Tropical Cyclones and Climate Change

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What is our **physical understanding** of how tropical cyclone **intensity** responds to climate change?

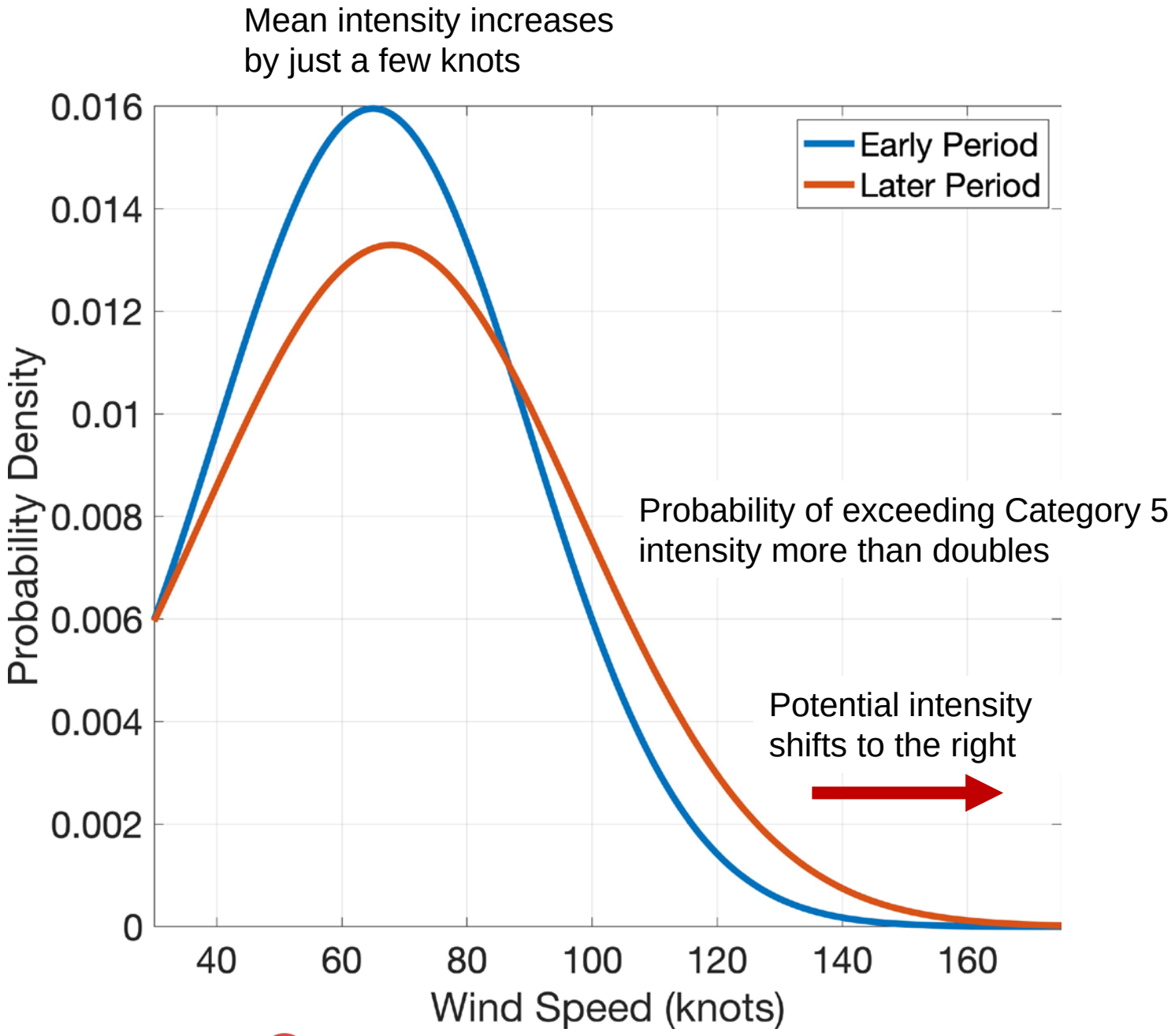
Potential Intensity –> How strong a tropical cyclone's winds ***can*** get, all other factors optimal.

Depends on two primary factors

1) Ocean surface temperature (and heat content).
2) The temperature and moisture state of the atmosphere.

Well-mixed greenhouse gas warming warms the oceans and increases potential intensity.

A small shift in the mean often occurs with a very large change in the extremes



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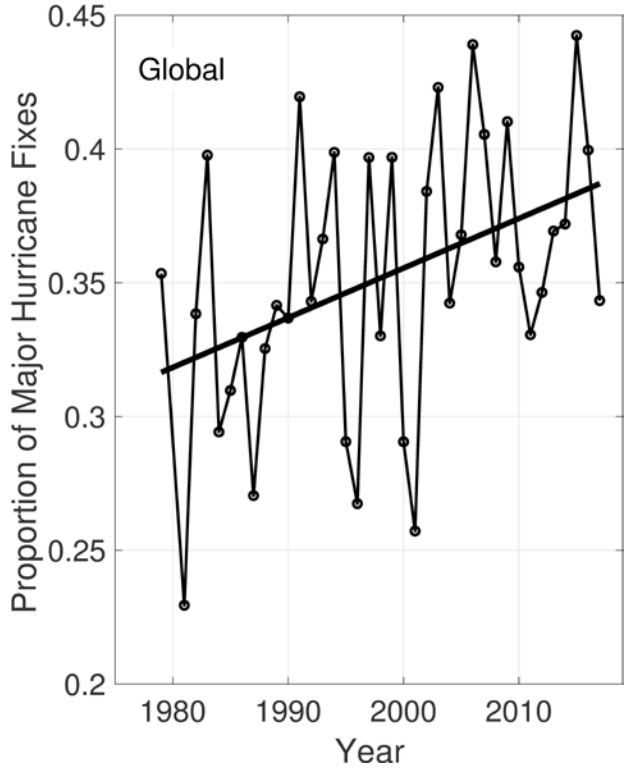
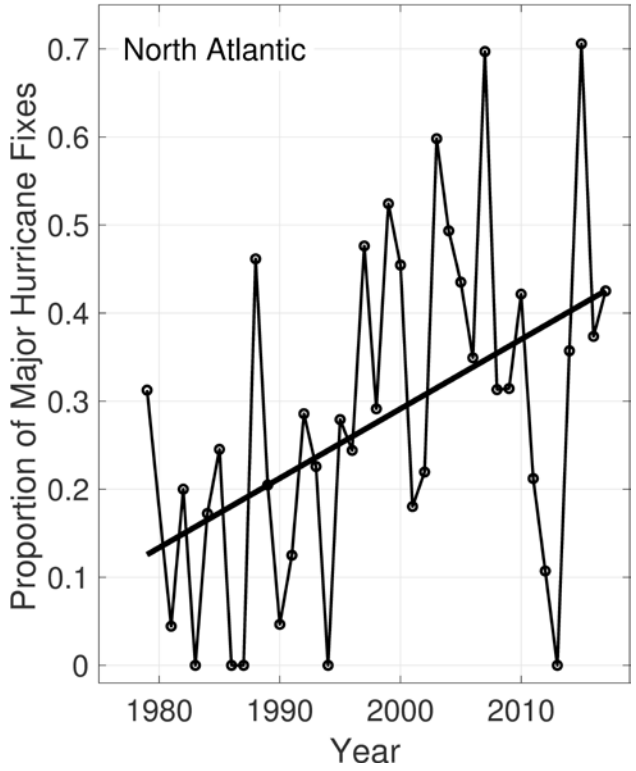
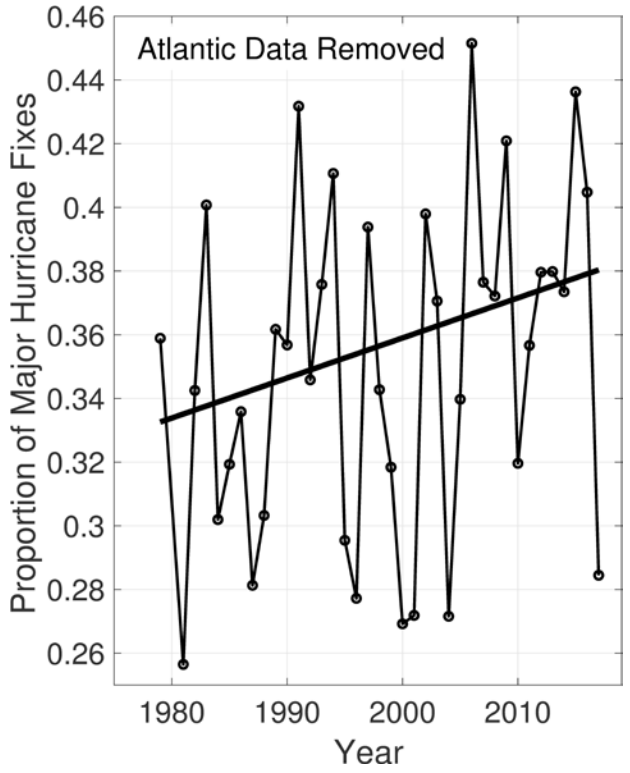
Increased likelihood of major tropical cyclone intensity







Globally, it's about **25%** more likely now that a tropical cyclone will be at major intensity (Category 3, 4, 5) than four decades ago.

In the Atlantic the proportion has more than doubled.
Most mortality and damage is caused by major tropical cyclones.

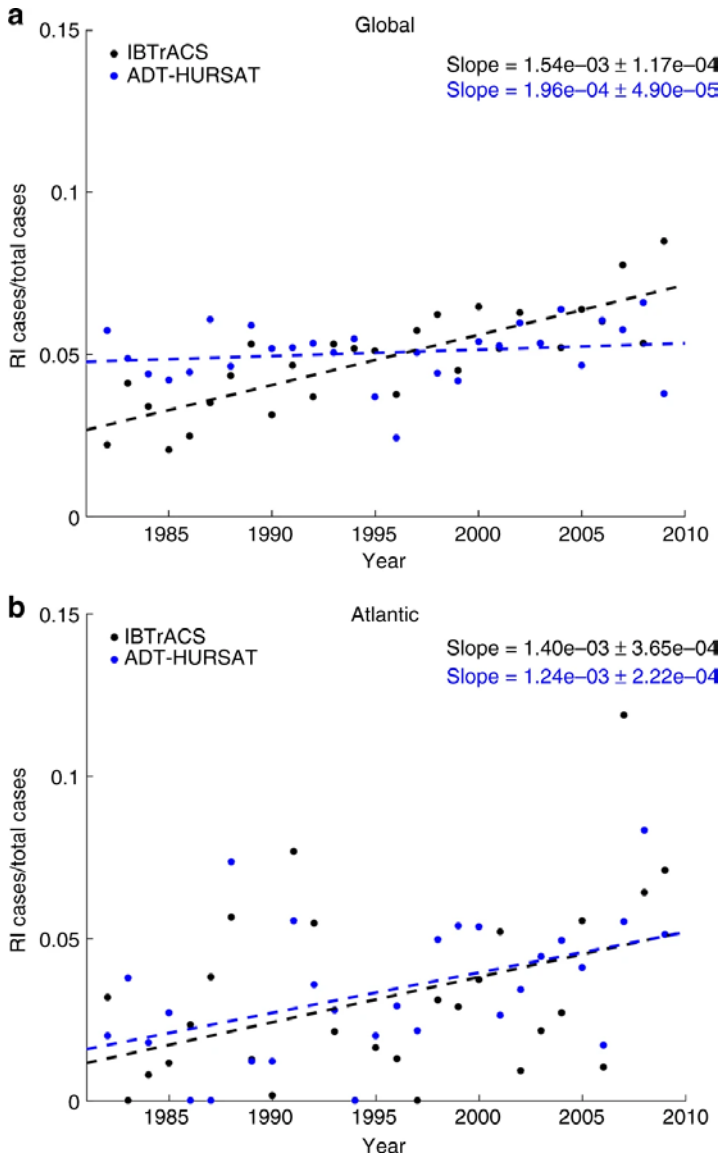
Kossin, *et al. PNAS* (2020)

Tropical cyclones are intensifying more rapidly

In the early 1980s, the chance of having a hurricane intensification event of 35 mph or more in a 24-hour period was about 1/100. 30 years later, the chance has increased by a factor of 5 to about 1/20.

The most rapid 24-hour intensification events (top 95%) are becoming even more rapid, by about an additional 5mph per decade.

This is a significant challenge for accurate forecasting.



Bhatia, *et al. Nat. Comms.* (2019)

What is our **physical understanding** of how tropical cyclone **rainfall rates** respond to climate change?

Tropical cyclone rain-rates increase with warming of the atmosphere.

Warmer air holds more water vapor, which increases by about 7% per °C of warming. Tropical cyclones are very good at turning this additional water vapor into rain.

Measuring past changes in rain-rates is difficult for several reasons and this signal has not been confidently observed yet. Based on simple physics though, it's likely that rain-rates have increased.

What is our **physical understanding** of how tropical cyclogenesis **(formation)** responds to climate change?

Increasing greenhouse gas concentration warms the ocean.

This, by itself, would increase formation rates.

However, it also tends to stabilize and dry the atmosphere, which tends to suppress formation.

The consensus is that greenhouse gas warming does not increase tropical cyclone frequency.

When a tropical cyclone *exists*, it is more likely now to

1) be at major tropical cyclone intensity
2) rapidly intensify
3) have greater rainfall rates

but there may not be more of them. This makes it difficult to assess changes in risk.

Physical understanding: a not-so-subtle subtlety

The atmosphere responds to warming differently, depending on what caused the warming.

Ocean warming by increased globally well-mixed greenhouse gas
vs
Regional warming by other factors

Internal / Natural: Atlantic meridional overturning circulation (AMOC) variability

External / Natural: Saharan dust concentration, volcanic eruptions

External / Anthropogenic: Sulfate aerosol pollution concentration

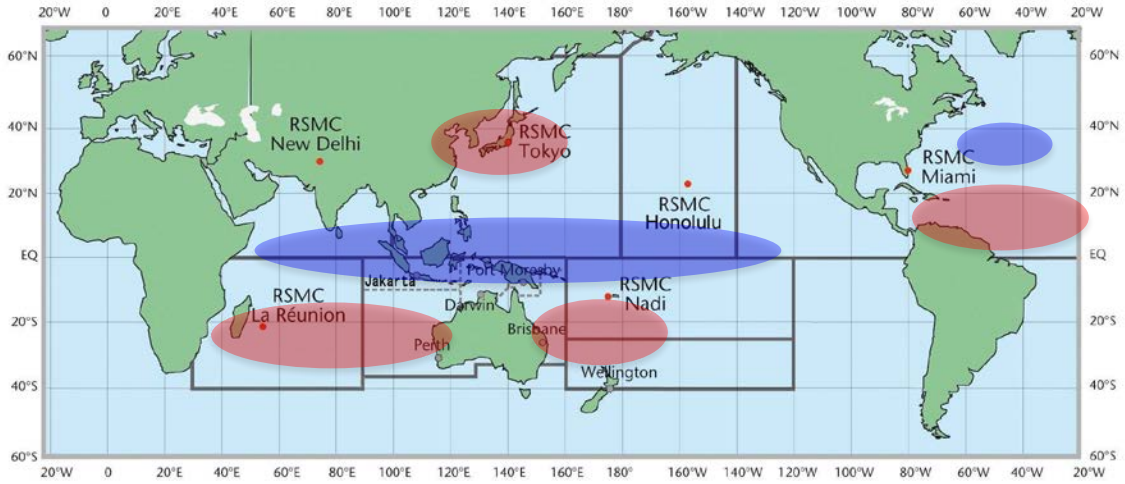
Regional warming generally causes increased genesis frequency. This has likely contributed substantially to the increased hurricane activity in the Atlantic since the mid-1990s.

Ramsay and Sobel, *J. Climate* (2011)
Emanuel and Sobel, *JAMES* (2013)

We've discussed tropical cyclone intensity, frequency and rain-rate changes.

Track changes can also substantially alter the risk landscape,
perhaps even more than frequency and intensity changes.

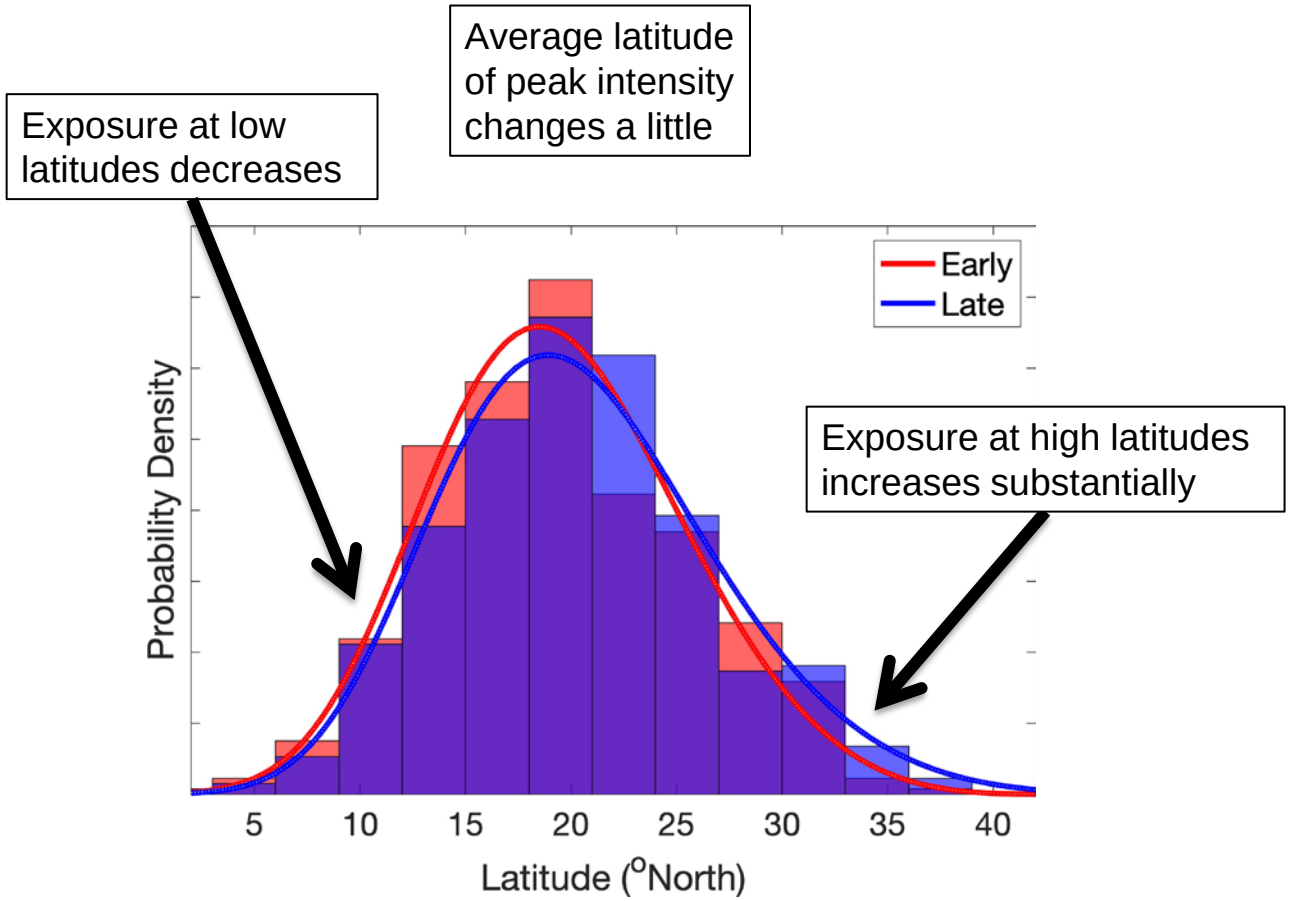
Tropical cyclones have migrated poleward in some regions,
most notably in the western North Pacific



This can increase hazard exposure in less prepared populous regions.

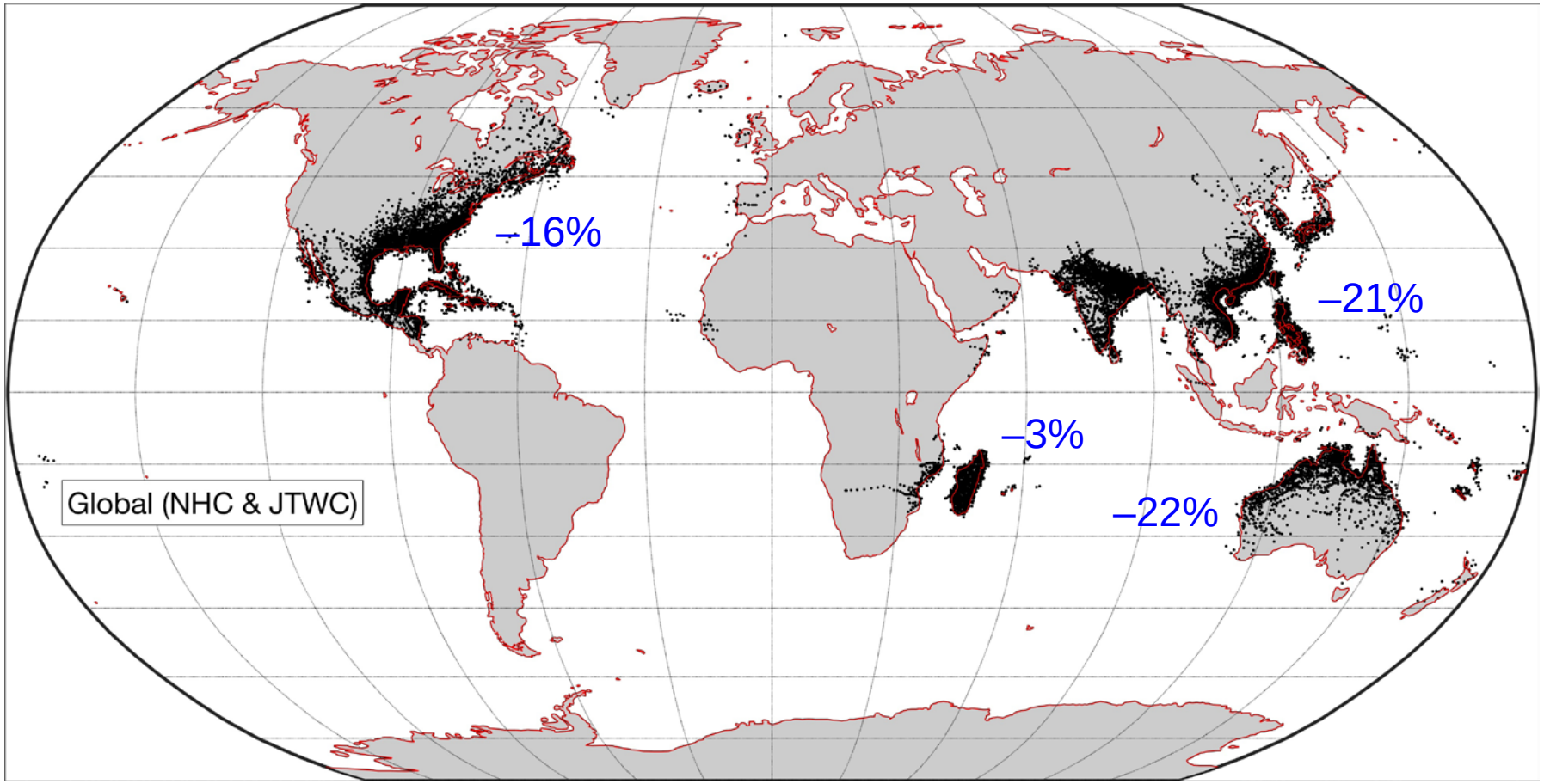
Kossin, *et al. Nature* (2014)

Poleward track shift in the western North Pacific



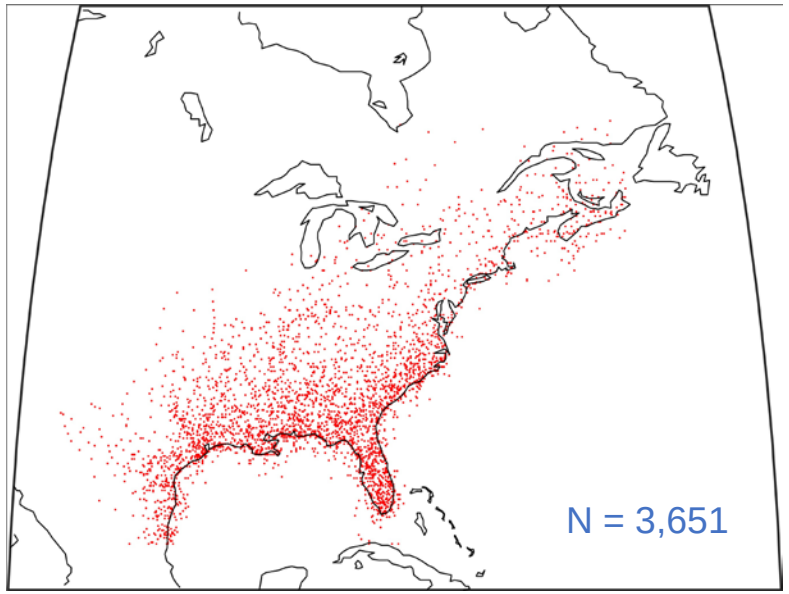
Kossin, *et al. J. Climate* (2016)

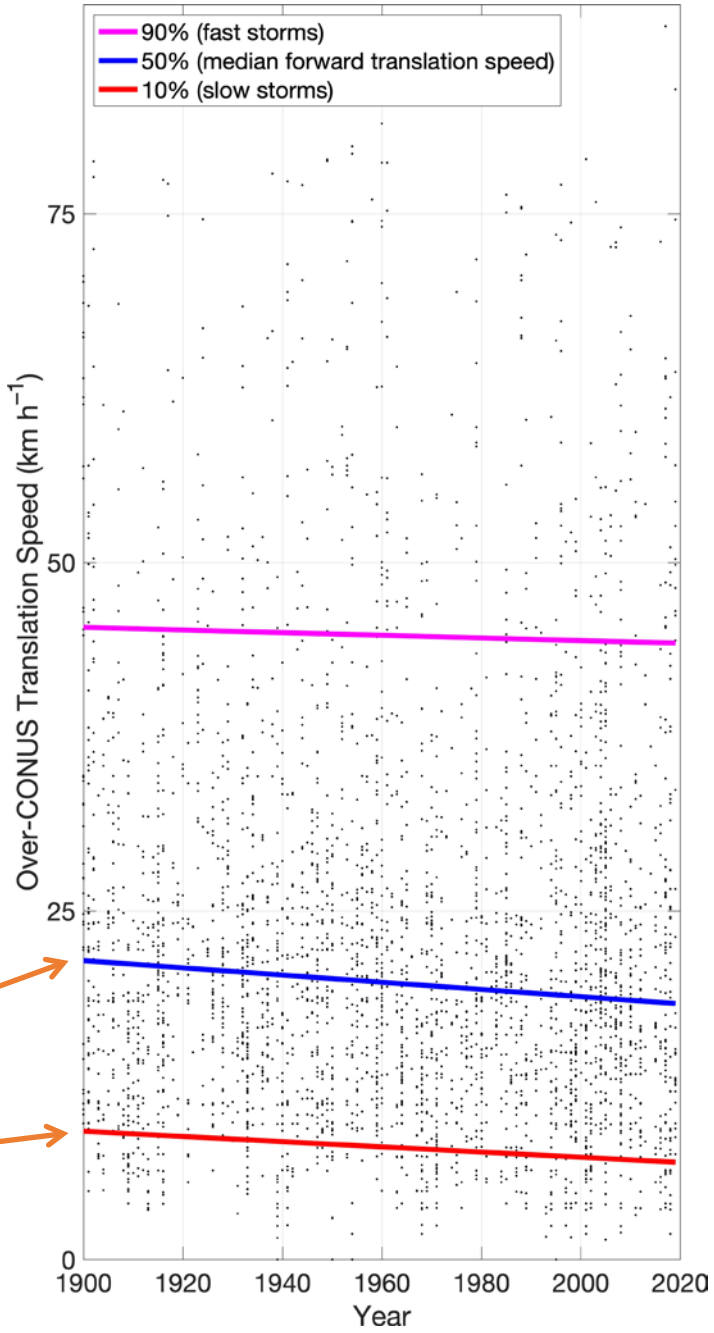
Tropical cyclones appear to be moving more slowly over land and they are “stalling” more often.



Kossin, *Nature* (2018)

Slowdown over CONUS since 1900





14% slowdown of the median

24% slowdown of the slowest 10th percentile

Hurricane rain-rate increases by about 7% per °C of warming, as warmer air holds more water vapor.

There's been about 1°C warming since 1900.

$$\text{local rainfall} \sim \frac{\text{rain-rate}}{\text{speed of motion}}$$

$$\text{change in local rainfall} \sim \frac{(1+7\%)}{(1-24\%)}$$

41% increase of local rainfall due to the combined effect of 7% more water vapor and 24% slower moving hurricanes

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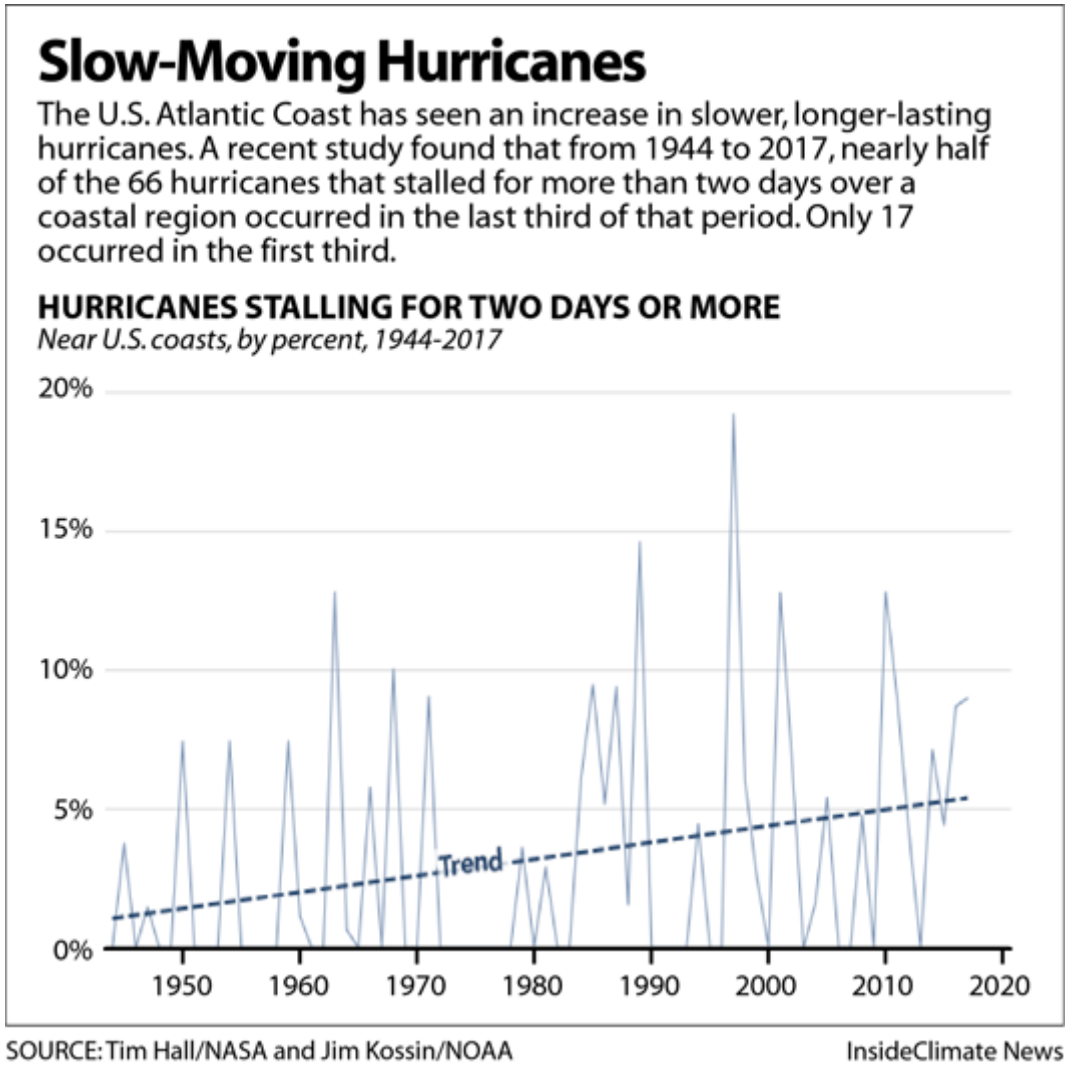
Adapted from Kossin, *Nature* (2019)

TCs are “stalling” over the United States more often



The increase in frequency of stalling events over the US is linked to increased rainfall.

Recent examples:

Hurricane Iota (2020)
Hurricane Eta (2020)
Hurricane Sally (2020)
Hurricane Dorian (2019)
Hurricane Florence (2018)
Hurricane Harvey (2017)

Cyclone Idai (2019)

Hall & Kossin *Nat. Clim. and Atmos. Sci.* (2019)

Questions / Comments for Discussion?

Projected changes in tropical cyclones

- Very confident that average TC intensity will increase, and the increases will manifest more clearly in the stronger TCs.
- Very confident that TC rain-rates will increase.
- Confident that total TC frequency will decrease or not change.
- Confident that the *proportion* of major TCs will increase.
- Less confident that the *frequency* of major TCs will increase.
- Confident that TCs will migrate poleward in some regions.
- Becoming more confident that TCs over land outside of the tropics will move more slowly and stall more frequently.