Hurricanes Harvey and Irma – Did Climate Change Play a Role?

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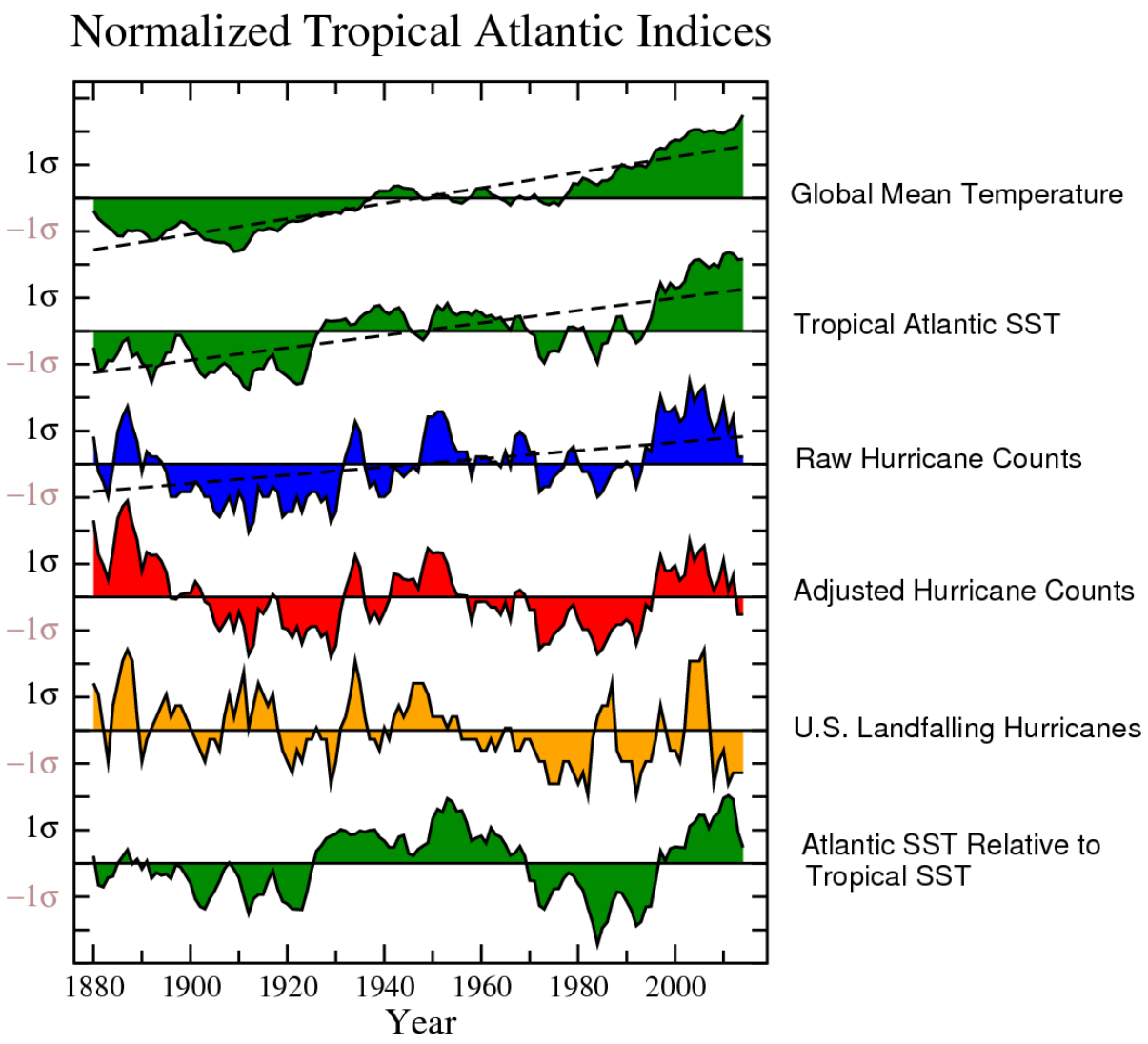
SUMMARY POINTS

- Hurricane Harvey's record rainfall totals were primarily due to the storm's slow movement over southeast Texas. There is no compelling evidence that climate change is making the occurrence of slowly moving landfalling hurricanes in the region, such as Harvey, more or less likely.
- Hurricane Irma was an exceptionally intense storm. It likely set a global record for the satellite era as the longest duration that a tropical cyclone has maintained surface wind speeds of at least 185 mph.
- There is indirect evidence that the severity of some hurricane impacts--specifically storm surge levels and rainfall rates--are being increased by anthropogenic climate change through increased sea level and atmospheric moisture. However, increased hurricane surge levels and hurricane rainfall rates have not been clearly detected in observed climate data.
- Scientists expect that hurricanes will become more intense on average—in the Atlantic and globally--as the climate continues to warm, but there is no clear observational evidence to date for this connection.
- Climate change is expected to increase the global frequency of very intense storms like Harvey, Irma, and Maria in the future, but quantifying the effect remains difficult, and there is only low confidence for such an increase in the Atlantic basin.

No clear evidence for detectable century-scale trend in Atlantic hurricane frequency



Source: Vecchi and Knutson (2011). Five-year running means, updated through 2016.

Ingredients:

Sea Level Rise

IPCC AR5:

"It is very likely that the mean rate of global averaged sea level rise was 1.7 [1.5 to 1.9] mm yr^{-1} between 1901 and 2010…"

"It is very likely that there is a substantial anthropogenic contribution to the global mean sea level rise since the 1970s."

Global Mean sea level rise in 2100 (vs. 1986-2005 mean) for RCP8.5: Likely range: 0.52-0.98 meters.

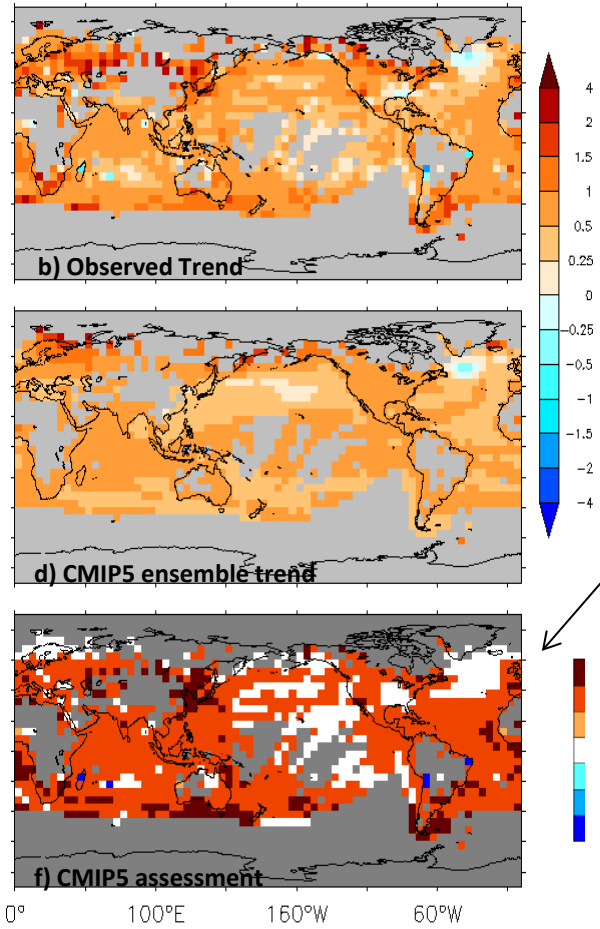
Models indicate that for a given hurricane, sea level rise leads to higher storm surge levels (e.g., Irish et al., *Climatic Change,* 2014.)

Ingredients:

Increased Sea Surface Temperatures in Tropical Atlantic and Gulf of Mexico

1901-2010 Surface Temperature Trends

CMIP5 all forcing



Detectable and attributable in part to anthropogenic forcing according to CMIP5 models.

- Attrib. anthropogenic warming, but > simulated
- Attrib. & consistent anthropogenic warming
- Detectable warming: < simulated
- No detectable trend
- Detectable cooling: < simulated
- Attributable anthropogenic cooling
- Detectable cooling: > simulated

Source: Knutson et al. J. Climate 2013 a

Ingredients:

Increased Atmospheric Moisture Content --> Extreme Precipitation?

IPCC AR5:

"…There is medium confidence that there is an anthropogenic contribution to observed increases in atmospheric specific humidity since 1973…"

"In land regions where observational coverage is sufficient for assessment, there is medium confidence that anthropogenic forcing has contributed to a global-scale intensification of heavy precipitation over the second half of the 20th century."

Model Projections:

Increased tropical cyclone rainfall rates: roughly same percent increase as in atmospheric moisture content (~7% per ^{o}C SST increase).

Ingredients:

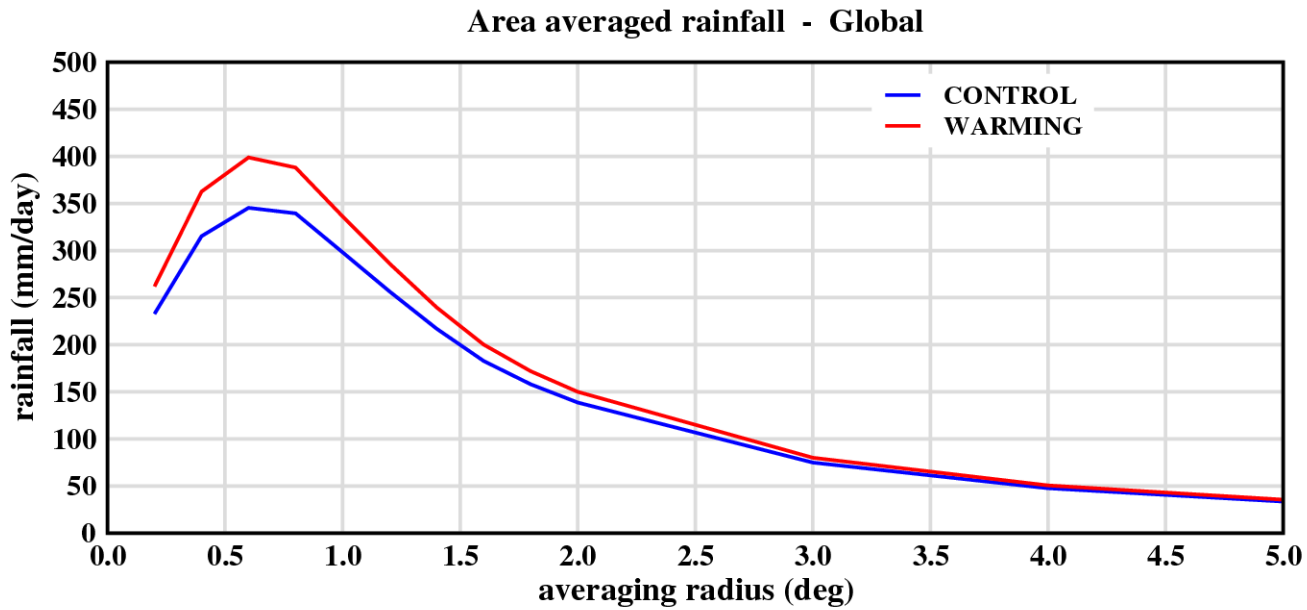
Tropical upper tropospheric warming?
Tropical atmospheric circulation?

IPCC AR5:

"…virtually certain that globally the troposphere has warmed since the mid-twentieth century with only ….low confidence (tropics….) in the rate and vertical structure of these changes."

"…there are multiple lines of evidence that the Hadley cell and the tropical belt as a whole have widened since at least 1979; however, the magnitude of the widening is very uncertain."

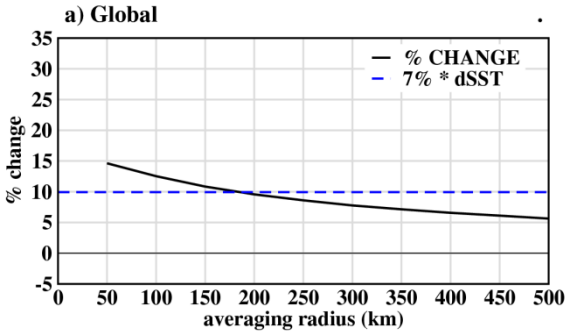
Tropical Cyclone Rainfall Rates: CMIP5 RCP4.5 models/downscaled storms



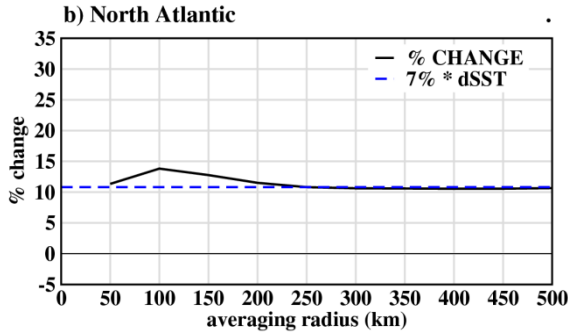
Note: TC rainfall rates (averaged over the storm lifetime) are based on the 10% rainiest tropical cyclones, restricting analysis to 30N-30S. Late 21st century projections (Warming) compared to present day (Control).

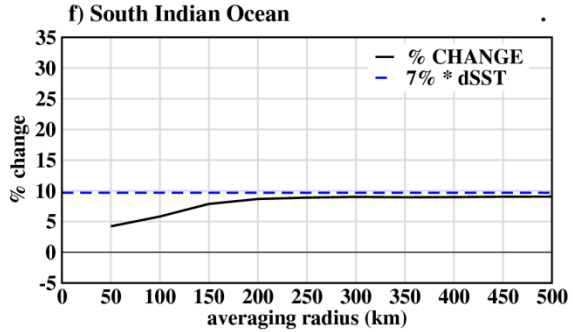
Source: Knutson et al., *J. of Climate* (2015).

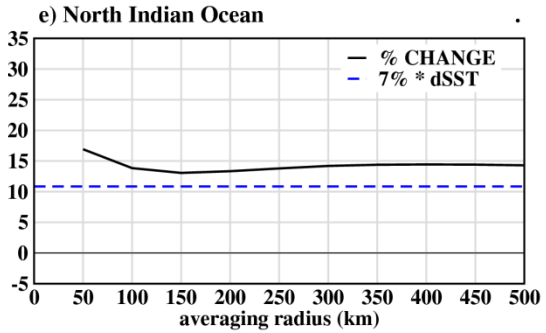
Simulated Increased Tropical Cyclone Rainfall Rates in a Warmer Climate

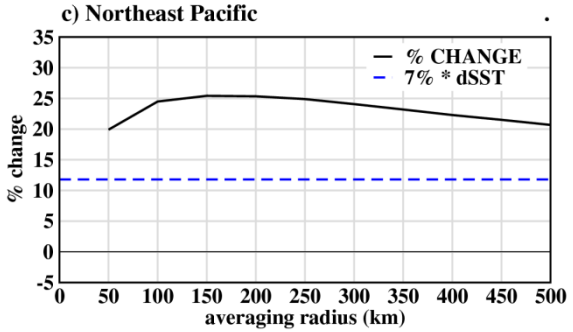


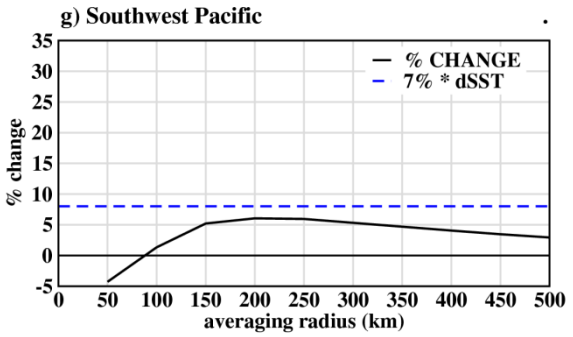
Model Projections (CMIP5/RCP4.5 downscaled): Percent change in tropical cyclone rainfall compared to simplified modeled water vapor increase (7% per ^{o}C SST increase) in each basin (dashed line).

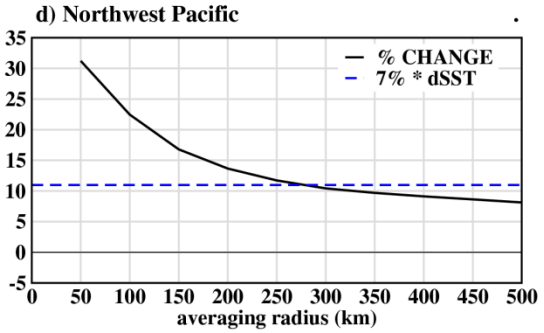






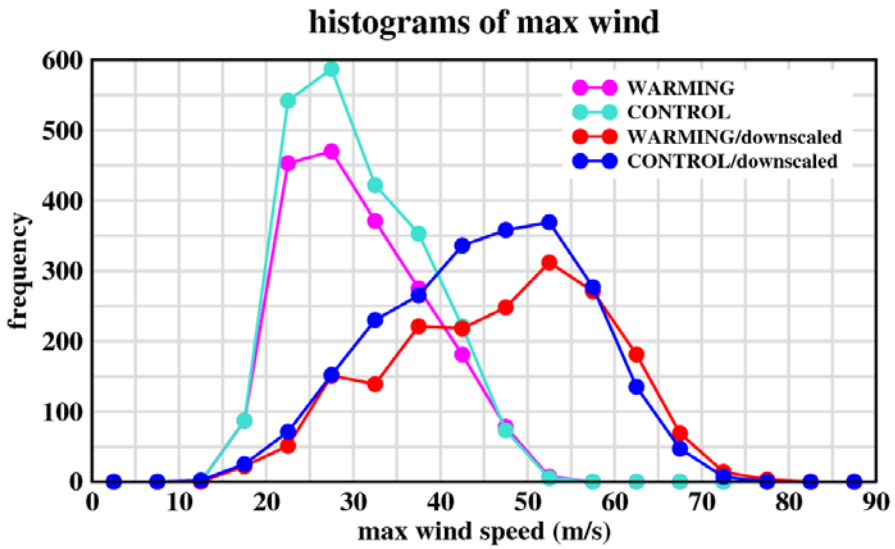


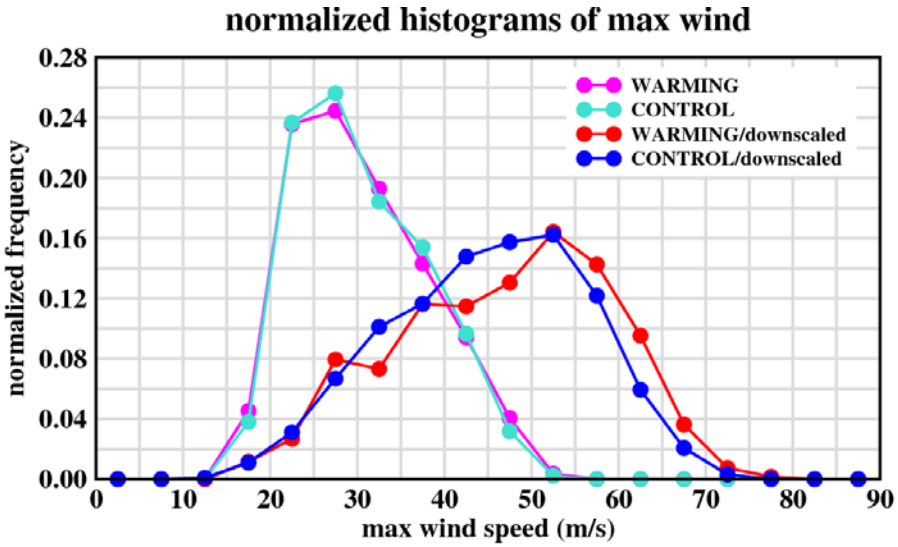




Source: Knutson et al., J. Climate (2015)

Global TC intensity distributions : CMIP5/RCP4.5 Late 21st Century Projection;
HiRAM 50km grid atmospheric model downscaled to GFDL Hurricane Model (6 km)





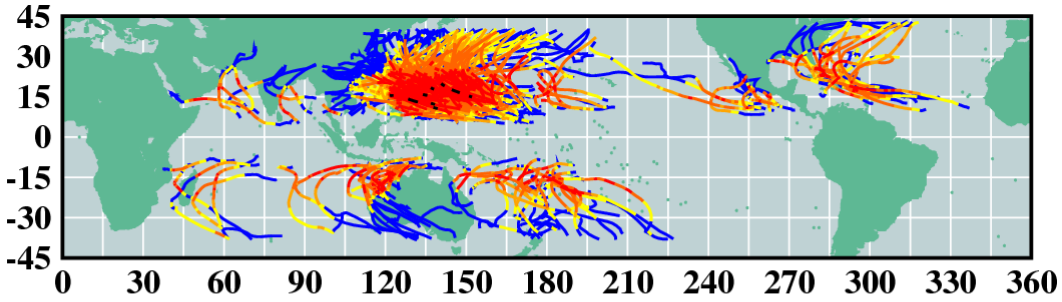
Despite fewer storms overall, there remains a tendency for higher average intensities and a greater number of intense tropical cyclones in the warmer climate.

<u>Hurricane wind speeds:</u>
Global avg: +4.1%
Atlantic avg: +4.5%

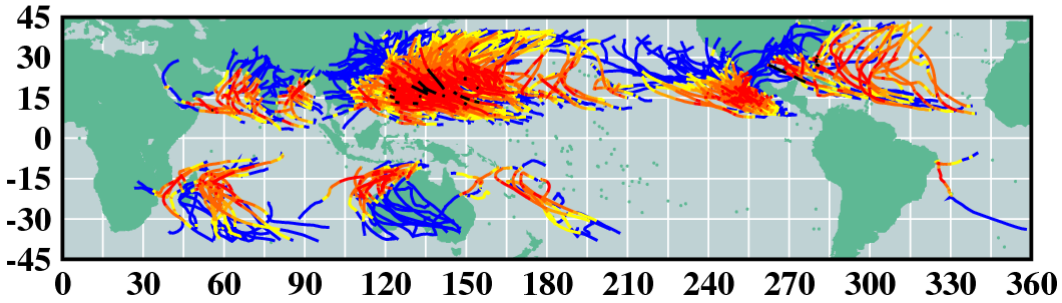
Source: Knutson et al., J. of Climate (2015).

Projections of Increased Cat 4-5 Tropical Cyclone Frequency by the Late 21st century (CMIP5/RCP4.5 scenario)

a) Present Day Simulation: 244 Cat 4-5 storms



b) RCP4.5 Late 21st Century: 313 Cat 4-5 storms



Storm Category

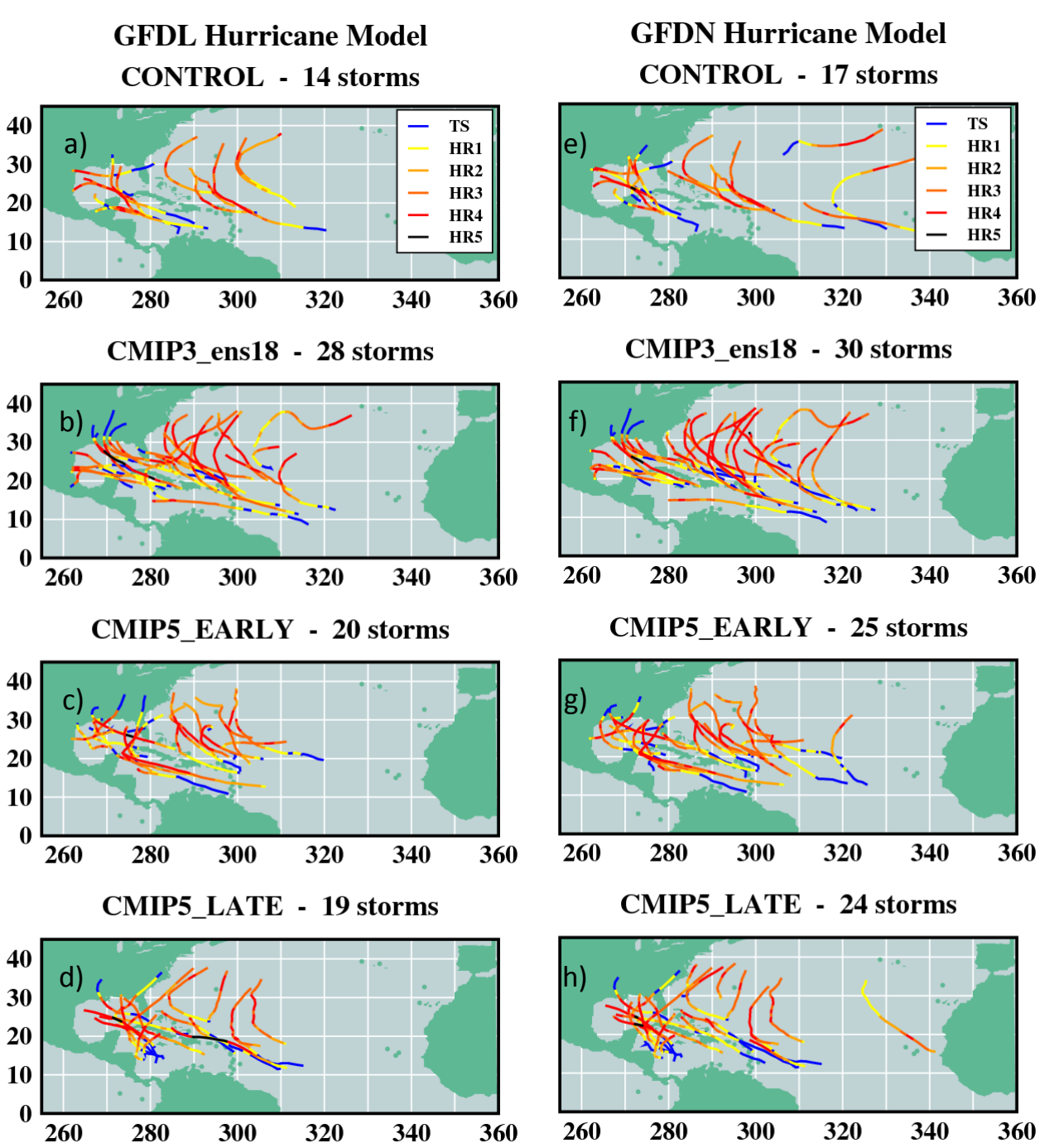
- TS
- HR1
- HR2
- HR3
- HR4
- HR5

Cat 4-5 frequency:
Global: +28%

Cat 4-5 Days:
Global: +35%

GFDL 50-km HiRAM model downscaled into GFDL 6-km grid hurricane model.

Source: Knutson et al., J. Climate (2015)



Left and right columns are based on two slightly different hurricane models.

Category 4-5 Hurricane Tracks (27 years)

Marginally significant increases with climate warming

+87%, p = 0.01; years 2081-2100
Increase in 6 of 10 CMIP3 models,
Significant in 3 of 10 models

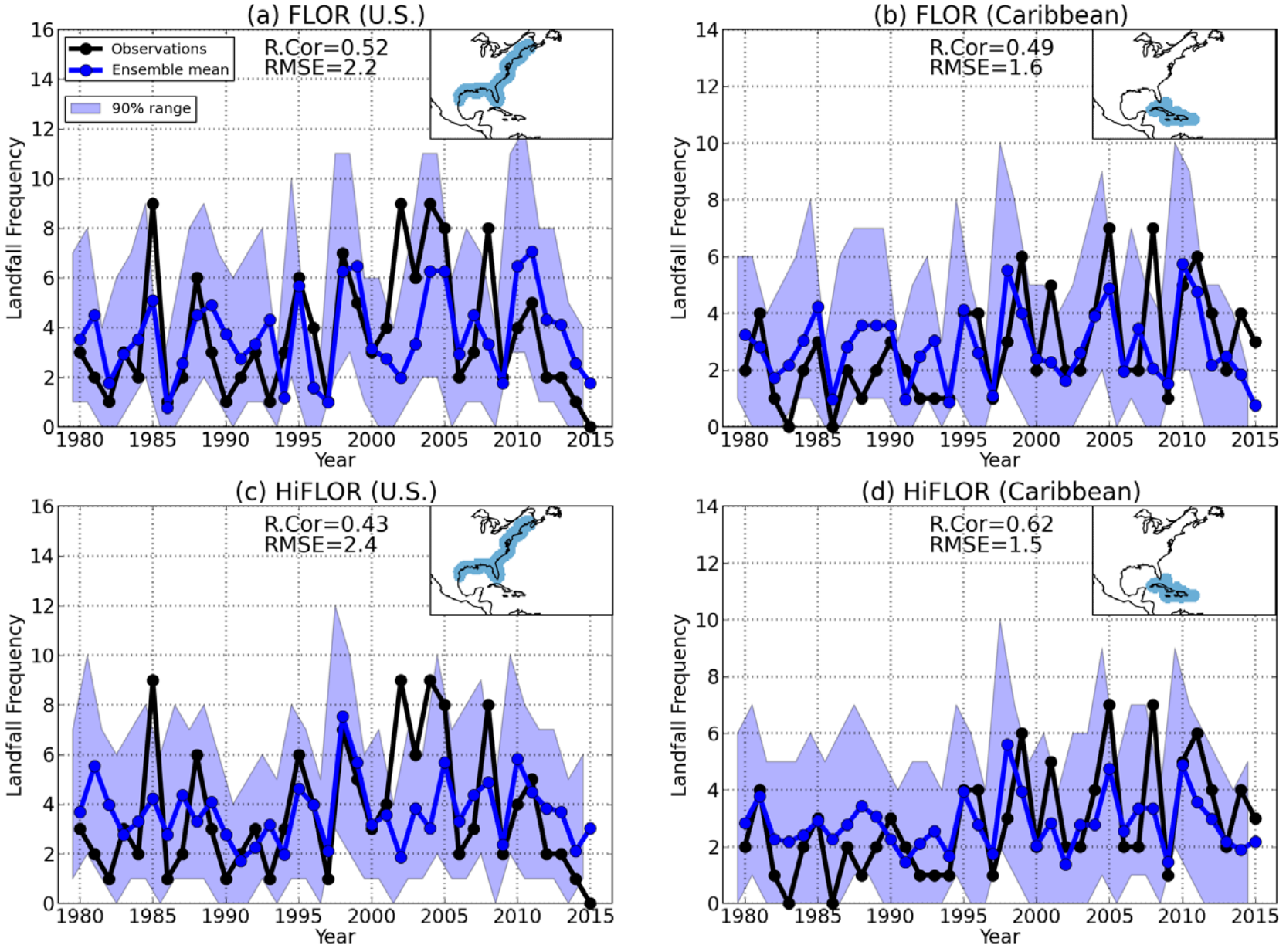
+45%, p = 0.06; years 2016-2035

+39%, p = 0.11; years 2081-2100

Knutson et al. J. Climate 2013 b

Can we predict tropical cyclone landfall in advance?

Seasonal predictions: July through November



50 km model, currently operational

25 km model, presently used to develop next generation

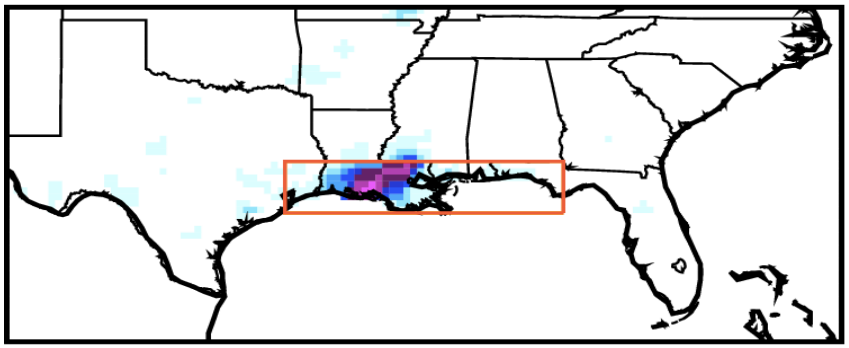
Murakami et al. (2016, JC)

Extreme Rainfall as and Event Definition: Central Gulf Example

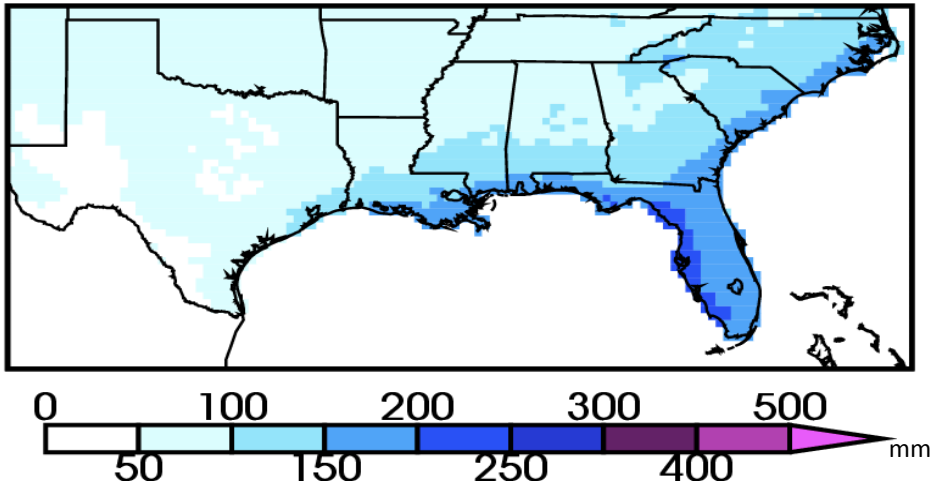
van der Wiel et al. 2017

12-14 Aug 2016: Rainfall Extreme Louisiana (Example)

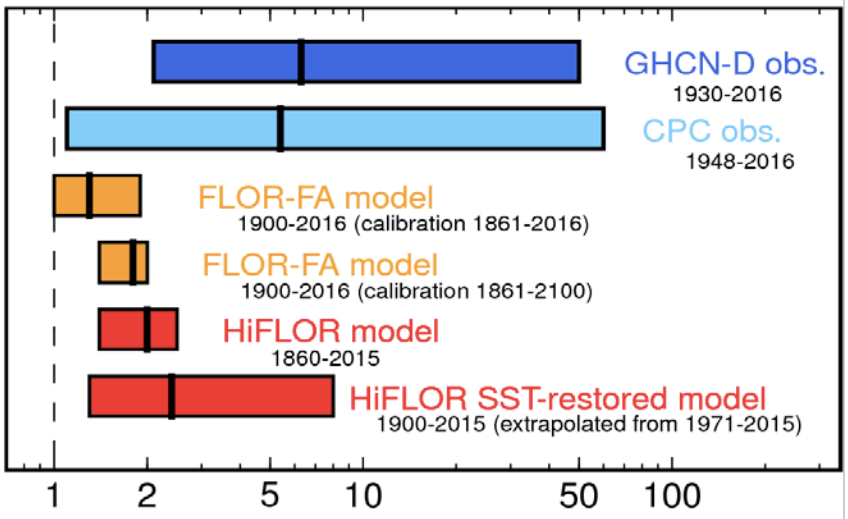
Total Rainfall 12-14 Aug; max = 535mm



Average August Total Precipitation



1900 vs. 2016 Risk of Extreme Central U.S. Gulf Rains



Change in Likelihood

(>1 is an increase in 2016)

Long term data sets (100s or 1,000s of years) can isolate causes for specific events and potential for reoccurrence in general or under identified conditions; can reduce uncertainty (due to the ability to generate additional data than available in observations)

Challenges in seasonal precipitation extremes

van der Wiel et al. 2016

	200 km	50 km	25 km
JJA			
SON			

Relative increase of the precipitation rate of the 5-yr returning event of daily precipitation (1990 vs. 2xCO2)

- Changes in precipitation extremes depend on resolution and season
- More work is needed to better understand why these differences exist and how to use these estimates for applications to build resiliency.
- We are building a new suite of models to do so.

References

- Murakami, H., et al. (2016). Seasonal forecasts of major hurricanes and landfalling tropical cyclones using a high-resolution GFDL coupled climate model. *Journal of Climate*, *29*(22), 7977-7989.
- Van der Wiel, K., et al. (2016). The Resolution Dependence of Contiguous U.S. Precipitation Extremes in Response to CO2 Forcing. *Journal of Climate, 29(22), 7991-8012.*
- van der Wiel, K., et al. (2017). Rapid attribution of the August 2016 flood-inducing extreme precipitation in south Louisiana to climate change. *Hydrology and Earth System Sciences*, *21*(2), 897.

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