Extreme Precipitation Trends

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April 25, 2017
Extreme Precipitation Trends

Workshops and Webinars

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Workshops

2014 Climate Matters Workshop, WGAC Earth Fair Workshops, 2013 NCA Workshop
2012 AGU Broadcast Conference Short Course
2011 NWA Meeting
2010 Climate Impact
2009 AGU Broadcast Conference Short Course

Webinars

2016 Learning from the Climate Changes in Past Centuries
2015 NASA Status of the Climate in 2015
2014 Wildfires and Climate Change
2013 Meteorological Mysteries: Top Weather Events of 2012
2012 Extreme Event Attribution Science
2011 All Things Climate Models
2010 Tropical Cyclones and Climate Change
2009 The Climate of China
2008 A Brief History of Climate Change Science
2007 A Deep Dive into the Southern Oceans
2006 Retrospective: Look at the Rising Curve

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CLIMATE CENTRAL

April 25, 2017
Extreme Precipitation Trends

Kenneth E. Kunkel, Ph.D.

NOAA Cooperative Institute for Climate and Satellites
North Carolina State University and National Centers for Environmental Information
Outline

- Types of floods
- Observed U.S. Trends of Extreme Precipitation
- Observed Global Trends of Extreme Precipitation
- The Future?
Types of Floods

- Flash
- Urban
- River
- Coastal
Flash Floods

• Usually in small, steep watersheds
• Caused by short-duration high-intensity rainfall
• Flood waters rise and fall rapidly
Flash Flood in former Neighborhood
~4 inch rain in 3 hours (July 2013)
Urban Floods

- These are also caused by short-duration high-intensity rainfall
- Urban areas have high percentages of surfaces impervious to water and thus runoff is immediate
Urban Flooding - Example

- July 17-18, 1996 in Chicago
- Up to 16 inches of rain in less than 24 hrs
- Over $600 million in damages
River Floods

- Caused by multiple moderate to heavy precipitation events occurring over days to weeks
- Snowcover and frozen ground will exacerbate floods
- Can last for days to weeks
River Flooding - Examples

- June-August 1993, Mississippi River
  - >34 inches precipitation in some locations
  - $15-20 billion in damages
  - 100,000 homes destroyed
Coastal floods

- Storm surges from tropical cyclones or coastal extratropical cyclones
Coastal Flooding - Examples

- October 2012, Hurricane Sandy
  - >14 ft surge (storm plus high tide)
  - $68 billion in damages
Sandy – Coastal Damage
Sandy – Coastal Damage
Observed U.S. Trends in Extreme Precipitation

• Extreme Precipitation Definition
• Recent research results
• Research Question: What are the long-term variations and changes in extreme event occurrence?
• Aim: analyze as long a period as possible
• Many past studies have used data from about 1950 to present; the observational network is relatively dense from about mid-20\textsuperscript{th} Century onward

• I and my colleagues have focused on analyses extending from the late 19\textsuperscript{th} - early 20\textsuperscript{th} Century; fewer stations available

• Sample analysis for 1950-2016: trends in number of 3 inch precipitation days
Daily precip > 3 inches, Station Trends
Many large upward trends in eastern part of U.S.

But, interspersed with downward trends (high spatial variability due to sampling of rare extreme events; **have to aggregate spatially**)

Few stations in intermountain west (Reason?: **Too few 3 inch events** to calculate trend)
Extreme Precipitation Analysis

• Definition - Events exceeding a threshold precipitation amount for a specified average recurrence interval and duration
  – Daily, 1 in 5-year events

• Research Finding from Third National Climate Assessment (through 2013): Strong upward trend in number of events in U.S.
  – Regional variations
Less than 10% missing data for 1895-2011
Extreme Precipitation (5-yr Storms)

- Relative Number of Extreme Events
- U.S. Average

The graph shows an increasing trend in the relative number of extreme precipitation events in the U.S. from the 1900s to the 2000s.
Extreme Heavy Precipitation

Map of the United States showing the relative number of extreme events in different regions. The map includes the following regions:
- Alaska
- U.S. Average
- Northwest
- Great Plains North
- Midwest
- Northeast
- Southwest
- Great Plains South
- Southeast
- Hawaii

Each region has a chart indicating the relative number of extreme events from the 1900s to the 2010s.
Update through 2016
National Average Frequency

National Average: 2-day, 5-yr recurrence events

Red Numbers indicate average time in years between extreme events at an average station. By definition, 5 years is the expected value. Lower numbers correspond with more frequent events.

<table>
<thead>
<tr>
<th>Years</th>
<th>Number of Events (per station per 5 years)</th>
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<tr>
<td>1901-1910</td>
<td>5.1</td>
</tr>
<tr>
<td>1911-1920</td>
<td>5.8</td>
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<tr>
<td>1921-1930</td>
<td>5.9</td>
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<td>1971-1980</td>
<td>4.9</td>
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<td>1981-1990</td>
<td>4.7</td>
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<td>1991-2000</td>
<td>4.0</td>
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<tr>
<td>2001-2010</td>
<td>3.9</td>
</tr>
<tr>
<td>2011-2016</td>
<td>3.8</td>
</tr>
</tbody>
</table>
Northeast U.S. Average Frequency

Northeast U.S.: 2-day, 5-yr recurrence events

Red Numbers indicate average time in years between extreme events at an average station. By definition, 5 years is the expected value. Lower numbers correspond with more frequent events.

- 1901-1910: 6.1
- 1911-1920: 6.7
- 1921-1930: 5.8
- 1931-1940: 4.4
- 1941-1950: 6.2
- 1951-1960: 4.7
- 1961-1970: 7.3
- 1971-1980: 4.9
- 1981-1990: 5.2
- 2001-2010: 3.0
- 2011-2016: 3.2
Dependence on Duration and Recurrence Interval

1, 2, 3, 5, 10, 20, 30 days
1, 2, 5, 10, 20-yr recurrence
### Trends by Duration and Recurrence

#### National

<table>
<thead>
<tr>
<th>Duration (day)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>10</th>
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</tbody>
</table>
Trends for NCEI Regions
Causes

• Have there been secular changes in the frequency, intensity, and other characteristics of the meteorological phenomena producing heavy precipitation?

• Are the recent increases primarily a result of increases in atmospheric water vapor concentrations?
Meteorological Types

- Extratropical Cyclones
  - Frontal (at least ~300 km away from center of surface or upper low)
  - ETC (near surface or upper low center)
- Tropical Cyclones
- Mesoscale Convective Systems
- Air Mass Convection
- North American Monsoon
- Upslope
Contribution by Type

>18,000 precip events were categorized for the period of 1908-2009
Trends by Type

Number of Events/Station/yr

Year


ETC  Frontal  Tropical

ETC  Frontal  Tropical
Trends by Type

Number of Events/Station/yr

Year


Monsoon Air Mass MCC Upslope
Causes

• Upward trend associated with an increase in the number of events associated with fronts and tropical cyclones. No trend in the number associated with the other meteorological types.

• No trend in the number of landfalling tropical cyclones. More extreme precipitation events per tropical cyclone.

• We have not investigated (yet) whether there are more fronts or the fronts have characteristics more conducive to extreme precipitation.
Causes

• Have there been secular changes in the frequency, intensity, and other characteristics of the meteorological phenomena producing heavy precipitation?

• Are the recent increases primarily a result of increases in atmospheric water vapor concentrations?
• Northeast quadrant of U.S.

• Water vapor environment associated with each extreme event obtained from calculated from precipitable water at nearest radiosonde stations

Water Vapor Change Associated with Extreme Events

86% of all events occur during this time period.
Causes

• This preliminary investigation suggests that increases in water vapor concentration are an important contributor to the upward trend.
Observed Global Trend

- 5-day duration, 10-yr recurrence interval
- 8326 stations
- Also
  - 1-day, 10-yr
  - 1-day, 1-yr
  - Precip above 99\textsuperscript{th} percentile
Stations with less than 10% missing

Station Locations, 1951–2014
Global Trend

10-Year, 5-Day, 1951–2014

Upward Trend
Downward Trend
- p<0.01
- 0.05<p<0.10
Global Average Frequency

30°–90° North

- Extreme Precipitation Index Anomaly (%)

Year


POT1d1y POT1d10y POT5d10y R99pTOT
Challenges

• **Finite network** of observing stations
• Inherent uncertainties in **sampling rare extreme** events
• Realities of observing network – missing data, station closings, etc.

• I and colleagues conducted a **sensitivity experiment** to evaluate certain sources of uncertainty, specifically those related to a **finite network and missing data**
Experiment

- Use the **modern**, rather spatially dense, climate observing **network** (>5000 stations) as the **reference**
- **Randomly choose stations** from this modern network to reproduce the density of the long-term network
- Randomly **shuffle the years** to produce an artificial time series of extreme events
- Calculate a national time series of extreme event occurrence
- **Repeat many times**
- Calculate the distribution of trends; this is an **estimate of the sampling uncertainty** of the long-term observing network
These experiment results indicate that the analyzed high (historically unprecedented) frequency of extreme precipitation events is robust.

Simulated Future Trends in Extremes

• Coupled-Model Intercomparison Project Phase 5 (CMIP5): Model simulations produced for IPCC Fifth Assessment Report

• Difference between 2070-2099 and 1976-2005 for high emissions scenario (RCP8.5)
• Water vapor increases in a warming climate because of the sensitive dependence of saturation vapor pressure on temperature (7% per °C)
Simulated Water Vapor Trends

- 30-yr maximum 850-500 mb precipitable water
High Emissions Scenario

Most of CONUS shows increases of 25-40%

Globally, increases are >20% everywhere
30-yr Maximum Daily Precipitation

Maximum Daily Precipitation Difference (%): (2071-2100) - (1971-2000), RCP8.5
Confidence in Water Vapor Increases

• High, if global warming continues
• Why? Because there is a direct link between air temperature and the amount of water vapor in the atmosphere over the oceans. As temperature increases, the capacity of the atmosphere to hold water vapor increases.
Implications

• What should be done about planning for future, specifically in **design and planning of runoff control structures** (long lifetimes)

• Extreme rainfall design values (e.g. the 100-yr storm) now in use are based solely on historical observations, essentially a **stationary climate assumption**

• Is that the least risky path forward?
Extreme Precipitation (5-yr Storms)

U.S. Average

Relative Number of Extreme Events

-0.4

1900s 20s 40s 60s 80s 00s
Concluding Thoughts

• Connections to flooding
  – Relatively **direct link** between short-duration extreme precipitation and **flash and urban flooding**
  – For **river flooding**, additional variables are important because the **temporal scales, spatial scales, and the runoff capacity** are larger. Also, **antecedent soil moisture** is important.
  – Hydrologic modeling
• Changes in extreme precipitation will arise from a number of factors. The two most important meteorological factors are atmospheric water vapor concentration (capacity of the atmosphere to produce extreme precipitation) and weather systems (opportunity)

• I hypothesize that as event duration increases (out to seasonal and beyond), the impact of synoptic meteorology (storm track and strength) becomes increasingly important on future changes.

• Water vapor increases are more certain than changes in synoptic meteorology
Implications for Flooding

• Short-duration urban flooding arising from intense local rainfall is likely to increase.
• River flooding depends also on weather system changes which are not understood as well, and thus there is less confidence about how that might change in the future.
QUESTIONS?
Extreme Precipitation Trends

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