Northern Eurasia Droughts and Heat Waves

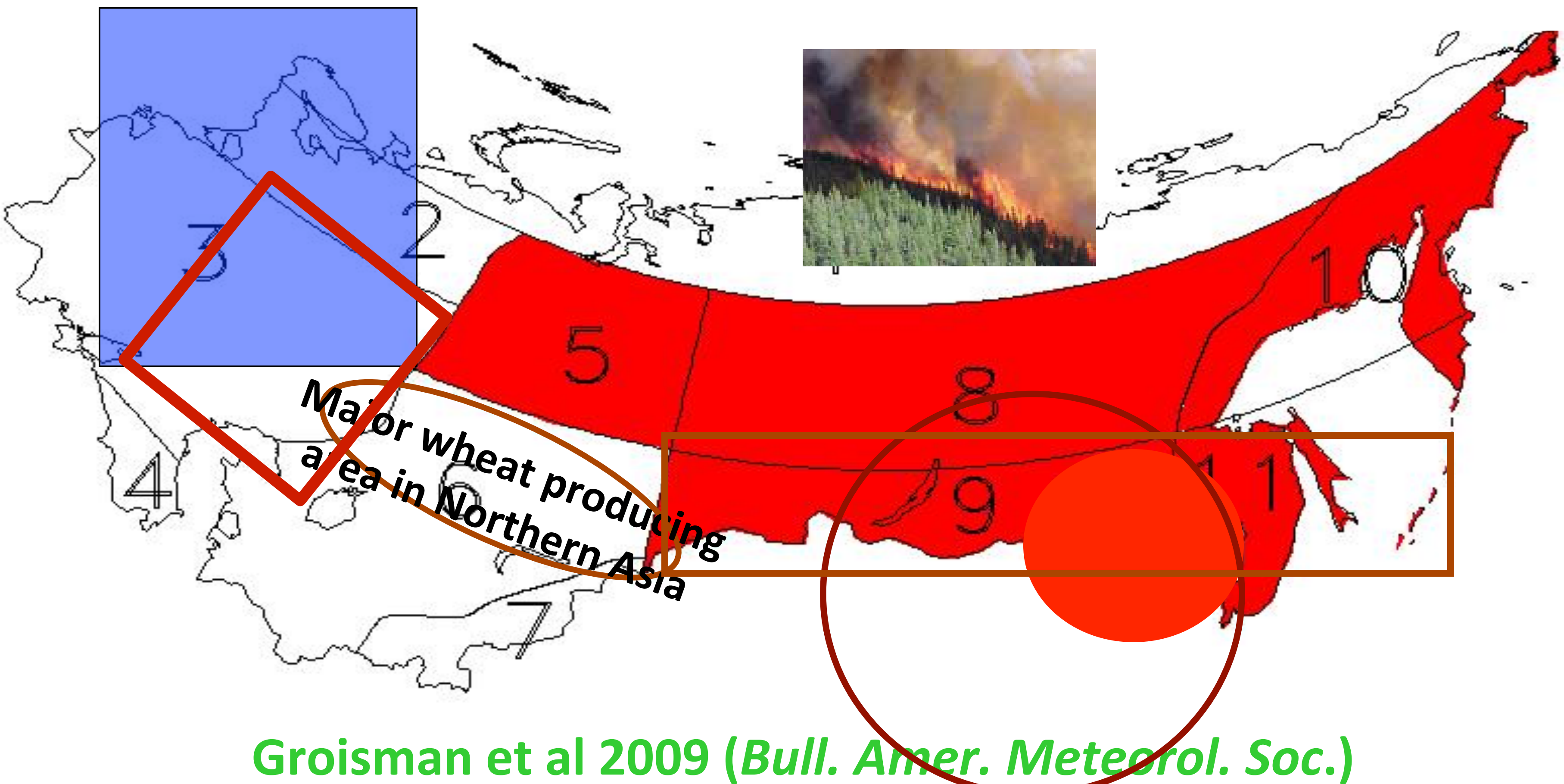
Northern Eurasia Earth Sciences Partnership Initiative (NEESPI): Drought-related Research

Pavel Groisman

NEESPI Project Scientist

Changes in the surface water cycle over Northern Eurasia that have been statistically significant in the 20th century

More humid conditions (blue),
more dry conditions (red),
more agricultural droughts (circled),
more prolonged dry episodes (rectangled).



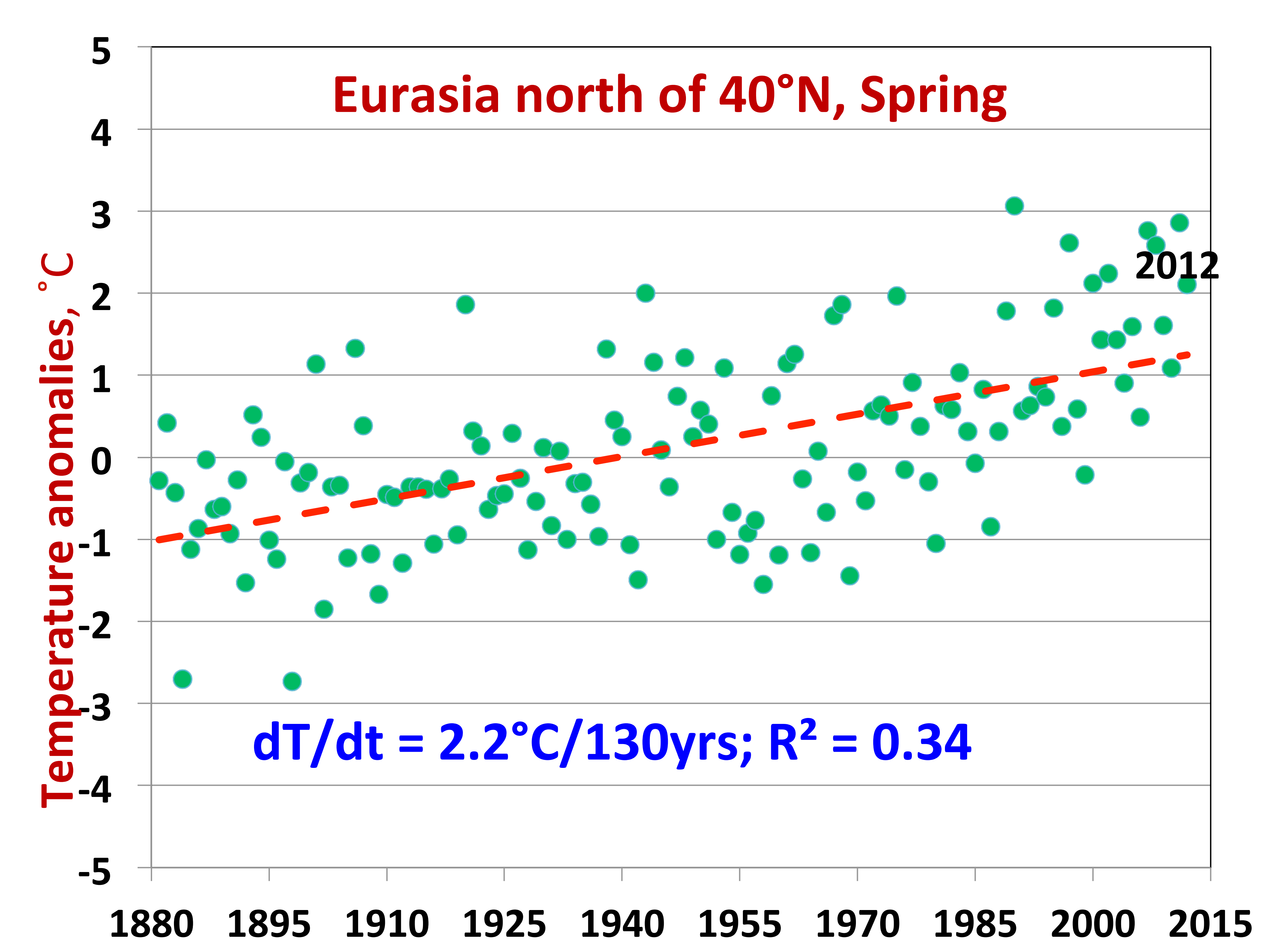
Groisman et al 2009 (*Bull. Amer. Meteorol. Soc.*)

Drought-related study topics in the NEESPI domain

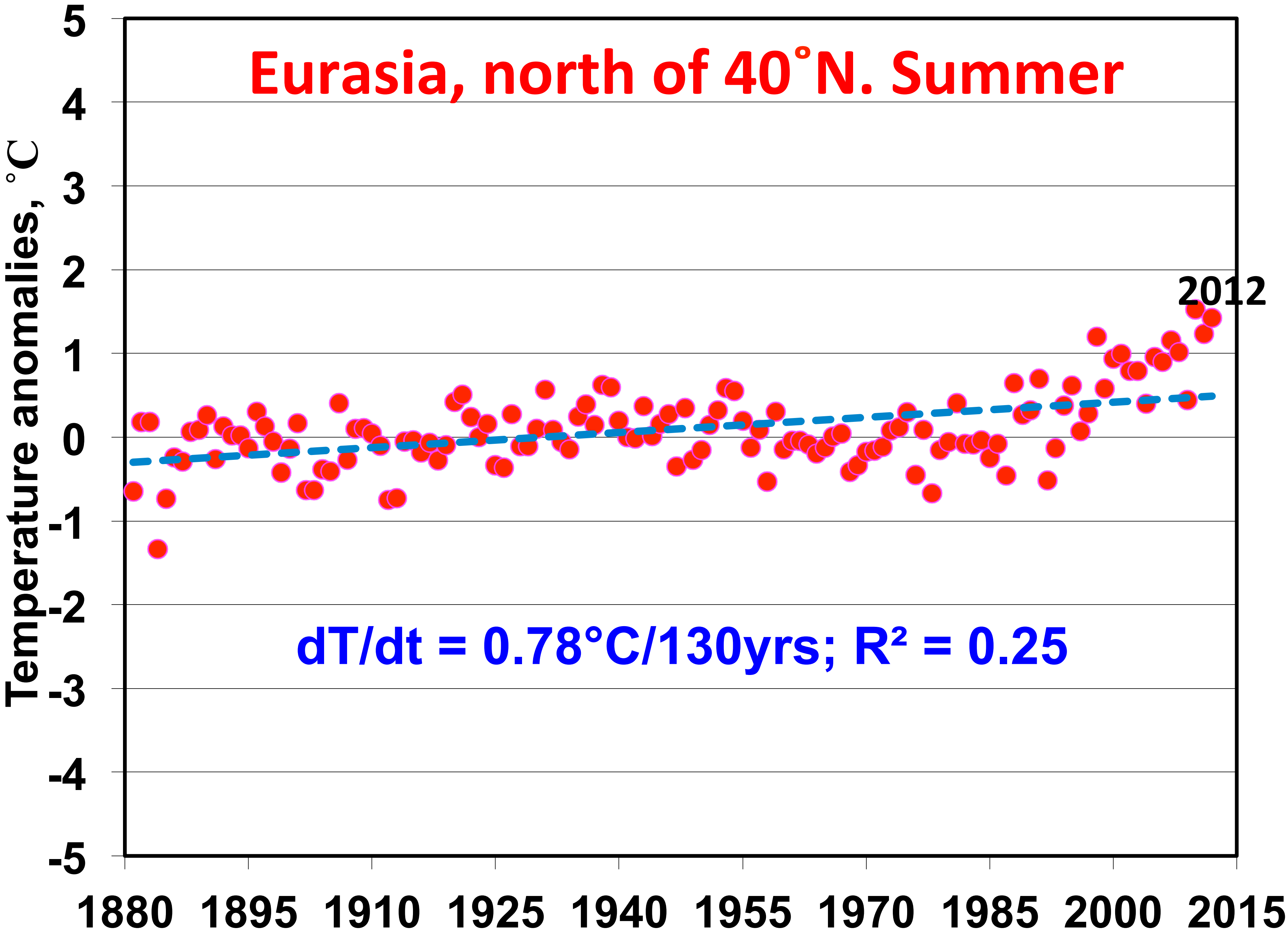
1. Long-term water deficit increase with shift in the seasonal cycle, snow cover changes, thawing permafrost, prolongation of the vegetation season, and glacier retreat
2. Agriculture droughts (frequently with the focus on the May -- July period)
3. Wild Fire
4. Heat waves
5. New challenge: ecosystems' shift

Changes in the seasonal cycle

- Spring warming
- Summer warming (in Siberia only}
- Snow cover
- Thaws (including the permafrost thaw)
- Glaciers' retreat
- Spring onset
- Vegetation season



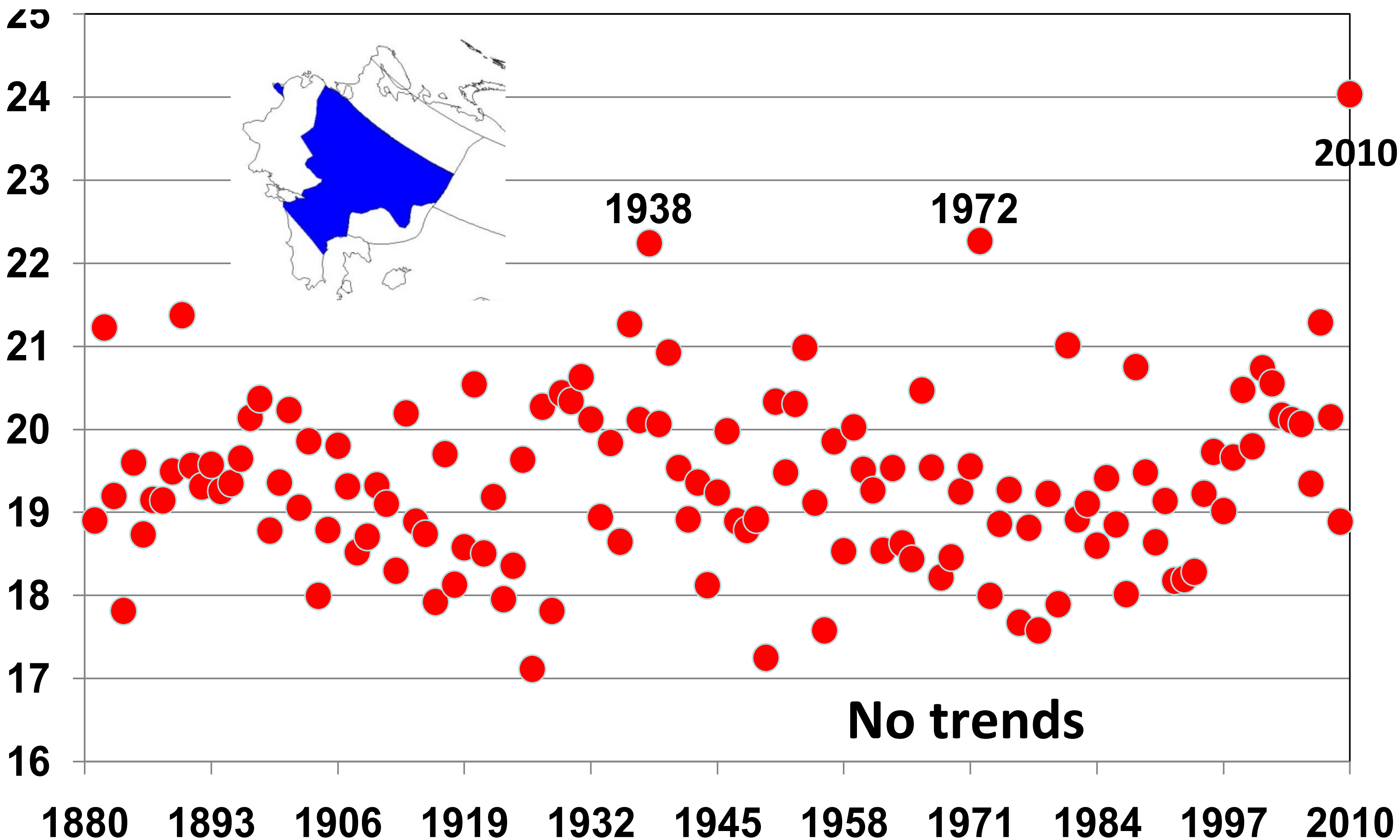
Eurasia north of 40°N, Spring
Temperature anomalies, °C
5
4
3
2
1
0
-1
-2
-3
-4
-5
2012
dT/dt = 2.2°C/130yrs; R² = 0.34
1880
1895
1910
1925
1940
1955
1970
1985
2000
2015



Eurasia, north of 40˚N. Summer
Temperature anomalies, °C
5
4
3
2
1
0
-1
-2
-3
-4
-5
2012
dT/dt = 0.78°C/130yrs; R² = 0.25
1880
1895
1910
1925
1940
1955
1970
1985
2000
2015

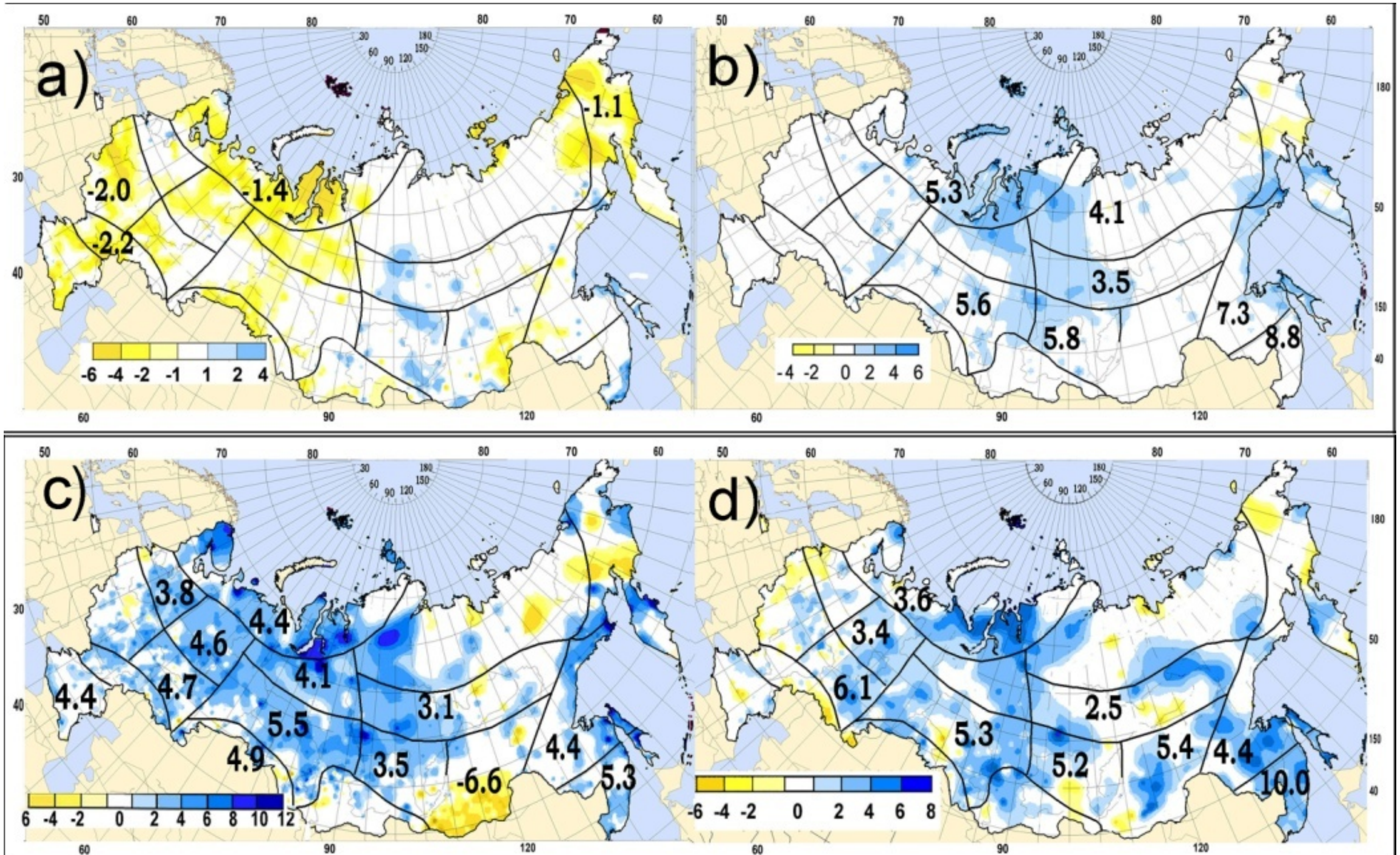
July-August surface air temperature (°C) area-averaged over European Russia south of 60°N

(Lugina et al 2006, updated)



CHANGE IN SNOW CHARACTERISTICS

Linear trend estimates at meteorological stations (indicated by color) and regionally-averaged (numbers) over quasi-homogeneous regions (%/decade), 1966-2010.



a) Number of days with snow covering > 50% of the area around a station

b) Mean winter snow depth

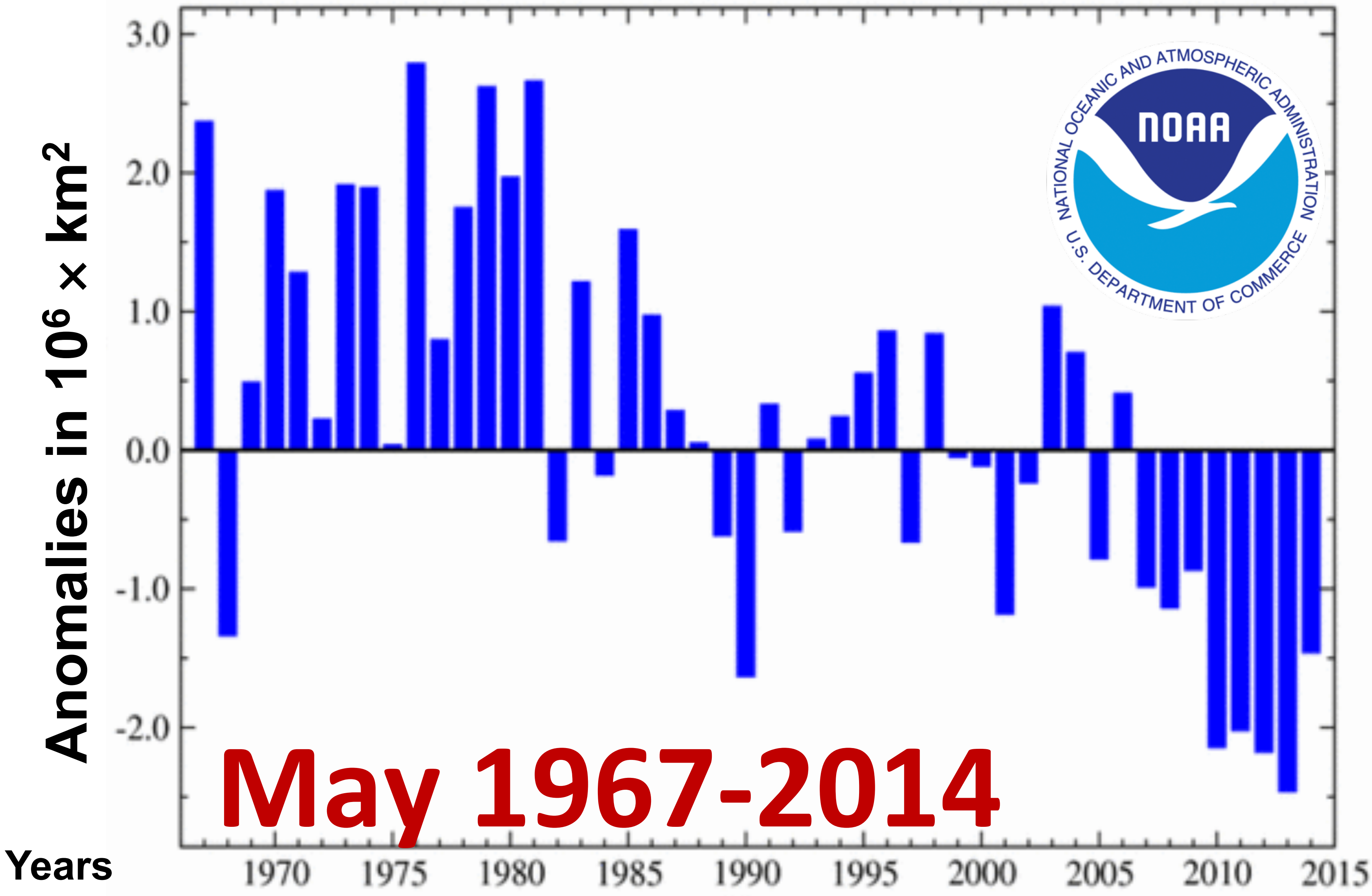
c) Maximum winter snow depth

d) Days with snow depth > 20 cm

Snow cover duration & density

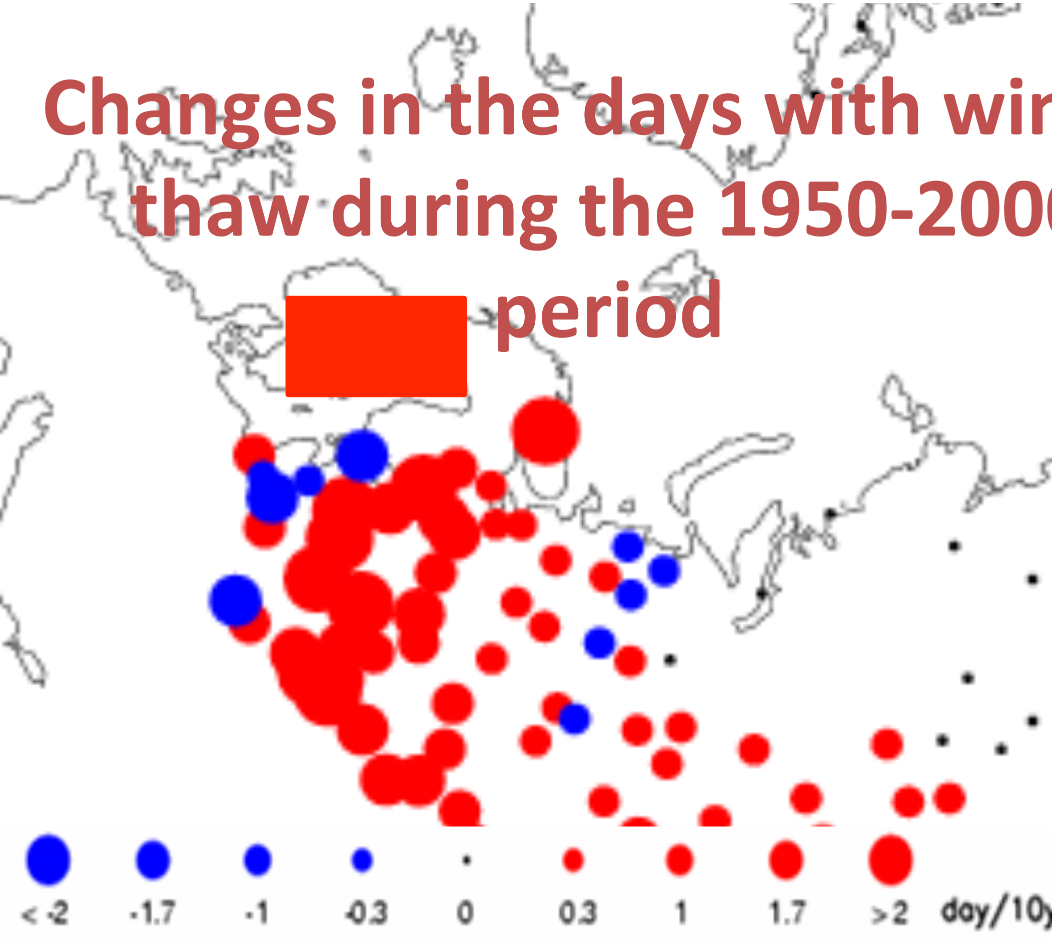
Max snow depth and max snow water equivalent

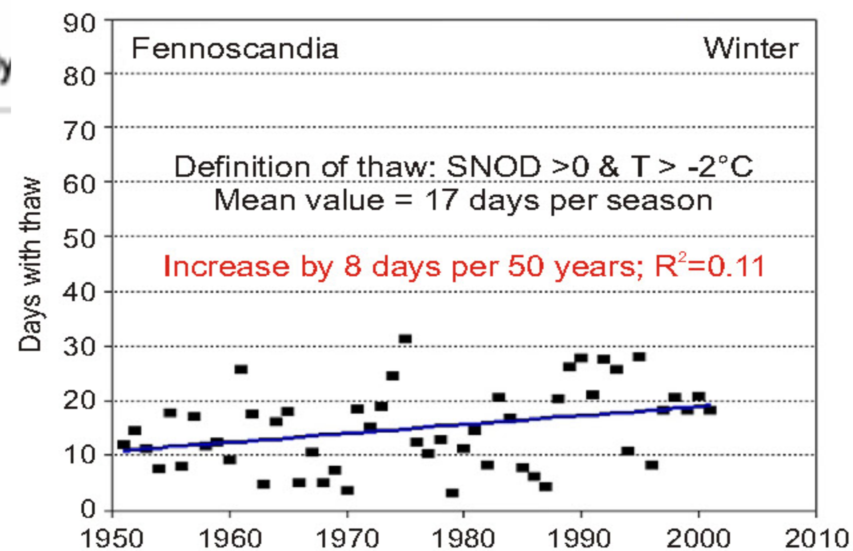
Snow cover extent anomalies over Eurasia



http://www.ncdc.noaa.gov/sotc/service/global/snowcover-eurasia/201405.gif

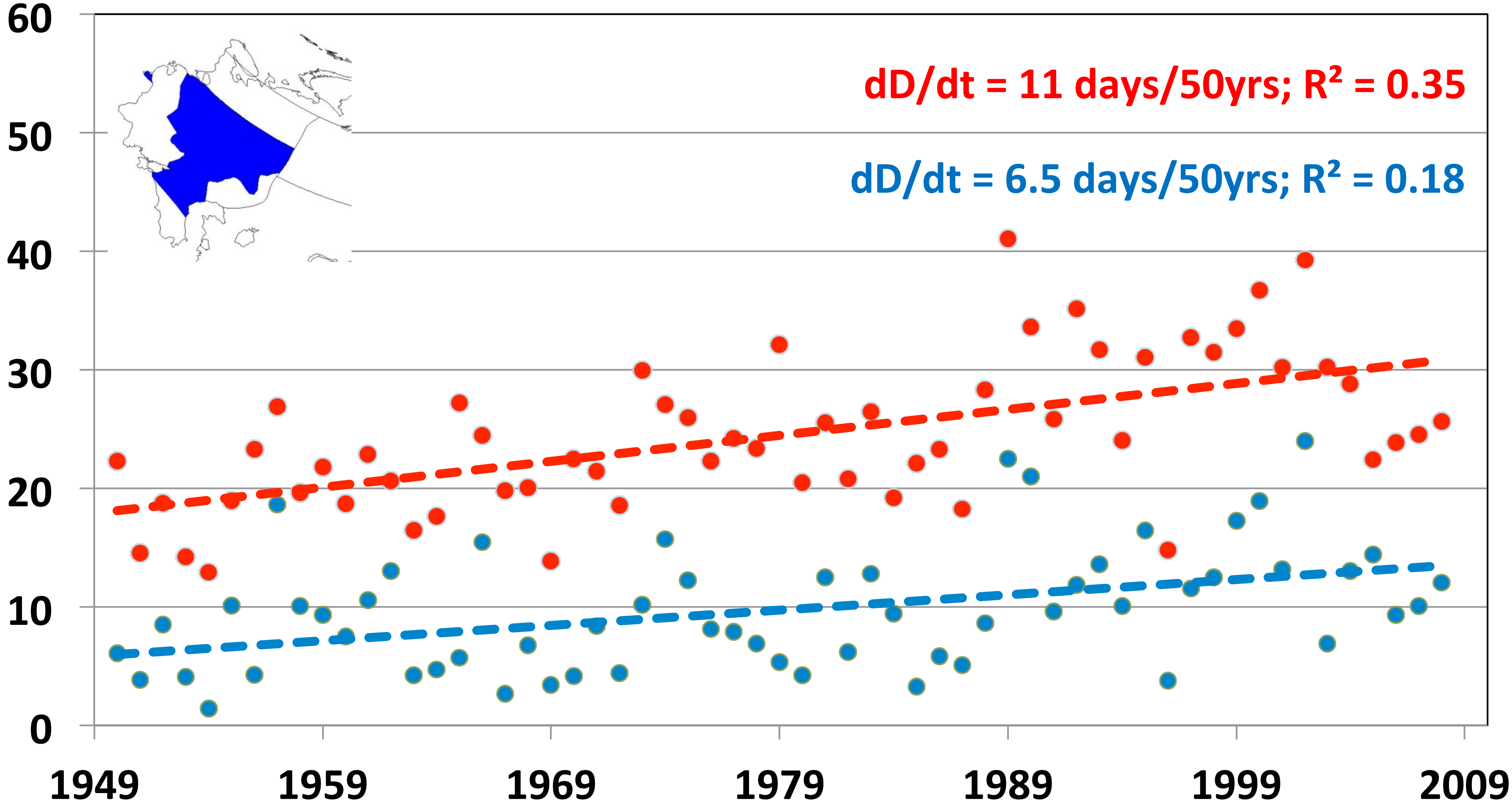
Changes in the days with winter thaw during the 1950-2000 period





Top. **Linear trend estimates in the seasonal number of days with winter thaw (days/10yr) (Groisman et al. 2003). Right. The same, but regional time series for Fennoscandia (Groisman et al. 2009)**

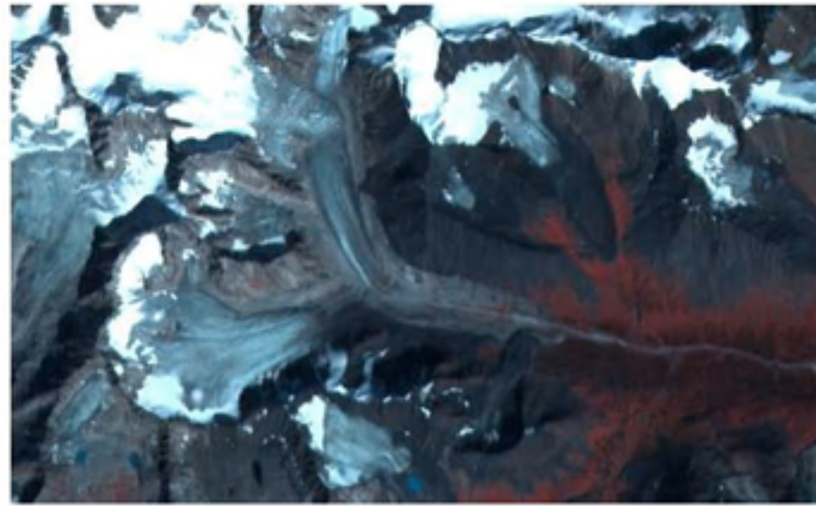
Annual and winter number of days with thaw over European Russia south of 60°N



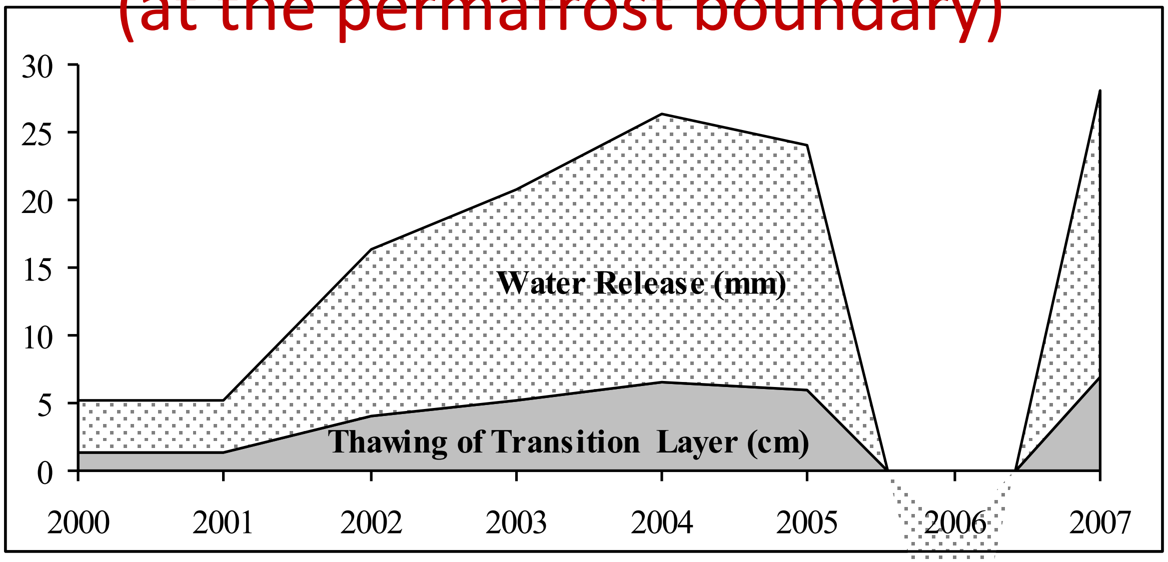
Glaciers’ retreat

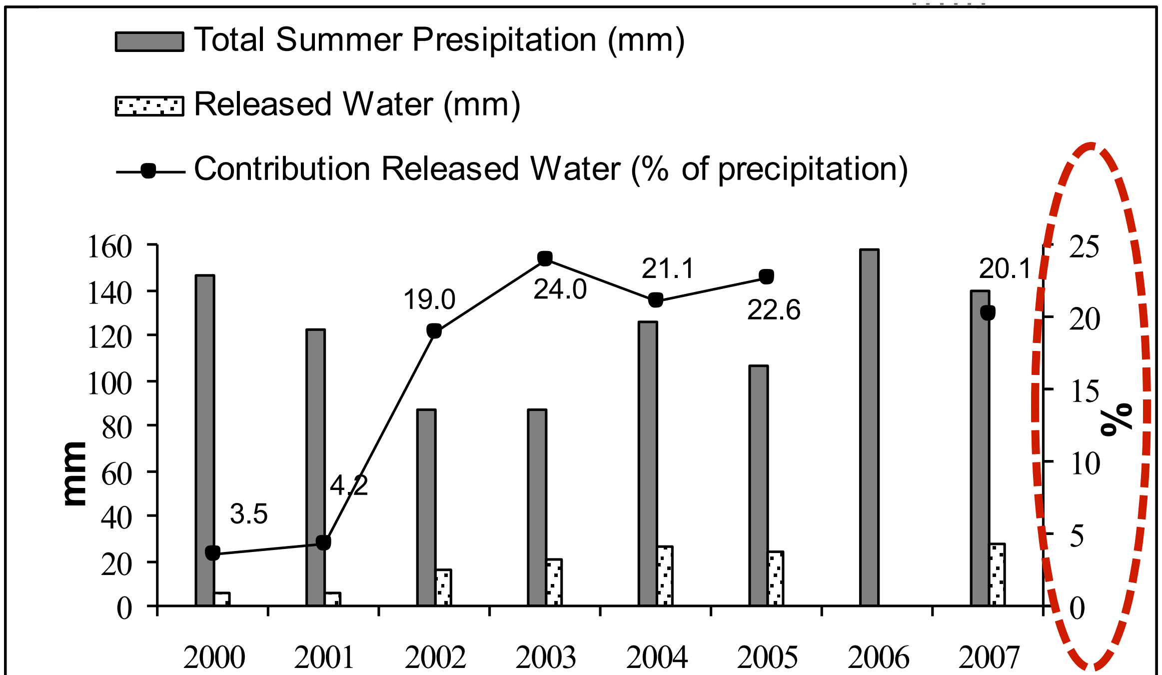
Upper Khovd River Basin on the boundary of Russia, Mongolia and China in Central Asia (Syromyatina et al. 2014)

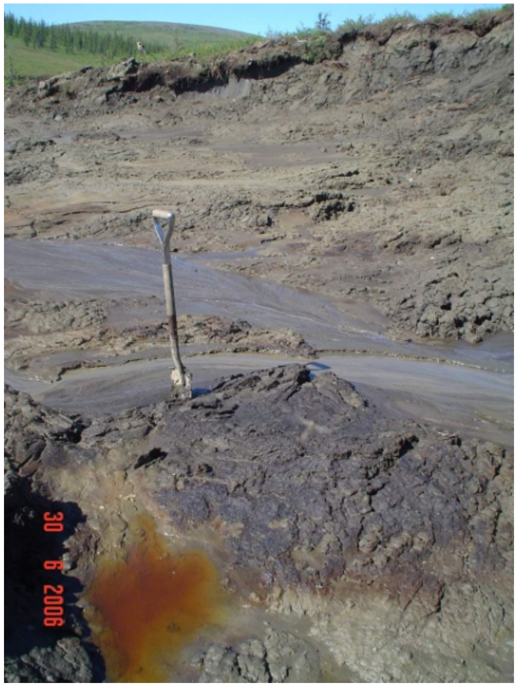
Photo by V.V. Sapozhnikov



Dynamic of water release from ice-rich transition layer (at the permafrost boundary)







Data by Davydov from Circum Polar Active Layer Monitoring (CALM) Sites in Chersky

Two possible scenarios after the permafrost thaw:

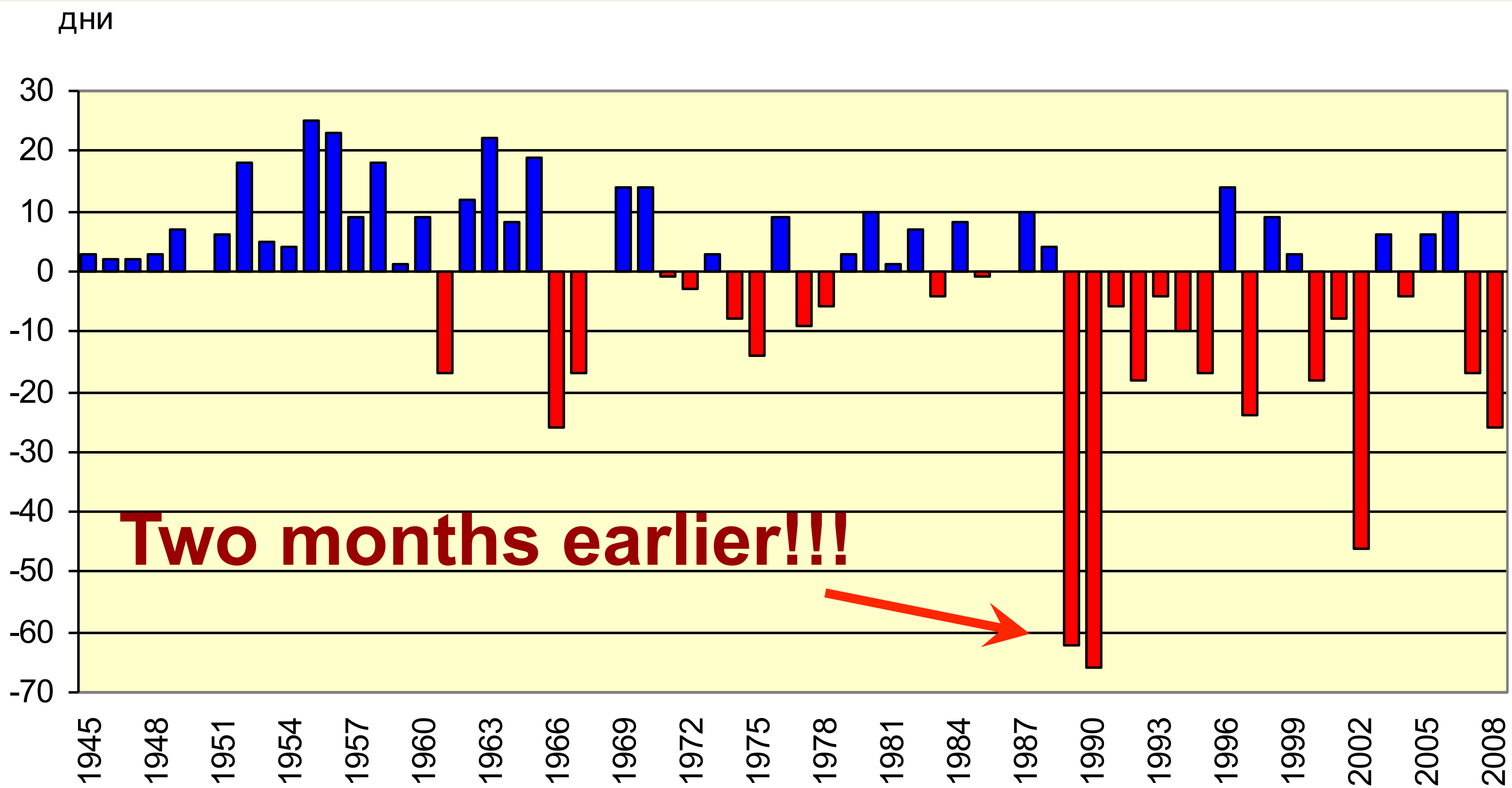
- **Wetlands**

- **Steppe (more frequent in East Siberia)** (V. Romanovsky, 2003)

NEESPI researchers addresses the issue by:

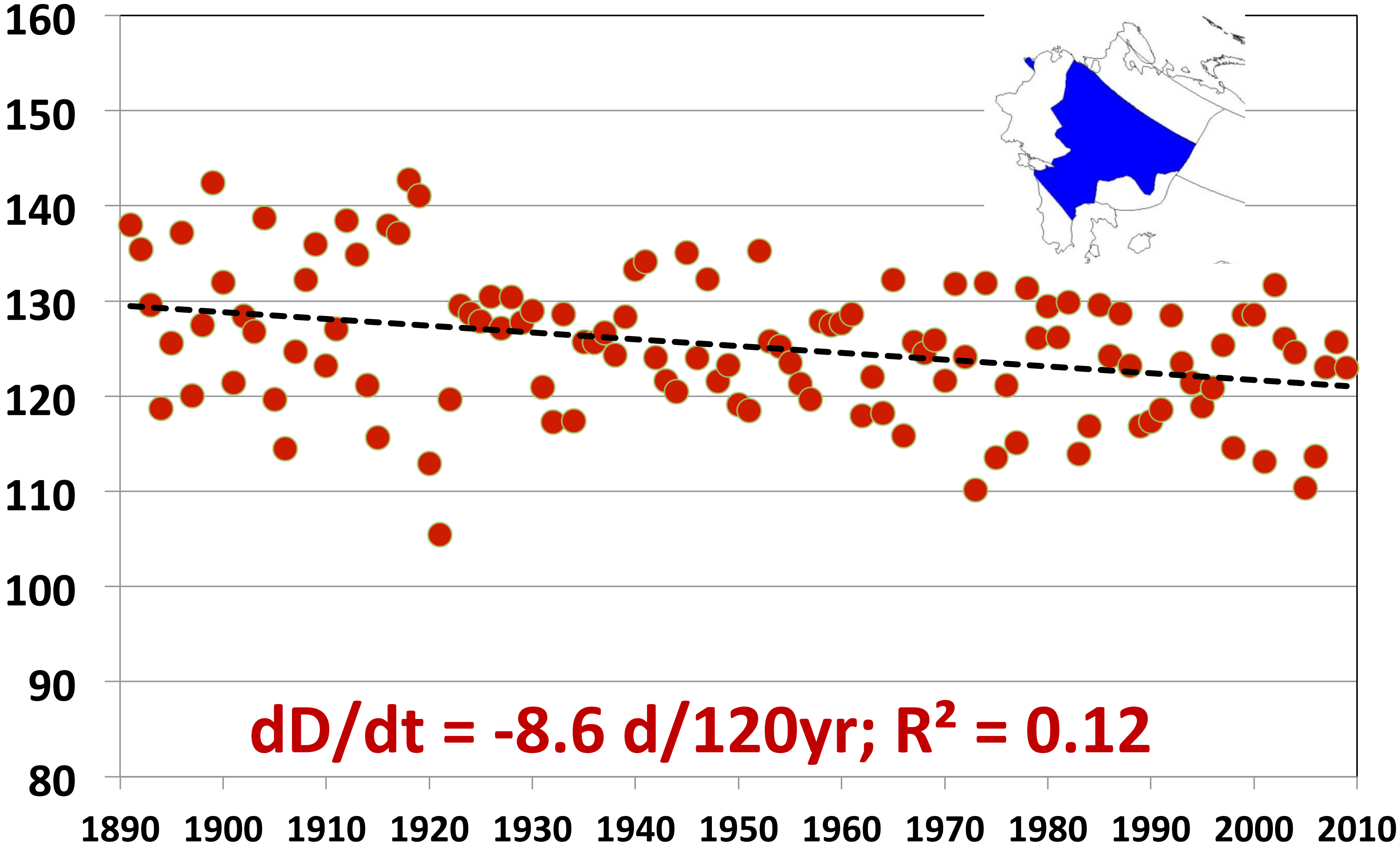
- **Monitoring (V. Romanovsky et al.; N. Shiklomanov et al.)**
- **Modeling (S. Marchenko et al.) , and**
- **Projections (Zhuang et al.).**

Anomalies (days) of the spring dates of daily surface air temperature transition through 0°C from the mean long-term values in central Belarus

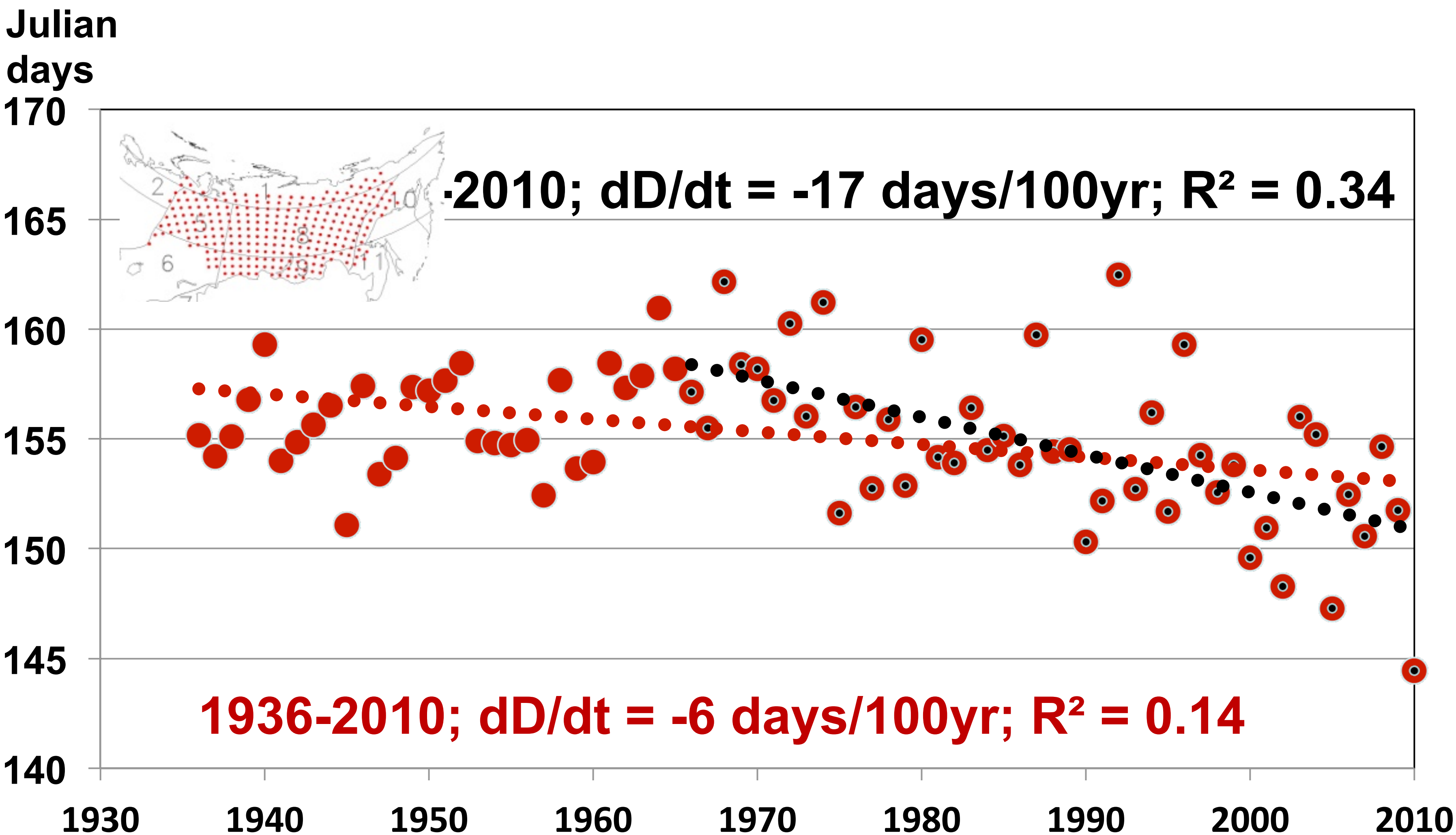


Elena V. Komarovskaya, 2009; Personal communication

Dates (D, Julian days) when vegetation season starts, Julian day in European Russia south of 60°N

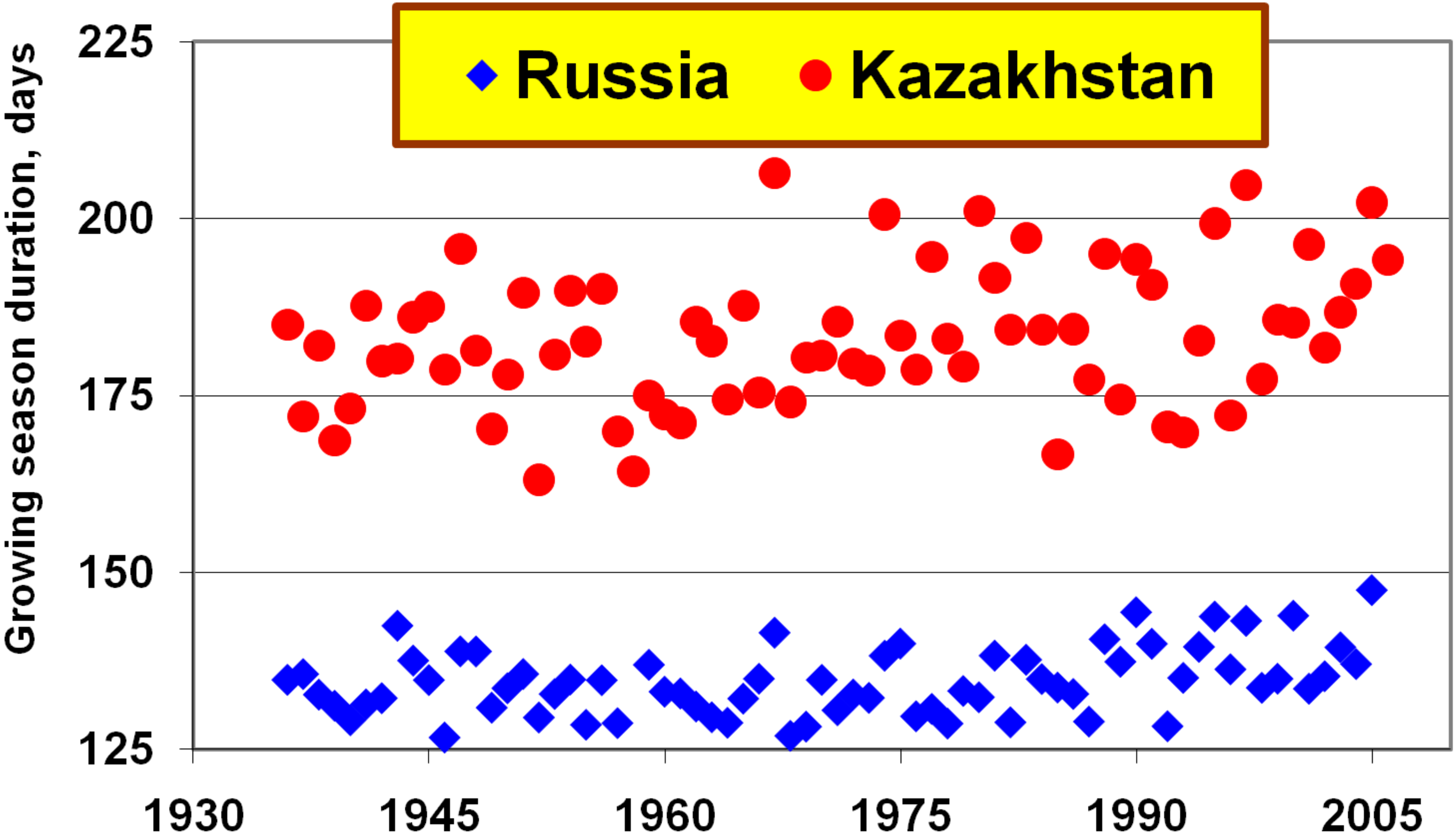


Begin of the no-frost season in Siberia



Dates when daily minimum temperature sustainably crosses 0°C in spring and remains above it

Duration of the growing season area-averaged over Russia and Kazakhstan



During the past 70 years, significant increase by 6 to 11 days (or by 5% to

Agriculture droughts

- Historical evidence
- Water vapor transport inside the continent
- Changes in the liquid precipitation distribution
- Prolonged no-rain episodes
- Drought indices
- Modeling of prolonged dry conditions

Russian Yearbooks (Letopisi) documented dry years, droughts, large fires (as well as early and late frosts, floods, poor harvest, unusually cold and mild winters, early springs, etc.).

- 11th century: Kiev, Novgorod, Gustyn, Moscow, Ustyug, Nikon Summaries
- 12th century: Kiev Summaries
- 13th century: Kiev, Tver, Ustyug, Pskov, and Troitsk Summaries
- 14th century: Ustyug and Troitsk Summaries
- 15th and 16th centuries: Ustyug Summaries

Examples of Letopisi Reports (first in 994 AD)

- **1063** … **"In Novgorod, The Volkhov River runs in the opposite direction for 5 days"…**
- **1124 … "died everybody and darkness and fear was everywhere" (from fires)**
- **1161 "…clear skies, hot weather, and dryness all summer, and wheat burned"…**
- **1193 " …"drought from May to mid-August"…**
- **1372-1374 "**… **it was so dry that unbearable smoke from fires of swamps, forests, and fields was everywhere, and spots on Sun were seen by bare eyes, and birds were falling on the ground, and water in rivers and lakes smell with smoke, and fish was dying"…**

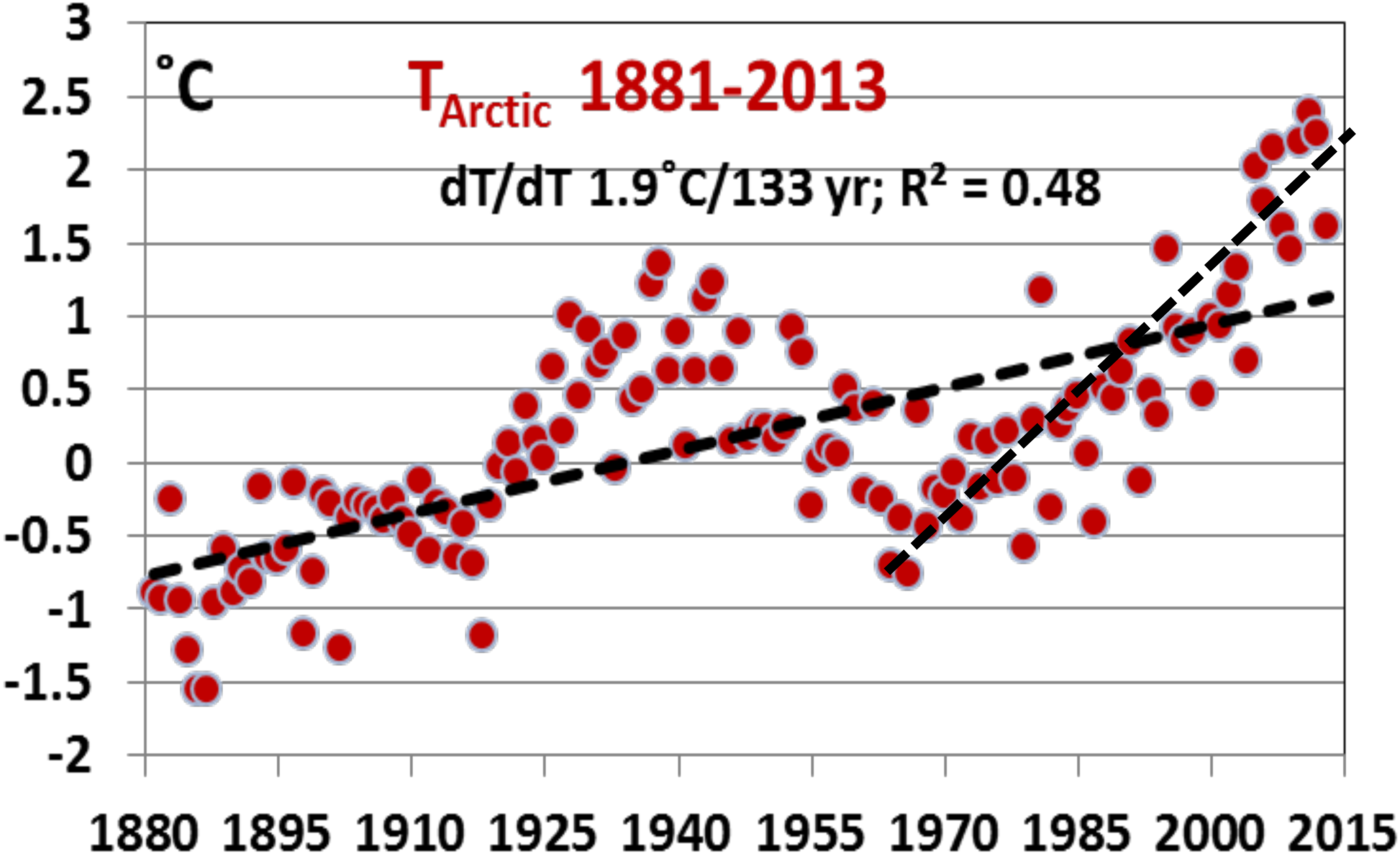
Generally, over Kiev Rus' (the area of present northern Ukraine, Belarus, and central part of European Russia), in the 11th century summers were mostly warm and dry.

However, on this background, the 1092 summer *was extremely dry*.

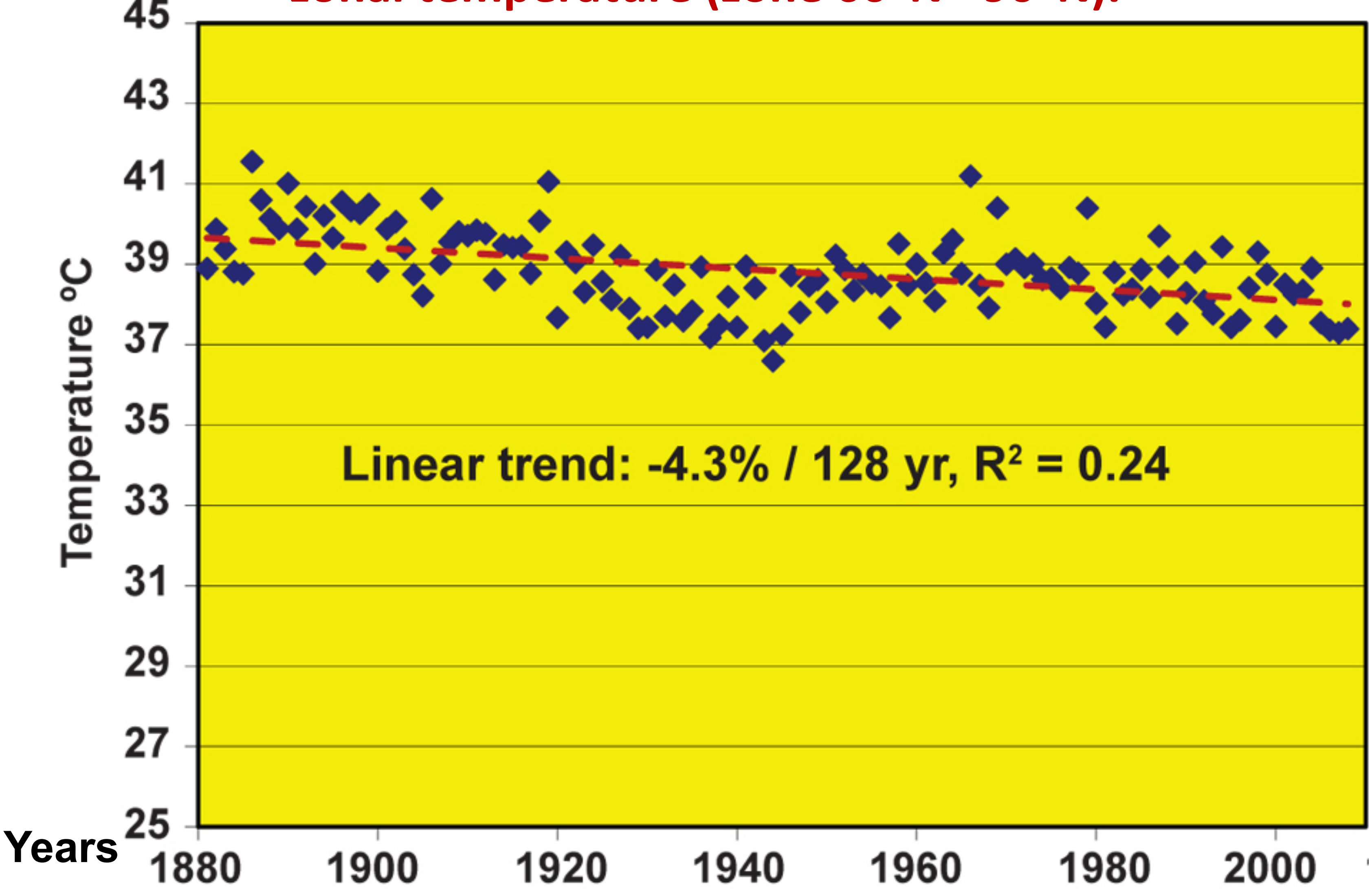
Letopisi witness:

- Clear skies throughout the entire summer
- Prolonged period without rainfall
- Extremely hot weather
- Widespread naturally caused forest fires
- Naturally caused peat bog fires (let us recall **that at that time wetlands were undisturbed** which is opposite to the present state of the affairs)
- Fields & pasture were "fired out" => land cover dried out
- In Kiev, in the following autumn and winter more than 7 thousand (of total 50,000) died from starvation. Losses beyond the capital city were (in percent) even higher.
- This unfortunate development was followed with widespread epidemics (of undefined type).
- In Moscow: "Huge circle was in the sky in this summer, a drought was so strong that soil was burned and many forest and swamps were set in fire themselves"

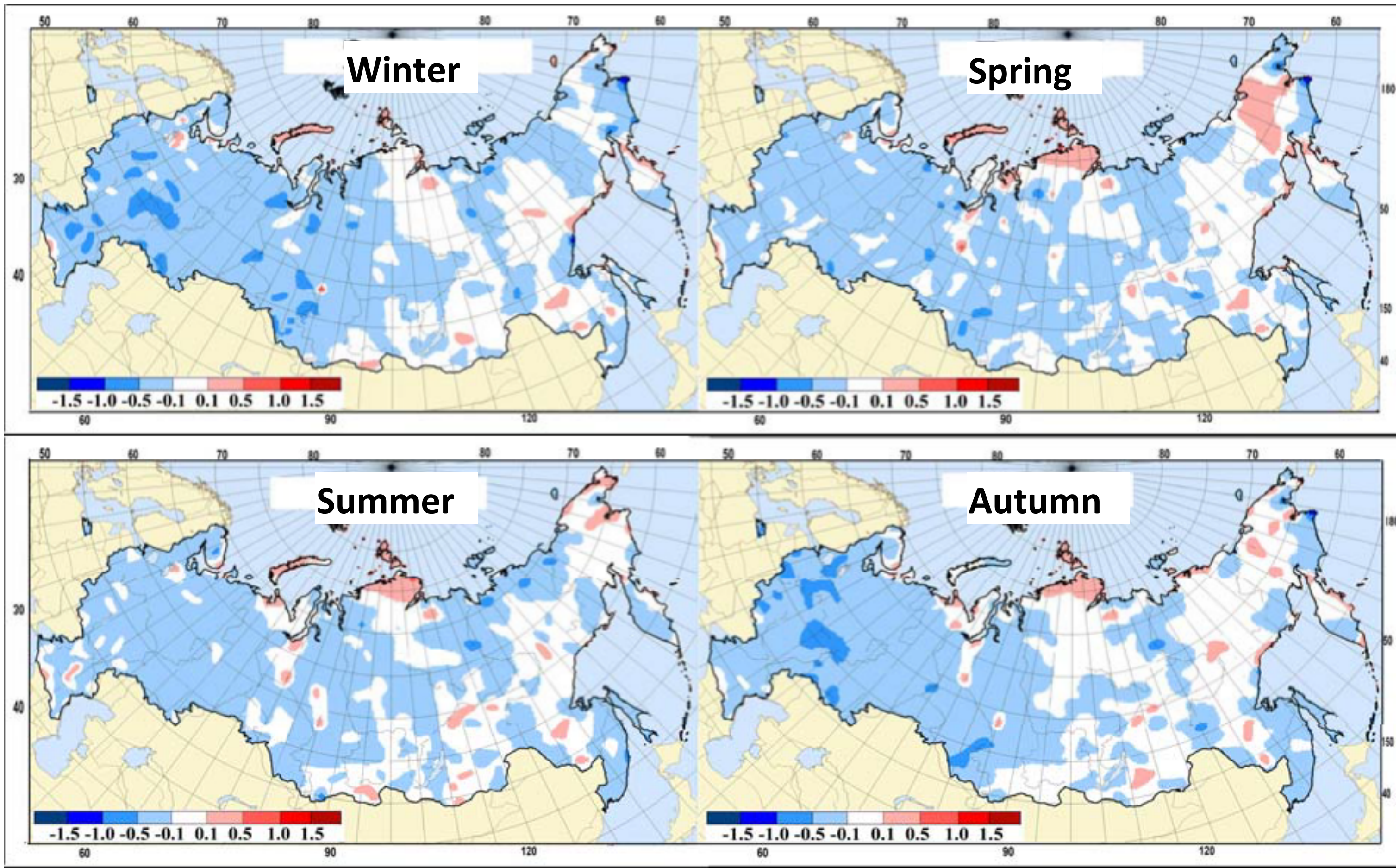
Annual surface air temperature anomalies area-averaged over the 60°N - 90°N latitudinal zone



Decrease in winter surface air temperature meridional gradients over the Northern Hemisphere estimated as a difference of tropical mean zonal temperature (zone 0°- 30°N) and polar mean zonal temperature (zone 60°N - 90°N).



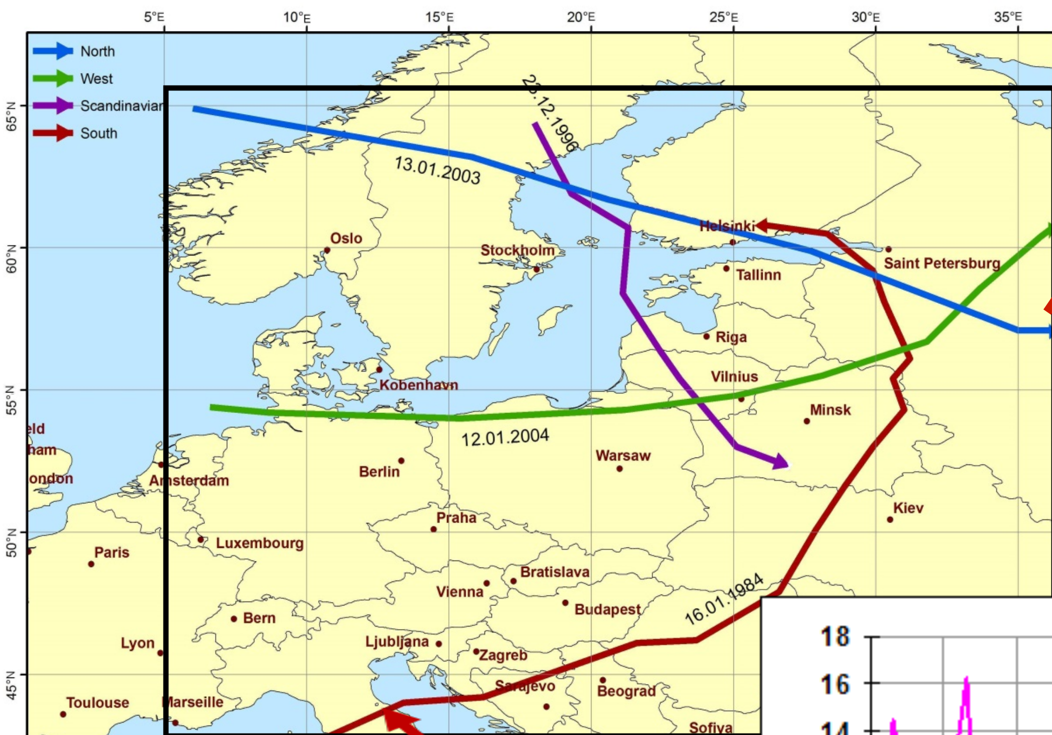
Wind Speed Trends over Russia, 1977-2011, Bulygina et al. 2013



Seasonal wind speed trends, in m (sec 10 yr)$^{-1}$

Shaded areas have statistically significant trends

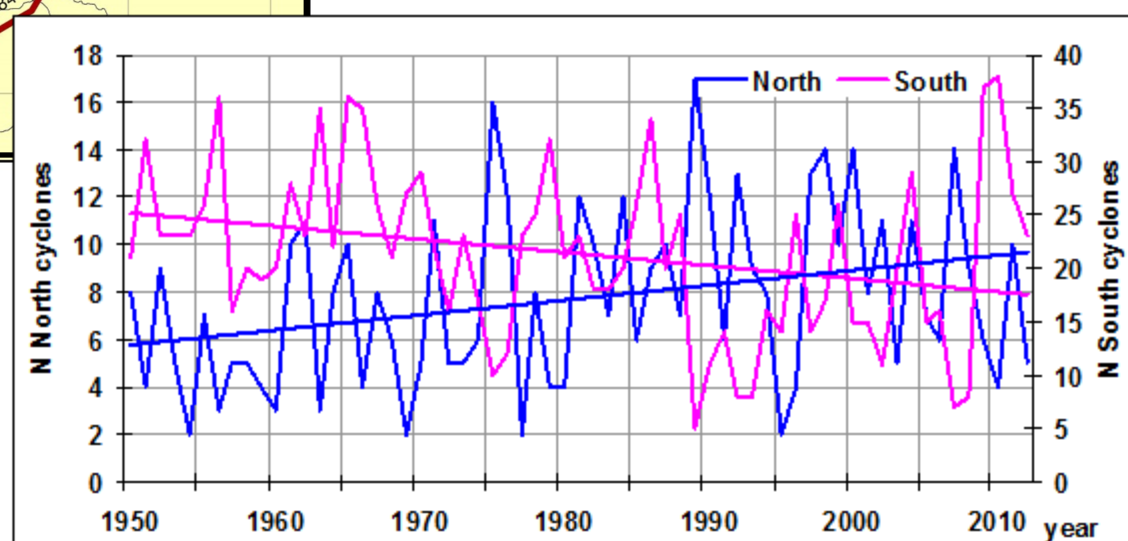
Dynamics of different types of winter extratropical cyclones sorted by their origination was linked to spring & winter runoff over Belarus



Increase in the frequency of "North" cyclones during the past 60 years, caused warmer winters (more thaw, snowmelt, and winter streamflow) and indirectly reduced peak spring streamflow.

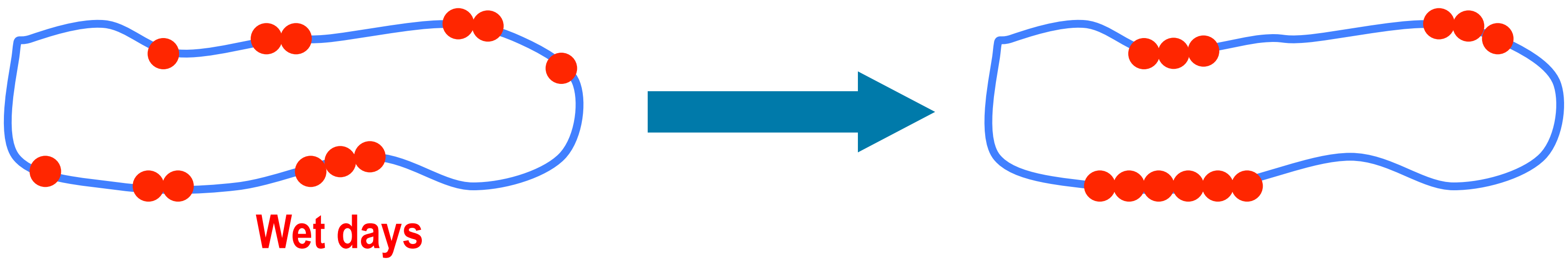
Partasenok et al. (2014, *Environ. Res. Lett.*)

Reduction of the number of winter storms brought by "South" cyclones also contributed to reduced peak spring streamflow.

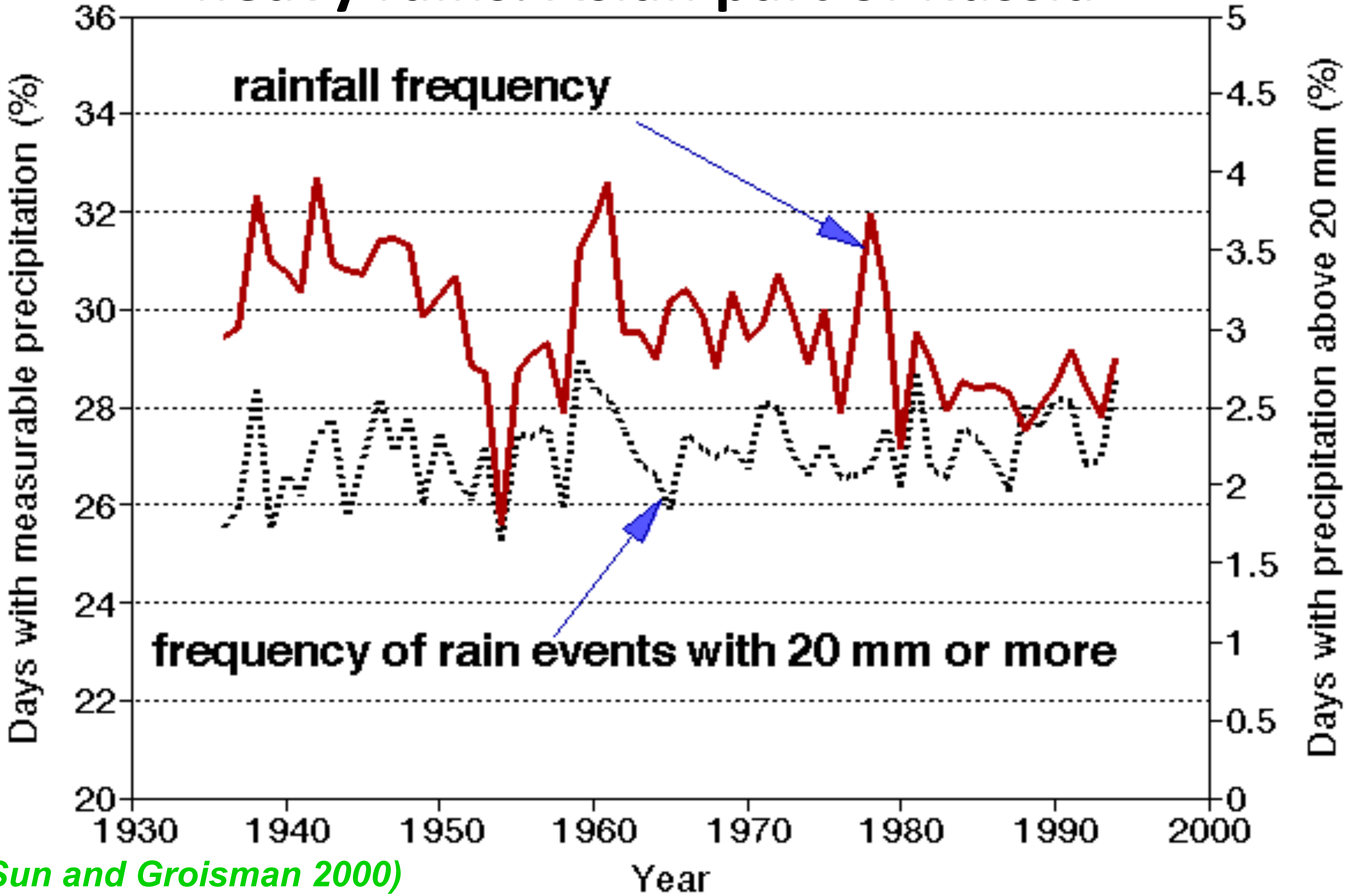


This kind of redistribution of precipitation events has been documented over most of northern extratropics (from southern Canada and USA to Europe, Russia, and Japan)

Beads with a fixed number of stones illustrate how we can have in the same region simultaneously increases in prolonged Wet Day and Dry Day Periods even with unchanged precipitation totals (design by O.G. Zolina).

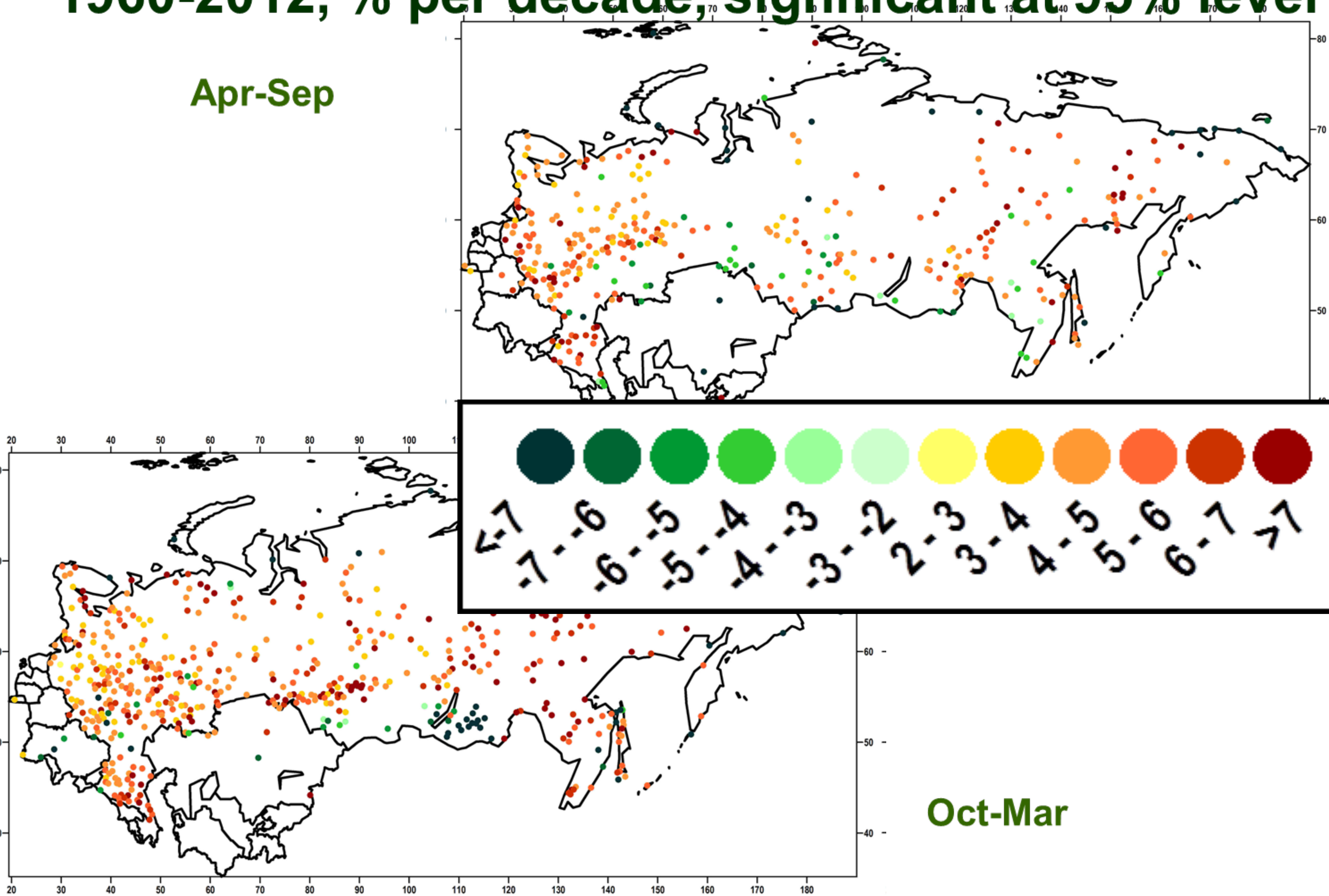


Summer frequency of rainy days and days with heavy rains. Asian part of Russia



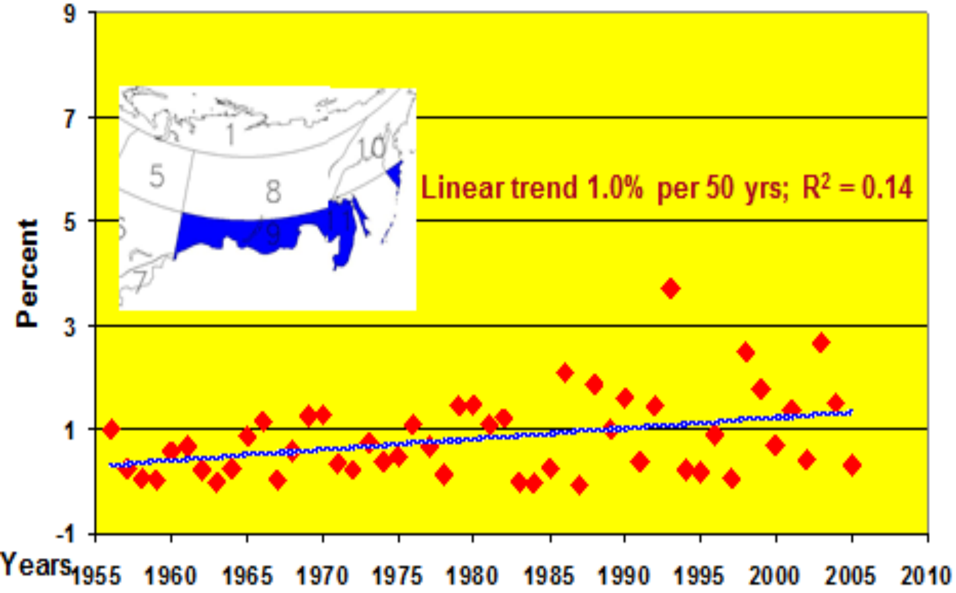
(*Sun and Groisman 2000*)

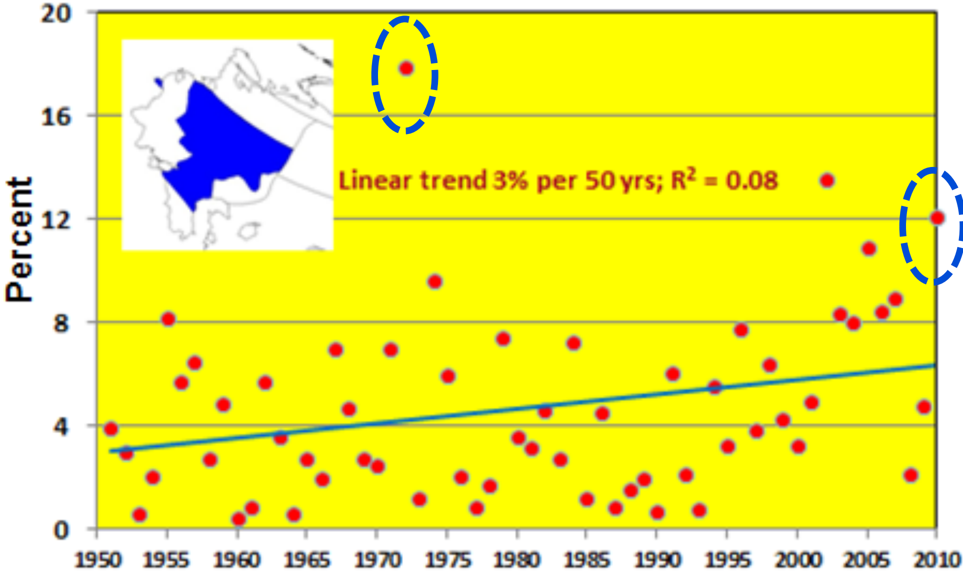
Russia: Linear trends in heavy precipitation (95%), 1960-2012, % per decade, significant at 95% level



Dry episodes above 30 days during the warm season over (left) Asian Russia east of 85°E and south of 55°N and (right) European Russia south of 60°N.

Both linear trends are statistically significant at the 0.05 level.

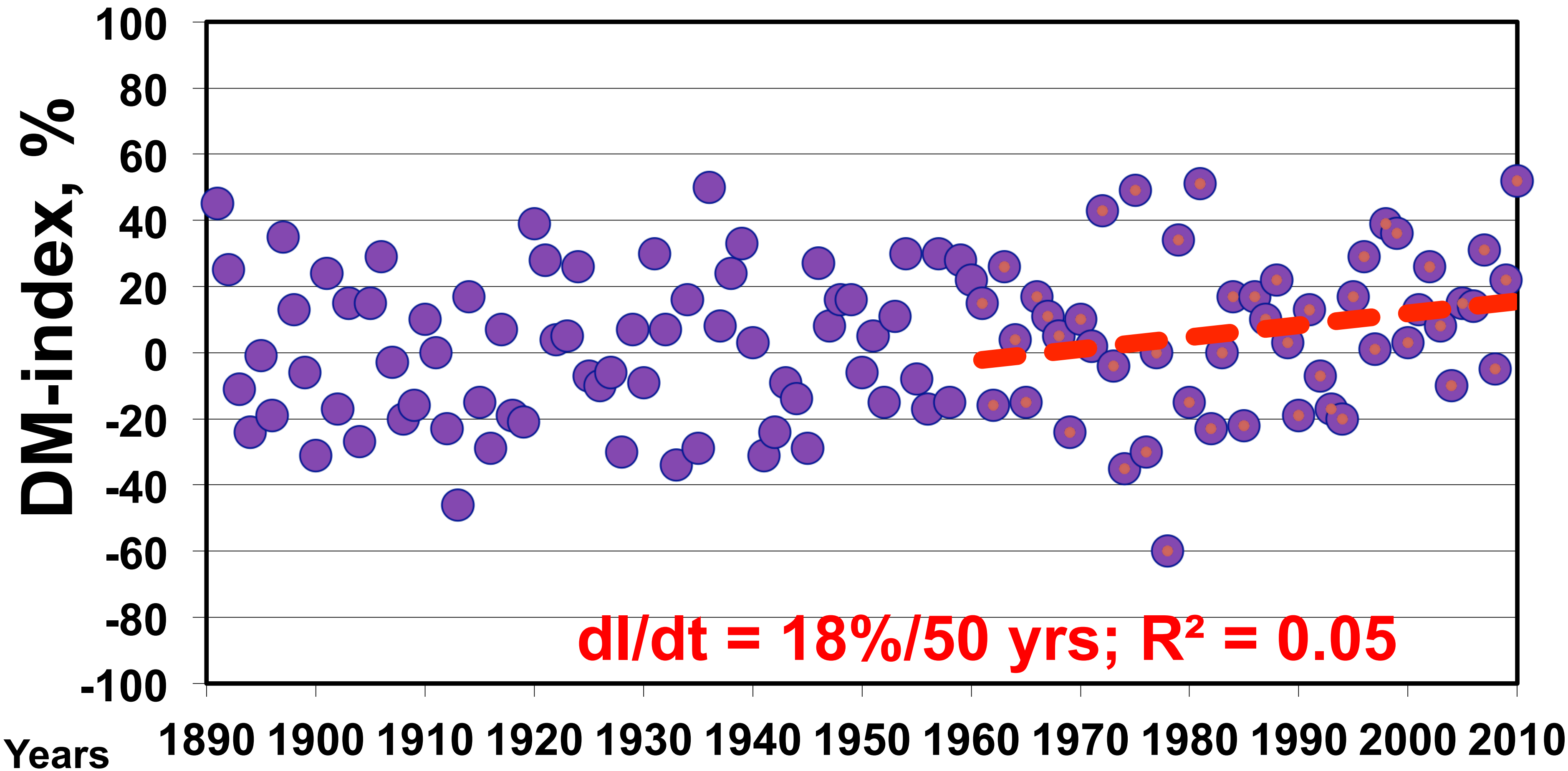




Groisman et al. 2013

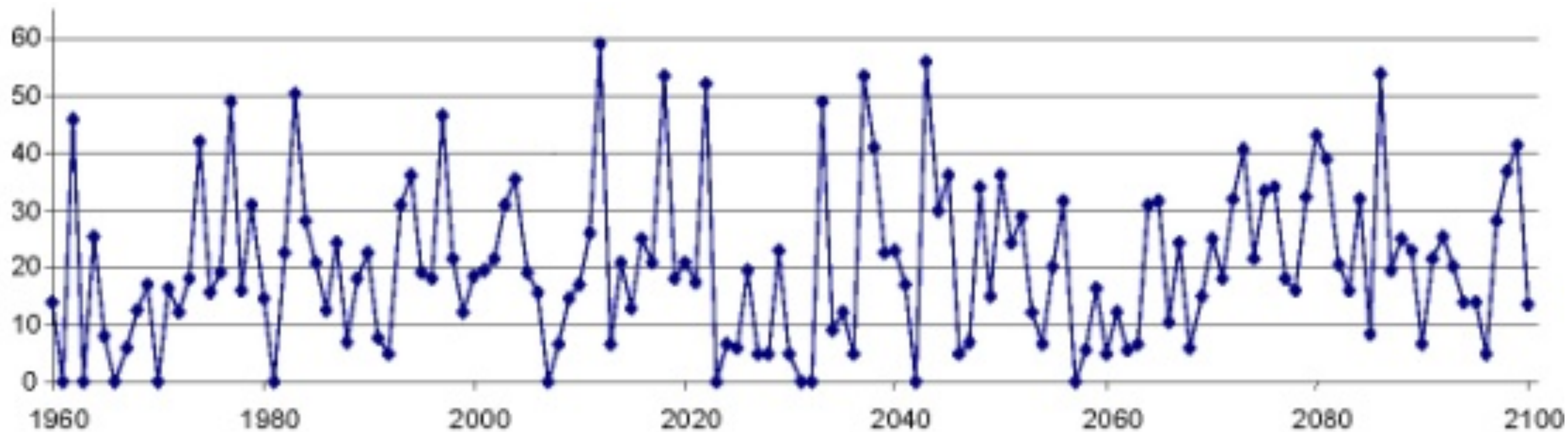
Agricultural regions of European Russia, Belarus, and Ukraine. May – July Drought Index.

Meshcherskaya and Blazhevich, 1997, updated to 2010



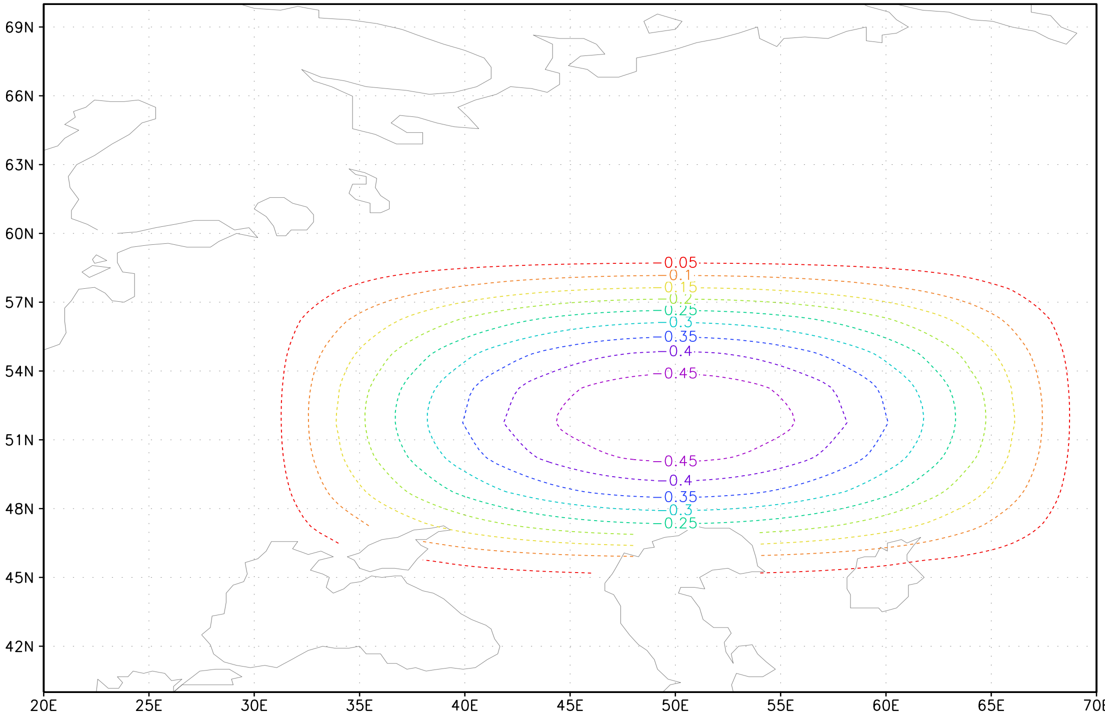
Areas with excessively dry conditions minus areas with excessively wet conditions, (% of total area)

Summer blocking-days number in the NH Euro-Atlantic sector (60W-60E) from IPSL-CM4 GCM simulations with SRES-A2 scenario for the 21st century (Mokhov et al. 2011)



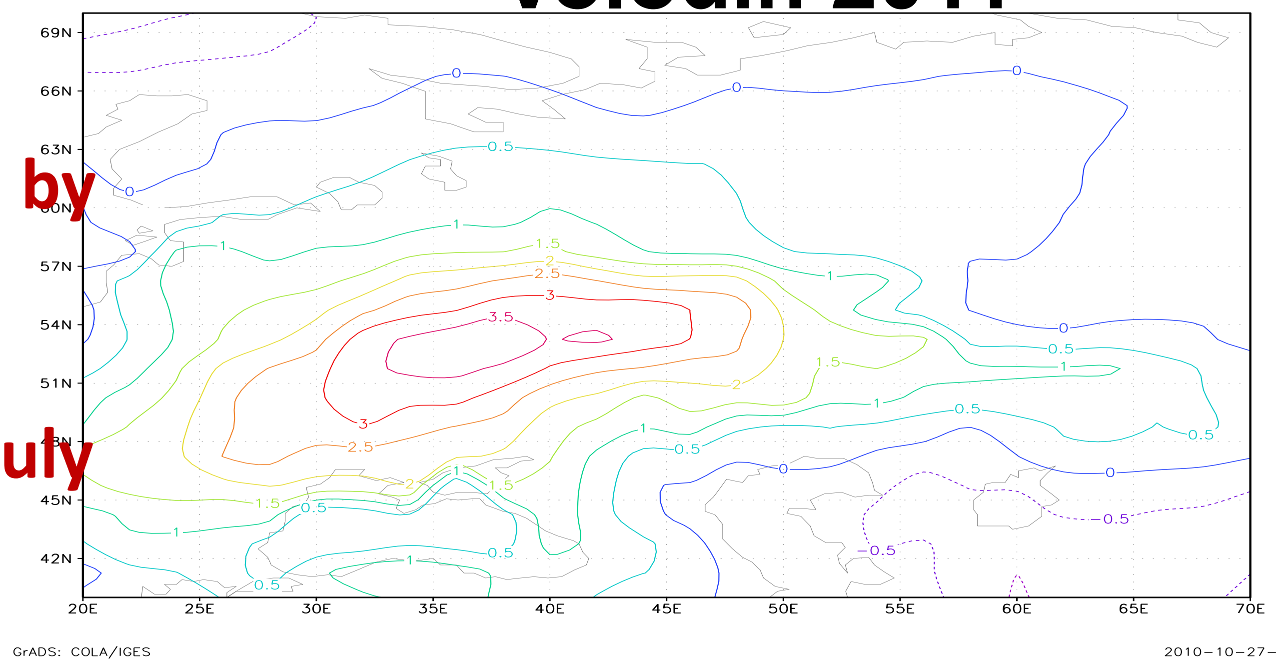
Note a substantial increase of years with prolonged (above 50) blocking-days summers in the 21st century (7 versus 1 in the 1951-2000 period).

- **Soil moisture anomalies in the upper 50 cm over Russia in the end of June 2010**

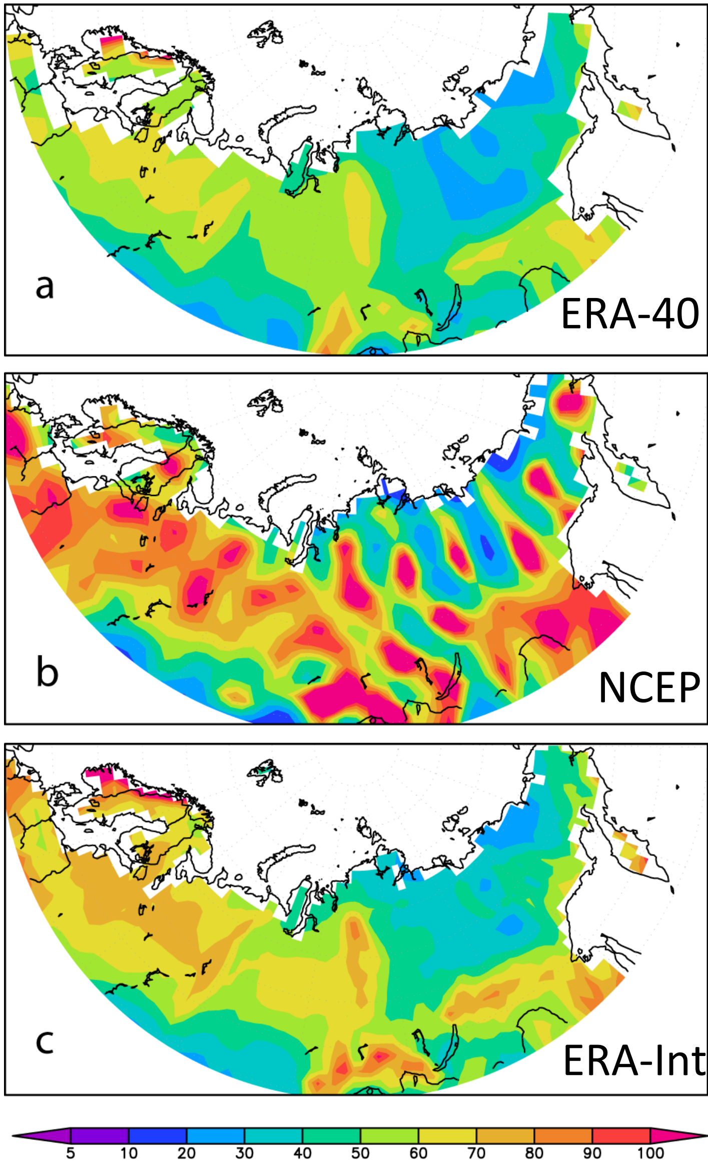


GCM experiment, Volodin 2011

- **Temperature anomalies caused by soil moisture anomalies over central Russia in July 2010**

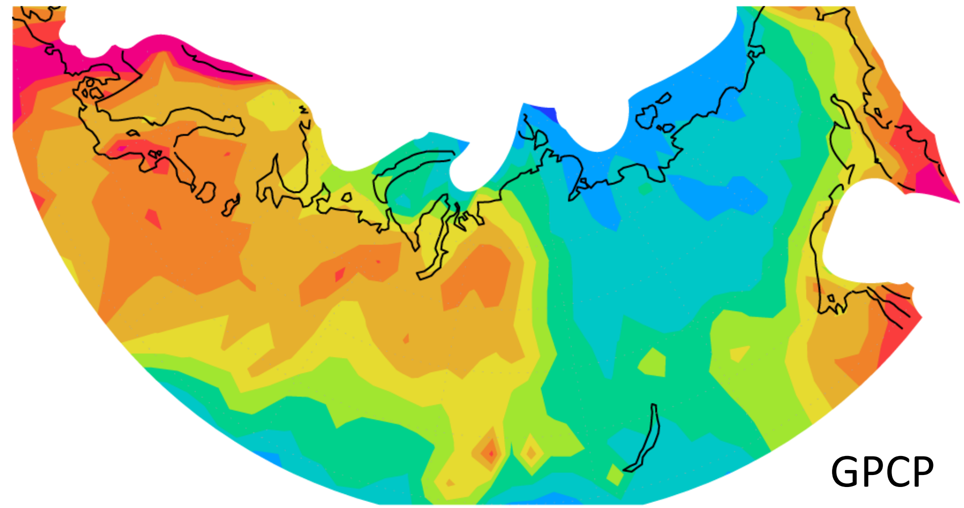


How good are reanalyses based on sparse in situ networks?



This scale is in cm

Annual mean precipitation



Color Scale:

Blues: from 100 to 300 mm

Greens: from 300 to 600 mm

Yellow/Gold: from 600 to 800 mm

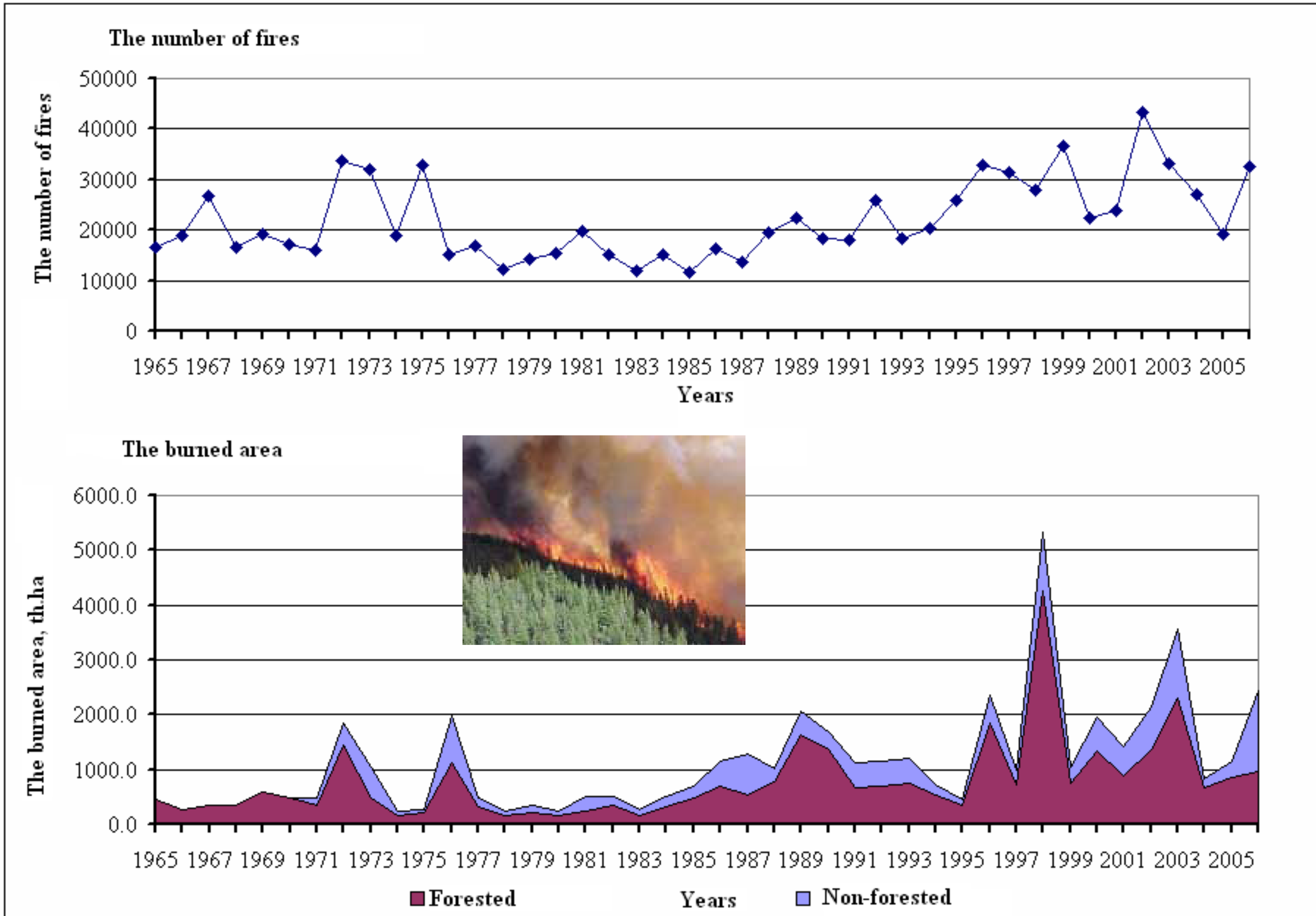
Reds: from 800 to >1,000 mm

Cherry et al. 2013

Wild fires

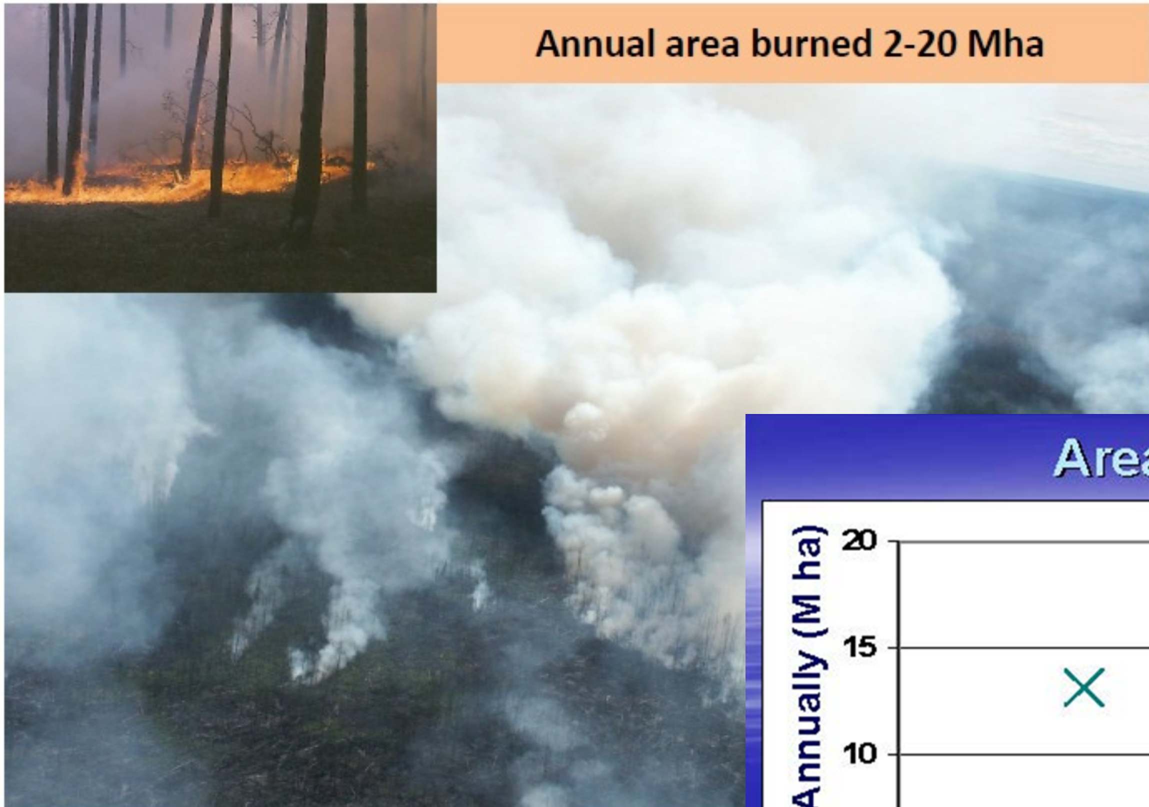
- Monitoring (in situ, air-borne, and satellites)
- Long-term time series of forest fire indices

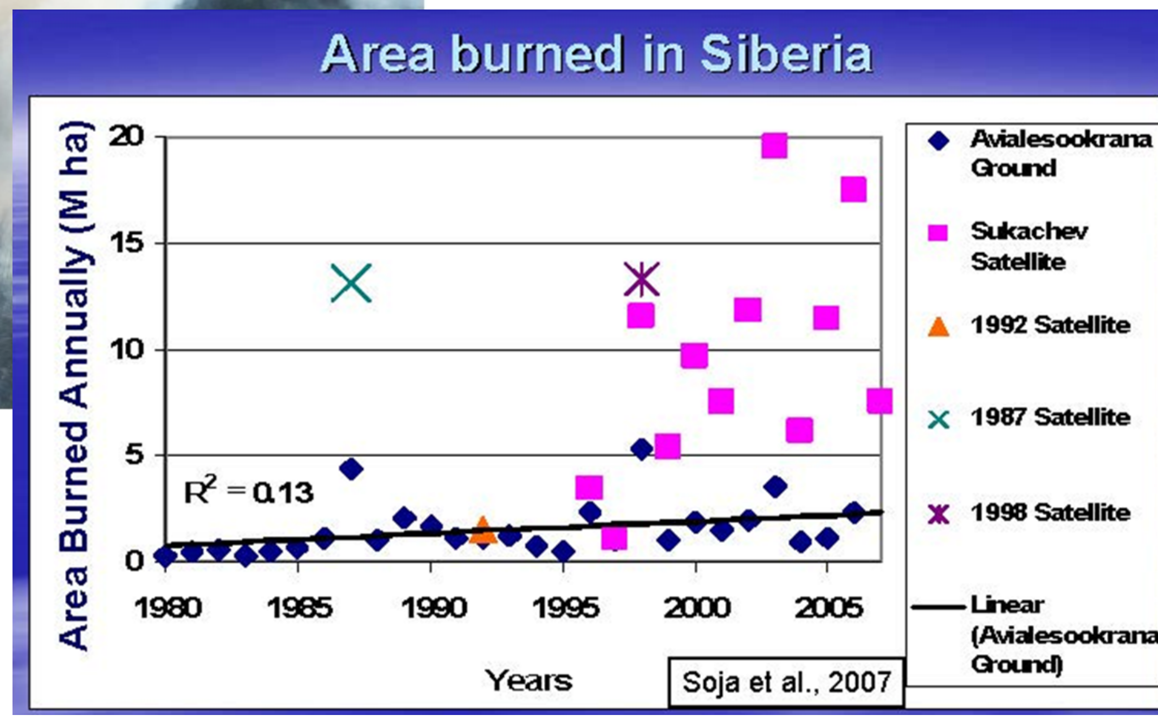
DYNAMICS OF FIRES NUMBERS AND BURNED AREA (PROTECTED TERRITORY OF RUSSIA)



Korovin and Zukkert 2003, updated

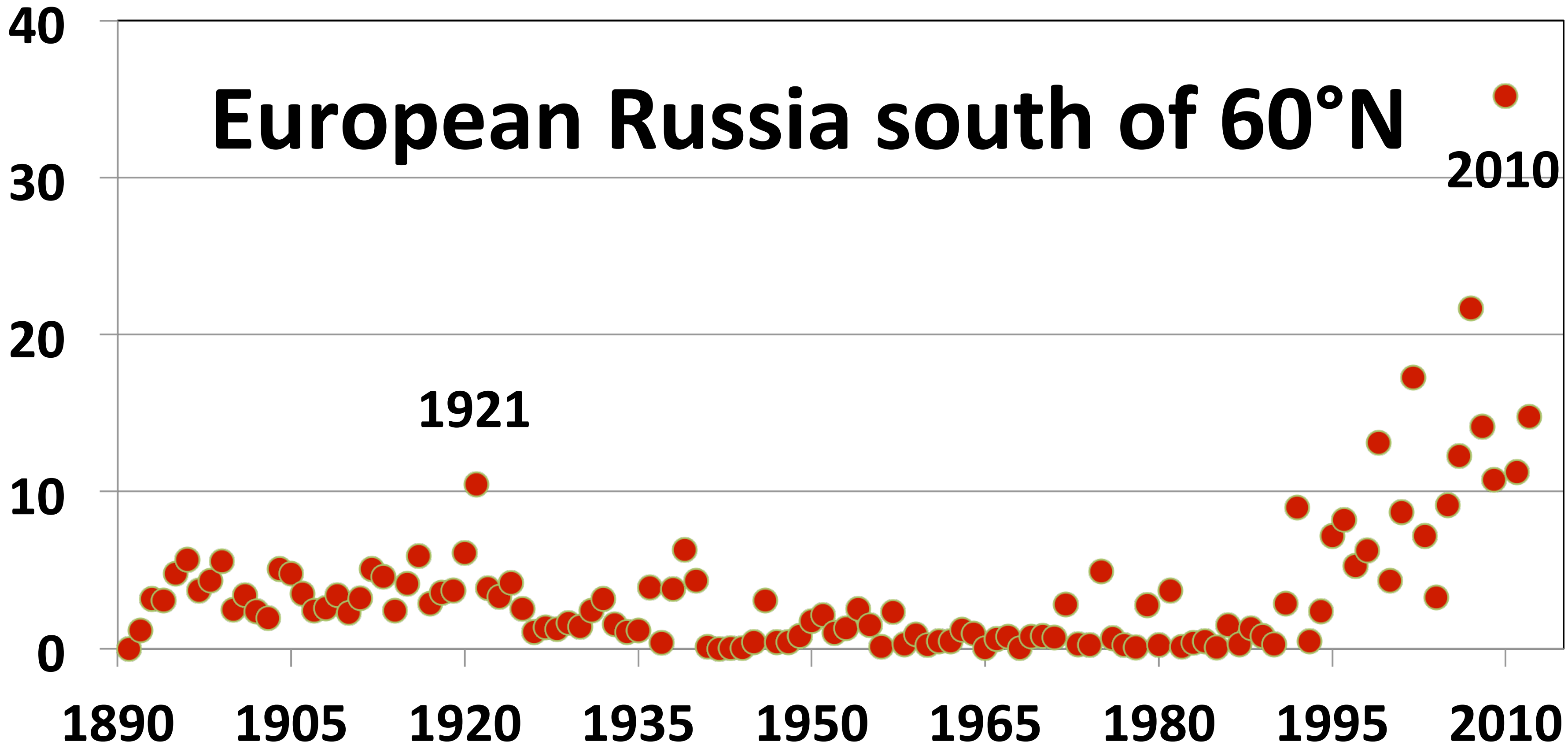
Fires in Boreal Forest of Russia





In Siberia, 9 of the last 12 years have resulted in extreme fire seasons (Soja et al. 2007)

Updated KBDI results for European Russia

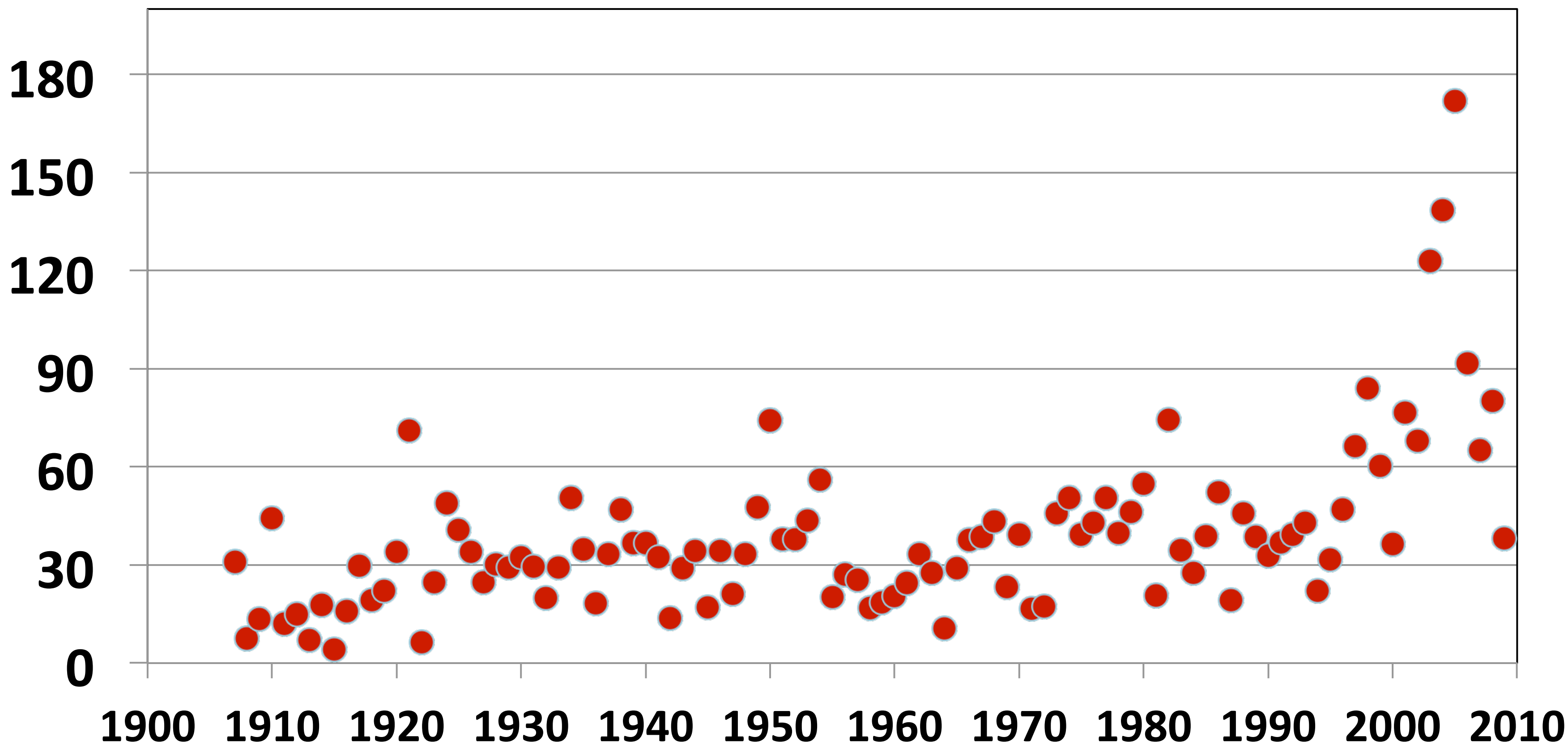


Days with KBDI in the upper 1% of their summer climatological values

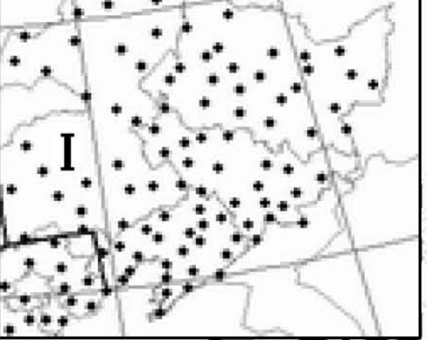
Potential Fire Danger Increase

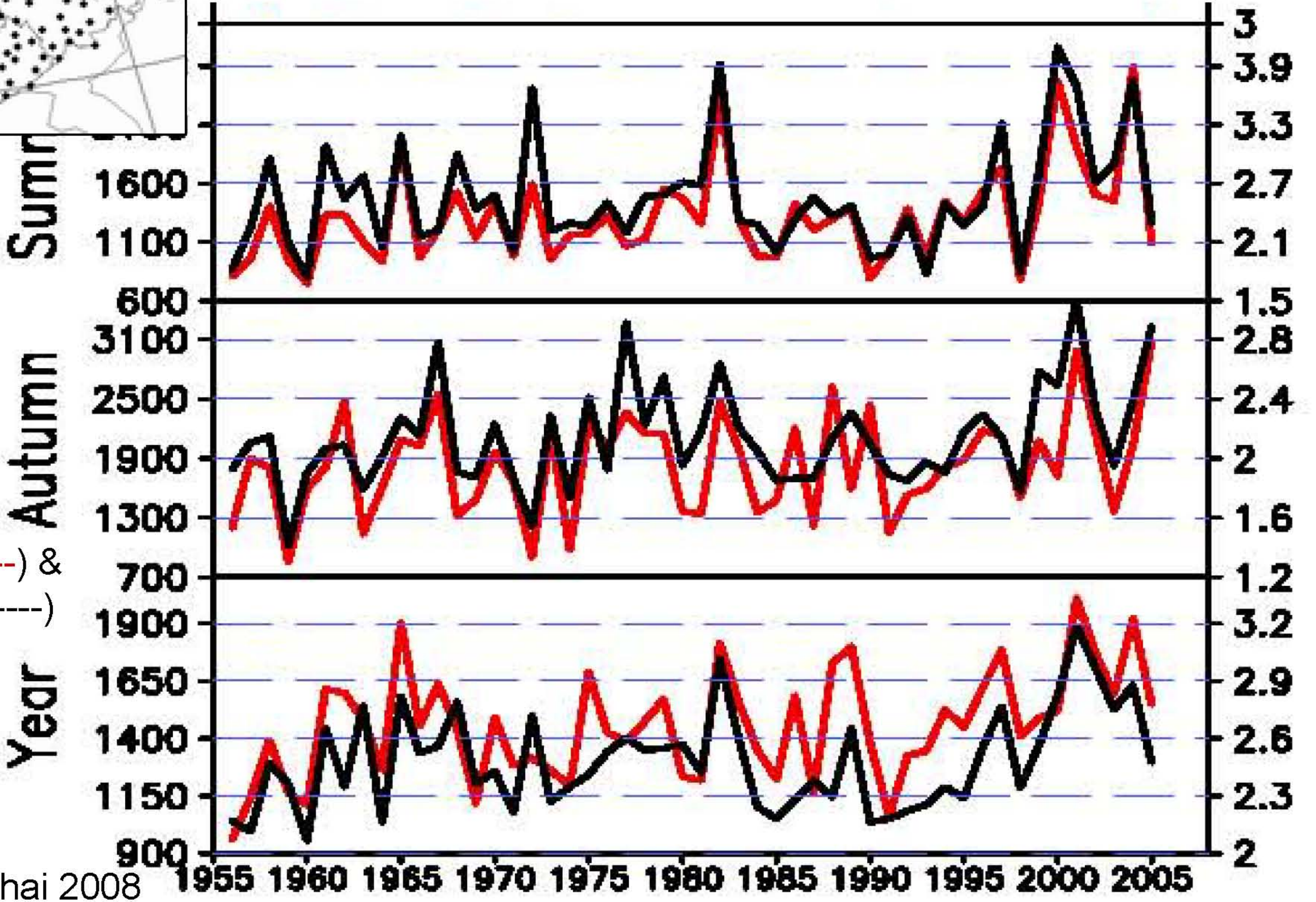
Annual number of days with KBDI > upper 10%-ile

Russian Far East south of 55°N



Seasonal and annual changes in forest fire indices in northeastern China





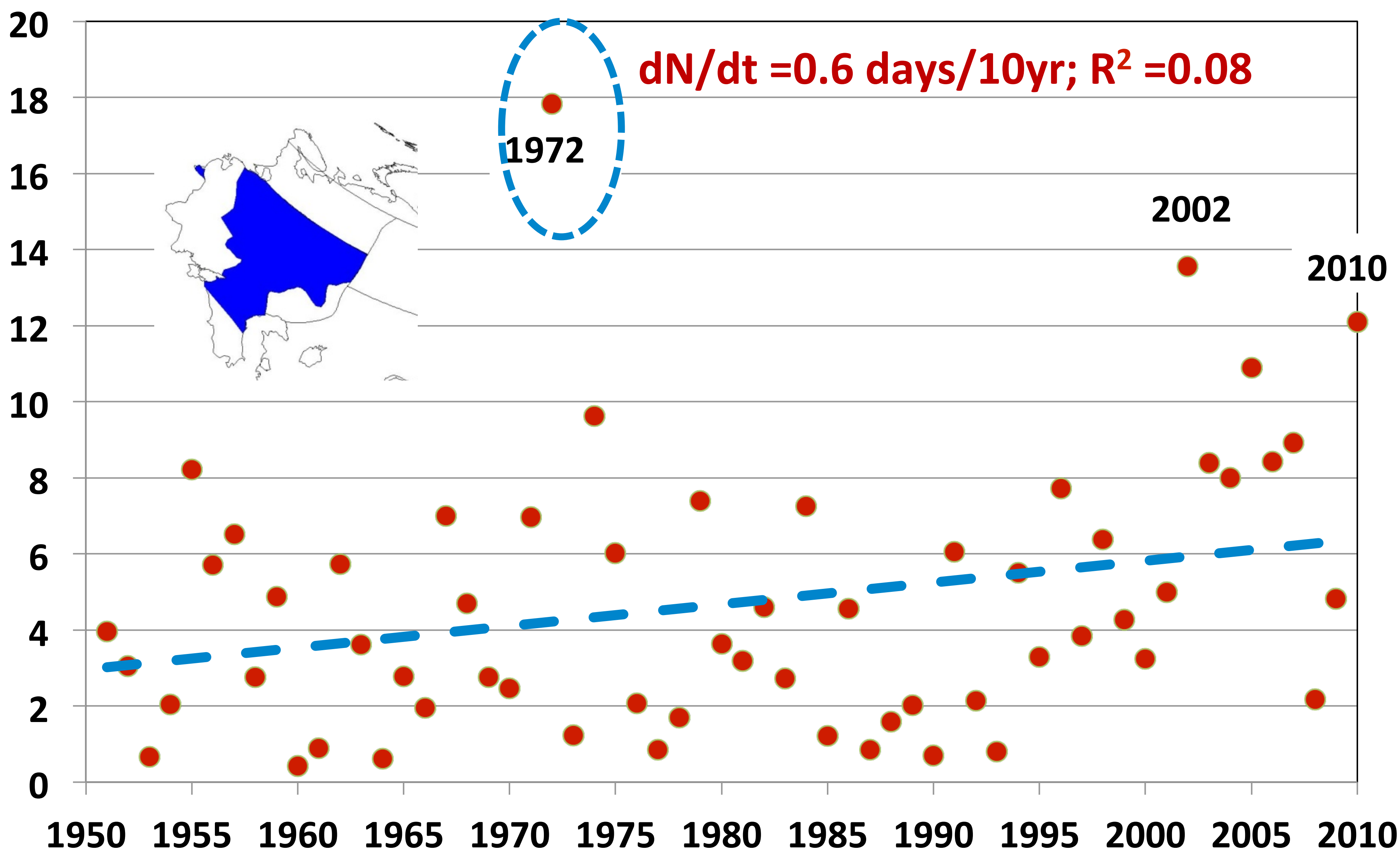
MNI (----) &
FFDI (-----)

Niu & Zhai 2008

Heat waves

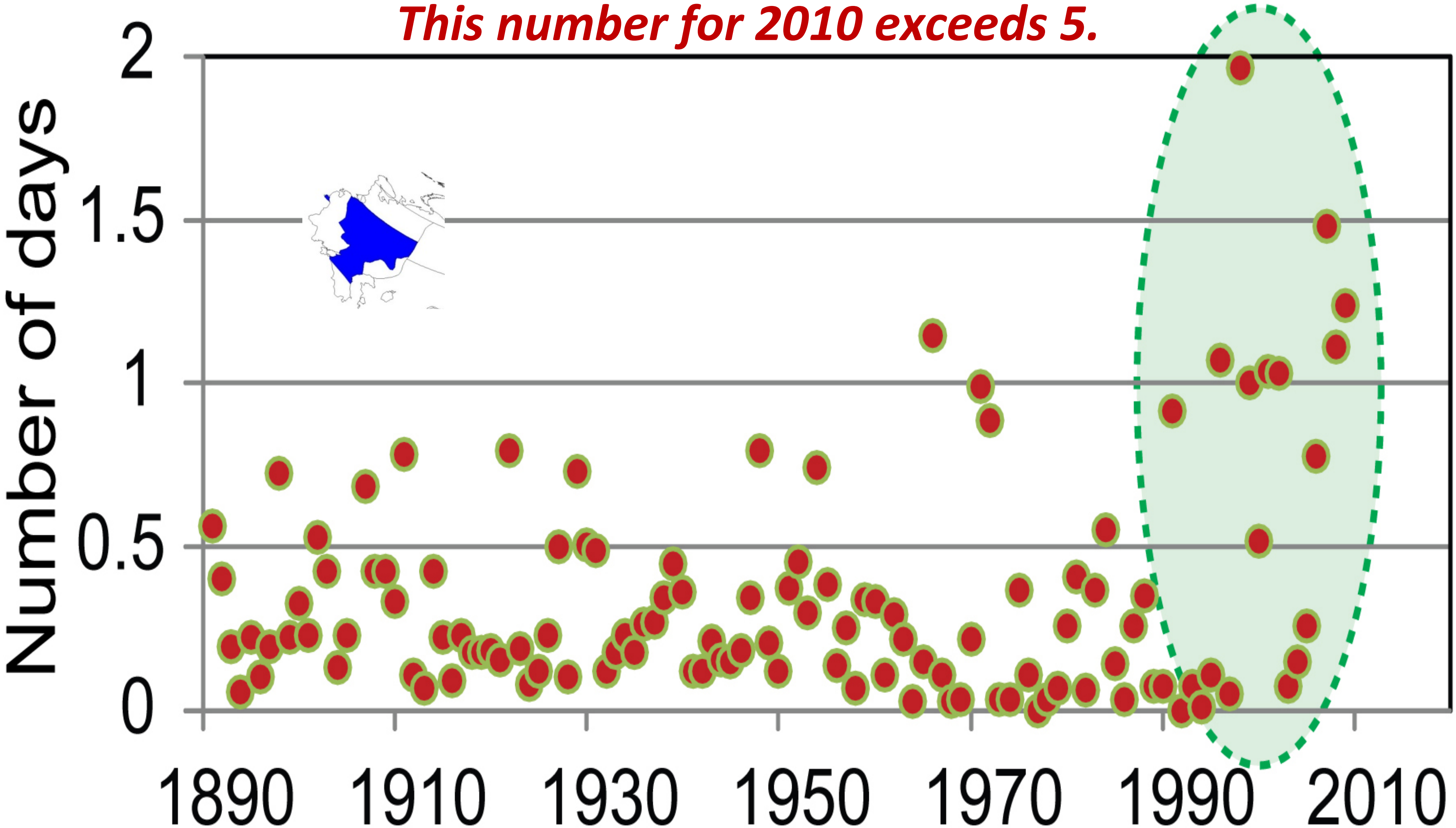
- Drier springs as precondition for heat wave
- Extreme temperature outbreaks
- Prolonged no-rain episodes
- Instability of the cyclonic weather arrival

Dry episodes above 30 days during the warm season over European Russia, south of 60°N, 1951-2010

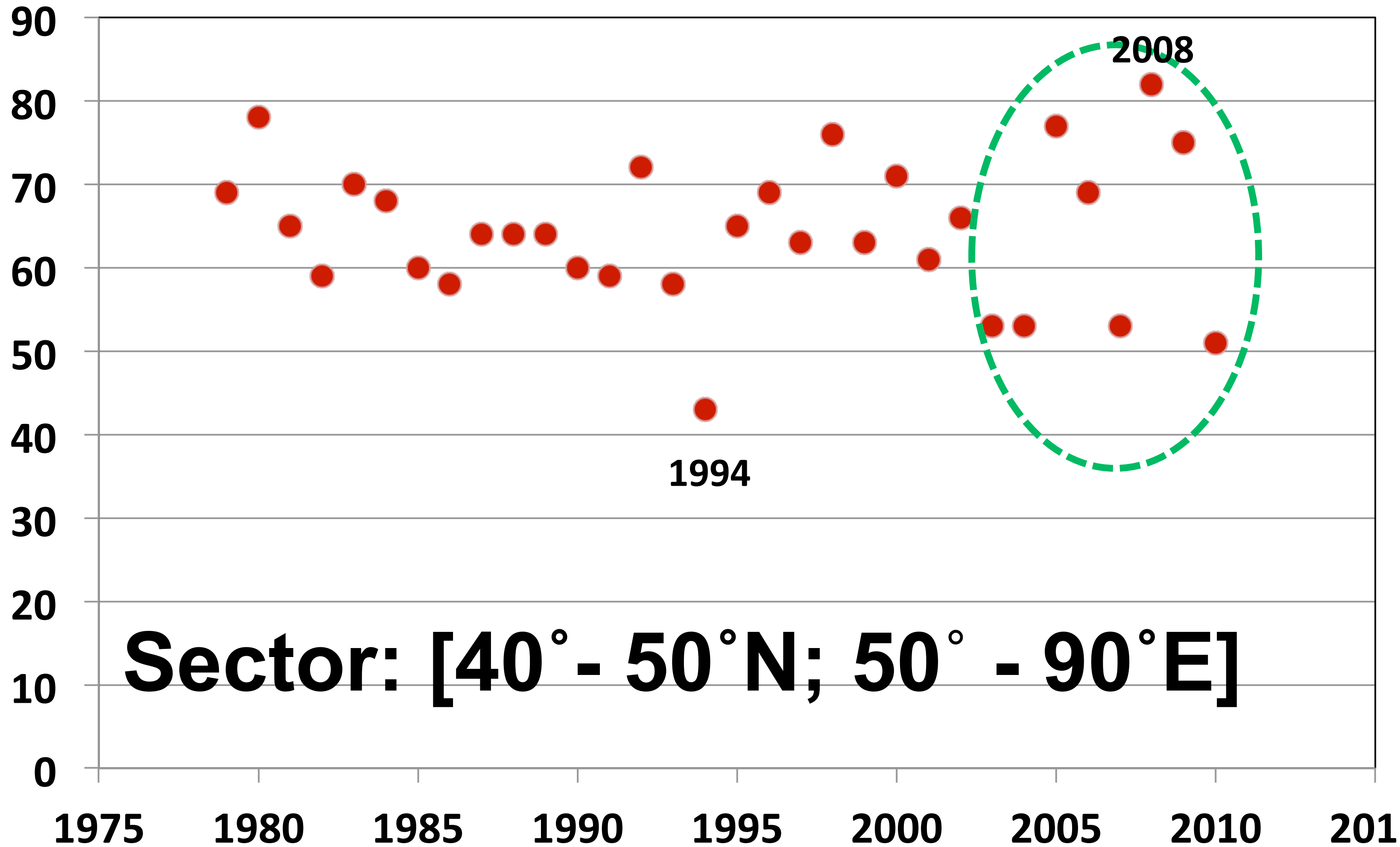


Number of days with "hot" nights (when minimum daily surface air temperatures remain above 23.9°C) area-averaged over European Russia south of 60°N during the 1891-2009 period.

This number for 2010 exceeds 5.



Summer (JJA) number of cyclones over Central Asia according to the ERA-interim Reanalysis

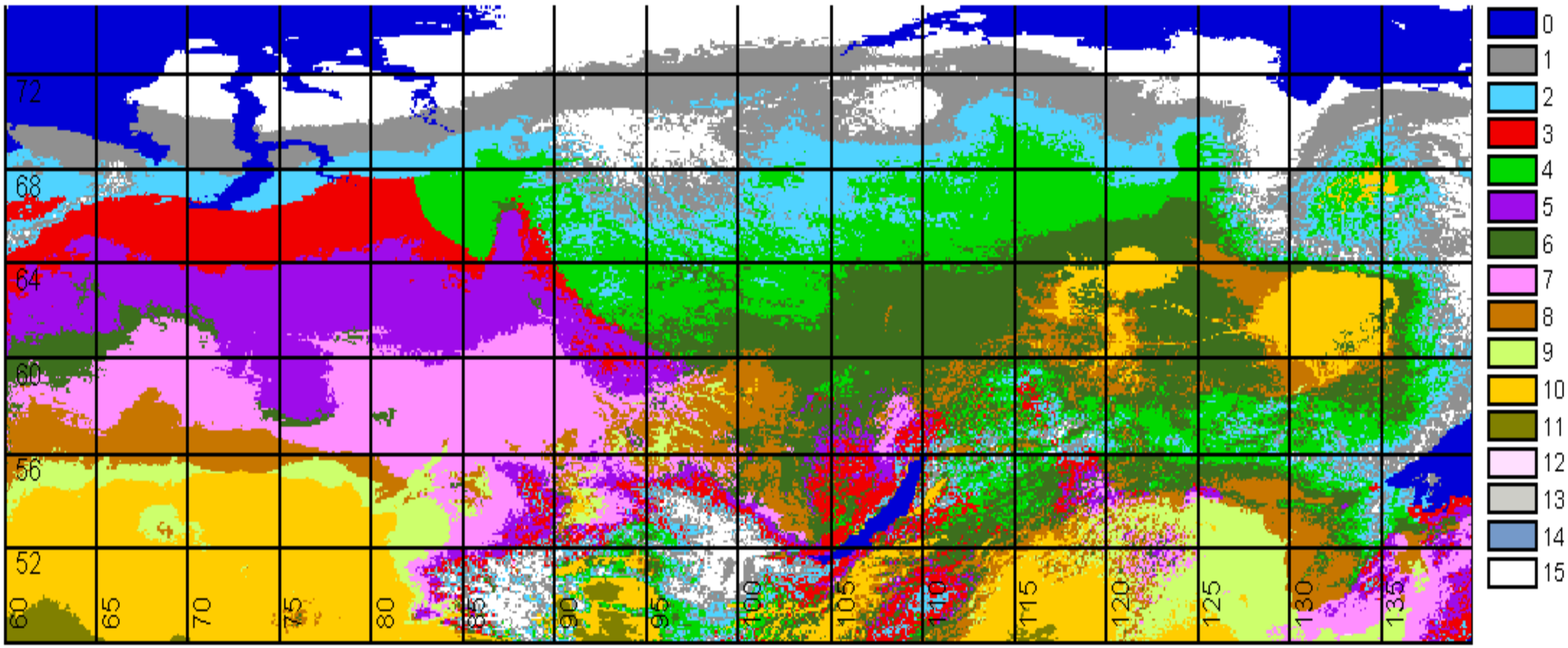


Archive of Tilinina et al. 2013, *J. Climate*

New challenge

Projected shifts in the biome boundaries

Current vegetation distribution over Siberia estimated by SiBCliM biosphere model (Tchebakova et al. 2008)

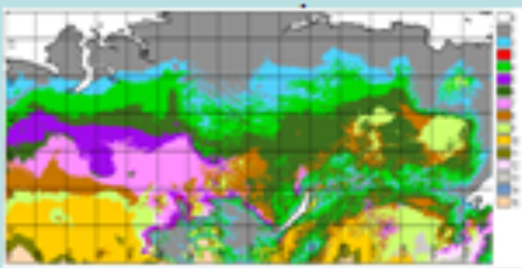


Vegetation classes: ***BOREA*L**: 1 – **Tundra**; 2 – **Forest-Tundra**; **Northern Taiga**: 3 – darkleaf, 4 – lightleaf; **Middle taiga**: 5 – darkleaf, 6 – lightleaf; **Southern Taiga**: 7 – darkleaf, 8 – lightleaf; 9 – **Subtaiga, Forest-Steppe**; 10 – **Steppe**; 11 – **Semidesert**; ***TEMPERATE***: 12 – **Broadleaf**; 13 – **Forest-Steppe**; 14 – **Steppe**, 15 – Cold desert

Light green – forest-steppe Gold - steppe

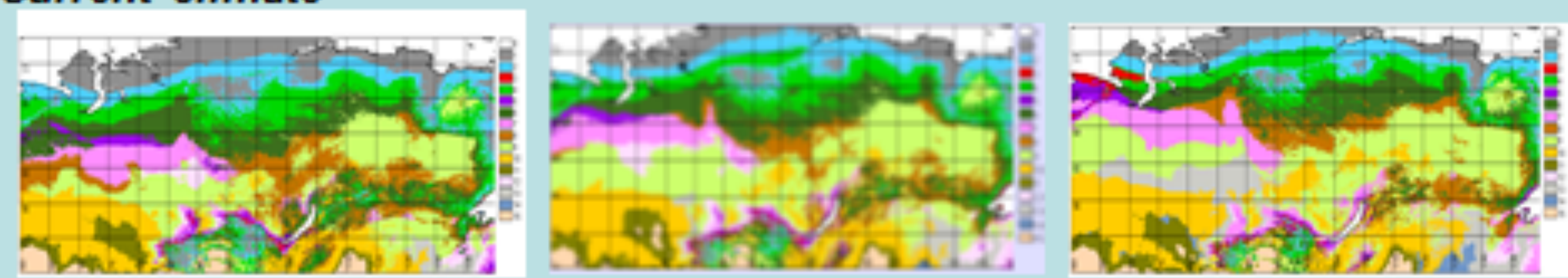
New Challenges: Biosphere changes

Climate and permafrost effects on vegetation distribution in Siberia in a changing climate

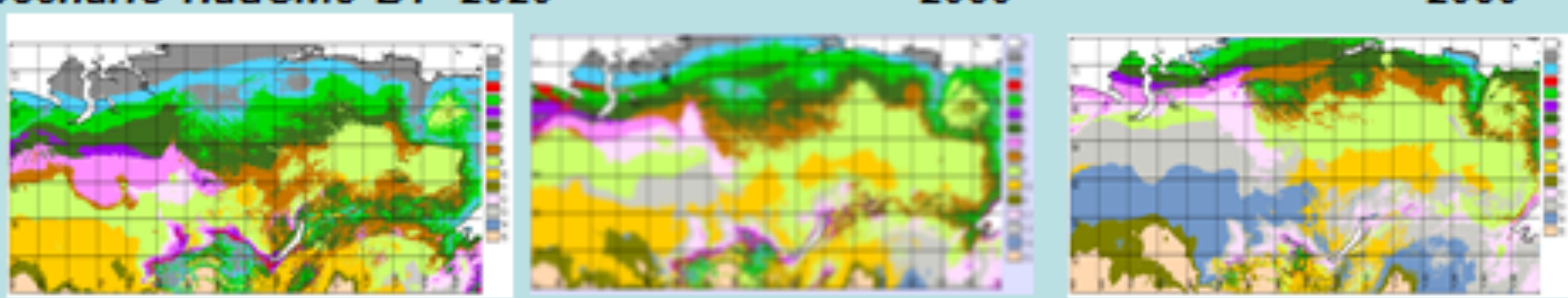


Current climate

*Vegetation change was mapped by coupling our bioclimatic vegetation model **SiBCiM** with bioclimatic indices and the permafrost distribution calculated from 2 climate change scenarios.*



Scenario HadCM3 B1 2020 2050 2080



Scenario HadCM3A1FI 2020 2050 2080

Light green – forest-steppe Gold - steppe Tchebakova et al. 2010

谢谢!

Thank you!

Спасибо!

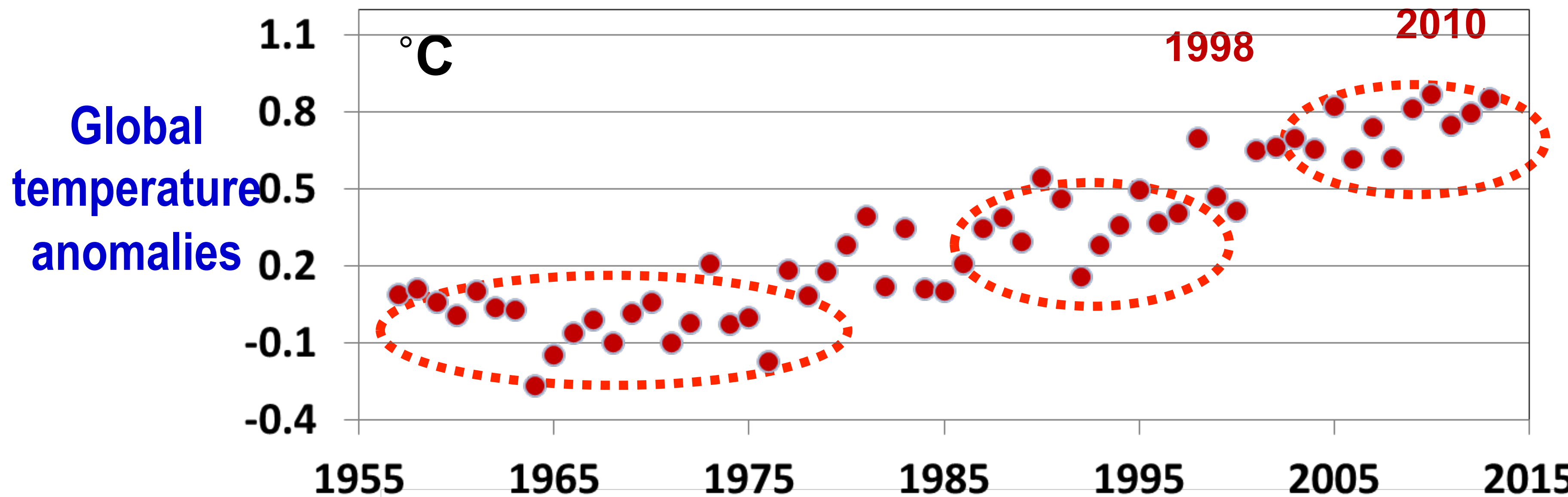
FOR MORE INFORMATION SEE THE NEESPI WEB SITE:

http://neespi.org

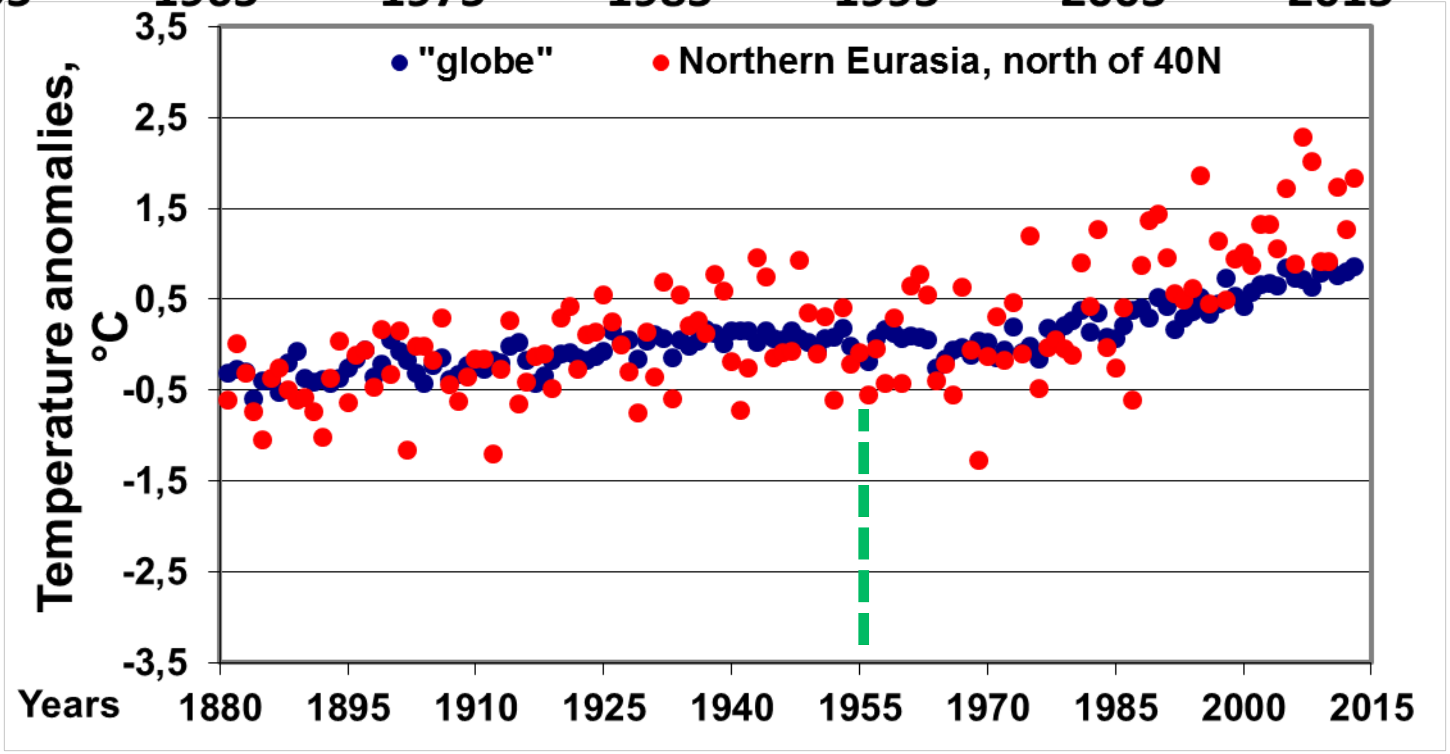
Side Note:
"NEESPI" is pronounced approximately like the Russian phrase for
"Don't sleep"
"NEFIg spati" is pronounced like the Russian *coll.* phrase for "Don't dare to sleep!"

Northern Eurasia Earth Science Partnership Initiative => Northern Eurasia's Future Initiative

Global Annual Surface Air Temperature Anomalies, °C

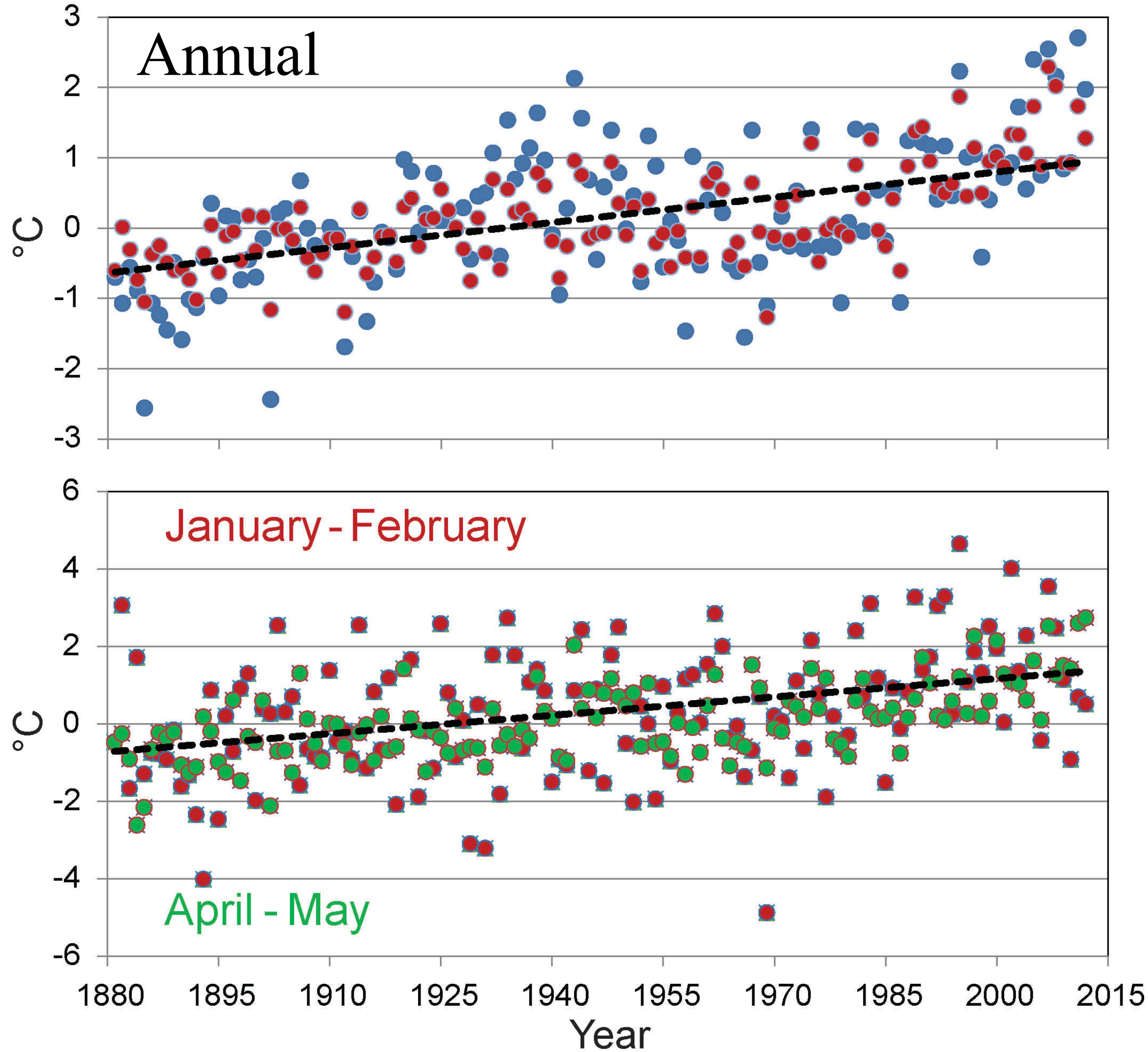


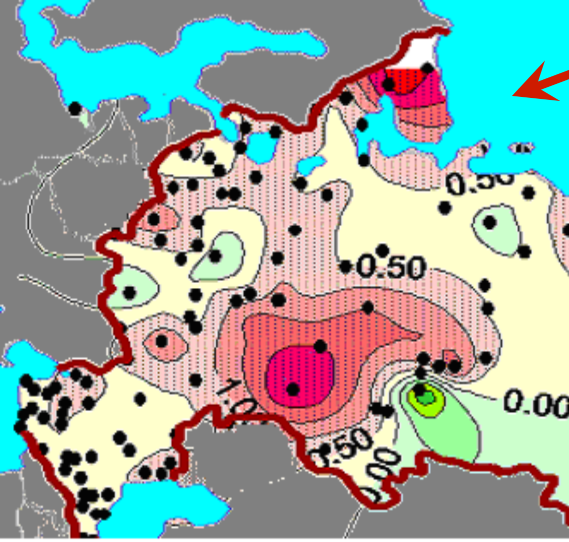
Rates of increase of annual temperature for the "globe" (60°S to 90°N) and Northern Eurasia are 0.91 °C/130 yr and 1.5°C/130yr respectively (Lugina *et al.* 2007, updated).



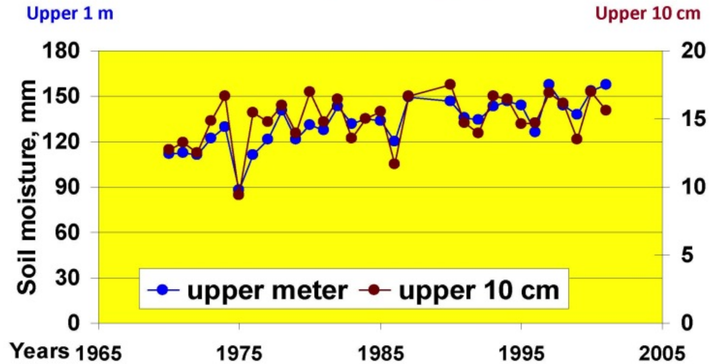
Surface air temperature anomalies area averaged over Northern Eurasia north of 40°N (red and green dots) and north of 60°N (blue dots).

Linear trends: (annual 1.75 °C per 132 years; seasonal: 2.1 °C per 132 years)





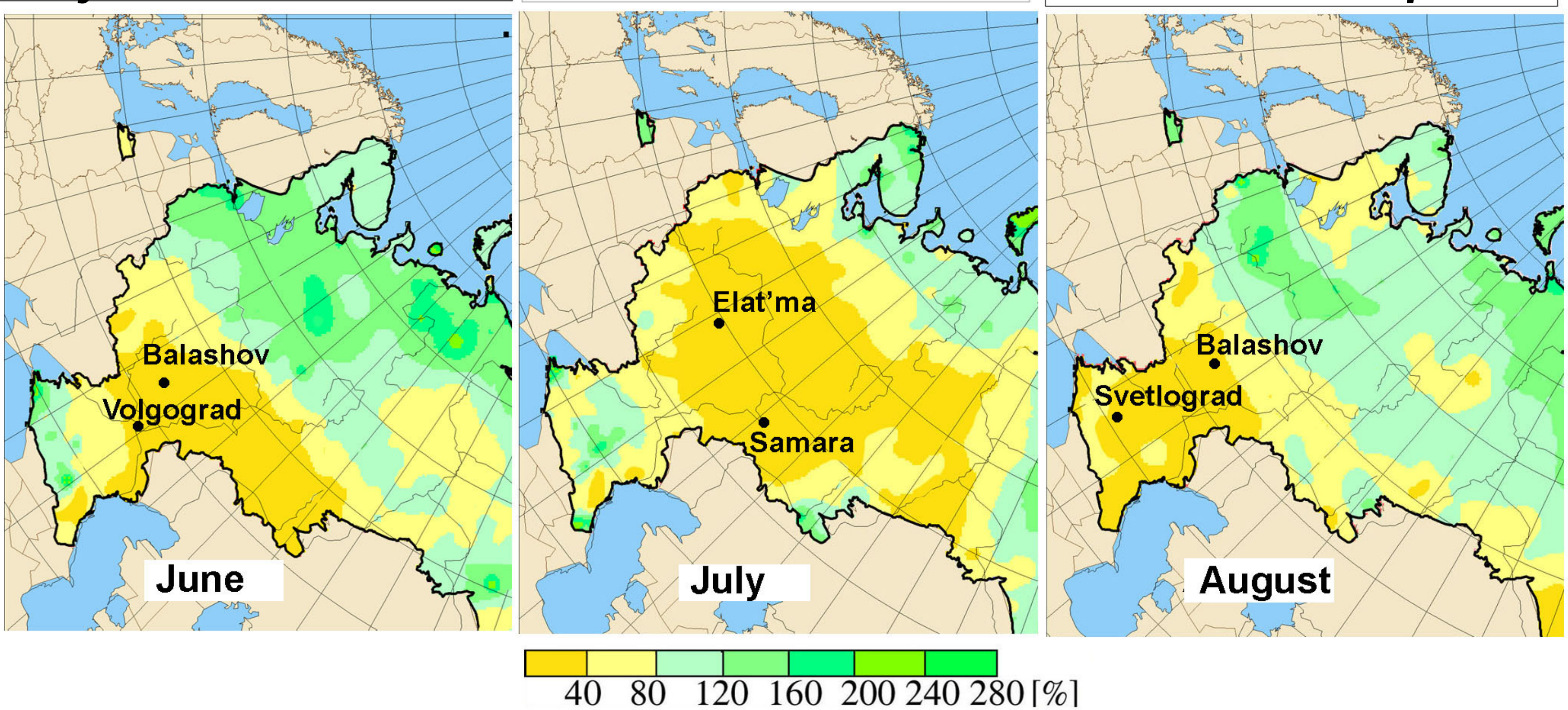
Annual precipitation. Linear trends for the 1936-2000 period (mm yr^{-1}).



r = 0.78; rates of change = 9.3%/10yr [R^2=0.58] and 5.5%/10yr [R^2=0.15] respectively.

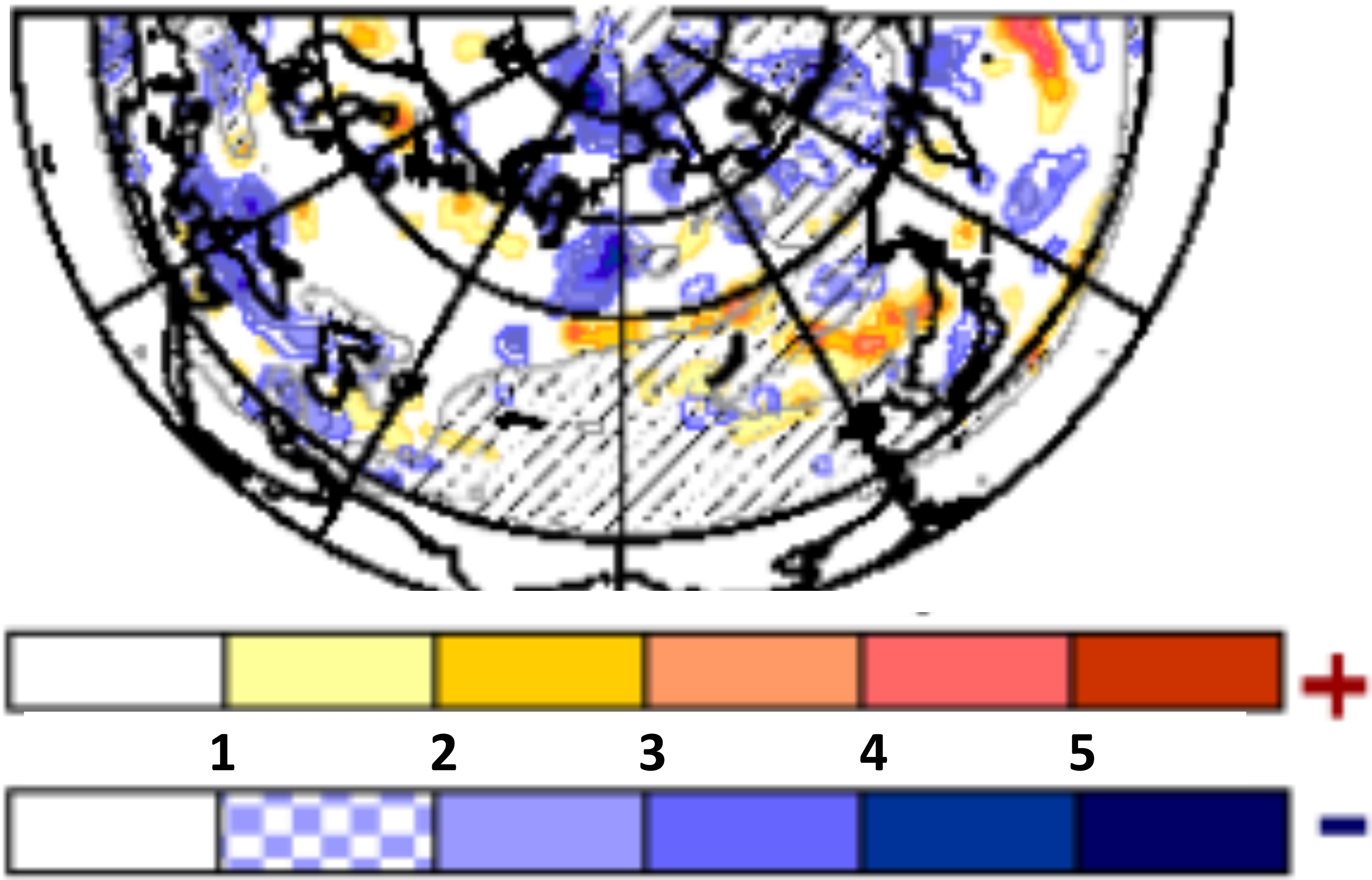
Upper layer soil moisture changes over European Russia south of 60°N during the warm season.

Monthly rainfall anomalies in the summer months of 2010 over European Russia

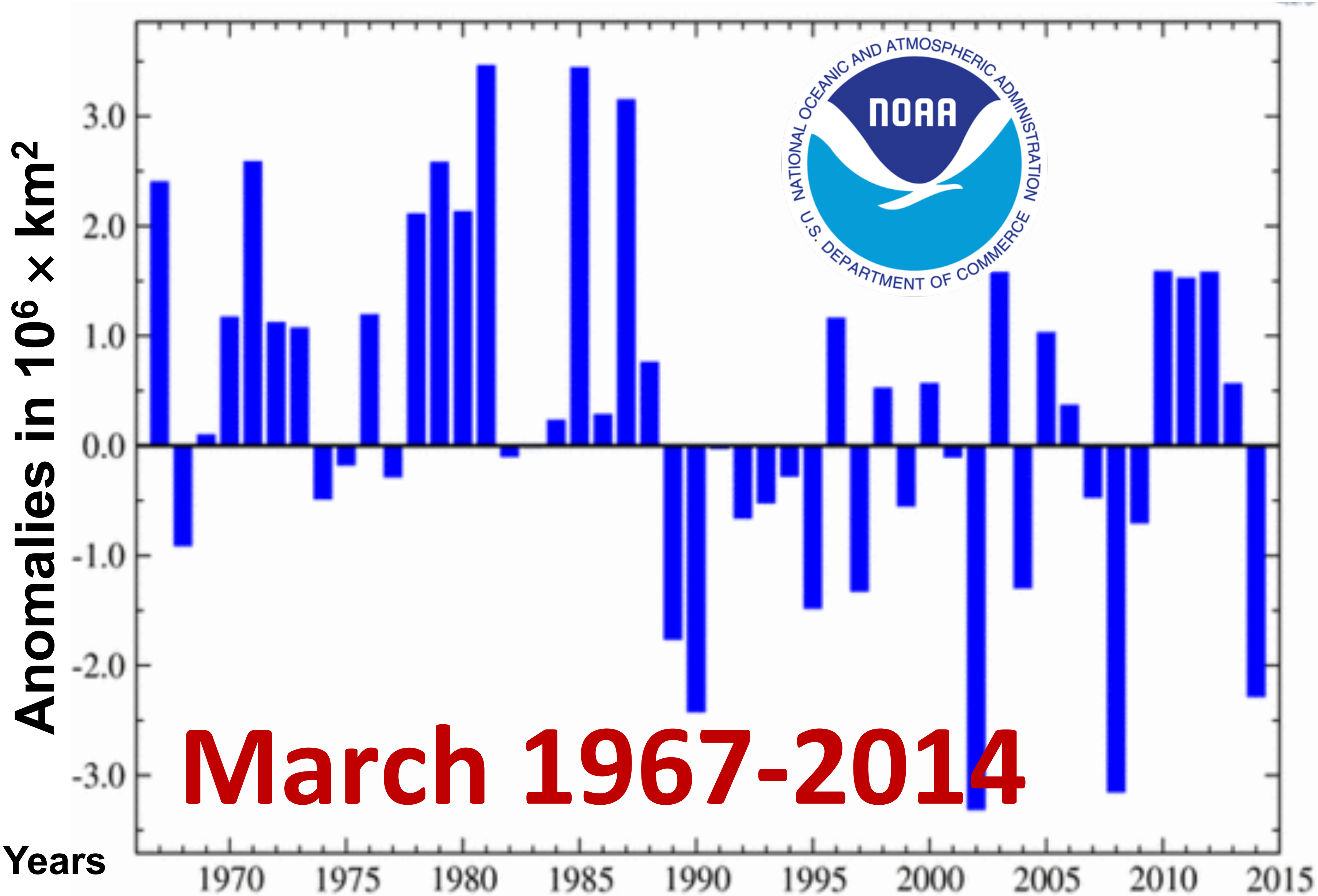


Number of reanalyses (of 5) showing statistically significant positive or negative trend in the cyclone counts for the 1979-2010 period in winter (DJF)

(Tilinina et al. 2013; *J. Climate*)

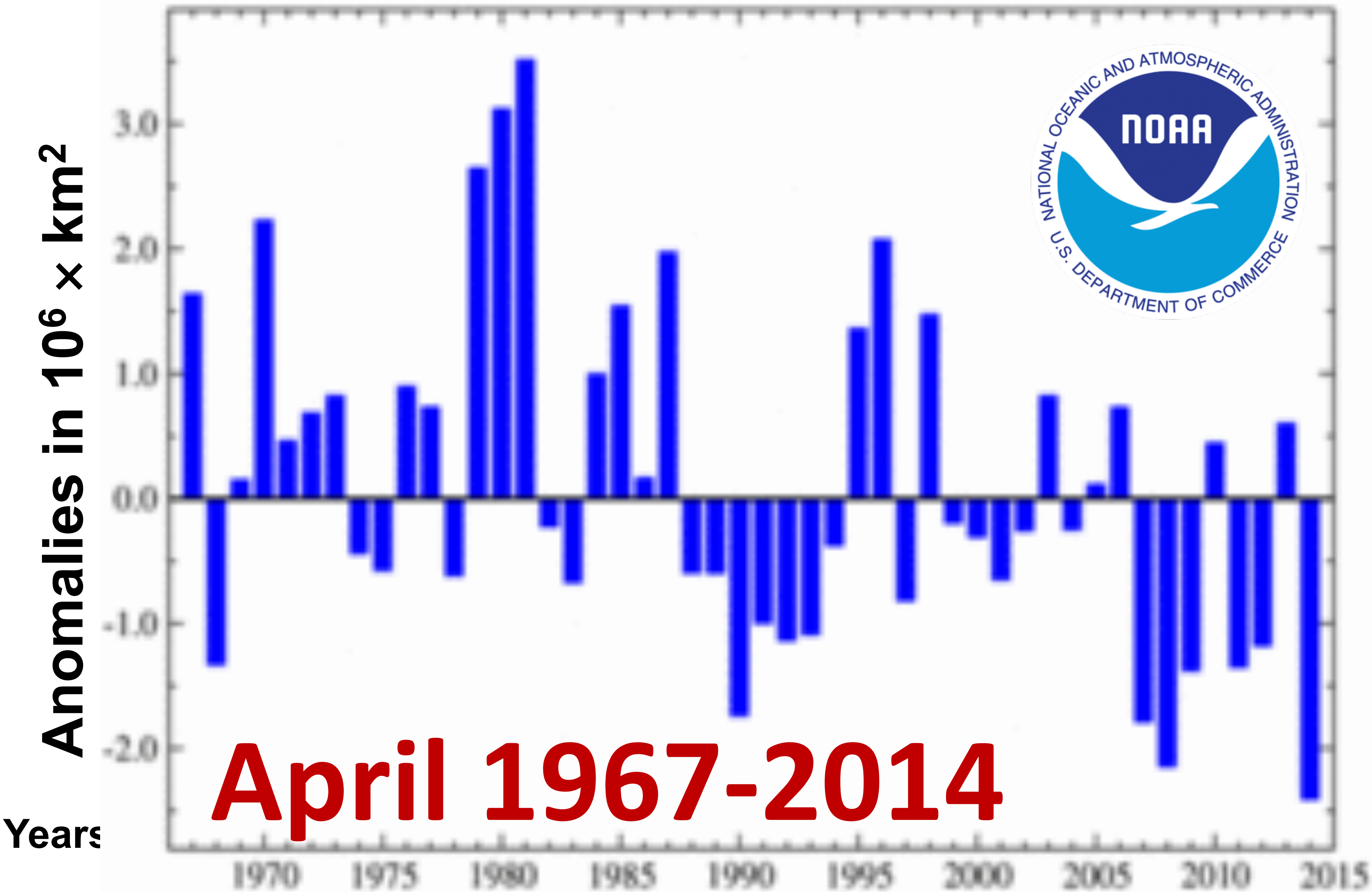


Snow cover extent anomalies over Eurasia



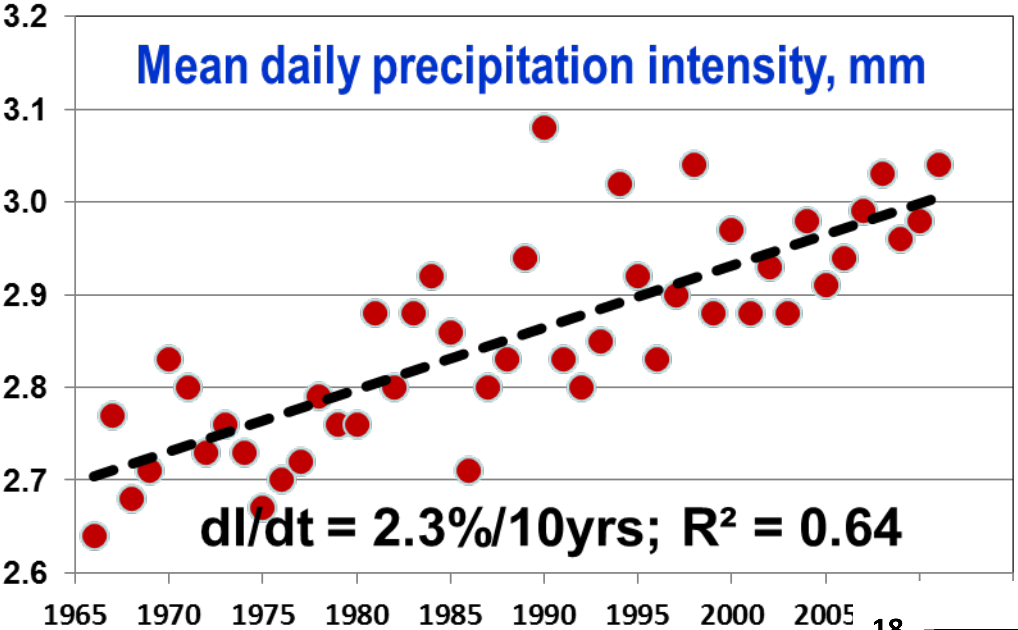
http://www.ncdc.noaa.gov/sotc/service/global/snowcover-eurasia/201403.gif

Snow cover extent anomalies over Eurasia

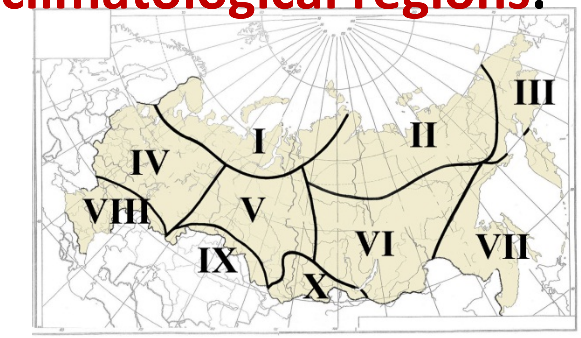


http://www.ncdc.noaa.gov/sotc/service/global/snowcover-eurasia/201404.gif

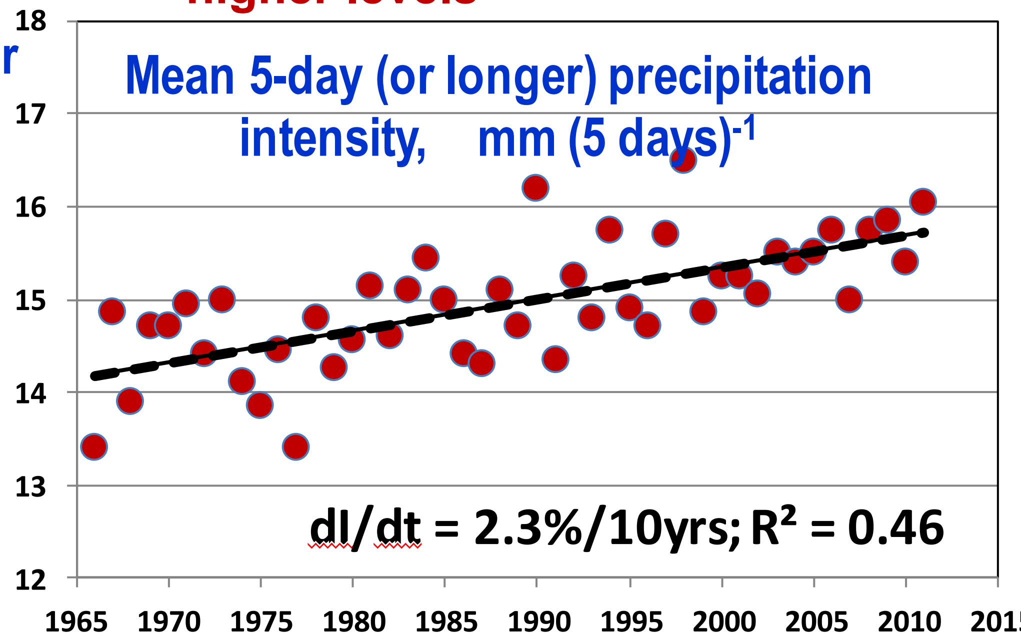
Nationwide precipitation intensity, I, changes over Russia



Russian climatological regions:



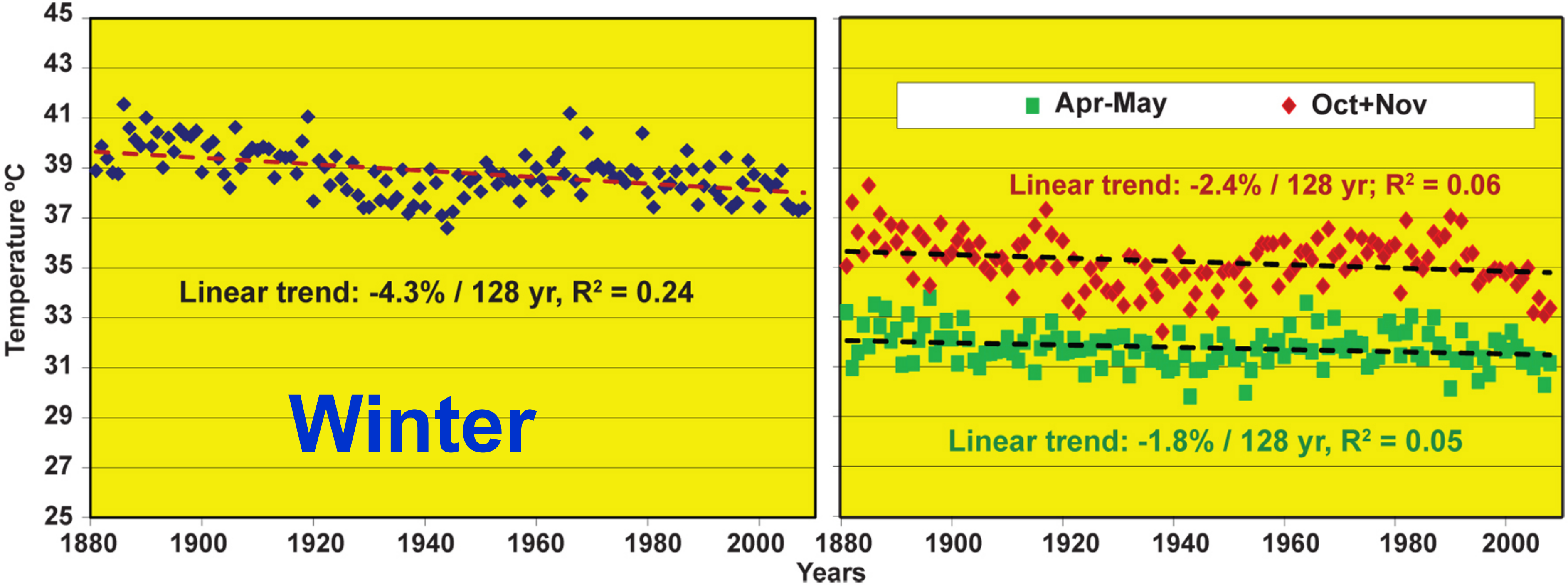
Precipitation intensity trends over all these regions are positive and statistically significant at the 0.05 or higher levels



To receive the nationwide time series, for each year and each station mean annual precipitation intensity was calculated as (totals/number of events). Thereafter, point estimates were area-averaged arithmetically within climatological regions shown in the map and, finally, these regional mean values were averaged again with the weights proportional to the areas of the

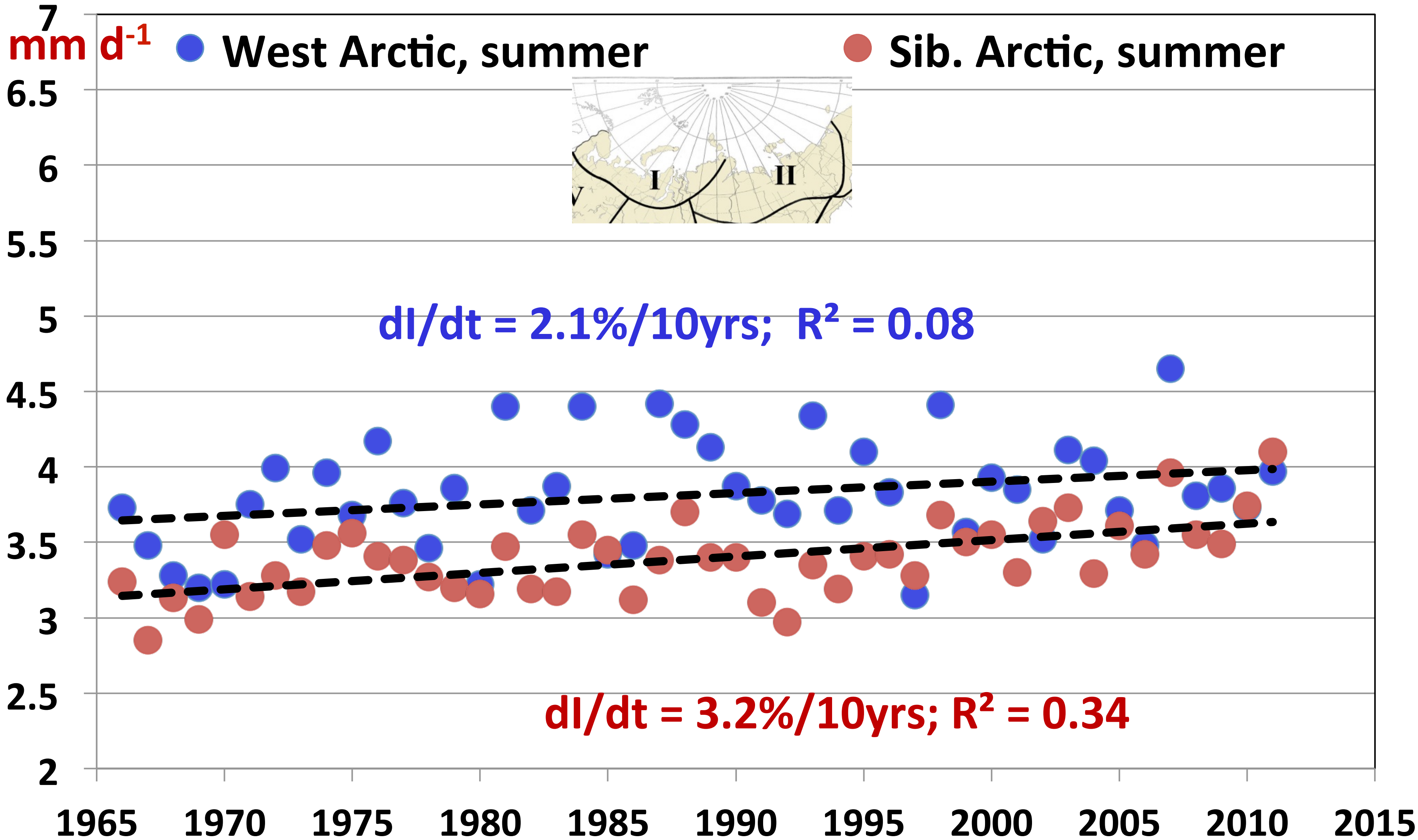
Decrease in surface air temperature meridional gradients over the Northern Hemisphere estimated as a difference of tropical mean zonal temperature (zone 0°- 30°N) and polar mean zonal temperature (zone 60°N - 90°N)

(Groisman and Soja 2009; *Environ. Res. Lett.*)

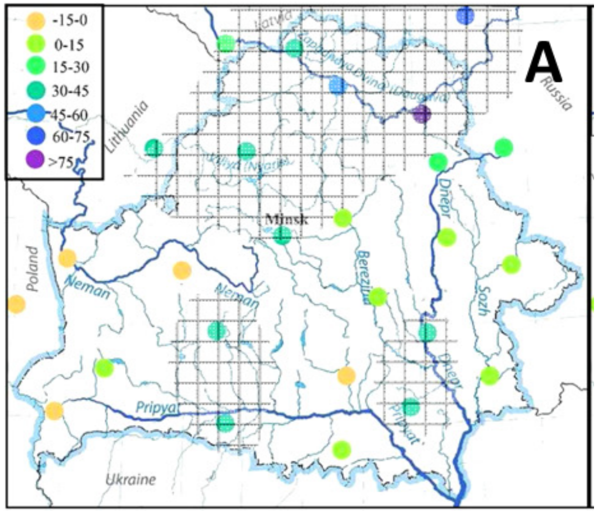


For Northern Eurasia climate, zonal heat and water vapor transport are of critical importance.

Mean summer precipitation intensity over Russian Arctic (mm d^{-1})



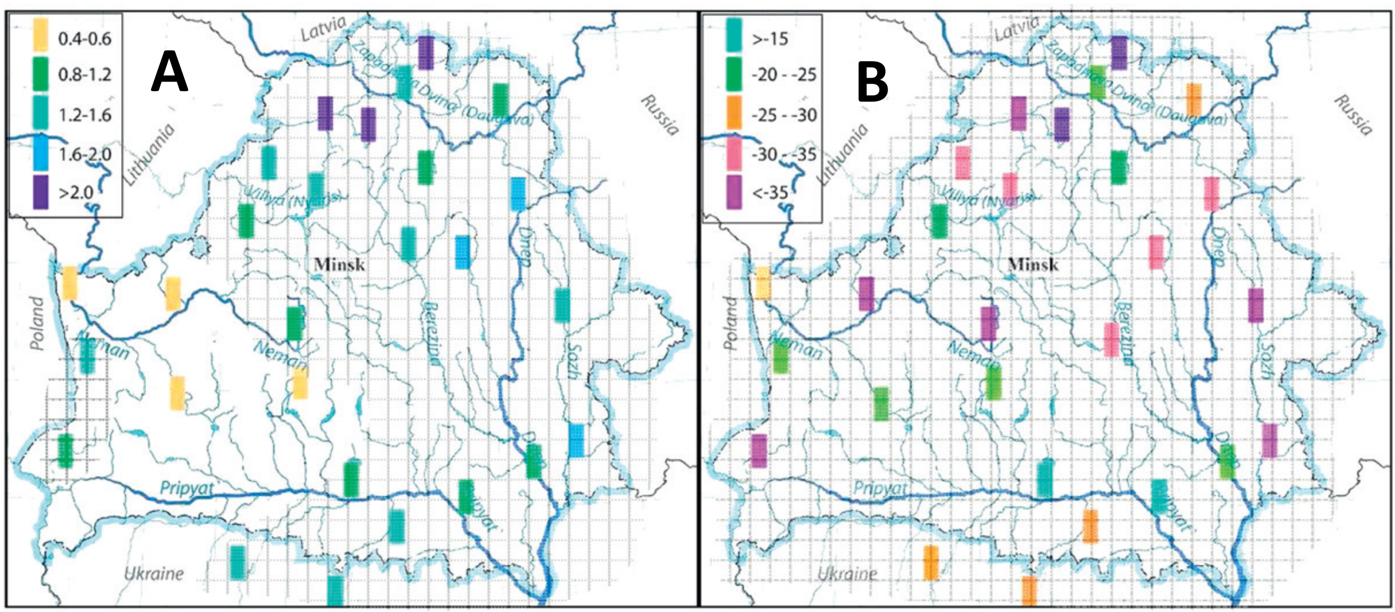
Cold season changes in the hydrological cycle over Belarus during the 1949-2010 period



Spatial distribution of the net winter precipitation (**left**, mm) and runoff (**bottom**, litre s^{-1} km^{-2}) change for the 1949–2010 period, during the winter (A) and spring (B) seasons.

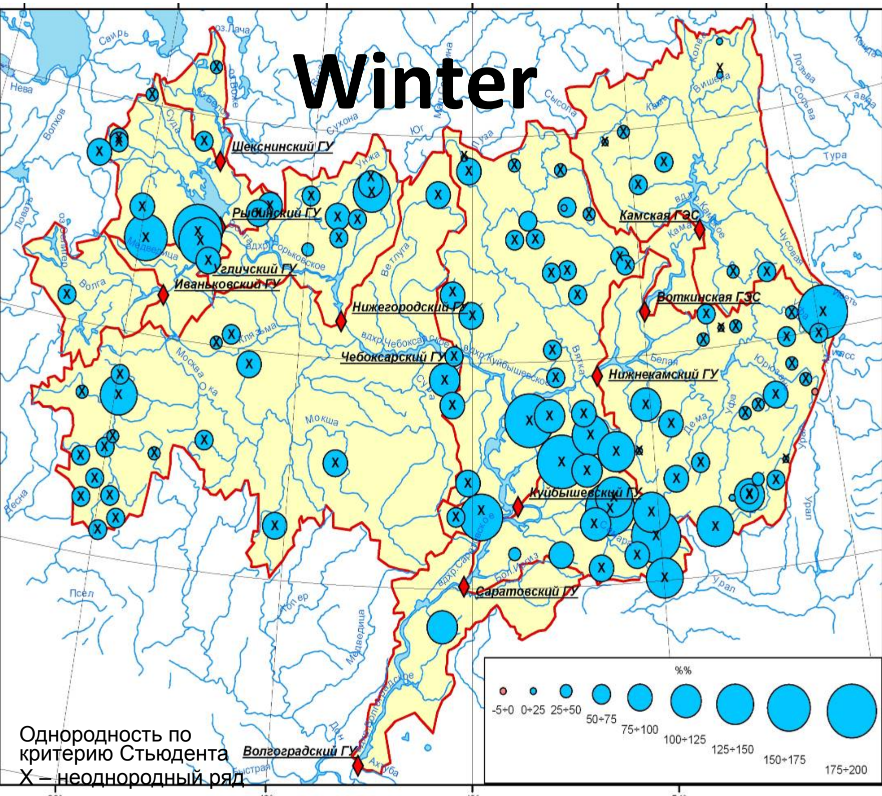
Partasenok et al. (2014, *Environ. Res. Lett.*)

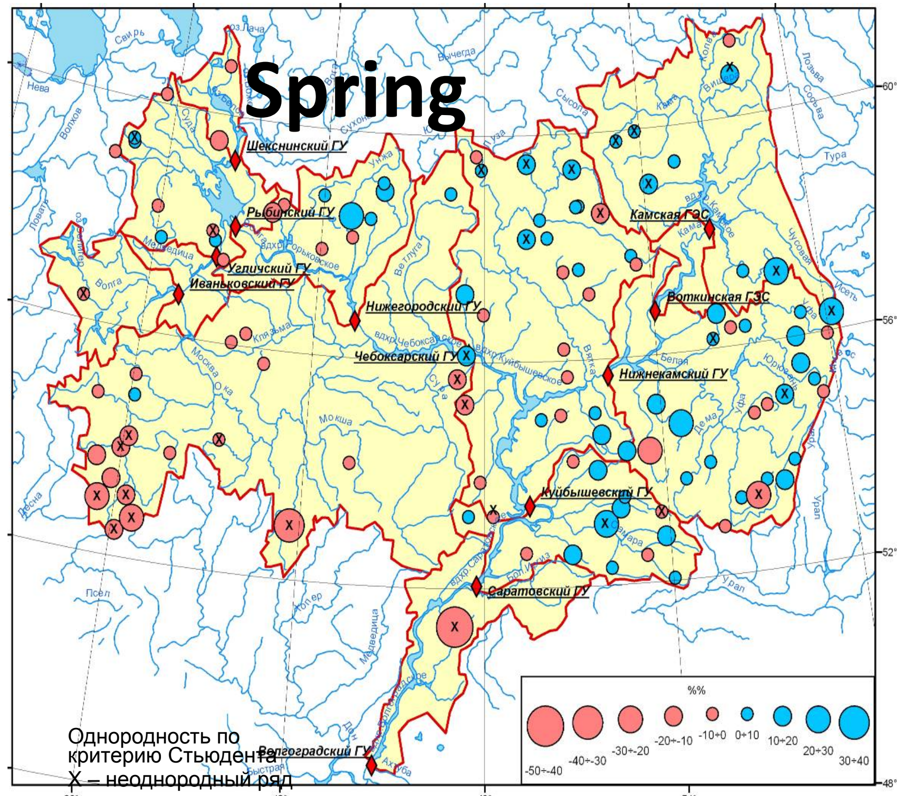
The hatched areas in the maps outline statistically significant values of change at the 0.05 level.



Changes of spring and winter runoff in the Volga River Basin

Relative runoff changes (%); long-term mean for the 1978-2010 period are related to the base period 1946-1977. Data of the State Hydrological Institute, Russia

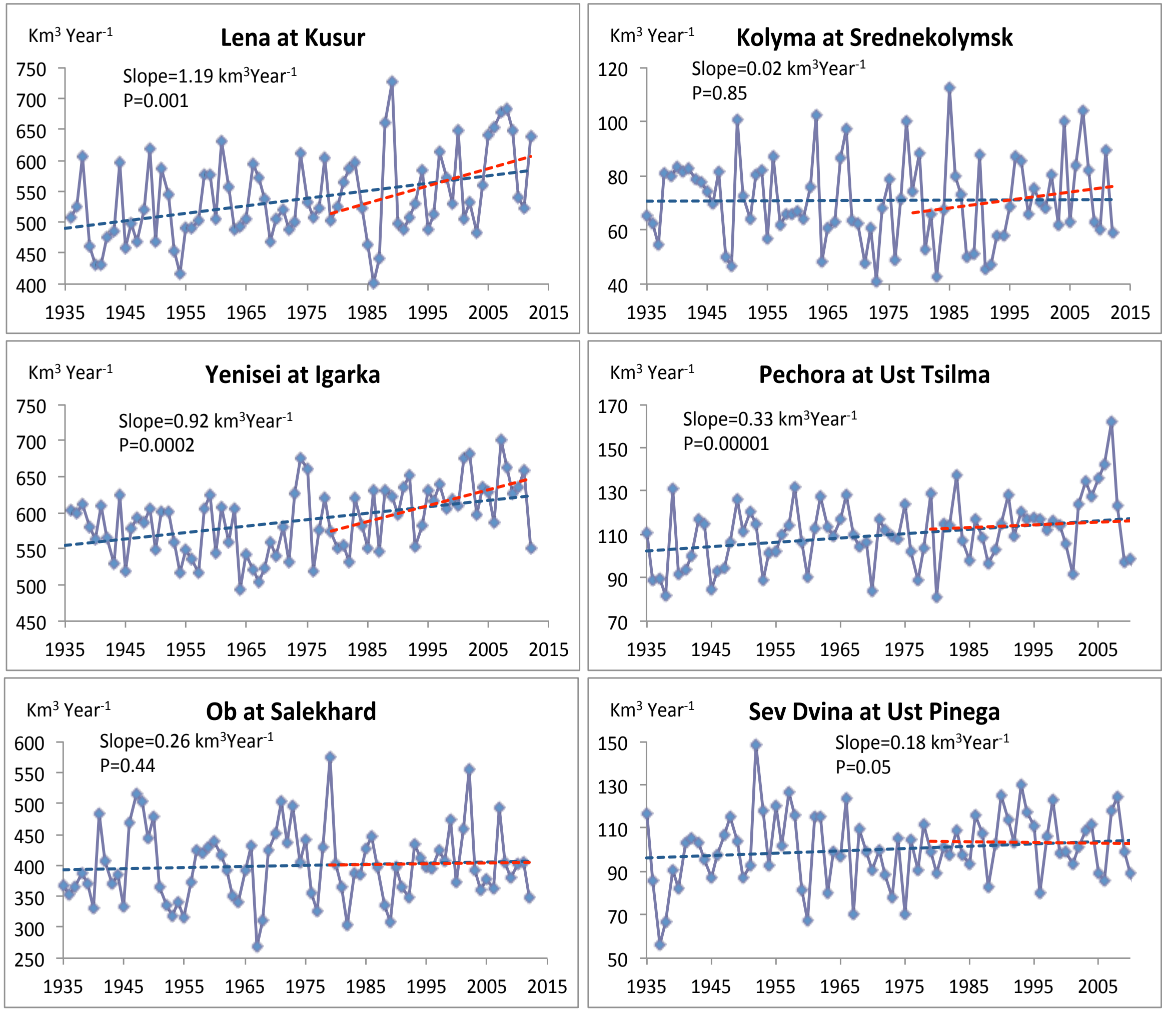




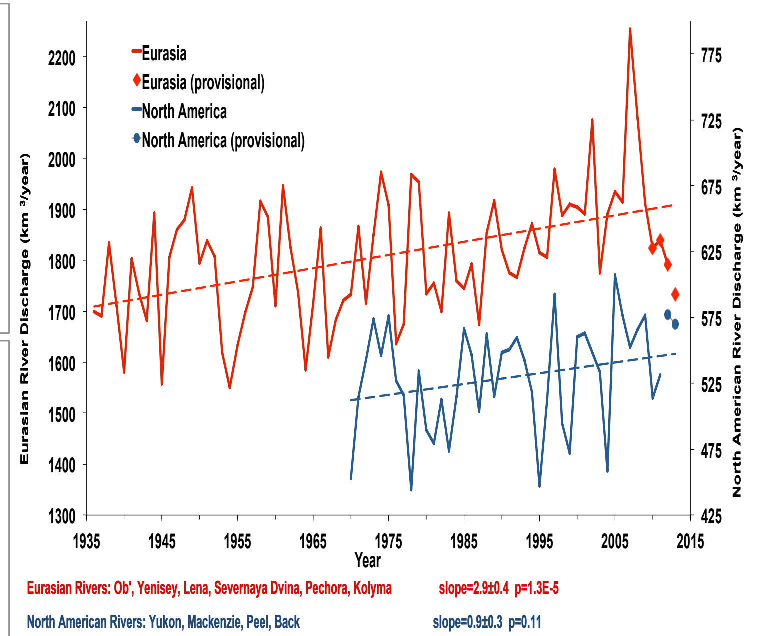
Increase of the frequency of extratropical winter cyclones moving eastward and crossing the northern part of Eastern Europe (over Belarus and westernmost European Russia) results here in:

- **less frequent Arctic air invasions**
- **milder winter seasons with more frequent thaws**
- **significant increase in winter runoff, and**
- **reduction of peak (spring) streamflow related to snowmelt.**

Acceleration of the water cycle in the Eurasian pan-Arctic

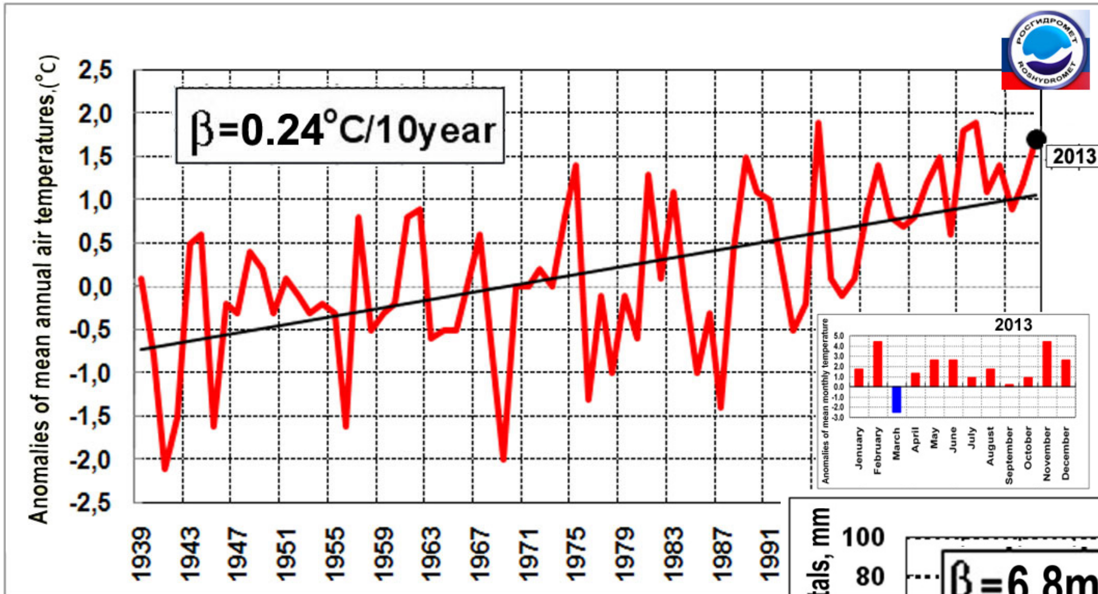


Annual discharge variabilities for the largest Russian rivers flowing to the Arctic Ocean. Dash lines show linear trend lines over 1936-2008 (blue) and over 1980-2008 (red). (html://R-ArcticNet.sr.unh.edu)

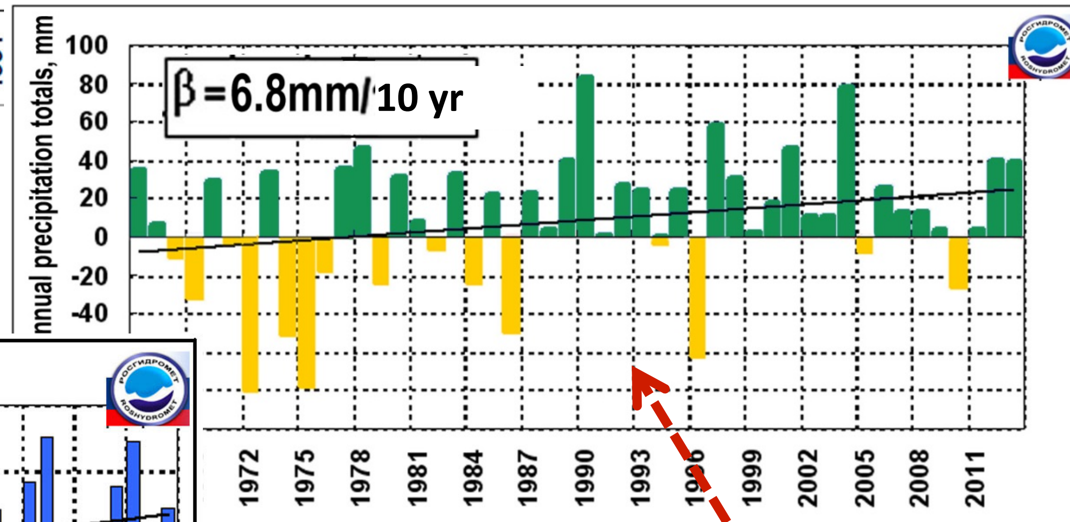


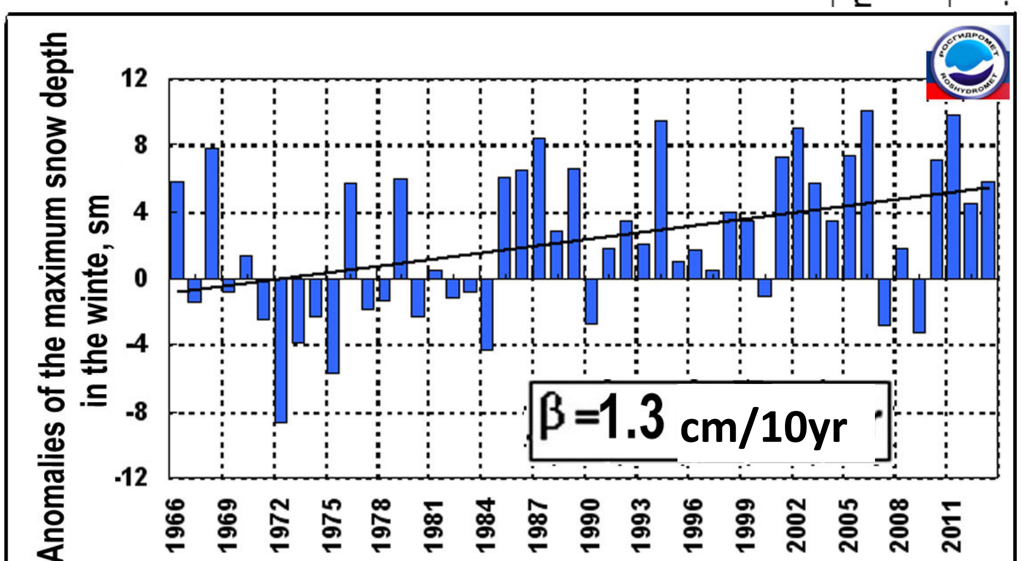
Total annual discharge to the Arctic Ocean from the six largest rivers in the Eurasian pan-Arctic for the 1936–2009 period (Shiklomanov and Lammers 2011; red line) and from the four largest North American Arctic rivers over 1970–2010 (blue line).

European part of the Russian Federation



Annual tendencies

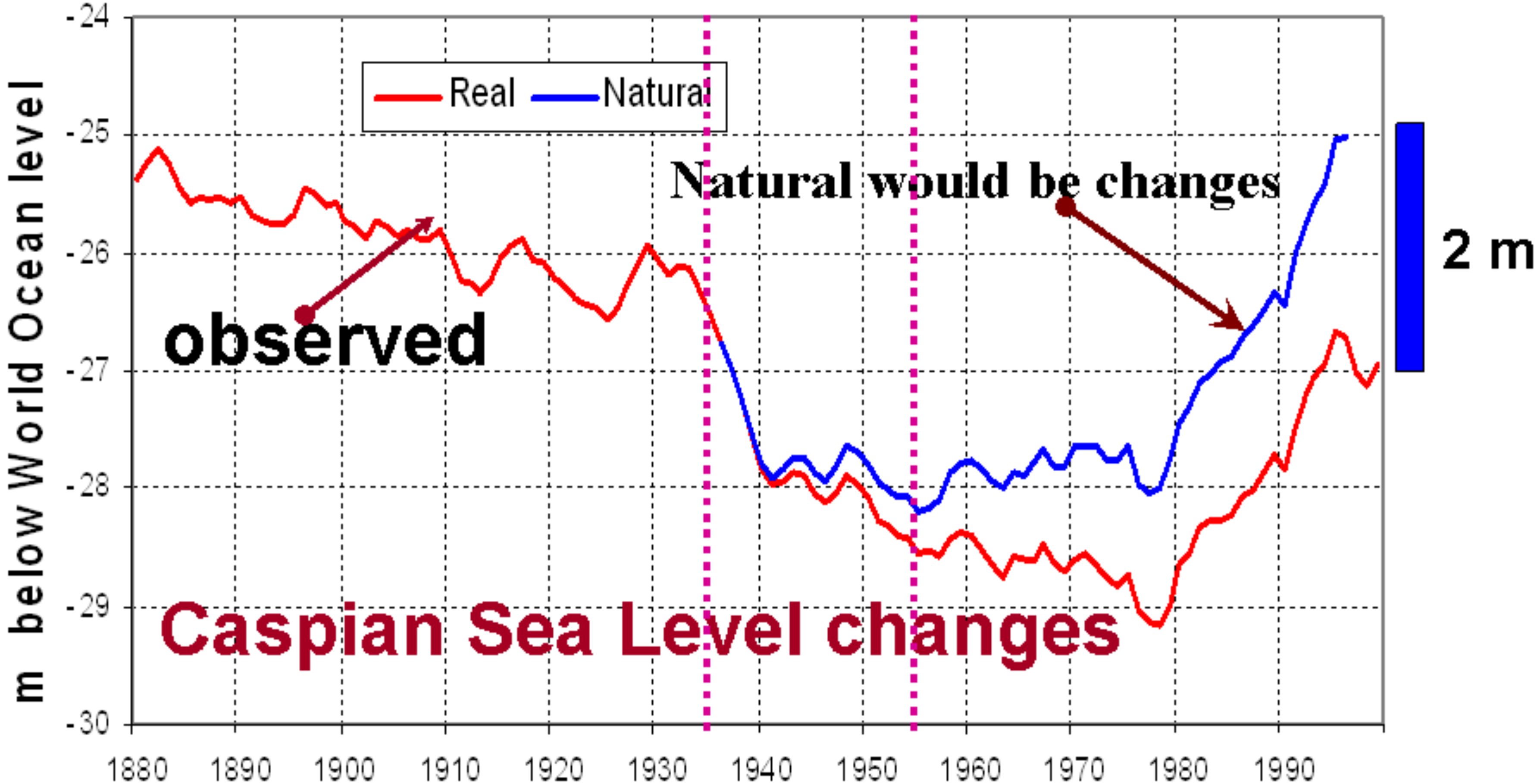




N.B. reported precipitation!!

Bulygina et al., Roshydromet.

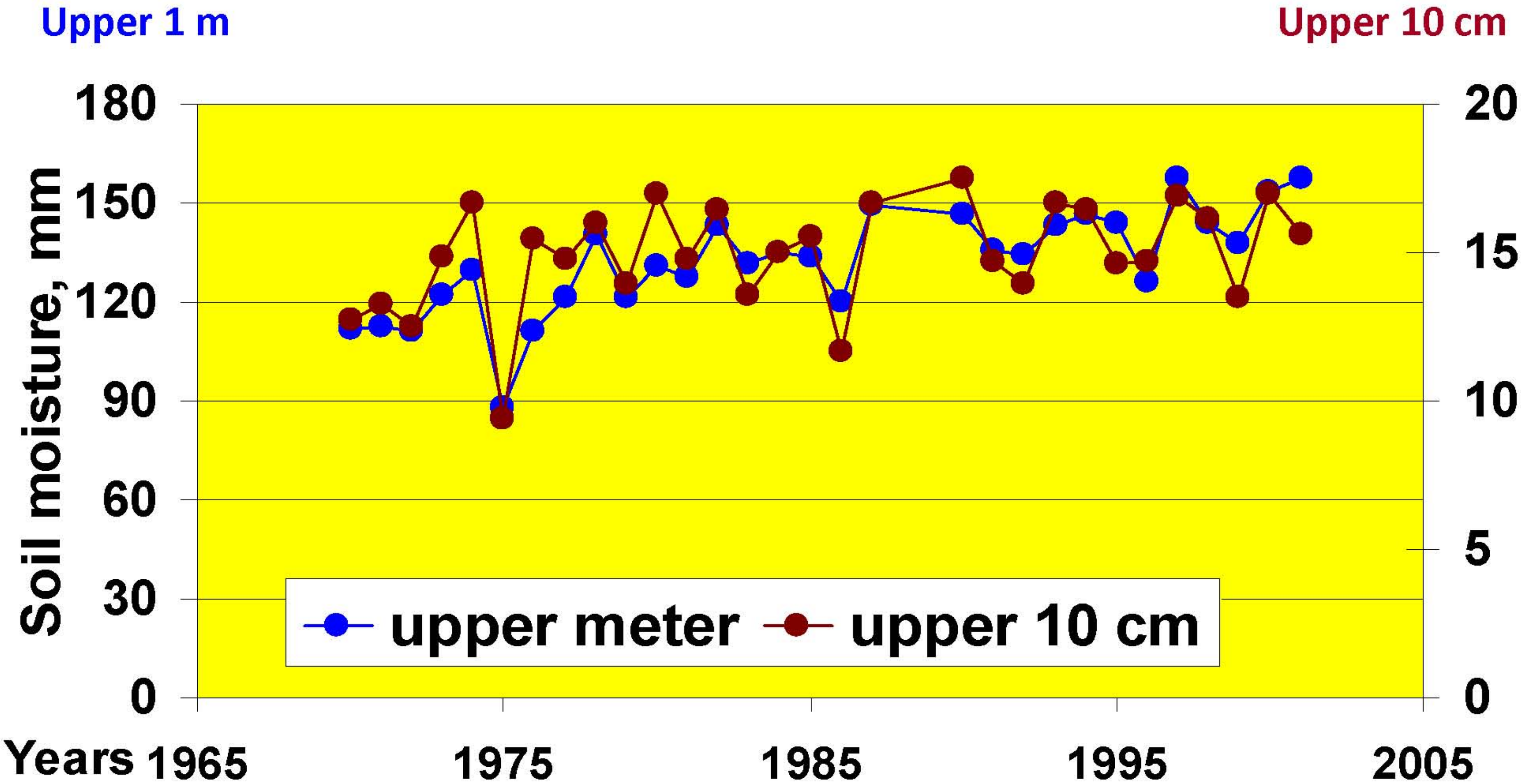
Observed and “natural” changes in the level of the largest in the world lake are significant and of similar magnitudes



Source: Shiklomanov (1976)

Update: Shiklomanov and Georgievsky (2003)

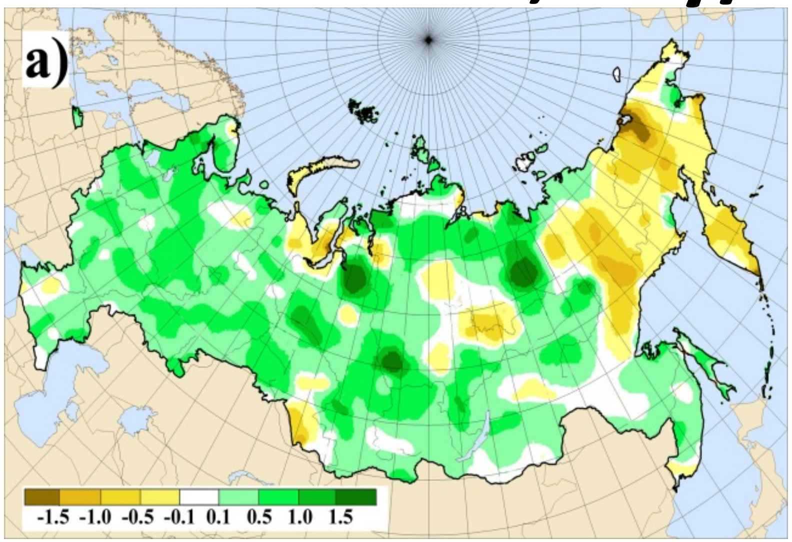
Soil moisture changes over European Russia south of 60°N during the warm season in the first upper 100 and 10 cm respectively (Speranskaya 2009)

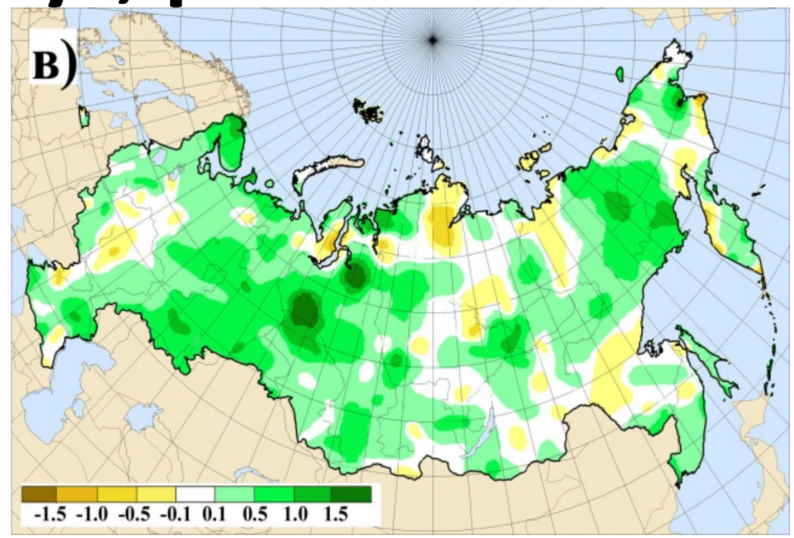


r = 0.78; rates of change = 9.3%/10yr [R^2=0.58] and 5.5%/10yr [R^2=0.15] respectively.

Changes in the number of days with heavy precipitation.

Linear trends; day/10yr; period 1971-2010





a) – winter; в) – summer

In the regions with color, the trend estimates are statistically significant at the 0.05 level. Heavy daily precipitation event is defined here as an event with totals that are above the upper 5th percentile of the daily distribution.