Contemporary Changes of the Hydrological Cycle over Northern Eurasia

"Современные изменения Гидрологического цикла Северной Евразии"

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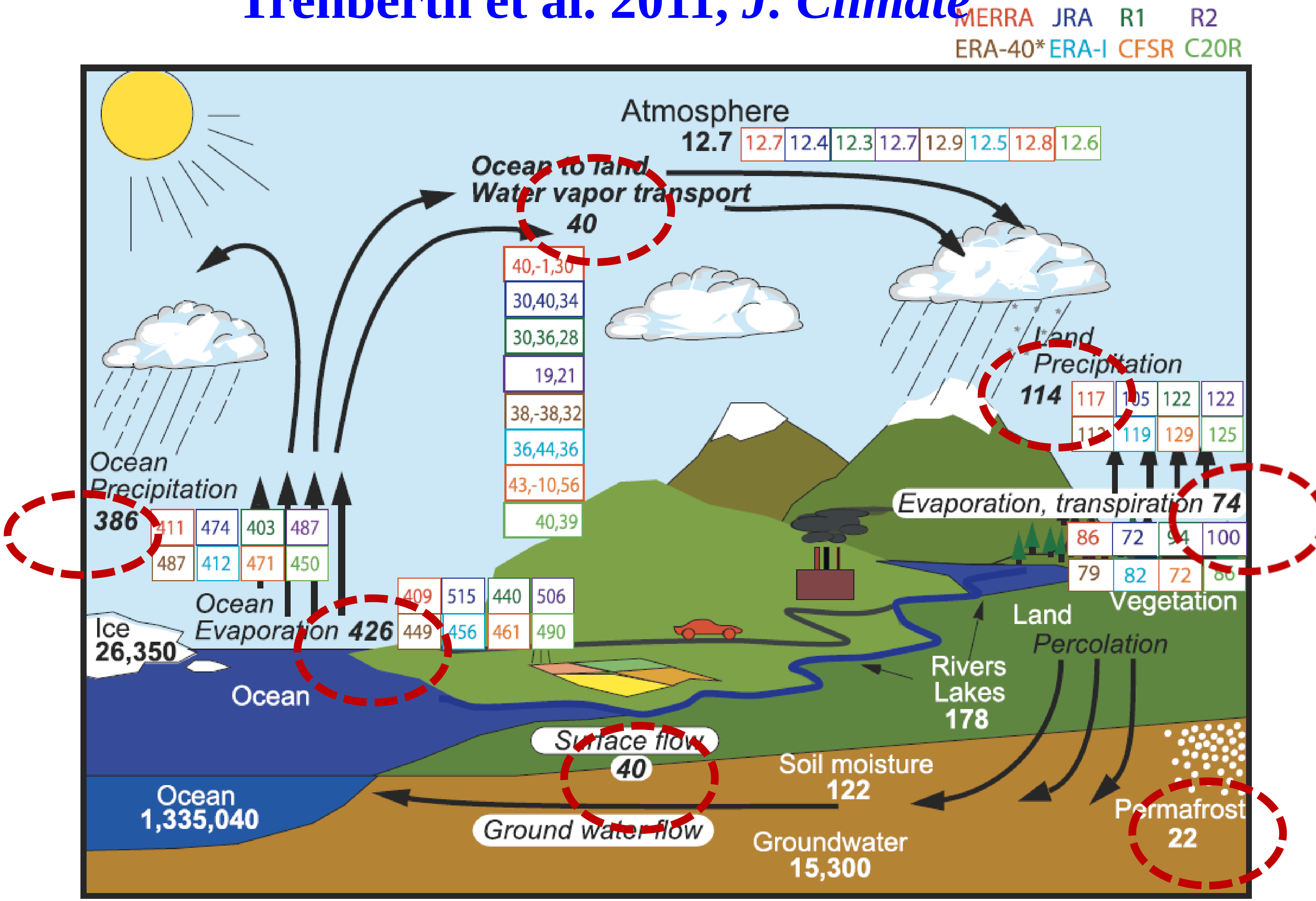
Global Hydrological Cycle and its Estimates

Trenberth et al. 2011, *J. Climate*



Units: Thousand cubic km for storage, and *thousand cubic km/yr* for exchanges *1990s

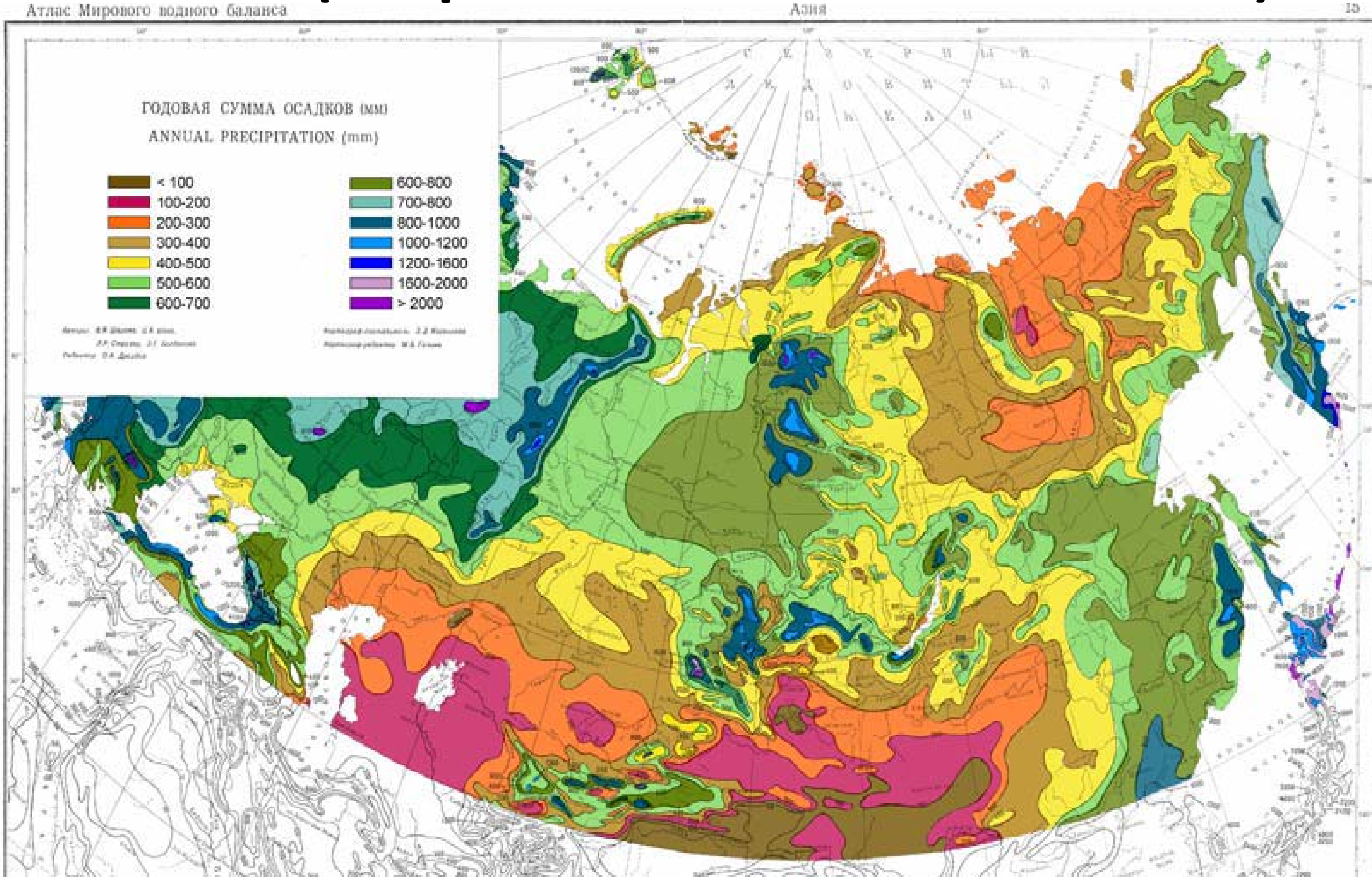
Global water budget in mm yr^{-1}

	Ocean	Land	Land/Ocean
Precipitation, P	1050	722	70%
Evaporation, E	1156	469	40%
P-E, 40×10^3 km^3	-106	253	N/A

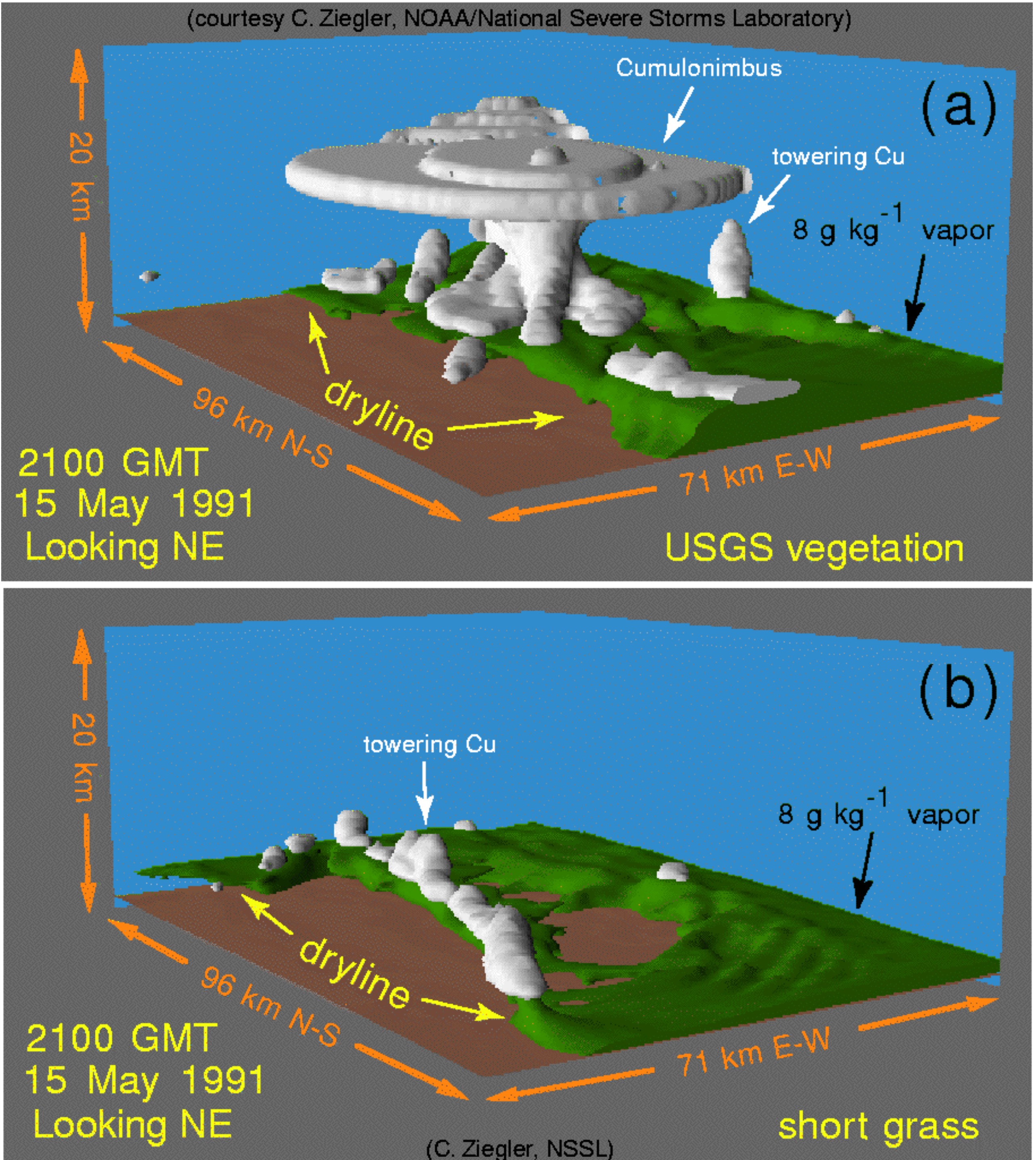
Transport to Land via Atmosphere; 9% of E

Runoff to Ocean + Δ storage (soil, ice, biosphere, and lakes); 54% of E

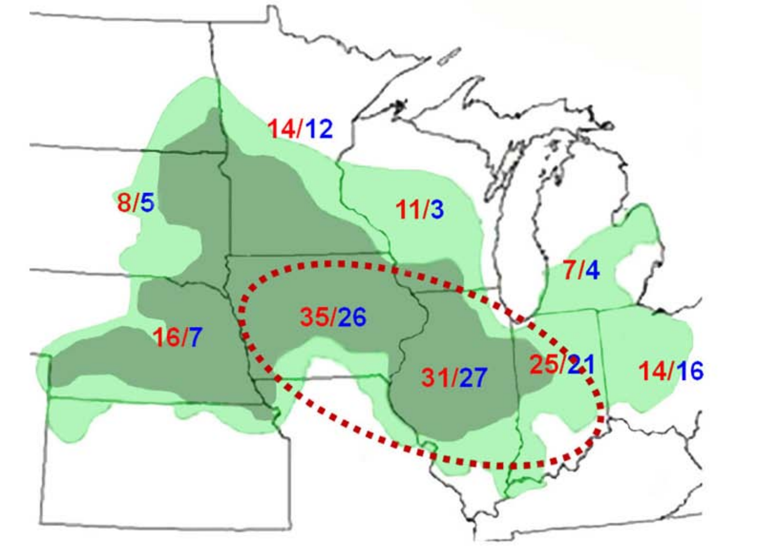
Annual precipitation (mm) over Northern Eurasia (adapted from Korzun et al. 1974)

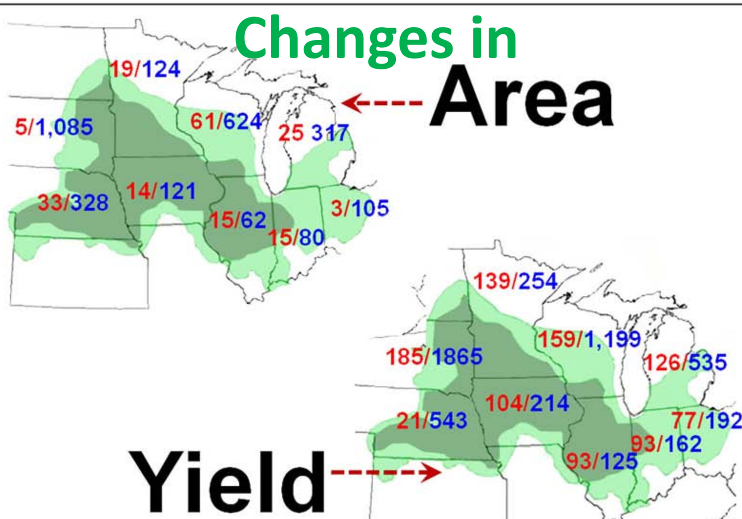


Effect of Land-Use Change on Deep Cumulonimbus Convection



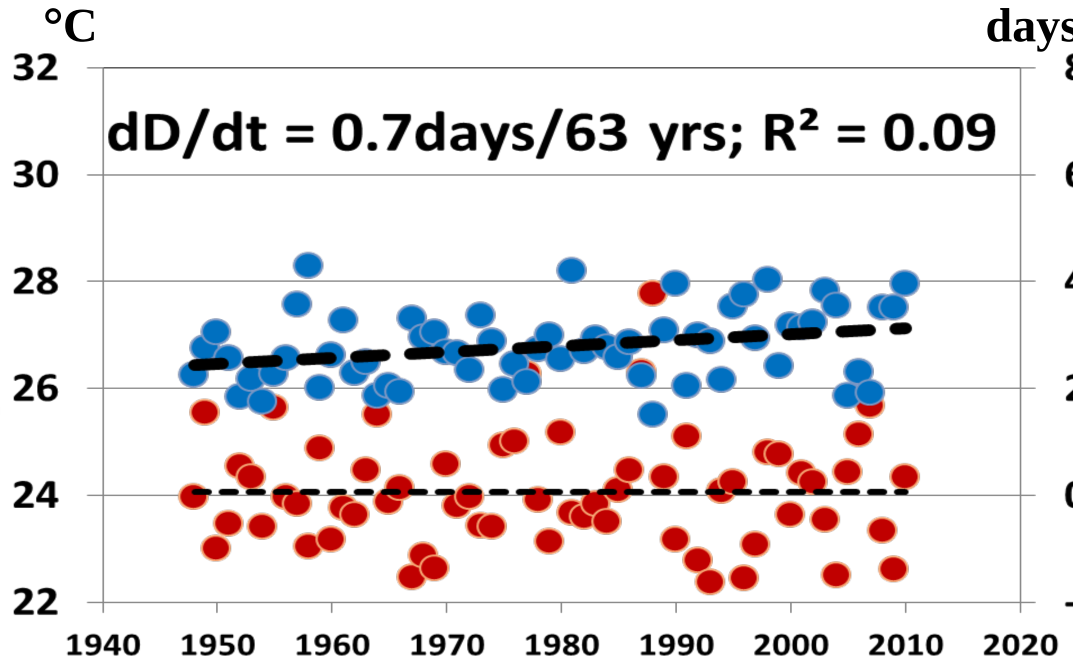
(Pielke, Sr. 2001, in *Rev. Geophys*.)



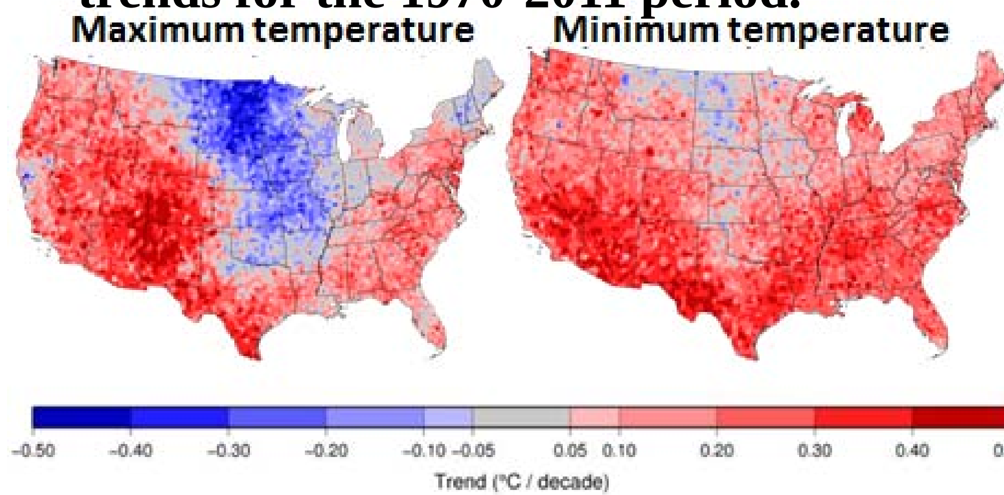


Top. U.S. Corn Belt States with the areas (% of total land area) occupied by corn (**red**) and soybean (**blue**) fields in last three decades. **Bottom.** Changes (**in %**) between 1979-2009 and 1948-1978 periods

May – July number of days with heavy (>50.4 mm) rainfall, D (blue), and T_{max} over the US Midwest

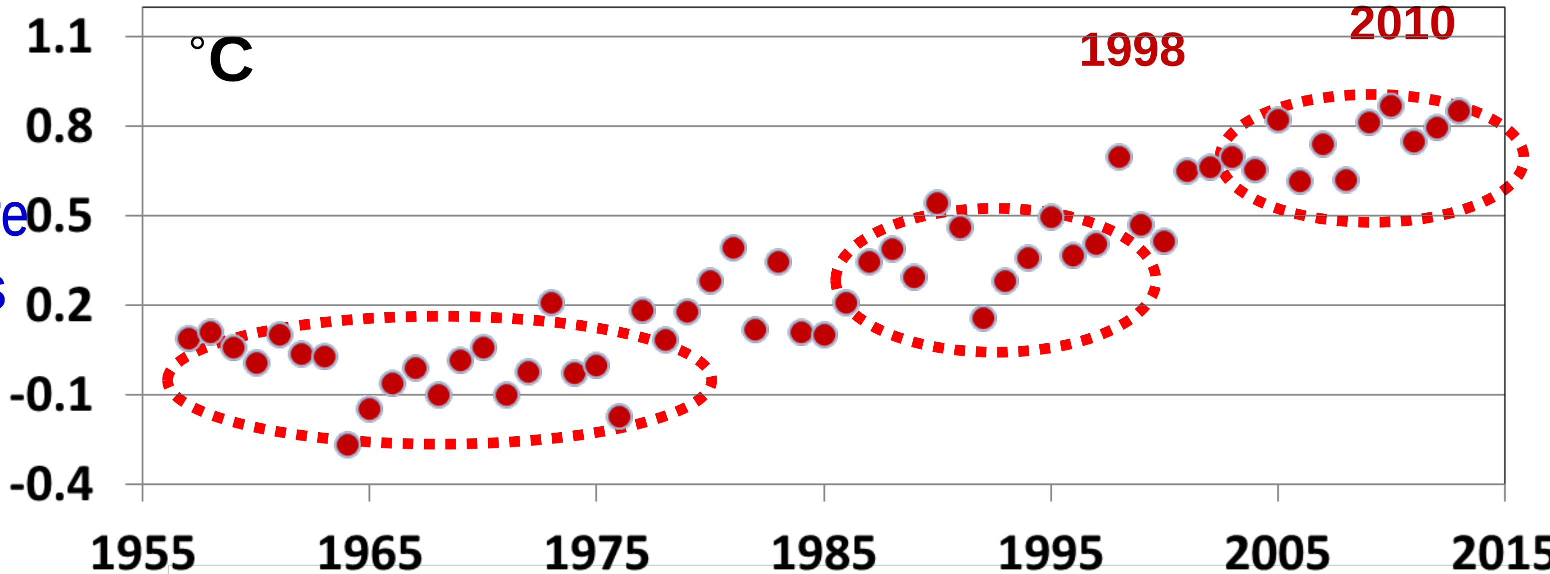


May-July surface air temperature linear trends for the 1970-2011 period.

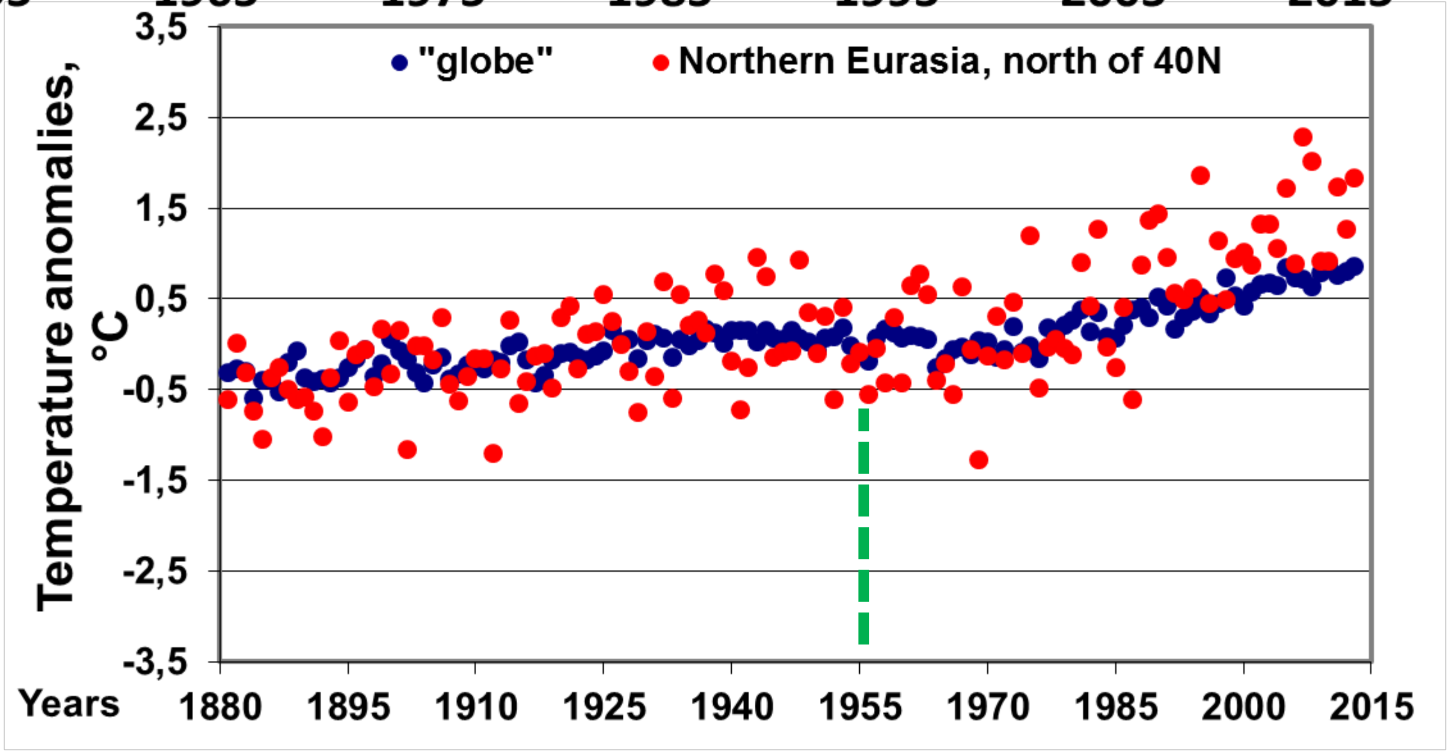


Global Annual Surface Air Temperature Anomalies, °C

Global temperature anomalies



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).



Two possible scenarios after the permafrost thaw:

- **Wetlands**

- **Steppe**

(V. Romanovsky, 2003)

Coastal southeastern United States

“Cold“(SST < 28.3°C) and “warm” (SST > 28.3°C) landfall tropical cyclones (TC) sorted by the TC strength for the 1985-2005 period;

SST here is a daily SST in front of TCs

• TC event class	All	Tropical depression	Tropical storm	Hurricanes with sustainable wind speed < 49 m s^{-1}	Hurricanes with sustainable wind speed > 49 m s^{-1}
Warm TC events	59	3	30	13	13
Cold TC events	23	2	13	8	0

$P < 0.02$

III to V cat.

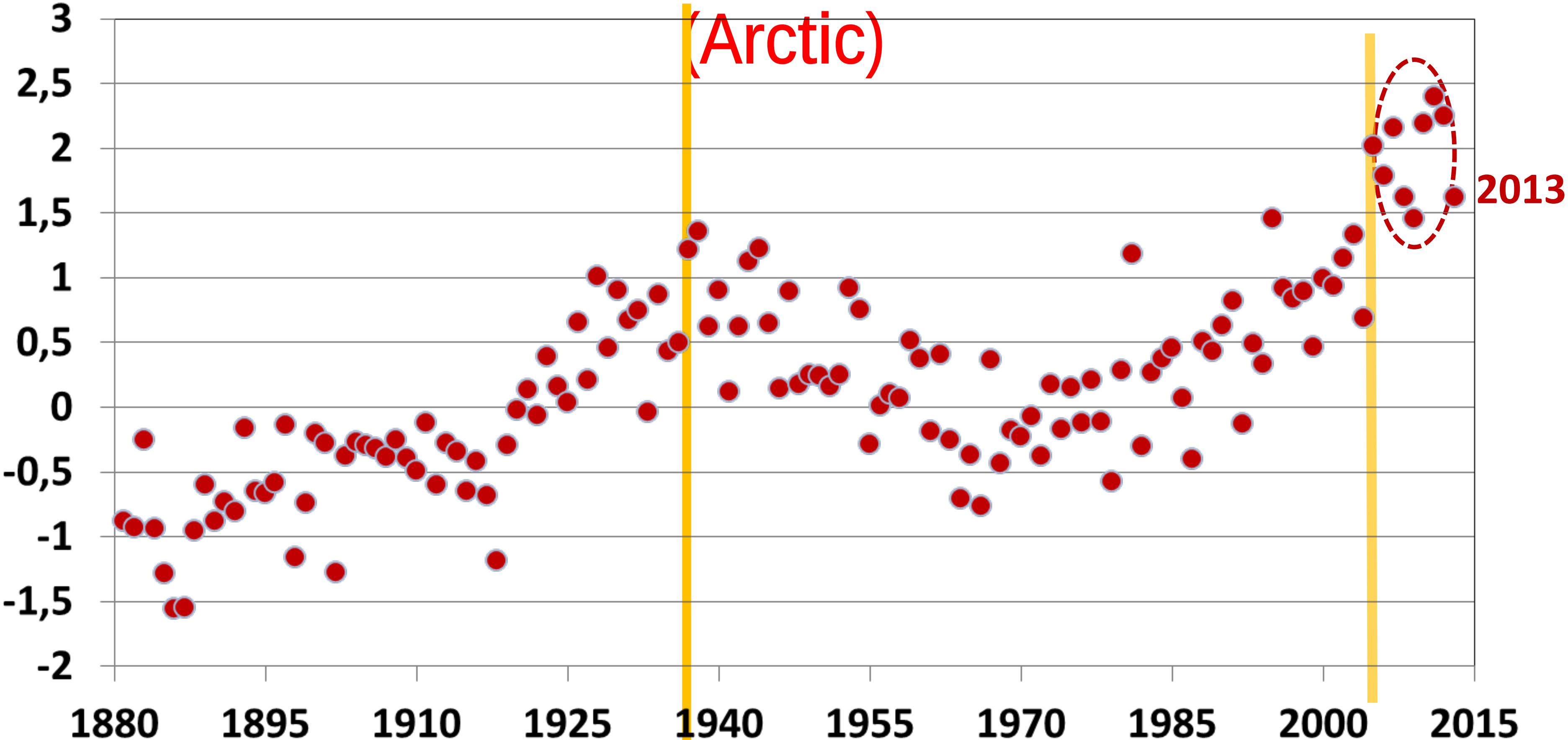
Total amount of rainfall per hurricane season (hs) over the southeastern U.S. during the 1985-2005 period from TC events

41 “cold” TC events	41 km^3 hs^{-1}
41 “warm” TC events	45 km^3 hs^{-1}

Partition cold/warm is made by SST during the few days before the landfall; SST{“warm”} -SST{“cold”} = 1.6°C

See, please, lecture by V. Semenov

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



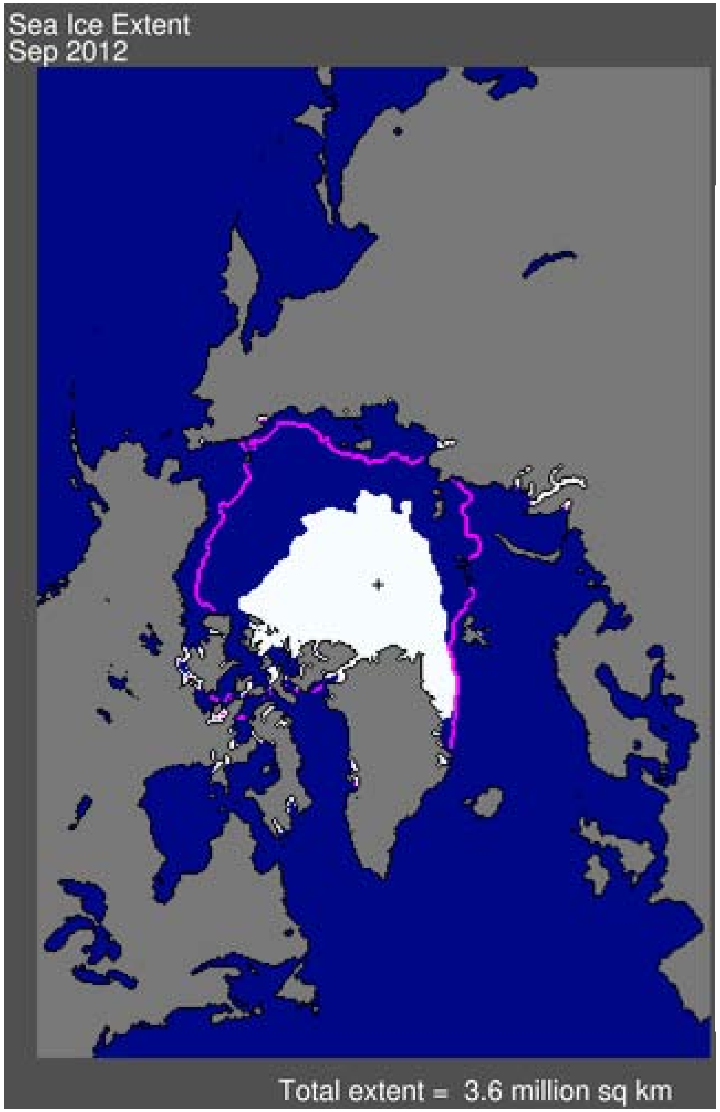
There were periods (e.g., 1936-2004) when there was no statistically significant linear trend (SWIPA 2011; Ch.1, updated).

Anomalies were calculated from the mean values for the 1951-1975 reference period.

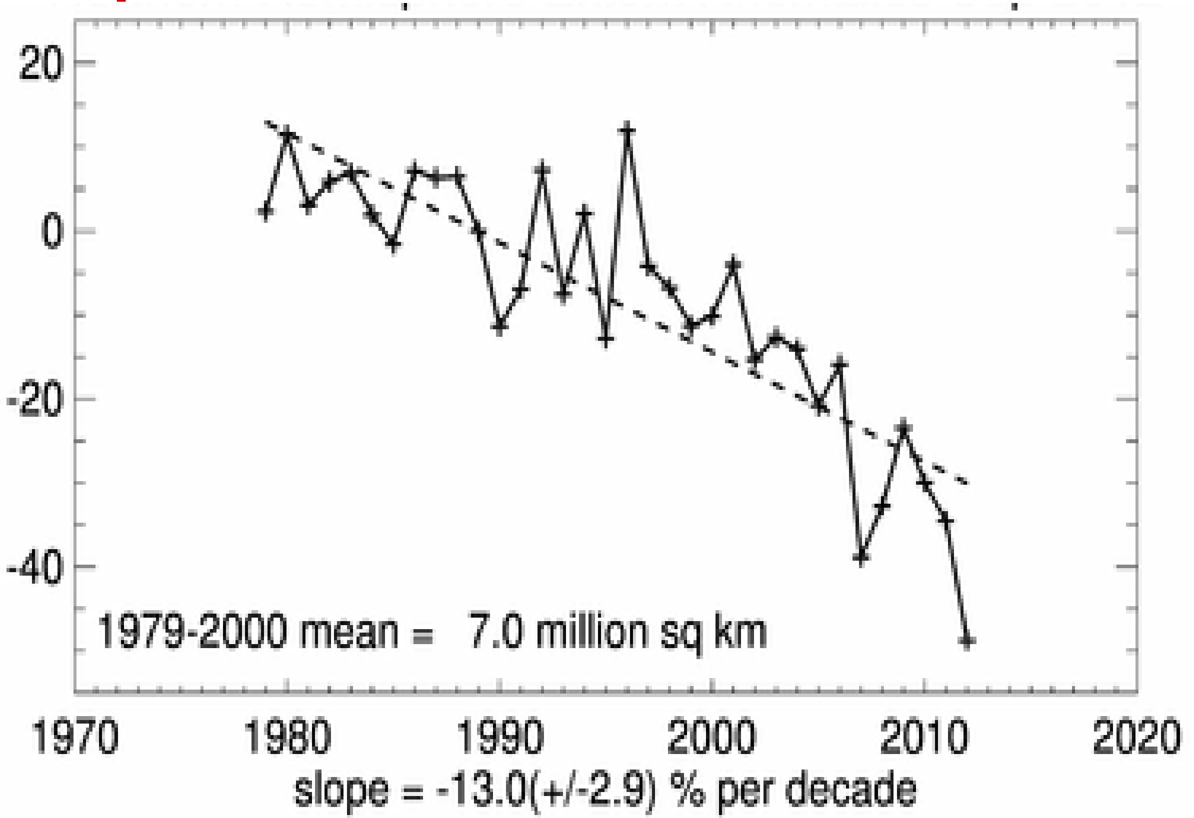
Two consequences of the Arctic warming

- Changes in the Arctic Sea Ice
- Changes in the meredional gradient of air temperature

Lowest recorded Northern Hemisphere sea ice extent in mid-September 2012

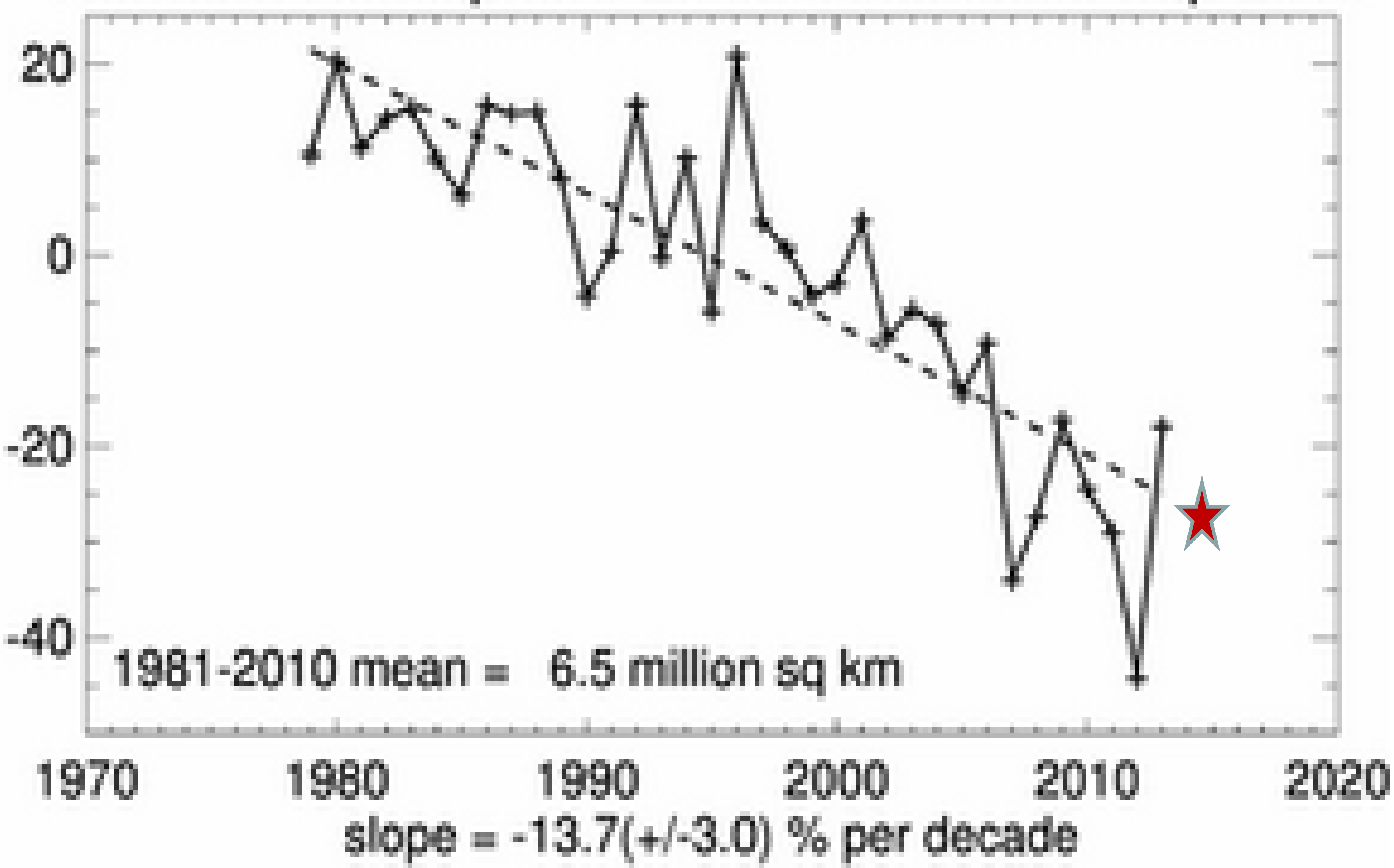


September 1979–2012 anomalies, %



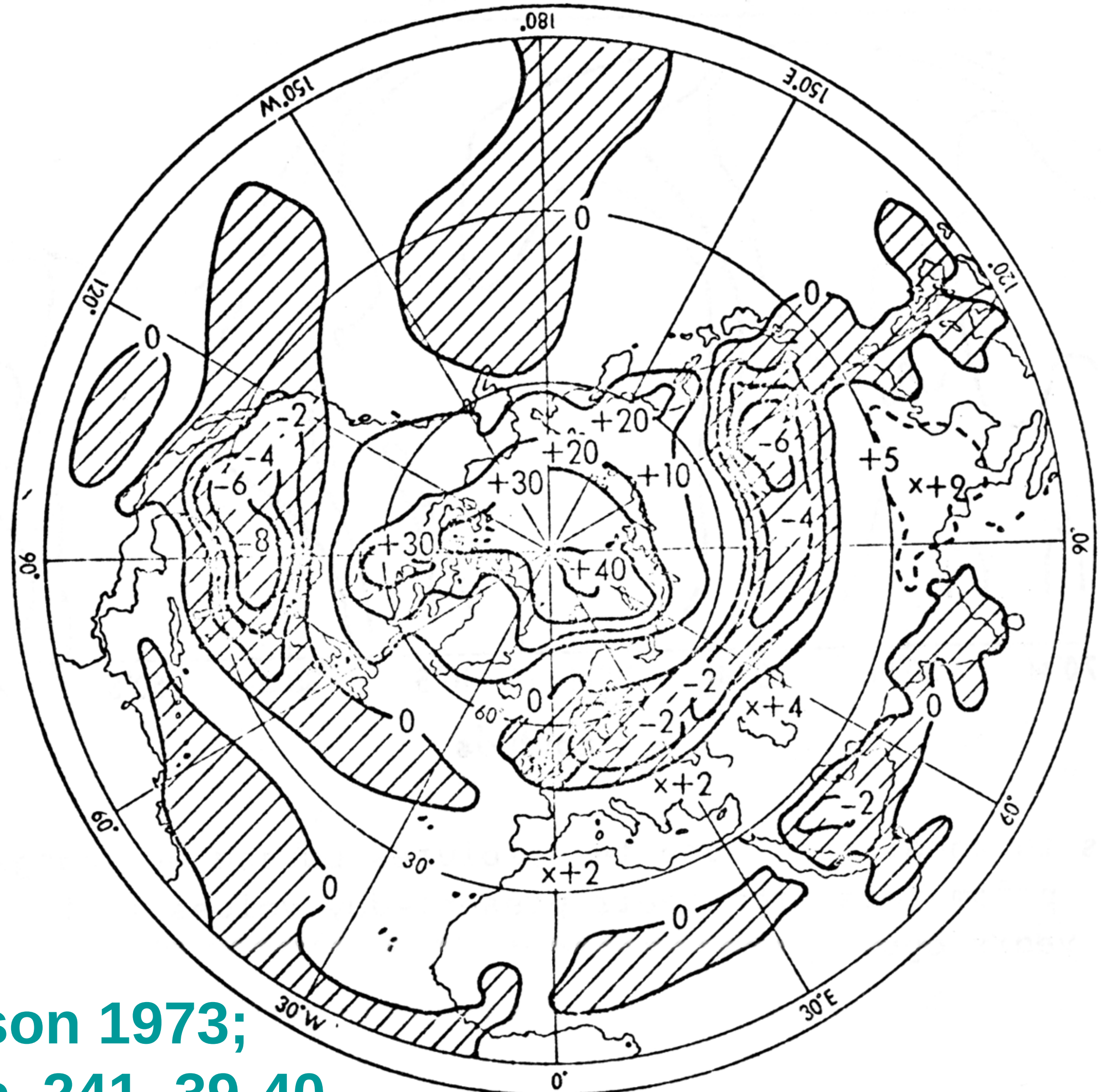
Source: U.S. National Snow & Ice Data Center, Boulder, Colorado, USA

Northern Hemisphere Sea Ice Extent. September 1979-2013 anomalies, %



One of the first UCMO GCM sensitivity experiments with polar ice replaced by water at 0°C

Changes in January surface air temperature. The Arctic becomes warmer by up to 40° C but the latitudinal belt south of 60°N over land becomes colder by up to 8°C.

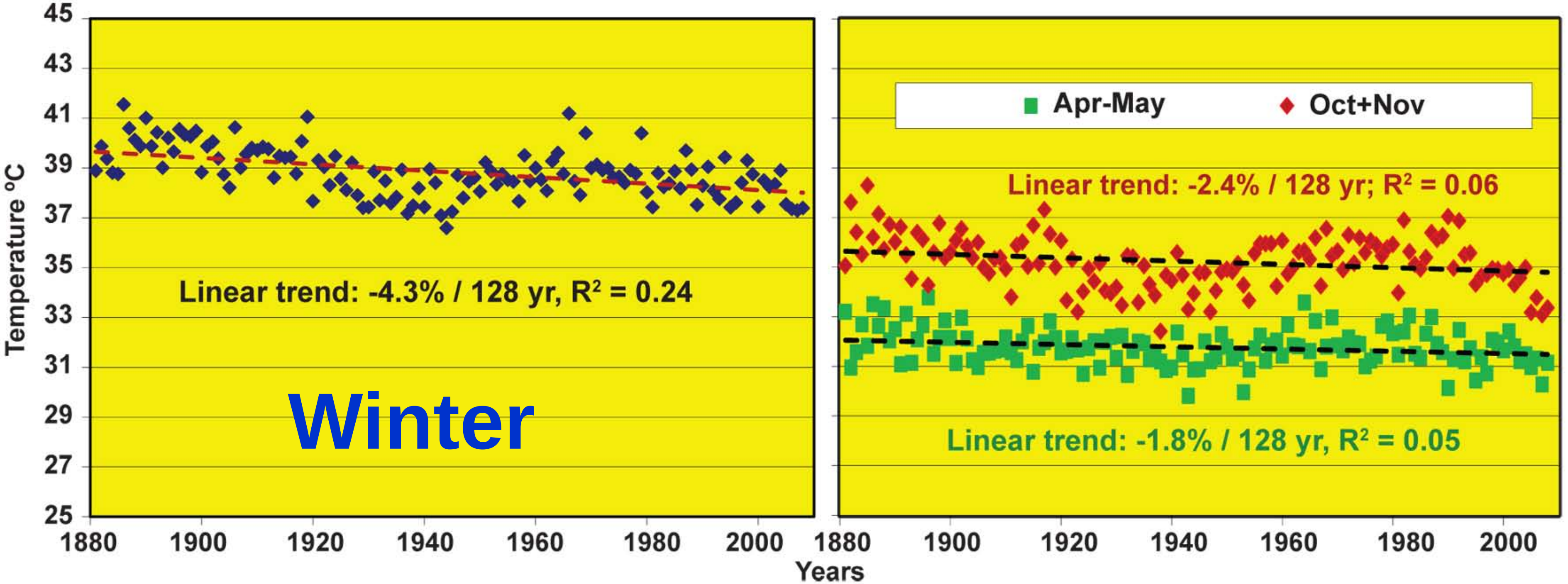


Newson 1973; *Nature*, 241, 39-40

Meridional temperature gradient changes: What do they mean for the Northern Hemisphere in the cold season?

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.

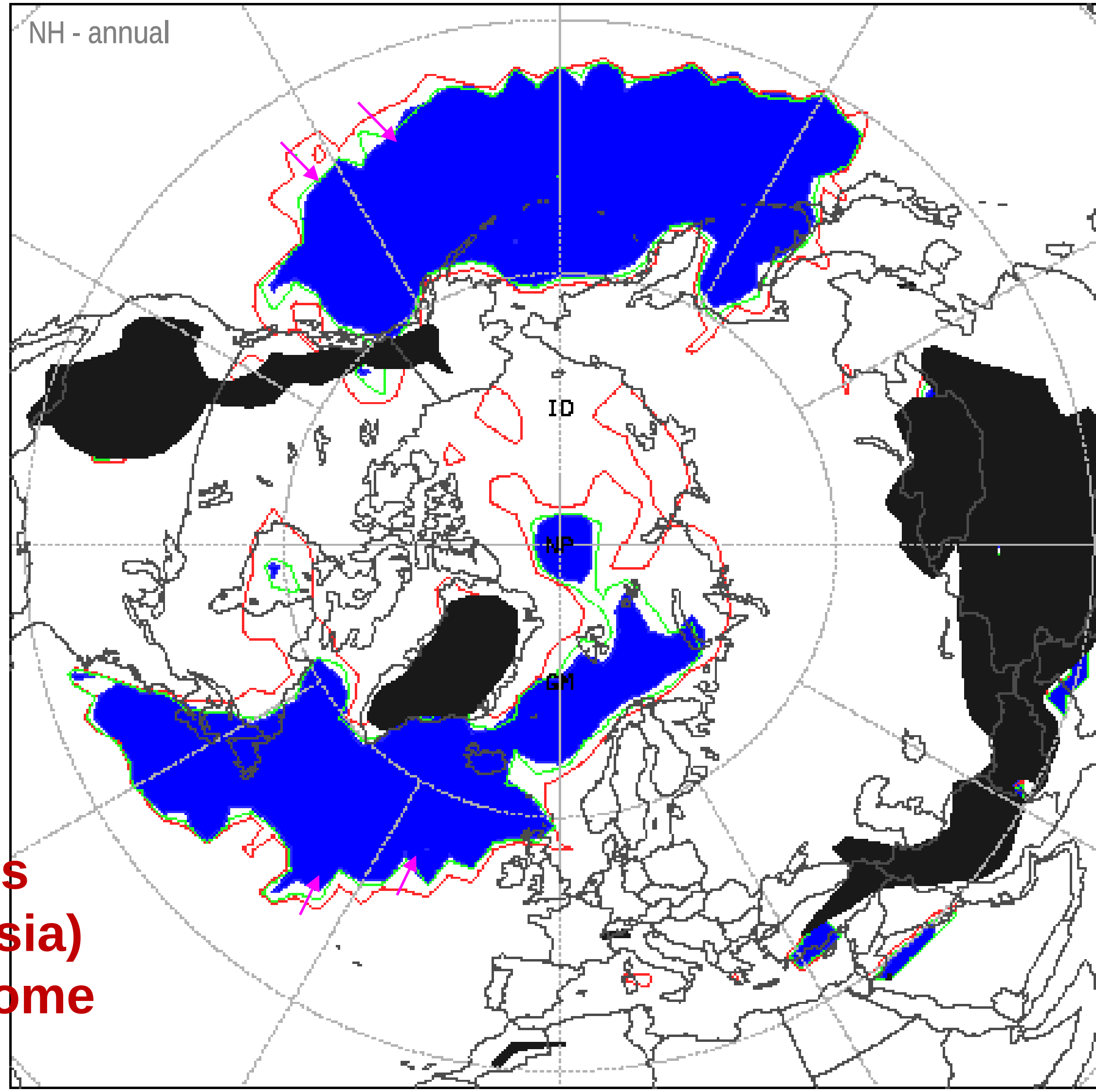
Possible consequences of the $-\partial T/\partial \varphi$ decrease

- Weakening of the westerlies
- Northward shift of the extratropical cyclone trajectories
- More frequent cold season blocking conditions of atmospheric circulation over Eurasia (cf., Mokhov 2006)
- More frequent penetration of “tropical weather” (e.g., late tropical cyclone remnants) in the extratropics (first report: Vetroumov 1977, *Meteorol. and Hydrol*.)

Major storm track regions in the 20th Century Reanalysis

defined by the 85th percentile contour of long-term mean strong cyclone counts

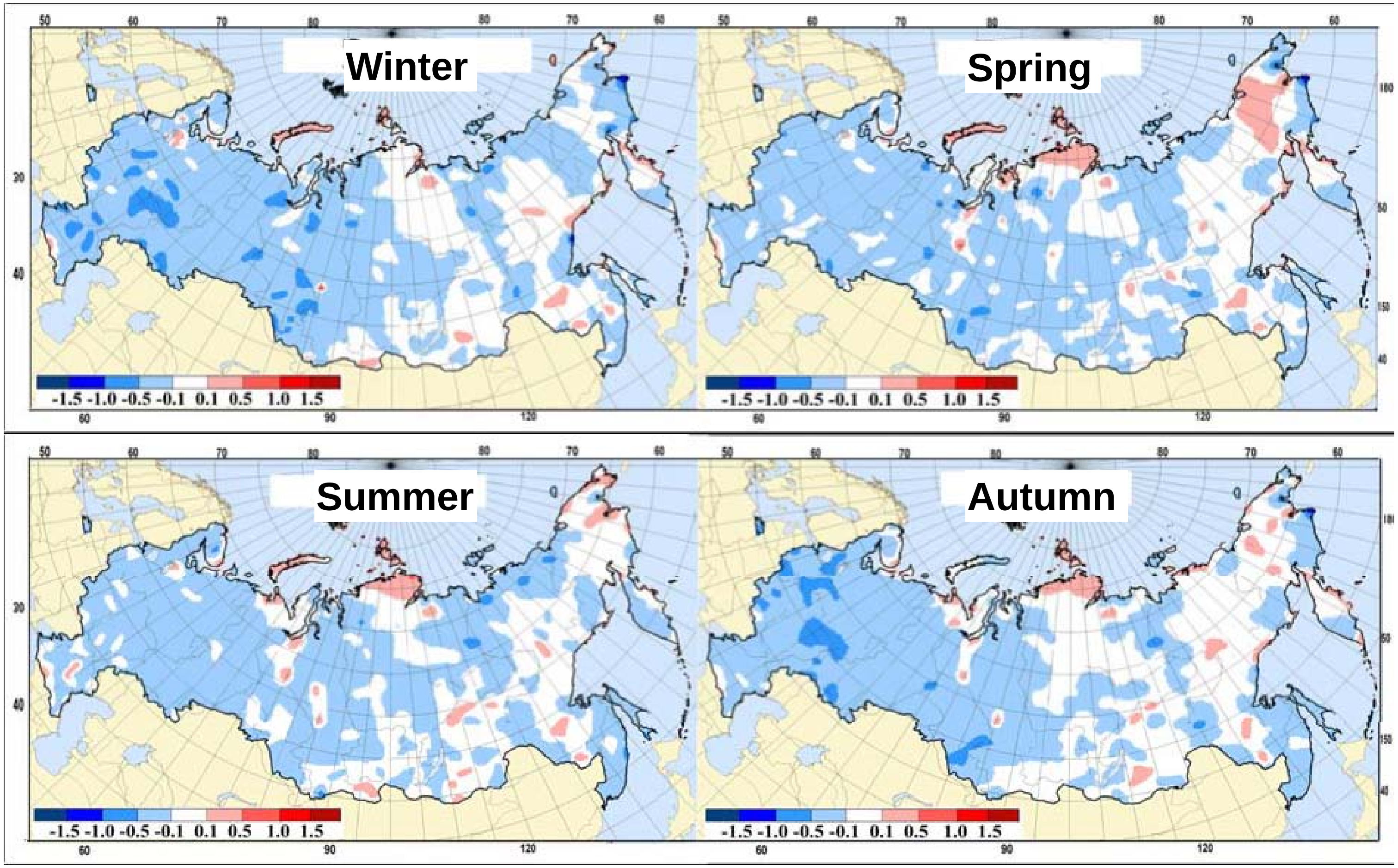
30-yr periods
Blue shading: 1979-2008 (current)
Green line: 1941-1970 (mid 20th century)
Red line: 1901-1930 (early 20th century)
Black shading: no data



Wang et al. 2012

=> Inside the continents (first of all, inside Eurasia) winter climate can become more continental)

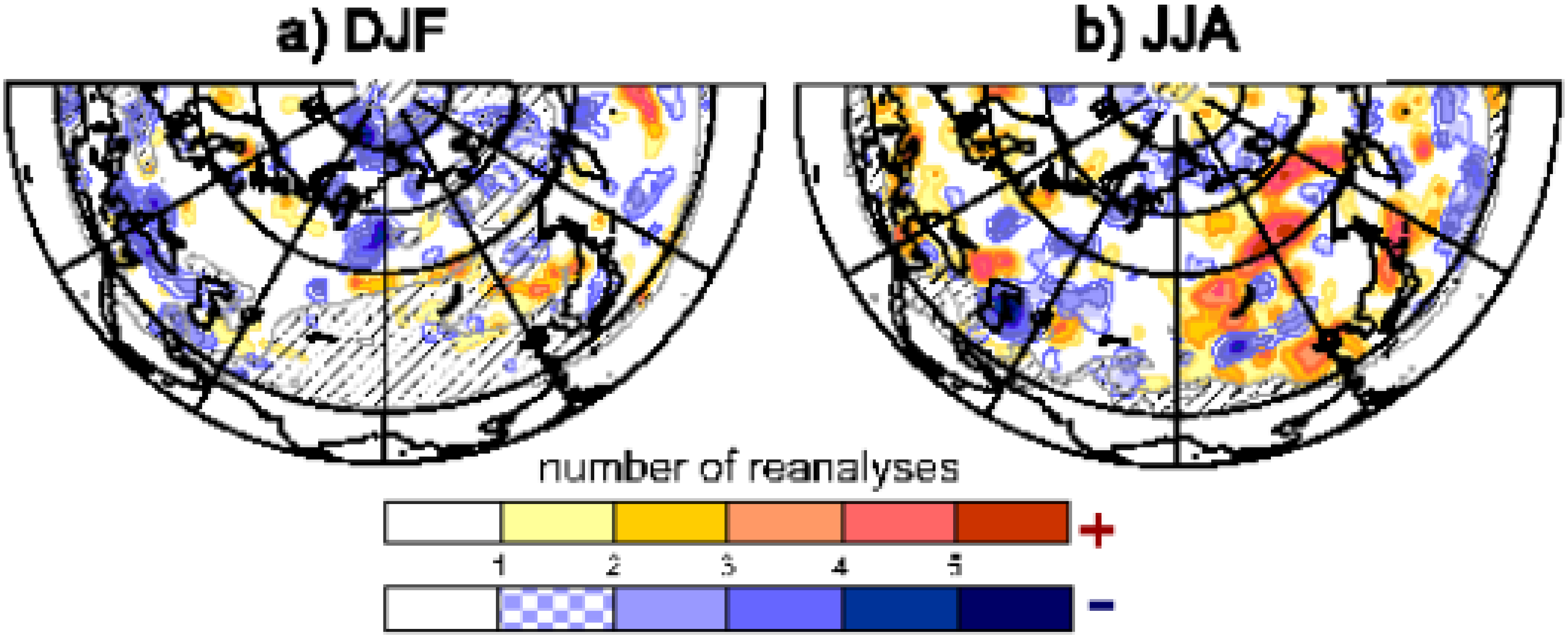
Wind Speed Trends over Russia, 1977-2011, Bulygina et al. 2013



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

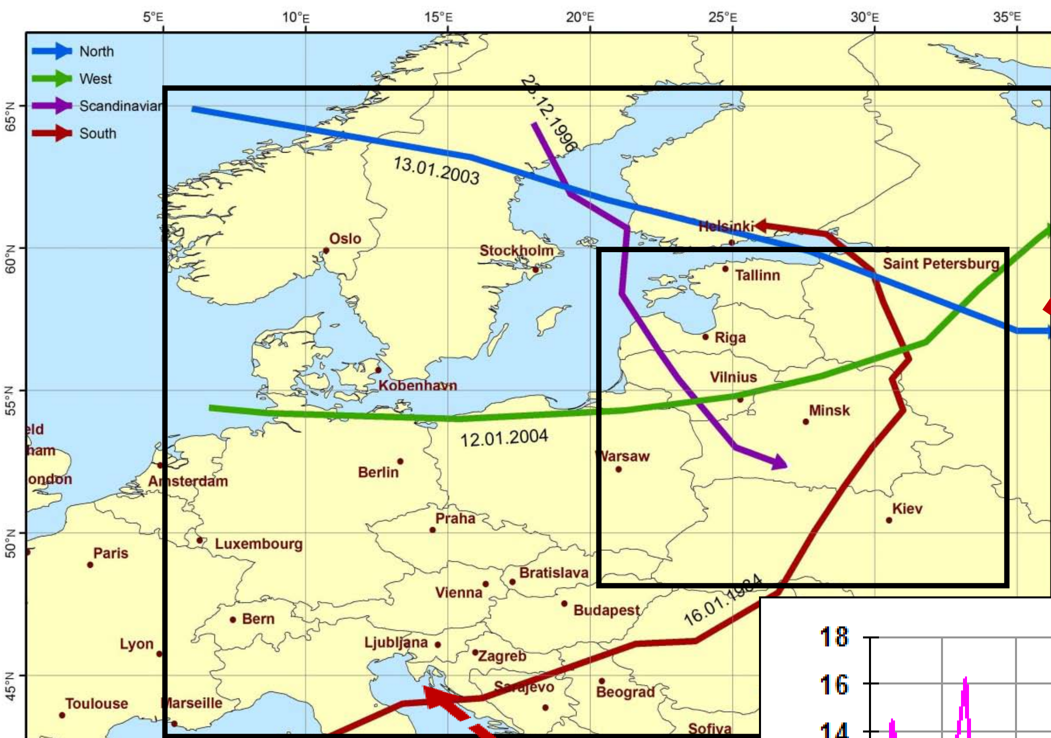
Shaded areas have statistically significant trends

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



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

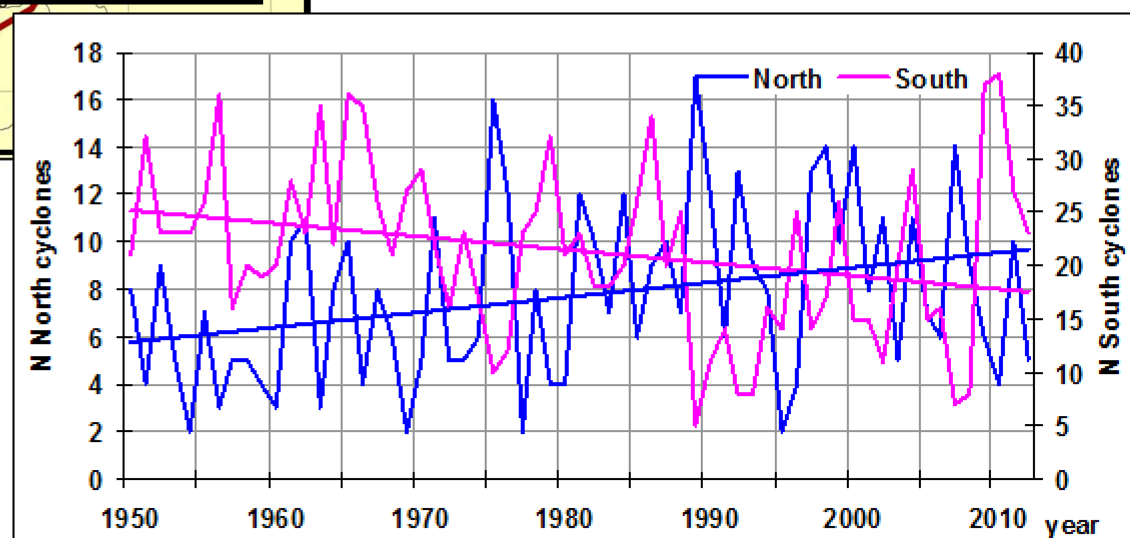
Two domains where dynamics of different types of winter extratropical cyclones sorted by their origination were linked to spring & winter streamflow over Belarus

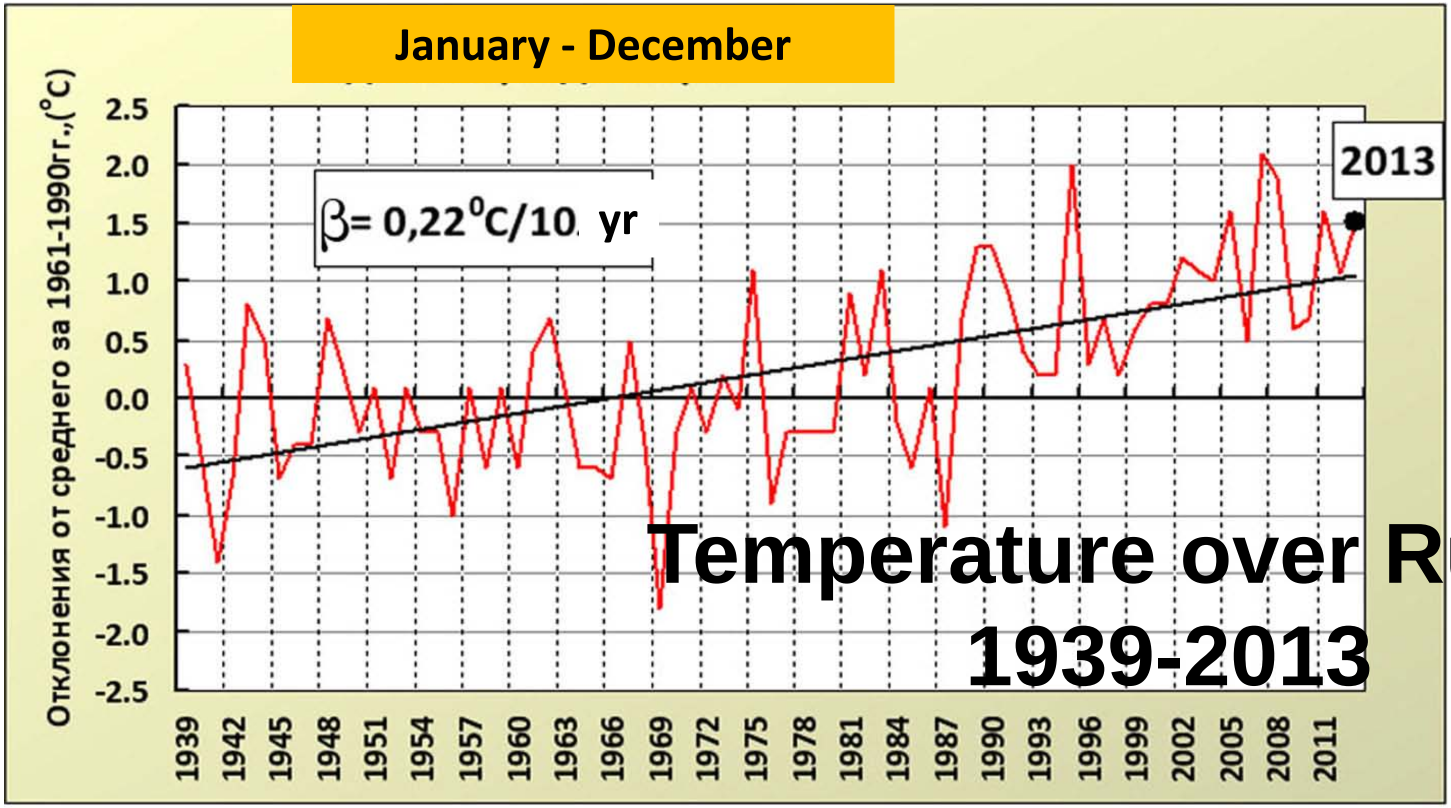


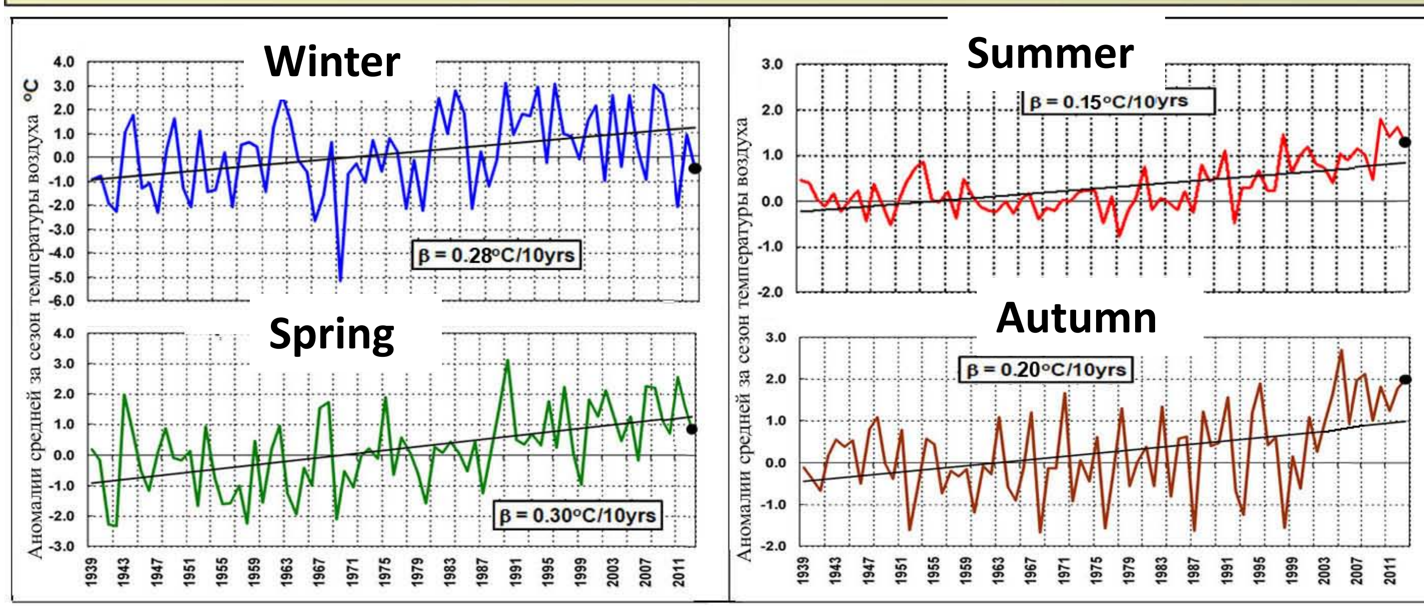
Increase in the frequency of "North" cyclones during the past 60 years, caused warmer winters (more thaw, snowmelt, and winter streamflow) and indirectly reduced peak spring streamflow.

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.



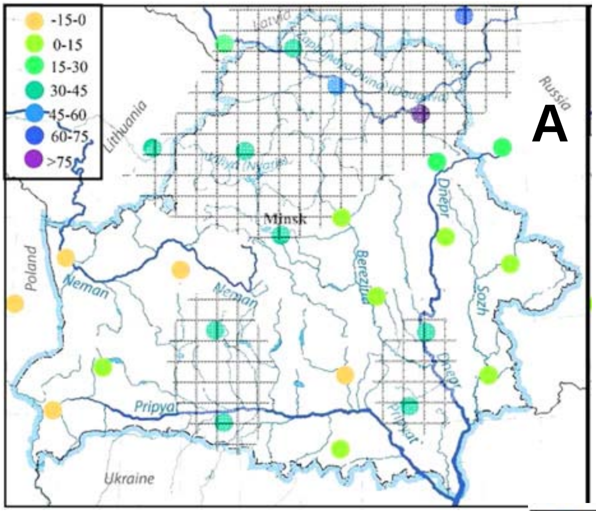

January - December
β= 0,22°C/10 yr
2013
Temperature over Russia; 1939-2013
Отклонения от среднего за 1961-1990гг.,(°C)
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
1939 1942 1945 1948 1951 1954 1957 1960 1963 1966 1969 1972 1975 1978 1981 1984 1987 1990 1993 1996 1999 2002 2005 2008 2011


Winter
β = 0.28°C/10yrs
Spring
β = 0.30°C/10yrs
Summer
β = 0.15°C/10yrs
Autumn
β = 0.20°C/10yrs
Аномалии средней за сезон температуры воздуха °C

Part 2. Spring Processes

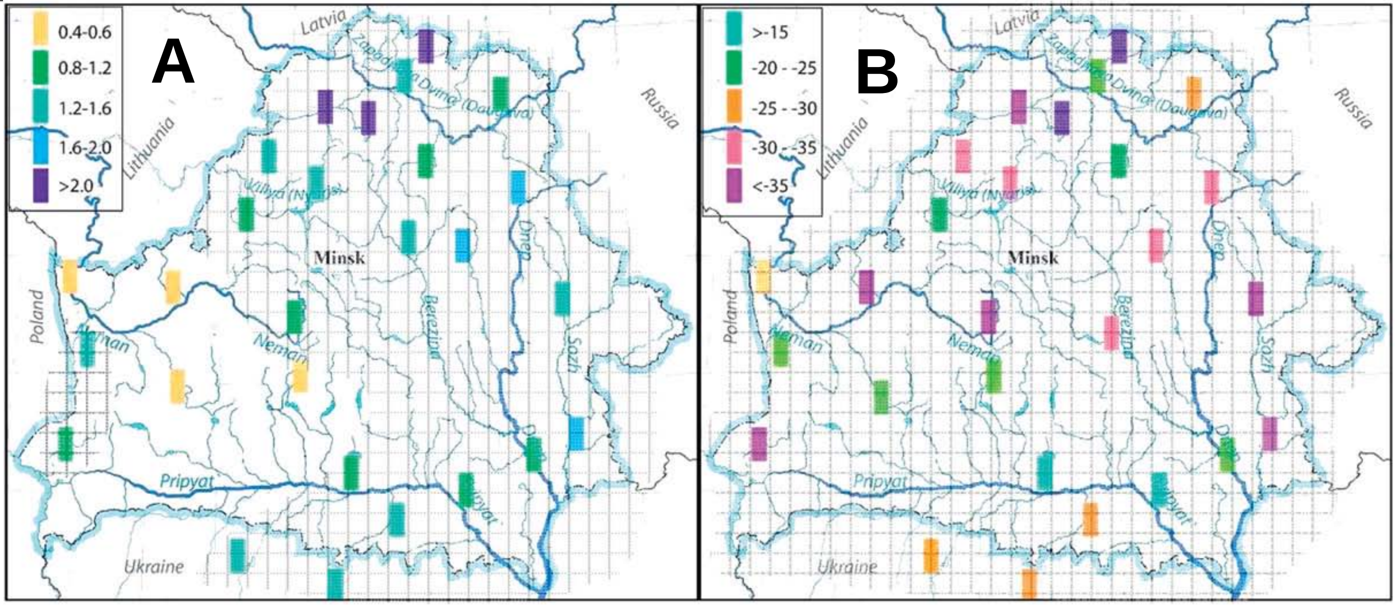
- Milder winter (thaws, increase in winter streamflow)
- Earlier snow cover retreat but
- Higher maximum snow depth and SWE prior to snowmelt
- Increase of the warm season duration

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



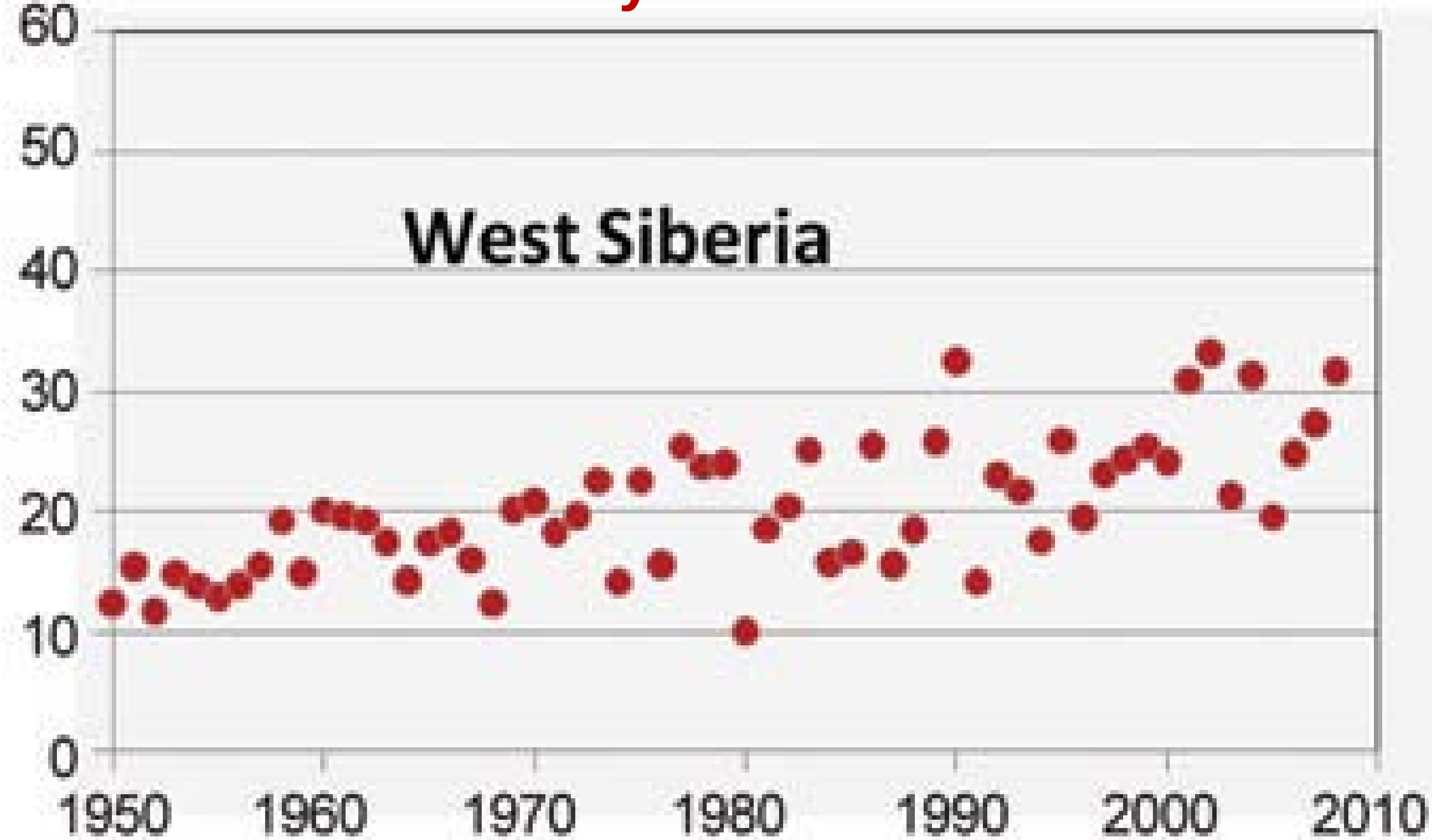
Spatial distribution of the net precipitation (**top**, mm) and streamflow (**bottom**, litre s^{-1} km^{-2}) change for the 1949–2010 period, during the winter (A) and spring (B) seasons.

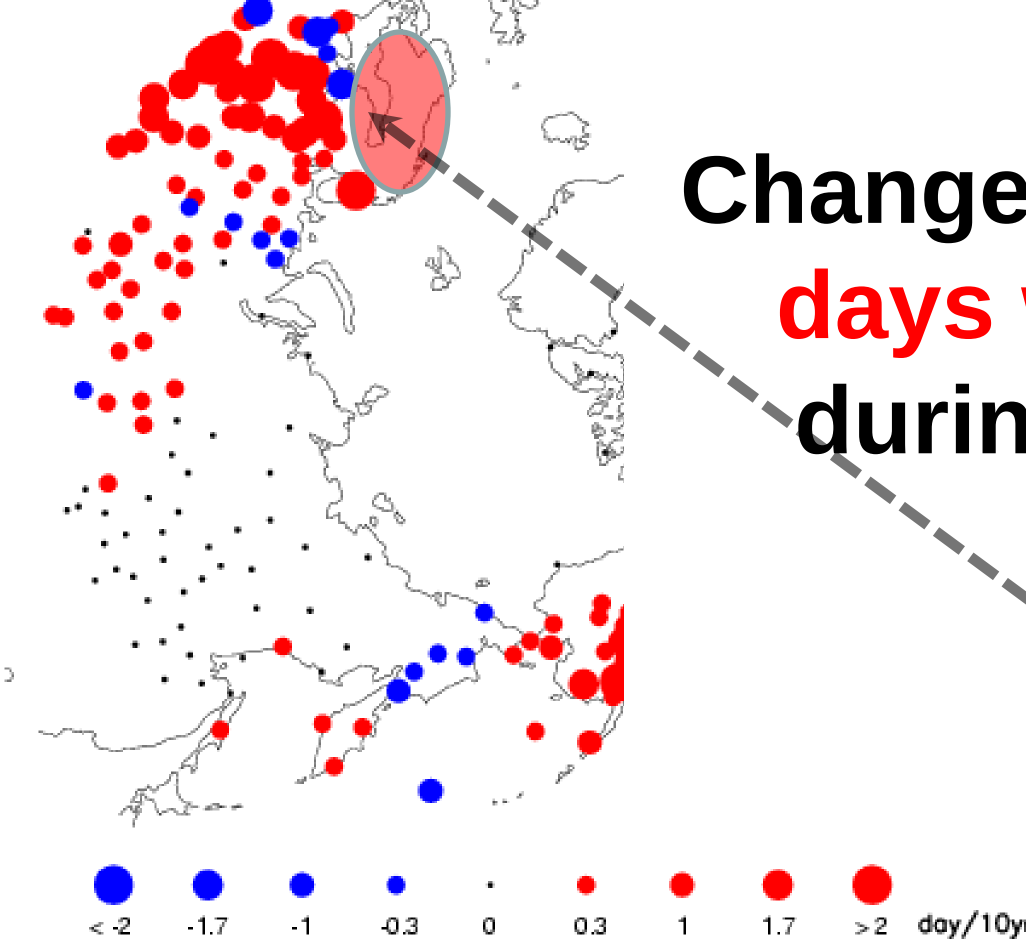
The hatched areas in the maps outline statistically significant values of change at the 0.05 level.



We define "days with thaw" as the days when the mean daily temperature is above -2°C while snow on the ground is above 5 cm.

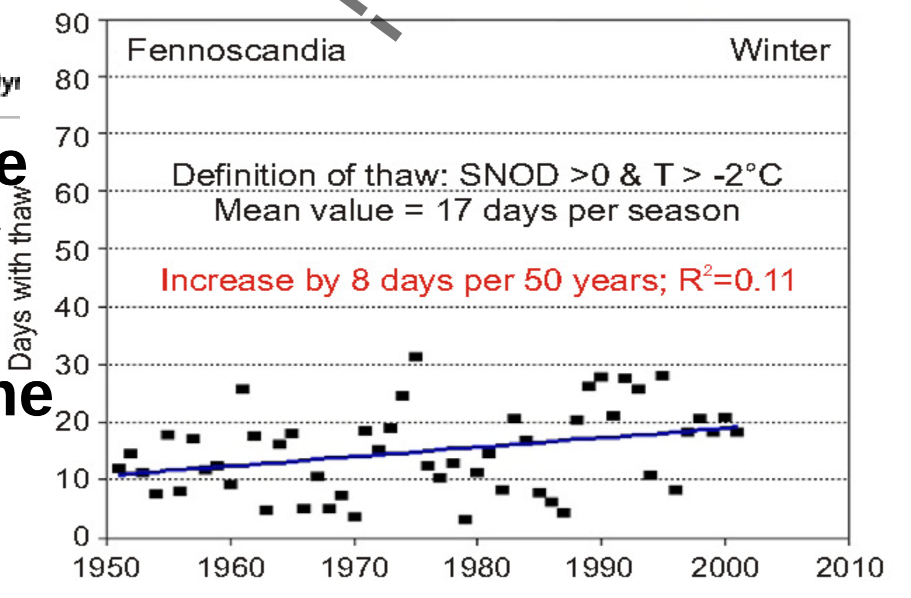
Annual number of days with thaw in West Siberia



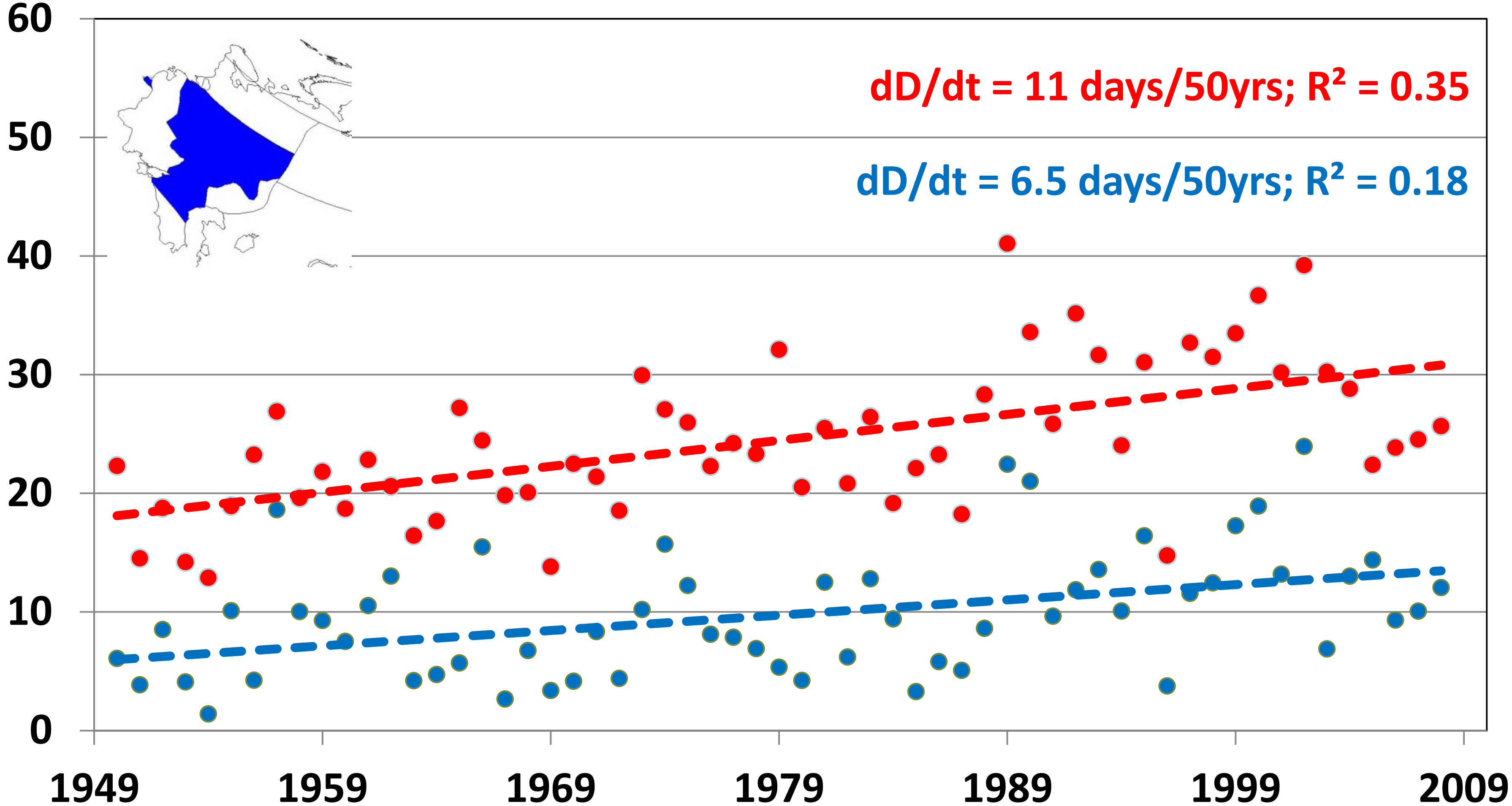


Changes in the number of days with winter thaw during the 1950-2000 period

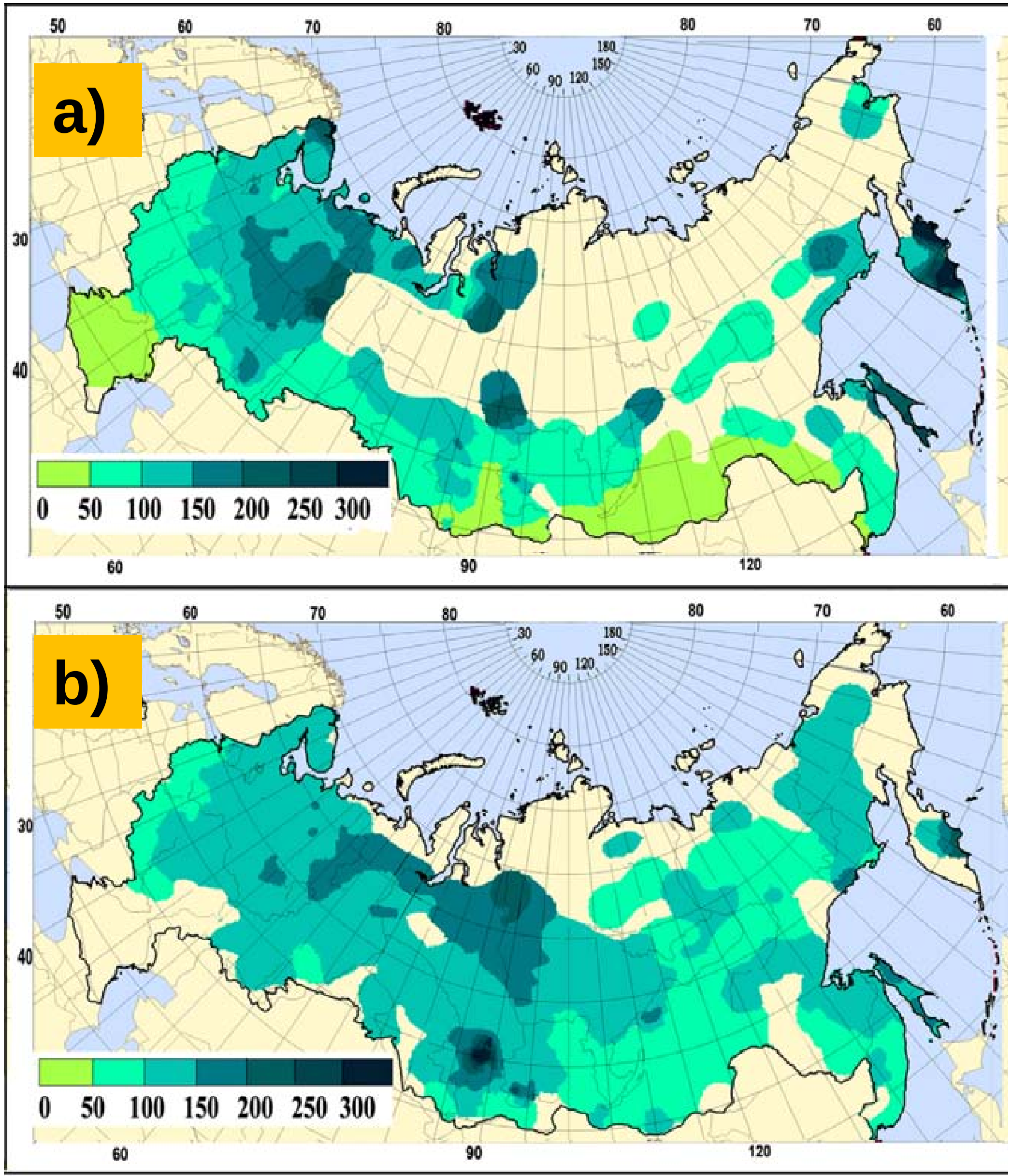
Top. Linear trend estimates in the winter number of days with thaw (days/10yr; Groisman et al. 2003). **Right.** The same, but regional time series for Fennoscandia (Groisman et al. 2009)



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



Maximum snow water equivalent, SWE
[Bulygina et al. 2011].

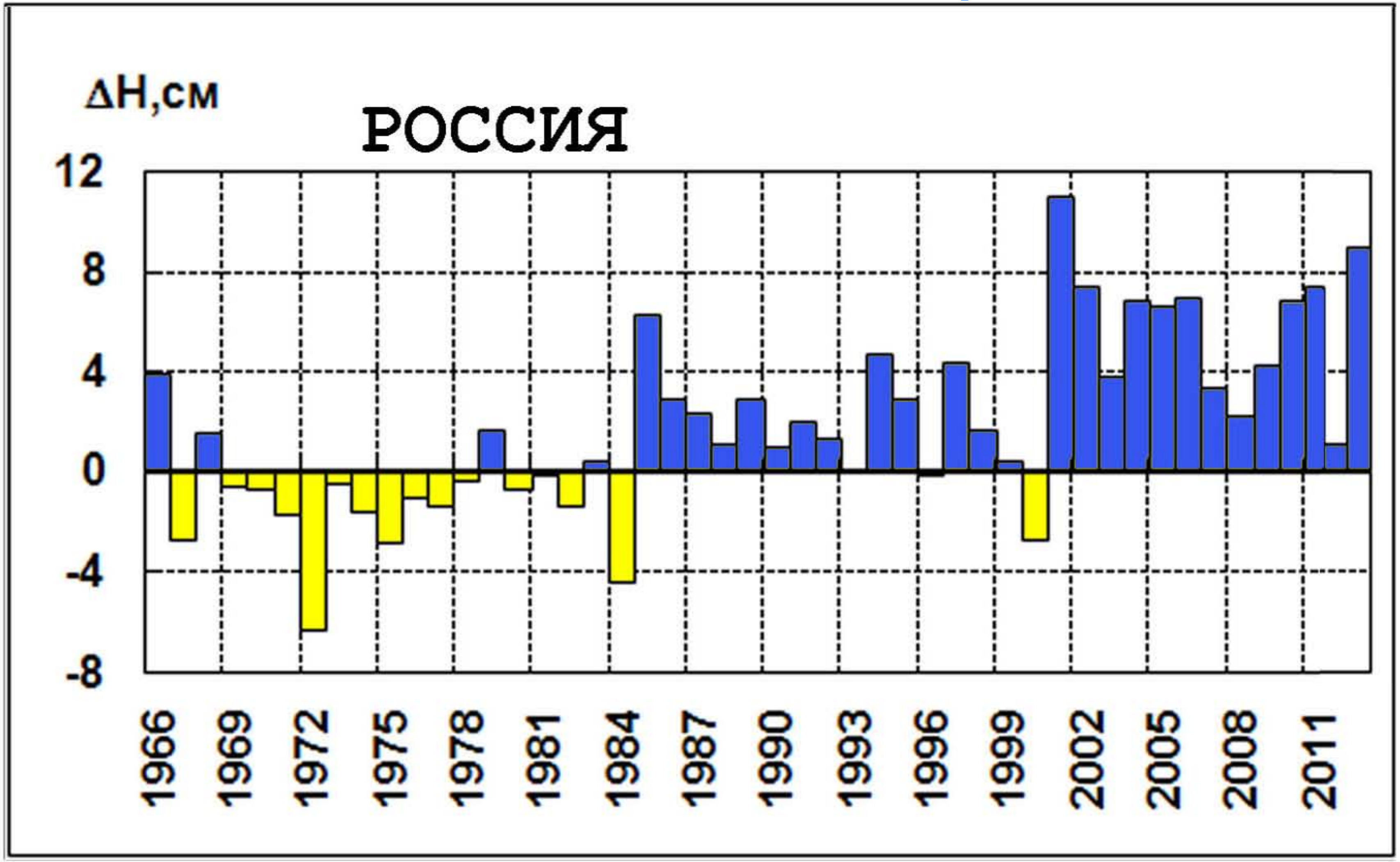


Long-term mean values (1966–2010) of maximum snow water equivalent in the field (a) and in the forest (b).

Changes of the maximum SWE over Russia (Bulygina et al. 2011)

Zone, region	Change in 1967-2009
• Arctic	No changes
• Fields of European Russia (ER), north of 55°N	Increase by 4 to 6%/10yr
• Southeast of “-”-”-”-”-”-”-” (ER)	Decrease by 4.5%/10yr
• Steppe-forest steppe of ER	No changes
• Fields of West Siberia	Increase by 6%/10yr
• Central East Siberia	Slight increase
• South of East Siberia	No changes
• Fields of Russian Far East	Increase by 3 to 6%/10yr

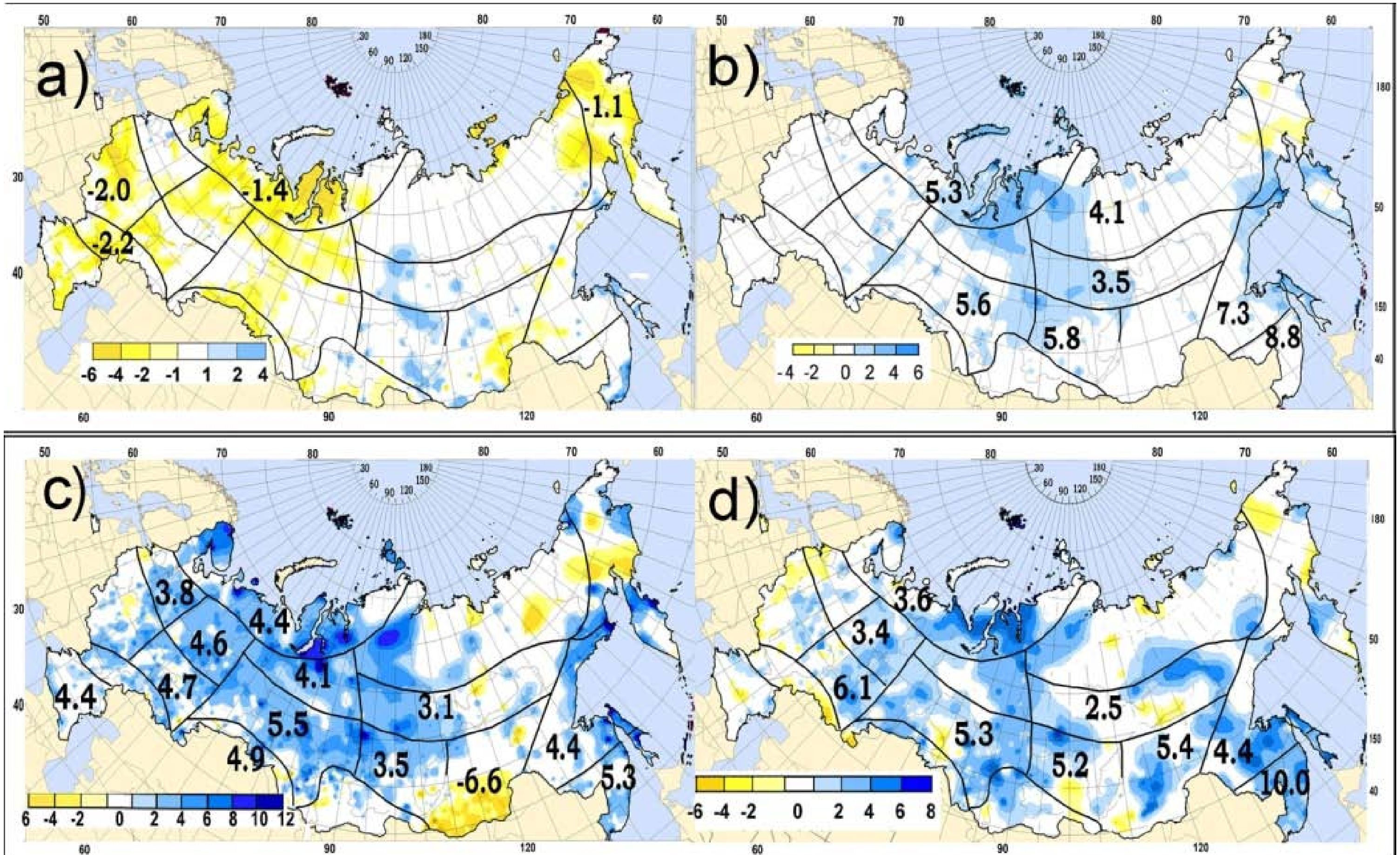
Anomalies of maximum cold season snow depth, cm area-averaged over Russia in deviations from the long-term mean values for the 1961-1990 period



The RIHMI data. 1966-2013 period

CHANGE IN SNOW CHARACTERISTICS

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

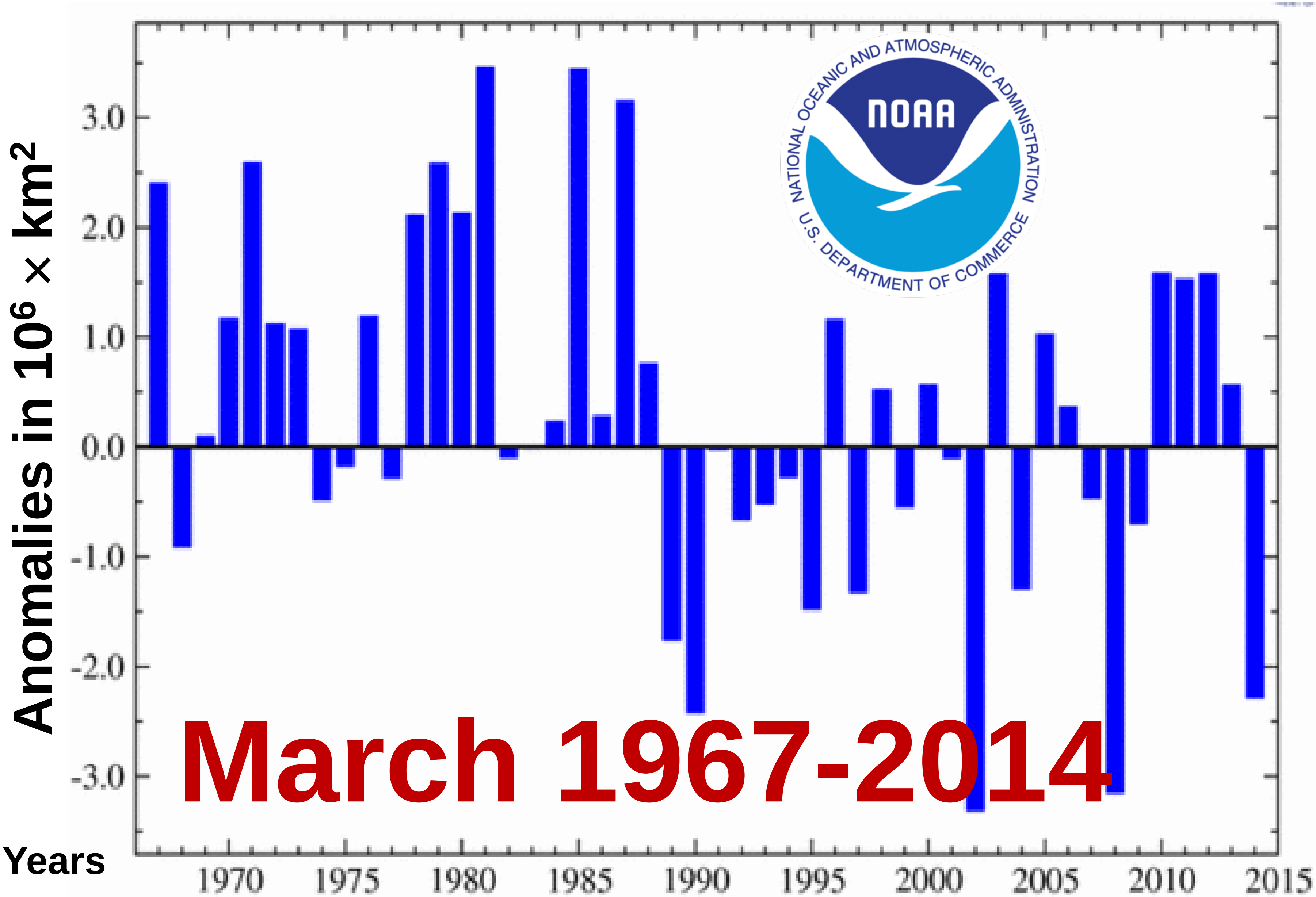


a) Number of days with snow covering > 50% of the area around a station
b) Mean winter snow depth
c) Maximum winter snow depth
d) Days with snow depth > 20 cm

Snow cover duration & density

Max snow depth and max snow water equivalent

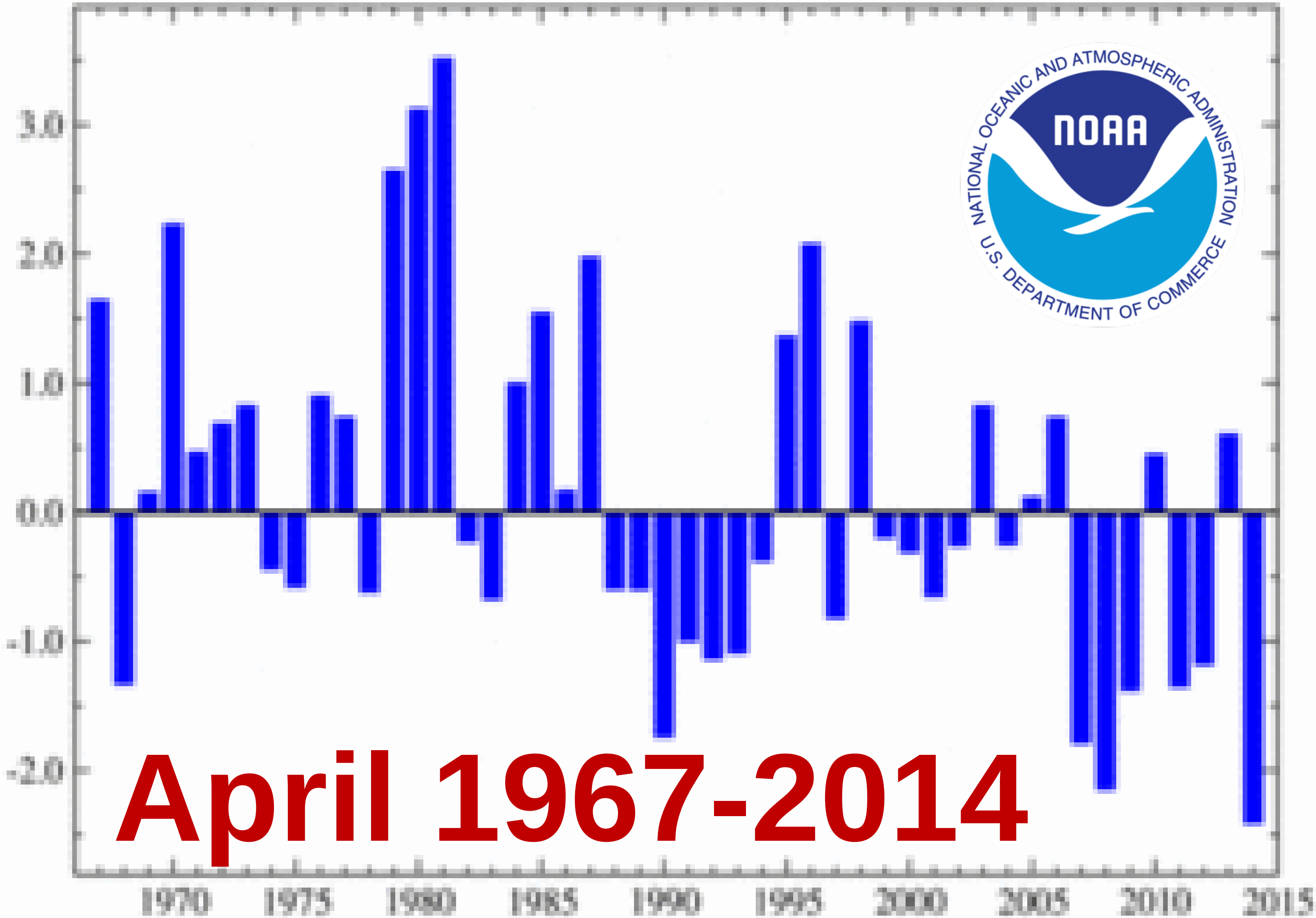
Snow cover extent anomalies over Eurasia



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

Snow cover extent anomalies over Eurasia

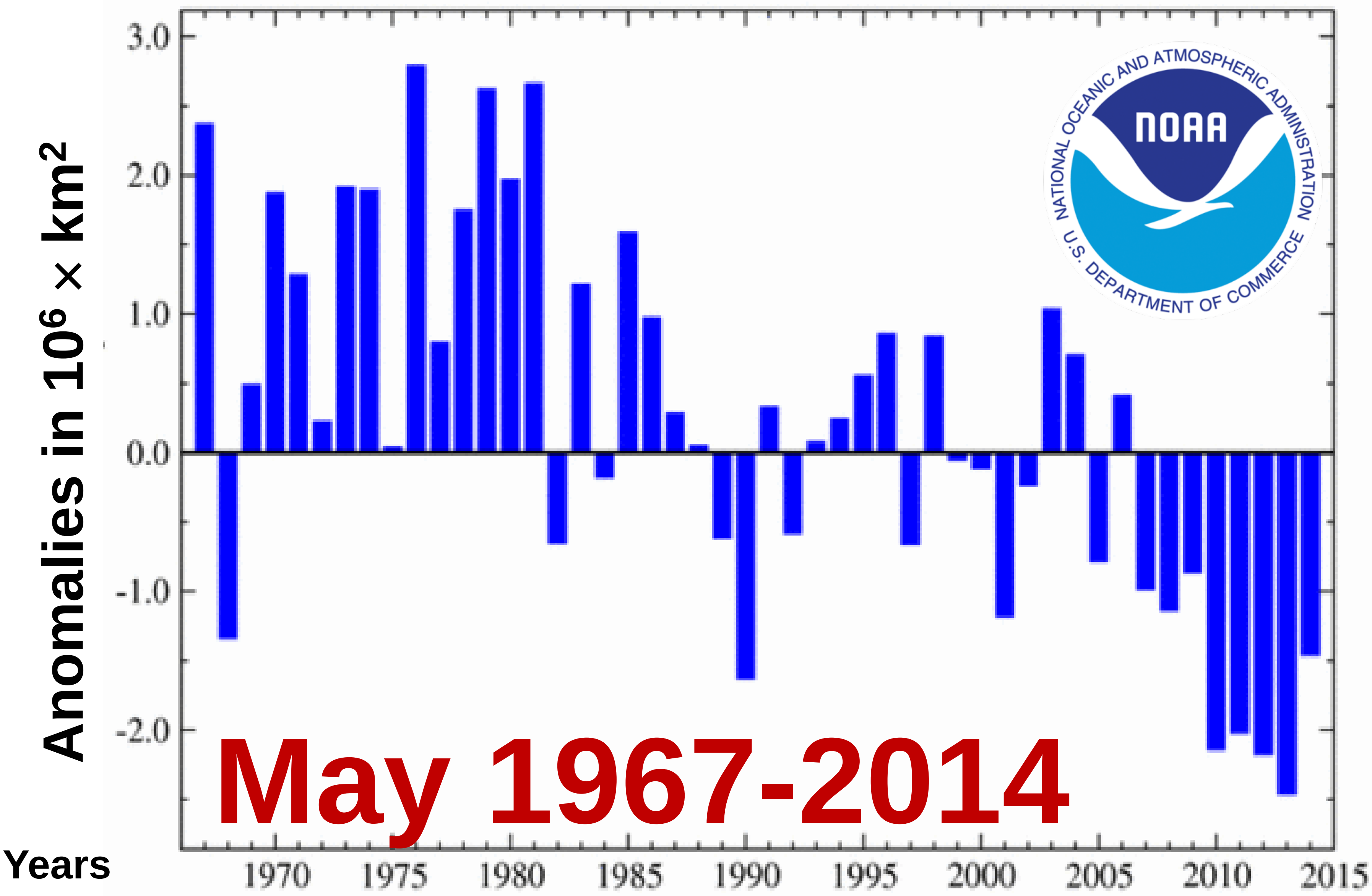
Anomalies in $10^6 \times km^2$



Years

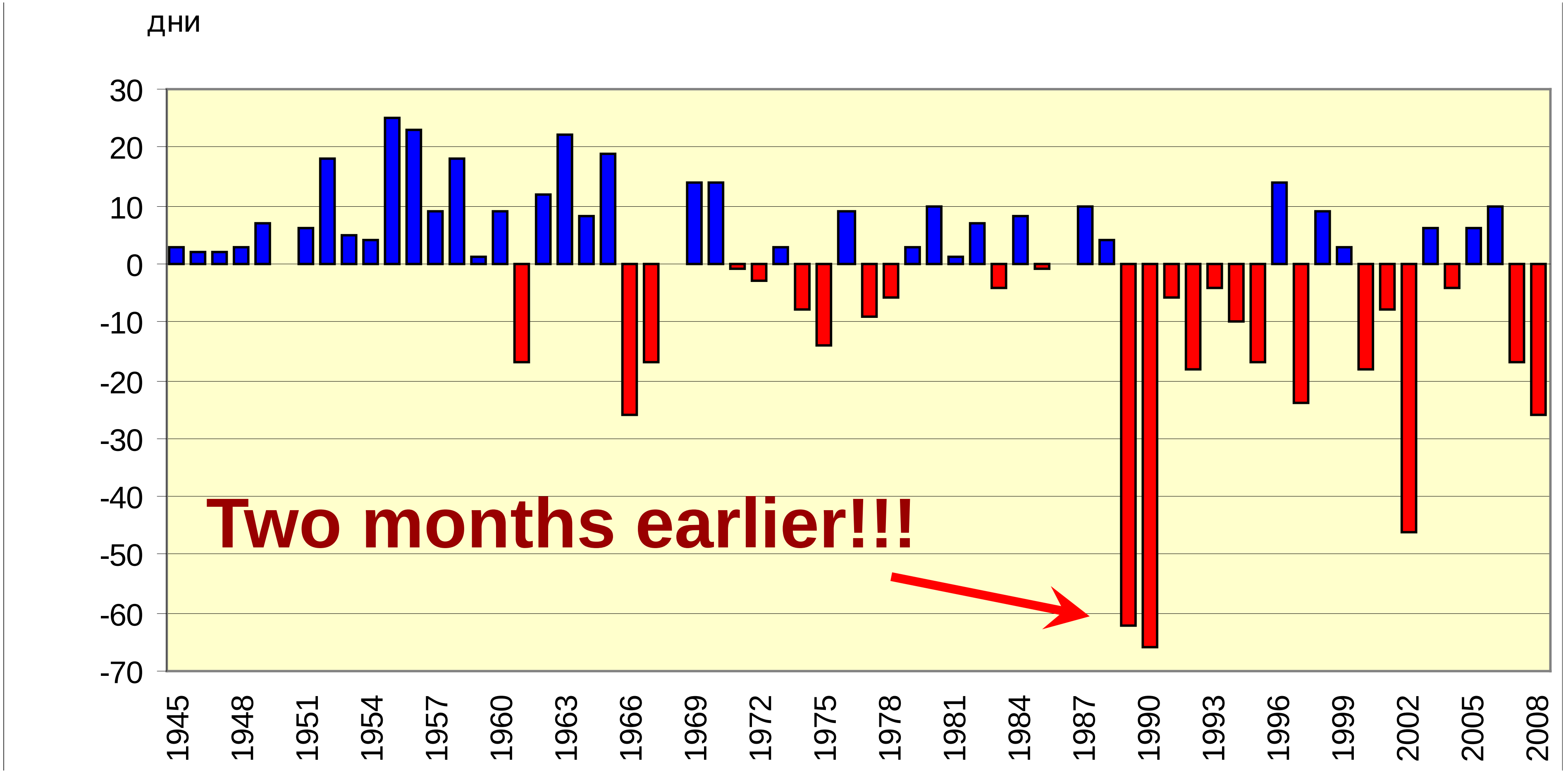
http://www.ncdc.noaa.gov/sotc/service/global/snowcover-eurasia/201404.gif

Snow cover extent anomalies over Eurasia



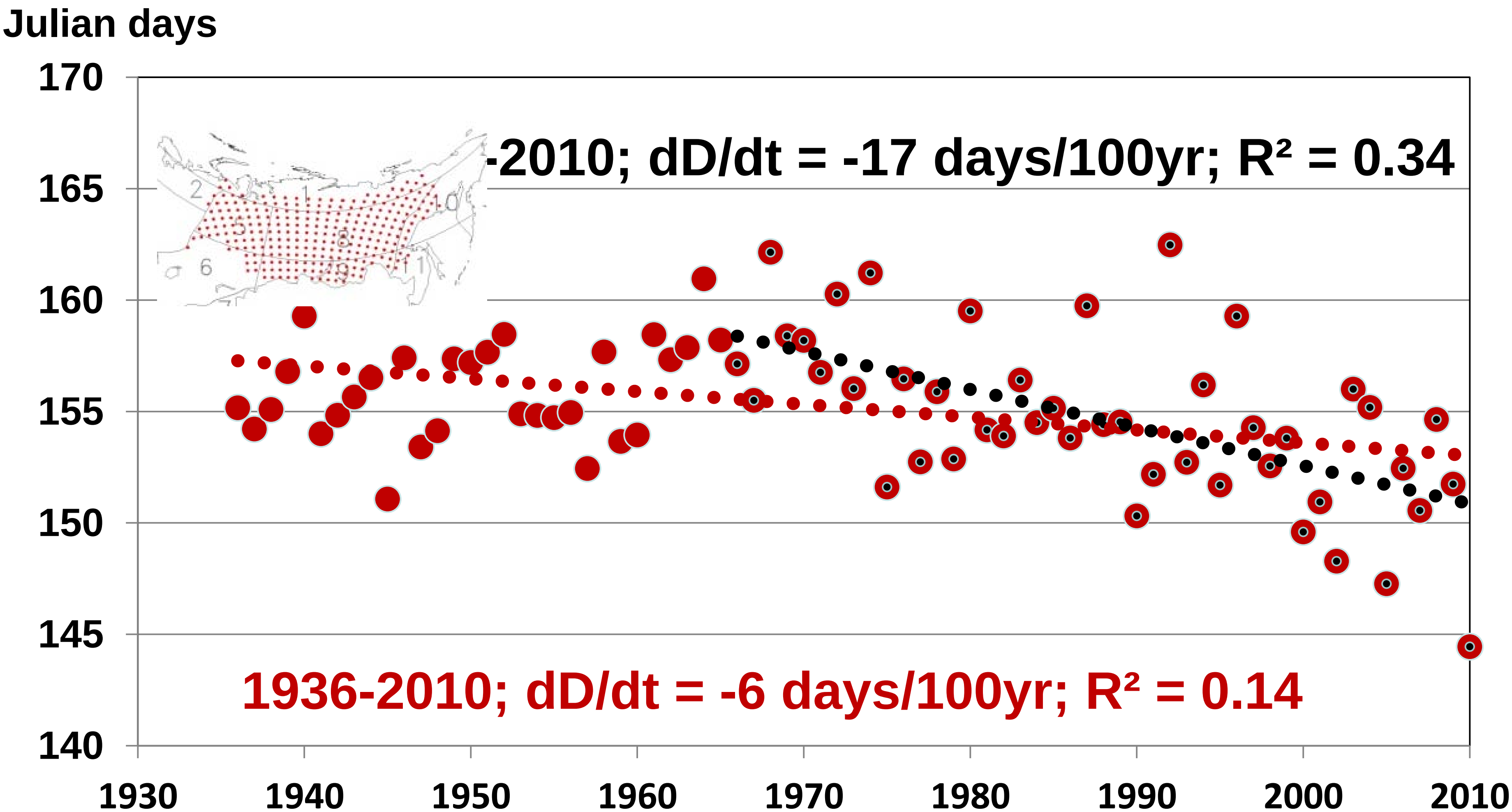
http://www.ncdc.noaa.gov/sotc/service/global/snowcover-eurasia/201405.gif

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



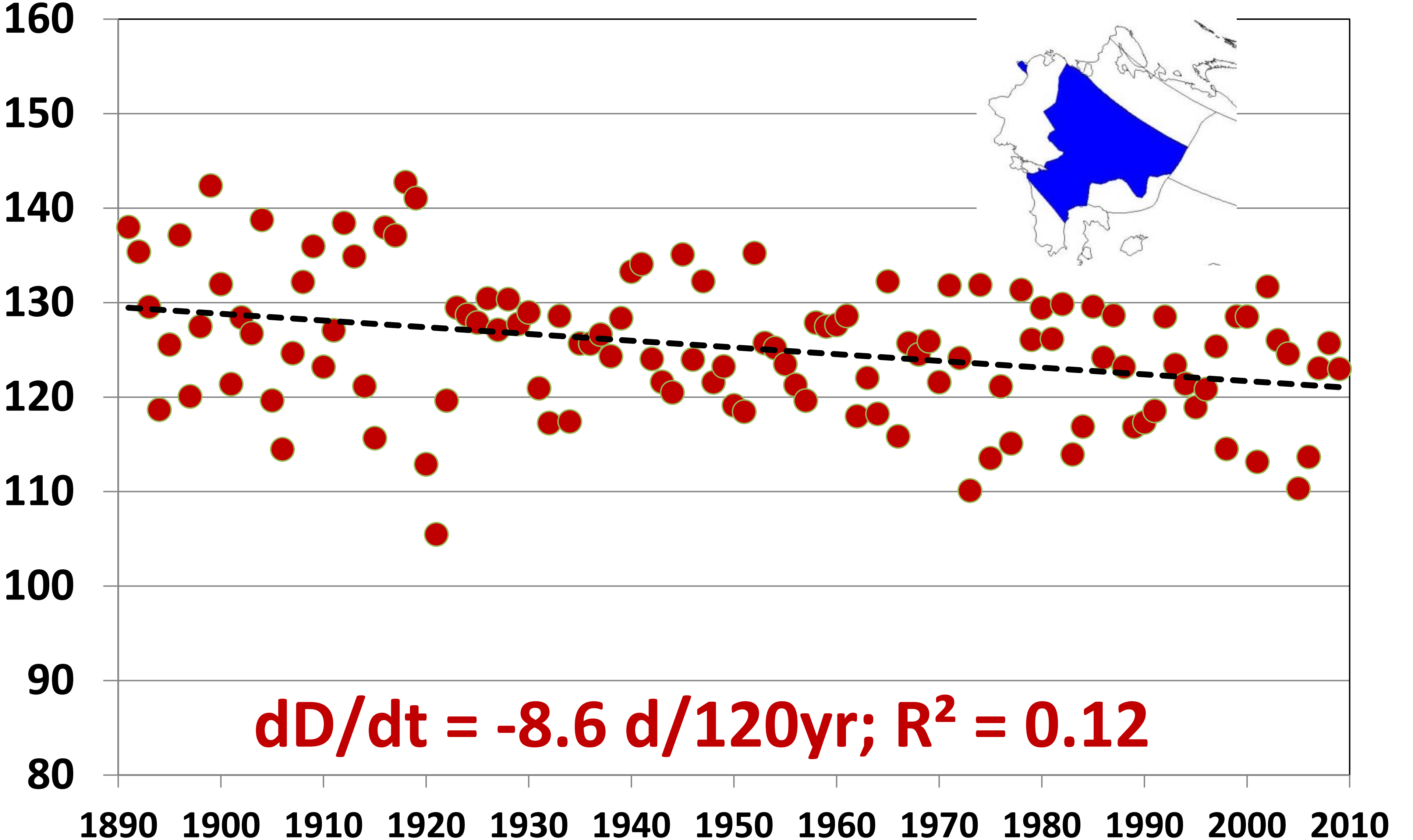
Elena V. Komarovskaya, 2009; Personal communication

Begin of the no-frost season in Siberia

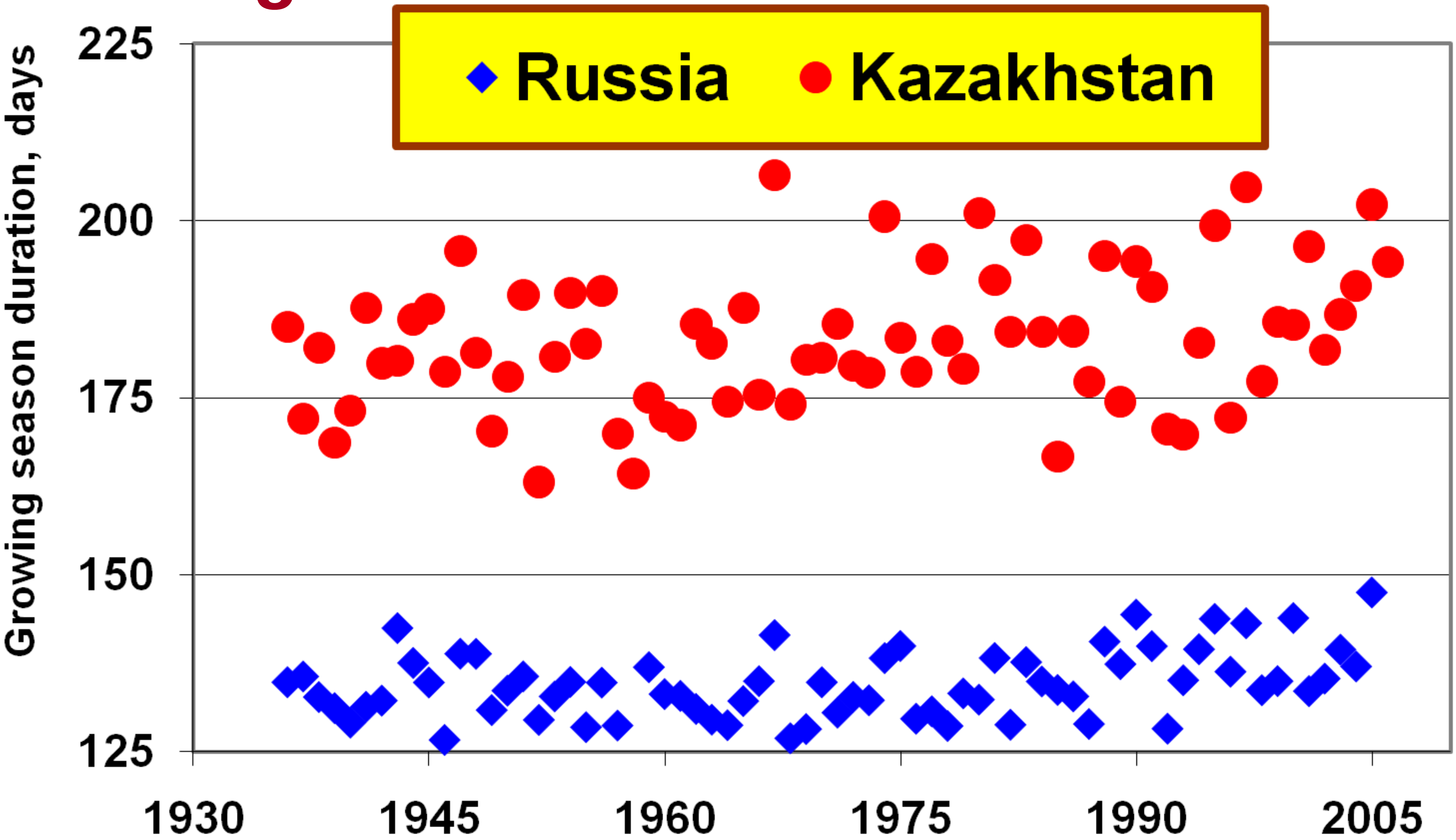


Dates when daily minimum temperature sustainably crosses 0°C in spring and remains above it

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



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



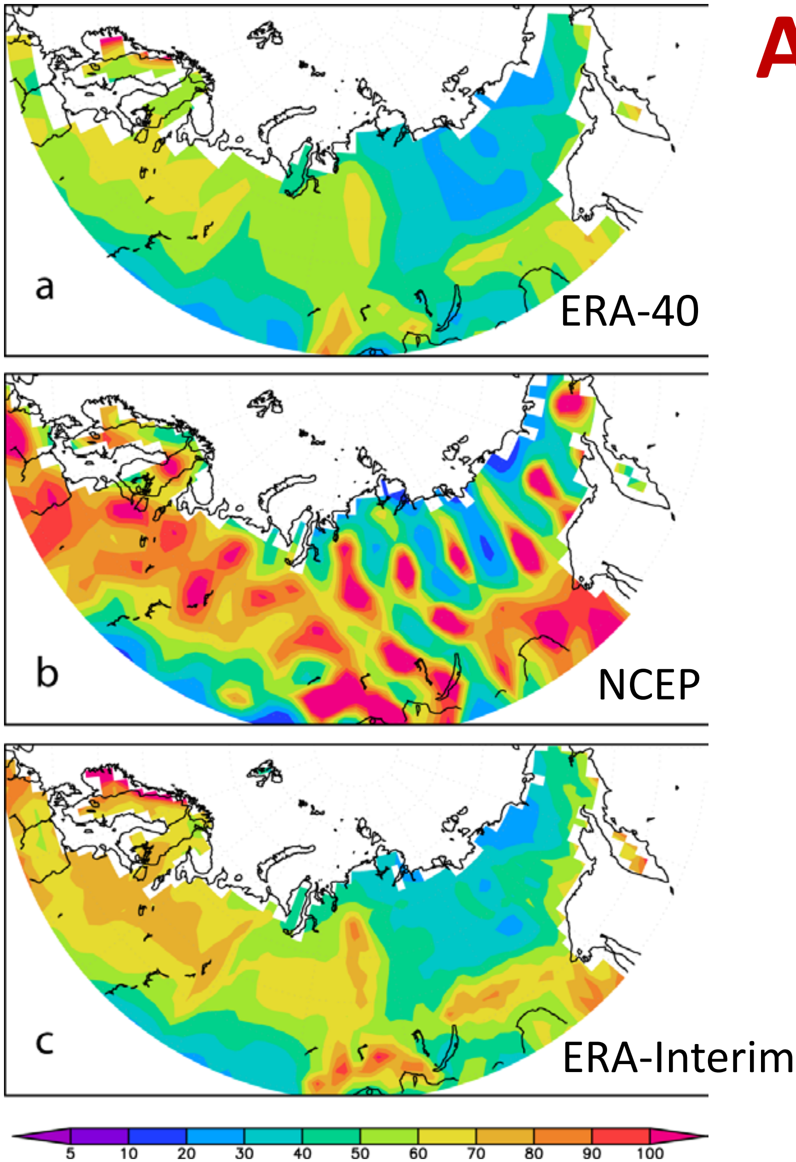
During the past 70 years, significant increase by 6 to 11 days (or by 5% to 6%)

Part 3.

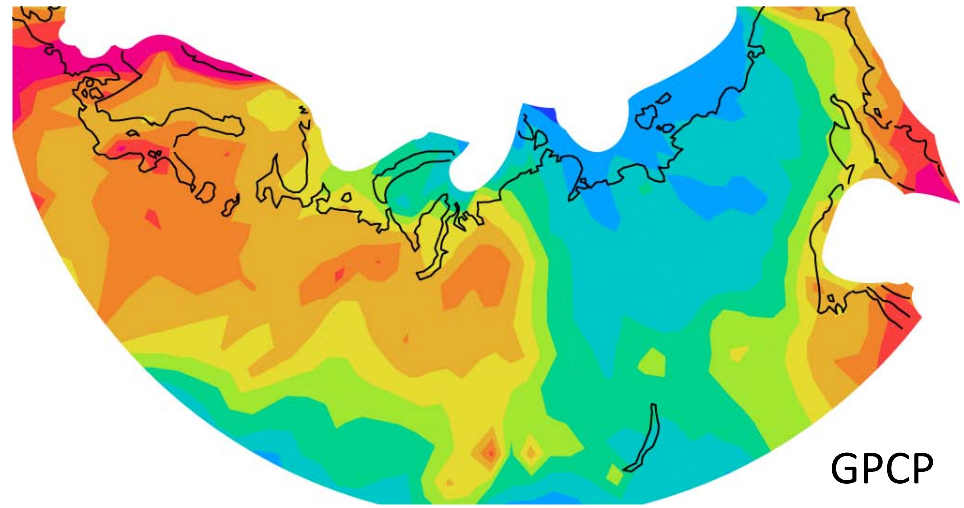
Precipitation changes over Russia

How good are reanalyses based on sparse in situ networks?

Annual mean precipitation



This scale is in cm



Color Scale:

Blues:	from 100 to 300 mm
Greens:	from 300 to 600 mm
Yellow/Gold:	from 600 to 800 mm
Orange/Red:	from 800 to >1,000 mm

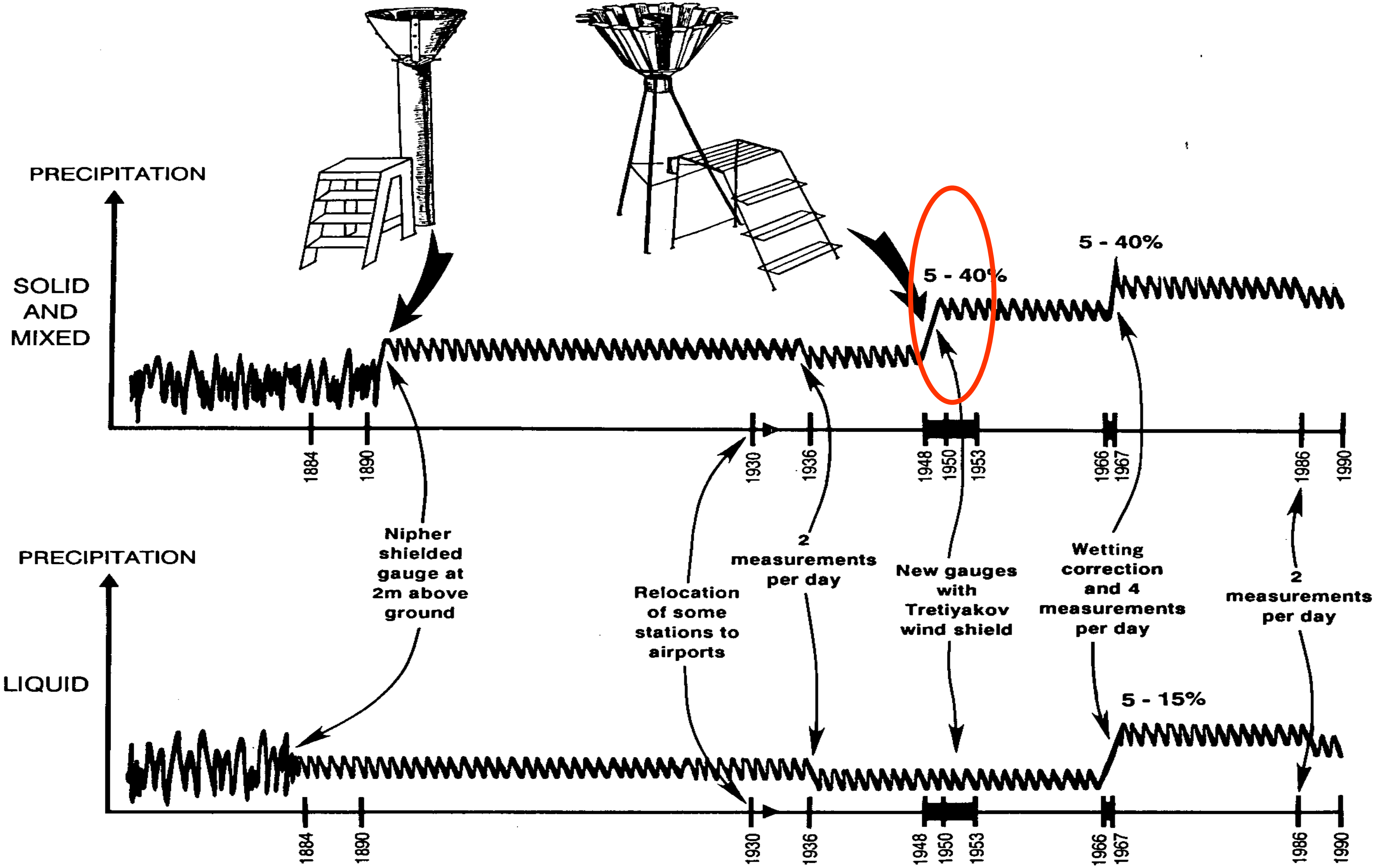
Cherry et al. 2013

Latest Analysis of precipitation changes for the Russian Federation:

Groisman, P.Ya., E.G. Bogdanova, V.A. Alexeev, J.E. Cherry, and O.N. Bulygina, 2014: Impact of snowfall measurement deficiencies on quantification of precipitation and its trends over Northern Eurasia. *Ice and Snow*, No. 2 (126), 29-43

(published in June 2014)

Systematic changes at the former USSR precipitation network



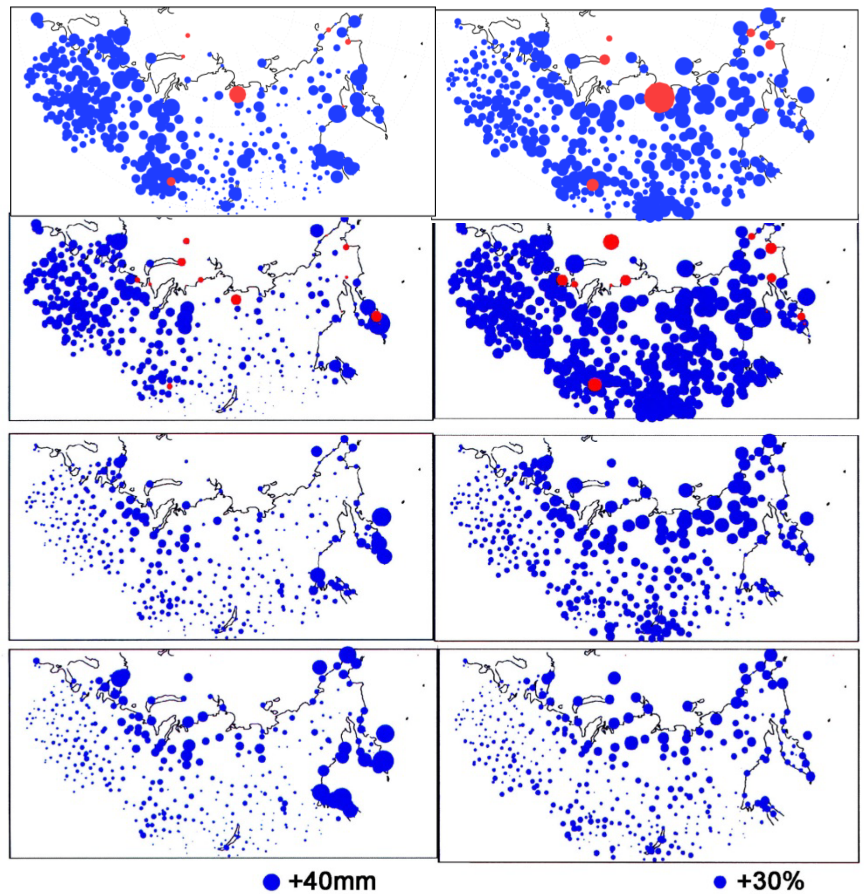
Mean differences of corrected and reported precipitation totals in mm (left) and percent of the long-term mean corrected precipitation (right) during the 1958-2010 period.

November – December

January - February

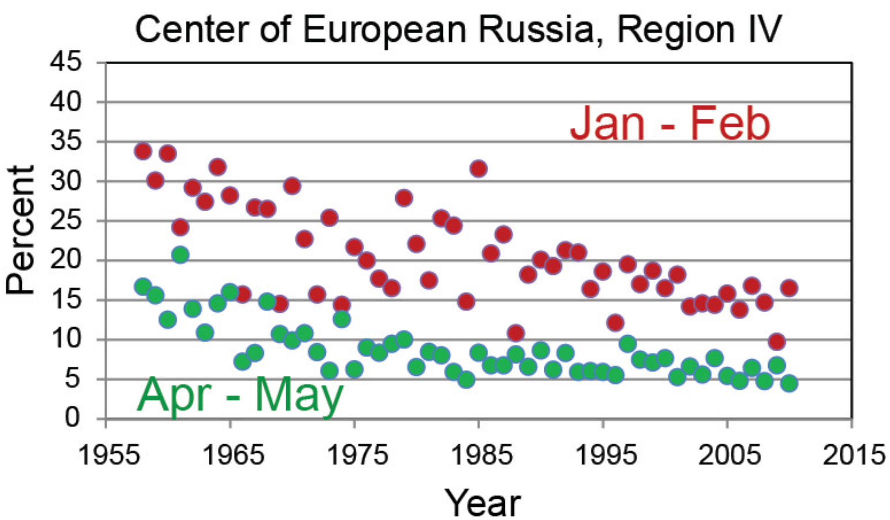
April - May

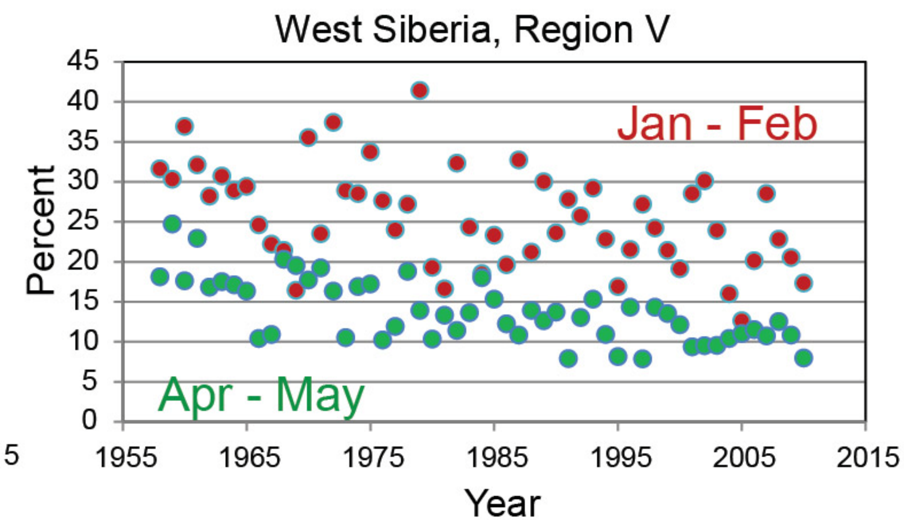
September - October



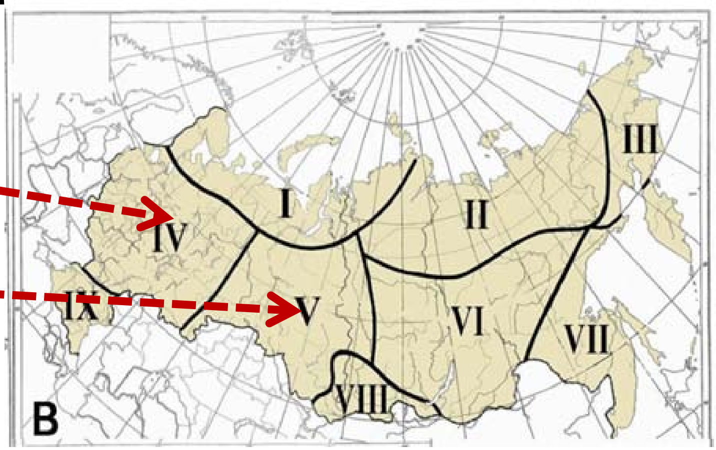
The diameters of the dots are proportional to the difference values shown in each plot. Positive differences (blue color) dominate over the negative differences (red; presented only in extremely windy areas in mid-winter with strong wind overcatch biases)

Precipitation corrections (in %) and their dynamics with time

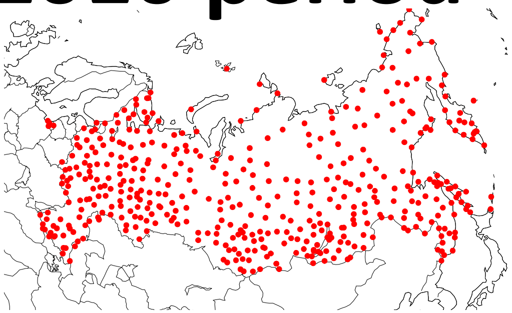


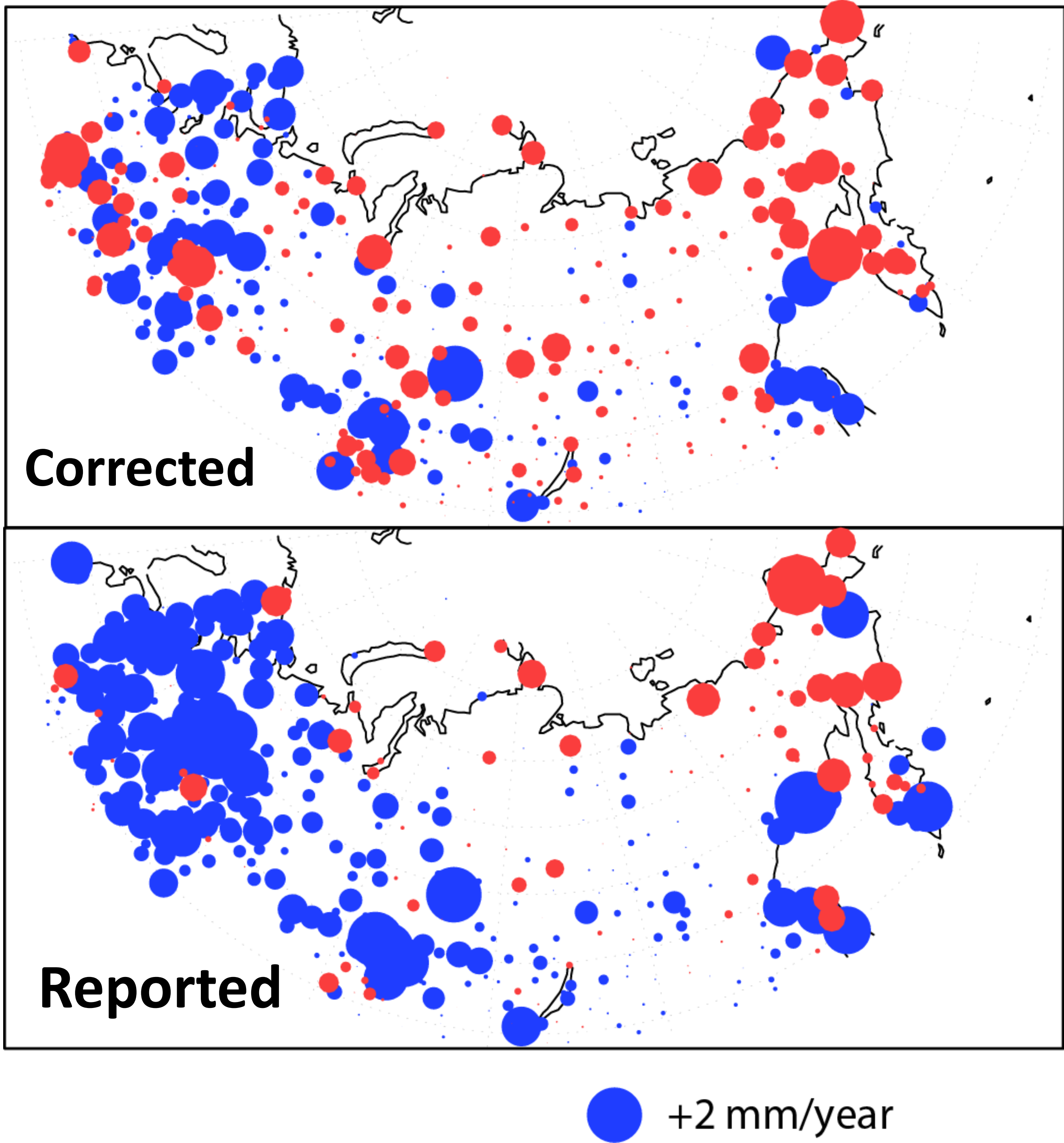


Corrections are regionally averaged over the center of European Russia (region IV) and West Siberia (region V) and are presented for January – February (red dots) and April – May (green dots).

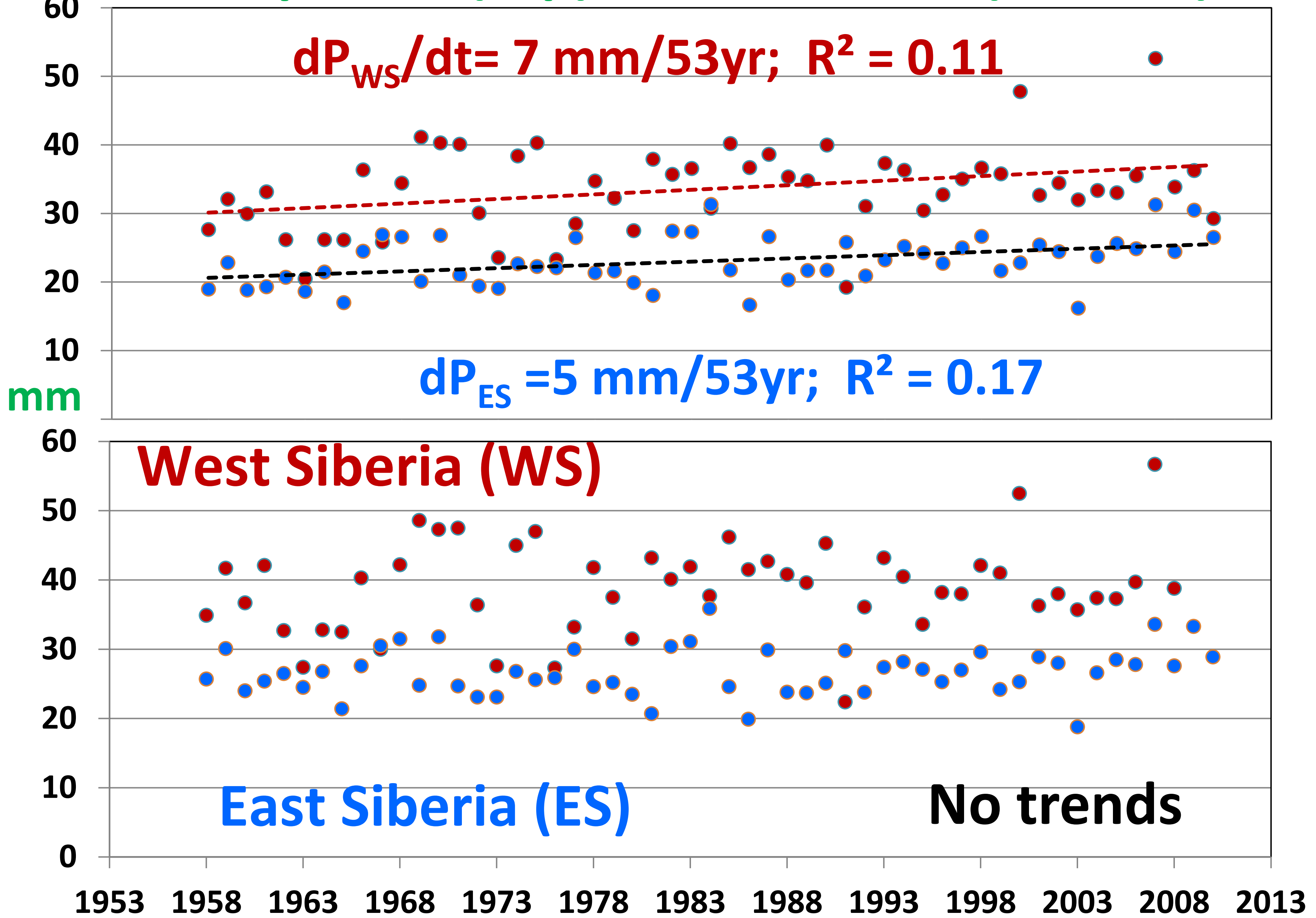


Linear trends (mm/yr) of the cold season precipitation (November to March) for the 1958-2010 period

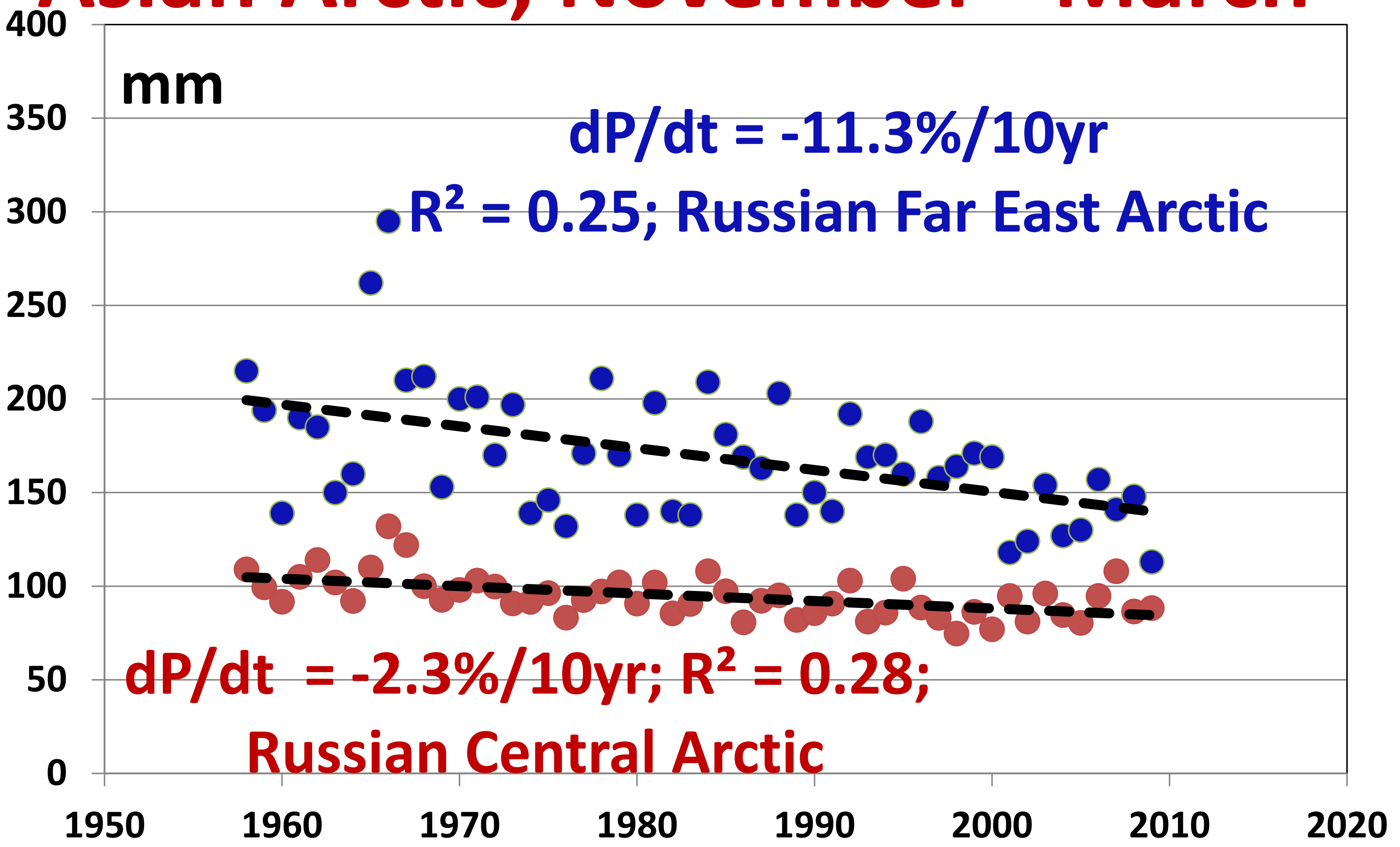




April-May precipitation trends over West and East Siberia; reported (top) and corrected (bottom) data

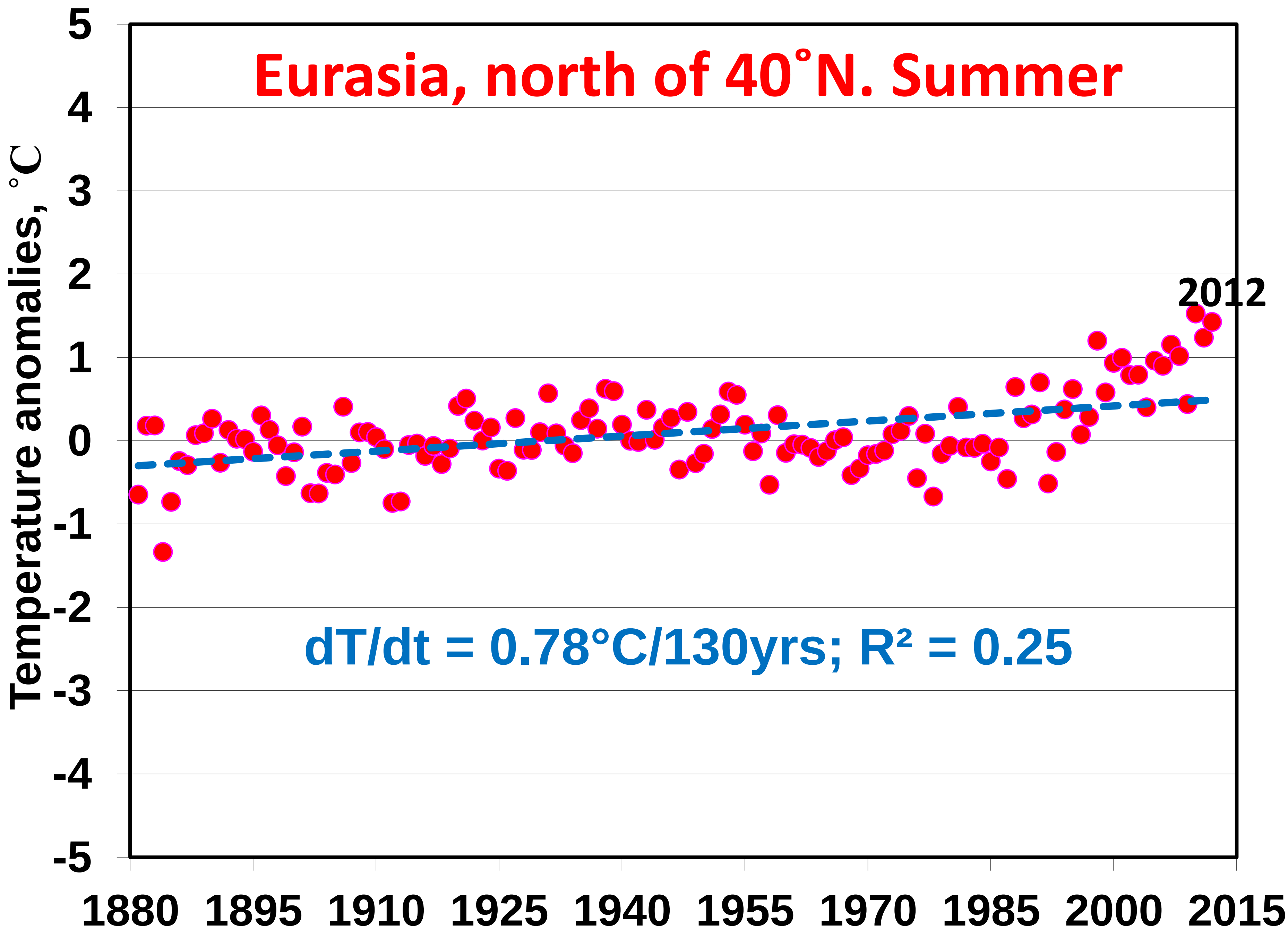


Regional precipitation trends in Asian Arctic, November - March



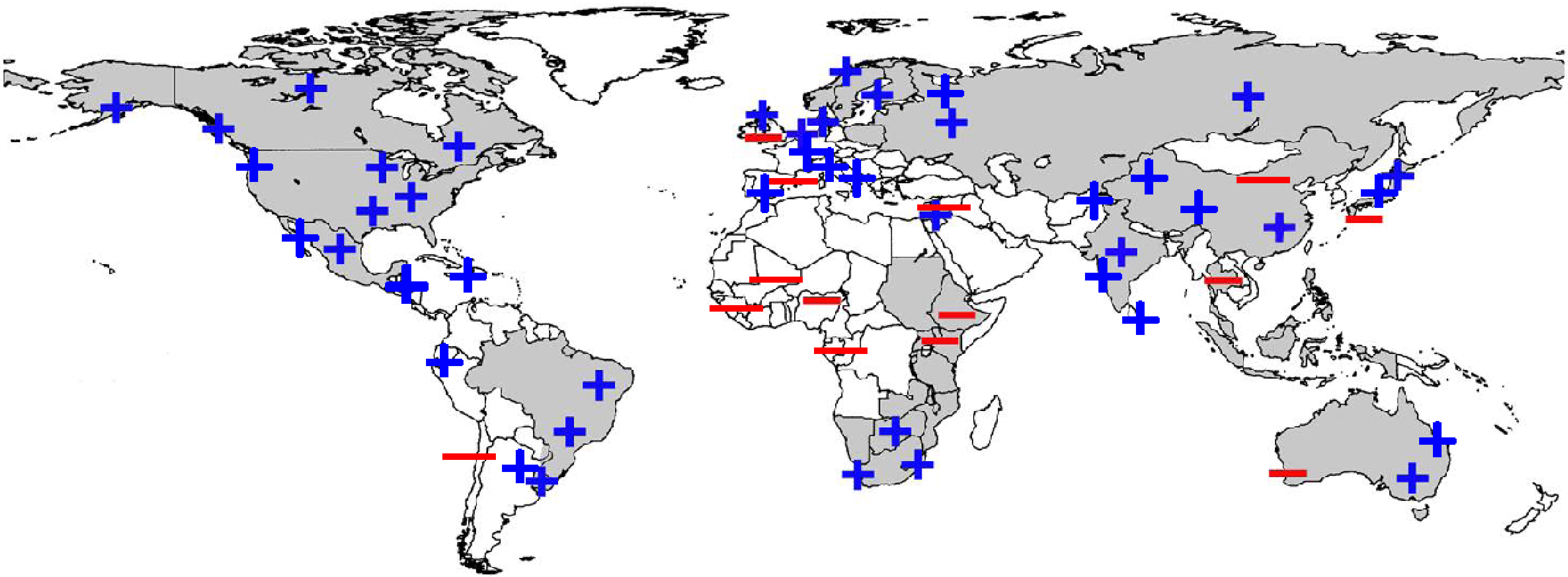
Part 4. Warm Season Processes

Changes in Intense Precipitation, Fire Weather Characteristics, and Frequency of the Prolonged Dry Periods



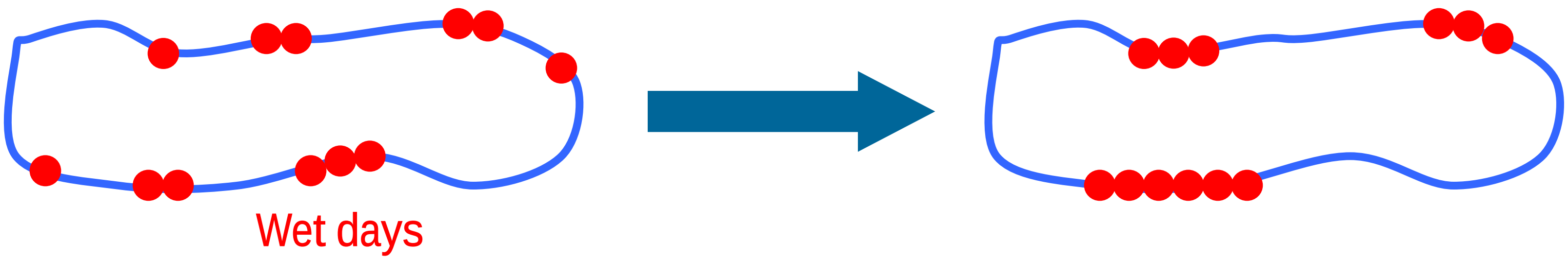
Eurasia, north of 40˚N. Summer
Temperature anomalies, °C
2012
dT/dt = 0.78°C/130yrs; R² = 0.25
5
4
3
2
1
0
-1
-2
-3
-4
-5
1880
1895
1910
1925
1940
1955
1970
1985
2000
2015

Regions with disproportionate changes in intense precipitation during the past decades compared to the change in the annual and/or seasonal precipitation

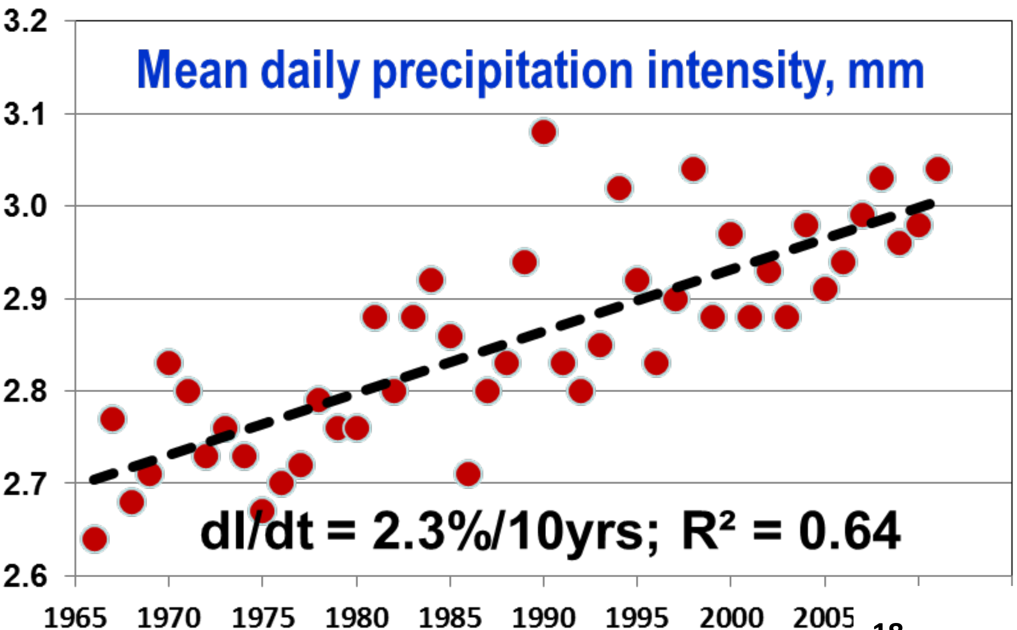


Easterling et al. 2000, substantially updated from Groisman et al. 2005, Zhai et al. 2005, Roy and Balling 2004, Aguilar et al. 2005, Brunetti et al. 2004, Cavazos 2008, Zolina et al. 2010; and finalized in Groisman and Knight 2012. Thresholds used to define “heavy” and “very heavy” precipitation vary by season and region.

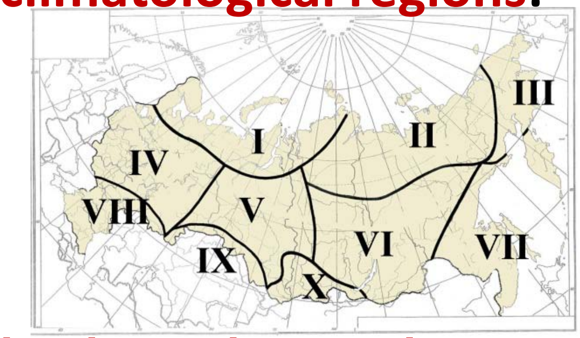
Beads with a fixed number of stones illustrate how we can have in the same region simultaneously increases in prolonged Wet Day and Dry Day Periods even with unchanged precipitation totals (design by O.G. Zolina).



Nationwide precipitation intensity, I, changes over Russia

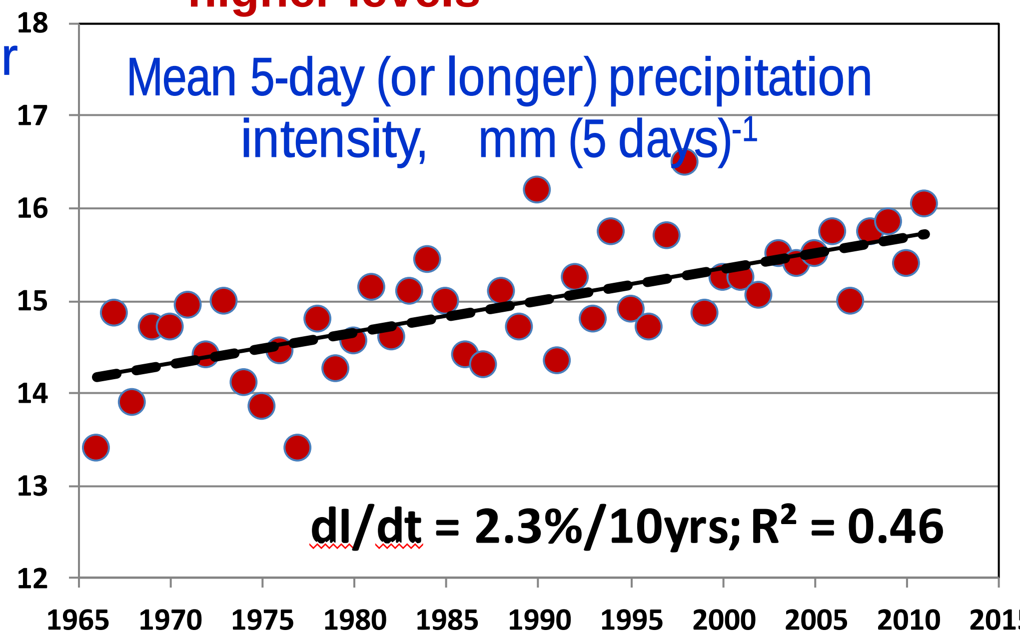


Russian climatological regions:

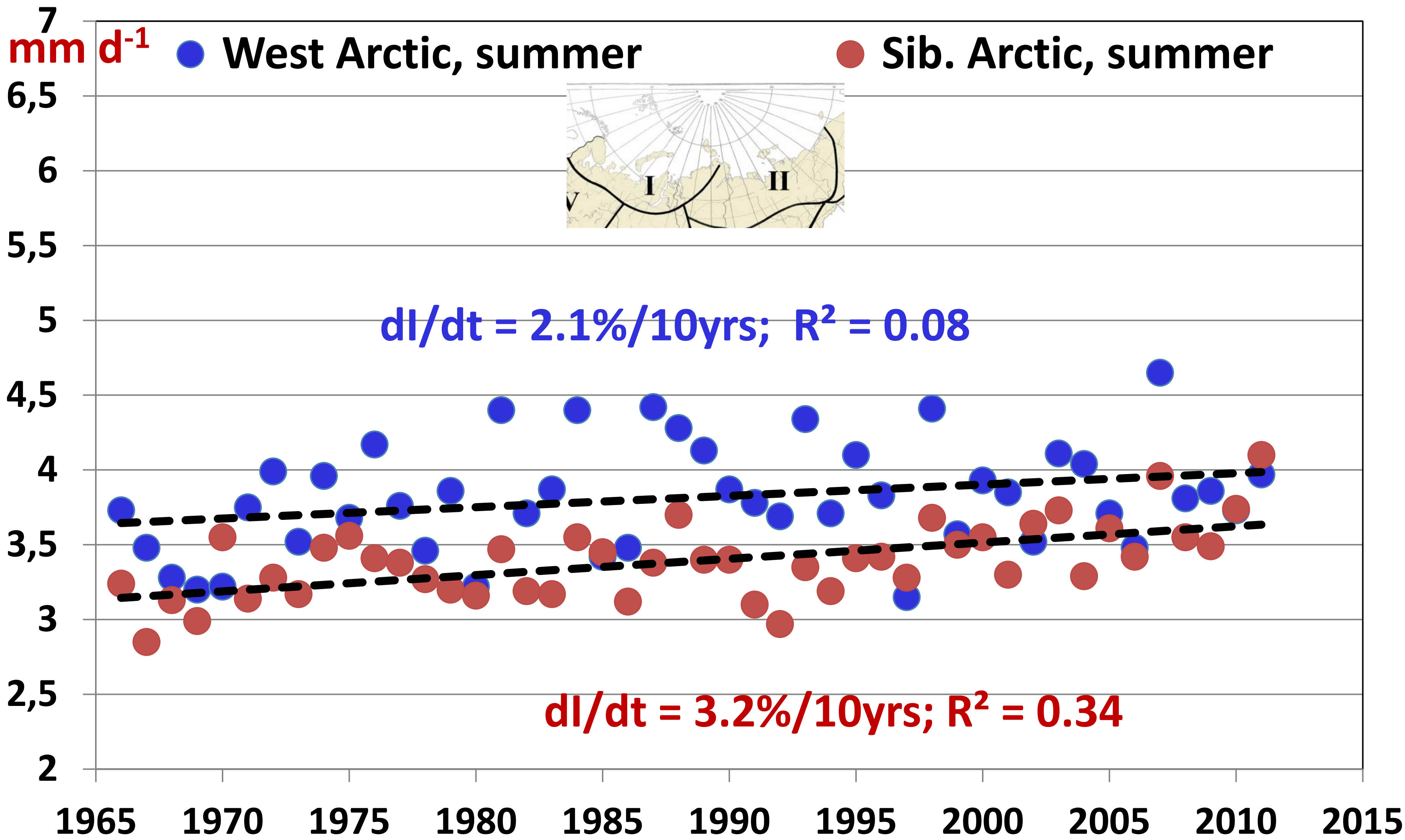


Precipitation intensity trends over all these regions are positive and statistically significant at the 0.05 or higher levels

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 regions.

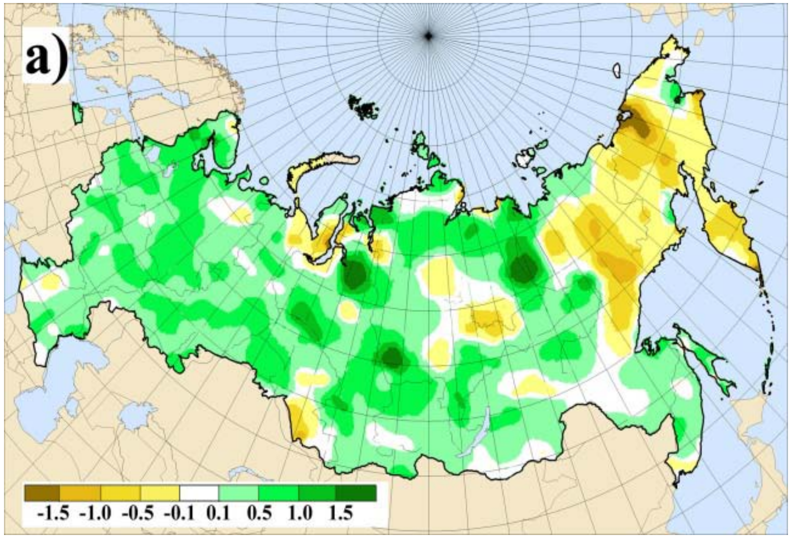


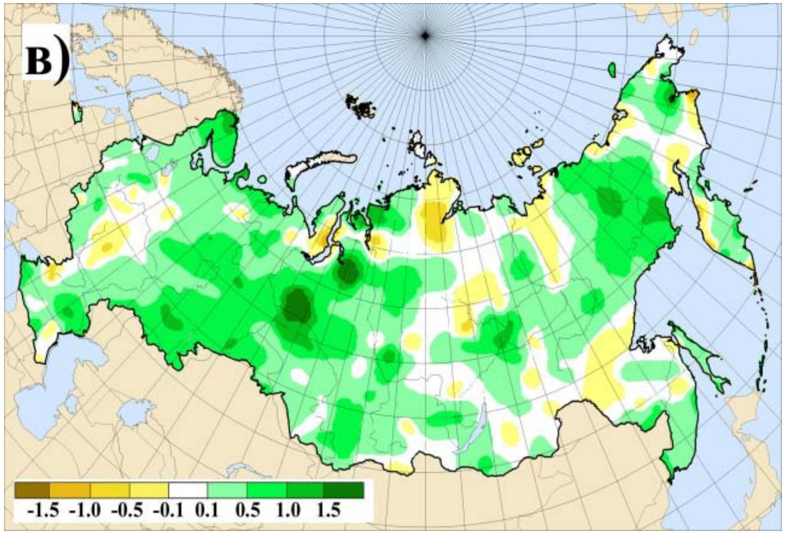
Mean summer precipitation intensity over Russian Arctic (mm d^{-1})



Changes in the number of days with heavy precipitation.

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



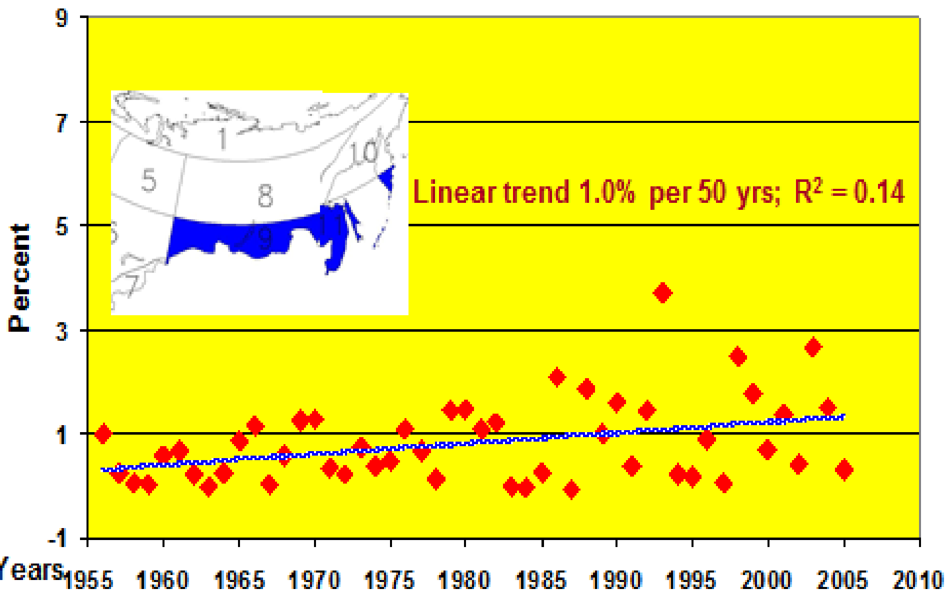


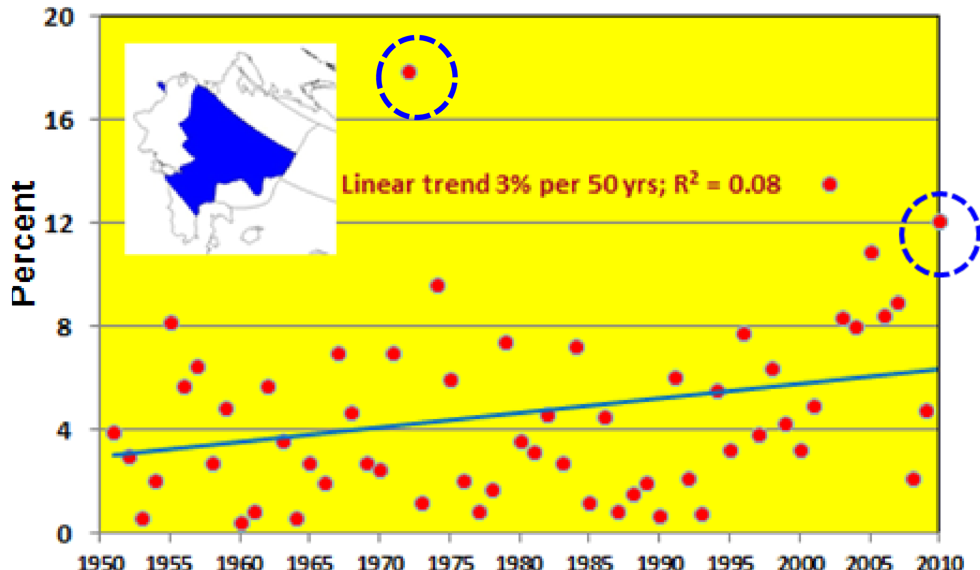
a) – winter; в) – summer

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.**

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.

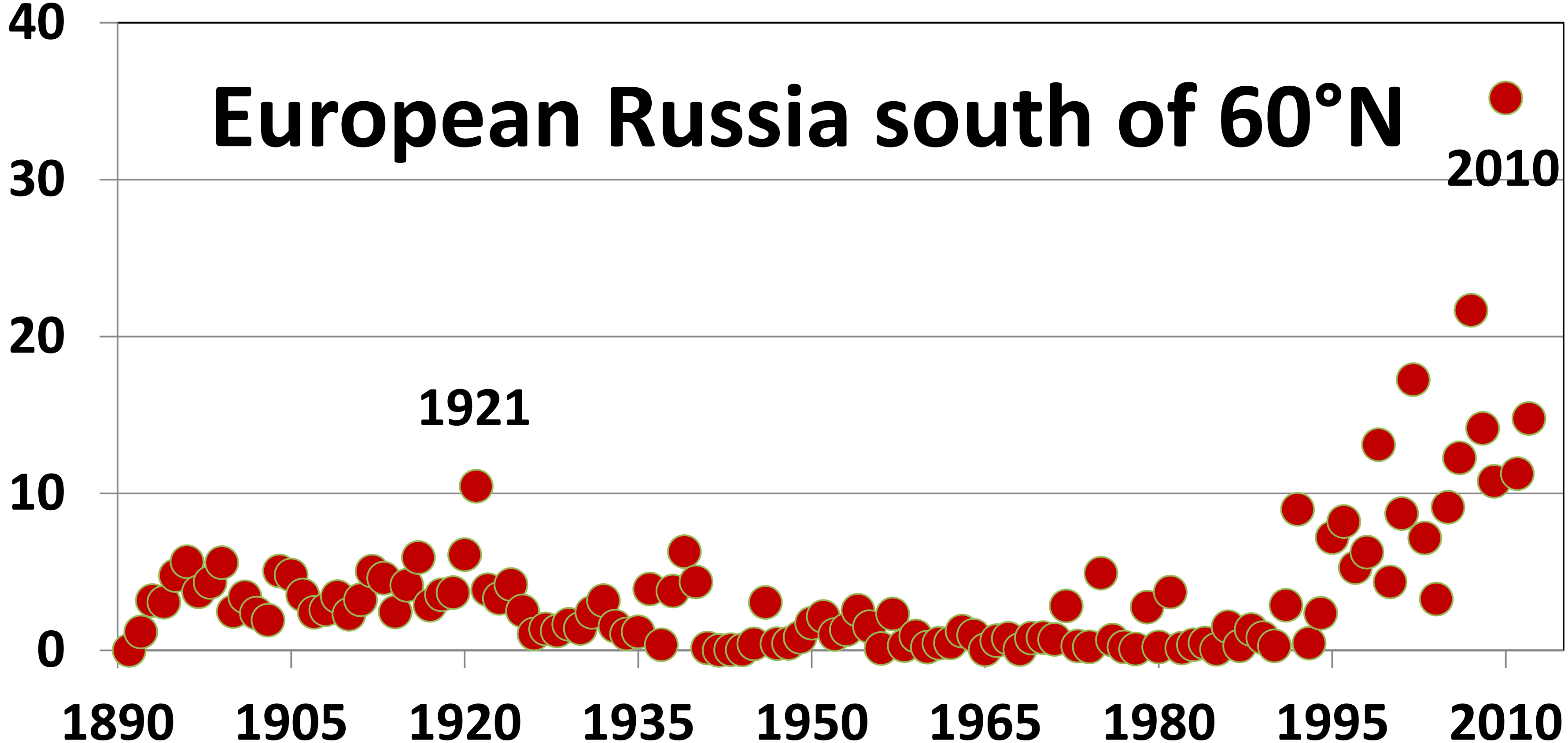
Both linear trends are statistically significant at the 0.05 level.





Groisman et al. 2013

Updated KBDI results for European Russia

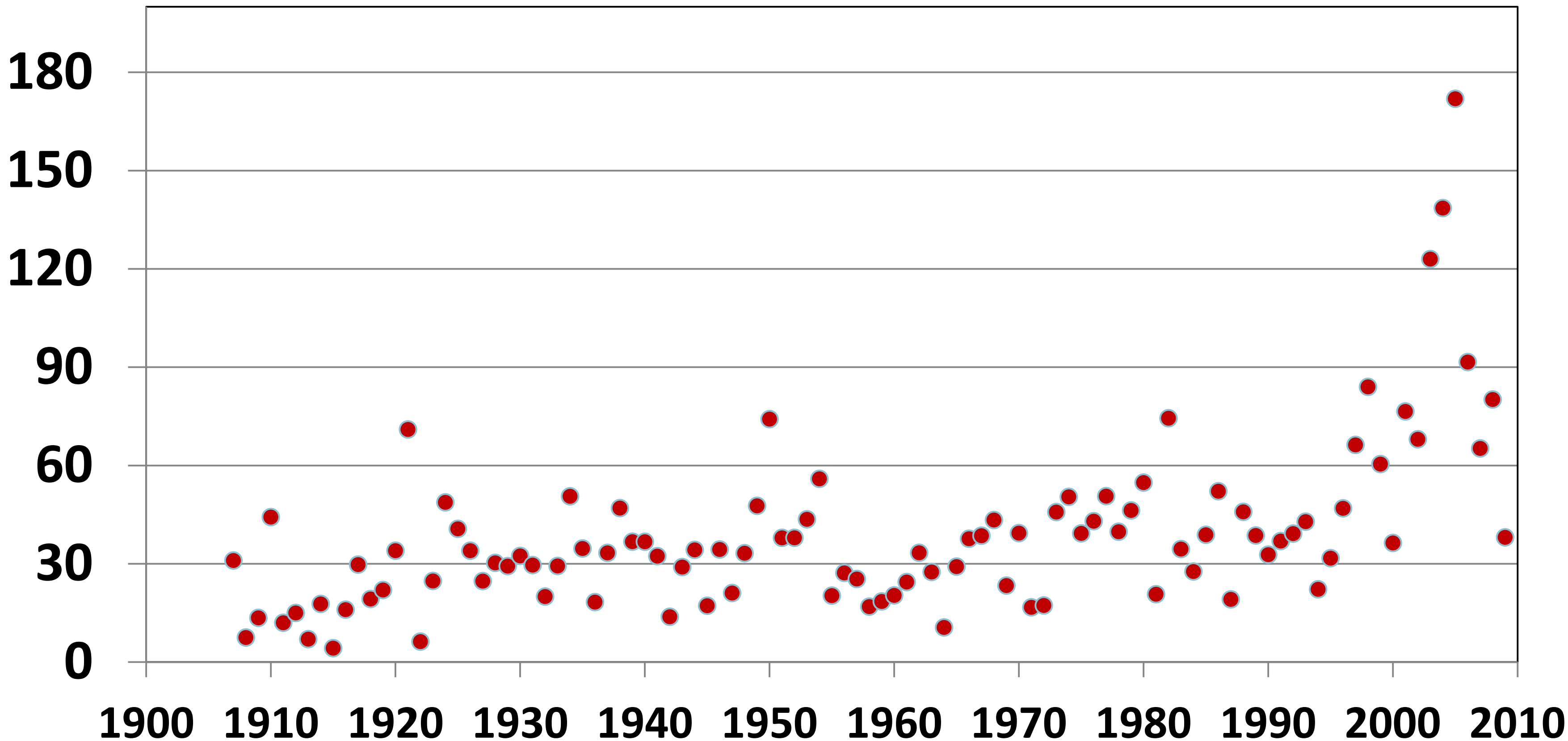


Days with KBDI in the upper 1% of their summer climatological values

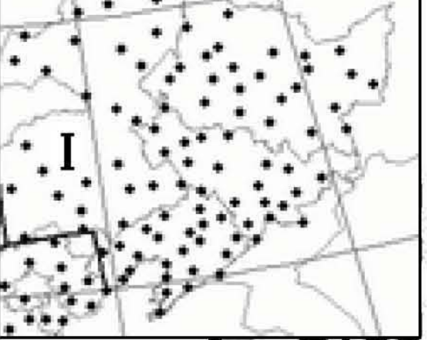
Potential Fire Danger Increase

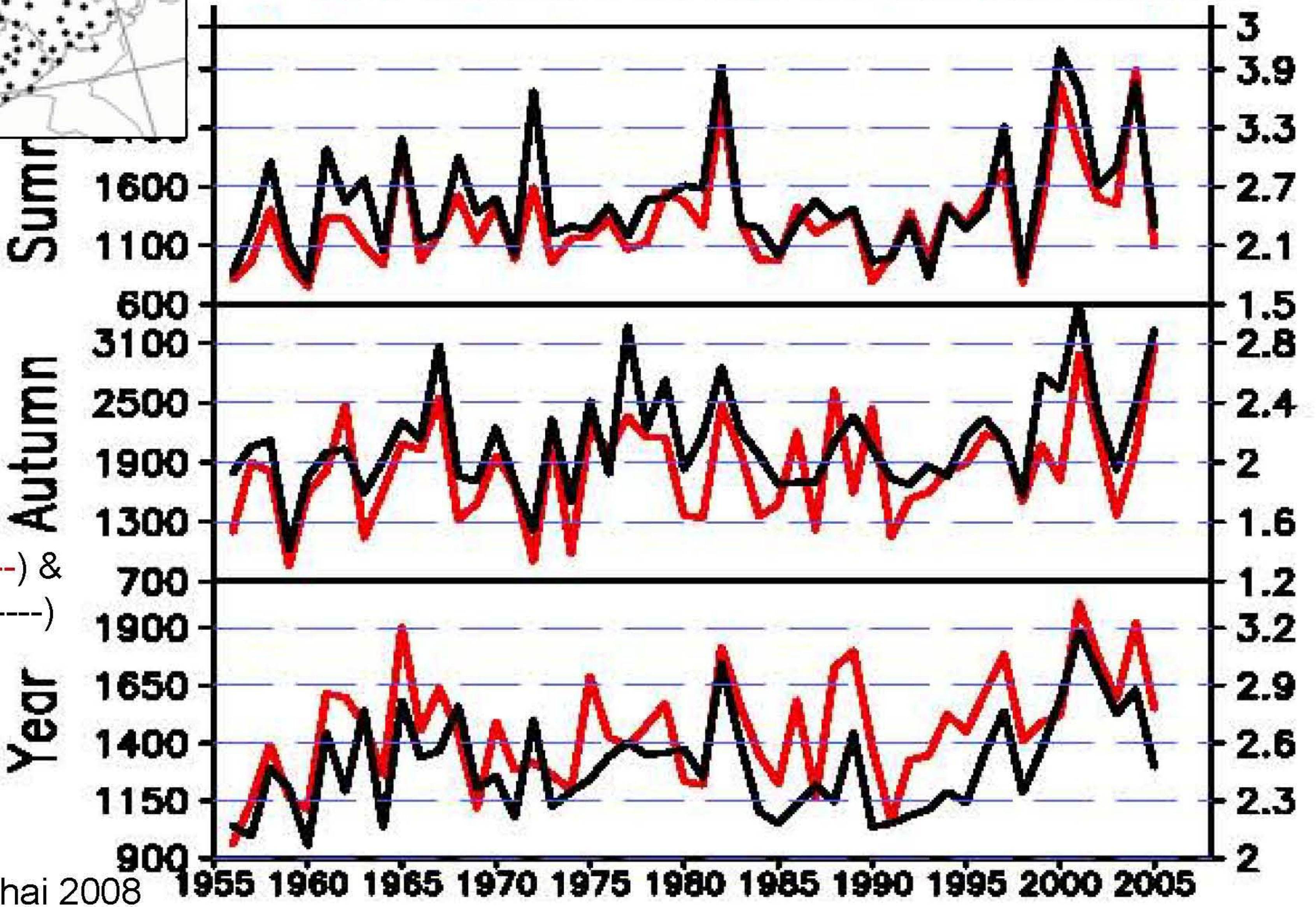
Annual number of days with KBDI > upper 10%-ile

Russian Far East south of 55°N



Seasonal and annual changes in forest fire indices in northeastern China



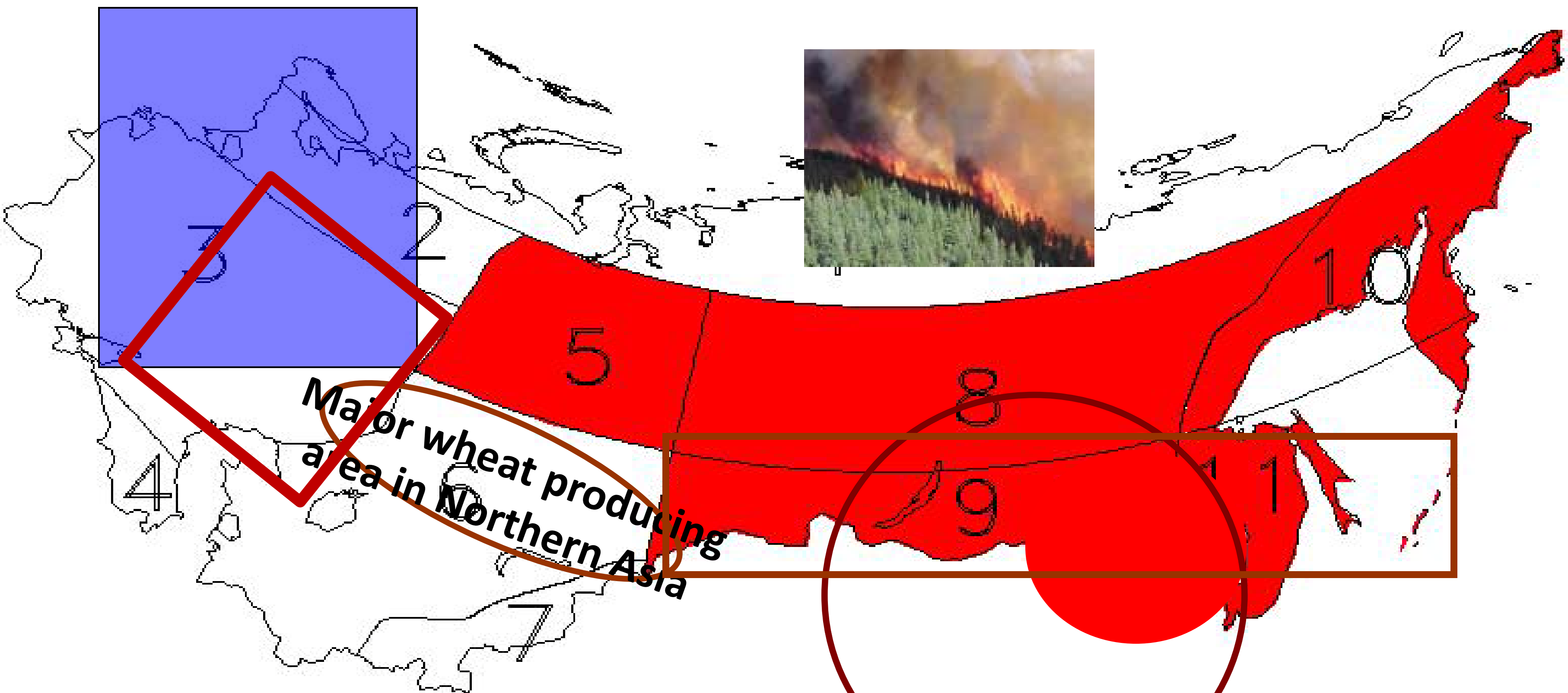


MNI (----) &
FFDI (-----)

Niu & Zhai 2008

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).

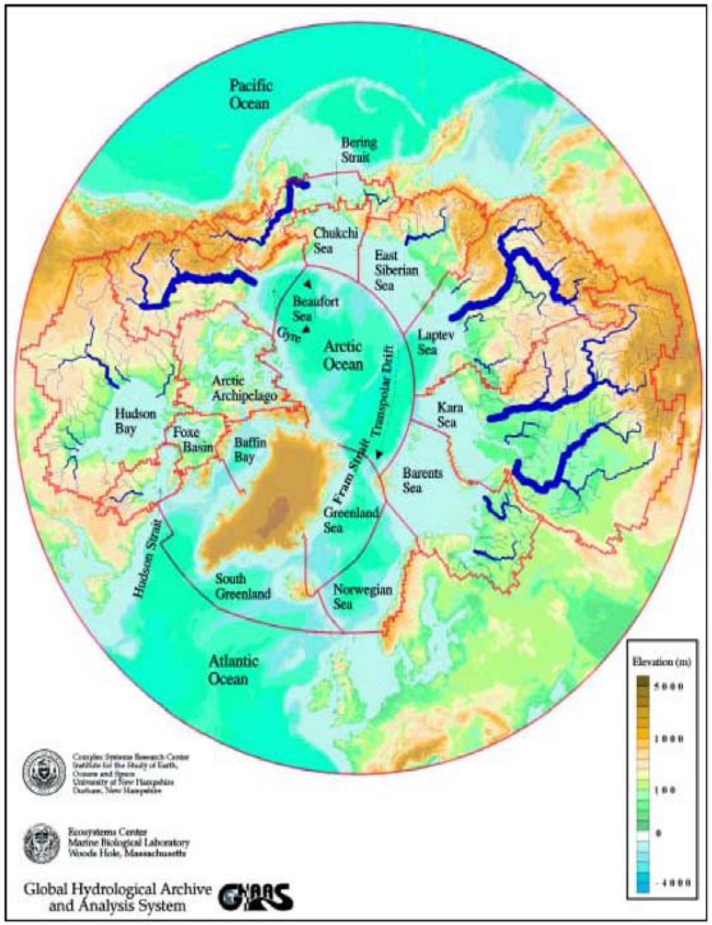


Groisman et al 2009 (Bull. Amer. Meteorol. Soc.)

Part 5. Changes in Streamflow

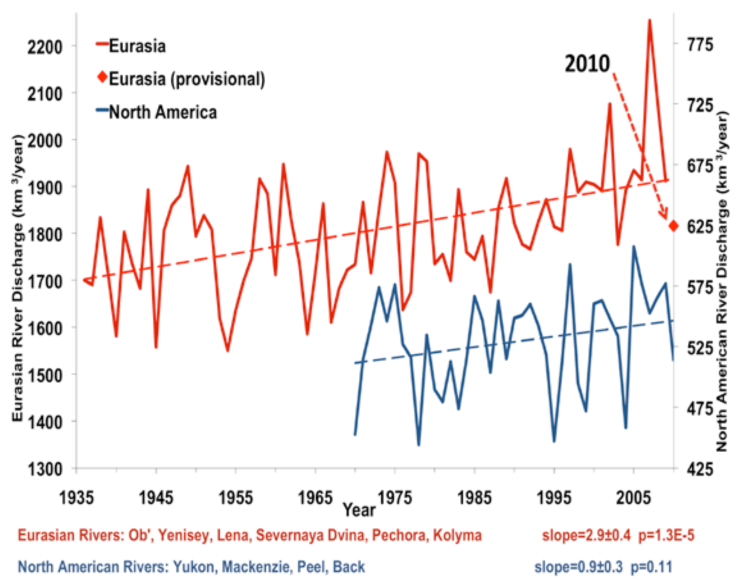
- Over most regions of Northern Eurasia in the last decades we observe a tendency to increase of annual streamflow
- Over the European part of Russia and Belarus a reduction of the amplitude of the seasonal streamflow is observed mostly due to increase of low flow.

Relative river discharge to the Arctic Ocean (Forman et al. 2000)



- **About 10% of the global river runoff is discharged to the Arctic Ocean, which is only 5% of the global ocean area and 1.5% of its volume.**
- ***The freshwater and sea ice outflow from the Arctic basin is subject to significant interannual oscillations that influence the salinity balance and winter convection processes of the Greenland Sea and the North Atlantic*.**
- **Changes in this outflow may affect the thermohaline circulation of the World Ocean**

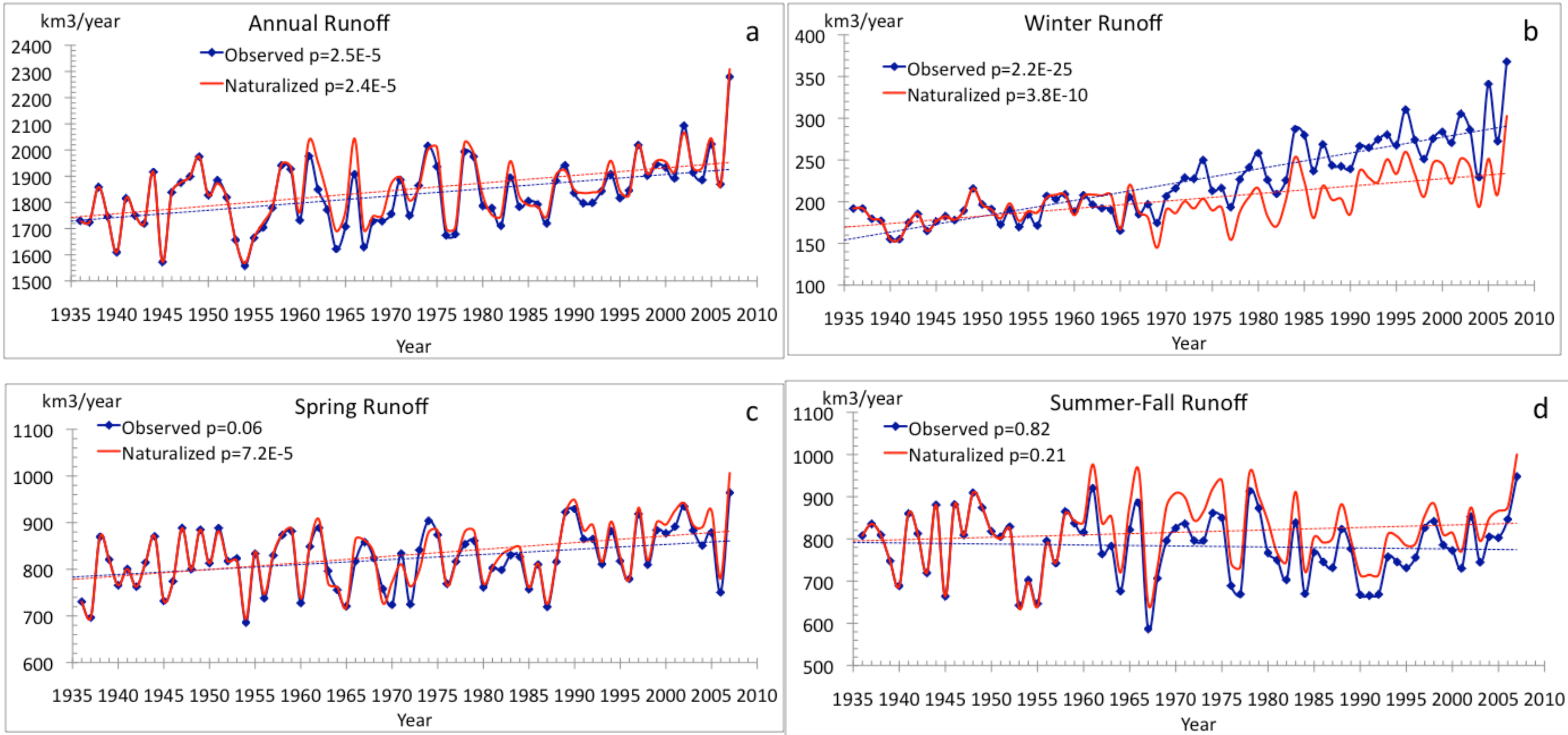
Acceleration of the water cycle in the Eurasian pan-Arctic



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).

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 Discharge of Six Largest Eurasian Arctic Rivers (Severnaya Dvina, Pechora, Ob, Yenisey, Lena and Kolyma)



Changes in annual and seasonal discharge based on observational data (blue line) and based on reconstructed (naturalized - excluding anthropogenic activity) data

Change in annual discharge of Eurasian rivers over 1936-2007 due to **climate change** is 210 km^3;

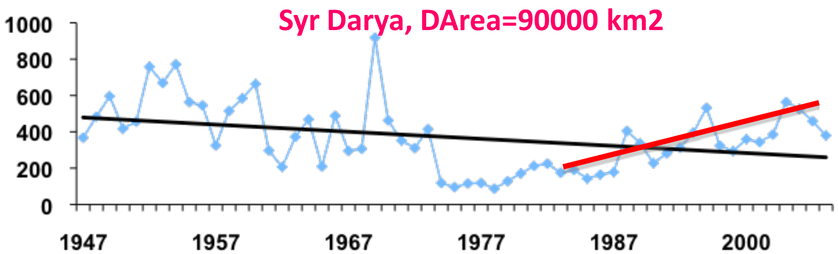
Winter discharge contributes 65 km^3 or 31% to this annual increase;

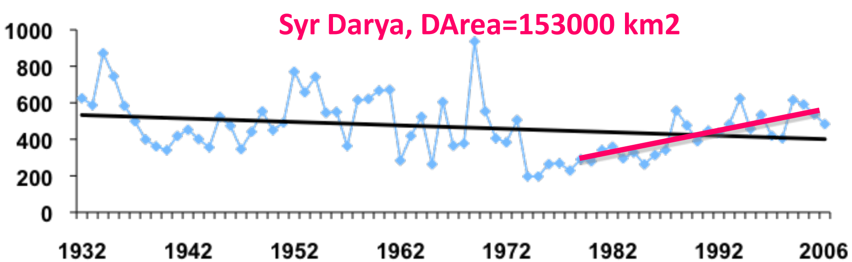
Spring discharge contributes 103 km^3 or 49% to this annual increase;

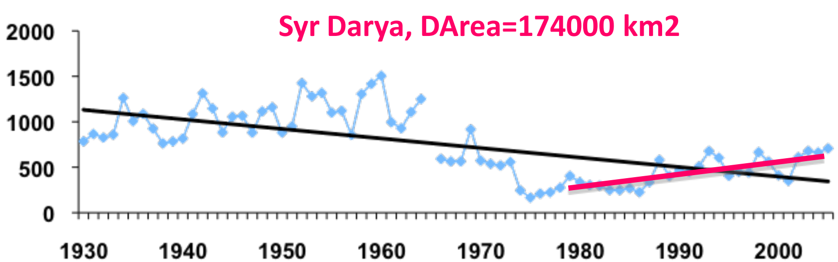
Summer-Autumn discharge contributes 42 km^3 or 20% to this annual increase.

Change in observed discharge – Syr Darya River

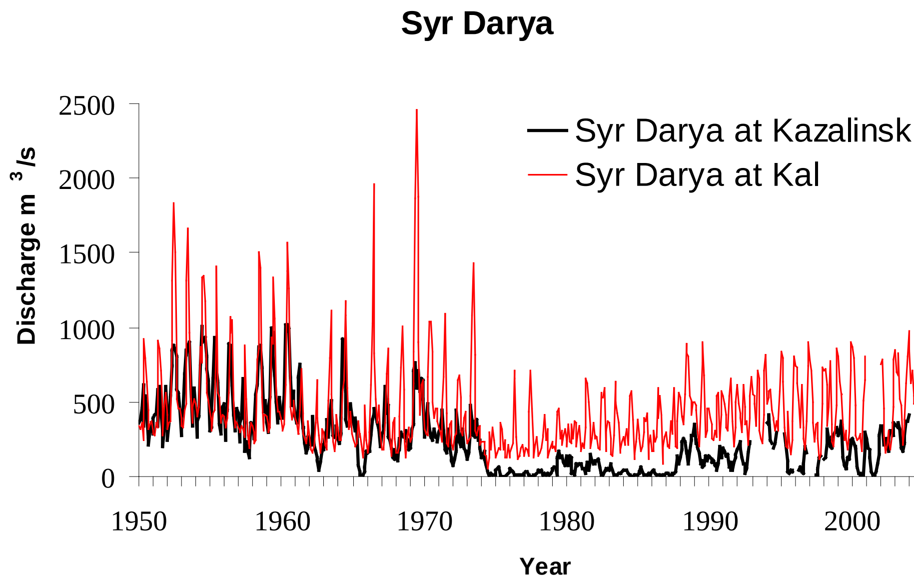
Annual discharge

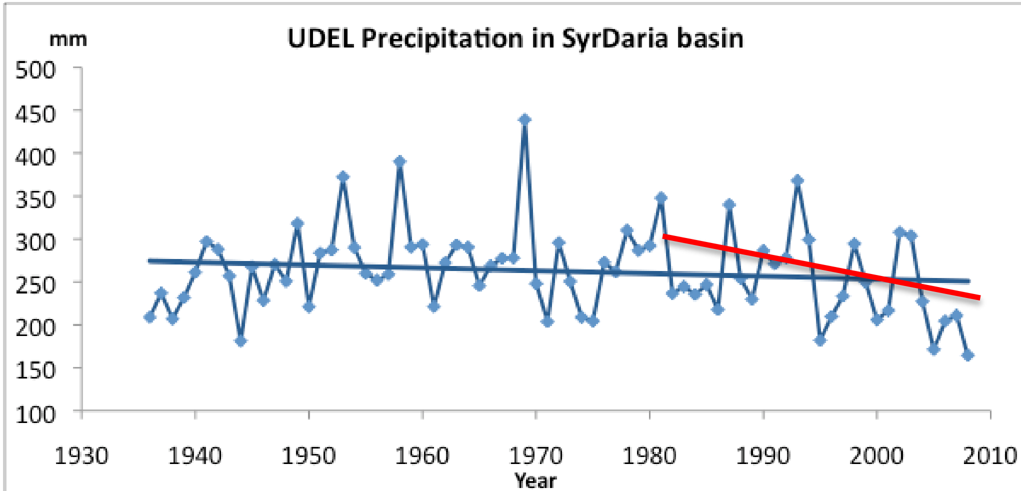






Monthly discharge

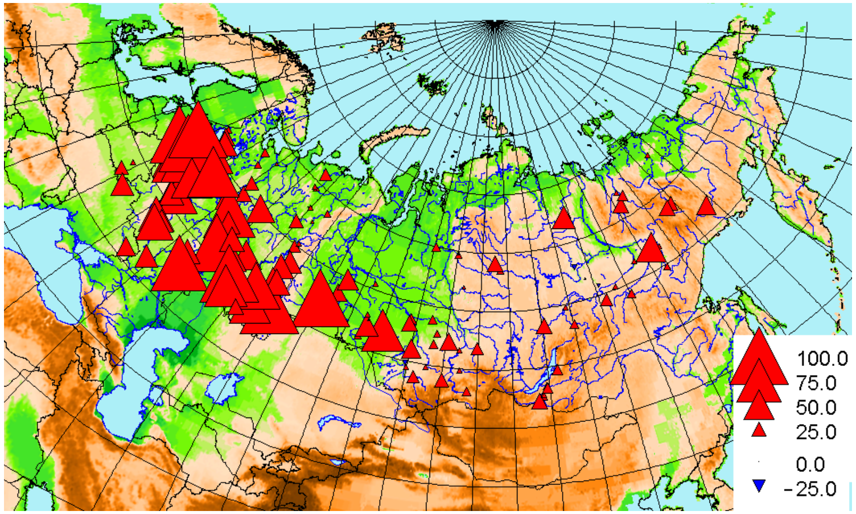




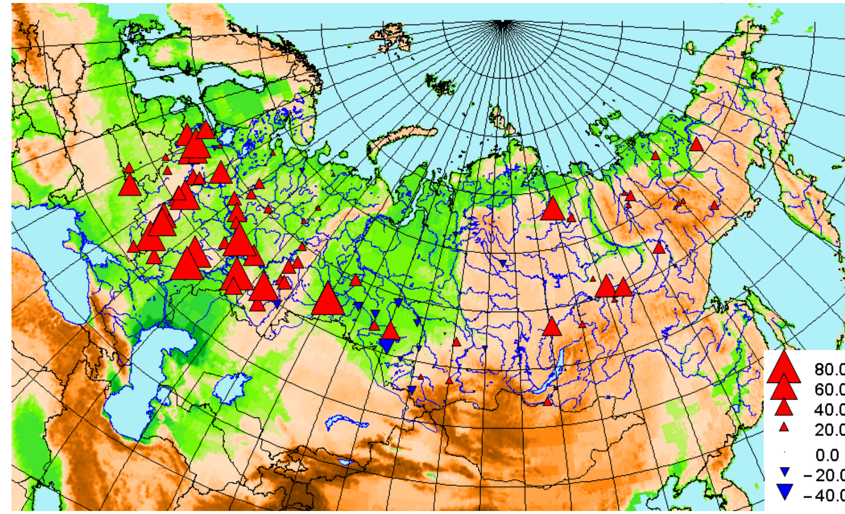
Recent Syr Darya River discharge increases Is probably due to:

1) Increased glacier and snow melt at high elevations
2) Decline in human water use
3) Increasing precipitation? (but not all data sets show this)

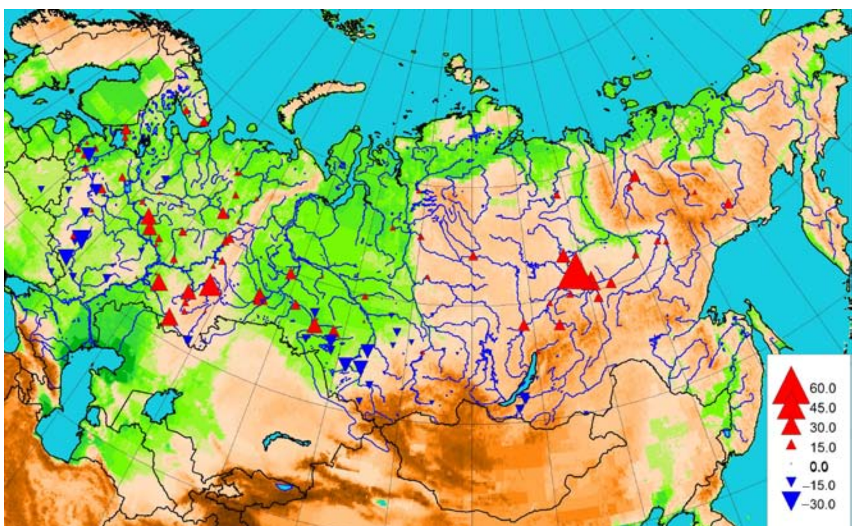
Anomalies of Winter runoff over 1978-2005 (%)



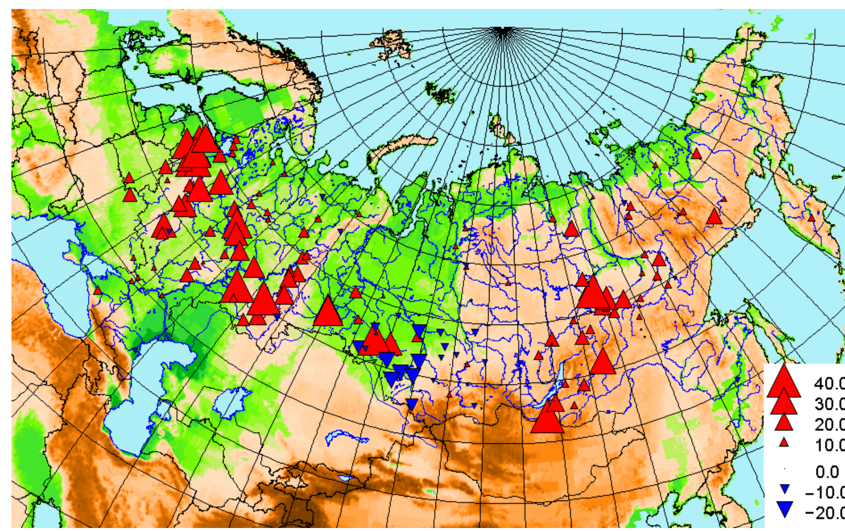
Anomalies of Summer-Fall runoff over 1978-2005 (%)



Anomalies of Spring runoff over 1978-2005 (%)



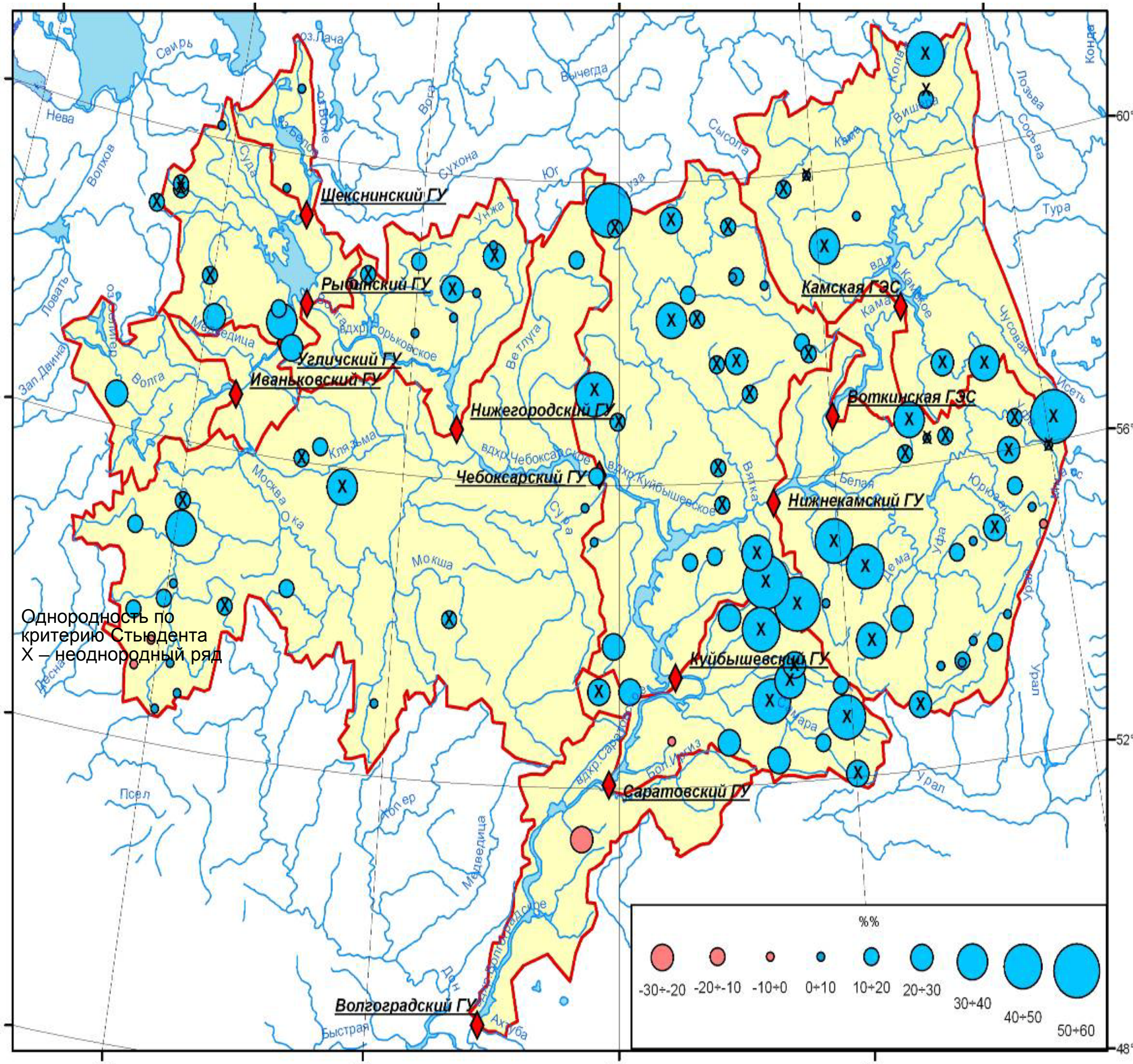
Anomalies of Annual runoff over 1978-2005 (%)



Anomalies of seasonal runoff over 1978-2005 related to the base period 1940-1977

Updated from ACIA, 2005

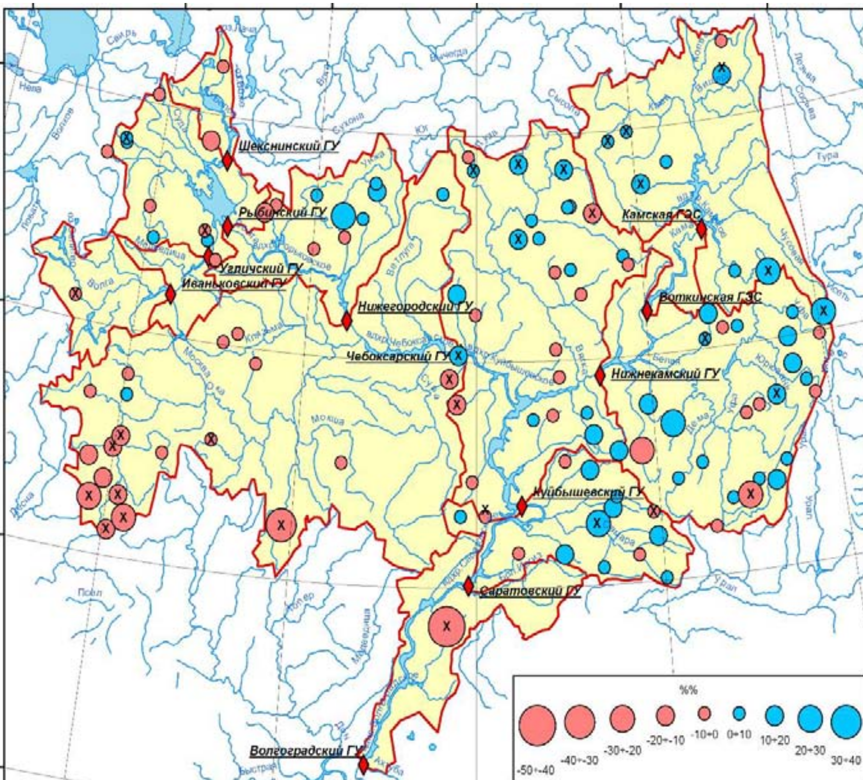
Change in observed discharge – the Volga River Basin



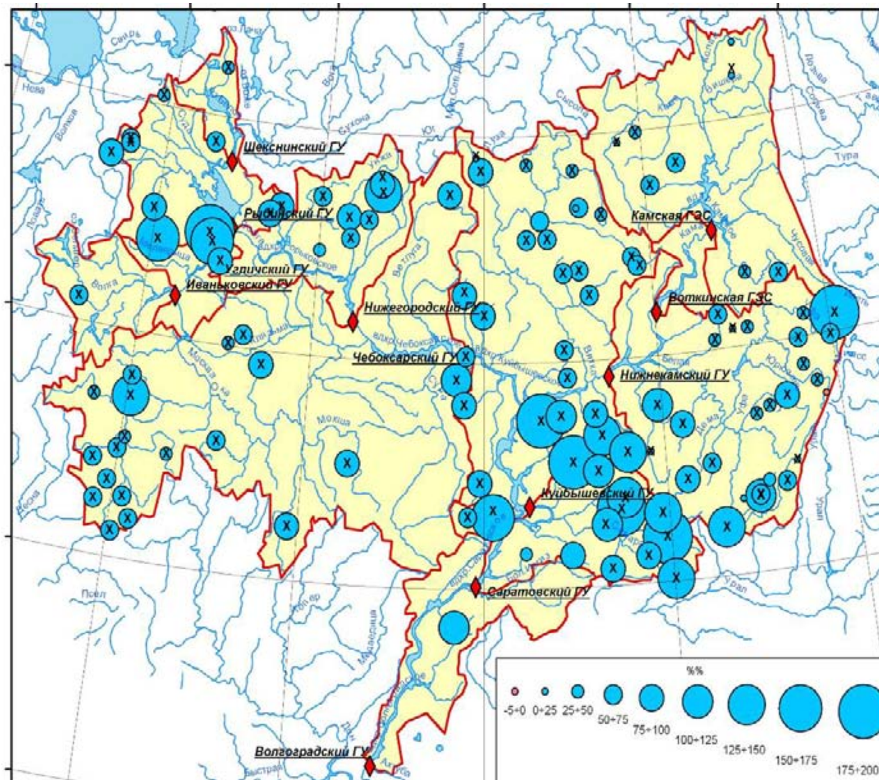
Relative changes (%) of annual runoff in the Volga River Basin long-term mean for the 1978-2010 period related to the base period 1946-1977.

Russian State Hydrological Institute, 2013

Changes of spring and winter runoff in the Volga River Basin



Однородность по
критерию Стьюдента
X – неоднородный ряд



Однородность по
критерию Стьюдента
X – неоднородный ряд

Spring

Winter

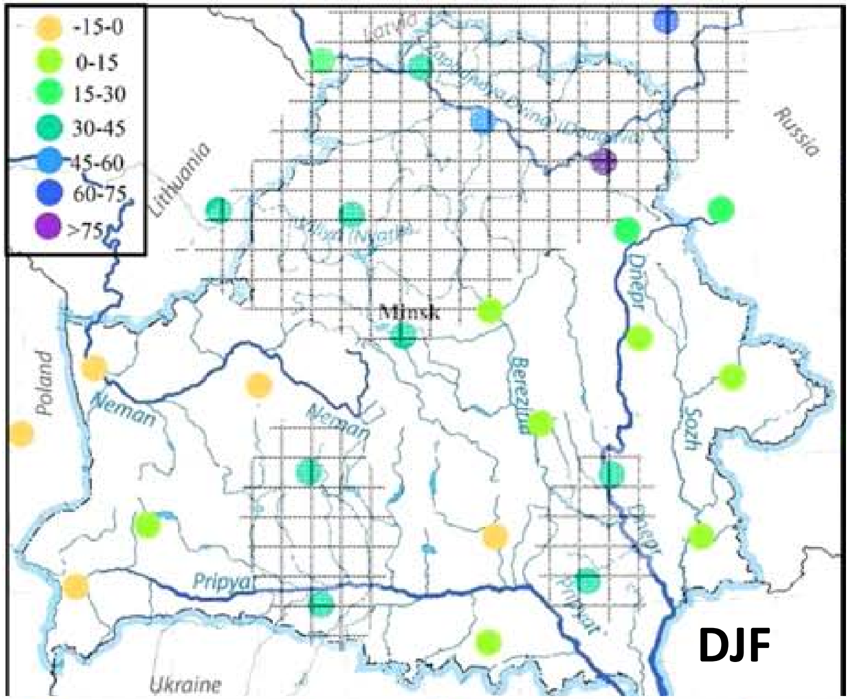
Relative runoff changes (%); long-term mean for the 1978-2010 period are related to the base period 1946-1977.

Russian State Hydrological Institute, 2013

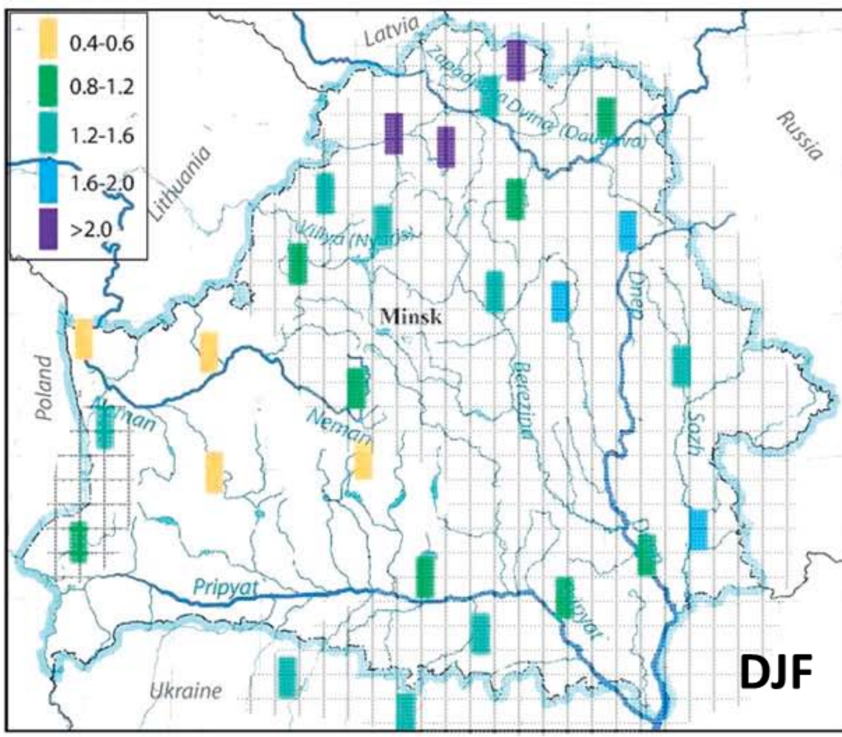
Belarus. Period 1949-2010.

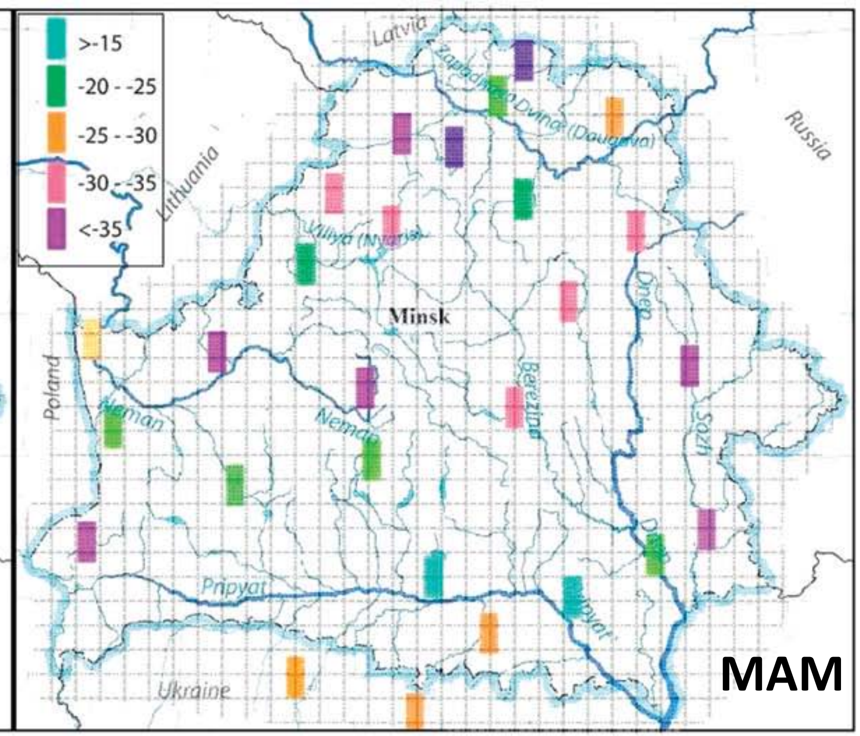
Net change (**top**) in winter precipitation, mm and (**bottom**) winter (DJF) and spring (MAM) streamflow liter s $^{-1}$ km^{-2} .

In the hatched areas, the changes are statistically significant at the 0.05 level.

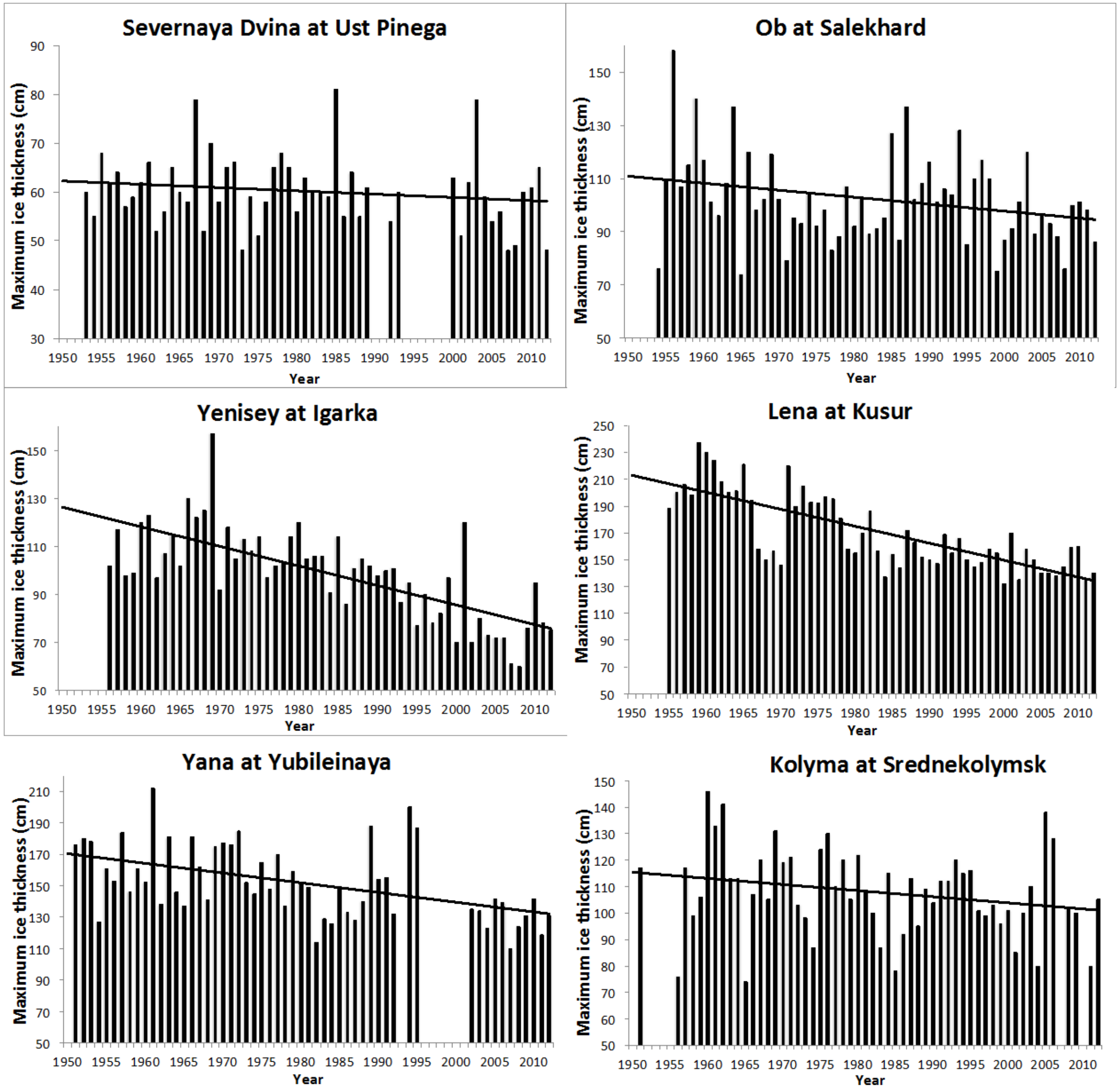


Partasenok et al. 2014





Changes in river ice thickness in the Russian Arctic

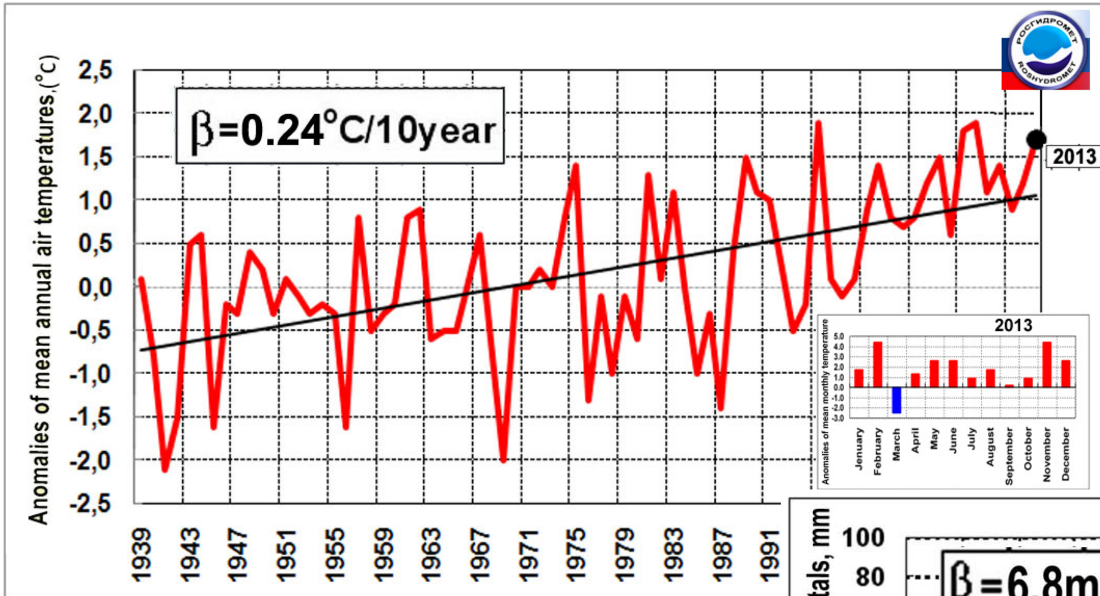


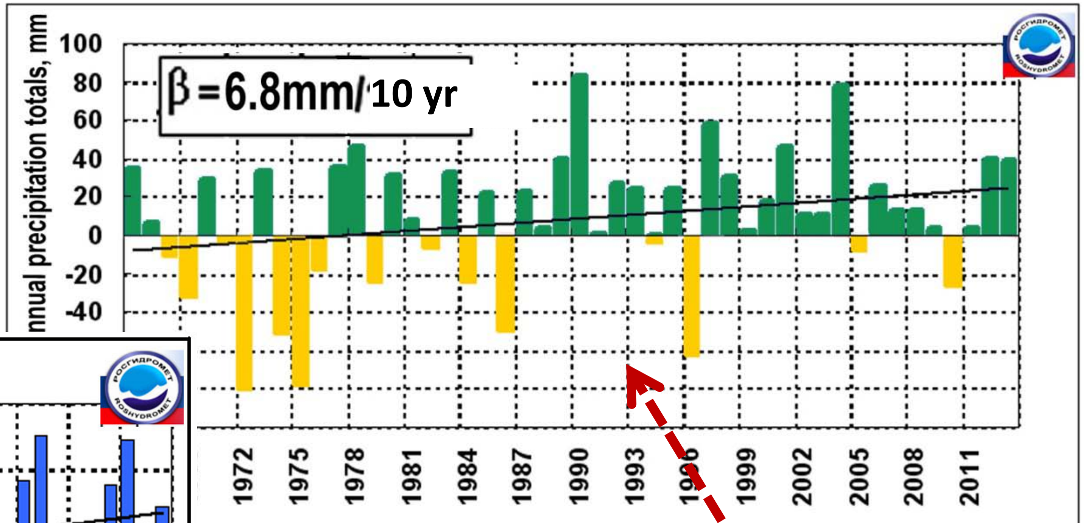
Maximum winter ice thickness (cm) at downstream gauges on large Russian rivers flowing to the Arctic Ocean. Solid line show linear trends (Shiklomanov & Lammers, 2014)

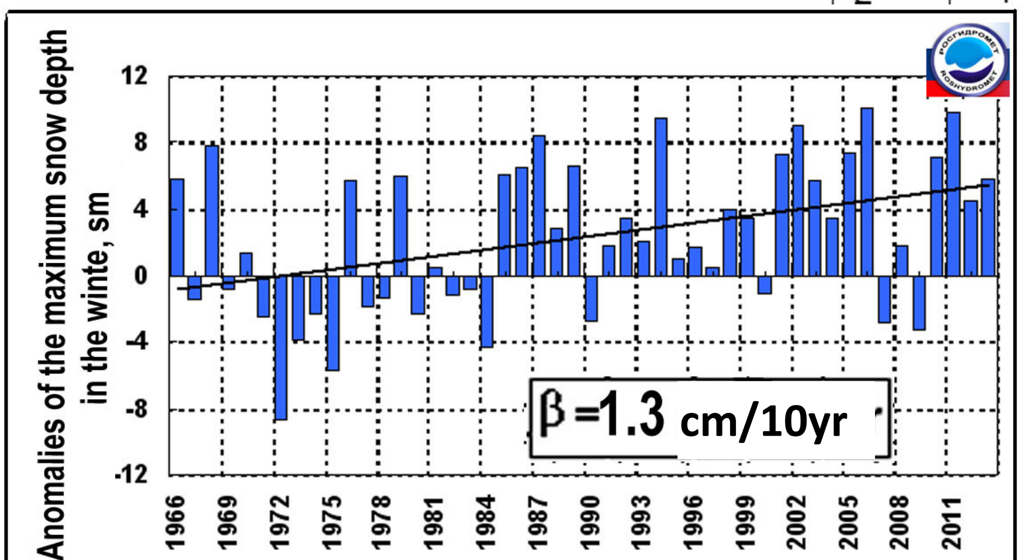
Part 6.

Case Study: European Russia

European part of the Russian Federation

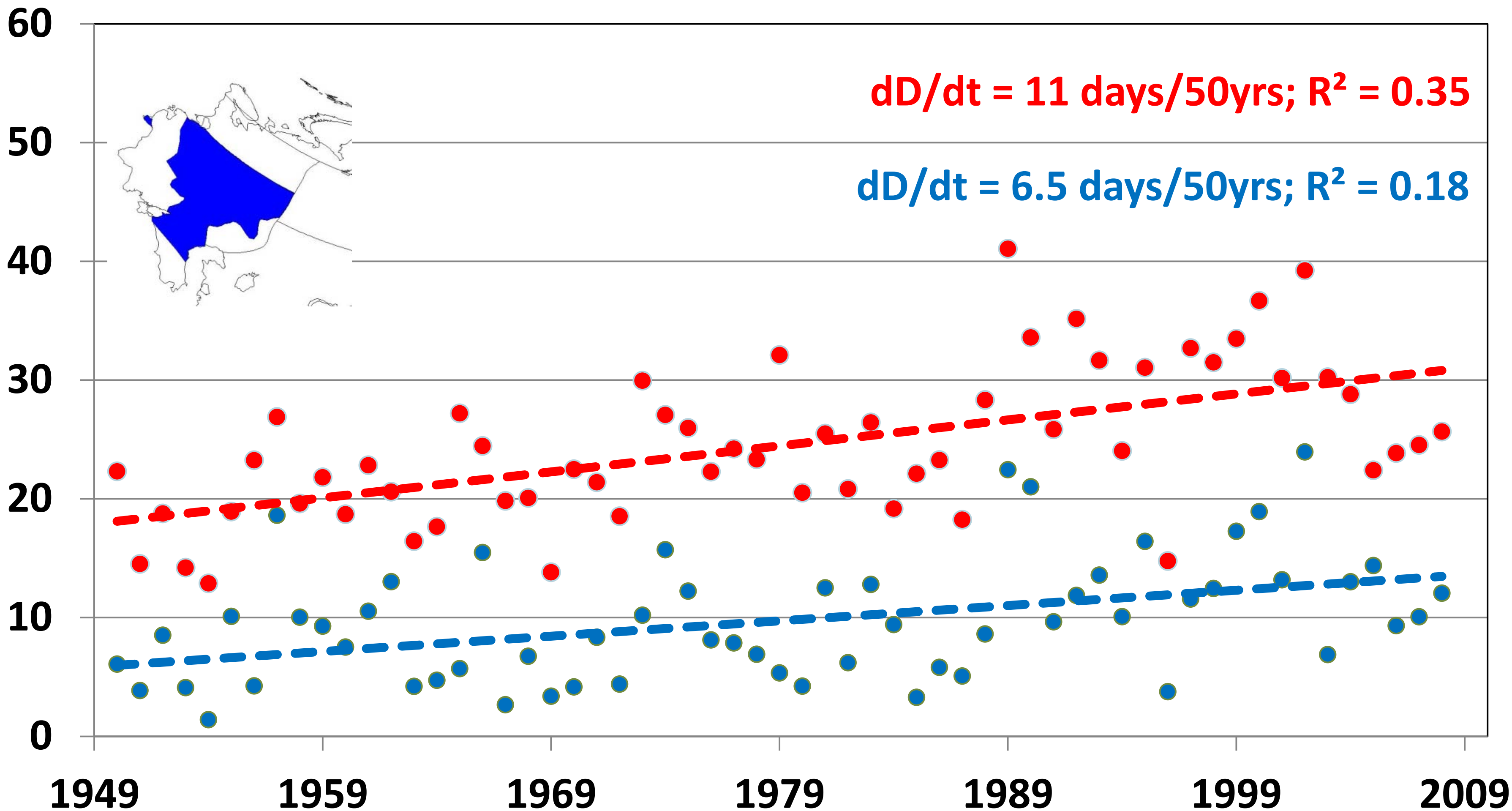






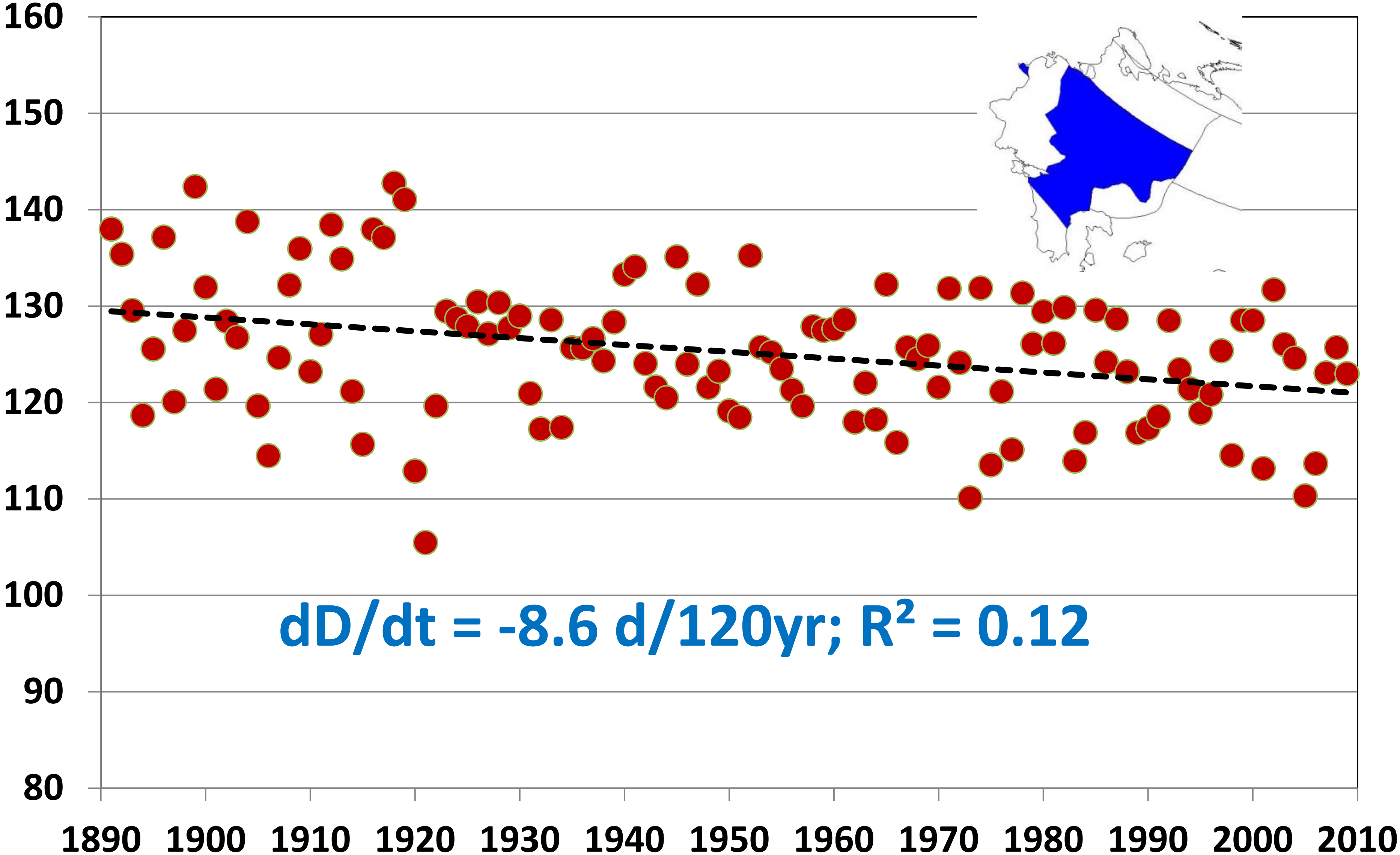
N.B. reported precipitation!!

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



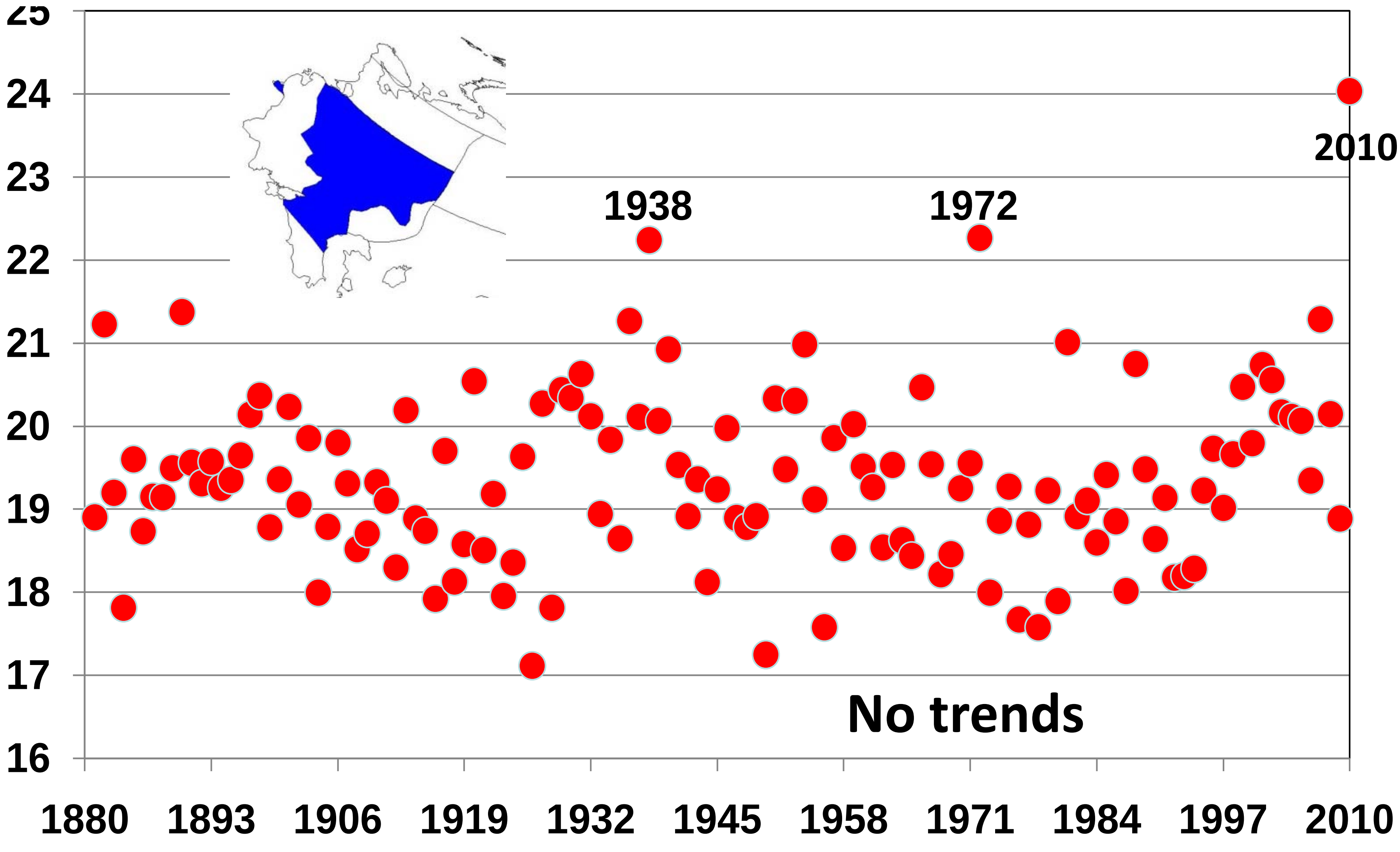
Days with thaw are defined as the days when the mean daily temperature is above -2°C while snow on the ground is above 5 cm.

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

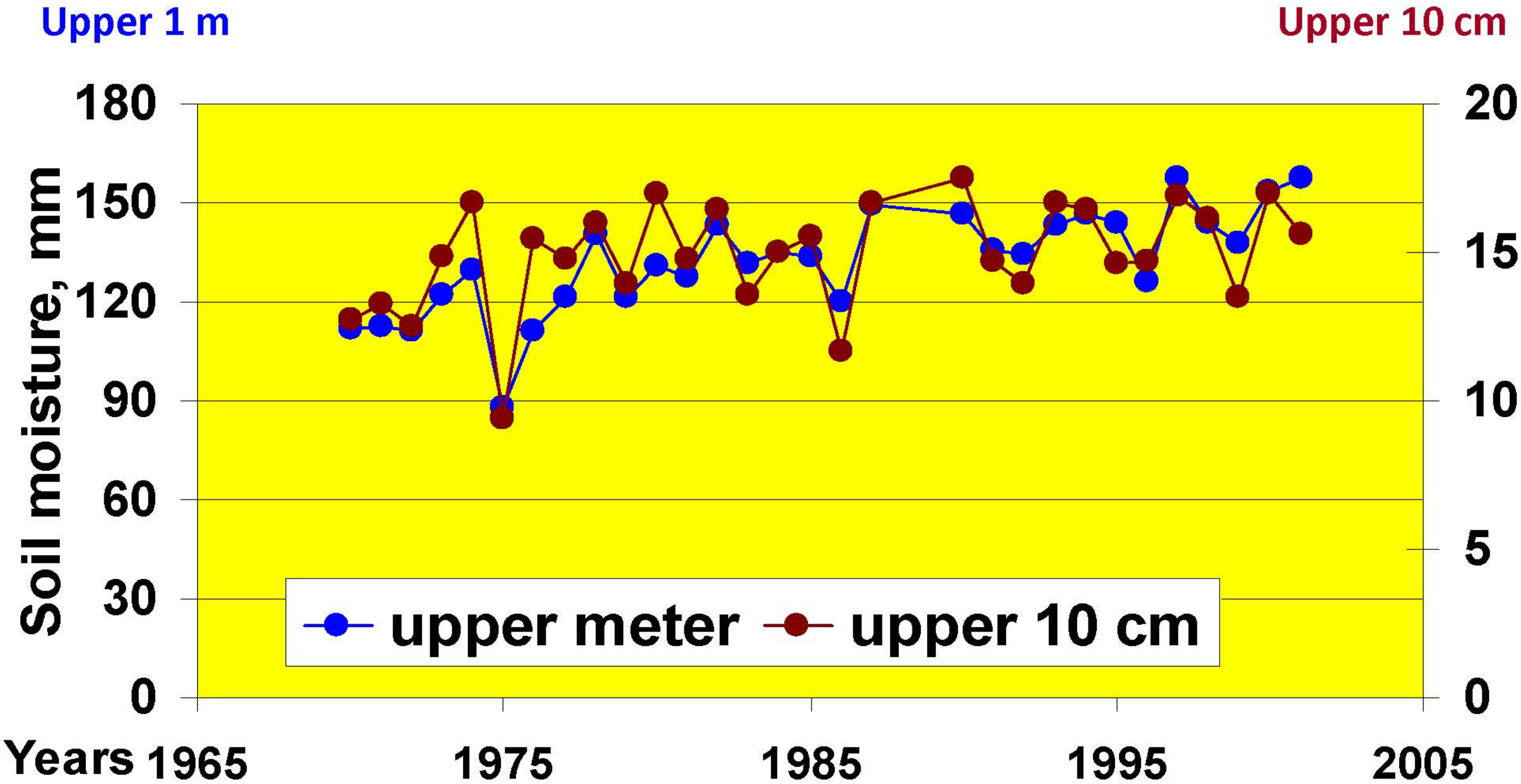


July-August surface air temperature (°C) area-averaged over European Russia south of 60°N

(Lugina et al 2006, updated)

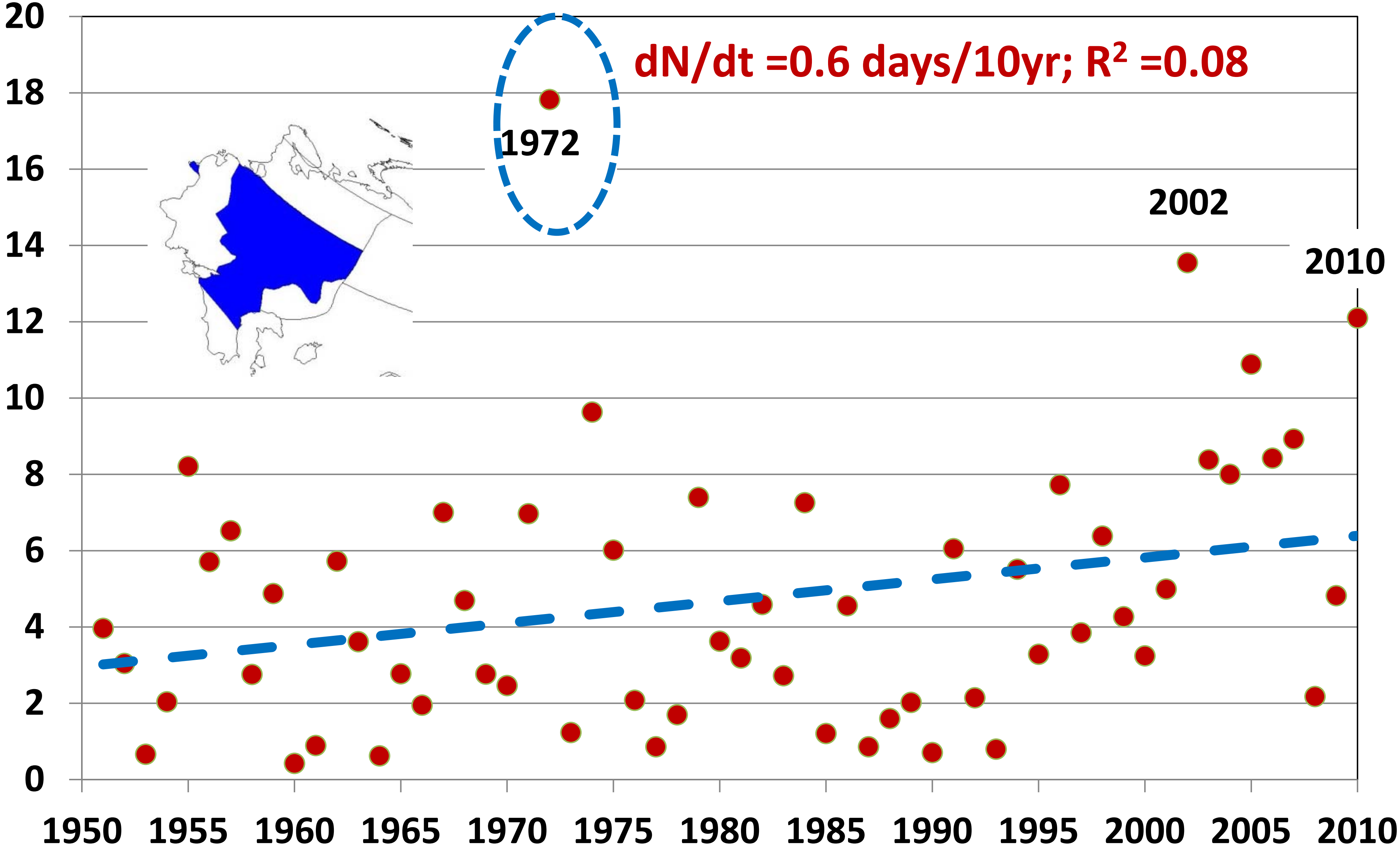


Soil moisture changes over European Russia south of 60°N during the warm season in the first upper 100 and 10 cm respectively (Speranskaya 2009)



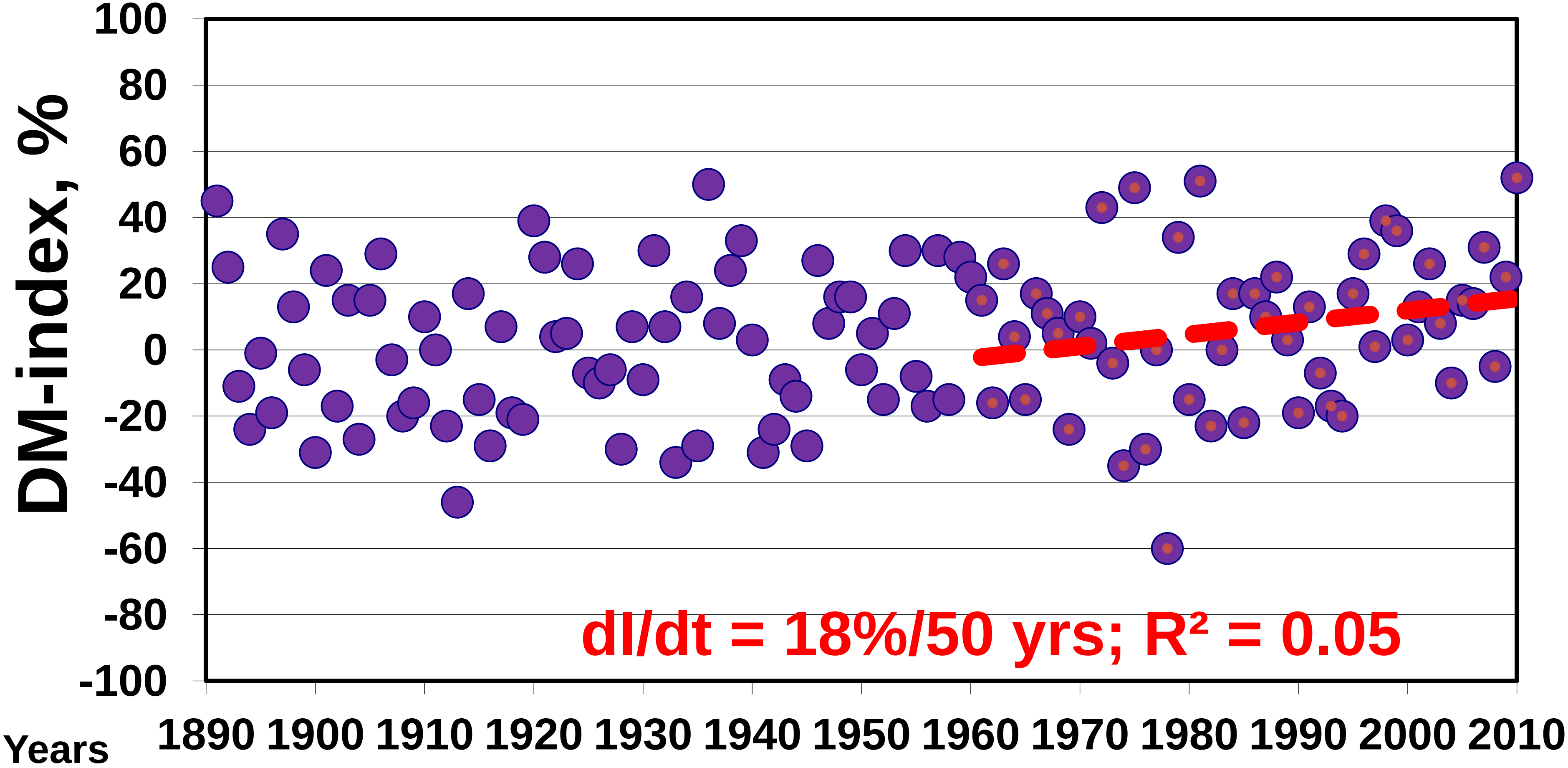
r = 0.78; rates of change = 9.3%/10yr [R^2=0.58] and 5.5%/10yr [R^2=0.15] respectively.

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



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

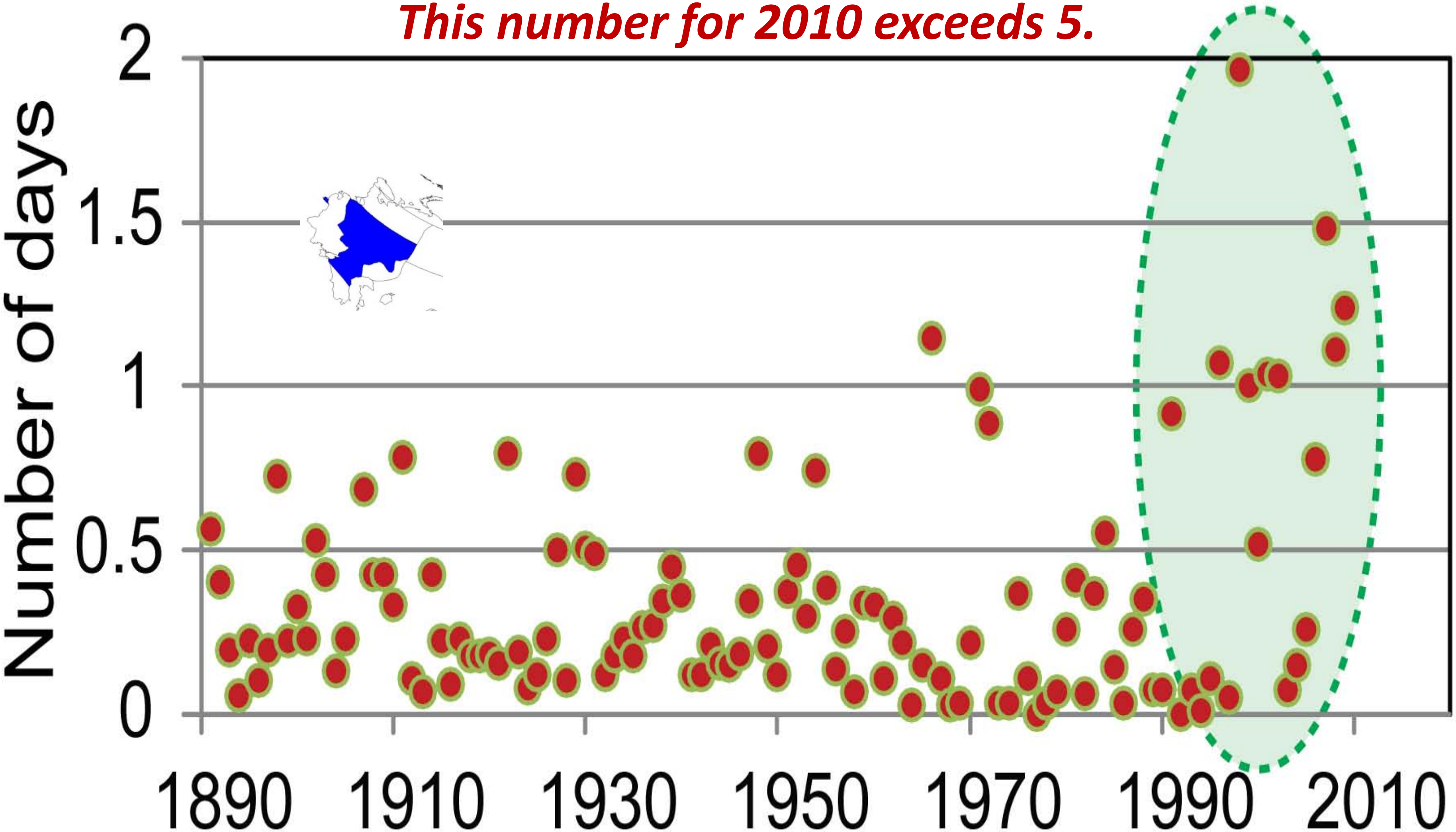
Meshcherskaya and Blazhevich, 1997, updated to 2010



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

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.



That’s it!

谢谢!

Thank you!

Спасибо!