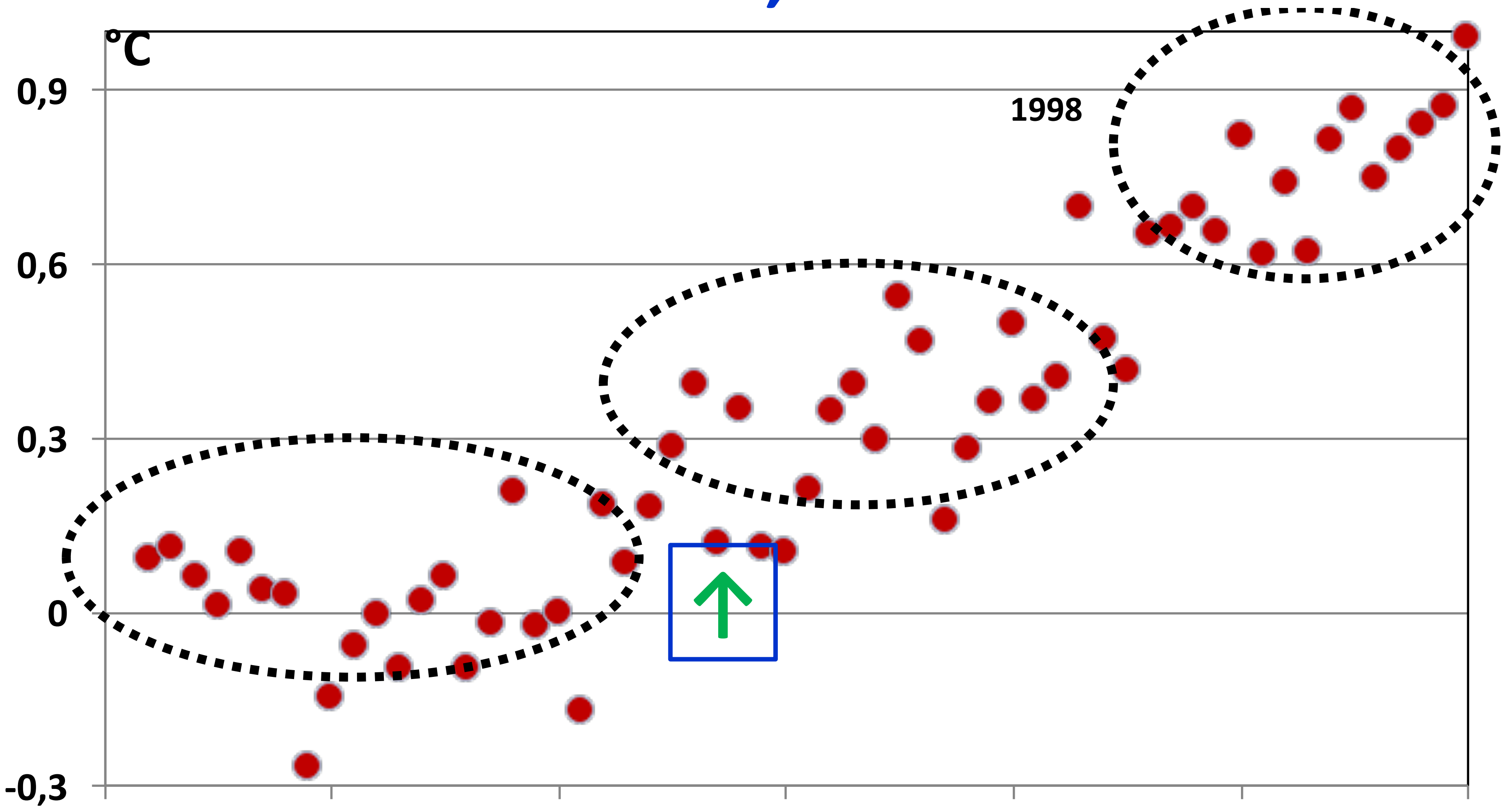
# Contemporary global climatic changes and their manifestation in the Dry Land Belt of Northern Eurasia

**Pavel Groisman**
*IORAS, Moscow, Russia*
*HS&S and NCEI NOAA, Asheville, NC USA*

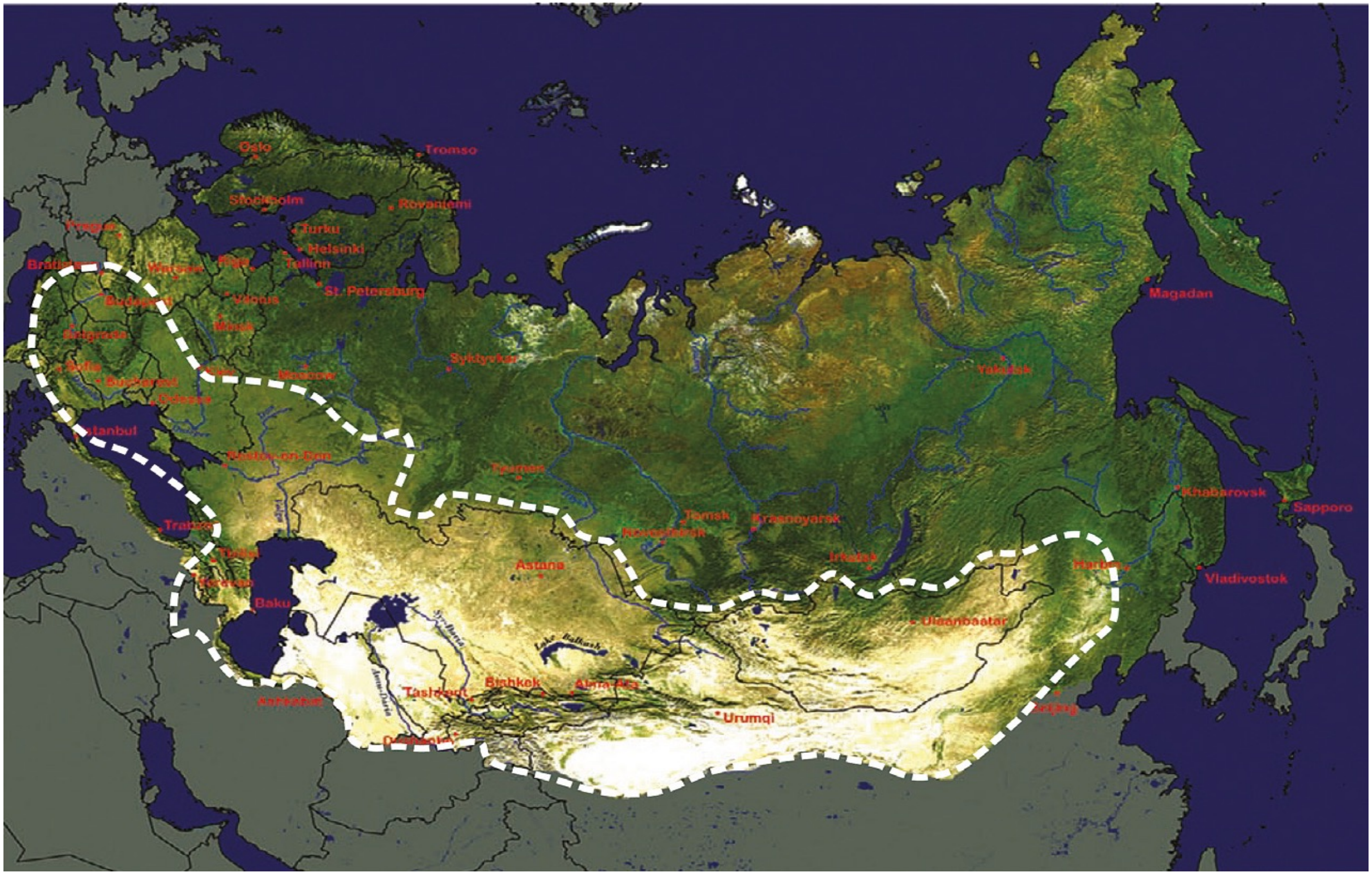
# Global surface air temperature anomalies, 1957-2015




N.B.: The last value (2015) is a preliminary estimate.

**Reid et al. 2016: Global impacts of the 1980s regime shift. *Global Change Biology*, 22, 682–703.**

# Dry Land Belt (DLB)




MODIS 1-km true color composite from 20 to 28 August 2004 with shaded relief adjustment (GTOPO30). Green corresponds to vegetation land. Light brown and yellow indicate sparse vegetation and arid areas, respectively.

# CHANGES IN THE ARCTIC

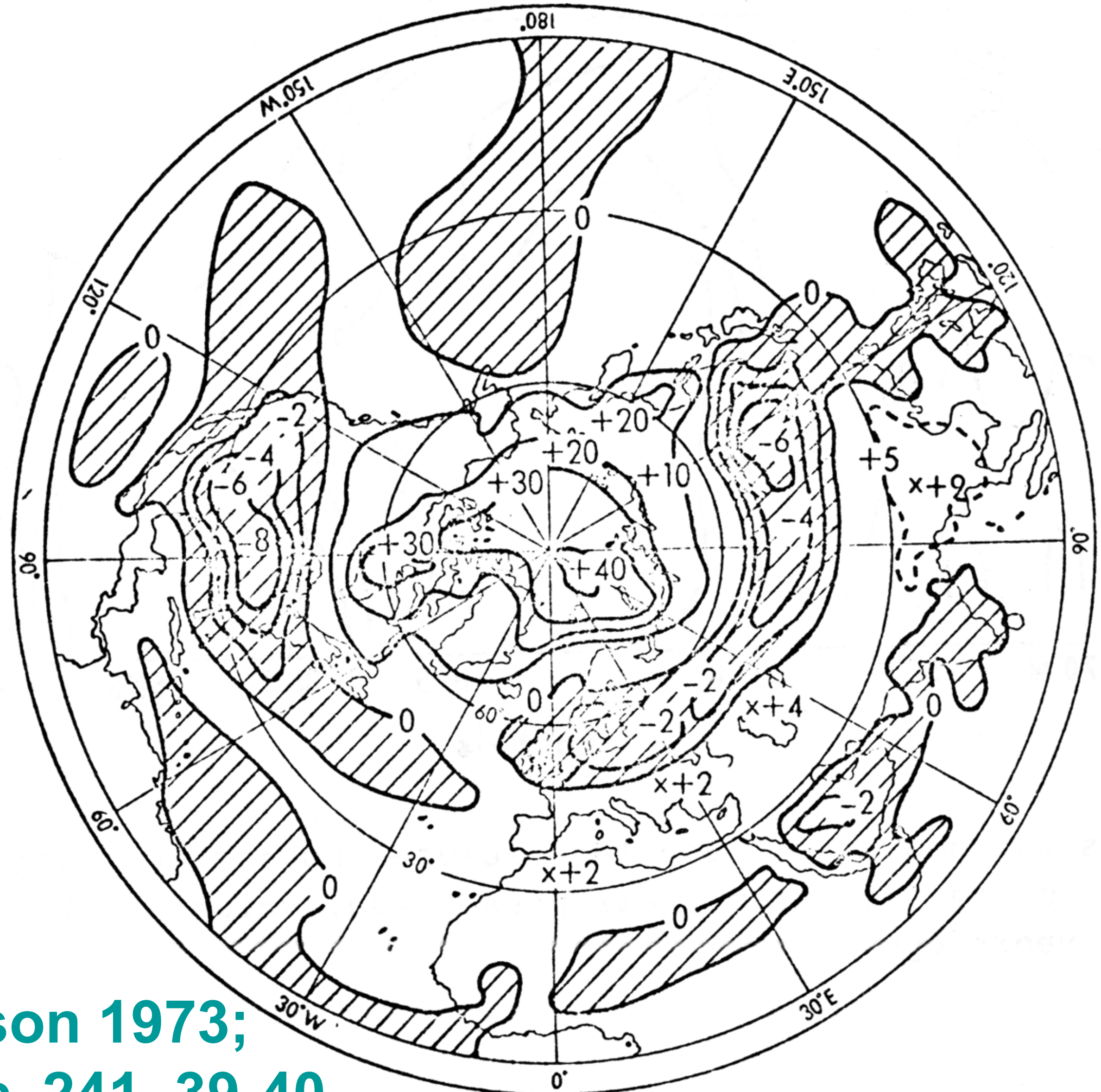
What do they bring for the DLB

# Arctic Sea Ice Retreat

- https://www.climate.gov/news-features/videos/old-ice-arctic-vanishingly-rare

# 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.

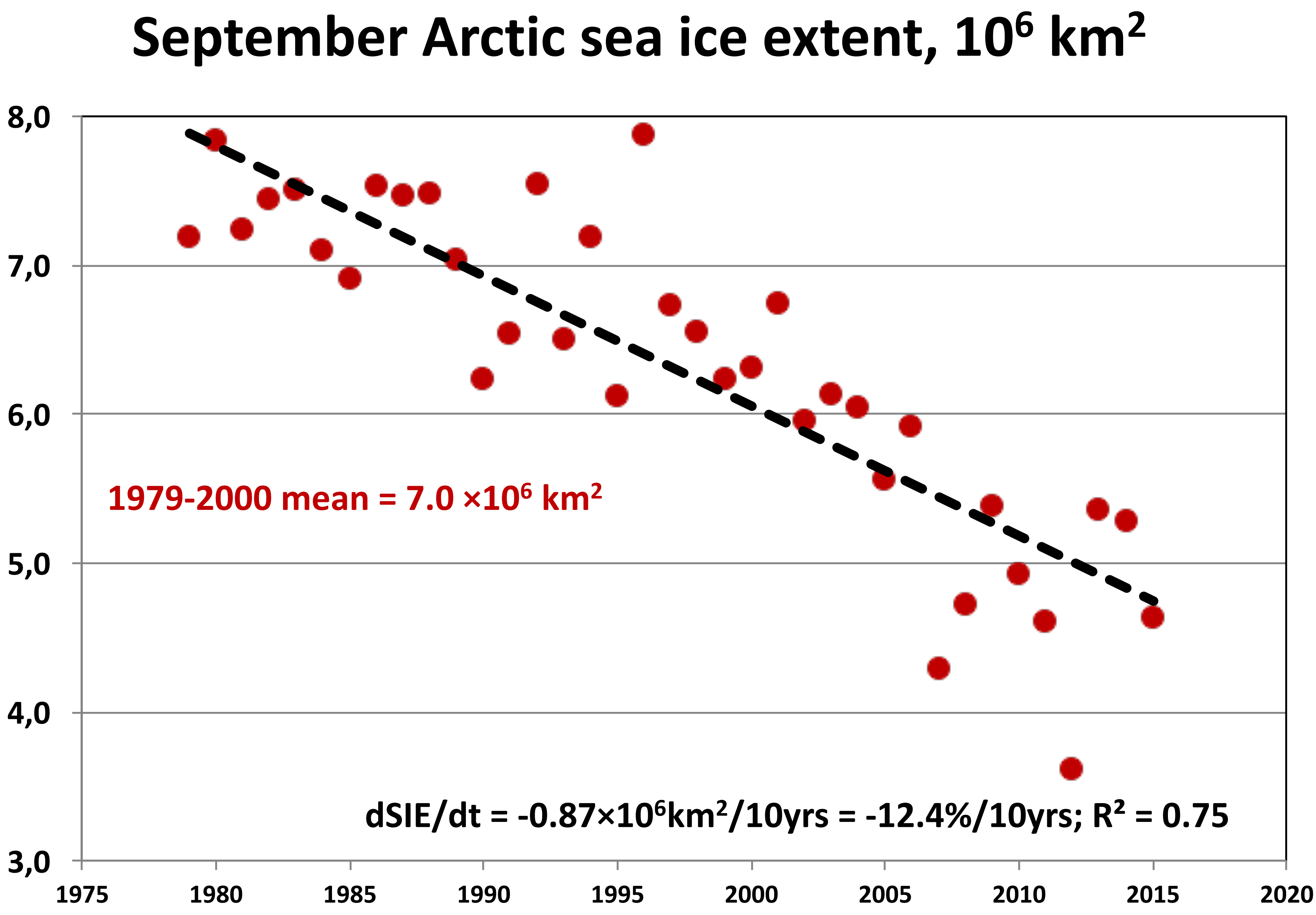



Newson 1973; *Nature*, 241, 39-40

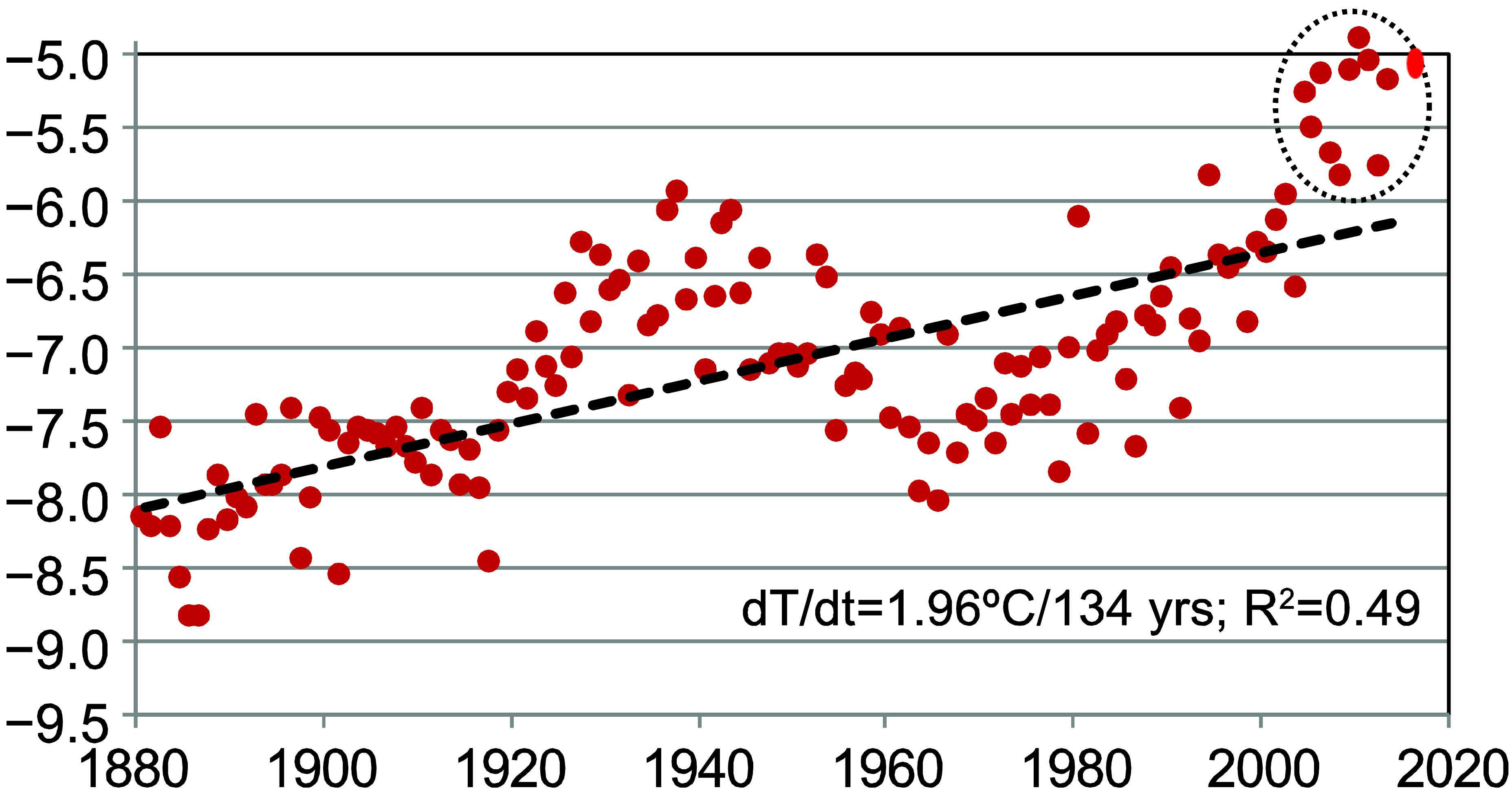

So far, the lowest recorded Northern Hemisphere sea ice extent was in mid-September 2012

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

Median sea ice boundary


September Arctic sea ice extent, 10⁶ km²
8,0
7,0
6,0
5,0
4,0
3,0
1979-2000 mean = 7.0 ×10⁶ km²
dSIE/dt = -0.87×10⁶km²/10yrs = -12.4%/10yrs; R² = 0.75
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

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

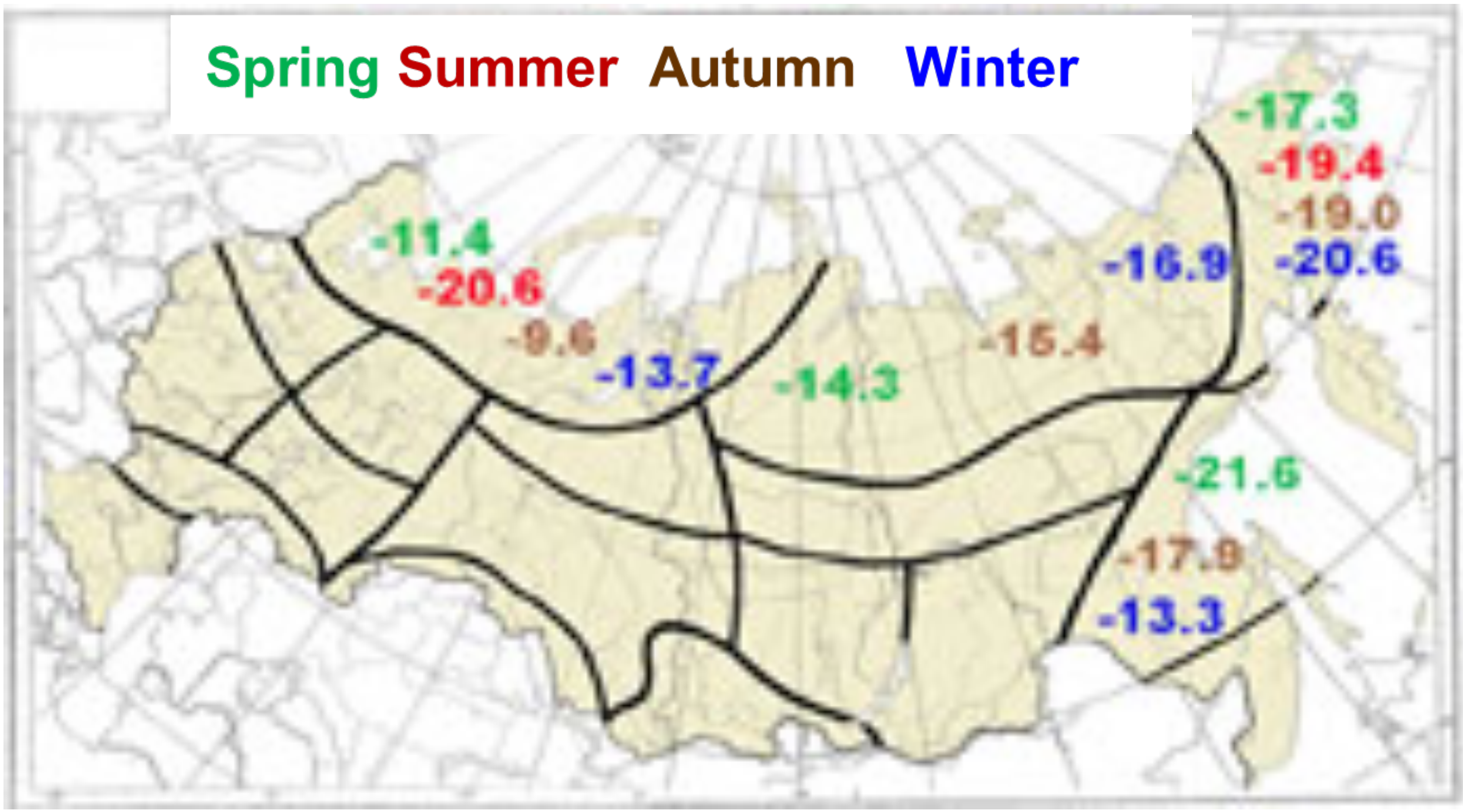


# No (small) heat/water vapor transport from the Arctic Ocean into Siberia

- Dufour, A., O.G. Zolina, and S.K. Gulev, 2016: Atmospheric Moisture Transport to the Arctic: Assessment of Reanalyses and Analysis of Transport Components. *J. Climate*, **19,** *DOI:* *http://dx.doi.org/10.1175/JCLI-D-15-0559.1*

# Trends in the number of days with strong wind speed above 15 m $s^{-1}$ over Russia

[Bulygina et al. 2013]




**Period 1977-2011. Units: [%×(10 yr)$^{-1}$].**

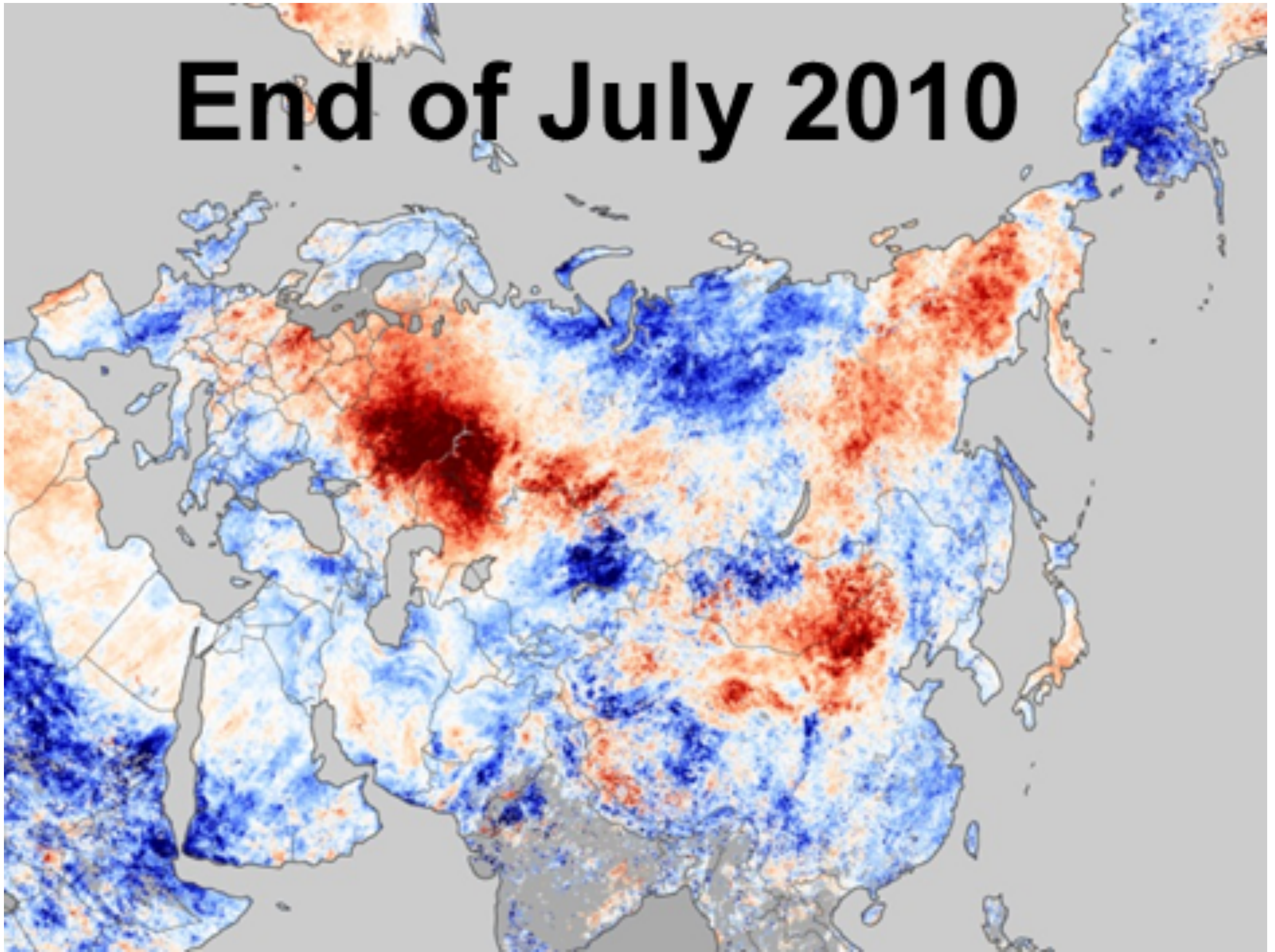
**Only statistically significant at the 0.05 level estimates are shown.**

# Forest fires in Northern Eurasia

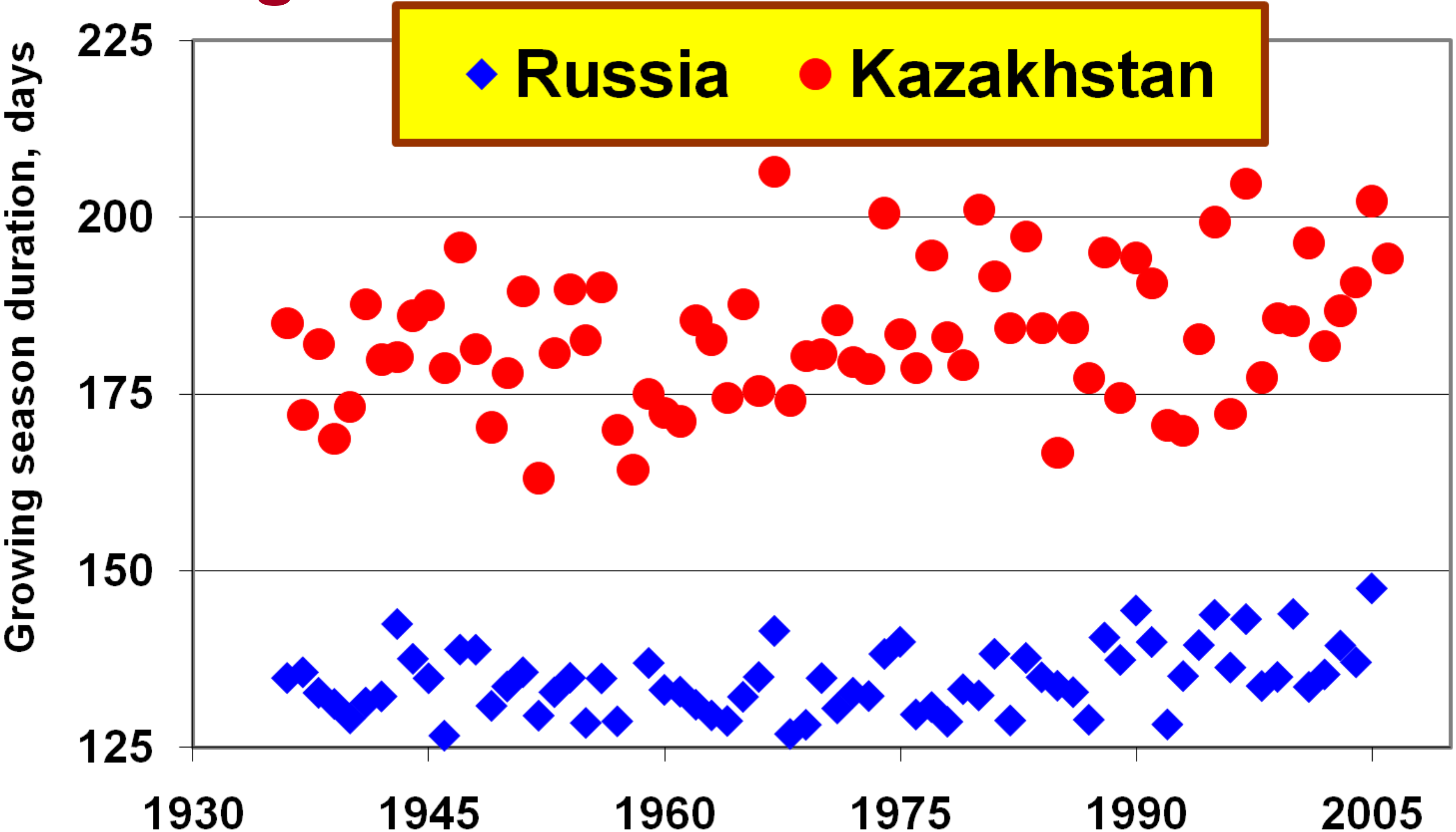
- https://www.youtube.com/watch?v=Z9A6QsGZ4Zk

# New level of Extreme Events

***Temperature Anomalies:***

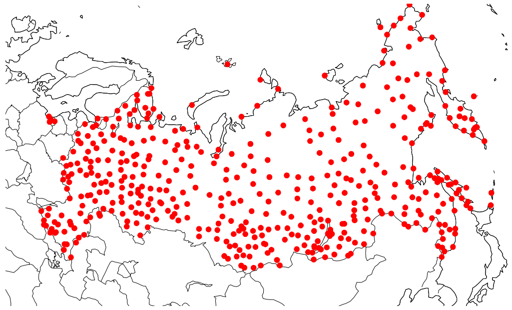


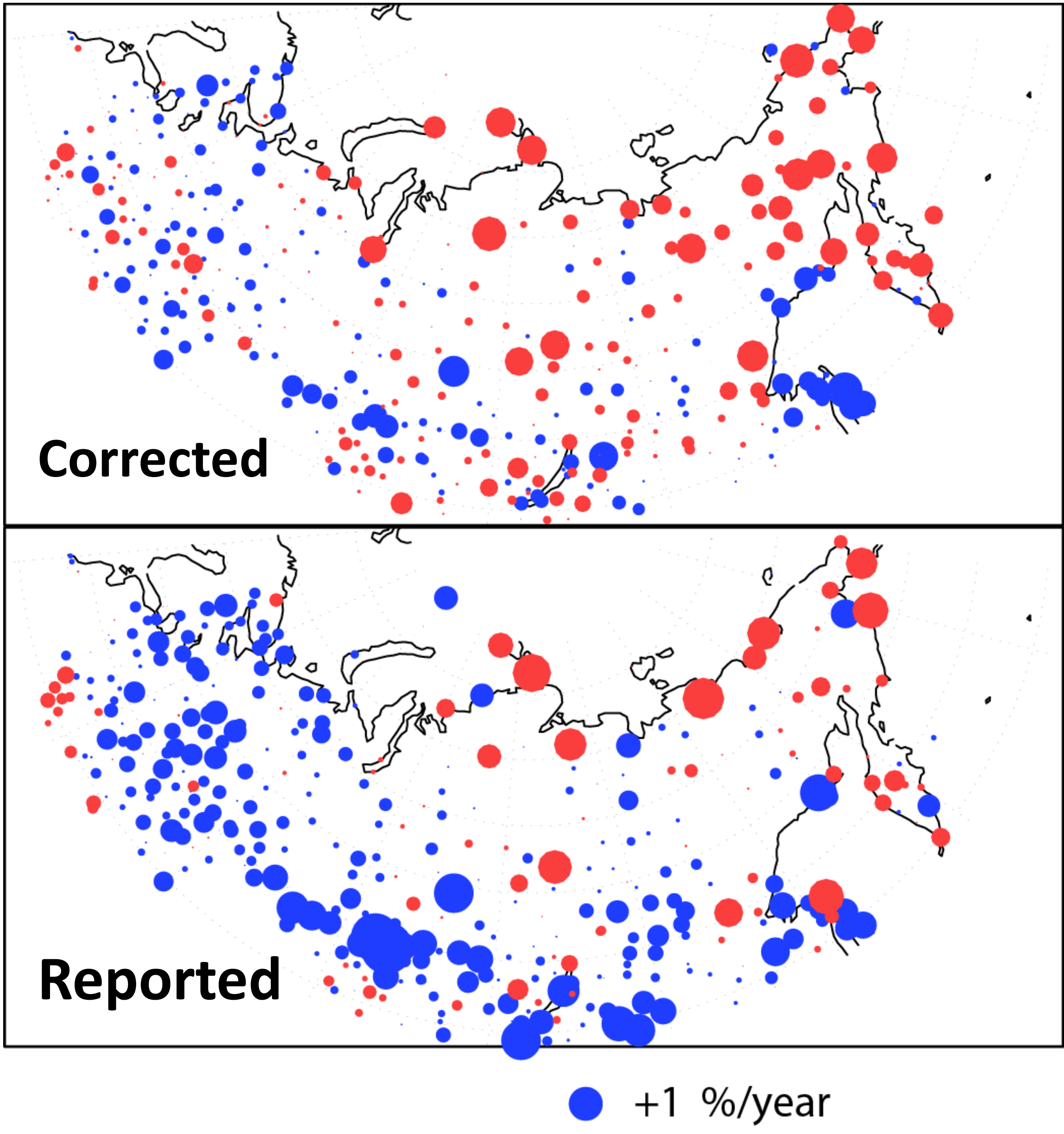
# Duration of the growing season area-averaged over Russia and Kazakhstan



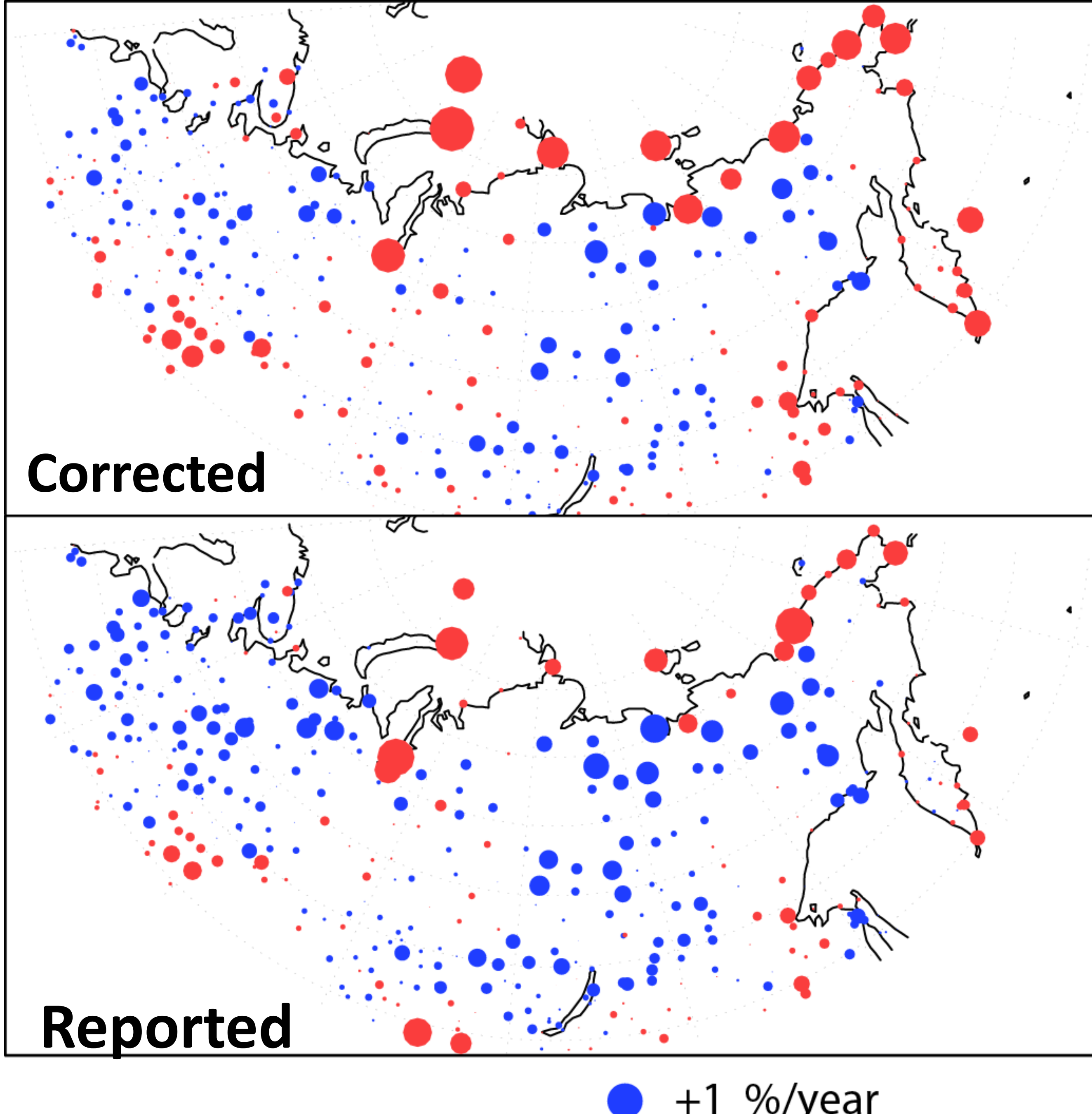

During the past 70 years, significant increase by 6 to 11 days (or by 5% to 6%)

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

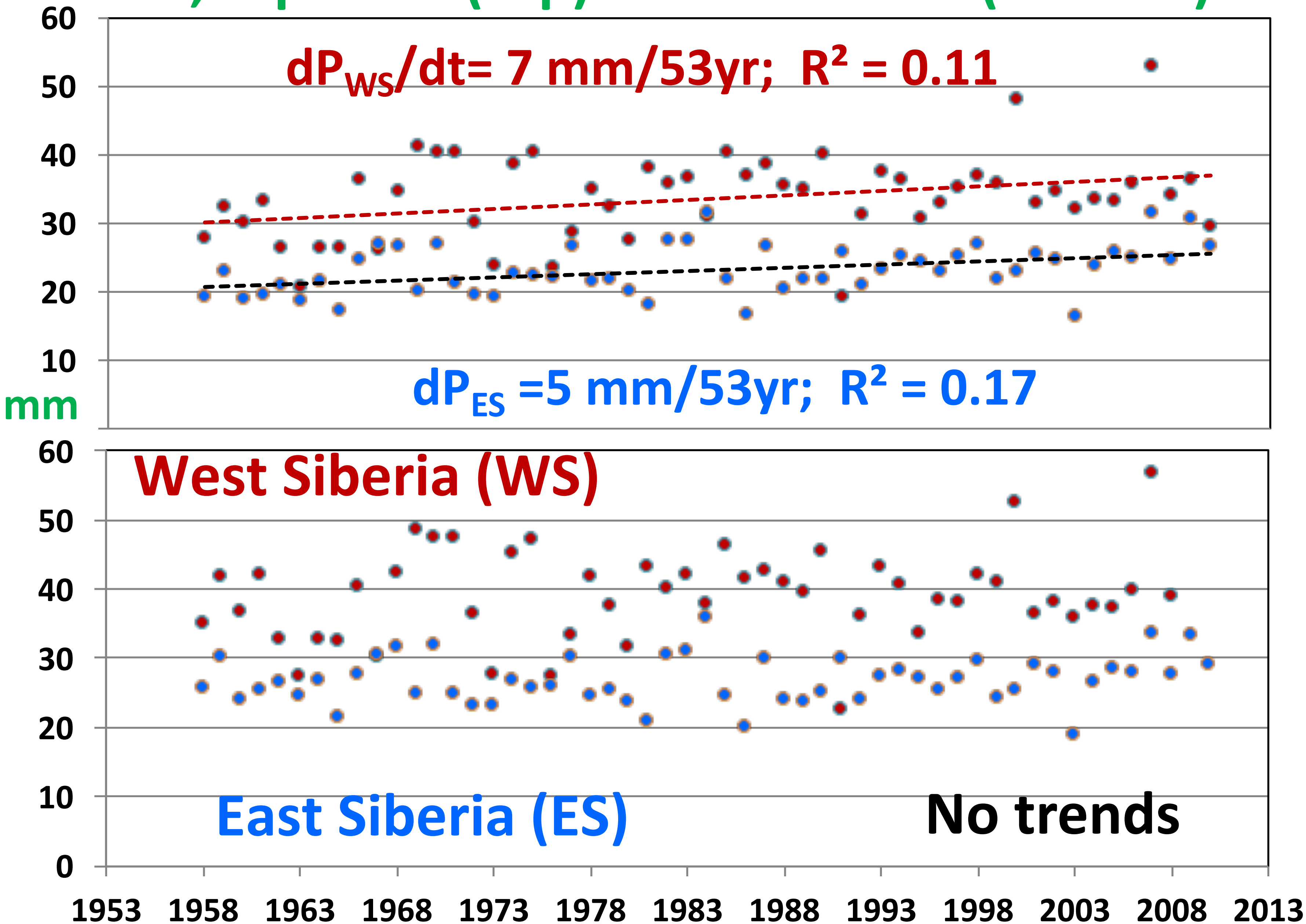




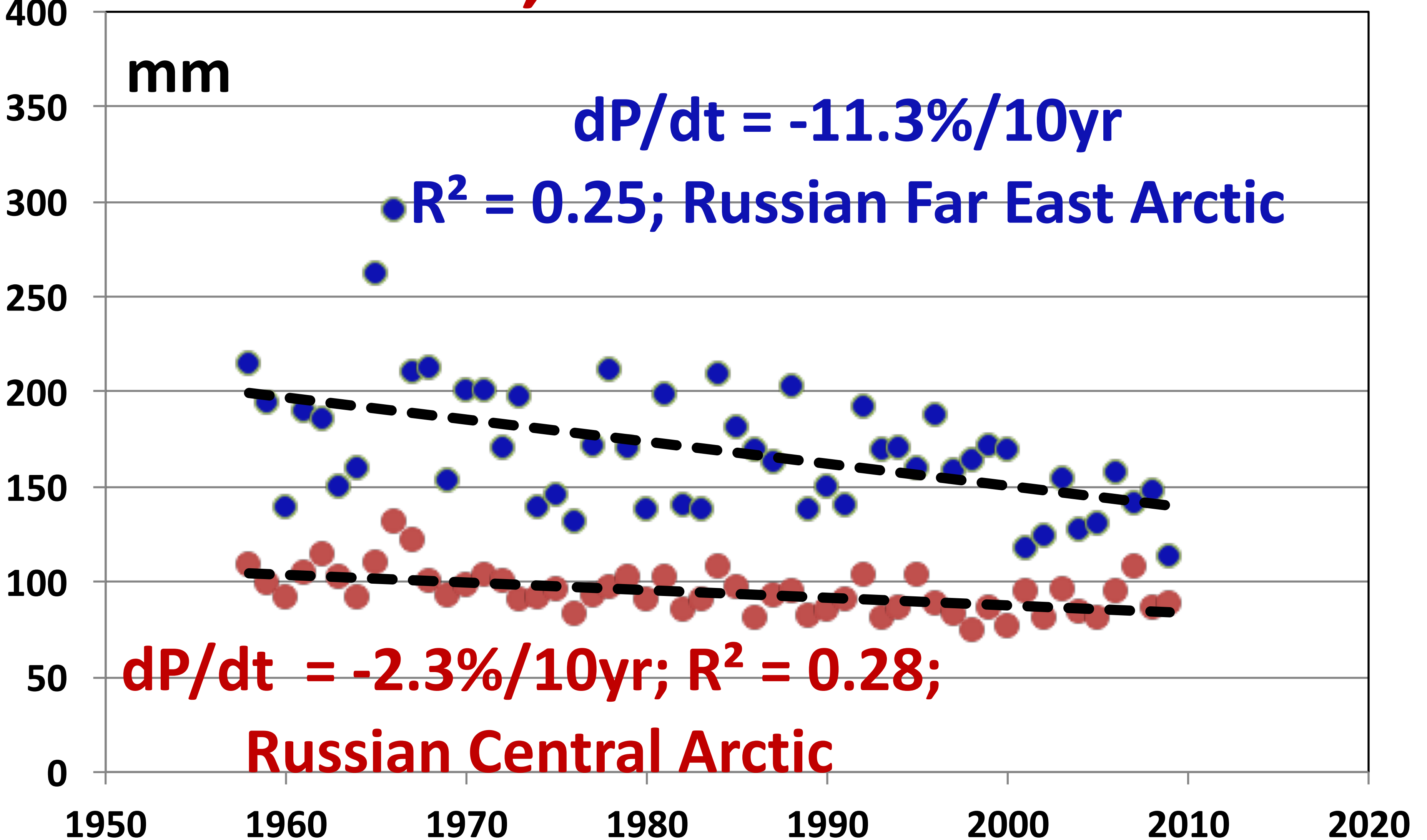
**Linear trends (%/yr) of the summer precipitation (June-August) for the 1958-2010 period**



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

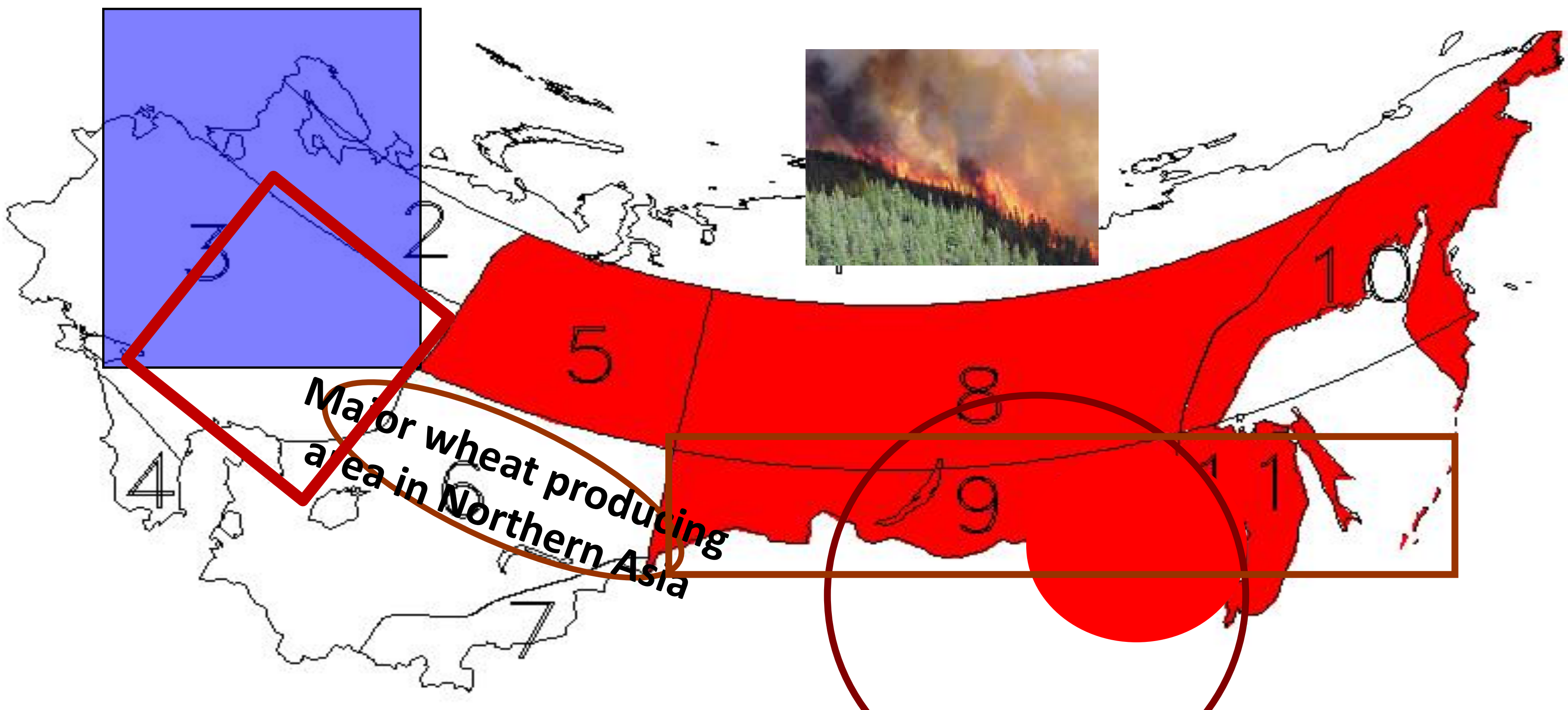


# Regional precipitation trends in Asian Arctic, November - March



# 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).**

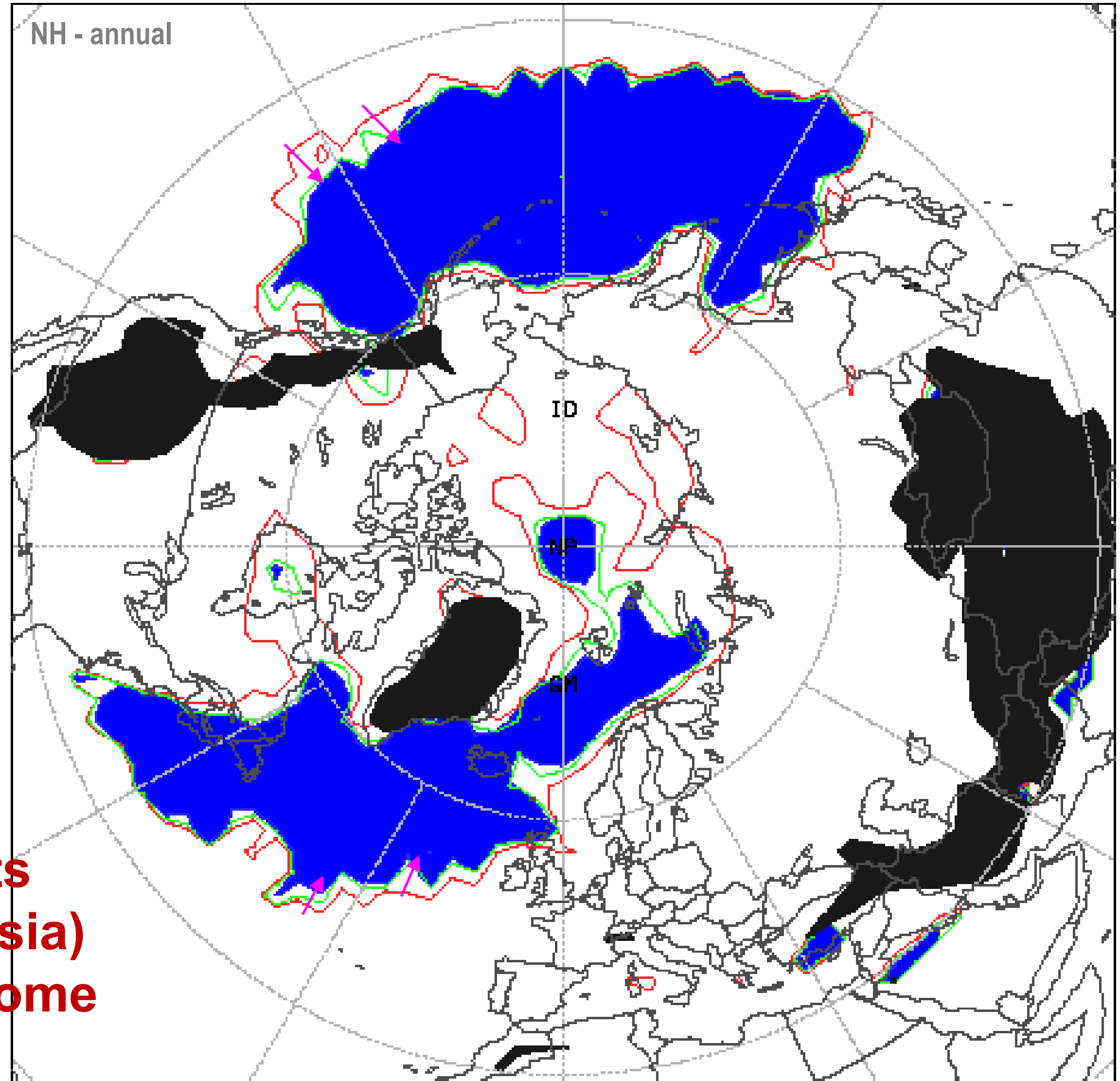



Groisman et al 2009 (Bull. Amer. Meteorol. Soc.)

# Major storm track regions in the 20th Century Reanalysis

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

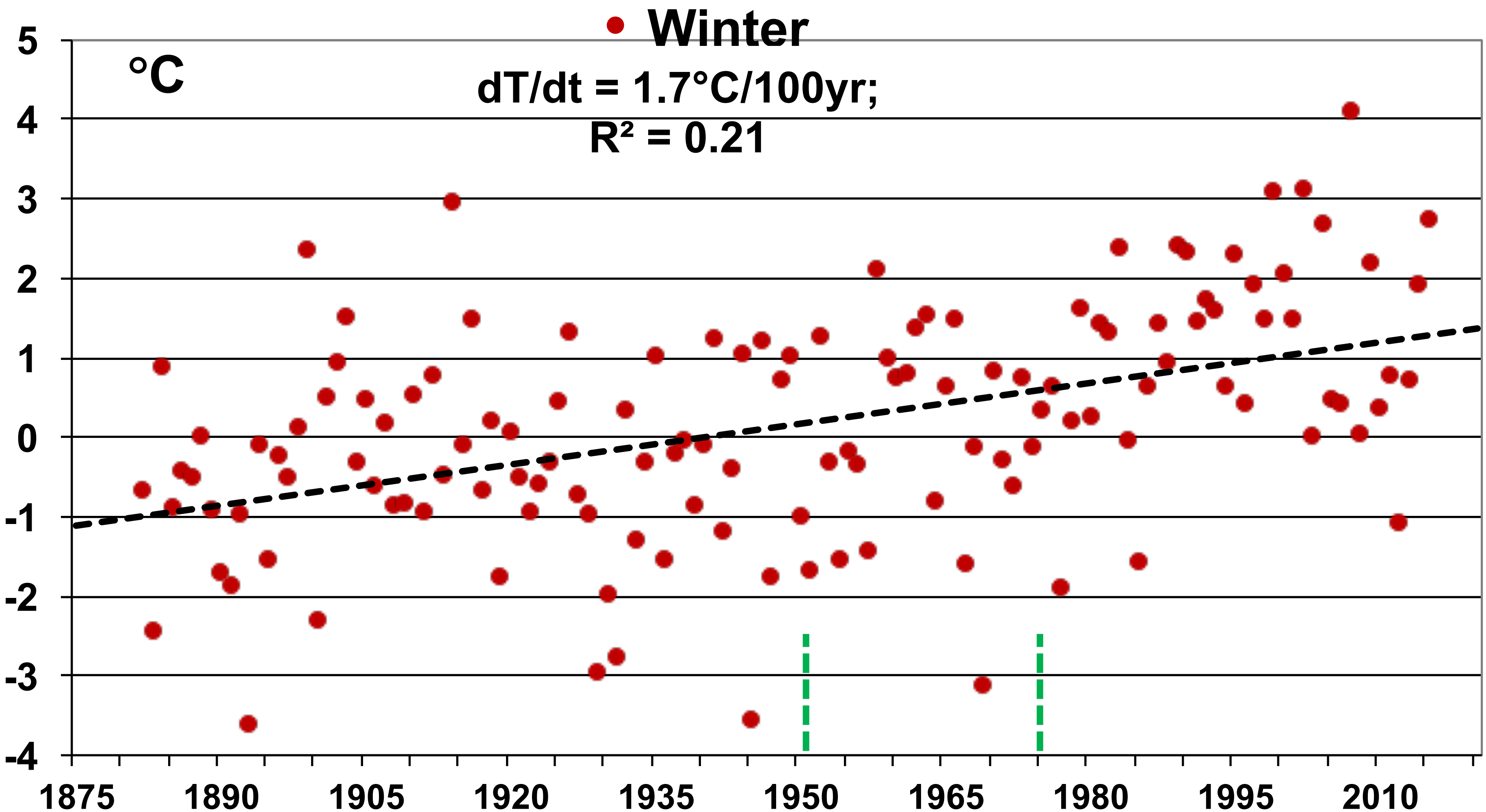
30-yr periods
Blue shading: 1979-2008 (current)
Green line: 1941-1970 (mid 20th century)
Red line: 1901-1930 (early 20th century)
Black shading: no data




**Wang et al. 2012**

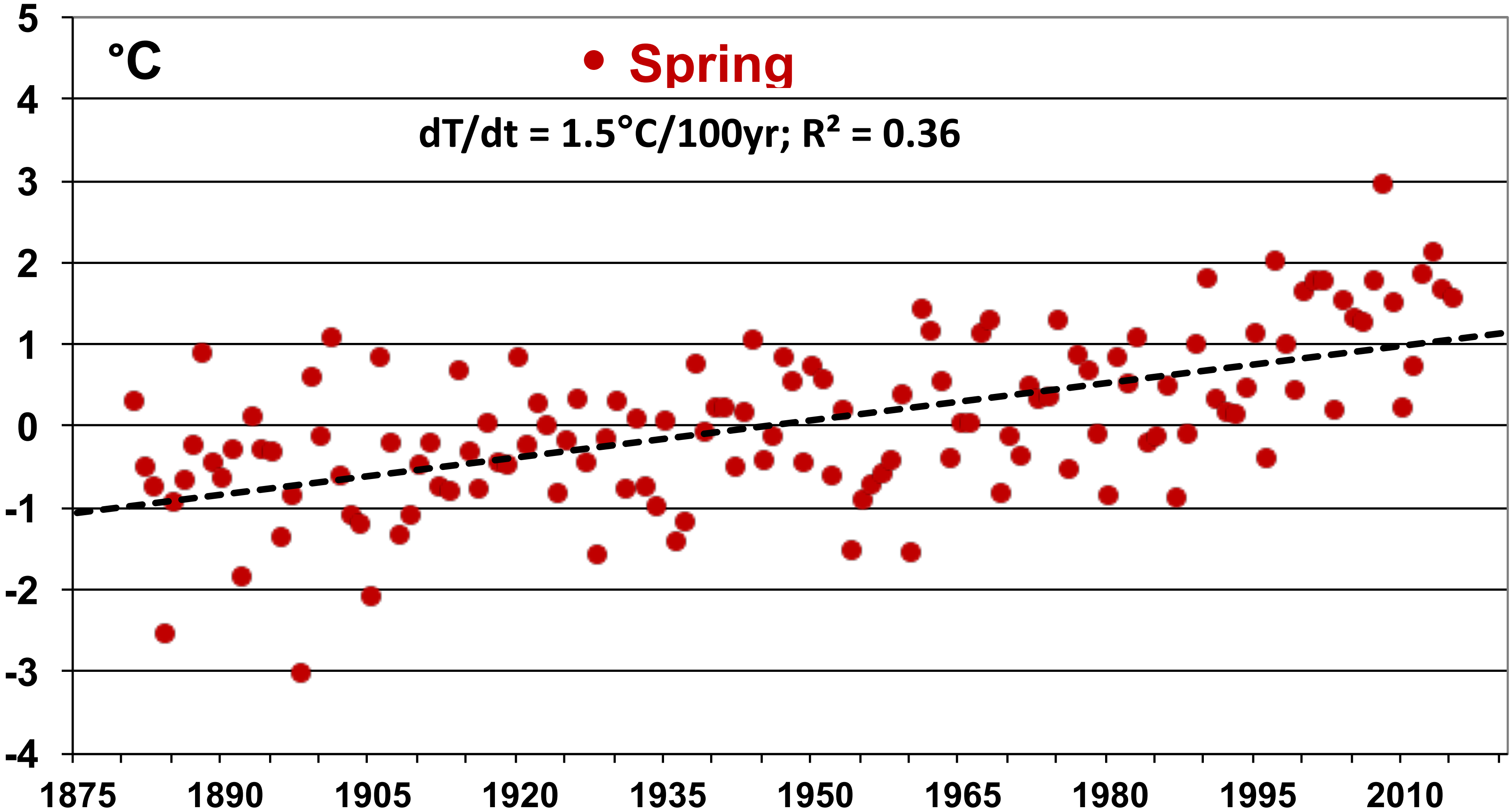
**=> Inside the continents (first of all, inside Eurasia) winter climate can become more continental)**

# Mean winter surface air temperature anomalies area-averaged over the DLB



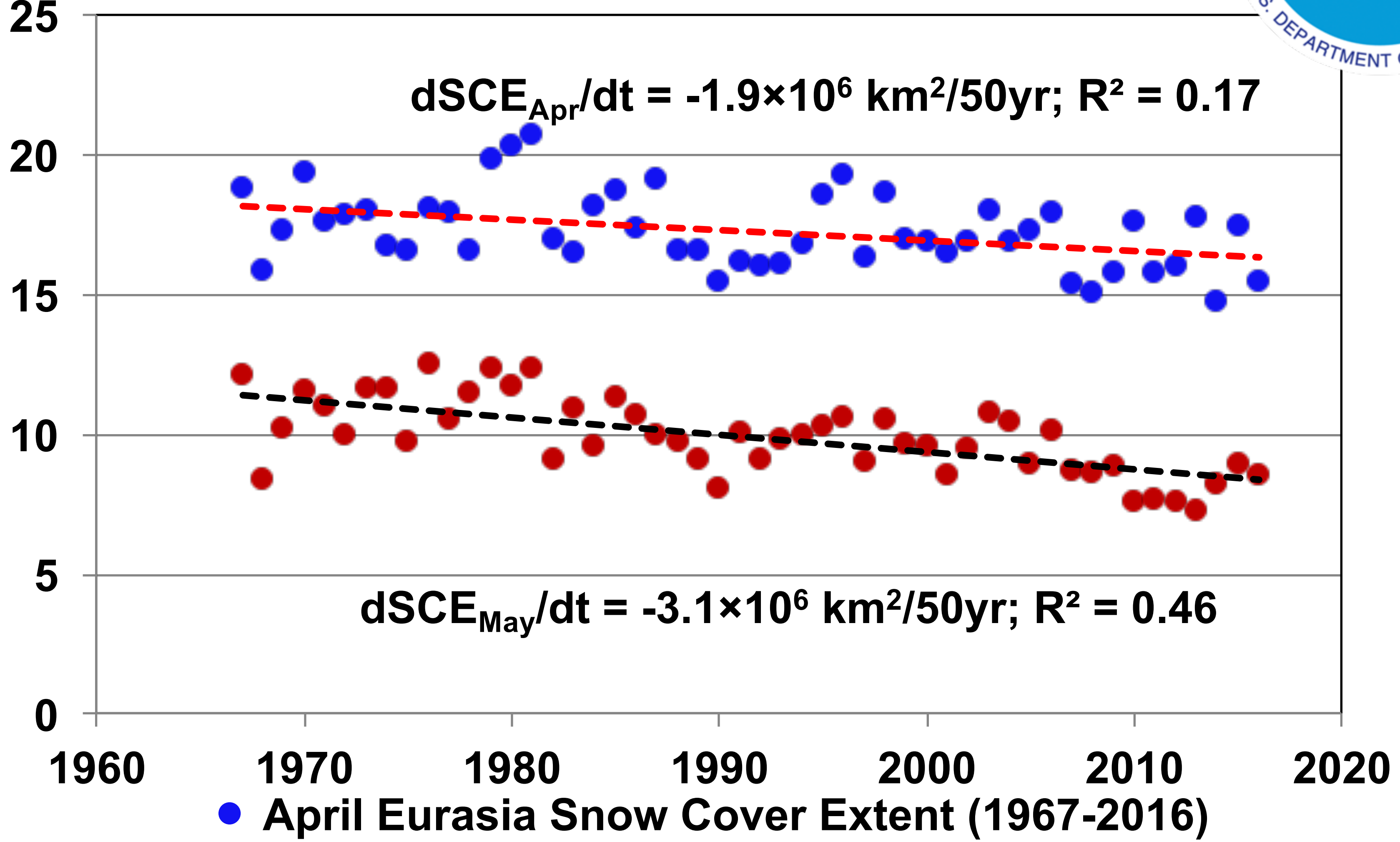

***1881-2015; reference period 1951-1975***

# Mean spring surface air temperature anomalies area-averaged over the DLB




*1881-2015; reference period 1951-1975*

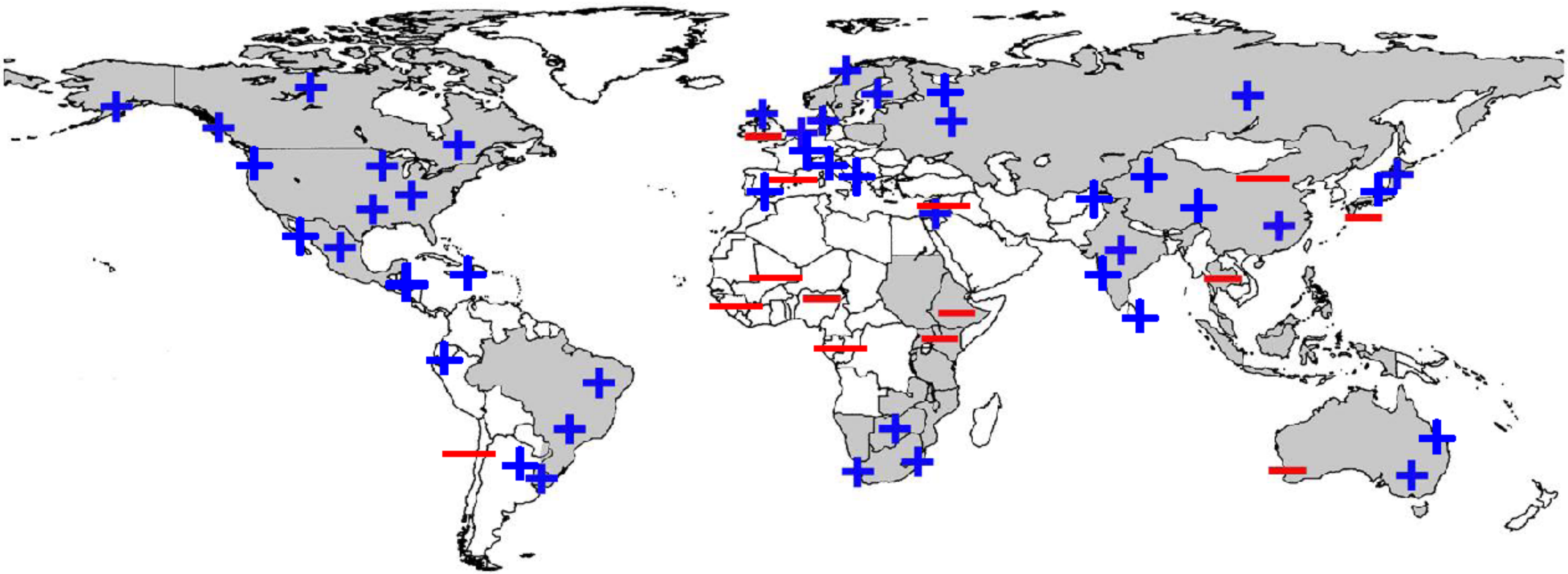
# Snow cover extent anomalies over Eurasia, $10^6$ $km^2$



# Intense precipitation

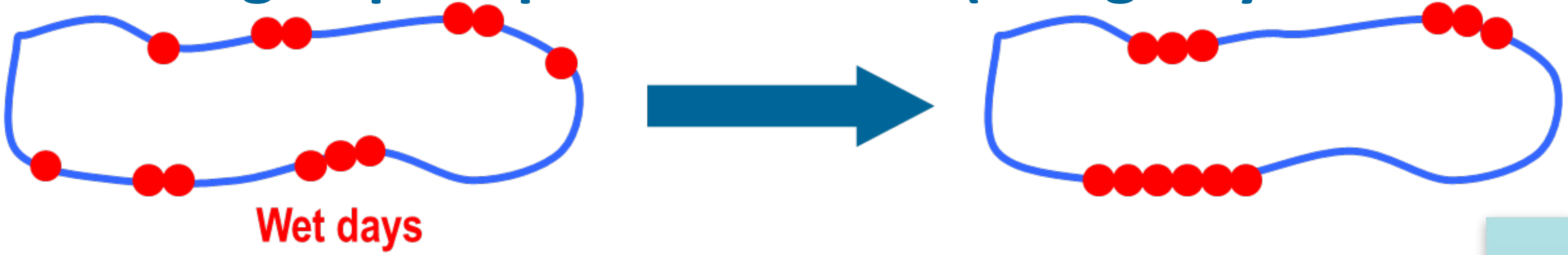
**and freezing rain frequency**

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

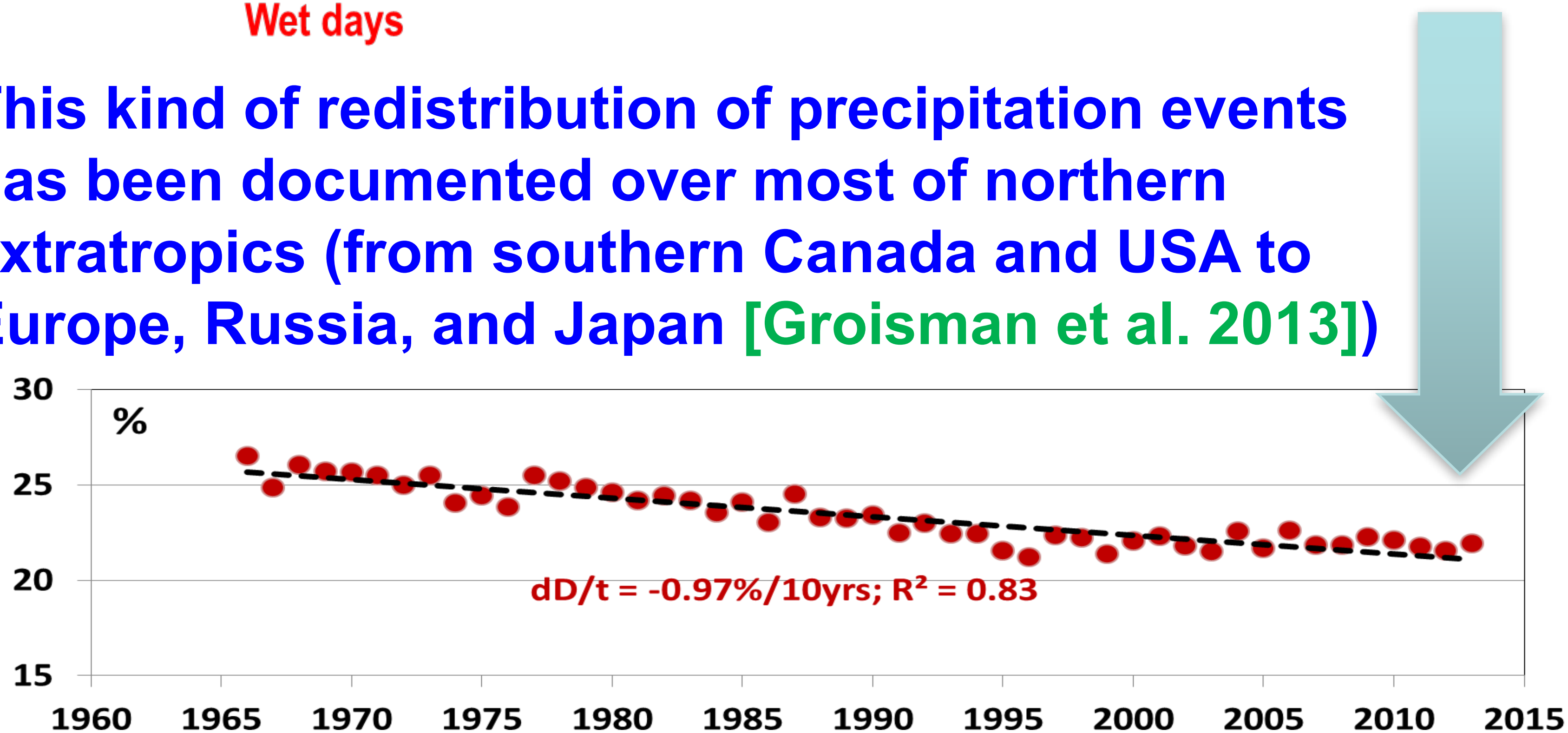


Easterling et al. 2000, substantially updated from Groisman et al. 2005, Zhai et al. 2005, Roy and Balling 2004, Aguilar et al. 2005, Brunetti et al. 2004, Cavazos 2008, Zolina et al. 2010; and finalized in Groisman and Knight 2012. Thresholds used to define “heavy” and “very heavy” precipitation vary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



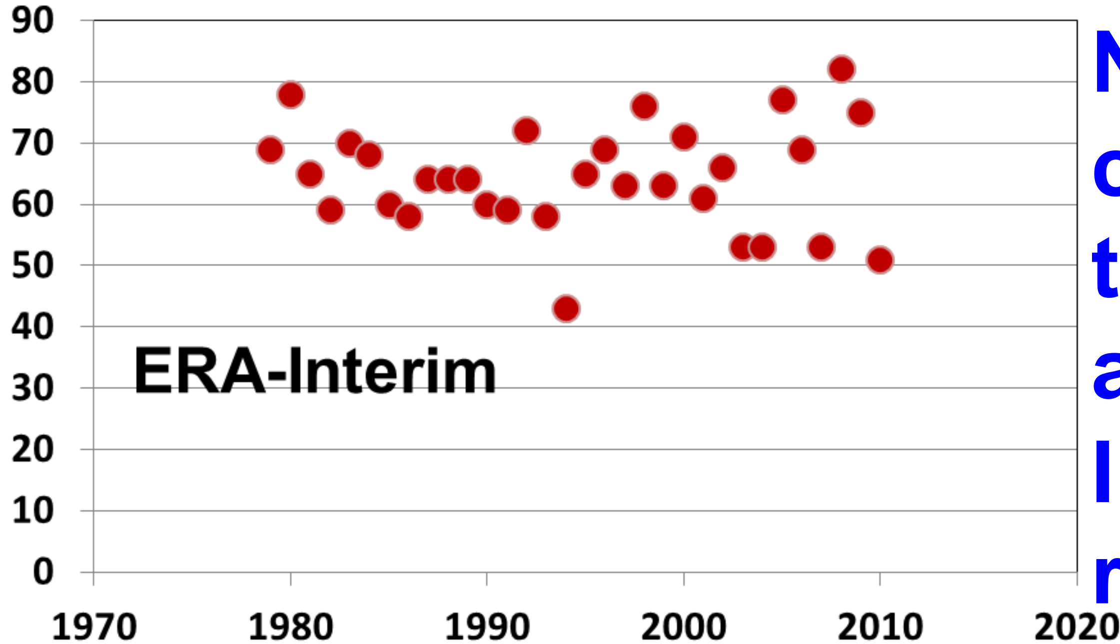

**This kind of redistribution of precipitation events has been documented over most of northern extratropics (from southern Canada and USA to Europe, Russia, and Japan [Groisman et al. 2013])**




**Percent of "hours with weather events" reported at the Russian synoptic network (rain, snow, drizzle, etc.) is decreasing [Groisman et al. 2015].**

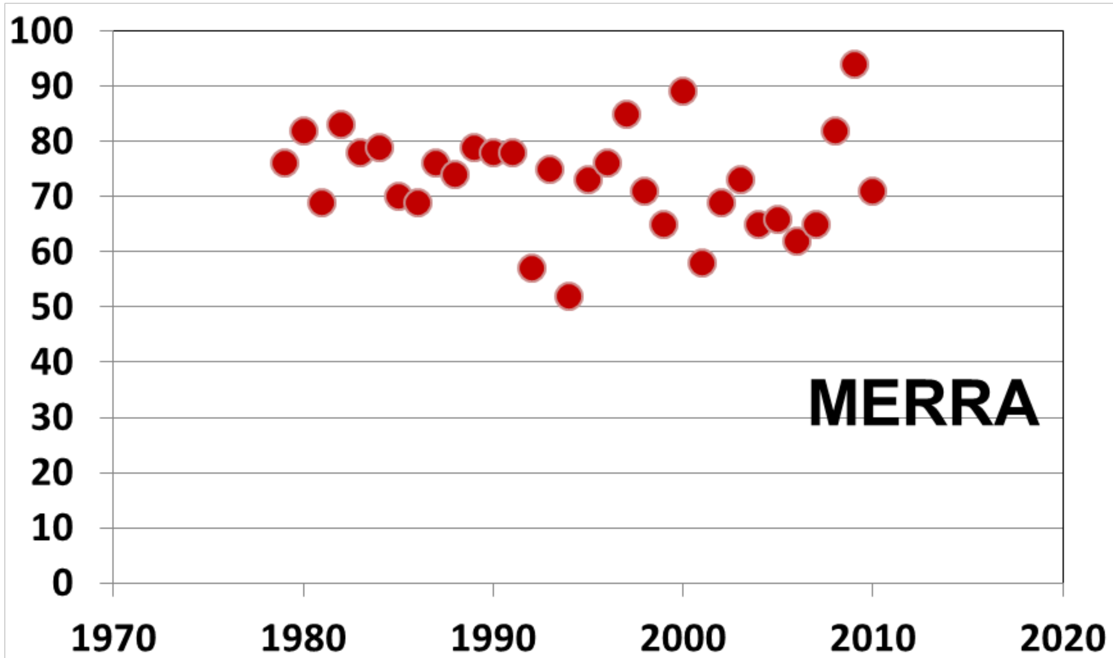
# Summer season

# Central Asia, Summer.

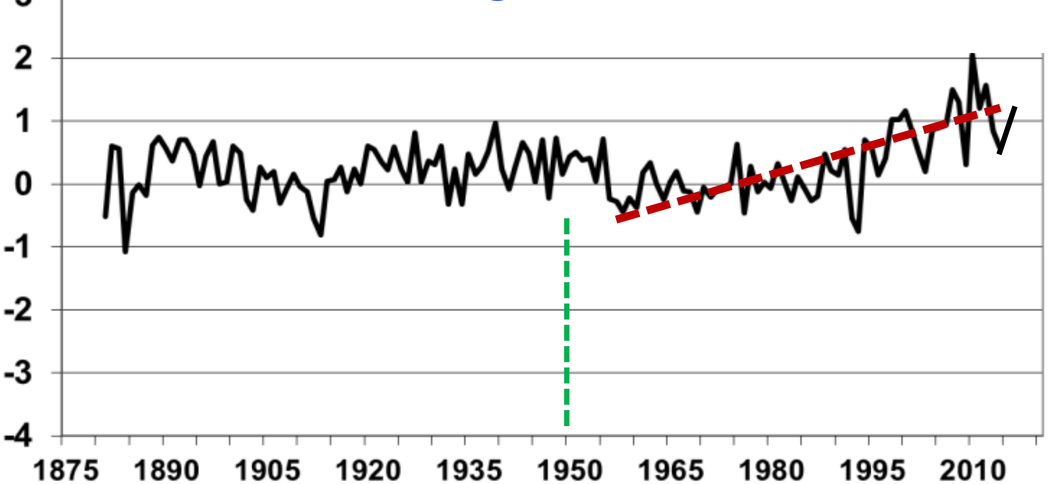


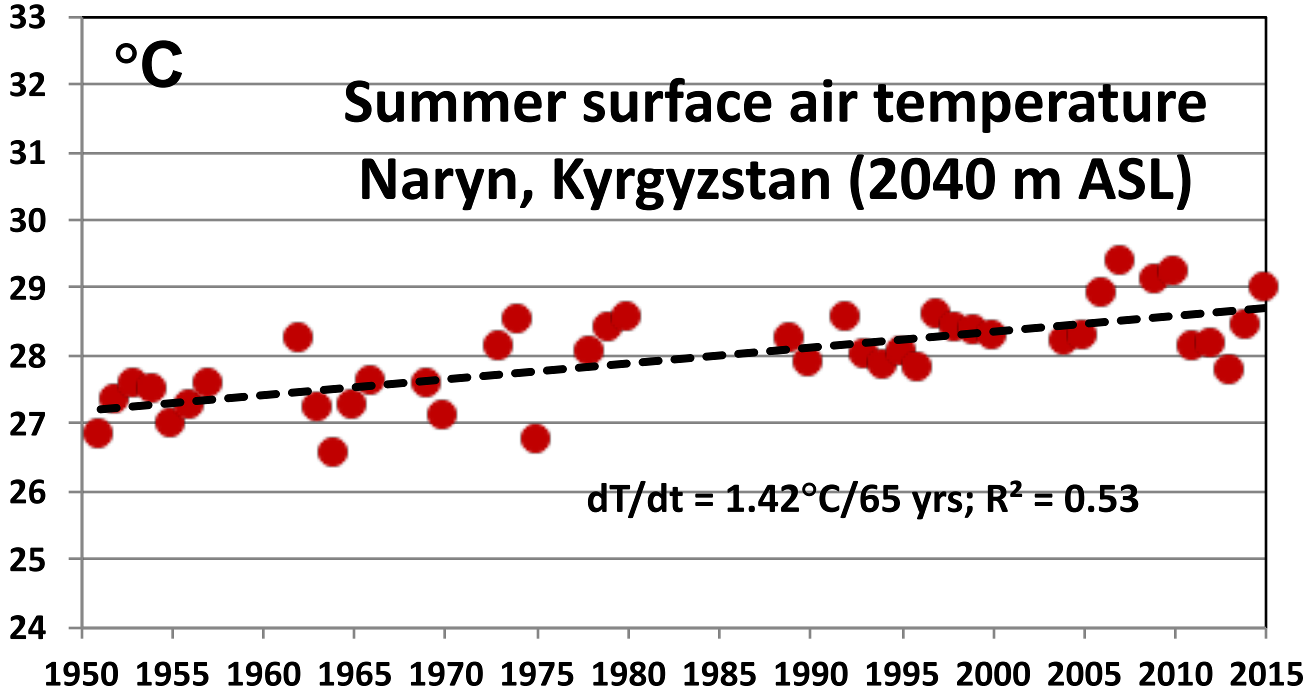

**Number of cyclones that enter the Sector according to ERA-Interim and MERRA reanalyses**

**Sector: [40˚- 50˚N; 50˚ - 90˚E]**



# Mean summer surface air temperature anomalies area-averaged over the DLB, *reference period 1951-1975*



# Impact of 1.5°C summer warming over glaciers in Central Asia

- Krenke formula: $A_{mm} = (T_{summer} + 9.5)^3$

**where A is total melt in mm and T- temperature above the glacier**

| Glaciers' Melt Change | Impact of 1.5 °C increase of $T_{summer}$ from -9° | -7° | - 6° | - 5° | -4° | -3° |
|---|---|---|---|---|---|---|
| Melt, mm | 16 | 217 | 475 | 886 | 1486 | 2311 |
| Percent of annual precipitation: 600 mm | 3% | 36% | 79% | 148% | 248% | 385% |
| 900 mm | 2% | 24% | 53% | 98% | 165% | 257% |
| 1200 mm | 1% | 18% | 40% | 74% | 124% | 193% |

# River Discharge within three neighboring valleys in the Tian Shan Mountains (Zailijskiy Alatau)

| River Basin | Level of glaciation | Discharge tendency |
|---|---|---|
| Kaskelen | Low glaciation | Decrease |
| Malaya Almatinka | Moderate glaciation | Moderate increase |
| Bolshaya Almatinka | Extensive glaciation and buried ice | Very strong increase |

Prof. Maria Shahgedanova, Walker Institute for Climate System Research, The University of Reading, United Kingdom, Personal Communication

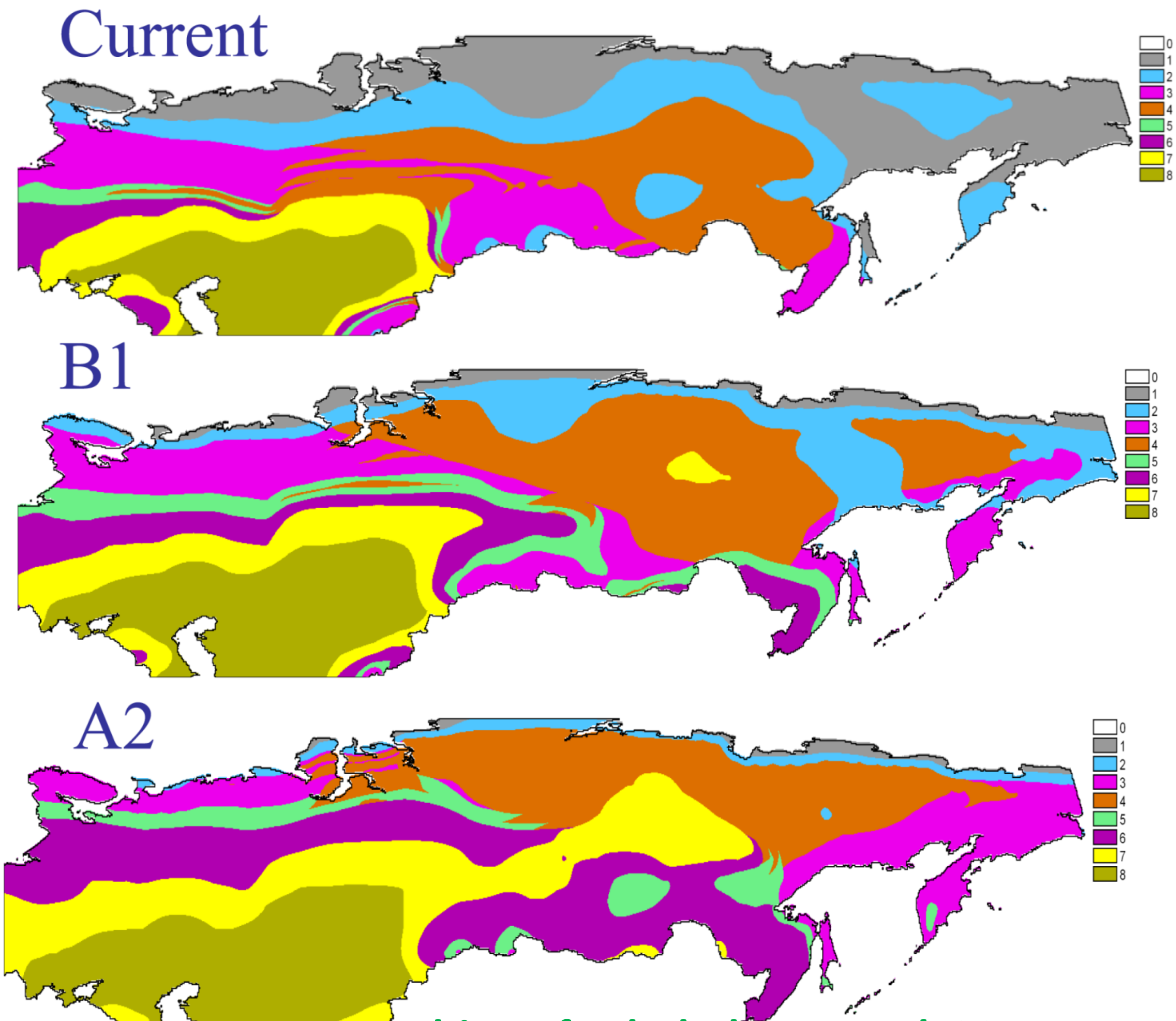


# Possible reasons of runoff changes

- **Precipitation increase?**
- **Decline in anthropogenic withdrawals?**
- **Changes in cryosphere contribution to runoff**?
  - Permafrost thaw
  - **Glaciers' melting**
- **Increase in runoff coefficient** ?
  - More overland flow due to changes in precipitation temporal distribution
  - Earlier spring peak flow
  - Increase of winter flow when evapotranspiration losses are minimal
  - The depletion of soil freezing depth
- **All the above?**

# Projected Biosphere Changes

## Vegetation distribution in Northern Eurasia in current climate, ensemble B1 and A2 scenarios by 2090




Vegetation classes:

1 – Tundra (*grey*),
2 – Forest-Tundra (*blue*),
3 – Dark taiga (*light pink*),
4 – Light Taiga,
5 – Mixed (*green*),
6 – Broad-leaved (*dark purple*),
7 – Steppe (*yellow*),
8 – Semidesert (*khaki*).

Archive of Tchebakova *et al*. 2016.

# Conclusions

- Contemporary global changes have already left their signature on the DLB environment
- Regional temperature increase has shifted the spring season, increased the weather variability, and impacted the water cycle and the cryosphere
- Present runoff increase in some mountainous regions of Central Asia may be temporary and is related to glaciers' storage discharge
- Thoughtful land use and water management in anticipation of inevitable dryer climatic conditions should be planned well ahead the occurrence of these conditions.

# Runoff

Will be provided in the follow-up talk
by Prof. A.I. Shiklomanov

# PART 2. Freezing Precipitation and Freezing Events over Northern Eurasia and North America

Pavel Groisman[1,4,7] , Xungang Yin[2], Olga Bulygina[3,4], Irina Partasenok[5,4], Eirik Førland and Inger Hanssen-Bauer [6]

(1) UCAR at NOAA National Centers for Environmental Information, Asheville, North Carolina, United States (pasha.groisman@noaa.gov)
(2) ERT, Inc., at NOAA National Centers for Environmental Information, Asheville, North Carolina, USA
(3) All-Russian Research Institute of Hydrometeorological Information - World Data Centre, Obninsk, Russia
(4) RAS P.P. Shirshov Institute for Oceanology, Moscow, Russia
(5) Center of Hydrometeorology and Control of Radioactive Contamination and Environmental Monitoring, Minsk, Belarus
(6) Norwegian Meteorological Institute, Oslo, Norway
(7) Hydrology Science and Services Corporation, Asheville, North Carolina, USA.

# Objective:

**To improve our understanding of future changes in hazardous cold/shoulder season precipitation and storms, especially occurring near 0°C. These extremes can be devastating and are subject to changing climate.**

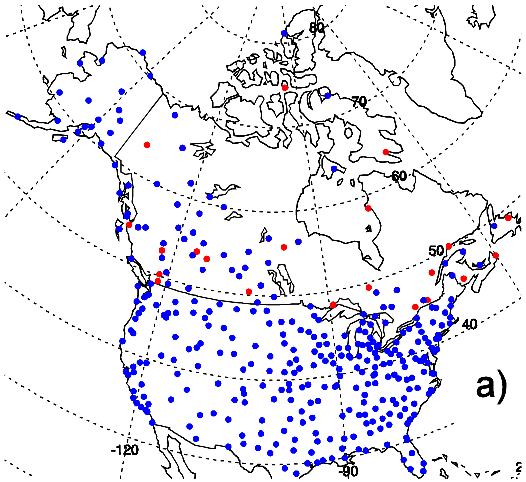
# Specific Phenomena around °C

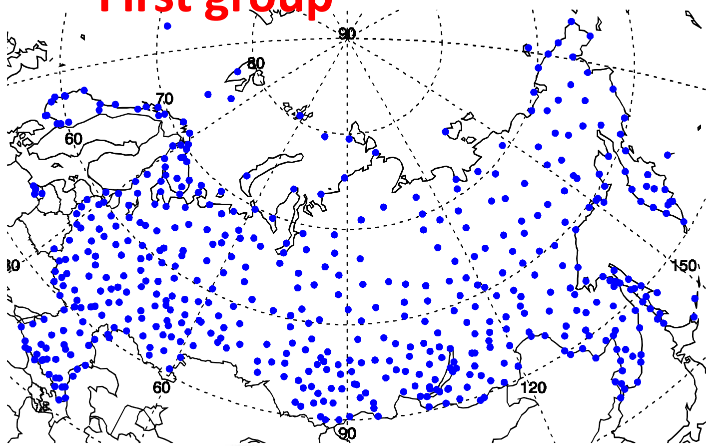
1. **Freezing rain and freezing drizzle**
2. **Heavy snowfall/rainfall transition**
3. **Large fraction of blizzards occurs near 0°C**
4. **Rain-on-snow events**
5. **Ice load on infrastructure**

**The focus of this presentation section is on the first group of variables from the above list over Northern Eurasia, North America, and Europe**

# Long-term synoptic stations used in our analyses; 1- and 3-hourly data for the past 40 years

First group

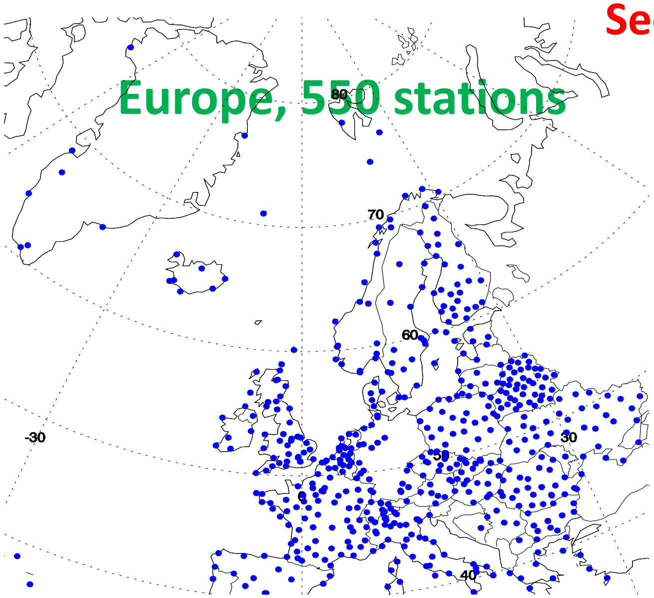


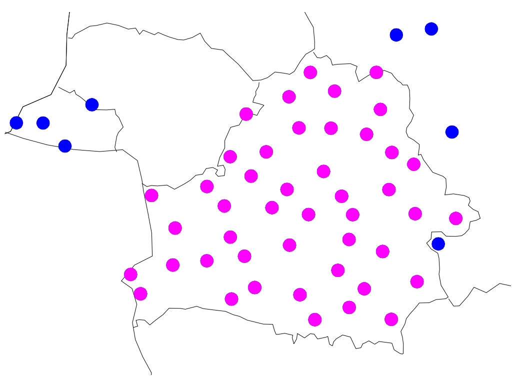

Groisman et al. 2016: Recent changes in the frequency of freezing precipitation in North America and Northern Eurasia. *Environ. Res. Lett.* 11, 045007 (published on April 2016).

Second group

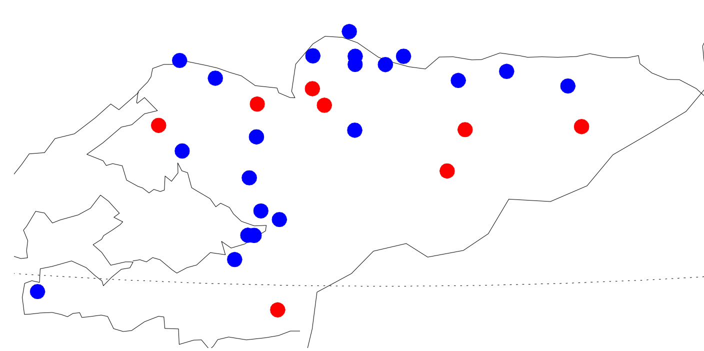
Europe, 550 stations




Belarus



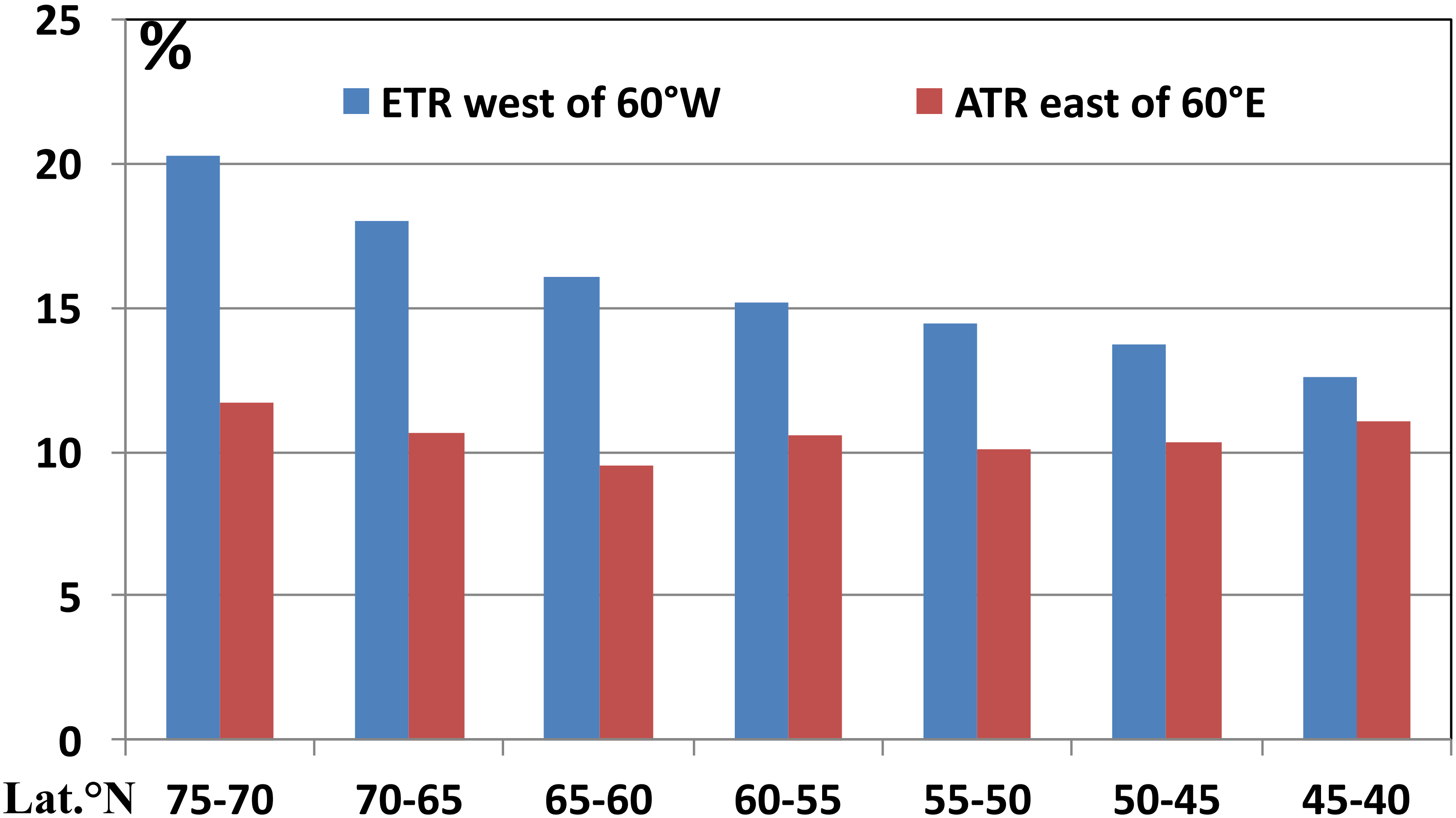
Kyrgyzstan



# End of the sub-section introduction

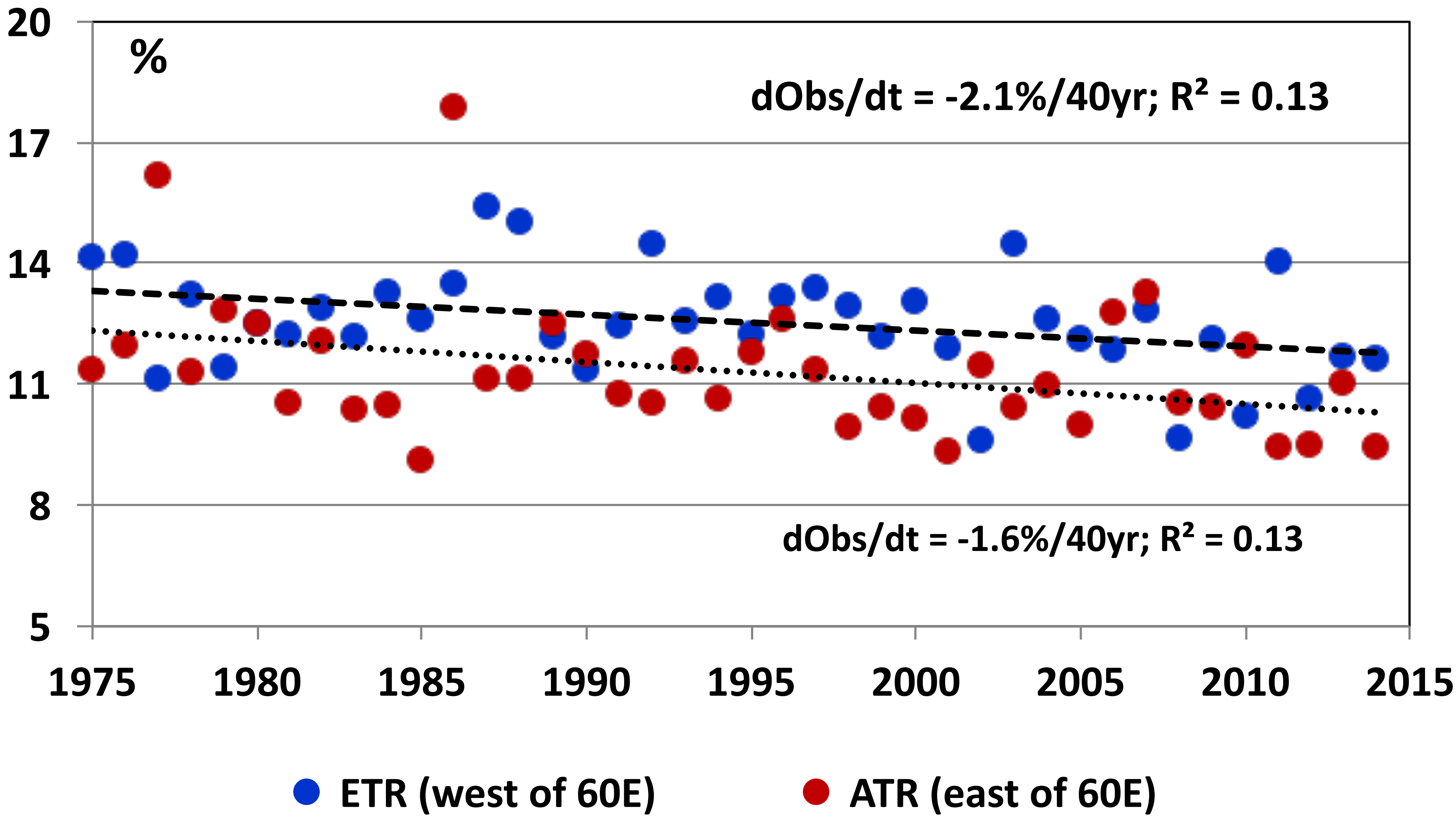
- Our ERL paper (*Environ. Res. Lett*. **11**, 045007) presents our results only for the USA, Canada, Norway, and Russia
- The current presentation in addition to the results for these 4 countries expands our findings to Europe, Belarus, and Kyrgyzstan
- Next two slides show that the “near 0°C weather conditions” are quit frequent over Russia from the Arctic Islands to the Caucasus Mountains and southern Primor’e.

# Percent of observations with the surface air temperature within the ± 2°C interval over latitudinal zones of Russia




**ETR – European territory of the Russian Federation**

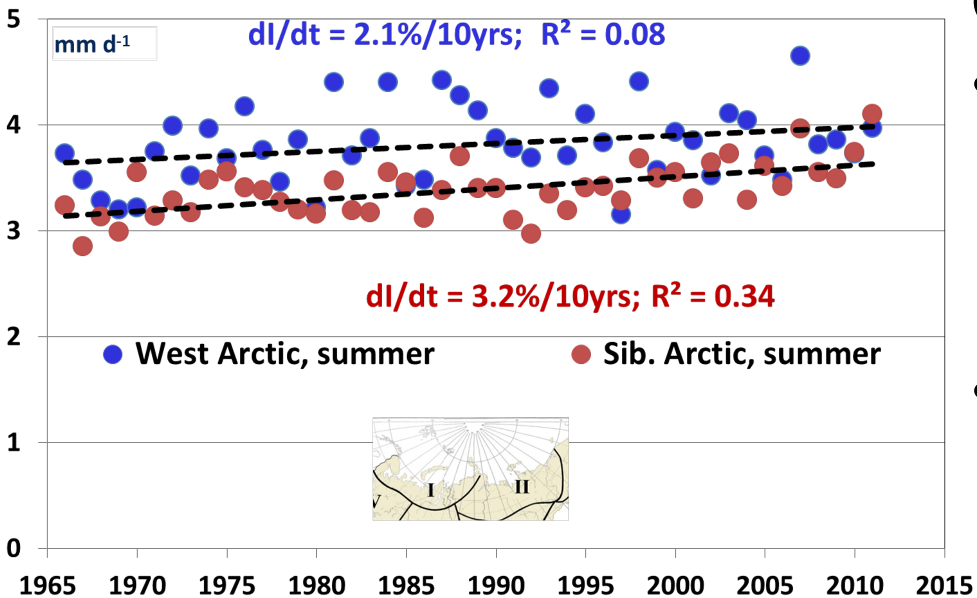
# Percent of observations with the surface air temperature within the ± 2°C interval over the 40°N - 45°N zone of Russia




**ETR – European territory of the Russian Federation;**

**only in the southernmost areas, we observe temporal changes**

# Ice load on infrastructure

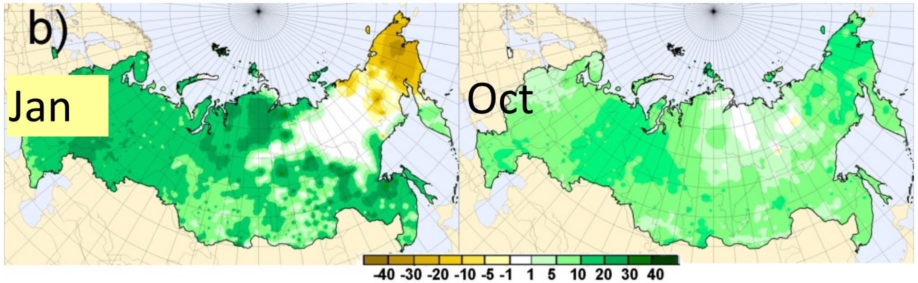



Mean summer precipitation intensity over the Russian Arctic, mm d $^{-1}$

Over Russia we observe:

- a nationwide increase in precipitation intensity over Russia even in the Arctic (Groisman et al. 2013) and
- an increase in mid-winter and autumn of the near-surface water vapor pressure (Bulygina et al. 2015).

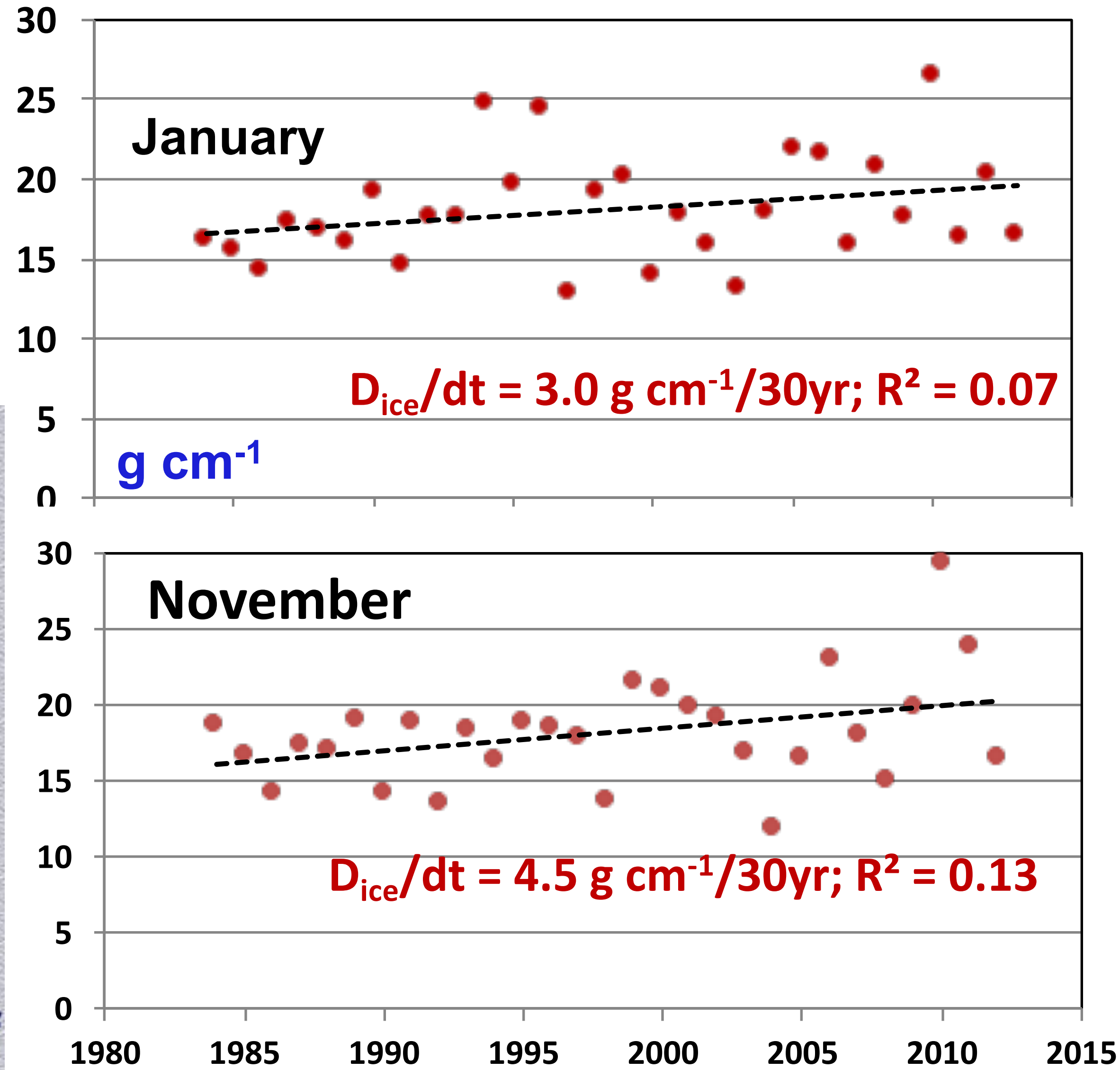
When temperatures are near 0°C, increases in near-surface water vapor pressure and precipitation intensity may lead to increase of maximum ice loads on terrestrial and off-shore infrastructure and ships in high seas.




Long-term mean near-surface water vapor pressure changes (%) between the 1980-2010 and 1961-1990 periods

# Changes in Icing Events (maximum monthly regional mean values) in the West Arctic in Russia

Instrumental monitoring of icing and hoar frost

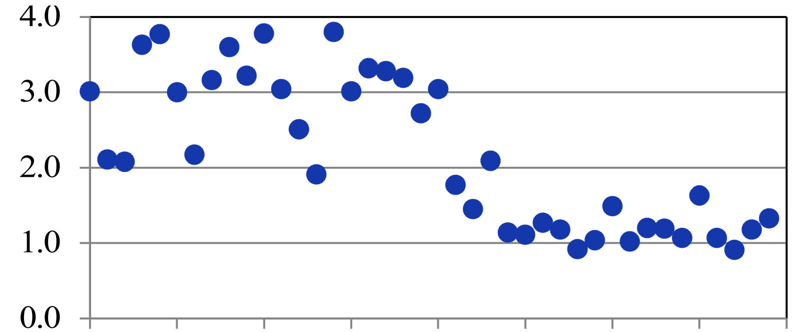


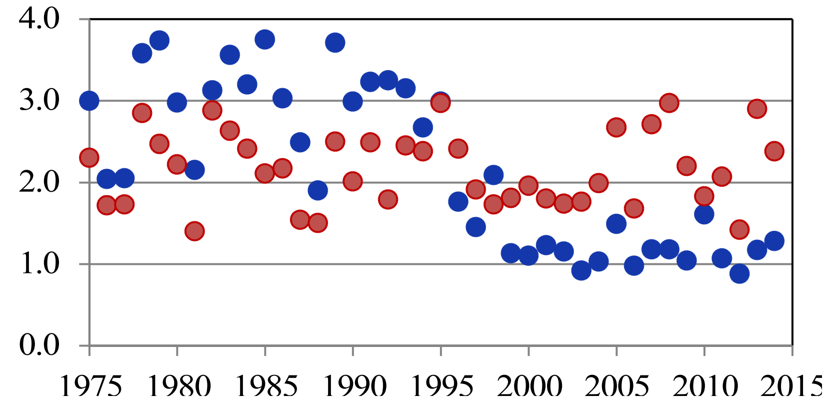

*Bulygina et al. (2015; Environ. Res. Lett.)*

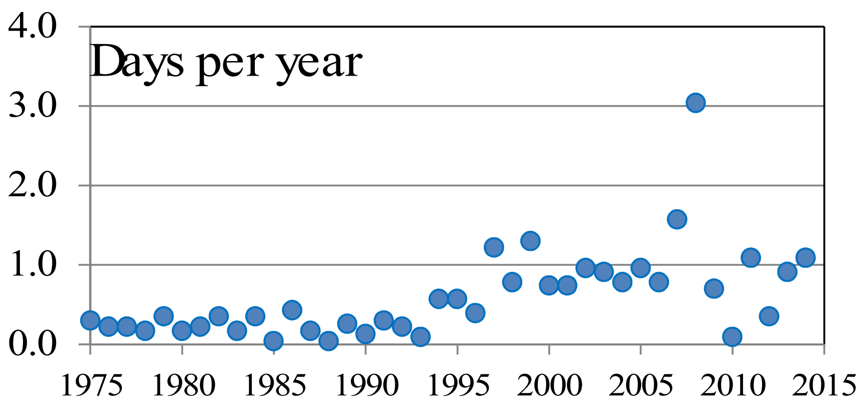
# Inhomogeneity issues due to automation

**Top.** Average number of days with freezing drizzle reported by the U.S. and Canadian stations.

**Bottom**. Average number of days with freezing drizzle (blue dots) and freezing rain (red dots) for the United States only.




## … and reporting

Region-wide mean changes in the frequency of **moderate and heavy freezing rain events** (days year$^{-1}$) that followed the introduction of METAR reporting formats in August 1996 over Northeastern U.S. (east of 80°W and north of 40°N).

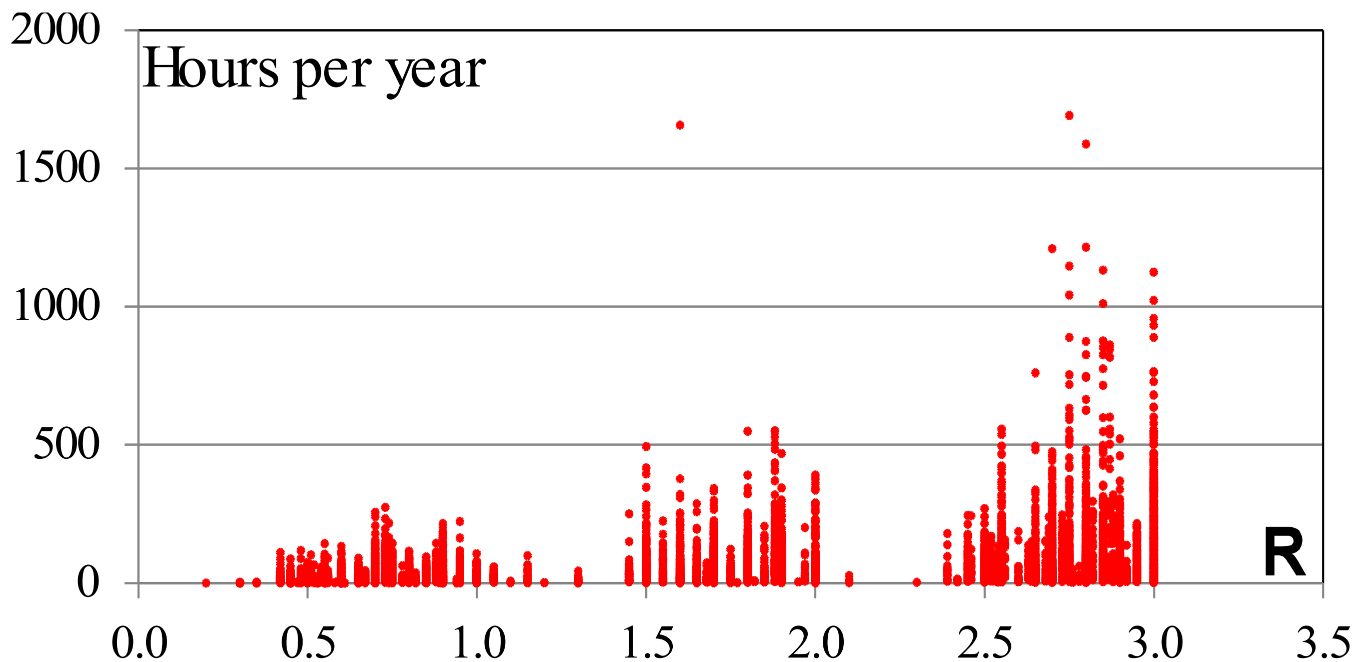
# Insufficient temporal coverage by 3-h. reports

Annual number of hours with gololed when at least one freezing event was observed during the year sorted by **R**, ratio of the number of these hours to the number of 3-h. reports of freezing events over 444 Russian stations for the 1977-2011 period

**=> true annual number of freezing events, NFE:**

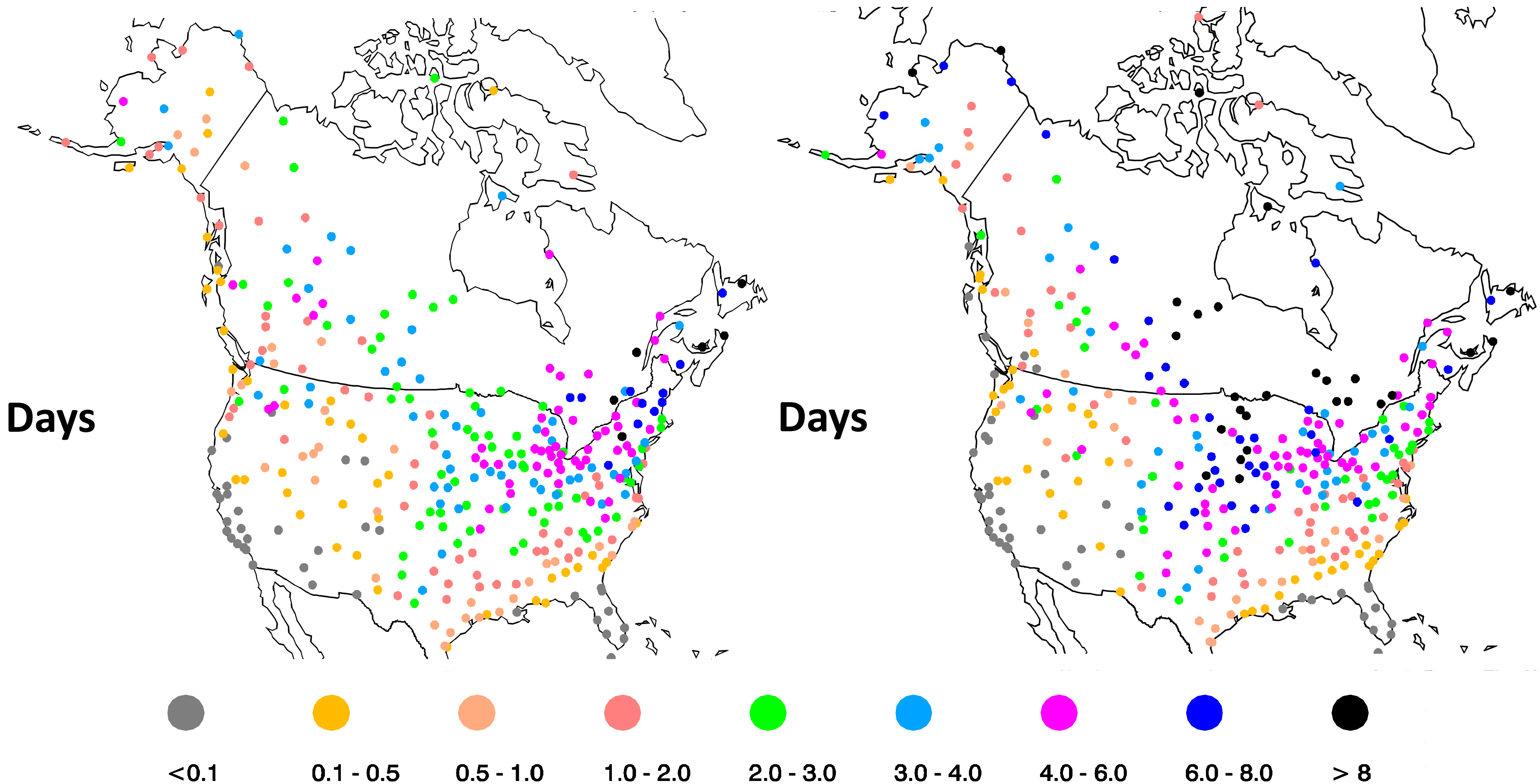
$$\mathbf{NFE} = \begin{cases} NFE_{reported} \times 3/\max(R,0.5) & (\text{if } NFE_{reported} \neq 0) \\ 0 & (\text{otherwise}) \end{cases}$$

**We have to "scale-up" the event numbers based upon 3-h reports everywhere when 3-h reports are used: Russia, Kyrgyzstan, most of Fennoscandia, and East Europe.**



# CLIMATOLOGY

# Climatology of freezing events over North America for the 1975-1994 period

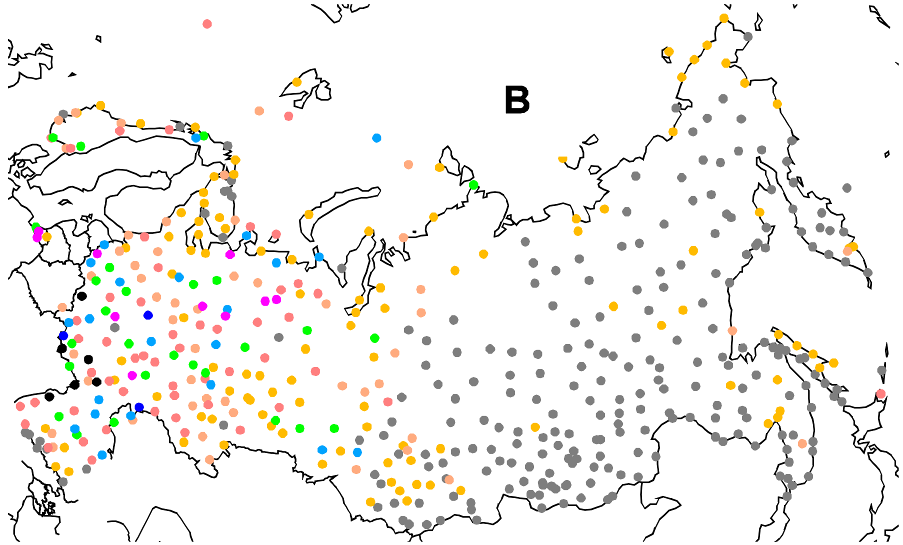



Annual freezing rain frequency

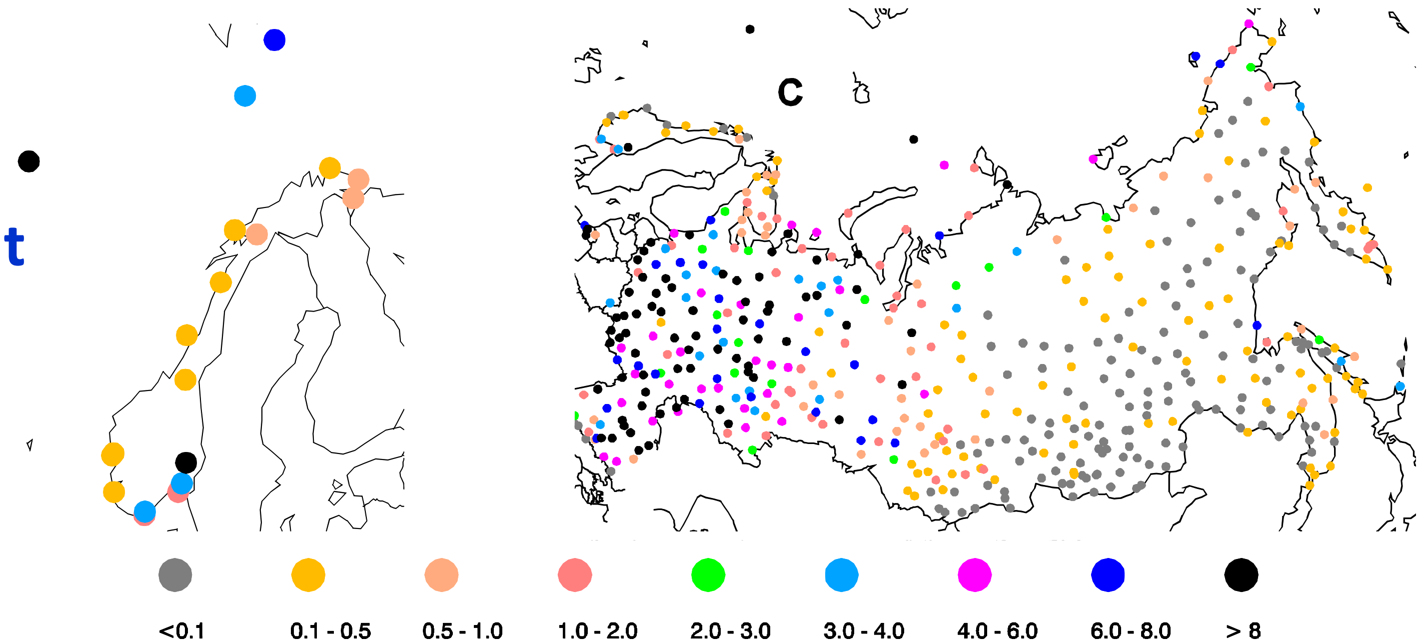
Annual freezing drizzle frequency

# Climatology of freezing events over Russia and Norway

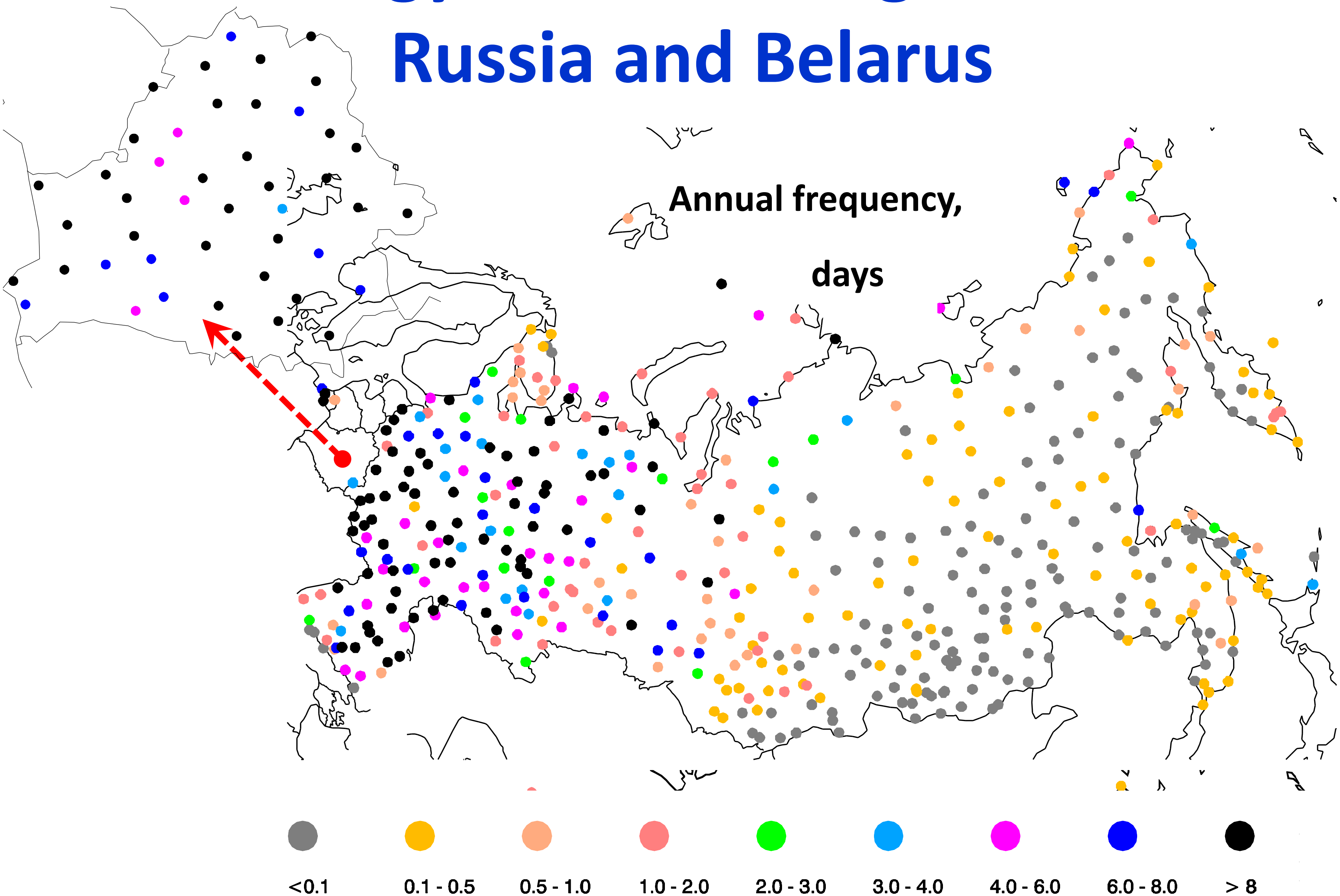
Annual frequency of freezing rain days



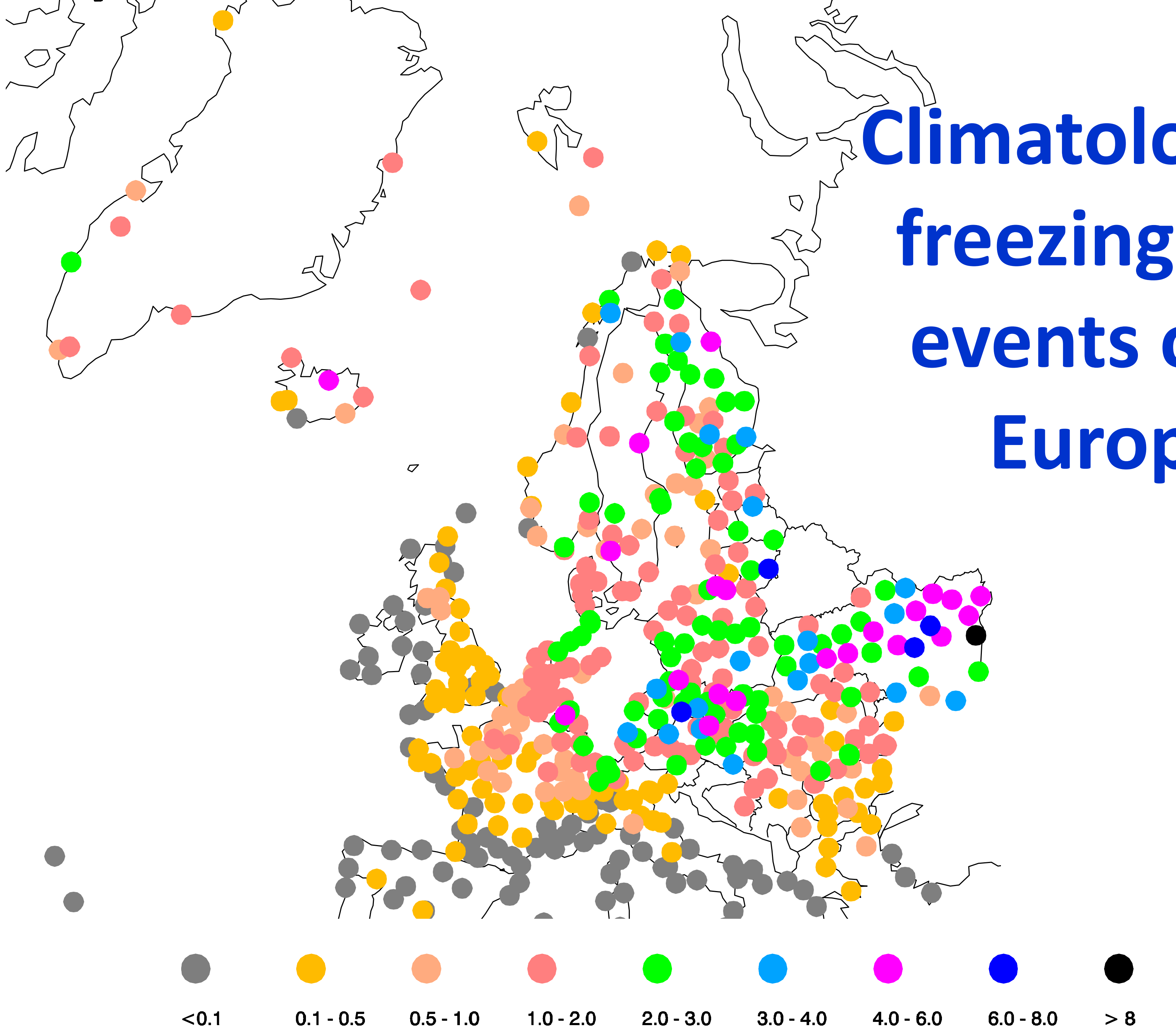

The same, but for freezing drizzle days



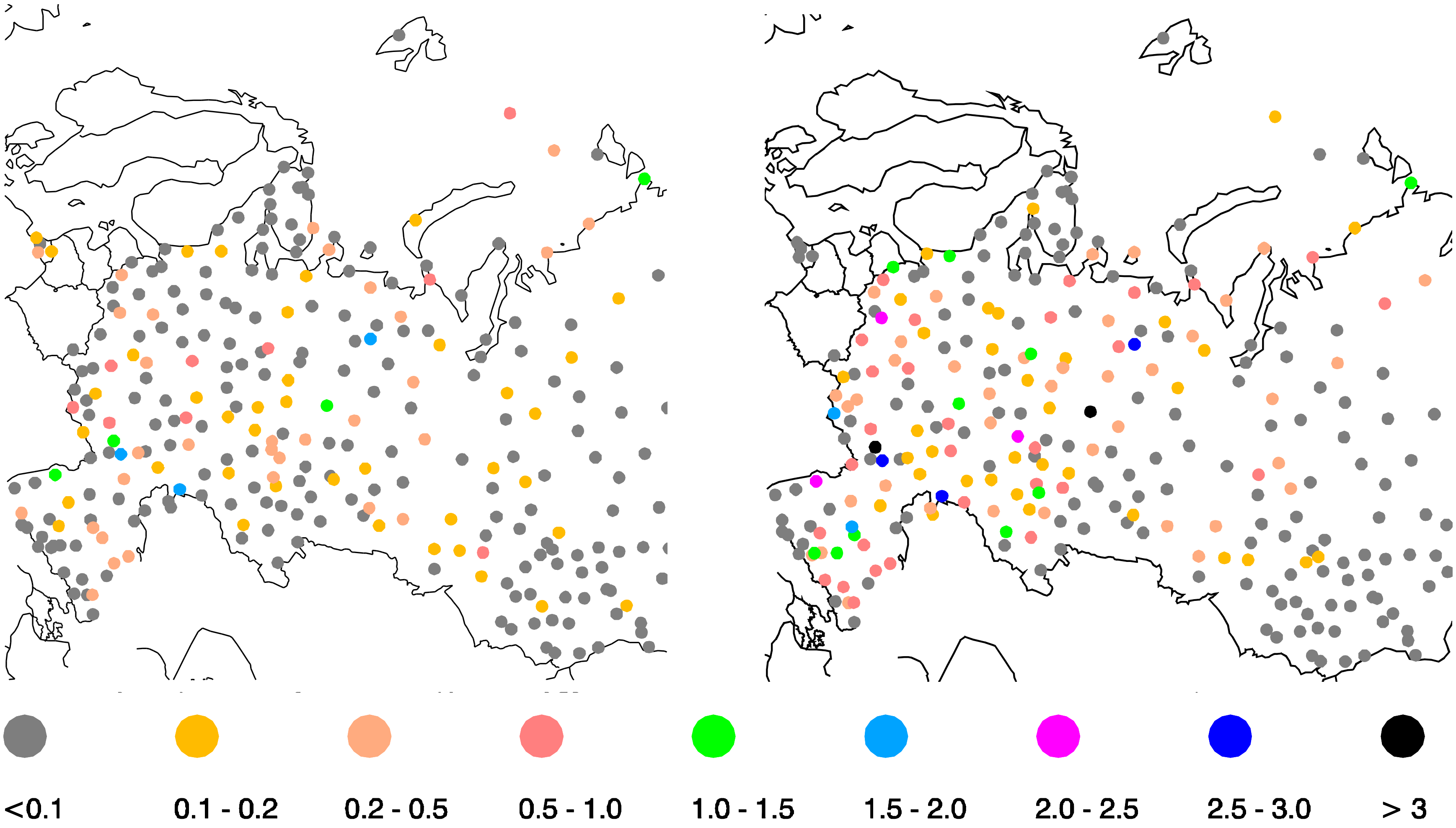
# Climatology of all freezing events over Russia and Belarus



# Climatology of freezing rain events over Europe



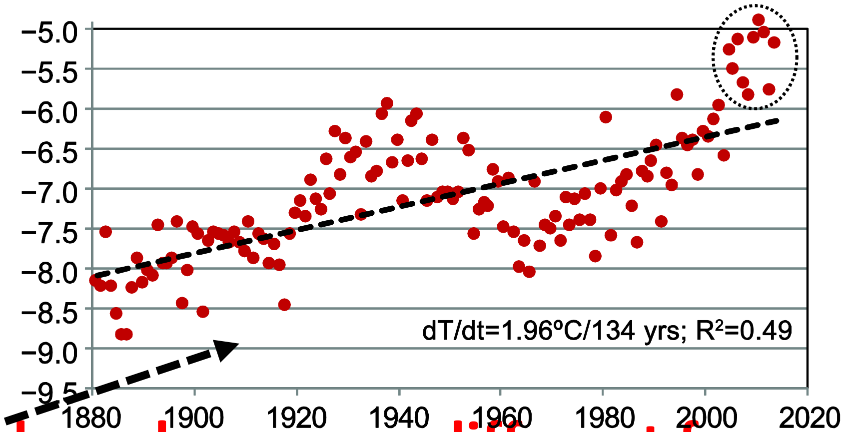
# Annual frequency of moderate and heavy freezing events




**Freezing rain days** **Freezing drizzle days**

# CHANGES IN THE LAST DECADE

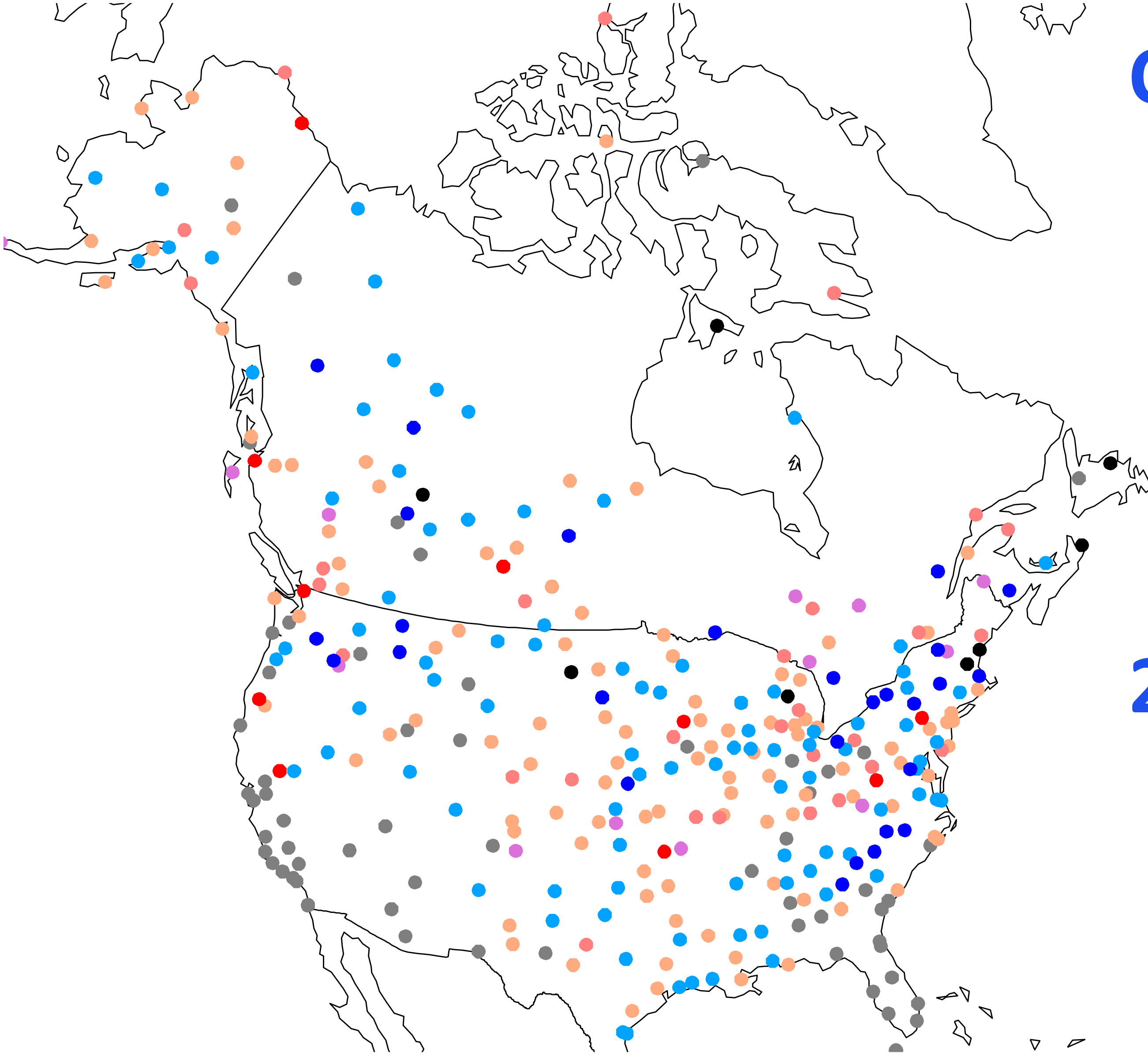
# Recent changes in the freezing precipitation frequency

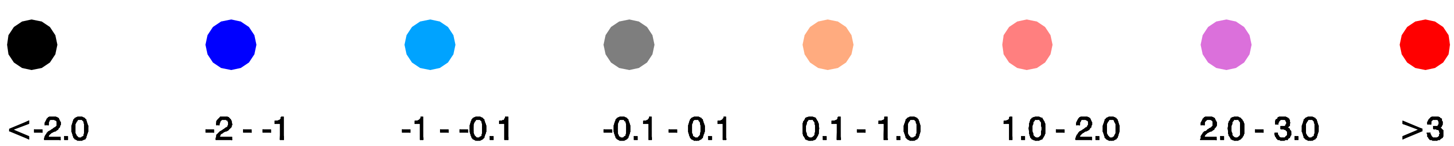



Climate conditions in the last decade have been very different from the past decades.  For example, each year the Arctic (60°-90 °N) surface air temperature was warmer than any year during the period of instrumental observations.

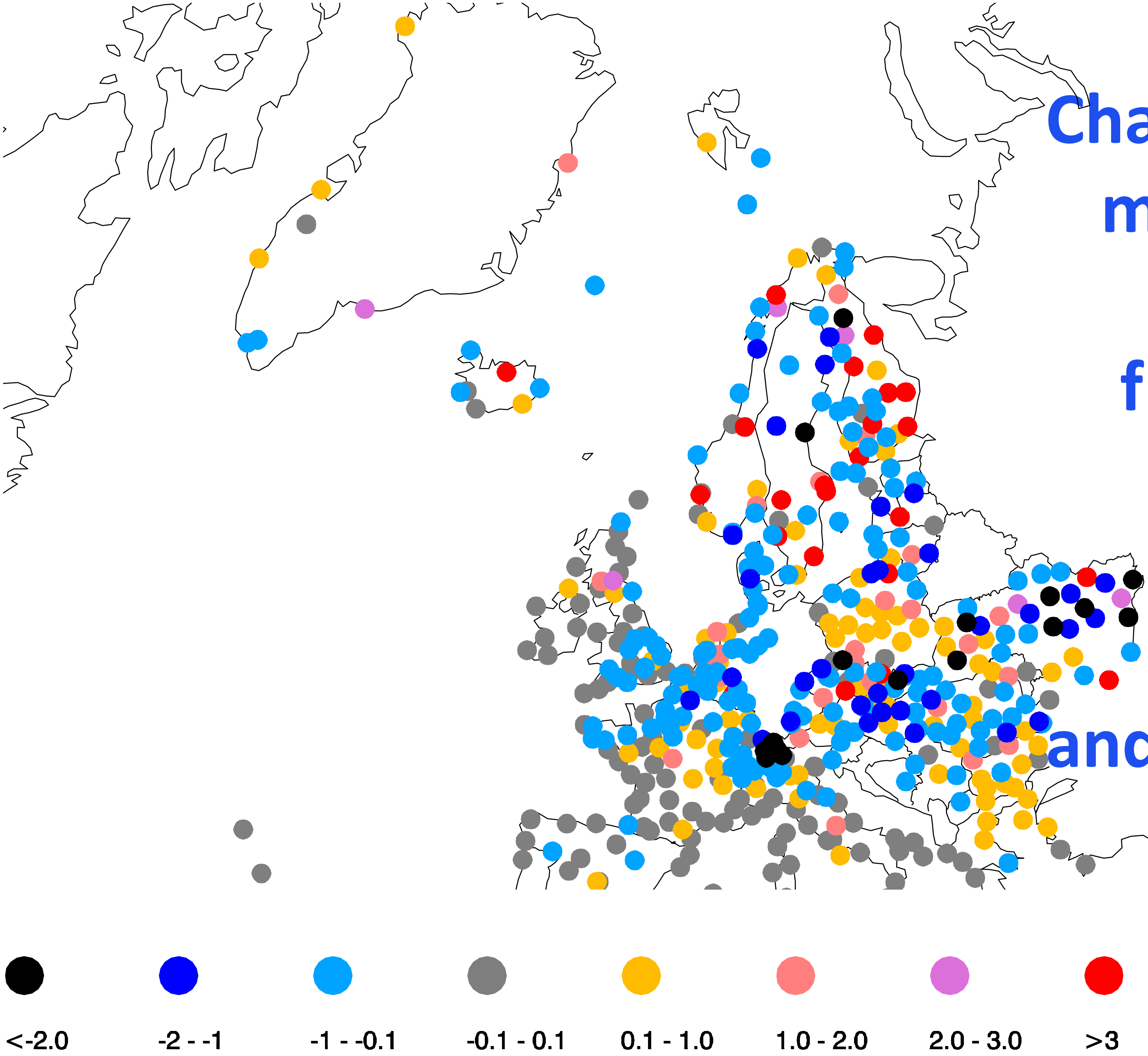
Therefore, we conducted change assessment in the freezing precipitation characteristics by comparing them in the last decade (2005-2014) with those for the previous three decades (1975-2004). We show these changes in day $yr^{-1}$ for freezing rain,  freezing events (Northern Eurasia), freezing drizzle (for Russia only), and separately for occurrences of intense freezing rain and drizzle over Russia. Thereafter, we present a Table with regional climatologies and the estimates of the last decade change for selected climatic regions of Russia, Norway and North America.

# Changes of the mean annual numbers of days with freezing rain between 2005-2014 and 2075-2004 periods





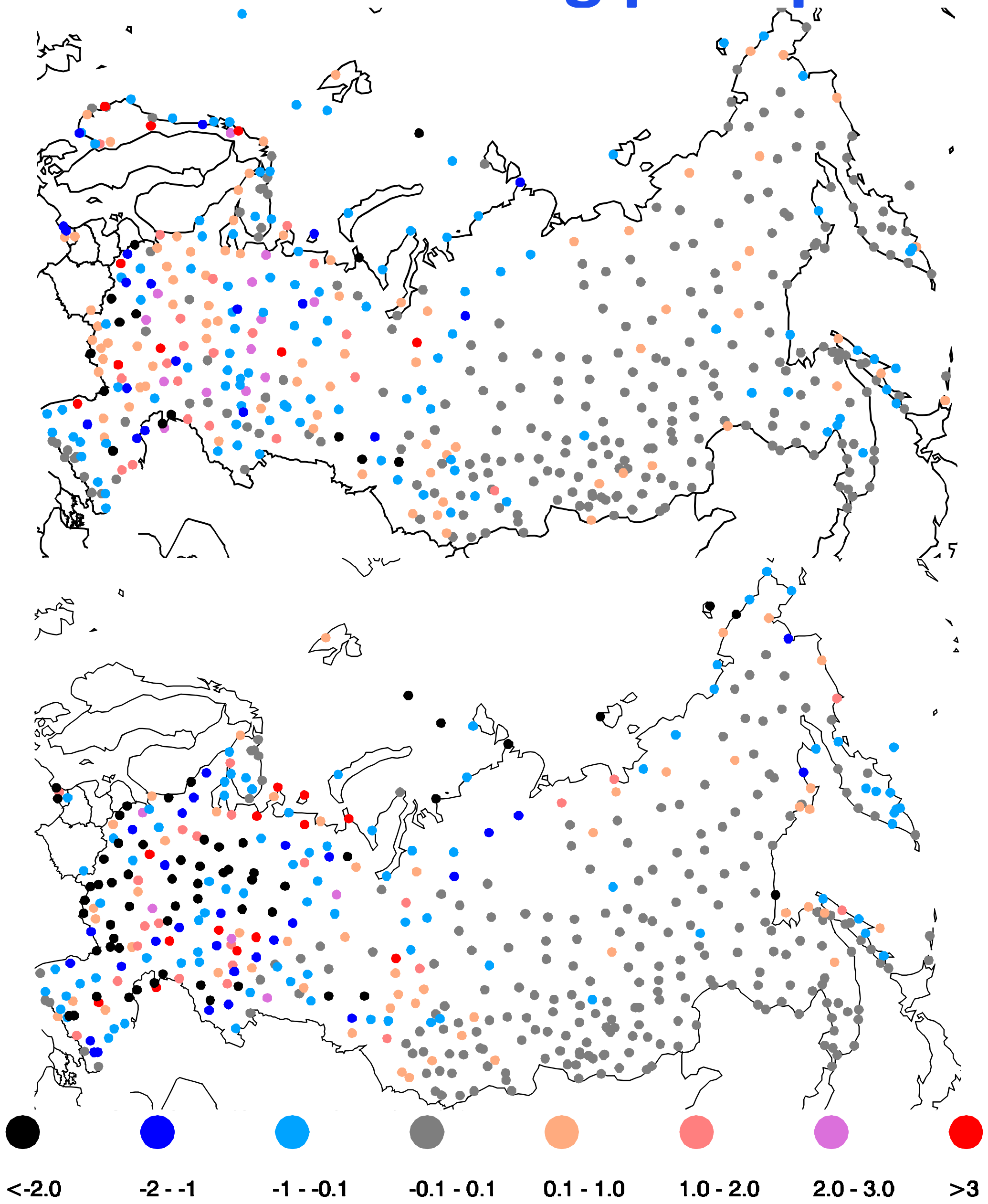
# Changes of the mean annual number of freezing rain days between 2005-2014 and 1975-2004 periods over Europe



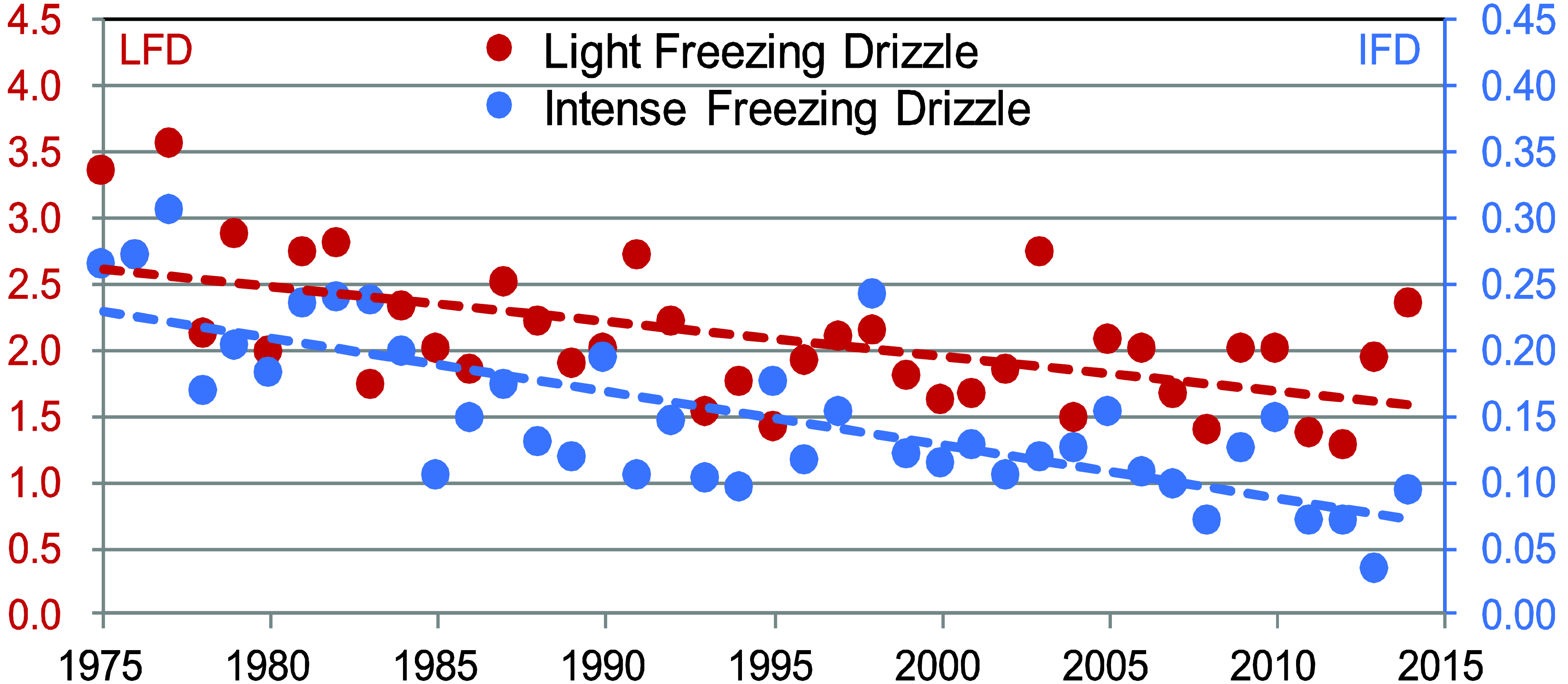
# Changes of the mean annual numbers of days with freezing precipitation between 2005-2014 and 1975-2004 periods

- **Freezing rain days**

- **Freezing drizzle days**

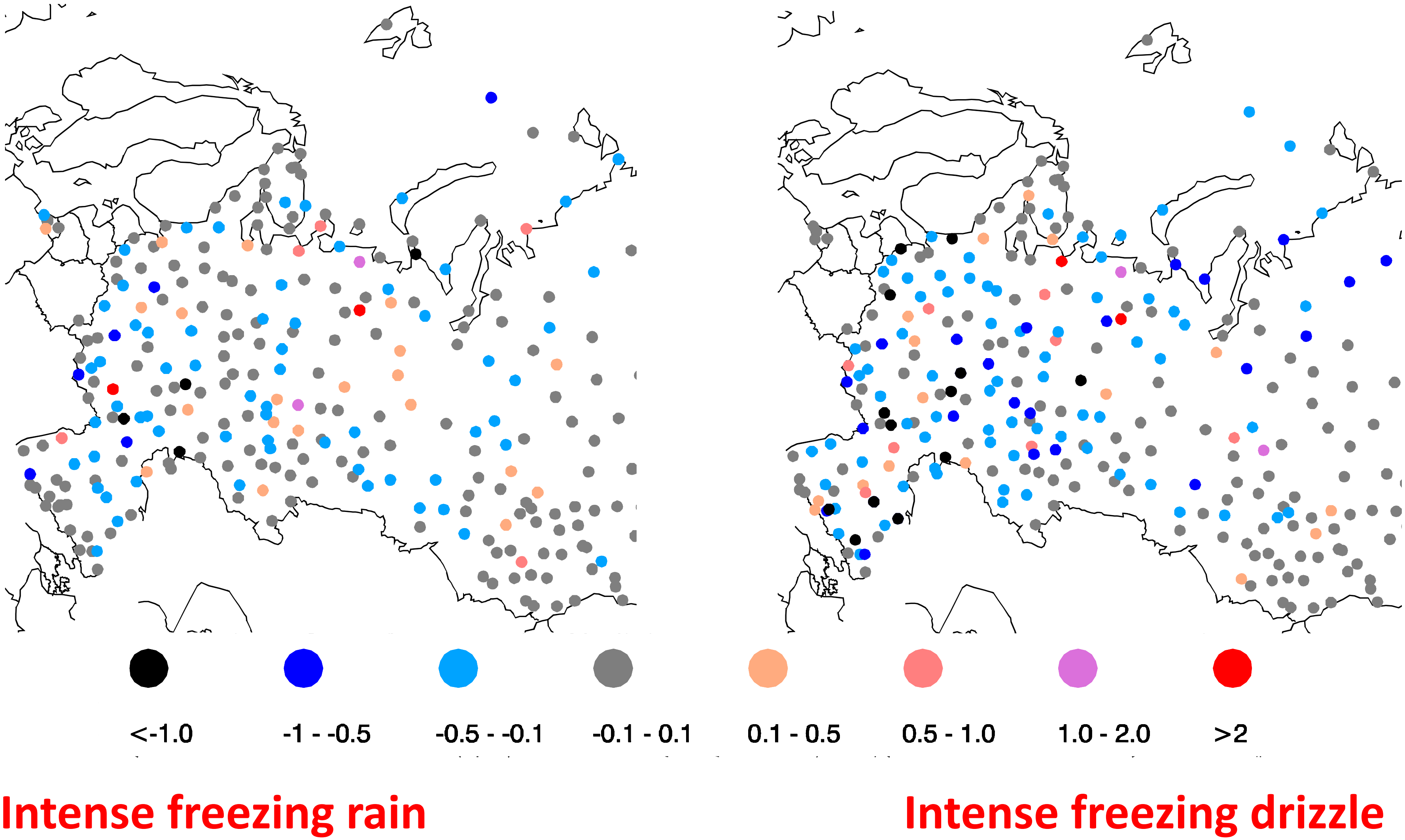


# Annual Freezing Drizzle Frequency area-averaged over Russia

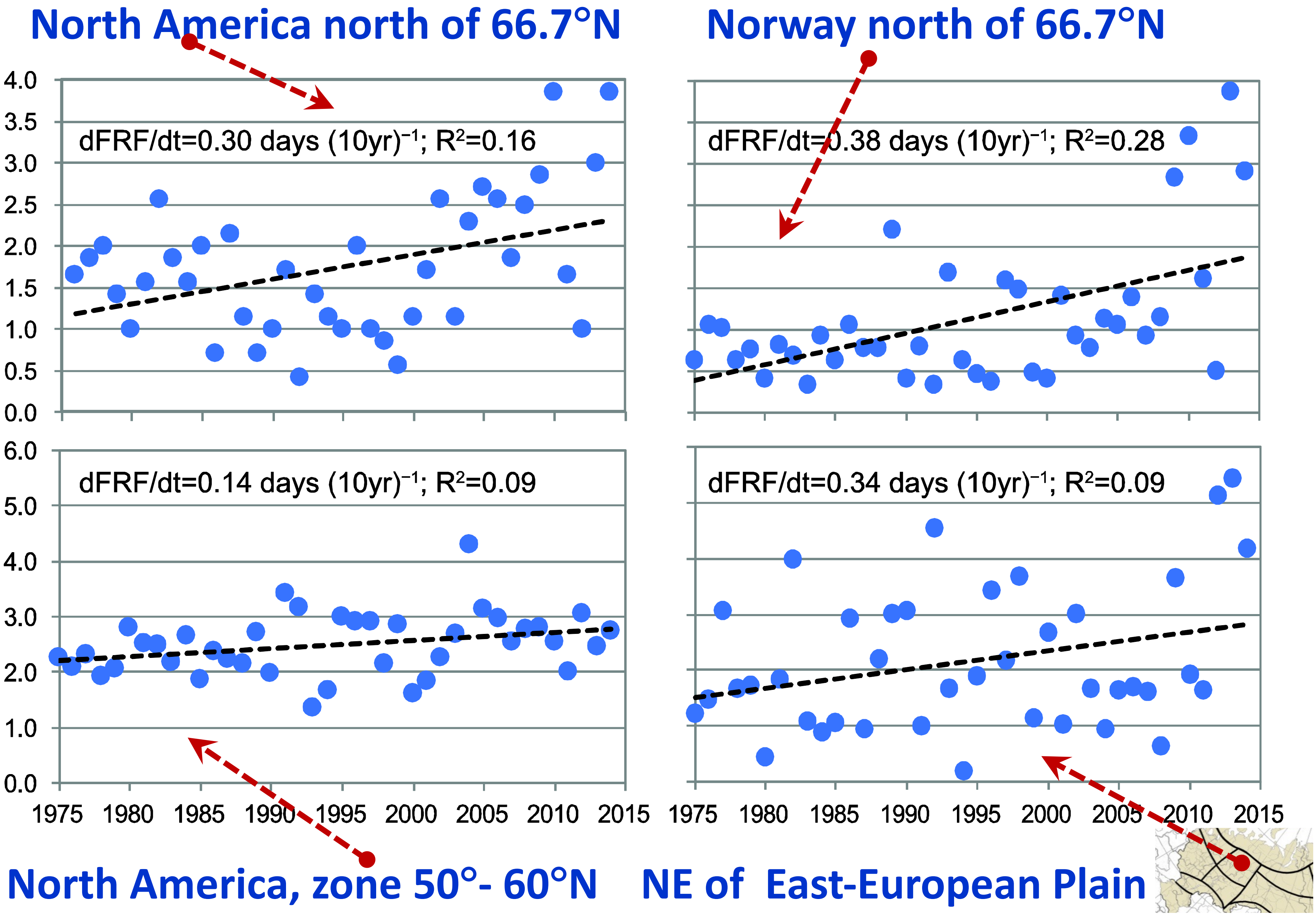



**Light and intense freezing drizzle event frequency arithmetically averaged over the long-term stations of the Russian federation. Light freezing drizzle occurrence (LFD) is approximately 10 times larger than this occurrence for intense freezing drizzle (IFD).**

# Changes of the mean annual numbers of days with intense freezing precipitation between 2005-2014 and 1975-2004

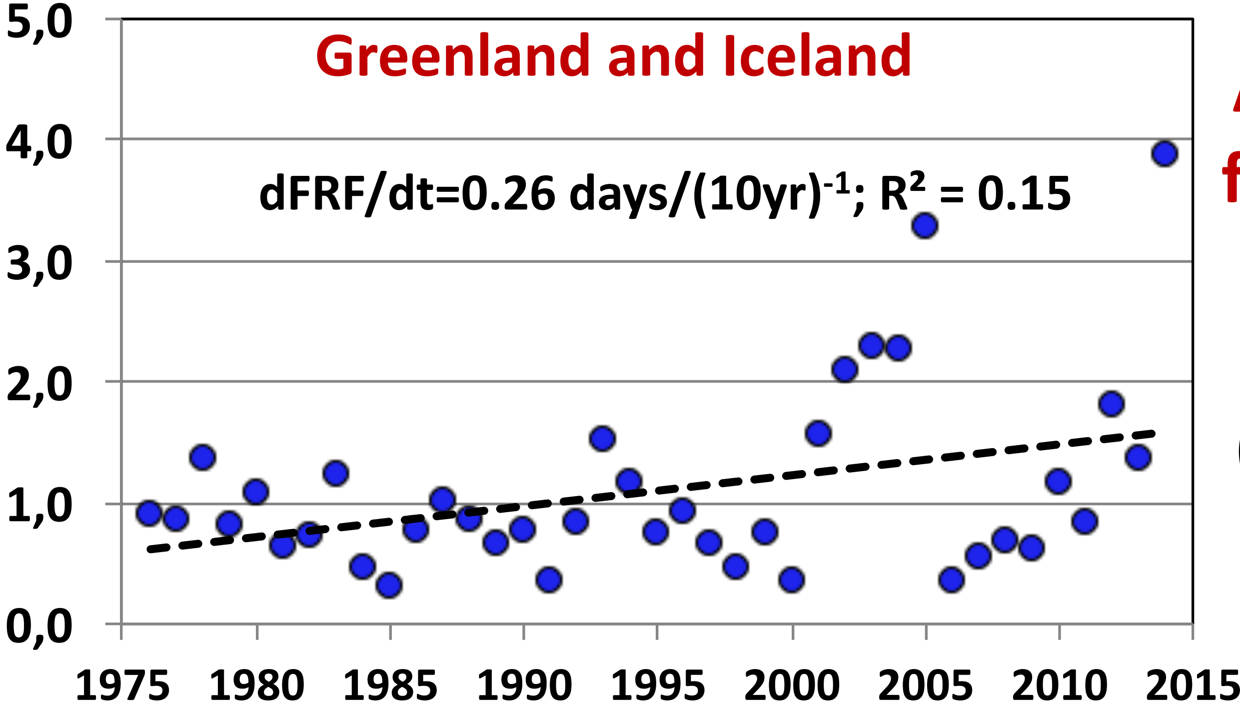


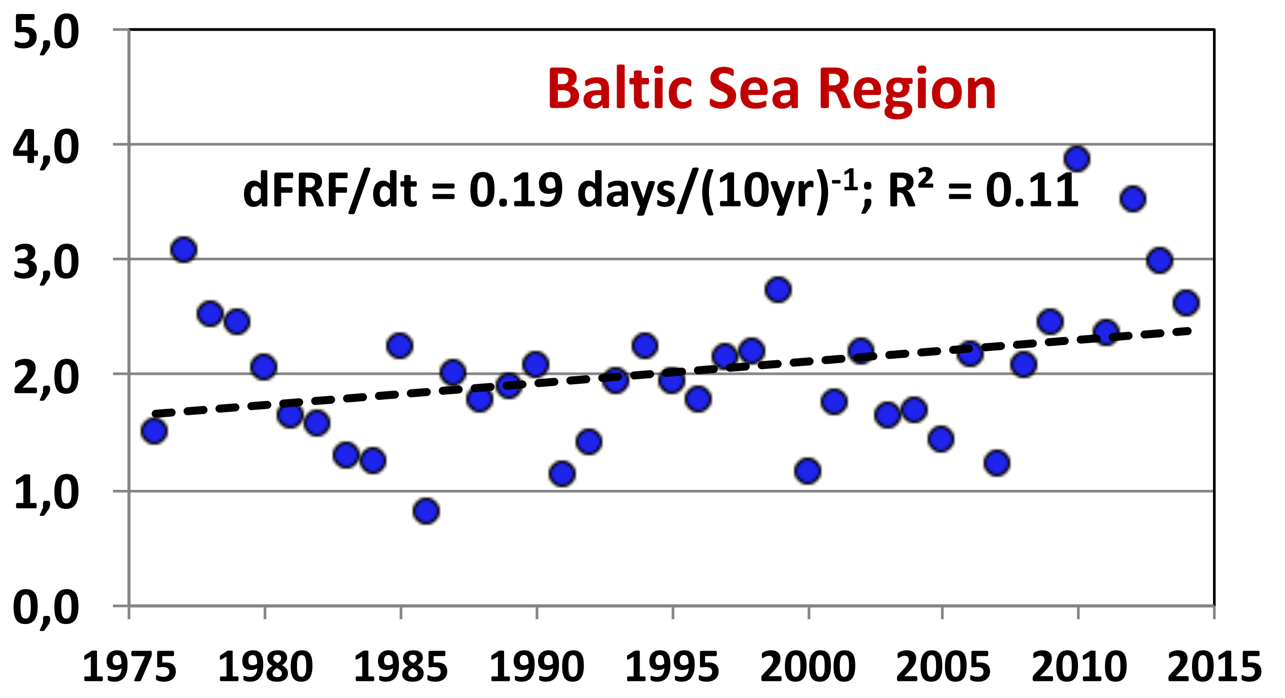
# Annual freezing rain frequency, FRF, area-averaged over



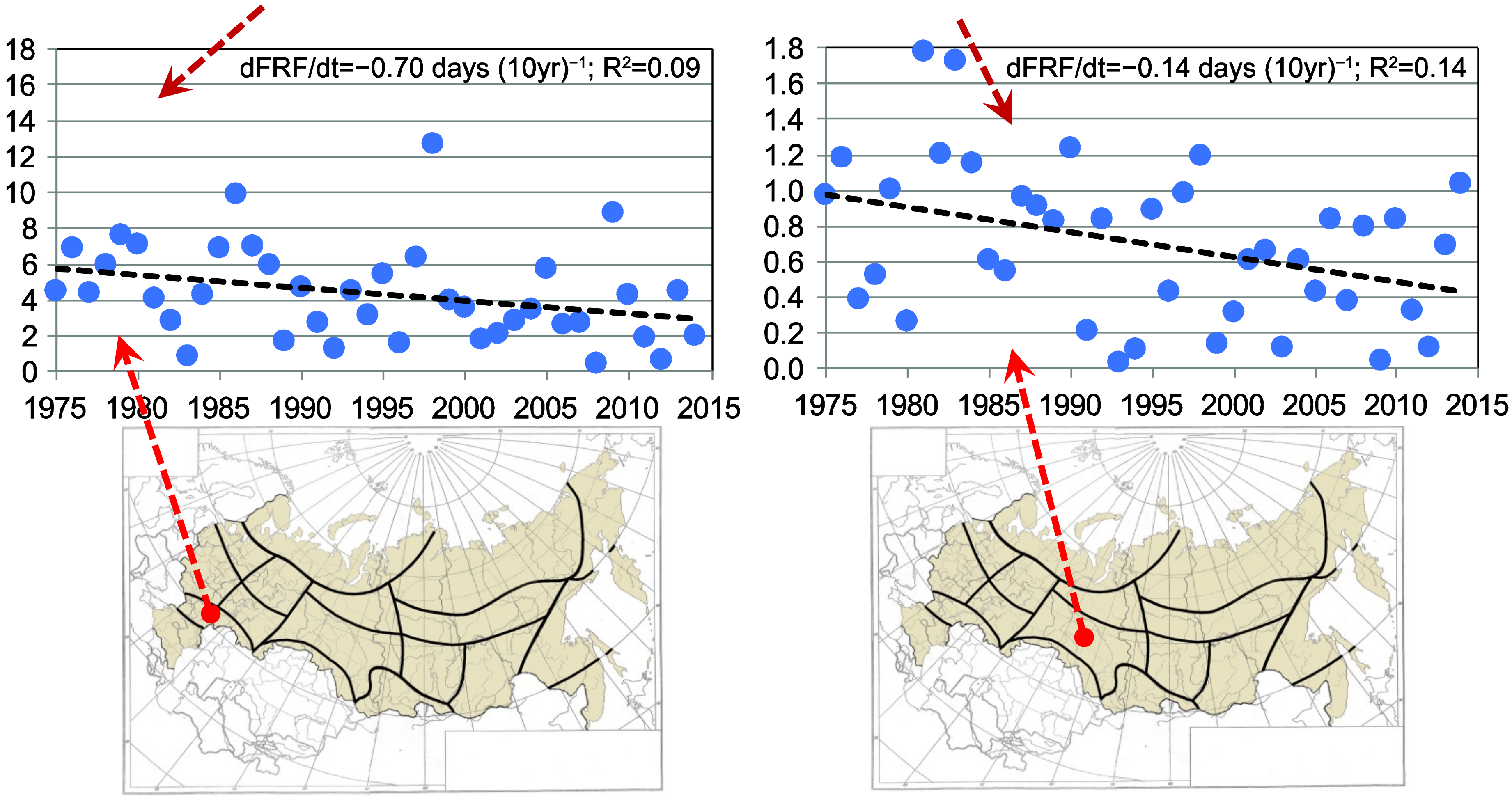
**Annual freezing rain frequency, FRF, area-averaged over Northern Europe**

**(without Russia and Norway)**



# Annual freezing rain frequency, FRF, area-averaged over the Steppe Zone of European Russia and the southern West Siberia



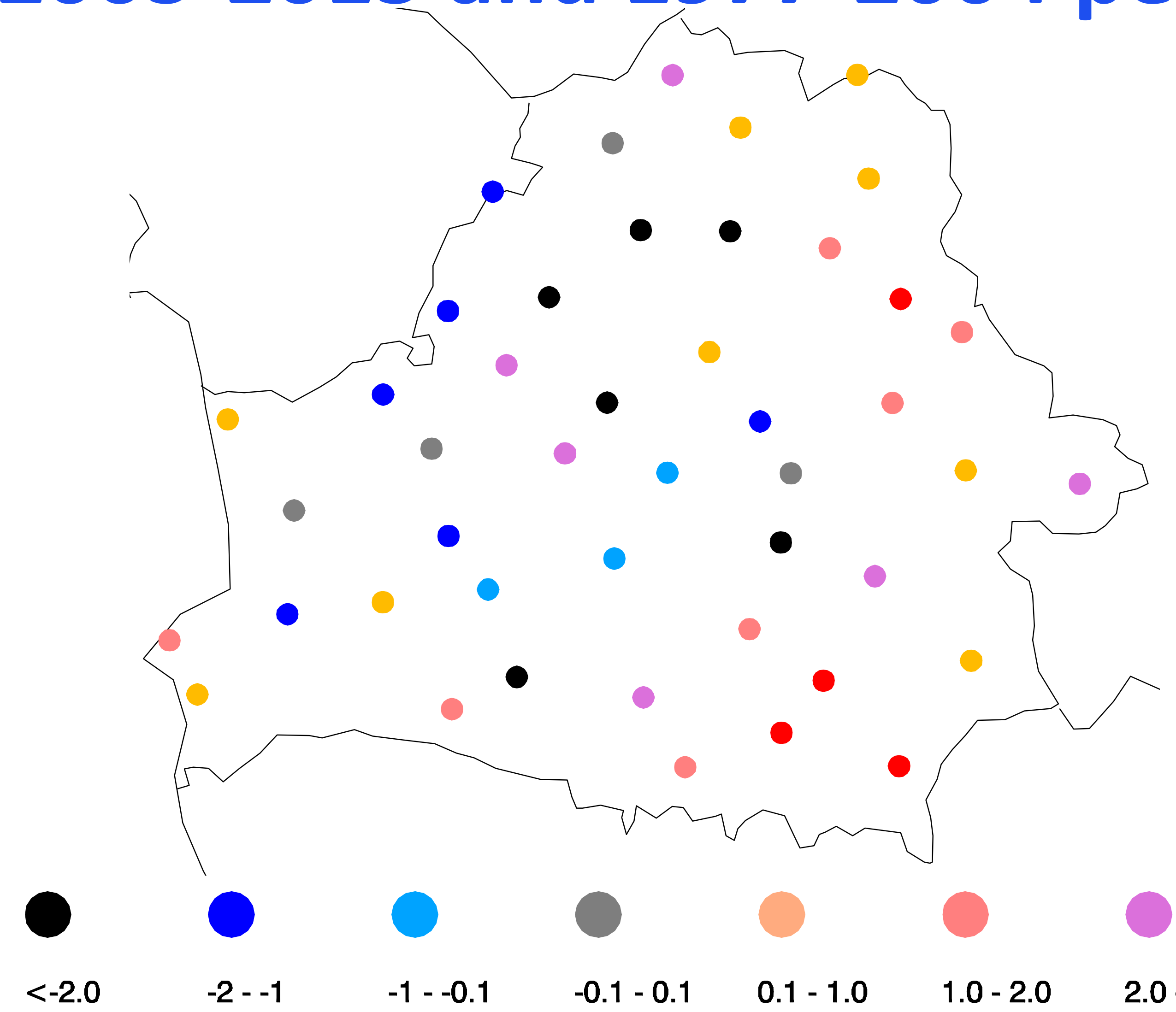

- **Note the order of magnitude scale difference between the continental Siberian region and the Steppe Region of European Russia**

## Annual frequency of all freezing precipitation events (freezing rain, freezing drizzle, and ice rain) over Kyrgyzstan during the 1966-1990 period and recent changes in this frequency during the $21^{st}$ century

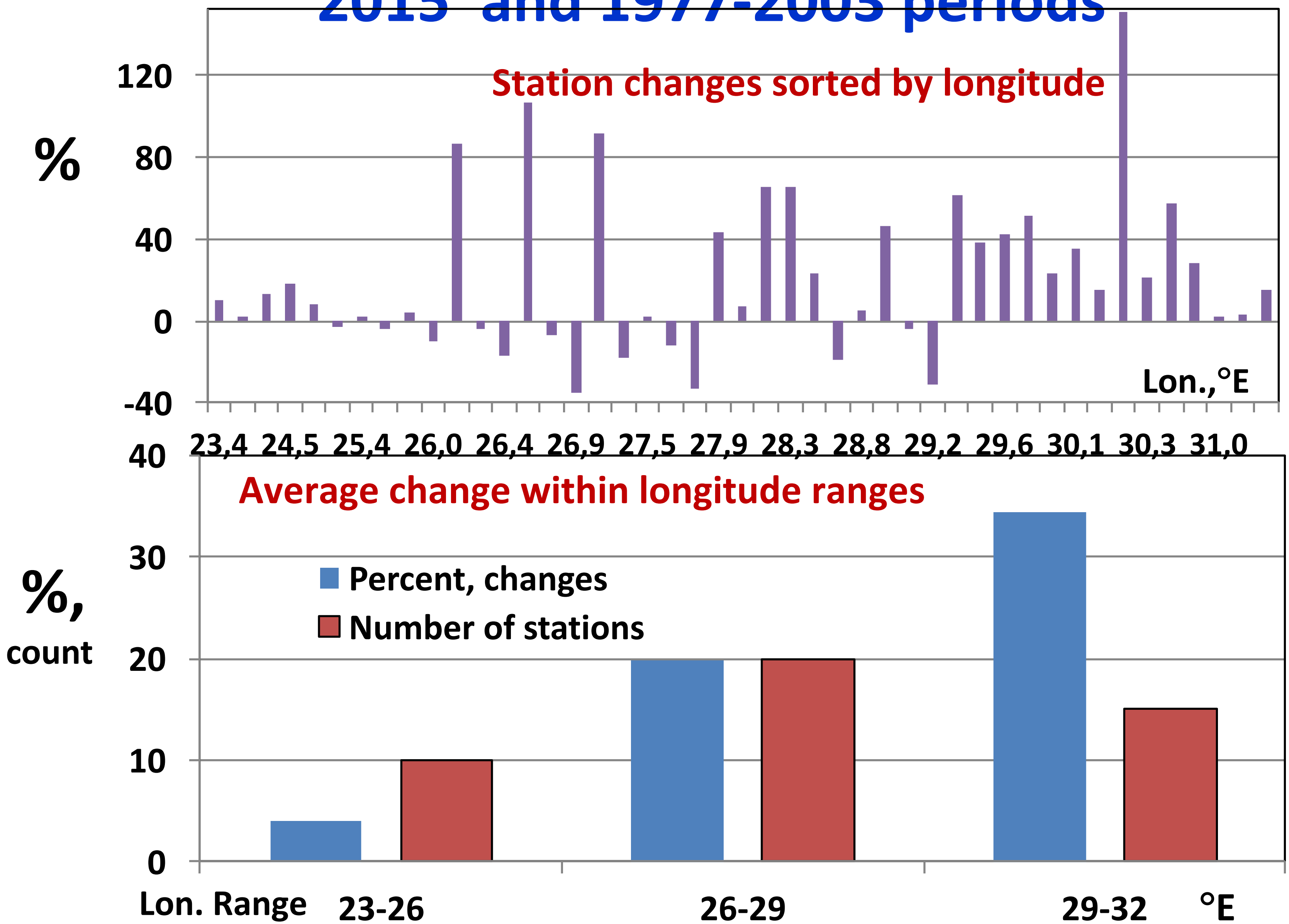
| Freezing events at different elevation | below 1 km | from 1 to 2 km | above 2 km |
|---|---|---|---|
| Climatology, days$(yr)^{-1}$ | 0.98 | 0.61 | 0.25 |
| Changes between two periods, days$(yr)^{-1}$ | -0.31 | -0.16 | 0.50 |

Data of 26 synoptic stations. For the 2009-2011, the data were not available for analysis

# Changes of the mean annual numbers of days with all freezing events between 2005-2015 and 1977-2004 periods



# Changes in the annual number of freezing precipitation-hours over Belarus between 2004-2015 and 1977-2003 periods



# Long-term regional mean values of freezing rain frequency over Norway and selected regions of North America and Russia for 1975-2014 and differences between the mean values for the last decade (2005-2014) and the previous 30-yr-long period (1975-2004)

| Region | Regional mean values days $yr^{-1}$ | Diff. days $yr^{-1}$ | Significant changes by following tests |
|---|---|---|---|
| North America north of 66.7°N | 1.8 | **1.06** | **t- & L- tests** |
| North America, between 50°N and 60°N | 2.5 | ***0.28*** | ***L-test & $R_s$- test*** |
| North America, between 36°N and 50°N east of 95°W | 4.0 | 0.05 | |
| North America south of 36°N, east of 85°W | 0.8 | **-0.21** | **t-test** |
| Norway south of 66.7°N | 1.1 | **1.05** | all three tests |
| Norway north of 66.7°N | 1.1 | **1.10** | all three tests |
| Russian Atlantic Arctic | 1.4 | ***-0.20*** | ***L- & $R_s$- tests*** |
| Northwest of the Great East European Plain | 1.3 | 0.28 | |
| Northeast of the Great East European Plain | 2.2 | ***0.77*** | ***L- & $R_s$- tests*** |
| Southwest of the Great East European Plain | 4.2 | 0.32 | |
| Southeast of the Great East European Plain | 1.8 | 0.28 | |
| Steppe Region of European Russia | 4.3 | **-1.30** | **L- & $R_s$- tests** |
| Northern Caucasia Steppes and Piedmont | 2.1 | 0.16 | |
| Northern part of the forest zone of West Siberia | 1.0 | ***0.67*** | ***t-test*** |
| Southern part of the forest zone of West Siberia | 0.7 | **-0.20** | **L- & $R_s$- tests** |
| Steppe zone of West Siberia | 0.9 | -0.33 | |

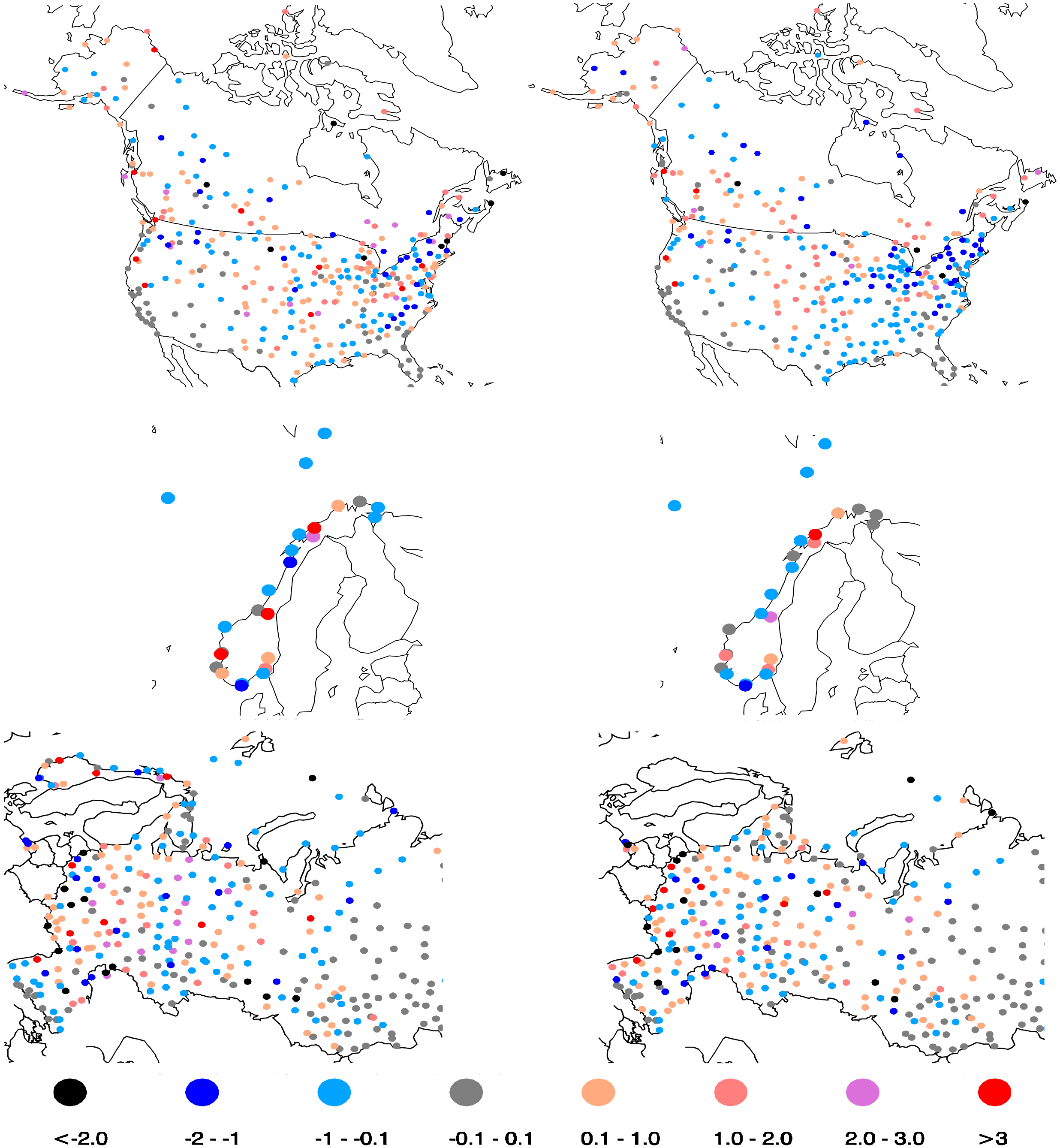
Statistically significant changes at the 0.05 level are in bold and at the 0.10 level are in bold italic

# Conclusions

- **Near 0°C precipitation events are widespread and may represent/create natural hazards; their frequency and intensity are changing in contemporary climatic changes, and these changes are not yet well understood and/or documented**
- **Automation (where it was introduced) and temporal paucity (e.g., 3-h. versus 1-h. reports) affect the homogeneity of reporting of freezing events (especially, for freezing drizzle, intense freezing events)**
- **Using synoptic data for the past 40 years, we estimated the climatology of the frequency of freezing rain and drizzle occurrence for North America, most of Europe, Russia, and Kyrgyzstan and their changes in the past decade**
- **During the last decade, substantial changes in the annual freezing rain occurrence were found:**
  - **On the southern edge of our study domain (southeastern U.S., Central Europe, southern Russia) the frequencies of freezing events decreased along with the duration of the cold season;**
  - **In the Arctic (Norway, Baltic Sea region, north of North America, Greenland, some taiga areas in Russia) and at high elevations (The Tian Shan Mountains), they "followed" the expansion of the short warm season;**
  - **Changes in the occurrence of freezing drizzle were estimated only for Russia. We found a statistically significant nationwide decrease in this element.**

***Acknowledgements: The work was supported by the Ministry of Education and Science of the Russian Federation (grant 14.B25.31.0026) and NASA LCLUC Program (grant "How Environmental Change in Central Asian Highlands Impacts High Elevation Communities").***

Stability test comparing different partitions of the past 40 years in 2 groups




**Last 10yrs – previous 30yrs; Last 20yrs – previous 20 yrs**

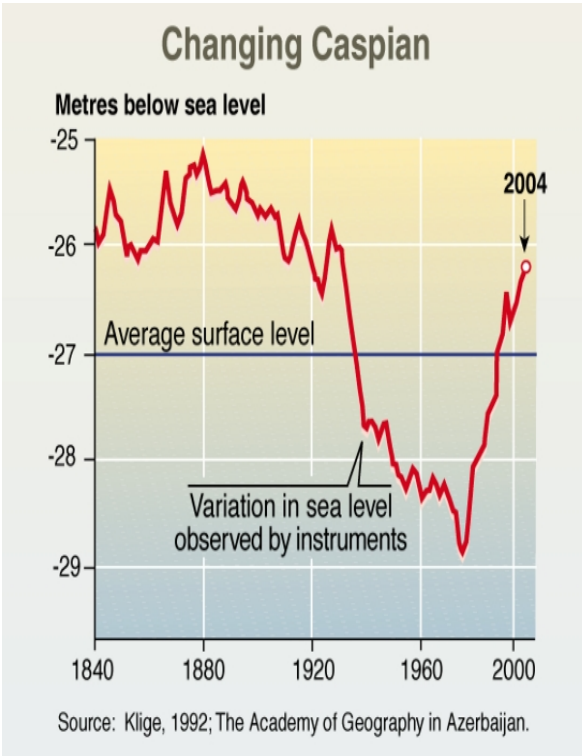
谢谢！

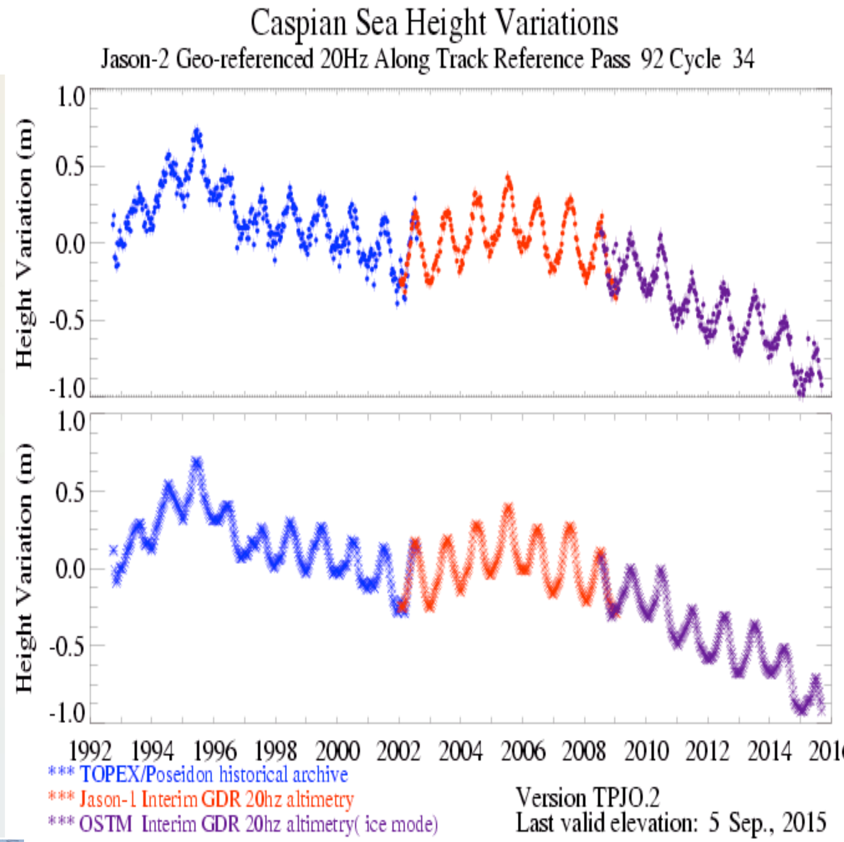
Thank you!

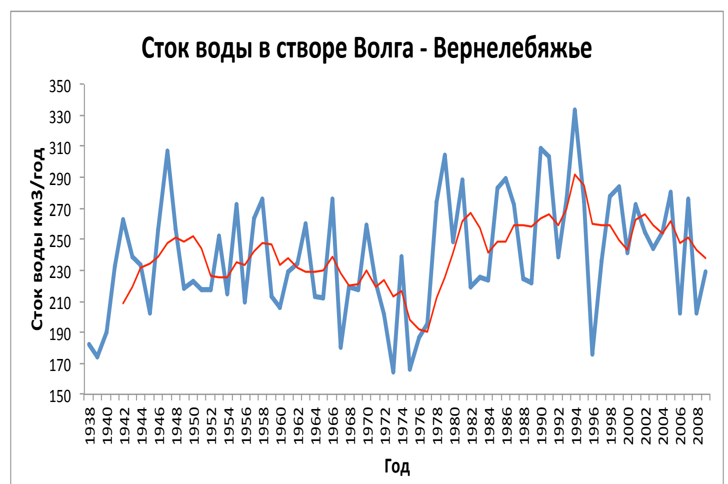
Спасибо!

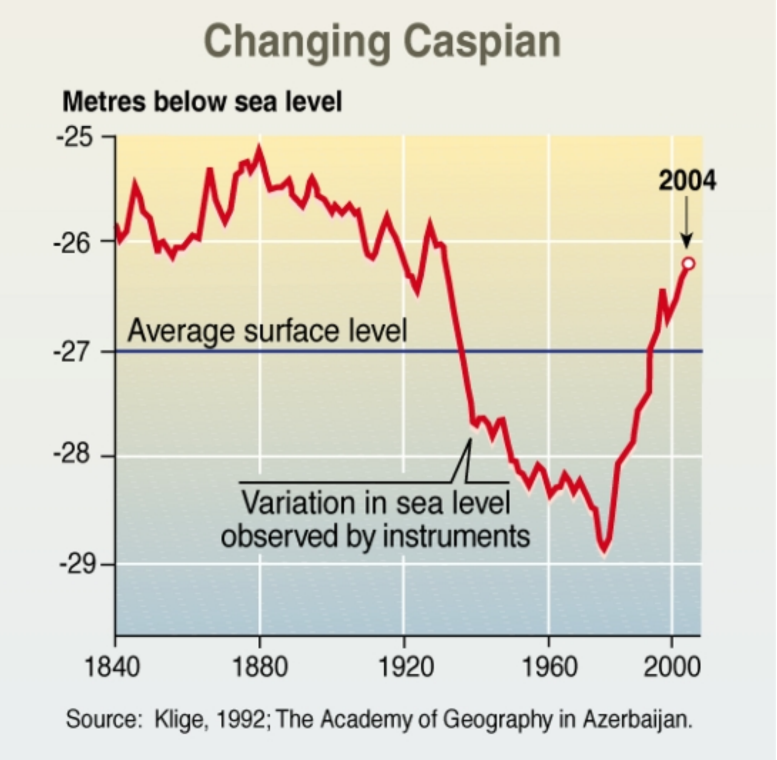
Рахмат!

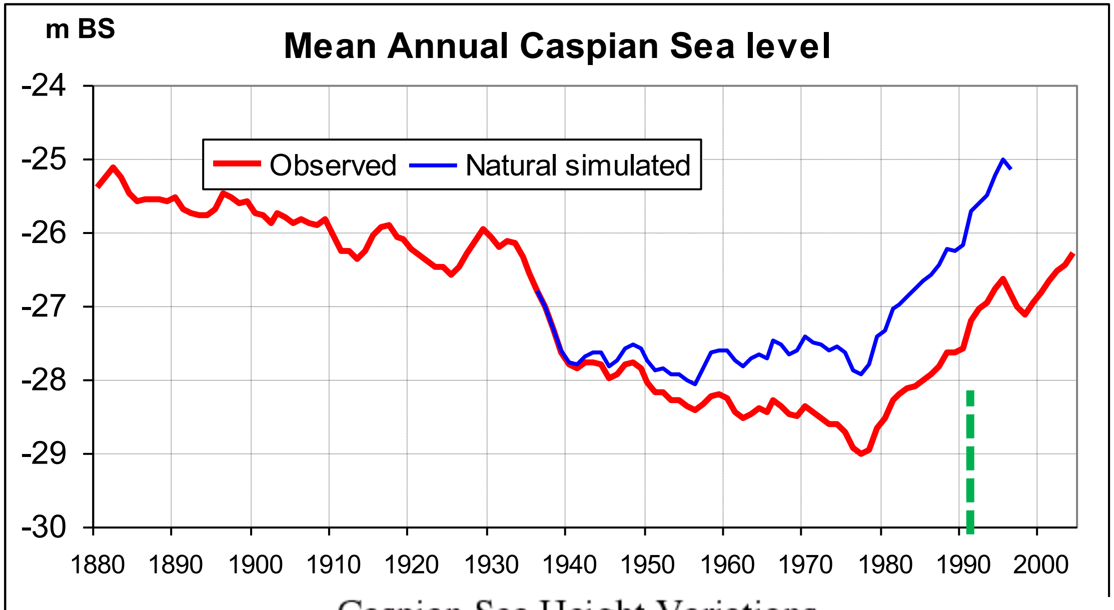
# Changes of the Caspian Sea level



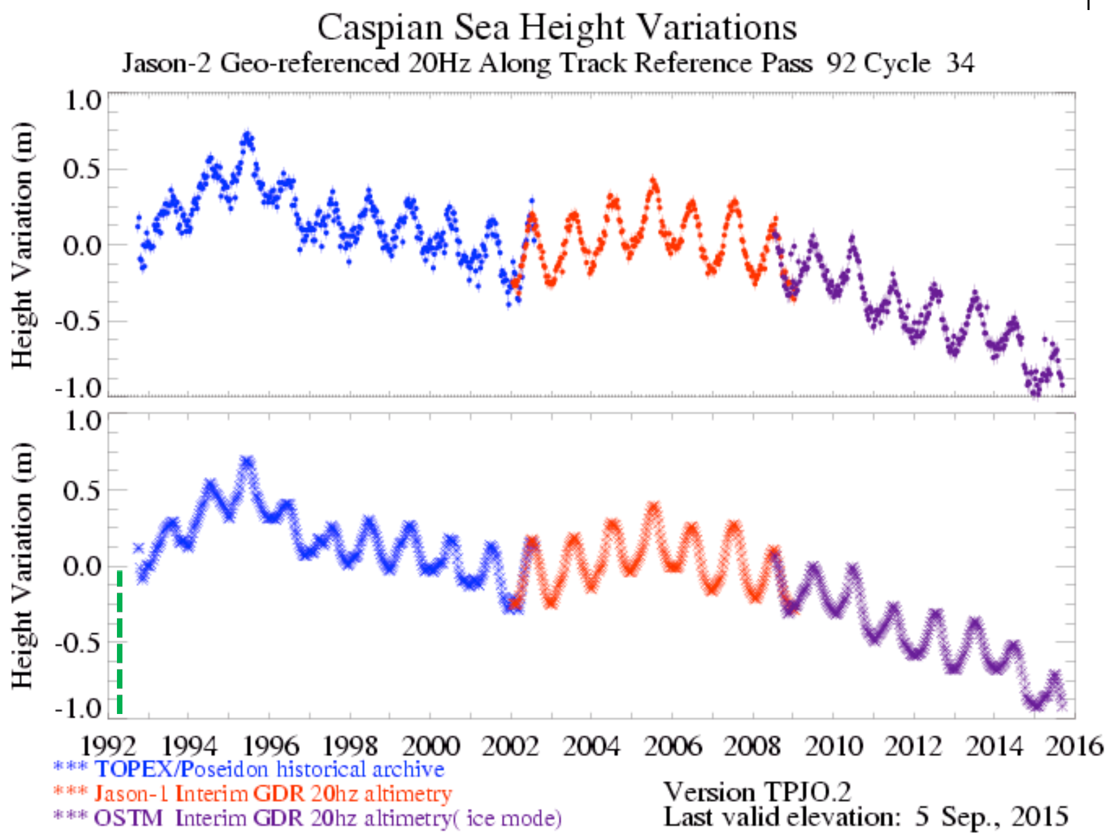





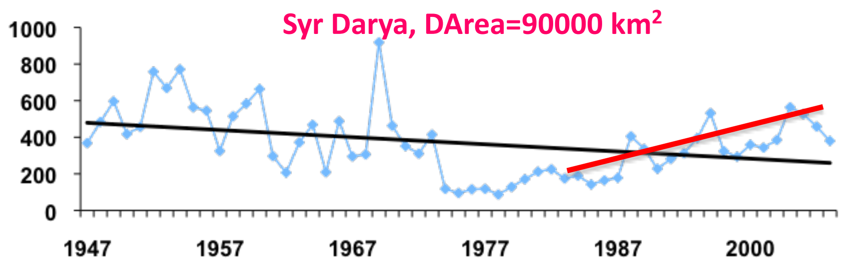



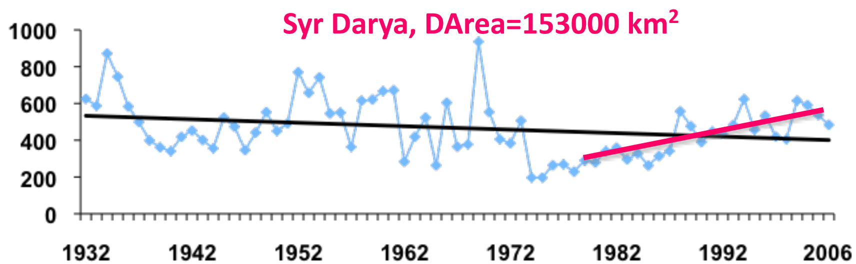

Flooded Infrastructure built in 60-70s

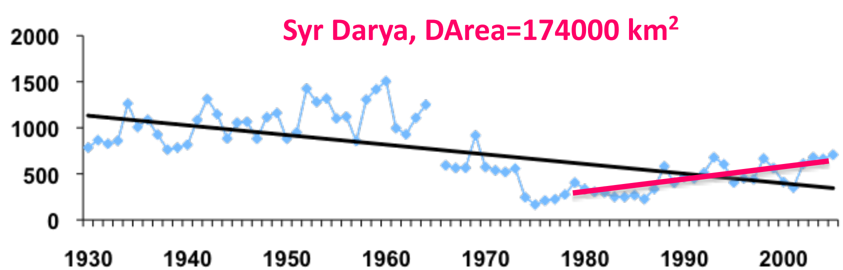


# Change in observed discharge – Syr Darya River

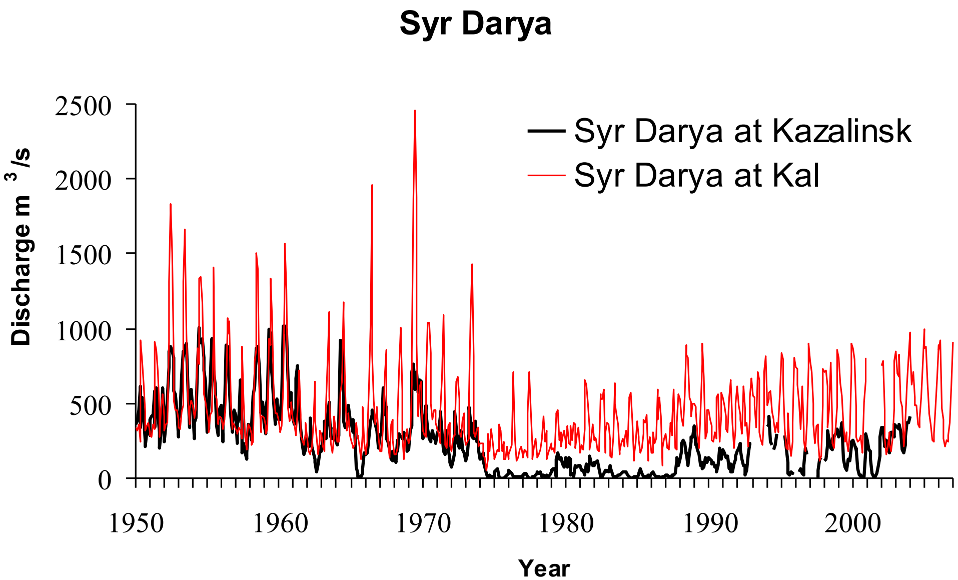
## Annual discharge

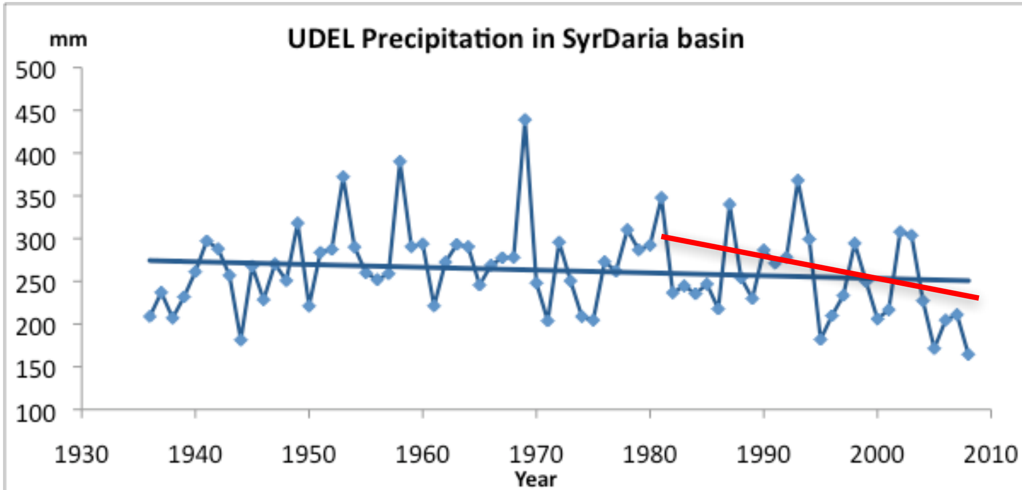



## Monthly discharge




**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 datasets show this)

# Tian Shan Mountains and Syr Daria upstream annual discharge variations