Changes in Intense Precipitation Over the Conterminous U.S.: Observational Evidence and Possible Causes

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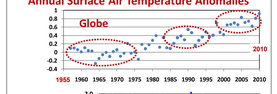
PART 1 - Background

Annual Surface Air Temperature Anomalies

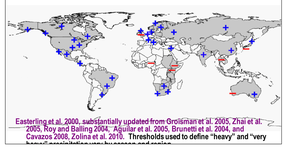


Mean centenary rate of change of the annual surface air temperature over the Northern Hemisphere is 1.83 C/100yr; R² = 0.63 (Lugina et al. 2007, updated; for 2010 the data are Jan-Nov. average).

Global warming manifests itself at least at the continental scale

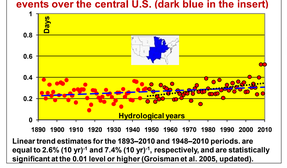
- There is a reason to look for large scale changes in extremes → we are looking for changes in area-averaged characteristics of extreme events
- Another option would be to search for smaller-scale changes in extremes related to regional and local factors (e.g., land use change and/or water withdrawal)

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



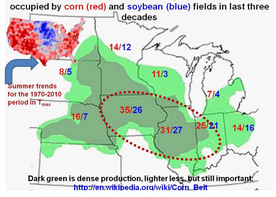
Easterling et al. 2000, substantially updated from Groisman et al. 2005, Zhai et al. 2005, Roy and Balling 2004, Aguilar et al. 2005, Brunetti et al. 2004, and Cavazos 2008, Zolina et al. 2010. Thresholds used to define "heavy" and "very heavy" precipitation vary by season and region.

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)



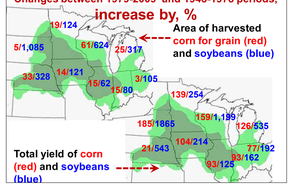
Linear trend estimates for the 1893–2010 and 1948–2010 periods. are equal to 2.6% (10 yr)⁻¹ and 7.4% (10 yr)⁻¹, respectively, and are statistically significant at the 0.01 level or higher (Groisman et al. 2005, updated).

U.S. Corn Belt States with the areas (% of total land area) occupied by corn (red) and soybean (blue) fields in last three decades

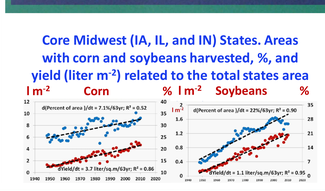


Dark green is dense production, lighter less, but still important. http://en.wikipedia.org/wiki/Corn_Belt

Changes between 1979-2009 and 1948-1978 periods, increase by, %



Core Midwest (IA, IL, and IN) States. Areas with corn and soybeans harvested, %, and yield (liter m⁻²) related to the total states area



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)

Terminology used in presentation

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 ≤ 25.4 mm d⁻¹

Heavy precipitation 25.4 < P ≤ 76.2 mm d⁻¹ or mm (event)⁻¹

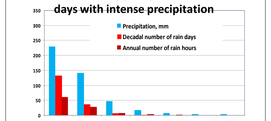
Very heavy precipitation 76.2 < P ≤ 154.9 mm d⁻¹ or mm (event)⁻¹

Extreme precipitation P > 154.9 mm d⁻¹ or mm (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

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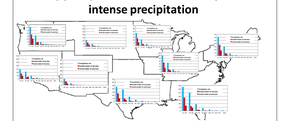

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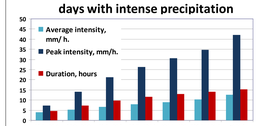
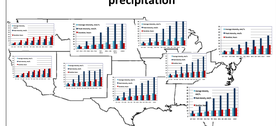


Mean daily and peak precipitation intensity mm h⁻¹; and mean duration of daily precipitation events, hours.

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



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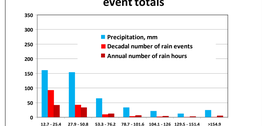
Nationwide climatology of various characteristics of hourly intense precipitation as a function of multi-day intense precipitation event totals



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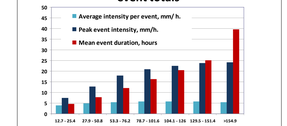
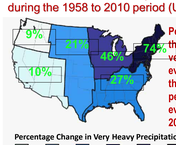


Mean daily and peak precipitation intensity mm h⁻¹; and mean duration of daily precipitation events, hours.

PART 3 - Changes In Intense Precipitation

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



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

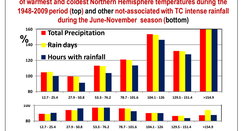
Percent increases in the amount falling in very heavy rain events defined as the heaviest 1 percent of all daily events from 1958 to 2010 for each region

Methods of assessing changes in intense precipitation

Assessing the 1948–2009 period, we compared

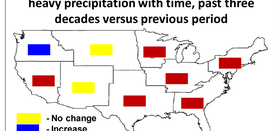
- the first 31 years and the last 31 years of our sample from HPD and COOP networks
- the warmest 31 years and the coolest 31 years (using as guidance the mean annual surface air temperature of the Northern Hemisphere (TNH), or regional (e.g., over the Central and contiguous US)
- intense precipitation 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.

Comparison of intense precipitation characteristics 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 during the June-November season (bottom)



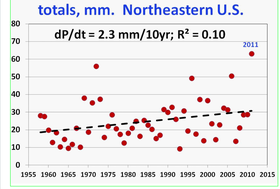
Estimates of precipitation characteristics for these 31-yr periods were averaged and their ratios (in percent per station) are shown sorted by day rainfall intensity ranges (in mm, x - axes)

Changes of the fraction of moderately heavy precipitation 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.

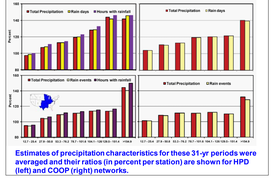
Upper 1% of the summer rainfall totals, mm. Northeastern U.S.



Central United States

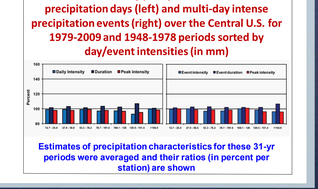
- On average, more than 70% of annual precipitation falls during ~25% of days with intense precipitation
- About half of intense precipitation totals comes from moderately heavy events that comprise more than 70% of all days with intense precipitation
- In the last three decades. only 0.1% of intense 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)



Estimates of precipitation characteristics for these 31-yr periods were averaged and their ratios (in percent per station) are shown for HPD (left) and COOP (right) networks.

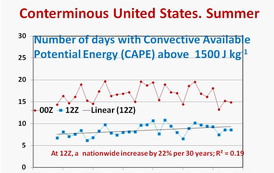
Comparison of mean and peak intensity and duration of hourly precipitation for intense precipitation days (left) and multi-day intense precipitation events (right) over the Central U.S. for 1979-2009 and 1948-1978 periods sorted by day/event intensities (in mm)



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

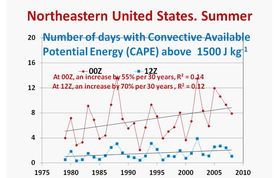
PART 4 -Changes in the frequency of high values of the Convective Available Potential Energy

Conterminous United States. Summer



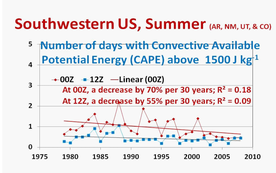
Archive of the North American Regional Reanalysis (NARR)

Northeastern United States. Summer



Archive of the North American Regional Reanalysis (NARR)

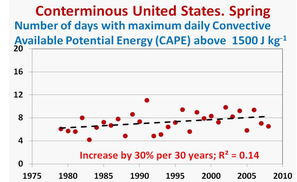
Southwestern US, Summer (AR, NM, UT, & CO)



Archive of the North American Regional Reanalysis (NARR)

Conterminous United States. Spring

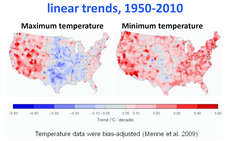
Number of days with maximum daily Convective Available Potential Energy (CAPE) above 1500 J kg⁻¹



Archive of the North American Regional Reanalysis (NARR)

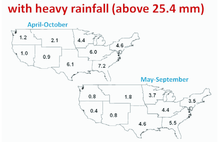
PART 5 - T_{max} and T_{min} relationships with the frequency of heavy precipation in the warm season (Apr-Oct)

Summer (JJA) surface air temperature linear trends, 1950-2010



Temperature data were bias-adjusted (Menne et al. 2009)

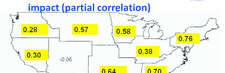
Long-term mean number of days with heavy rainfall (above 25.4 mm)



Correlation of in the warm season T_{min} with D, the number of days with heavy precipitation >25.4 mm.

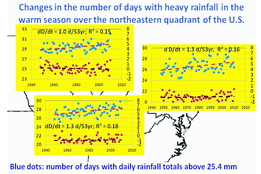
On the interannual time scale, D is negatively correlated with T_{min} over most of the contiguous U.S. except the Great Lakes and Northeast where it is positively correlated with T_{min} (and these correlations remain intact after detrending).

Correlation of in the warm season T_{min} with D, the number of days with heavy precipitation (>25.4 mm), after the removal of the T_{max} impact (partial correlation)



After the removal of the T_{max} impact, mean seasonal T_{min} is statistically significantly correlated with the number of days with heavy rainfall over most of the contiguous U.S.

Changes in the number of days with heavy rainfall in the warm season over the northeastern quadrant of the U.S.



Blue dots: number of days with daily rainfall totals above 25.4 mm

Red dots: Mean seasonal maximum temperature (April-October)

Conclusions for part 5.

- On an interannual time scale, D, the number of days with heavy precipitation, are negatively correlated with seasonal T_{max} except the Great Lakes and Northeast regions where they are positively correlated with Tmin
- After removal of the T_{max} impact, D are positively correlated with T_{min} everywhere across the contiguous U.S. (CONUS)
- The northeastern quadrant of CONUS is the only region where heavy rain events became more frequent during the warm season. Among other U.S. regions this quadrant is also characterized by
  - significant correlations between D and T_{min} (Great Lakes and Northeast) and
  - an intensification of land use (Midwest and Great Lakes)

No increase in T_{min} in the central U.S. during the 1950-2010 period can be attributed to droughts of the 1950s (South) and a significant land use change (Midwest, cf. Part 1). Over Midwest during the growing season (May-Sep) and the early growing season (May-July), D has no relationship with T_{min} and increases by 25%/ 63yr.

Conclusions

- 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.

Among possible causes of observed changes in the Central United States can be:

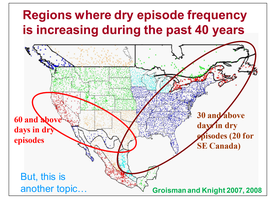
- Global factors associated with changes of global/hemispheric temperatures:
  - Increase in the atmospheric water holding capacity
  - Large scale changes in atmospheric circulation
- Local factors associated with land use and water management:
  - Intensification of agriculture in the region
  - Irrigation westward of the Central United States (Great Plains)
- All of these factors; many of which being collinear

We do not see among possible causes of observed changes in the Central United States:

- Changes in regional temperatures
- Changes in hurricane intensity/Frequency

- Prior to planning for adaptation and mitigation measures for detrimental consequences of these observed changes, the causes of this increase should be carefully investigated using a suite of models
- Projections of future changes critically depend upon correct partitioning of impact and feedbacks of global and/or regional factors responsible for ongoing changes
- Changes in intense precipitation over the contiguous United States during the past four decades coincide with (or are a part of) general changes in precipitation spectra over the region, in particular with an increase in the frequency of the prolonged no-rain periods in the warm season over most of the nation (cf., last slide)

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



Nov. 2011