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Impact of Data Paucity and Handling Techniques on Intense Precipitation Analyses

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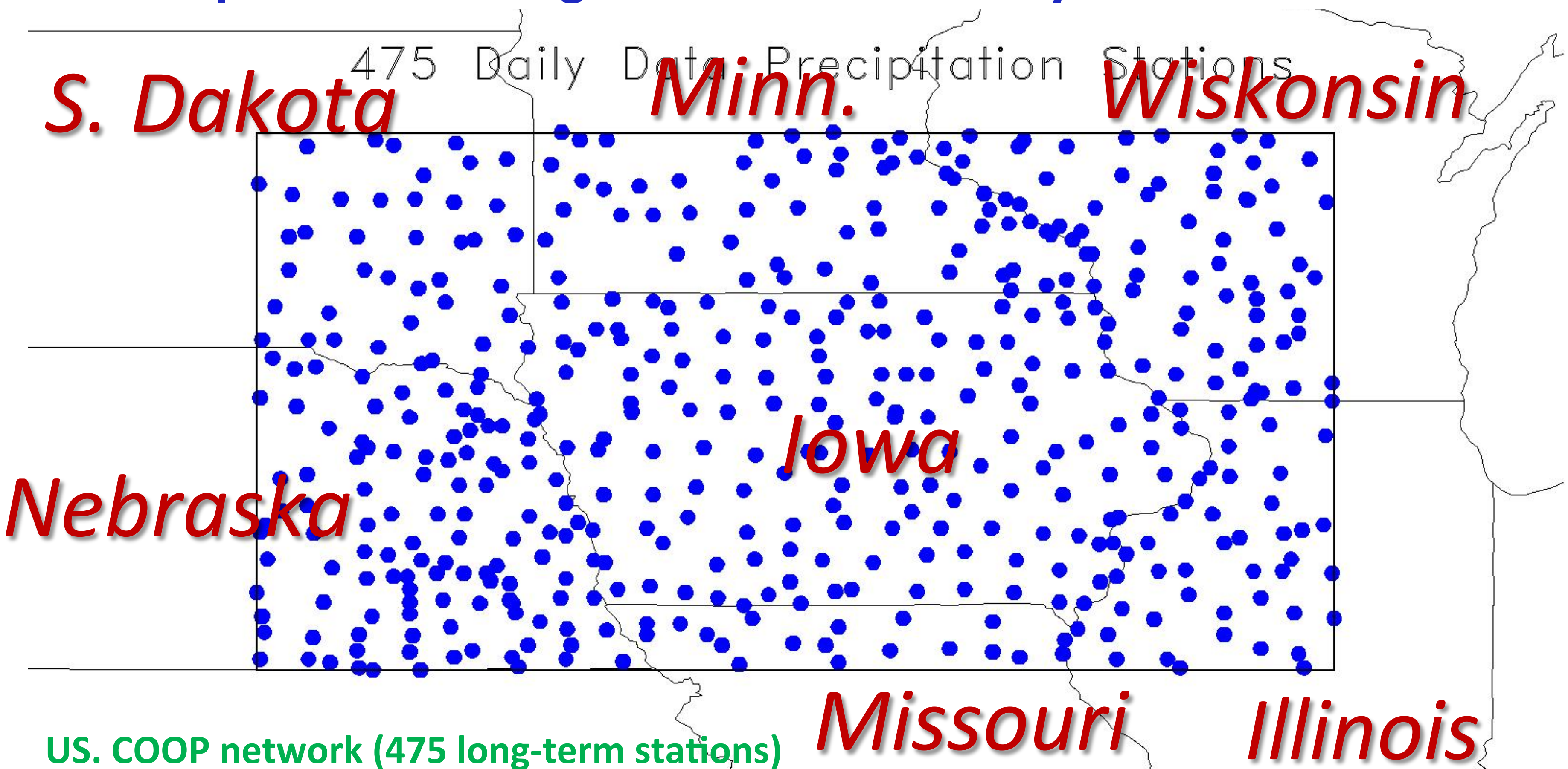
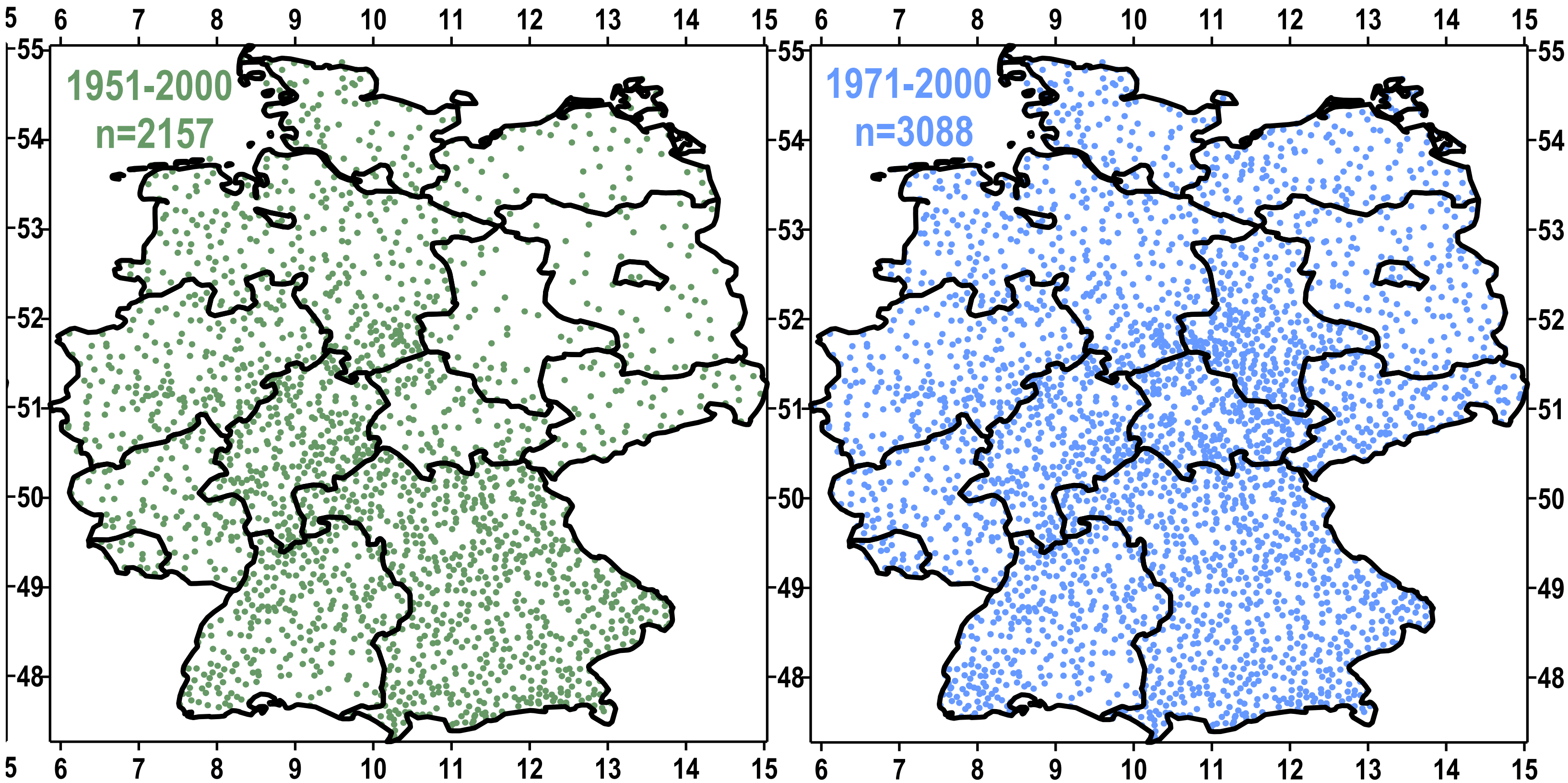
Part 1. Networks, observations, and methods that impact our conclusions about extremes

1. Observations
2. Methods of gridding
3. Examples for two regions well-covered by in-situ observations



US. COOP network (475 long-term stations)

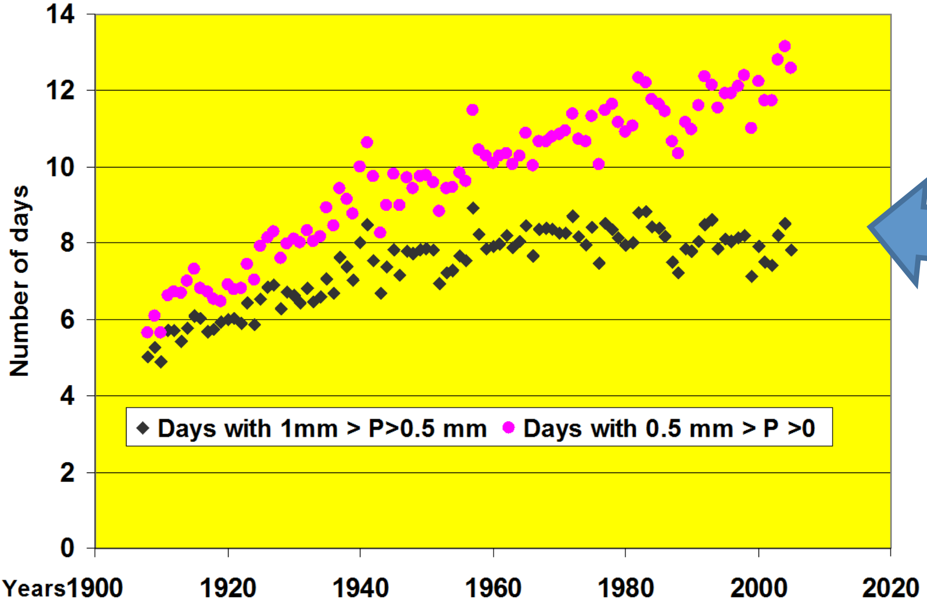
Germany has about the same area as the selected Midwestern Quadrant. It has ~7,500 rainfall stations and more than 2100 of them have long-term time series



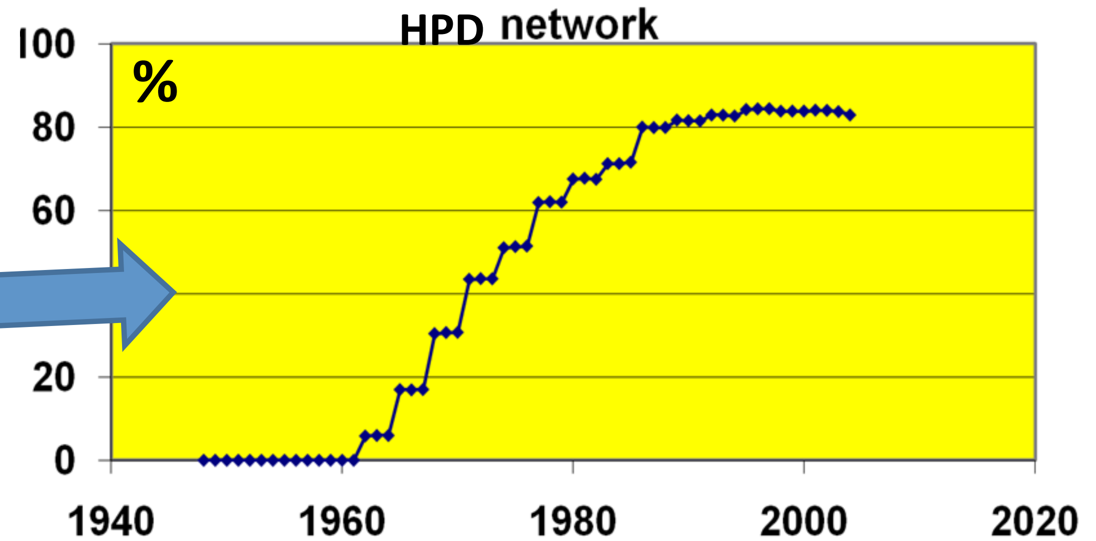
STAMMEX; Zolina et al. 2013. *Bull. Amer. Meteorol. Soc.* in review

- We shall compare extreme rainfall reported by two gridded products over Germany (Spatial and Temporal Scales and Mechanisms of Extreme Precipitation Events over Central Europe, STAMMEX, 0.1° x 0.1° and ECA&D (European Climate Assessment & Dataset; E-OBS dataset of several hundred stations, 0.25° x 0.25°) and the Midwestern U.S. reported by two gridded data sets (NOAA NCDC TD-3721, 0.5° x 0.5° and NOAA ESRL, 0.25° x 0.25°) and by in situ Cooperative (COOP) station data.

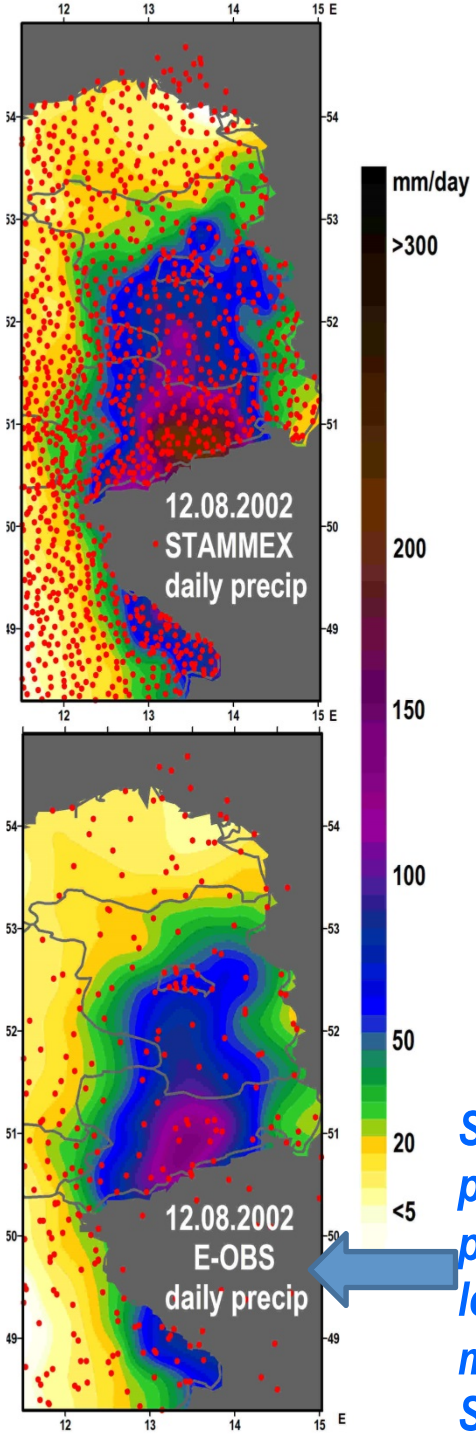
When observations quality interferes with our ability to study changes in intense precipitation



- Mean number of days with non-zero very light daily precipitation over the conterminous United States.

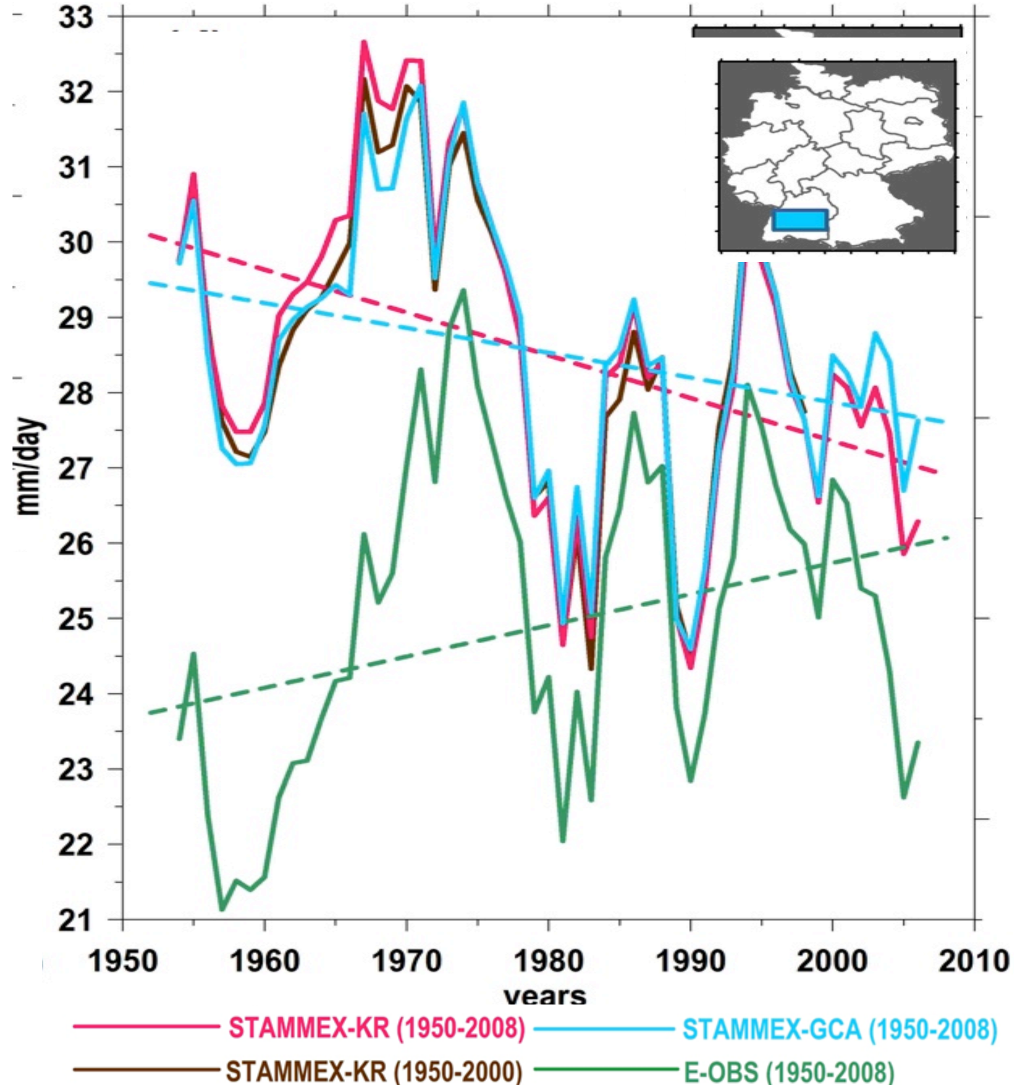


- Fraction (%) of recording rain gauges with 0.1 inch accuracy among the U.S. hourly precipitation (HPD) network.



Left. Daily rainfall for 12.08.2002 over Saxony and around it derived from STAMMEX (top) and E-OBS (bottom) grids.

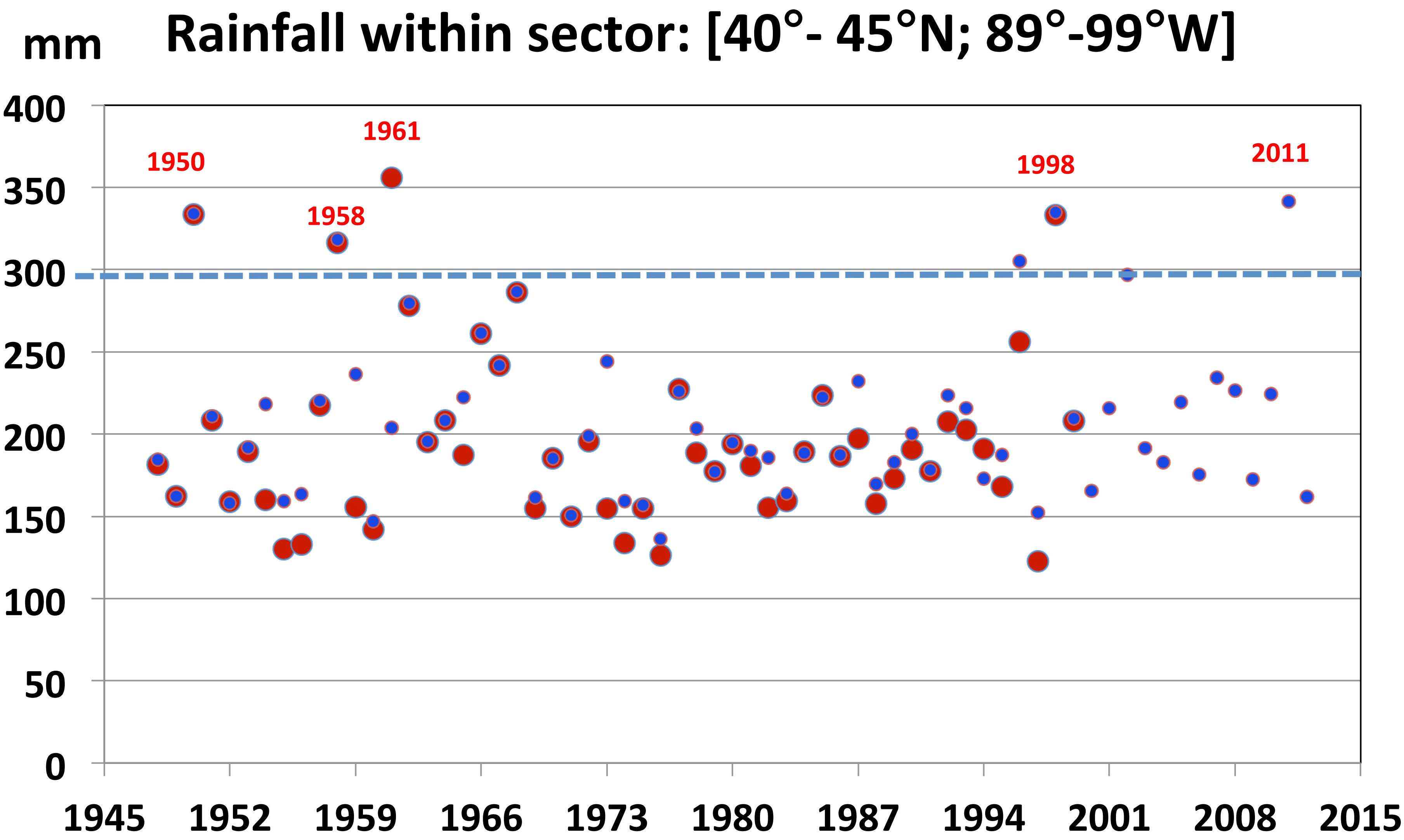
Right. Upper 1st percentile of daily summer rainfall time series over Baden-Württenberg.



STAMMEX grids accurately replicate location and values of maximum daily precipitation (more than 265 mm d^{-1}). A coarser resolution network E-OBS precipitation grids show twice as small daily precipitation (133 mm d^{-1}) located about 50 kilometers northwest where STAMMEX reports nearly 100 mm d^{-1} higher values. Both data sets use the same 0.25° × 0.25° grid but STAMMEX employs 5 times more rainfall stations.

Zolina et al. 2013

Midwestern USA. Annual maximum daily precipitation



Comparison of **in situ** and gridded **TD 3721** extremes

Midwestern USA. Annual maximum daily precipitation

Rainfall within sector: [40°- 45°N; 89°-99°W]

	1950	1958	1998	2011
In situ	334	318	335	342
TD 3721	334	316	333	-
Date of event	July 9th	July 2nd	June 14th	July 28th
ESRL	311	313	309	-
	Same events		Sep. 14th	

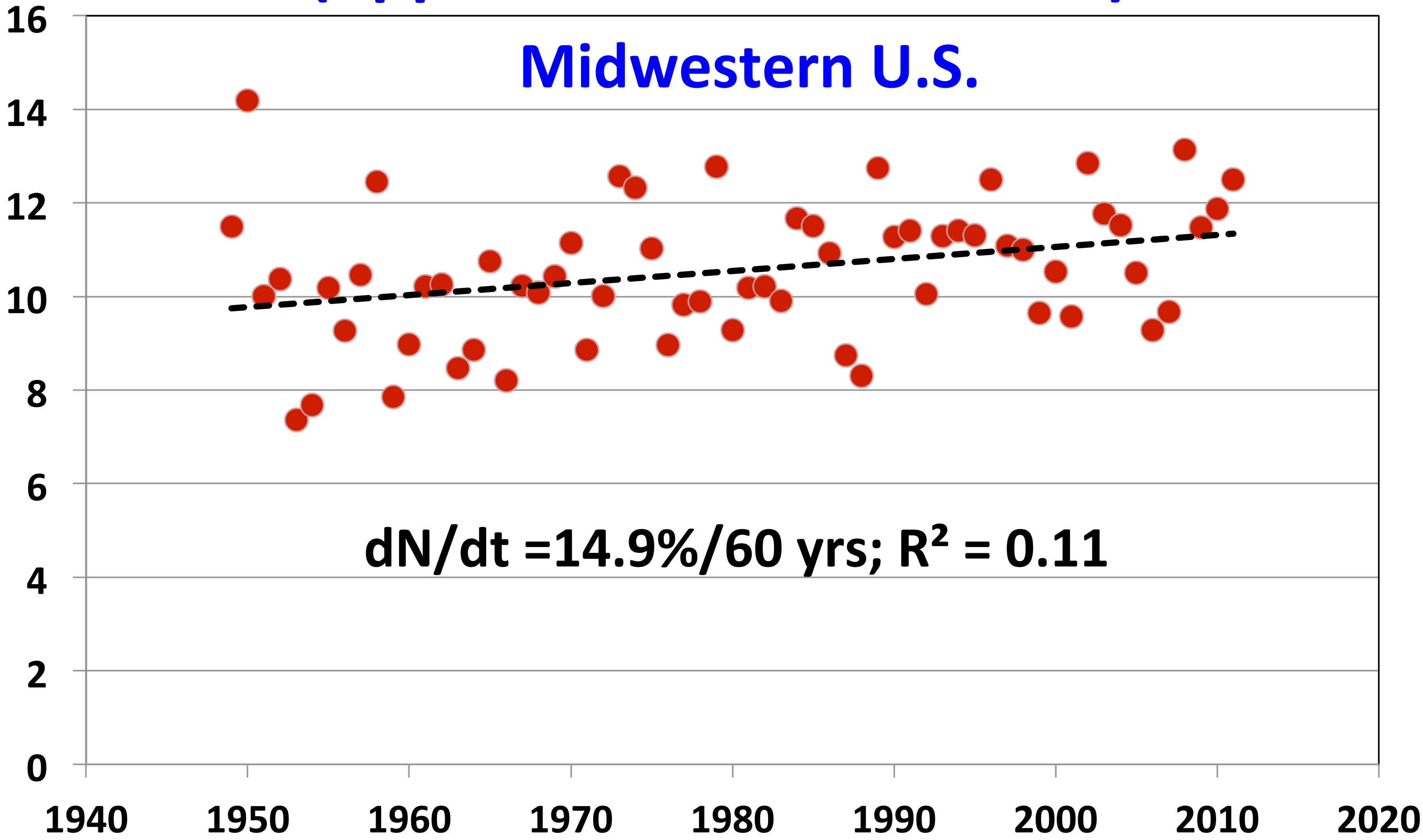
Comparison of in situ and gridded TD 3721 and ESRL extreme daily rainfall values in selected years

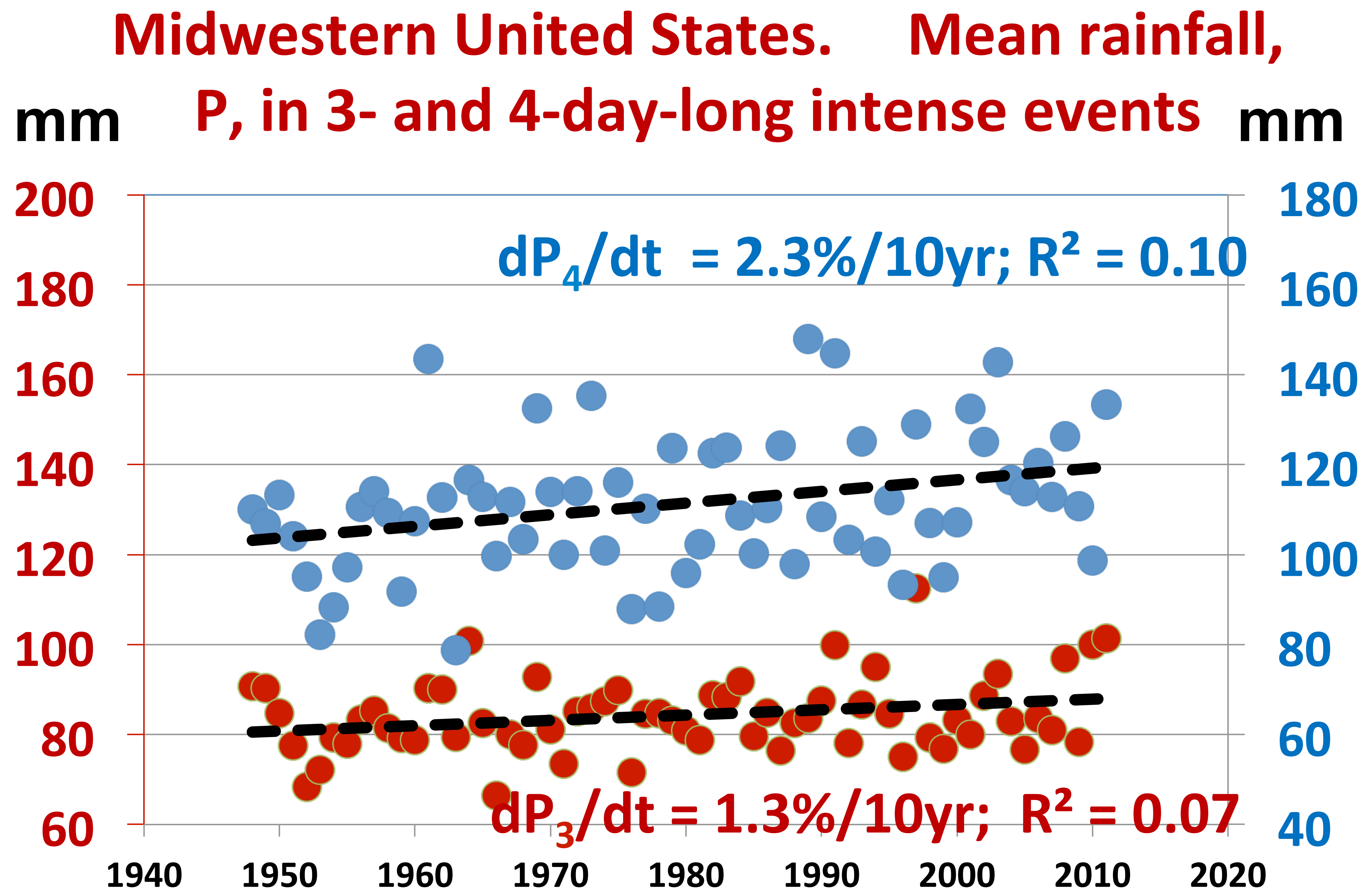
Annual maximum daily precipitation at the stations of Midwestern U.S. (sector: [40°- 45°N; 89°-99°W]) during the 1948-2012 period as a function of the network density.

Selected percent of station data	Mean number of stations	Average annual maximum rainfall during the entire period, mm	Absolute maximum rainfall, mm, and year for the entire period
100%	452	208	342 (2011.07) in one of samples
70%	316	198±15	342 (2011.07)
40%	181	184±23	335 (1998.06)
10%	45	149±30	335 (1998.06)
5%	22	129±30	226 (1977.08)
2%	9	110±27	226 (1977.08)
1%	4	92±27	226 (1977.08)

CONUS is encompassed by about twenty 5° x 10° grid cells.

Number of days with heavy precipitation (upper 10% of rain events)





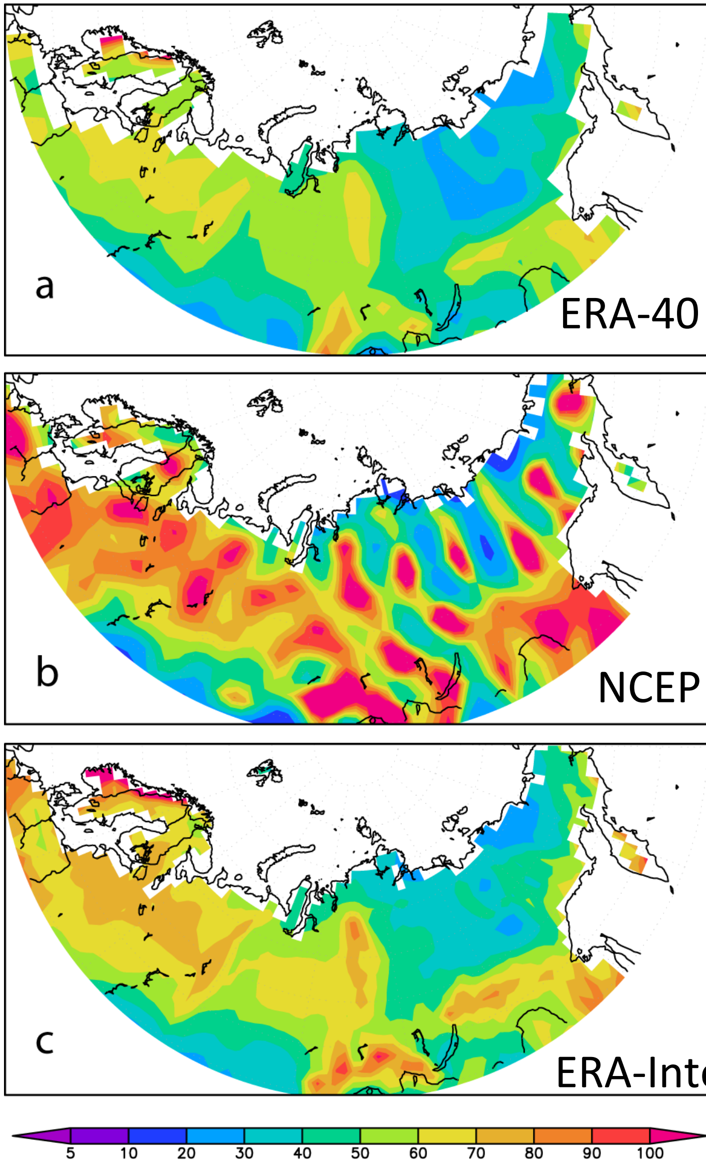
Day with intense precipitation is defined as a day with P > 12.7 mm

“Take home” messages

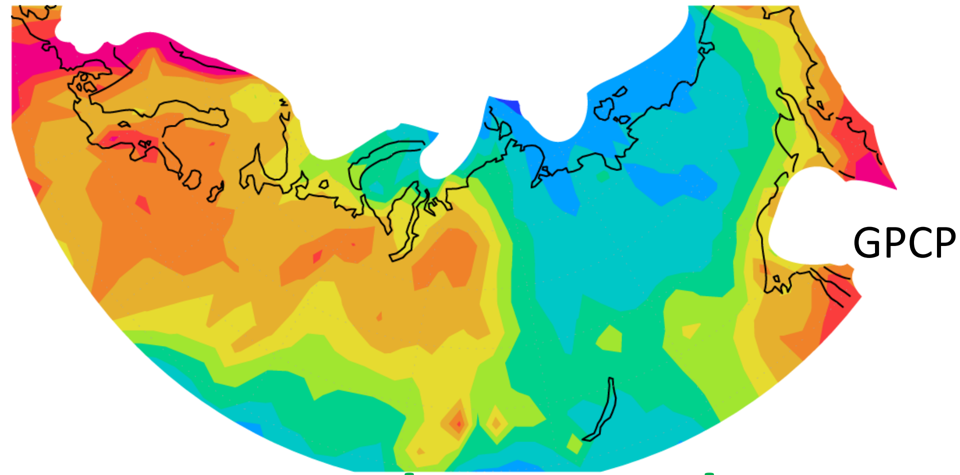
- Stability with time and reasonable spatial distribution of observational rain gauge networks are critical for precipitation extremes quantification and detection of their changes. In particular,
  - Different interpolation and pre-processing techniques for dense networks report similar extreme values but may “catch” different absolute extreme events
  - **The same, but for sparse networks may give misleading results on locations, values, and trends of extreme events**
- Annual maximums are poor indicators of extreme rainfall changes
- **It does matter** what networks and methods we use to study extreme precipitation changes.

How good are reanalyses based on sparse in situ networks?

Annual mean precipitation

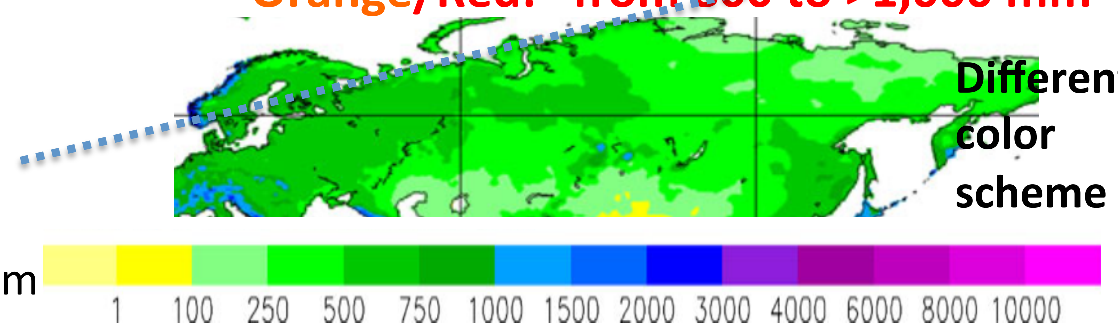


This scale is in cm; scale step =100 mm



Cherry et al. 2013

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



Different color scheme

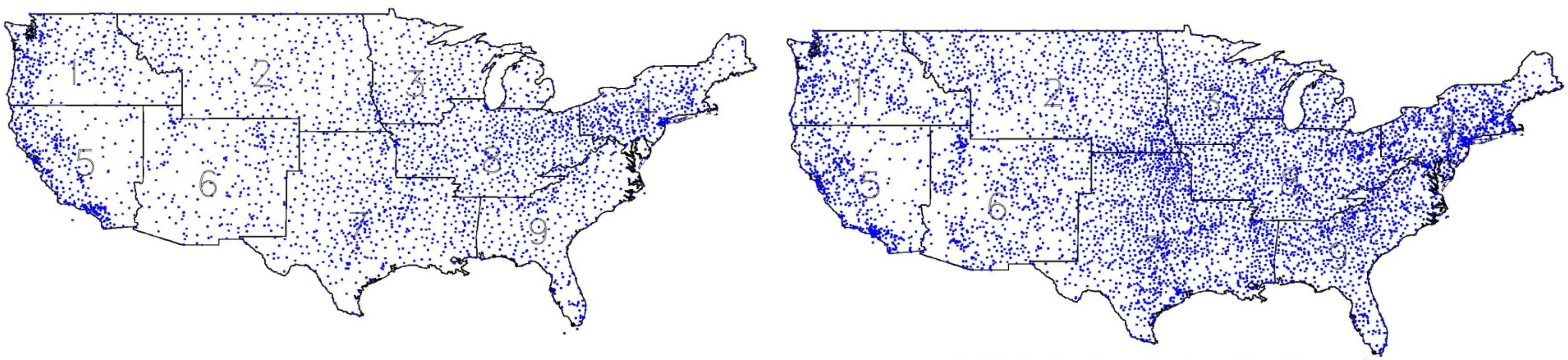
This scale is in mm; scale step =250 mm

GPCC; Schneider et al. 2013

Part 2.

Intense precipitation climatology over the conterminous U.S.

Our analyses are based upon hourly and daily precipitation data over the conterminous United States



Two station networks used in our analyses of hourly and daily precipitation.
Blue dots on the maps show distribution of 3076 long-term hourly (HPD; left) and 5885 daily stations (COOP; right)

Annual thresholds, P, for upper 0.3% of daily precipitation events in different parts of the world

Region	P, mm
South & Southeastern U.S.	105
Southwestern U.S. (four corners)	45
Northeastern Australia	140
Southwestern Australia	55
Amazon River Basin	95
Southern Brazil & Uruguay	120
Russian Arctic	20
Kazakhstan	30
India	150
South Africa	80
Southeastern Canada	50
Fennoscandia	45

Terminology used in presentation for the conterminous United States

Day with intense precipitation P>12.7 mm d^{-1}

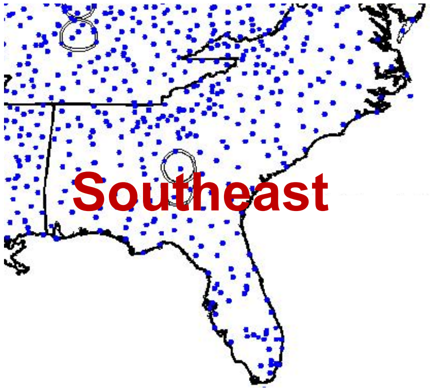
Multi-day intense event is constructed from consequtive intense precipitation days

Moderately heavy precipitation $12.7 < P \leq 25.4$ mm d^{-1}

Heavy precipitation $25.4 < P \leq 76.2$ mm d^{-1} or mm $(\text{event})^{-1}$

Very heavy precipitation $76.2 < P \leq 154.9$ mm d^{-1} or mm $(\text{event})^{-1}$

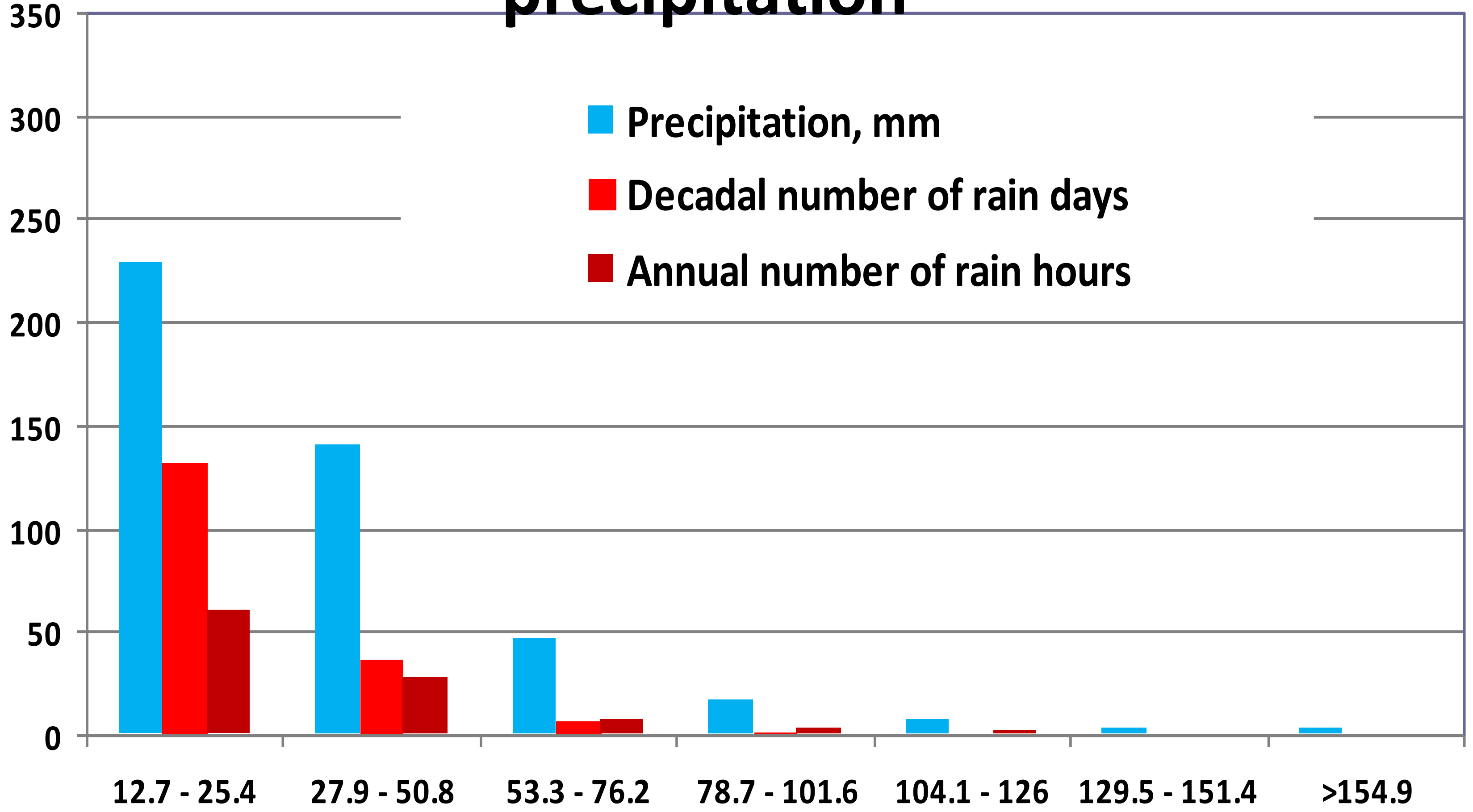
Extreme precipitation $P > 154.9$ mm d^{-1} or mm $(\text{event})^{-1}$



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

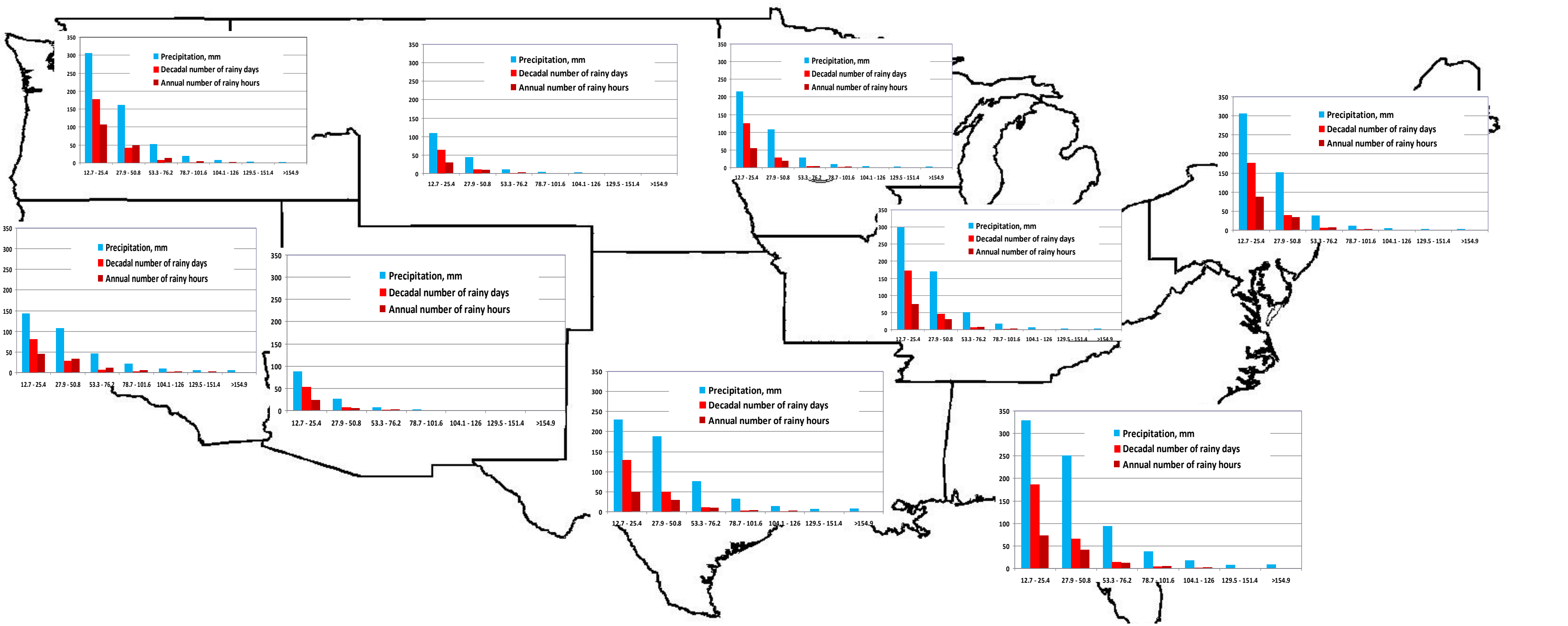
Precipitation event range, mm	Annual rainfall, mm	Decadal number of rain days	Annual number of rain hours	Average intensity, mm/ h.	Duration, hours	Peak intensity, mm/h.
12.7 - 25.4	329	187	73	4.6	3.9	8.9
27.9 - 50.8	250	66	40	6.1	6.1	16.8
53.3 - 76.2	93.5	15	12	7.9	8.1	25.2
78.7 - 101.6	36	4	4	9.1	9.9	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 daily precipitation totals in the days with intense precipitation



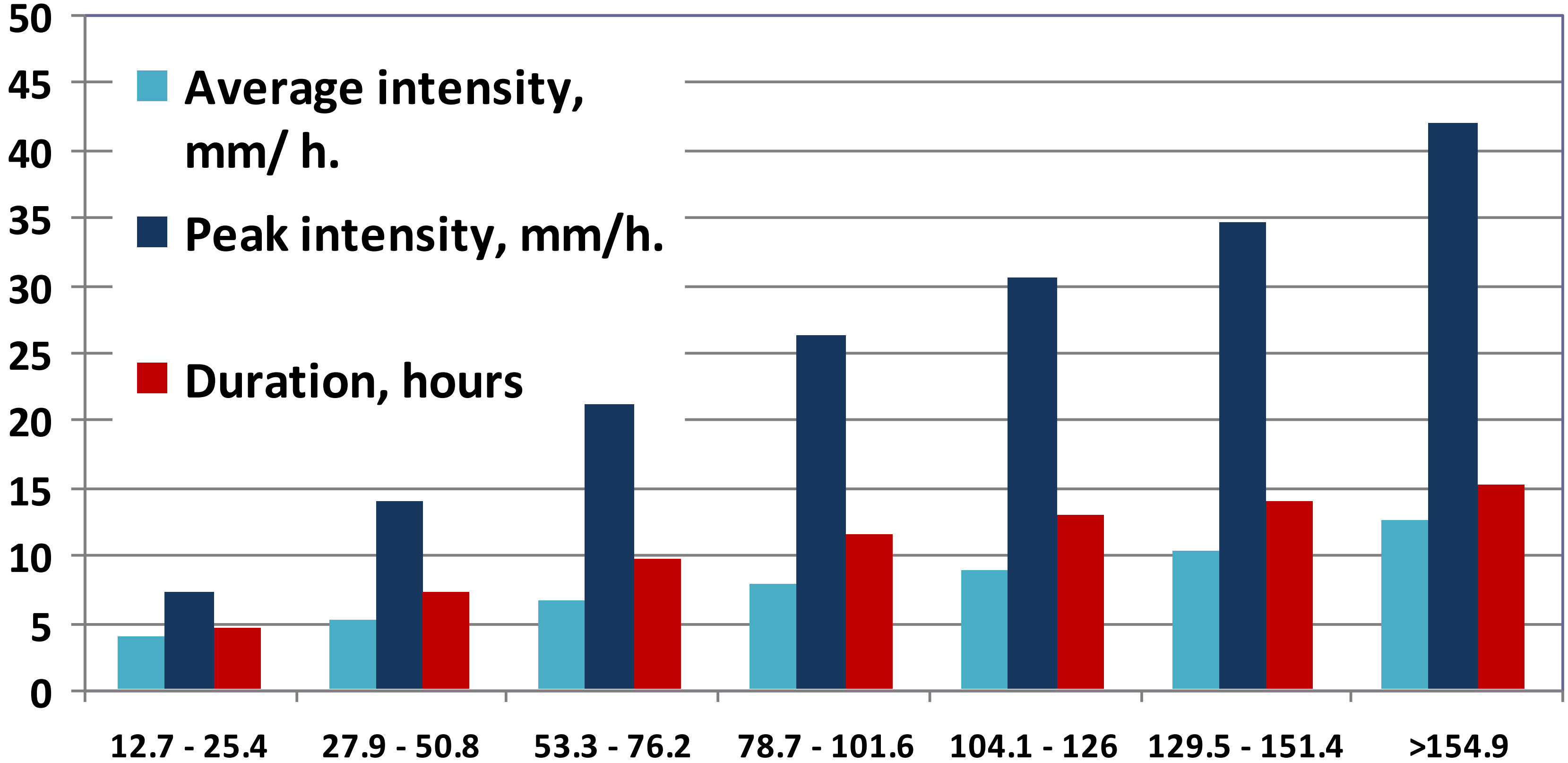
Mean point annual intense precipitation, mm; mean point decadal number of days and mean point annual number of hours with intense precipitation

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



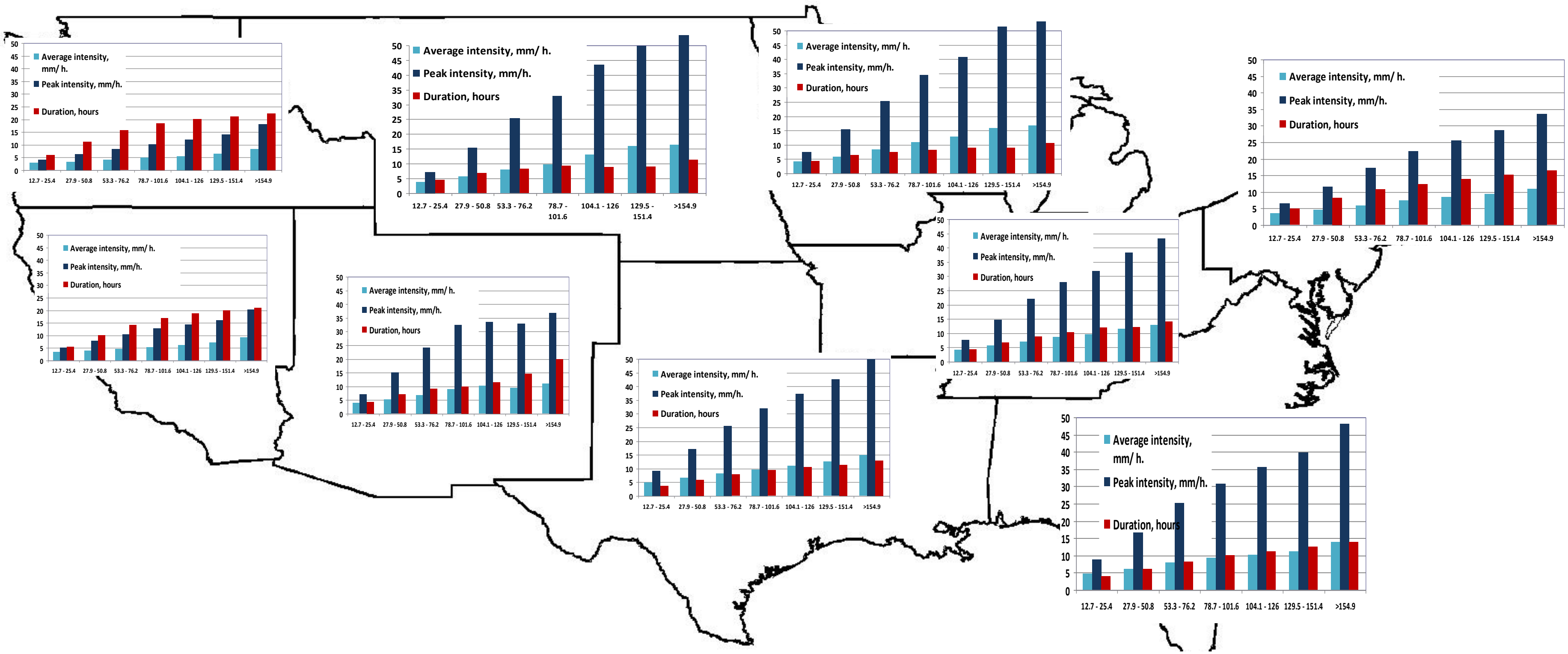
Mean point annual intense precipitation, mm; **mean point decadal number of days** and **mean point annual number of hours with intense precipitation**

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



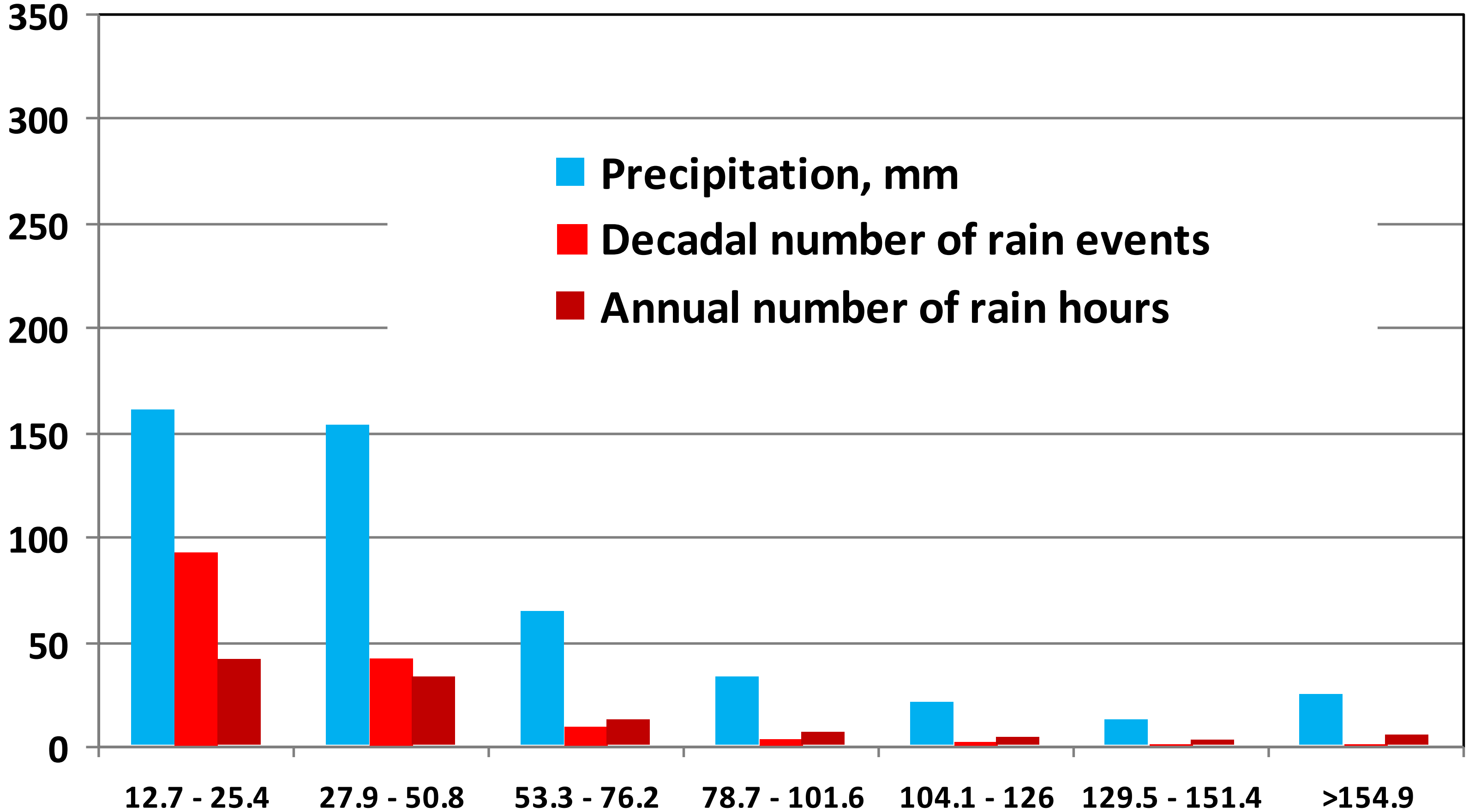
Mean daily and peak precipitation intensity mm h^{-1}; and mean duration of daily precipitation events, hours.

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



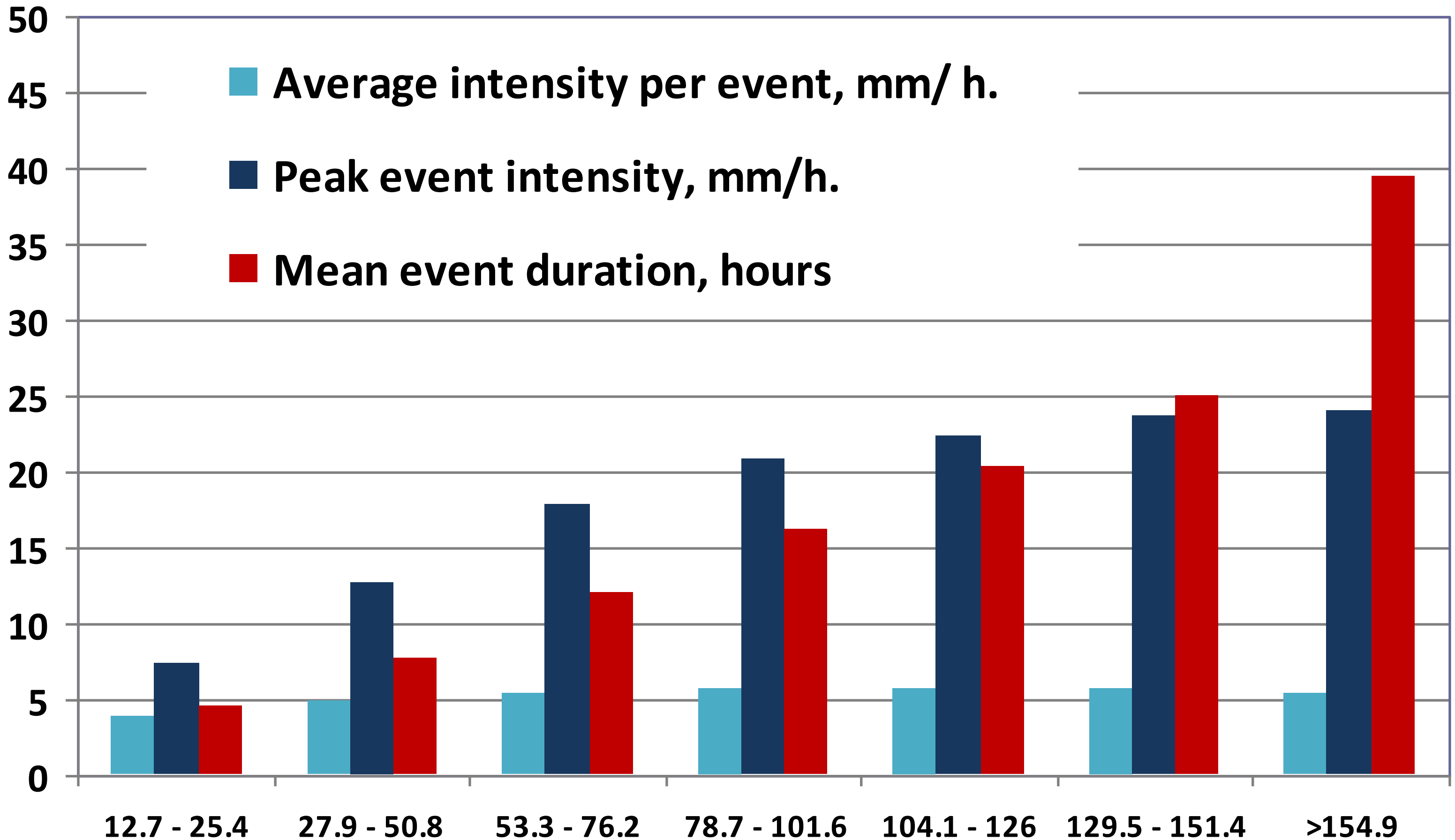
Mean daily and peak precipitation intensity mm h^{-1}; and mean duration of daily precipitation events, hours.

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.

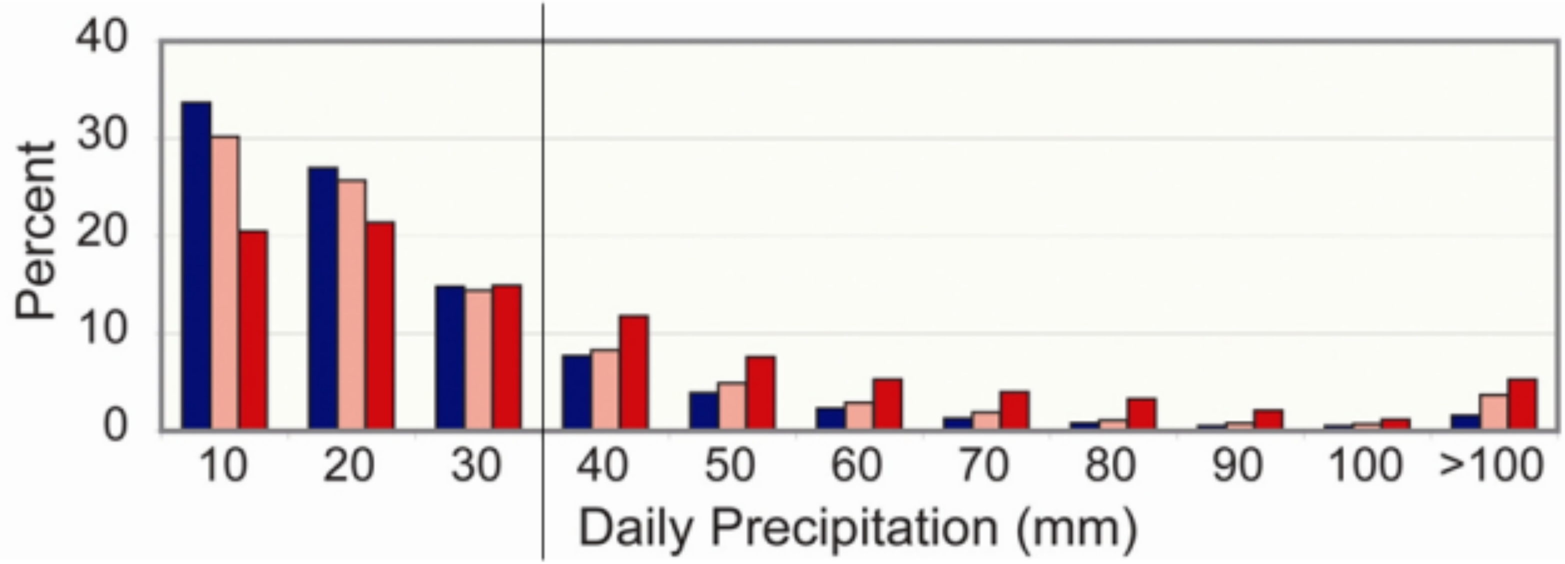
Nationwide climatology of various characteristics of hourly intense precipitation as a function of multi-day intense precipitation event totals



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

Part 3.
Changes in Precipitation Intensity and Prolonged Dry Periods

Higher temperatures => increase in precipitation intensity

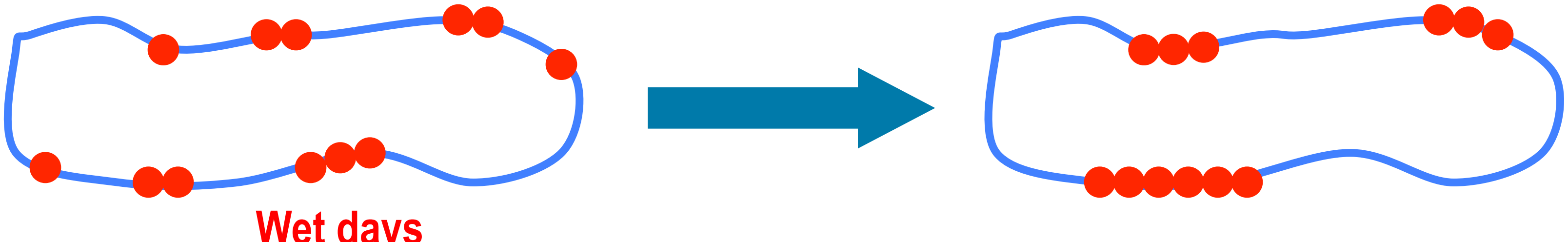


- **Climatology of the intensity of daily precipitation in 10 mm/day categories for stations with the same mean seasonal precipitation (~230 mm) and different temperature regimes (<19°C, blue bars; between 19°C and 29°C, pink bars; and > 29°C, red bars)**

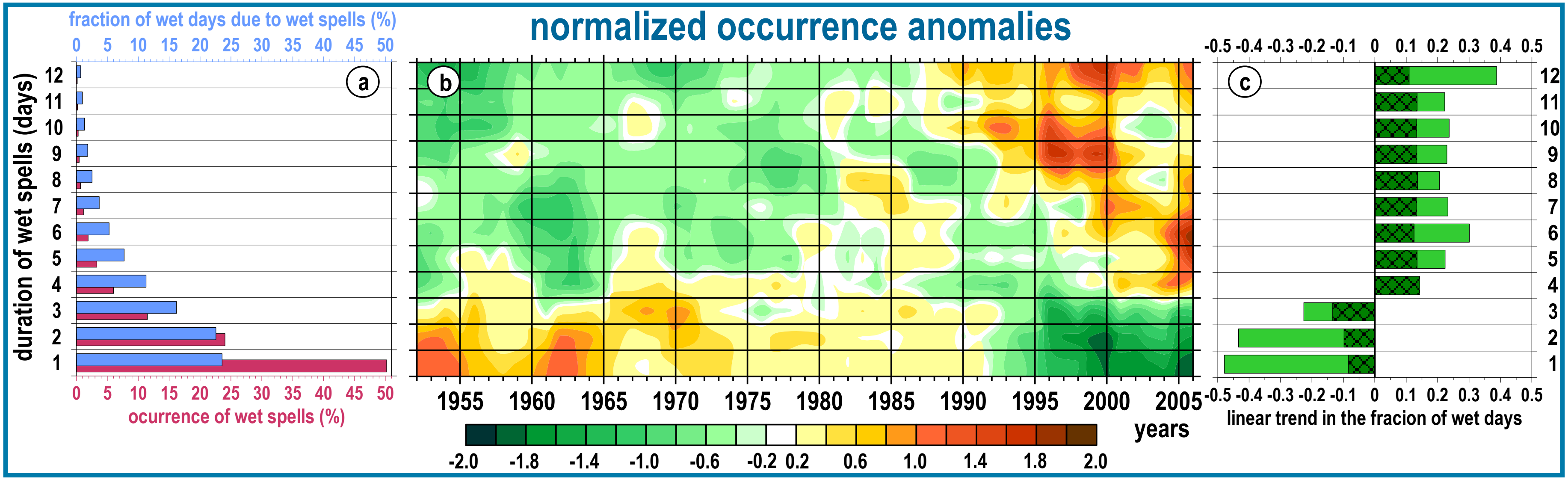
[*Karl and Trenberth 2003, Science*]

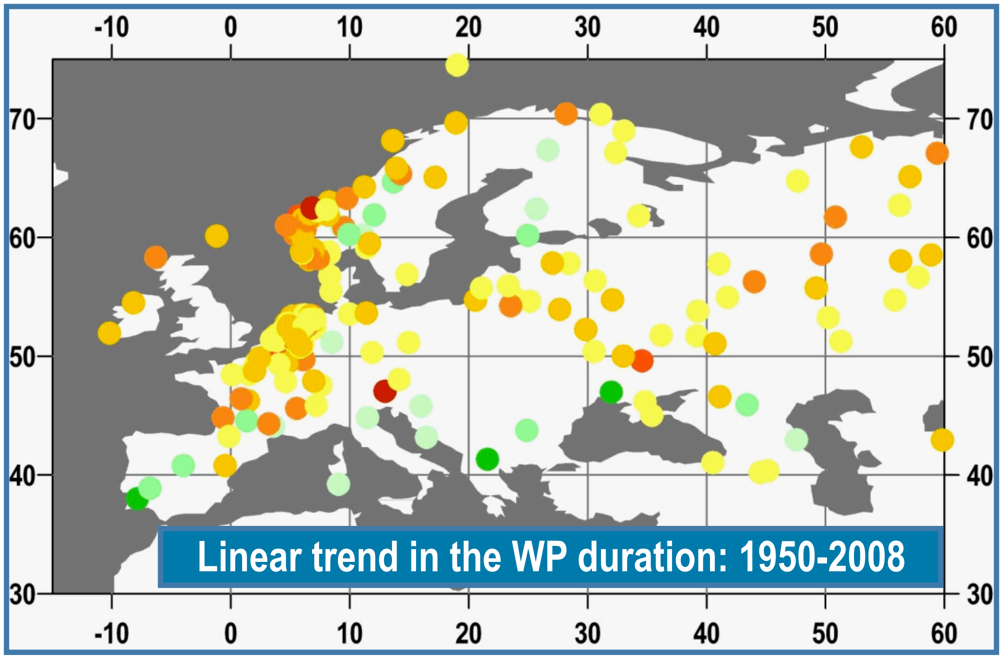
… and (by implication) a possible reduction of the frequency of rainy days

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).



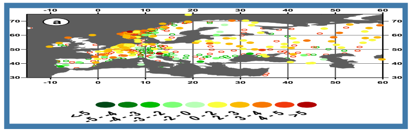
Changes in the duration of European wet periods





Frequencies of the 1- to 3-day long wet events have decreased while prolonged precipitation events (up to 12 days in a raw) have increased.

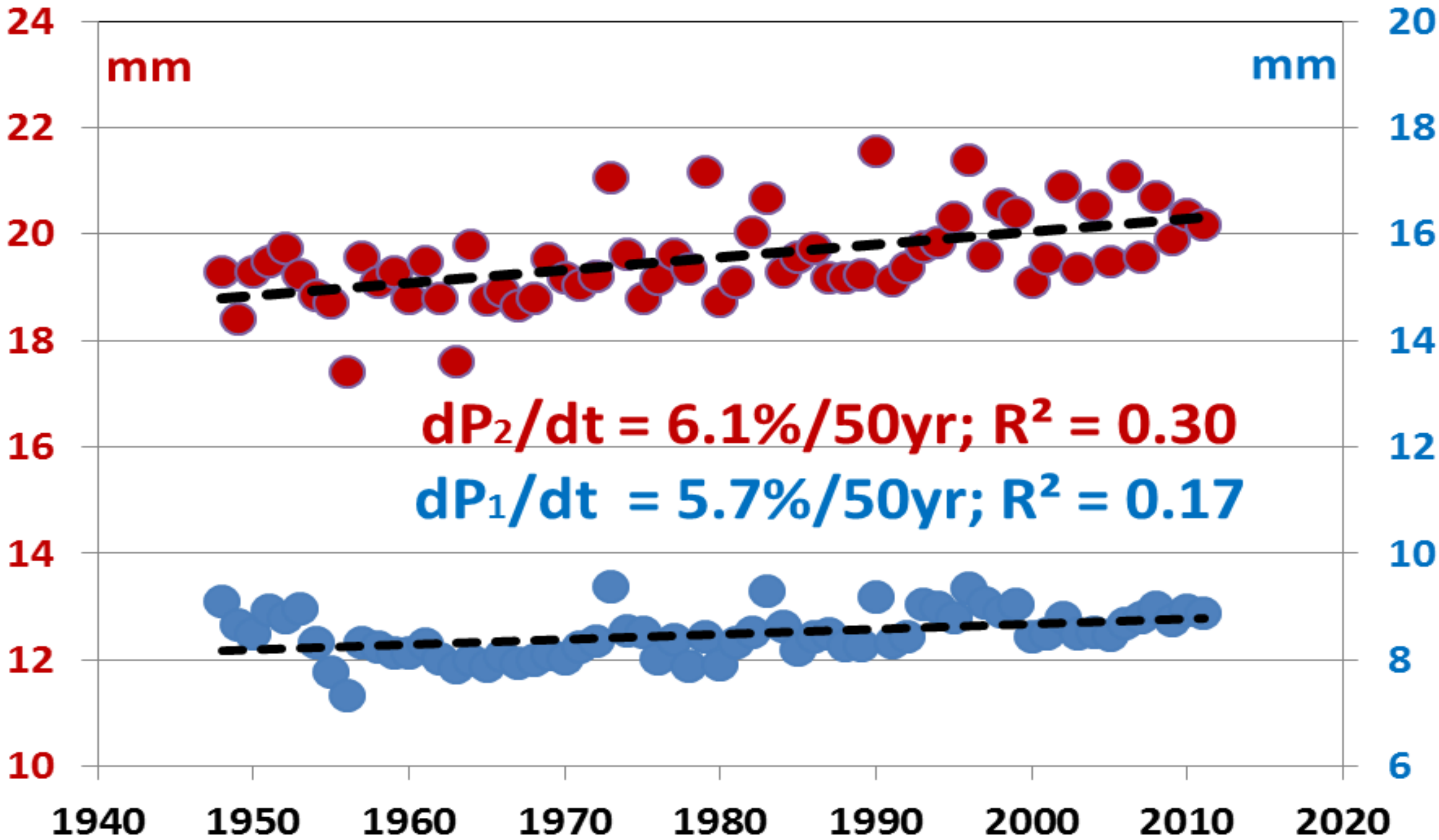
It is not the effect of changing number of wet days!!!



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

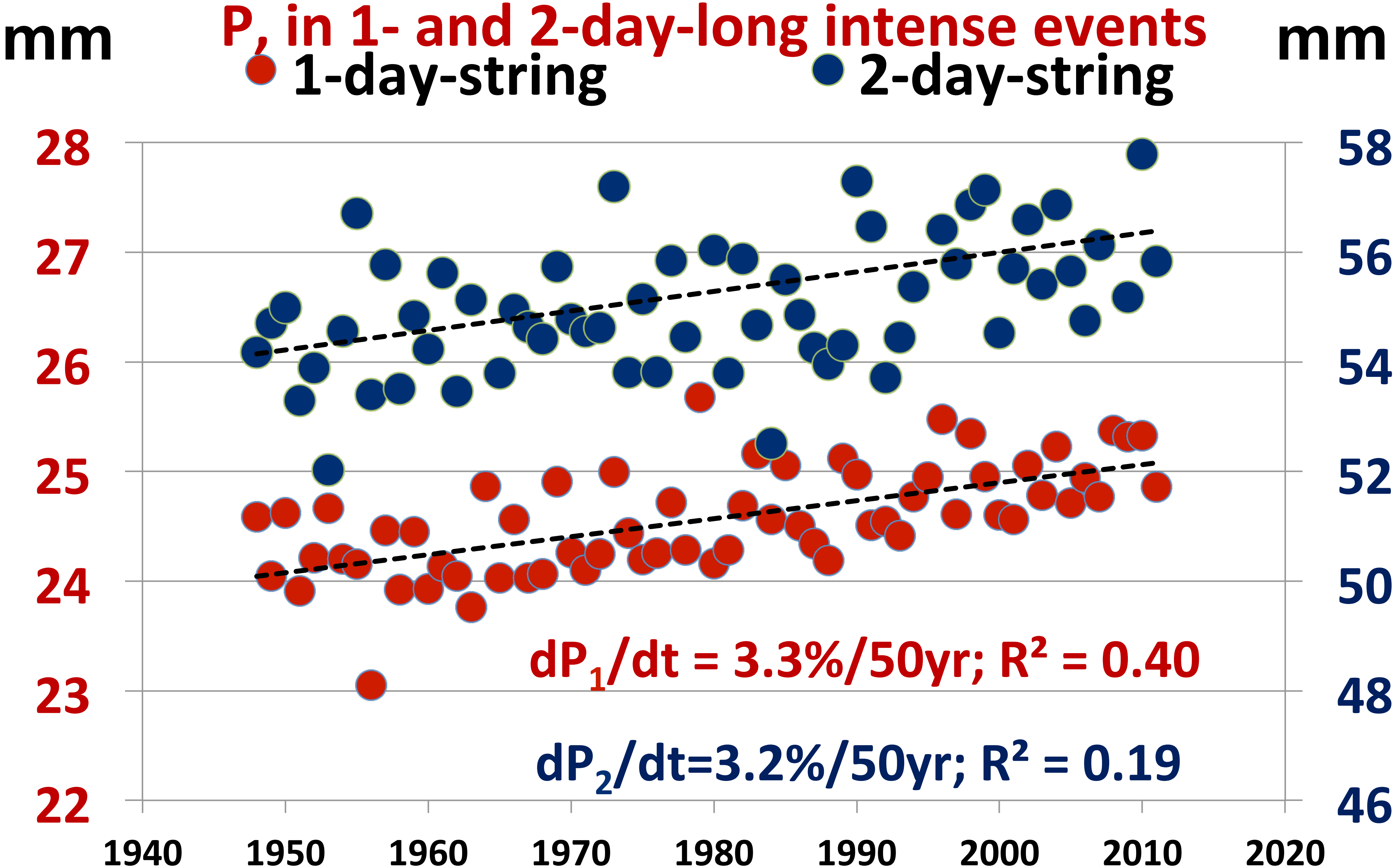
Precipitation Intensity

Mean precipitation per event that comes with 1-day- and 2-day-long events over the contiguous United States



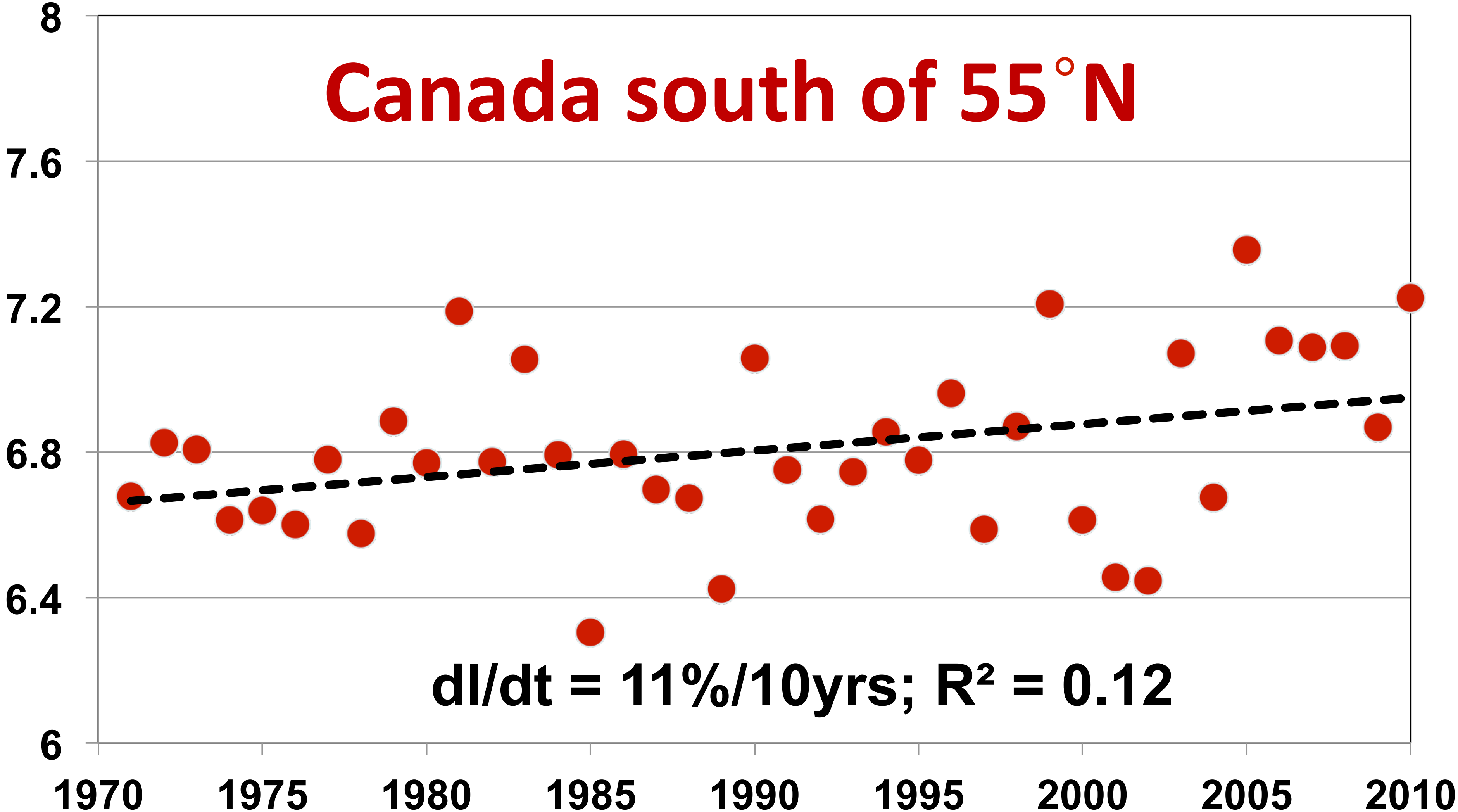
The estimates of precipitation intensity in 1-day-long (P_1, mm day^{-1}) and two-day-long (P_2, mm (2 days)$^{-1}$) are based upon all precipitation events above 0.5 mm at ~6,000 long-term U.S. cooperative stations during the 1948-2011 period (Updated archive of Groisman et al. 2012).

Contiguous United States. Mean precipitation, P, in 1- and 2-day-long intense events

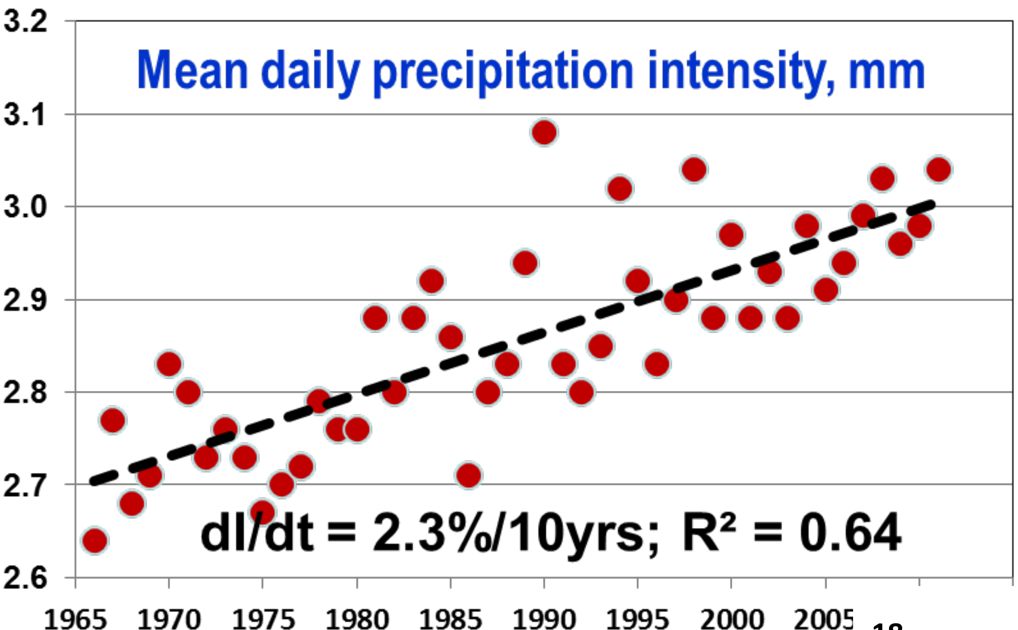


Day with intense precipitation is defined as a day with P > 12.7 mm

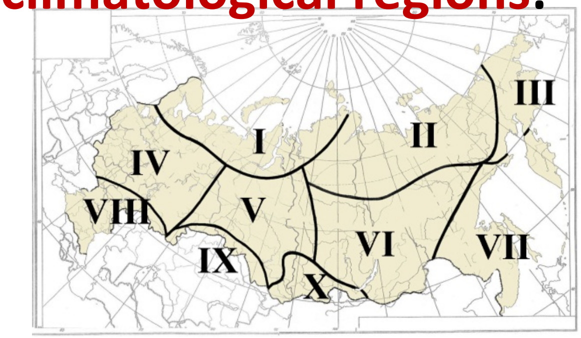
Mean annual precipitation intensity, mm d^{-1} over Canada south of 55°N



Nationwide precipitation intensity, I, changes over Russia

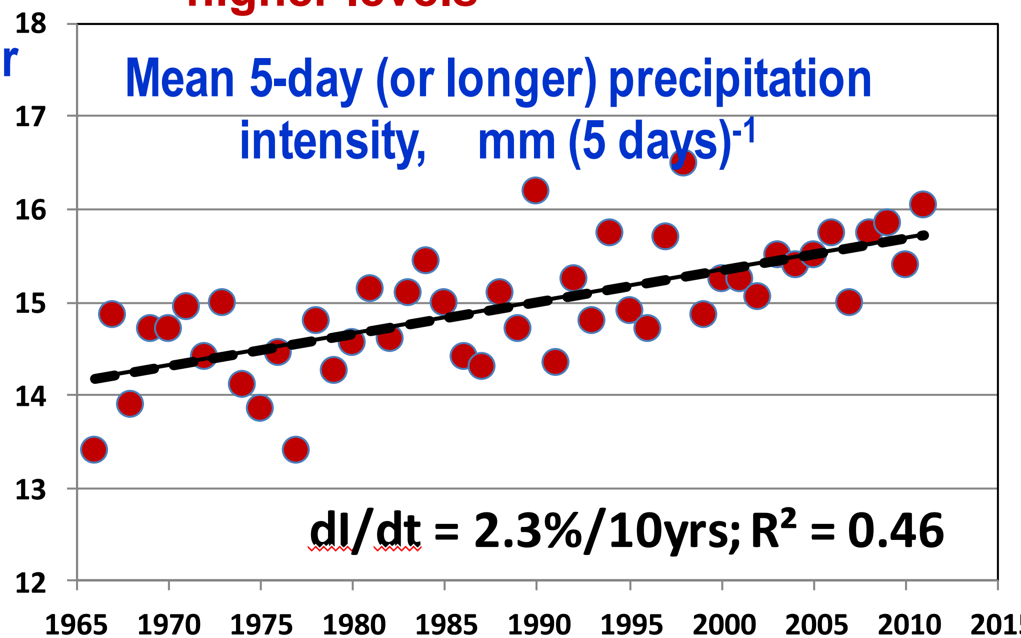


Russian climatological regions:

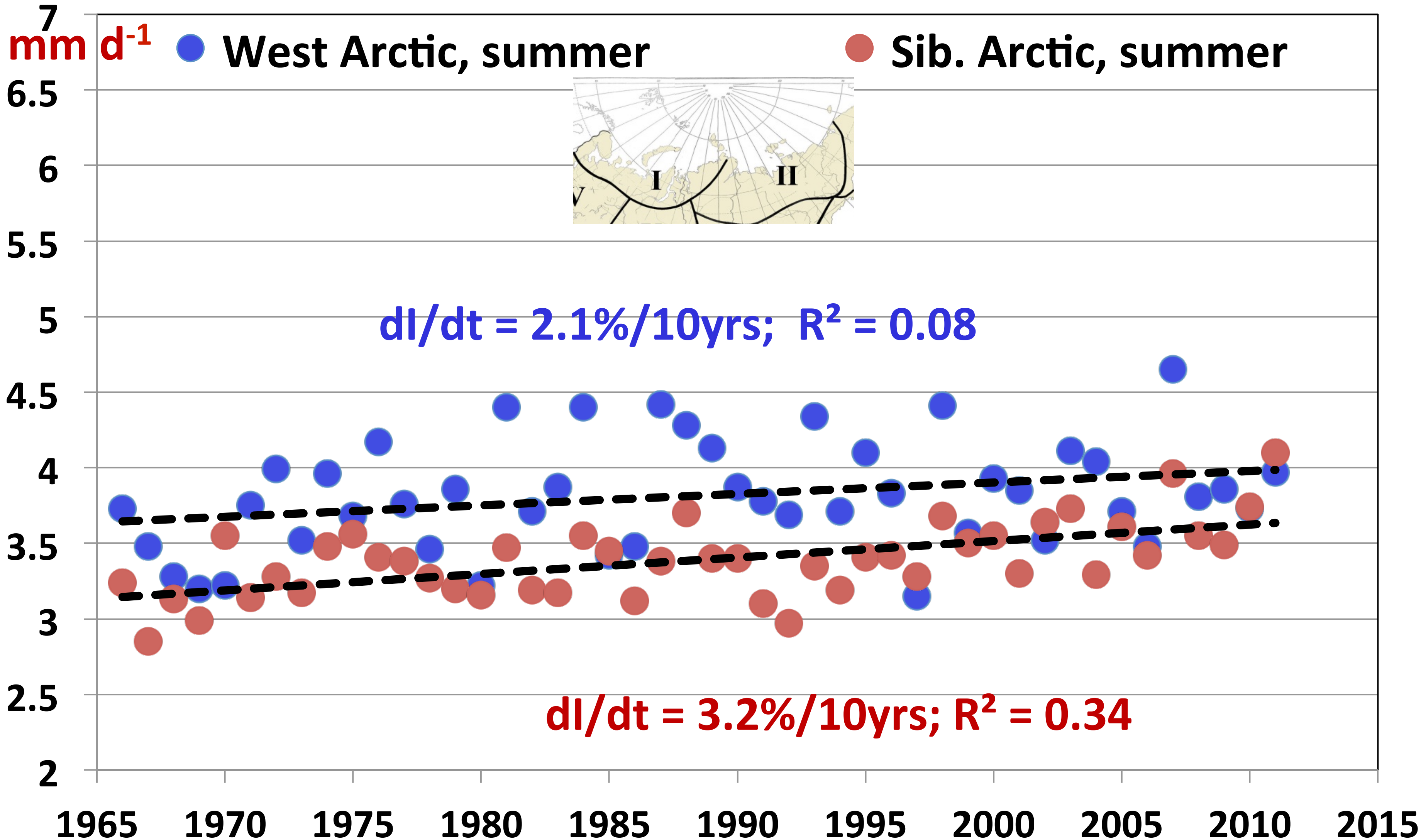


Precipitation intensity trends over all these regions are positive and statistically significant at the 0.05 or higher levels

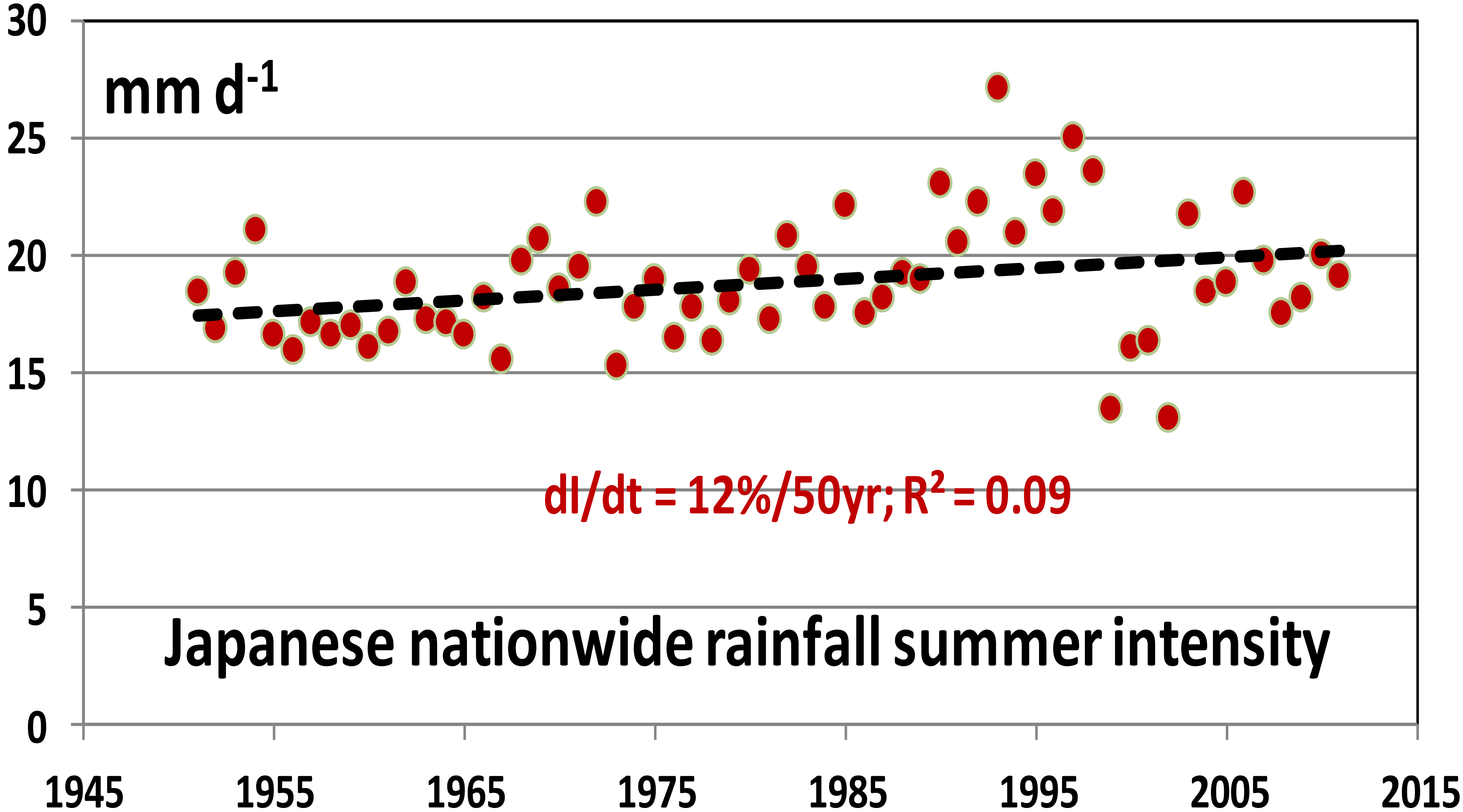
To receive the nationwide time series, for each year and each station mean annual precipitation intensity was calculated as (totals/number of events). Thereafter, point estimates were area-averaged arithmetically within climatological regions shown in the map and, finally, these regional mean values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



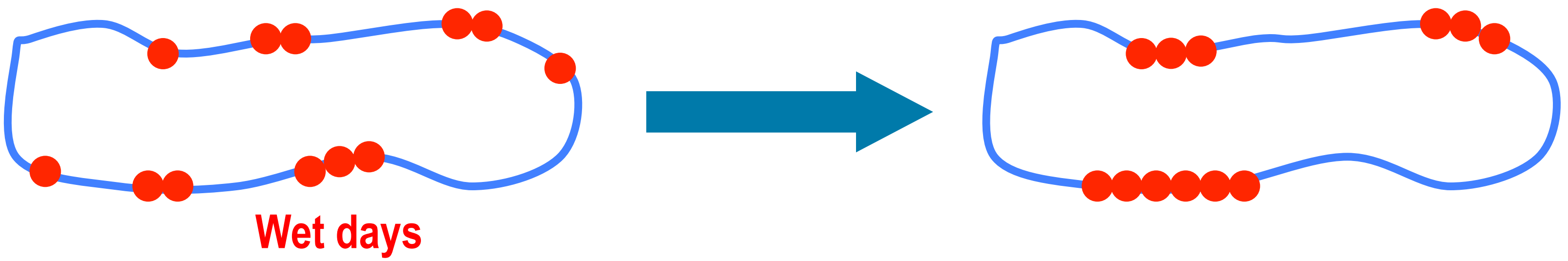
Mean summer precipitation intensity over Russian Arctic (mm d^{-1})



Mean summer (JJA) rainfall intensity, mm d^{-1} over Japan

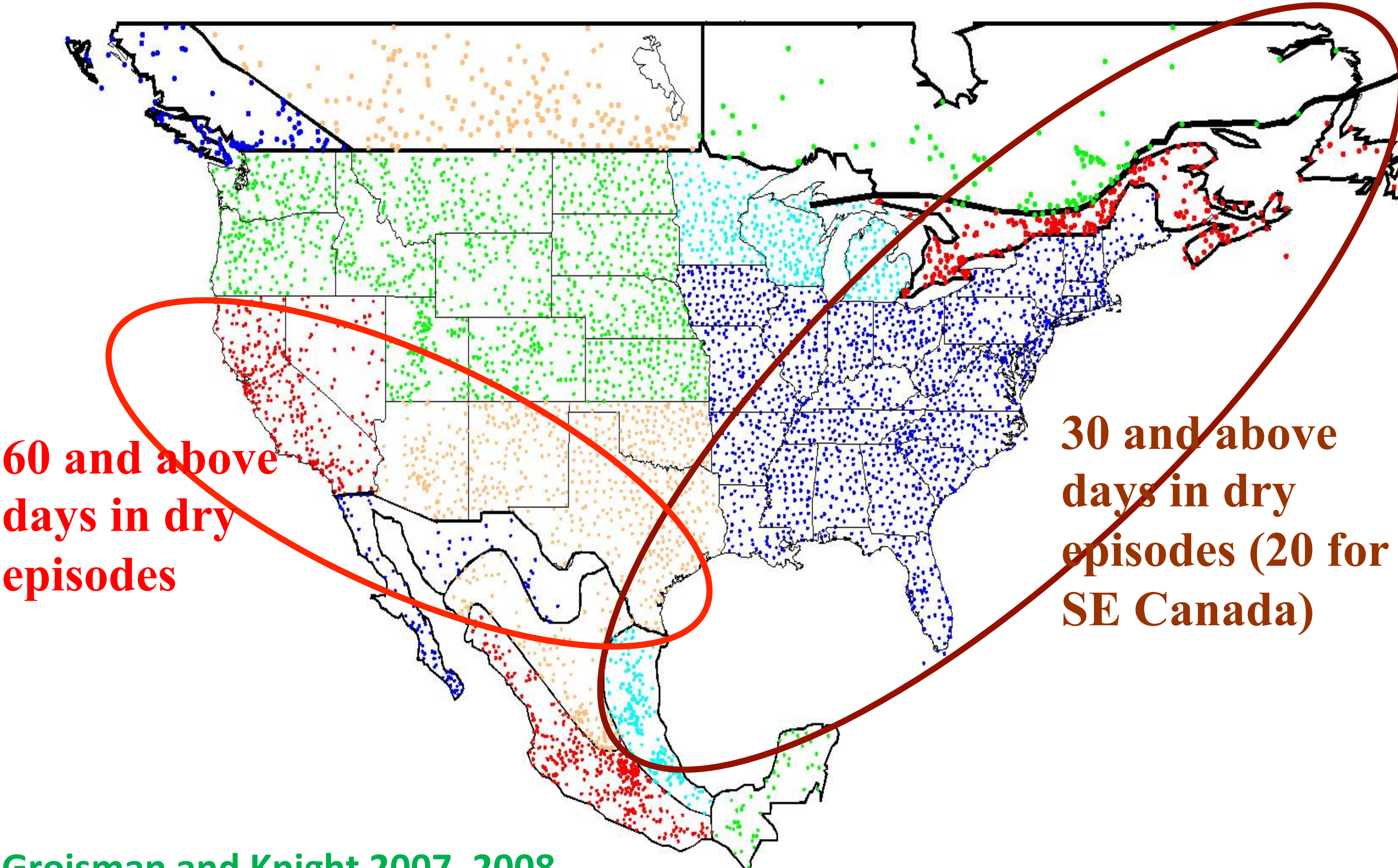


Beads with a fixed number of stones illustrate how we can have in the same region simultaneously increases in prolonged Wet Day and Dry Day Periods even with unchanged precipitation totals (design by O.G. Zolina).



Prolonged No-rain Periods, Warm Season Dryness, and Potential Forest Fire Danger

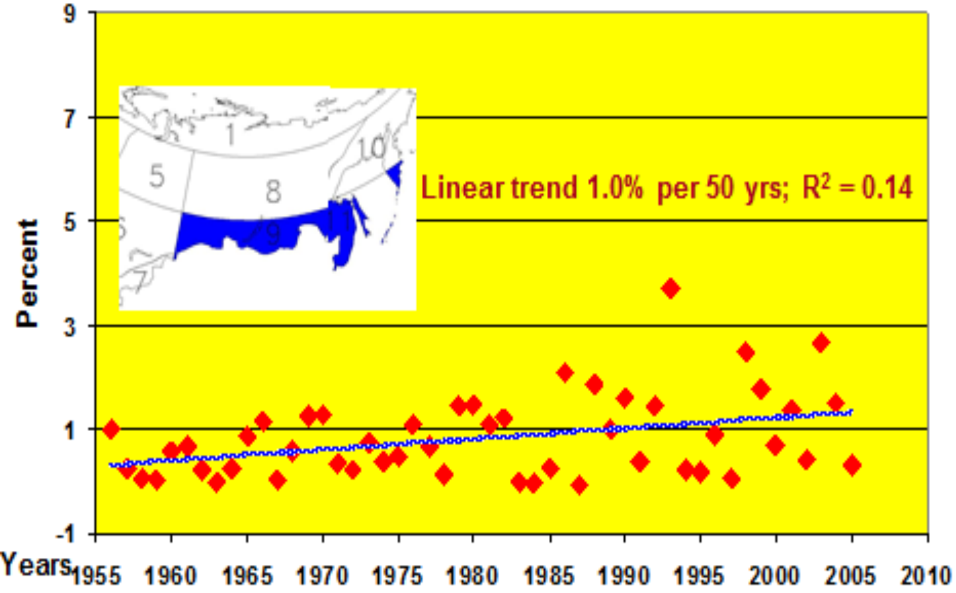
Regions where dry episode frequency was increasing during the past 40 years in the warm season

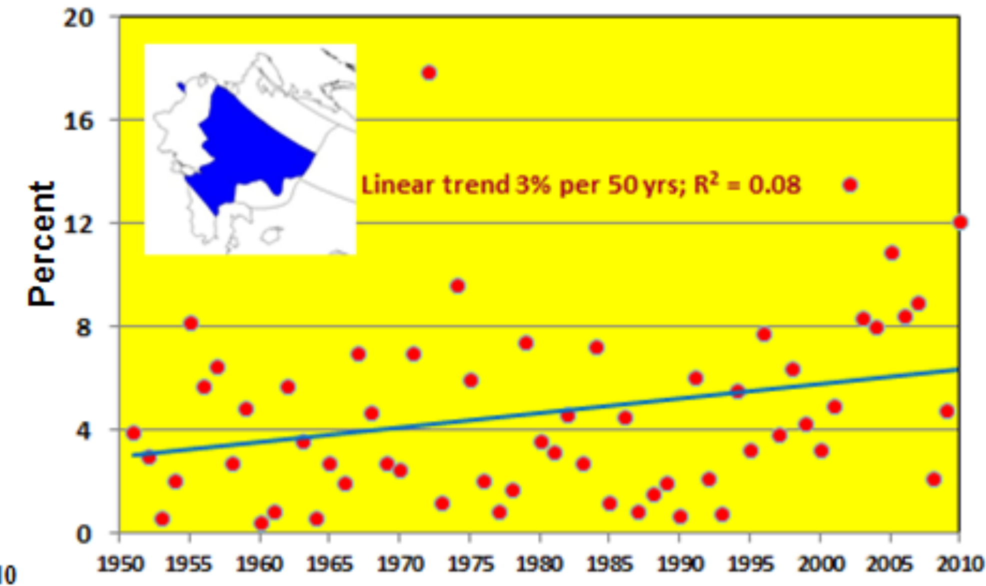


Groisman and Knight 2007, 2008

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.



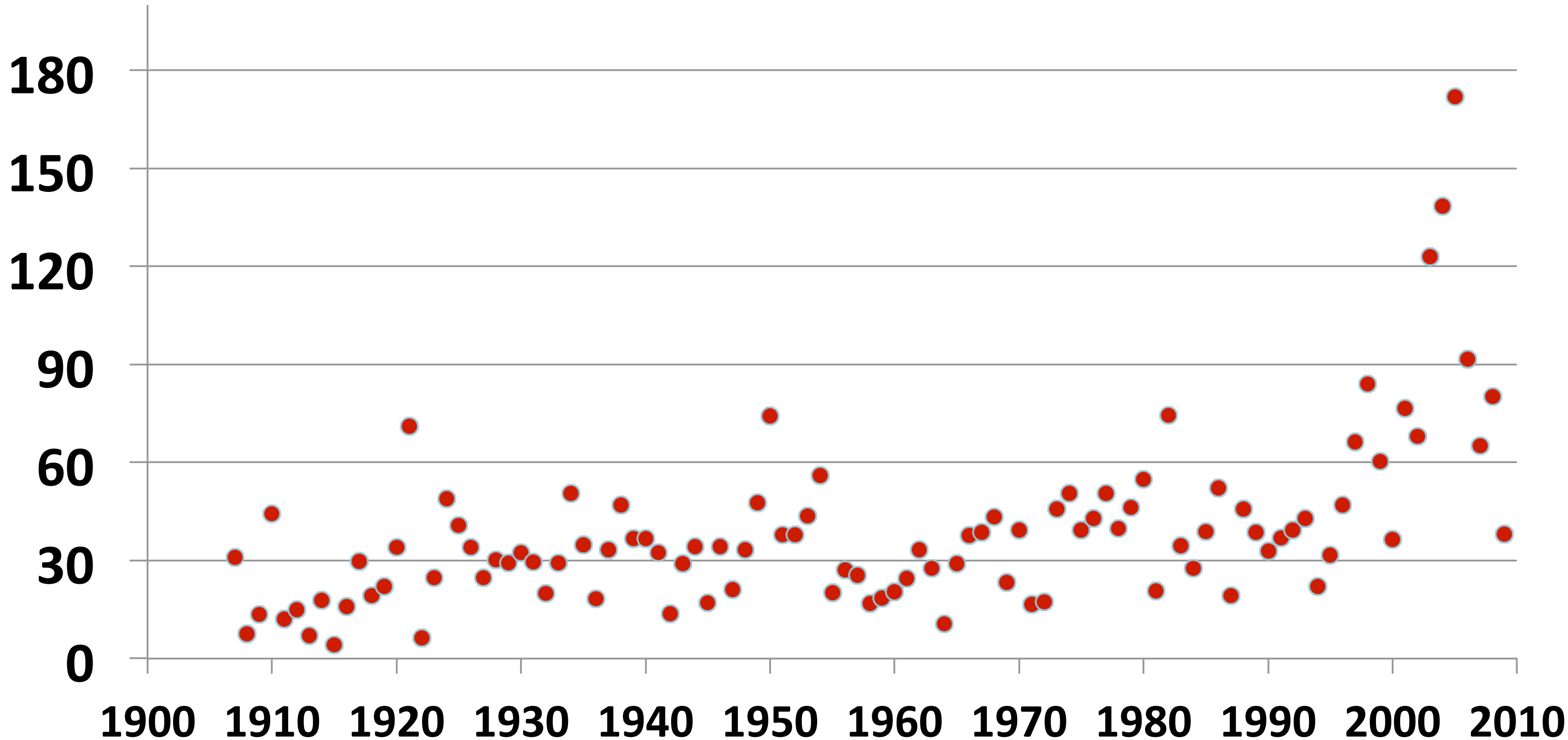


Groisman et al. 2013

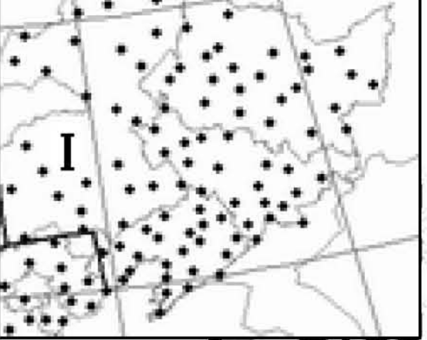
Potential Fire Danger Increase

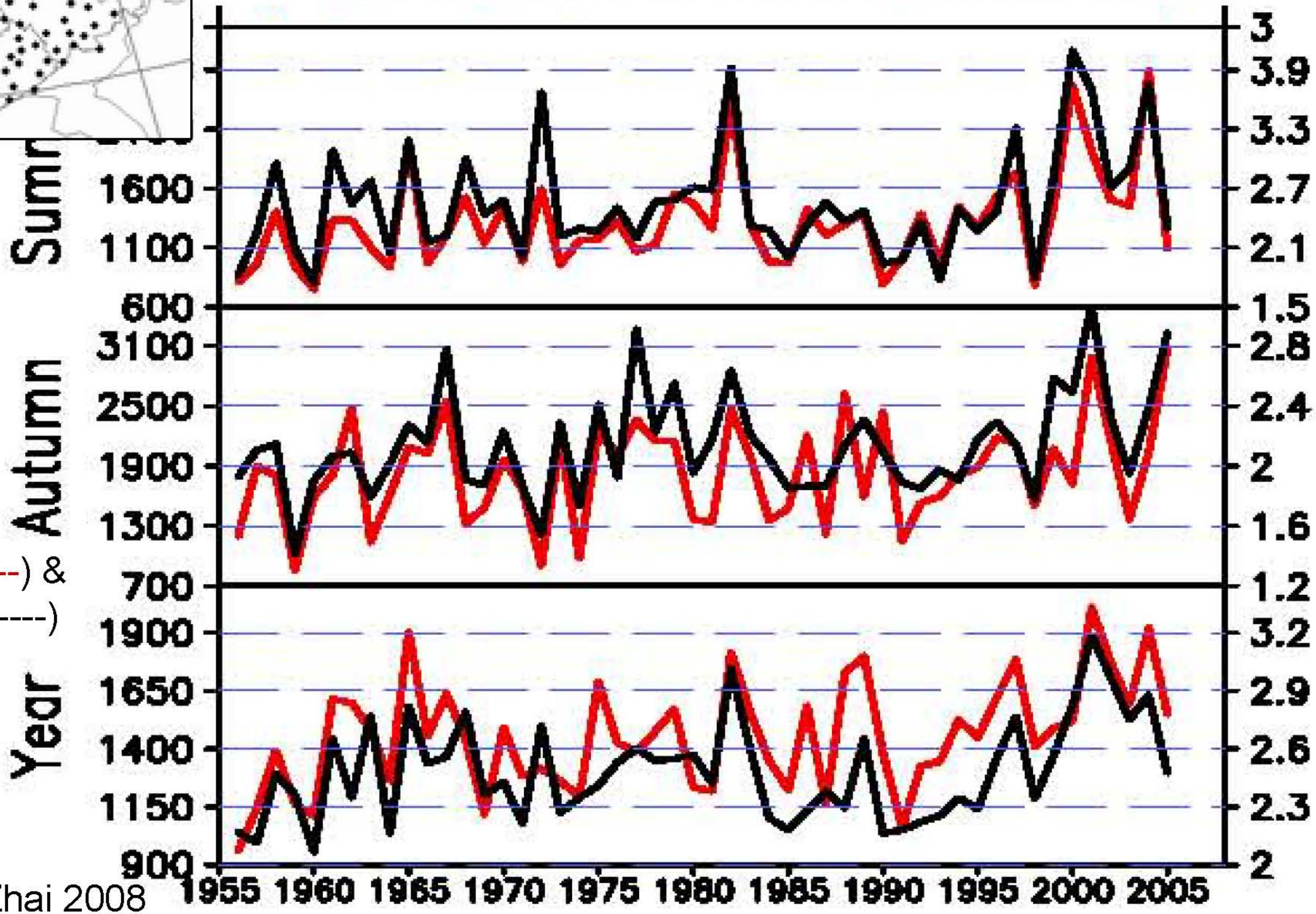
Annual number of days with KBDI > upper 10%-ile

Russian Far East south of 55°N



Seasonal and annual changes in forest fire indices in northeastern China

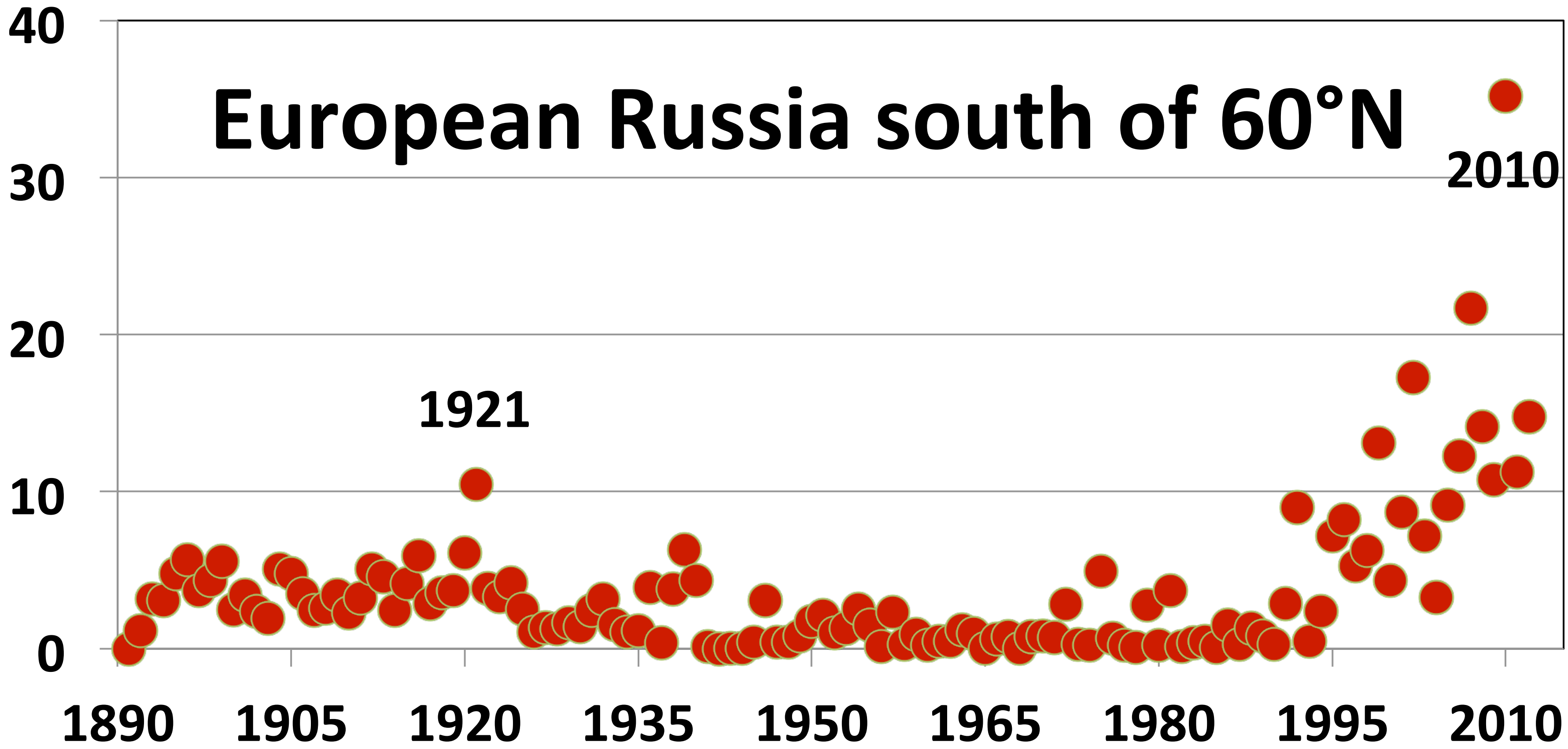




MNI (----) &
FFDI (-----)

Niu & Zhai 2008

Updated KBDI results for European Russia

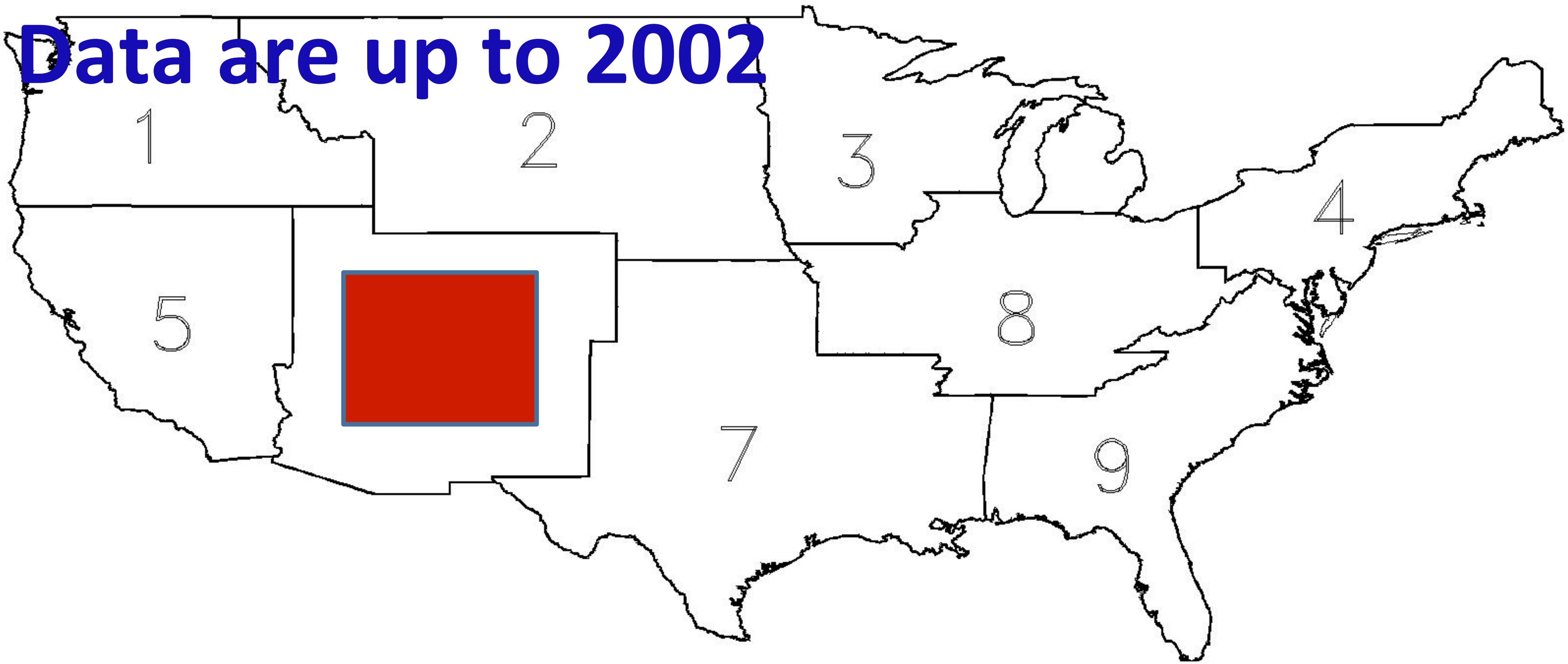


Days with KBDI in the upper 1% of their summer climatological values

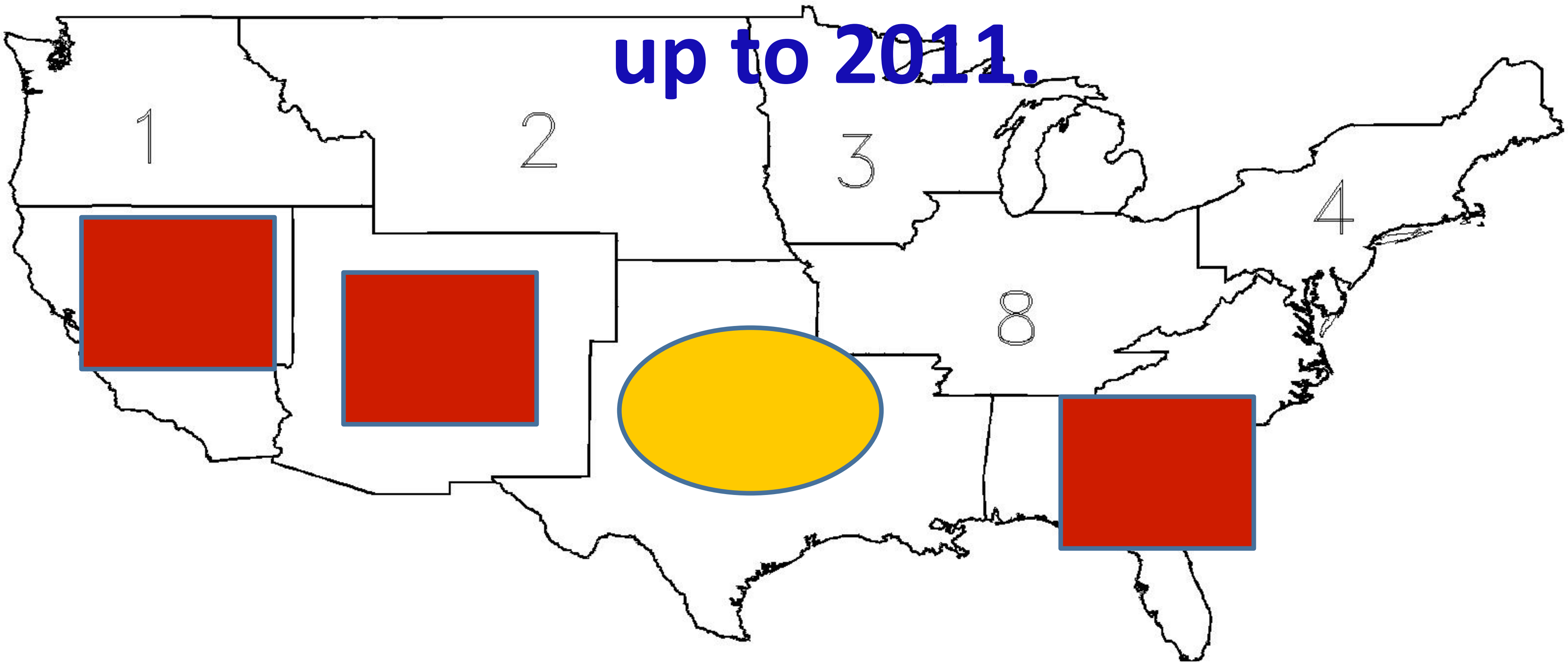
Region with a significant increase in summer dryness derived from the analyses of the Keach-Byram Drought Index (KBDI).

Groisman et al. 2004, *J. Hydrometeorol.*

Data are up to 2002

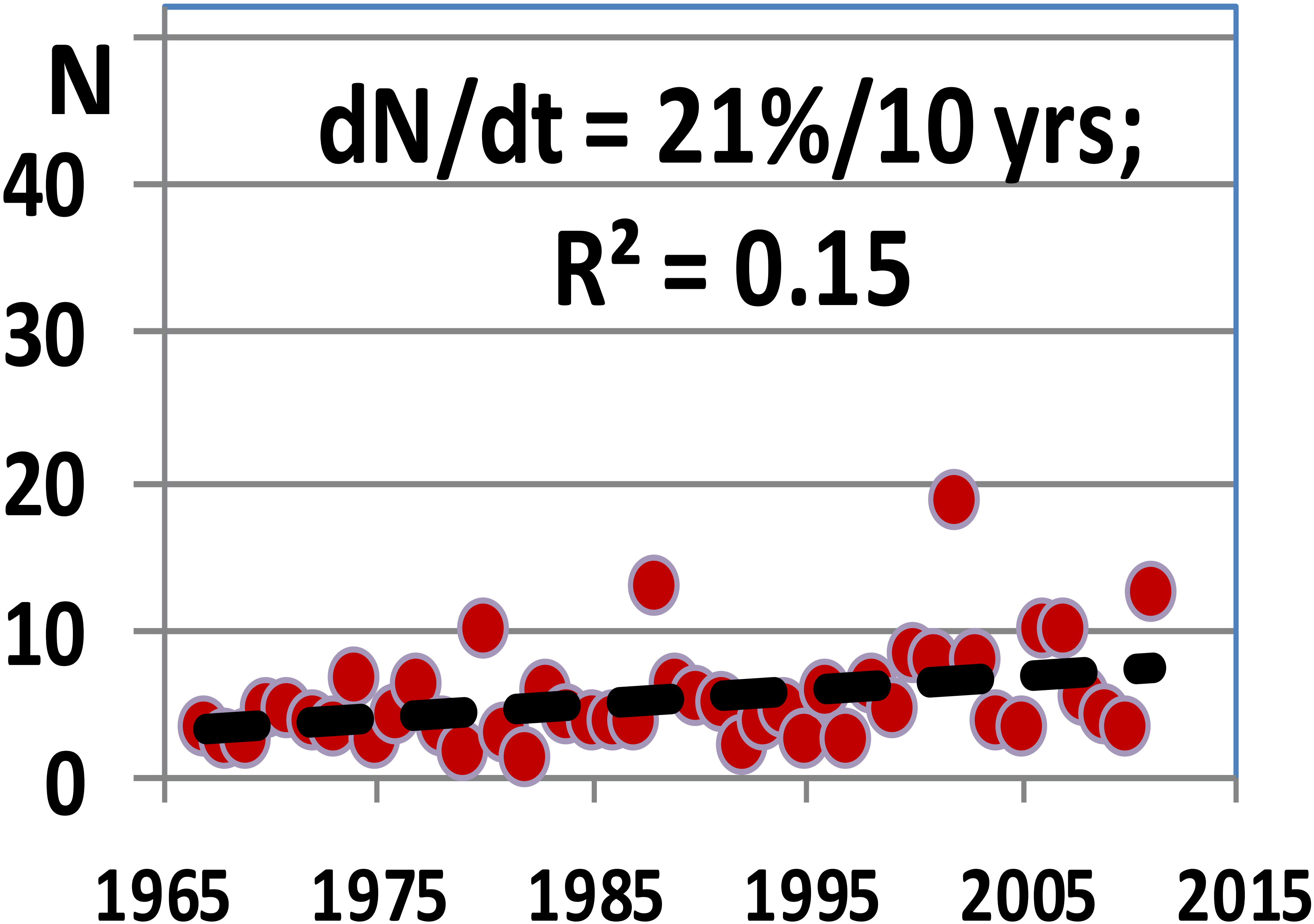


Regions with significant increases in summer dryness derived from the analyses of KBDI. Analysis is similar to Groisman et al. (2004), but the data are up to 2011.



Next Slide will show

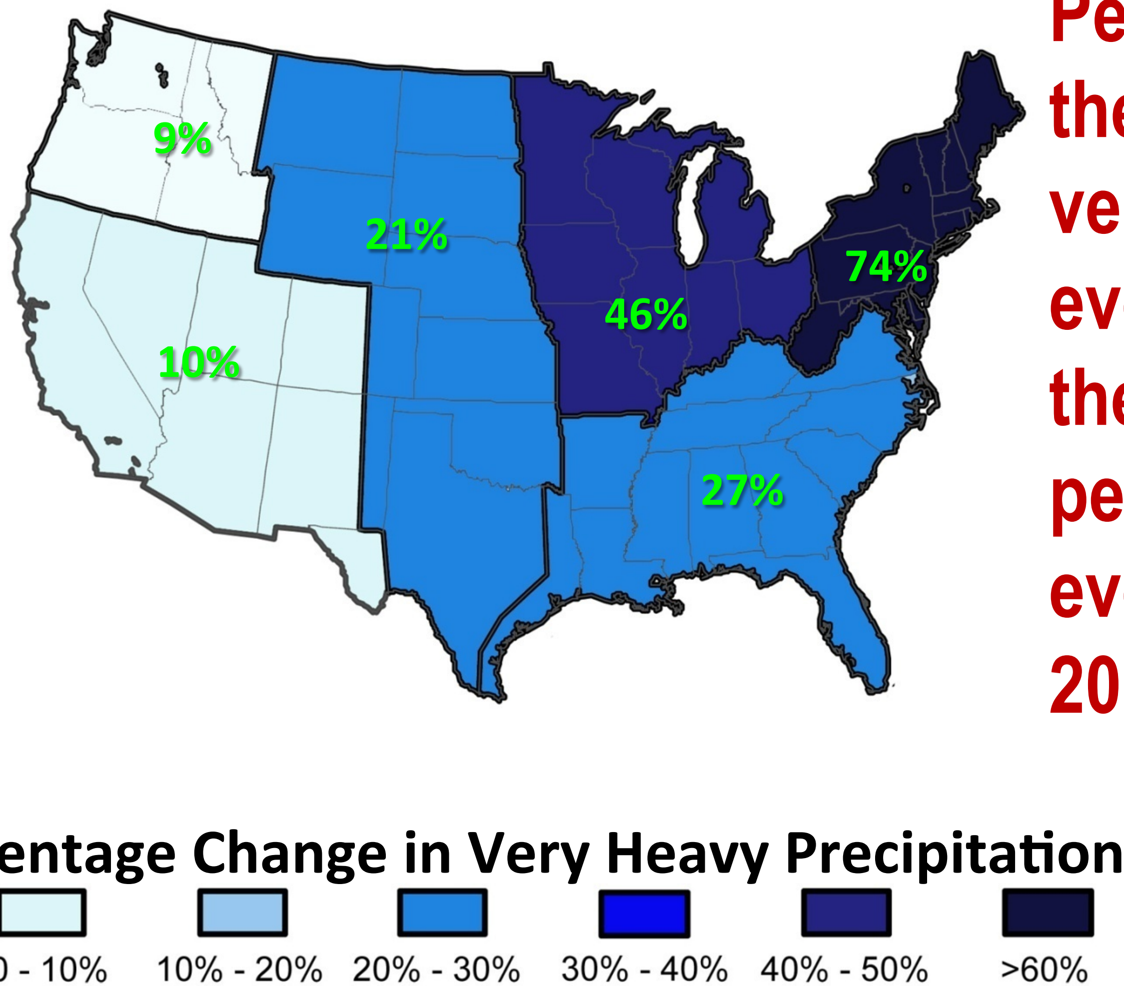
changes in the number of summer (JJA) days with KBDI above the upper 5% of its local distribution, N, area-averaged over the contiguous U.S. during the 1967-2011 period above the upper 5% of its local distribution, N, area-averaged over the contiguous U.S.


N
dN/dt = 21%/10 yrs;
R2 = 0.15
40
30
20
10
0
1965
1975
1985
1995
2005
2015

Part 4

Changes in intense precipitation over the contiguous U.S.

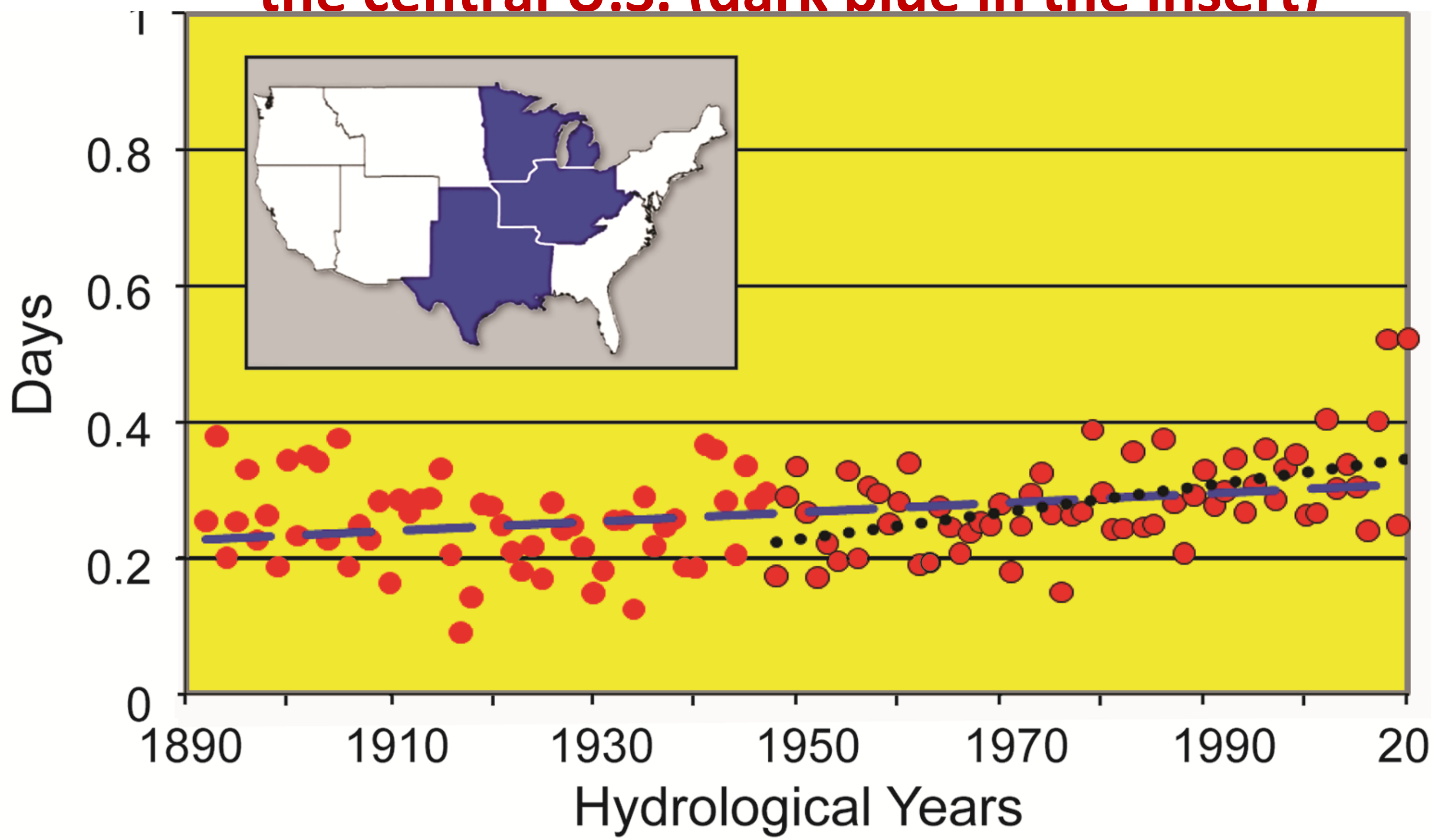
Observed Increases in Very Heavy Precipitation during the 1958 to 2010 period (USGCRP 2009)



Percent increases in the amount falling in very heavy rain events defined as the heaviest 1 percent of all daily events from 1958 to 2010 for each region

Changes in the Eastern half of the nation are statistically significant at the 0.05 or higher levels and, over the Great Plains, at the 0.1 level

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)



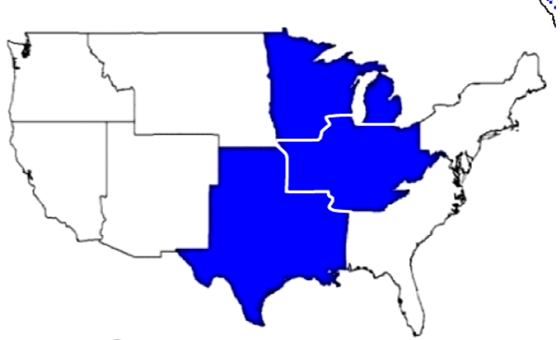
Linear trend estimates for the 1893–2010 and 1948–2010 periods. are equal to 2.6% (10 yr)$^{-1}$ and 7.4% (10 yr)$^{-1}$, respectively, and are statistically significant at the 0.01 level or higher (Groisman et al. 2012*, J. Hydrometeorol*.).

Method of assessing changes in intense precipitation used in the next 7 slides

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 as guidance the mean annual surface air temperature of the Northern Hemisphere (TNH), or regional (e.g., over the Central and contiguous US)
- 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 combinations of the above.

Groisman et al. 2012, 2013

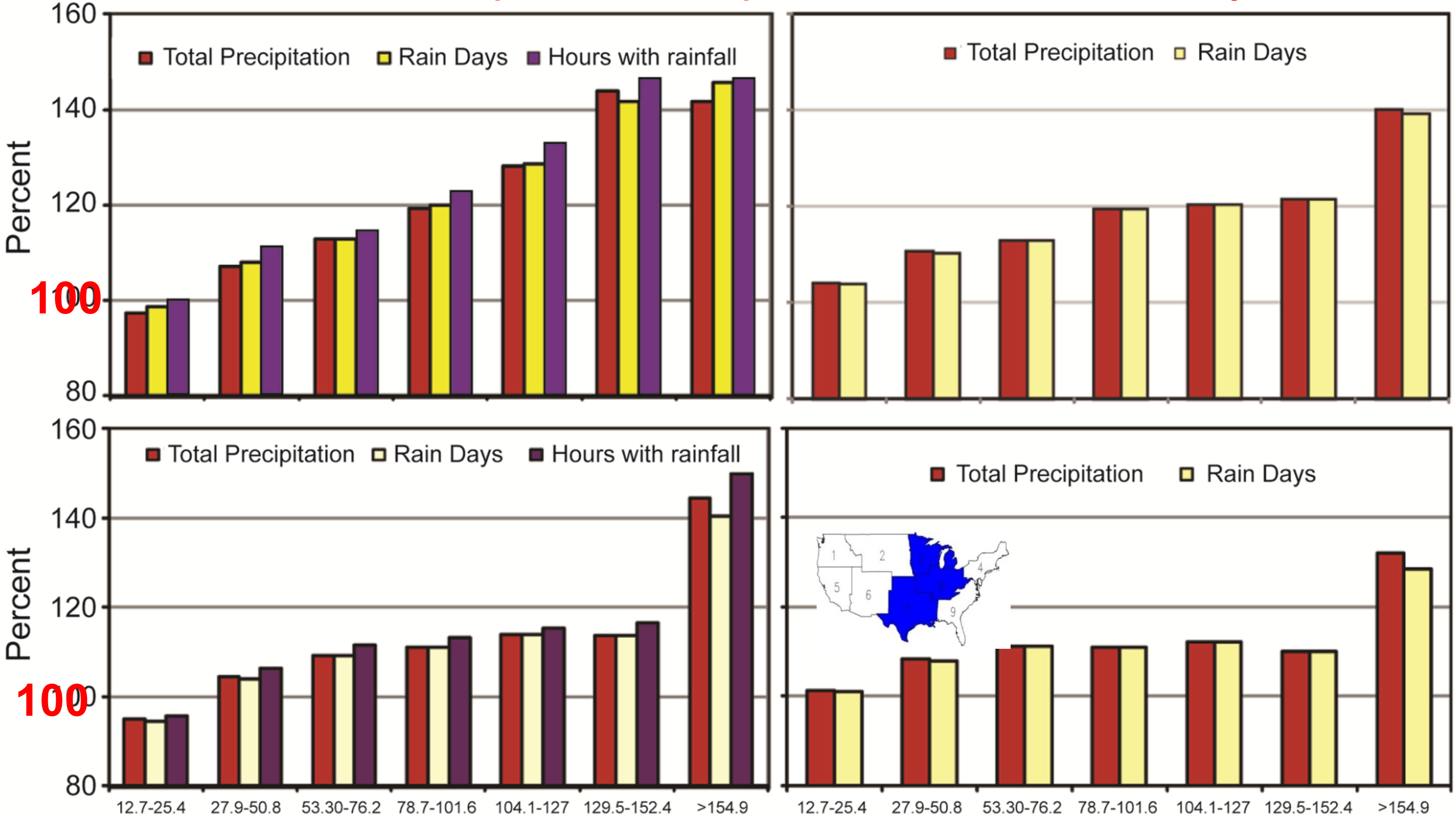


Central United States

- 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 that comprise more than 70% of all days with intense precipitation
- In the last three decades. only 0.1% of intense rain days were 6-inchers and they brought ~0.8% of intense precipitation in the last decades (but 40 years ago they brought only ~0.6%)
- All trends in very heavy precipitation during the past 119 years are ascribed to the 1948–2010 period and the second half of this period is responsible for most of them

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.

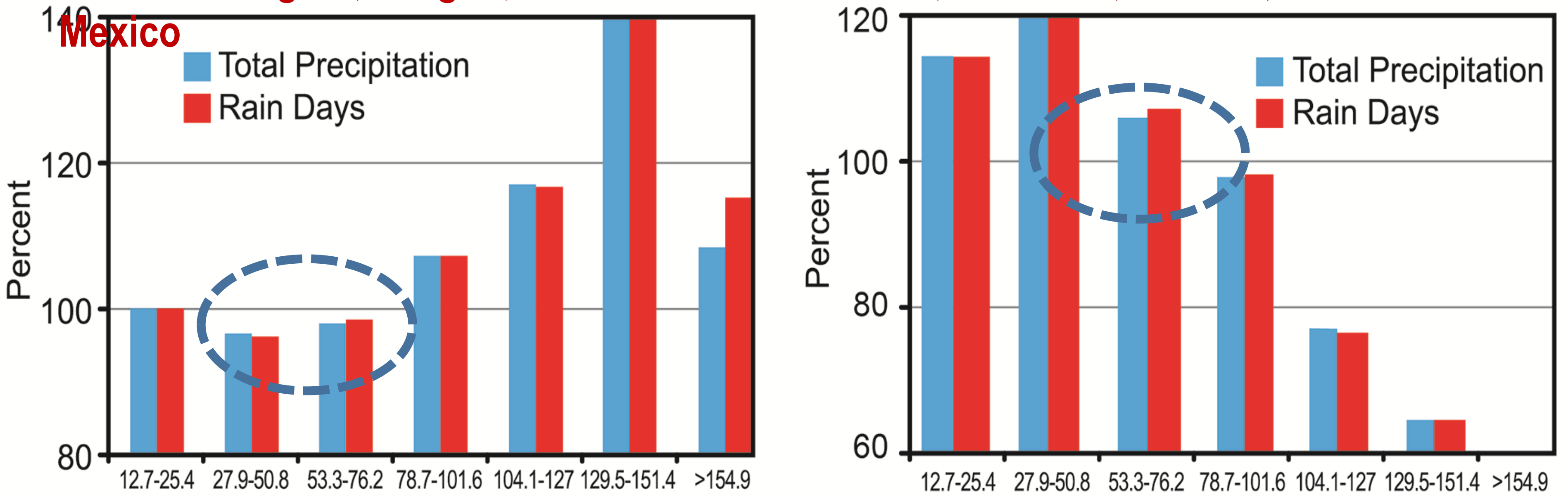


Estimates of precipitation characteristics for these 31-yr periods were averaged and their ratios (in percent per station for the past 31 years to those for the previous 31-yr-long period) are shown for hourly (left) and daily (right) networks

Trap related to estimates of "extreme" precipitation by parameterized distributions with parameters estimated using a part of the distribution tails

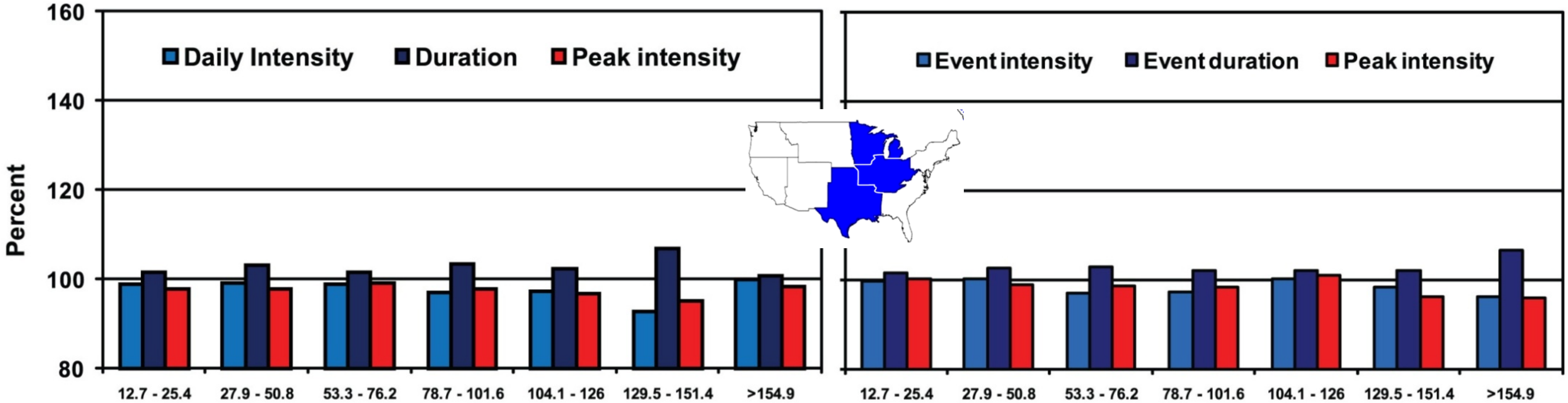
Washington, Oregon, and Idaho

Utah, Colorado, Arizona, and New Mexico



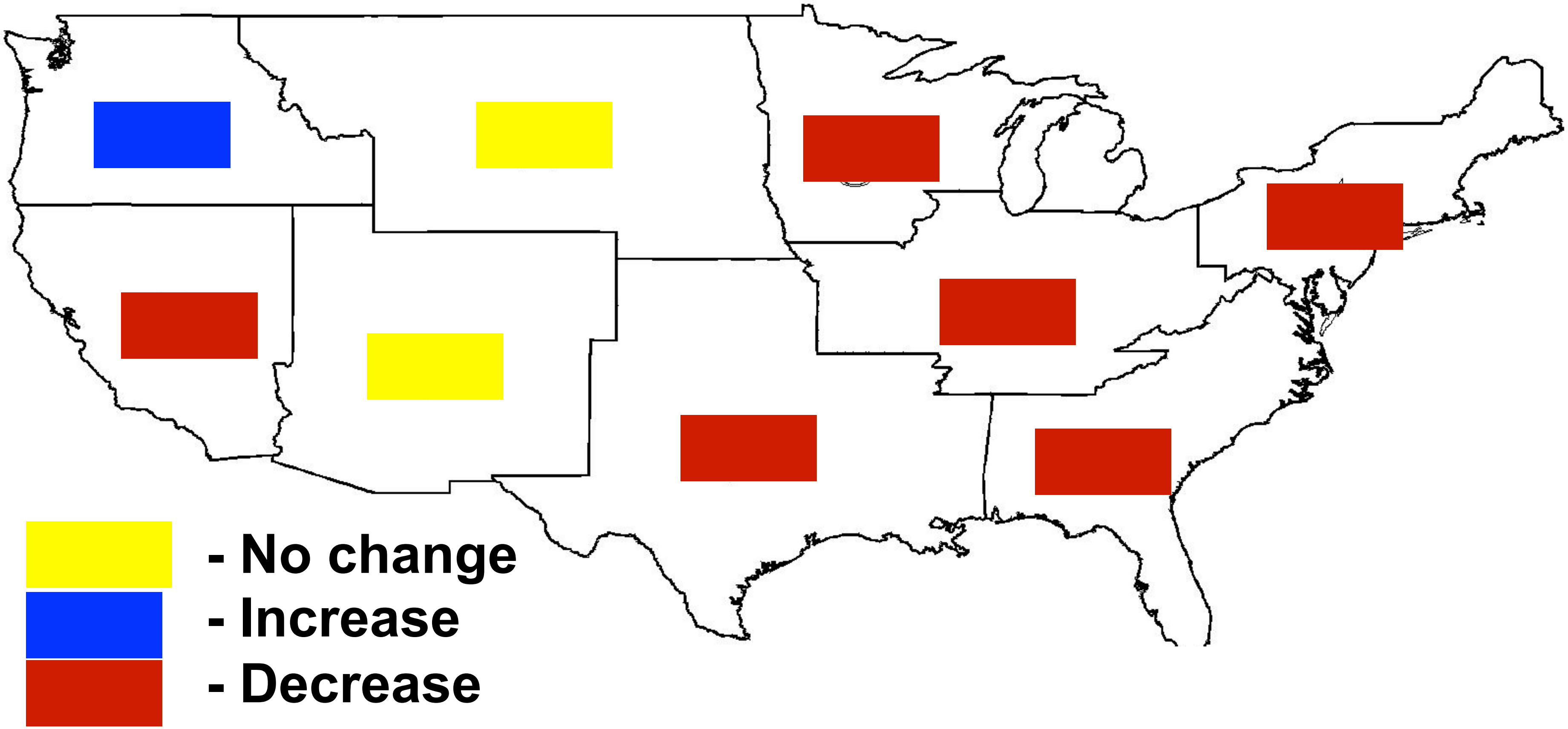
- **Same as the previous Figure but for daily precipitation events over the northwestern (left) and southwestern (right) United States**

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 of the fraction of moderately heavy precipitation (from 12.7 to 25.4 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.

- We documented a significant increase in very heavy and extreme precipitation during the past several decades over the Central U.S. (which comprises more than 35% of the contiguous U.S.)
- There are invariants in the current intense precipitation changes over all regions of conterminous United States (e.g., maximum hourly rainfall intensity did not change with increase of the frequency of intense rain events)
- We observe a statistically significant redistribution among the intense precipitation days and multi-day events over most of the conterminous Unite States: while moderately intense precipitation events (in the range from 12.7 mm to 25.4 mm per day or per multi-day event) did not appreciably change , the fraction of very heavy and extreme precipitation days and events increases.

Rainfall from tropical cyclones that make their landfall over the Eastern U.S.

Abbreviations used in the next three slides:

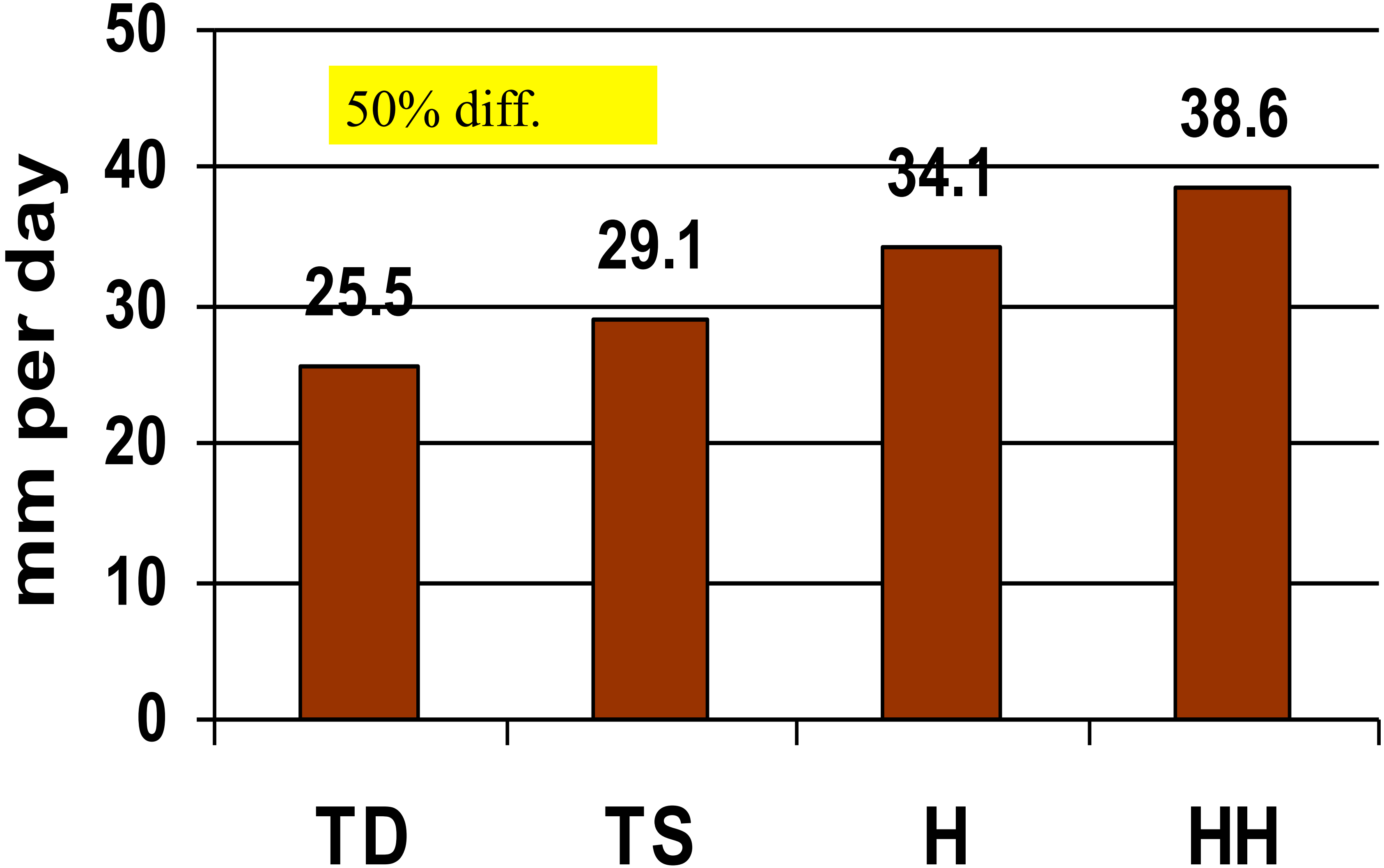
- **Tropical depressions TD**
- **Tropical storms TS**

  (max. sustainable wind speed, W, 18 m s^{-1} < W < 33 m s^{-1})
- **Hurricanes, 1-2 categories H**

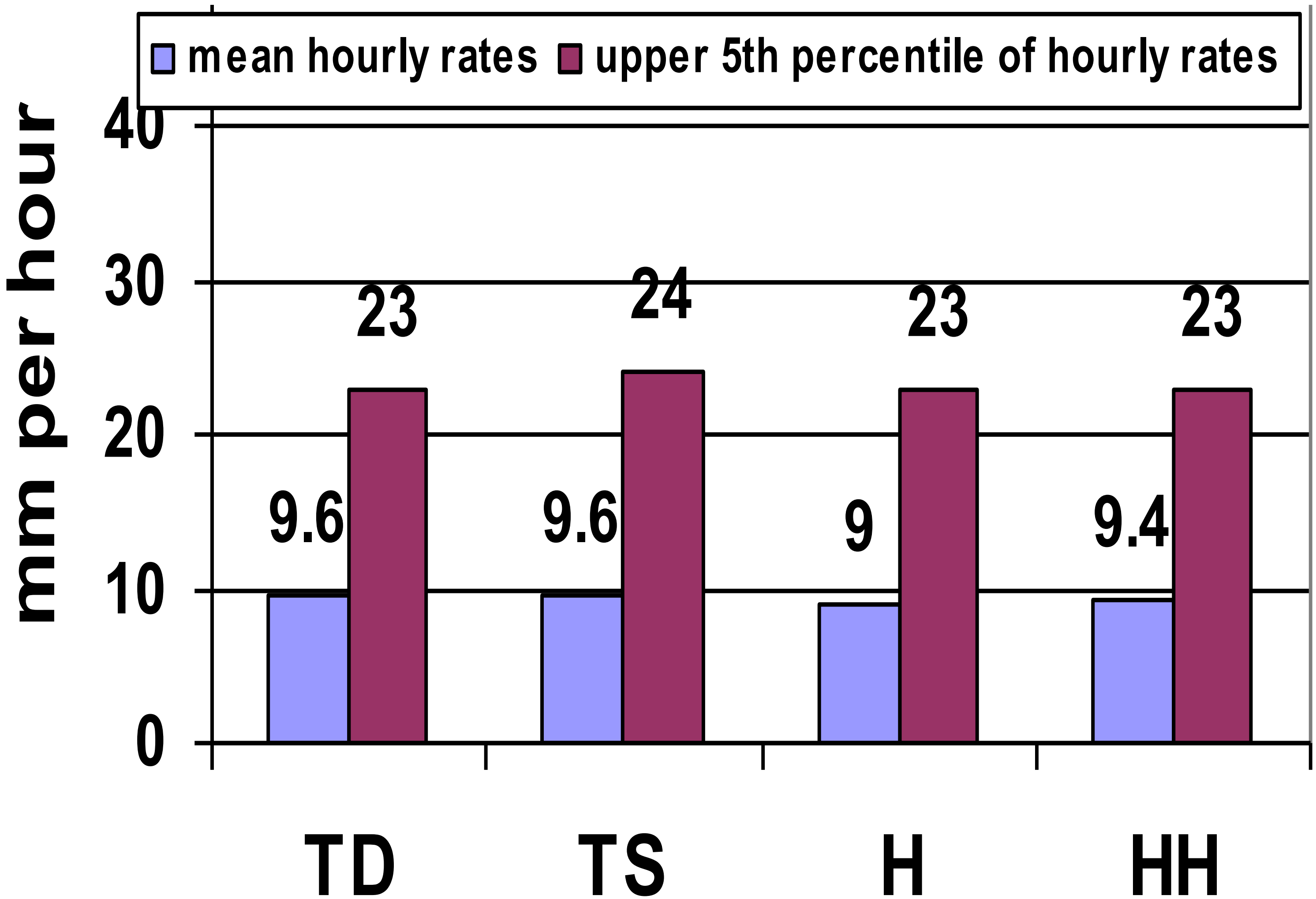
  ("Moderate" hurricanes, 33 m s^{-1} < W < 49 m s^{-1})
- **Hurricanes, 3-5 categories HH**

  ("Strong" hurricanes, W >49 m s^{-1})
  - **categories on Saffir-Simpson Hurricane Scale**

Mean daily precipitation totals over the 1°x1° grid cells of the southeastern United States for days with tropical cyclone (TC) rainfall above 5 mm



Mean hourly precipitation rates over the 1°x1° grid cells of the southeastern United States for days with tropical cyclone (TC) rainfall above 2.5 mm



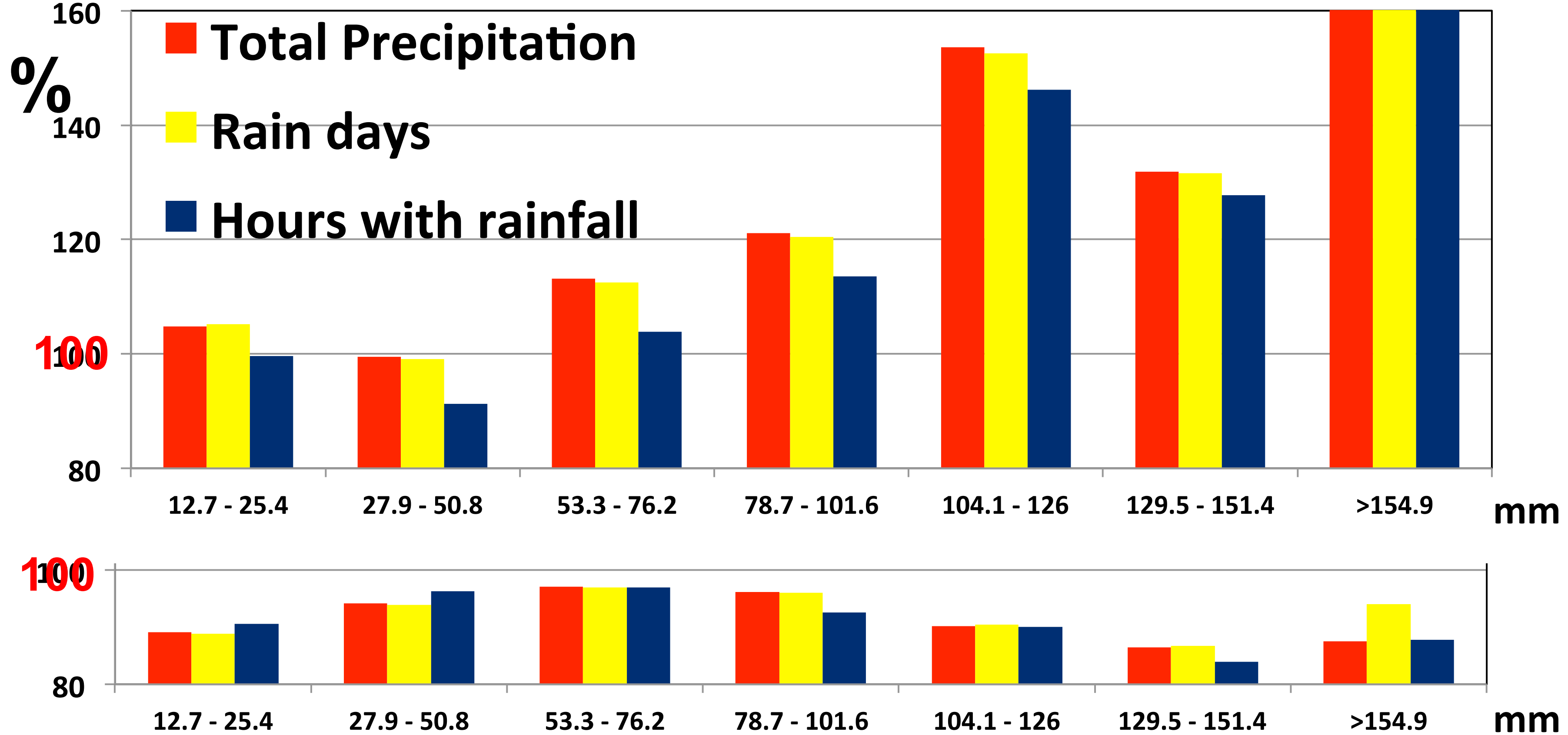
Coastal southeastern United States

"Cold"(SST < 28.3°C) and "warm" (SST > 28.3°C) landfall tropical cyclones sorted by the TC strength for the past 21 years (1985-2005). SST here is a daily SST in front of TCs

TC event class	All	TD	TS	H	HH
Warm TC events	59	3	30	13	13
Cold TC events	23	2	13	8	0

P < 0.02

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.

(Groisman et al. 2013)

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

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

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

"Take home" message

- Numerous observational studies show that in the past several decades precipitation has become more intense over most of the extra-tropics.
- At the same time, (and often in the same regions) precipitation events may occur less frequently or come in sequences of prolonged no-rain and wet periods; European Russia and most of the contiguous U.S. are among these regions.
- In the regions where extreme precipitation can be caused by different causes (western U.S., Southeast) non-linearity does not allow the use of simple parameterizations of extreme rainfall distribution and causes of extremes must be analyzed separately.

谢谢!

Thank you!

Спасибо!