WCRP Poster: TH106A

Changes in Precipitation Intensity and Duration Distributions over Northern Extratropics Related to Extreme Rainfall and Droughts: New Tendencies Emerging During the Last Decades

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Part 1: Introduction

Theoretical expectations for increase in intense rainfall in the 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.

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.

Barriopedro, D., E.M. Fischer, J. Luterbacher, R.M. Trigo, and R. Garcia-Herrera, 2011: The Hot Summer of 2010: Redrawing the Temperature Record Map of Europe. *Sci.*, **332**, No. 6026, 220-224.

Everything else will be an 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

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

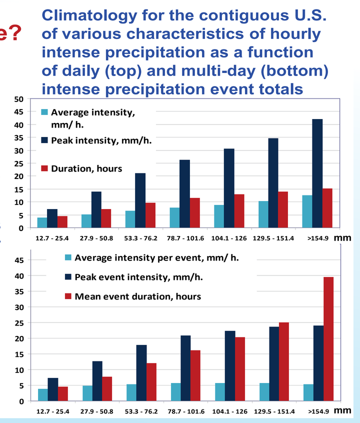
What time scale to use?

- hours
- days
- months
- cold/warm season

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

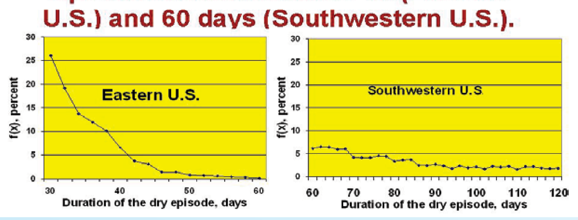
- Kamchatka 8 - 9
- Russian Arctic 7 - 8
- Forest and steppe zones of N. Eurasia 2 – 5
- Central Asia 0.5 - 2

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



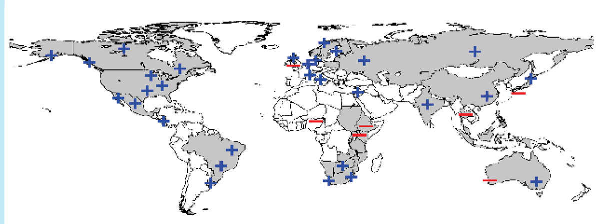
Lengthy intervals of "dry" days without sizeable rain during the warm season (when daily T > 5°C). We assess the percent of the warm season (%) with dry days intervals above 20, 30, 40, 50, 60, 90 days, etc.

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

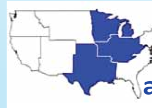


Part 2: Increase in Intense Precipitations

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



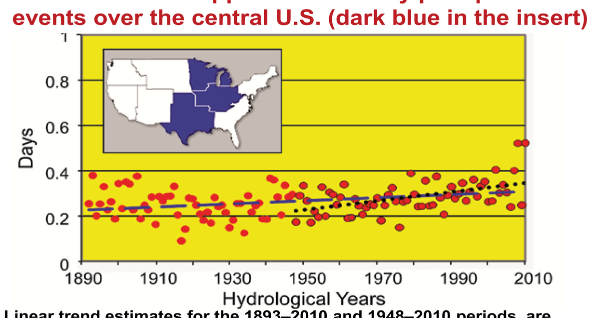
Easterling et al. 2000, substantially updated from Groisman et al. 2005, Zhai et al. 2005, Roy and Balling 2004, Aguilar et al. 2005, Brunetti et al. 2004, Cavazos 2008, and Zolina et al. 2010. Thresholds used to define "heavy" and "very heavy" precipitation vary by season and region.



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

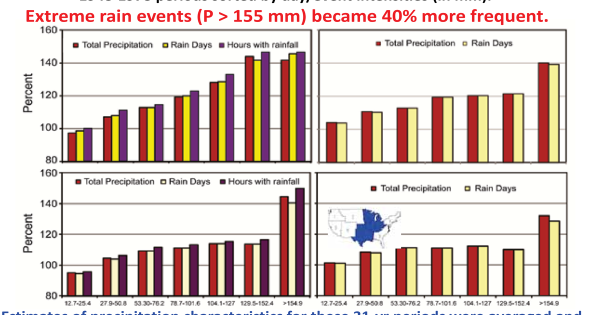
- On average, more than 70% of annual precipitation falls during ~25% of days with intense precipitation
- About half of intense precipitation totals comes from moderately heavy events (less than 25.4 mm) that comprise > 70% of all days with intense precipitation
- Only 0.1% of intense rain days are 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 1948–2010 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)



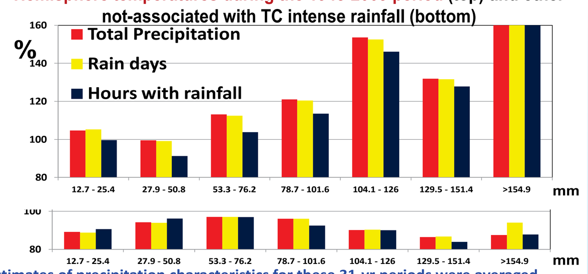
Linear trend estimates for the 1893–2010 and 1948–2010 periods. are equal to 2.6% (10 yr)$^{-1}$ and 7.4% (10 yr)$^{-1}$, respectively, and are statistically significant at the 0.01 level or higher (Groisman et al. 2011).

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) networks

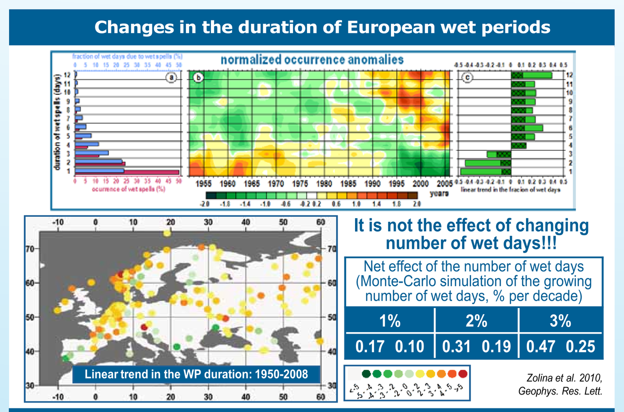
Comparison of intense precipitation characteristics during the June-November season over the Southeastern U.S. associated with tropical cyclones (TC) for the 31 years of warmest and coldest Northern Hemisphere temperatures during the 1948-2009 period (top) and other not-associated with TC intense rainfall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



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

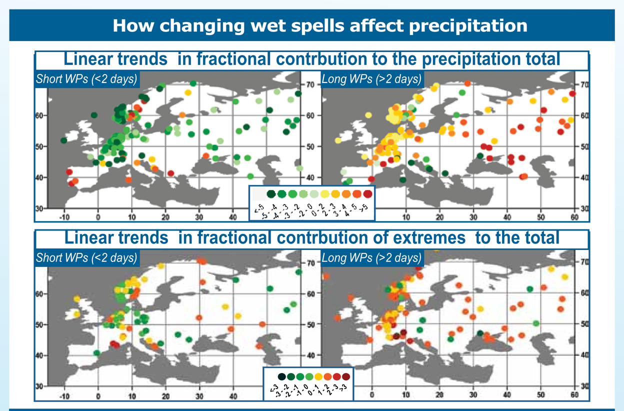
Part 3: Non-linearity

Changes in the duration of European wet periods



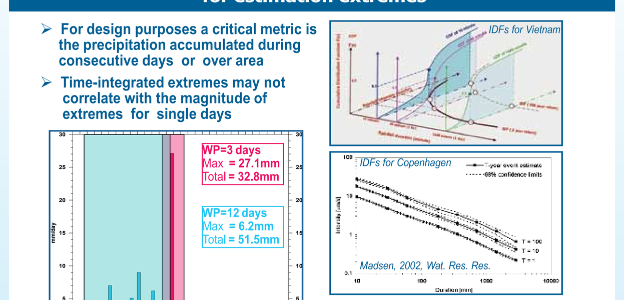
1%	2%	3%
0.17 0.10	0.31 0.19	0.47 0.25

How changing wet spells affect precipitation



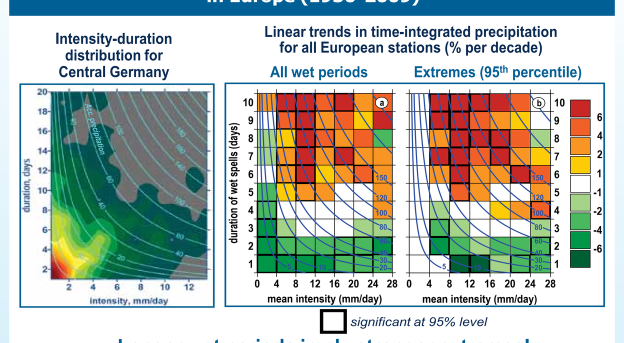
Duration of precipitation: essential metric for estimation extremes

- For design purposes a critical metric is the precipitation accumulated during consecutive days or over area
- Time-integrated extremes may not correlate with the magnitude of extremes for single days



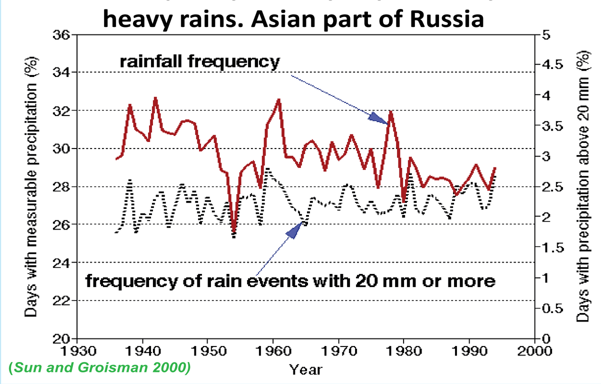
IDF (intensity-duration-frequency)-distributions developed in engineering hydrology, however for minute- and hourly time scales only, not yet applied to climate studies

Changes in the IDF distributions for daily precipitation in Europe (1950-2009)



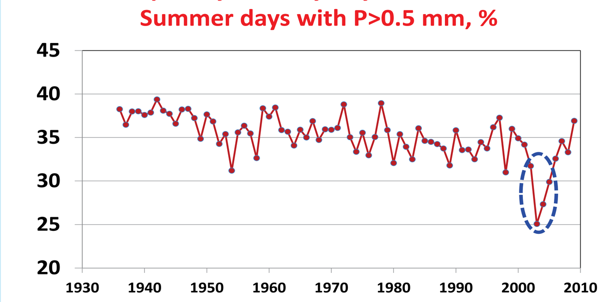
Longer wet periods imply stronger extremes!

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



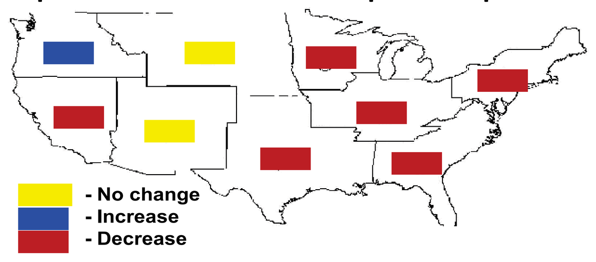
(Sun and Groisman 2000)

Summer frequency of rainy days over Asian Russia
Summer days with P>0.5 mm, %



(Sun and Groisman 2000, updated)

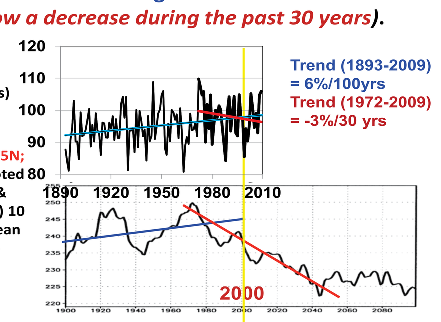
Changes of the fraction of moderately heavy precipitation (from 13 to 25 mm) with time, past three decades versus previous period



Fraction of "moderately intense" precipitation in 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*).

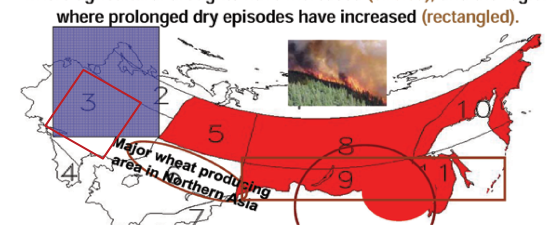
- Observations (Northeast and Midwest regions) for 1893-2009.
- ECHAM4 (35N-45N; 75W-85W; adapted from Semenov & Bengtsson 2002) 10 year running mean values for 1900-2090.



(Groisman et al. 2005, updated to 2009)

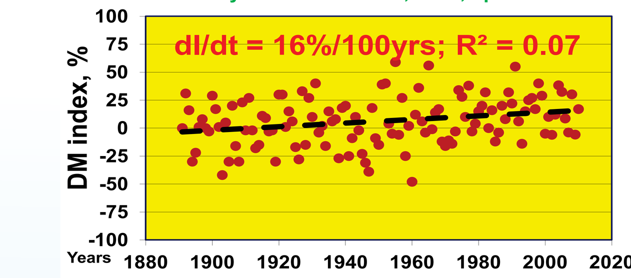
Part 4: Dry Episodes

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 (rectangle).



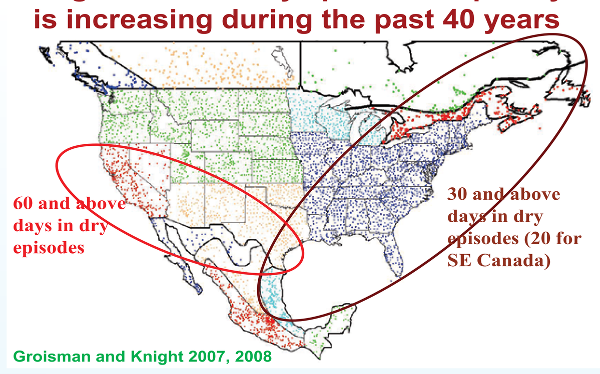
Groisman et al. (Bull. Amer. Meteorol. Soc. 2009, updated)

Agricultural regions of West Siberia and Northern Kazakhstan. May – July Drought Index.
Meshcherskaya and Blazhevich, 1997, updated to 2010



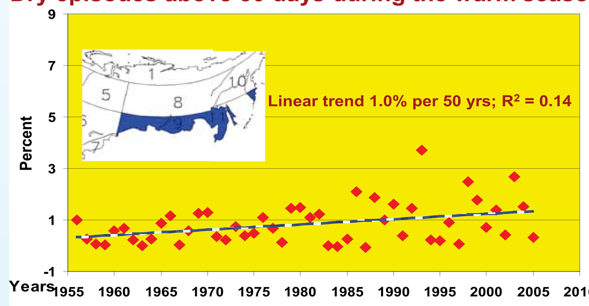
Areas with excessively dry conditions minus areas with excessively wet conditions, (% of total area)

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



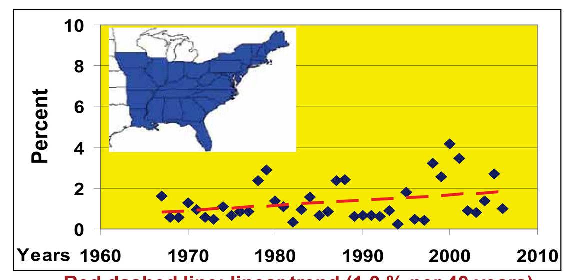
Groisman and Knight 2007, 2008

Dry episodes above 30 days during the warm season

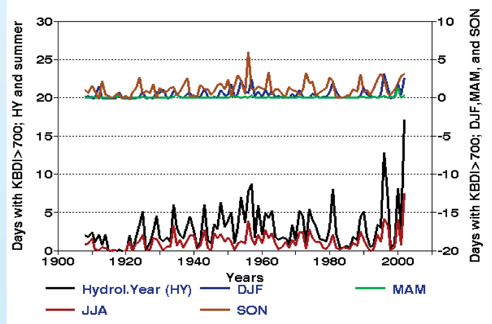


Russia east of 85°E, south of 55°N

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). (Groisman and Knight 2008)

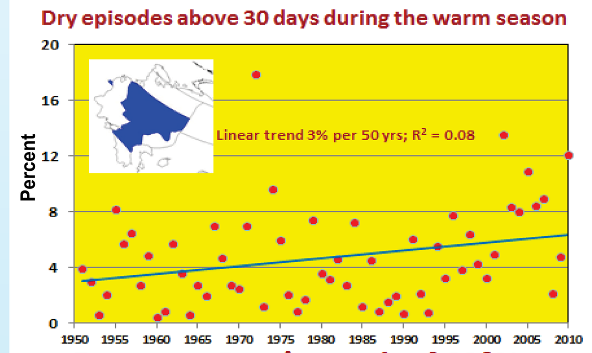


Annual and seasonal number of days with regional Keetch-Byram Drought Index (KBDI) above 700 (highest drought danger) over four states in Southwestern United States (AZ, UT, NM, CO).

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.*)

Dry episodes above 30 days during the warm season



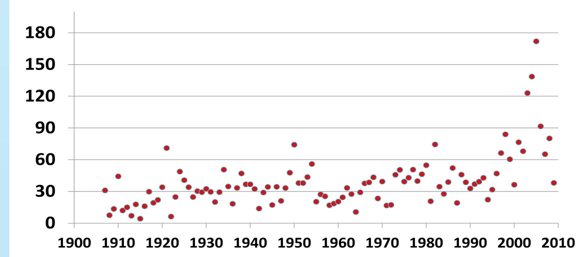
European Russia south of 60°N

Summary of Findings (Parts 2,3,4)

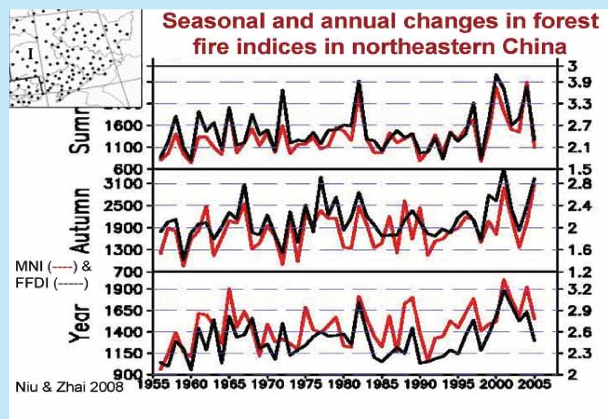
- An observational evidence of changes in precipitation spectra over Northern Extratropics was quantified for the past 40 to 50 years with focus on extremes on both sides of daily (for the United States, daily and hourly) rainfall distribution in the warm season. In the last decades these changes intertwine with significant surface air warming.
- 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, Europe, and Northern Asia.
- Over Europe, During the last 60 years wet spells have become longer by about 15-20%. Lengthening was not caused by the net effect of wet days. Extreme precipitation associated with longer wet spells have intensified by 12-18%, while extremes associated with short wet spells became weaker.
- These changes are a new phenomenon and became evident only in the past several decades.

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



Niu & Zhai 2008

Part 5: Atmospheric Pressure Changes over Northern Atlantic and Europe with Global Warming

Sea level atmospheric pressure (SLP) changes with the hemispheric warming by 0.5°C

Winter

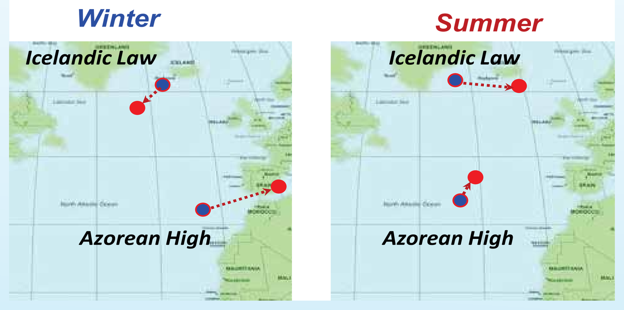
- Weakening of the cyclonic activity over North Atlantic
- Shift of Azorean High to northeast
- A general increase of atmospheric pressure in the 55°N-70°N zone

Summer

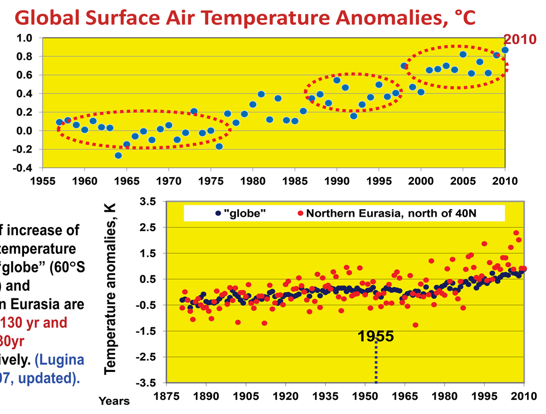
- Strengthening of the cyclonic activity over North Atlantic
- Shift of Azorean High to northeast
- Increase of atmospheric pressure over Europe

Adapted from Vinnikov (1976, "*Climate Sensitivity*")

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)

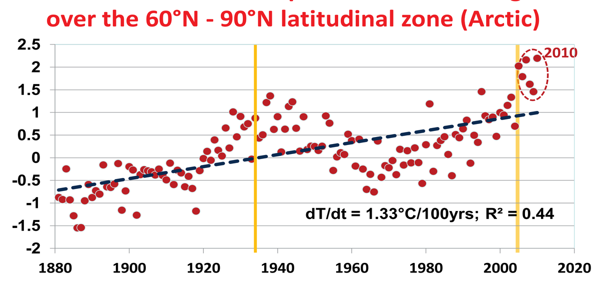


Global Surface Air Temperature Anomalies, °C



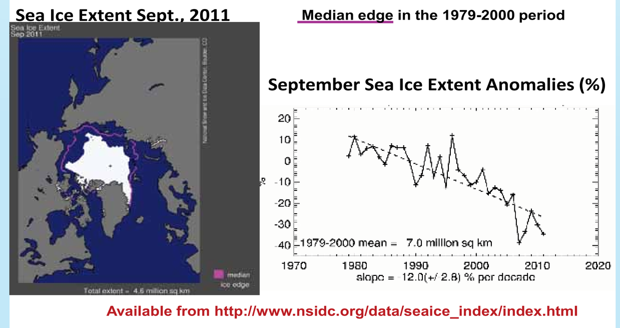
Rates of increase of annual temperature for the "globe" (60°S to 90°N) and Northern Eurasia are 0.91 °C/130 yr and 1.5°C/130yr respectively. (Lugina et al 2007, updated).

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



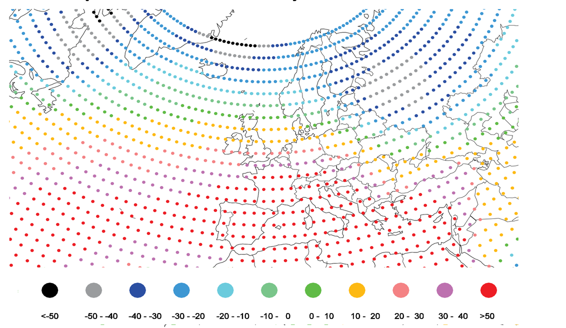
Linear trend for the entire period of instrumental observations is 1.73°C/130 yr but there were periods (e.g., 1936-2004) when there was no statistically significant linear trend (Groisman et al. 2006, updated).

Northern Hemisphere Sea Ice Extent and its Anomalies (%) 1979-2011

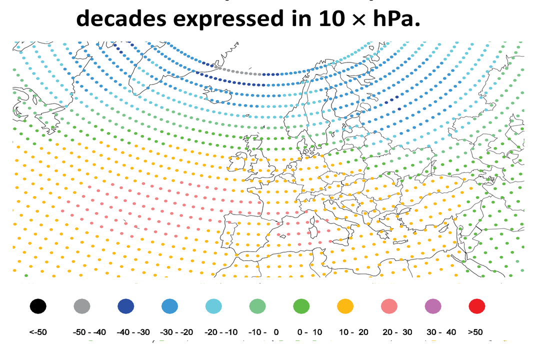


Available from http://www.nsidc.org/data/seaice_index/index.html

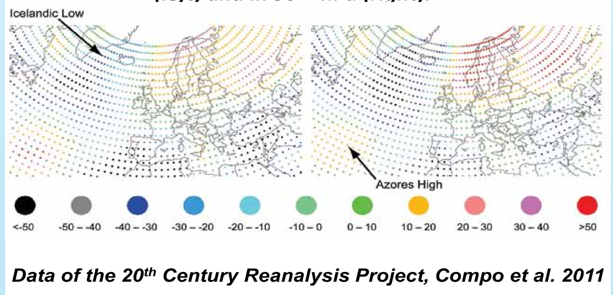
January Sea Level Pressure (SLP) changes in the last three decades compared to the previous three decades expressed in percent of its monthly standard deviation



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

What to watch with global warming in the extratropics?

- Dry and wet spells within the warm season may become more prolonged
- Further increase in intense rainfall/above 25mm/
- Duration of the warm season/e.g., 3 versus 4 months/
- Atmospheric pattern associated with dry spells/T(0°N) – T(90°N); Blockings/Slow moving anticyclones
- Earlier spring onset/by 1 – 2 weeks/and snow water equivalent changes//it is increasing in Russia/
- In Northern Eurasia, a closer look at the Arctic is needed/droughts to Russia come with dry Arctic air and most of water vapor transport originates in Northern Atlantic/
- Thorough accounting for land use change is warranted to avoid mixing its and global warming effects/e.g., Midwestern U.S./