Observational Evidence of Changes in Precipitation Spectra over Northern Extratropics related to Extreme Rainfall and Droughts: New tendencies Emerging during the Last Decades

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CITES 2011, (July 8, 2011, Tomsk, Russia)

Theoretical expectations for increase in summer dryness:

Manabe, S., R.T. Wetherald, and R.J. Stouffer, 1981: Summer dryness due to an increase of atmospheric CO_2 concentration. *Climatic Change*, **3**, 347-386

Manabe, S., R. T. Wetherald, P. C. D. Milly, T. L. Delworth, R. J. Stouffer, 2004: Century-scale change in water availability: CO_2 quadrupling experiment. *Climatic Change*, **64**, 59-76.

+ Presentations at the Drought Workshop (Barselona, Spain, March 2011)

Theoretical expectations for increase in intense rainfall in extratropics

Allen M. R. and Ingram W. J., 2002: Constraints on future changes in climate and the hydrological cycle, *Nature*, **415**, 224–232.

Intergovernmental Panel on Climate Change IPCC, 2007: Climate Change 2007: The Physical Science Basis [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

U.S. Climate Change Science Program (USCCSP), 2008: Weather and Climate Extremes in a Changing Climate. North America, Hawaii, Caribbean, and U.S. Pacific Islands. Synthesis and Assessment Product 3.3. 162 pp.

Everything else will be the empirical evidence

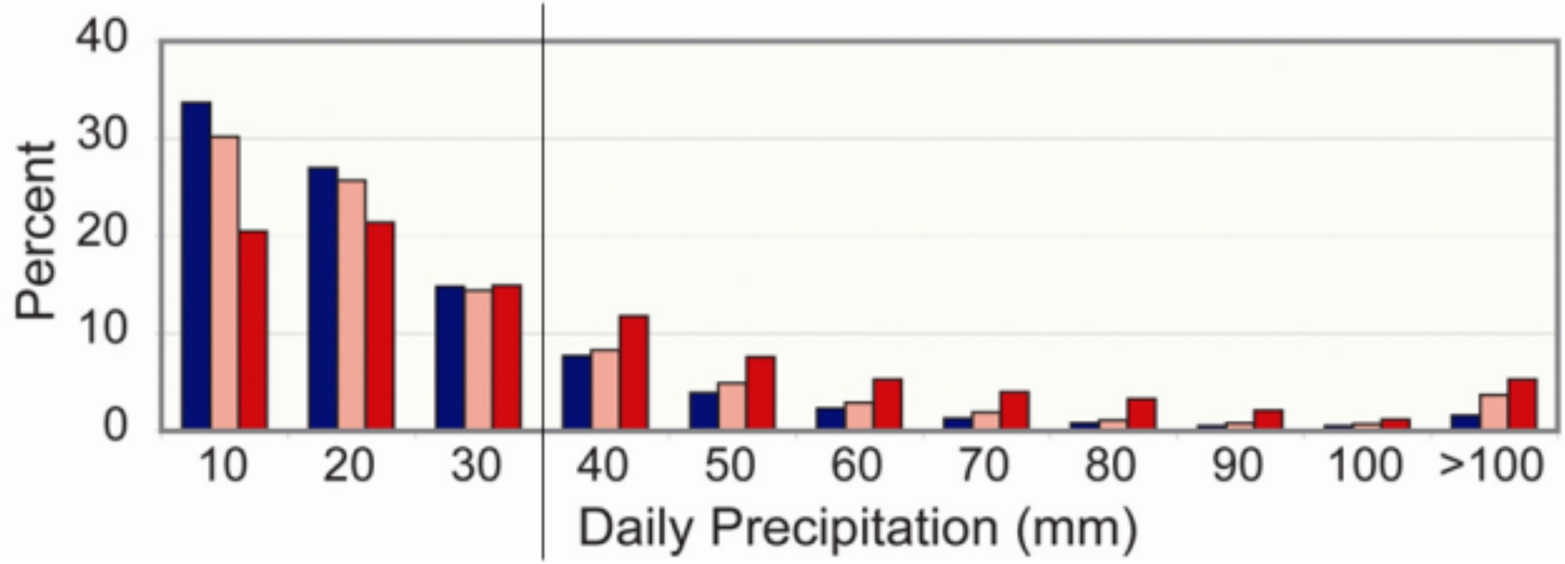
Characteristics of precipitation spectra that are of our concern (in addition to changes in totals)

- Wet spell events
  - Total amount
  - Peak intensity
  - Duration
  - Accumulated totals
  - Thresholds of "extremes"

- Dry spell events
  - Pre-history
  - Duration
  - Position in the seasonal cycle
  - Thresholds of "extremes"

- under *extremes* we understand exceptionally rare and damaging events that may cause property and human life losses and trigger environmental changes

Higher temperatures => increase in precipitation intensity



- **Climatology of the intensity of daily precipitation in 10 mm/day categories for stations with the same mean seasonal precipitation (~230 mm) and different temperature regimes (<19°C, blue bars; between 19°C and 29°C, pink bars; and > 29°C, red bars)**

[Karl and Trenberth 2003, Science]

… and (by implication) a possible reduction of the frequency of rainy days

Rationale to look at the last 4 to 5 decades across Northern Extratropics

- a disproportional increase in precipitation coming from intense rain events (Groisman et al. 2005)
- an extension of the vegetation period with intensive transpiration
- an insignificant change in total precipitation

All the above could lead to prolonged periods without precipitation (even when seasonal rainfall totals increase)

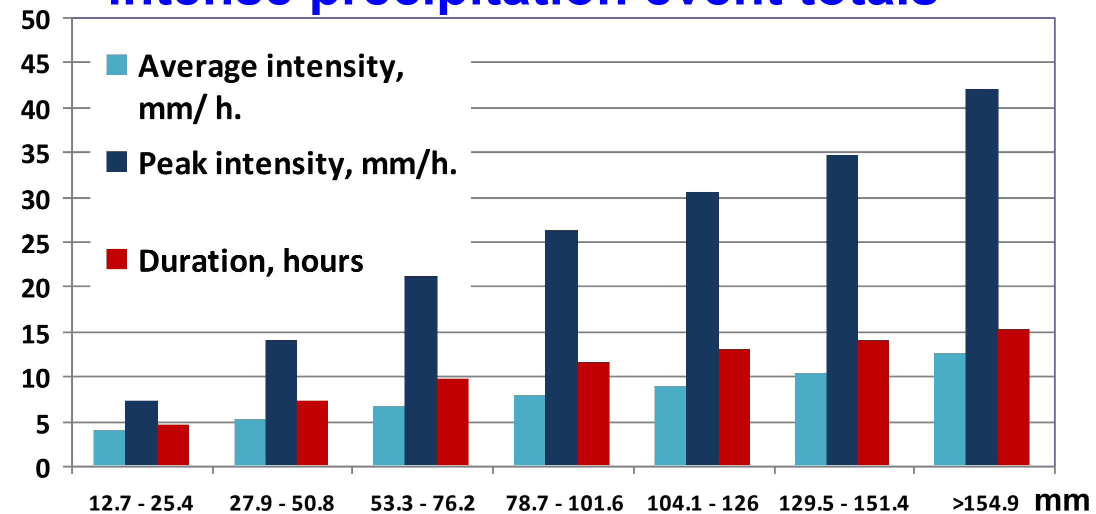
With global warming, more and more frequently we observe:

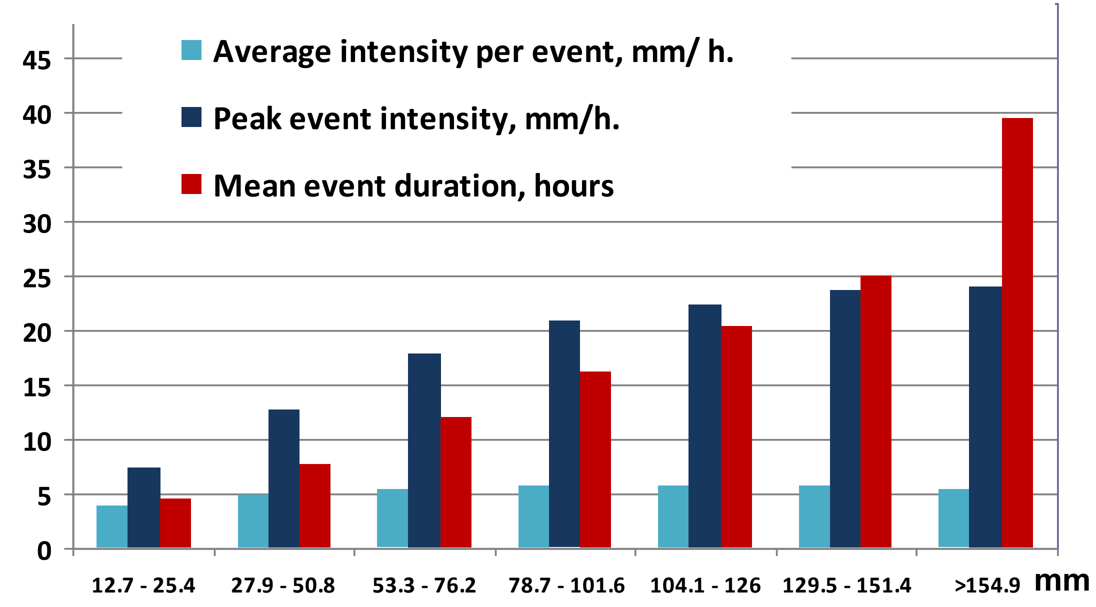
- **Increase in temperature derivatives ➔ evapotranspiration may ↑ ;**
- **Earlier snowmelt & more frequent thaws ➔ more cold season precipitation become unavailable in the warm season;**
- **Only moderate increase in precipitation but increase in thunderstorm activity ➔ more warm season precipitation goes into runoff;**
- **All the above ➔ possibility of drier summer conditions ➔increase in forest fire danger and prolonged no-rain episodes + direct human impact**

What time scale to use?

- hours
- <u>days</u>
- months
- cold/warm season

Climatology for the contiguous U.S. of various characteristics of hourly intense precipitation as a function of daily (top) and multi-day (bottom) intense precipitation event totals



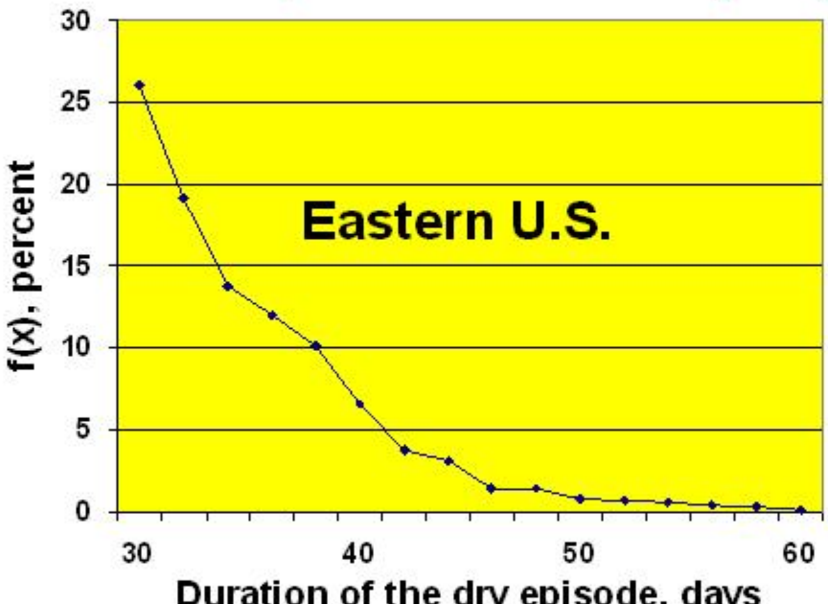


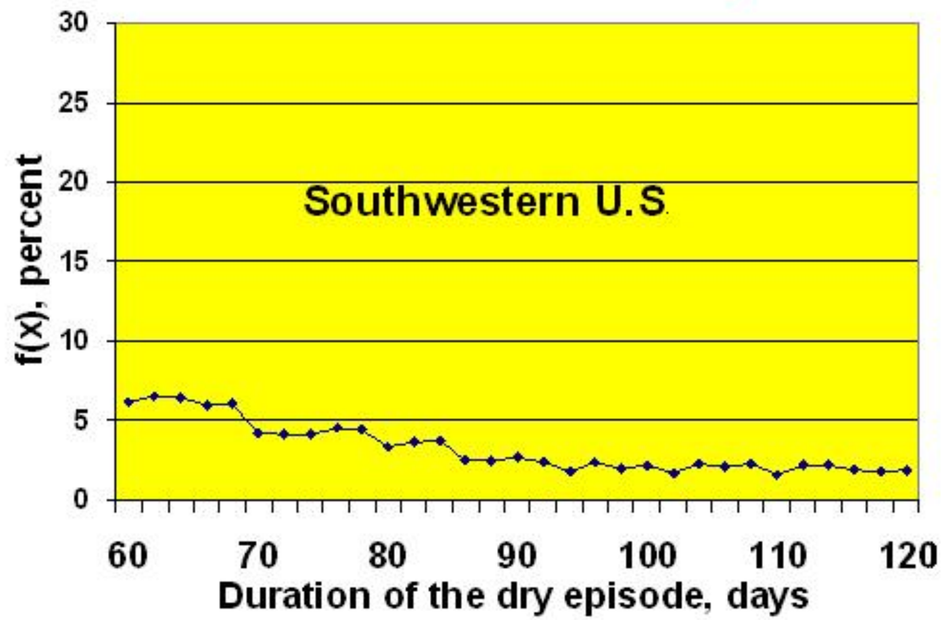
Rainfall duration in July days with precipitation over the former USSR (hours)

- **Kamchatka 8 - 9**
- **Russian Arctic 7 - 8**
- **Forest and steppe zones of N. Eurasia 2 – 5**
- **Central Asia 0.5 - 2**

Lengthy intervals of "dry" days without sizeable rain during the warm season (when daily T > 5°C). We assess the percent of the warm season (%) with dry days intervals above 20, 30, 40, 50, 60, 90 days, etc.

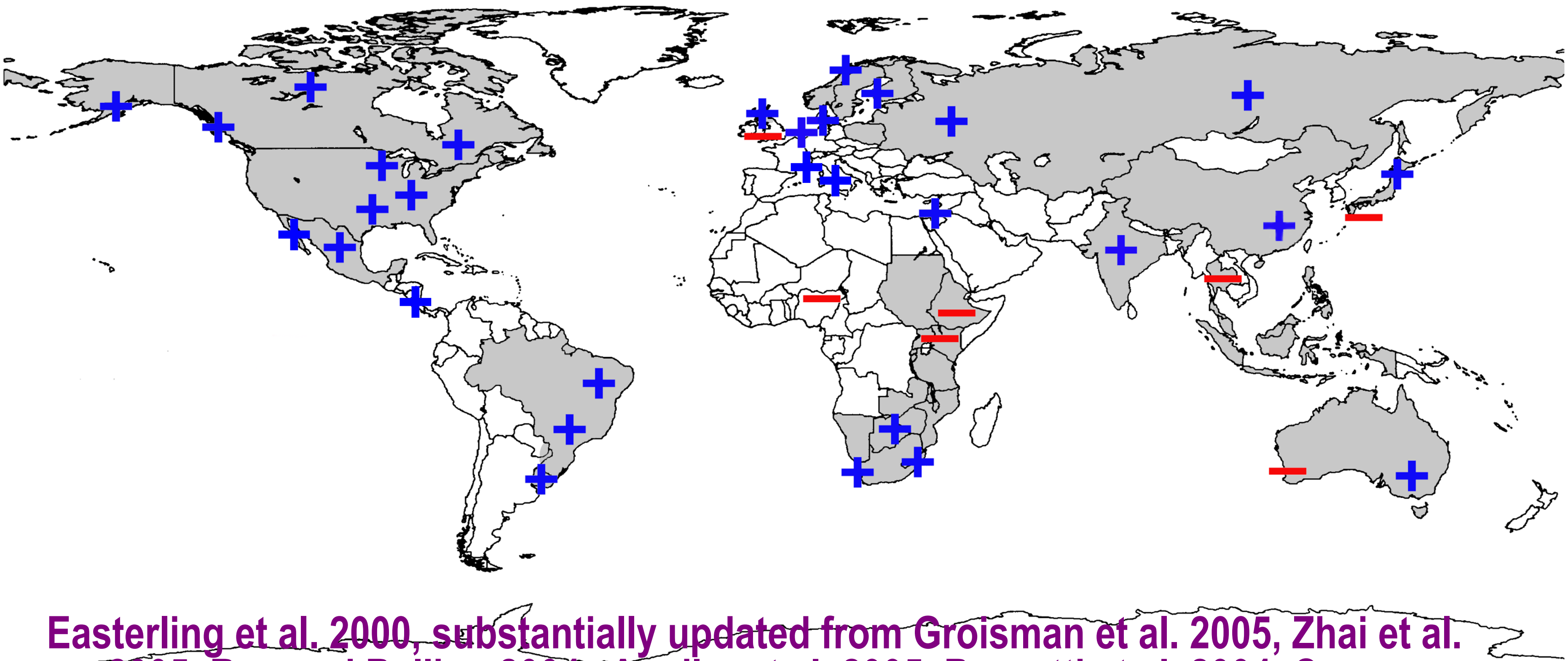
Distribution function of the prolonged dry episode durations above 30 (Eastern U.S.) and 60 days (Southwestern U.S.).



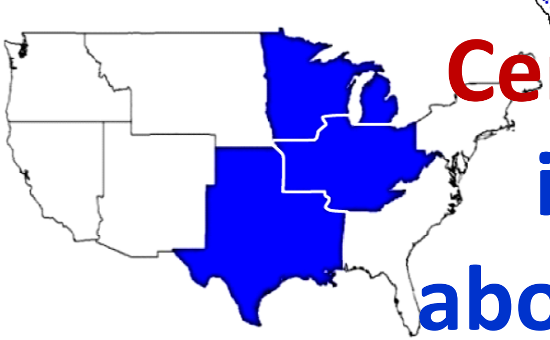


Increase in intense precipitation

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



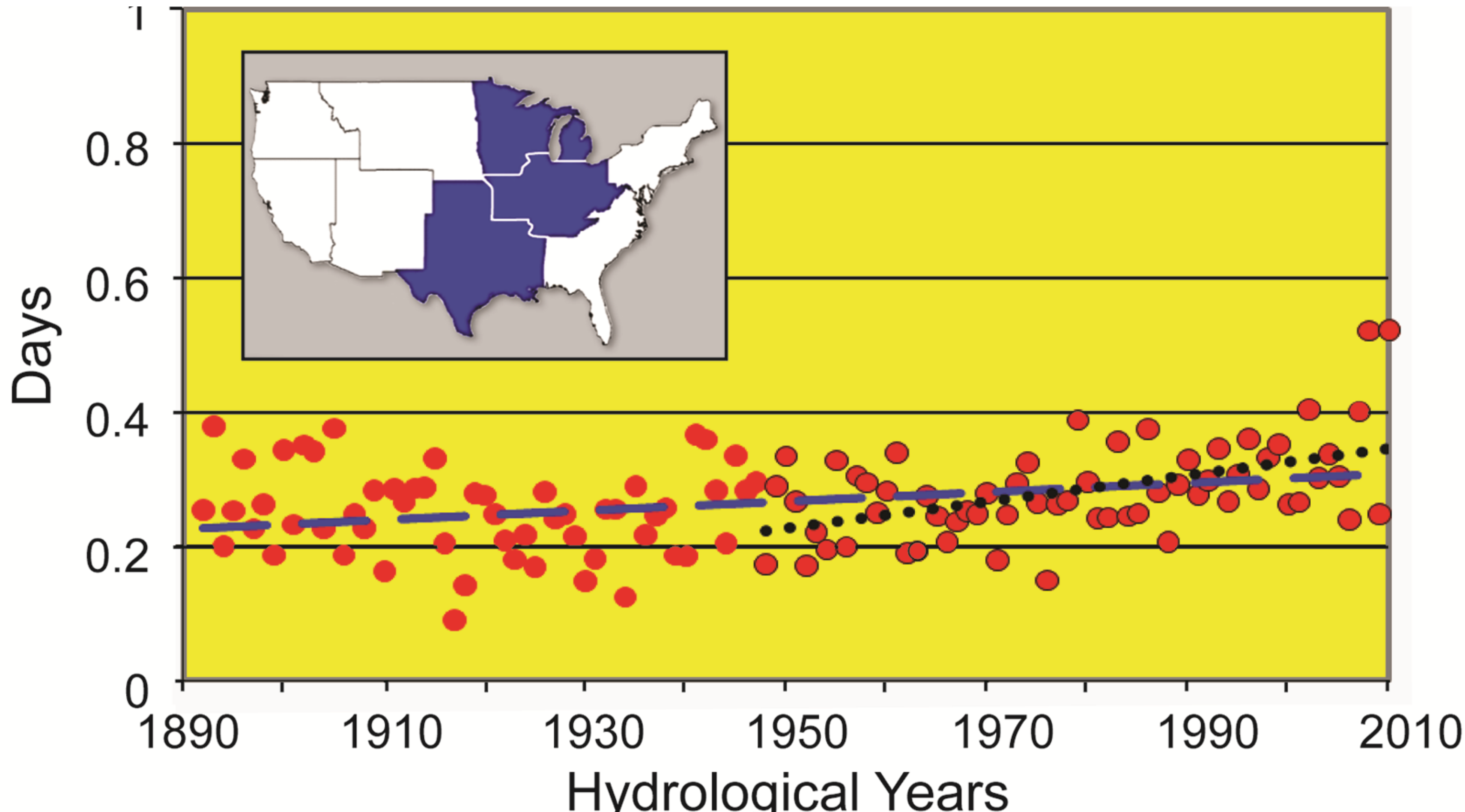
Easterling et al. 2000, substantially updated from Groisman et al. 2005, Zhai et al. 2005, Roy and Balling 2004, Aguilar et al. 2005, Brunetti et al. 2004, Cavazos 2008, and Zolina et al. 2010. Thresholds used to define “heavy” and “very heavy” precipitation vary by season and region.



Central United States (we define as intense daily rainfall with total above 0.5 inch, i.e., above 12.7 mm)

- On average, more than 70% of annual precipitation falls during ~25% of days with intense precipitation
- About half of intense precipitation totals comes from moderately heavy events (less than 25.4 mm) that comprise > 70% of all days with intense precipitation
- Only 0.1% of intense rain days are 6-inchers and they bring ~0.8% of intense precipitation in the last decades (but 30 years ago they brought only ~0.6%)
- All trends during the past 118 years are ascribed to the 1948–2009 period and the second half of this period is responsible for most of them

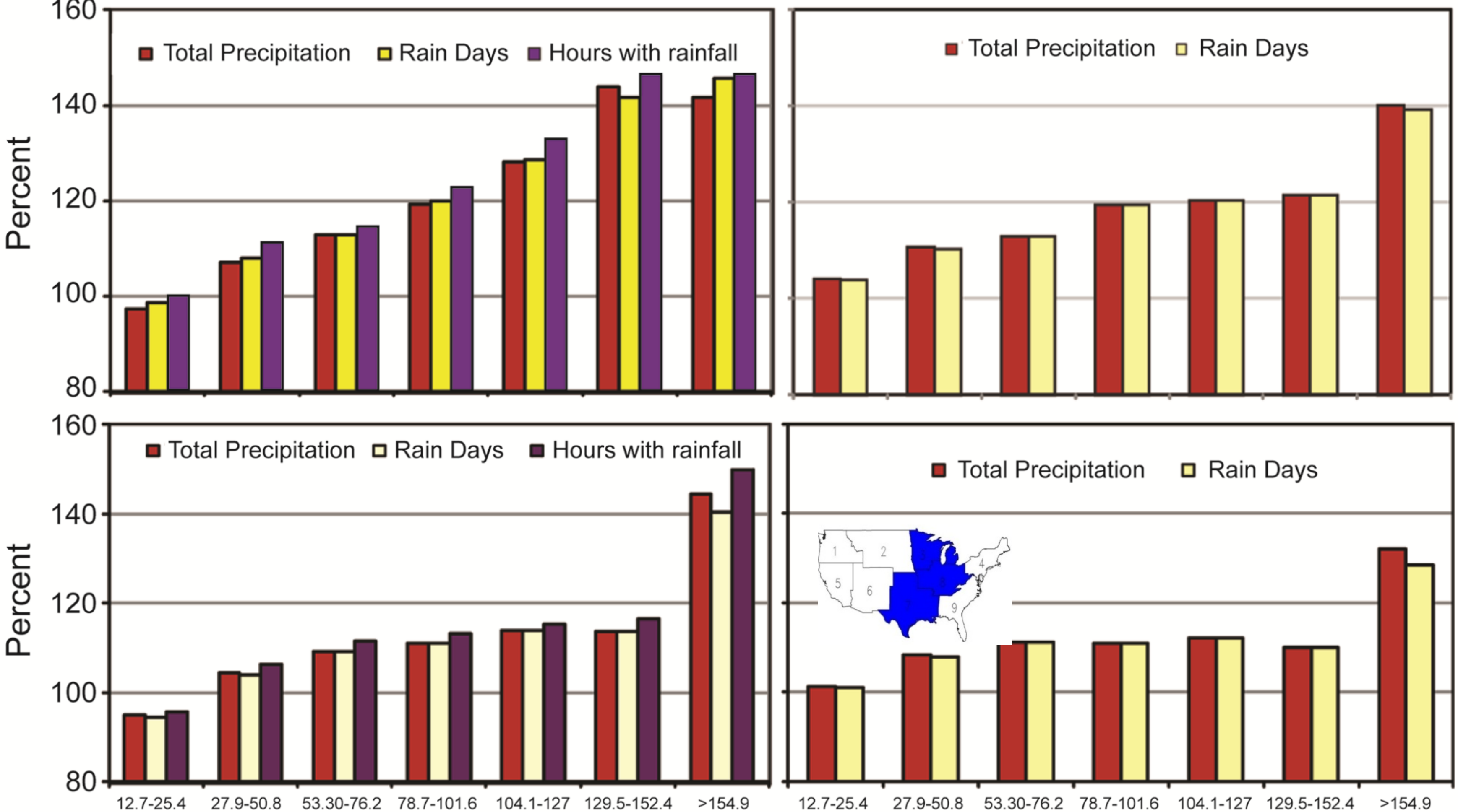
Annual number of days with very heavy precipitation defined as an upper 0.3% of daily precipitation events over the central U.S. (dark blue in the insert)



Linear trend estimates for the 1893–2010 and 1948–2010 periods. are equal to 2.6% (10 yr)$^{-1}$ and 7.4% (10 yr)$^{-1}$, respectively, and are statistically significant at the 0.01 level or higher (Groisman et al. 2011).

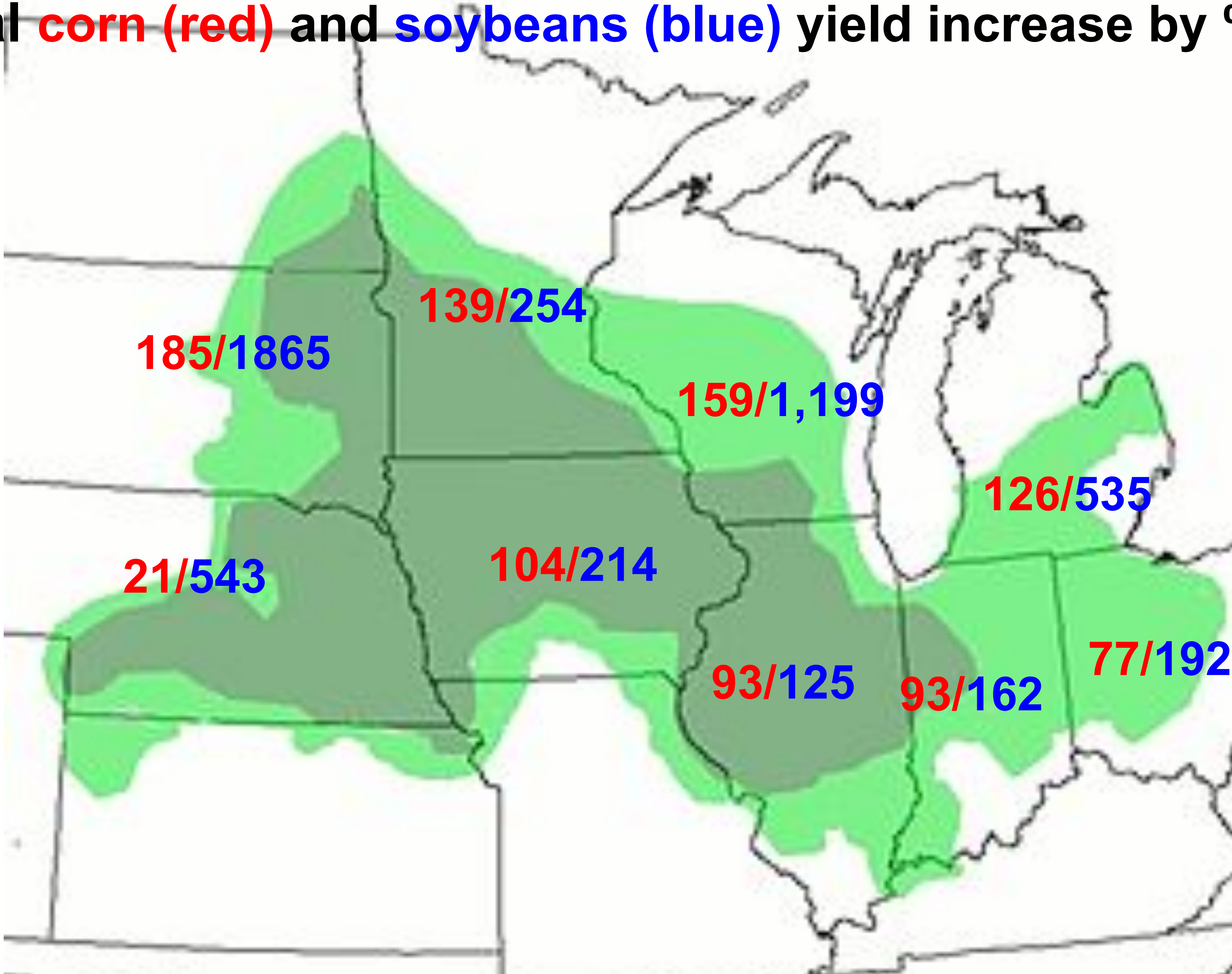
Comparison of intense precipitation days (upper line of plots) and multi-day intense precipitation events (lower plots) over the Central U.S. for 1979-2009 and 1948-1978 periods sorted by day/event intensities (in mm).

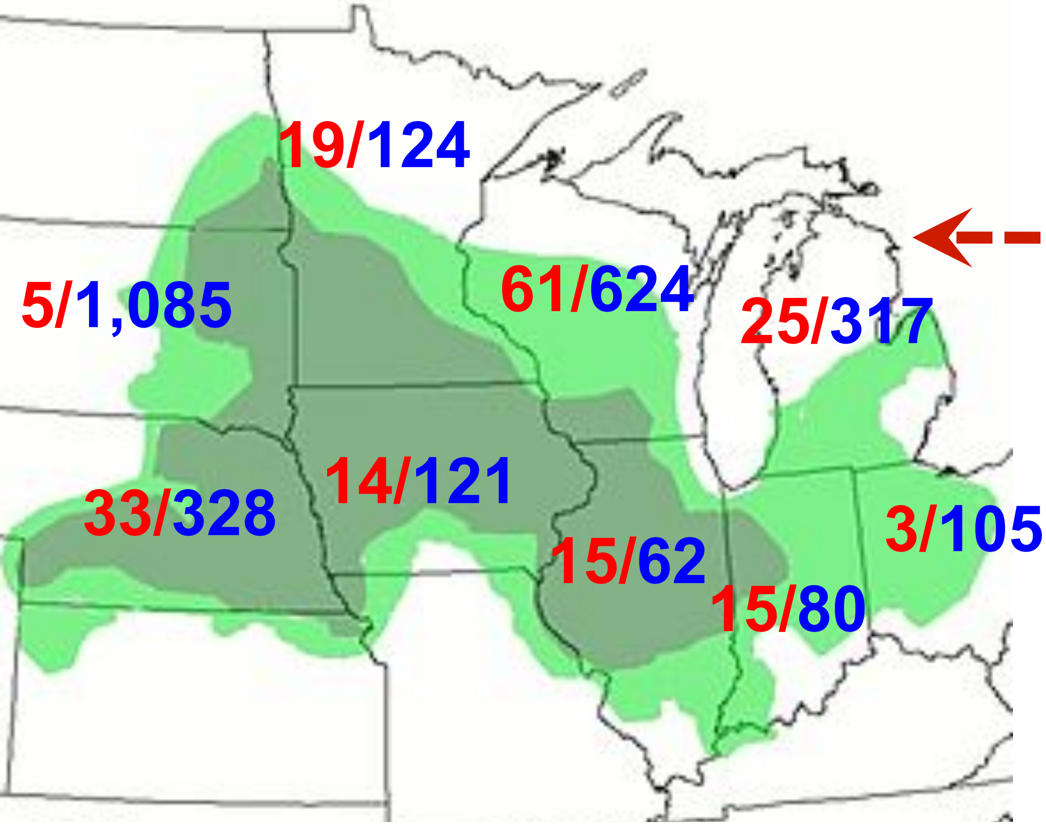
Extreme rain events (P > 155 mm) became 40% more frequent.



Estimates of precipitation characteristics for these 31-yr periods were averaged and their ratios (in percent per station for the past 31 years to those for the previous 31-yr-long period) are shown for hourly (left) and daily (right)

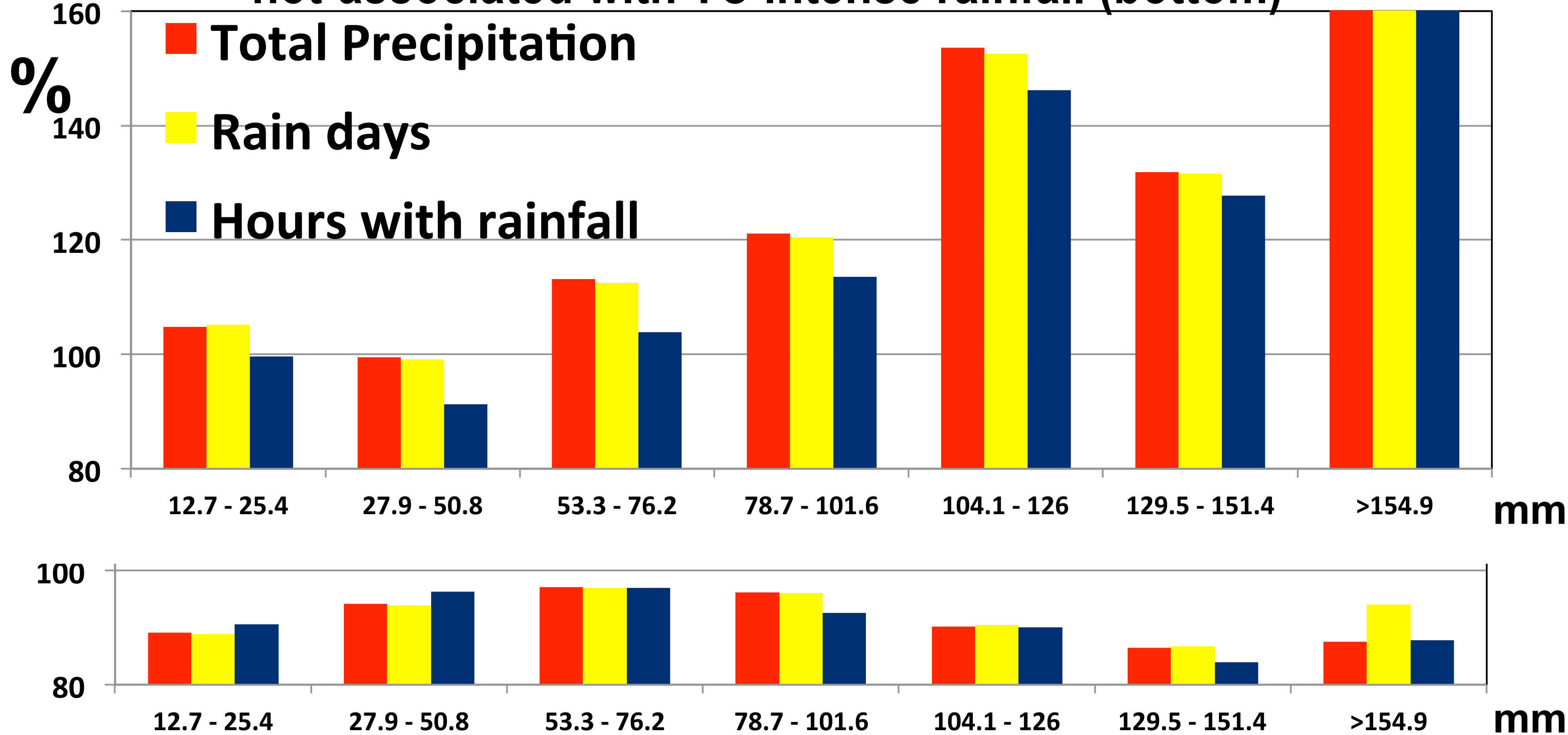
Changes between 1979-2009 and 1948-1978 periods. Total corn (red) and soybeans (blue) yield increase by %





Area of harvested corn for grain (red) and soybeans (blue)

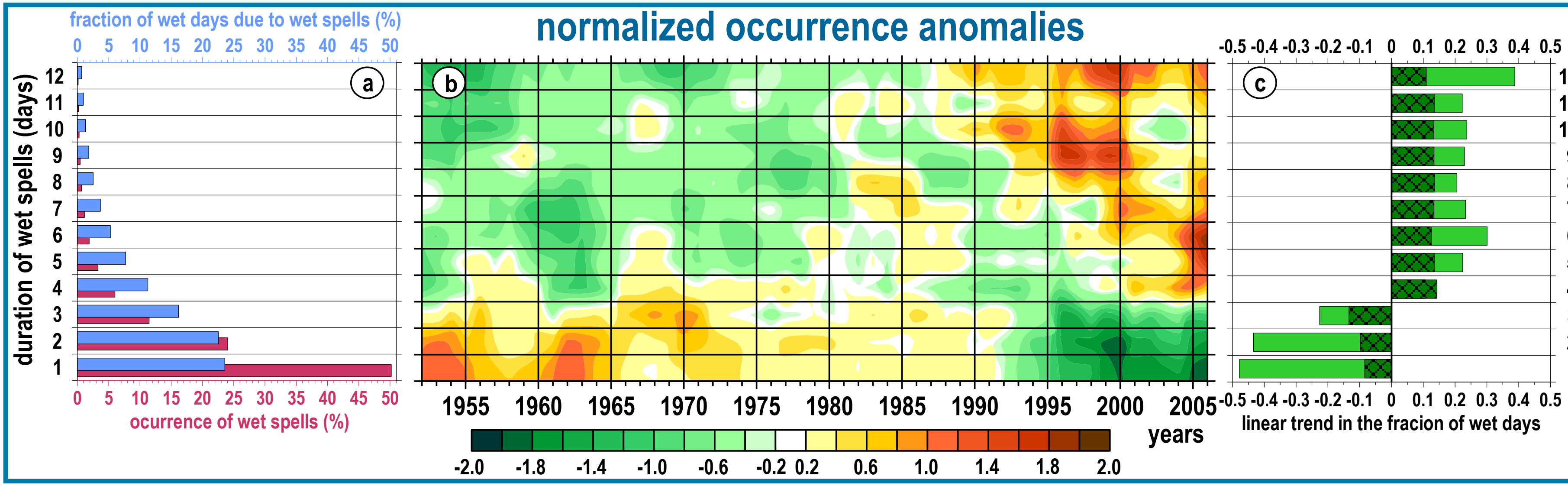
Comparison of intense precipitation characteristics during the June-November season over the Southeastern U.S. associated with tropical cyclones (TC) for the 31 years of warmest and coldest Northern Hemisphere temperatures during the 1948-2009 period (top) and other not-associated with TC intense rainfall (bottom)

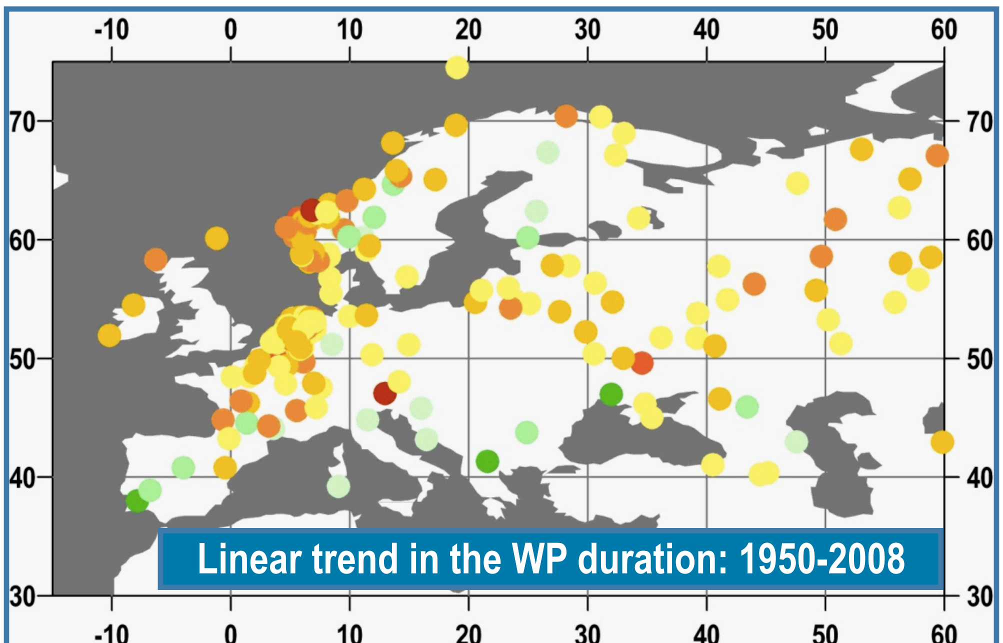


Estimates of precipitation characteristics for these 31-yr periods were averaged and their ratios (in percent per station) are shown sorted by day rainfall intensity ranges

Non-linearity

Changes in the duration of European wet periods

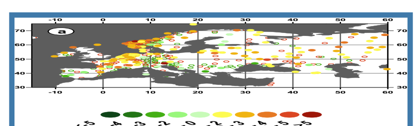




It is not the effect of changing number of wet days!!!

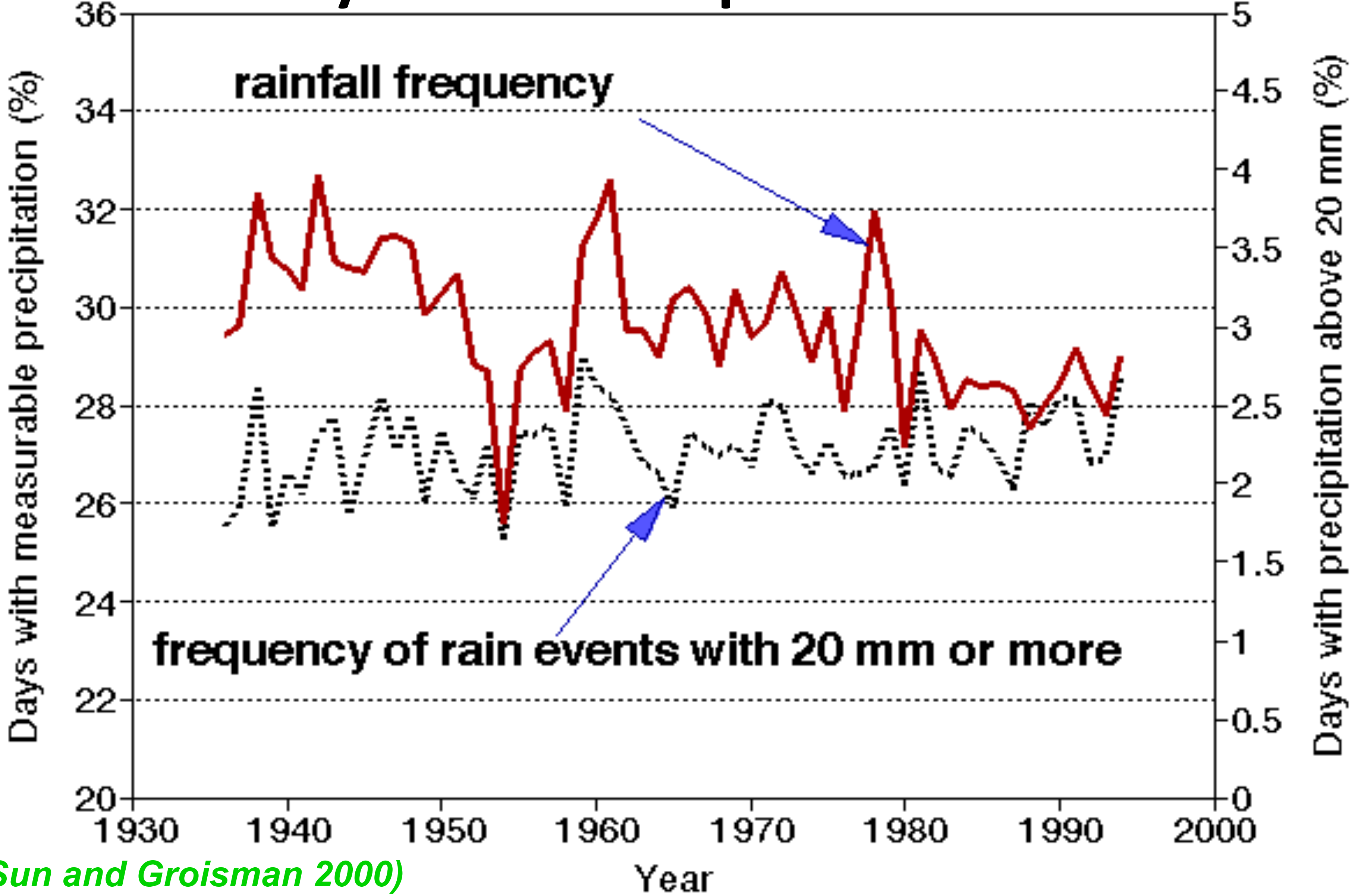
Net effect of the number of wet days (Monte-Carlo simulation of the growing number of wet days, % per decade)

1%	2%	3%
0.17±0.10	0.31±0.19	0.47±0.25



Zolina et al. 2010, *Geophys. Res. Lett.*

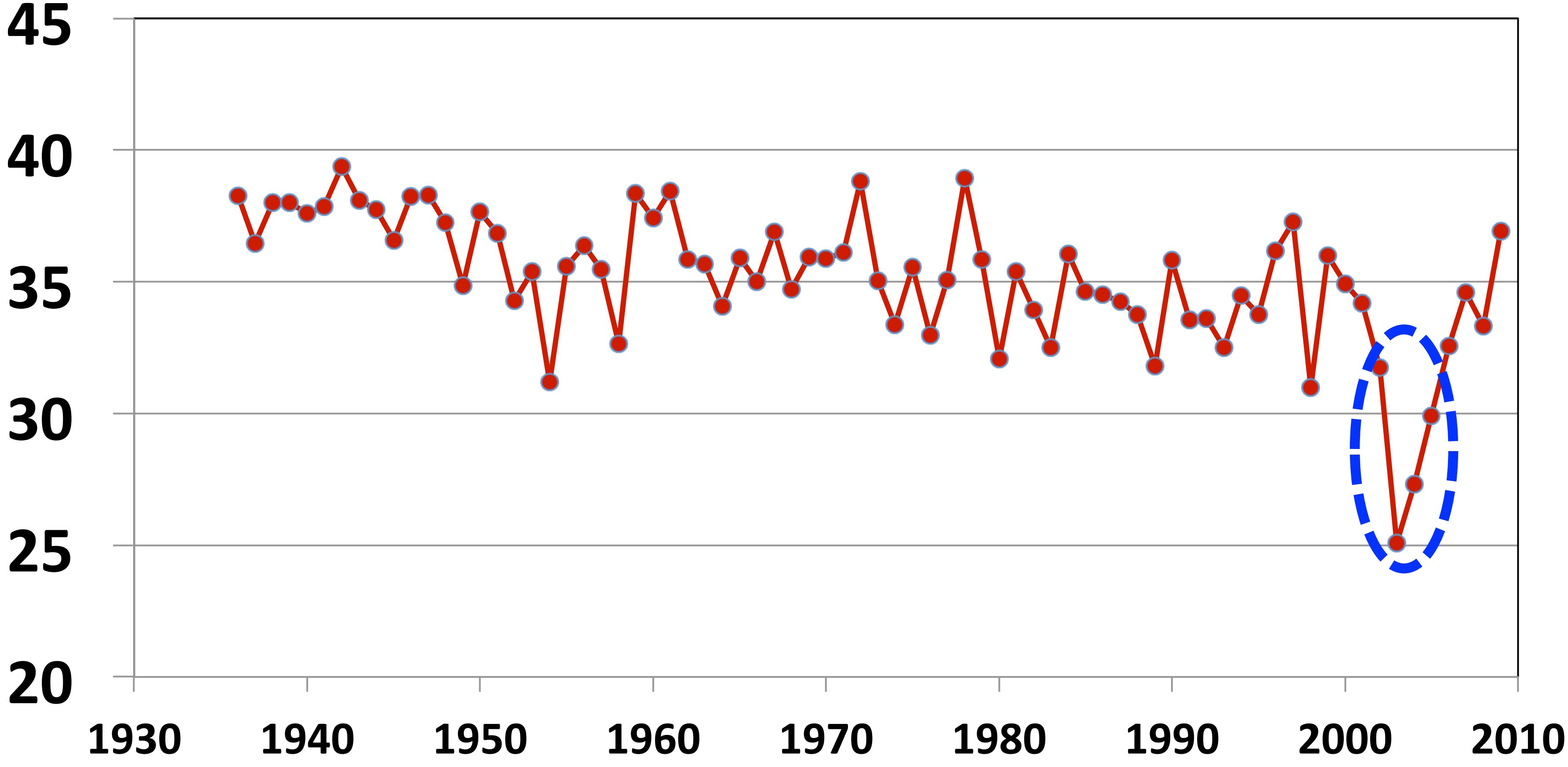
Summer frequency of rainy days and days with heavy rains. Asian part of Russia



(*Sun and Groisman 2000*)

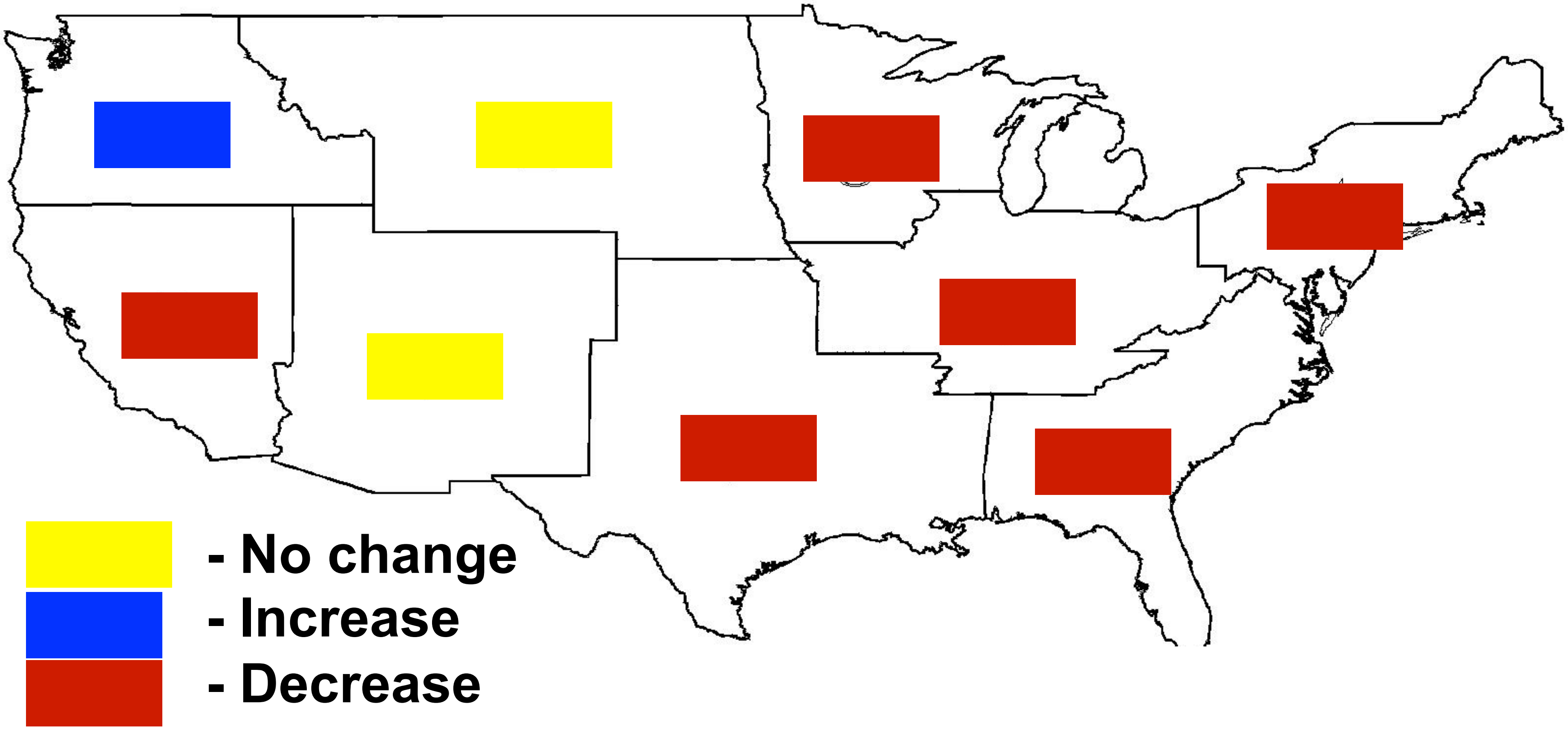
Summer frequency of rainy days over Asian Russia

Summer days with P>0.5 mm, %



(Sun and Groisman 2000, updated)

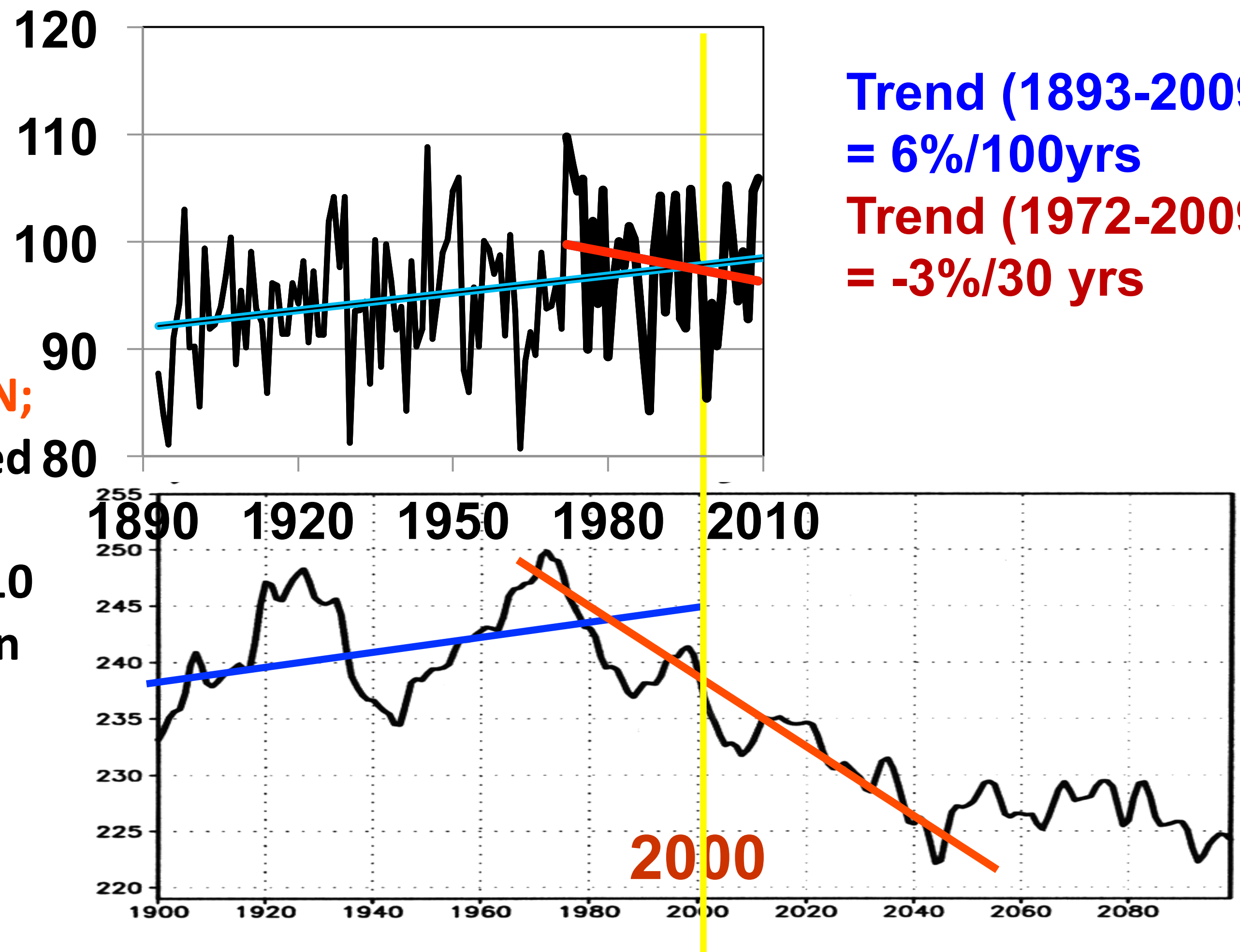
Changes of the fraction of moderately heavy precipitation (from 13 to 25 mm) with time, past three decades versus previous period



Fraction of "moderately intense" precipitation within the intense precipitation spectra is decreasing over most of the contiguous U.S.

Frequency of rainy days over the northeastern quadrant of the contiguous United States (*both show a decrease during the past 30 years*).

- **Observations** (Northeast and Midwest regions) for 1893-2009.
- **ECHAM4 (35N-45N; 75W-85W;** adapted from Semenov & Bengtsson 2002) 10 year running mean values for 1900-2090.



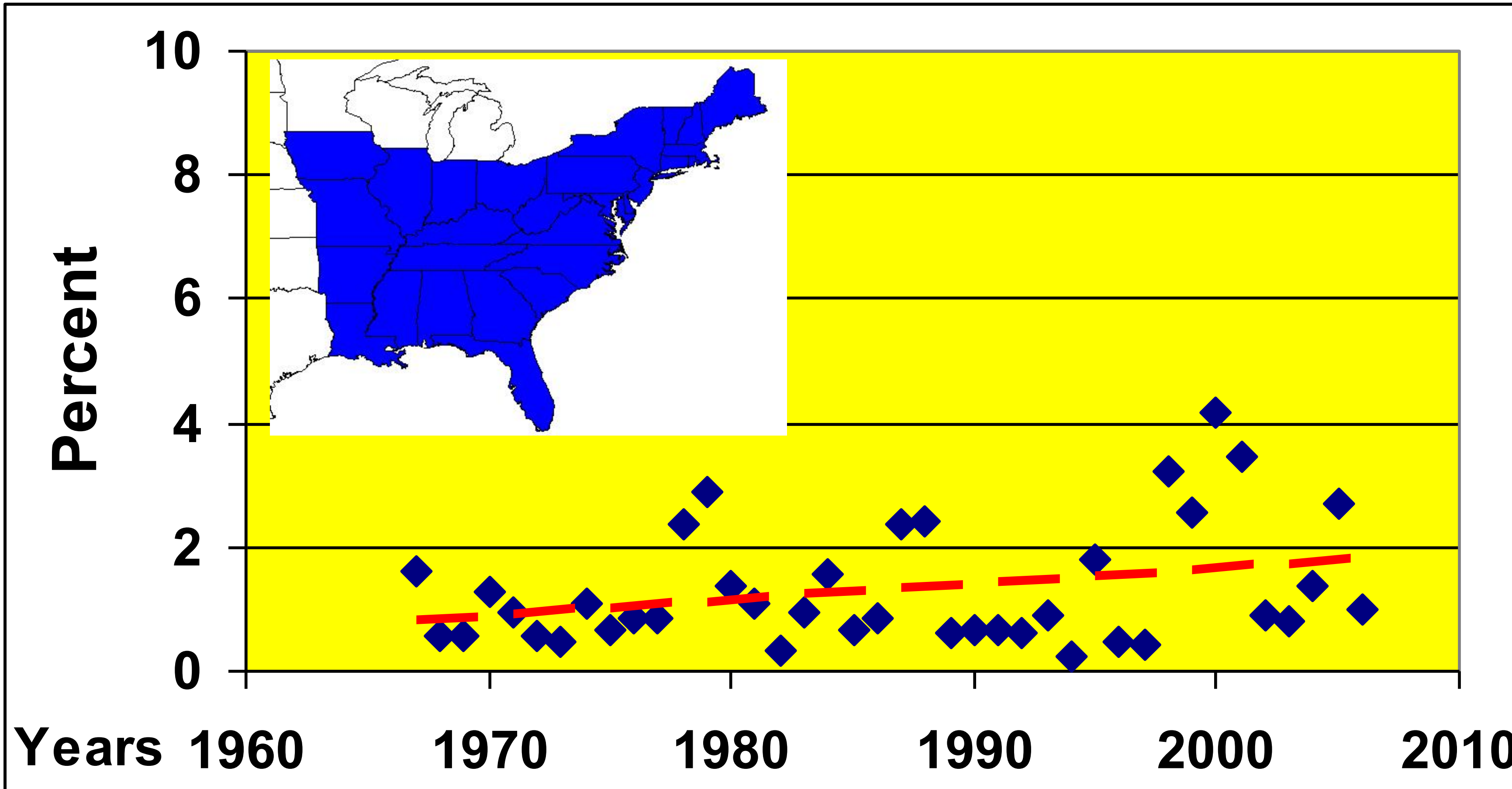
Trend (1893-2009) = 6%/100yrs

Trend (1972-2009) = -3%/30 yrs

(Groisman et al. 2005 updated)

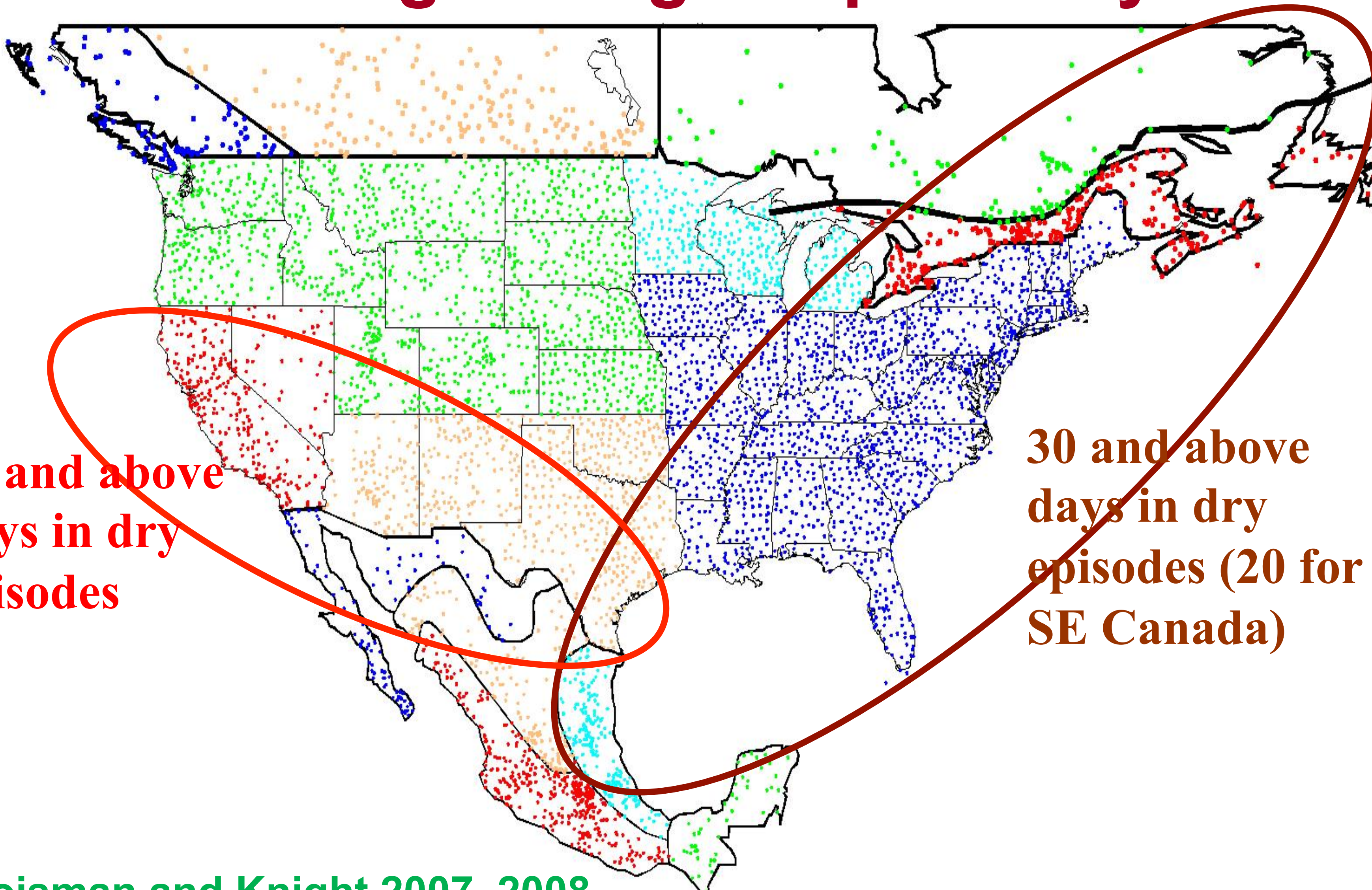
Dry episodes

Fraction of the dry day episodes with 1-month or more length during the warm season area-averaged over the Eastern United States

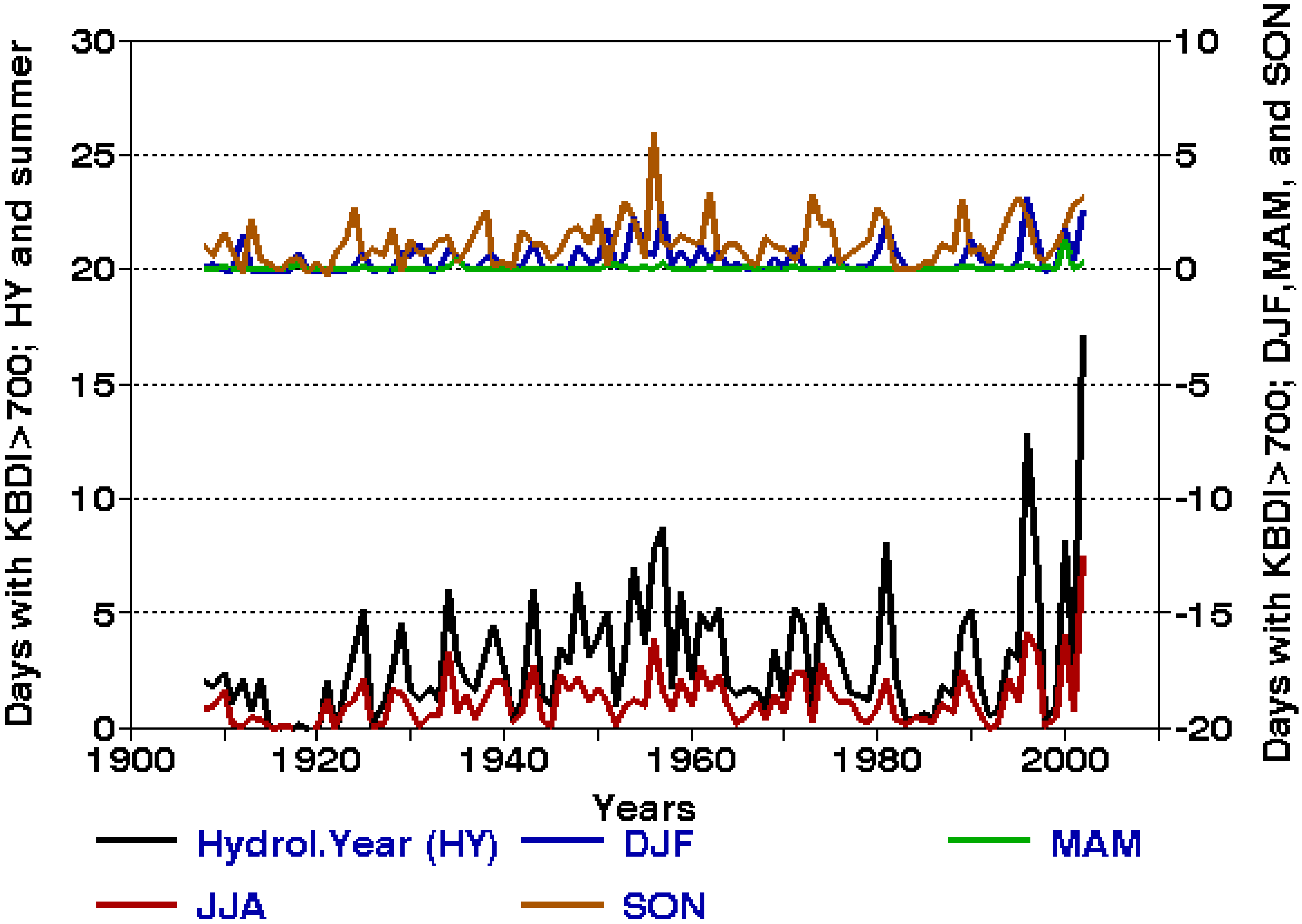


Red dashed line: linear trend (1.0 % per 40 years)

Regions where dry episode frequency is increasing during the past 40 years



Groisman and Knight 2007, 2008



Annual and seasonal number of days with regional Keetch-Byram Drought Index (KBDI) above 700 (highest drought danger) over four states in Southwestern United States (AZ, UT, NM, CO).

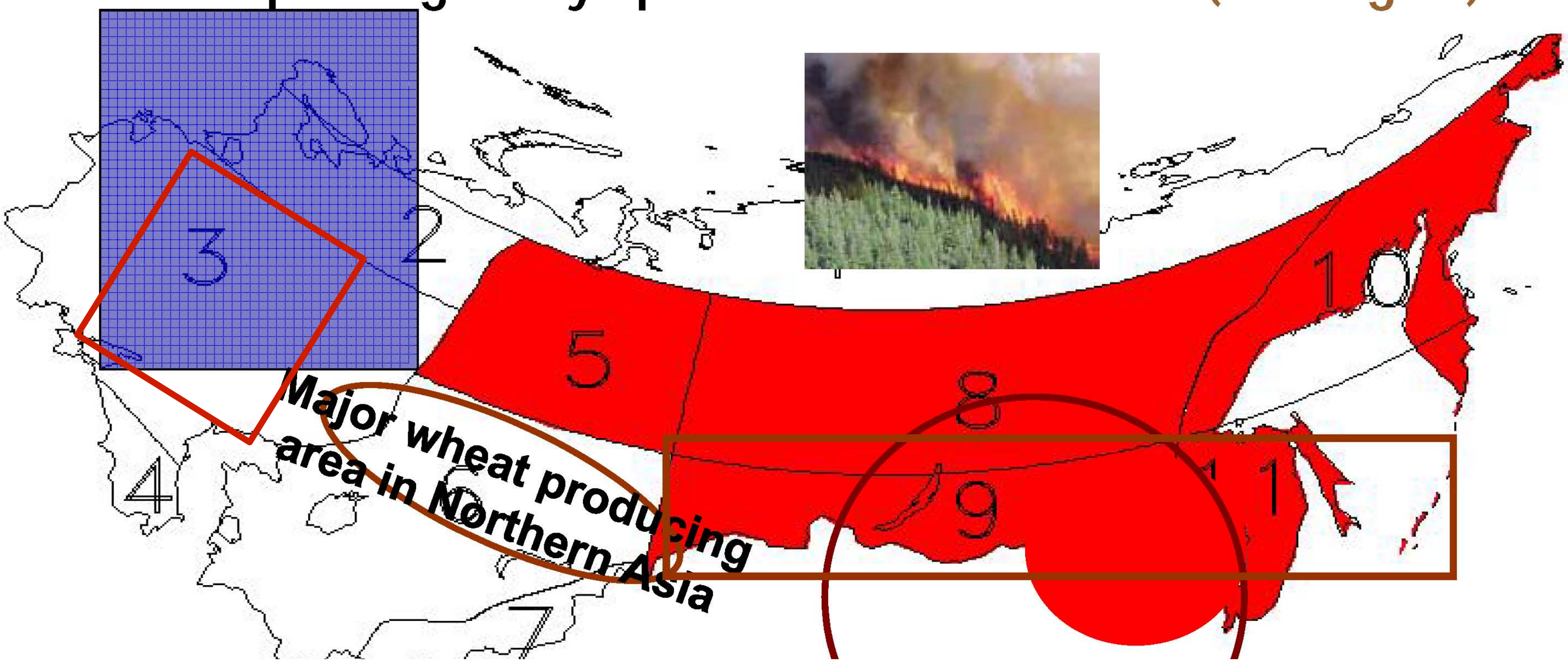
KBDI is an index of potential fire danger.

Linear trends of all time series except MAM are statistically significant at the 0.05 level.

Figure 18c. from Groisman et al. 2004 (*J. Hydrometeorol.)*

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

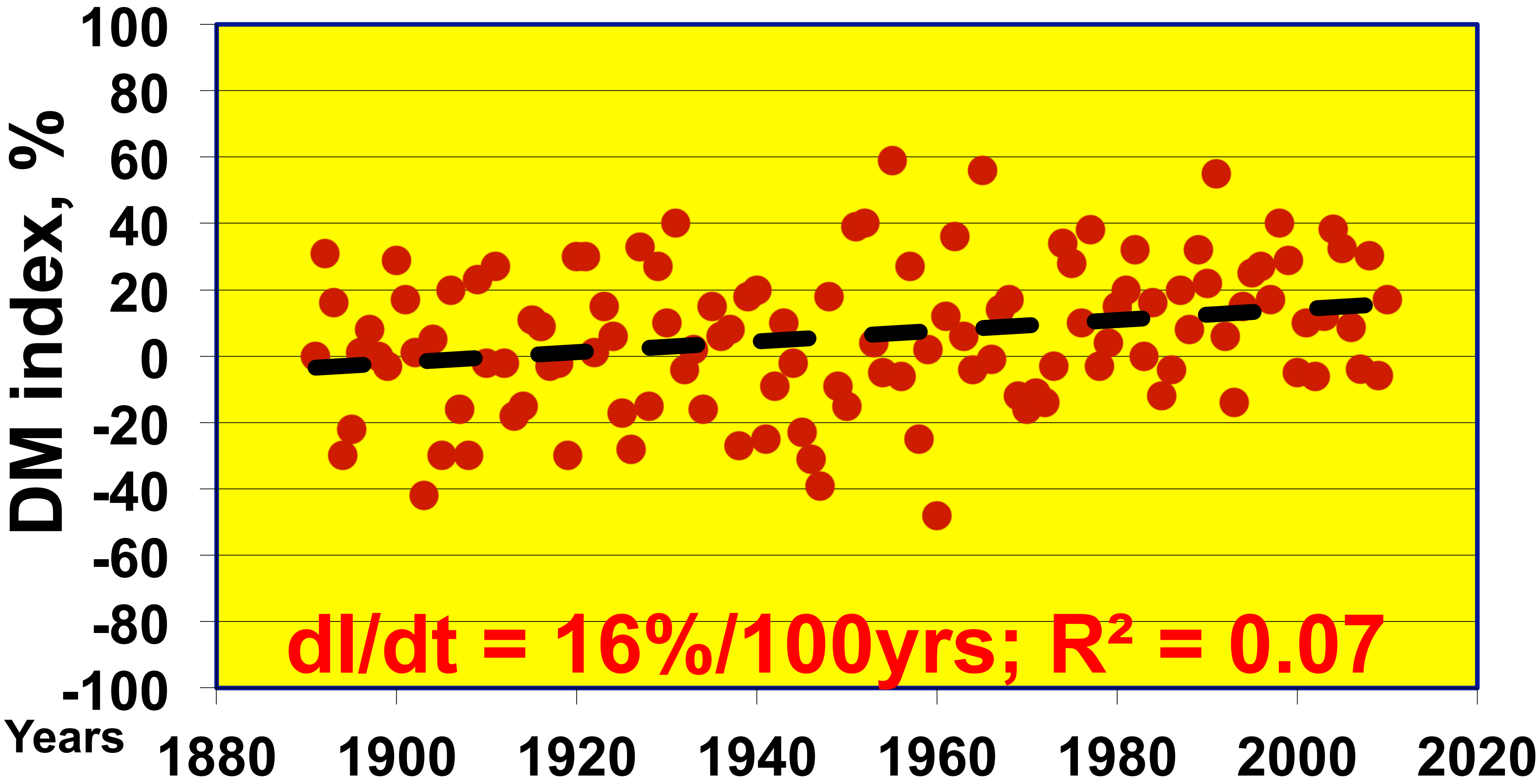
Regions with more humid conditions (blue), regions where potential forest fire danger has increased in the 20th century (red), the region where agricultural droughts have increased (circled), and the region where prolonged dry episodes have increased (rectangled).



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

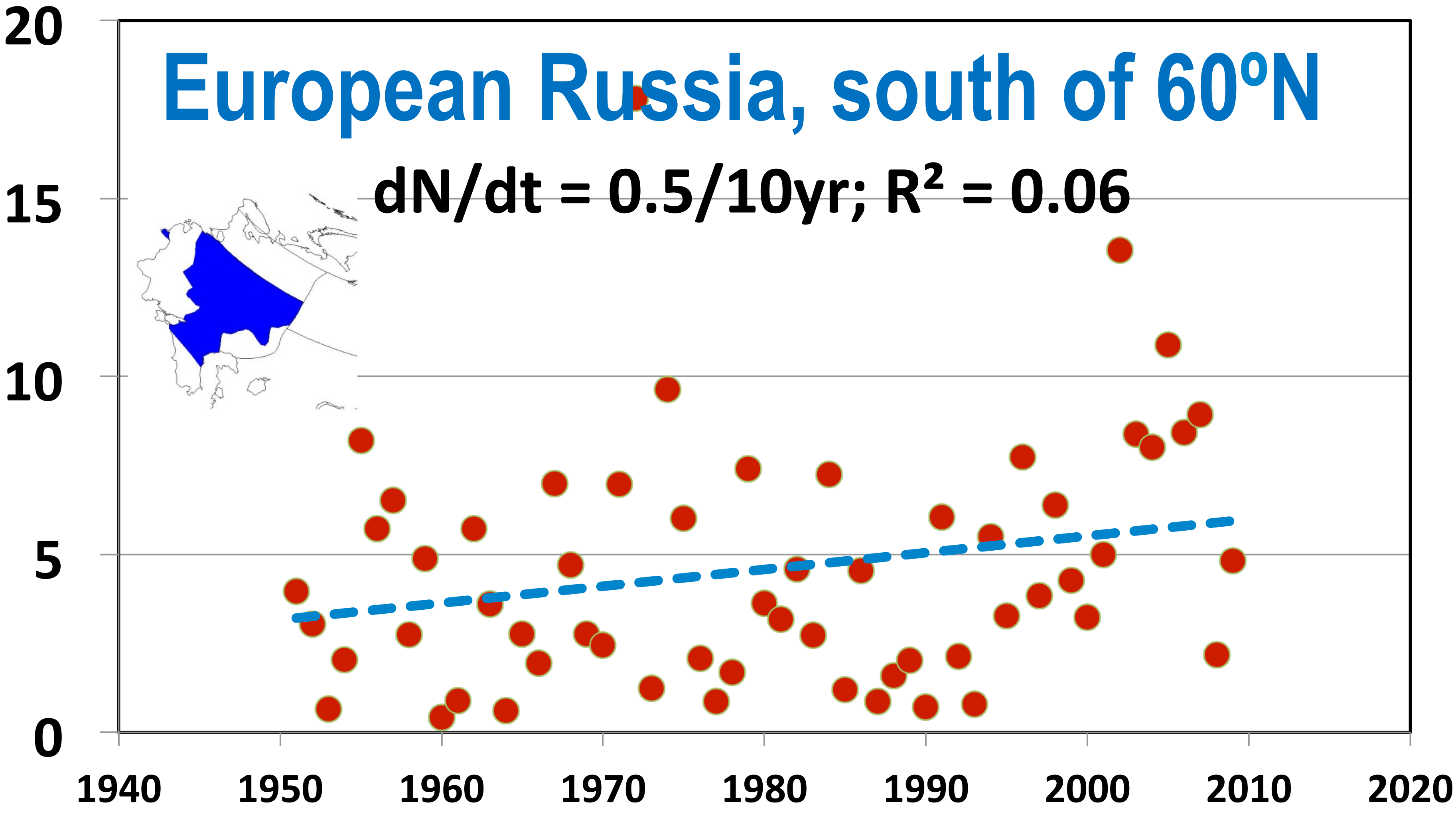
Agricultural regions of West Siberia and Northern Kazakhstan. May – July Drought Index.

Meshcherskaya and Blazhevich, 1997, updated to 2010

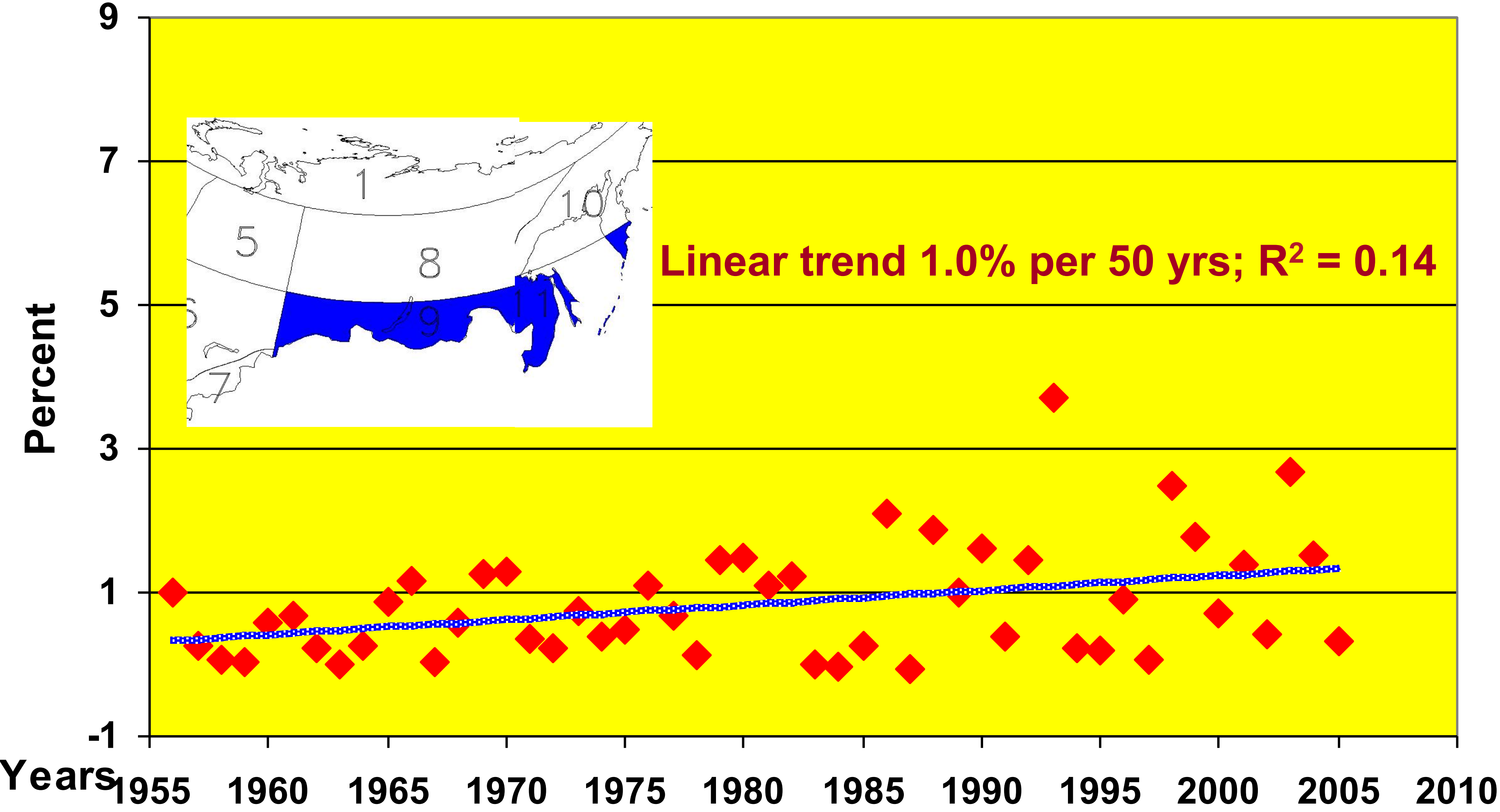


Areas with excessively dry conditions minus areas with excessively wet conditions, (% of total area)

Dry episodes above 30 days during the warm season, 1950-2009

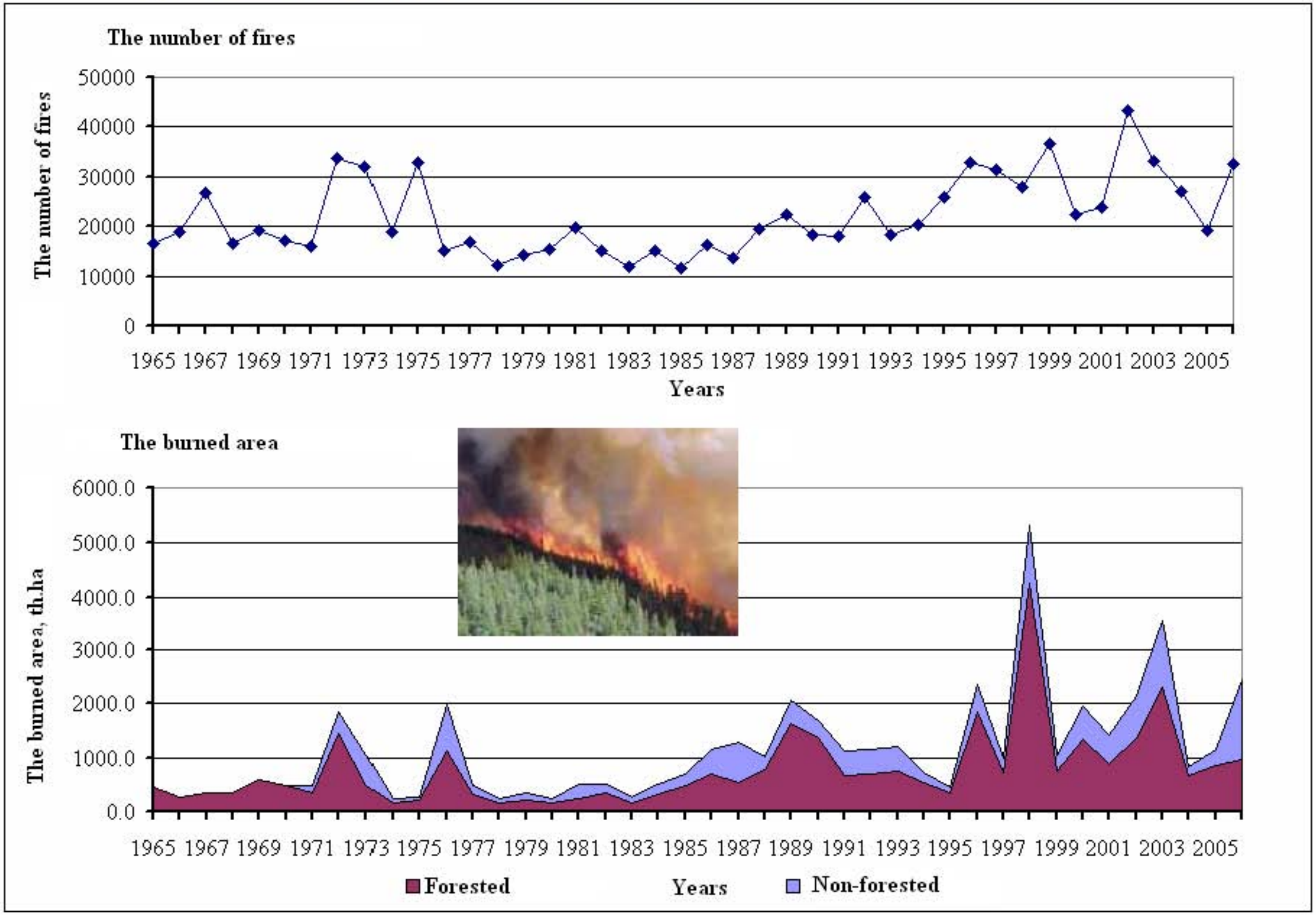


Dry episodes above 30 days during the warm season



Russia east of 85°E, south of 55°N

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

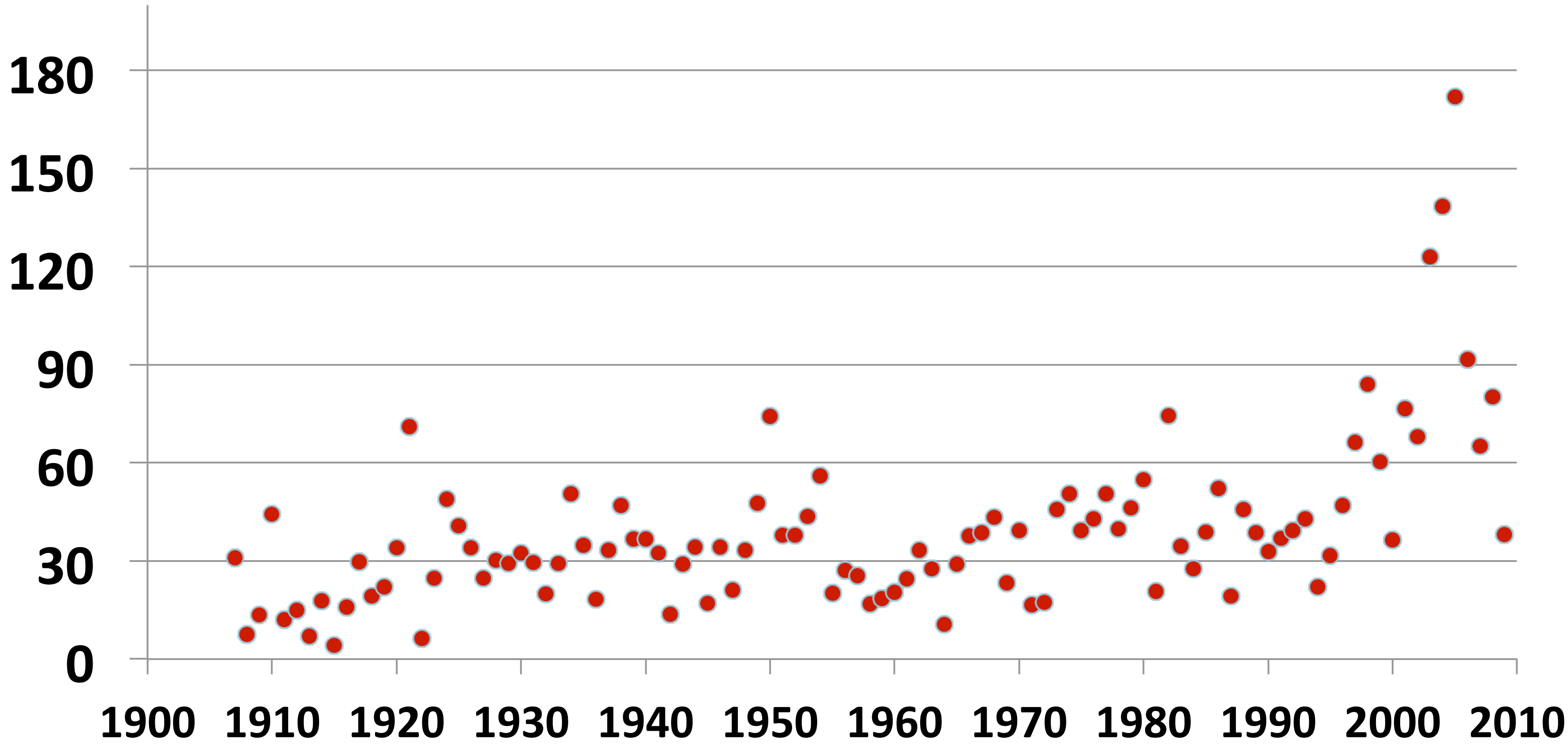


Korovin and Zukkert 2003, updated

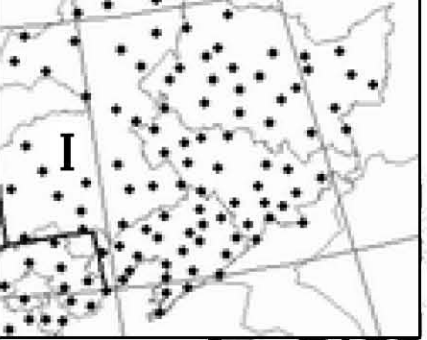
Potential Fire Danger Increase

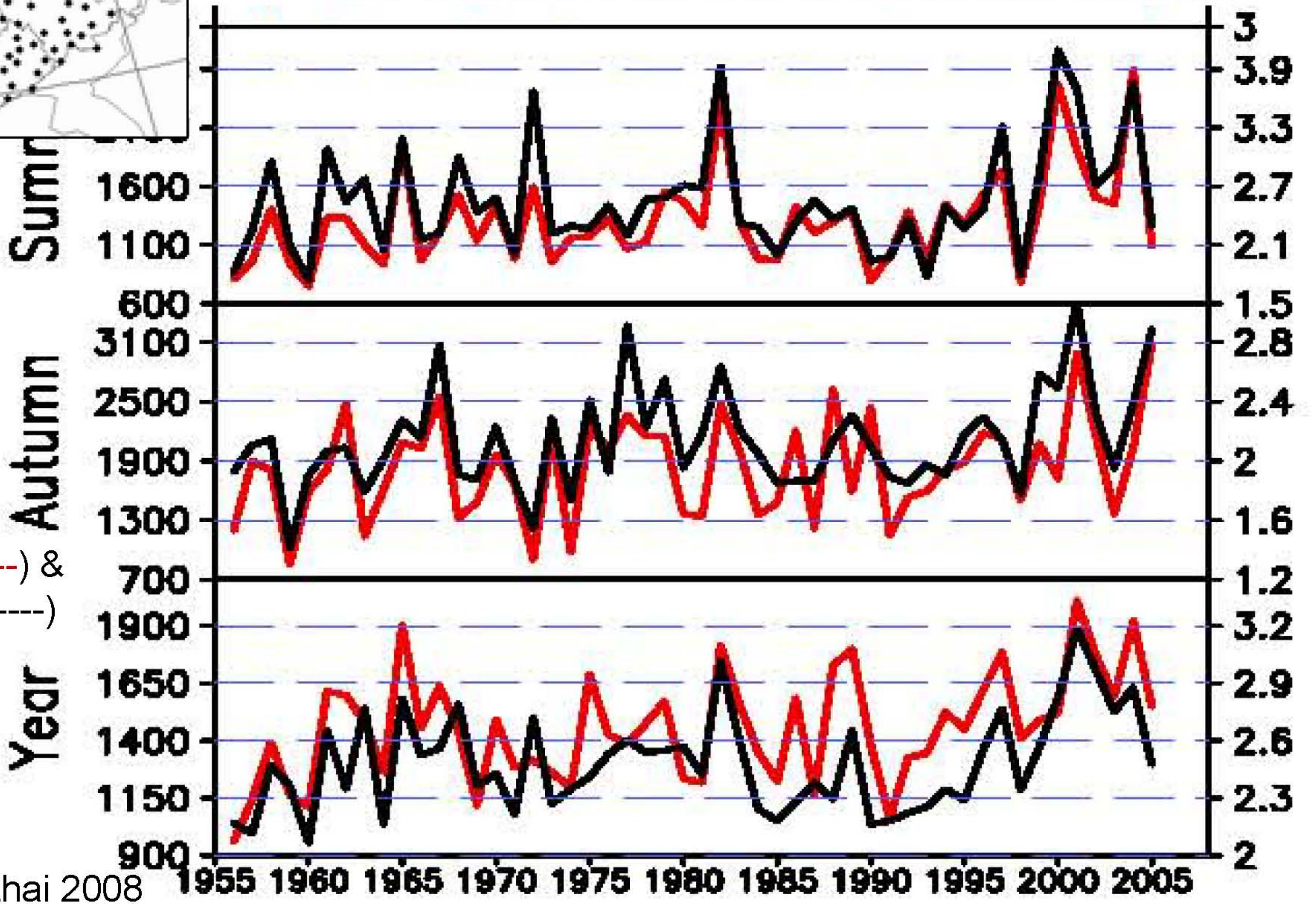
Annual number of days with KBDI > upper 10%-ile

Russian Far East south of 55°N



Seasonal and annual changes in forest fire indices in northeastern China





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

Niu & Zhai 2008

Summary of findings

- An observational evidence of changes in precipitation spectra over **Northern Extratropics** was quantified for the past 40 to 50 years with focus on extremes on both sides of daily (for the United States, daily and hourly) rainfall distribution in the warm season.
- A notable change in rainfall rate distribution was found. Increase in heavy rainfall frequencies while mean precipitation grows slower or decreases is accompanied with **increased frequencies of no-rain periods over most of North America south of 55°N and Northern Eurasia south of 60°N**. **These changes are a new phenomenon and were observed only for the past several decades.**

Atmospheric pressure changes in the past decades over the North Atlantic and Europe

Changes in position of two major characteristics that control atmospheric circulation over North Atlantic with global warming by 0.5°C

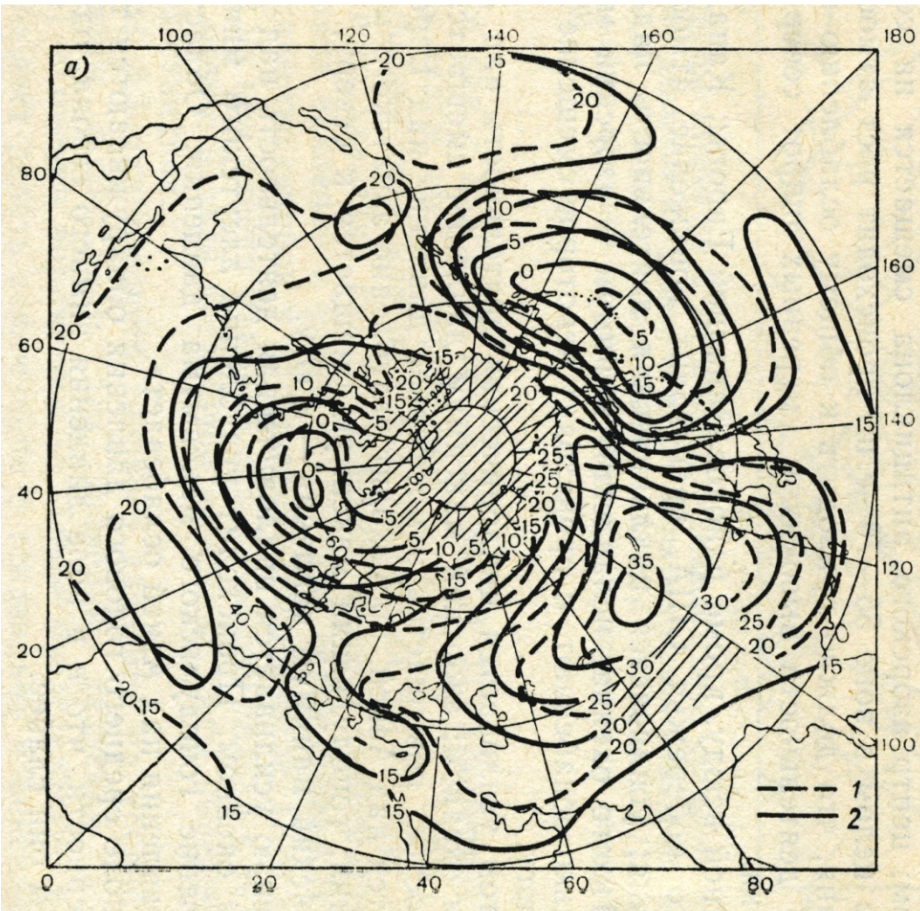
(as projected by Groisman 1983)

Winter

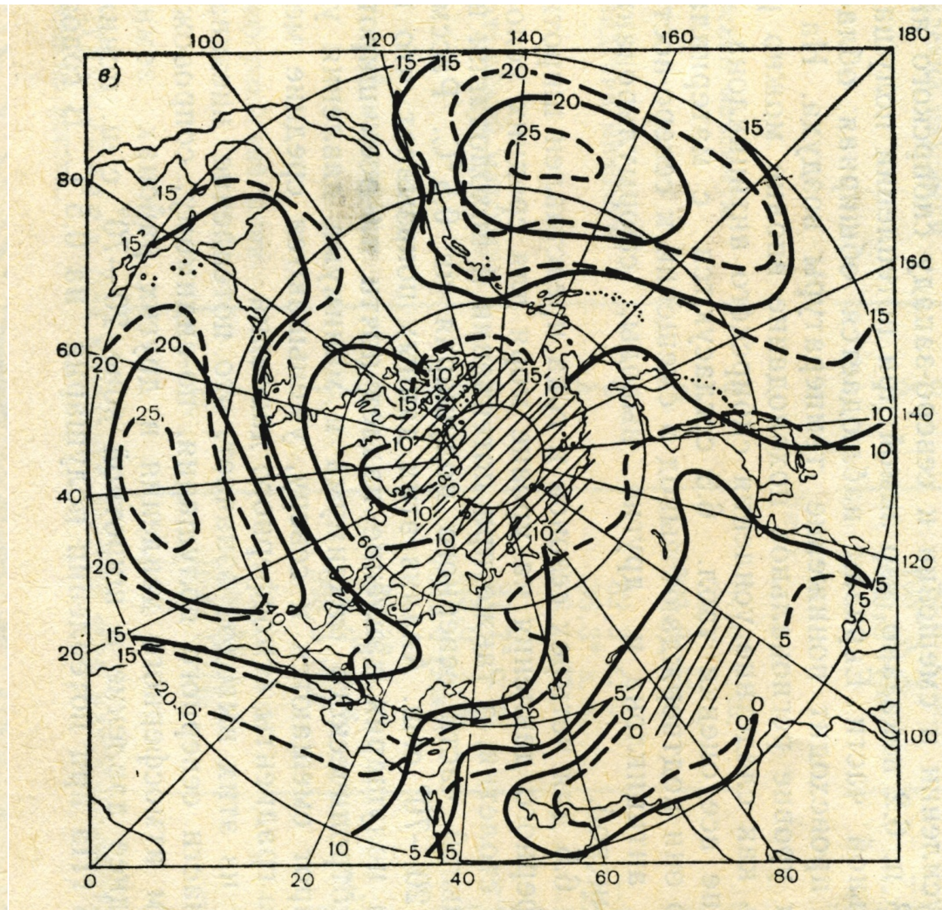
Summer

SSP pattern (hPa-1000) with the Hemispheric warming (solid) and cooling (dashed lines) by 0.5°C

Winter

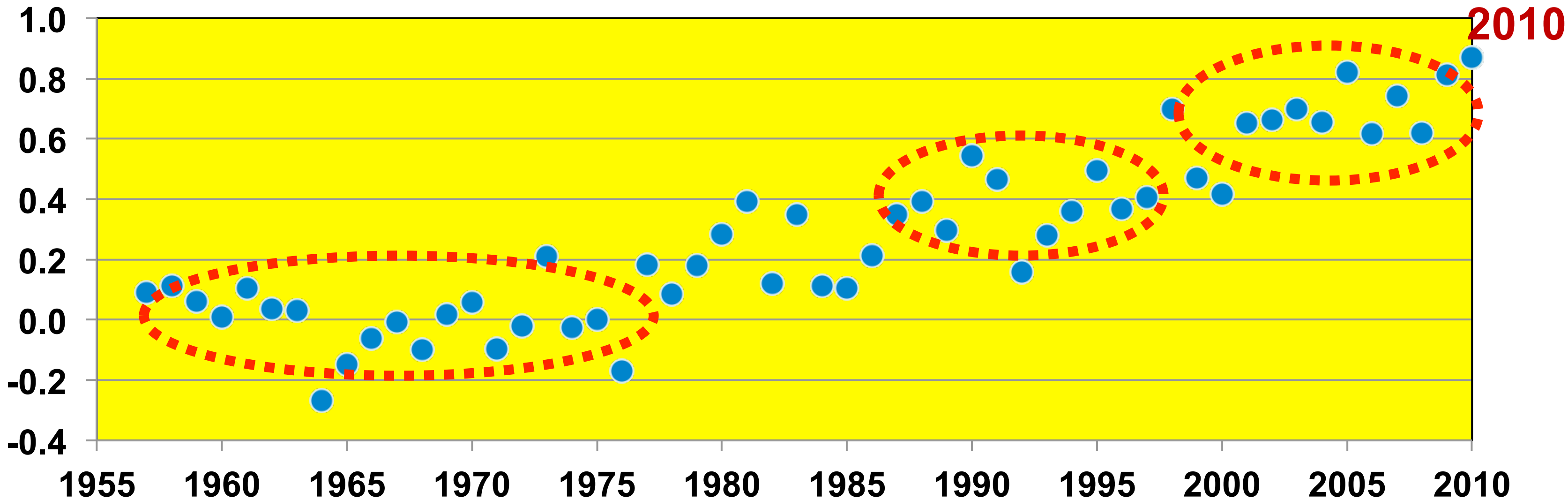


Summer

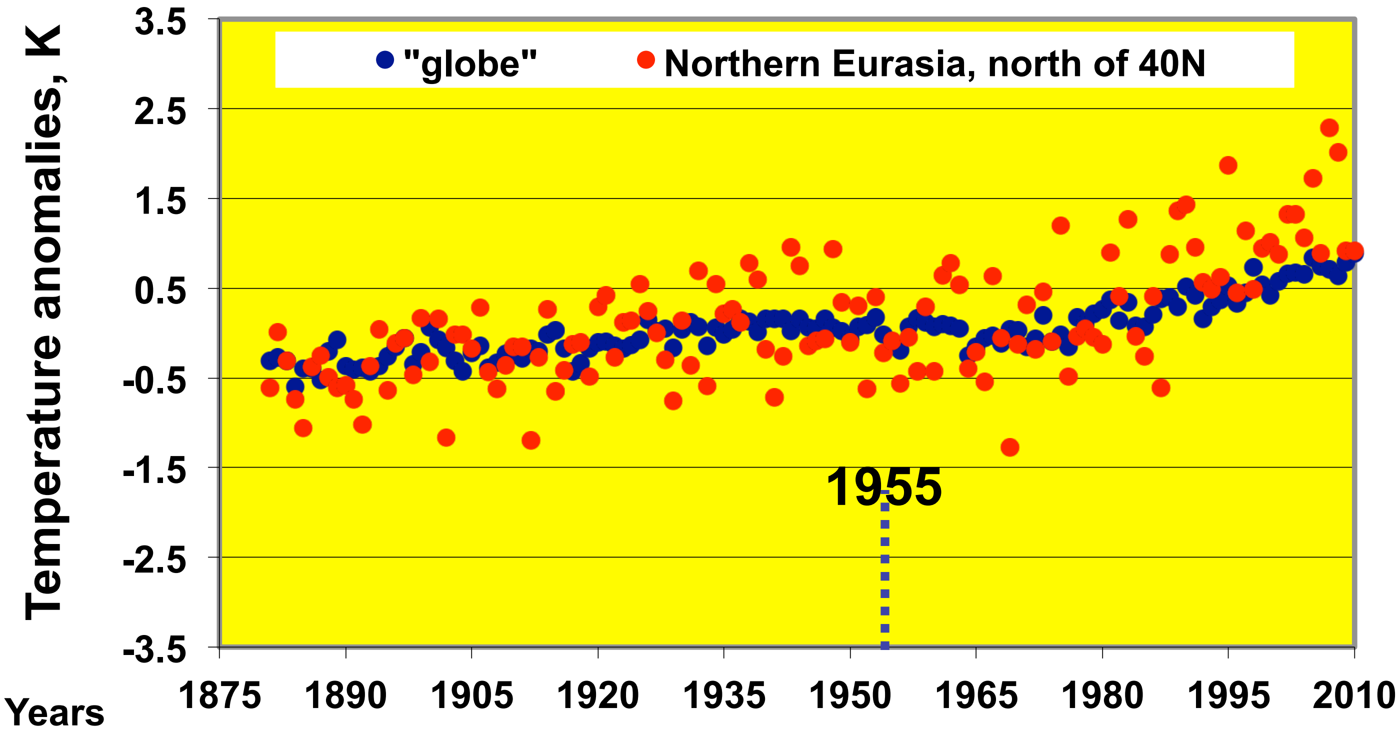


Vinnikov and Kovyneva (1983)

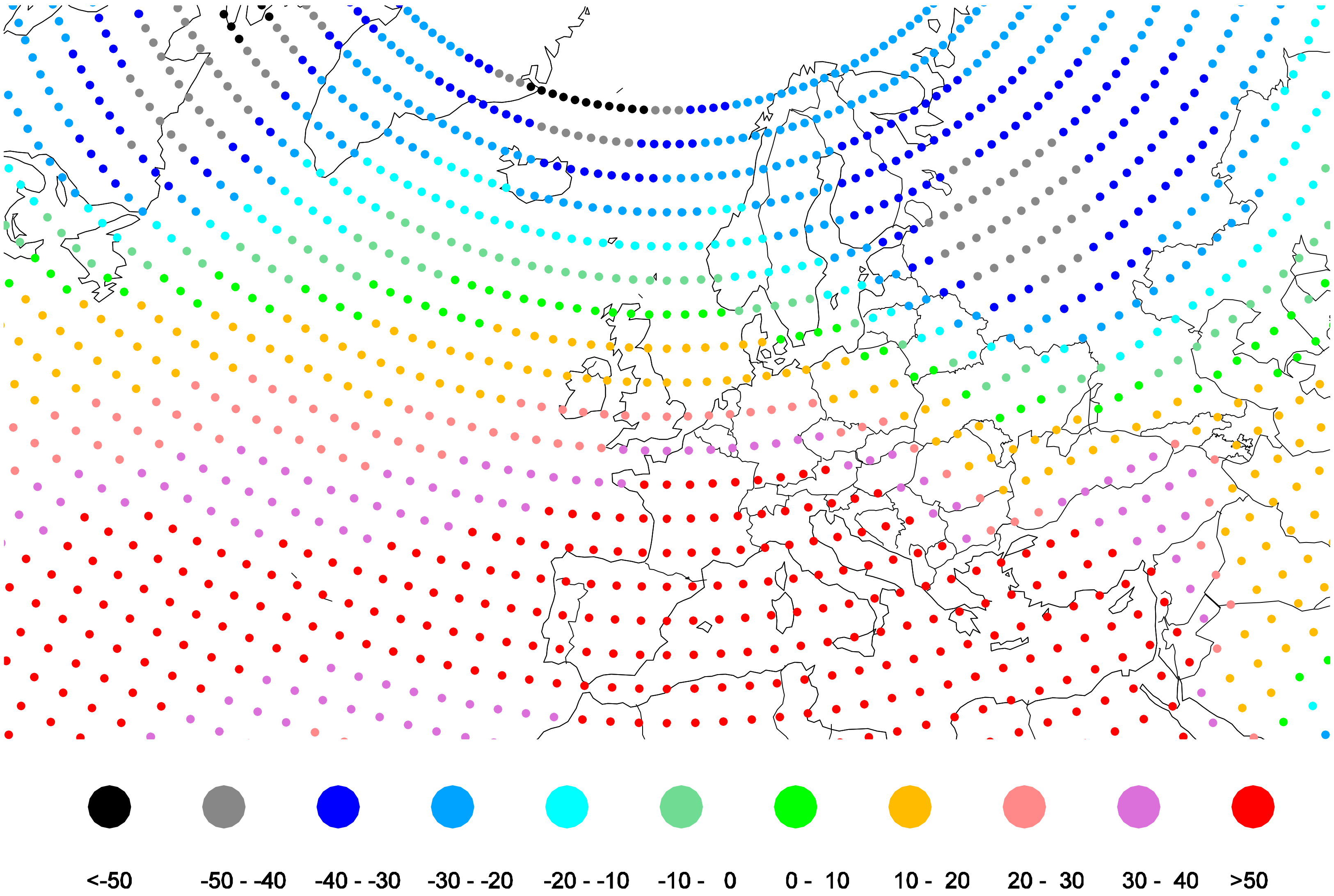
Global Surface Air Temperature Anomalies, °C



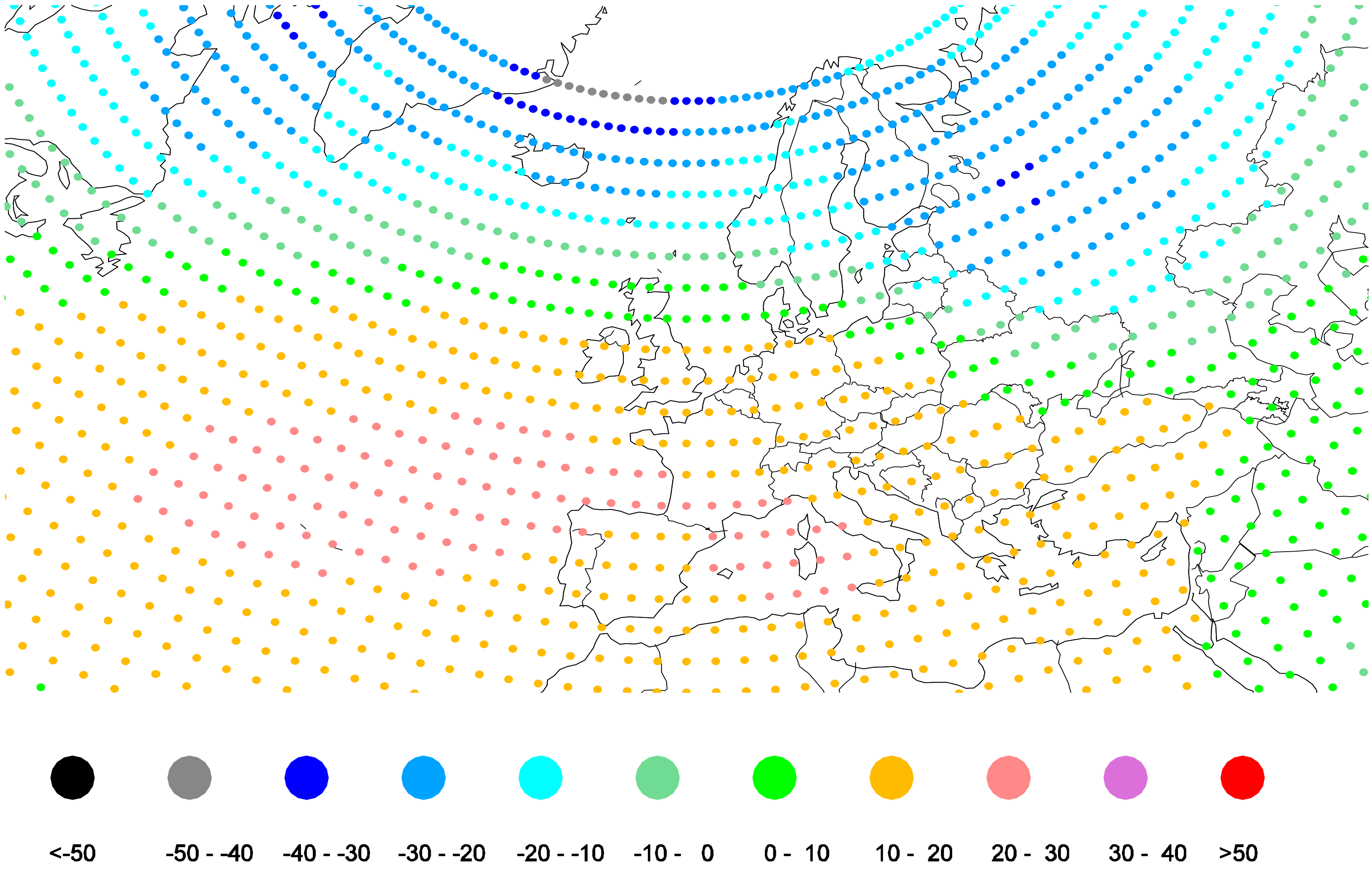
Rates of increase of annual temperature for the "globe" (60°S to 90°N) and Northern Eurasia are 0.91 °C/ 130 yr and 1.5°C/ 130yr respectively. (Lugina *et al* 2007, updated).



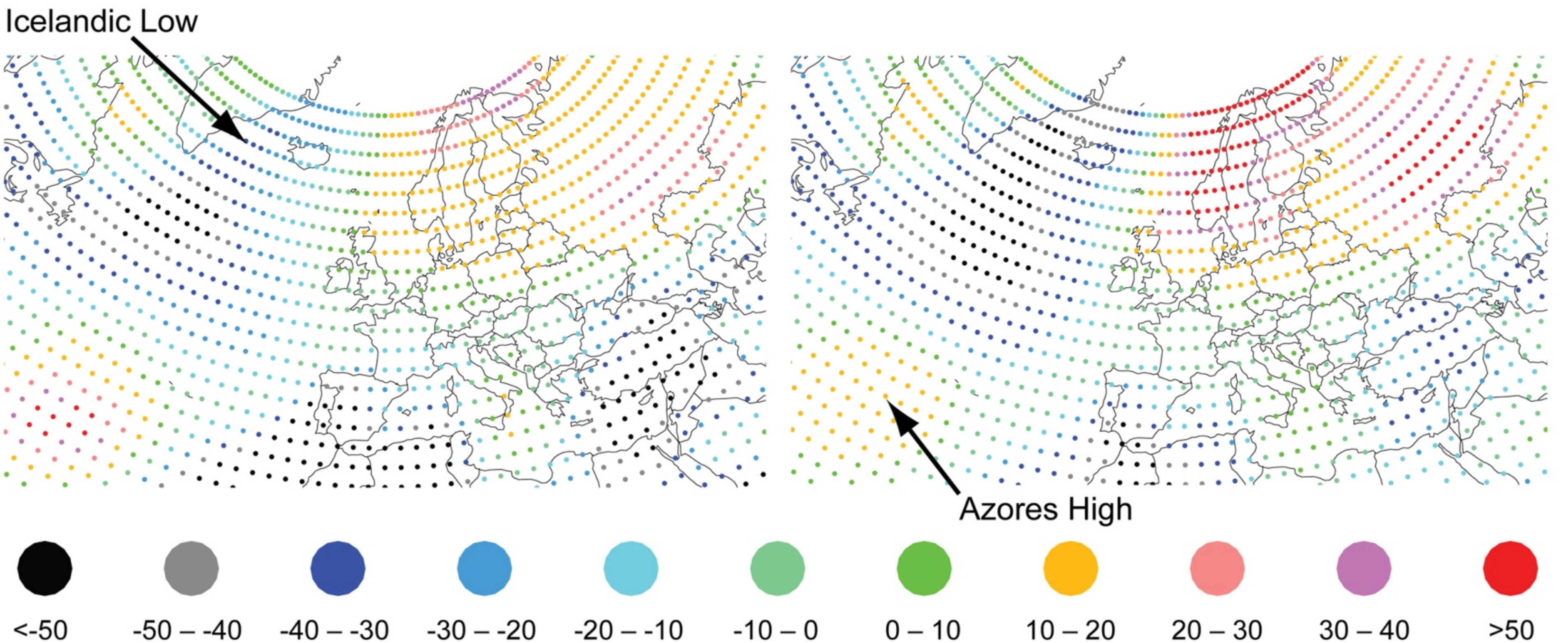
January Sea Level Pressure (SLP) changes in the last three decades compared to the previous three decades expressed in percent of its monthly standard deviation



January Sea Level Pressure (SLP) changes in the last three decades compared to the previous three decades expressed in 10 × hPa.

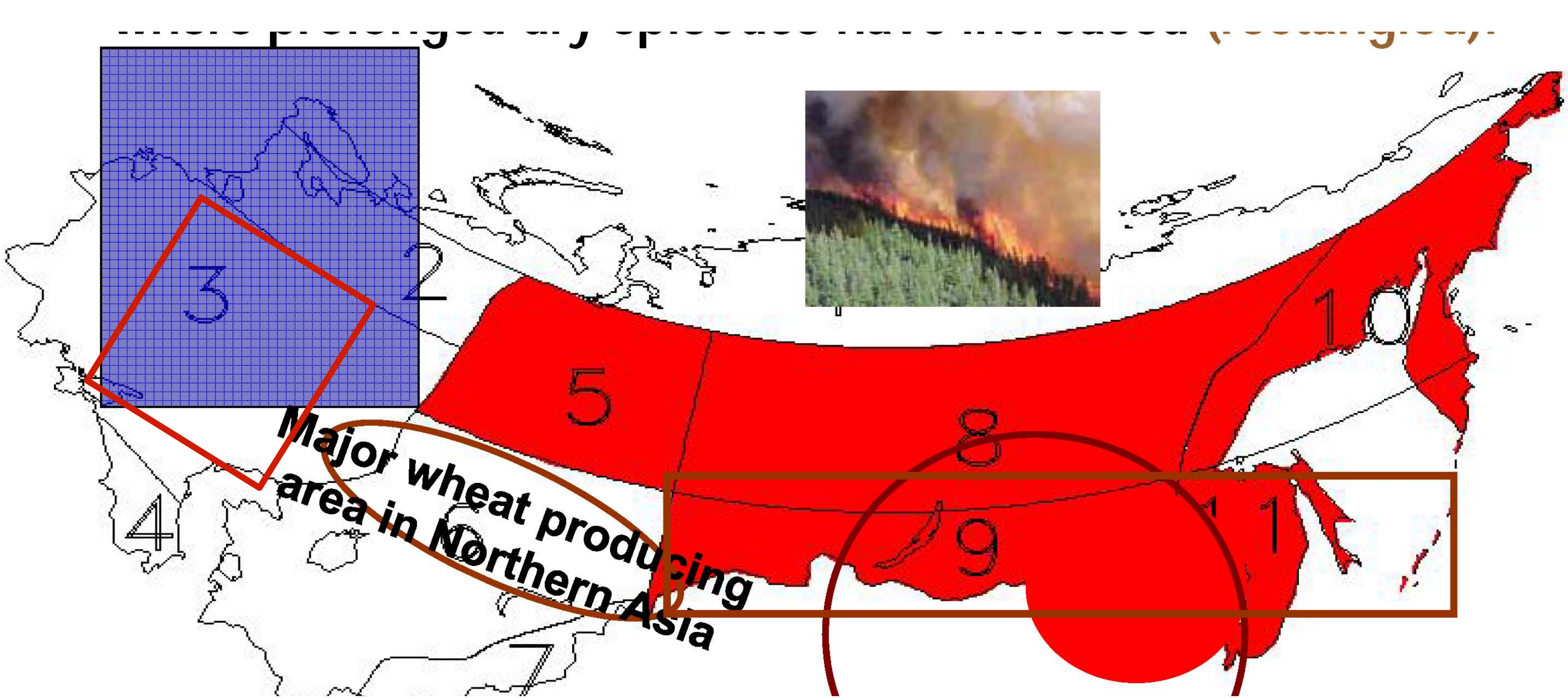


July Sea Level Pressure (SLP) changes in the last three decades compared to the previous three decades expressed in percent of its monthly standard deviation (left) and in 50 × hPa (right).

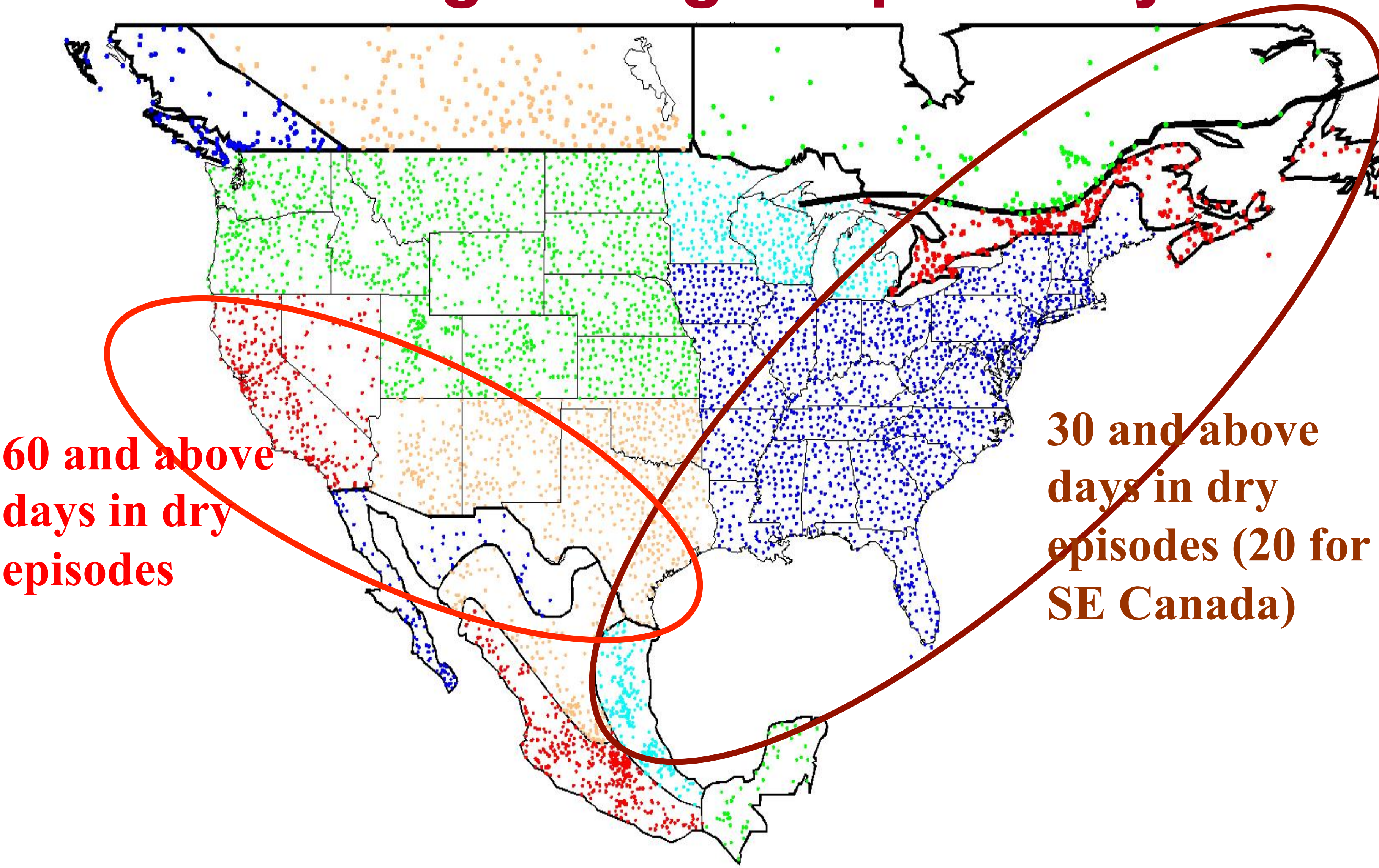


Data of the 20th Century Reanalysis Project, Compo et al. 2011

For the past 50 years, characteristics of fire weather, agricultural droughts, and prolonged no-rain periods over northern Asia and, to some extent, over European Russia signal about increases in pprobability of dangerously dry summers



Regions where dry episode frequency is increasing during the past 40 years



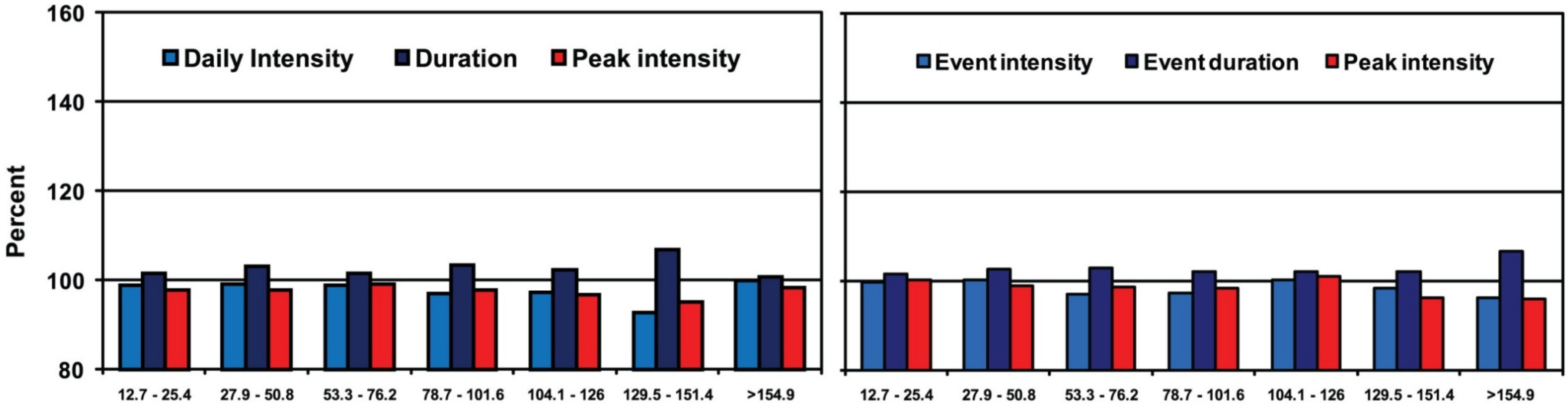
What to watch with global warming in the extratropics?

- Distribution of dry spells within the warm season
- Duration of the warm season /e.g., 3 vs 4 months/
- Atmospheric pattern associated with dry spells /T(0°N)-T(90°N); Blockings/
- Earlier spring onset and cold season SWE /by 1-2 weeks/
- In Eurasia, a closer look on the Arctic is needed / droughts to Russia comes with dry Arctic air/

THANK YOU!

Additional slides

Comparison of mean and peak intensity and duration of hourly precipitation for intense precipitation days (left) and multi-day intense precipitation events (right) over the Central U.S. for 1979-2009 and 1948-1978 periods sorted by day/ event intensities (in mm)



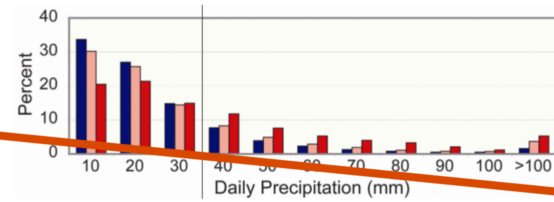
Estimates of precipitation characteristics for these 31-yr periods were averaged and their ratios (in percent per station) are shown

Changes in rainfall intensity

Why do we expect changes?

- *Climatology*
- *Models*
- *Models + Observations*

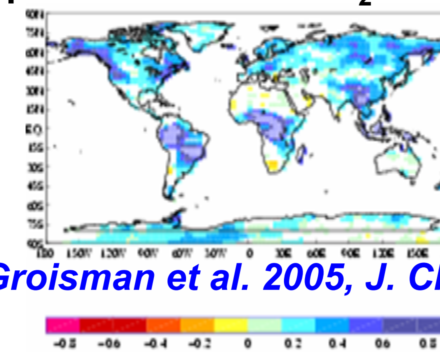
Higher temperatures => increase in precipitation intensity



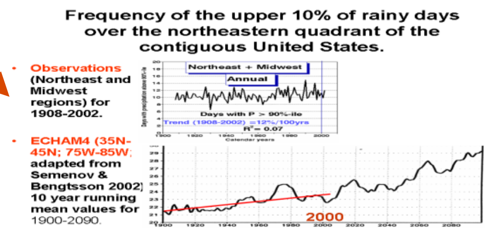
- Climatology of the intensity of daily precipitation in 10 mm/day categories for stations with the same mean seasonal precipitation (~230 mm) and different temperature regimes (<19°C, blue bars; between 19°C and 29°C, pink bars; and > 29°C, red bars)

[Karl and Trenberth 2003, Science]

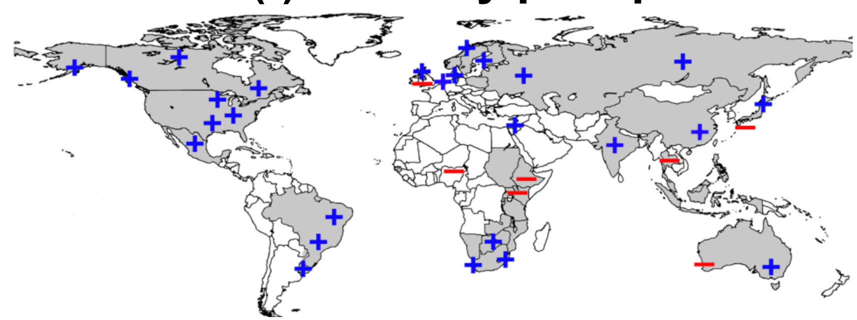
Projected changes in "very heavy" precipitation with the CO_2 doubling



Groisman et al. 2005, J. Climate

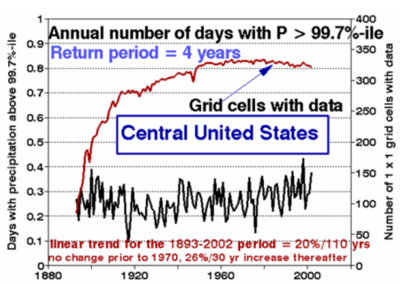


Regions with disproportional increase (+) and decrease (-) in heavy precipitation

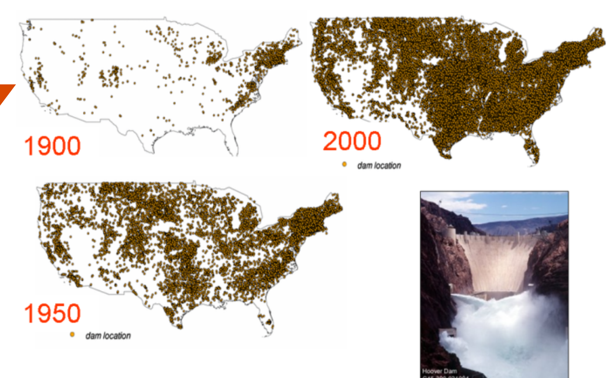


What have we already observed?

Regions with statistically significant annual increases in "very heavy" precipitation over the United States

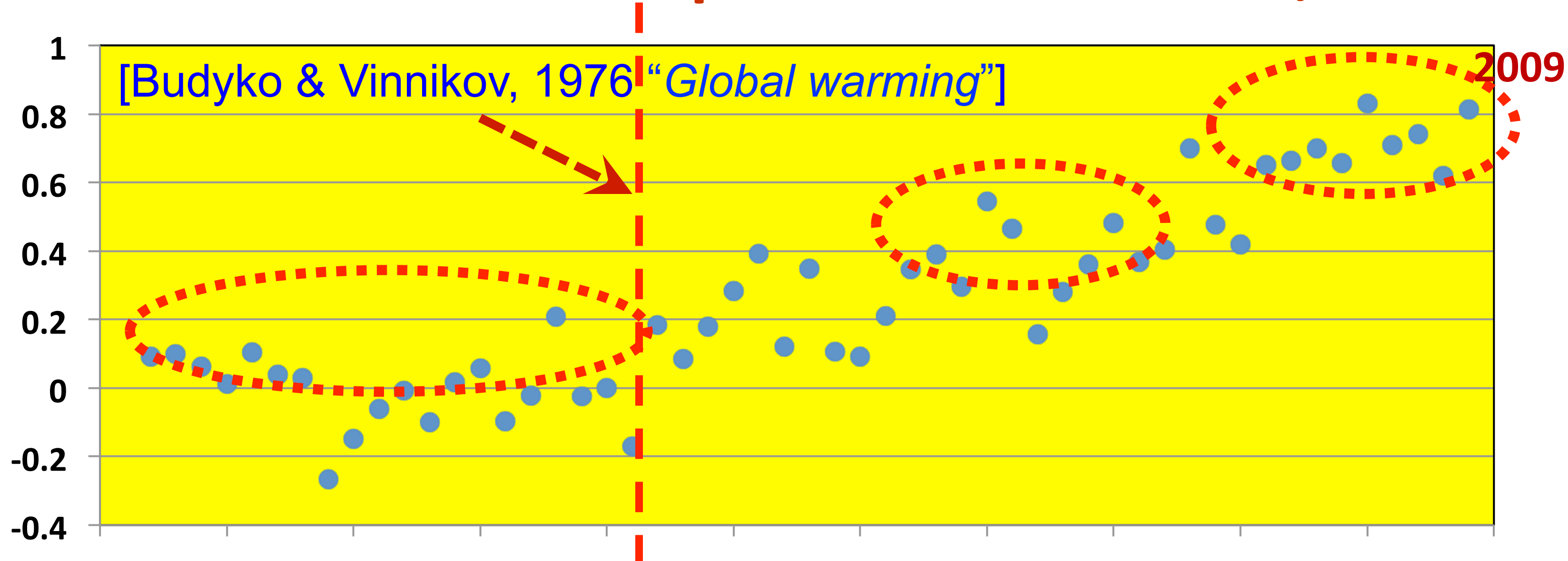


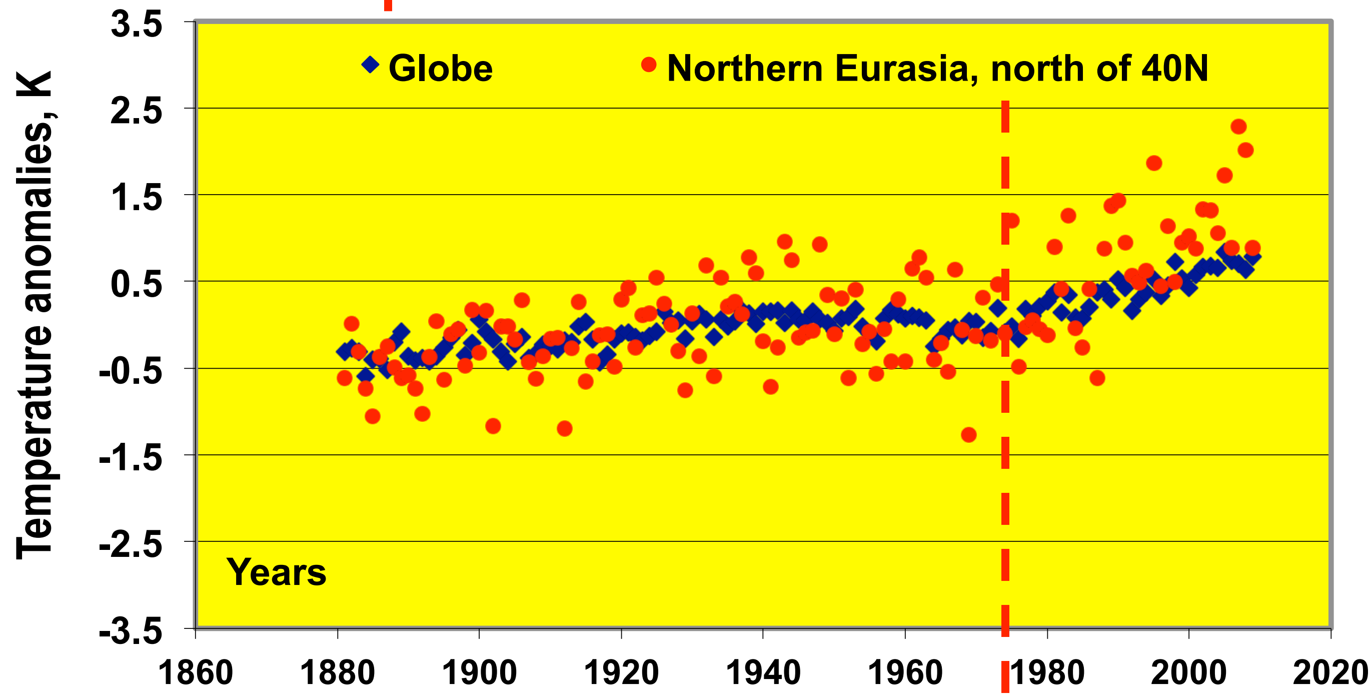
U.S. National Inventory of Dams (Vörösmarty 2004)



Why are changes in the rainfall intensity not so visible in changes in flood events?

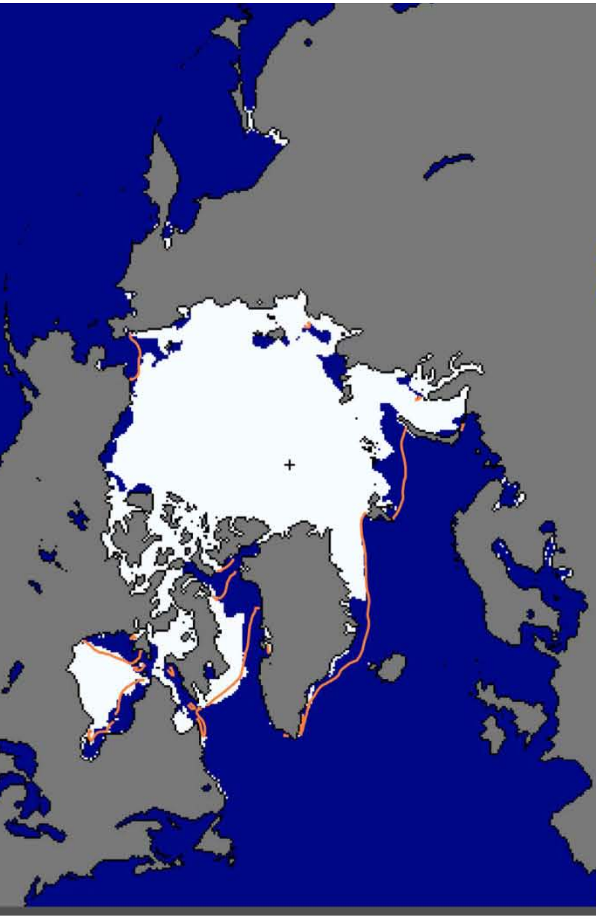
Global Surface Air Temperature Anomalies, °C





Rates of increase of annual temperature for the "globe" (60°S to 90°N) and Northern Eurasia are 0.86 °C/129 yr and 1.4 °C/129 yr respectively. (Lugina *et al* 2007, updated).

🡐 State on July 2, 2009; ---- median 1979-2000

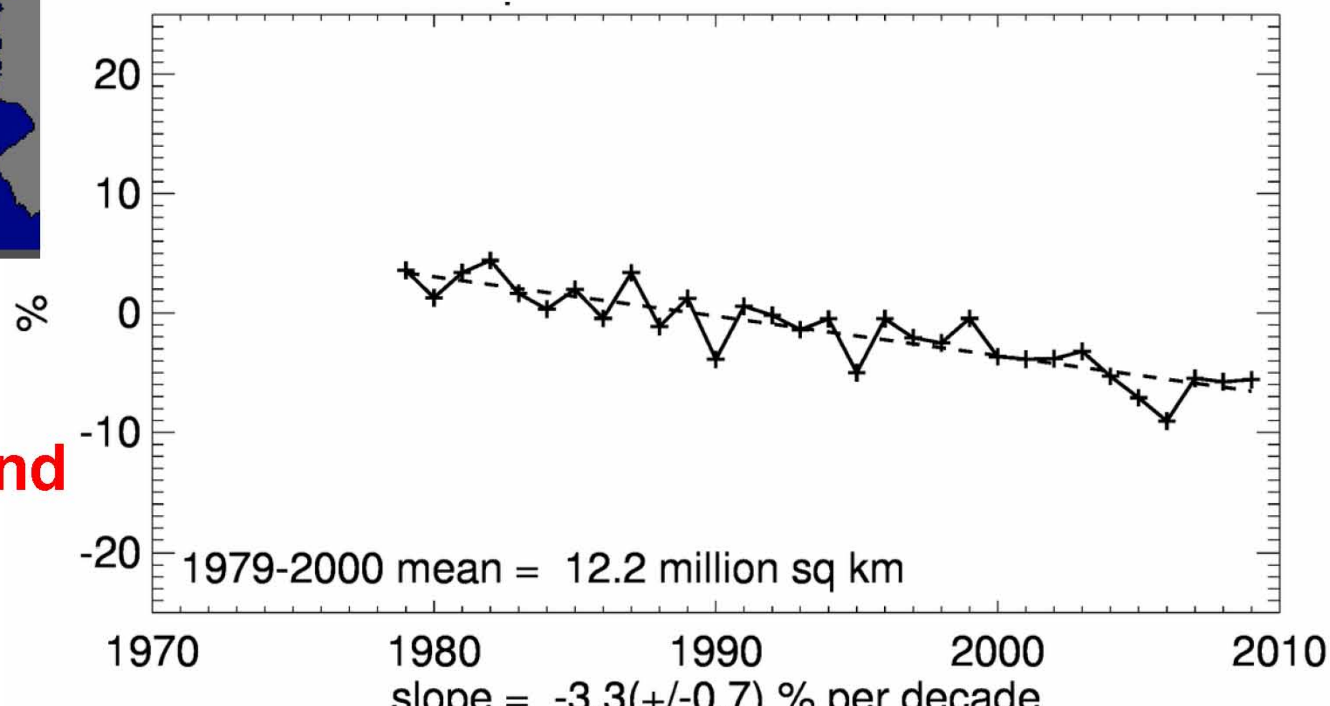


Northern Hemisphere Sea Ice Extent, 1979-2009

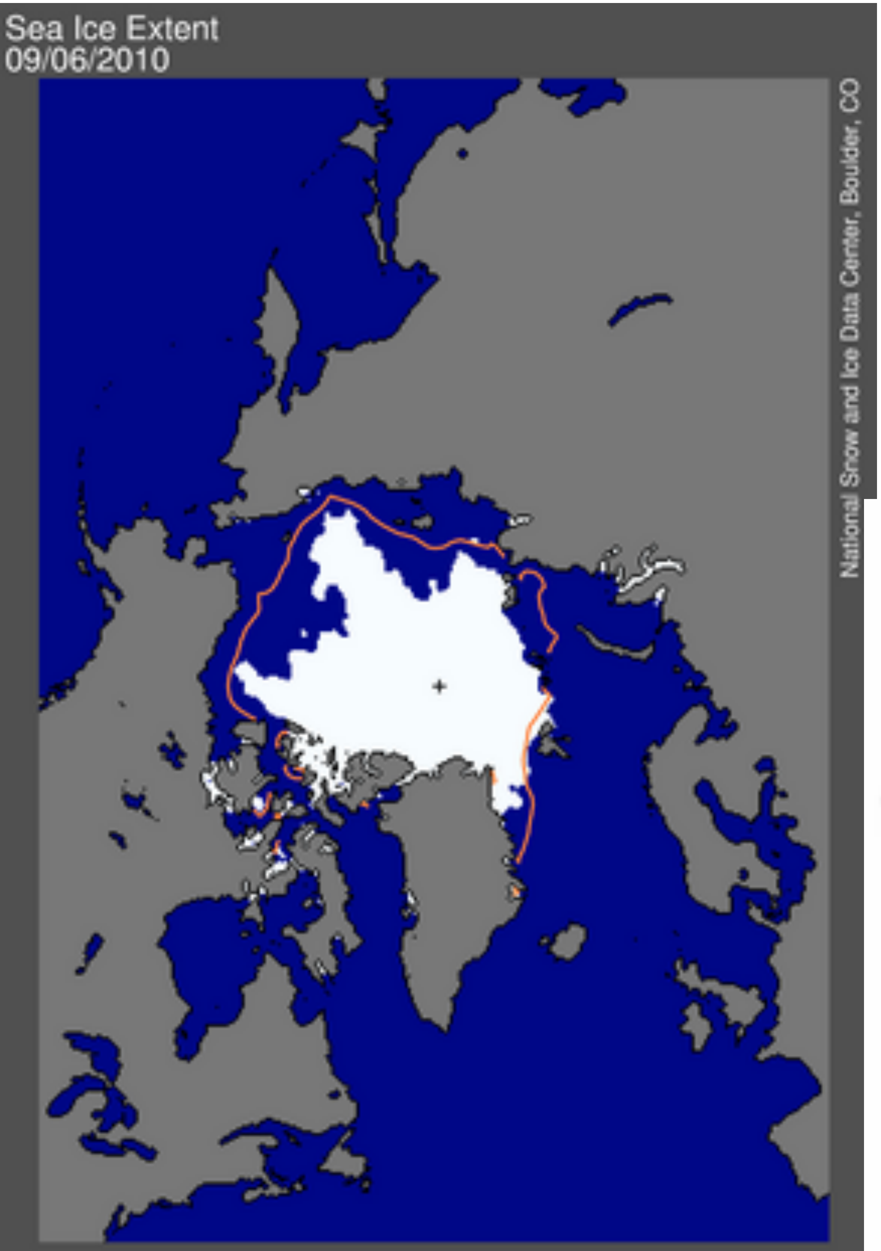
Available from the U.S. National Snow and Ice Data Center

http://www.nsidc.org/data/seaice_index/index.html

June time series and its linear trend ➔

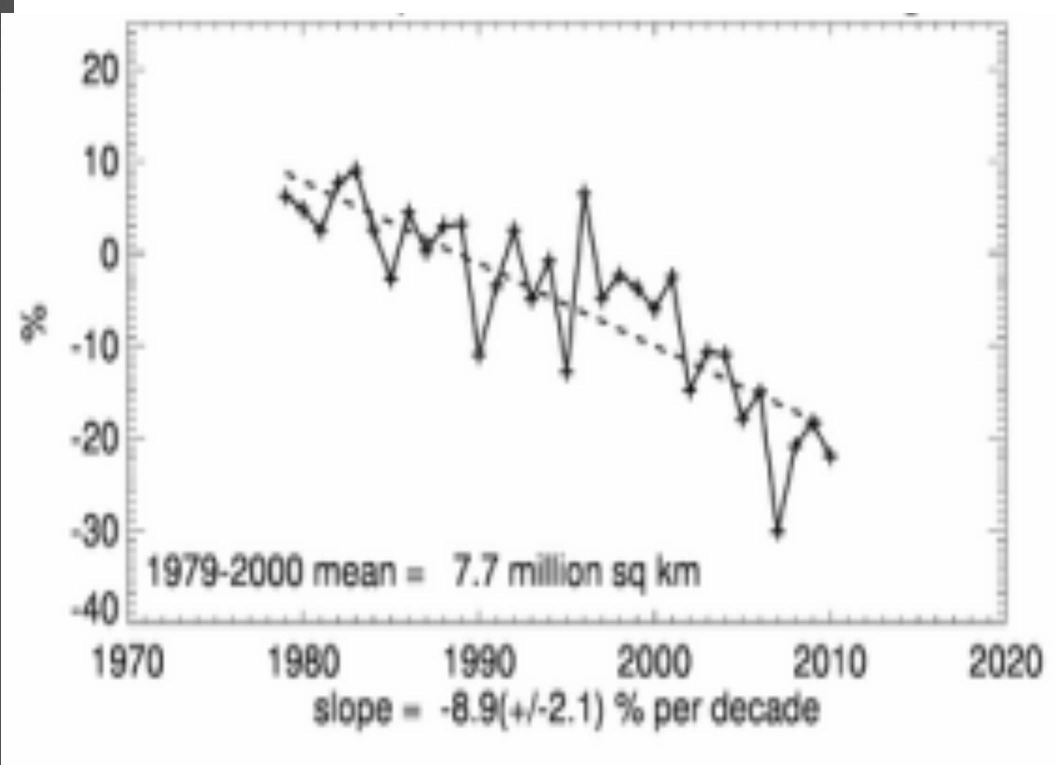


The same as above but “now”

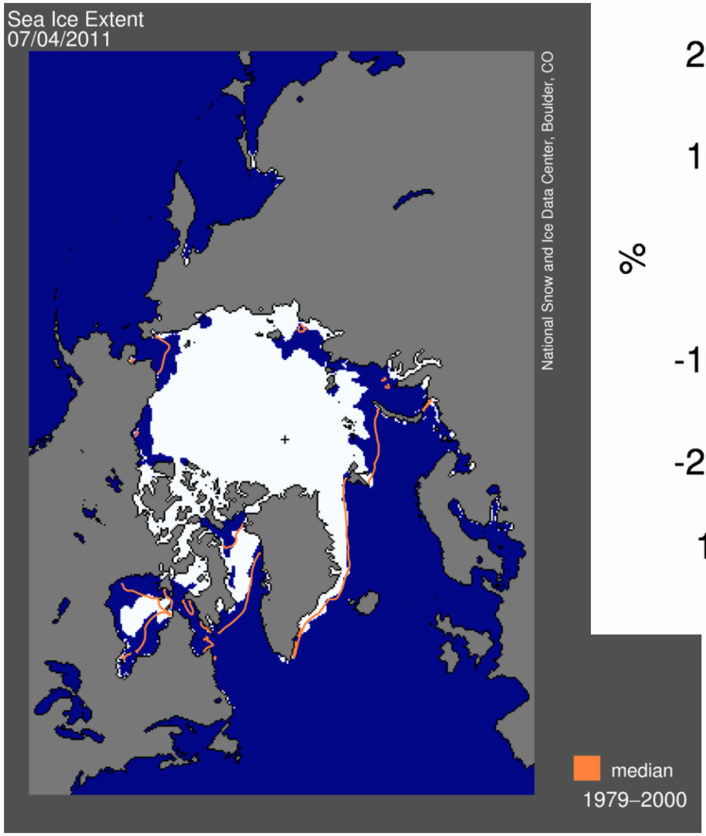


← As on Sept. 6, 2010

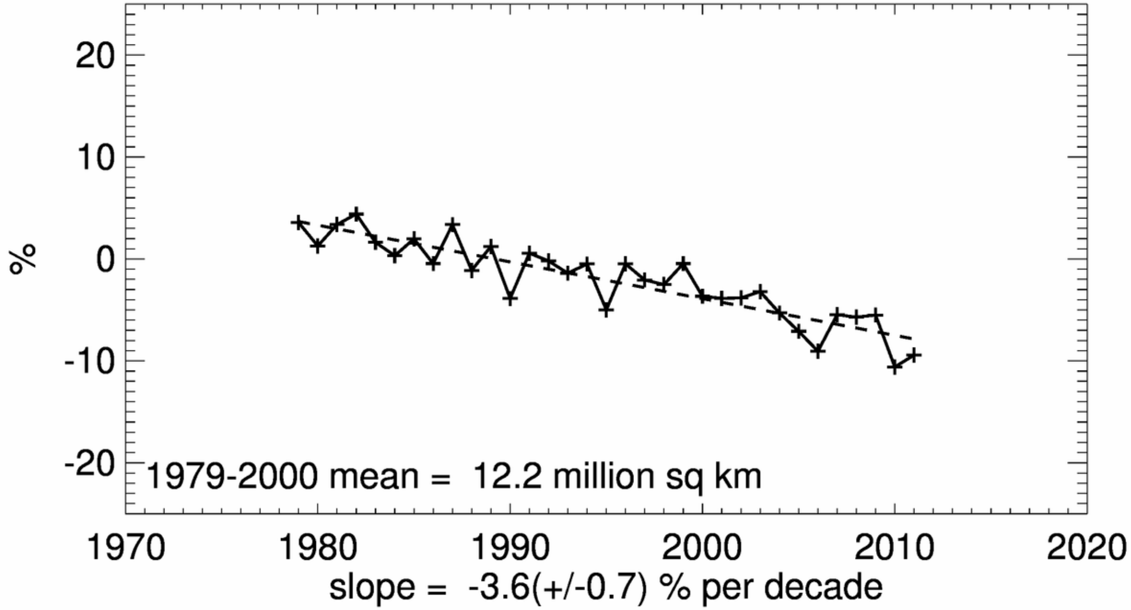
Arctic Sea Ice extent anomalies at the end of August (up to 2010)

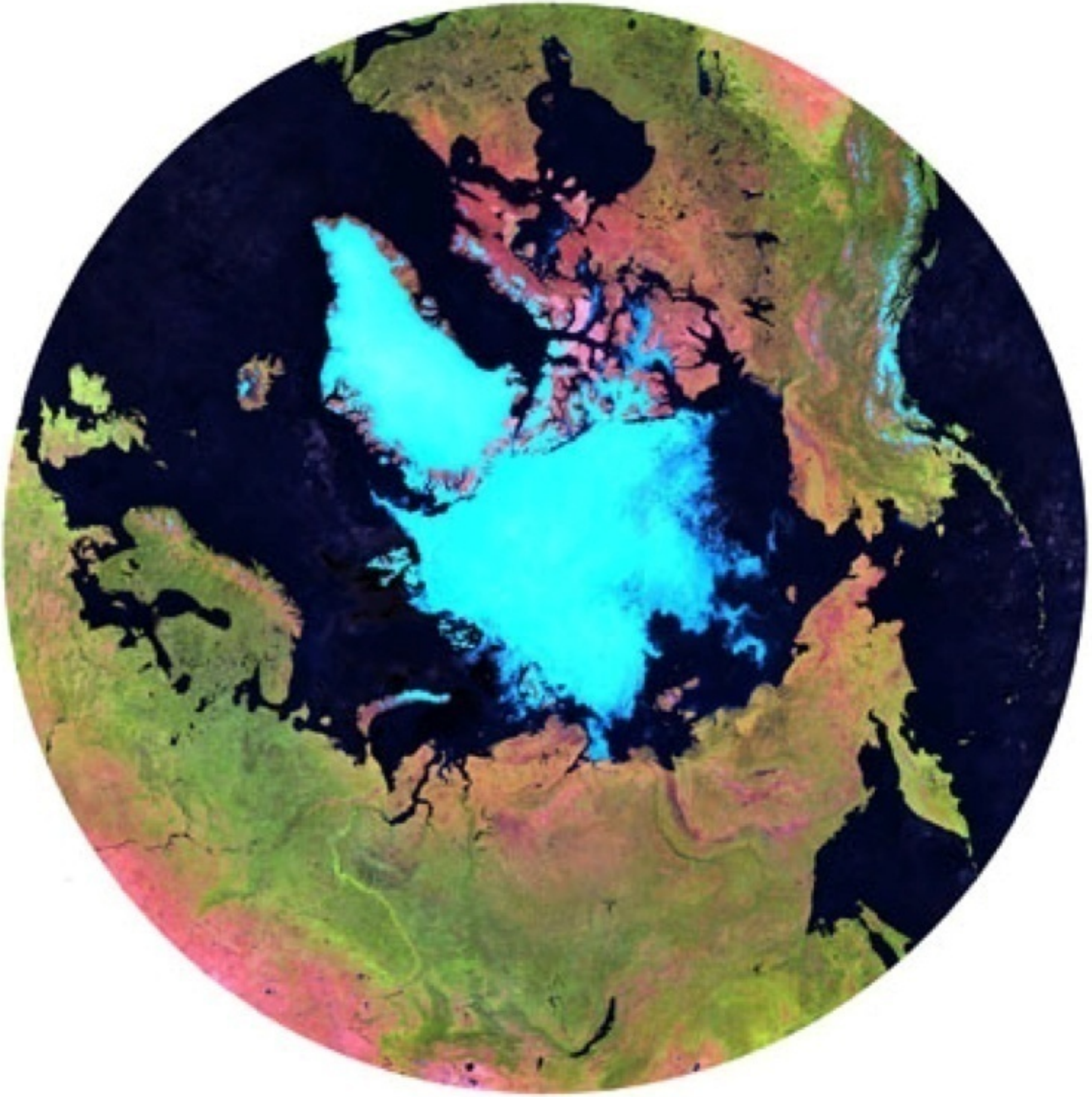


Sea Ice Extent on July 4, 2011



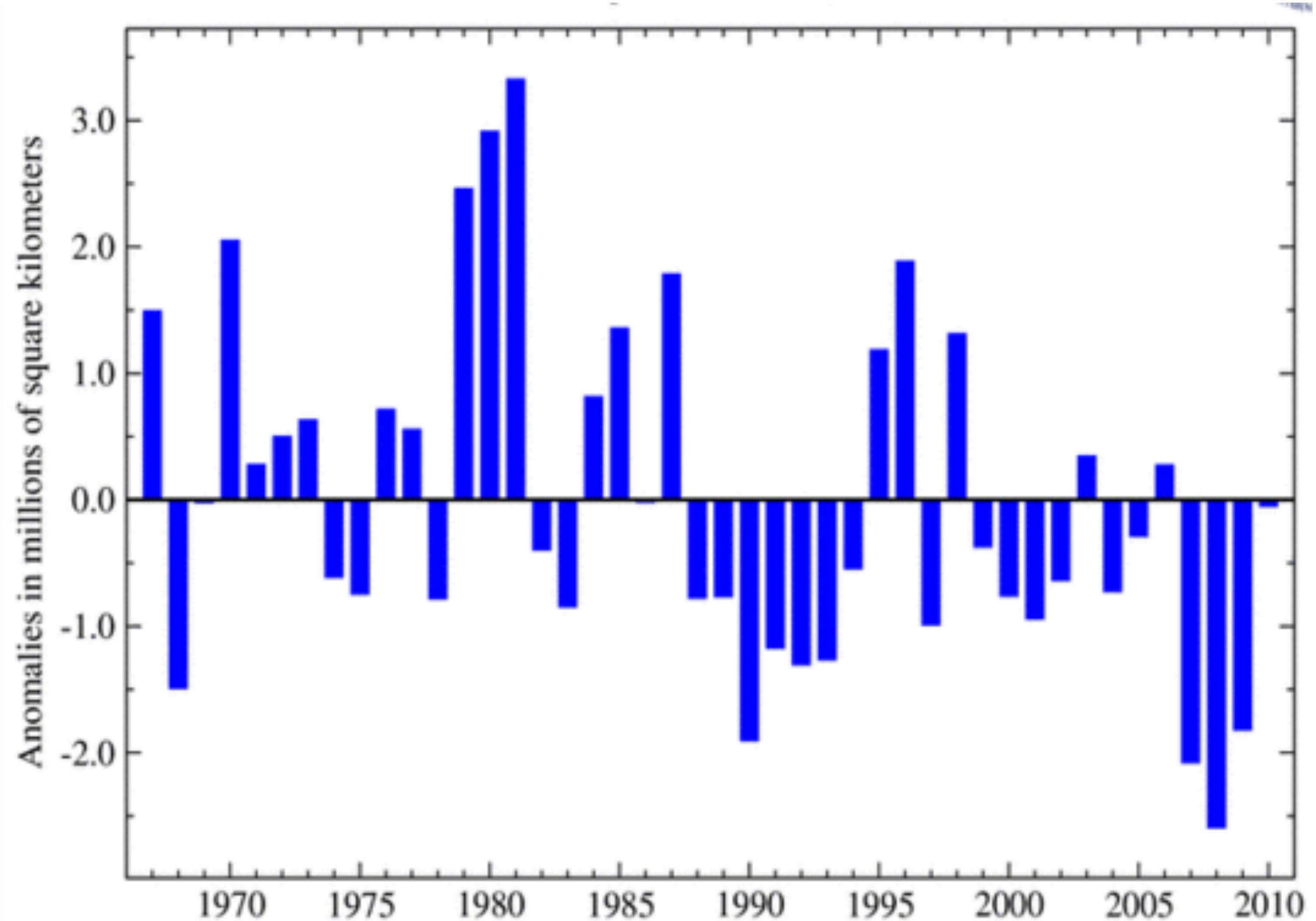
Northern Hemisphere Sea Ice Extent Anomalies (%) in June 2011





Terra-MODIS RGB, July-Sept 2008, 250 m resolution. Cloud free composite. (Trishchenko *et al* 2009). Please, note large areas of ice-free water in the Arctic during this three-months-long season.

April snow cover extent anomalies over Eurasia

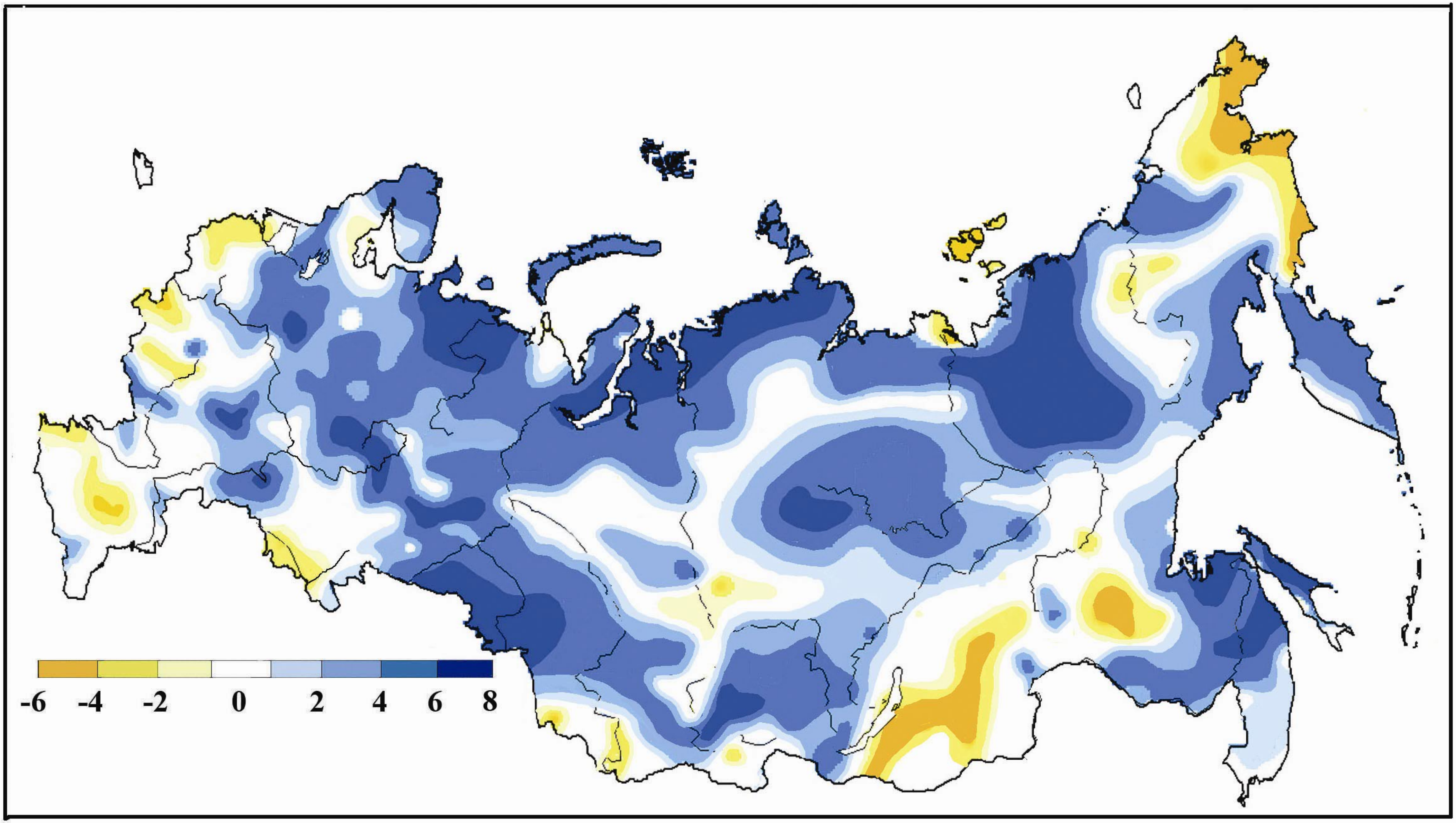


Snow cover extent from NOAA satellites for 1967-2010. NOAA NCDC 2010: State of the Climate. Global Analysis April 2010. [Avail. at *http://www.ncdc.noaa.gov/sotc/index.php?report=global&year=2010&month=apr*]

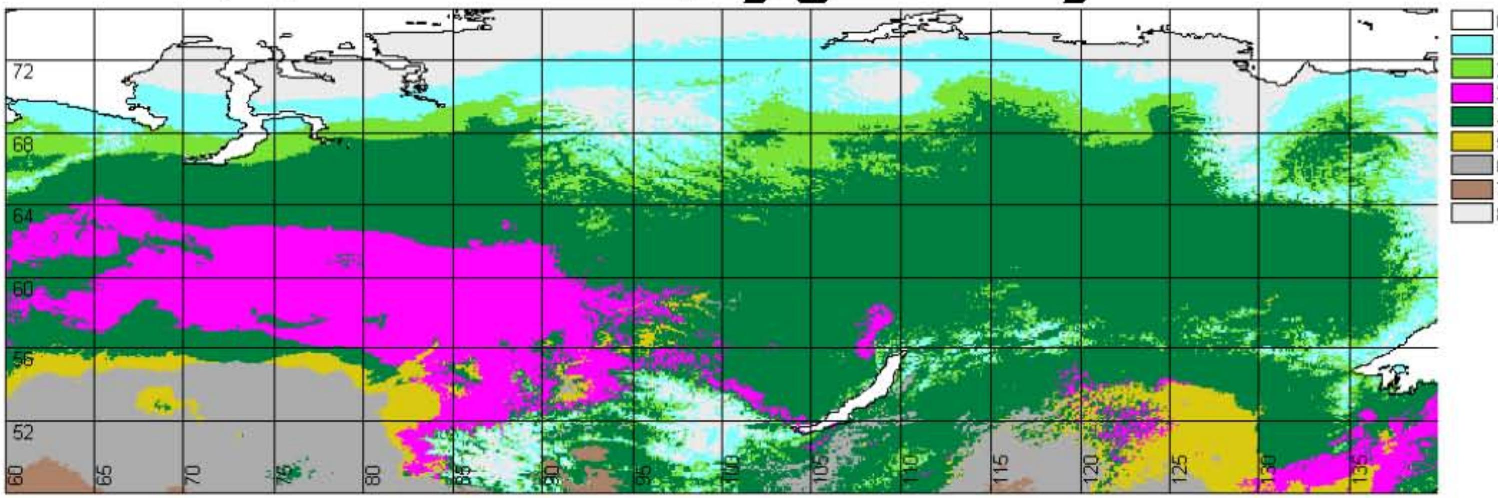
Changes of the maximum snow water equivalent over Russia

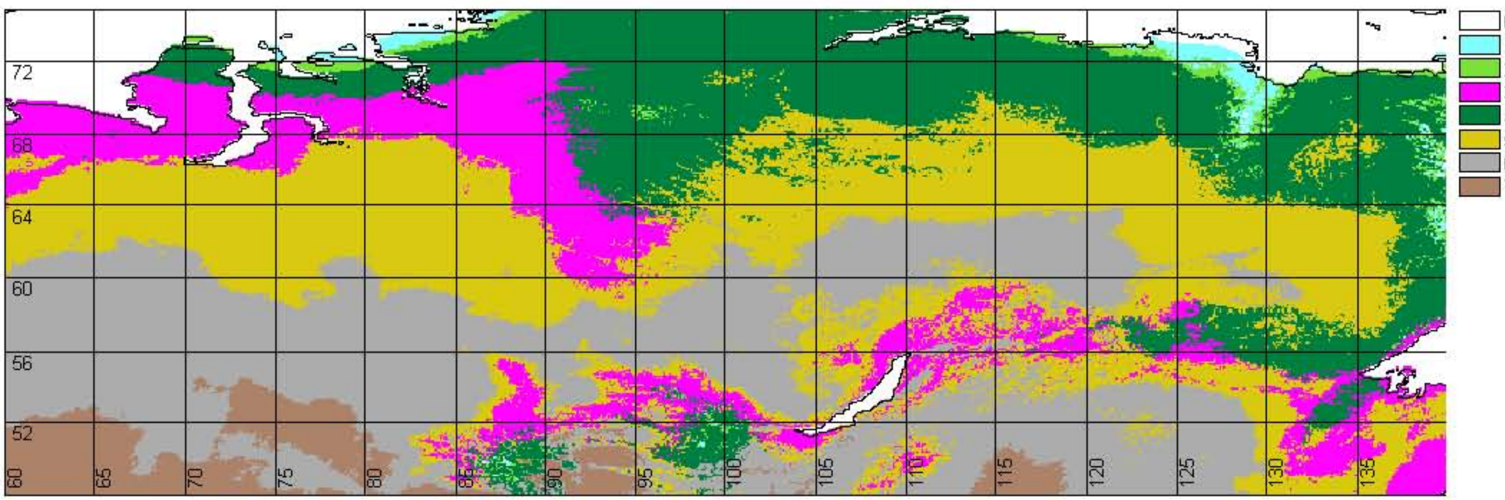
Zone, region	Change in 1967-2009
• Arctic	No changes
• Fields of European Russia, north of 55°N	Increase by 4 to 6%/10yr
• Southeast of "-"-"-"-"-"-" (ER)	Decrease by 4.5%/10yr
• Steppe-forest steppe of ER	No changes
• Fields of West Siberia	Increase by 6%/10yr
• Central East Siberia	Slight increase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

Linear trend coefficients in the time series of the number of days with snow cover exceeding 20 cm for 1951-2006 (Bulygina et al. 2009, *Environ. Res. Lett.)*



Biome distribution over Siberia in current (a) and 2090 (b) climates (Vygodskaya et al. 2007)





Water (0),Tundra (1), forest-tundra (2), darkleaf taiga (3) and lightleaf taiga (4), forest-steppe (5), steppe (6), semidesert (7), and polar desert (8).


Central Yakutia

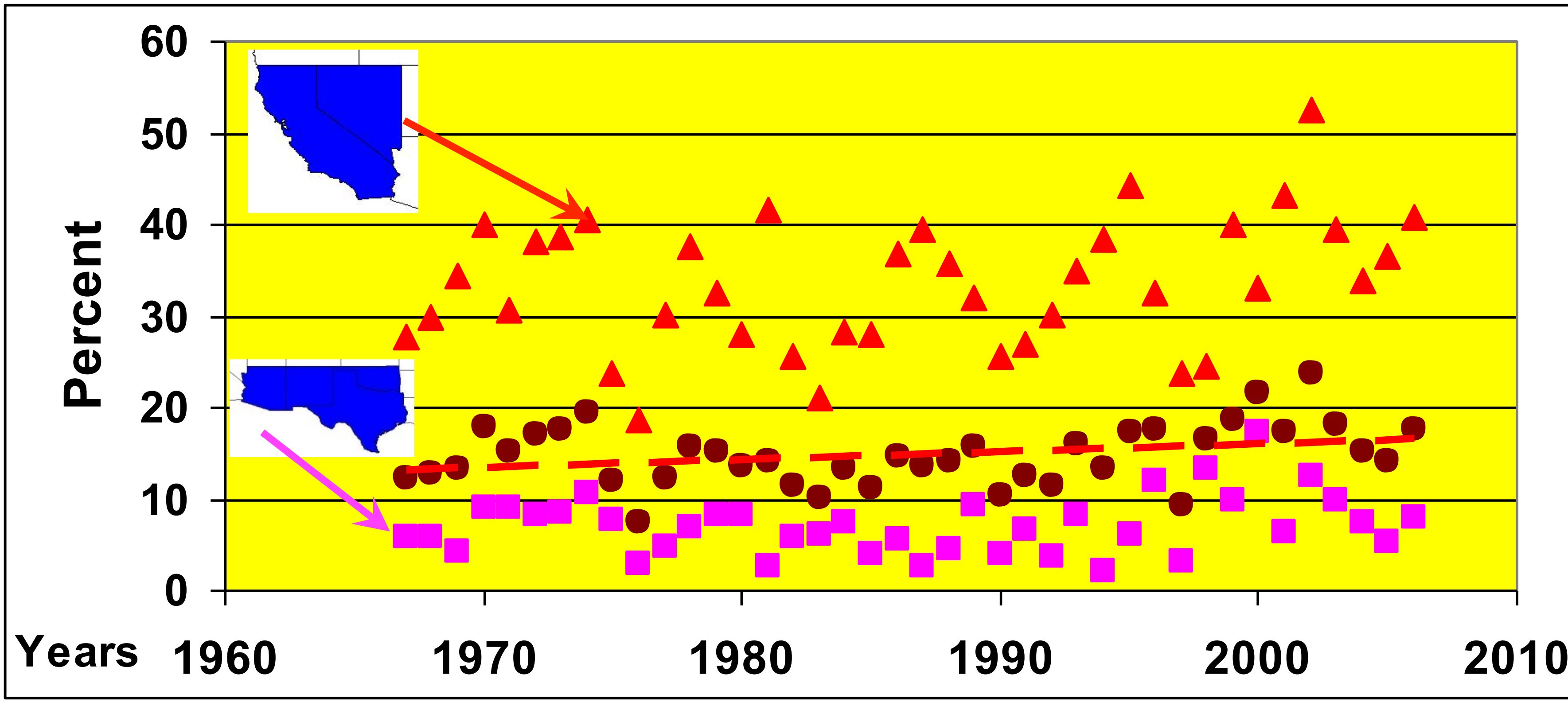
Changes in derived-temperature characteristics over Northern Eurasia during the past 1951-2004 period.

All trend estimates are statistically significant at 0.01 or higher levels.

Characteristic	Trend estimates, %/54 yrs: Former USSR	Trend estimates, %/54 yrs: Siberia & Russian Far East south of 66.7°N
Heating-degree days	-7	-7
Degree-days below 0ºC	-15	-14
Degree-days above 15ºC	11	20
Duration of the growing season		
T> 10ºC	9	14
T> 5 ºC	8	12
Duration of the frost-free period	8	11

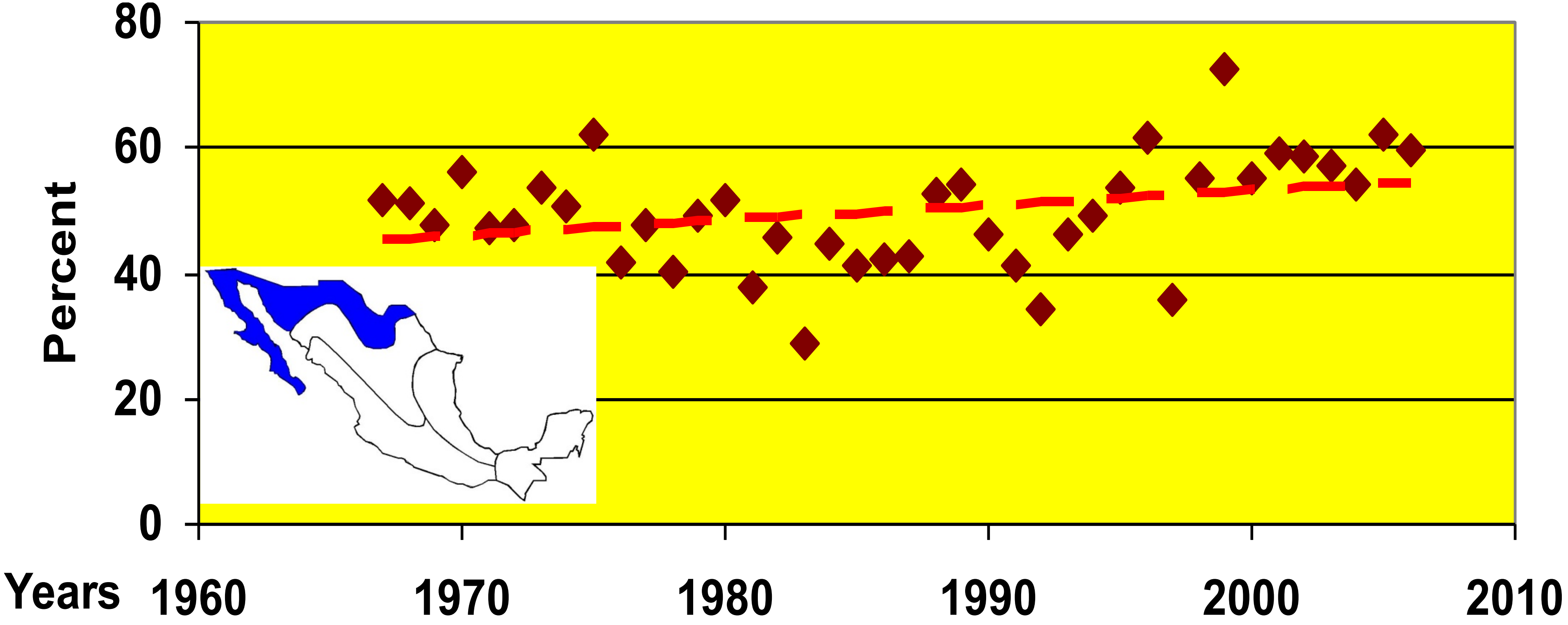
(ACIA, 2004; archive of Ch. 2)

Fraction of the dry day episodes with 2-month or more length during the warm season during the past 40 years area-averaged over the southwestern United States (dots), CA and NV (triangles), and TX, OK, NM, and AZ (squares)



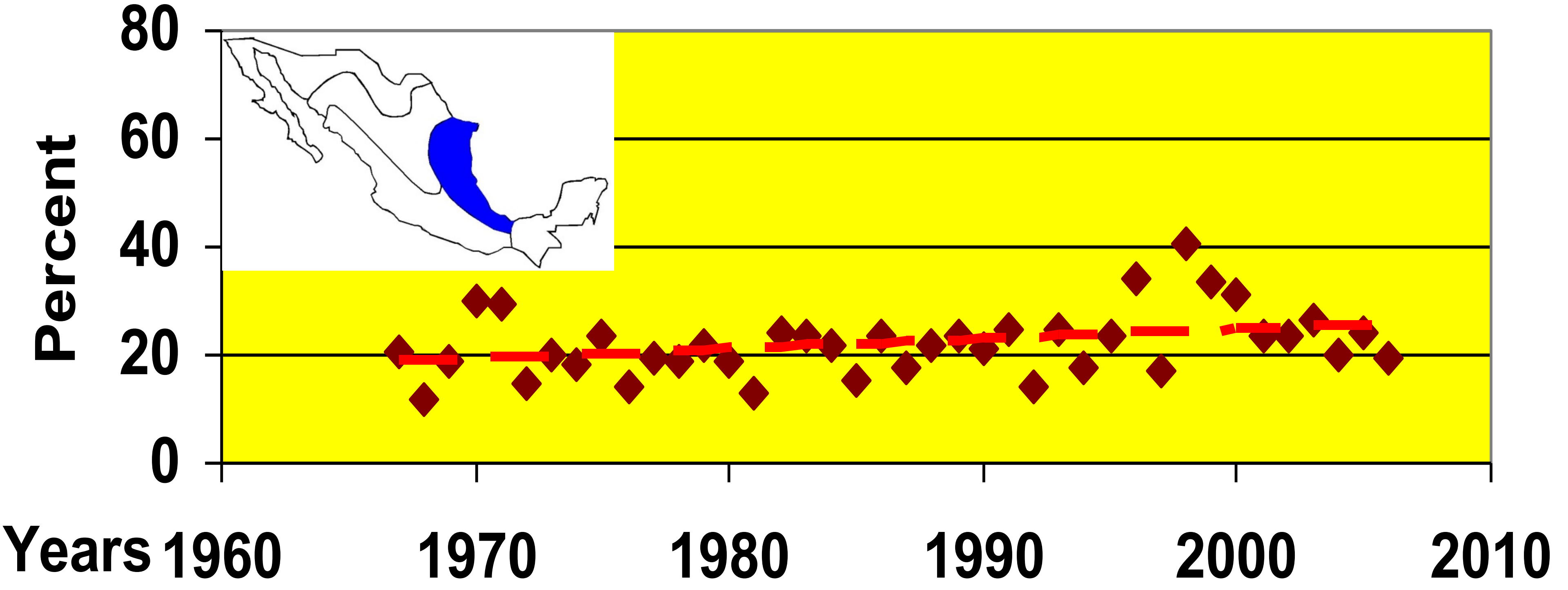
Red dashed line: linear trend (3.6 % per 40 years)

Northern Mexico, fraction of strings of dry days longer than 60 days



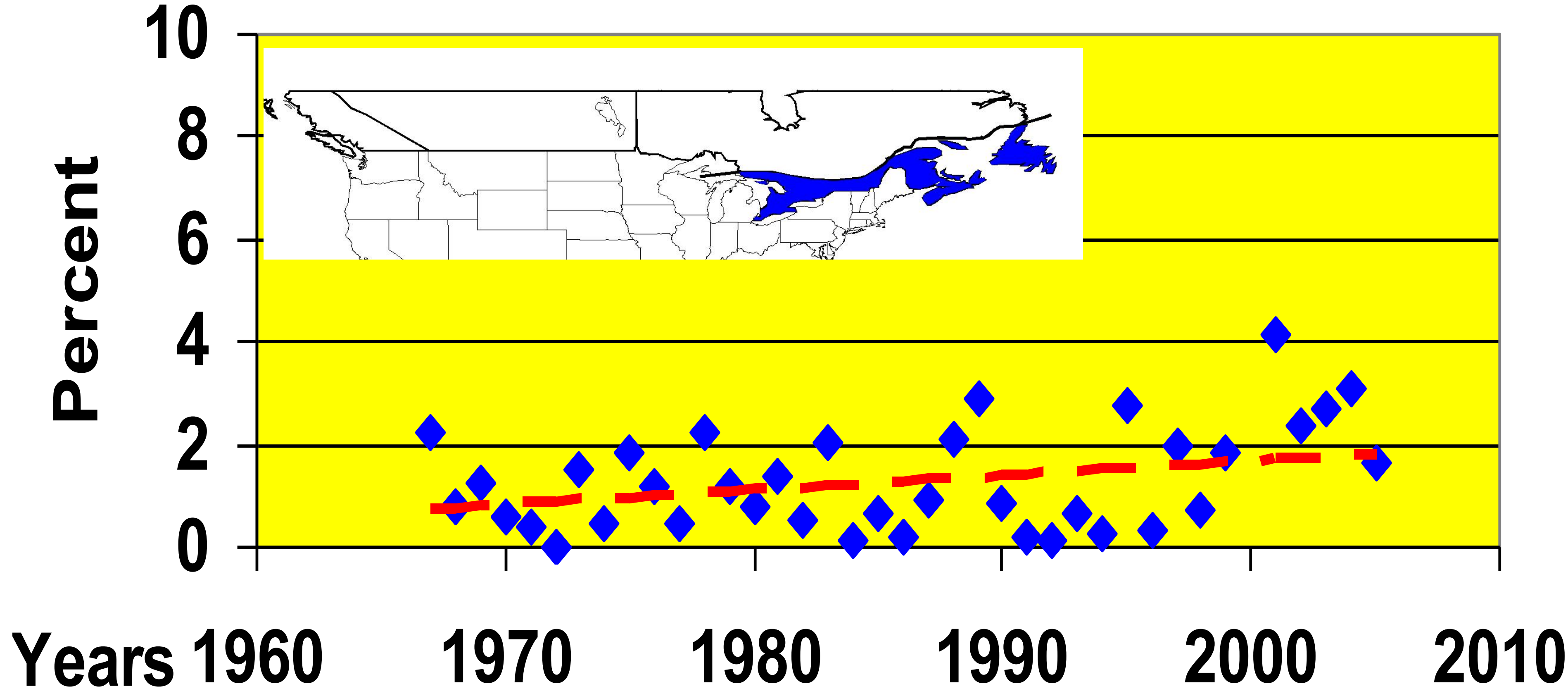
Red dashed line: linear trend (9.4% per 40 years)

Gulf coast of Mexico, fraction of strings of dry days longer than 30 days



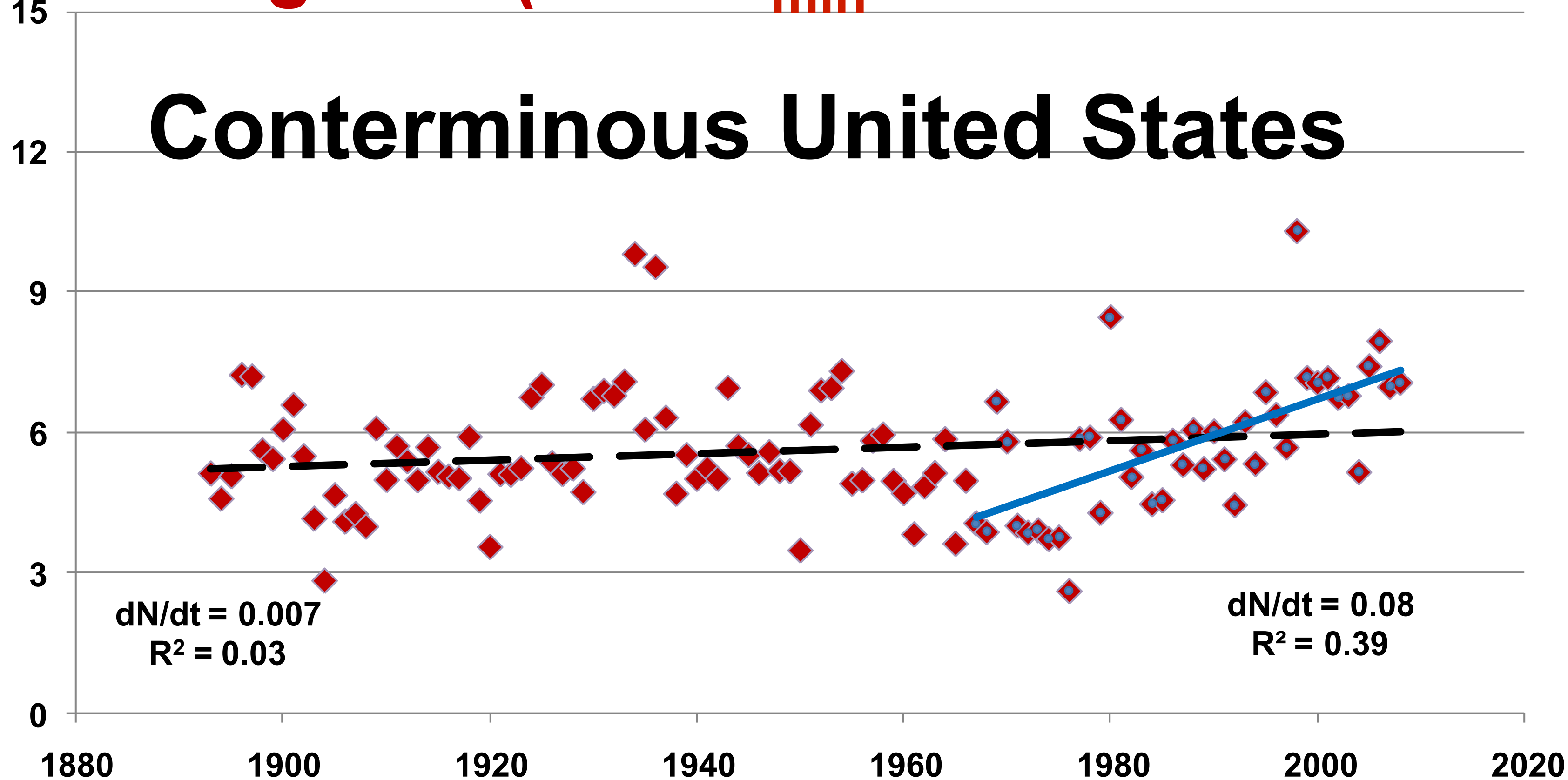
Red dashed line: linear trend (7.3% per 40 years)

Southeastern Canada, fraction of strings of dry days longer than 20 days



Red dashed line: linear trend (1.3% per 40 years)

Nationwide-averaged annual number of "hot nights" (with T_{min} >75°F or > 23.9°C).

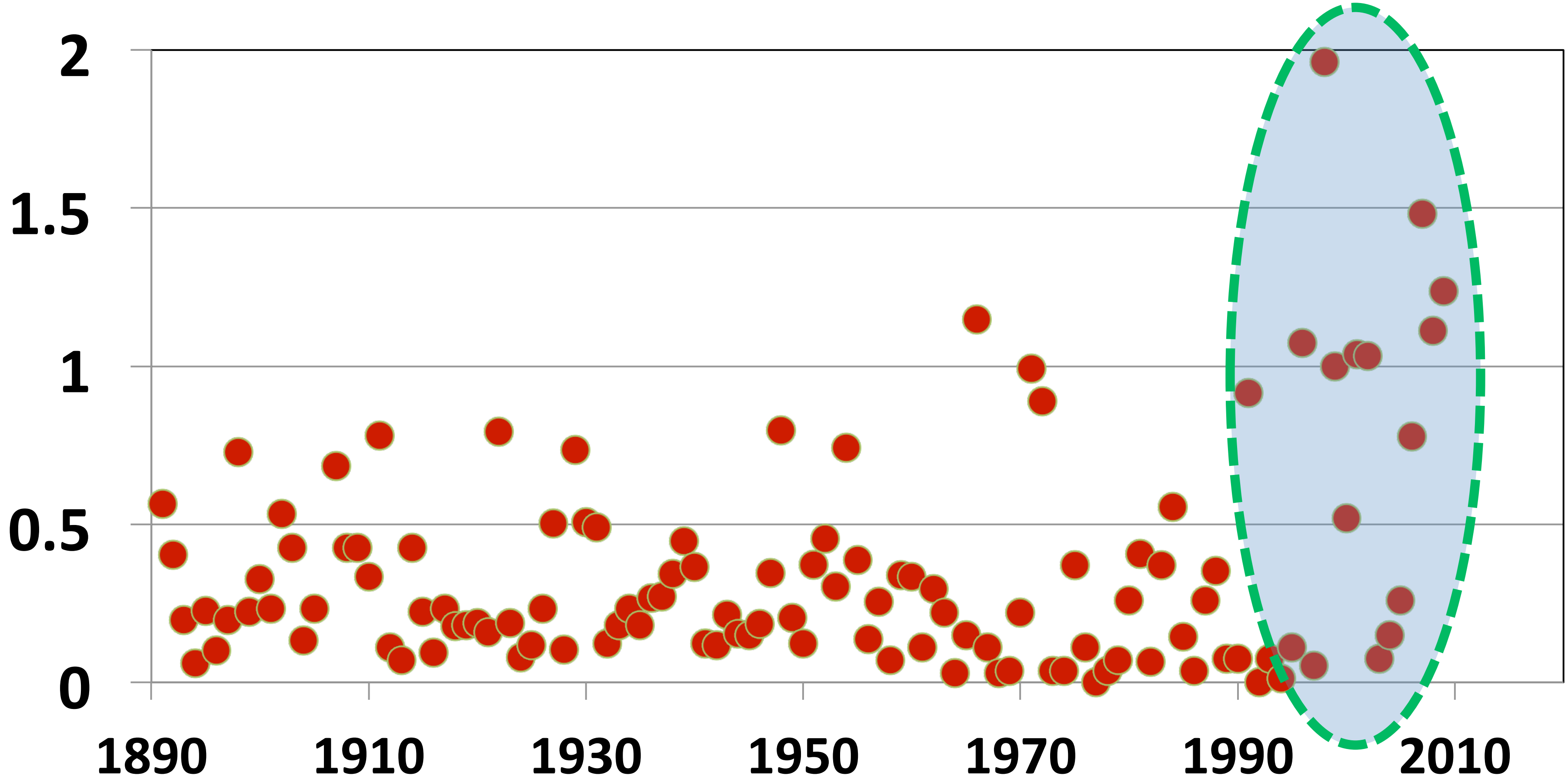


Impact of hot nights on human health (a relative frequency of heart attacks) is well established. Now, with minimum temperature continuing to rise, this impact became more severe everywhere in the eastern and southern United States. During the past four decades, there was an approximately 60% nationwide increase in the number of "hot nights" and in the Northeast the number of such nights increased by 170%.

What does it mean, when 2% of the warm season is occupied by dry episodes that are 30 or more days long?

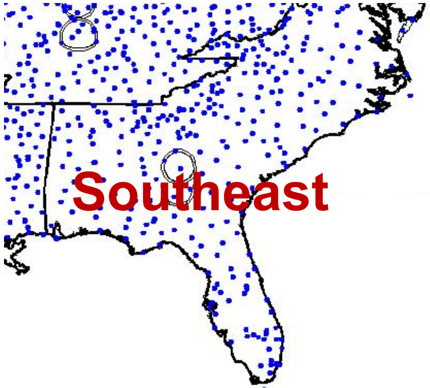
- Example: warm season = 200 days therefore during the past 55 years (period for climatology calculations in the USA) we observed: 200 x 55 x 0.02 = 220 such days or maximum 7 such dry episodes during the past 55 years with return period of ~ 8 years ([220/30] = 7).

European Russia south of 60°N, number of days with T_{min} above 75°F (≥23.9°C). 1891-2009



Global warming manifests itself at least at the continental scale ➔

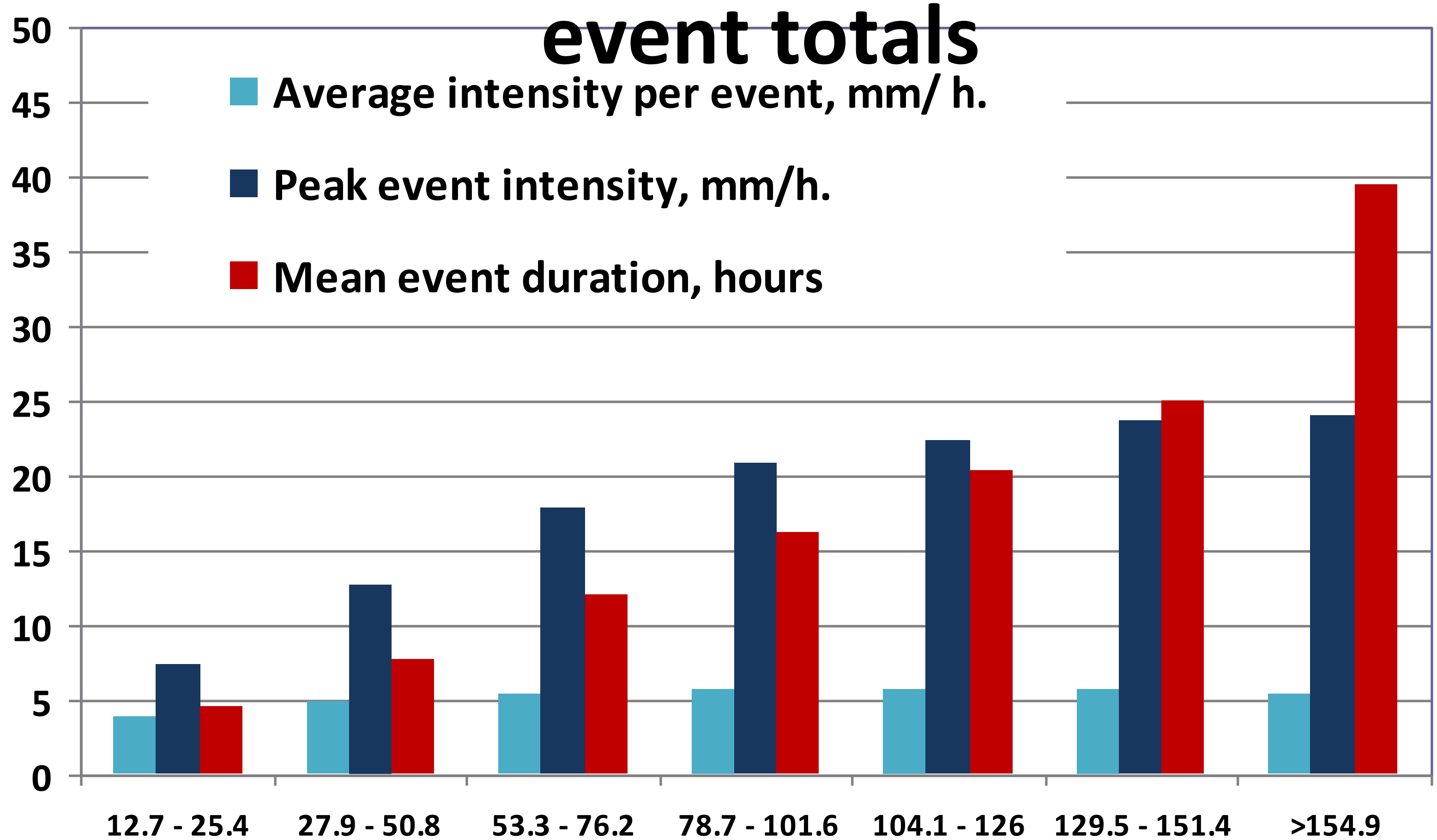
- There is a reason to look for large scale changes in extremes ➔ we are looking for changes in area-averaged characteristics of extreme events
- Another option would be to search for smaller-scale changes in extremes related to regional and local factors (e.g., land use change and/or water withdrawal)



Example of intense precipitation statistics for Southeast for 1948-2007 based on 220 HPD gauges, per station

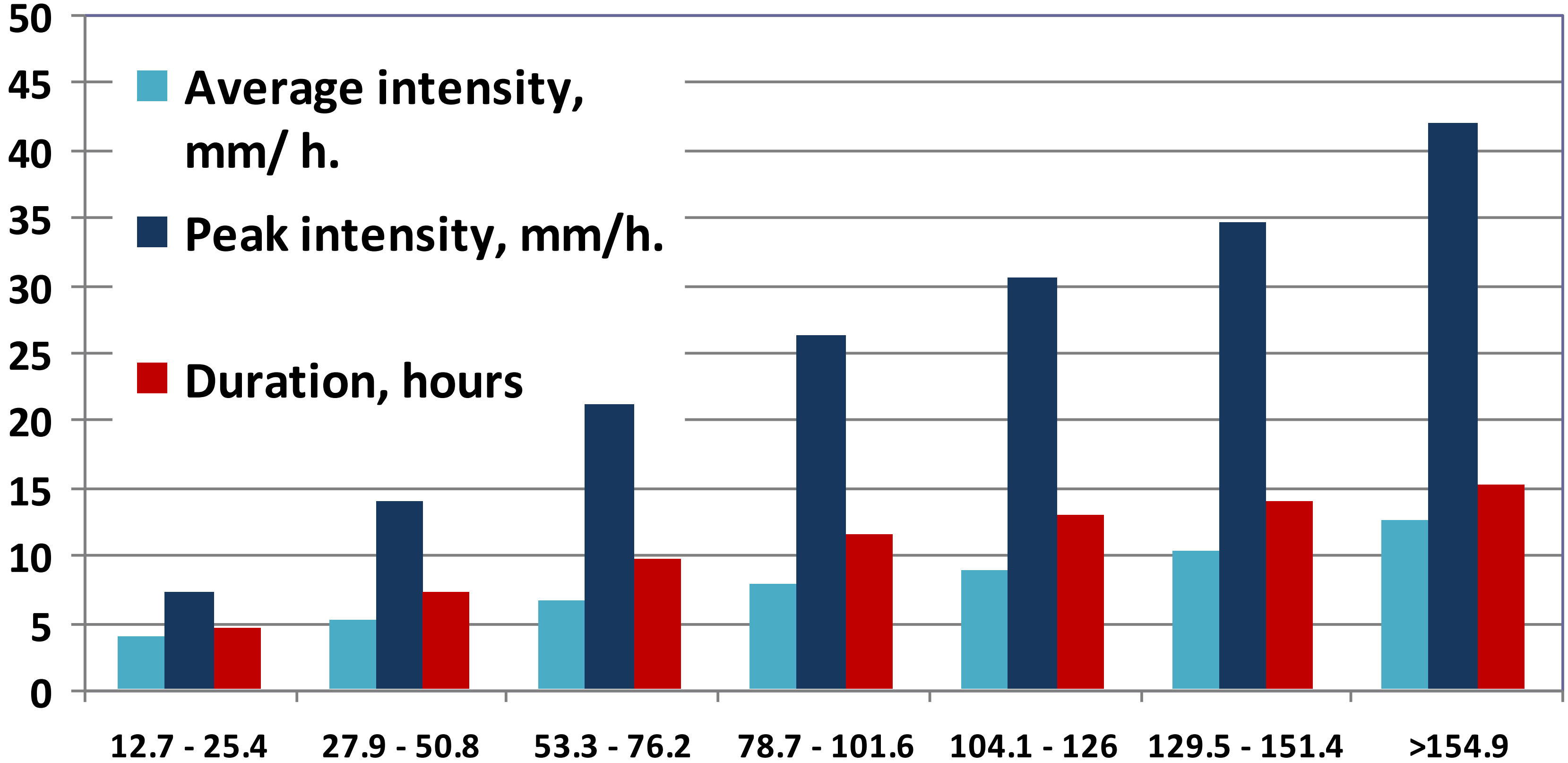
Precipitation event range, mm	Annual rainfall, mm	Decadal number of rain days	Annual number of rain hours	Average intensity, mm/ h.	Duration, hours	Peak intensity, mm/h.
12.7 - 25.4	329	187	73	4.6	3.9	8.9
27.9 - 50.8	250	66	40	6.1	6.1	16.8
53.3 - 76.2	93.5	15	12	7.9	8.1	25.2
78.7 - 101.6	36	4	4	9.1	9.9	30.7
104.1 - 126	16.5	1.4	1.6	10.2	11.2	35. 6
129.5 - 151.4	7	0.5	0.6	11.2	12.6	39.9
>154.9 mm	8.3	0.4	0.6	13.8	14.5	48.0

Nationwide climatology of various characteristics of hourly intense precipitation as a function of multi-day intense precipitation event totals



Mean daily and peak precipitation intensity mm h^{-1}; and mean duration of daily precipitation events, hours.

Nationwide climatology of various characteristics of hourly intense precipitation as a function of daily precipitation totals in the days with intense precipitation



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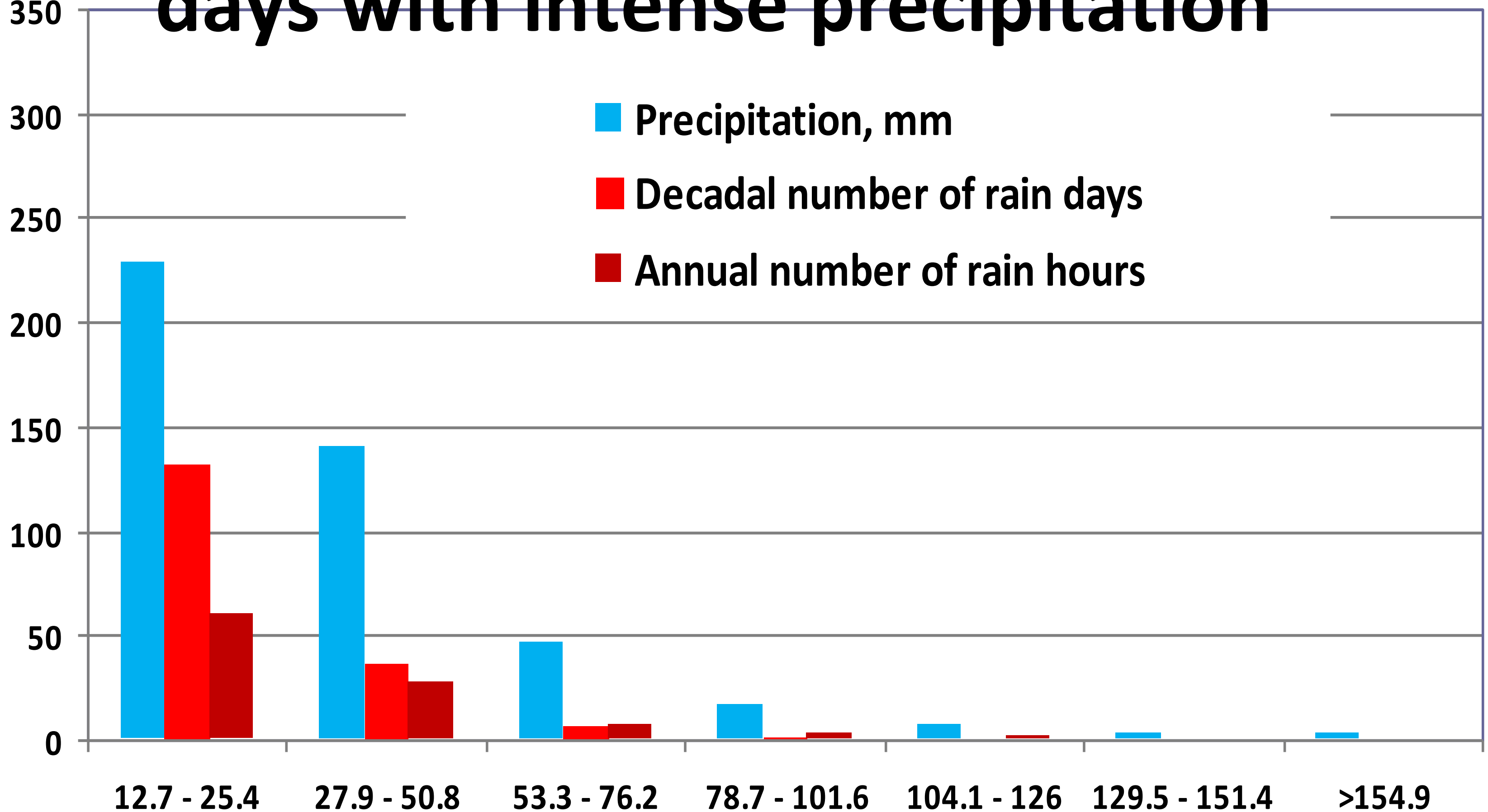
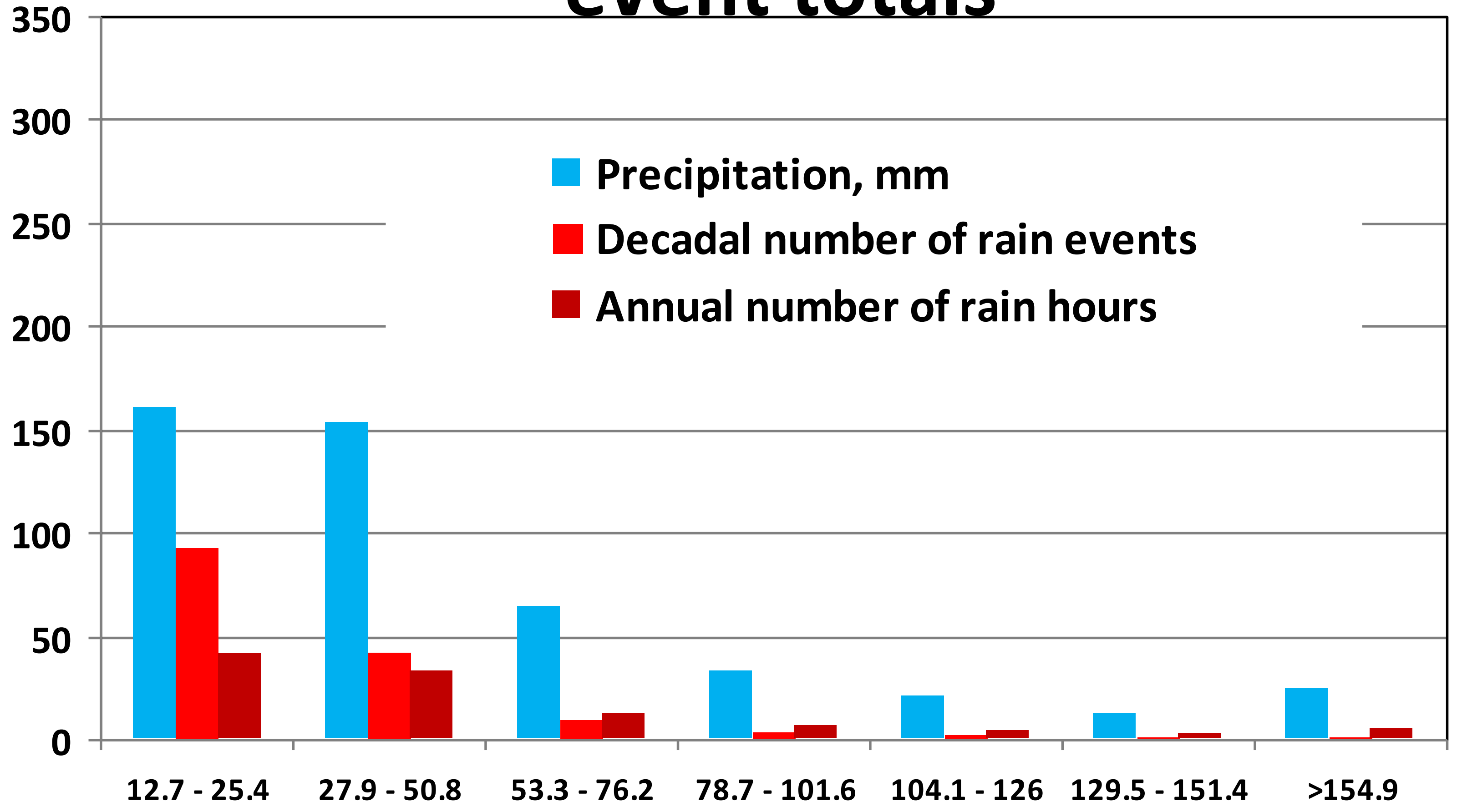


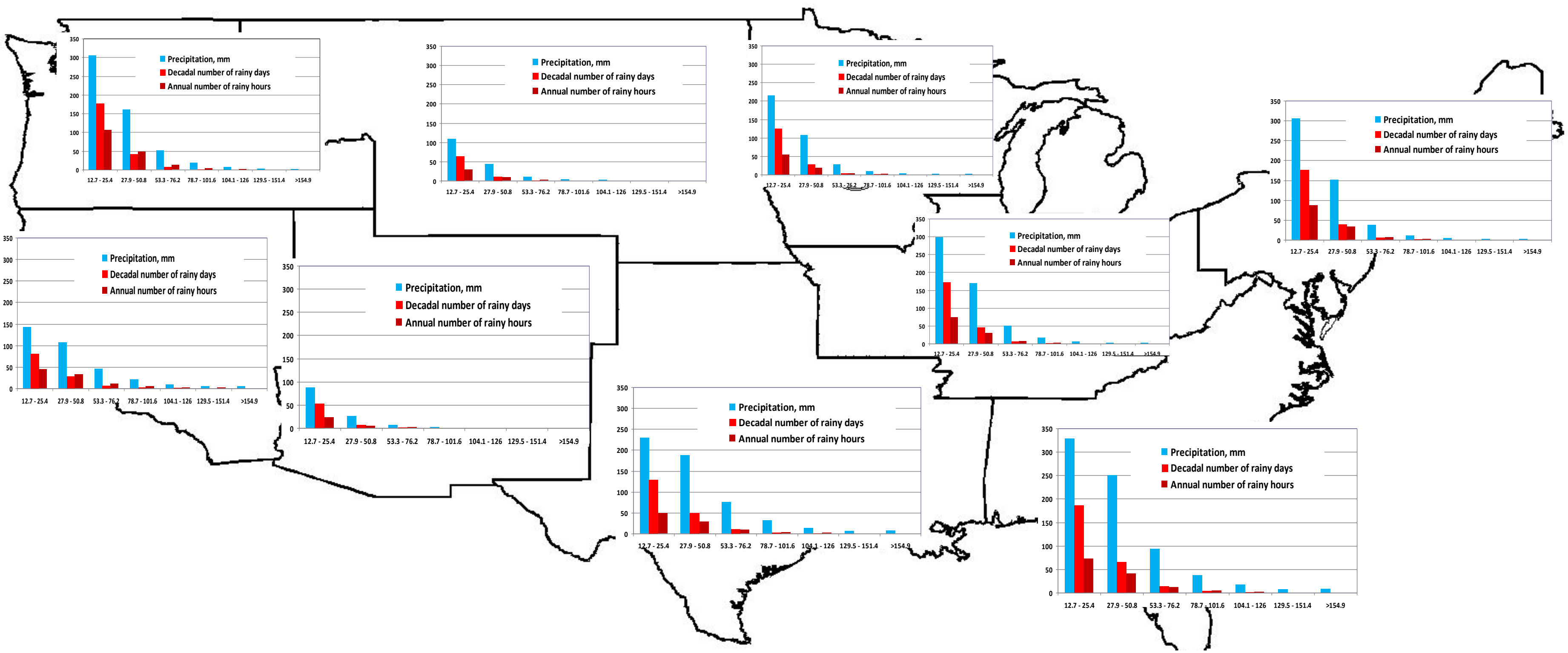
Mean point annual intense precipitation, mm; mean point decadal number of days and mean point annual number of hours with intense precipitation

Nationwide climatology of various characteristics of hourly intense precipitation as a function of multi-day intense precipitation event totals



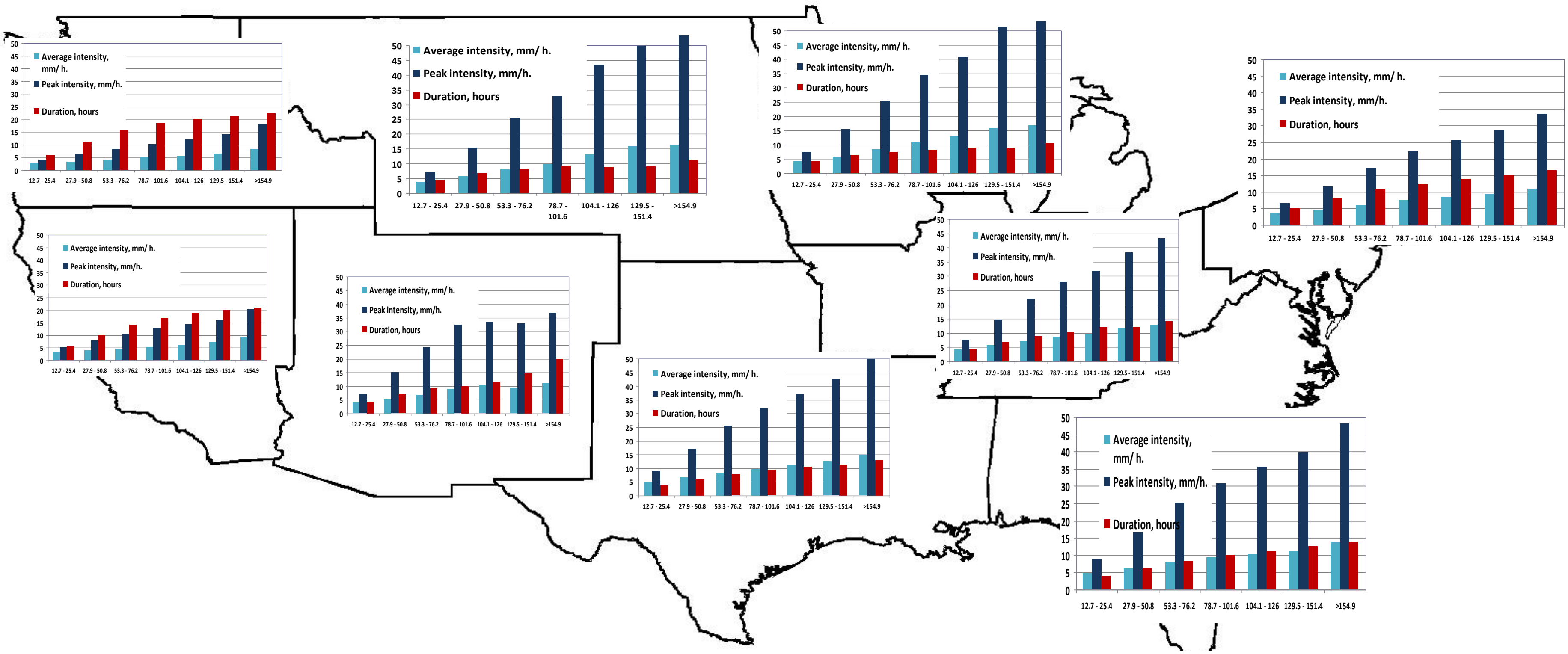
Mean point annual intense precipitation, mm; mean point decadal number of events and mean point annual number of hours with intense precip.

Regional climatology of various characteristics of hourly intense precipitation as a function of daily precipitation totals in the days with intense precipitation



Mean point annual intense precipitation, mm; mean point decadal number of days and mean point annual number of hours with intense precipitation

Regional climatology of various characteristics of hourly intense precipitation as a function of daily precipitation totals in the days with intense precipitation



Mean daily and peak precipitation intensity mm h^{-1}; and mean duration of daily precipitation events, hours.

Changes in intense precipitation

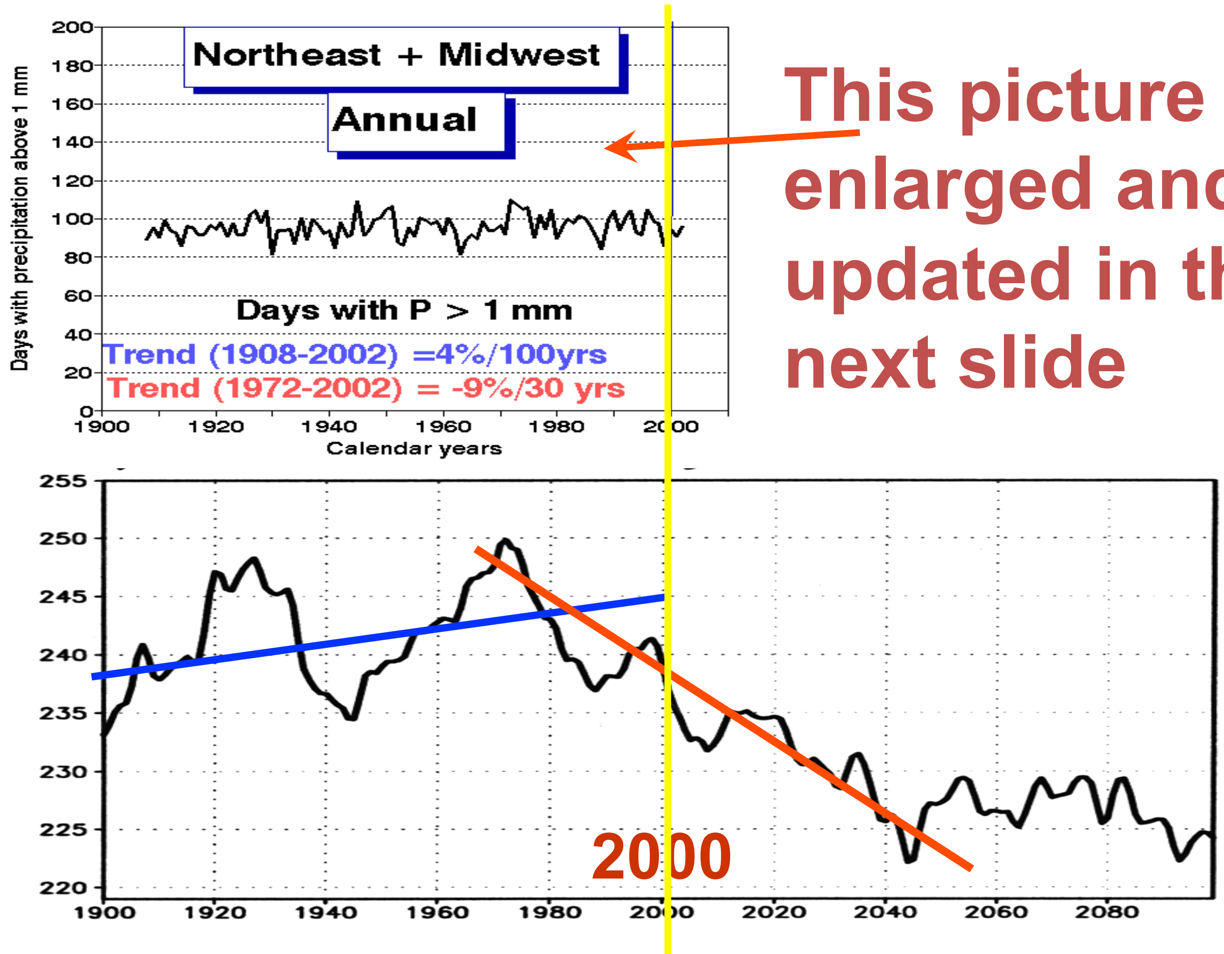
Assessing the 1948–2009 period, we compared

- the first 31 years and the last 31 years of our sample from HPD and COOP networks
- the warmest 31 years and the coolest 31 years using the mean annual surface air temperature of the Northern Hemisphere (TNH) and of the CONUS as guidance
- intense precipitation derived from tropical cyclones (TC) in the hurricane season (June through November) and intense precipitation that originated without direct TC impact, and
- various other combinations.

Frequency of rainy days over the northeastern quadrant of the contiguous United States (*both show a decrease during the past 30 years*).

- **Observations** (Northeast and Midwest regions) for 1908-2002.

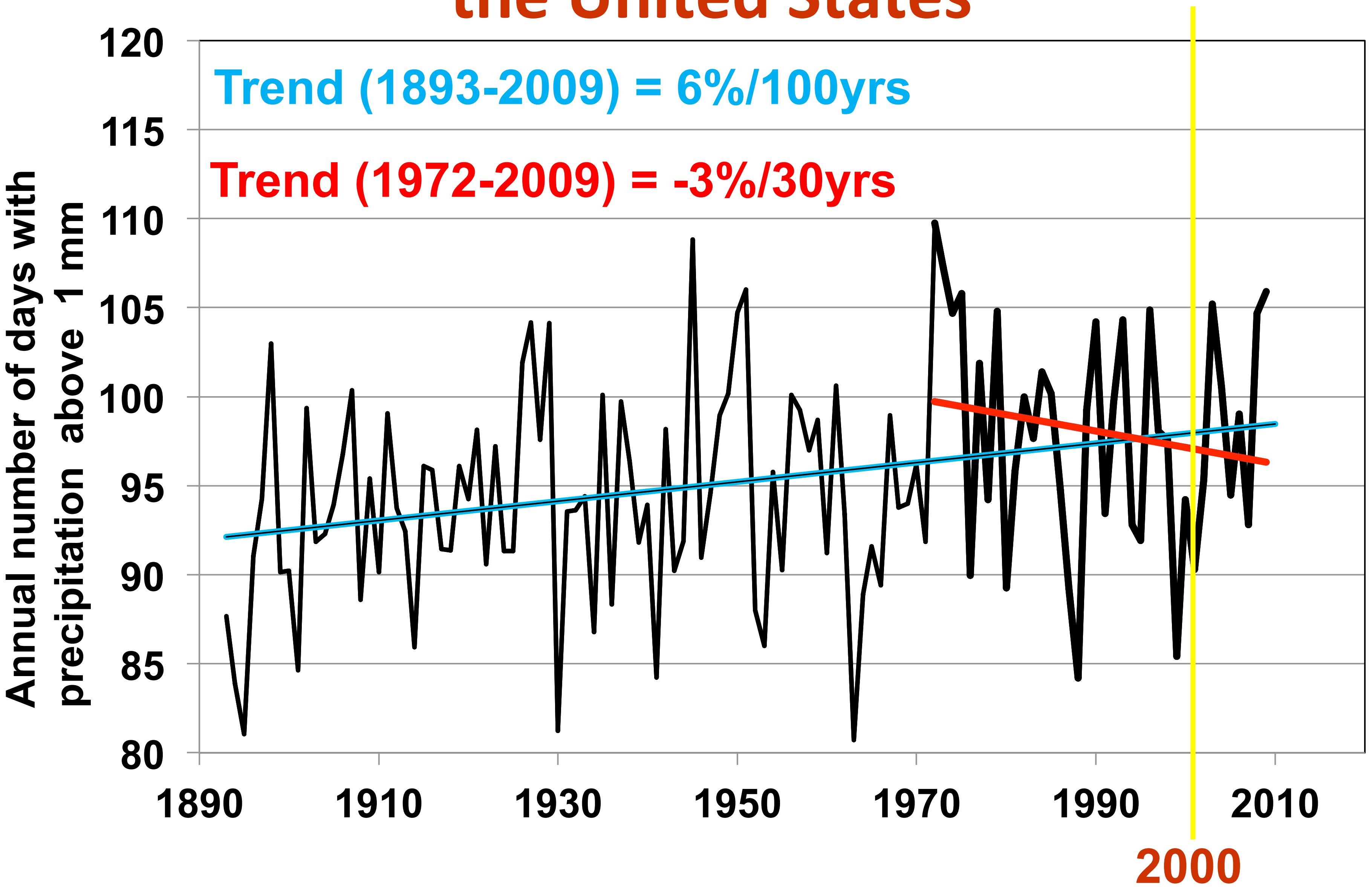
- **ECHAM4 (35N-45N; 75W-85W;** adapted from Semenov & Bengtsson 2002) 10 year running mean values for 1900-2090.



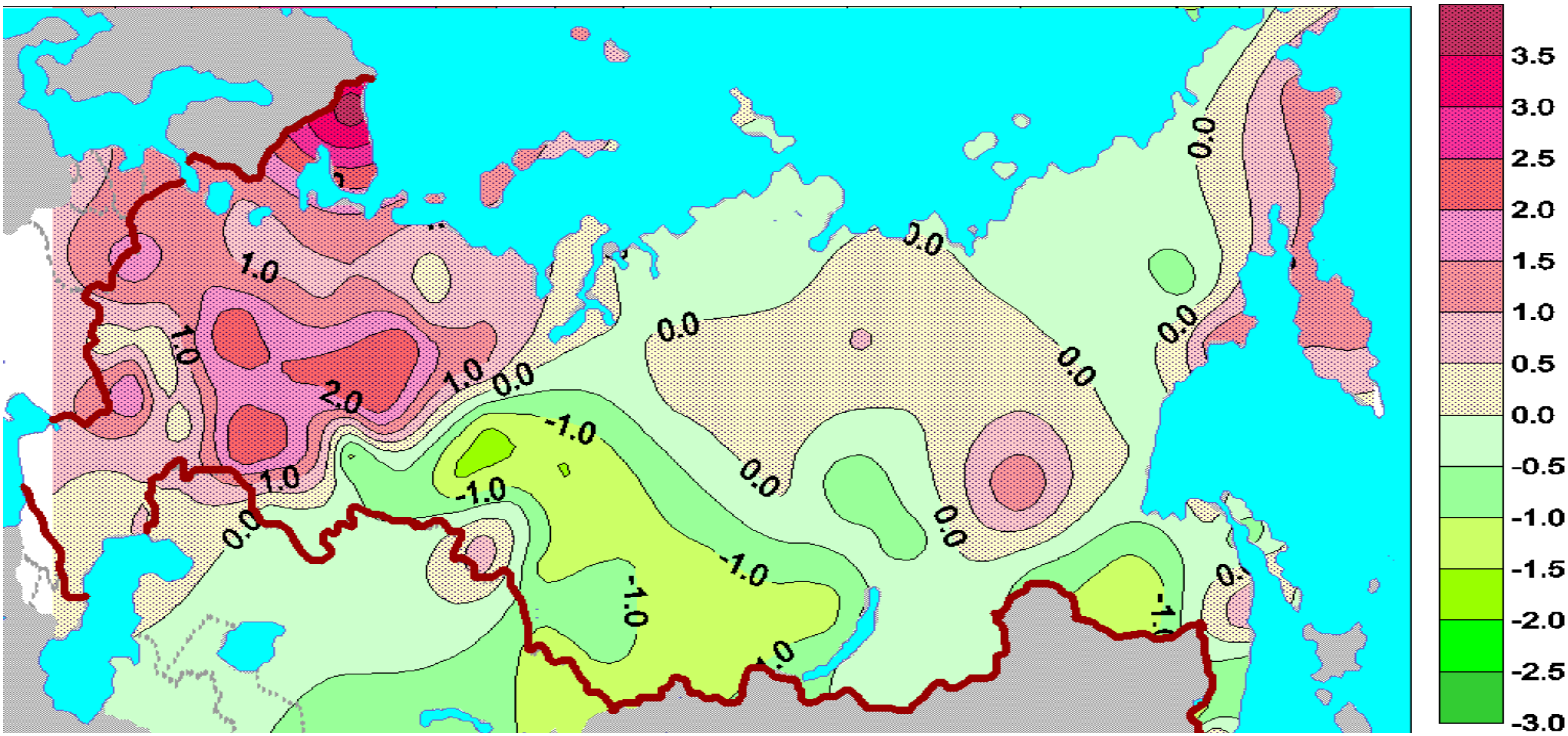
This picture is enlarged and updated in the next slide

(Groisman et al. 2005)

Rainy days over the northeastern quadrant of the United States



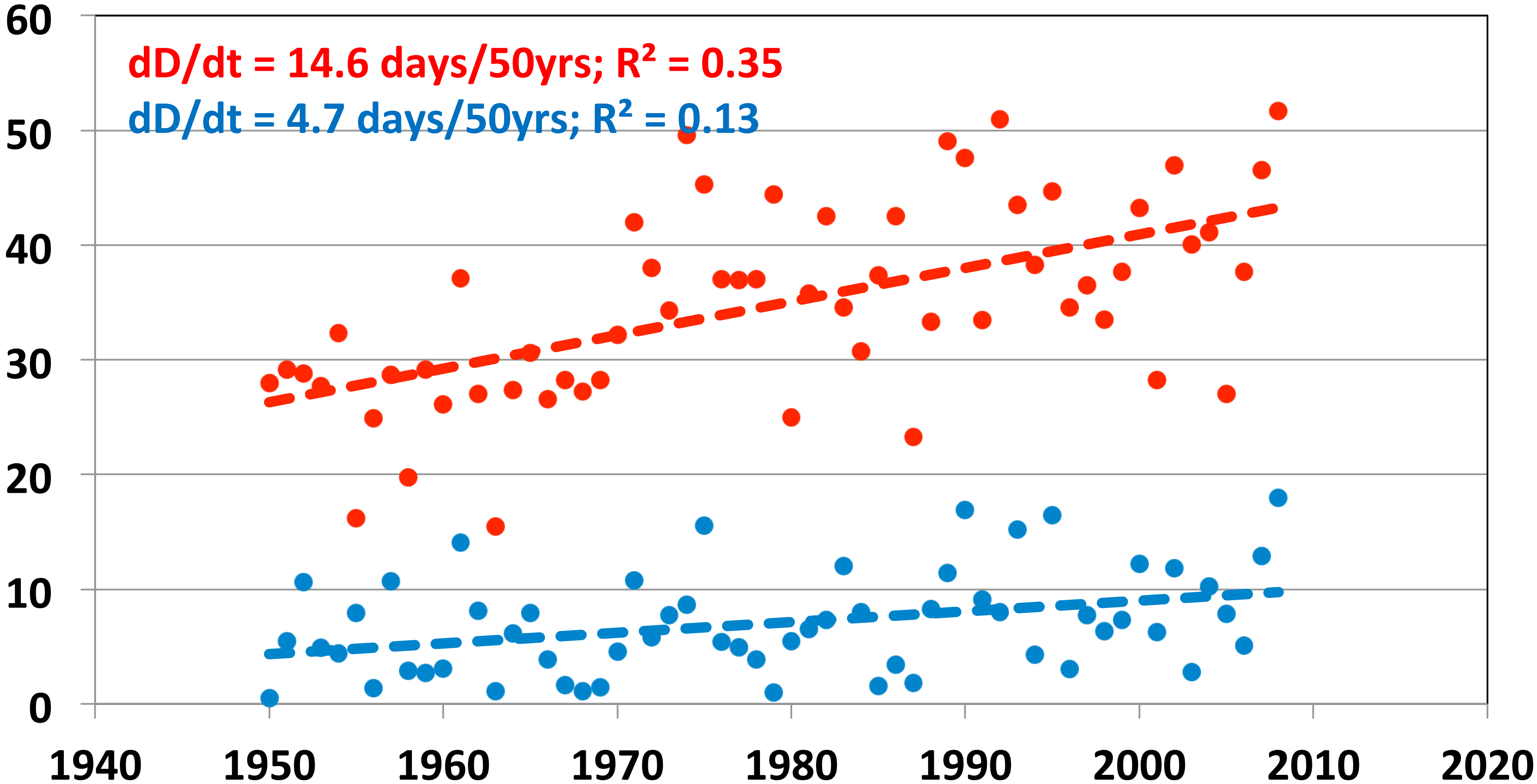
Changes of bias-corrected annual precipitation over Russia



Linear trends (mm yr $^{-1}$), the 1936-2000 period

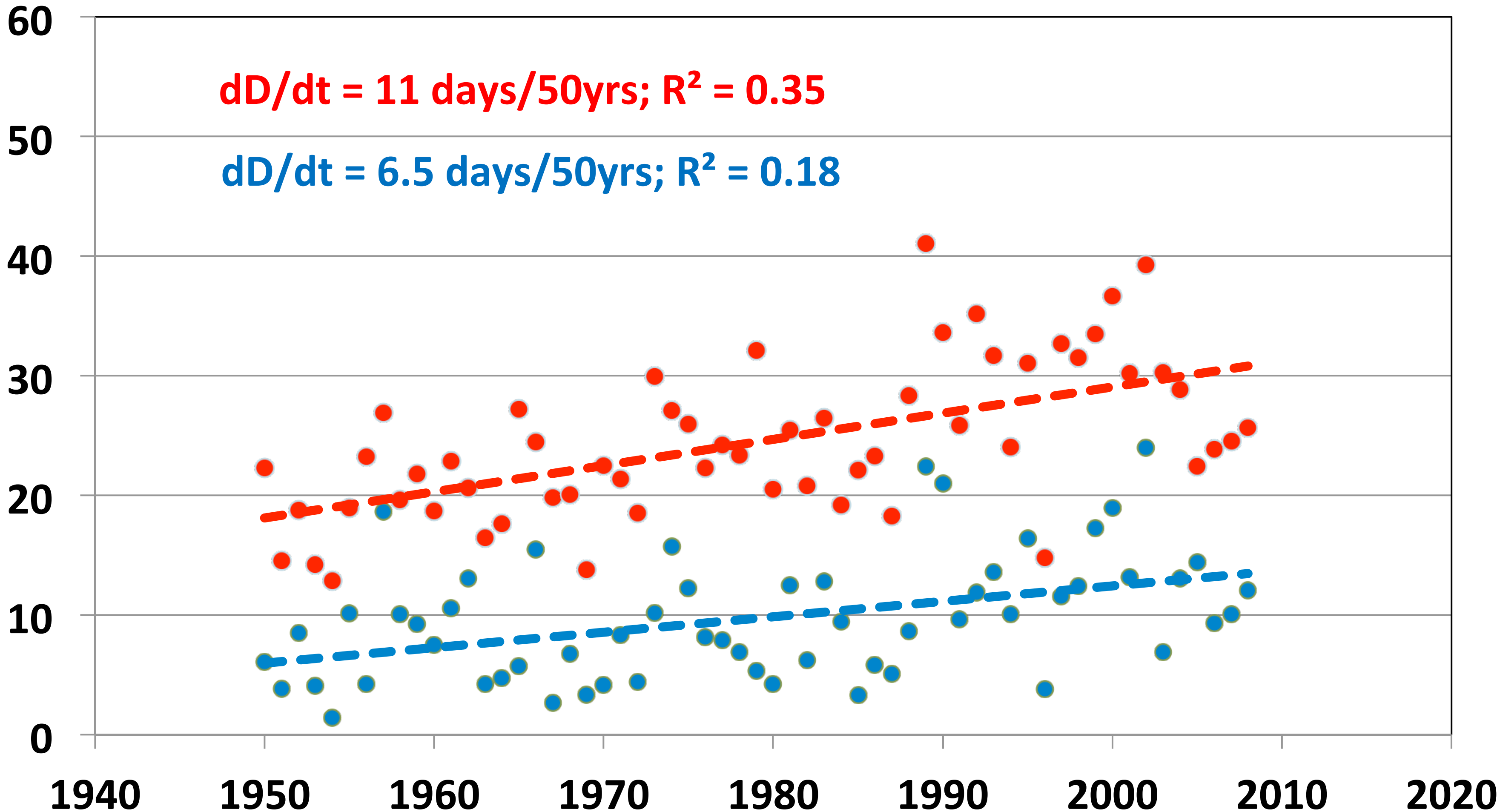
E.G. Bogdanova (2010, Personal communication)

Annual and winter number of days with thaw over European Russia north of 60°N and south of the Arctic circle



- 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

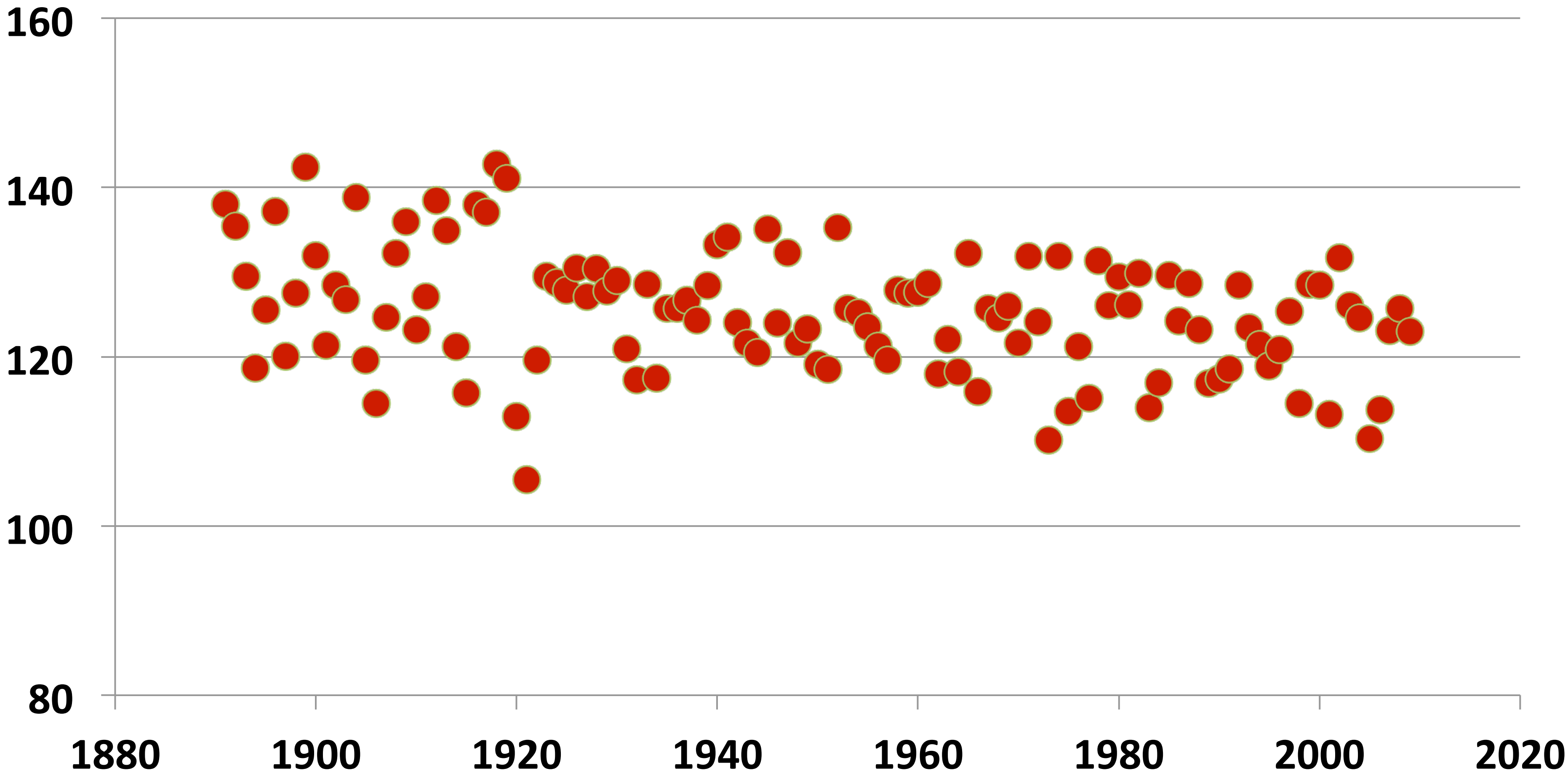
Annual and winter number of days with thaw over European Russia south of 60°N



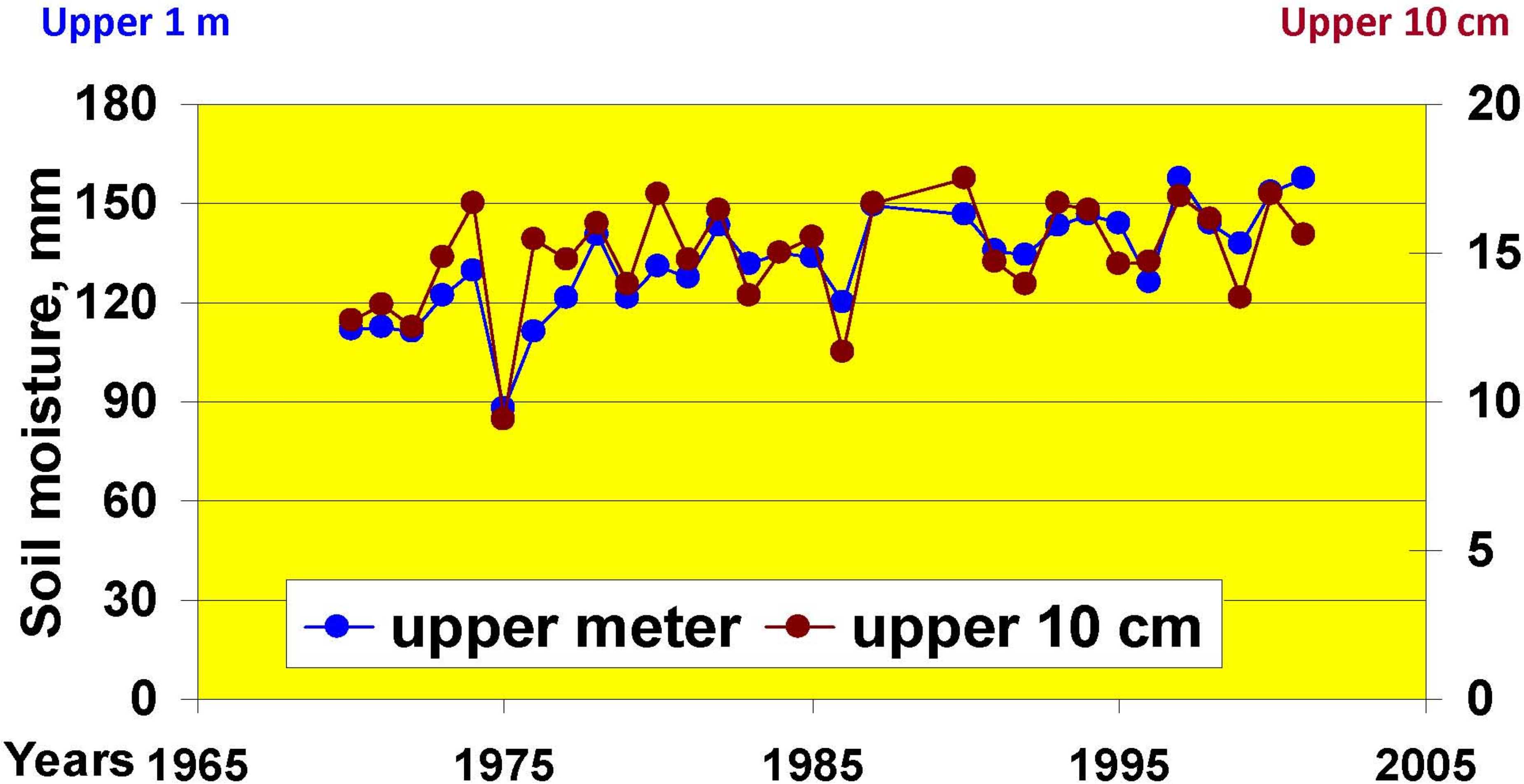
- Days with thaw are defined as the days when the mean daily temperature is above -2°C while snow on the ground is above 5 cm

Dates when vegetation season starts
Julian day

European Russia south of 60°N

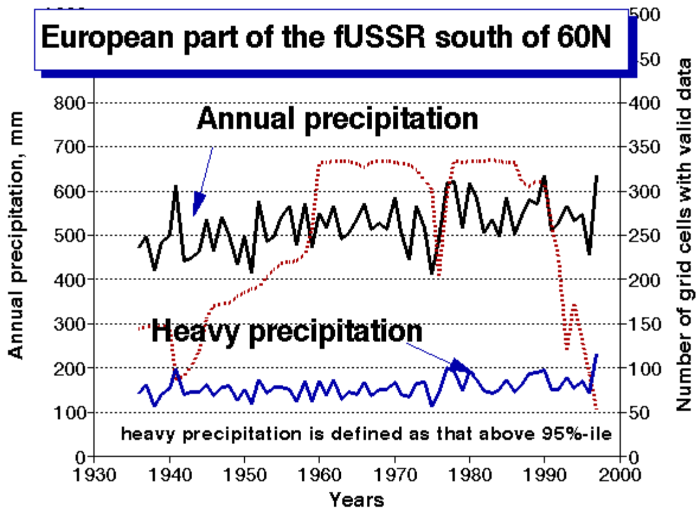


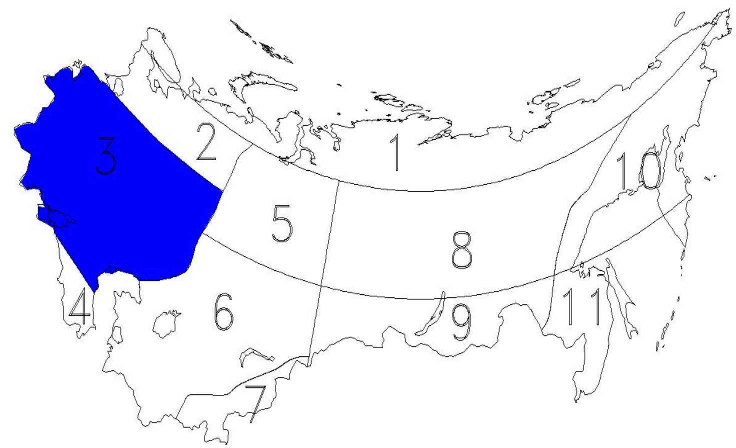
Soil moisture changes over European Russia south of 60°N during the warm season in the first upper 100 and 10 cm respectively (Speranskaya 2009)



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

Trend characteristics (1936-1997 years) of the annual precipitation for western USSR

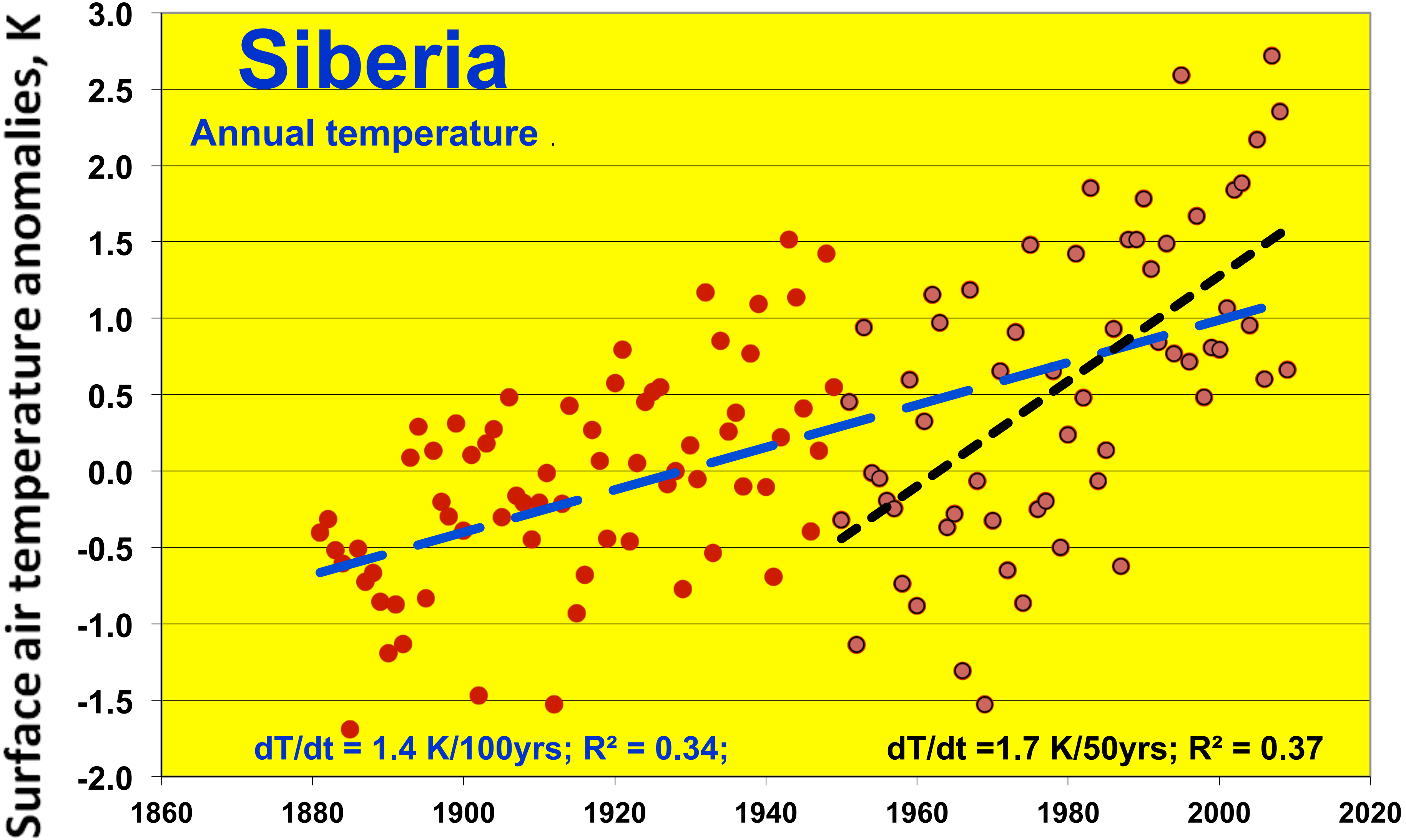




- Linear trend and its variance
- %/10yrs %

	%/10yrs	%
Total P:	2.4	18
“Heavy” (upper 10%)	2.9	15
Very heavy (upper 1%)	4.0	15
“Extreme” (upper 0.1%)	5.0	10

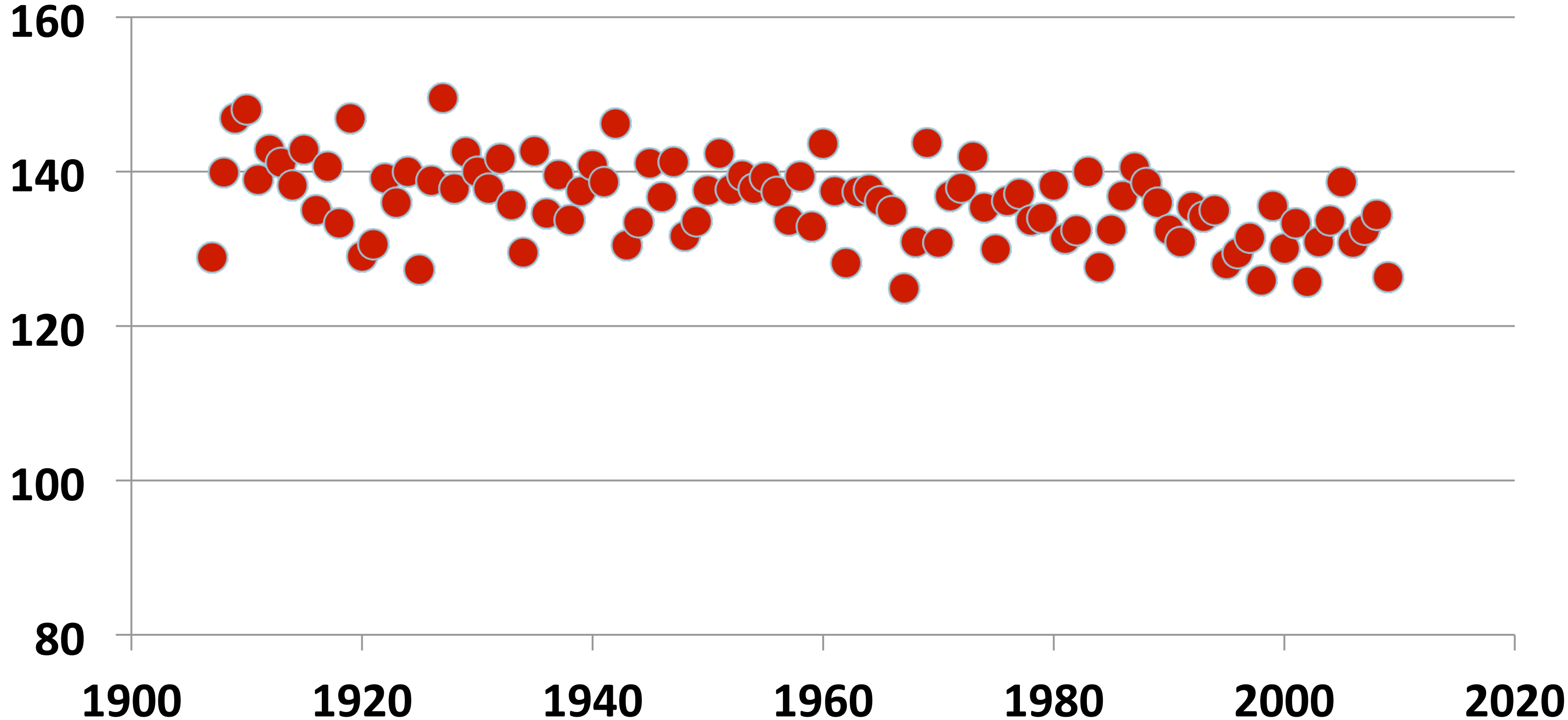
Annual surface air temperature anomalies



Anomalies from the mean for the 1951-1975 period; Archive of Lugina et al. (2007)

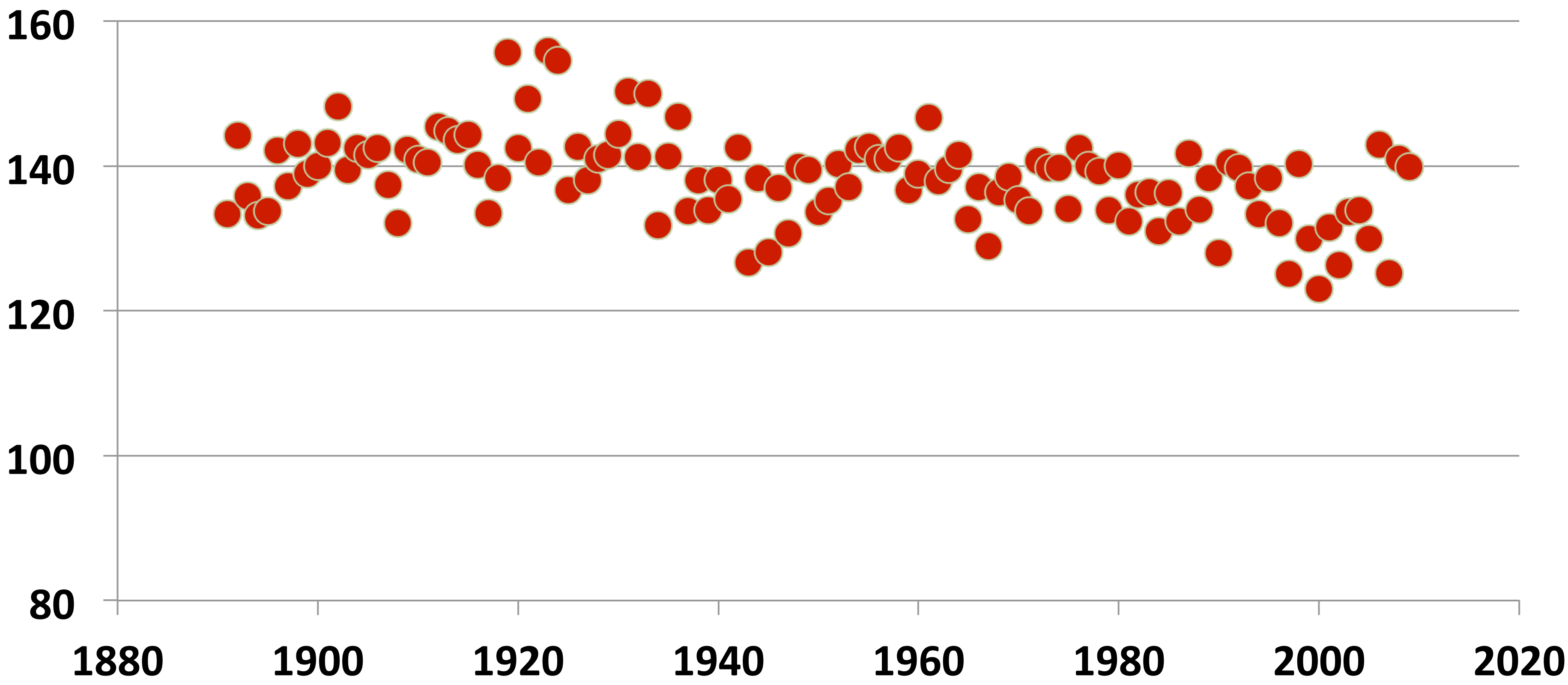
Dates when vegetation season starts, Julian day

Russian Far East



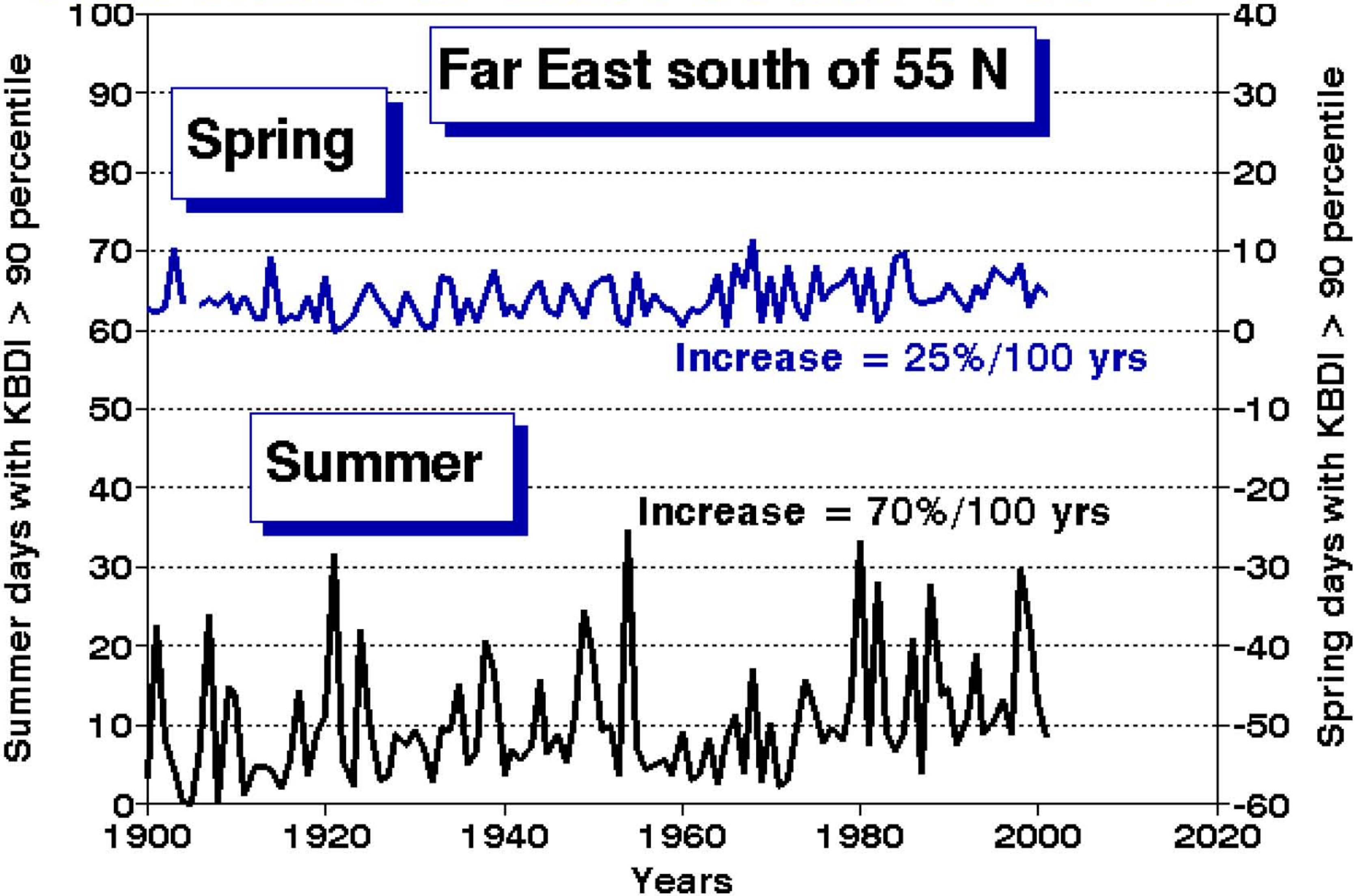
Dates when vegetation season starts, Julian day

Siberia south of 55N



Potential Forest Fire Danger Increase.

Russian Far East south of 55°N



Groisman et al. 2007, "*Global and Planetary Change*", 56, 371-386.