Seeking the New Abnormal

John Nielsen-Gammon
Texas A&M University
Texas State Climatologist
US Multi-Day Rainfall Records

<table>
<thead>
<tr>
<th>Location</th>
<th>2 days</th>
<th>3 days</th>
<th>5 days</th>
<th>7 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hawaii</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harvey</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maui</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TX nr</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kauai</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FL nr</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TX</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PA nr</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Greatest US Storms: 5 days, 10,000 sq mi

Average Rainfall (inches)


Historic analyses: Applied Weather Associates; US Army Corps of Engineers

John Nielsen-Gammon, Texas A&M University
Greatest US Storms: 5 days, 10,000 sq mi

Average Rainfall (inches)

- Harvey 33.28"
- 1899 Texas
- 1967 Beulah
- 1940 Louisiana
- 2016 Louisiana
- 1994 Texas
- 1998 Georges
- 2010 N. Carolina
- 2010 Alex
- 1994 Alberto
- 1999 Floyd

Historic analyses: Applied Weather Associates; US Army Corps of Engineers
John Nielsen-Gammon, Texas A&M University
## (Central/Eastern) US Depth-Area-Duration All-Time Records Before Harvey

<table>
<thead>
<tr>
<th>Area\Duration</th>
<th>2 Days</th>
<th>3 Days</th>
<th>4 Days</th>
<th>5 Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,000 sq mi</td>
<td>Louisiana, August 1940</td>
<td>Louisiana, August 1940</td>
<td>Louisiana, August 1940</td>
<td>Louisiana, August 1940</td>
</tr>
<tr>
<td>2,000 sq mi</td>
<td>Louisiana, August 1940</td>
<td>Louisiana, August 1940</td>
<td>Louisiana, August 1940</td>
<td>Louisiana, August 1940</td>
</tr>
<tr>
<td>5,000 sq mi</td>
<td>Louisiana, August 1940</td>
<td>Texas, June 1899</td>
<td>Texas, June 1899</td>
<td>Texas, June 1899</td>
</tr>
<tr>
<td>10,000 sq mi</td>
<td>Georges, Florida 1998</td>
<td>Texas, June 1899</td>
<td>Texas, June 1899</td>
<td>Texas, June 1899</td>
</tr>
<tr>
<td>20,000 sq mi</td>
<td>Georges, Florida 1998</td>
<td>Beulah, Texas 1967</td>
<td>Beulah, Texas 1967</td>
<td>Beulah, Texas 1967</td>
</tr>
</tbody>
</table>
(Central/Eastern) US Depth-Area-Duration All-Time Records After Harvey

<table>
<thead>
<tr>
<th>Area \ Duration</th>
<th>2 Days</th>
<th>3 Days</th>
<th>4 Days</th>
<th>5 Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,000 sq mi</td>
<td>Harvey</td>
<td>Harvey</td>
<td>Harvey</td>
<td>Harvey</td>
</tr>
<tr>
<td>Louisiana, August 1940</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,000 sq mi</td>
<td>Harvey</td>
<td>Harvey</td>
<td>Harvey</td>
<td>Harvey</td>
</tr>
<tr>
<td>5,000 sq mi</td>
<td>Harvey</td>
<td>Harvey</td>
<td>Harvey</td>
<td>Harvey</td>
</tr>
<tr>
<td>10,000 sq mi</td>
<td>Harvey</td>
<td>Harvey</td>
<td>Harvey</td>
<td>Harvey</td>
</tr>
<tr>
<td>20,000 sq mi</td>
<td>Harvey</td>
<td>Harvey</td>
<td>Harvey</td>
<td>Harvey</td>
</tr>
<tr>
<td>50,000 sq mi</td>
<td>Harvey</td>
<td>Harvey</td>
<td>Harvey</td>
<td>Harvey</td>
</tr>
</tbody>
</table>
Greatest US Storms: 5 days, 10,000 sq mi

Historic analyses: Applied Weather Associates; US Army Corps of Engineers
John Nielsen-Gammon, Texas A&M University
Climate change rainfall contribution? (Me, guessing)

Historic analyses: Applied Weather Associates; US Army Corps of Engineers
John Nielsen-Gammon, Texas A&M University
Climate change rainfall contribution? (Me, guessing)

Average Fall (inches)

100,000 homes?
10,000 homes?
1,000 homes?

Historic analyses: Applied Weather Associates; US Army Corps of Engineers
John Nielsen-Gammon, Texas A&M University
Great US Storms: 5 days, 10,000 sq mi

100,000 homes?

10,000 homes?

1,000 homes?

Average Fall (inches)


33.28”

Climate change rainfall contribution? (Me, guessing)
Van Oldenborgh et al. (2017)

Historic analyses: Applied Weather Associates; US Army Corps of Engineers
John Nielsen-Gammon, Texas A&M University
Great US Storms: 5 days, 10,000 sq mi

Historic analyses: Applied Weather Associates; US Army Corps of Engineers
John Nielsen-Gammon, Texas A&M University

100,000 homes?
10,000 homes?
1,000 homes?

Average Fall (inches)

33.28”

Climate change rainfall contribution? (Me, guessing)
Van Oldenborgh et al. (2017)

Risser and Wehner (2017)
Average Annual Maximum 7-Day Precipitation (inches), SE Texas
Yearly Maximum Observed 2-Day Rain, Long-Term Stations, Harris County

Maximum Observed 2-Day Rain
Number of Stations Reporting
Yearly Odds of a Two-Day 8" Event at Any Long-Term Harris County Station
Average Annual Maximum 7-Day Precipitation (inches), SE Texas

Comparison with Risser & Wehner 2017,
Average Annual Maximum 7-Day Precipitation (inches), SE Texas
(d) average annual 3-day precip extreme

(f) GHCN-D 13 stations, Return period

- 3-Day Rainfall Total (inches)
- Return period [yr]

- GEV scale fit 1900
- GEV scale fit 2017
- Houston 2017

[Link to paper](http://iopscience.iop.org/article/10.1088/1748-9326/aa9ef2/meta)
3-Day Rainfall Total (inches)

Return period [yr]

(f) GHCN-D 13 stations, Return period

GEV scale fit 1900
GEV scale fit 2017
Houston 2017

(f) GHCN-D 13 stations, Return period

3-Day Rainfall Total (inches)

Return period [yr]

(f) GHCN-D 13 stations, Return period

3-Day Rainfall Total (inches)

Return period [yr]

GEV scale fit 1900
GEV scale fit 2017
Houston 2017
(f) GHCN-D 13 stations, Return period

3-Day Rainfall Total (inches) vs. Return period [yr]

- GEV scale fit 1900
- GEV scale fit 2017
- Houston 2017

(f) GHCN-D 13 stations, Return period

- 2017: 175-year
- 2055: 70-year
- 1900: 500-year

GEV scale fit 1900
GEV scale fit 2017
Houston 2017

3-Day Rainfall Total (inches)

Return period [yr]
Drought: Consider the Possibilities

Total Rainfall Amount

- Increase
- Steady
- Decrease

Heavy Rain Intensity

- Steady
- Increase
Drought: Consider the Possibilities

**Total Rainfall Amount**

<table>
<thead>
<tr>
<th>Heavy Rain Intensity</th>
<th>Increase</th>
<th>Steady</th>
<th>Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steady</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Drought: Consider the Possibilities

Total Rainfall Amount

- Increase
- Steady
- Decrease

Heavy Rain Intensity

- Increase
- Steady
- Decrease
Drought: Consider the Possibilities

Total Rainfall Amount

<table>
<thead>
<tr>
<th>Heavy Rain Intensity</th>
<th>Increase</th>
<th>Steady</th>
<th>Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steady</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Drought: Consider the Possibilities

Heavy Rain Intensity

Total Rainfall Amount

<table>
<thead>
<tr>
<th>Increase</th>
<th>Steady</th>
<th>Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steady</td>
<td><strong>X</strong></td>
<td></td>
</tr>
<tr>
<td>Increase</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

John Nielsen-Gammon, Texas A&M University
Drought: Consider the Possibilities

**Total Rainfall Amount**

<table>
<thead>
<tr>
<th>Heavy Rain Intensity</th>
<th>Increase</th>
<th>Steady</th>
<th>Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steady</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Drought: Consider the Possibilities

**Total Rainfall Amount**

<table>
<thead>
<tr>
<th>Heavy Rain Intensity</th>
<th>Increase</th>
<th>Steady</th>
<th>Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steady</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

John Nielsen-Gammon, Texas A&M University
Drought: Consider the Possibilities

Total Rainfall Amount

Heavy Rain Intensity

- Increase
- Steady
- Decrease

Historical

- Increase
- Steady
- Decrease
Drought: Consider the Possibilities

Total Rainfall Amount

Heavy Rain Intensity

- Increase
- Steady
- Historical
- Decrease

Model Projections

John Nielsen-Gammon, Texas A&M University
Messages

• Harvey was exceptional
• Odds of extreme rainfall have increased
  – And will continue to increase
  – Odds change ballpark estimate: Factor of 3 (2-8) per °C global warming
  – Amount change ballpark estimate: 15% (10-30%) per °C global warming
More Messages

• Annual rainfall amounts have increased
  – But may decrease in future

• Future drought intensity depends on:
  – Intensity of heavy rain
  – Overall rainfall amounts
  – Increasing temperatures (a given)

• Houston has been unlucky
Comprehensive Rainfall Survey (NSF-funded project)

- Data being collected
  - Weather & climate (COOP, WBAN)
  - Hydrological (HCFCD, LCRA)
  - Popular networks (CoCoRaHS, WU)
  - Independent “backyard” observers
- Analysts: Texas A&M, AWA, MetStat
- Please share your data!
  - [http://climatexas.tamu.edu/harvey/survey/](http://climatexas.tamu.edu/harvey/survey/)
  - ng@tamu.edu
Bonus Slides
Measure of Stalling: Corral Size

- Contains all storm locations over three days
Harvey’s corral radius: 123 km centered at 12 UTC Aug 27
Average maximum sustained wind while stalled: 50 kt (26 m/s)
How Slow Can Tropical Cyclones Go?

“Stalling”: 1 in 7.4
Stalled Tropical Cyclones: Month, Intensity
Coastal Stalls At Least As Slow and Intense As Harvey

- One of 2 costliest Atlantic storms ever
- One of 5 deadliest known Atlantic storms
- One of 5 deadliest known Atlantic storms

Flora 1963
Harvey 2017
Mitch 1998
5 Days 1910
Record Totals (mm)
Juan (1985)
Number of Coastal Stalls:
100 km inland to 50 km offshore

- Other
- Cuba
- Mex/CentAm
- USA
Probability of Harvey Rain

- Probability of strong stall
- Conditional probability of moisture channel
Stalled Tropical Cyclones: Month, Intensity
Probability (per century) of Strong Stall in 1°x1° Box

• 1917-2017: 0.08
• 1967-2017: 0.13
• Superstall (<100 km): 0.02
Comparison Between Harvey and Probable Maximum Precipitation

Lines being below the square boxes means that Harvey did not exceed the previously estimated Probable Maximum Precipitation for the Gulf region.
Greatest US Storms: 5 days, 1,777 sq mi

Average Rainfall (inches)

1940 Louisiana
1899 Texas
1967 Beulah
1979 Claudette
2002 Texas
1994 Texas
1997 Danny
1954 Alice
2016 Louisiana
1994 Alberto

Historic analyses: Applied Weather Associates
John Nielsen-Gammon, Texas A&M University
Greatest US Storms: 5 days, 1,777 sq mi

Average Rainfall (inches)

Historic analyses: Applied Weather Associates
John Nielsen-Gammon, Texas A&M University
Contact Information

• John Nielsen-Gammon
• n-g@tamu.edu
• http://climatetexas.tamu.edu