Rainfall and Flooding: Historical Trends and Future Projections

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Targeted Questions to Address:

- How has our understanding of changes and model projections evolved since 2008? ***Greater confidence in detection of anthropogenic influence on precipitation (mean and extremes); some preliminary detection of flooding increase over upper midwest US (not attribution). CMIP5 model historical runs have a low bias or 'drying bias' in extratropical precipitation trends.***

- What is current best practise, including the most appropriate models, downscaling approaches and analysis techniques? ***CMIP5 multi-model analysis; optimal fingerprinting detection and attribution (Zwiers, Zhang, Min); gridpoint based (univariate) regional trend analysis (Knutson) showing regional detail.***

- Is current practice at a state where it can be relied upon for long-term business decisions? ***Yes. Projected precipitation changes (means and extremes) should be considered at some level, in my opinion.***

- What are the recognised gaps and uncertainties in current practise – and what needs to be done to close these gaps and address the uncertainties? ***Why are model historical trends in precipitation biased low? Is future flood risk increase being underestimated? Continued work to refine D&A conclusions.***

Targeted Questions to Address (Part II):

- Do existing climate models show skill in sufficiently resolving regional differences in rainfall? ***Climatologies looks reasonable, but I have concerns that CMIP5 models have a 'dry bias' in historical mean precipitation trends in the extratropics.***

- Are we seeing projected differences to the tail of the distribution i.e. a longer tail? ***Yes. We see this for the tropical cyclone precipitation projections for example.***

- Do we see discernible changes in steering winds? ***The most robust long-term circulation change is a poleward shift in southern hemisphere jet stream. The tropical Hadley circulation has expanded, but there may be a large role for natural variability in the recent expansion. GFDL tropical cyclone projections do not indicate a systematic slow-down of TC propagation speeds like that seen in observations by Kossin (2018).***

- How well do the models resolve snowfall and lightning frequency? ***Snowfall climate simulations for high mountain regions is improved with higher resolution models that better resolve the topography. Lightning frequency?***

Recent Assessment Statements about Flooding

IPCC AR5 WG2, p. 185 (2014)
"In summary, there continues to be a lack of evidence and thus low confidence regarding the sign of trend in the magnitude and/or frequency of floods on a global scale."

U.S. 4th National Assessment (Climate Science Special Report, 2017):
"Detectable changes in some classes of flood frequency have occurred in parts of the United States and are a mix of increases and decreases. Extreme precipitation, one of the controlling factors in flood statistics, is observed to have generally increased and is projected to continue to do so across the United States in a warming atmosphere. However, formal attribution approaches have not established a significant connection of increased riverine flooding to human-induced climate change…"

Recent Assessment Statements about Flooding

IPCC AR5 WG2, p. 214 (2014)

Low confidence in attribution or projections of flooding.

IPCC SREX Report (2012):

“There is limited to medium evidence available to assess climate-driven observed changes in the magnitude and frequency of floods at regional scales because the available instrumental records of floods at gauge stations are limited in space and time, and because of confounding effects of changes in land use and engineering. Furthermore, there is low agreement in this evidence, and thus overall low confidence at the global scale regarding even the sign of these changes.

Recent Assessment Statements about Flooding

IPCC SREX Report (2012): (Projections)

"Projected precipitation and temperature changes imply possible changes in floods, although overall there is *low confidence* in projections of changes in fluvial floods. Confidence is *low* due to limited evidence and because the causes of regional changes are complex, although there are exceptions to this statement. There is *medium confidence* (based on physical reasoning) that projected increases in heavy rainfall would contribute to increases in local flooding in some catchments or regions."

Significant trends (1962-2011) in central U.S. flood events (Mallakpour and Villarini, 2015)

Flood magnitude

Flood frequency

(Figures not available for public distribution)

- Stronger evidence for detectable increases in flood frequency than magnitude. No attribution claim for anthropogenic forcing.

- For flood frequency, peaks over threshold approach, where threshold set to have two events per year on average. For flood magnitude: annual maximum daily values are analyzed.

Source: Mallakpour and Villarini, *Nature Climate Change* (2015)

Significant trends (1962-2011) in central U.S. flood events (Mallakpour and Villarini, 2015)

Flood magnitude Flood frequency

Spring

Summer

Fall

Winter

(Figures not available for public distribution)

- Stronger evidence for detectable increases in flood magnitude and frequency during summer.

Source: Mallakpour and Villarini, *Nature Climate Change* (2015)

Significant trends (1962-2011) in central U.S. heavy precip. events (Mallakpour and Villarini, 2015)

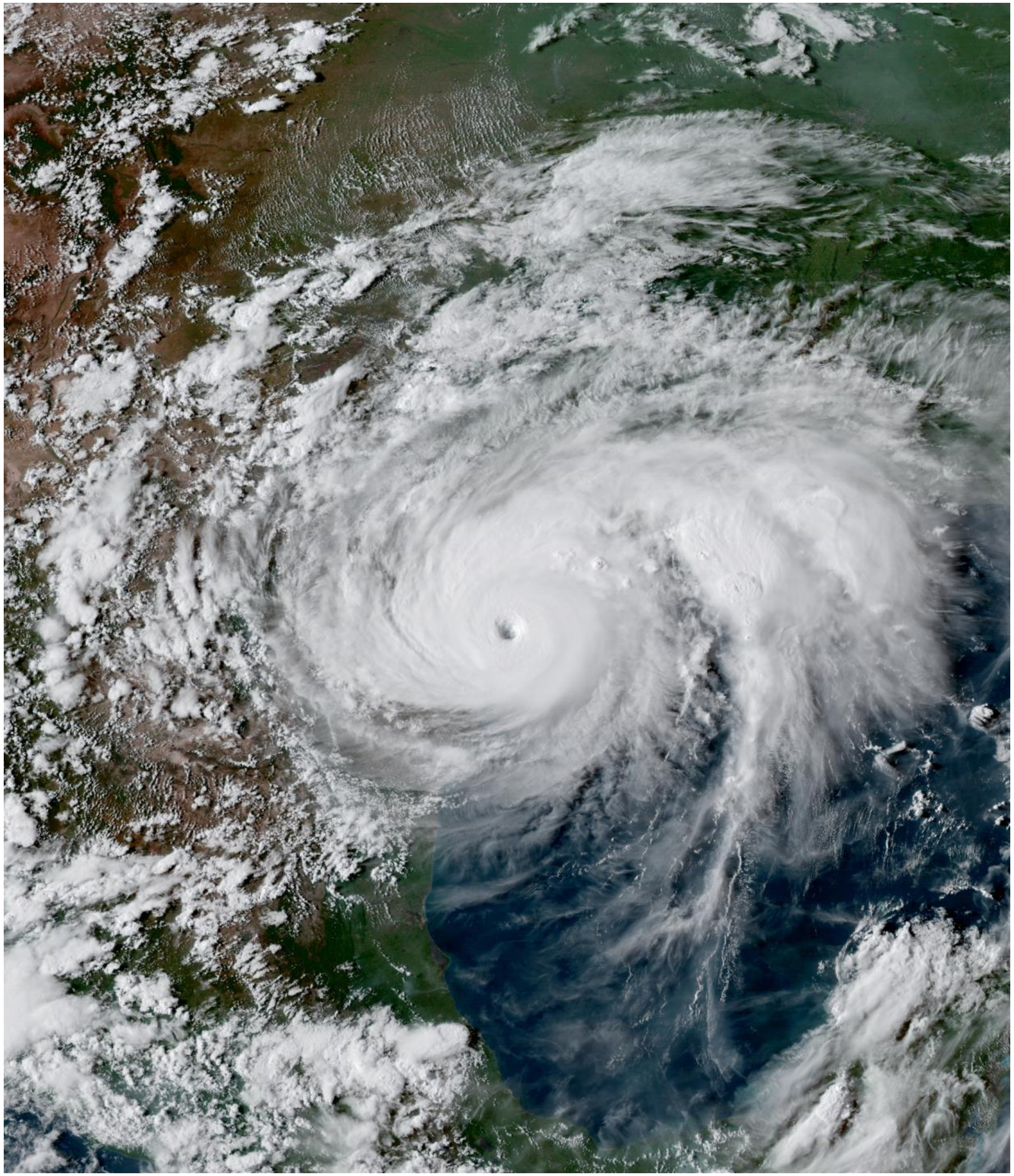
Heavy precipitation event magnitude

Heavy precipitation event frequency

(Figures not available for public distribution)

- Stronger evidence for detectable increases in heavy precipitation frequency. No attribution claim for anthropogenic forcing .
- For extreme precip. frequency, peaks over threshold approach, where threshold set to have two events per year on average. For extreme precipitation magnitude: annual maximum daily values are analyzed.

Source: Mallakpour and Villarini, *Nature Climate Change* (2015)

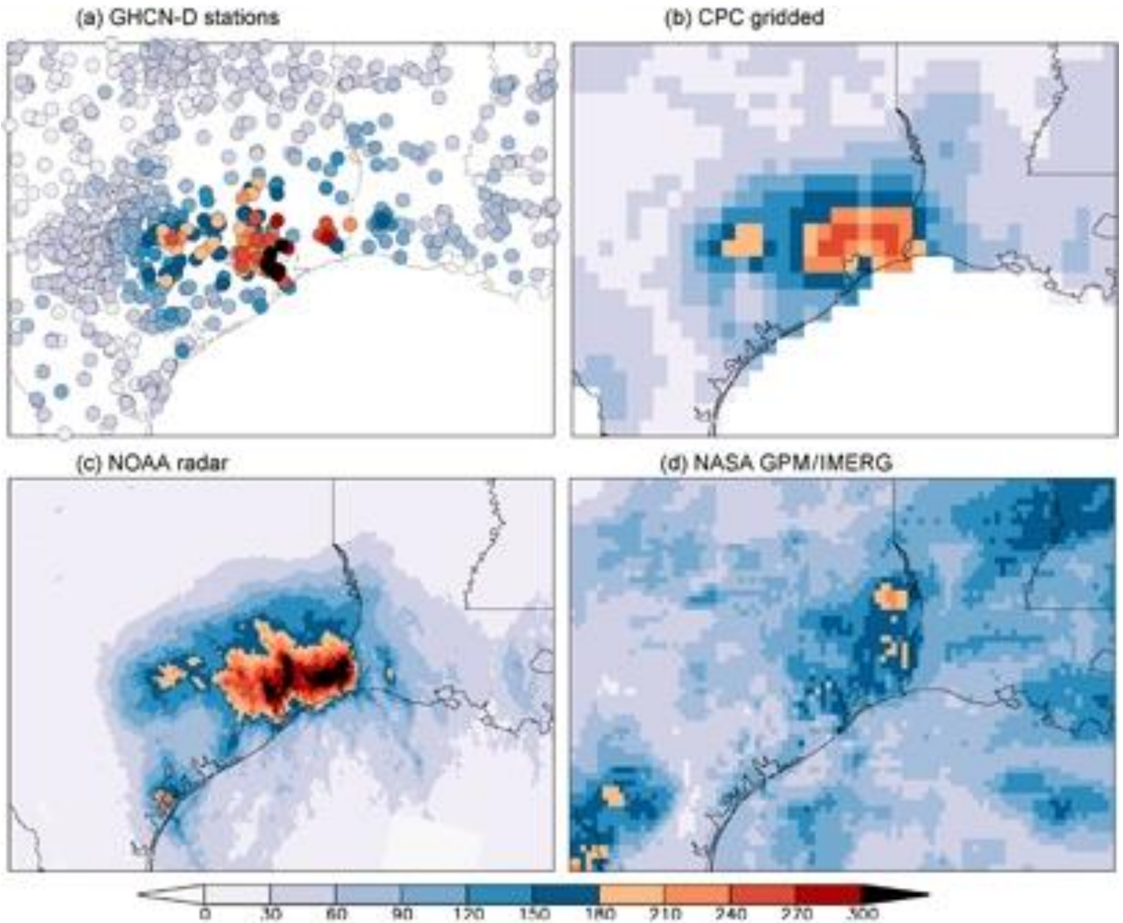


Source: Wikipedia

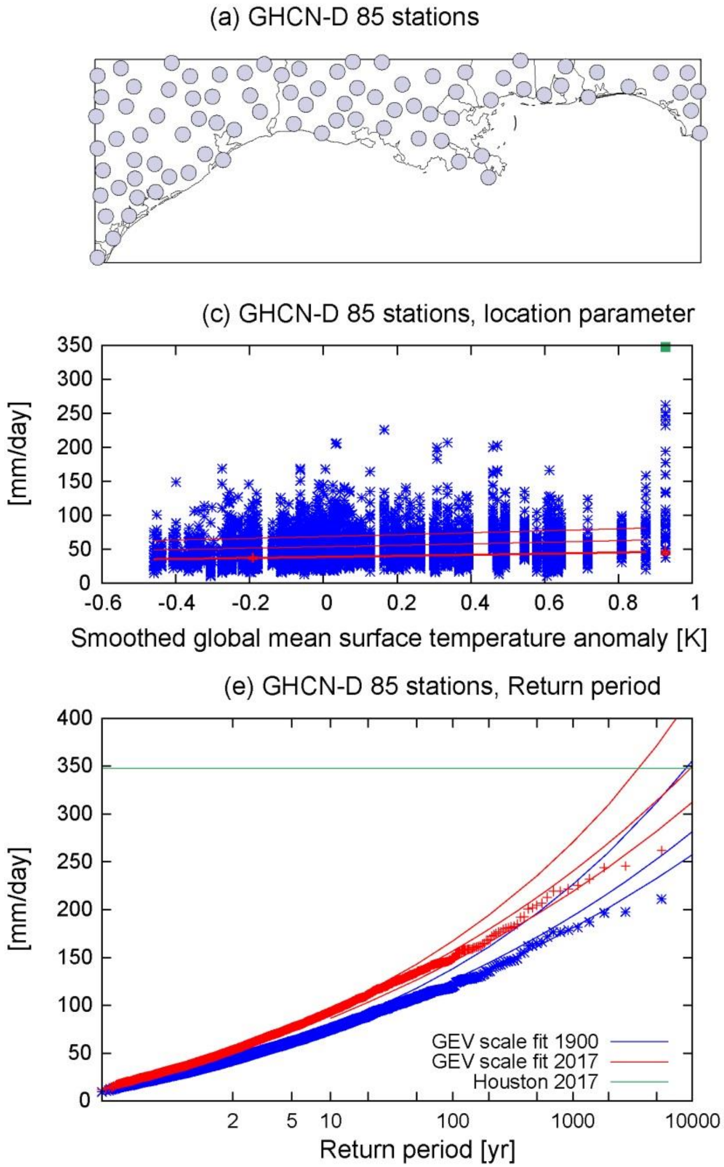
Harvey Aug. 17-Sept.1, 2017

- 1-min. sustained winds: 130 mph (at landfall)
- 938 mb (Cat 4)
- Damage est: $198 B
- 91 fatalities (90 in U.S.)
- Rainfall total: 60.58 inches (record for US Tropical cyclone)
- Stalling characteristic
- Rapid intensification (Aug. 24-25) to Cat 4 near Texas

Hurricane Harvey Event Attribution:
Observed maximum three-day averaged rainfall January–September 2017 (mm dy^{-1})



Source: Figure 3 from Attribution of extreme rainfall from Hurricane Harvey, August 2017
Geert Jan van Oldenborgh et al 2017 Environ. Res. Lett. 12 124009 doi:10.1088/1748-9326/aa9ef2

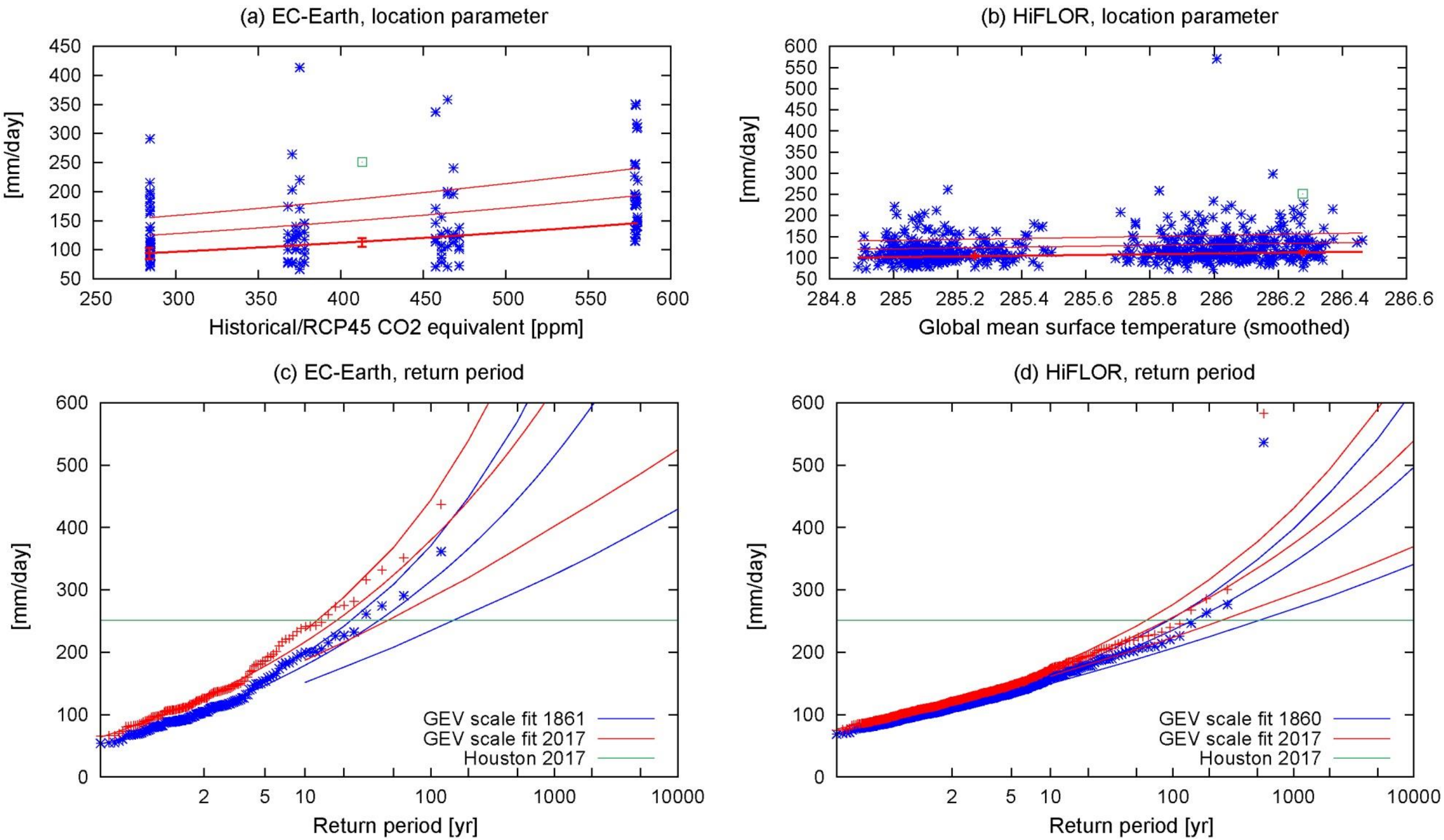


Generalized Extreme Value (GEV) fits for annual maximum three-day average precipitation rate along the US Gulf Coast. Based on GHCN-D station precipitation data.
(A rare event, some return intervals exceeding 1000 yr.)

Time-dependent fits (for 1900 and 2017) based on scaling with smoothed global mean surface temperature:
Observed extreme precipitation has increased by 12-22% since 1880 in the region (~2x water vapor content increase at constant relative humidity).

Source: Figure 4 from Attribution of extreme rainfall from Hurricane Harvey, August 2017
Geert Jan van Oldenborgh et al 2017 Environ. Res. Lett. 12 124009 doi:10.1088/1748-9326/aa9ef2

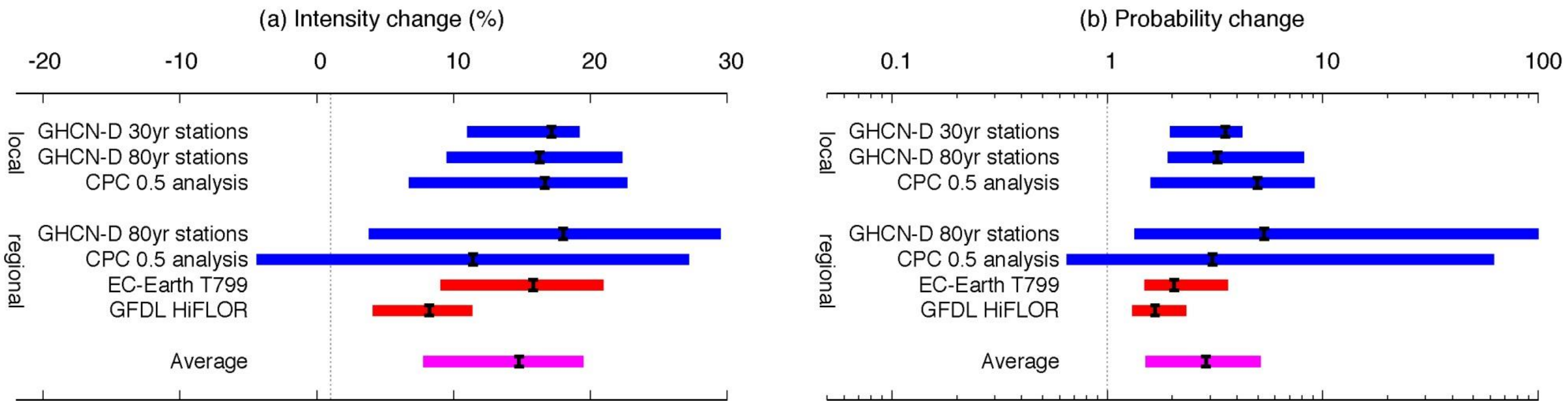
Modeled 3-day average eastern Texas precipitation vs. climate and GEV fitted parameters



-> Global warming made Harvey's precipitation 8-19% more intense; and 1.5 to 5x more likely.

Source: Figure 6 from Attribution of extreme rainfall from Hurricane Harvey, August 2017
Geert Jan van Oldenborgh et al 2017 Environ. Res. Lett. 12 124009 doi:10.1088/1748-9326/aa9ef2

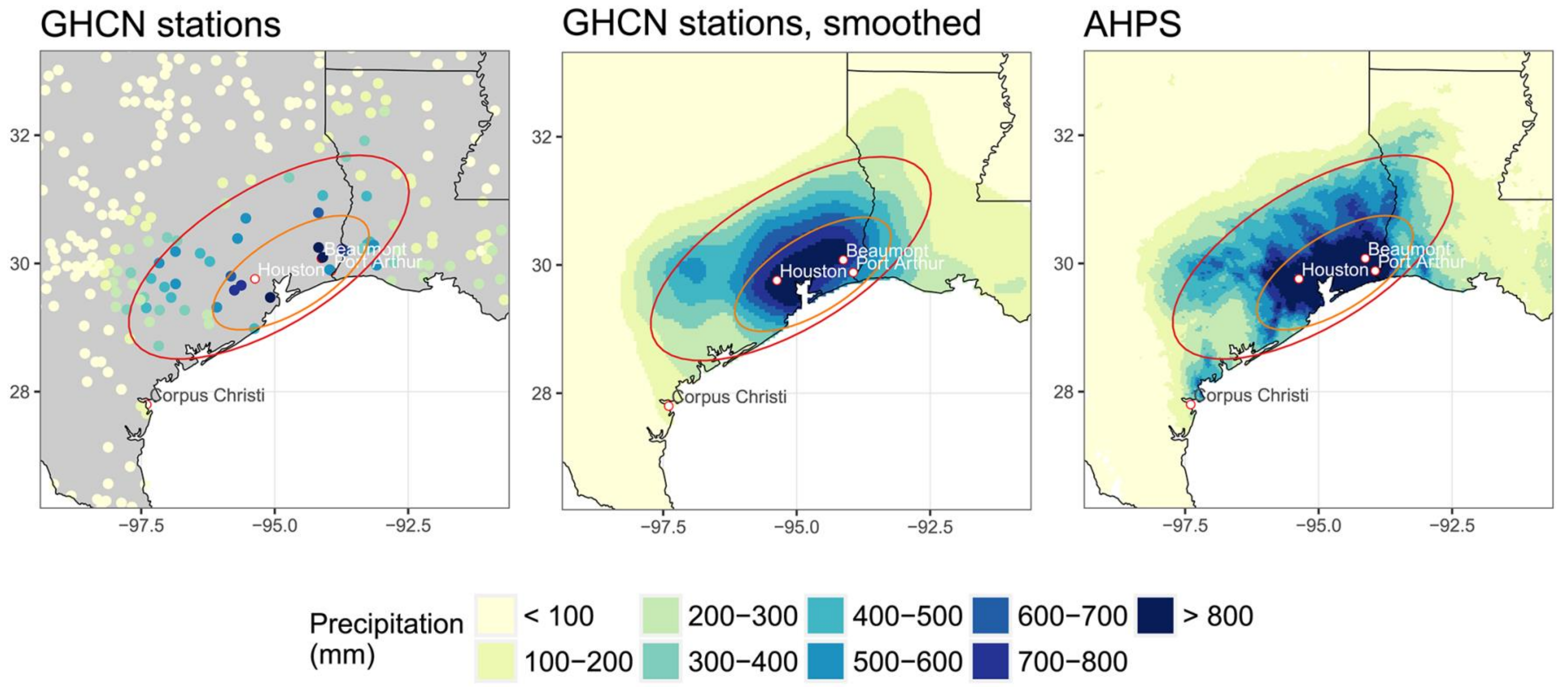
Summary of modeled and observed changes in intensity and probability of occurrence



Note: See also analysis of Aug. 2016 flood-producing extreme rainfall in south Lousiana (van der Wiel et al., Hydrol. Earth Syst, Sci. (2017).

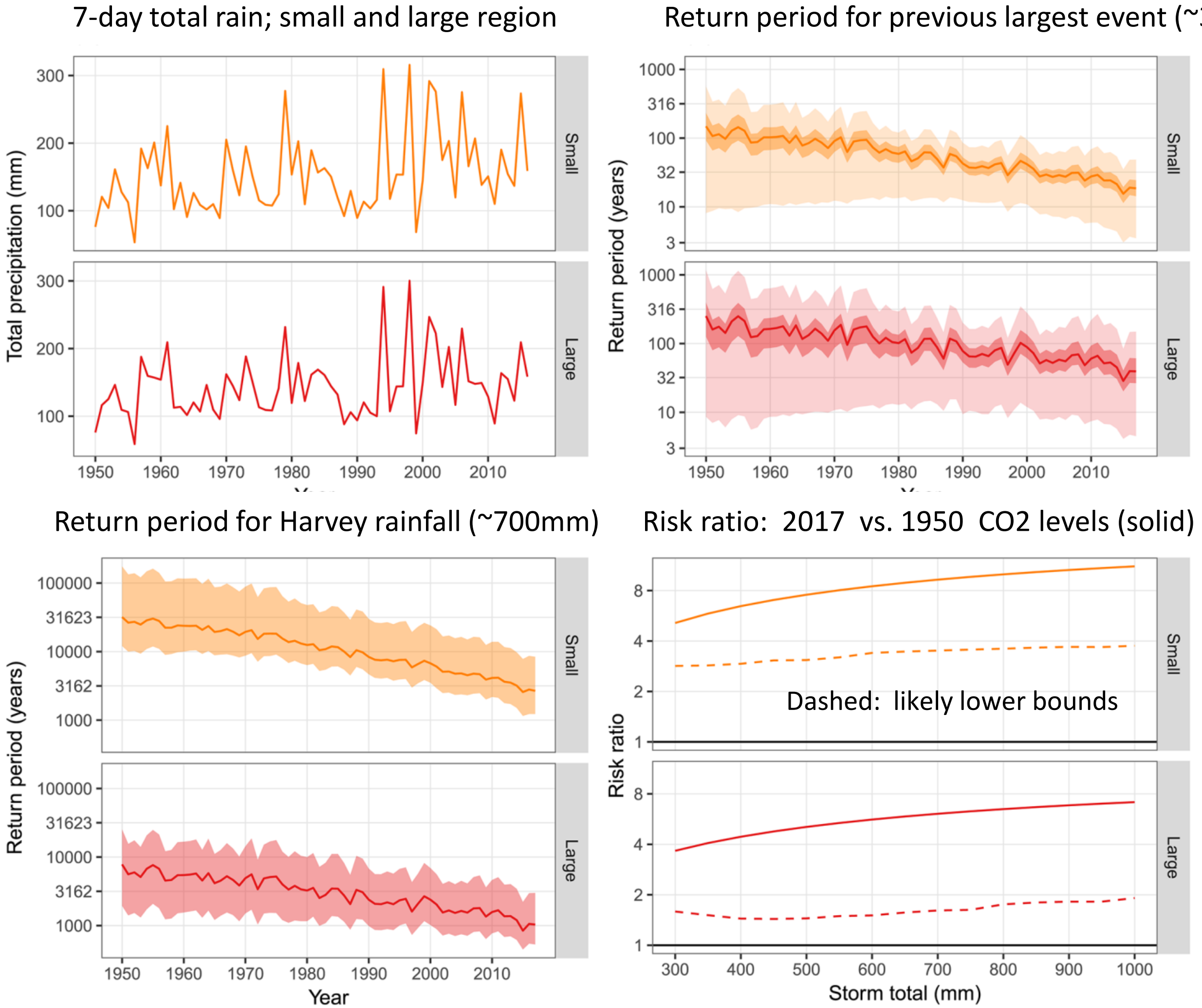
Source: Figure 7 from Attribution of extreme rainfall from Hurricane Harvey, August 2017
Geert Jan van Oldenborgh et al 2017 Environ. Res. Lett. 12 124009 doi:10.1088/1748-9326/aa9ef2

Attributable Human-Induced Changes in the Likelihood and Magnitude of the Observed Extreme Precipitation during Hurricane Harvey



Source: Risser and Wehner, Geophysical Research Letters (2017)

Attributable Human-Induced Changes in the Likelihood and Magnitude of the Observed Extreme Precipitation during Hurricane Harvey



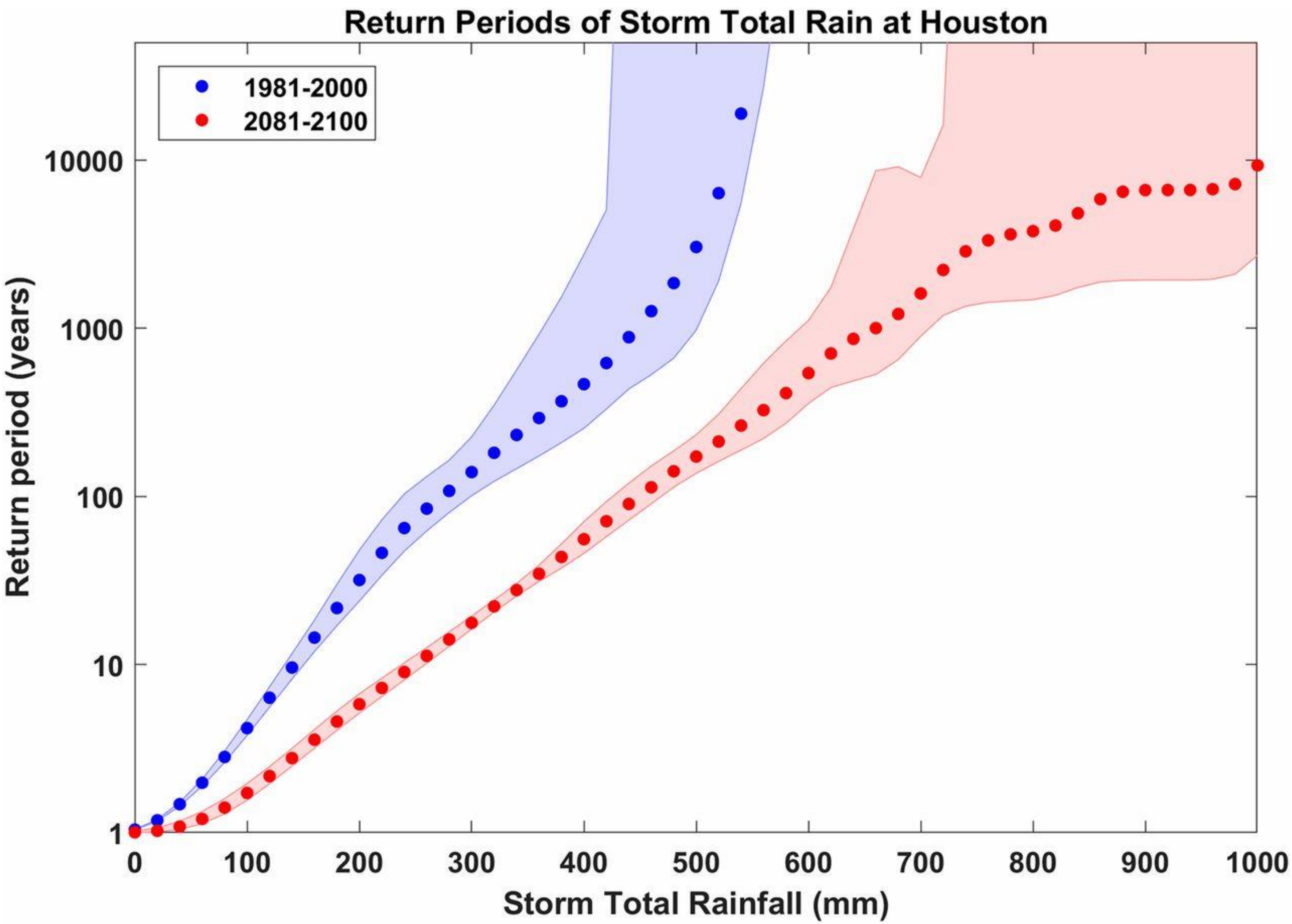
Extreme value statistical analysis using $\log_n(CO_2)$ or NINO3.4 SST as covariates.

<u>Anthropogenic climate change:</u>

- likely increased rain amount at least 19% (best estimate: 38%)
- likely increased chances of observed rainfall at least 3.5 x (best estimate: 9.6 x).

Source: Risser and Wehner, Geophysical Research Letters (2017)

3,700 simulated events each from six global climate models (Historical and RCP8.5); Shading: 1 st. dev. in storm frequency distribution



A 500mm rainfall event in Texas: 6x more likely by 2017 vs. 2000).

Source: Kerry Emanuel PNAS doi:10.1073/pnas.1716222114

PNAS

Multi-model projected median return period for 100-yr flood (20th century) by 2080s

(Figures not available for public distribution)

One hydrologic model, driven by 11 CMIP5 models, RCP8.5 scenario.

Source: IPCC AR5 WG2 (after Hirabayashi et al. 2013)

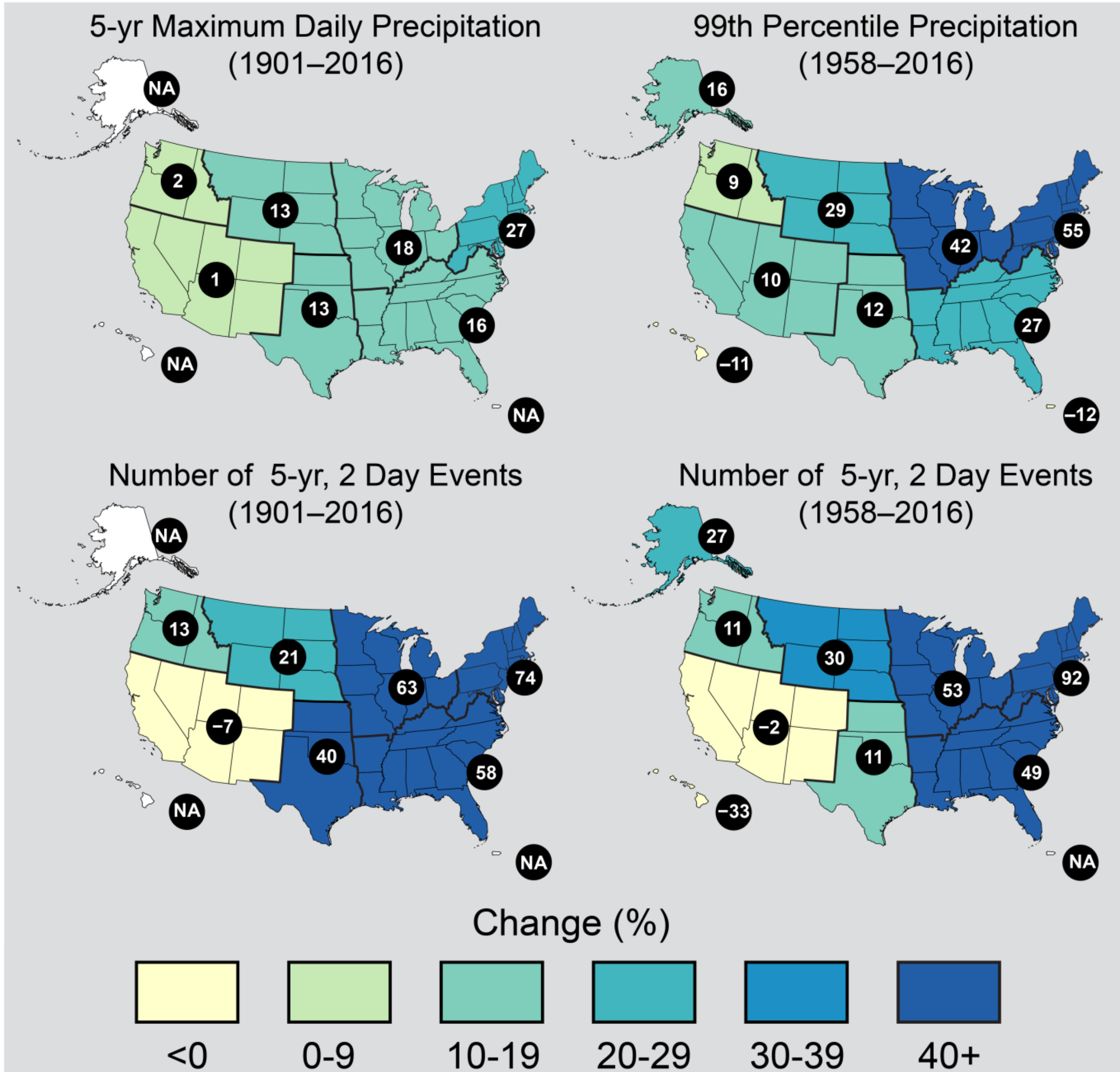
Projected changes in rain-on-snow (ROS) events; RCP8.5 scenario (2071-2100)

(Figures not available for public distribution)

- Low elevations: Rain-on-snow events less frequent (smaller snowpack)
- Higher elevations: Rain-on-snow events more frequent (snow -> rain)

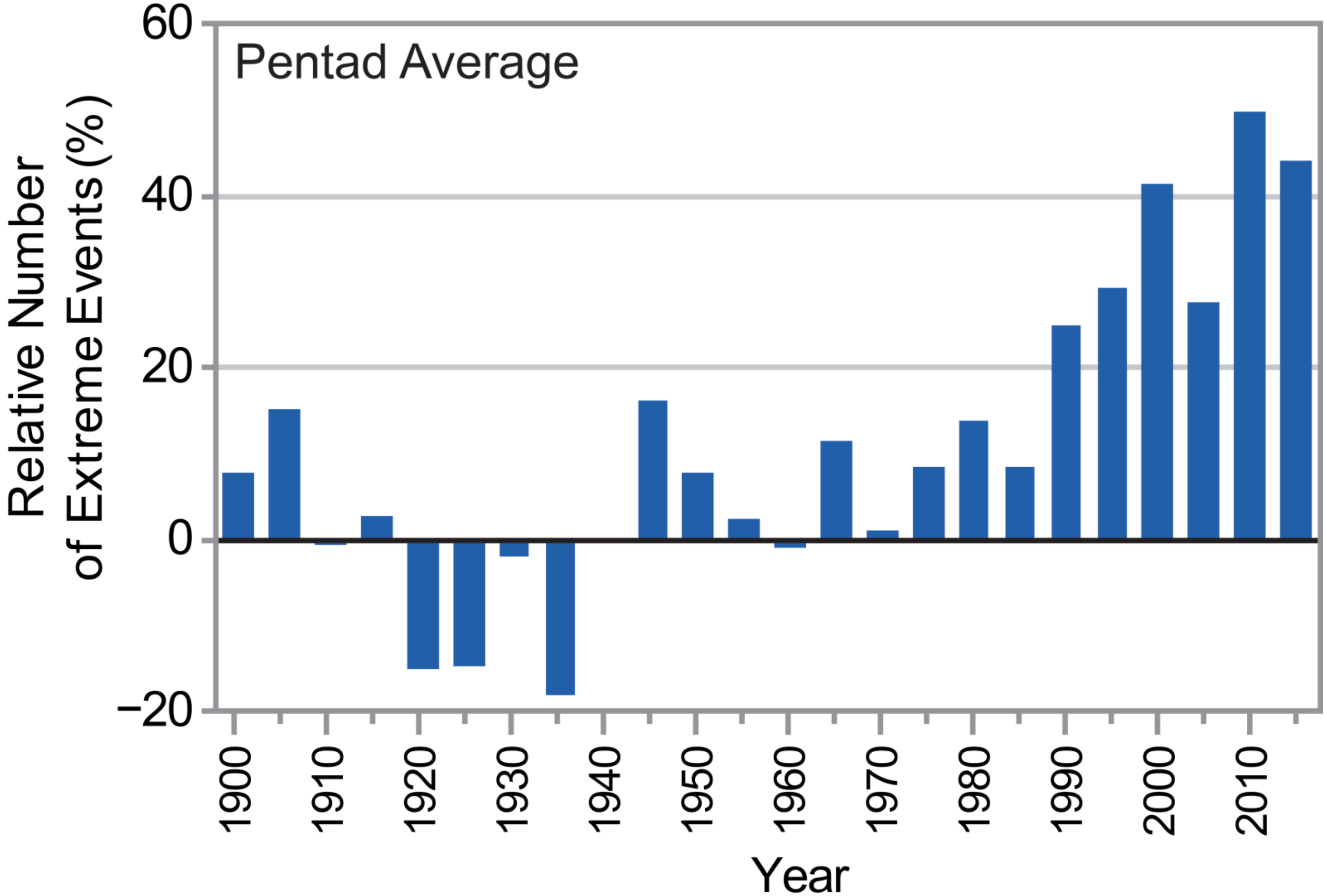
Source: Musselman et al., 2018, *Nature Climate Change*

Observed Change in Heavy Precipitation



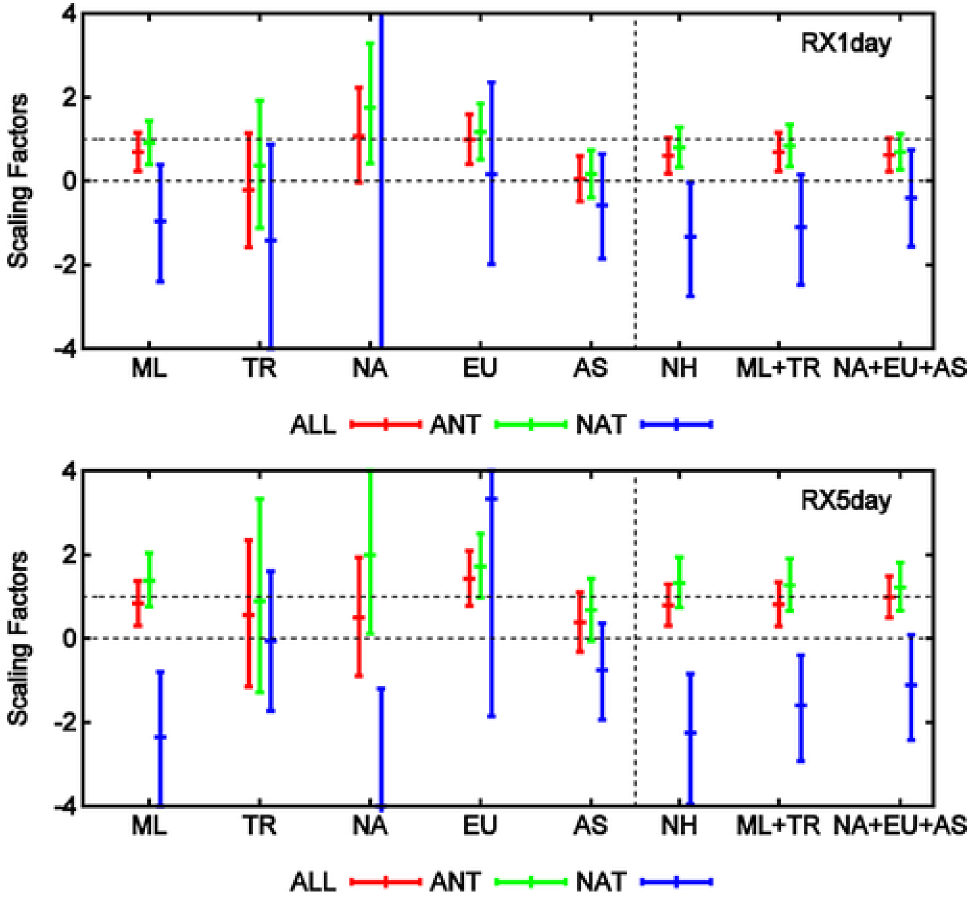
Source: CICS-NC and NOAA NCEI

2-Day Precipitation Events Exceeding 5-Year Recurrence Interval



Source: Climate Science Special Report, Figure source: CICS-NC and NOAA NCEI)

Attribution of increases in precipitation extremes to human influence (1951-2005)



ANT = Anthropogenic Forcing
NAT = Natural Forcing

Rx1day: annual maxima of daily precipitation

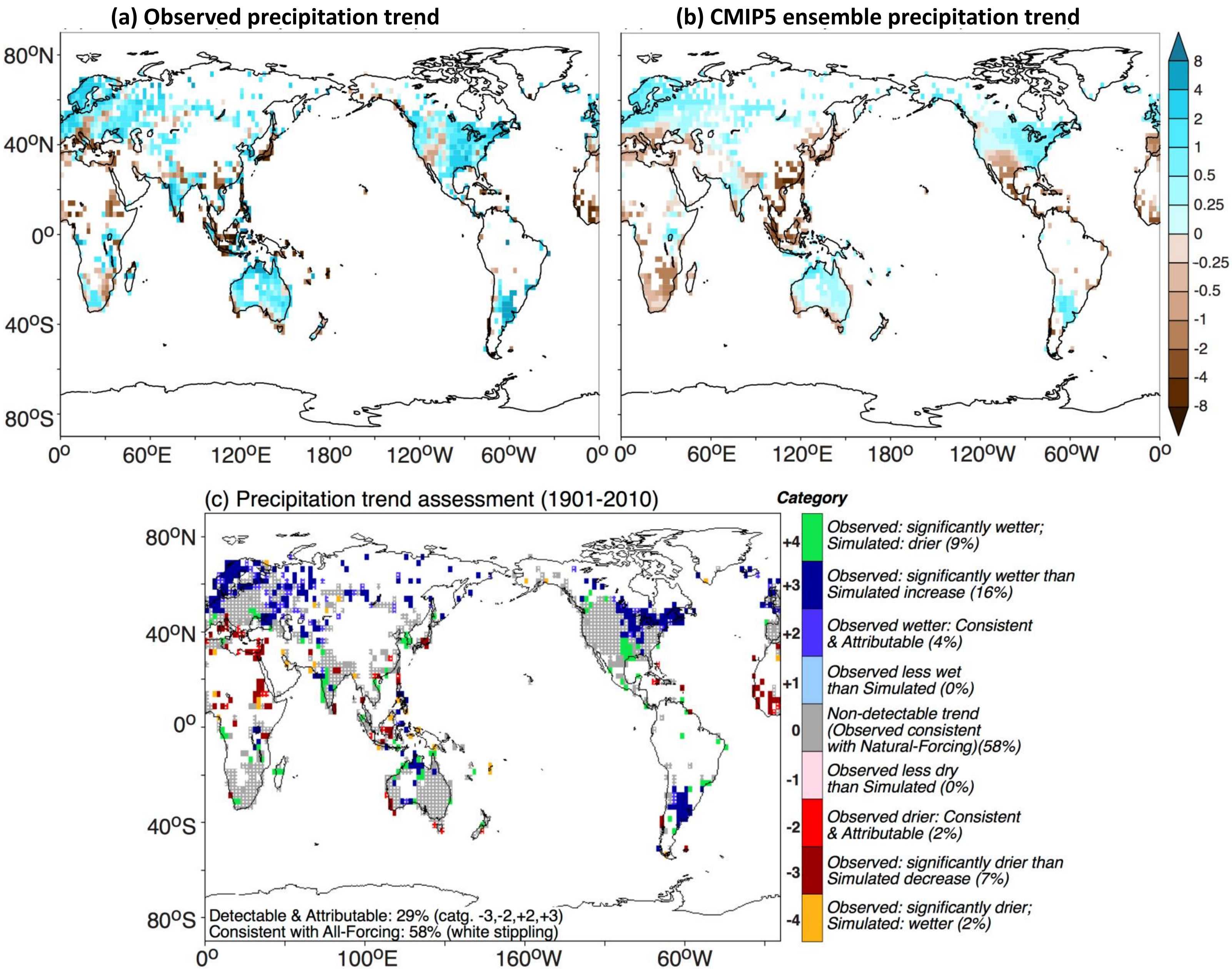
Rx5day: annual maxima of 5-day precipitation

NA = North America region (western hemisphere land)
ML = mid-latitudes
TR = northern tropics
EU = Europe
AS = Asia
NH = northern hemisphere

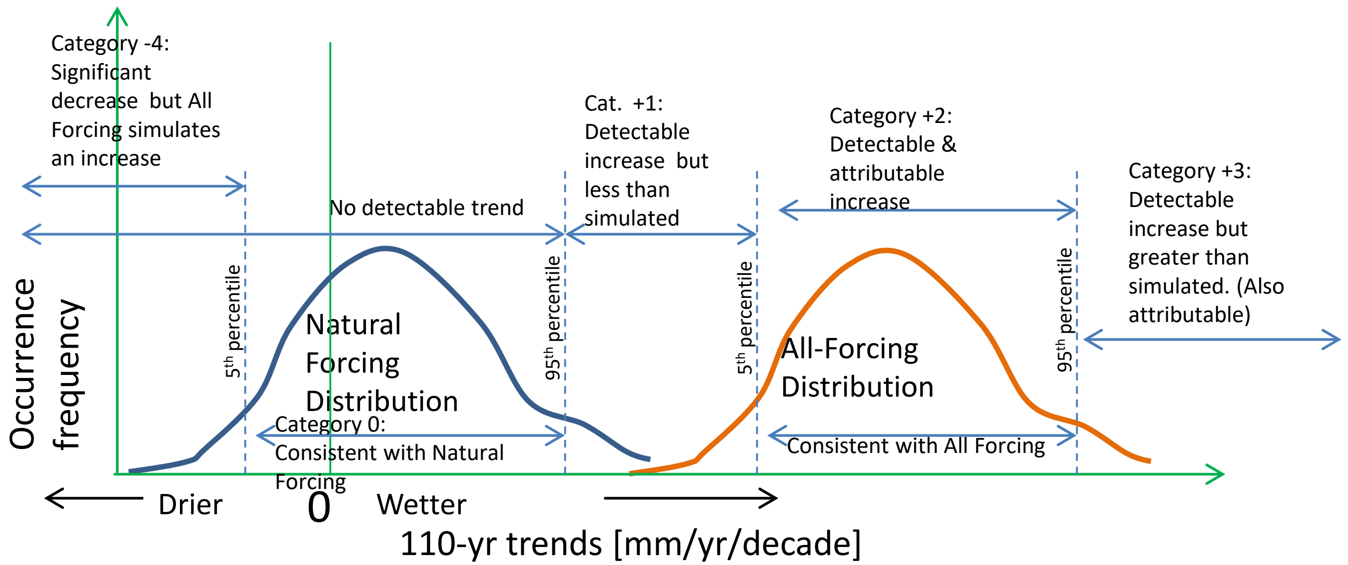
Bars: 5-95% confidence intervals, single-signal optimal detection

Source: X. Zhang et al. (2013) Geophysical Research Letters.

1901-2010 Precipitation Trend Assessment

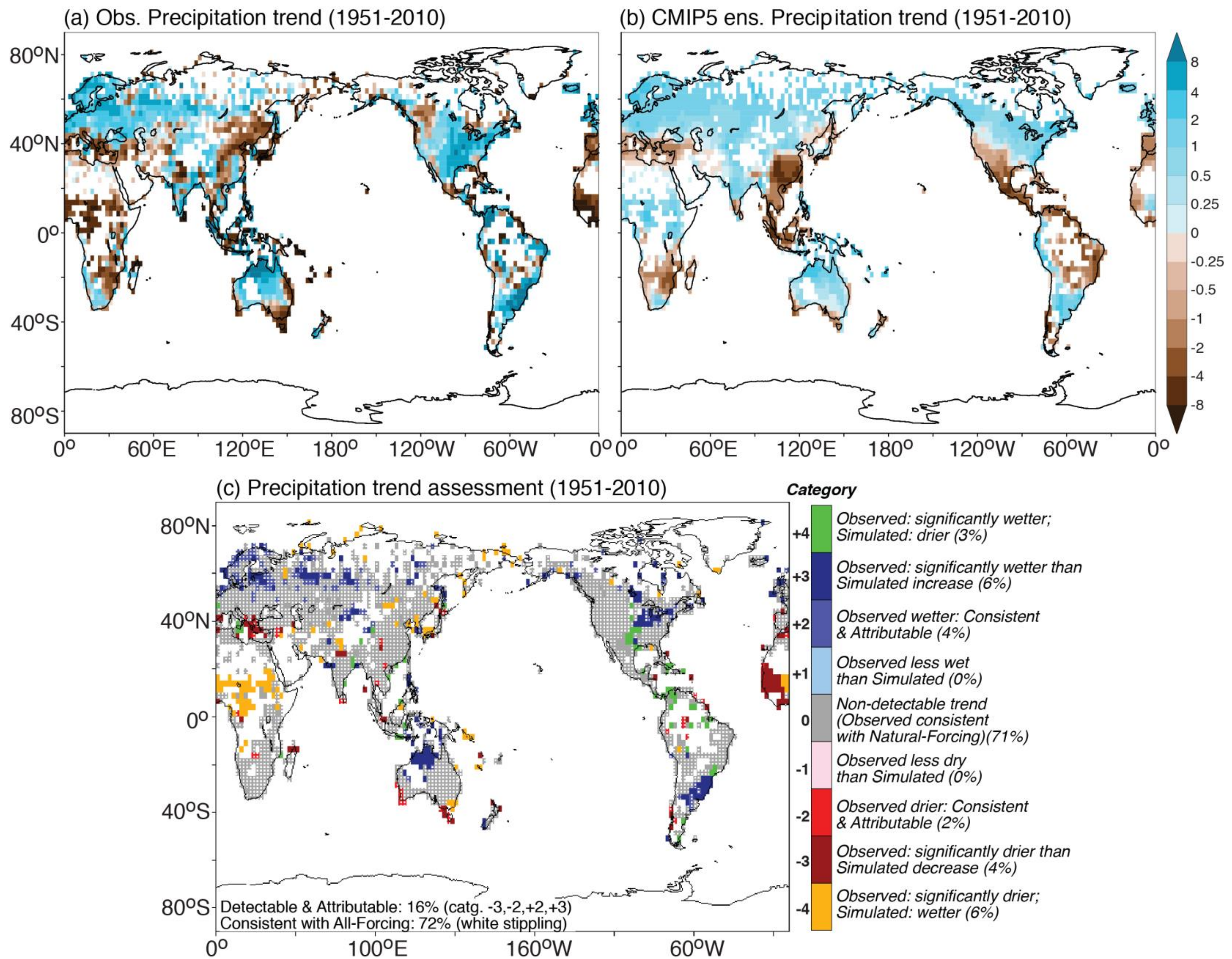


Source: Knutson and Zeng, *J. Climate* (2018)



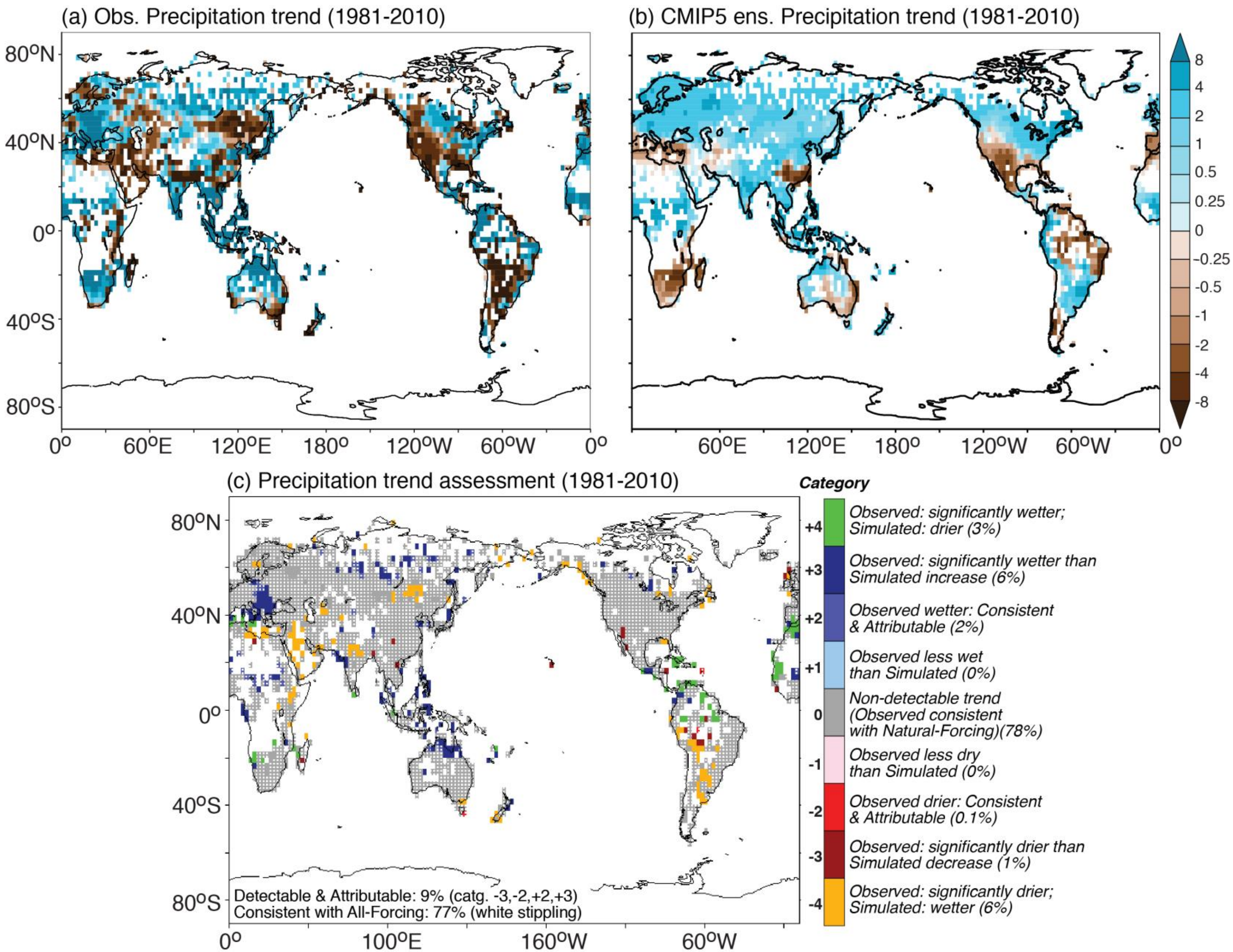
Source: Knutson and Zeng, *J. Climate* (2018)

1951-2010 Precipitation Trend Assessment



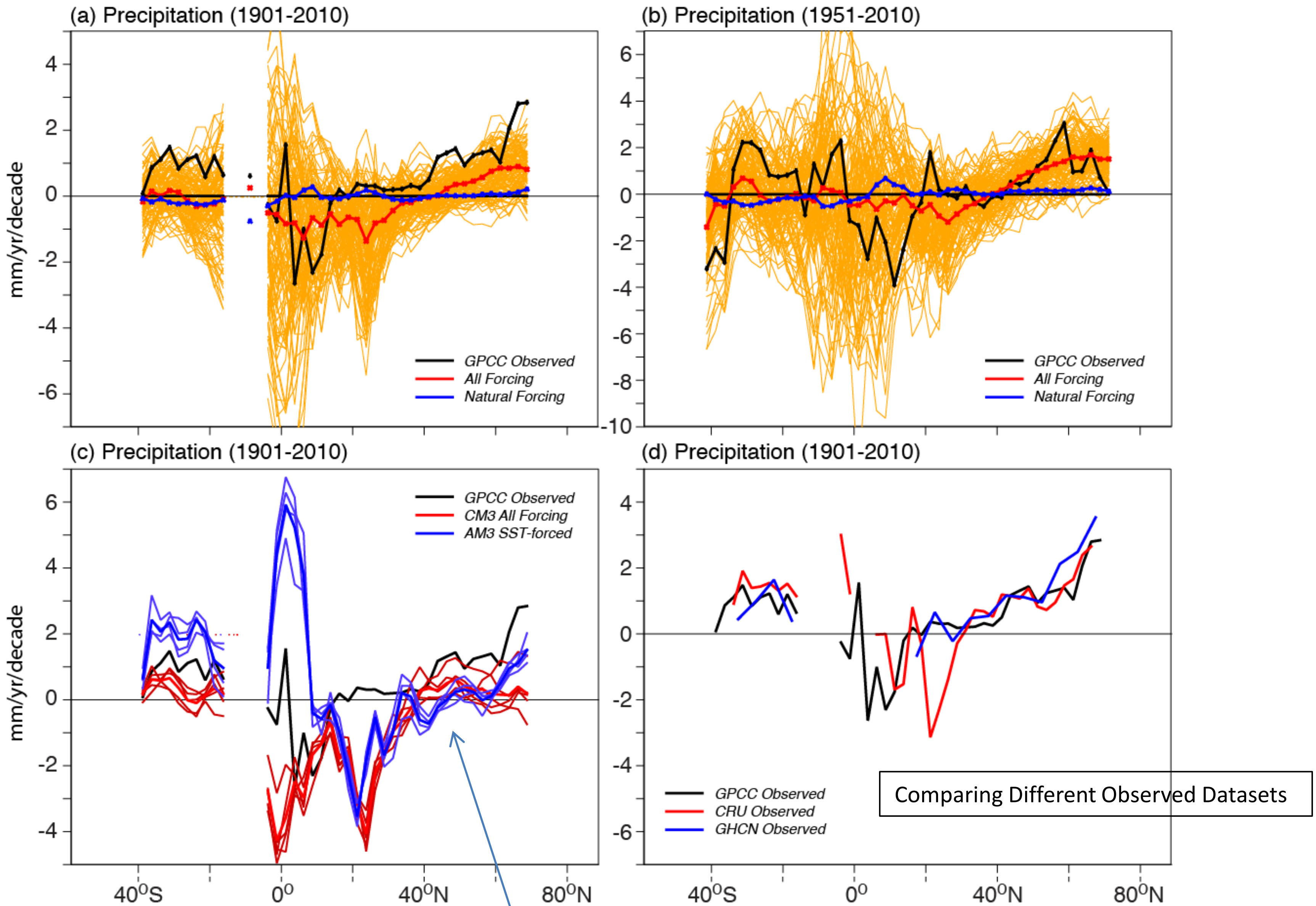
Source: Knutson and Zeng, *J. Climate* (2018)

1981-2010 Precipitation Trend Assessment



Source: Knutson and Zeng, *J. Climate* (2018)

Zonal Averages of Precipitation Trends



Attempt to simulate observed trend using atmospheric model with specified SST and forcings

Source: Knutson and Zeng, *J. Climate* (2018)

Summary and Conclusions

- Flooding: Difficult problem for attribution. "…*medium confidence* (based on physical reasoning) that projected increases in heavy rainfall would contribute to increases in local flooding in some catchments or regions…" (IPCC SREX Report). Some significant flooding increasing trends and cases of anthropogenic influence on extreme precipitation events have been identified.

- Mean Precipitation: Evidence for attributable anthropogenic increases over a number of extratropical land regions. Observed trends are typically stronger than CMIP5 modeled trends (1901-2010). Less extensive regions of significant decreases (drying) trends over land. Drying regions include: Mediterranean region, parts of Africa, SW Australia.

- Precipitation Extremes: "medium confidence that anthropogenic forcing has contributed to a global scale intensification of heavy precipitation over the second half of the 20th century in land regions where observational coverage is sufficient for assessment." (IPCC AR5).