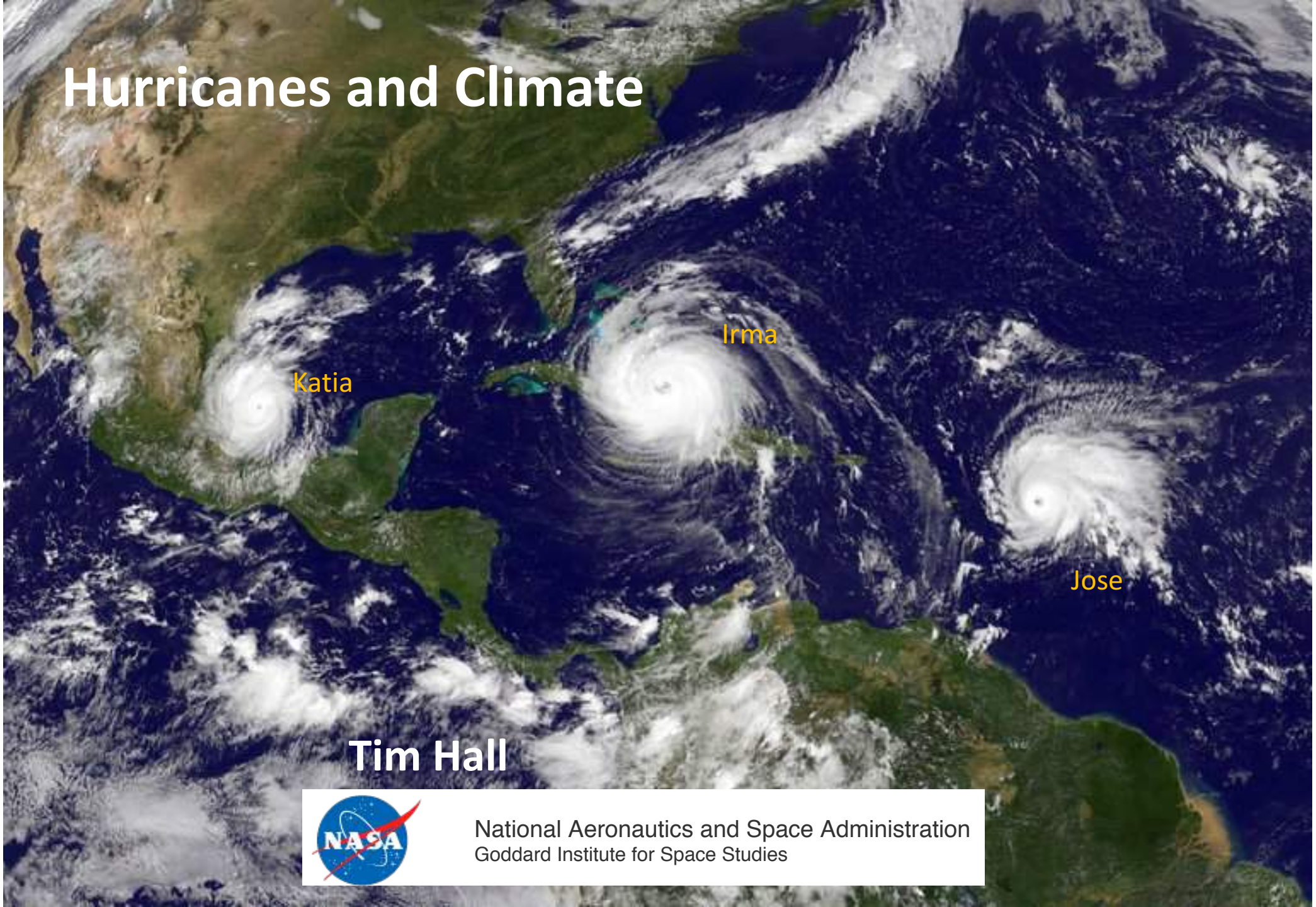
Hurricanes and Climate



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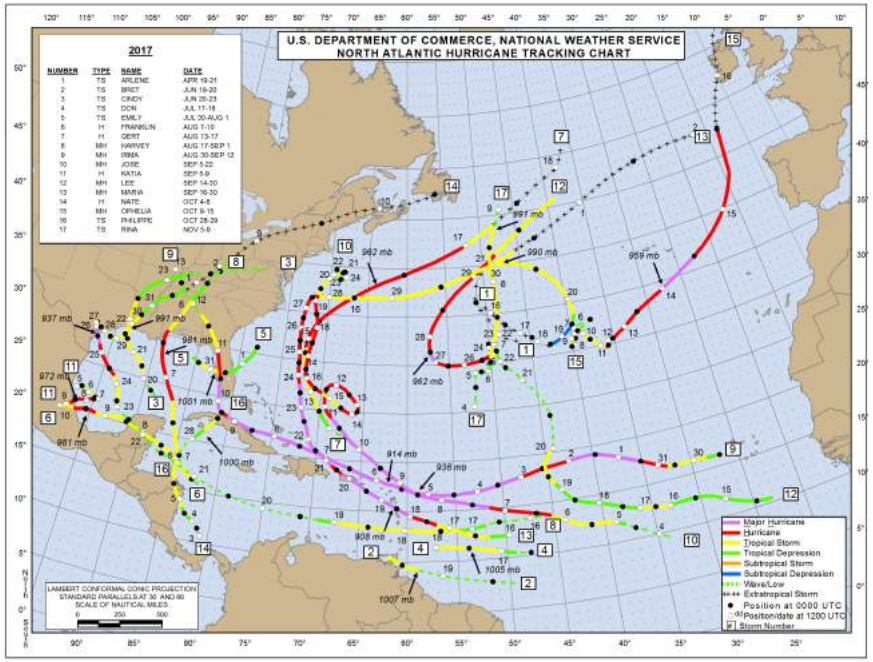
2017 North Atlantic Season



2017 Atlantic TC Activity Thru November

Forecast Parameter	Observed 2017 Atlantic TC Activity	Atlantic Full Season 1981-2010 Median	2017 as Percentage of Full Season Median	2017 All-Time (Since 1851) Full Season Rank	All-Time Record (Year)
Named Storms (NS)	17	12.0	142%	T-9	28 (2005)
Named Storm Days (NSD)	91.25	60.1	152%	11	126.25 (2005)
Hurricanes (H)	10	6.5	154%	T-8	15 (2005)
Hurricane Days (HD)	51.25	21.3	241%	6	61.50 (1893 & 1995)
Major Hurricanes (MH)	6	2.0	300%	T-3	7 (1961 & 2005)
Major Hurricane Days (MHD)	19.25	3.9	494%	6	24.50 (1961)
Accumulated Cyclone Energy (ACE)	226	92	246%	7	259 (1933)

2017 saw 25% of all historical Cat 5 landfalls

The Top Five Costliest U.S. Hurricanes on Record

Name	Year	Cost
Katrina	2005	$161 Billion
Harvey	2017	$125 Billion
Maria	2017	$90 Billion
Sandy	2012	$71 Billion
Irma	2017	$50 Billion

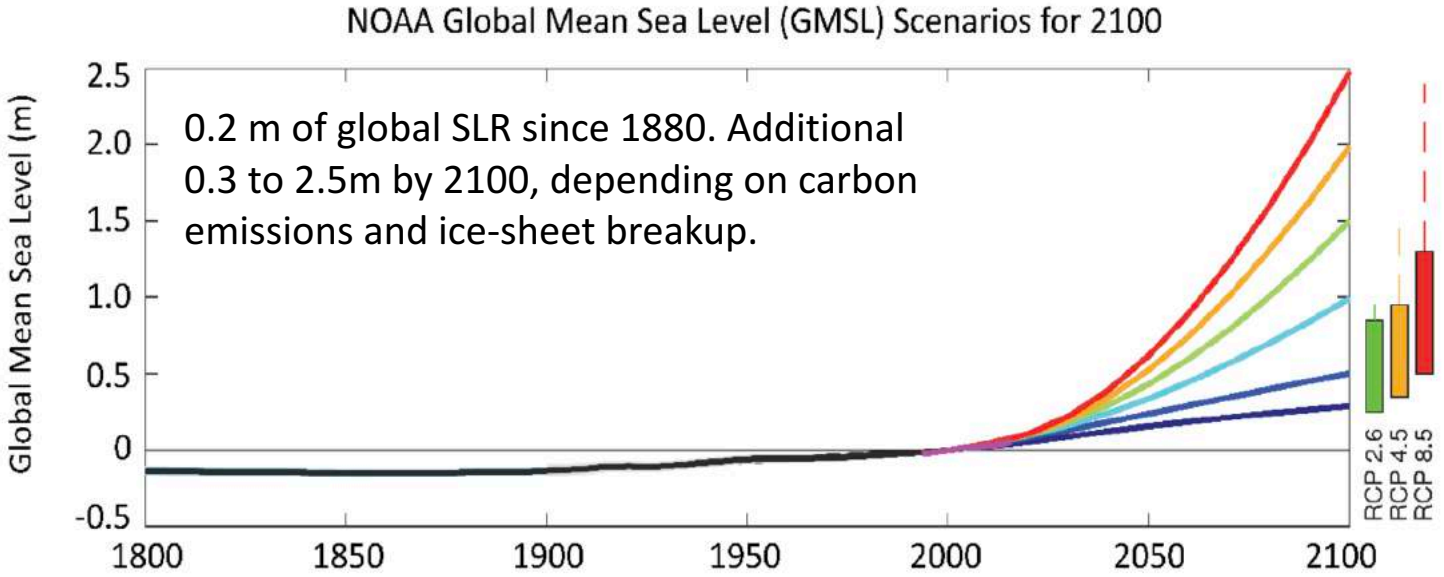
But hurricane-climate analysis is based on a long-term view and physical understanding, not just one active season. Long-term climate impacts on hurricanes include …

more certain

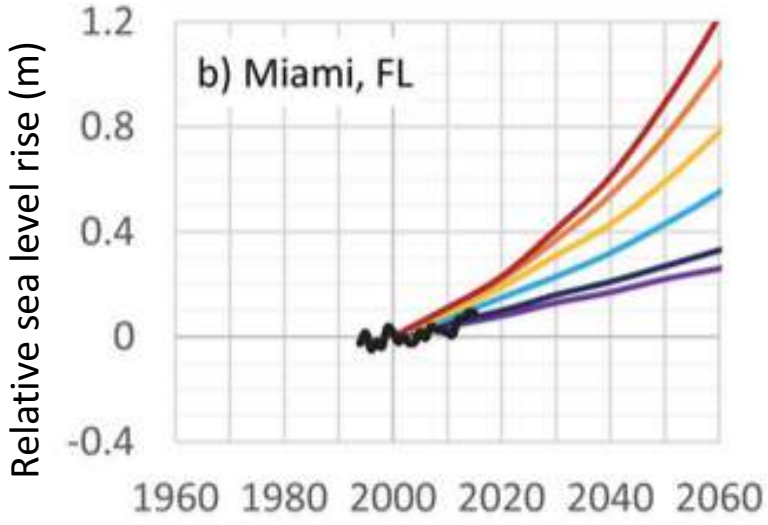
1. **Sea-level rise leads to greater storm surge.**
2. **Warmer air, more moisture, more intense rain events.**
3. **Warmer ocean increases intensity of hurricanes.**
4. **Changing jet stream leads to more meandering hurricane tracks.**
5. **Lower atmospheric stability, fewer total tropical cyclones.**

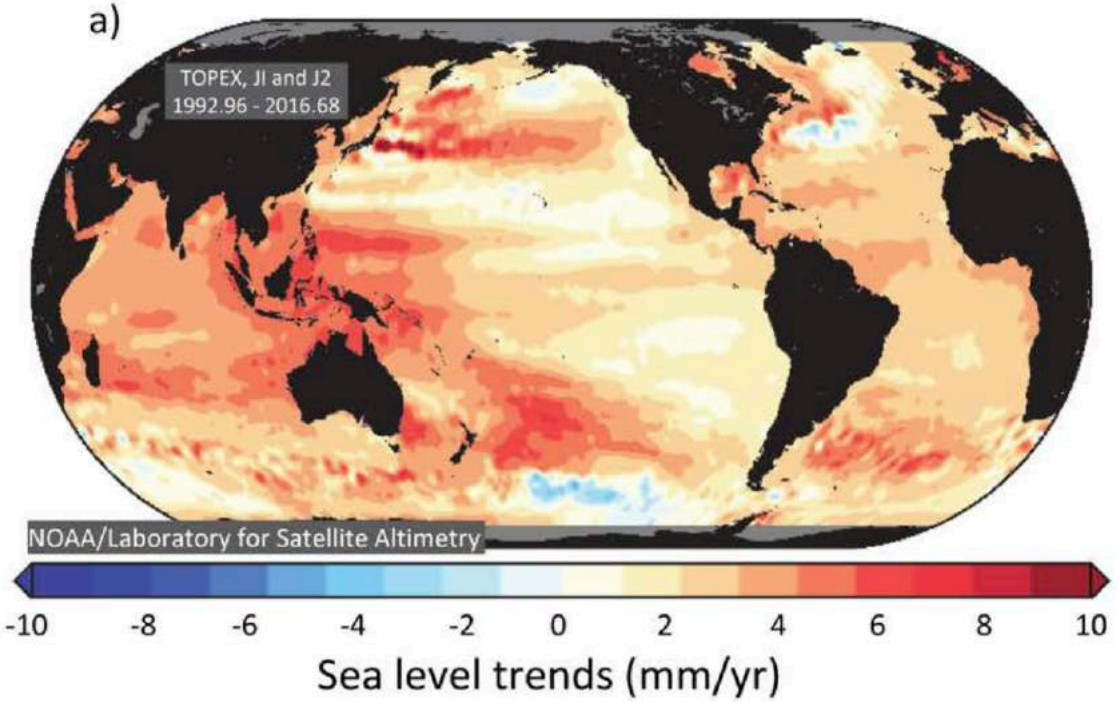
less certain

Sea Level Rise and Storm Surge

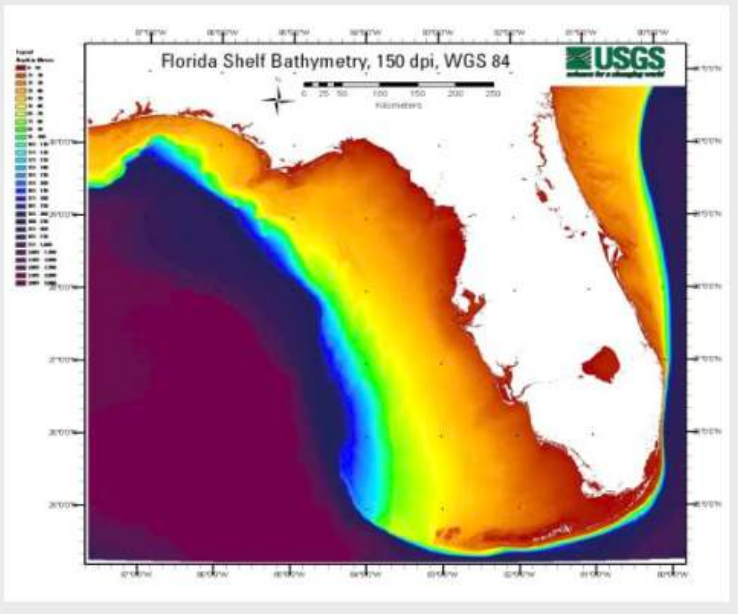


0.2 m of global SLR since 1880. Additional 0.3 to 2.5m by 2100, depending on carbon emissions and ice-sheet breakup.

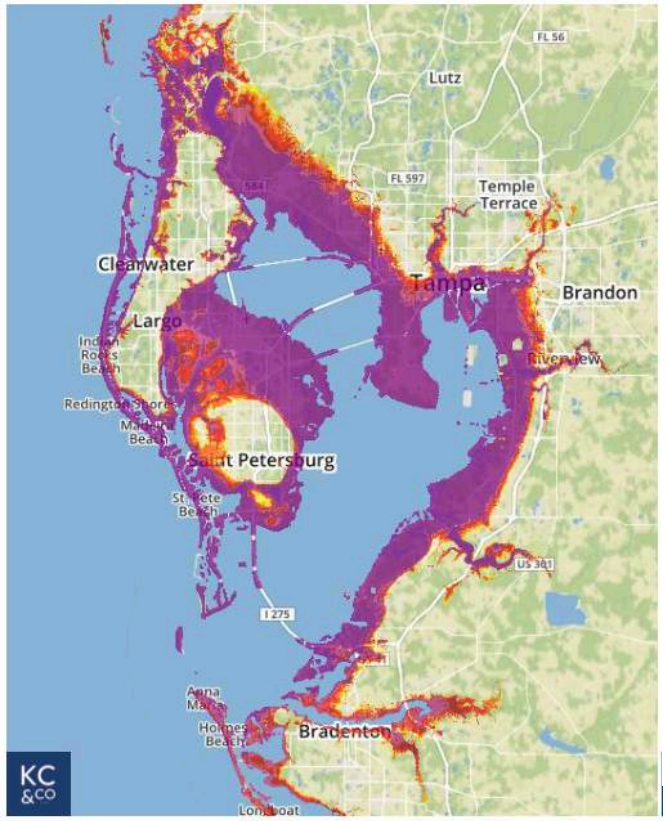




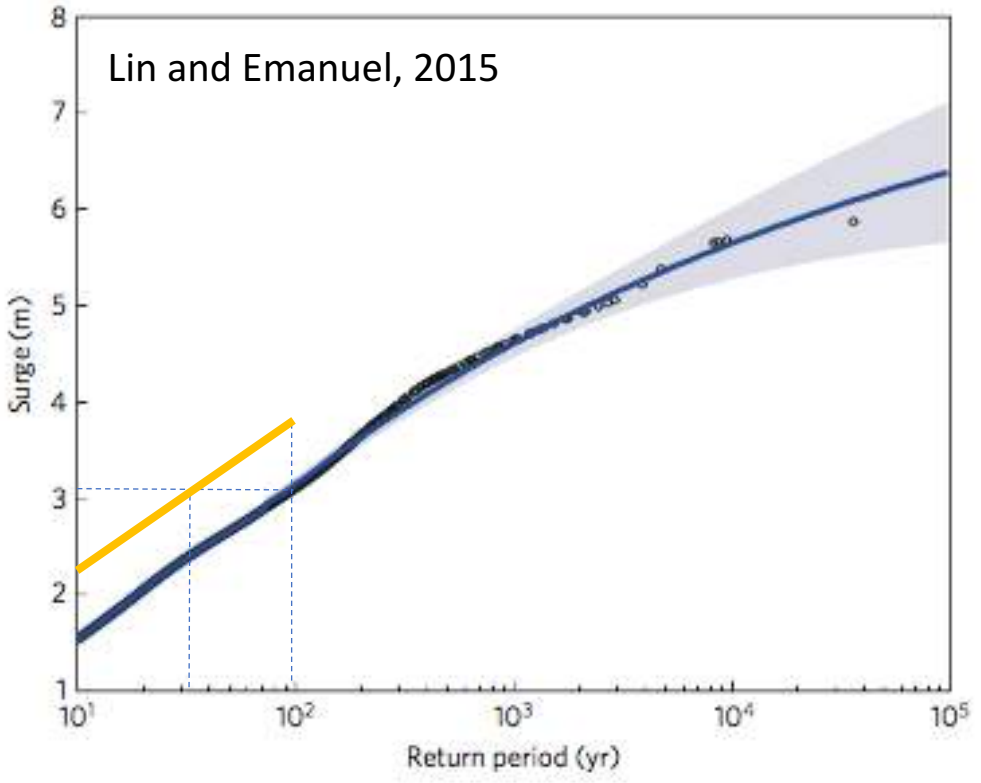
Tampa ranked the most surge-vulnerable city in the US (*KCC Report, 2015*)



- Shallow coastal water means same displaced volume of water causes higher surge.
- Tampa Bay is a funnel trapping incoming water.



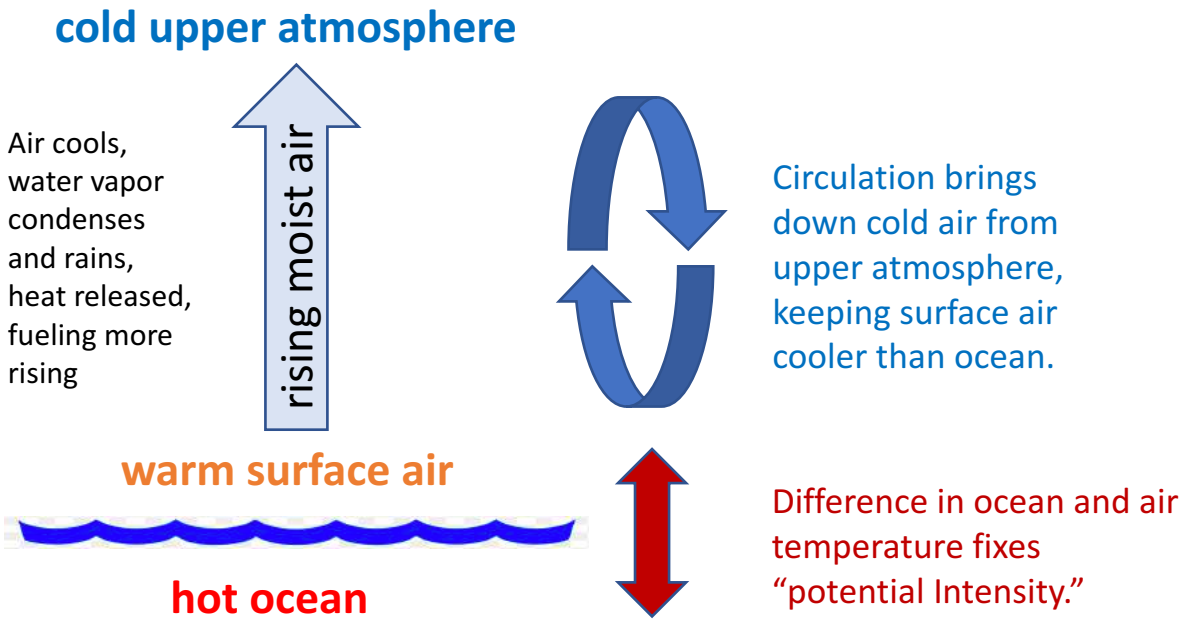
100-year flood (10 ft surge): $175B
50% of population below 10 ft.
(*KCC Report, 2015*)



Tampa surge height for different average return periods current conditions.
Add 30 inches of SLR (red):
100-yr surge is now 30-yr surge.
Three times more likely.

Note: 3% chance per year → 60% over 30-year mortgage

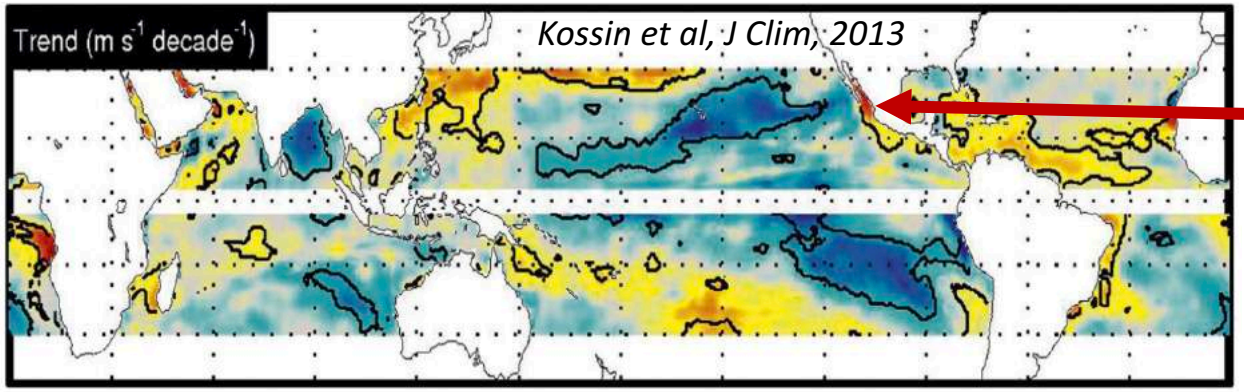
Hurricane Intensity: The Speed Limit is Increasing

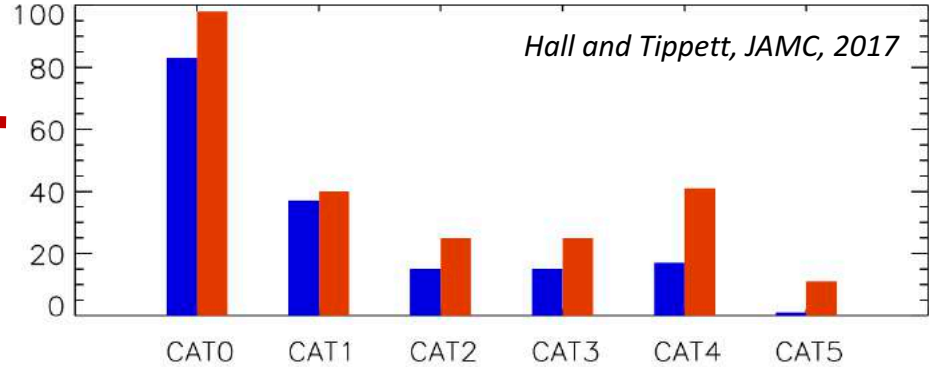


Ocean temperature and the vertical variation in atmospheric temperature fix the "potential intensity," the thermodynamic Speed Limit on hurricane intensity. The ocean is warming, but the upper atmosphere is not. That difference drives increased intensity.

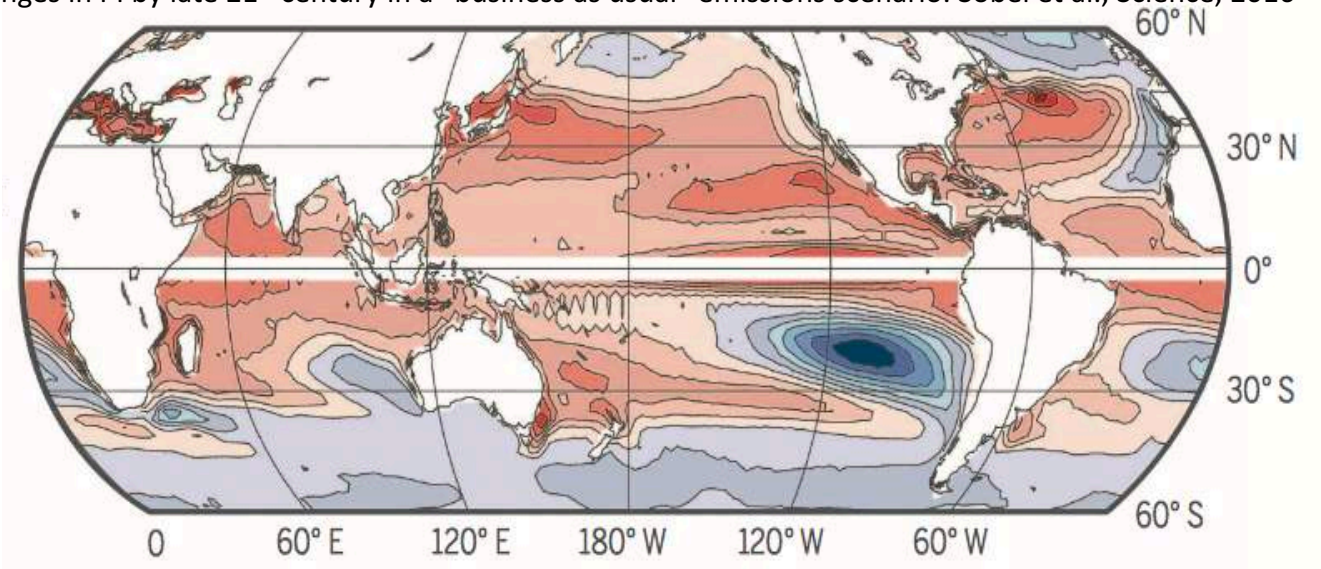
- **The Speed Limit is increasing.**
- **Not all hurricanes reach their speed limit, but some do (Irma, Maria).**
- **Higher speed limit means more hurricanes reach the highest intensity categories.**
- **Some will reach intensities never seen historically.**

Potential Intensity trends 1979-2010 and impacts on actual intensity





Changes in PI by late 21st century in a "business as usual" emissions scenario. Sobel et al., Science, 2016



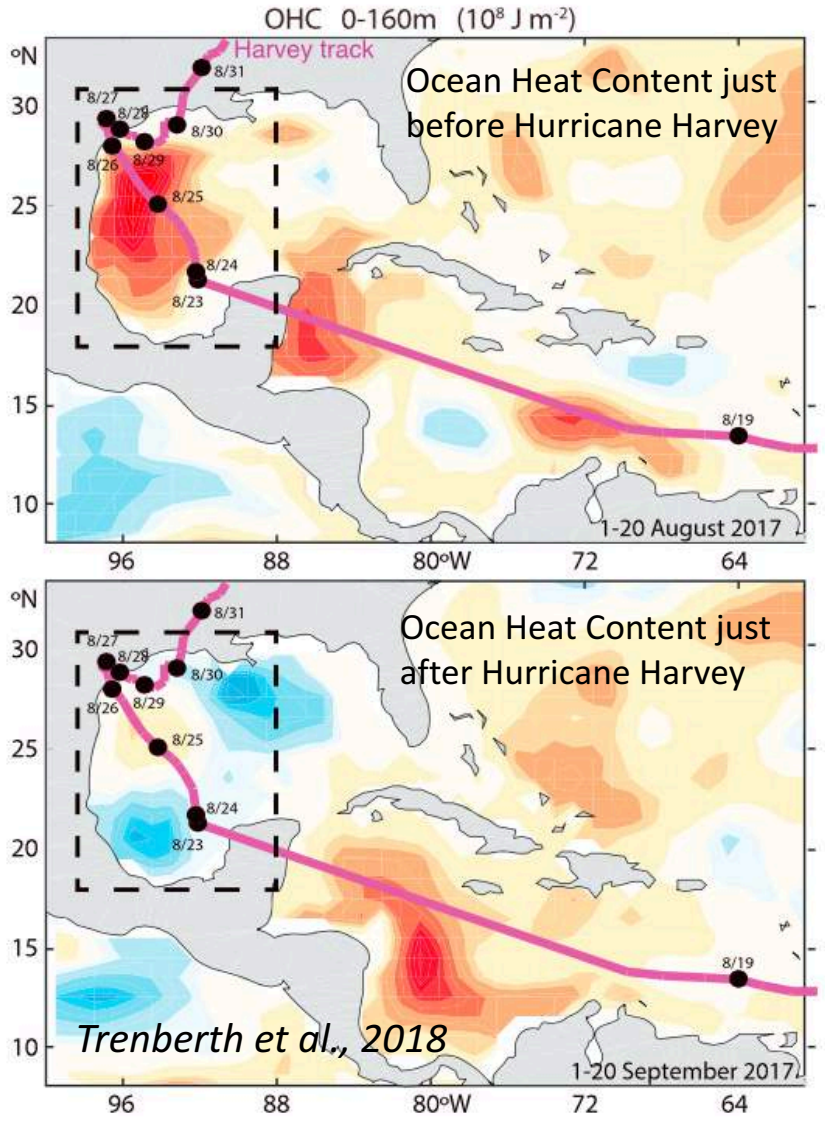
- **Potential Intensity increasing**
- **Some reduction in TC frequency.**
- **But, greater number reaching highest intensities. (Lots of regional uncertainty.)**

The destructive energy ("power dissipation") varies as V^3.

(twice the wind speed → 8 times the wind hazard)

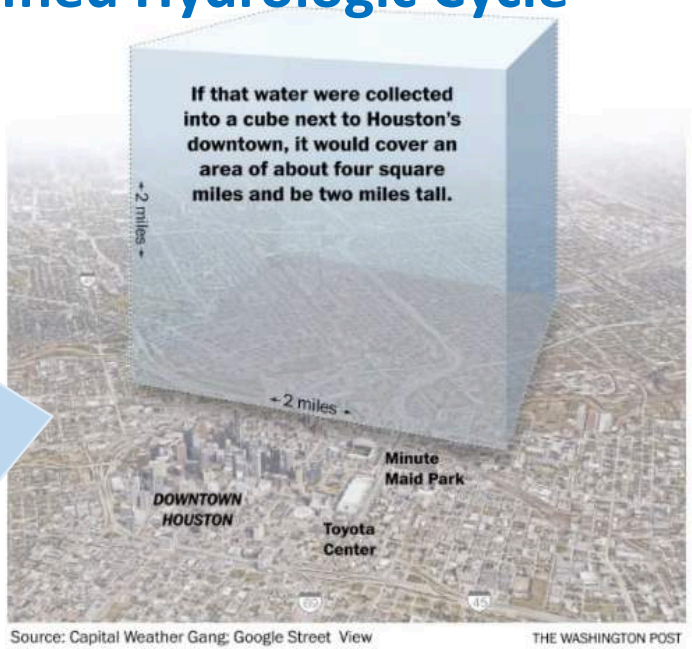
It's the few strongest land-falling hurricanes that do most of the damage.

When It Rains, It Pours: Hurricane Harvey and the Intensified Hydrologic Cycle



Where did that heat energy go?

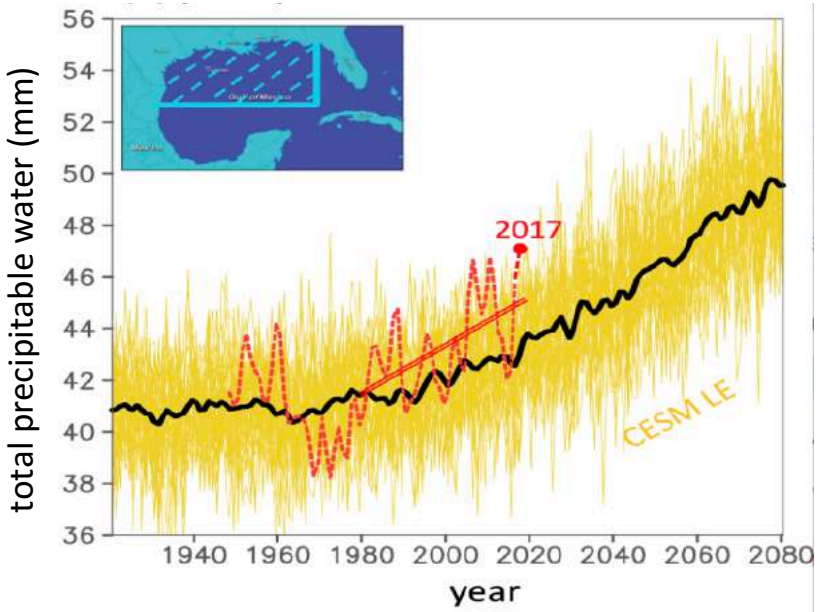
All accounted for: heat of evaporation held by water vapor, followed by latent heat release at condensation and two cubic miles of rain on Houston.



More Ocean Heat → More Water Vapor → More Intense Rain Events

20% to 38% of Harvey's rainfall due to Gulf warming.
Wang et al., ERL, 2018.

Harvey rainfall 4 times more likely.
Risser and Wehner, GRL, 2017.

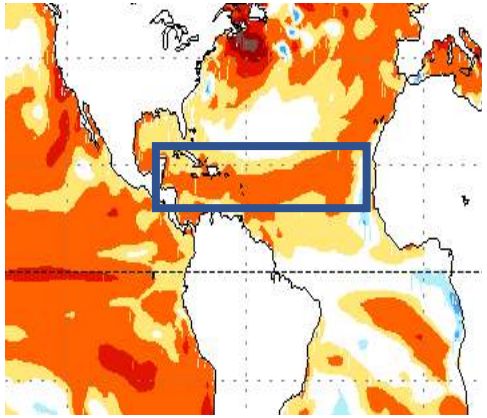


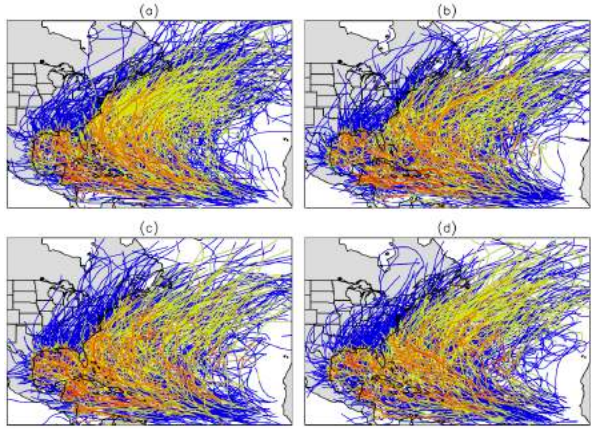
Across US, fraction of rain falling in most intense events is increasing.

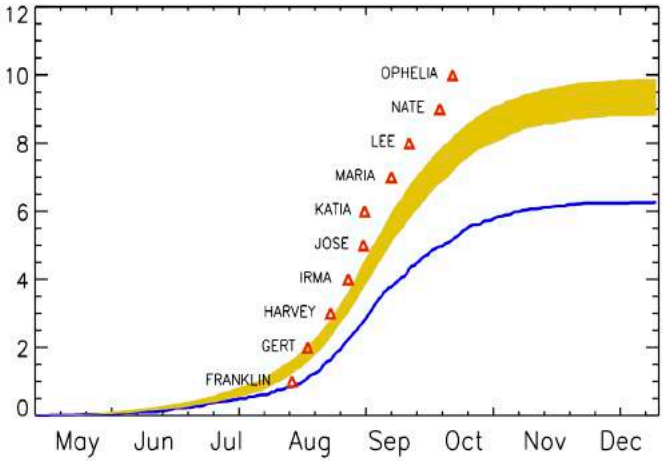
2018 forecasts using stochastic hurricane model (*Hall and Yonekura, J. Clim., 2013; Hall, InsuranceLinked.com, 2017*)

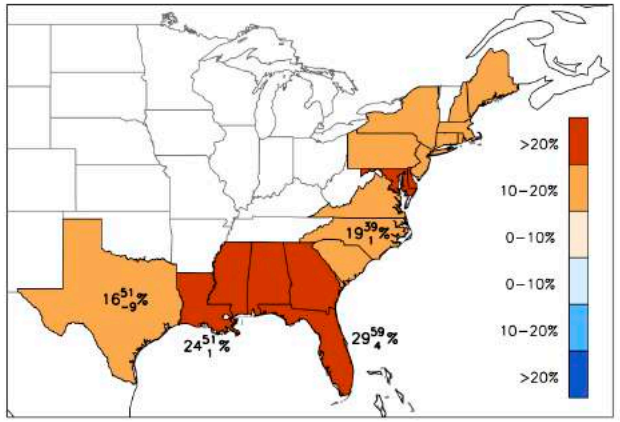
2018 Seasonal Hurricane Forecast: Average Activity

2017



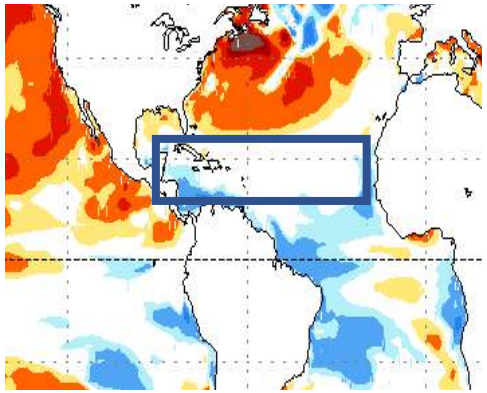


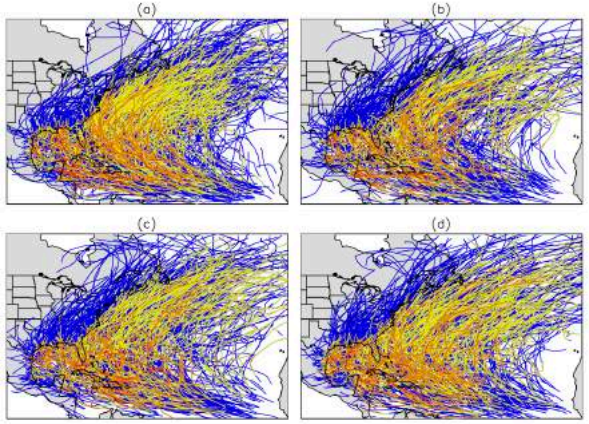


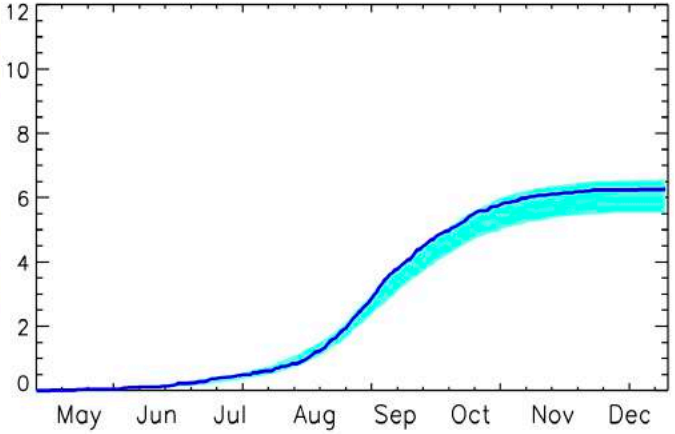


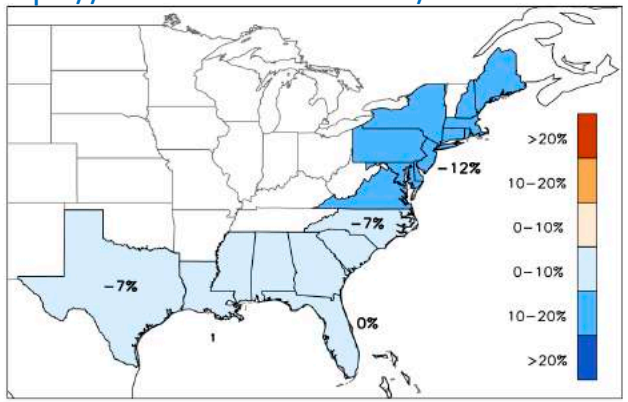
https://insurancelinked.com/and-were-off

2018









SST forecast **simulations** **hurricane counts** **landfall rates**

But … Andrew, 1992 !