature, snow accumulation, atmospheric composition, marine and continental biogenic activity, aerosol loading/volcanic eruptions, continental dust source regions, forest fire activity, anthropogenic emissions, solar variability and radionuclide deposition. Thus, ice cores need to be collected in Arctic islands and in the high mountains of Northern Eurasia. Also, it has been shown that records of previous climates may be extracted from temperature profiles of deep wells in permafrost because energy transfer is limited to conductive heat transfer only. Analysis of the fossil indicators of permafrost changes (including subsea, subglacial and periglacial permafrost) and glacial history and dynamics with complementing paleothermometery analyses of permafrost can yield valuable information on temporal and spatial climatic dynamics. Given the fact that large parts of Central Asia and Siberia were not glaciated during the last Ice Age, we now realize that many of the geomorphologic features that evolved under different climates are still evident. Actually, each ecosystem has its stored memory (peat, ice, buried soil and wood, lake sediments). Historical records (including data on climate extreme events since the 10th century and on land use since the 17th century) are another source of the environmental information for the pre-instrumental period that should still be carefully examined. It would be possible to resolve many of the complex interactions of atmospheric, terrestrial and oceanic processes through an integrated examination of mass and energy fluxes through these systems, thus constructing a more complete picture of past climates and improving our understanding of climatic forcing mechanisms and feedbacks, and to calibrate climate models.

D. NEESPI MODELING STRATEGY

The NEESPI modeling component concentrates on developing and validating models of different systems and scales capable of reproducing Northern Eurasian natural system states and evolution observed in the past and present, describing interactions of the Northern Eurasian socio-environmental systems with global systems, and, finally, assessing the predictability and, when possible, projecting the future of Northern Eurasia in the context of global and regional change. Proposed modeling efforts are to be organized on three scales: local, regional and global. Such structuring determines clear links between observational and modeling components of NEESPI. The three-scale approach implies using or developing a wide range of models, including atmospheric boundary layer models, soil-vegetation-atmosphere transfer models of different levels of complexity, permafrost models, air pollution models, data assimilation schemes, regional 3-D atmospheric models coupled to comprehensive land surface components, regional high-resolution hydrologic models (including river routing), dynamic general vegetation models, global climate models, including, general circulation models and Earth system models of intermediate complexity; and integrated assessment models. The modeling activity is to be supplemented with developing model diagnosis and intercomparison tools, data assimilation, and down- and up-scaling techniques.

Local scale modeling. A local scale signifies a scale finer than 10 km^2. It is the scale of single experimental point sites at which individual fluxes or cycle components can be measured directly and individual processes can be modeled explicitly. In forested areas it corresponds to elementary inventory unit (stand). Such studies are crucial before integrating the processes at regional or global scales.

Modeling priorities at the local scale include recognizing the most important processes specific for different Northern Eurasia regions and those affecting the regional and global environment. Local-scale modeling is focused on developing (1) detailed parameterizations of the surface processes crucial for different Northern Eurasia regions (e.g., areas of permafrost, swamps, lakes and wetlands, complex relief, non-uniform vegetation and soil, high level of ground water, insufficient soil water content); (2) advanced algorithms to describe impacts of anomalous weather and climate events (e.g., droughts, floods) on water and carbon cycles of different vegetation types; (3) sophisticated approaches (1- and 3-D) to describe energy, water and carbon storages and exchanges between soil, mixed (coniferous and broadleaf species) forest stands and the atmospheric boundary layer; (4) parameterizations of exchange of atmospheric pollutants (greenhouse gases, aerosols) between the land surface and the atmosphere; and (5) new methods to describe spatial heterogeneities of the land cover and meteorological input parameters that allow up-scaling the effects of the heterogeneities to the regional scale.

Regional scale modeling. A regional scale signifies a range of 10-10^6 km^2. At this scale, local-scale processes are integrated over heterogeneous land surfaces. Interactions in the horizontal between the local scale processes come to a focus. Horizontal interactions can be either direct (e.g., horizontal flows within river catchments), or indirect (e.g., between land surface points via atmospheric circulation). Regional scale modeling provides a bridge between local ecosystem behavior and sub-continental through global-scale phenomena. The finer spatial scales are particularly important for assessing extreme events.

Modeling priorities at the regional scale include direct incorporation of improved parameterizations developed in local-scale studies and developing different types of models, such as (1) atmospheric regional models customized for Northern Eurasia sub-regions; (2) comprehensive air pollution models; (3) dynamic general vegetation models; (4) comprehensive river routing models combined with land surface, vegetation and permafrost models; and (5) two- and three-dimensional permafrost models that include the thermal effect of changing vegetation, moving ground waters, and changing ground surface geometry. Techniques are to be advanced of one-way and two-way nesting of hydrological, permafrost, dynamic general vegetation and other environment component models into regional climate models; as well as data assimilation schemes that incorporate modern satellite products and ground-based observations.

Global scale modeling. Studies of direct and feedback effects of Northern Eurasia within the Earth system require employing comprehensive Global Earth-system Models (GEMs, based on atmosphere-ocean general circulation models with biological components), and those of intermediate complexity. These studies are closely connected with simulating observed and potential future climates. For current and past climates, this includes testing the model for predictive global and regional skill. Thereafter, we may be in a better position to develop reliable projections of the future climate. A major emphasis within the NEESPI modeling program is given to developing and improving GEM representations of the land surface including terrestrial cryosphere, aerosols, carbon cycle, dynamic vegetation and atmospheric chemistry. Progress in improving the corresponding model components is heavily dependent on the progress in local and regional modeling. Foci of NEESPI global-scale modeling are: (1) incorporation of improvements in process understanding at local and regional levels into comprehensive interactive hydrological, vegetation, and cryospheric components of GEMs; (2) studying effects and feedbacks of environmental changes in Northern Eurasia in the global context; (3) studying feedbacks between the atmosphere and land surface at the decadal, centennial, and millennial time scales and comparison with instrumental, historical, and palaeo data; (4) estimates of extreme ranges in climate change impacts in past and in present for the entire Northern Eurasia; (5) assessing the predictive skill of the models using the spectrum of important simulated climate variables; and (6) projecting the future.

Integrated assessment modeling. A systematic, integrated environmental change assessment study is to be conducted for Northern Eurasia and its parts aimed at representation of the environmental (climate) change problem within the framework of a quasi-closed system such that the social and environmental consequences of policies to adapt to or to limit the environmental (climate) change are seen in their totality. An explicit mechanism for incorporating and addressing stakeholders' (decision-makers) questions and concerns regarding global change is to be developed to carry out integrated assessment as applied to Northern Eurasia. The mechanism should provide, first at all, for the interests of the major industry/agricultural sectors (oil and gas industries, energy production, forestry, and agriculture) and related societal and economic activities.

Interaction between NEESPI modeling and observational components. There are three main aspects of mutual concern of the NEESPI modeling and observational components: (1) observational data needed for model development and validation; (2) assimilation of observational data into model runs; and (3) employment of models in planning and directing observational campaigns and optimizing observational networks.

Interaction between NEESPI modeling components and modeling components of related on-going programs. NEESPI modeling activity inevitably overlaps with modeling components of a number of already existing programs, and thus includes learning from them. Expectations of model development and improvement are associated with the increasing international activity in the field of model intercomparison exercises, allowing the identification of model errors, their causes, and how they may be reduced. NEESPI-oriented diagnostic subprojects are to be initiated (if not already) in major on-going model intercomparison projects (MIPs) and similar international efforts.

E. IMPACT ON SOCIETY AND THE FEEDBACK LOOP

The impacts of climate change on society, and the feedbacks of societal actions on climate, will be an important part of the NEESPI research program. Studies that address these societal issues can be grouped into the following five major groups.

Human health and well-being. Studies are needed to analyze the interconnections between climate and human health. In particular we need to investigate how past and future climate changes in Northern Eurasia interact with urban and industrial development and social/political changes, and their combined effects on land use/land cover change, on the productivity of the land, and on ecosystem services. This includes studies of the vulnerabilities and capacities of human and ecosystems to adapt to these changes. Lessons must be learned from past land use practices and ecosystem responses throughout Northern Eurasia in order to develop more sustainable natural resource management and future development practices. Studies are needed to assess and inventory the nature, extent and severity of the pollution problems associated with industrial development, as well as with nuclear and toxic test sites, dumps, spills, and accident sites. These studies should include health effect studies of the people living in affected areas, possible mitigation actions, and improved decisions and policies for future actions proposed. Studies are needed to identify relative vulnerabilities of targeted societies and populations (urban, rural, indigenous, those in close proximity to mining and industrial operations) to health impacts from environmental, weather, pollution, and climate factors, and to identify mitigation actions to reduce risks.

Ecosystem Health. Projects that seek to better understand and quantify the effects of global and regional changes on biodiversity, productivity and sustainability of ecosystems and their interactions in Northern Eurasia should be encouraged.

Agricultural and forest productivity. Research work is needed to improve the description and quantification of the impacts of climate and environmental variability and change on agricultural and forestry productivity, to include a feedback loop that accounts for social, economic, political and governmental policies, practices, and management. In particular, while improving current biophysical descriptions of agricultural and managed forestry systems within existing ecosystem models, we need to include in these models genetic and management factors, as well as influences of policies and social factors.

Water management and quality. Studies are needed to analyze lessons learned from previous water management projects in Northern Eurasia and elsewhere and to find methodologies for integrating these lessons into future planning efforts on water management projects in the region. In particular, these lessons should be used to assess the proposed plans to transfer river waters from Siberian rivers to Central Asia. Studies are needed to assess the magnitude and impacts of pollutants as well as the present and potential impacts of anthropogenic influences and climate change on quality of water supplies in Northern Eurasia. Implications of this assessment should be analyzed and possible mitigation measures suggested when and where needed.

Natural hazards and disturbances. Studies are needed to more clearly define the frequency and intensity of extreme events, extensive fires, and natural disasters in the different regions of Northern Eurasia as well as the vulnerabilities of the people in the region to these events and their capability to cope with disasters. This should include improved efforts to monitor, predict, and to feed back that information to people in the region for emergency preparedness. Assessment of anticipated additional effects that could result from environmental changes in the region on the severity and nature of the extreme events, extensive fires, and natural disasters and their impacts on people of the region should also be done. In particular, studies are needed on the evaluation of risks associated with "dirty fires" and anthropogenic accidents that involve radioactive and toxic materials and on the relationships between human activities, ecosystem changes, climate changes, and the initiation of the large dust storms. Assessment of the impacts of extreme desertification and dust events on human and ecosystem health and development viable strategies to mitigate these effects and improve land management practices are needed.

In summary, NEESPI needs to implement a general modeling framework linking socio-economic factors, crop, pollution, land use, ecosystem, and climate models with observational data to address key research questions within Northern Eurasia. As an integral part of these activities, a set of educational activities for students, educators, and the general public is needed as well as interaction with appropriate components of the related ongoing scientific and operational programs. A major objective of NEESPI will be to provide information, which empowers society and decision-makers to plan and react

wisely, to mitigate negative and to benefit from positive consequences of environmental changes.

8.4. Milestones to accomplish the project goals

These milestones will be developed at the NEESPI Implementation Plan stage. The project goals (listed in Chapter 2) are repeated below to round up the story. In the next decade under the NEESP Initiative, we would like to have:

- An integrated observational knowledge data base for environmental studies in Northern Eurasia that includes validated remote sensing products
- Systems proven in the research domain in collaboration with operational partners that can serve the emergency needs of the society (early warning / management / mitigation of floods, fire, droughts, and other natural disasters)
- A suite of process-oriented models for each major terrestrial process in all its interactions (including those with the society)
- A suite of global and regional models that seamlessly incorporate all regionally specific feedbacks associated with terrestrial processes in Northern Eurasia and serve as a major tool for both future environmental change projections and for informed decisions on land use and environmental protection policies.

The "physics" of the abovementioned suite of models dictate the measurement and field research requirements (and not vice versa). The initial steps to accomplish the project goals (approximately over next three years), therefore, should be:

1. Development and testing of sophisticated process-oriented models for major terrestrial processes in Northern Eurasia and collection of measurements that support these models (flux towers, boreholes, socio-economic studies, and data digging).
2. Identification of insufficiently known macro-parameters of the above models and efforts to evaluate these parameters (i.e., an addressed search for means of their determination from space and on the ground).

Thereafter, blending of the acquired information and models should be conducted into an integrated observational knowledge data base for environmental studies in Northern Eurasia. This data base should already include validated remote sensing products and a suite of models that describe a block of processes within Northern Eurasia. Finally, linking the above with Global Climate Models and their extensive use for numerous practical applications in the region (and worldwide) should complete the research objectives of NEESPI.

Scientific Background Appendix.

This appendix contains a sample of materials prepared by the Science Plan authors to Chapters 2 and 3. This information (mostly, scientific background information) was considered potentially valuable for the readers of the Science Plan and preserved in this appendix.

2. SCIENTIFIC QUESTIONS AND MOTIVATION

Part of Chapter 2 related to Climatic and environmental changes in Northern Eurasia was moved to Scientific Background Appendix

2.6. Physico-geographic description of Northern Eurasia.

The geographic realm of Northern Eurasia spans from the Scandinavian fiords in the west to chains of volcanic islands along the Pacific coast in the east, and from the frozen Arctic tundra in the north to the deserts of the Caspian lowlands and plateaus of Gobi and Takla-Makan in the south. This area serves as a home for most of the earth's biomes including tundra, taiga, leaf forest, steppe and desert. Over vast, flat areas of the East European Plain and Siberian Highlands, the biomes and climatic regions have typical zonal orientation where continentality increases eastward. That is, the further eastward, the less the influence of the warm Atlantic Ocean that moderates to some extent the continental climate. The exceptions to this rule of zonality are the climates of the montane biomes in the Caucasus, Ural, Tian-Shan, and Altai Mountains.

The large landmass of Eurasia causes an extreme range in seasonal temperatures, especially in the central parts of the continent, where the difference between summer and winter reaches a record high in comparison with any other non-mountainous climatic region on the planet. The important climate forming factor of central Siberia is the Arctic Ocean. Cold and dry air masses may form over the Arctic in summer as well as in winter. Siberian rivers, in turn, discharge relatively warm water back to the Arctic Ocean, playing a critical role in the delicate energy and fresh water balances of the oceanic thermohaline circulation. In contrast to the interior of the continent, the moderating influence of the Atlantic Ocean on Northwestern Eurasia leads to much lower seasonal changes and relatively high year-round precipitation. The eastern portion of Northern Eurasia (loosely referred as the Far East) is subject to another maritime influence, the warm Kuroshio of the Pacific Ocean. The heat energy of this current feeds typhoons and other weather systems, causing their deep penetration to eastern parts of the continent.

The flora and fauna of Northern Eurasia is affected by its climatic and geographic variety and is represented by a unique diversity of terrestrial and aquatic species (Vlasova 1976). The following physico-geographic zones with distinctively different biomes are distinguished over Northern Eurasia (Figure 1.2). We use two macro-climatic characteristics: the annual surface radiative balance, R, and the dimensionless Budyko radiative dryness index, (R/Lr), defined as a ratio of R to the energy it takes to evaporate annual precipitation, (where L is latent heat of vaporization, and r is annual precipitation totals; Budyko 1971).

- **Arctic Desert** is characterized by the presence of ice and snow cover, negative air temperature throughout the year, a negative, or close to zero, radiation balance, and R/Lr varies from 0 to 0.2.
- **Tundra Zone** is characterized by a severe, lengthy winter, cool short summer with a long polar day, mean summer surface air temperatures from zero to 10°C with low positive radiation balance and radiative dryness index from 0.2 to 0.4. It has high soil moisture, no forests, moss and lichen cover, with shrubs and grass as the prevailing

landscape. Meadows and bogs are also a common occurrence. Soils are gley and weakly podzolic with widespread permafrost over most of the zone. The vulnerability of tundra nature to different anthropogenic impacts is exceptional, taking into account the degree of sensitivity to impacts on the ground surface. The soil deformation and thermoerosion may occur even after a single movement of caterpillar transport. With permafrost and high air transparency, the tundra environment is more vulnerable to pollution than other areas. Particularly vulnerable to pollution are shrub lichens, which are the main fodder of reindeers.

- **Forest-Tundra** is a transitional physico-geographic zone between tundra and forest zones. It is characterized by a combination of forest and tundra elements, as well as thin tundra forests. While referred to as transitional, a substantial area of Eastern Eurasia is occupied by forest-tundra landscape. In Eastern Eurasia, the forest-tundra and up to 75% of forest zone are underlain by permafrost. This makes the zone especially vulnerable to human industrial activity. Gas and oil production, mining, and logging cause catastrophic changes in the habitats of plants and animals. Cutting areas, drilling sites and areas with disturbed vegetation cover do not recover and become boggy. The depth of permafrost seasonal thawing increases, forming thermokarst (sagging deformation of soil surface) and degradation of biomes (3.4, 3.6.1).
- **Boreal Forest Zone** is subdivided into taiga, north, middle and south areas with mixed forest, as well as leaf-bearing (deciduous) forests. This zone is characterized by a snowy winter, a warm summer (with the mean temperature of the warmest month being above 10°C), a positive radiation balance, and a ratio of R/Lr that varies from 0.4 to 1.0. Optimal moistening for the boreal forest occurs when R/Lr is within the 0.8 to 1.0 range. Soil and ground water have low salinity. The major type of soil is podzolic and swampy, coniferous and deciduous forests prevail, and bog moss is widespread. The boreal forest is the largest ecosystem in Northern Eurasia. The area of forested land, however, has steadily decreased during the 20th century, compared to the pre-industrial period (e.g., 16-17th centuries). In West Europe (beyond the Russian boundaries), the forested area has decreased by 68%, from 4.69 10^6.km^2 to 1.52 10^6 km^2, and in Russia by 31%, from 11.75 10^6 km^2 to 8.08 10^6 km^2 (The Last Frontier Forests World Resources Institute - Washington,1997). The major cause for this reduction is the forest clearing for agricultural and developmental needs. A major cause of forest destruction is forest fires, the number of which grows with climate warming and through fault of local population.
- **Forest-Steppe** is a transitional type of landscape that is characterized by a combination of steppe and forest areas. Large forests or groves among steppe areas are widespread on watersheds; there is a considerable amount of precipitation (with high evaporation, greatly varying soil moisture, widespread development of gray podzolized soils and leached chernozem (black soil). Flora and fauna is mixed (i.e., consist of the elements of forest and steppe flora and fauna). This is the most productive agricultural region in Northern Eurasia. Therefore, natural biomes of most of this zone have been replaced by agricultural land. Historical records indicate that natural boundaries of the forest-steppe zone have been highly variable during the past 2-3 millenniums.
- **Steppe** is characterized by a continental climate, a positive radiation balance, a varying radiative dryness index from 1 to 2, lack of forests on watersheds, and a prevalence of grassy vegetation on black and dark nut brown soils.
- **Semi-Deserts** are characterized by a very dry continental climate with R/Lr between 2 and 3, weak development of local hydrographic network, widespread saline soils, and

sparse vegetation consisting of xerophyte grass and shrubs. Semi-deserts are distinguished by natural contrasts (e.g., high temperature ranges in the seasonal and diurnal cycles and presence of oases with very different but regionally restricted ecosystems). They respond rapidly to the disturbances in ecosystem equilibrium. Significant changes took place in these areas in the last decades of the 20th century. The basic cause of these changes was a technogenic factor, i.e. application of modern technology in mining industry, road construction, and mechanization of agriculture on the irrigated lands. When these technical means are used, vegetation is destroyed, fixed sands start moving, and the ground water level becomes lower. Irrigation with excessive watering resulted in salinization of soils, excluding them from land-tenure over a significant part of the zone. The desertification process is going on within the zone. It is determined as a suite of natural and anthropogenic processes leading to destruction of ecosystems in arid areas. It has been established that of 45 factors that identified desertification, 87% are associated with irrational nature utilization by human society and only 13% are caused by natural processes.

- **Deserts** are extremely arid zones with a positive radiation balance and R/Lr greater than 3. Deserts are characterized by a negligible amount of precipitation, a hot summer and high daily and annual air and soil temperature amplitudes. Ephemerals and perennial xerophyte semi-shrubs and shrubs are typical plants. Bare soil prevails. Constant surface water streams are absent. Deserts in Northern Eurasia are extensive (in fact, they are the largest in the extratropics) and are a major source of mineral dust.
- **Subtropics** (dry and wet). The zone is transitional between temperate and tropical belts. There are observed seasons of a year with mild winters. Depending on rainfall amount there are distinguished wet and dry subtropics. Rich vegetation in the wet subtropics is represented by broad-leaved forests (oak, hornbeam, beech) and evergreen shrubs. A very small portion of Northern Eurasia is included into this zone.
- **Glaciers** are a natural accumulation of ice mass mostly self-moving. Section 3.6.1 describes this zone in detail.
- **Mountain regions.** Four types of vertical belts are identified in these regions: Arctic tundra; tundra-taiga; forest-meadow; and subtropical and desert belt. The foothills and mountainous zones with greatest biodiversity (such as the Caucasus, Tyan Shan, and Altai) are the areas where human population pressure may lead to the most pronounced land-use change. Overgrazing, trampling, and nutrient pollution deposition tend to destabilize vegetation, leading to erosion and loss of soil. The high levels of endemism in many montane floras and their inability to migrate upward means that these species are most vulnerable.
- The **coastal zone** in Northern Eurasia is extensive (Figure 2.5). It contains over 40% of the entire population of Northern Eurasia and more than a half of its economic resources. Capitals of several countries of the region (Stockholm, Helsinki, Tallinn, Riga, Baku, and Istanbul) and major industrial centers (St. Petersburg, Odessa, Rostov, Arkhangelsk, Vladivostok, Sapporo, to mention a few) are also located in this zone. In the coastal zone, tendencies of increasing population, economic activity (especially prospecting and exploitation of oil and gas fields), sea level rise, degradation of sea coast due to wave and thermal erosion, denudation, slope processes, and pollution of the coastal bays (especially in the river deltas near large cities) are intensifying.

2.7. Natural variability, anthropogenic impact, environmental and climatic changes in Northern Eurasia

Over the past 5,000 years, the climatic changes in Northern Eurasia were among the largest in the world (Wigley et al. 1981; Lamb 1988; Klige et al. 1998; Selivanov 2000; Jones et al. 2001). Global warming reported by instrumental observations during the past century was also largest in the interior parts of Northern Eurasia [IPCC 2001]. During last few decades mean annual temperature in these regions has increased by 3K, more than anywhere else (Figures 2.2 and 2.7).

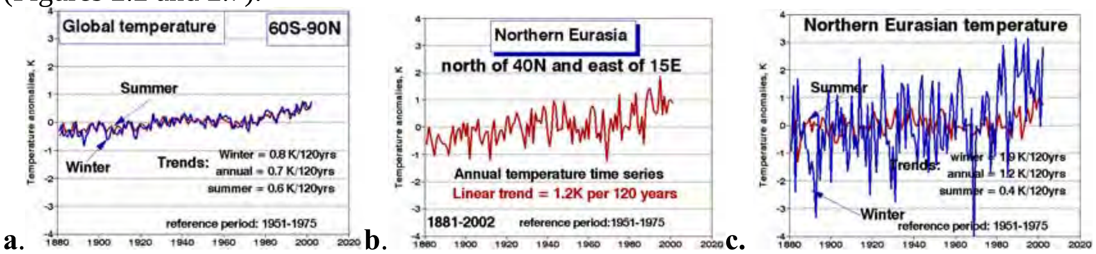


Figure 2.7. Zonal and North Eurasian surface air temperature changes during the past 120 years. (a) global (for zone from 60ºS to 90ºN); and regional surface air temperature area-averaged over Northern Eurasia: (b) annual and (c) seasonal time series. [Data source: CDIAC; Archive of work of Lugina et al. 2003].

Finally, model projections of the future climate changes related to increasing of greenhouse gases in the atmosphere show that this region has the greatest change response (IPCC 2001). Changes in the surface energy balance are accompanied by changes in terrestrial hydrology. In the continental boreal climate of Northern Eurasia, temperature changes directly affect the duration of the frost-free, snow-free, and growing seasons, and thus cause changes in evapotranspiration.

Further, this part of the world is “protected” by mountain ridges from the direct influx of water vapor from the tropics except along the easternmost part of the Pacific coast (Kuznetzova 1978; Shver 1976). Major sources of water vapor in that area include the Atlantic Ocean, the Arctic Ocean, and their coastal seas. Large interior lakes like the Caspian Sea, Baikal, and (up to the recent years) the Aral Sea also contribute. Thus, the advection by extratropical storms is the major means of moisture transport. This makes precipitation conditions of the interior of Northern Eurasia highly variable and very sensitive to circulation changes. Thus, relatively modest changes in the global circulation of the atmosphere and ocean may substantially affect climate and environmental conditions in Northern Eurasia. Historically, small shifts in storm tracks resulted in enormous variations in water balance of interior lakes, in deep ground water circulation systems, and in corresponding shifts of the ecosystem boundaries. Paleoclimatic, archeological, and historical records indicate propagation of forested and steppe areas far southward into the desert and semi-desert areas during “wet” epochs and their retreat and desertification during the prolonged periods of insufficient precipitation. These changes were quite swift (with a time scale of several decades) and were accompanied by prosperity and/or collapse of local agricultural and nomadic civilizations (Wigley et al., 1981; Lamb, 1988; Gumilev, 1990; Kaplin and Selivanov, 1995; Pirazzoli, 1996; Selivanov, 2000; Jones et al., 2001; Kobak et al. 2002; and many others).

Because of the short growing season in the north, most agricultural production in Northern Eurasia is concentrated in the southern part of the region in the forest-steppe and steppe zones. These zones are the regions of increased societal water demand (Vörösmarty et al. 2000). Unfortunately, most of agricultural fields and pasture in these zones are not irrigated and are prone to frequent droughts. Water availability has become a central issue for social and ecological sustainability. Regretfully, conclusions derived from present Global Climate Models are dissimilar when addressing the water cycle changes over the region. The sources of these differences must be carefully assessed and resolved in the future.

During the past century, the anthropogenic impact on the environment has been significant. Deforestation, soil degradation at the agricultural fields, intensive industrial development, conversion of the natural environment into agricultural land and pasture, urban development, water withdrawal, irrigation, and man-induced forest fires have changed landscape and thus impacted regional ecosystems and climate. The state-run centralized economy of the former USSR and other countries of the region significantly enhanced the anthropogenic impact that, in many cases, had unforeseen negative consequences (e.g., Box inserts A2.1 and A2.2).

Box insert A2.1. Figure 2.8 shows one of the many striking effects of human activity on the region. Only forty years ago, the Aral Sea was the world's fourth largest lake and the second largest lake in Central Asia. In 1949, it had a surface area of 66,000 km^2 with an average depth of 16 m and maximum of 68 m. Its waters supplied local fisheries with annual catches of 40,000 tons. The deltas of its major tributaries hosted dozens of smaller lakes and biologically rich marshes and wetlands covering a total of 550,000 ha. Anthropogenic impact in the Aral Sea area began long before the past century. But, during the last fifty years, the Aral Sea has virtually dried up. The water level dropped 14 m, the lake surface decreased to 26,000 km^2, and water salinity reached 25-30 g/L that resulted in the loss of all fish species. Today, the Aral Sea is literally disappearing from the world map. Extensive water withdrawal from the major rivers that feed the lake caused this ecological disaster. If water withdrawal occurs at the present rate, most of the Sea (greenish area in the center) will evaporate in the next 10 years. The exposed seabed consists of vast salt tracts, whose sand and dust, polluted with pesticides, are carried by the wind up to a distance of many hundreds kilometers at an estimated rate of 15 to 75 million tons a year. During dust storms this mixture can cause ecological consequences in regions windward of Northern Eurasia. In Section 3.4, we discuss these issues and other examples of human alteration of major ecosystems in Eurasia in greater detail.

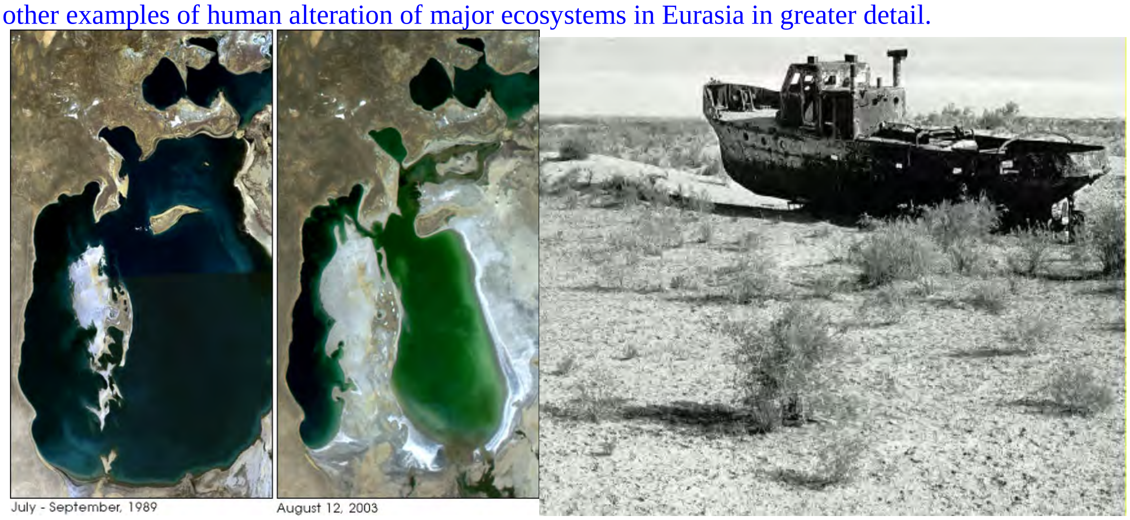


Figure 2.8. Remains of the Aral Sea in 1989 (left) and in 2003 (center). On the satellite images, dark colors represent areas that are still covered by water and white color shows the salt-covered dry bottom that is quite fresh and has not yet been mixed with sand.

Box insert A2.2. The Caspian Sea is the world's largest lake. It does not have outflow and thus is salty. Most of its influx (~80%) comes from the Volga River that has been covered by a set of reservoirs during the 20th century. These reservoirs and water withdrawal for irrigation and other types of water consumption caused a systematic decrease in the River streamflow that affected the Sea level, and thus the coastal zone, fisheries, urban development, and transportation. During the past sixty years, Figure 2.9a shows a relatively stable Sea level up to the late 1970s and then an increase in the Sea level that would have happened without the anthropogenic impact. However during the 1950-1980 period, this natural process had been temporarily reversed by the regional anthropogenic impact misguiding the water managers. The misjudgment caused enormous economic and environmental losses when protective measures "to save the Sea" (the dam construction to separate the Kara-Bogaz-Gol Bay from the Sea) were implemented and finally failed.

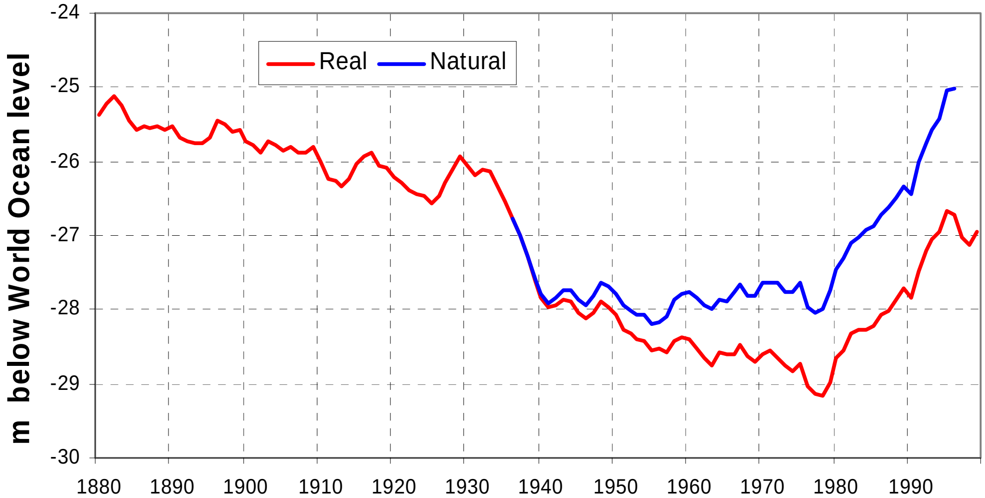
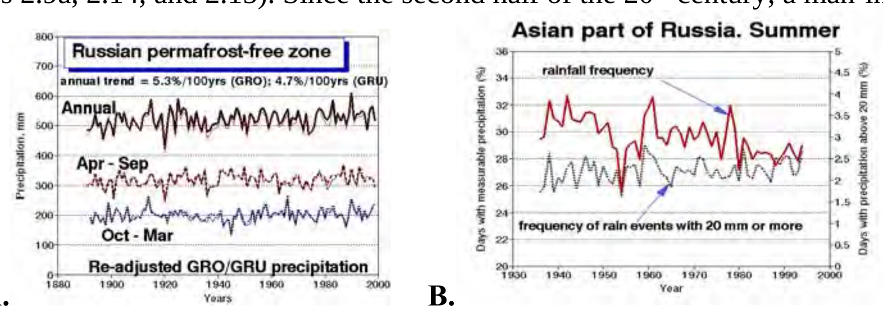


Figure 2.9a. Observed and "natural" changes of the Caspian Sea level (Shiklomanov 1976; Shiklomanov and Georgievsky 2003). "Natural" changes are the changes that would have happened if there were no anthropogenic impacts on the river inflow into the Sea.

Figure 2.9b. Northern part of Kara-Bogaz-Gol Gulf, Turkmenistan. Left on 9 September 1985, Right on 3 June 2000. The total current area of the Gulf is ~12,500 km^2, with an average depth of 10 m. The Gulf is quite shallow, which causes even more dramatic changes in the water level than can be seen along the coast of the Caspian Sea. In 1984, the Gulf was completely dry due to dam building to stop the Caspian Sea level decrease. When the water in the Caspian Sea began to rise again, an aqueduct was built so that the Gulf water level could rise again [Source: CALMIT/LNL].

All global climate models, when used to assess the scenarios of future changes in chemical composition of the atmosphere, predict a significantly and disproportionately high rate of warming over Northern Eurasia. Most of the models also predict an overall precipitation increase in high latitudes, but increasing soil dryness in the interior regions of the continent (already arid) during the summer (IPCC 2001; Mokhov et all. 2003). These changes will shift climatic zones, and have affects on a) the spring onset and duration of the growing season, b) periods of snow cover, and c) periods with GPP. *It is probably too early to speak about shift of climatic zones, but other projected changes are already occurring.* Specifically, during the past century, the regional annual mean temperature has increased by more than 1 K and by ~0.5 K in summer (Figure 2.7); this regional warming was steady and during the past several decades has accelerated (Figure 2.2). During the same century, precipitation over the former USSR territory has increased by ~ 5 to 10% (Groisman 1991; Gruza et al. 1999; Groisman and Rankova 2001). Regionally, a steady precipitation increase was observed in Scandinavia and Eastern Europe, no rainfall increase was observed in Central Asia, and non-linear changes were documented for Eastern Siberia: a notable increase during the first half of the past century was followed by a slight decrease during the past several decades and notable changes in precipitation intensity (Groisman 1991; Gruza et al. 1999; Figure 2.10). Dryer conditions were gradually introduced during the past century in the steppe areas of Western Siberia and Kazakhstan (Figure 2.11). Earlier spring onsets and earlier spring snow cover retreat were documented over Eurasia (Bulygina et al. 2000c; Brown 2000; Groisman et al. 1994; Figure 2.12) and specifically over all mountainous systems of Northern Eurasia (e.g., Figure 2.13). More winter and spring thaws in the eastern half of Northern Eurasia was a result (Groisman et al. 2003a). A significant continental increase of streamflow into the Arctic Ocean and the Caspian Sea was observed (Box insert 2.2; Figures 2.9a, 2.14, and 2.15). Since the second half of the 20th century, a man-induced



A. **B.**

Figure 2.10. Precipitation changes over the major permafrost free zone of the Russian Federation (Groisman and Rankova 2001). (B) Summer frequency of wet days and days with heavy rains over Siberia (Sun and Groisman 2000).

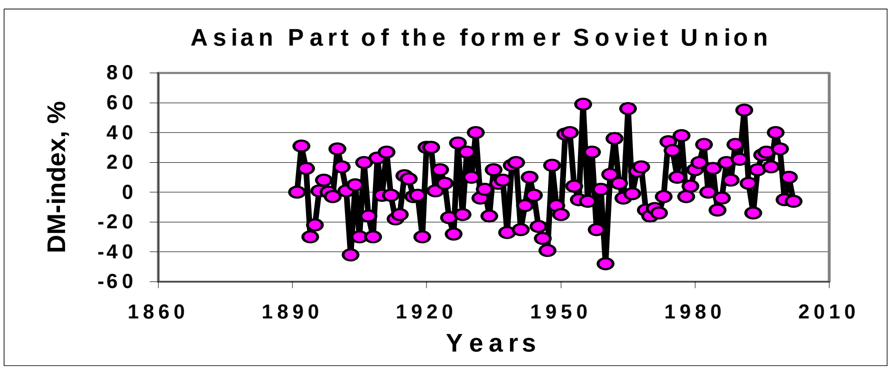


Figure 2.11. Time series of the DM index for May, June, and July over the major cereals-producing region of the Asian part of the former USSR (western Siberia and northern Kazakhstan). Area differences, in percent for the period 1891-2002 are updated from Mestcherskaya and Blazhevich (1997) and characterize the spread of dry conditions over the region. The observed linear trend (16%/100yrs) is statistically significant at the 0.05 level.

degradation of dry lands has increasingly contributed to the desertification process. In several regions of Central Asia, Mongolia, and Northern China, this process is currently under way (Kust 1999; Zolotokrylin 2003; Erdenejav, 2000; 3.6.3). It occurs mostly over arid and semiarid lands, but sometimes also over dry sub-humid lands that have been degraded by human activities. Analyses of the desertification monitoring data during the past two decades using remote sensing tools (NDVI) gave the following results. The northern limit of the area subjected to the desertification process in Central Asia has remained stable. The area expanded southward as a result of draining the Aral Bottom and landscapes of the Amu-Darya and Syr-Darya delta plains. Comparison of the past decade (1992-2001) to the previous decade (1982-1991) revealed a tendency of reduction of the desertification in the Caspian Lowland and its intensification in the areas between the Aral Sea and Lake Balkhash (Zolotokrylin 2003).

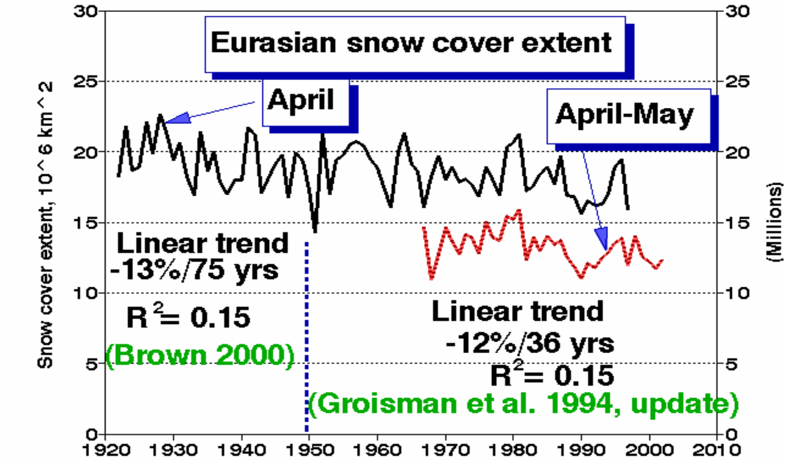


Figure 2.12. Eurasian snow cover extent in late spring (April, April-May) according to reconstruction by Brown (2000) and satellite visual imagery (Robinson et al. 1993; Groisman et al. 1994, updated).

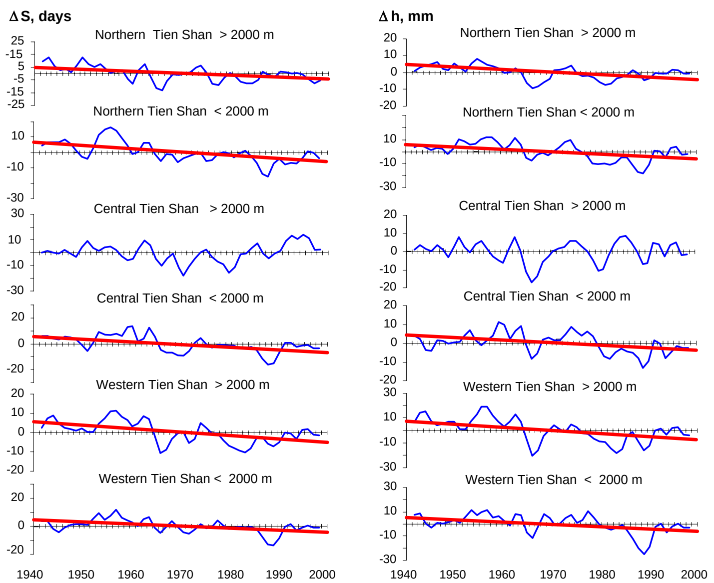


Figure 2.13. The snow duration ΔS and snow thickness Δh changes in Tien Shan (Aizen et al. 1997a).

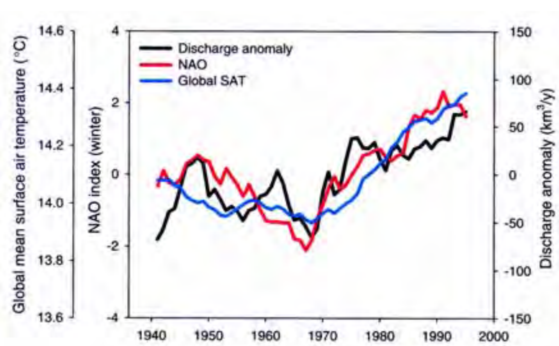


Figure 2.14. Eurasian Arctic river discharge anomalies (Peterson et al. 2002).

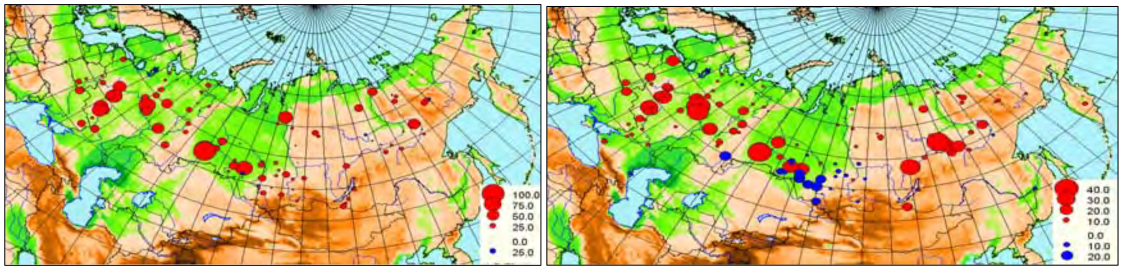


Figure 2.15. Resent changes in North Eurasian streamflow. Deviations (%) of winter (left) and annual (right) runoff for 1978-2000 compared to the long-term mean for ~ previous 55 years. Georgievsky et al. (2003). Note that the scales of changes are different in these two maps.

Besides climatic changes, significant environmental changes have occurred over Northern Eurasia during the past century. Among the most prominent are:

- Lake level changes, including the first and forth largest lakes in the world, Caspian and Aral Seas (Figure 2.16; Box inserts A2.1 and A2.2);

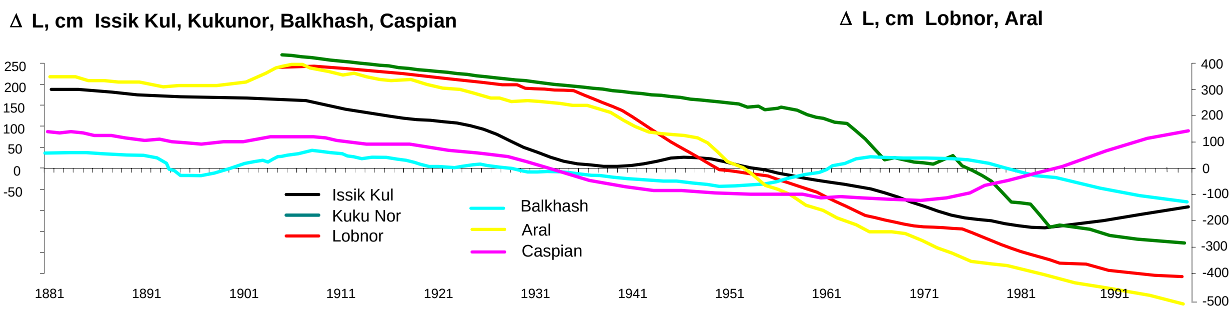


Figure 2.16. The lake level changes in Central Eurasia north of 40°N (instrumental data)

- More frequent droughts and forest fires (Figures 2.11 and 2.17)
- Large scale irrigation projects in Polessie, southern Russia, Ukraine, and Central Asia
- Construction of numerous dams, channels, river regulation, water withdrawal and consumption, streamflow changes, and snow melioration
- Conversion of "virgin lands" (mostly steppe of Kazakhstan, Ukraine, and Russia) in agricultural land (some of them have been gradually abandoned in the past decade);
- Intensive logging, man-caused fires, and fire suppression;
- Large scale reforestation projects in southern Russia and The Ukraine (forest-protection stripes)
- Land withdrawal for urban and industrial development
- Changes of air, soil, and water quality in the areas around industrial centers as well as far downstream (and downwind), especially in the regions affected by the air transport from industrial centers of Western Europe
- Acid rains
- Inadvertent (or ill-conceived) negative anthropogenic changes: soil erosion; degradation of fallow fields overgrown with shrubs; drainage of bogs and bogged forests in attempt to increase the forest productivity; removal of the upper soil layer in tundra and the permafrost zone for road and pipeline constructions; logging in the water-protection forest areas; woody debris remains after logging, along the rivers' and lakes' banks and sea shores (which are potential CO_2 source and disturb flood regimes and runoff); dams and reservoirs that lead to bogging the adjacent territories; introduction of agro-mono-cultures (e.g., cotton in Central Asia); overloading soils with chemical fertilizers; livestock waste infiltration into ground waters and rivers; deflation after pasture overloading; etc.

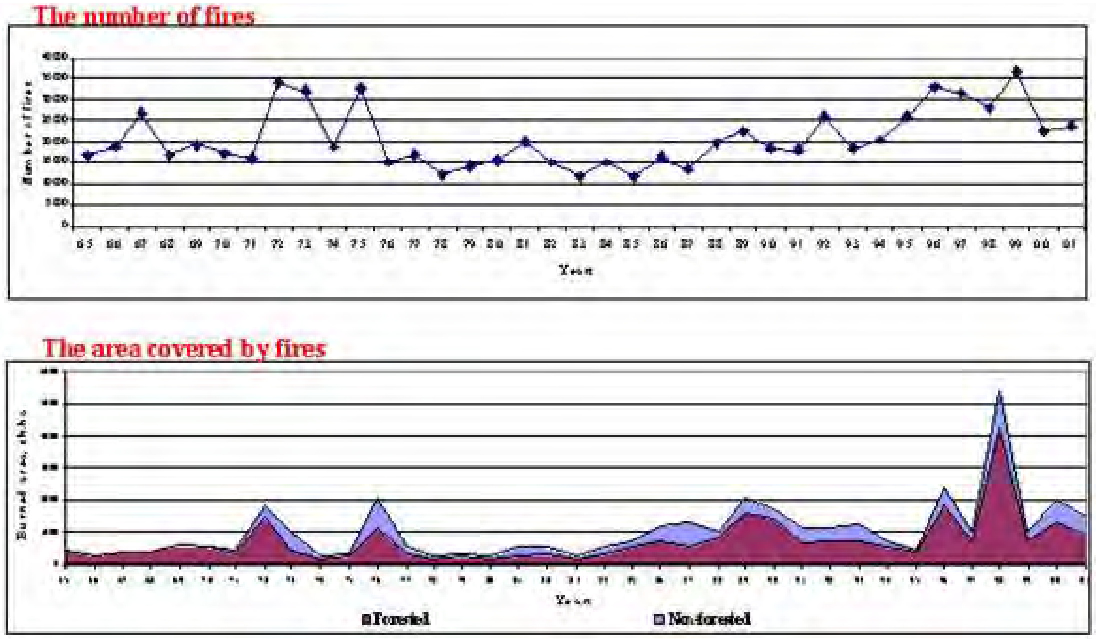


Figure 2.17. Dynamic of fire numbers (top) and the area covered by fire (bottom) in Russia during the 1965-2001 period.

Most of the above listed changes have been caused, at least in part, by HA and thus, are *forced* changes. To reveal the climatic component in these changes is not a trivial task (see however, Box inserts A2.2 and 3.6.1). However, each of these environmental changes did occur. They interacted with climate, influenced, and were influenced by it. **The future regional models (blocks of the global change models) that seek a realistic description of the past changes in Northern Eurasia and their global feedbacks must, therefore, include a changing external forcing and internal feedbacks that characterize these environmental changes**. A vague name for these changes is a *land cover change forcing*, although not all of them affect the land cover itself (IPCC 2001; Pielke 2002).

Historical vegetation changes were more dynamic in southern regions with an earlier beginning of agricultural activities: in the forest-steppe and steppe zone in East Europe (Dinesman 1977; Serebryannaya, 1982), in the foothills of the Caucasus, and in south of Mongolia (Dinesman and Savinetsky 1997; Savinetsky 2000), in Central Asia (Klige et al. 1993, 1996), on continental dunes in the interior of Poland (Jaskovski, 2002), and generally over the interior of Eurasia (Selivanov 1994, 1996, 2000). In other words, natural changes in these regions were grossly enhanced by anthropogenic impacts much earlier than it could be anticipated. The above-mentioned regional models should, therefore, account for the HA impact even when used to reproduce the pre-industrial epoch in these regions. For example, one of the most famous environmental changes in the history of Medieval Central Asia (diversion of the Amu-Darya streamflow from the Caspian Sea to the Aral Sea) was made by the Mongol army during the siege of Khoresm City in the 13th Century.

To complete the story, it should be emphasized that significant environmental changes occurred over Northern Eurasia during the past 6K years, when the most vivid impact of the last glaciation was mostly gone and the global climate did not vary too much. Nevertheless, in Northern Eurasia shifts of climatic zones by several hundred km, intra-area changes in species composition, substantial variation in lake levels and the areas and humidity conditions of arid, semi-arid, and steppe zones were documented. These last zones seem to be the most volatile in the past millennia (Kobak et al. 2002; Zubakov and Borzenkova 1983;

Khotinsky 1977, 1984; Selivanov 2000; Kozharinov and Puzachenko 2004; Table 2.1; Figure 2.18).

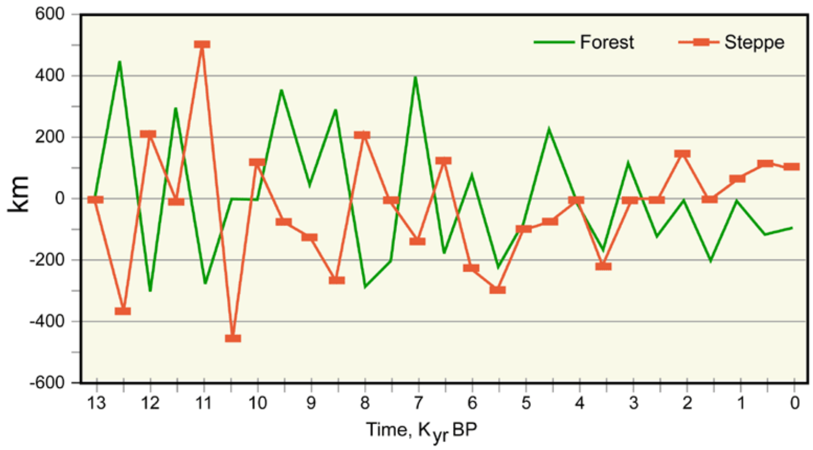


Figure 2.18. Changes of the northern boundaries of forest and steppe zones along the 39°E during the past 13 thousand years (Kozharinov and Puzachenko 2004).

Table 2.1. Phytomass and Net Primary Productivity (NPP) of Siberian vegetation in the mid-Holocene and in contemporary climate (Monserud et al. 1995).

Vegetation Type	Areas, Mha		Phytomass, Pg		NPP, Pg yr^{-1}	
	mid-Holocene	Present	mid-Holocene	Present	mid-Holocene	Present
Tundra and Mountain tundra	67.2	142.2	1.29	2.73	0.23	0.48
Forest-Tundra (spruce, larch)	23.8	18.4	1.02	0.79	0.09	0.07
Forest-Tundra (larch)	39.9	16.5	1.73	0.72	0.19	0.07
Dark north taiga (spruce, larch)	132.1	56.6	14.14	6.06	0.87	0.37
Light north taiga (larch)	35.5	118.3	1.89	6.3	0.19	0.63
Dark middle taiga (cedar, spruce)	167.1	56.4	31.39	10.6	1.32	0.45
Light middle taiga (larch, pine with spruce)	124.1	189.5	17.13	26.16	0.81	1.24
Dark south taiga (Fir, spruce, pine)	86.9	76.6	17.84	15.73	0.68	0.6
Dark mountain forest	36.4	44.0	4.36	5.27	0.24	0.29
Birch sub-taiga	18.8	19.6	3.45	3.59	0.24	0.26
Birch with broad-leaf species	14.1	0.00	2.63	0.00	0.15	0.00
Light subtaiga (larch, pine with linden and steppe)	26.7	20.3	4.39	3.34	0.22	0.17
Birch forest-steppe	16.3	48.2	0.96	2.83	0.14	0.42
Forest-steppe (birch, pine)	11.0	3.6	1.14	0.37	0.04	0.1
Mixed grass mesophytic steppe	91.8	76.6	1.57	1.31	1.57	1.31
Semidesert and desert	4.6	9.5	0.04	0.07	0.03	0.06
Total	896.3	896.3	104.97	85.87	7.01	6.43

Some dominant species of the modern boreal forest existed in their territories during the Late Pleistocene and Holocene (Vygodskaya et al., 1995; Kozharinov and Puzachenko, 2002). For example, a dominant species of the modern European dark-leaf taiga *Picea abies* formed forests with co-dominant species across East Europe during the last 15 000 years. There were some changes within the communities, though. The main determining environmental factor of the spruce forest dynamics during the last 7 000 years was the heat and water supply (Kozharinov and Puzachenko 2002). Thus, *Pine sylvestris* forests in Poland preserved during a part of the Subboreal period were climatically unstable in the Subatlantic then, as well as now (Jaskovski, 2002). These, and similar "within the biome" changes occurring over large areas affect the large-scale biogeophysical and biogeochemical properties of the biome and thus, generate appropriate feedbacks.

By the mid-Holocene (4,500-6000 before present, BP), the main vegetation pattern in Northern Eurasia looked like the present (Khotinsky 1984; Monserud et al. 1998), although quantitative differences were noticeable (Table 2.1). During that period, the climate was milder and wetter (reconstructed January temperature were higher by ~ 3.7 ^{o}C, July temperature by ~ 0.7 ^{o}C, and annual precipitation was higher by 95 mm; note that the temperature changes are already close to those observed during the past century!). The forest border moved far northwards and some European warm-loving tree species, like linden and elm, advanced into West Siberia from the Ural. A distinct feature of vegetation cover in Siberia was more developed dark taiga on the east bank of the Yenisei River.

By the Late Holocene, 2,500-3,000 BP though, a Siberian tundra-forest border moved southwards. Larch and pine dominated the forests east of the Yenisei River and cedar dominated the forests west of the river. In the southern mountains, the dominating role of cedar and sometimes spruce in the upper belts increased; fir and spruce outcompeted light species like pine and larch in the middle belts. Both events were related to a moister climate (Nastchekin, 1975). It can be concluded that climate became more severe and caused these changes.

Scientific Background Appendix. Chapter 3

3.1. Terrestrial Ecosystem Dynamics .

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3.1.2 Ecosystem pattern and key features

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3.1.2.1 Tundra

The tundra biome occupies the Northern limit of the Eurasia. In Russia, the tundra biome occupies near 280 10^6 ha or 16% of total country area. The structure and functioning of tundra ecosystems are strongly governed by climate gradients and local geomorphology (Chapin et al., 2000), leading to complex mosaic of landscape types and intrazonal elements (Figure 3.5). Main landscape types in Russian tundra biome (Zamolodchikov, Karelin, 2001) presented by arctic deserts and arctic tundra (25% of total biome area), typical tundra (27%), south sub-arctic tundra (16%), forest-tundra (17%) and different variants of mountain tundra (16%). The vegetation cover is presented by different combination of dwarf shrubs, grasses, mosses and lichens. The canopy height is low usually not exceeding 30-50 cm. The aboveground biomass of specific plant groups is close correspondent to projective cover. This situation allows the two-dimensional view on production processes and facilitates the using of remote sensing techniques (Oechel at al., 2000a). The structure and functioning of tundra ecosystems are strongly affected by the presence of the perennially frozen ground. Physical, chemical and biological processes are strongly slowed down within the permafrost body under low temperatures. Warm seasons melt of a thin uppermost ground layer (called an “active layer”) on the atmosphere/lithosphere boundary results in multifold increase and acceleration of these processes. A dynamics of active layer strongly depend on soil temperature behaviour, which is mostly driven by air temperature, solar radiation, albedo, heat conductivity of vegetative and soil cover, soil moisture, ground water mobility, snowpack thickness, etc. Particular combinations of these controls in different permafrost landscapes are rather variable, which makes it difficult to predict a permafrost dynamics at regional and global scale.

3.1.2.2 Forests

Forests are a significant global reservoir of the organic matter and a powerful regulator of water and energy exchange and biogeochemical cycle. A single country in Northern Eurasia, Russia, has 22 % of the global forest resources and 38% of the Eurasian forest resource (FAO 2001). The magnitude of the forest area suggests its role in the global climate system, as potential sink or source of atmospheric carbon (Stocks et al. 2002). It is difficult to overestimate role of forests as source of many goods of vital importance for human society, as a habitat for wild animals of taiga, as a natural habitat for indigenous population of the North. Distribution of forests over territory of the Northern Eurasia as well as forest composition and productivity are determined by temperature and humidity gradients, continentality and also by soil forming rocks and relief. About 75 % of forests are growing on permafrost, including regions of Central and East Siberia, as well as Far East. Significant part (41 %) of Russian forests is categorized as mountain forests therefore altitude is also important factor of forest distribution in Northern Eurasia.

The boreal coniferous forests are the dominant biome in the Northern Eurasia, and six tree genera mainly form forest stands: 16.0% of Russian forest area is covered by pine (*Pinus* sp.), 10.6 %- by spruce (*Picea* sp.), 36.6% - by larch (*Larix* sp.), 2% -by fir (*Abies* sp.), 12.9 %- by birch (*Betula* sp.), and 2.8% -by aspen (*Populus tremula*). In European part pine, spruce, birch and aspen are most representative. Ural and Western Siberia forests are dominated by *Picea obovata, Pinus sibirica*, and also by *Abies* sp. Eastward pine forests are widely distributed. In the Asian part of Russia, larch covers 38% out of total area in forest. Significant areas of birch- and aspen-dominated secondary forests are the result of extensive forest exploitation, mainly during 20th century.

In Russia, most of forests (76%) falls within the southern (128 millions ha) and middle (461millions ha) taiga (Utkin and Zukert, 2003). The southern boreal zone has a dominance of conifers and scattered occurrences of the broad-leaved trees. A contribution of herbs and shrubs into the vegetation composition is relatively high. Both the middle and northern boreal zone have conifer dominance, with Birch spp. as the main deciduous trees. Herbs are mainly restricted to nutrient-rich sites. The northern boreal zone deviates from the middle boreal zone by the addition of a number of northern vascular plants and an abundance of willow Salix spp thickets as well as by higher abundance of bryophytes and lichens (Esseen et al, 1997).

Southward of zonal tundra, forest-tundra and sparse north taiga forests occupy large area (143 million ha) (Utkin and Zukert, 2003). In European part of Russia, Western Siberia and Krasnoyarsk region, southward of taiga, temperate forest (mixed and deciduous) are located and they transit to forest-steppe. Area of these forest is insignificant (3- 4% out of total forest area). Forests of steppe zone, semi-desert and desert amount to 1 -1.5% out of forest area. These south forests are dominated by oak on west and by birch and aspen on east.

The main source of information on geographical distribution of the forest over Northern Eurasia and its structure is national inventories. Accuracy and availability of these data significantly differ from one country to another. E.g. in Russia by 1998 the forest area inventoried with use of high resolution air photographs and selective field observation was 61%; about 24% were inventoried only by using of false-colour satellite photographs and 15% were inventoried by air visual survey at the 1950-60th of 20th century (mainly in remote unmanaged forests situated in forest tundra and sparse taiga zones). As the accurate and up-to-date data on forests is important input for number of the NEESPI research and development the creation of uniform and comprehensive database on forest cover for entire Northern Eurasia is considering among other priorities. The appropriate methods to derive qualitative and quantitative characteristics of the forests with use of earth Observation data combined with available in-situ information have to be developed to ensure data accuracy and reliability.

3.1.2.3 Grasslands and associated arid ecosystems

Grasslands, semi-arid and arid ecosystems, constitute a significant portion of total land area in Northern Eurasia and act as a “food basket” for the global population being the main area for agricultural production. These systems have experienced dramatic land-use changes over the last several decades. Over the last decade, these changes have accelerated due to policy reforms. The scale and magnitude of these land-use dynamics are relatively unknown (Desertification and Soil Degradation, Moscow, 1999).

Grasslands and arid ecosystems of Northern Eurasia are quite different and include the following biomes (from north to south) (Dobrovolskiy, Urusevskaya, 1984):

- Plots of grasslands inside broad-leaf forest and forest-steppe subzones with high annual grass productivity (5-8 t/ha), annual precipitation of 400-500 mm and evaporation ratio of 1.0-1.2;
- Steppe grasslands with extremely high annual grass productivity (12-15 t/ha), annual precipitation of 350-450 mm and evaporation ratio of about 0.8-1.0;
- So-called "true" or "real" steppes with very high annual grass productivity (8-12 t/ha), annual precipitation of 300-400 mm and evaporation ratio of about 0.6-0.8;
- Dry steppes with high annual grass productivity (5-8 t/ha), locally alkaline soils, annual precipitation of 250-350 mm and evaporation ratio of about 0.3-0.6;
- Semi-desert grasses and semi-sub-shrubs with weak annual productivity (3-5 t/ha), big areas of alkaline and saline soils, annual precipitation of 150-250 mm and evaporation ratio of about 0.2-0.3;
- Desert ecosystems with extremely weak annual productivity (<3 t/ha), areas of saline soils, annual precipitation of 50-150 mm and less and evaporation ratio below 0.2.

Besides these belt-like zones and subzones of grasslands and arid ecosystems, the specific biomes of grasslands, semi-arid and arid ecosystems are located to the pre-mountains regions of Altai, Sayan. Tyan-Shan, Pamir, Kopetdag, Caucasus, Ural and other mountains areas. The specificity of these biomes depends on the climatic conditions (prevailing winds, macro- and micro-climate), altitude, and soil-forming rocks.

In addition to the mentioned biomes it is necessary to withdraw that despite of the similarity of ecosystems in the belts, they differ also from the west to the east with the formation of so-called "facies changes" that occur as the result of the increase of climatic continentality and of the growth of the contrast between warm and cold year seasons.

The total annual productivity of grasslands ecosystems in Northern Eurasia is the highest among other ecosystems of the area. Also it characterized by the relatively high content of living biomass in the topsoil. The content of the dead organic matter (soil humus) is also very high in chernozem soils of the steppe regions (up to 900-1200 t/ha) and decreases to 50-100 t/ha in arid conditions. Despite of these features, the accumulation of dead organic matter in steppe area is much less than in forests and reach zero in deserts.

Another common feature of these ecosystems is the lack of water that increase from north to the south and limits the potential productivity. But in the regions of rivers deltas and other flood-lands or under the irrigation the annual production is large. Thus, these areas and the relatively northern grasslands are intensively used for agricultural purposes. Due to aridity, some regions, peculiarity, closed river basins, represent globally important geochemical accumulations of alkaline and neutral salts (Kust, 1999).

3.1.2.4. Peatlands are characterized by the unique ability to accumulate and store dead plant material originating from mosses, sedges, reeds, shrubs, and trees as peat, under waterlogged conditions. Peatlands have extremes of high water and low oxygen content and vary from low to high availability of nutrients. Peatlands are the most widespread of all wetland types in Northern Eurasia, representing up to 70% and even more of their area. Mire is a peatland on which peat is currently forming and accumulating. It is difficult to determine whether a mire/peatland ecosystem works as a sink or source of carbon at a given moment. This source/sink function can change from year to year with long- or short-term climatic changes working as a triggering mechanism. Paludified lands and forests having thin peat layer (<30 cm) are especially sensitive to such functional changes.

The Russian Federation possesses vast areas of peatlands (peat >30 cm) and paludified lands (peat <30 cm) estimated over 370 million ha, which make up over 20% of its territory (Vompersky et al., 1994; 1996). Peatlands cover 139 million ha (Vompersky et al., 1994; 1996) of the Russian Federation, which corresponds to 8,2% of the country given by State Land Inventory (Peatlands of Russia…, 2001). During two last centuries up to 0,85–1,5 million ha was disturbed by peat extraction, not less then 4 million ha drained for forestry, and up to 5 million ha (including over-moistened mineral lands) – for agriculture (Peatlands of Russia …, 2001). Comparatively not large to whole country territory these lands are concentrated in certain regions arising in some cases serious environmental problems. Nowadays many of them are not used, not restored and re-cultivated, thus have additional specific impact on the environment.

Peatlands of Northern Eurasia are extremely diverse and include a wide variety of peatland types, from tundra palsa and polygon mires to aapa mires, raised bogs, fens and swamps within boreal zone. They exist from the marine Baltic Sea cost throughout severe continental region in East Siberia and to monsoon Far East. They can be treeless or keep tree cover with commercial wood stock exceeds 150-200 m^3ha^{-1}.

The basic data on Northern Eurasia's peatlands (area, geographical distribution etc.) is not yet sufficiently identified. Comparison and gap analysis of existing information on basic characteristics like peat covered area, peatlands type, peat depth and storage is still a key question for the problem strongly announced on the scientific level (Vompersky, 1994; 1999) and stated on the official one (Peatlands Action Plan …, 2003). There is a strong need to improve data on the peat covered area over Northern Eurasia considering nature diversity of the regions, peatland/mire typology and peat depth. Remote sensing data could make a valuable contribution to peatlands inventory and for hard-to-reach northern and eastern regions could have no alternative.

Peatlands provide a wide range of wildlife habitats supporting important biological diversity. They play an important role in maintaining freshwater quality and hydrological integrity, carbon stores and sequestration. Peatlands contain one-third of the world's soil carbon and 10 % of the global freshwater volume (Wise …, 2002). Only in Russia peatlands could store from 113.5 (Vompersky et al., 1996) to 210 Gt C (from the data for the USSR obtained by Botch et al., 1995), which make up 20–50 % of the world peatland carbon. Peatlands present high variety of natural conditions thus have quite different peat accumulation rate, contribution to the other components of the carbon balance, GHG emission etc. (Vompersky et al., 1998; Vasiliev, Titlyanova, Velichko, 1999; etc.). The accurate data on carbon and water storage, carbon accumulation rate, GHG emission for Russian peatlands must developed using adequate methodological approach to be worked out.

From a conservation point of view, it is important that most of the peatlands are relatively intact and offer a rare opportunity for conserving areas large enough to allow natural hydrological and ecological processes to occur. World largest peatland territories are West Siberian mire massif and Polistovo–Lovatsky mires are biggest in Europe. Russian peatlands support globally significant biodiversity, and provide a variety of hydrological and biogeochemical functions valuable to people throughout Eurasia.

3.1.2.5 Fresh water systems

Fresh water systems of Northern Eurasia consist of water objects of different rank (temporary watercourses, rivers, lakes, ponds, water reservoirs and underground aquifers) and connecting them in the process of water flows cycle together with abiotic elements and biota. On the territory of the former USSR only there are about 3 million rivers (Domanitsky et al., 1971) with total length exceeds 9.6 million km. The largest rivers are – Yenisei (average annual runoff 572 km^3), Lena (537 km^3), Ob (405 km^3), Amur (306 km^3). Among lakes small ones with areas of less than 1 km^2 also prevail. The Baikal Lake is the world largest fresh water body has 23 thousand km^3 of water volume. Fresh water systems are in close connection with different components of the environment (climate, geological structure of territory, relief, soil and biota) and human activity, which is the factor of formation and functioning of fresh water systems and water user. Important role in functioning and dynamics of fresh water systems belongs to their catchments.

Boundaries and state of Fresh water systems vary within broad limits depending on climatic conditions and impact of other factors, first of all anthropogenic ones.

Besides socio-economic functions Fresh water systems (rivers, interior lakes, and reservoirs) play very important role as factor of environmental sustainability as well as important link of global and regional cycles of carbon and other biogenic elements (chapter 3.2).

On vast and low populated territories of Northern Eurasia fresh water systems remain practically in the natural state and fulfil functions of biosphere sustaining. At the same time in the most populated regions the natural environment is to a great extend transformed by man, and problems of providing acceptable state of fresh water systems are very acute there.

In the natural state the majority of fresh water systems of Northern Eurasia belong to hydrocarbonate class with water mineralization of 200-400 mg/l. In the most populated regions hydrochemical composition of water is dramatically changed. As a result of discharge of sewage water and other waste of economic activity into rivers and water bodies almost all of them are polluted. Among the contaminants there are petroleum products, phenols, biogenic elements, salts of heavy metals. Because of low temperatures in the water the processes of self-purification in the majority of rivers and water bodies of Northern Eurasia go on slowly, that is why the fresh water systems are especially vulnerable. Biotic component of fresh water systems is also very vulnerable to external impacts including anthropogenic ones. At the same time it fulfils extremely important functions of regulation of fresh water systems state, their self-purification and self-recovering. In the best way fresh water systems fulfil their regulating, and to a considerable degree, resource functions as well when values of their parameters are close to the natural ones. The important task is identification of optimum between economic demands in water and biological resources of fresh water systems and their possibilities for restoration and keeping of medium formation functions by them.

The important index of fresh water ecosystem change is degree of transformation of structure and metabolism of biocoenosis or their ecological modifications (Izrael, Abakumov, 1991). In populated regions of Northern Eurasia many rivers and water bodies are in the state of anthropogenic ecological tension, ecological and metabolic regress by hydrobiological indices.

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3.1.3. Soils

No less important than plants are the soils' and soil cover. Soil climatic zonality is caused by changes in temperature-precipitation ratio from north to south. This results in gradual changes of major natural zones. In polar desert, the soil development is very limited due to the extremely severe environment. Cryozems and shallow weakly-developed soils characterize the zone. The tundra zone mainly is occupied by a diversity of soils, in which gleyzems prevail. It is important to note that deep peat soils are very limited in this zone, but gleyzems with shallow peat horizons (within 30-50 cm) extend widely. This illustrates that the tundra zone is too cold for deep peat formation. The share of gleyzems decreases due to better drainage conditions compared with the tundra zone. However, at the same time, the proportion of deep peat soils considerably increases following improvements in thermal conditions. The middle taiga contains a great portion of Al-Fe-humic and metamorphic soils. It is important to note that this zone favours conditions for the formation of sod organic horizons in soils and supports the development of deep peat. The southern taiga is widely occupied by texture-differentiated and peat soils. The temperate forest zone is dominated by texture-differentiated and metamorphic soils. This zone presents a mosaic of forest and meadow-steppe vegetation and is also characterized by the expansion of humic-accumulative soils. The steppe zone is occupied by humic-accumulative soils, and the semi-arid dry-steppe condition also favours them. Lastly, low-humic accumulative calcareous soils and a range of salt-affected soils, such as alkaline clay differentiated and halomorphic, occupy deserts (Stolbovoi, 2002. Soils; In: Stolbovoi V. and I. McCallum, 2002). As a result of heterogeneity of parent rocks, relief, vegetation and land use the variety of soils in each zone is much higher than the general picture of the climatic zonality described above.

Soils act as a reservoir for carbon in the form of soil humus. In this case any type of soil degradation as a rule leads to disengage of soil carbon to the atmosphere and the lack of such data provides mistakes in the modelling of global carbon cycle and global climate. Second point is that soils are the living place for more than 80% of terrestrial animals and act in this case as the necessary element for biodiversity conservation issues. And at last, soils act as a "shield" for litho- and hydro- spheres preventing their destruction and pollution and providing the sustainability of their chemical composition (Dobrovolskiy, Kust, 2003). Unfortunately, the new understanding of the role of soils in the biosphere is very young scientific concept and there are almost no data on soils on this issue. The most of soils data have been collected only for the agricultural and (much less) for forestry purposes; they were presented in the forms of land cadastre and not renewed for past 20 years. Moreover, these data are disintegrated, most of them were not published and are stored in "hard copies" in the storages of different organizations (Kust, Kutuzova, 2003). The conclusion can be made is that *there is a lack of present uniform soil data available to use for the adequate assessment of the real role of soil cover in the environmental changes of Northern Eurasia*

The rigorous continental climate over significant part of Northern Eurasia is the reason for permafrost formation, which occupies an area greater than 10 million square kilometers. In the European part, permafrost occurs only in the tundra and the forest-tundra zone. In Siberia and Far East to the east of the Yenisei the permafrost is spread almost everywhere, except for south Kamchatka, Sakhalin Island, and Primorjie. The following types of permafrost are distinguished on the basis of how they are propagated (Kotlyakov and Khromova, 2002. Permafrost; In: Stolbovoi V. and I. McCallum, 2002):

Continuous permafrost is distributed throughout the northern part of the Bolshezemelskaya tundra; on the Polar Urals; in the tundra of West Siberia; in the northern part of the Middle-Siberia tableland, on Taimyr Peninsula, Severnaya Zemlya, Novosibirskie Islands, Yano-Indigirka and Kolyma lowlands; in the mouth of the river Lena; on the plain of Central Yakutiya and on Prilenskoe plateau; on the Verkhoyanskii, Cherskii, Kolymskii, and Anadyrskii ranges, on the Yukagirskii tableland, and on Anadyrskaya plain. The thickness of perennially frozen layers is around 300–500 m and greater; a maximal thickness of 1,500 m was recorded in the basin of the river Markhi, which is one of tributaries of the Vilyui River. As a rule, the rock temperature varies from –2 down to –10°C, but sometimes it can be lower.

Discontinuous or sporadic permafrost occurs in the Bolshezemelskaya and Malozemelskaya tundras; on the Middle-Siberian tableland between the rivers Nizhnyaya and Podkamennaya Tunguskas; in the south part of the Near-Lena plateau, and in Zabaikaljie. The thickness of the layers here varies from 10 to 150 m, but sometimes reaches 250–300 m. The temperatures are usually from –2 up to 0°C.

Insular permafrost occurs on the Kola Peninsula; on the Kanin Peninsula; and in the Pechora River basin; in the taiga zone of West Siberia; on the south of the Middle-Siberian tableland, along the coast of the Sea of Okhotsk; and on Kamchatka. The thickness of the layers is from several meters to several tens of meters, and the temperatures are close to 0°C. Insular permafrost occurs in the mountains, frequently along the periphery of regions of contemporary glaciations.

3.1.4 Driving forces of the large-scale ecosystem dynamics

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***Tundra ecosystem*.** The dynamic of tundra ecosystem caused by climate change, considerably varying between different Arctic regions (Serrese et al., 2000) and resulting in both positive and negative feedbacks in “permafrost – active-layer – vegetation – atmosphere – climate” interactions (Chapin et al, 2000). As an example, tundra landscapes in Alaska (USA), North-European Russia and East Siberia under local warming converted to source of carbon dioxide to atmosphere (Oechel et al., 1993, 1995; Zimov et al., 1996; Zamolodchikov et al., 2000) and presented the positive feedbacks to Global Changes. Far-East tundra increased the carbon sink activity and provided the negative feedbacks (Zamolodchikov et al., 2003). *The described situation stresses the necessity of the development of adequate methodological base to generalize known effects on permafrost area of Northern Eurasia.*

The system of climate-tundra feedbacks includes not only the carbon dioxide balance. The lakes and overhumidified tundra soils are important sources of methane fluxes (Zimov et al., 1997). The climate changes can lead to increase of unfrozen periods and stimulate the methane emissions. On the contrary, the drying of climate results in restricting of tundra wetlands and correspondent decreasing of methane emissions. Additional problems in prediction of tundra biome dynamics are created by changes of feedbacks hierarchy under long-term climate influence with stimulation of negative feedbacks (Camill and Clark, 2000; Oechel et al., 2000b). *To improve conclusions of climate change effects on tundra ecosystems, it is necessary to have more observations on the system functioning in different regimes over long-term scales.*

The specific question is the current destruction of shores of Arctic seas. In Siberian Arctic the ground of coast and islands contain considerable amount of ice. During the summer melting of the ground ice the coast is destroying very quickly. The speed of coast destruction can reach 10-20 m per year with preliminary estimation of average level 6 m per year (Semiletov, 2001; 3.6.2). During this process the terrestrial substances enter the seawater, affecting the biogeochemical cycles in marine ecosystems. *The scales of coast destruction and ecosystem effects need to be investigated.*

The frequency of tundra fires was expected to increase during global warming (Oechel, 1993). The recent catastrophic fire events in Far-East part of Eurasian tundra confirm above prediction. Tundra fires often lead to complete destroying of aboveground vegetation cover and up to 15 cm of top organic soil horizons. The direct CO_2 emissions from tundra fires constitute up to 50 tC ha^{-1}. The most of tundra territories in Russia are not fire protected, which is leading to absence of data on fire events and burnt areas. The period of post fire regeneration of carbon pool in vegetation is near 10 years, in soil near 100 years (Zamolodchikov et al., 1998). *The up to date and accurate data on tundra fires, including burned area and fire severity have to be collected on the regular basics.*

The important part of tundra ecosystem is reindeer populations as major consumer of net primary production. The reindeer husbandry presents the base of life for many native people, among them Nenets, Evenks, Chukchi and others. At present the reindeer husbandry in Russia is in deep depression, the total population of domestic reindeers decreased from 2.5 to 1.5 millions during last ten years (Jernsletten, Klokov, 2002). The reasons are both natural and social. *The system approach to studies of tundra biome demands the consideration of reindeer population dynamics as possible object for optimization* (3.4).

The industrial influence on tundra biome is expressed mainly in resource exploration and pollutions (3.4). The total tundra area damaged by anthropogenic factors, extending from the Kola Peninsula to Chukotka, is about 470 000- 500 000 km^2 (Kryuchkov, 1990). The damages are frequently associated with acidifying pollutants, heavy metals, other toxic substances, and with land disturbance (AMAP Assessment report, 2002). Large-scale dispersion of heavy metals has been observed on tundra areas. The metals most concern about effects in the Arctic are mercury, cadmium. They are present at high levels for a region remote from most anthropogenic sources. The processes of industrial exploration present essential threats to ecosystem structure and functioning (Forbes et al., 2001). The exploitation of gas in Yamal, oil in South Chukotka and coal in Vorkuta region (Virtanen et al., 2002) are among major examples. Any types of building and transport activity in tundra lead to disturbances of vegetation cover and hydrological regimes, by this way changing of soil heat conductivity and permafrost degradation. The analogical processes are observed in polluted zones in Cola peninsula and southern part of Taymyr peninsula. *The remote sensing technique is considered as most appropriate to estimate the impact of human caused disturbances on regional scale* (Virtanen et al., 2002).

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***Forest ecosystem*.** The current pattern of forest vegetation reflects the combined effects of anthropogenic and natural disturbances over a range of time scales. Nowadays the growth of forest trees and the functioning of the forest ecosystems are affected by multiple stresses as a combination of climate change and disturbances. Forest ecosystems of northern Eurasia are subjected to climate changes that may result in changes in length of growing period and snow cover, production and vegetation carbon storage enhancement, replacement of tundra with boreal forest, warming permafrost and fire frequency increase. But, recently an increasing number of studies have been revealing advances in the onset of phenological spring phases from 1 to 3 days per decade that are related to air temperature (Menzel and Fabian, 1999; Bradley et al., 1999; Menzel, 2000; Chmielewski and Rötzer, 2000; Rötzer et al., 2000; Menzel , 2003**).** Changes of the length of the growing season for the northern hemisphere which have been derived from CO2 records (Keeling et al., 1996) and satellite data at relatively coarse spatial resolution (Myneni et al., 1997) generally confirm analyses of phenological data. However, the data which demonstrate opposite trends also exist (Kozhevnikov,1996; Kullman,1996; Minin,2000; Hogda et al, 2001; Kozlov, Berlina, 2002). some observations in Northern regions were already said to contradict the general predictions on global warming (Normile, 1995; Polyakov et al. 2003)

Thus, there still exist major uncertainties in predicting of the length of the growing season changes. The accuracy of predictions can be increased by the coordinated investigations of past changes in both biotic and abiotic environment (Houghton et al, 1996) taking into account regional variations.

Analyses based on satellite data suggest that both production and vegetation carbon storage have generally been enhanced across the boreal forests in recent decades (Myneni et al, 1997; 2001; Randerson et al, 1999; Zhou et al, 2001), an observation that is consistent with climate warming. One hypothesis for the mechanism of increased production is that warming increases decomposition of soil organic matter to release nitrogen in forms that can be taken up by plants. Since production is often limited by plant nitrogen supply in boreal forests (Van Cleve and Zasada, 1976; Van Cleve et al., 1981; Chapin et al., 1986; Vitousek and Howarth, 1991), an increase in nitrogen availability to plants should increase production. Several boreal warming experiments and modeling studies have provided support for this mechanism (Van Cleve et al., 1990; Bonan and Van Cleve, 1992; Bergh et al., 1998; Stromgrem and Linder, 2002; Clein et al., 2002). Increased N deposition, management changes, increased CO_2 are also possible explanations for these records (Erisman and de Vries, 2000). Increased accumulation of soil organic matter in European forests has also been observed. One of hypothesis is that increased N deposition causes an increased rate of soil organic matter accumulation due to an increased biomass of assimilative organs and litter production and a reduced decomposition of organic matter (Berg and Matzner, 1997).

The hypotheses explaining production and carbon storage enhancement across the boreal forests in recent decades have not been critically evaluated for ecosystems in northern Eurasia.

The replacement of tundra with boreal forest occurred in earlier warm periods of Holocene in northern Eurasia (MacDonald et al., 2000). Over the last half century, treeline advances into tundra have been documented in Alaska (Cooper, 1986; Suarez et al., 1999; Lloyd et al., 2003; Lloyd and Fastie, 2003), Canada (Morin and Payette, 1984; Scott et al., 1987; Lavoie and Payette, 1994). There are also some evidences of this phenomenon in Russia (Gorchakovsky and Shiyatov, 1978). Because significant part (41 %) of Russian forests is categorized as mountain forests investigations of tree line variations in mountains is of great importance.

Permafrost maintains a perched water table that keeps moisture in the root zone and maintains forest cover. Loss of permafrost is expected to increase soil drainage and may result in aridization in these areas and loss of forest cover. There are some indications that this process may have started already as river run-off to the Arctic Ocean increased during the last decades occurred even though the amount of precipitation remained the same or slightly decreased (Peterson et al. 2002). Additional processes, such as thermokarst may further impact the functioning of forests. The areas where permafrost has recently thawed, boreal forests have been replaced by grasslands and wetlands. (3.6.1).

While treeline advance and warming permafrost may effect on climate change, investigations of temporal and spatial variations of these phenomena are challenging.

Vegetation type and distribution have large impacts on regional and global climate through effects on terrestrial carbon storage (Smith and Shugart, 1993) and on water and energy exchange (Charney et al., 1977; Shukla et al., 1990; Bonan et al., 1992). Forest ecosystems through water/energy and radioactively active gases exchange with the atmosphere may respond to climate change in ways that tend to enhance warming (positive feedbacks) and through effects that tend to mitigate warming (negative feedbacks) (3.5; Smith and Shugart, 1993; McGuire and Hobbie, 1997; etc.). Increase in fire frequency has the potential to quickly release large amounts of carbon (Goulden et al, 1998; McGuire et al, 2003) (positive feedbacks), and these responses may more than offset increases in carbon storage that might arise from the slow expansion of boreal forests into tundra regions (negative feedbacks) (McGuire and Hobbie, 1997). On the other hand, fire may result in replacement of coniferous forests with deciduous forests with higher albedo. A longer growing season and reduced snow cover would decrease albedo and result in atmosphere heating (positive feedbacks). On the other hand, longer growing season in ecosystems of Northern Eurasia should enhance terrestrial carbon storage (Frolking et al, 1996). An expansion of temperate forests into regions now occupied by boreal conifers could also lead to negative feedbacks. On the contrary, replacement of tundra with boreal forest would decrease albedo and result in atmosphere heating. Climate change can generate both positive and negative feedbacks in "permafrost – active-layer – vegetation – atmosphere – climate" interactions (Chapin et al, 2000).

The present and future role of Northern Eurasia cannot be adequately understood without better knowledge of response of forest ecosystems to climate change. Of particular concern is the likelihood of amplifying feedback loop that can cause a further warming

Important changes in forest cover of the Northern Eurasia that may affect climate include changes associated with disturbances, such as fire, insect outbreaks, timber harvest, agricultural establishment and abandonment and air pollution. Human influences on the disturbance regime include both direct effects, such as harvesting or inducing and/or suppressing natural disturbances (fires, insects, flooding, etc.), and indirect influences from altering the forest environment. Indirect influences include both climate change and atmospheric pollution, and their effects on tree health and survival. Because of natural and human- induced disturbances forest area in Northern Eurasia is a gigantic mosaic of successions (Smirnova, 2004). The area of pristine forests dramatically decreased. European-Ural area, Russian cradle of slash-and-burn farming, metallurgy and timber harvest, is characterized by the most large-scale changes. In last three centuries land use and cuttings have resulted in elimination of more productive forests on the area of 70 million ha in European part of Russia (Utkin and Zukert, 2003).

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Periodically Northern Eurasia forests are subject to massive insect infestations that occur on millions of hectares causing forest dieback or damage. The outbreak of Siberian gypsy moth *Dendrolimus sibiricus superans* was identified mostly in taiga regions on areas from 8 to 10 million ha in 2001-2002, which is much higher than long-term averages (Isaev 1997, FSFMR 1998, Shvidenko and Goldammer 2001, GFMC 2003). These outbreaks are induced by a combination of favourable weather conditions (optimal temperature, low levels of precipitation and humidity) and occur with a periodicity of 15 to 25 years. Harsh climatic conditions have, thus far, limited the outbreaks to areas below 60^{o} north latitude. However, with increased warming, outbreaks may occur in the forests north of this line since desirable food species are available. *Adequate detection and mapping of insect outbreaks is essential for understanding of their impacts and the assessment of potential for northward expansion*.

The forests of northern Eurasia represent a wood resource of global significance. Forests are heavily managed for wood production and harvest resulting in losses of the organic matter and nutrients. In general, forest harvest and management results in lower vegetation and soil carbon stocks than equivalent unmanaged forests. For example, forests in Fennoscandia are so heavily managed for wood production and harvest that both vegetation and soil carbon are lower in comparison with other areas of the boreal forest (McGuire et al., 2002). Wood harvest could reduce carbon storage in Siberia's boreal forest (Rosencranz and Scott, 1992) and may have already done so in far eastern Siberia where illegal logging has apparently been increasing over the past decade. However, carbon loss from this activity, which results in the export of wood to China and other Asian countries, may be offset by the drop in legal commercial logging associated with the breakup of the Soviet Union. Legal timber harvest in boreal Eurasia has changed substantially since 1993 with all regions experiencing substantially lower harvest. The decline, as reflected in official statistics, has varied among regions between 40% and 60% of pre-1990 harvest rates.

Agricultural activities in northern Eurasia have also been changing rapidly over the last decade. According to official statistics 29 million ha of arable lands were lost in Russia from 1990 to 1999 (Russian Statistical Yearbook, M., Goscomstat RF, 642 pp). Ongoing analyses of satellite data indicate that most of the abandoned agricultural land is converted to young forest regrowth (Bergen and Zhao, 2003; Utkin and Zukert, 2003). While the abandonment of agricultural lands is likely increasing carbon storage in northern Eurasia, the increase has not been well quantified. *Because of the changing dynamics of logging and agriculture in northern Eurasia, it is important to understand how these disturbance regimes are changing throughout northern Eurasia to better understand net changes in carbon storage associated with these activities.*

Nowadays air pollution is important driving factor of forest dynamics. Accordingly modern hypotheses the growth of forest trees and the functioning of the forest ecosystems are effected by multiple stress as a combination of direct air pollution, indirect soil-mediated acidifying impacts of S , N deposition and eutrophication, and changes in weather conditions, either acting directly via drought or indirectly via pest infestation or fungi attack (Erisman and de Vries, 2000).

Currently in Europe S and NO_3 deposition has decreased strongly but the deposition of NH_4 stayed relatively constant in the past decades. (Erisman and de Vries, 2000). Although there has been a 50 % decline in industrial activity in Russia since 1992, pollution decreased by only 25 % and their impacts are still a severe problem. At the north end of the Siberian transect there exists the world's largest pollution induced forest decline caused by Noril'sk smelters. The most powerful in Northern Europe sources of atmospheric pollution, "Severonikel' and "Pechenganikel" smelters, are located in the Kola Peninsula. There are about 230 million ha of forested area at risk from sulphur and nitrogen deposition in Russia (Nilsson and Shvidenko, 1999).

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The different types of disturbances are often linked. For example, in some forest types the probability and intensity of fire may increase following insect outbreaks because of increases in available fuel. In other cases salvage logging (recovering the usable timber following a disturbance) can reduce the total area of living forest that is disturbed in a given year by all agents combined. It is common to try to replace natural disturbances (such as wildfires) with commercial harvesting, using a combination of protection and scheduled logging. In Sweden and Finland, for example, logging has become the main disturbance type; and large-scale natural disturbances resulting from wildfire, insect outbreaks, or storms have been almost non-existent for half a century (Lähde et al., 1999). The interactive effects of disturbances and climate change need to be studied.

Up to date large-scale dynamic processes in forests of Northern Eurasia have not been adequately explored. Forest ecosystem dynamics caused by multiple stresses as a combination of climate change and disturbances may result in changes of surface albedo, evapotranspiration, hydrological regime, carbon sequestration, and integrally in global climatic change.

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Fresh Water Systems. Climatic short-term and long-term dynamics is a one of the main forces of hydrological changes that are characterized by rhythms of different duration and amplitude (Belyaev, Georgiadi, 1992; Klige et al., 1998). From the beginning of 20th century and especially since 30th the increasing role begins to play the anthropogenic factor, which is imposed on natural variability.

Intensity of anthropogenic impact in river channels and in water bodies as well as on their catchments was constantly increasing during the whole 20th century till the 1980-1990th (Koronkevich, 1990). The fresh water systems of central and southern parts of Russian plain, southern part of Siberia and Western Siberia were characterized by extraordinarily high intensity of river runoff resources use. (Voronkov, 1970; L'vovich, 1974; Water Resources…, 1987; Shiklomaniov, 1989; 2002; Koronkevich, 1990, etc.). The state of fresh water systems was to a high degree determined by intensity and distribution of anthropogenic load in the watersheds. Expansion of arable lands, especially irrigated ones, increased use of fertilizers, the total number of cattle live-stock, etc., increase in industrial production accompanied with increased withdrawal of water from rivers and underground waters, return of waste waters, including not well purified, into rivers resulted in the fact that by the end of the 1980s the norm of annual runoff had decreased in different regions on 20-30 % (Shiklomanov, Georgievsky, 1995), and quality of water had noticeably deteriorated.

Consequences of socio-economic changes in the 1990s were of a completely different character. On the one hand, reduction of industrial and agricultural production with considerable changes of structure of land use reduced the anthropogenic load upon waters. For example, under decrease of industrial and agricultural production by the end of the 1990s up to two-three times as compared with threshold of the 1980-90s use of water in Russia decreased by 25-30% on the average (Koronkevich, Zaitseva, 2003). On the other hand reduction of nature protection, including water protection, activities and change of the structure of anthropogenic impacts upon water brought opposite results.

These changes were occurring against the background of climate dynamics, which were linked to the beginning of the global climate changes, resulting from the anthropogenic emission of greenhouse gases to atmosphere.

Available estimations of consequences of probable climate warming for Fresh water system, which methods of calculation still more not extremely enough, show, that, for example, conditions of river runoff formation, water regime of Fresh water systems can be changed essentially (chapter 3.3). Thus character of changes will be non-uniform over territory of Northern Eurasia. In boreal zone and, especially, in Siberia the river runoff will be increased, in a forest-steppe and steppe zone it can be decreased. Respective alterations will take place and with a water regime of fresh-water bodies and surrounding seas, and also with riverine export of organic and mineral substances. Additional inflow of fresh waters to Arctic Ocean can lead to regional climatic changes (chapter 3.3).

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3.2. Biogeochemical Cycles

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3.2.1.3. Responses of Biogeochemical Cycles in Northern Eurasia to Global Change

The biogeochemical cycles of terrestrial ecosystems in Northern Eurasia may respond to global change in ways that tend to enhance warming (positive feedbacks) and through effects that tend to mitigate warming (negative feedbacks) (Smith and Shugart, 1993; McGuire and Hobbie, 1997; McGuire et al. 2000a; Chapin et al. 2000; Clein et al. 2002). The net effect will depend on the balance between the two and positive feedbacks to warming are of imminent concern. For example, increases in fire frequency and soil warming have the potential to quickly release large amounts of carbon (McGuire et al. 2003b,c; Goulden et al. 1998), and these responses may more than offset increases in carbon storage that might arise from the slow expansion of boreal forest into tundra regions (e.g., McGuire and Hobbie, 1997) or increased productivity due to increasing CO_2 (McGuire et al. 1997) or N fertilization associated with N deposition (Kauppi et al. 1992; Berg and Matzner, 1997). Similarly, if permafrost thawing results in the expansion of lakes and wetlands, then releases of CH_4 and carbon storage in the form of peat are both likely to be enhanced (Reeburgh and Whalen, 1992; Zimov et al. 1997), but it may take up to 500 years until the enhanced storage of carbon in the wetlands offsets the enhanced radiative forcing associated with CH_4 emissions (Roulet, 2000). Responses of CH_4 emissions to warming in northern wetlands may be quite rapid. During a warm year Dlugokencky et al. (2001) has estimated CH_4 emissions from northern wetlands were enhanced by ~11 Tg above the 1982-1993 mean emissions (1998). High levels of N deposition may also have negative consequences on ecosystem function, as negatively charged nitrates leach from the soil and carry away important cations such as potassium, calcium, and magnesium (Aber, 1992). To predict the effects of climate and land cover change on the future dynamics of CO_2 and CH_4 exchange in northern Eurasia, it is important to understand the processes involved and their spatial and temporal dynamics. Predicting the long-term influence of elevated CO_2 concentrations on the carbon stocks of forest ecosystems remains a research challenge (Bolin et al. 2000; Prentice et al. 2001, Arneth et al. 2002). Ecosystems that initially absorb C in response to higher atmospheric CO_2 will become 'saturated' or even later release CO_2 if increasing temperatures lead to enhanced decomposition and respiration (Cao and Woodward, 1998; Scholes et al. 1999). Fires and other disturbances could increase in frequency and intensity if temperatures increase and precipitation patterns change. The net impact of these, and other global changes, is an area of active research (e.g., Woodwell et al. 1998). Changes in land use also affect the biogeochemical cycles in forest, grassland, and other ecosystems. Land use changes in the Eurasian region are associated with dramatic social and economic transitions occurring in the past decade. For example, the reorganization of the former Soviet Union and the increased globalization of commodity markets have resulted in marked changes in land-use during the last decade: large tracts of croplands have been abandoned (~ 30 million ha in Russia from 1988-2000, Kljujev et al. 2001); some degraded rangelands have been rehabilitated; timber harvest initially declined and currently is about one third of the level it was in 1990; peatland drainage has virtually ceased; and fire control has declined. The dynamics of land use, which are driven by different socio-economic factors in China, Mongolia, Russia and the other former Soviet Union Republics, have implications for biogeochemistry. In addition, significant expansion of the extraction of natural resources (oil, gas, etc.) has started in a number of regions (West Siberia, Taymyr, others) and has been accompanied by an influx of people and development of infrastructure in extremely fragile landscapes. There is evidence that the stability of permafrost has been affected in areas disturbed by resource extraction activities; Ivanov 2003, which has consequences for the dynamics of biogeochemical cycles. However, how these changes have affected biogeochemical cycles in not well documented and is not well understood. The future trends of land use are uncertain and will likely affect the future storage of carbon and the dynamics of other biogeochemical cycles in the region.

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3.2.3. Patterns and Variability

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These atmospheric analyses are consistent with analyses based on forest inventory data, which indicate that Russia was responsible for a carbon sink of 0.3 to 0.4 Pg C per year in the early to mid-1990s (Liski and Kauppi, 2000; Myneni et al. 2001 Figure 1.2a and Zhou et al. 2003, Fig 1.2b; Shvidenko and Nilsson, 2003). One analysis for Russia based on forest inventory data from 1961 to 1998 estimates that Russian forests have been a net C sink of 0.32±0.06 Pg C yr^{-1} over the entire period with inter-annual variation of between 0.17 to 0.45 Pg C yr^{-1} (Shvidenko and Nilsson, 2003). When changes in land use are considered, the C stocks in Russian forest lands are estimated to have increased by 0.43 Pg C yr^{-1} over the period from 1961 to 1998, with non-forested lands contributing an additional 0.09 Pg C yr^{-1} over the same period (Shvidenko and Nilsson, 2003). The uncertainty of these estimates is large and the future of this carbon sink depends on a complex interaction of climatic variation and human activities.

Most methane emission scenarios expect continuing growth of the methane emissions (Nakecenovic et al. 2000) in near future. Estimates of CH_4-C exchange between Russian soils and the atmosphere suggest that Russia is a source of methane of between 5 to 100 Tg C yr^{-1} (Zavarzin and Vasilieva 1998). A recent (1999-2003), puzzling decline of the atmospheric methane growth rate (Dlugokencky et al. 2003), after previous drop in 1990s, has called for more attention to understand the basic mechanisms responsible for climate controls and anthropogenic impacts on methane emissions. This recent drop is correlated with reduced fossil fuel emissions from the former Soviet Union (Olivier and Berdowski, 2001), but can not be fully explained by it. Large wetland areas of Scandinavia and Northern Russia are likely to feel the heat of the warming climate, possibly resulting in changing methane emissions and carbon accumulation rates. In North Eurasia, West Siberia can be designated as a key area for understanding changes in methane emissions, because it serves as both a major wetland area and natural gas exploration and transportation region. Long term observations of the seasonal and interannual dynamics of wetland methane exchange are conducted in Canada and Scandinavia, but only fragmentary data exist for West Siberia, because those observations require well maintained automated systems deployed in the field. Current understanding of the spatial variability of methane emissions is based on spatial and temporal extrapolation of the observations using process-based models (e.g., Walter et al., 2001 and Cao et al., 1998), that incorporate surface heat balance and hydrology to simulate the variations of the water table and temperature, which are the major environmental factors controlling the dynamics of methane production and emission in anaerobic peat mass environment. Spatial representation of the wetlands in those models follow existing maps of the wetland typology (Matthews, Fung, 1987) which can be refined in North Eurasia only at regional level where some detailed maps of wetlands are available. The future dynamics of methane in Northern Eurasia are highly uncertain, as methane emissions could decrease if the increasing aridity that has been observed continues, while increased fire severity has the potential to release substantial amounts of methane from burning peatlands as methane released from such fires is on the order of 1 - 2% or more of consumed carbon. The release of methane associated with fire emissions has substantial the potential to affect radiative forcing of the climate (Kajii et al. 2002).

Currently, the global anthropogenic emissions of NO and SO_2 into the atmosphere exceed natural rates from terrestrial ecosystems by about 8 and 4 times, respectively (Galloway, 2001). In Europe, NO_3 and S deposition has decreased substantially in recent decades, but the deposition of NH_4 has stayed relatively constant (Erisman and de Vries, 2000). Forests in Europe currently receive inorganic nitrogen deposition (wet and dry) ranging from less than 1 kg ha^{-1} yr^{-1} in Northern Norway and Finland to more than 60 kg ha^{-1} yr^{-1} in the Netherlands and Czech Republic (Macdonald et al. 2002). The deposition of N and S over the area of the Former Soviet Union ranged from 5 to 30 kg ha^{-1} yr^{-1} and from 8 to 35 kg ha^{-1} yr^{-1}, respectively, in the latter half of the 20th Century (Vasilenko, 1991). For the period 1990-2001, the emissions of NO_x and S decreased in Russia in association with decreased economic activity, but it is expected that these emissions will again increase and reach levels comparable to 1990 values by 2020 (Annuary….., 2001). The deposition of heavy metals in Europe was also substantial during the latter half of the 20th Century. Since reaching a peak during the 1960's, the deposition of heavy metals in Europe has decreased markedly as a result of improved emission controls, closure of polluting industries, and phasing out of lead in gasoline (Johansson et al. 2001). While it is well known that there are substantial sources of heavy metal pollution located in Russia (for instance, Cu-Ni smelters in Norilsk, in the Kola peninsula, and elsewhere), the absence of a national monitoring program means that the patterns and variability of heavy metal pollution has not been well quantified. While the levels of pollution have not been well quantified, their effects on terrestrial biogeochemical cycles are clearly evident. For example, approximately 3 million ha of forest tundra around the largest smelter in the world in Norilsk (which emits about 2 million tons of sulfur oxide emissions per year in addition to heavy metals) has been completely destroyed with no vegetation growth possible because of the levels of soil contamination associated with the deposition of heavy metals.

3.3. Surface Energy and Water Cycles.

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Introduction

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In the diagnostic mode of weather modeling (the re-analysis mode) any erroneous parameterizations or misinterpretations of the processes that define the behavior of the system are corrected by the data. There is no such helping hand when we are trying to project future climate and state of environment or assess their vulnerability. All basic processes must be described as accurately and completely as possible within the model because the quality[60] ….

3.3.2. Processes that directly feed back to the Global Earth System

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- **Changes in surface albedo related to vegetation changes, shift of ecological zones, and land use changes**

These changes directly affect the surface heat and water balance and are discussed in 3.4 and 3.5 in detail. While it is possible to reconstruct some of these changes over time[61], large-scale environmental monitoring became a reality only in the era of remote sensing. During the last two decades, the area of forested land, green vegetation (NDVI), forest fire scares, agricultural fields, and their changes with time are objectively monitored and documented from satellites[62]. The period of this monitoring is still too short to permit confident conclusions about a shift of ecological zones, but pilot estimates (e.g., Figure 2.1) have already indicated large-scale changes in the biogeochemical cycle over Northern Eurasia with global implications (3.2). Off-line land surface models convert the observed changes in vegetation into the direct climate feedback estimates related to albedo, evapotranspiration, and sensible heat flux changes[63]. For example, there is substantial spatial variability in winter albedo within the boreal forest due to the spatial mosaic of coniferous forests, deciduous forests, and non-forested wetlands and burn scars. The latter have a higher albedo of ~ 0.6 in the cold season when the short-statured vegetation is snow covered. Thus, it is important to know the proportion of the landscape occupied by short-statured ecosystems within boreal forest. During summer, the albedo of deciduous stands and boreal non-forested wetlands is higher than the albedo of coniferous forests (Rauner 1972; Chapin et al. 2000a). Therefore, changes in the land cover composition directly affect surface heat balance.

- **Thawing of permafrost**.

Degradation of permafrost and changes in the soil carbon cycle in Northern Eurasia have the potential to noticeably affect the atmospheric CO_2 and CH_4 concentrations and, therefore, global climate. About half of the Northern Eurasian terrain has permafrost (Figure 2.3). Section 3.6.1

[60] To achieve this quality, the models' output is compared with the observational evidence and the behavior of the underlying processes described in the model is tested in specially designed field and laboratory experiments. The best approach to develop valid projections of the future is to strive for a comprehensive model that accurately simulates past and present climates and states of environment and apply it for future projections or, at least, assess the predictability of the modeled system (Pielke 1998; IPCC 2001; Chase et al. 2004; Real et al. 2004).

[61] e.g., the lake levels, changes in the area of agricultural land (3.4; Golubev et al. 2003), and reports of the forest harvest and inventories (Shvidenko and Nilsson 2002).

[62] 4.1; Tucker 1979; Vygodskaya and Gorshkova 1987; Vygodskaya et al. 1997; Conard et al. 2002; Wagner et al. 2003; Zolotokrylin 2003.

[63] Nakaegawa et al. 2000; Stewart et al. 1998; McGuire and Hobbie 1997; McGuire et al. 2000a, b.

describes the increasing trends of the near-surface permafrost temperature over Northern Eurasia. The increase in permafrost temperatures may change many of its physical properties that can have negative effects on infrastructure but the *dominant non-linearity* occurs when permafrost starts to thaw near the surface. At that time, many processes (some of them very destructive) will be triggered or intensified. The most significant impacts on ecosystems, infrastructure, carbon cycle, and hydrology will be observed in areas where the permafrost contains a considerable amount of ground ice (Nelson et al. 2001, 2002). As a result, dramatic changes in vegetation, surface and subsurface hydrology, and in the carbon cycle should be expected. Section 3.6.1 specifically addresses all issues related to this process.

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- **Ongoing aridization of the continental interior and dust storms.**

Temperature rise without appreciable changes in precipitation (or even its decrease) can lead to aridization in steppe, semi-arid and arid climatic zones of Northern and Central Eurasia. Additional causes for aridization could be of anthropogenic origin (water withdrawal and/or intense agricultural use) and glaciers and permafrost degradation. Whatever the causes may be, an increase of the dust load in the troposphere may be a result. Mineral aerosols, or dust, are a dominant component of the total atmospheric aerosol burden. Most dust particles are lofted into the atmosphere by aeolian (wind) erosion of arid and semi-arid lands, which cover approximately 33% of the global land area. Current estimates of the global annual mean dust burden range from 1000 to 5000 Tg/yr. With an average transport time of up to several weeks, mineral particles can be transported great distances downwind from the source, causing diverse effects on health, environment, and climate (Figure 3.3.3). *Once lifted into the atmosphere, both anthropogenic and natural components of mineral aerosols play an important role in air quality, atmospheric chemistry, ecology, biogeochemical cycles, cloud formation, rainfall, agriculture, Earth's radiation budget, and, hence, climate change.* Since Central and East Asia is the second largest source of atmospheric dust in the world, a quantitative understanding of Eurasian dust sources, transport routes, and effects on the climate system on regional and global scales is urgently needed. Section 3.6.3 addresses these issues in detail.

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3.3.3. Processes of major societal importance

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The following two processes are only partly a function of SEWC, but directly and substantially affect society and human health and thus are included below.

- ***Impact on agricultural production***

  An artificially controlled environment of arable lands is less flexible than a natural environment, unless it is irrigated and there is no water shortage. It is controlled for a purpose, being managed for maximum harvest. But, the biodiversity on the agricultural lands is suppressed and natural soil resources are exploited and gradually depleted. Therefore, societal changes and climatic changes are affecting the agricultural environment (that was previously adjusted for maximum productivity of a specialized harvest) greatly and making it highly sensitive to external forcing. Scale and frequency of droughts in agricultural regions and changes in irrigation norms and water consumption in Northern Eurasia due to the global warming are the major areas of concern (Menzhulin et al. 1995, 1996; 3.4).

- ***Atmospheric/water pollution***

  Quality of human health and life conditions, negative effects on land, riverine, and coastal zone ecosystems are direct effects of pollution (3.4, 3.6.3). Its indirect effects include modification of surface radiation balance by atmospheric aerosols and the water cycle by impact on cloud formation (by providing additional condensation nuclei).

3.3.4. Surface Energy and Water Balance: Quantifying the Components and their Interactions

3.3.4.1. Climatology

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Atmospheric transport of water vapor

A relatively dense spatially distributed network of aerological stations has allowed for early estimation of major characteristics of the water vapor distribution in the atmosphere and its transport over most of Northern Eurasia within the former Soviet Union boundaries (Kuznetsova 1978, 1983; IWP 1984). These studies were based on the aerological data from the 1960s when the network was already well established and observations were frequently made four times per day at 156 aerological stations. Kuznetsova (1983) assessed the total amount of water vapor transferred annually and its fraction that finally ends as runoff over the former USSR territory. It appears, that while the atmosphere over the western half of Northern Eurasia is more humid, most of the water vapor (~88%) passes over it (or recirculates) and the "utilization" of the water vapor in Siberia is more effective. About half of the water vapor is converted to soil moisture and eventually streamflow. One of the semi-closed branches of the water cycle originates in the Northern Atlantic: evaporation from the ocean, atmospheric moisture transfer to Eurasia by westerlies, precipitation, runoff into the Arctic Ocean, and return to the Northern Atlantic via oceanic currents. *At present, there is no clear understanding of the characteristics of these highly variable processes that control the energy and water budgets of Northern Eurasia. This problem can be addressed with a focused regional modeling effort and a multi-facet observational program.* Modern estimates based on satellite observations (Randel et al. 1996) show similar results for total water content of the atmosphere (Figure 3.3.6), but it is not yet possible to assess the differences as an indication of climatic changes of the water content in the atmosphere due to very different methodologies used to determine these estimates. Observations of the near-surface atmospheric humidity indicate that the water vapor content in the atmosphere has been increasing during the past century (Sun and Groisman 2000). This is consistent with the increasing atmospheric water vapor holding capacity with regional warming.

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3.4. Land Use Interactions: Societal-Ecosystem Linkages

Four expanded contributions to the Chapter (while partially used in the Chapter) are presented here in their entirety

Contribution to 3.4 **"Managed Land, Terrestrial Carbon Cycle and Climate Feedbacks Over Northern Eurasia: Building Interactive Hierarchies of Data and Models of Agricultural Land-Use for NEESPI' by Cynthia Rosenzweig and Francesco N. Tubiello, NASA-Goddard Institute for Space Studies and Columbia University, New York, NY USA and Gunther Fischer International Institute for Applied Systems Analysis, Austria**

Recent assessments have identified the contribution of agriculture and forestry practices as responsible for roughly two-thirds of the total carbon sink into Northern Hemisphere land. Yet a great deal of spatial and temporal refinement is necessary to document current distributions of land dynamics, their inter-annual variability, and their future changes. Research work is needed to improve the description and quantification of the impacts of climate variability and change on of agricultural and forestry productivity, as well as to describe how management and land use changes feed back on the regional climate and carbon cycle. The fundamental scientific questions are as follows: What are the effects, over the next decades, of land-cover and land management of large-scale agricultural systems on the regional carbon cycle in Northern Eurasia? What are the important feedbacks among current and future climate variability and change, water use, crop production systems, land management, and the related land-based carbon fluxes? Specifically, NEESPI-LULUC would focus on research that will result in a modeling network hierarchy over Eurasia that covers three orders of scales and processes: 1) Expansion of agricultural sites network database and point dynamic crop modeling, extending methodologies from work already developed for previous national and international assessment work (e.g., US National Assessment; EPA Country Study Programs, including several countries in the former Soviet Union); 2) detailed 5X5 km grid land use database and dynamic agro-ecological zone model (AEZ); and 3) Further development of interactive agricultural-land use modules for a general circulation model (GCM).

At the basis of this network is the recognition that assessing carbon fluxes from land requires a multi-scale approach in space and time, as well as an interdisciplinary one. The site network that we propose to be at the core of NEESPI-LULUC provides ground-truth for the overlying levels (process model and data development, calibration and validation based on local agricultural practices and contact with local agronomists; and satellite observation); the fine-grid AEZ model provides the needed land coverage and a dynamic modeling capacity to allow for resolving inter-annual changes in land management, as well as providing the proper framework to compute effects connected to future climate change; finally, the third level (GCM) provides the ability to "extract" to very large spatial scales (2.0° x 2.5° Lat. x Long.) the underlying carbon flux signals, properly validated at the lower scales, and to investigate the feedbacks between current and future land use change and climate itself, and how these in turn may affect the fluxes computed at the underlying scales. A vigorous plan for use of county and regional land use data (field, statistical, satellites) is strongly needed in order to strengthen the assessment and linkages among the proposed hierarchical levels.

Background

We know that over the last 20 years land-based carbon emissions from land have been progressively masked by increased land uptake (IPCC, 2001). Atmospheric measurements, inversion methods, land-based modeling and data estimates all suggest that there are two large terrestrial carbon sinks at work in today's earth system: one is extra-tropical, divided between North America and Northern Eurasia, while the other is tropical (Schimel et al., 2001). While both terrestrial sinks seem to have the same uptake strength, or roughly 1-2 Gt C yr^{-1}, deforestation in the tropics tends to counterbalance uptake so that net carbon emissions from the tropics are about zero (Watson et al., 2001). In the Northern Hemisphere however, net effects from land use are small --possibly because forest regrowth and woody encroachments nearly equal fluxes from agriculture (McGuire et al., 2001) –so that a net carbon flux is "seen" from the atmosphere into the Northern Hemisphere (Pacala et al., 2001).

Much uncertainty remains with regards to the exact *biophysical mechanisms* responsible for current land carbon uptake, as well as in the estimation of *land use emissions* to the atmosphere. In terms of ecosystem dynamics: climate change, climate variability, rising CO_2 concentrations, and N deposition have all been identified and tentatively quantified as collectively responsible for the apparent land sink (Schimel et al., 2001). In terms of land use activity, rather simplified accounting methods, prescribing carbon loss from soils and plant stocks following deforestation and land conversion, have been employed to estimate land-use related carbon emissions (Houghton, 2000). Uncertanties in biophysical mechanisms and land use emissions clearly limit our ability to answer two relevant scientific questions: What has happened to the anthropogenic carbon emitted in the past? What atmospheric CO_2 trajectory will result from future carbon emissions? In order to improve our predictive ability around such questions, the U.S. Carbon Science Plan (Sarmiento et al., 1999) has listed four goals related to land-based carbon cycle science, namely: 1) Quantify and understand Northern Hemispheric uptake; 2) Analyze past and future land-use impacts; 3) Improve linkages between carbon and climate models; and 4) Develop linkages between physical and socio-economic modeling.

Within such efforts, it is necessary to improve current biophysical descriptions of agricultural and managed forestry systems within existing ecosystem models, focusing on plant growth and yield as a function not only of climate, but also as a function of genetic and management factors such as crop and cultivar characteristics, irrigation and fertilization schedules, rotation types, soil management, etc. (McGuire et al., 2001).Yet, there has been a deficit in closing the gap among site-level crop modeling studies, land use dynamic, and terrestrial carbon modeling, including critical linkages with climate modeling. We propose that NEESPI-LULUC develops strong interdisciplinary collaborations among researchers with expertise covering crop, ecosystem modeling and carbon cycle, as well as climate change impacts land and water resources, adaptation and management strategies, and vegetation-climate interactions within regional and general circulation models. Such expertise should include ground-truthing of data, models, and scenarios using field, statistical, and satellite data. Integration of research and education at the local to international level needs to be an essential component of this effort.

NEESPI-LCLUC: Science questions and work plan

Previous efforts in terrestrial carbon cycle research have focused on projecting carbon emissions from managed land using both simple accounting methods and terrestrial ecosystem models modified to include crops (e.g., Ramakutty and Foley, 1998; McGuire et al., 2001). Others have focused on using detailed crop modeling studies in order to understand, at farm to regional levels, the impacts of projected climate change on future productivity and land use, including the effects of adaptation and mitigation (e.g., Reilly et al., 2001; Fischer et al., 2001a; Tubiello et al., 2002). Others still have concentrated on modeling land-use dynamics as a function of both climate and socio-economics (e.g., Lambin et al., 1999). NEESPI-LULUC expertise needs to cover research and education components in the areas of crop, ecosystem and carbon cycle modeling (e.g., McGuire et al., 2001; Tubiello et al., 2002), climate change impacts land and water resources, adaptation and management strategies (e.g., Rosenzweig and Parry, 1994; Reilly et al., 2001; Fischer et al., 2001a), and vegetation-climate interactions within general circulation models (Tubiello and Rosenzweig, 1998). For example, we implemented a series of land evaluation steps widely know as the agro-forestry ecological zones model (GAEZ), and applied this methodology to the territory of the former Soviet Union, Mongolia, and China (see figures below; Fischer et al., 2001b). GAEZ has also been applied on a global level to investigate agricultural productivity and risk as a function of historical climate variability and future climate change (e.g., Fischer et al, 2001a). For Eurasia, the model operates on a resolution of 5X5 kilometer, including 148 crop 52 forest and 6 grassland land use types.

NEESPI-LULUC proposes to focus on improving the assessment of future carbon emissions arising from regional land use and productivity. During a proposed research period of three-five years, NEESPI needs to implement a general modeling framework linking crop, land use and ecosystem models, and climate, to investigate key research questions within regional case studies, specifically Northern Eurasia. *Focus on this region is justified by a need to better resolve spatial and inter-annual distributions of Northern Hemispheric carbon fluxes, considering that Northern Eurasia is responsible for a sizeable portion of the carbon sink at northern extra-tropical latitudes. At the same time, pronounced observed and projected patterns of warming in the Eurasian region over the coming decades may be associated with high impacts on ecosystems, land use and management, greatly affecting carbon cycle dynamics*. An integral part of these activities, we aim to generate a set of educational activities for students, educators, and the general public. <u>The scientific questions that need investigation are as follows: What happens to carbon emissions from land-use changes in Northern Eurasia under climate change, over the next 30-50 years? How does climate change interact with regional impacts of likely regional adaptation and mitigation strategies during this period</u>? Proposed research activities focus on three phases:

i) Global linkages among field, statistical, and satellite data, dynamic ecosystem and land use models, and a climate model;
ii) Regionalized simulations and link to global climate;
iii) Workshops and educational activities involving students, faculty, and stakeholders.

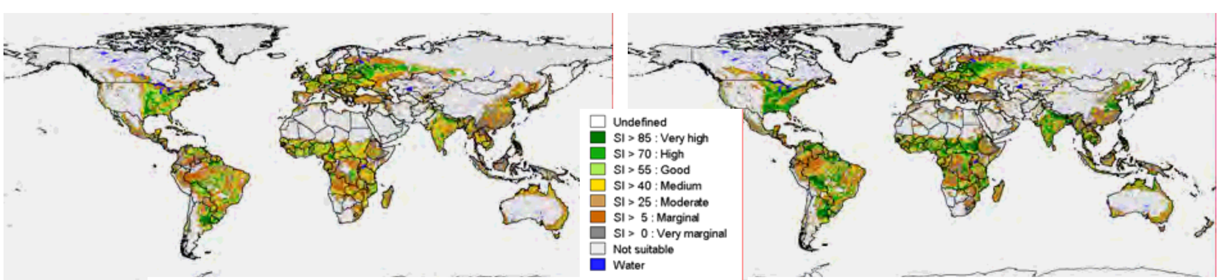
The ability to predict carbon emissions and sequestration due to land-use activity depends on a correct representation of crop-management dynamics and the proper scaling to regional levels. This multiple tasks can only be achieved by merging existing modeling approaches in a meaningful manner. Dynamic crop models excel in describing the local interactions between management, genetics, environment and plant growth, including effects of elevated CO_2 and their interactions with water and N regimes (Tubiello et al., 1999; Tubiello and Ewert, 2002). These models have been extensively validated locally, though this characteristic has severe limitations with respect to spatial scaling (Ewert et al., 2001). On the other hand, land use models are very well-suited for larger scale agro-ecosystem computations, focusing on dynamic management adaptation, including under climate change, but are in general poorly calibrated against reported data. Finally, terrestrial ecosystem models are the proper tool for calculating large-scale natural ecosystem carbon and N fluxes (Xiao et., 1997). However, they have non-dynamic land use components and poor agricultural crop simulation capacity. Clearly all three approaches must be considered in order to improve projections of land-based carbon emissions, including the effects of climate change. Finally, climate models must be modified to interactively simulate these effects as climate changes through time.

In brief, site, county and regional-level data (field and satellite), together with site-level dynamic crop model simulations, must be used to calibrate and validate increasingly larger scale resolutions for land use (0. 1°X0.1°) and ecosystem (0.5°X0.5°) models, up to GCM grid scale (2.5X2.5 and 4X5), both under current and future climates, up to the period 2050. Once a consistent set of data and modeling results has been achieved (validation), changes in land-use and management—computed with a agro-ecological zone model--can then be translated into carbon emissions using an ecosystem model. Finally, feedbacks between land-use, carbon cycling and regional climate can be assessed within GCM coupling. Adaptation to climate change in the form of likely management practices (planting dates, cultivar, crop, irrigation and/or fertilization changes) need also be evaluated, first at the site level—where management decisions are actually implemented—and then scaled regionally in terms of land use and carbon cycle dynamics.

Finally, the proposed LULUC NEESPI plan further seeks to analyze sets of scenario simulations, with current climate as well as under climate change conditions, with and without adaptation/mitigation. Comparisons of ensemble runs will help us assess the strength of the interactions between climate change, land use and carbon emissions.

Model Integration: Land use and carbon dynamics

Computations with an agro-ecological zone model (AEZ) evaluate the suitability of a particular land unit for crop production, including factors such as the quality of the soil, the local climate conditions, and the possibilities of using different types of inputs such as fertilizers, pesticides, machinery, etc. The model then evaluates various mixes of crops that are possible under the specific conditions of a plot using bio-physically-base computations of crop growth and yield. The figure on this page is an overview of the flow and integration of information implemented in the IIASA AEZ. Biophysical calculations of attainable yields in a land unit start with estimating site-specific maximum biomass and yield potentials as possible under prevailing climatic conditions. Then, agro-climatic constraints, soil constraints, and terrain limitations are assessed against crop requirements to derive attainable yields. The procedure takes into account yield losses occurring due to temperature limitations, moisture stress, pests and diseases, and workability constraints. Production is estimated for different levels of management and inputs. Following the crop suitability assessment, the productivity assessment also considers



Predicted rainfed cereal suitability *Predicted irrigated cereal suitability*

Figure 3.4.2. Predicted cereal suitability

(a) production increases resulting from multiple cropping; and (b) fallow requirements to maintain soil fertility and structure. Land utilization types (LUT) are then defined from the coupling of the resulting agronomic, forestry, and technical specifications. *GAEZ distinguishes 148 crop LUTs, 52 forest LUTs, and 6 generalized grassland land use types*. Assessment of alternative LUTs is typically performed by superimposing various thematic maps including different attributes of land such as climate, soil, altitude, landform, terrain slope, present land cover/use, and administrative boundaries. For Eurasia, the model operates on a resolution of 5X5 kilometer. The work we have developed to date has resulted in a database containing extended information on all feasible land utilization types for each grid cell. It can be used to tabulate or map potential arable land by crop or zone. The database contains also the geo-referenced agronomic data for district, regional, and national land-use planning scenarios. Linkages between GAEZ and an carbon-ecosystem model (CEM) will provide a powerful tool that can be used to analyze carbon emissions from land as a function of: 1) land management dynamics; and 2) agro-ecosystem production and dynamics.

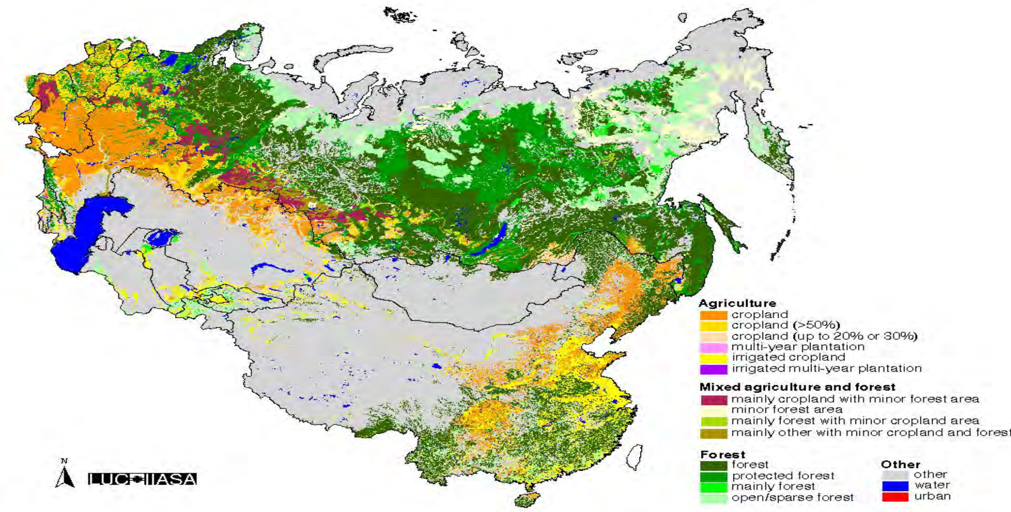


Figure 3.4.3. Agricultural and forested land

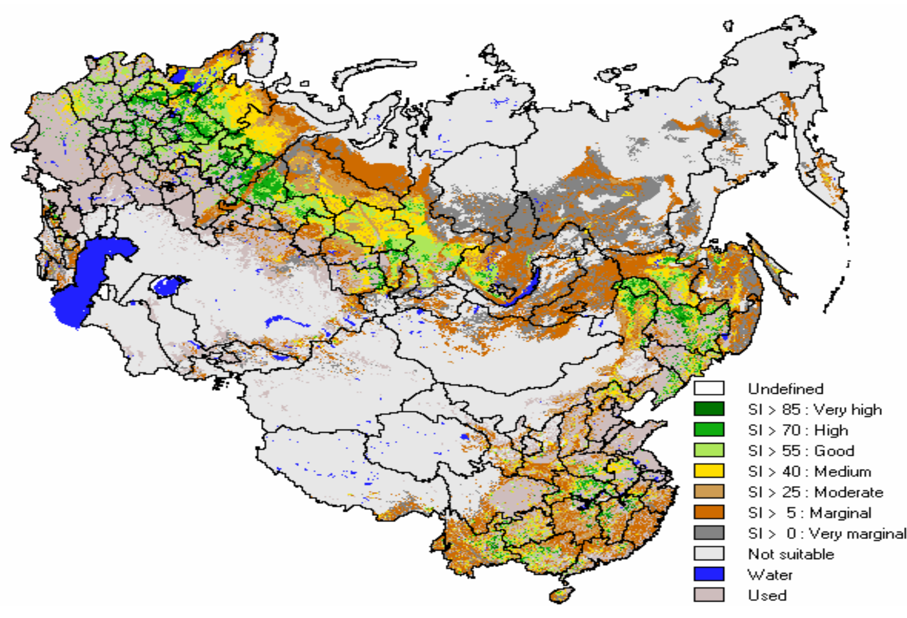


Figure 3.4.4. Suitability for conservation forestry (excluding cultivated and urban areas).

Sensitivity studies: management versus climatic effects. The linked GAEZ-CEM models can further be used to investigate, within current climatic conditions, key dynamics affecting inter-annual variability of carbon emissions. These have at least two interacting components: one

related to climate variability; the second related to crop management. Existing models with simple
agronomic approaches can only resolve the first of these two factors, while we will be capable of analyzing both. To this end, daily time series of biomass growth during growing periods, including leaf area index development, must be generated under varying management.

Climate change impacts, adaptation and mitigation

Climate change and elevated CO_2 will affect agro-forestry systems productivity, altering local food and fiber supply, thus affecting the magnitude of land carbon fluxes and their spatial distributions. Impacts will depend on the severity of climate change as well as on the adaptation capacity of regional systems. GISS has already compiled a set of over 100 agricultural sites for dynamic crop model simulations under current conditions and climate change. These will be used in evaluating/developing the AEZ simulations over the NEESPI region. Using such modeling tools, NEESPI LULUC focus will be on analysis of plausible sets of adaptation/mitigation responses in terms of consequences for carbon emissions. *Specifically, it is generally projected that the impacts of climate change on agriculture can be quite small where large adaptation capacity exists, in terms of changes in crop management (water and/or fertilizer), crop adoption, and land conversion (e.g., Reilly et al., 2001). However, little attention has been given so far to consequences of those adaptation adjustments in terms of their potential for either carbon emissions or sequestration*. For example, if agricultural production in Eurasia does move north, as the currently projected increases in temperatures and growing seasons suggest (see figure), how much more carbon will be lost to the atmosphere from land conversion? What happens to regional soil carbon stocks when additional irrigation is applied, for example to counteract drier, hotter summer in continental interiors?

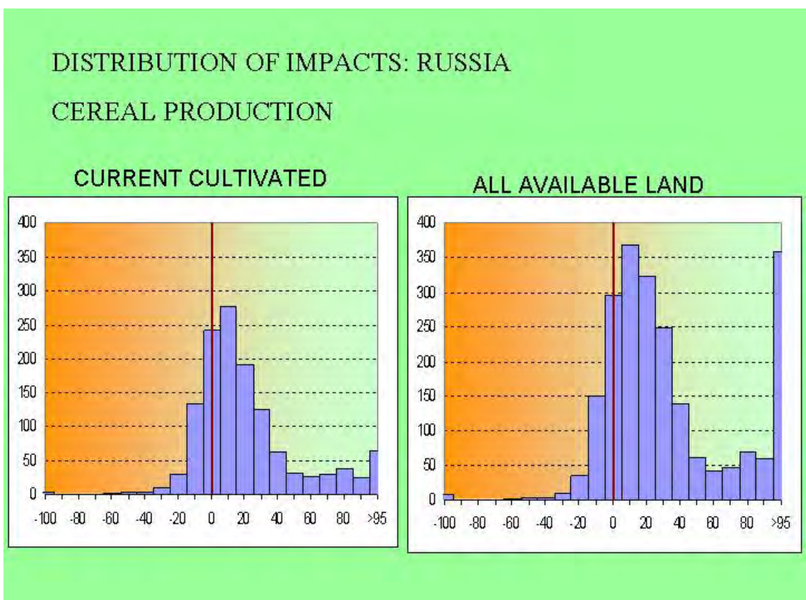


Figure 3.4.5. Projected impact on cereal production in Russia.

As argued elsewhere (e.g., Reilly et al., 2001; Tubiello et al., 2002), it is important to consider contrasting projections of future climate change if system vulnerability and/or dynamics are to be assessed. In addition to GCM projections, it would be wise to compile sensitivity tables of agriculture and forestry production in Eurasia in response to ranges of temperature and precipitation change. Such table can often be of great use in quickly assessing impacts of additional GCM projections over a region.

GCM land surface model: interactions of land use, carbon and climate

In addition to the climate change simulations using fixed climate scenarios as described above, NEESPI-LULUC proposed to focus on a full- coupling of land use, carbon and climate models. Under work funded by NSF and NOAA, for example, we are already modifying the GCM “cultivated” category to include multiple descriptors of crop type and management, with testing for the U.S. Midwest and agricultural China; the current 4X5 version of the GISS-GCM covers the US central plains and China with about 8 grid-boxes each. Similar simulations at GCM resolutions are proposed under NEESPI similarly to the research examples below. Specific regions for Northern Eurasia will include major crop production areas such as the Ukrainian wheat belt as well as seimi-arid marginal production areas in Central Asia. Specific study areas will be selected at GISS and IIASA in collaboration with local agronomists and land managers from participating NEESPI countries.

Example. Case study under current funding: interannual variation of agricultural yield, leaf area coverage, water and carbon fluxes in the continental US and China. *We have accumulated a detailed dataset of crop yield data at the county level, covering wheat and maize yields and planted/harvested areas from 1950 to date. We also have developed methods for aggregating such data at the regional level, covering regions that can be spanned within the coarse GCM resolution. The regions we propose for detailed analysis are: Northern mid-west plains (North and South Dakota, Nebraska, Kansas); southern mid-west plains (Oklahoma, Texas); northwest US and Canada (Montana, Saskatchewan); and Northeast, Central, and South China. The simulations are as follows:*

- Baseline simulations 1950-2000, *with GCM running with observed sea-surface temperatures predicting leaf-area index development, fraction of vegetation (i.e., planted versus base soil) over time, and crop yields. Available satellite data for the US and China over this period, as well as crop yield datasets are being used to assess the goodness of GCM simulations. Model sensitivity to management studied by simulating an “all rainfed” case versus an “all irrigated” one.*
- Climate change scenario without adaptation.
- Climate change scenario with adaptation**.**

All stages of proposed activities under NEESPI-LULUC will be integrated by education at the undergraduate, graduate and post-doc level. Analysis of land use and land use change within NEESPI propose to integrate climate, agro-ecological zone and cropping systems, and carbon cycle-cycle modeling, in order to capture the key interactions between climate impacts, adaptation and mitigation responses.

3.4.6. Biodiversity. Expanded version of Sub-section

Contribution by Kathleen Bergen and Mykola Zalogin

Potential Effect of Land-Use and Climate Change on Biodiversity in Northern Eurasia

Global biodiversity is under particular risk from global climate change. Already hemmed in by habitat loss, pollution and over-exploitation, species and natural systems are now faced with the need to adapt to new regimes of temperature, precipitation and other climatic extremes. Biodiversity science and management have increasingly difficult challenges to face in the new millennium.

At the simplest level, changing patterns of climate will change the natural distribution limits for species or communities. In the absence of barriers it may be possible for species or communities to migrate in response to changing conditions. Vegetation zones may move towards higher latitudes or higher altitudes following shifts in average temperatures. Movements will be more pronounced at higher latitudes where temperatures are expected to rise more than near the equator. In most cases natural or man-made barriers will impact the natural movement of species or communities. Arctic tundra and alpine meadows may become squeezed by the natural configuration of the landscape, while these and many other natural systems may be further confined by human land-use patterns (Figure 3.4.6). Many national parks and protected areas are now surrounded by urban and agricultural landscapes which will prevent the simple migration of species beyond their boundaries.

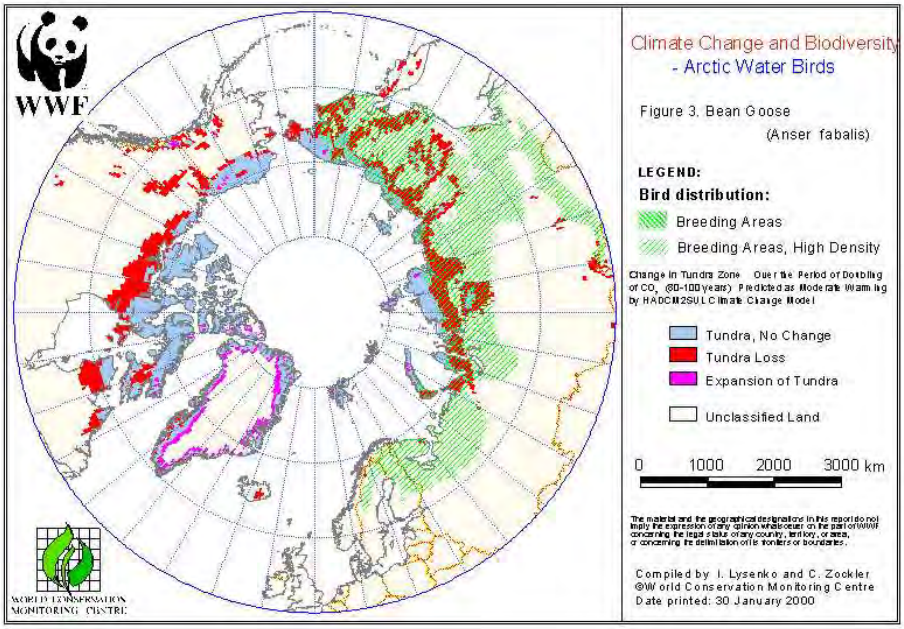


Figure 3.4.6. Change of arctic water birds distribution area. (Source: Biodiversity and Climate Change Programme, UNEP World Conservation Monitoring Centre).

Perturbations to rainfall and drought patterns will also be of critical importance. Increased flooding would have implications for large areas, especially riverine and valley ecosystems. On the relatively narrow habitats of the coastal margins, especially where these are backed by areas of intense human use, rising sea levels may lead to the squeezing out of important coastal habitats. Rising sea temperatures will further affect the distribution and survival of particular marine resources. Studies have shown dramatic changes in the distribution and survival of the Pacific salmon in the late 1990s (citation?). In addition to causing a warming effect, increased concentrations of atmospheric carbon dioxide are known increase rates of photosynthesis in many plants, as well as improving water use efficiency. In this way the climate changes may increase growth rates in some natural and agricultural communities.

Characterizing of Biodiversity

Biodiversity is characterized at several scales – species, community, ecosystem – and includes both plant and animal diversity. Northern Eurasia has significant diversity of ecosystems. Using World Wildlife Fund categories (WWF), Northern Eurasia is comprised primarily of the following diversity of ecosystems: Tundra, Boreal Forest-Taiga, Temperate Broadleaf and Mixed Forests, Temperate Coniferous Forests, Steppe Grasslands, Flooded Grasslands, Montane Grasslands, Desert and Xeric Shrubland. These ecosystems in turn have variability in the levels of biodiversity within them and in their degree of present intactness. Ecosystem diversity if often studied and described in terms of intactness or fragmentation. “Hot spots” is a term currently popular for describing regions with high levels of biological endemism of individual species of plants and animals and under threat of loss of that diversity.

Biodiversity in Boreal Russia

Russia alone has been cited as having "one-fifth of the worlds forests, the longest coastline of any nation, and a host of rare, endemic and highly charismatic species, including Amur tigers, Siberian Cranes, Baikal seals, and the Saiga antelope (Dinerstein et al, 1994)." The status of entire Russian ecosystems in terms of their intactness is important in responding to land-use and climate change with more or less resilience. While limited to European Russia, an important study completed in 2001 assessed forest ecosystem intactness by use of remote sensing and GIS methods. Last Intact Forest Landscapes of Northern European Russia was published jointly by Global Forest Watch and Greenpeace Russia. They found that forest landscapes that are still intact make up only about 14% of the total forest area of European Russia and stress that "conservation of large intact landscapes is a robust and cost-effective way to conserve biological diversity (Yaroshenko et al., 2001)". Other scientific studies have identified geographic regions of Russia known in general for high species richness and endemism. These include 1) the Caucasus Mountains, the Altai and Sayan mountains of southern Siberia, the south of the Russian Far East and the Lake Baikal watershed (Olson and Dinerstein, 1998). A similar study determined that mountainous territories on Russia's southern borders were the greatest centers of endangered species diversity: Maritime state, Krasnodar state, Dagestan republic, Sakhalin province and the Jewish province (Griffen, 1999). Biodiversity conservation in the Russian Federation and former Soviet Union relied upon a nature reserve system of Zapovedniki. Currently approximately 85 zapovedniks (16 of which are biosphere reserves) remain along with 26 national nature parks. These are currently facing staffing and financial hardships but form a basis for biodiversity science and conservation (Colwell et al, 1997; Dinerstein et al, 1994. Species are well documented and listed in Russia's Red Data Book (Eliseev et al., 1985).

Biodiversity in Caucasus and Semi-Arid Regions

According to Conservation International, a group that has identified a select number of global scale "hot spots", the location in Northern Eurasia that has attained "hot spot" status is the Caucasus Mountains in southwestern Northern Eurasia. Both the topography and the vegetation of the Caucasus is very diverse including significant areas of grassland steppes, semidesert, desert, swamp forests, arid woodlands ecosystems. Scattered throughout the hotspot are broadleaf forests, montane coniferous forests, and shrublands. Today, only about 50,000 square kilometers, 10 percent of the hotspot's original area, remains pristine (http://www.biodiversityhotspots.org/xp/Hotspots/caucasus/). The Caucasus region contains 1600 endemic plant species (of 6300 species) and 59 endemic vertebrate species (of 632), 10 threatened species and 3 critically endangered species.

Biodiversity in Europe and the Ukraine

In many European countries, half of the known vertebrate species are threatened. More than one-third of Europe's bird species are in decline, mainly due to damage to their habitats by land-use changes and increasing pressure from agriculture and forestry (Tucker and Heath 1994; Tucker and Evans 1997). In Europe and Central Asia, about 300 wetland sites are protected under the Ramsar Convention, in addition to some 70 world natural heritage sites and biosphere reserves, also important for wildlife preservation (EEA 1995). There is need to incorporate biodiversity considerations into other policy areas. The all- European strategy of biological and landscape diversity preservation is an innovative approach to stopping and turning back the degradation of biological and landscape diversity in Europe, because it strives to unite all of the initiatives and different projects in a European framework. One of the main elements of the strategy's philosophy is the principle that the preservation efforts will be successful only then, when socio-economic factors will be taken into account.

Data obtained by Ukrainian researchers and outcomes of international projects give evidence that the main factors contributing to a decrease of biodiversity sustainability in Ukraine are 1) fragmentation of landscapes, 2) complete tilling of soil and chemical pollution reaching 75-85% in some oblasts, and 3) nearly complete shift in water yield and chemical composition of water in surface water reservoirs. Similar examples are observed on the European scale. The application of advanced information technologies, such as remote sensing (RS) and geographical information system (GIS), is very efficient tools for investigation of such factors. Also, the government policy on nature conservation remains reluctant to drastic changes in state of biodiversity. Moreover, the current legislation on protected areas is not consistent with today challenges and sometimes is worst than at the beginning of 20th century (Figure 3.4.7).

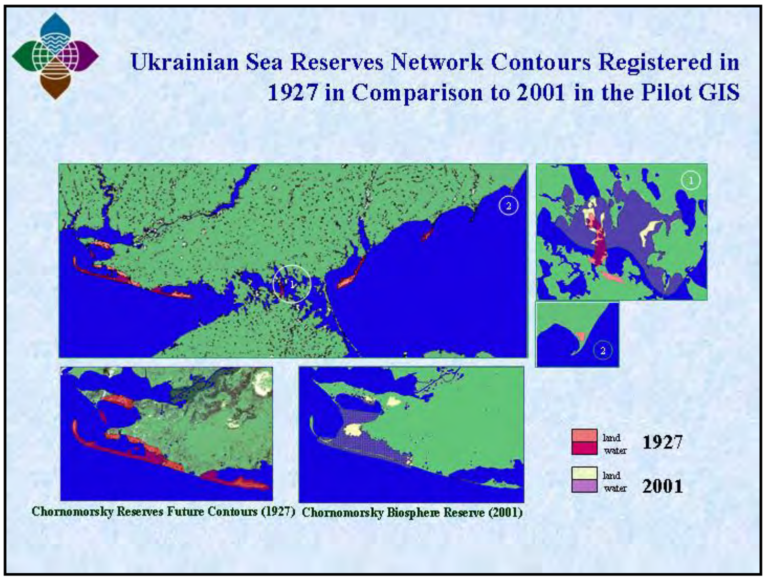


Figure 3.4.7. Ukrainian Sea Reserves Network Contours Registered in 1927 in Comparison to 2001 in the Pilot GIS. (Source: Ukrainian Land and Resource Management Center, ULRMC).

According to the data of 1996-2003, the number of endangered species of mammals increased both in the Eastern and in the Western parts of Europe. In terms of practical actions, reasonably anthropocentric approach was recommended or completion of red lists, combined with urgent designing of quasi-natural ecosystems and protection of functionally steady aggregations rather than species as such (Zagorodniuk, 2000). In scope of this and other approaches following priorities could be proposed:

- enhance the application of IT (RS, GIS and Internet);
- migratory species monitoring and conservation;
- zoning of the protected territories the most threatened by global climate changes;
- Management of transboundary protected areas and territories, development of Northern Eurasian Protected Areas network;
- biodiversity and sustainable agriculture.

The NEESPI could contribute to the updating the global biodiversity model (GLOBIO) as well as to the improving scenarios “2010” and “2100” related to biodiversity. NEESPI should consider supporting projects that seek to use remote sensing, GIS/ geospatial technologies, and modeling to better understand and quantify the relationship between biodiversity and land-cover/use change and climate change and their interactions in Northern Eurasia. There are a number of national and international groups that NEESPI should investigate coordinating with. NEESPI should seek to coordinate with the Biodiversity Program within NASA on this topic as well as World Resources Institute, Conservation International, World Wildlife Fund, Greenpeace Russia, and other groups in United States, Northern Eurasia, and Europe. Within Northern Eurasia there are a number of regional and local conservation groups and science efforts underway.

Box insert 3.4.3. Atmospheric pollution and health issues. Contribution by Eugene L. Genikhovich.

The atmospheric pollution in Northern Eurasia seems to be an important socioeconomic factor, especially, in Siberia and Ural regions. In many cities there the level of pollution is extremely high, and it is reflected there in high levels of morbidity and mortality. The actual information about the levels of air pollution is collected on the local, regional, national, and, in certain instances, international levels and the results of processing of corresponding data are usually published on the regular basis. In particular, the monitoring data obtained in the framework of the EMEP program in 1978 - 1998 are analyzed by Barrett et al. (2000). The most resent information about air pollution in Russia was presented in the national report published by Izrael et al. (2002, 2003). Table 2.4.3 taken from this report lists the most polluted Russian cities where short-term (20 min averaged) concentrations of one of the pollutants, monitored in 2001, were at least once higher than the tenfold value of the corresponding Maximum Permissible Concentration (the Russian National Ambient Air Quality Standard). The values of MPC (usually both, short- and long-term ones) are established in Russia for more than 2000 species.

Table 3.4.3 shows that in 2002 short-term averaged concentrations higher than 10 MPC were observed in 48 Russian cities. In relation to annually averaged concentration, the cities were sorted using the Air Pollution Index (API) that is the sum of five highest partial indices (for each pollutant, the partial API is determined as the ratio of its mean annual concentration to corresponding MPC raised to the power 0.85, 1.0, 1.3 or 1.5 depending on the toxicity group the pollutant considered belongs to, which is identified in the official list of MPCs). In 2002 the list of the most polluted Russian cities based on this API sorting included 31 cities with the total population over 15 million people. The environmental situation did not improve in 2002 (see Izrael et al., 2003). That year 35 Russian cities with the total population over 20 million people were included in the list of the most polluted cities. Among those, 20 cities were located in Eastern Siberia and Far East regions.

Table 3.4.3. Russian cities with highest in 2001 short-term concentrations exceeding 10 MPC (Izrael et al., 2002)

City	Pollutant (Cmax/MPC)
Arkhangelsk	Methylmercaptan[1] (1360 μg/m^3)
Achinsk	Benzo(a)perene (12.2)
Barnaul	Nitrogen dioxide (10.6), phenol (10.7), particulate matter (10.4), hydrogen sulfate (10.9)
Berezniki	Ethylbenzene[2] (10.8)
Bratsk	Benzo(a)perene (22.2)
Vladivostok	Formaldehyde (12.0)
Vologda	Benzo(a)perene (12.1)
Volgograd	Hydrochloride (12.7)
Gubakha	Ethylbenzene[2] (15.6)

Ekaterinburg	Ethylbenzene[2] (30.2)
Zima	Benzo(a)perene (26.5)
Kansk	Benzo(a)perene (21.8)
Kemerovo	Hydrochloride (17.2)
Korsakov	Particulate matter[3] (27.3)
Krasnoyarsk	Benzene (19.5), toluene (13.0), benzo(a)perene (20.1)
Kurgan	Benzo(a)perene (20.0)
Kyzyl	Benzo(a)perene (10.1)
Magadan	Benzo(a)perene (12.2)
Magnitogorsk	Ethylbenzene[2] (19.0), nitrogen dioxide (11.4), benzo(a)perene (15.0)
Minusinsk	Benzo(a)perene (13.8)
Mirnyi	Hydrogen sulfate (22.4)
NizhniTagil	Ethylbenzene[2] (13.5)
Novoaleksandrovsk	Soot (10.3)
Novodvinsk	Methylmercaptan[1] (6078 $\mu g/m^3$)
Novokuibyshev	Xylene (18.5)
Novokuznetsk	Phenol(14.0)
Novorossijsk	Nitrogen dioxide (12.6)
Omsk	Ethylbenzene[2] (16.0), phenol (14.8), hydrogen chloride (10.5), acetaldehyde (103.6)
Orenburg	Nitrogen dioxide (14.9)
Partizansk	Benzo(a)perene (10.7)
Pervouralsk	Hydrofluoride (18.2)
Perm	Hydrochloride (19.0), nitrogen dioxide (10.5), ethylbenzene[2] (22.6), formaldehyde (12.1)
Samara	Benzo(a)perene (10.8)
St. Petersburg	Nitrogen dioxide (13.2)
Selenginsk	Benzo(a)perene (11.9)
Solikams	Ethylbenzene[2] (10.3)
Sterlitamak	Benzo(a)perene (10.0), hydrochloride ((12.5)
Taganrog	Nitrogen dioxide (13.3)
Ulan-Ude	Benzo(a)perene (34.8)
Usolie-Sibirskoe	Benzo(a)perene (15.2)
Ussurijsk	Benzo(a)perene (15.9)

Ufa	Nitrogen dioxide (24.0), benzo(a)perene (13.8), carbon monoxide (13.0)
Khabarovsk	Benzo(a)perene (14.6)
Chelyabinsk	Ethylbenzene[2] (16.4)
Chita	Benzo(a)perene (38.0)
Shakhty	Nitrogen dioxide (11.5)
Shelekhov	Benzo(a)perene (28.7)
Yuzhno-Sakhalinsk	Benzo(a)perene (14.6), soot (17.7), particulate matter [3] (11.3), nitrogen dioxide (10.5)
[1] – Cmax is given without normalizing with MPC. [2] – Daily averaged concentrations are normalized with the short-term MPC. [3] - Daily averaged concentrations are normalized with the long-term MPC.	

Correlations between the air pollution and adverse health effects in Russia were studied in numerous publications. For example, Bezuglaya and Zavadskaya (1998) were using data on the number of cases of first-time found malignant tumors in 47 Russian cities during 1986 – 1990 (these data were collected in the information system "AGIS – Health" run by the Russian Ministry of Public Health). They found, in particular, that the annual coefficients of correlation between these numbers and API in the cities considered were varying for different years between 0.42 and 0.69 and, for the whole sample, this coefficient of correlation was equal to 0.60; thus, from 20% to 50% of this morbidity could be associated with the air pollution. Accordingly to these authors, about 11% to 16% of respiratory diseases in Russia were also related to the air pollution. Ozkaynak et al. (1998) linked concentrations of TSP (Total Suspended Particles) in Yekaterinburg and Nizhni Tagil with acute respiratory and cardiovascular mortality (ARM and ACM, correspondingly). Their findings were as follows: 11% to 16% of ARM in Yekaterinburg was associated with previous day's TSP; 5% to 9% of ARM in Nizhni Tagil was associated with same day's TSP; 2% of ACM in Nizhni Tagil was associated with previous day's TSP. The impact of high levels of pollution on human health is also illustrated with the following results of spectral analyses of lung tissue samples from lung cancer patients in Magnitogorsk, the city that hosts one of the largest Russian steel works (Table 3.4.4).

Table 3.4.4. Spectral analysis of lung tissues in Magnitogorsk, 1997 (after Koshkina, 1998)

Chemical	Concentration		
	Background level	Magnitogorsk	
		Healthy tissue	Malignant tissue
Ag	0.0007	6.77	0.72
Zr	2	9.13	8.05
Ca	-	-	222
Co	0.02	0.69	1.46
Ni	0.047	1.79	0.44
Mo	0.03	no	12.23
Sr	-	no	0.22
Si	-	53.33	793.6

Sb	0.06	203.3	153.2
Au	0.063	no	1.63
Cr	0.092	2.8	4.95
Be	0.007	0.16	0.22
Zn	11	61.39	47.53
Cd	0.35	3.11	7.25
P	780	5091	3649
Pb	0.39	6.53	1.14
Cu	1.2	3.06	1.32
Fe	3600	no	125.5
K	1900	558.11	466
Na	1800	1855	1572

The regional effects of atmospheric pollutants depend on the strength of the emission sources and on meteorological and climatic conditions, each of these factors being varied in space and time. One of the principal questions still to be addressed is how this complex picture of atmospheric pollution and its impacts on the human health and environment could be influenced by the projected climatic changes and what are corresponding possible climatic feedbacks and socioeconomic impacts.

Box insert 3.4.4. Consequences of Chornobyl Disaster. Contribution by M. Zalogin.

The April 26, 1986, explosion of the fourth reactor at the Chornobyl Nuclear Power Plant (CNPP) is considered to be one of the worst man-made accidents of the 20th century, leading to wide-scale radionuclide contamination in the region (Figure 3.4.8). The "Chornobyl Exclusion Zone (CEZ)" is an established and largely secured area around and including the nuclear power plant, located approximately 80 kilometers from Kyiv, and extending northward to the border with Belarus. More than 160,000 people have been resettled from the CEZ since 1986 to mitigate health impacts of the catastrophe.

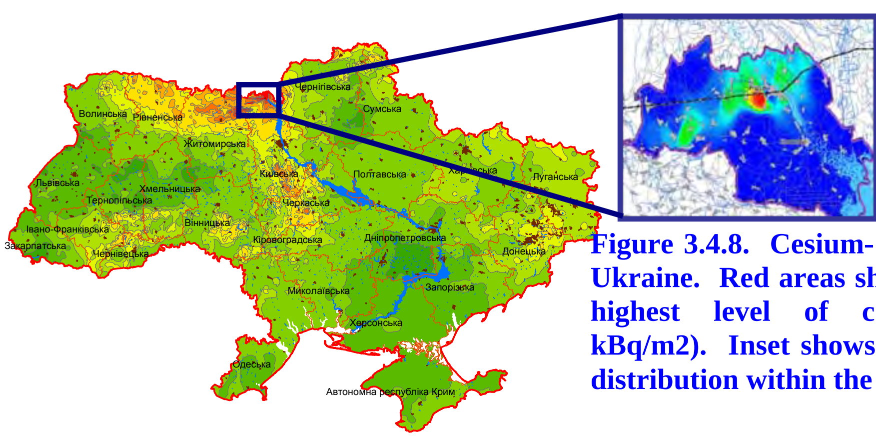


Figure 3.4.8. Cesium-137 Contamination of Ukraine. Red areas show locations with the highest level of contamination (3,700 kBq/m2). Inset shows overall radionuclide distribution within the CEZ.

Permanent and temporary waste depositories were created in 1986 and 1987 as part of the first priority operations designed to decontaminate the territory within a 10 km zone immediately surrounding the CNPP. According to expert assessments, the radioactivity concentrated in these radioactive waste depositories equals 13 * 10^{15} Bq . Radioactive contamination in the CEZ continues to spread through natural processes outside of the larger 30 km exclusion zone. Estimates are that 90% of radionuclide dispersion is related to water transport into the Prypyat River by various mechanisms (Derevetz et al, 2003).

About 20 km south of the CNPP, the Prypyat River converges with the larger Dnipro River in a reservoir known as the "Sea of Kyiv." The Dnipro River provides water for approximately 33 million residents, or two-thirds of the population of Ukraine, of which 10 million are living directly adjacent to the waterway downstream from Chornobyl.

Approximately 10% of radionuclide dispersion is due to vegetation fires within the CEZ (Caletnik, 2003) with the potential to release airborne radionuclides to the greater Trans-Polissya region of northern Ukraine and neighboring countries such as Belarus, Russia, Poland and the Baltics. CEZ forests act as a protective shield slowing the spread of radioactive contamination by absorbing radionuclides. In 1992, "Chornobyl Forest," a state-owned, specialized industrial forestry complex, started its activities within the CEZ. This enterprise aims to protect the CEZ's forests from fires and poachers, protects vegetation from pests and diseases, and also plants young trees to sequester radionuclides in the biological chain. Forest planting in contaminated territories is one of highest priorities in the entire program to remediate the consequences of the Chornobyl disaster. Forests around Chornobyl continue to play an important role, decreasing levels of radionuclides migration and further nuclear contamination by more than 50% (Caletnik, 2003).

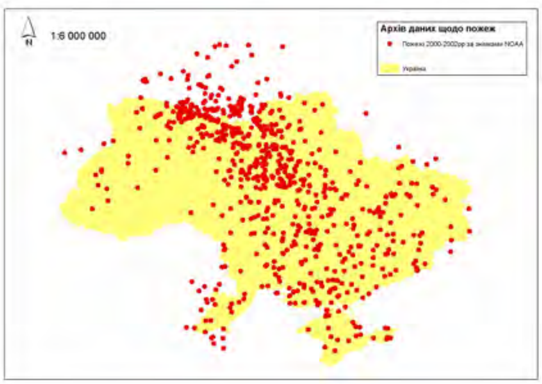


Figure 3.4.9. Fires Identified Between 2000 and 2002 Based on Analysis of NOAA AVHRR Imagery Acquired by ULRMC.

On the other hand, the fires in highly contaminated forest area around the CEZ dramatically affect a nature European region and health of population. The problems of transbondary radionuclides transportation caused by forest fires is very critical for this region which is associated with high density of fires (Figure 3.4.9).

Administrative regulations for the CEZ require that the duration of forest fires be limited in burn time to a maximum of three hours. The implementation of this regulation requires substantial human and financial resources in order to fight vegetation cover fires within the CEZ (Figure 3.4.10). Accordingly, improvements in the ability to predict climatic conditions that may lead to increased forest fire threats are greatly needed and can support the planning, response and deployment processes of the Administration of the CEZ.

Figure 3.4.10. Firefighters in the CEZ.

Chapter 3.5. Ecosystems and climate interactions.

Three extended references (in green) were removed from the chapter but are preserved below

Introduction. The climate system and terrestrial ecosystems interact as they change. The interactions enhance and/or moderate the changes making these changes non-lineary[64] There are theoretical indications that the particular state of the ecosystem may make the history of the global climatic changes intransitive[65]. Gradually, Human Activity (HA) has become a part of these interactions by affecting the atmosphere, hydrosphere, cryosphere, and biosphere[66]. ……

…

3.5.1.1 Major feedbacks

…..

Biogeophysical feedbacks. …. Vegetation provides shade, affects surface energy balance (Figure 3.5.2), controls evaporation, runoff, soil moisture, snowmelt, and a partition between sensible and latent heat losses[67]. …

….

The entire section presented below (3.5.2) was moved from Chapter 3.5 to the Scientific Background Appendix

3.5.2. Observed impacts of *changes* in ecosystems and climate on each other

3.5.2.1.Climatic changes that have most directly affected the biosphere and society

[64] Budyko 1971; Graetz, 1991; Bonan et al., 1992; Botkin and Nisbert, 1992; Field et al., 1992; Prentice et al., 1992; Raich et al., 1992; Shugart et al. 1992; Mooney et al., 1999; Rosema et al., 1993; Denning et al., 1995; Vygodkaya et al., 1995b; Keeling et al., 1996; Melillo et al., 1993, 1996; Braswell et al., 1997; Margolis and Ryan, 1997; Ryan et al., 1997; Cao and Woodward, 1998; Churkina and Running, 1998; Galloway and Melillo, 1998; Houghton et al., 1998; Pielke et al., 1993, 1998; Liski et al., 1999; Schulze et al. 1999, 2001; Valentini et al., 2000; Eastman et al. 2001; Pielke 2001; Kabat et al. 2004

[65] I.e., a possibility of the multiple long-term equilibriums of the Global Earth System exists under the same external conditions (Pielke 1998). One of the regions of the possible intransitivity is in the Central East Asia desert area (Claussen 1998). Another example is in the boreal forest zone of Northern Eurasia, where a millennium-scale process of paludification, i.e., gradual moss coverage of the surface and mire development could be an autogenous process (Pajula 2000). For example, the surface air temperature and precipitation conditions ~10,000 years ago may be approximately the same as the present at certain locations. But, now we have there a well developed moss cover that insulates the ground while10 to 6,000 years ago the moss cover was absent (or undeveloped) and the entire regional ecosystem (first of all, the soil temperature regime) was different.

[66] E.g., Kirikov, 1979; Osipov and Gavrilova, 1983; Schulze et al., 1989a;1989b; Vitoussek and Howard, 1991; Berendse at al., 1993; Godbold and Huterman, 1994; Houghton, 1995; Santer et al., 1995; Sirotenko et al., 1995; Melillo, 1996; Aber and Driscoll, 1997; Foster et al., 1997; Sokolov, 1997; Lloyd, 1999; Vitoussek and Field, 2001.

[67] Molchanov 1961; Rauner 1972; Ross 1875; Pavlov 1975; Monteith 1975, 1976; Skatveit et al., 1975; Fedorov, 1977; Bihele et al., 1980; Varlagin and Vygodskaya, 1993; Vygodskaya 1981; Abrazhko 1992; Vygodskaya et al., 1995a, 2004; Chapin et al. 1996, 2000; Pielke 2001; Molchanov, 2000; Pielke 2000; Baldocchi et al. 2000; Sellen, 2001; Oltchev et al. 2002; Tchebakova et al., 2002; Lynch et al. 2003; Avissar et al.2004; Kelliher et al., 1993a,b, 2001, 2004; Kurbatova et al., 2002.

While changes in surface air temperature and precipitation are most commonly addressed in the literature, changes in their derived variables (variables of economic, social and ecological interest based upon daily temperatures and precipitation) have received less attention. The list (incomplete) of these variables (indices) includes: frequency of extremes in precipitation and temperature, frequency of thaws, heating degree days, spring onset dates, growing season duration, sum of temperatures above/below a given threshold, days without frost, day-to-day temperature variability, precipitation frequency, precipitation type fraction, frequency of rain-on-snow events, characteristics of potential forest fire danger, and many similar characteristics of the thermal and hydrological regimes**.** In practice, these and other indices are often used instead of "raw" temperature and precipitation values for numerous applications. These include modeling of crop-yields, prediction and planning for pest management, plant-species development (e.g., Table 3.5.1), greenhouse operations, food-processing, heating oil consumption in remote locations, electricity sales, heating system design, power plant construction, energy distribution, reservoir operations, floods, and forest fires. These indices provide a measurement for the analysis of changes that might impact agriculture, energy, and ecological aspects of terrestrial and aquatic systems of Northern Eurasia. Figures 2.11, 3.5.4, and 3.5.5 and Tables 3.5.2 and 3.5.3 provide estimates for changes in some of these indices for Northern Eurasia during the 20th century.

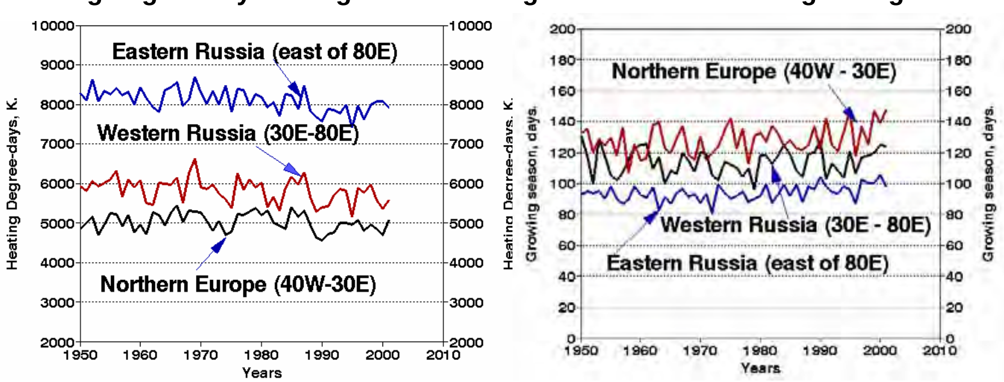


Figure 3.5.4. Example of changes in temperature regime over Eurasia north of 50° N that affect heating costs and agriculture production (Groisman et al. 2003a).

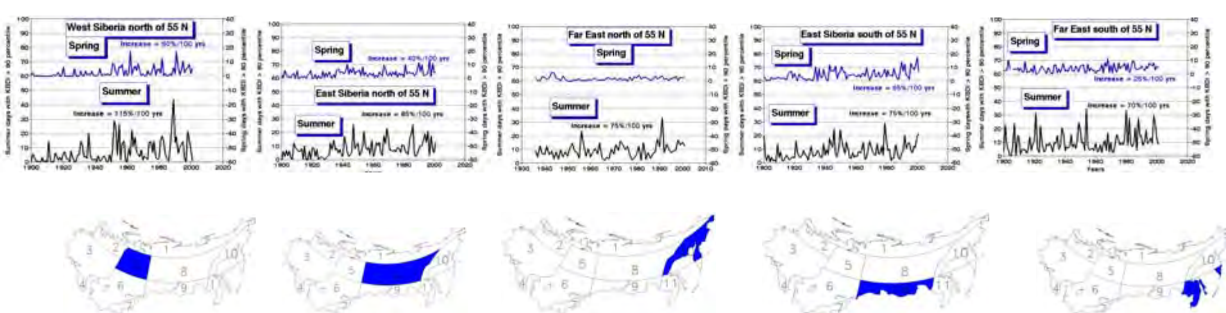


Figure 3.5.5. Region partition of Siberia and the Russian Far East and time series of the number of summer and spring days with daily KBDI values above the upper 10 percentile of its seasonal distribution. The index makes use of daily temperature and precipitation data. Higher values of this index characterize a higher potential for forest fire.

Table 3.5.2. Changes in temperature-derived characteristics over Northern Eurasia east of 30°E, north of 50°N during the past 50 years (adapted from Groisman et al. 2003a).

Characteristic Region	Trend, %/50 yrs
Heating-degree days: East of 80ºE West of 80ºE	**-6** **-7**
Degree-days below 0ºC: East of 80ºE West of 80ºE	**-12** **-19**
Degree-days above15ºC: East of 80ºE (only)	**12**
Duration of the growing season (T> 10ºC) East and West	**8**
Frost-free period: East of 80ºE (only)	**10**

Table 3.5.3. Increase in mean regional frequency when summer KBDI (index of potential forest fire danger introduced by Keetch and Byram [1968]) exceeds the "non-zero" 90th percentile of its distribution during the reference period 1961-1990 (Groisman et al. 2003b).

Regions south of 66.7° N	Period assessed	Frequency changes, %/100yr
West Siberia, north of 55° N	1900-2001	115
East Siberia, north of 55° N	1900-2001	85
Far East, north of 55° N	1936-2001	75
East Siberia, south of 55° N	1900-2001	75
Far East, south of 55° N	1900-2001	70

3.5.2.2. Environmental changes that have most directly affected regional climate and society

On a small scale, the climatic consequences of the land cover changes are vivid and we observe direct changes of near-surface regional climate associated with oasis effects and effects of cities, such as changes in strong winds, temperature, and humidity. Other regional climatic changes are less obvious and have a meso-scale nature. So, in the areas adjacent to large reservoirs in the steppe zone of southern Russia and the Ukraine, precipitation has decreased (Kuznetsova 1983). Heat islands around big cities affect the circulation around them and modify precipitation patterns. Landscape alterations, which change its heterogeneity, affect the transport of heat, moisture, and momentum in the atmosphere and feedback in cloud formation and regional precipitation (Pielke 2000; Avissar et al. 2004). The large scale consequences of the environmental changes on the regional climate, however, are uncertain and should be studied on comprehensive global models (Pielke et al. 1991, Pielke 2001)

All cause by HA changes of environment (listed in 2.8) were d*esigned* to directly affect the society. Building a pond, irrigation system, channel, factory, pipeline, or road; all these HA served some societal need and have their rationale. However, frequently, the long-term and/or large-scale consequences of HA were left unaccounted for (or intentionally neglected). Now, many years later, some of these consequences are vivid, considered as negative, and efforts are made to reduce their impact on human health, agriculture production, fishery, and regional environment. Others appear to be unexpectedly beneficial. In addition to burning fossil fuels, some of the consequences of HA (e.g., decomposition of woody debris remains after careless logging) add greenhouse gases to the atmosphere. Other HA (e.g., reforestation) help to reduce their amount. In 3.5.1, we listed major feedbacks that are associated with land cover and land use changes (LCLUC). They are numerous, complex, and quite powerful. Thus, it would be reckless to continue the "business as usual" HA that affects LCLUC without careful projections of its remote consequences (Marland et al. 2003). It is better first, to investigate the feedbacks in the entire scope of the potential impact of the projected type of HA, to ask the question "What should be better understood of this impact?", to find the answers, and then to act according to the newly acquired knowledge. ***The rich history of environmental changes, societal experiments, climatic changes, and high natural variability in Northern Eurasia allow creation of reasonably well documented "training samples". They can be used for testing and fine-tuning the comprehensive suite of models. Then the best of these models should be used to project major expected environment consequences of each future large-scale project prior to its implementation.***

One type of HA (pollution) practically always has negative consequences. Effects of air and water pollution on ecosystems are considered in 3.4. Water contamination has created major social problems in several regions such as the low reaches of Central Asian rivers (and remains of Aral Sea), the Sea of Azov, the northern coast of the Black Sea, and the Baltic Sea. It is discussed in 3.6.2. Below we outline a couple of possible feedbacks of the pollution impacts.

- For the major part of Northern Eurasia, anthropogenic emissions remain localized in comparatively small, hot spots, including major cities, industrial agglomerations, and transportation routes. However, the high sensitivity of the regional ecosystems, e.g., tundra and the boreal forest, to pollution, some of which comes from the outside of the region (e.g., anthropogenic CO_2, N trace gases from Europe), makes the consequences of anthropogenic impact noticeable (3.4). Aquatic systems (eutrophication, acidification, nitrate leaching to groundwater), biodiversity (not all species can sustain the pollution level imposed on them and their frost, drought, or pest resistance would decrease), and soils affected by acidification are at risks. Specific risks are found in northwestern and western regions of Northern Eurasia which receive additional air pollution from industrial western countries and where headwaters of main rivers of Eastern Europe are located. One of the terrestrial ecosystems' functions here is a boundary protection absorbing industrial CO_2. Exactly in these European regions of Northern Eurasia, there are soil areas "with an exceeded buffering capacity and high nitrogen deposition" (Renn et al., 2001) which are predicted to increase. The resulting biochemical feedbacks of pollution here will affect neighboring countries, too (3.4).
- The Aral Sea story is a very striking example (Box insert 2.1). The Aral Sea disaster is an effect of an enormous irrigation project and a significant increase of aridity, including degradation of glaciers and permafrost in the Sea Basin during the last several decades. Its shrinkage coupled with the desertification of the surrounding area caused huge changes in evapotranspiration and aerosol loading in the troposphere. Biochemical and biophysical feedbacks from transport and deposition of these aerosols are affecting environment, soils, economics, human health, and climate (3.4, 3.6.3).

Chapter 3.6. Topic of special interest

Several sub-sections and box inserts presented below were moved from Chapter 3.6 to the Scientific Background Appendix

3.6.1. COLD LAND REGION PROCESSES

3.6.1.1. Introduction

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Geography of the Cold Regions in Northern Eurasia

The zones with permafrost and mountain glaciers in Northern Eurasia can be subdivided into three major parts (see Figure 3.6.1): the entire arctic tundra biome in the northeast and a narrow coastal zone across Siberia and European part of Russia, the boreal forest (taiga) with permafrost (in the northern Scandinavia, north-eastern European Russia, the north of West Siberia, most of Central and East Siberia, northern Mongolia, north-east China, and the Russian Far East), and high elevation mountain permafrost and glaciers (mountain ranges such as Ural, Chersky, Koryak, Kamchatka, Alati-Sayan, the Tien Shan, and other ranges of Central Asia, and the Caucasus). The majority of the area is drained by the major rivers flowing into the Arctic Ocean (Ob, Yenisei, Lena, Kolyma although in the Far East other rivers flow to the Pacific Ocean and there is internal drainage in some of the basins in Central Asia). Zonally, the vegetation zones transition occurs southward from tundra to boreal forest to forest-steppe and steppe/desert, but there are also opposite vertical gradients in the mountain regions.

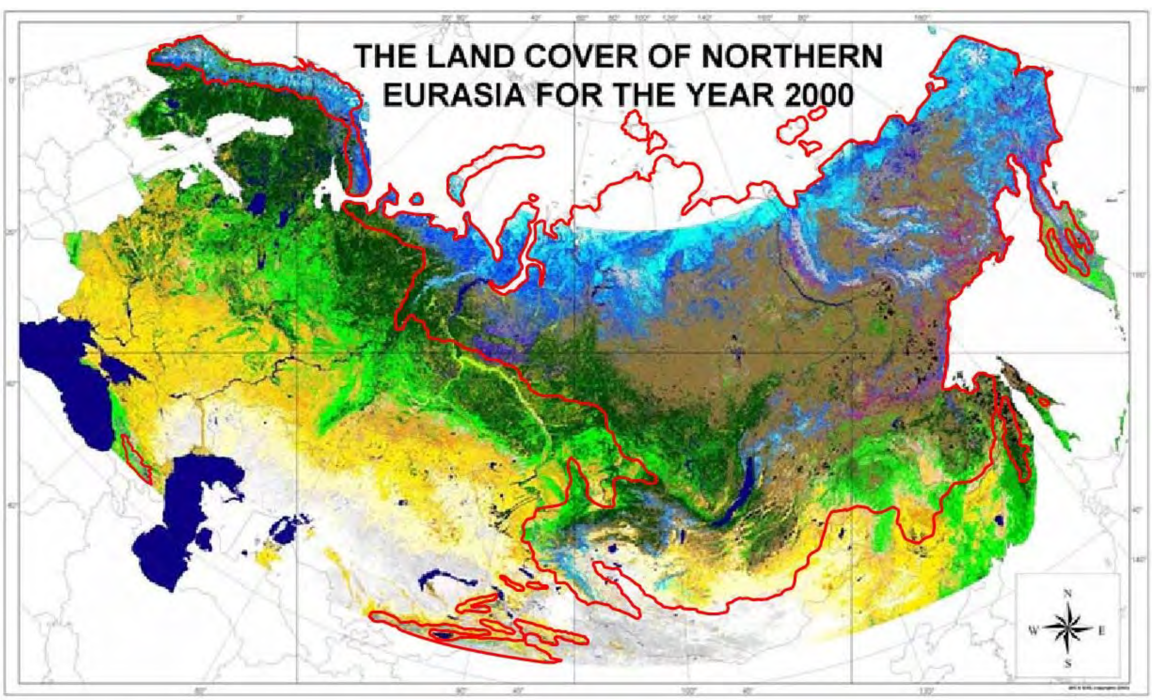

Figure 3.6.1. The land cover type distribution and the boundary of the Cold Land Regions in Northern Eurasia.

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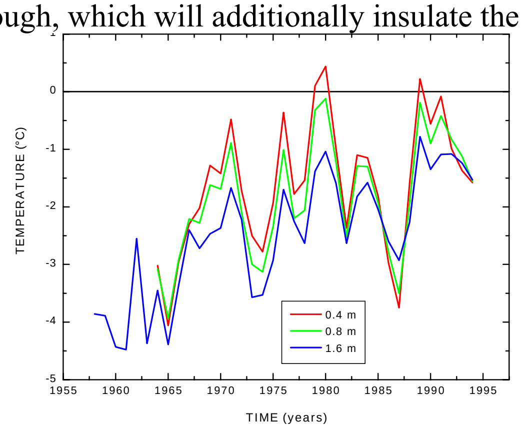
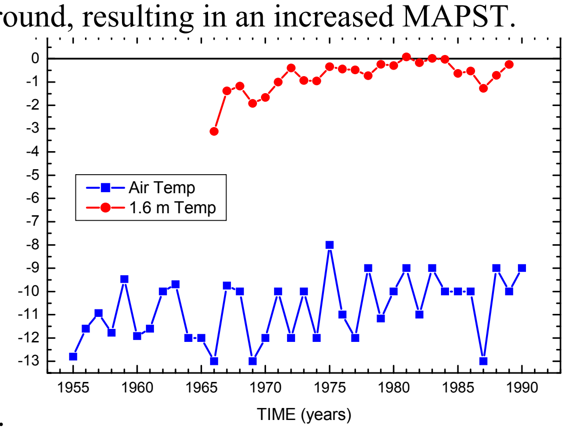
3.6.1.2. Contemporary and predicted permafrost changes in the Cold Land Regions.

All Global Climate Model projections for the next 100 years are such that permafrost and glaciers (especially temperate glaciers) will progressively degrade. This process will start from the south and lower elevations and progress northward and to the higher elevations. In the polar areas, where permafrost will still be stable, the depth of the seasonal active layer will increase significantly (Anisimov et al. 1997; Nelson et al. 2001; Stendel and Christensen 2002; Sazonova and Romanovsky 2004).

Analysis of the long-term records of the near-surface permafrost temperature dynamics, obtained from different parts of the permafrost zone in northern Eurasia, shows a significant warming trend during the last 30 years (Pavlov 1994; Oberman and Mazhitova 2001; Romanovsky et al. 2001 and 2002). Ground temperature trends generally follow the trends in the air temperatures with more pronounced warming in the lower latitudes (between 55° and 65° North). This recent climate warming brought soil temperatures in Northern Eurasia to a surprisingly high level, about 1 to 3°C warmer than long-term averages (Figure 3.6.2a). Within some areas the permafrost temperatures now are very close to 0°C (Figure 3.6.2b) and at some sites a long-term permafrost degradation already started (Fedorov 1996; Fedorov and Konstantinov 2003; Gavriliev and Efremov 2003). The mean annual permafrost surface temperature (MAPST) is important because it reflects the existence and thermal stability of the permafrost. When MAPST exceeds 0°C, the winter freezing front does not reach the surface of the permafrost (permafrost table) by the end of cold season, resulting in a talik formation and the start of permafrost degradation. The permafrost degradation could also start with MAPST still below 0°C. If the increasing active layer thickness reaches the ice horizon, or the ground layer with high ice content, the ice begins to melt and the ground subsides. Surface water will flow into the deepening trough and can form pools and lakes (thermokarst formation). This new presence of water on the surface will help thermal energy to penetrate the ground faster, resulting in an acceleration of the permafrost degradation. In winter, more snow will settle into the deepening trough, which will additionally insulate the ground, resulting in an increased MAPST.



A.



B.

Figure 3.6.2. Mean annual air and ground temperatures in East Siberia (a) at different depths at the Churapcha meteorological station (62.03°N, 132.6°E) and (b) surface air and ground temperatures at 1.6 m depth at the Tongulakh meteorological station (60.7°N, 114.9°E). Threshold at 0ºC is outlined. Data were obtained from the Monthly Climate Bulletin (Klimatologicheskii spravochnik … 1961-1992).

This will prevent the winter freeze from penetrating to the permafrost table, further accelerating degradation of permafrost (Kudryavtsev et al. 1974; Yershov 1998). Because of these effects, once permafrost begins to thaw and a significant settlement of the ground surface occurred, the process would continue even through colder winters, which would otherwise be expected to resist the degradation process.

If recent trends continue, it will take several centuries to millennia for permafrost in the present discontinuous zone to disappear completely in the areas where it is now actively warming and thawing. However, negative consequences of this degradation will be pronounced from the very beginning because the highest ice content in permafrost usually is found in the upper few tens of meters (Figure 3.6.3). Future projections of changes in permafrost temperature and integrity strongly depend on a specific scenario of the future climate changes and on quality of the permafrost models used for these projections (Anisimov et al. 1997; Sazonova and Romanovsky 2003; Sazonova et al. 2004; Malevsky-Malevich et al. 2004). While the increase in permafrost temperatures may change many of its physical properties that can have some negative effects on infrastructure, the major threshold occurs when permafrost starts to thaw from its top down. At this moment, many processes (some of them very destructive) will be triggered or intensified. The most significant impacts on ecosystems, infrastructure, carbon cycle and hydrology will be observed in areas where permafrost contains a considerable amount of ground ice. In the polar areas, where permafrost will still be stable, the depth of the seasonal active layer will increase significantly.

Figure 3.6.3. Extremely ice-rich permafrost (so called "Ice Complex") at the Duvaniy Yar site on the Kolyma River, East Siberia (photo by S. Davidov).

3.6.1.3. Past changes in North Eurasian glaciers and future predictions of their dynamics.

In the NEESRI-region there are about 175,000 km^2 of area covered by glaciers (Figure 3.6.4), which constitutes 26% of all mountain glaciers and subpolar ice caps on Earth, outside the Greenland and Antarctic ice sheets. About 30% of NEESR-region glaciers are in the Russian Arctic; others are unevenly distributed between several large Central Asia mountain regions and high latitude Siberian mountain ranges. The distribution of glaciers in the Russian part of the Arctic (Figure 3.6.1.4) shows distinct eastward decrease in glaciation because of a decrease in precipitation and an increase in the continentality in that direction. The major sites of glaciation in the Russian Arctic archipelagos lie along the branches of the atmospheric trough which originates in the North Atlantic.

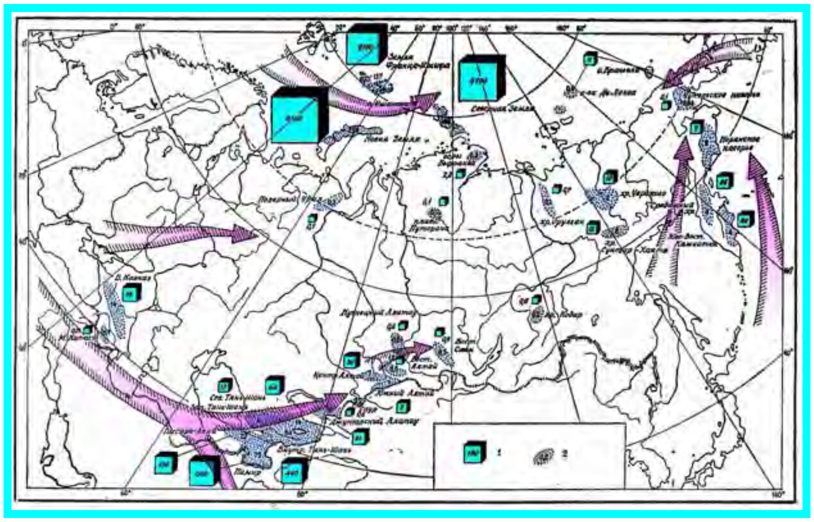


Figure 3.6.4 Glacier regions of northern Asia. Ice volume in km^3 is shown as cubes, arrows show major low-pressure tracks (Krenke 1982).

Throughout the previous century, glaciers in the Cold Land Regions of northern Eurasia showed a negative mass balance; their volume is decreasing (Table 3.6.1) presumably in response to climate warming in the Northern hemisphere (Jania and Hagen 1996; Dowdeswell et al. 1997; Serreze et al. 2000; Dyurgerov and Meier 1997, 2000; Meier et al. 2003). Minor advances in ice margins of some Arctic glaciers are significantly smaller than widespread retreat (Glazovsky 2003). The marine ice margins reveal the digression trend all over the Western Russian Arctic in the second half of 20th century. The largest net recession occurs on Novaya Zemlya (on average –1.5 km, maximum –5.56 km). Because of the general recession of marine ice margins, the ice-covered areas on Russian archipelagos have diminished by 725 km^2 (-375 km^2 on Franz Josef Land, -284.2 km^2 on Novaya Zemlya and -65.4 km^2 on Severnaya Zemlya). The average rates of the glacier front retreat are -30 m/yr for Novaya Zemlya, -17 m/yr for Franz Josef Land, and -3 m/yr for Severnaya Zemlya (Glazovsky 2003). Recent studies show that mass balance of the dry arctic glaciers is mostly affected by the summer temperatures, but for the wetter regions fall and spring temperatures are just as important. Glaciers on Severnaya Zemlya, Franz Josef Land and, in lesser extent, on Novaya Zemlya belongs to the dry type, therefore summer temperature changes might strongly influence their mass balance and dynamics in the future.

Table 3.6.1. Long-term changes in area and volume of glaciers in selected mountain regions

Region	***Time period***	Loss of area, %	Loss of volume, %	*References*
Caucasus	1894-1970	-29	-50	Meier et al. 2003
Elbrus (Central Caucasus)	1887-1997	-14		Zolotarev et al. 2002
Tien Shan	1955-1995	-15	-22	Meier et al. 2003
Zailisky Alatau (W. Tien Shan)	1955-1990	-29	-32	Vilesov et al. 2001
Akshiyrak (internal Tien Shan)	1943-2001	-26		Khromova et al. 2003
Gissar-Alai (Pamirs)	1957-1980	-16		Shetinnikov 1998
Adylsu (Caucasus)	1974-2000	-5		Nosenko et al. 2003
Polar Ural	1953-2001	-55		Nosenko et al. 2003

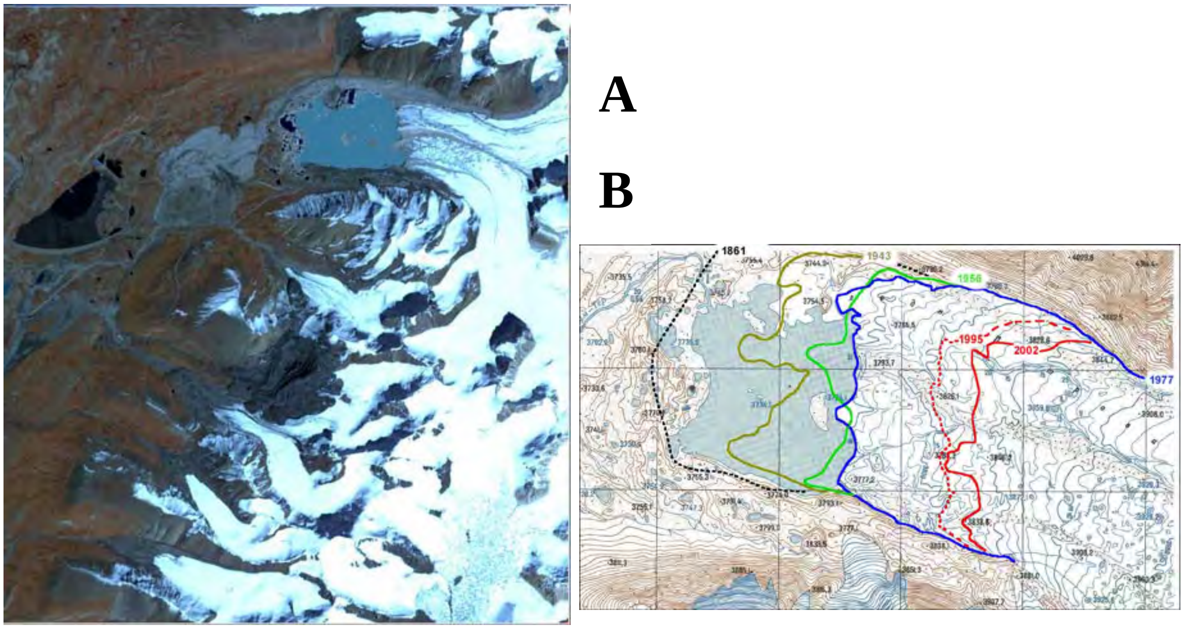


Figure 3.6.1.5. Example of a central Tien Shan glacier recession. Petrova Glacier in the Akshiyrak area, ASTER image, September 2002 (A), and instrumental topographic data (B) (Aizen and Kuzmichonok, 2003).

The 143 glaciers in Polar Urals occupy only 28.7 km^2. New assessment based on set of ground photogrammetry data and ASTER images shows strong reduction of Polar Ural glaciers from 1953 to 2000. They lost nearly half of their area in this period, and the negative trend in the last decade seems to accelerate (Nosenko et al. 2003). There are 96 glaciers in the northern, highest part of the Byrranga Mountains in the Taymyr Peninsula with a total area of 30.5 km^2. From 1960 to 1977, more than 10 glaciers have disappeared (Govorukha 1989).

In central Asian mountains there are approximately 30,000 glaciers with a total area equals to approximately 25,000 km^2 there. During the period 1940-1998, the average rise in air temperature was 0.01°C per year in Tien Shan and Pamir high altitudes (Aizen et al. 1997) and 0.02°C per year in the Altai alpine regions (Aizen et al. 2003). A strong warming signal occurred with significant correlation of temperature trends with elevation, i.e., increase in air temperature is larger at the high elevation where the glaciers and mountain permafrost are most common (Aizen et al. 1997; Marchenko 1998a). This increase in air temperature already has a noticeable effect on glaciers and mountain permafrost. During the period from the 1950s to the 1990s, 80% of glaciers were retreating in central Asia (Haeberli 1990). A negative glacier mass balance is typical for central Asian glaciers (Aizen et al. 1997a,b). In the Tien Shan Mountains, glaciers covered 7,273 km^2 in 1955 (Krenke, 1982). This area has been reduced by 29.1% by the end of the last century. Rough estimations show that glaciers lost up to 27% of their mass. Up to 12% of glaciers with area less than 1 km^2 have disappeared. The largest glacier recession has occurred in northern and central Tien Shan (Figure 3.6.5). During 1952-1998, Altai glaciers lost about 10% of their mass and were retreating by 2-8 m per year.

Records of temperatures in permafrost and the active layer at 3330 m in the Tien Shan Mountains, Central Asia, have indicated a positive trend from -0.8°C to -0.3°C under the natural conditions and up to -0.1°C under an anthropogenic load (Marchenko 1997). The seasonal soil thaw has increased by 35%. Pleistocene and Holocene moraine complexes are wide spread in the periglacial area in Central Asia. Typically, it is an ice-rich formation. The upper layer (10-15 m) of such deposits contains 10-50% of excess ice. Alluvial and lacustrine sediments very often contain 30-60% or more of excess ice. During the Holocene, these formations have kept most of this ice, but recent warming caused degradation of ground ice and accompanying changes of landscapes. General circulation models suggest that the increase in summer diurnal temperatures over central Asia is likely to be higher relative to that in other regions (ICCP, II, 2001). Therefore, we expect a further degradation of glaciers and alpine permafrost.

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3.6.2. COASTAL ZONE PROCESSES.

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Box Insert 3.6.1 . Example: The Sea of Azov and its basin

The Sea of Azov and its basin is a system highly susceptible to climatic and anthropogenic impacts. Approximately 15% of the population of Russia and the Ukraine is located in the basin area of 0.57 x 10^6 km^2, along with approximately 20% of the industrial and 25% of the agricultural production of these countries. Most of the basin is in a steppe climatic zone, which receives unpredictable and insufficient moisture. Water resources of the basin consist of the Don River (28 km^3yr^{-1}), the Kuban River (12 km^3yr^{-1}) and a few small steppe rivers (~2 km^3yr^{-1}). The annual streamflow of the Don and Kuban Rivers have very high interannual fluctuations (from 22 to 68 km^3yr^{-1}). The spring runoff makes, up to 56% of the total annual river volume (and about 70% for the Don River alone). Twenty percent of the Kuban River streamflow originates from the melting high-mountain snow and glaciers of the Caucasus Mountains.

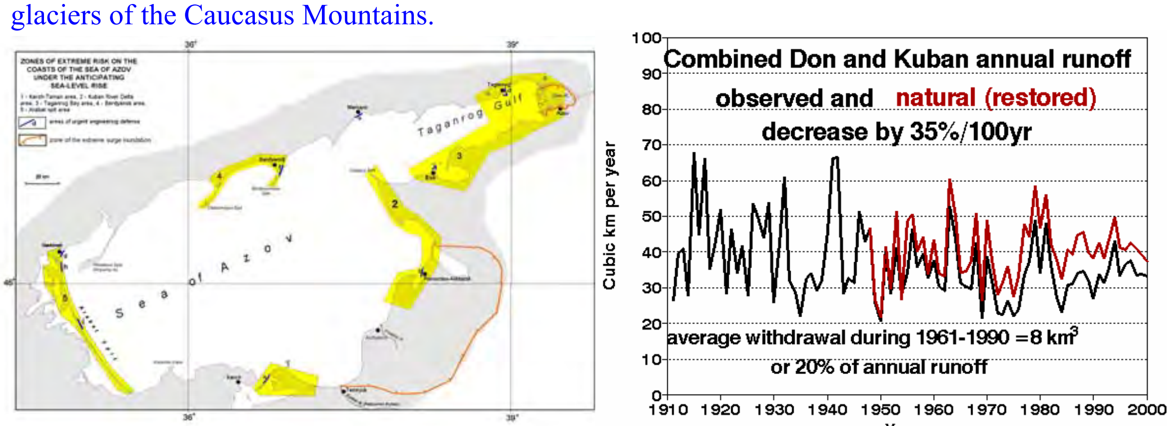

Figure 3.6.11. Sea of Azov coastal zones at extreme risk, and variations of actual and natural (estimated without human impact) runoff into the Sea (km^3 yr^{-1}).

Fluctuations of water and bioorganic matter runoff considerably affect the Sea ecosystem. The Azov is a shallow (the mean depth is 7 m) water body with a small area of 0.04 x 10^6 km^2 and volume of 320 km^3. Its hydrological regime is formed by interaction of river inflow with saltier Black Sea water and very salty waters from Sivash Bay, the lagoon in the western part of the Sea of Azov. Streamflow and inflow of the Black Sea waters each contribute 13% of total Sea volume, and precipitation contributes ~ 5%; the outflow to the Black Sea and Sivash Bay is 21%, and the evaporation from the water surface is 10% of the Sea volume (Fedosov and Vinogradova 1955). Streamflow has the greatest effect near river mouths. The major areas of river input are the Taganrog Bay in the Don River mouth and the extensive Kuban River mouth in the southeastern corner of the sea, where the greatest volume of biogenic river runoff accumulates.

The basin area is characterized by extraordinarily high water withdrawal that affects the state of the Sea's marine ecosystem (Koronkevich et al. 1999). Up until 1952 the river runoff was mainly determined by climatic fluctuations, and only to a small extent influenced by construction of numerous ponds on small rivers (Sementsov and Eremenko 2000). Filling the Tsimlyanskoe reservoir (from 1952 to 1955) with the maximum withdrawal of river runoff coincided with increased atmospheric precipitation. The response of the marine ecosystem to this major disturbance was a small increase of the Sea's salinity (up to 11-11.2 pro mille) and a decrease of productivity due to reduction of autochthonous biogenic runoff. From that time until the late 1980s, an expansion of arable lands, an increase in irrigation and fertilizer use, a growth in livestock population, an increase in industrial production accompanied by increased water withdrawal, and a return of waste waters resulted in a loss of 30% of annual Don runoff and 44% of Kuban annual runoff to the Sea, significant changes in the rivers' hydrograph, and deterioration of the water quality (Shiklomanov and Georgievsky 1995; Lurje and Panov 1999). The nitrogen content in the streamflow increased, especially since the construction of large reservoirs on the Don and Kuban, and the content of phosphorus decreased (Bronfman and Khlebnikov 1985; Environment of Ukraine 2001). In the late 1980s, the human impact became equal to or even greater than the natural processes, causing dramatic changes in the Sea's ecosystem (Shlygin 1975; Bronfman et al. 1979; Smolyakova and Shlygin 1980; Remizova 1984; Makarov et al. 2000). The most pronounced negative consequences of the anthropogenic load manifested themselves in the years with low river runoff. The average salinity increased considerably, reaching critical values for the survival of the natural ecosystem (13.4 – 13.8%o). The natural balance of the biogenic elements nourishing the Sea was disturbed by a nitrogen surplus and a deficit of phosphorus (Bronfman and Khlebnikov 1985; Environment of Ukraine 2001). In the Taganrog Gulf and the adjacent sectors of the northern Sea of Azov along the Ukrainian coast, blooms of blue-green algae started to develop periodically due to a surplus of autochthonous organic matter (Tamaitchuk 2002). In the open part of the Sea (the part most subjected to Kuban River runoff impact), regions with anoxic bottom waters have been recorded (Simonova, 1987). In the 1990s, many of these tendencies were reversed due to a reduction of anthropogenic impact and an increase in precipitation. During the past 15 years, desalination of the Sea to a level equal to that obtaining during the first half of the 20th century and a reduction of biogenic matter content in the waters of the Sea have gradually taken place (Environment of Ukraine 2001). However, the natural potential of the Sea of Azov did not recover (Yakushev et al. 2003).

Coastlines of the Sea of Azov are retreating under present conditions at a rate of up to 5-7 m/yr at coastal scarps composed of loose Quaternary sediments (loesses), and at a rate of up to 2-3 m/yr at depositional bodies such as beaches, spits and barriers. The process is, and will continue to be aggravated by changes in water salinity. The problem is that productivity of mollusk shells, of which the majority of depositional bodies are composed (up to 90-95% at several coastal segments), depends heavily upon water salinity. *Cerastoderma glaucum (Cardium edule),* the most important "beach builder", flourishes at a water salinity of 11-12 pro mille. This organism suffers much from either higher or lower salinity, and decreased productivity of this mollusk results in faster degradation of beaches. Intensive development of coastal areas creates substantial problems in terms of coastal dynamics and water pollution. For example, in the middle 1990s, an underground lens of kerosene from the air force base in Eisk, the Taganrog Gulf, was eroded, polluting coastal waters.

Box insert 3.6.2. Coastal Zone of the Pechora Sea

The Pechora Sea is located in the southeastern corner of the Barents Sea between the islands of Kolguev and Vaigach (Figure 3.6.12). Here, intensive economic development is occurring in the coastal zone and in the inner shelf due to the prospecting for, exploring, and exploiting of numerous oil and gas fields. The estimated resources of exploited fields are 2.4×10^9 tons of oil and 1.2×10^{12} m^3 of natural gas. The density of these resources in the coastal zone is 19,300 ton/km^2, the highest in Russia (Romankevich et al., 2003). Prospecting for and exploiting

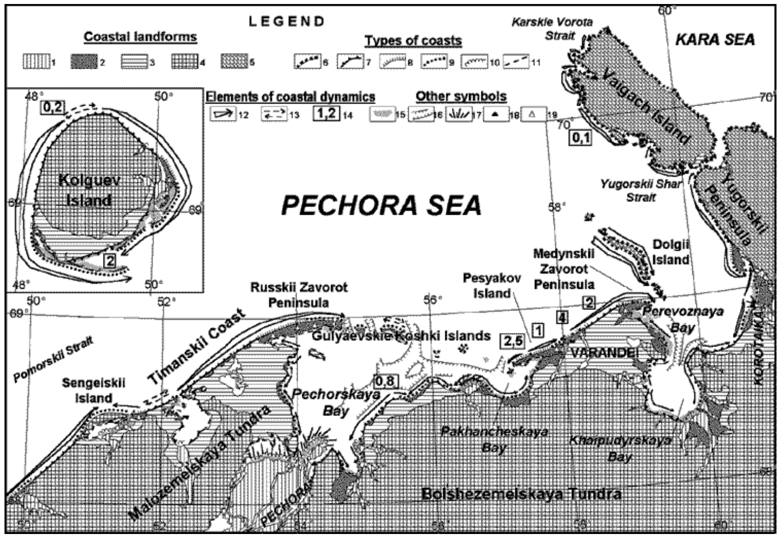

Figure 3.6.12. Morphology and dynamics of the Pechora Sea coasts (modified from Kaplin and Selivanov 2003; Ogorodov 2003). See "1" in Figure 2.5.a for the general position.

these resources has already damaged the natural ecosystem and degraded the living conditions of the local population. The traditional economy of the local population is based on reindeer breeding and salmon fishing. Both occupations suffer much from the present development activity. Tractor-trailer traffic, oil, gas leakages from exploited fields and pipelines crossing the coastal zone, increasing coastal erosion due to a reduced sediment supply, and re distribution of along shore sediment flows all threaten to destroy the unique ecosystem in this region. Unfortunately, the Pechora Sea coastal zone ecosystem is highly vulnerable to both natural changes and anthropogenic impact. This vulnerability is determined by the following factors:

- A high ice content of the permafrost coastal slopes in loose Quaternary sediments and depositional bodies like spits and barriers;
- A high intensity of tides and wind surges; and
- A strong impact on the coastal zone dynamics of the highly variable sediment supply from the Pechora River and smaller rivers and the alongshore movement of these sediments.

The human impact has already created serious problems for the traditional economy and the coastal zone ecosystem. Coastal retreat and related processes (decrease of potable water quality, degradation of a unique salmon population) are among the most important adverse consequences. Presently, several coastal areas of the sea retreat at an average rate of over 4 m yr^{-1}. In some areas, the increasing development activity has resulted in the doubling of this retreat rate (Ogorodov 2003). The most economically developed Varandei area has suffered the most from these processes. This area, which was a peninsula several decades ago, has become an island. Coastal erosion in the Varandei area has greatly intensified due to both natural factors (sea level rise, decrease of river sediment supply from the Pechora River and sea floor) and anthropogenic activities. Several living and industrial quarters in the Varandei settlement area have already eroded. Oil tanks that were quite far from the coast line in the past are now in serious danger. The distance from several oil tanks to the coastal scarp decreased by over 40 m since their construction in 1987, to a distance of less than 6 m in 2000 (Figure 3.6.13; Ogorodov 2003). The local airport is also situated in the zone of possible erosion during the next decades.

During the present century, the projected global warming and sea-level rise will most likely be aggravated by the "Arctic amplification" effect (3.3.2). Thus, intensified Pechora Sea coast destruction is a very probable scenario, due to continued thawing of permafrost and related processes such as thermoerosion, thermoabrasion, and thermodenudation (Kaplin and Selivanov 2003). The erosion may reach a rate of over 10 m yr^{-1}. Many industrial and infrastructure facilities in the region are currently located within several dozen meters of the present shoreline. Among them are existing and/or planned oil/gas exploitation areas, pipelines, infrastructure and housing developments. They all will be inevitably destroyed during this century. Specifically, the barrier islands/peninsulas in the outer parts of the Pechora Sea are doomed to partial or complete degradation over the next several decades. Furthermore, coastal retreat and degradation will be enhanced in the bays with high tides. The general tendency for coastal erosion to prevail over deposition may be amplified by a decrease in river sediment discharge. This has occurred recently in the Pechora River basin, one of a few Arctic slope regions with decreased precipitation and runoff during the past several decades (van Eerden 2000; Razuvaev et al. 2003). All of these facts clearly prove the necessity for integrated studies of coastal zones in Northern Eurasia, especially of the most vulnerable Arctic coasts, for justification of their economic development strategies.

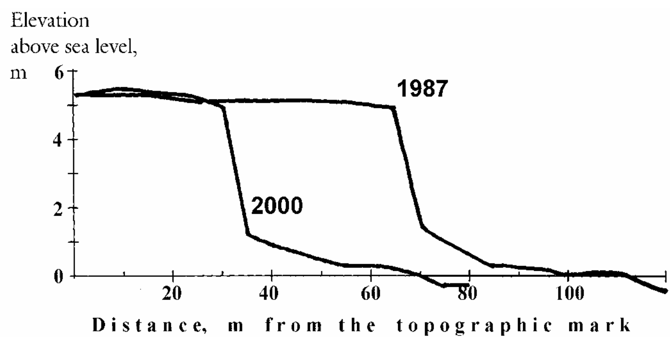

Figure 3.6.13 Endangered oil tanks in the coastal zone (Varandei settlement, the Pechora Sea coast) and the shoreline retreat in this particular region from 1987 to 2000 (Ogorogov 2003).

Box Insert 3.6.3. The Baltic Sea issues (pollution and coastal erosion)

Introduction. The Baltic Sea is a semi-enclosed large non-tidal brackish water body of 390 000 km^2 influenced both by natural conditions and by the 80 million people living within the large drainage area (2 mln. km^2). It has a very limited connection with the North Sea which does not exceed 5-7% of the total water budget. The Baltic Sea is characterized by brackish water conditions that result from riverine and precipitation inputs of freshwater and periodic wind driven inflow of saline water from the North Sea. Under average conditions, salinity decreases and the halocline deepens from west to east and north due to the increasing distance from the North Sea influence. A corresponding decrease in oxygen content is also observed. The salinity fluctuates markedly due to the intermittent nature of the saline water influx. No significant inflows of saline waters from the North Sea have been observed since 1994. This has led to a reduction in salinity in the Baltic Sea, particularly in the north and east, which has been exacerbated by increased levels of precipitation in recent years. Being semi-enclosed, the Baltic Sea is flushed slowly and it takes 25-30 years for complete water renewal. Therefore, changes in biogeochemical processes are slowly reflected in the sea system over several decades. There are several international agreements covering various aspects of the sea and coastal zone study, monitoring, and management. Several international bodies are working in this area with mandates to harmonize research activities and industrial developments and make regular assessments of the state of the marine and coastal environments. The Helsinki Commission (HELCOM) is one of them. *Currently, dozens of European Union (EU)-funded programs are being run by various science institutions in the area Thus the aim of the NEESPI activities in this region is not a duplication of those projects but* re-*consideration of their results and major findings through the prism of NEESPI goals.*

Pollution problem of the Baltic Sea. Excessive amounts of ***nitrogen and phosphorus*** *compounds* entering the sea cause eutrophication, disturb the balance of the Baltic marine ecosystem, and cause biological, chemical and physical changes in the population structure of flora and fauna. The excessive nutrients encourage plant growth, particularly micro-algae. The algae sink to the seabed where they are metabolized by benthic bacteria in processes that require oxygen. If the numbers of algae are excessive, this decay can lead to a completely anoxic seabed, devoid of much of its life. In 1996-1997 benthic communities in the Gulf of Finland collapsed as a result of oxygen deficiency caused by eutrophication.

The majority of these nutrients enter the Baltic Sea from rivers draining surrounding farmlands and cities; just five rivers, the Neva, Daugava, Vistula, Oder and Nemunas, account for almost half of the nitrogen entering the Baltic Sea. Extreme weather events exacerbate the pollution problem. For example, severe flooding of the Vistula and Oder rivers in 1997 and 2002 led to increased nutrient loading in the Gulf of Gdansk and the Pomeranian Bight, and subsequent algae blooms. In addition to *nutrients*, *hazardous substances,* and *oil,* there are other forms of pollution in the Baltic, including *dumped munitions, dredging* and *spoil dumping.* Thus "time-bomb" effects should be taken into account when various scenarios of climate change are applied to the Baltic Sea and its coastal zone. Due to temperature rise, coastal erosion, sea level rise, and other processes, harmful substances could be released to the Baltic Sea. ***Hazardous substances*** are those which are toxic, persistent, and liable to bioaccumulate, or give other cause for concern, such as affecting the endocrine system. They include organochlorines, heavy metals and hydrocarbons. The Baltic Sea is semi-enclosed, and these chemicals remain for a long time in the coastal water. Therefore, despite the reduction of input during the past decade, concentrations of polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDT) are still much higher in the Baltic than in the North Sea. The main pathways by which hazardous substances enter the Sea are from industrial and municipal wastes draining into the rivers, atmospheric input, and shipping. Most ***oil*** comes from ships ignoring international law by discharging oily waste and flushing tanks and cargo holds. Oil spills contaminate the surface water and smother marine plants and animals. Many chemicals in oil are toxic, and can have serious cumulative effects as they build up in ecosystems. Spills can also have severe repercussions for tourism, while the necessary clean-up operations may themselves unavoidably harm marine life and coastal habitats. Oil can negatively impact fisheries; toxic compounds can damage eggs (especially those which float, such as cod eggs), and larvae, and spills will effectively shut down any fisheries in the area due to concerns about toxins and oil fouling fishing gear. Many of the Baltic States, and also HELCOM, operate monitoring planes and vessels to detect oil pollution and those responsible. Based on the results of pilot (experimental) satellite monitoring of the Baltic Sea carried out in the 1980s and subsequent space-borne observations (Victorov 1996), in 2003 several Baltic states launched project OCEANIDES which aims to use satellite imagery to monitor and map oil spills in the Baltic Sea.

Coastal zone problems in the Baltic Sea. Currently much effort is applied to study the problem of Baltic Sea pollution. It seems that less effort is expended to study global climate change effects on the Baltic Sea and its coastal zone. An attempt to analyze potential impacts of future climate change on the freshwater inflow to the Baltic Marine Area was made by Graham et al (2000). Based on regional downscaling of Global Climate Models carried out within the Swedish regional climate modeling program, it appears that global warming may lead to a changed annual cycle and less pronounced spring floods as winters become less stable. According to these scenarios, freshwater inflow to the Baltic Marine Area will generally increase in regions fed by the northernmost parts of the drainage area and decrease in the Baltic Proper. One project - the SEAREG project - focuses on assessing the socio-economic and environmental impacts of climate change in the Baltic Sea region, especially the sea level rise and the changing river runoff patterns. Both these changes may lead to major flooding events, which would severely impact the spatial development of cities and regions, as well as the sustainable development of the entire Baltic Sea Region. The German, Polish, Russian (Kaliningrad area), and Lithuanian Baltic coasts are flat, low-lying and micro-tidal and hence vulnerable to sea level rise. These coasts are not so highly developed as the North Sea coasts, but there are important harbours and cities such as Gdansk. Further east and north, Lithuania and Estonia still benefit from glacial rebound and hence relatively less sea level rise. The main concern here is for the extensive coastal wetlands, which are also under threat from economic development. Unfortunately, the Russian and Latvian Baltic coasts are understudied. At the opposite site of the Finnish Gulf, Finland may actually benefit from global sea level rise, because it would stop relative sea level fall, which is problematic for water transport infrastructure. These benefits have yet to be estimated. The level of the largely enclosed Baltic Sea is not only influenced by global sea level rise, but also by precipitation and temperature change in the Baltic Basin (Tol, 2000). Overall, the diversity of Europe's coasts and their vulnerabilities to sea level rise is striking. This diversity is not due simply to great differences in the natural environment. Economic standards and decision making cultures are also very different. It is also clear that sea level rise cannot be studied in isolation from other changes (climatic and otherwise). In a number of cases, looking at sea level rise alone may even yield a bad first approximation of the ‘real’ impacts of sea level rise. To understand the impacts of sea level rise, a better understanding of the social dimensions and capacity for adaptation is required (Tol 2000).

Box insert 3.6.4. Coastal zone changes in the Eastern North Eurasian Arctic and biogeochemical consequences of these changes.

Transport of terrestrial material. Most of the eroded terrestrial organic matter accumulates in coastal zones; however, significant amounts of this material are transported further offshore by different processes, such as sea ice, ocean currents, and turbidity currents. The near-shore system of *the Laptev and East Siberian seas is the most climatically sensitive area in the Arctic and the highest rates of coastal retreat occur* here (Are 1999; Grigoriev and Kunitsky 2000; Figure 3.6.14). The broad shelves of the Arctic are important to many processes, and export of

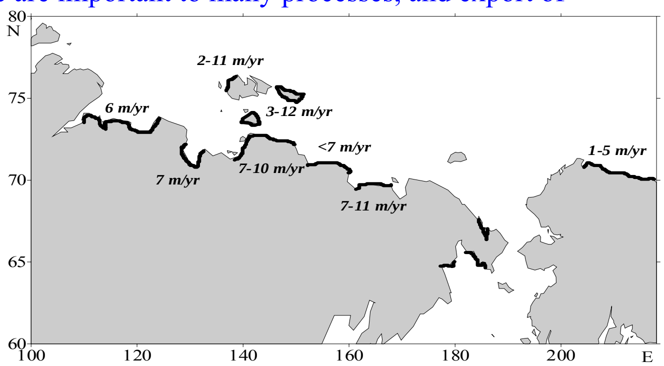

Figure 3.6.14. Rates of coastal erosion along the North Asian Arctic Rim (Semiletov, 2003).

terrestrial eroded carbon from these shelves plays a crucial role in regional fluxes of carbon, nitrogen and phosphorus. The high rates of coastal erosion and deposit of organic materials are often associated with coastal ice-complexes. Smith and Hollibaugh (1993) estimate that about one third of land-derived organic matter is re-mineralized rapidly within estuaries and coastal zones. The increase of pCO_2 in the surface sea water in the coastal zone from west to east in the Laptev and East Siberian Seas system is correlated with an eastward increase in the on-shore area covered by the ice complex deposits. Because permafrost with higher ice content is more susceptible to thermokarst and coastal thermal erosion processes, it is possible that the eastward increase in pCO_2 values might be related to the general eastward increase in land surface erosion (Figure 3.6.14) induced by thermokarst, coastal thermal erosion, and sea hydrodynamics (3.6.1). Apparently, a fraction of the terrestrial carbon does get remobilized and released in CO_2 form to the atmosphere and ocean in the near-shore environment. High values of pCO_2 were found both near the mouths of the Siberian rivers and at the coastal sites located far from the riverine inflow (Semiletov et al. 1996; Semiletov 1999a,b; Semiletov et al. 2004): pCO_2 values reach 4,000 ppm in the bottom water and up to 1,500-2,000 ppm at the surface (Semiletov 1999a,b; Figure 3.6.15). A high positive CO_2 gradient (more than 1000 μatm) between the surface waters and air in the sites remote from the river's influence indicate the existence of non-river sources of CO_2 for the coastal waters [Semiletov 1996, 1999a]. The existence of anomalously high values of pCO_2 in the water adjacent to a rapidly retreating coastal ice complex is correlated well with the low oxygen saturation (down to 30%) and high nutrient values (Figure 3.6.15), which could result from destruction of the eroded organic

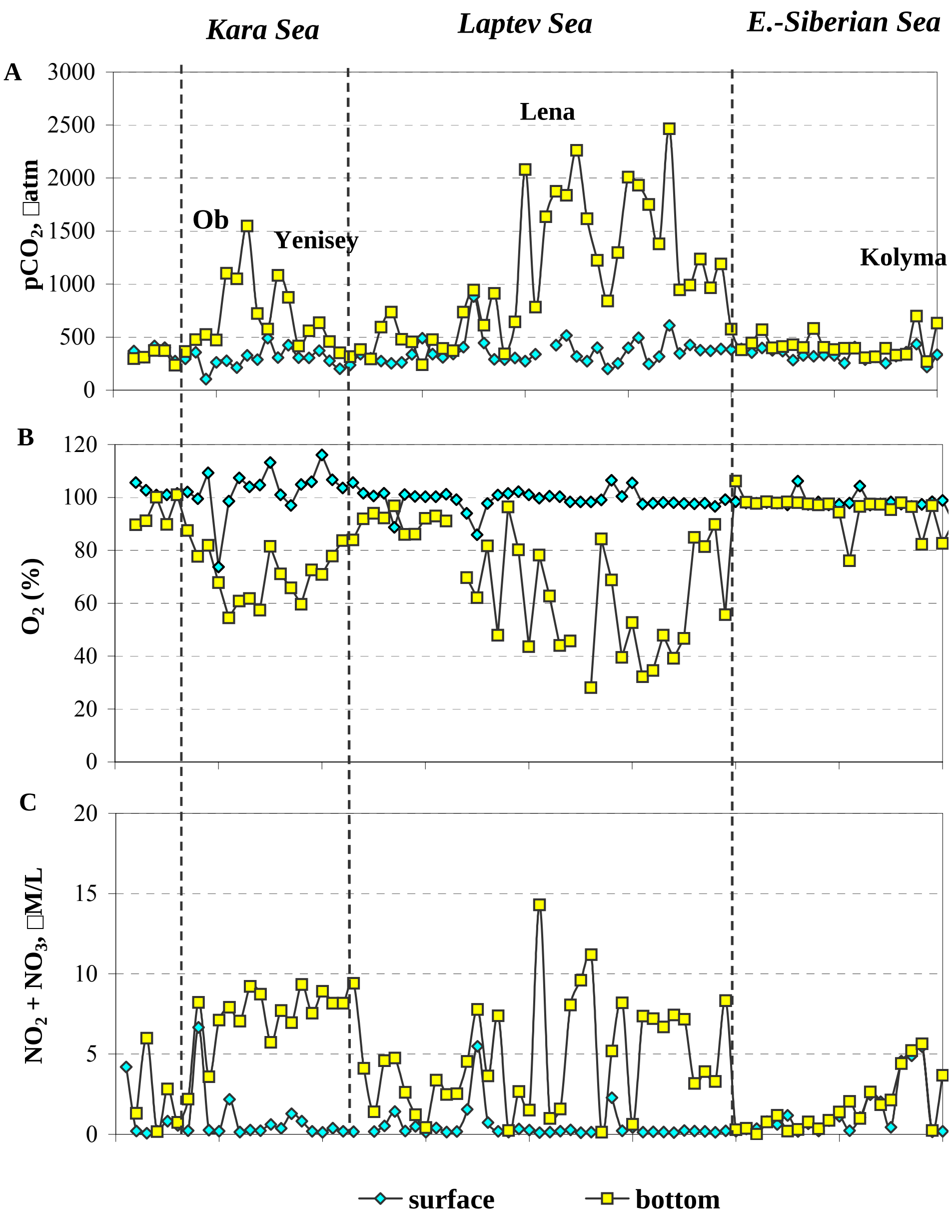

Figure 3.6.15. Distribution of (A) - CO_2 partial pressure, µ atm, (B) - oxygen saturation (%) and (C) - nitrate-nitrite sum (µ M/l) in the coastal zone of the Eurasian Arctic seas in 2000 (Semiletov 2003). The highest values of pCO_2 and nutrients found in the near-shore zone are due to coastal erosion. At the same time, low values of dissolved oxygen (down to 40% of saturation) indicate high rates of destruction of old terrestrial organics. Results are supported by the data of previous expeditions (Semiletov 1999a,b).

carbon. This source of organic matter may be more significant over the wide and shallow northeastern Asian shelves than over the narrow shelf of the North American shelves. An evaluation indicates that about 50-70Tg of eroded solid matter is deposited offshore along the Laptev and East Siberian coastline (Grigoriev and Kunitsky 2000), whereas a major portion of the fluvial sediment load is dispersed within the delta channels (Rachold et al. 1996). Following Rachold et al. (1996), we assume that only 5 Tg of the Lena River sediment load reaches the Laptev Sea shelf. It has been argued that coastal thermal erosion in the Laptev and East Siberian Seas makes a significant contribution to the coastal sediment input: it may be up to one order of magnitude higher than the fluvial sediment discharge (Semiletov 1999b; Dudarev et. al. 2001). The finding of anomalously high concentrations of benthic organisms (up to 100-200 g C per square meter) within the depressions in the Laptev Sea shelf (Gukov et al. 1999) could be associated with near-shore accumulation of the coastal old organic carbon.

Global Change, erosion, and the Biogeochemical Cycle in the coastal zone. Present data indicate that under global warming, the rate of coastal erosion in the Arctic might change from a few meters per year, which it is now, to tens of meters per year. During the 20th century, many small ice complex islands disappeared along the Siberian coast; for example Semenovsky and Vasilievsky islands in the Laptev Sea, and St. Diomid Island in the East-Siberian Sea (Gavrilov et al., 2003). According to Tomirdiaro (1990) and Are (1999), mean rates of coastal erosion in the Arctic are near 2-6 m per year, whereas the coastal ice complexes of the Siberian Arctic have been retreating at annual rates of up to 11-30 m (Tomirdiaro 1990). Bottom erosion can be high also (Gavrilov et al. 2003). Observations of the Northern Route Hydrographic Service show an increase in the sea water depths in the near-shore zone of up to 0.8 m over 14 years (Tomirdiaro 1990). This is also important for navigation. Therefore, *coastal and sea bottom erosion can cause changes in the lifestyle of native people and can also affect navigation in the future*.

Many factors influence Arctic sea coastal retreat[68]. Rates of coastal retreat might be increased by changes in the coastal marine hydrology[69] and by observed decrease in the ice cover and increase in open water season on the Arctic shelves (Morrison et al. 2000; Manson et al. 2001). The increase of about 15 cm per 100 years in sea surface height (IPCC 2001) could accelerate terrestrial material transport into the sea. During the glacial-interglacial transition and sea level rise (by ~ 100-120m), a huge amount of buried terrestrial organic carbon was involved in biogeochemical cycling (Fahl and Stein 1999; Bauch et al. 2000). The coastline at 7.5kyr BP was 150-250 km north of its current position (Romanovsky et al. 2000). This means that the rates of coastal permafrost degradation and flooding of coastal lowlands were extremely high over the past millennia. Crude calculations of the mean transport of particulate organic carbon from land to the Laptev and East Siberian Seas estimate 2.5 - 7.0 Tg yr^{-1} and we can assume that during the last 5,000 years, when the sea level did not change significantly, total transport of eroded carbon was equal to 12.5-35 Gt {Semiletov 1999b). This is a significant portion of the modern dissolved carbon capacity of the Arctic Ocean (about 450Gt). Thus, the off-shore transport of eroded carbon and its consecutive degradation will influence the carbonate system, nutrients, and sedimentation, especially in the near-shore zone, and affect the productivity of the coastal marine ecosystems, both past and present (Semiletov 1999a, b). Evidence of recent 50-year large-scale changes in redox conditions in the Arctic Ocean basin sediments (from oxic to anoxic diagenesis) most likely originated with the enhanced organic carbon fluxes to the sea floor (Gobeil et al. 2001). This might be related to a reduction in the ice cover, which led to an increase in coastal retreat causing an increased seaward transport of terrestrial carbon previously sequestered in the coastal permafrost. It could also be a significant factor for the increase in atmospheric burden of the main greenhouse gases, because the upper 100 m layer of permafrost alone contains not less than 10,000 Gt of organic carbon that could be involved in biogeochemical cycling in the form of methane (CH_4) and CO_2 (Semiletov 1999a). The current atmospheric CO_2 and CH_4 burdens are ~750Gt C- CO_2 (Quay et al. 1991). Therefore, small changes in the current carbon stock of coastal permafrost might significantly affect present and future concentrations of the main greenhouse gases in the atmosphere.

[68] Permafrost ice content, height and slope of bluff, air temperature, direction and speed of winds, duration of open water season, water temperature, waves, tides, ice-edge dynamics, timing of freeze-up and break-up, surges and currents, and near-shore bathymetry.

[69] E.g., the increase in seasonal amplitudes of the Siberian rivers' discharge and temperatures in their watersheds after the 1970s (Savelieva et al. 2000) indicate that the contemporary climatic changes manifest themselves not only by global warming, but also by secular changes in the atmospheric circulation. These changes are observed, for example, in the temporal change in the atmospheric CO_2 seasonal amplitudes (Conway et al. 1994).

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