GEWEX NEWS

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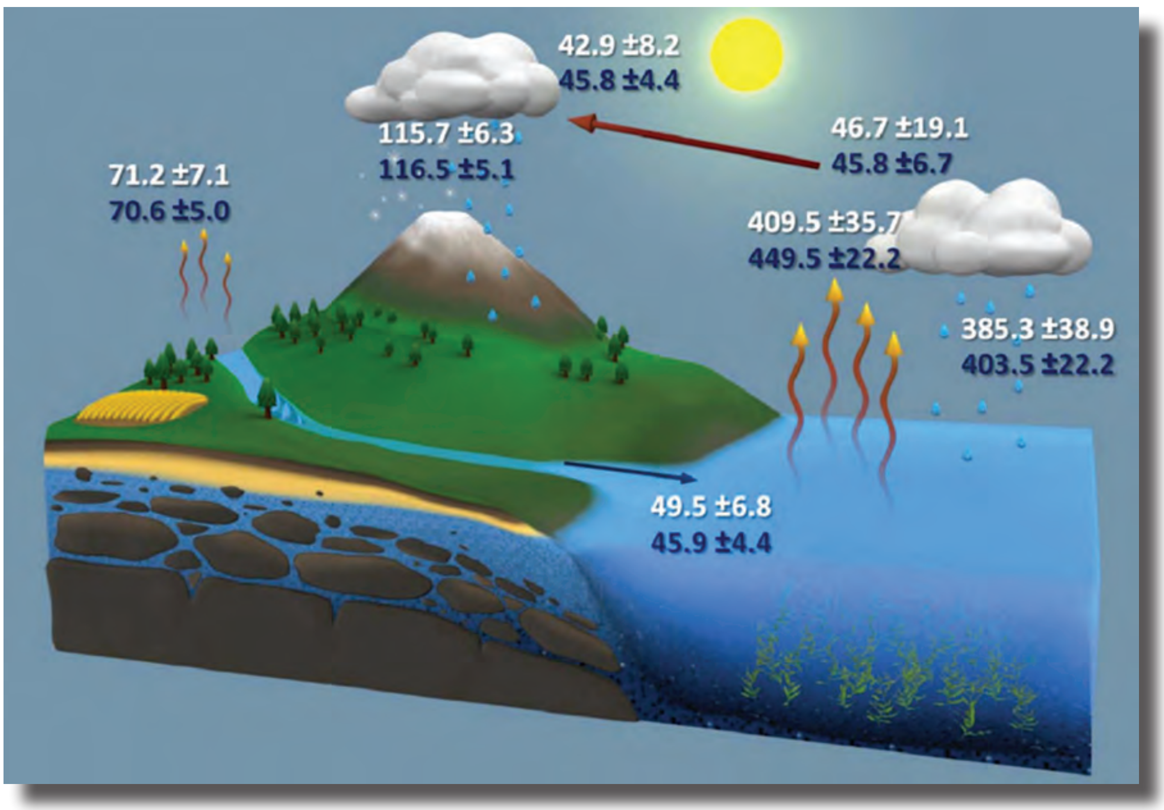
NASA NEWS Program Makes Significant Progress in Synthesis of a State-of-the-Art Global Water and Energy Cycle



Mean annual fluxes (1000 km^3/yr) of the global water cycle, and associated uncertainties, during the first decade of the millennium. White numbers are based on observational products and data integrating models. Blue numbers are estimates that have been optimized by forcing water and energy budget closure and taking into account uncertainty in the original estimates (after Rodell et al., 2015). See article by R. A. Schiffer et al. on page 4.

Also Inside

Commentary

Scratching At and Below the Surface

Peter van Oevelen
Director, International GEWEX Project Office

A little over a year ago, in July 2014, we held the International Scientific Conference on the Global Water and Energy Cycle in The Hague, which was a successful and fun event that we look back upon with pride and satisfaction. An important task of the International GEWEX Project Office is to organize scientific conferences, meetings and workshops, particularly to support the GEWEX Panels and working groups in their activities. Today, with the enormous number of science meetings held worldwide, it is a constant challenge to find balance in determining the right number and kind of meetings needed to keep our community informed and actively engaged. These gatherings serve as an important tool in ensuring that GEWEX, as a part of the World Climate Research Programme (WCRP), stays relevant and provides the necessary inputs to adjust its goals and activities as needed. In addition to the above-mentioned activities, the IGPO, along with the GEWEX Scientific Steering Group, has the task to ensure that GEWEX research activities stay current and relevant.

One shift in the mission of GEWEX has arisen from Future Earth's emphasis on a much stronger social context to environmental change research. GEWEX and its counterparts in the project must renew the push to connect science to applications. In the past, GEWEX activities, such as the Hydrological Applications Project (HAP) and its predecessor, the Water Resources Applications Project (WRAP), met with varying success. Part of making the transition from science to applications effective is a having a better understanding between the parties on their respective goals and objectives. For example, some scientists want to incorporate better physical models into numerical weather prediction (NWP) systems. This does not necessarily lead to better predictions, and the NWP centers have limitations to consider before they can update their operational models. Implementing the physical models is not always straightforward, and despite the best intentions, better science does not always lead directly to better applications.

In the past GEWEX focused primarily on the geophysical system, where human interactions were largely ignored. Hydrometeorological models have since improved and to keep the models relevant, anthropogenic influences have to be taken into account. GEWEX now includes the human component as an active part of its activities through the WCRP Water Grand Challenge and in the formulation of the GEWEX Science Questions. One of the bigger difficulties lies in the acquisition of data related to human activity, such as reservoir management decisions, industrial water, and extraction. These data are often not easily accessible, and when they are available, they are often not very reliable. The reasons for this can be of a political nature, such as to avoid disputes over trans-boundary waters, or of a socio-economical nature, such as in the case of irrigation practices. New and better Earth observation systems, such as the National Aeronautics and Space Administration (NASA) Surface Water and Ocean Topography Mission (SWOT) or the follow-on to the Gravity Recovery and Climate Experiment (GRACE-FO), may help alleviate some, but not all of the difficulties in obtaining data for water availability and extraction. The accounting of our global fresh water resources remains a difficult but important challenge.

The article on page 4 provides a good example of how the NASA Energy and Water Cycle Study (NEWS) is helping to improve the methodologies for using Earth observation techniques to quantify global water and energy budgets. Because subsurface water is so difficult to quantify, GEWEX is expanding its focus in this area through the new GEWEX Soils and Water Initiative (see page 8), which aims to improve observations, models, predictions and data assessments. This latter activity has been long overdue in my view and I am glad to see it getting the attention it deserves.

Although the fundamental science questions related to the water and energy cycle are still as valid today as they were during the formation of the GEWEX Project in the late 1980s, it is important for programs such as GEWEX to keep evolving to ensure that their research is relevant today in the broad social and scientific context. As a community, GEWEX must ensure that its priorities reflect that relevance.

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IN MEMORIAM

Paul F. Twitchell

Paul F. Twitchell passed away on July 6. He was the senior project scientist and editor of *GEWEX News* from 1990 until 2002, when he and his wife Eunice moved back to Wellesley, Massachusetts, to be closer to family. Paul was a dedicated and loyal member of the International GEWEX Project Office. He took on any task with great dedication and enthusiasm. During his time at IGPO he assisted in developing and promoting GEWEX in a wide variety of venues. Having served for many years as a program manager with the Office of Naval Research (ONR), Paul received his Ph.D. in Oceanography from the University of Wisconsin. He was a professor at the Naval Academy and also supported the U.S. Air Force Air Weather Service as an Air Force Reservist, retiring as a Colonel. We will miss this special man.

International Prize for Model Development

Nominations Due October 1

As the demand for more accurate regional weather and seasonal predictions, as well as climate projections, increases, the need to improve the weather and climate models that underpin those predictions and projections becomes more urgent.

In recognition of the essential role that model development plays in weather and climate science, the World Climate Research Programe and the Worldwide Weather Research Programme are seeking nominations for the WCRP/WWRP International Prize for Model Development. The prize will be awarded annually for an outstanding contribution to weather and climate model development by an early- to mid-career researcher (defined as within the first 10 years of their career). It comprises a certificate signed by the Chairs of the WCRP Joint Scientific Committee and WWRP Scientific Steering Committee, and funding for the recipient to present the results of his/her research at a major relevant conference or meeting of their choice.

The deadline for nominations is 1 October 2015. For details on eligibility, required nomination material and the selection process, please see: *http://www.wcrp-climate.org/wmac-activities/ipmd2015*.

Join Students and Experts to Discuss the California Drought at the 2015 AGU Fall Meeting

Sheila Saia

Graduate Student, Soil and Water Group, Biological & Environmental Engineering, Cornell University, Ithaca, New York; on behalf of and affiliated with the Young Hydrologic Society and the AGU Hydrology Section Student Subcommittee

The ongoing California drought will likely cost the state more than $2 billion in agricultural revenue losses (Howitt et al., 2014) and has reduced surface water supplies for domestic and ecological use (Famiglietti, 2015). Solving complex social, political, economic and environmental issues requires an interdisciplinary approach that promotes collaborations between academic researchers, government agencies and private interests. Given the ongoing relevancy of complicated issues like the California drought, it is important that students and early career scientists receive training to help them initiate and carry out effective interdisciplinary collaborations.

Early career scientists are encouraged to attend the Meet the Expert Session entitled "California Drought: Current State and Ways Forward" at the American Geophysical Union (AGU) Fall Meeting Student and Early Career Scientist Conference on 13 December 2015. At this session, attendees will learn about the state of California's water resources from a panel of experts and discuss the influence of drought on ecology, agriculture and economics. The goals of this session are for students and early career scientists to discuss emerging research and policies related to the California drought and brainstorm collaborative approaches for solving multifaceted water resources issues such as those in California. For more information about this year's Student and Early Career Scientist Conference, see: *http://fallmeeting.agu.org/2015/students/student-early-career-scientist-conference/*.

This Meet the Expert Session and Student and Early Career Scientist Conference is an initiative of the Young Hydrologic Society (YHS). YHS board member and AGU Hydrology section student representative Tim van Emmerik discussed the benefits of last year's conference: "100 young scientists gathered to meet peers, participate in workshops to improve their academic skills and lay the foundations for lifelong academic friendship." The 2015 conference is a great opportunity for young scientists to get more out of the Fall Meeting.

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The First Decade of Integrated NASA Energy and Water Cycle Studies

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It is commonly acknowledged within the Earth science community that significant progress in understanding and predicting the complex processes controlling the global energy and water cycle is beyond the capability of individual scientists pursuing narrowly focused research agendas. It is also recognized that a coordinated crosscutting approach integrating community research systematically leads to improved capabilities. In 2003, with encouragement by Ghassem Asrar and Jack Kaye of NASA Headquarters, NASA began planning an integrated energy and water cycle study emphasizing observationally based advancements in process understanding, modeling, prediction and consequences. The resulting NASA Energy and Water cycle Study (NEWS) Program was built upon existing NASA-supported basic research in atmospheric physics and dynamics, radiation, climate modeling and terrestrial hydrology to address how global precipitation, evaporation and the cycling of water are evolving in a changing climate.

The scientific framework for the water and energy cycle focus area is outlined in the NASA Earth Science Enterprise Strategy that was issued in October 2003. It is one of six focus areas that define the scientific content of the NASA Earth Science Program, and includes both research and technology components. Its implementation is planned through NEWS, whose grand challenge is *to document and enable improved, observationally based predictions of energy and water cycle consequences of Earth system variability and change*. It is well known that water cycle prediction skill in weather and climate models significantly lags behind temperature prediction skill, mostly due to the issues of predicting clouds, boundary layer and surface complexities. Therefore, the NEWS grand challenge should introduce innovative knowledge and modeling advancements that lead to a breakthrough improvement in the nation's energy and water cycle prediction capability.

The NEWS research linkage to the international science community is primarily through the World Climate Research Programme (WCRP), particularly the GEWEX Project. It includes complementary elements of the Climate and Ocean Variability, Predictability and Change (CLIVAR) and Climate and Cryosphere (CLIC) projects. GEWEX has overall WCRP responsibility for providing an international interface with all the national space agencies concerning energy and water cycle related global climate research requirements, instruments, data and science support. Other international connections include the International Geosphere-Biosphere Programme and the International Human Dimensions Programme.

NEWS has made significant progress on integrating NASA results into a state-of-the-art global water and energy cycle synthesis. The NEWS team initially focused on a coordinated description of the complete global energy and water cycle using existing satellite and ground-based observations, and laying the foundation for essential NEWS developments in model representations of atmospheric energy and water exchange processes. Many challenges still remain; to address the NEWS goal, a long-term commitment will be required along with continued partnerships with NASA mission and science teams, national observation and prediction systems, and with international programs.

Implementation of NEWS

The NEWS Program was initially planned in three phases, with each successive phase being focused on a range of research activities representing advances beyond the current status of observations, modeling and applications. The emphasis during Phase-1 has been to exploit current capabilities and prepare for future developments of NEWS Program elements.

Phase-2 will focus on addressing deficiencies and building a viable "prediction" system, and Phase-3 on the delivery of an end-to-end system to address the NASA Earth Science Vision, namely: (a) comprehensive observations to accurately quantify the state and variability of the global water and energy cycle, including time series data sets with no major gaps; (b) routine analysis of variability in storage, transports and fluxes of water; (c) routine prediction of key water cycle parameters (including clouds, precipitation, radiation interactions, energy budgets and surface hydrological variables); and (d) improved forecasts for use in water management and decision support. Along the way, NEWS observation plans were superseded by the 2007 NASA Decadal Survey, which redefined global observing system priorities, and by the establishment of the NASA Making Earth System Data Records for Use in Research Environments (MEaSUREs) Program, which is focused on product generation, availability and utilization.

It was envisioned that the NEWS Program would build upon existing NASA-supported basic research in atmospheric physics and dynamics, radiation, climate modeling and terrestrial hydrology. While these NASA programs fund research activities that address individual aspects of the global energy and water cycles, they are not specifically designed to generate a coordinated result. The implementation concept for NEWS is specifically intended to promote innovative mechanisms to work across these programmatic boundaries, based on the NEWS Implementation Plan central issue of assessing the key uncertainties in seasonal-to-annual and longer-term energy and water cycle predictions, and outlining model improvements needed to reduce these uncertainties.

The NEWS Team is organized into integration working groups that identify and make the necessary connections to partner and coordinate with water and energy cycle research and application activities within NASA, as well as nationally and internationally.

Accomplishments in Phase-I

NEWS compiled the first-ever satellite-based energy and water cycle climate data record, including continental and oceanic averages of the Earth's radiation balance, as well as precipitation, evaporation and water vapor (Schlosser and Houser, 2007; Rodell et al., 2015; L'Ecuyer et al., 2015). The accompanying uncertainty evaluation adds a believability measure for application of these data and is helping to guide future satellite technology decisions. This new integrated global water and energy assessment is being used in conjunction with NASA's Modern Era Retrospective-Analysis for Research and Applications (MERRA) reanalysis, to study and improve predictions of weather and climate variability (Bosilovich et al., 2011 and Bosilovich, 2013). The integrated water and energy satellite studies have provided insights into the mechanisms and severity of mid-western U.S. floods and droughts, and can be used to help in mitigating future damage caused by these extremes (Wang et al., 2014a).

NEWS-sponsored research using satellite observations has improved or created new estimates of water cycle variables, both fluxes and reservoirs, including their relationship with other important environmental processes. MODIS data from the Terra and Aqua satellites have been used in multiple ways to better understand snow and in-land water dynamics, especially in the climate-change-affected regions of the northern latitudes. Additional satellite data from AQUA (AMSR-E instrument) and QuikScat have been combined with MODIS to better assess snowmelt timing and dynamics. Multiple satellite data streams and hydrologic models have been used to better understand agriculture areas and drought dynamics (Wang et al., 2014a,b,c). Satellite data have also been used to better understand and estimate the movement of water in the atmosphere, with some particular emphasis on the water flux from the world's oceans. In many cases these advances represent a strong contribution towards improving climate model representation of water cycle attributes.

NEWS has facilitated the integration of NASA results into a state-of-the-art synthesis of the global water and energy cycles. The NEWS team combines data from NASA observing missions to provide insights about how the Earth (and the human population) moves water and energy around, including how the water cycle is accelerating. NEWS supported research also allows for an independent assessment of the range (or uncertainty) in global evapotranspiration estimates from remote sensing-driven models where the models were driven by common forcing data, based on EOS AQUA and TERRA sensor data (MODIS, AIRS, CERES). Continued work using the 1984–2008 International Satellite Cloud Climatology Project (ISCCP) and Surface Radiation Budget (SRB) Project radiation data sets is ongoing. At the same time, NEWS has fostered the development of radically new model representations of energy and water exchange processes that resolve significant process scales and spatial variability in ground boundary conditions (Bosilovich et al., 2011). Such process-resolving models may be first constructed as independent stand-alone modules that can be tested against ad hoc field measurements and systematic observations at selected experimental sites. The codes may be simplified through statistical sampling of process-scale variables or otherwise reduced to generate integrated fluxes representative of each grid-element in a climate model. This is supported by a broad exploration of potential new observing techniques concerning all aspects of the energy and water cycle, and initiating relevant technical feasibility and scientific benefit studies.

NEWS teams and collaborations have produced excellent science results with other groups. The NEWS Climatology Working Group of about 20 Principal Investigators (PIs) and co-investigators integrated numerous satellite data sets to estimate the global and continental-scale means and variations of both the water and energy cycles. All fields have associated errors attached and these are used to make adjustments to achieve balance, if appropriate. This activity alone makes NEWS worthwhile and unique. Individual instrument science teams create algorithms and analyze results from MEaSUREs to produce Climate Data Records (CDRs). The NEWS activity is attempting to integrate all of the primarily satellite-based observations into a complete picture of the energy and water cycles to show the means, and the seasonal and interannual variations and trends, using water and energy cycle conservation equations as an additional constraint. This is a huge undertaking requiring significant resources over a sustained period.

In addition to the climatology activity, NEWS has also made substantial integrative progress on water and energy cycle modeling, variability and extremes, latent heat fluxes and cloud-radiation processes. This kind of integrated science is uniquely challenging, and is critical to the NASA Earth science mission and complements other areas of Earth science, including instrument science teams, climate data record development, and Earth system model development.

NEWS Working Groups

The working group structure reflects the scientific priorities of the investigators, while still adhering to the basic objectives and goals of the NEWS Program. The current structure consists of the following working groups.

Cloud and Radiation Working Group–Links clouds, precipitation and the energy budget with an initial focus on the southeastern Pacific, stressing the importance of boundary layer clouds to the radiative energy budget, the relationships between clouds and radiative effects, and impacts of precipitation on cloud and radiative properties.

Extremes Working Group–Focus is on understanding severe drought in the United States. The 2012 drought may not have been predictable based upon current schemes employed for such purposes; however, it may have been anticipated due to knowledge of key precursors such as favorable (remote) sea surface temperature patterns and reduced regional soil moisture and winter snow packs. The Working Group will examine the extent to which the 2012 drought could have been anticipated and how to put recent severe droughts in perspective.

Climate Shift Working Group–Examines and documents the pre-1998 climate shift. During the last 25–30 years of satellite and reanalysis information, global warming of the Earth's surface and increases in ocean water vapor are evident, primarily in the pre-1998 period, with a leveling off of these increases in the post-1998 period. This "climate shift" is similar to an earlier interdecadal change event in the late 1970s and has been linked to changes in ocean-atmosphere interactions linked to Pacific Decadal Variability (PDV), although other processes (e.g., the Atlantic Multidecadal Oscillation, aerosols) could also be involved. There is also evidence that other components of the water (and energy) cycles show a shift at approximately the 1998–2000 point. However, not all the global data sets and reanalyses agree or have homogeneity issues. The objective of this working group is to understand and better document the "shift," and the strengths and weaknesses of global data sets and reanalyses to build a group consensus as to "what happened," which data sets and reanalyses can be used, and with what level of confidence. This activity will also point to possible actions to improve the data sets and reanalyses to enable more confident studies in the future.

Evaporation and Latent Heating Working Group–Evaluates latent heating over a selected region for the NEWS time period of 1998–2007 in order to determine mean seasonal flux, interannual variability and the statistical distribution of events. This will lead to an analysis of extremes and other aspects of the distribution, and how they relate to surface variability and atmospheric transport variability. An analysis of the extremes can then be tied to specific weather events, such as atmospheric rivers or cyclonic events, and an analysis of trends in the transport over the time period.

Examples of Significant NEWS Research Highlights

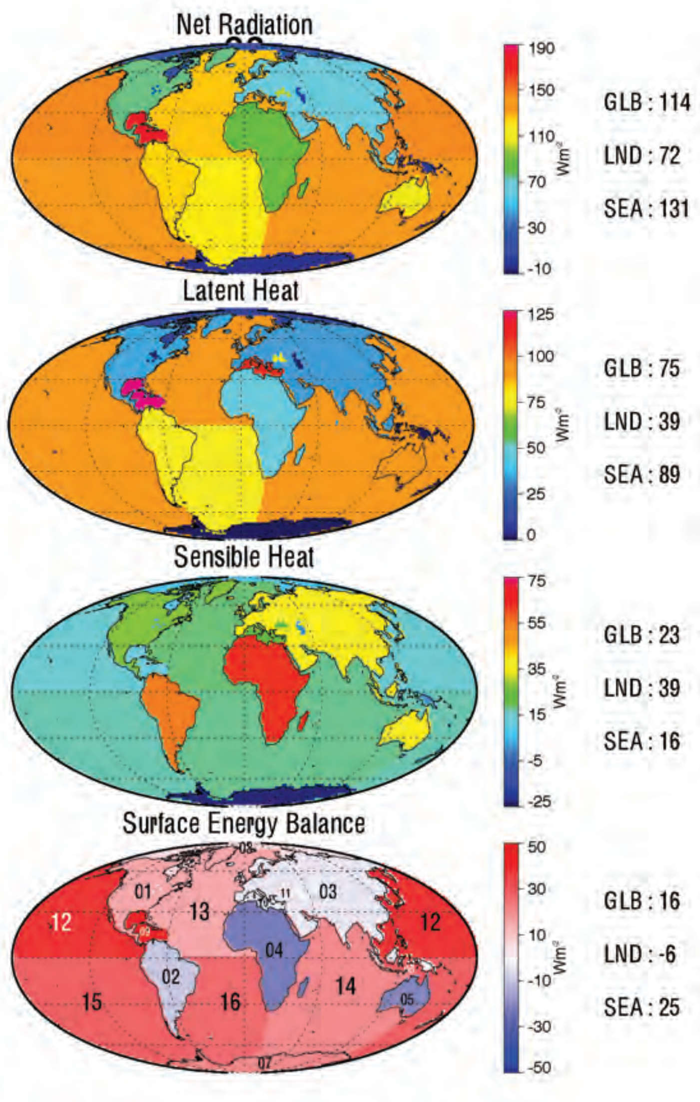
The Observed State of the Water Cycle in the Early 21st Century–The first objectively balanced estimates of the water cycle and energy budget were produced based primarily upon the recent Golden Era (2000–2010) of NASA Earth observations (Rodell et al., 2015). Combining the available data sets revealed that annual mean estimates of the net radiative flux to the Earth's surface exceeds corresponding turbulent heat flux estimates by 13–24 Wm^{-2}. This is more than an order of magnitude larger than the best estimates of the current forcing by increased greenhouse gas concentrations in the atmosphere. The largest imbalances occur over the global oceans where component flux algorithms operate independently in the absence of closure constraints. Unlike previous studies that have sought to correct these imbalances through primarily ad hoc adjustments to specific fluxes, the NEWS team pioneered a novel approach to reintroduce energy and water cycle closure information into independently derived flux data sets, thus explicitly account for uncertainties in all component fluxes. This approach has been applied to a 10-year record of satellite observations to estimate all atmospheric and surface energy fluxes and their seasonal cycles globally and for each of seven continents and nine ocean basins. These new benchmarks of global and continental energy budgets and their seasonal variability will be critical for evaluating the energetic forcings and water cycle consequences of climate change and evaluating their representation in climate prediction models.

In the majority of cases, the observed annual surface and atmospheric water budgets over the continents and oceans close with much less than 10% residual. Observed residuals and optimized uncertainty estimates are considerably larger for monthly surface and atmospheric water budget closure, often nearing or exceeding 20% in North America, Eurasia, Australia and neighboring islands, and the Arctic and South Atlantic Oceans. The residuals in South America and Africa tend to be smaller, possibly because cold land processes are a non-issue. Fluxes were poorly observed over the Arctic Ocean, certain seas, Antarctica and the Australasian and Indonesian Islands, leading to reliance on atmospheric analysis estimates. Many of the satellite systems that contributed data have been or will soon be replaced. Observation integrating models will be critical for ameliorating gaps and discontinuities in the data records caused by these transitions. Continued development of such models is essential for maximizing the value of remote sensing observations. Next generation observing systems are the best hope for significantly improving global water budget accounting (Rodell et al., 2015).

The Observed State of the Energy Budget in the Early 21st Century–New observational benchmarks of global and continental energy budgets and their seasonal variability were documented using data from the recent Golden Era (2000–2010) of Earth observing satellites (L'Ecuyer et al., 2015). Comparisons of the data sets have revealed that the net radiative flux received at the Earth's surface exceeds turbulent heat flux estimates by 13–24 Wm^{-2} (see figure on next page). The largest imbalances occur over oceanic regions where the component algorithms operate independently of closure constraints. Rigorous assessment of the uncertainties in each data set suggests that these surface energy imbalances fall within anticipated error bounds, but the systematic nature of the required adjustments across different regions, and the fact that their magnitudes often approach acceptable limits, suggest that biases may be present in one or more data sets.

There are a few reasons to favor these new estimates over recently published alternatives. First, they derive from primarily observational or observation-integrating data sets that incorporate state-of-the-art information from NASA's network of Earth observing satellites. In addition, they incorporate explicit estimates of the uncertainties in all component fluxes obtained through rigorous comparisons against high-quality direct measurements, product intercomparisons and sensitivity studies. Most importantly, the updated energy budget simultaneously satisfies all relevant energy and water cycle closure constraints using an objective variational optimization approach (see figure on cover).

To reintroduce energy and water cycle closure into independently derived flux data sets, a novel variational method for objectively imposing balance constraints was introduced that explicitly accounts for uncertainties in all component fluxes. Applying the analysis to a 10-year record of satellite obser-



Annual mean flows of energy into and out of the Earth's surface on continental scales derived from observations during the golden era of Earth observation in the early 21st century. Net radiation absorbed at the surface is shown in the upper map while latent and sensible heat transfer from the surface to the atmosphere is shown in the middle two maps. The implied surface energy imbalances when these fluxes are combined are highlighted in the map at the bottom revealing the importance of the objective optimization procedure introduced by NEWS (L'Ecuyer et al., 2015).

vations suggests that, globally, 180 Wm^{-2} of atmospheric longwave cooling is balanced by 74 Wm^{-2} of shortwave absorption and 106 Wm^{-2} of latent and sensible heating. At the surface, 527 Wm^{-2} of downwelling radiation is balanced by 399 Wm^{-2} of thermal emission, 22 Wm^{-2} of shortwave reflection, and 106 Wm^{-2} of turbulent heat transfer. The results imply that residual heat flux into the oceans (0.45 Wm^{-2}) is consistent with recent observations of changes in ocean heat content. Budgets are also presented for each of the seven continents and nine ocean basins on annual and monthly scales (L'Ecuyer et al., 2015).

Probable causes of the abnormal ridge accompanying the 2013–2014 California drought were the El Niño–Southern Oscillation (ENSO) precursor and anthropogenic warming footprint. New research by Utah State University scientists has shown evidence connecting the amplified wind patterns, consisting of a strong high pressure in the west and a deep low pressure in the east, to global warming. Evidence suggests that the amplification of the dipole can be traced to human influences. The 2013–2014 California drought was initiated by an anomalous high-amplitude ridge system. The anomalous ridge was investigated using reanalysis data and the Community Earth System Model (CESM). It was found that the ridge emerged from continual sources of Rossby wave energy in the northwestern Pacific starting in late summer and subsequently intensified into winter. The ridge generated a surge of wave energy downwind and further deepened the trough over the northeast U.S., forming a dipole. The dipole and associated circulation pattern is not linked directly with either ENSO or the Pacific Decadal Oscillation; instead, it is correlated with a type of ENSO precursor. The connection between the dipole and ENSO precursor has become stronger since the 1970s, and this is attributed to increased greenhouse gas loading as simulated by the CESM. Therefore, there is a traceable anthropogenic-warming footprint in the enormous intensity of the anomalous ridge during winter 2013–2014 and the associated drought (Wang et al., 2014b).

Future NEWS Research

Significant progress has been made on addressing the NEWS grand challenge and its associated research questions; however, the ultimate goal of a breakthrough improvement in the nation's energy and water cycle prediction capability has not yet been achieved. Through the integrated NEWS science program, we expect to demonstrate advanced global observation, data assimilation, improved representation of physical processes in climate models and better prediction systems that can be used to quantify the hydrologic consequences of climate change and produce useful seasonal and longer-range hydrologic predictions based on observed initial values and changing boundary conditions. While the NEWS research program is expected to yield incremental advances and breakthroughs over an extended period of time, progress in achieving its long-term objectives will be measured against its success in making significant contributions to:

- Developing and deploying an experimental integrated energy and water cycle global observing system.
- Documenting the global energy and water cycle through obtaining a complete observational record of all associated geophysical parameters.
- Building a fully interactive global climate model that encompasses the process-level forcings on and feedbacks within the global energy and water cycle.
- Creating a global land and atmosphere data assimilation system for energy and water variables.

- Assessing the variability of the global energy and water cycle on time scales ranging from seasonal to decadal, and space scales ranging from regional to continental to global.

- Supporting the application of climate prediction capabilities for estimating the impact of climate variability and climate changes on water resources over a variety of spatial and temporal scales.

While NEWS has made significant advances during its first decade, fundamental challenges remain. Addressing these challenges requires a long-term commitment to the NEWS goal and requires continued long-term partnerships with the NASA mission and science teams, national observation and prediction systems, and international programs, such as GEWEX, CLIVAR, the Global Earth Observation System of Systems (GEOSS) and the Global Water System Project (GWSP). For more information about NASA NEWS, see: *http://www.nasa-news.org*.

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New GEWEX Soils and Water Initiative

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The soil science community has been exploring ways to broaden disciplinary participation and foster collaboration in addressing important societal challenges where soil is a key component (beyond the traditional agricultural scope). In 2012, the Soil Systems and Critical Zone Processes (SSCZP) Technical Committee was established jointly by the Hydrology and Biogeosciences sections of the American Geophysical Union (AGU). In 2013 this committee organized two conferences to involve other disciplines, such as ecology, atmospheric science, biogeochemistry and geological sciences. The first conference, the Soil Systems and Critical Zone Processes–Integrating Life Support Functions across Disciplines, was held in Monte Verita, Switzerland (*http://www.intersoil2013.ethz.ch/*). This was followed by the AGU Chapman Conference on Soil-Mediated Drivers of Hydrological and Biogeochemical Processes Across Scales, which was held in Tucson, Arizona (*http://chapman.agu.org/soil-mediated/*). Additional meetings were organized in 2014 and these and the follow-up discussions crystalized the need to foster stronger links in the climate community for incorporating soil processes into land climate models. The need for improving the parameterization and scaling of soil processes into regional and global climate models was also noted.

During this period the leadership within GEWEX became more proactive in addressing a fundamental element mostly missing in its activities related to global water and energy exchanges, namely subsurface water and its related processes at both global and regional scales. This is particularly relevant to GEWEX Global Land-Atmosphere System Studies (GLASS) Panel process studies, GEWEX Data and Assessments Panel (GDAP) global observations, and GEWEX Hydroclimatology Panel (GHP) regional hydrological activities. The GEWEX International Scientific Conference held in The Hague, The Netherlands in 2014, provided an ideal forum for exploring these topics of mutual interest to GEWEX and the soil community, and to develop plans for an initiative promoting the synergistic inclusion of soil and near-surface water flows into some of the GEWEX activities. This initiative is tentatively called **GEWEX Soils and Water (GSW)** and as this activity is in the early planning stages, references to potential parties are indicated but formal relationships have not been established in most cases except for those directly involved in GEWEX.

Proposed Activities for GEWEX Soils and Water (GSW) Initiative

In response to discussions following the 2014 GEWEX Science Conference, six potential activities for the GSW are under consideration (names in brackets indicate potential leads).

1. **Integration of critical zone observatories (CZO) and other eco-hydrological observatories related to GEWEX activities.** These may include the Terrestrial Environmental Observatories (TERENO), the Integrated Carbon Observation System (ICOS), and the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI). Activities may include design, sensor selection, monitoring protocols and creating a data repository. [GHP]

2. **Formation of a global lysimeter network.** The current program to inventory, standardize and expand coverage of lysimeter observations would fit well within the GEWEX platform and also link nicely with the protocols of some of the newly developed CZOs. [FZ Julich and GHP]

3. **Development of an International Soil Modeling (ISM) Consortium** (*https://www.soil-modeling.org/*). This would provide coherence and better linkages between climate and soil modelers with respect to available models and their capabilities, data sets for model testing and a model repository. [FZ Julich and GLASS]

4. **Development of linkages with the Global Soil Map Initiative** (led by Dominique Arrouays and Alex Mbratney; *www.globalsoilmap.net*). A global consortium is producing a global digital soil map to describe soil properties at fine spatial resolution (approximately 100 m) supplemented by interpretation and functionality options (for applications ranging from food production to climate change and environmental degradation).

5. **Expansion of simple and low cost soil moisture monitoring networks.** The model of the Texas Soil Observation Network (TxSON; *www.beg.utexas.edu/soilmoisture/*) would be expanded to other regions in the world to provide timely and spatially distributed soil moisture information for decision making, and remote sensing and hydroclimate model calibration. [GHP and GDAP]

6. **Incorporation of near-surface and point and microscale soil processes in regional and global hydrologic and observational models** (surface evaporation physics, plants-soil interactions, carbon and other nuanced biogeochemical processes). [GLASS]

Other Potential GSW Topics

The above topics provide a starting point for GSW. There are many more that will probably be included in this activity, such as the use of ground-based and laboratory-based data for interpretation and evaluation of remote sensing data. The 2016 Soil Science Society of America Thematic Conference on Remote Sensing of Soils (in coordination with GDAP) is an example of an essential activity. GEWEX could also enhance the use of global and regional soil moisture databases by operationalizing and unifying them (e.g., *https://ismn.geo.tuwien.ac.at/*), for use by stakeholders, water managers and scientific communities (in coordination with GHP, GLASS, and GDAP). This can be expanded by systematic efforts to solve the soil water content measurement challenge through establishing links with sensor companies and water managers (potential relevance for the International Soil Moisture Network). Given the stronger attention to the human effects on the water cycle within GEWEX, the human component in accelerating the agro-urban water cycle should be addressed as well. For example, vast volumes of wastewater are modifying the water cycle near megacities and in arid regions (e.g., 40% of irrigation water in Israel is recycled wastewater).

Interested Entities for Engagement with the GSW Activities

The GSW Initiative will build upon collaboration with existing activities that have overlapping interests, such as the Soil Science Society of America (SSSA), the AGU SSCZP, the Geological Society of America Soils and Soil Processes Interdisciplinary Interest Group, and the European Geophysical Union Soil Systems Section. National agencies may include the U.S. Department of Agriculture and National Science Foundation, and the European CZO Network and GlobalSoilMap Initiative. An important role is also envisioned for academic and private organizations, such as the Water for Food Institute at the University of Nebraska, the World Food System Center at ETH Zurich, the World Food Center at the University of California at Davis and water sensor manufacturers (e.g., Acclima, Decagon, RainBird, Campbell Scientific and Eijkelkamp).

Steps for the Establishment of GSW Synergistic Activities

In February–March 2014, GEWEX distributed a document outlining potential synergism between the soil and climate communities for comment from a core group in the soil and water community. The response was overwhelmingly positive. A working group was formed that could readily become engaged and provide substantive value to the GEWEX effort. A few of the representatives volunteered to pitch the idea to the broader GEWEX community and beyond, and identify potential relationships with existing climate-soil activities (in particular with the GLASS, GHP and GDAP Panels). A white paper will be developed to outline benefits and opportunities for the respective communities, namely GEWEX, SSSA, the Geological Society of America, the AGU and the European Geosciences Union. To communicate plans to the broader community, joint sessions or discussion panels will be established at upcoming conferences. To better coordinate all these activities, two major events will be organized in 2016. The first, the Austin International Conference on Soil Modeling, will be held March 29–1 April 1 2016 in Austin, Texas, and will focus on establishing an International Soil Modeling Consortium. The second event will be an exploratory workshop held in Leipzig, Germany to identify and prioritize topics and establish working teams and a timeline for next steps of the GSW activity.

Other issues that may be addressed are critical gaps in land climate models, how detailed land surfaces should be represented, educational and communication challenges and capacity building. This is not meant as a complete list of potential activities but as a first step in outlining activities of interest. The GSW shows much promise and has garnered enthusiasm and support from the community. That said, we welcome enthusiastic individuals to join us to shape this activity and make it a success!

10 Years of NEESPI Accomplishments and Future Plans Highlighted at Synthesis Workshop

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During the past 10 years, the Northern Eurasia Earth Science Partnership Initiative (NEESPI), a GEWEX Regional Hydroclimate Project (RHP), has addressed large-scale and long-term manifestations of climate and environmental changes over Northern Eurasia (north of 40°N) and their impact on the global Earth system. Originating from a bilateral U.S.-Russia program between the National Aeronautics and Space Administration (NASA) and the Russian Academy of Sciences (RAS), NEESPI has truly become an international research program with multi-agency support. The NEESPI Science Plan was prepared in 2004 by a team of more than 100 geoscientists from 11 countries (*http://neespi.org/science/science.html*). The Plan's Executive Summary was prepared in English, Russian, and Chinese and later published in Groisman and Bartalev (2007). Over the years, NEESPI progress has been reported in programmatic papers (e.g., Groisman et al., 2009, 2014; and Groisman and Soja, 2009), and several overview books (e.g., Gutman and Reissell, 2011; Groisman and Lyalko, 2012; Groisman and Gutman, 2013; and Chen et al., 2013).

The implemenation of NEESPI has included 172 projects focusing on different environmental issues in Northern Eurasia, each of them typically lasting 3 years and funded by various national and international agencies. Over the years, NEESPI engaged more than 750 scientists from over 200 institutions in 30 countries. More than 80 Ph.D. students defended their theses while conducting their research within the NEESPI framework. The Initiative revitalized the scientific community working on Earth studies over Northern Eurasia by convening NEESPI sessions at many international meetings, including the American Geophysical Union, European Geosciences Union (EGU), and Japan Geoscience Union annual events, and by organizing more than 30 NEESPI workshops. Since 2009, two training sessions at early career scientists' summer schools were convened with the intent not only to share cutting edge science with young researchers, but also to cultivate a new generation of scientists.

NEESPI has created a new research realm through the self-organization of NEESPI scientists into a broad research network, accumulation of knowledge while developing new tools (observations, models and collaborative networks) and producing new knowledge, some of which can be directly applied to supporting decision making for societal needs. With more than 1480 peer-reviewed journal publications and 40 books to its credit, NEESPI's activities have resulted in significant scientific outreach.

NEESPI Synthesis Workshop

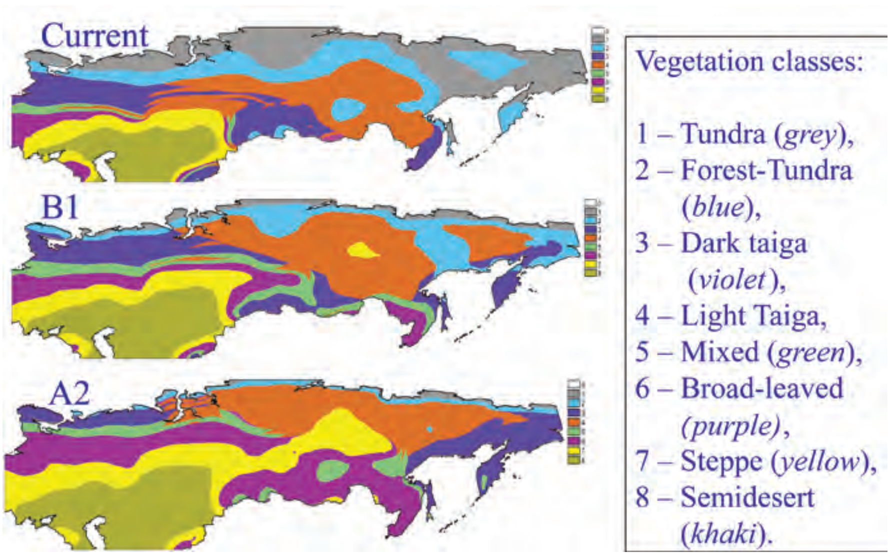
"Ten Years of NEESPI: Synthesis and Future Plans" was held at the Charles University in Prague, Czech Republic on 9–12 April 2015. The Workshop was organized and sponsored by NEESPI, the World Meteorological Organization, NASA, Charles University, P.P. Shirshov RAS Institute of Oceanology (Grant 14.B25.31.0026) and private companies. More than 70 invited participants from Japan, China, Russia, Ukraine, the European Union and the U.S. attended. Students from the Charles University were welcomed along with early career scientists who had attended the "Transatlantic Training in East European and Baltic Countries in the Area of Earth Observations," that was held in Prague in parallel with the Workshop.

The Workshop included overview synthesis lectures and science planning for the orderly transition of NEESPI to the Northern Eurasia Future Initiative (NEFI) Program (*http://neespi.org/meetings/*). Additionally, 18 posters were presented during the breaks. Results of the Workshop were delivered at the dedicated public splinter meeting held during the EGU Assembly in Austria on 16 April 2015. See: *http://neespi.org/web-content/PragueWorkshopSynthesisBriefing.pdf and http://neespi.org/web-content/PragueWorkshopOutreachPlans.pdf*.

Overview presentations at the Workshop included programmatic talks delivered by representatives of the NEESPI founding institutions. Drs. Gutman (NASA) and Georgiadi (RAS) discussed the NEESPI achievements over the past decade and how these organizations benefited from the project. R. Lawford highlighted the NEESPI role in GEWEX as one of its RHPs and discussed the potential links of future Northern Eurasia studies with the Group on Earth Observations (GEO) and Future Earth.

Studying biosphere dynamics in Northern Eurasia and understanding the impacts of the region's terrestrial ecosystems on the global carbon cycle have been key research efforts of NEESPI. Results, synthesis of international efforts, current assessment and future projections of biospheric changes in Northern Eurasia were presented in overview talks by H. Shugart, A. Shvidenko, M. Heimann and A. Soja, as well as in poster presentations by V. Kharuk and E. Kukavskaya. It was shown that biospheric changes have already become visible and their projections (see figure on page 11) hint at the continental-wide shifts in ecosystems with global consequences on carbon, energy and water cycles. Furthermore, terrestrial water cycle and cryosphere changes over Northern Eurasia have strong interactions with the regional carbon cycle. Overviews of these interactions and the projections of their changes were provided in presentations by D. Lettenmaier and V. Romanovsky.

Northern Eurasia is one of the largest land masses and the only one that is substantially isolated from the tropical air masses by mountain ranges and plateaus in the center of the



Vegetation distribution over Northern Eurasia in current climate and by the year 2090 calculated by the RuBCliM ecosystem model (archive of Shuman et al., 2015) using the Coupled Model Intercomparison Project Phase-5 ensemble global circulation model output for B1 and A2 scenarios (i.e., for corresponding greenhouse gases induced global warming to 2090 by 3–5°C and 6–8°C).

continent. Water supply into the western three quarters of this region is provided by extratropical cyclones that come with the westerlies. This is an unstable source and droughts and floods frequently occur here with any deviation of the "normal" flow of weather events. The distribution and frequency of these extreme events have recently changed. S. Gulev's synthesis of extreme weather events over Northern Eurasia showed that changes in the seasonal cycle, particularly the earlier spring onsets and depletion in the frozen water storage (glaciers, seasonal snow cover and permafrost), lead to a longer warm season and exaggerate the strength and duration of extreme events in this season.

The NEESPI research domain can be loosely partitioned into northern (the Arctic and boreal zones) and the Dry Latitudinal Belt of Extratropical Eurasia (DLB; see figure on next page). NEESPI research shows that the boundary between two parts of this domain is dynamic, has changed in the past, and most probably will change in the near future (see figure above). Changes in terrestrial cryosphere may reshape the landscapes of the Arctic due to permafrost thaw and internal continental dry regions related to the growing water deficit (weaker westerlies and retreating glaciers). The reshaping has already affected socio-economic systems in the Arctic (reported by N. Shiklomanov) and in the DLB (reported by J. Qi). In the latter, the natural dangers from inclement weather overlap with growing direct anthropogenic pressure on ecosystems. Population growth and economic development in large parts of DLB are considered more a cause concern than changes to the climate. The growing demand to expand and redirect research in Northern Eurasia, from studying mostly physical processes to investigating the consequences of their changes, became a driving force in the development of new approaches and foci within the NEESPI successor, NEFI. Interactions of environmental changes (natural and human-induced) with societal activity have not been well covered in past NEESPI studies. However, these studies are gradually moving to the forefront of regional research due to vulnerability of the regional environment triggered there by both intensification of human activity and climatic changes that are among the largest in the world.

Synthesis of hydrological, biospheric, cryospheric, climatic and socio-economic models within a suite of interactive models empowered by expanded observational input remains a key tool for understanding and projecting dynamics in Northern Eurasia (Kicklighter et al., 2014). Presentations by Q. Zhuang, D. Kicklighter, and E. Monier examined the role of Earth system modeling with foci on Northern Eurasia. Synthesis of the current state of these models, their perspectives and their deliverables (projections) were discussed.

Future Research Directions

Nine NEFI research foci emerged in discussions within the NEESPI community during the past 12 months and a consensus was reached at the Workshop.

1. Global change, particularly the warming of the Arctic
2. Increasing frequency and intensity of extremes (intense rains, floods, droughts, and wild fires)
3. Retreat of the cryosphere (snow cover, sea ice, glaciers and permafrost)
4. Changes in the terrestrial water cycle (quantity and quality of water supply available for societal needs)
5. Biosphere changes (ecosystem shifts, changes in the carbon cycle, land cover degradation and dust storms)
6. Pressure on agriculture and pastoral production (growing demand, changes in land use and food security)
7. Changes in infrastructure (roads, new routes, construction codes, air, water and soil pollution, and strategic planning)
8. Societal actions to mitigate negative consequences of environmental changes and to benefit from positive consequences
9. Quantification of the role of Northern Eurasia in the global Earth and socioeconomic systems to advance research tools with an emphasis on observations and models

The NEESPI study area is loosely defined as the region between 15°E in the west, the Pacific Coast in the east, 40°N in the south, and the Arctic Ocean coastal zone in the north. The green corresponds to vegetated land and the light brown and yellow indicate sparse vegetation and arid areas, respectively. The Dry Latitudinal Belt of Northern Eurasia is sketched on the map by the dashed white line (Groisman et al., 2009).

It was noted that during the past decade, the global Earth system has changed significantly, with changes in Northern Eurasia being substantially larger than the global average (Groisman and Gutman, 2013; Karl et al., 2015). However, not all components of the Earth system follow global trends. Current analyses show unexpected features and distributions, from shifts of the seasonal cycle in various climatic characteristics to changes in intensity, frequency and spatial and temporal distributions of extreme events. These changes have already occurred but their impacts on (and feedbacks to) several components of the Earth system are ongoing. In many aspects, this may be transitional but their development (especially the role of human activity) may define the future trajectory of regional changes and their feedbacks. This is especially important because socio-economic situations in the major nations of Northern Eurasia have significantly changed, including their abilities to withstand and adapt to adverse manifestations of environmental change.

The primary NEESPI science question was: "How do Northern Eurasia's terrestrial ecosystem dynamics interact with and alter the biosphere, atmosphere and hydrosphere of the Earth?" For NEFI, this question has been expanded to: "What will the changes in these dynamics and interactions mean for societal well-being, activities, health and decision making?" The legacy of NEESPI is in its established connections, the ongoing synthesis of previous studies and the new generation of scientists that emerged from the NEESPI projects. We know much more, we acquired new tools (observations and models) and we can gradually switch from scientific research to developing applications that directly address societal needs. Moreover, during the past decade, further climate and environmental changes have occurred, some of which now require direct responses on behalf of societal well being and human health.

After the Workshop, the Initiative groups began preparation of three documents: (1) a topical review paper to be published in the *Environmental Research Review Letters*; (2) a succinct paper for a strong impact journal with key NEESPI findings and planned NEFI work; and (3) a white paper entitled "Northern Eurasia: Facing the Challenges and Pathways of Global Change in the 21st Century" that will be distributed across the international science institutions and national sponsoring agencies.

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Soil Moisture-Precipitation Coupling: Reconciling Spatial and Temporal Perspectives

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Soil moisture-precipitation feedback is a long-standing research topic, both within GEWEX [particularly the Global Land/Atmosphere System Study (GLASS) Panel (e.g., Koster et al., 2004; Santanello et al., 2009; and van den Hurk et al., 2011)] as well as in the broader research community. In recent years, various publications have suggested some apparently contradicting results regarding the sign of soil moisture-precipitation coupling—it has been identified as positive in several locations based on temporal relationships (e.g., Findell et al., 2011), while negative relationships (rain falling on drier soils) were found in spatially based analyses (e.g., Taylor et al., 2012). A new publication in *Nature Communications* (Guillod et al., 2015) provides a joint analysis of both spatial and temporal soil moisture-precipitation coupling relationships, pointing to a possible reconciliation between the reported spatial- and temporal-based findings.

Coupling Processes

An impact of soil moisture on precipitation can be expected from various considerations. First, the evaporation of soil moisture is a direct source of water vapor into the atmosphere, and thus can alter the occurrence of precipitation. This direct effect, often termed moisture recycling (e.g., Eltahir and Bras, 1996), is generally considered a positive feedback, with wetter soils increasing the likelihood of rainfall, both locally and at downwind locations. Second, one-dimensional (1D) indirect effects can be expected from the influence of the surface (sensible and latent) heat fluxes on the dynamics of the planetary boundary layer, which can theoretically induce feedbacks of either sign, depending on the atmospheric conditions (Findell and Eltahair, 2003; Gentine et al., 2013). Third, a more recent line of work has identified spatial indirect effects, whereby soil moisture heterogeneity may favor the occurrence of rainfall over locally drier patches through impacts on atmospheric circulation at the mesoscale (Taylor et al., 2011). GLASS activities have contributed to answering several of these questions, both in global climate modeling simulations as part of the various phases of the Global Land-Atmosphere Experiment (GLACE; Koster et al., 2004; Koster et al., 2011; Seneviratne et al., 2013) and in the context of the Local Land-Atmosphere Coupling (LoCo) Working Group, which has focused on diurnal interactions, such as the impact of morning soil moisture and surface fluxes on afternoon (convective) precipitation (van den Hurk and Blyth, 2008; Santanello et al., 2009; and van den Hurk et al., 2011).

Debate

The sign and the strength of the soil moisture-precipitation feedback has been a strongly debated topic for decades (Seneviratne et al., 2010). While several studies identified positive temporal coupling mechanisms that are often based on models or reanalysis products (Koster et al., 2004; Findell et al., 2011), a more recent study (Taylor et al., 2012) based upon spatial analyses has highlighted the strong dominance of negative coupling in observations, which contrasts with a strong positive signal in global climate models. Other studies have noted that soil moisture-precipitation feedback can be model dependent (e.g., Hohenegger et al., 2009). Hence, observational studies remain crucial to identifying relationships and improving the representation of the underlying processes in models.

Observational studies, however, have their own limitations. In particular, the attribution of relationships to causality is difficult for two main reasons. First, the impact of precipitation on soil moisture tends to dominate the relationship between the two variables. Second, atmospherically driven precipitation persistence can obscure the effect of soil moisture on rainfall, and lead to spurious correlations, even when a time lag between soil moisture and rainfall is considered (Salvucci et al., 2002; Guillod et al., 2014).

Spatial Approaches

To isolate the impacts of soil moisture from those of atmospheric persistence, the analysis from Taylor et al. (2012) compares on a given day, the morning soil moisture values at locations of maximum afternoon rainfall to those at nearby locations without rain. This circumvents the obscuring effects of atmospheric persistence, as the synoptic atmospheric conditions are very similar at neighboring locations. However, the focus on the spatial dimension might direct the analysis towards processes related to induced mesoscale circulations (i.e., third category of coupling processes above), and one cannot ignore that these differ from the traditional understanding of soil moisture-precipitation feedbacks, as soil moisture gradients could be largely independent of larger-scale soil moisture. This could explain the discrepancy between the results from Taylor et al. (2012) and those from earlier studies that considered only the temporal dimension (e.g., Findell et al., 2011).

In fact, while negative coupling mechanisms via mesoscale circulations could interact with moisture recycling and other effects at the larger scale, the variety of diagnostic techniques and data sets used in previous studies precludes direct comparison. Hence, in the here-presented new study (Guillod et al., 2015), a consistent framework was designed to compare temporal and spatial relationships and was applied to remote-sensing observations.

Analysis Framework

We used a range of 3-hourly precipitation data sets (e.g., the Climate Prediction Center MORPHing Technique, CMORPH; Joyce et al., 2004) and estimates of morning root-zone soil moisture anomalies from the Global Land Evaporation: the Amsterdam Methodology (GLEAM; Miralles et al., 2011), all of which are available at 0.25° latitude and longitude. Our analysis was conducted in two steps. First, following Taylor et al. (2012), the location of rainfall maxima (L_{max}) and rainfall minima (L_{min}) within a domain (L_{evt}) of 5x5 grid-cells centered at locations of afternoon rainfall maxima were recorded for each day. Various filters were applied to the events to exclude complex topography, water bodies, non-convective seasons, days with morning rainfall, or overlapping events. Second, the pre-event soil moisture patterns corresponding to each event were analyzed using three metrics: (1) a spatial metric, based on the difference in soil moisture between L_{max} and L_{min}; (2) a temporal metric, based on soil moisture at L_{max}; and (3) a heterogeneity metric, based on the standard deviation of the 25 (pre-event) soil moisture values within L_{evt}. For each metric, event values were compared to values on non-event days at the same location, and the difference between event and non-event values were expressed as quantiles on the null distribution (see Guillod et al., 2015).

Spatial Relationships

Figure 1a shows the results of the spatial metric, the analysis by Taylor et al. (2012) applied to different data sets (see above). The dominance of small quantiles indicates that afternoon rain is more likely to occur over soils that are drier than their surroundings. This confirms the results by Taylor et al. (2012), and thus indicates that these do not depend on the use of surface soil moisture as a surrogate for root-zone soil moisture.

Temporal Relationships

Conversely, the results from our analysis of temporal dynamics (Figure 1b) show that in most regions, the analyzed precipitation events occur on days when soils are wetter than usual. Even though this approach can be impacted by externally driven precipitation persistence (as described above), it still reveals useful information. Both spatial and temporal metrics used in combination allow the conclusion that precipitation events tend to occur when soils are wet and where soils are drier than the surrounding regions. Thus, in terms of observed frequencies, both the perspective of a positive temporal coupling (Figure 2a) and that of a negative spatial coupling (Figure 2b) hold, leading to the joint perspective proposed in Figure 2c.

The Role of Spatial Heterogeneity in Soil Wetness

The third metric, shown in Figure 1c, indicates that afternoon precipitation events are more likely to be triggered over heterogeneous morning soil moisture conditions. This suggests that the temporal and spatial relationships described above are interdependent because storms induced by spatial heterogeneity, via negative spatial coupling mechanisms, may in turn instigate a positive temporal coupling.

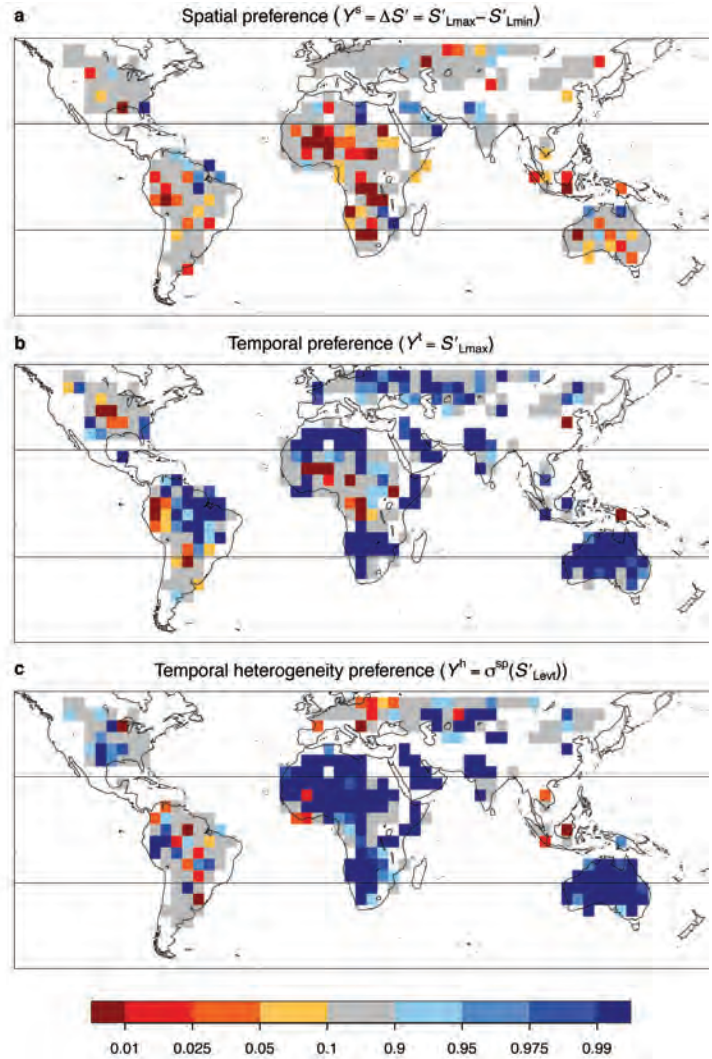

Figure 1. Preferences for afternoon precipitation over soil moisture anomalies. (a) Spatial, (b) temporal and (c) heterogeneity preference. Quantile of the coupling metrics in Guillod et al. (2015). High quantiles indicate that (a) soils are wetter at L_{max} than at L_{min}, (b) soils at L_{max} are wet relative to the mean seasonal cycle, and (c) soils are heterogeneous. Horizontal black lines indicate the latitudes at which different months are included in the analysis (see Guillod et al., 2015). Grey shading indicates nonsignificant relationships, grid cells with less than 25 events are white. From Guillod et al. (2015).

Persistence and Causality

There are various possible interpretations of the results. On the one hand, the positive temporal relationships might relate to atmospheric persistence alone [i.e., the atmosphere may sustain persistent large-scale features that favor sequences of dry (or wet) days regardless of soil moisture conditions]. In this case, only the spatial metric eludes this issue and soil moisture-precipitation feedback is negative. However, it is also possible that at least part of the positive temporal relationship depicts a causal link. This would imply that the feedback could be positive temporally while negative spatially—or in other words,

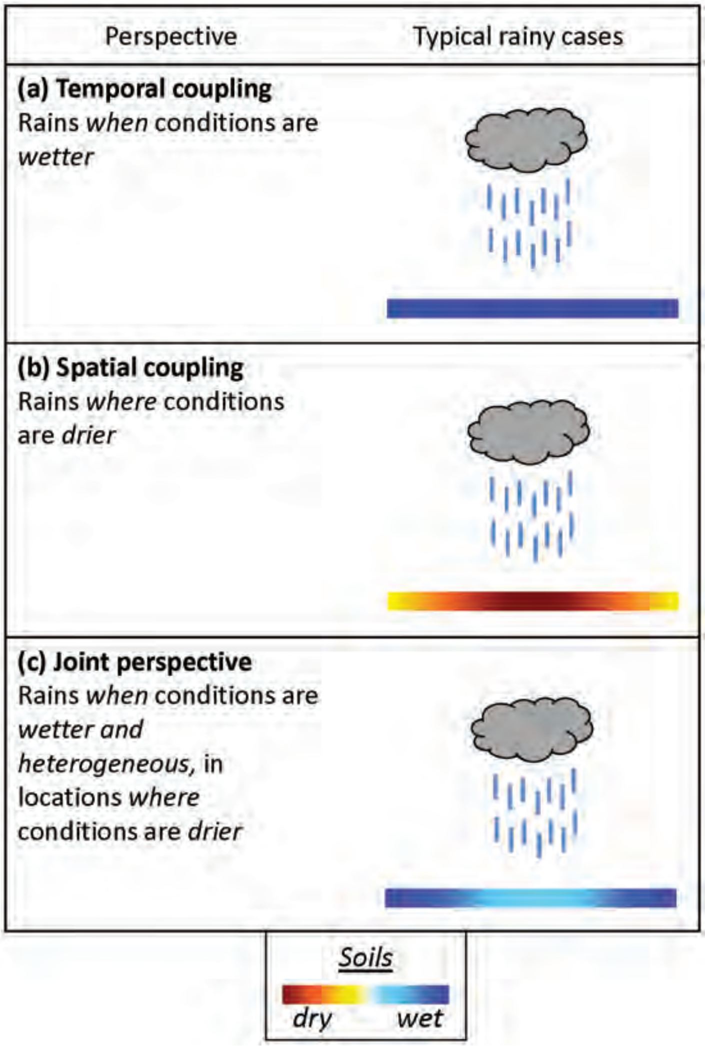

Figure 2. Representation of various perspectives on soil moisture precipitation coupling. Traditionally in the literature, temporal approaches (a) suggest that rain is more likely in wet conditions, while spatial approaches (b) emphasize rain over locally drier patches. The joint perspective presented here (c) highlights that both are valid, and thereby rain is more likely in overall wet conditions but is located over drier (less wet) patches. Shown here are typical soil moisture conditions preceding afternoon rainfall events but do not necessarily imply causal relationships. From Guillod et al. (2015).

the feedback would enhance temporal persistence while homogenizing soil moisture spatially. For example, localized precipitation events might induce soil moisture heterogeneity, which would generate further precipitation events on the next day via spatial coupling mechanisms, although not at the same locations as for the initial events, but in the drier patches. These combined effects could thus lead to a positive feedback at larger scales, which would be consistent with moisture recycling theories. However, their existence depends on multiple spatiotemporal interactions that are affected by atmospheric and soil moisture memories.

Discussion and Conclusions

The findings presented reconcile the conclusions from previous studies on soil moisture-precipitation feedback. Negative spatial and positive temporal coupling appear to be conceptually compatible, although it remains unclear as to what extent positive correlations reflect a role of soil moisture or the effects of atmospheric persistence. Similarly, the interpretation of the spatial metric of Taylor et al. (2012) depends on underlying assumptions: if rain events at L_{max} and L_{min} are assumed to occur independently, the metric investigates 1D indirect effects after removal of persistence. However, if spatial (mesoscale) mechanisms are assumed to take place, the metric investigates these and does not disentangle them from 1D local effects. In both cases, however, either negative spatial effect dominates over local temporal effect via boundary-layer dynamics, or the latter are also dominantly negative. Thus, our results suggest that a positive temporal feedback might more likely occur at larger (regional) scales than at local scales, pointing towards moisture recycling, rather than indirect processes via boundary-layer dynamics.

We have shown that afternoon rain occurs more often when soils are wet and where soils are dry. The disentangling of the various effects on soil moisture-precipitation relationships (atmospheric persistence, spatial coupling, indirect local effect from boundary-layer dynamics, moisture recycling) might ultimately have to rely on modeling experiments. Given the issues associated with the parameterization of convection (e.g., Hohenegger et al., 2009), improvement in the latter or studies using models with convection resolved explicitly will be key to uncovering the remaining mysteries of soil moisture-precipitation feedbacks.

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Meeting/Workshop Reports

GLASS Panel Meeting

Toulouse, France
18–19 May 2015

Michael Ek[1] and Aaron Boone[2]

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The GEWEX Global Land/Atmosphere System Study (GLASS) Science Panel Meeting was held at Météo-France in conjunction with the GEWEX Atmospheric Boundary Layer Study (GABLS-4) Workshop (see report on page 18). Community activities under the three GLASS Panel elements were reviewed and these included: (1) land model benchmarking to improve understanding and representation of land-surface processes; (2) understanding of land-atmosphere interaction and feedbacks; and (3) the role of the land surface in predictability (data model fusion).

PALS/PLUMBER

Martin Best reviewed the Protocol for the Analysis of Land Surface Models (PALS; material from Gab Abramowitz) and the PALS Land Surface Model Benchmarking Evaluation Project (PLUMBER), where 13 land-surface models (LSMs) were evaluated using data sets from 20 FLUXNET sites. The LSMs did well in performance benchmarks against the Penman-Monteith Model (no soil moisture stress), the Manabe Bucket Model, and simpler linear regression approaches. However, they had some problems in simulating sensible heat flux and in making full use of the atmospheric forcing information. Results were published this year in the *American Meteorological Society Journal of Hydrometeorology*.

Land-Atmosphere Interaction Activities

Land-atmosphere interaction under GLASS is addressed by the Local Land-Atmosphere Coupling (LoCo) Project and the Diurnal land/atmosphere Coupling Experiment (DICE) in cooperation with the GEWEX Global Atmosphere Systems Studies (GASS) Panel. Joe Santanello summarized the latest results under LoCo, specifically the evaluation of coupling metrics for the soil moisture-evaporation and soil moisture-precipitation relationships (temporal/spatial) in mesoscale modeling and for global climate models and reanalysis products and downscaling. The importance of using in situ and remotely sensed soil moisture observations [e.g., Soil Moisture Active Passive (SMAP) Mission] was noted, as well as planetary boundary layer (PBL) profiling, which remains a gap in Earth observations. An intensive observational period is planned for this summer at the Atmospheric Radiation Measurement Program U.S. Southern Great Plains (SGP) test bed site that will include surface flux measurements and enhanced soundings for local coupling studies. In August 2016, the Land-Atmosphere

Feedback Experiment (LAFE) will connect PALS and DICE efforts in a single site and (atmospheric) single column model (SCM) framework. Martin Best reviewed DICE progress for an initial 3-day SGP case study (i.e., evaluation compared with observations) of: (1) uncoupled LSM (atmosphere-forced) and SCM (surface-forced) runs; (2) coupled LSM-SCM runs; and (3) LSM-SCM runs with variations in forcings provided by output from the other LSM and SCM models with large errors in evaporation dominating the signal in land-atmosphere coupling. Also discussed was the effect of surface roughness and surface stress, which has been largely ignored in studies where the focus has been on energy and water fluxes.

PILDAS

Rolf Reichle reported on the Project for the Intercomparison of Land Data Assimilation Systems (PILDAS), which will evaluate the different data assimilation (DA) algorithms with several LSMs. Initially using synthetic observations, the evaluation will, in later phases, focus on coupled DA and use of actual satellite observations, such as the Soil Moisture and Ocean Salinity (SMOS) Mission and SMAP. GLASS will take the experimental plan and pilot results to the Working Group on Numerical Experimentation (WGNE) where operational centers of WGNE have a particular interest in DA.

Global Soil Wetness Project Phase 3

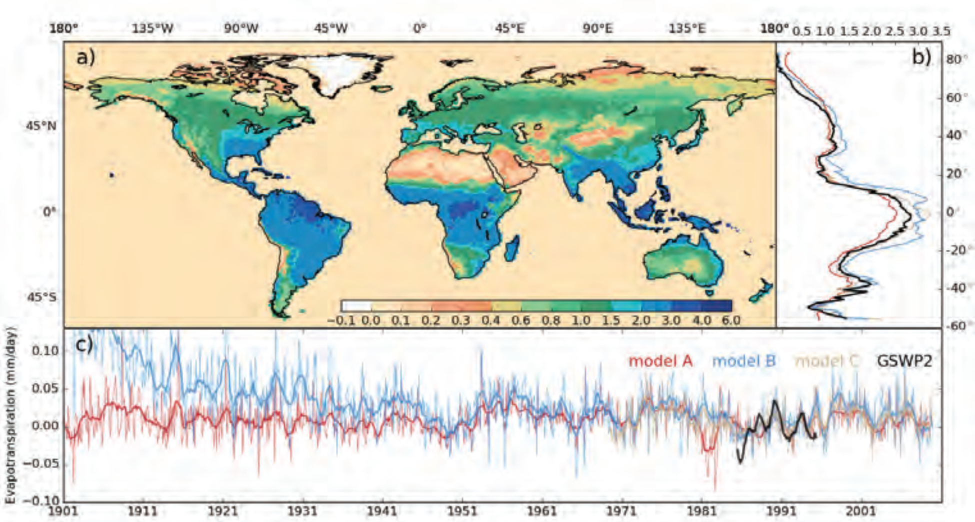
Hyungjun Kim provided an update on current plans for the Global Soil Wetness Project Phase 3 (GSWP3), which will generate 150+ year land model runs. It includes connections to the Land Surface, Snow, Soil-Moisture Model Intercomparison Project (LS3MIP) and the Climate Model Intercomparison Project Phase 6 (CMIP6), where PLUMBER-like evaluation can be used and requires coordination between GLASS PALS and related Integrated Land Ecosystem Atmosphere Processes Study (iLEAPS) efforts. Relevant to this, the Assistance for Land-surface Modeling Activities (ALMA) formatting standards were reviewed and it was recommended that GLASS move towards CMIP Climate Model Output Rewriter (CMOR) software. The coordination of GSWP3 with LS3MIP and CMIP6 was further discussed by Sonia Seneviratne (via telecon), as well as with the GLASS Land Use and Climate, Identification of Robust Impacts (LUCID) Project and the WCRP Working Group on Coupled Modeling (WGCM) Land-Use Model Intercomparison Project (LUMIP).

LUMIP and iLEAPS Connections to GLASS

David Lawrence gave a presentation on LUMIP, noting that LUMIP biogeophysical and biogeochemical metrics of land use change integrated into the International Land Model Benchmarking (ILAMB) Project can be used in evaluating the importance of natural and anthropogenic land use change, specifically for permafrost and carbon-permafrost feedbacks. Eleanor Blyth provided an overview of connections between GLASS and iLEAPS. Although both are intimately linked, most notably via vegetation and carbon processes (e.g., PALS/PLUMBER is a natural link with iLEAPS, since carbon is one of the evaluation metrics), GLASS has the GEWEX focus on energy and water while iLEAPS focuses on biogeochemical cycles.

Cross-Program Activities

In addition to the activities discussed above, the GLASS community is involved with a number of other cross-program efforts in WCRP, GEWEX and elsewhere. For example, Pere Quintana Segui summarized the Hydrological Cycle in the Mediterranean Experiment (HyMeX), which is a Regional Hydroclimate Project (RHP) within the GEWEX Hydroclimatology Panel (GHP). In HyMeX, land models are important in examining the nature of drought in the region, with additional information on groundwater, hydrometeorological extremes and water demands (societal impacts) required. The GHP Changing Cold Regions Network (CCRN) RHP, led by Howard Wheater, could be extended to include the Mackenzie River Basin with GLASS involvement in land surface and hydrology modeling, including cold season processes. GLASS Co-Chair Aaron Boone provided a brief update on the African Monsoon Multidisciplinary Analysis (AMMA) Land Surface Intercomparison Project Phase-2 (ALMIP2), which was focused on the local to mesoscale and whose main goal was to improve understanding and modeling of key surface, vegetation and hydrological processes over West Africa. This includes, for example, the subtle hydrology and vegetation processes in the region, such as large rooting depths, near-surface aquifers, soil



Several models are performing "fast-track" simulations over all or parts of the historical period in order to evaluate the input forcing for GSWP3 and to identify any potential problems before the official simulations begin in late 2015. An example of the results is shown above. Long-term interannual variability of global evapotranspiration (1901–2009; global 0.5°, excluding Antarctica) based on multimodel offline fast-track simulations in GSWP3 and GSWP2 baseline (B0) multimodel ensemble experiment (1986–1995; global 1.0° excluding Antarctica) shown as black lines in subpanel (b) and (c).

crusting, lateral transfer processes and strong runoff variability. In addition to GHP links to AMMA, it was suggested that sensitivity to surface forcing could be further investigated by expanding LoCo (or DICE) for the AMMA region. A new GEWEX effort that will involve GLASS is an initiative on soils to examine soil and soil heterogeneity effects (precipitation forcing, soil organics, influence of biota, depth to bedrock, etc.) first introduced by Dani Or at the 7th International GEWEX Science Conference in July 2014.

Paul Dirmeyer reviewed the World Weather Research Programme (WWRP)/WCRP Subseasonal to Seasonal Prediction Project (S2S), which may be a valuable resource for establishing and evaluating land-atmosphere coupling metrics over a range of operational forecast models. The Joint GEWEX/WCRP Monsoon Panel has strong overlap and cross-interest in S2S, with land-atmosphere interaction also playing an important role. Gerhard Krinner, co-chair of the WCRP Climate and Cryosphere (CliC) Project, provided a summary of LS3MIP/SnowMIP, and a general overview of CliC activities with the purpose of improving the understanding of the cryosphere and its interactions with the global climate system. Future GLASS-CliC collaborative efforts will involve use of cold season, cold regions and high-latitude observations (snow cover, surface fluxes over taiga and tundra, permafrost, etc.) to improve land-surface and large-scale hydrology models for ice and snow surfaces. The WWRP Polar Prediction Project (PPP) Year of Polar Prediction (YOPP) is being planned with a number of activities of joint interest to CliC and GLASS. Michael Ek, GLASS Co-Chair and member of WGNE, summarized his report to WGNE on relevant GLASS activities, especially land model benchmarking (PALS/PLUMBER), land-atmosphere interaction (DICE and LoCo) and land data assimilation (PILDAS). Joseph Santanello, the GLASS representative on the WCRP Modeling Advisory Council (WMAC), noted that within WMAC, the issue of urban climate could build on the GLASS Project for the Intercomparison of Land-surface Parameterization Schemes (PILPS)-Urban Project, and the GLASS community could be involved with future participation in a WCRP summer school on model development with focus on LSMs and land-atmosphere interaction.

Next Pan-GLASS Meeting

A Pan-GLASS meeting is tentatively planned for mid-2016 that would feature the three GLASS elements of benchmarking, land-atmosphere interaction and model data fusion. The meeting would have a number of joint sessions with other GEWEX panels and groups on the various parts of the terrestrial water cycle, including: (i) GASS (surface fluxes, atmosphere feedbacks); (ii) iLEAPS (impact of vegetation and transpiration, including seasonal changes); (iii) CliC (cold regions processes); (iv) GHP (regional hydrometeorology and climate, river flows); (v) the GEWEX Data and Assessments Panel (global remotely sensed data sets); (vi) the Climate and Ocean: Variability, Predictability and Change (CLIVAR) Project (impact of fresh water fluxes on ocean circulations); (vii) soil scientists and groundwater (aquifer) modelers (soil water stores); and (viii) human management of water and impacts, embracing social science.

First Workshop on the GABLS-4 Intercomparison

Météo-France, Toulouse, France
20–22 May 2015

Eric Bazile[1], Fleur Couvreux[1], Patrick Le Moigne,[1] and Christophe Genthon[2]

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The GEWEX Atmospheric Boundary Layer Study (GABLS) conducts intercomparison studies on boundary layer parameterization schemes used by numerical weather prediction (NWP) and climate models. The first three GABLS intercomparison studies dealt with moderately stable conditions. The 4th intercomparison case (GABLS-4) is focused on very stable conditions and is being conducted in collaboration with the GEWEX Panel on Global Atmospheric Studies (GASS).

The goal of GABLS-4 is to study real-time diurnal cycles over the Antarctic Plateau, focusing on the boundary layer and surface parameterization. In polar regions and under stable stratifications, models present large biases that are dependent upon the parameterizations used for the surface and boundary layers (Holtslag et al., 2013). The intercomparison uses observations collected at the Dome-Concordia (Dome-C) Research Station in Antarctica during the summer, and in particular the boundary-layer observations with turbulent fluxes and meteorological variable measurements acquired from the 45-m tower. Three types of numerical simulations were performed [single column model (SCM), large eddy simulation (LES) and offline land-snow model (LSM)] and compared to Dome-C in situ measurements. LSMs and SCMs with interactive snow schemes were run first, followed by SCMs and LESs that were performed for the observed surface temperature.

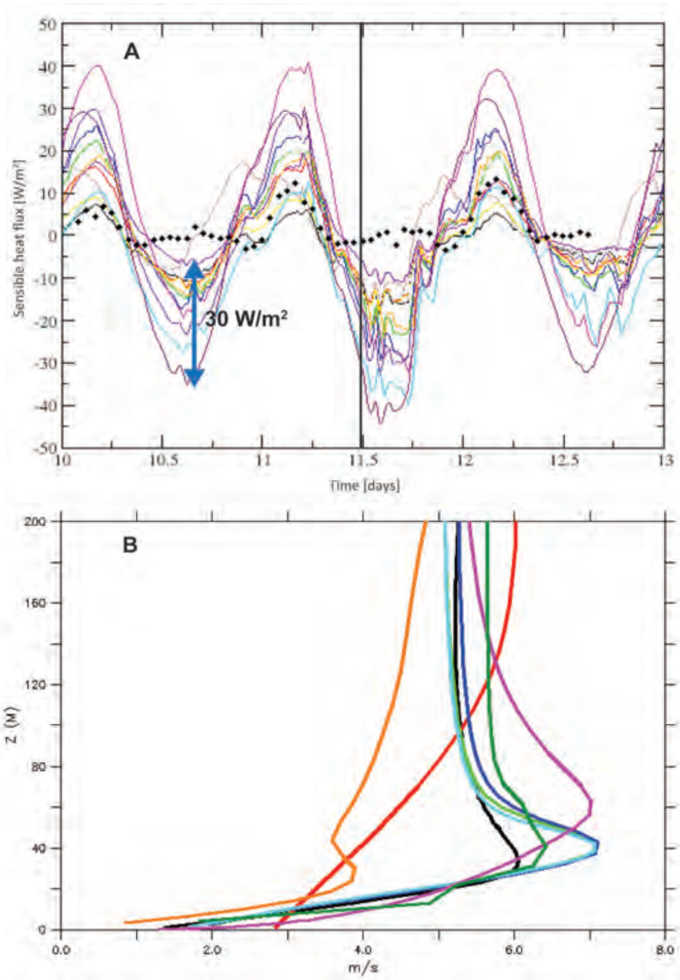
The First Workshop on the GABLS-4 Intercomparison was attended by 35 scientists and modelers from 21 institutes. The workshop comprised 25 presentations as well as many fruitful discussions. The purpose of the workshop was to: (i) present an overview of the experimental results received from the different groups; (ii) identify potential issues encountered; (iii) discuss the uncertainties in the observational measurements; and (iv) share general knowledge of the stable boundary layer. An afternoon session was dedicated to the GEWEX Diurnal Land-Atmosphere Coupling Experiment (DICE) Intercomparison Study, which shares a similar setup as GABLS-4.

The first day of the workshop was devoted to a general overview of results. A large variability in surface fluxes computed by the LSMs driven by atmospheric observations was highlighted. For example, on the "golden day" (11 December 2009, when all measurements were validated during at least 24 hours with a clear sky, low wind, a high Richardson number and a large diurnal cycle), the sensible heat flux maximum nocturnal amplitude computed by the LSMs was about 30 W/m^2 (see top panel in figure below). The high variability in the surface parameter settings, such as albedo, roughness lengths or emissivity, combined with different parameterizations of the surface layer and surface fluxes, can probably explain this large spread in the surface fluxes and will be further investigated.

Participants at the First Workshop on the GABLS-4 Intercomparison.

For the 1-dimensional intercomparison, 11 institutes submitted more than 40 experimental results with, among them, several sensitivity tests that focused on the atmospheric vertical resolution or on the boundary layer scheme. These tests were based on operational or research versions of NWP models with snow schemes of varying complexity, from single snow layer schemes to multi-layer snow models that represent more detailed physical processes.

First results from the intercomparison show that a relatively fine vertical resolution is required for SCMs to obtain a low-level jet below 50 m, with a first level at around 3 m (at a minimum). However, this depends upon the planetary boundary layer scheme used in the SCM (see bottom panel in figure).



Top Panel: Sensible heat flux computed by LSMs (Stage 0 Experiment). X-axis time – Golden day 10–11.5. Bottom Panel: Wind speed (m/s) profile at 18TU (minimum of T_S) for SCMs using a high vertical resolution.

The second day of the workshop focused on sensitivity studies and observations. Discussions focused on the challenges in measuring surface fluxes, especially sensible heat flux in very stable conditions, but also on estimates of the turbulent kinetic energy. Surface sensible heat flux was estimated by two methods: eddy covariance and the gradient relationship. The uncertainty is probably about 5 W/m^2 for a sensible heat flux of 10 W/m^2. The estimation of the roughness length was also discussed, and a value around 0.0007 m for the momentum was determined to be reasonable. Unfortunately, the estimation for the roughness of heat was more difficult to assess.

The preliminary LES results were presented on the last day of the workshop, followed by a general discussion. Since LESs have difficulties in reproducing the very stable layer close to the surface, it was suggested that a finer resolution of 5 m in the horizontal and 2 m in the vertical is needed. There is also a large variability in the sensible heat fluxes among the different models even though the surface temperature is prescribed. Currently, only one LES has been run with an interactive snow scheme, and it would be of great interest if more LESs could be run in a coupled mode in order to get a sufficiently large spread in results, which could be helpful for further SCM validation.

During the general discussion, several new experiments were proposed and adopted in order to understand and more clearly explain the large variability between the models. For each participant and all of the GABLS-4 stages, a reference simulation will be performed before October 2015 with several common values for the roughness lengths, emissivity, albedo, snow density, and atmospheric vertical grid. The workshop program and presentations are available at: *http://www.cnrm.meteo.fr/aladin/meshtml/GABLS4/GABLS4.html*.

Reference

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GEWEX/WCRP Calendar

For the complete Calendar, see: http://www.gewex.org/

23–28 August 2015—14th International Swiss Climate Summer School–Extreme Events and Climate—Ascona, Switzerland

24–28 August 2015—SPARC Workshop on Storm Tracks—Grindelwald, Switzerland

1–4 September 2015—ECMWF Seminar: Physical Processes in Present and Future Large Scale Models—Reading, United Kingdom

2–4 September 2015—GEWEX Executive Meeting—Washington, DC, USA

14–18 September 2015—SOLAS Open Science Conference, Paris, France

15–17 September 2015—Third Space for Hydrology Workshop: Surface Water Storage and Runoff: Modeling, In Situ Data and Remote Sensing—Frascati, Italy

15–18 September 2015—Monsoons and ITCZ: The Annual Cycle in the Holocene and the Future—New York, New York, USA

21–25 September 2015—9th HyMeX Workshop—Mykonos, Greece

29 September–2 October 2015—Annual GDAP Meeting—Xiamen, China

5–7 October 2015—Advancing Our Understanding and Modeling of Climate Extremes by Combining Physical Insights with Statistical Methodology—Oslo, Norway

5–9 October 2015—11th International Conference on Southern Hemisphere Meteorology and Oceanography—Santiago, Chile

13–16 October 2015—International Conference on Water Resources Assessment and Seasonal Prediction—Koblenz, Germany

15–16 October 2015—Translating Process Understanding to Improve Climate Models—Princeton, New Jersey, USA

20–23 October 2015—Earth Observation for Water Cycle Science 2015—Frascati, Italy

20–23 October 2015—WCRP/FP7 EMBRACE Workshop on CMIP5 Model Analysis and Scientific Plans for CMIP6—Dubrovnik, Croatia

26–28 October 2015—Land Modeling "LandMIP" Workshop—Zürich, Switzerland

26–30 October 2015—Land Surface, Snow and Soil Moisture Model Intercomparison Project Workshop—Zürich, Switzerland

3–5 November 2015—Linkages between Arctic Climate Change and Mid-Latitude Weather Extremes Workshop—Sheffield, United Kingdom

4–5 November 2015—GEWEX Water Vapor Assessment Workshop—Madison, Wisconsin, USA

9–11 November 2015—GEWEX Workshop on the Climate System of the Pannonian Basin—Osijek, Croatia

9–13 November 2015—23rd SPARC Scientific Steering Group Meeting—Boulder, Colorado, USA

16–20 November 2015—GHP Meeting—Entebbe, Uganda

17–19 November 2015—International Conference on Water and Energy Cycles in the Tropics—Paris, France

2 December 2015—Second Annual OzEWEX Workshop—Broadbeach, Queensland, Australia

14–16 December 2015—AGU Fall Meeting—San Francisco, California, USA

10–14 January 2016—96th AMS Meeting—New Orleans, Louisiana, USA

25–29 January 2016—GEWEX SSG-29 Meeting—Zürich, Switzerland

15–19 February 2016—Conference on Understanding Clouds and Precipitation Through Highly Resolved Process Modeling and Observations—Berlin, Germany

2–4 March 2016—Global Climate Observations: The Road to the Future—Amsterdam, The Netherlands

29 March–1 April 2016—Austin International Conference on Soil Modeling—Austin, Texas, USA

5–15 April 2016—WWRP/WCRP/Bolin Centre School on Polar Prediction—Abisko Scientific Research Station, Sweden

25–30 April 2016—WGNE 31—CSIR, South Africa

9–13 May 2016—2016 ESA Living Planet Symposium—Prague, Czech Republic

10–13 May 2016—Earth Observation and Cryosphere Science 2016—Prague, Czech Republic

10–13 May 2016—Conference on Earth Observation and Cryosphere Science—Frascati, Italy

17–20 May 2016—CORDEX 2016: International Conference on Regional Climate Change—Stockholm, Sweden

16–18 September 2016—CLIVAR Early Career Scientists Symposium—Qingdao, China

16–23 September 2016—CLIVAR Open Science Conference—Qingdao, China

13–17 February 2017—International Symposium on Cryospheric Processes, Climate Drivers and Global Connections—Wellington, New Zealand

GEWEX NEWS

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