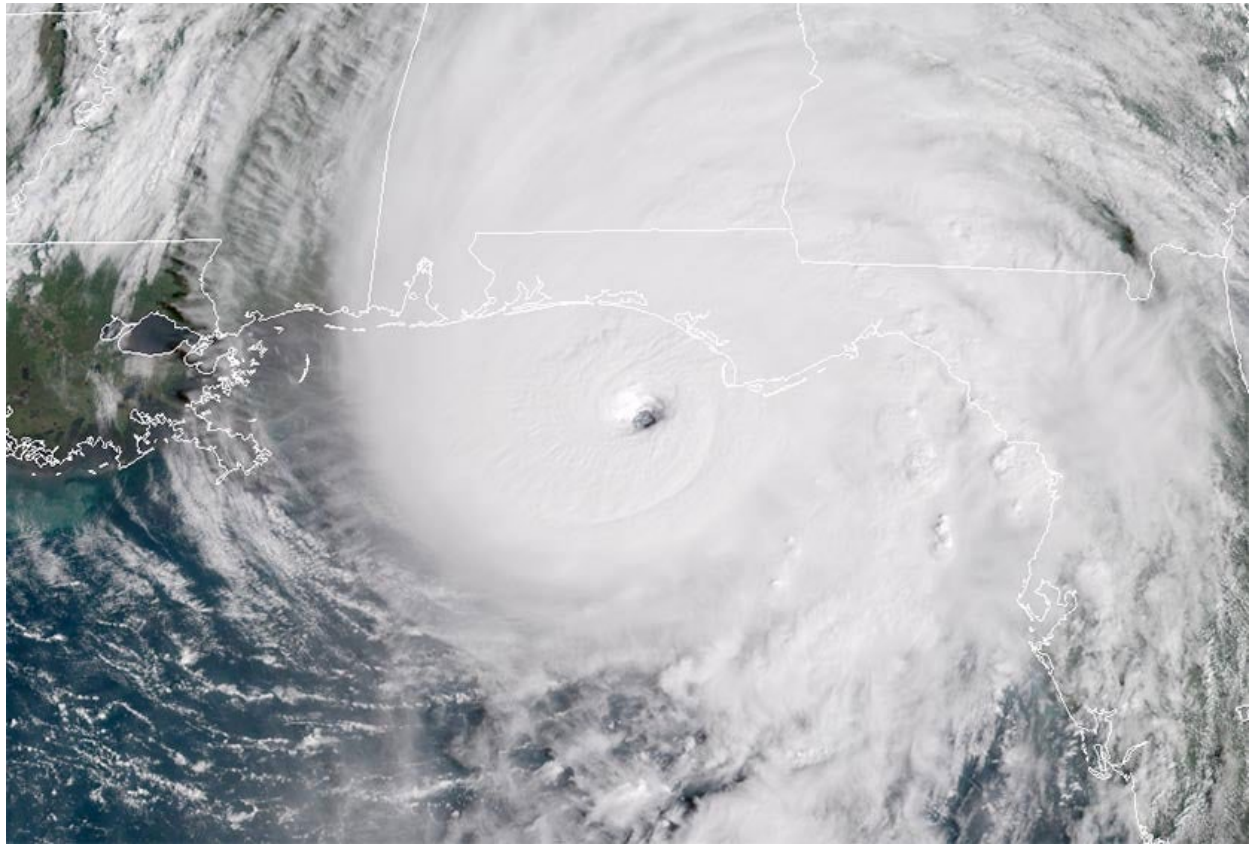
Current and Projected Tropical Cyclone Activity



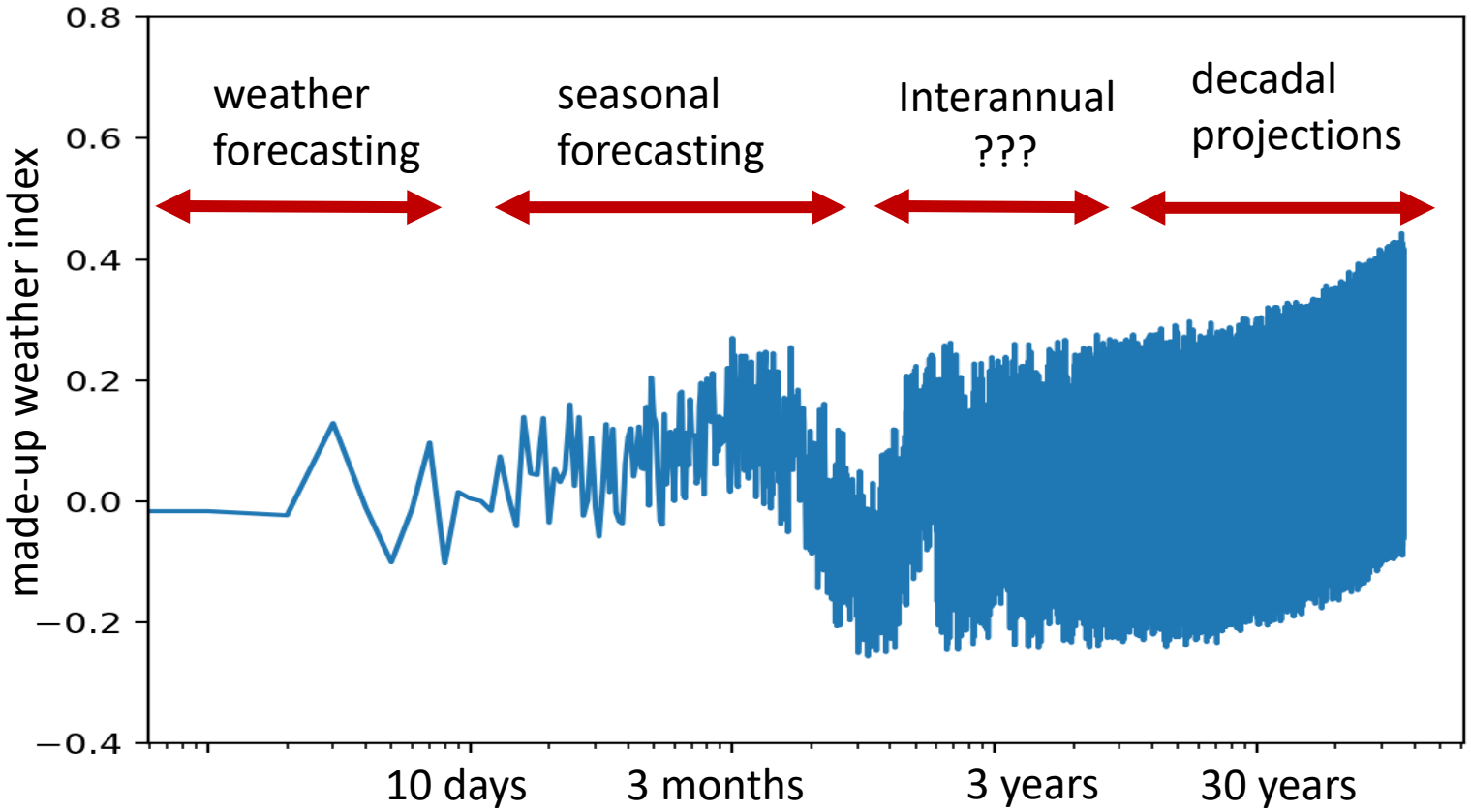
Tim Hall

S&P Global

Florida Hurricane Cat Fund Insurers Workshop, June 13, 2023

Timescales for Tropical Cyclone (TC) Forecasts and Projections

- **10 days:** Weather forecasting. Skill out to ~10 days. Specific events are forecast.
- **Months:** Seasonal forecasting. Probabilistic, e.g., increased/decreased odds of active season.
- **Several Years:** Most difficult. Too long for seasonal forecast, too short for climate change trends.
- **Decadal:** Shift in probabilities from long-term climate trends in relevant environment parameters.



(2023 seasonal forecast is for near normal activity. NOAA: 40% chance normal, 30% above, 30% below.)

Current Climate Impacts ("Attribution") vs Future Projection

- Florida-Commission work: ***2-year*** audit cycle of models used for annual insurance considerations.

- Future climate change impact on hurricane activity not relevant over 1 to 2 years.

- But impact from climate changes that's already occurred may be relevant.

- Is part of current TC activity due to climate change? If yes, then justification for including a climate-change signal in model development and evaluation.

Tools for TC-Climate Attribution and Projection

method	strengths	weaknesses
Direct global numerical simulation, e.g., global climate models (GCMs)	Physically-consistent, mechanisms implicit	Computationally prohibitive for large ensembles, often insufficient resolution to simulate realistic TCs
Regional models nested in GCMs	Better TC realism	Also costly for large TC ensembles
Numerical weather model simulations of individual events	Better realism and computationally feasible. Estimates climate impact (intensity, probability) on one event.	Not suitable for evolution in hazard over wide region due to multiple events and climate factors.
Purely statistical models, e.g., stochastic track models.	Cost effective for large ensembles, easier to reduce biases	Influenced by errors in data records, not always clear how to choose climate-change covariates, not justified for climate regimes well outside the historical record
Statistical-dynamical mix, or “downscaled” models.	Capture some strengths of physical and statistical modeling. “If the GCMs could simulate TCs, this is what they would do.”	No consensus on best downscaling techniques. Subject to observational biases and errors, depending on methods.

All “arrows in the quiver” are valuable and currently being used.

Long-term climate impacts on hurricanes include …

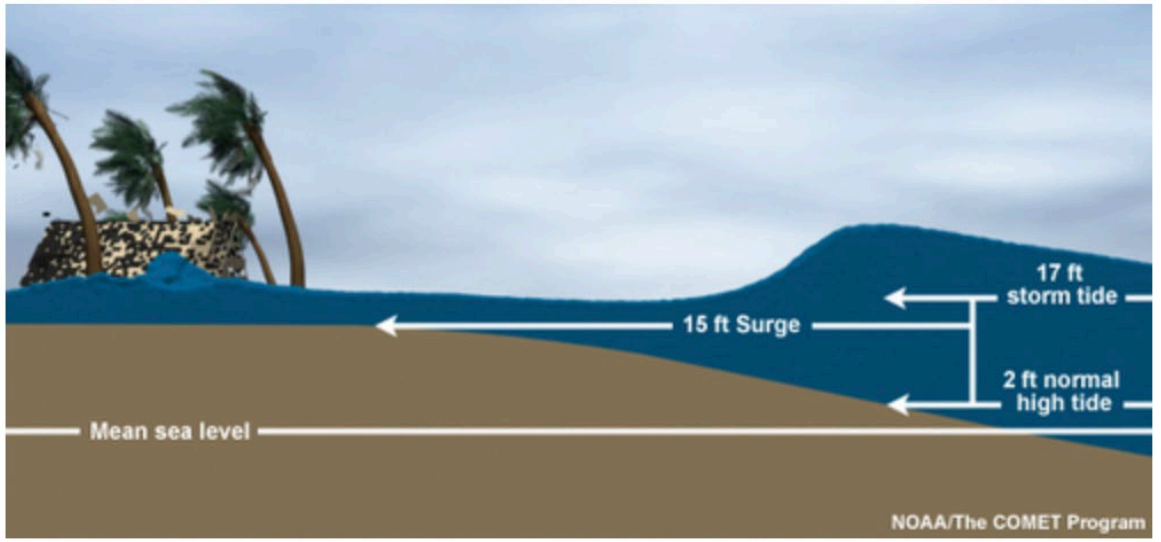
more certain

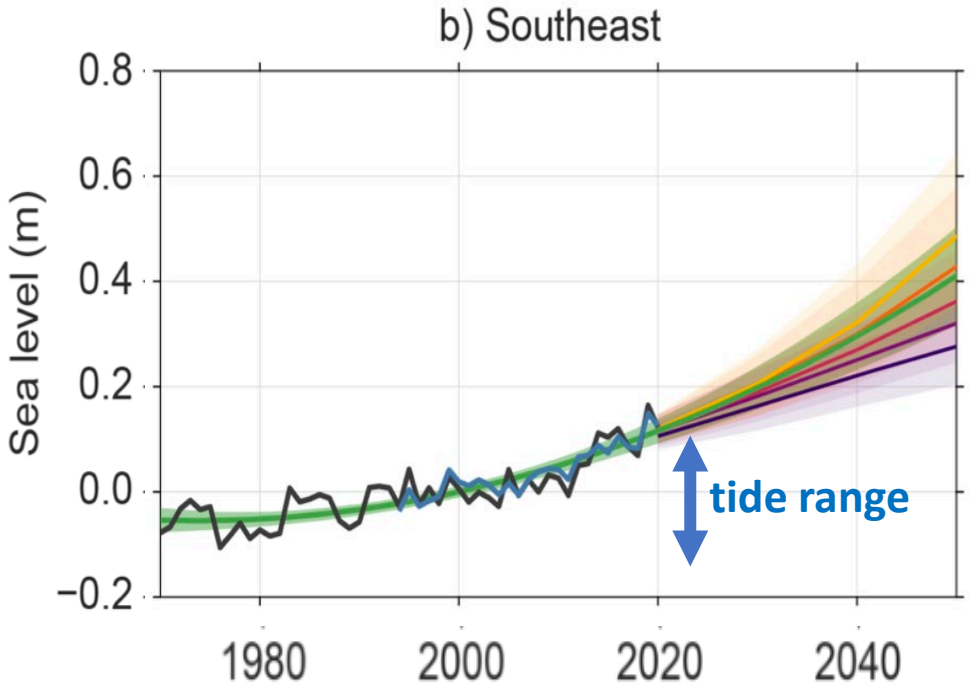
1. Greater storm surge from sea-level rise.
2. More intense rain events from warmer, moister air.
3. Increased intensity from warmer oceans and other factors.
4. Changes in TC propagation, due to changing large-scale wind patterns.
5. Change in annual TC counts.

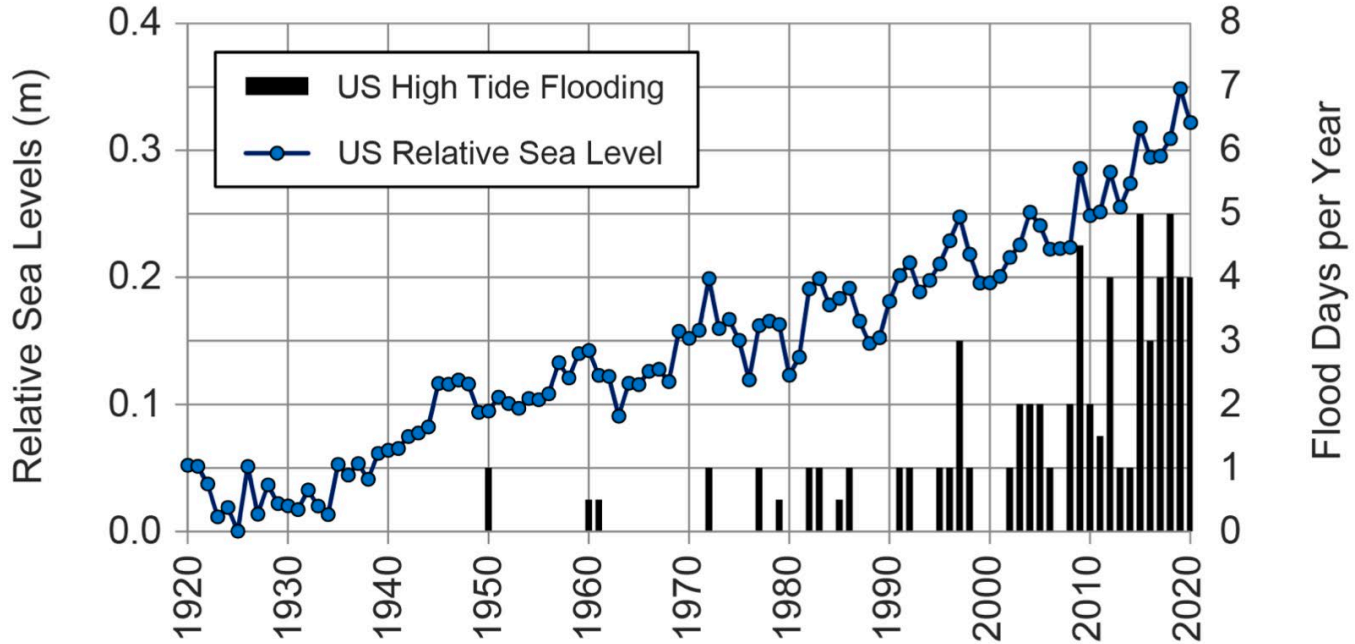
less certain

Sea Level Rise, Surge, and Tide

- Sea level rise → higher baseline for storm surge and tidal flooding
- Sea level rise to date comparable to tidal amplitude.
- Documented increase in coastal flood frequency, even clear sky.



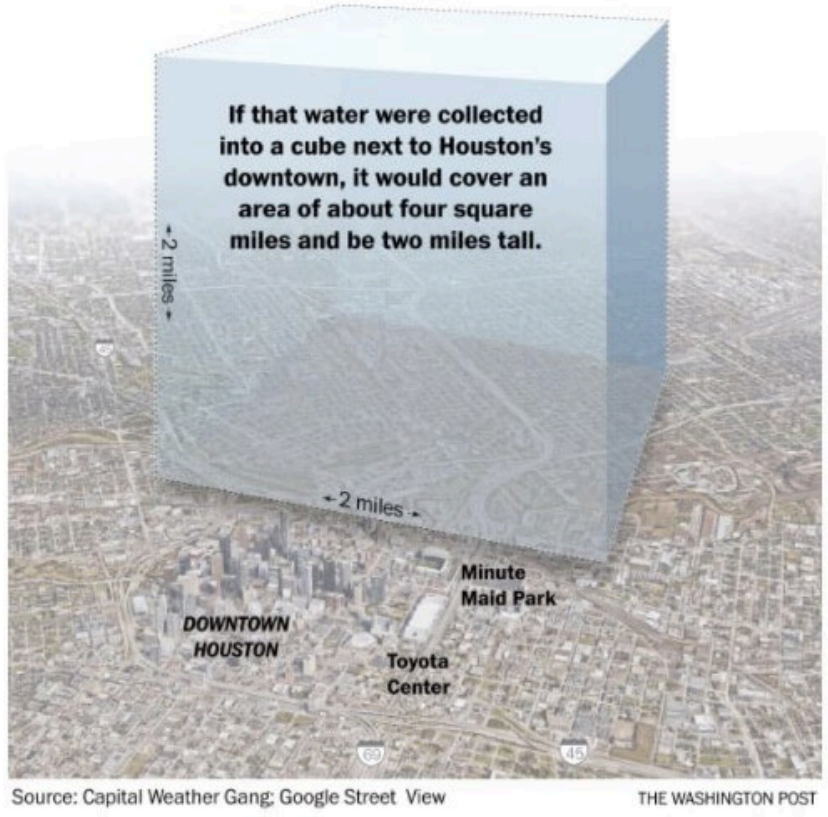


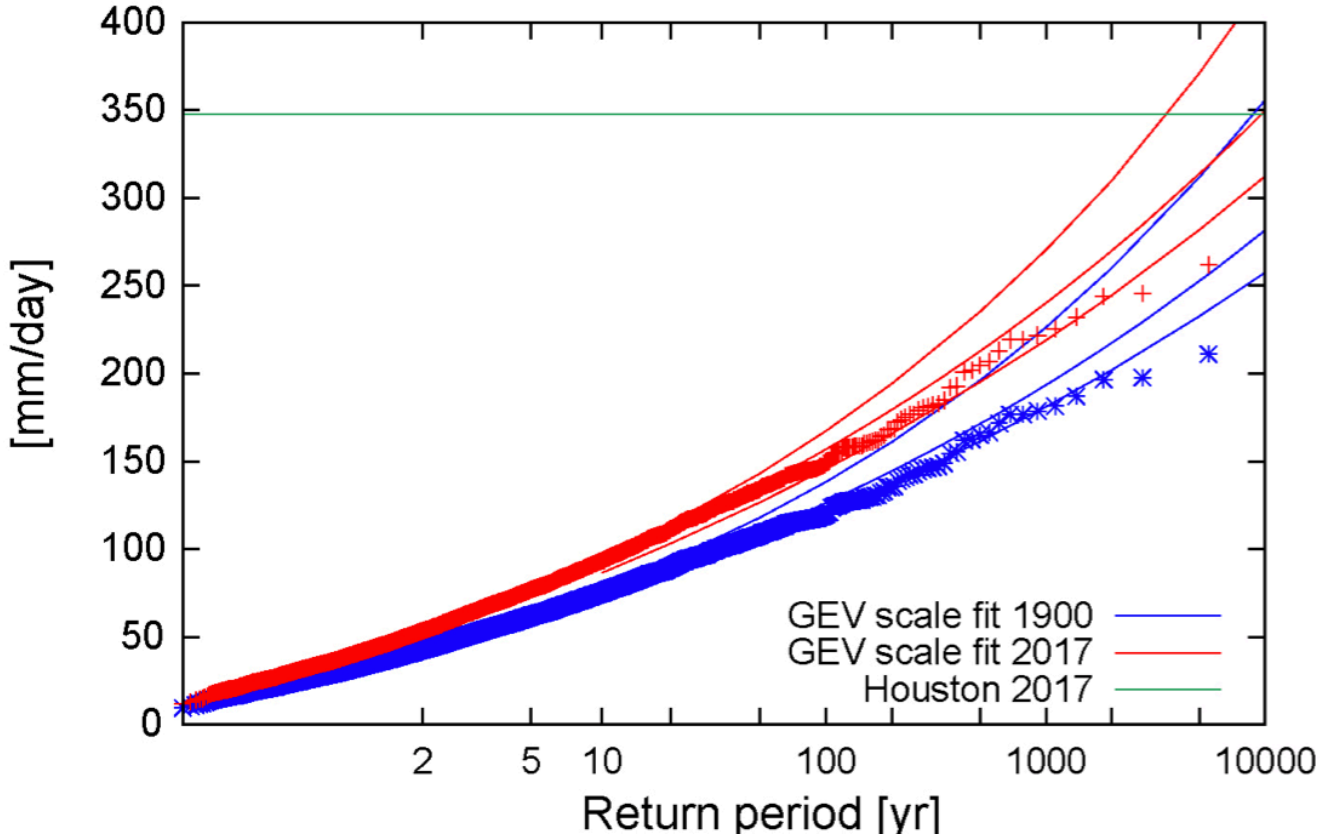


Sweet et al, 2022

Hurricane Rainfall

Climate-change mechanism: increased water vapor with warmer air, plus increased wind speed for air-sea exchange.



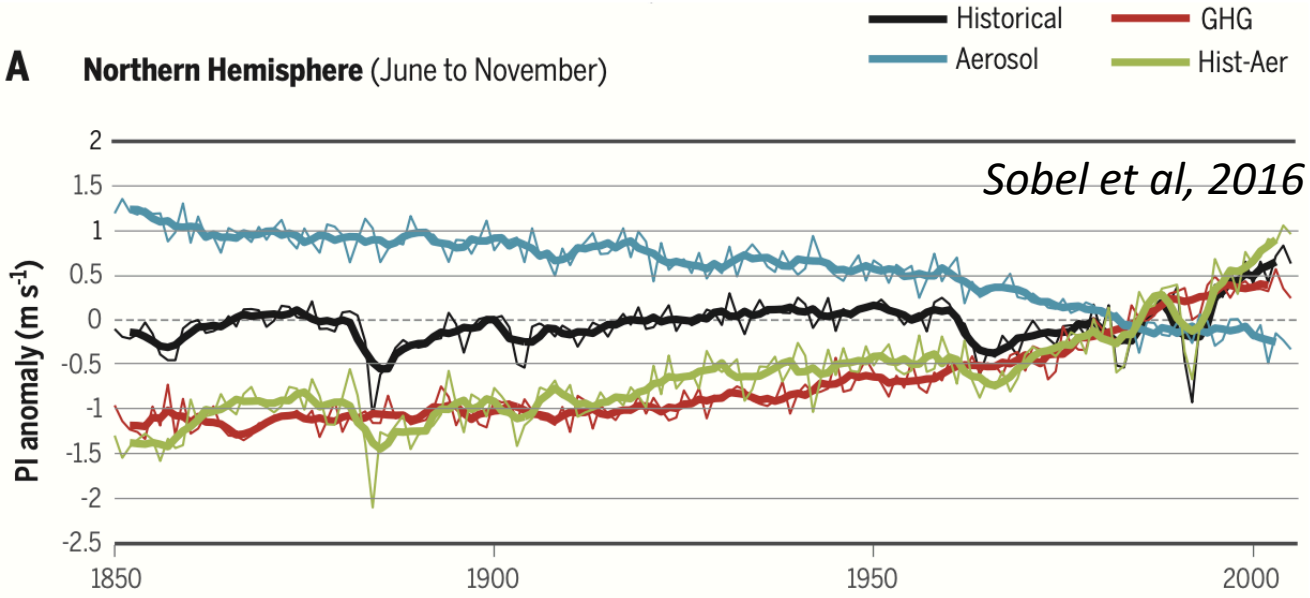


Attribution: Multiple dynamical model simulations of an event in Actual and "Counterfactual" climates

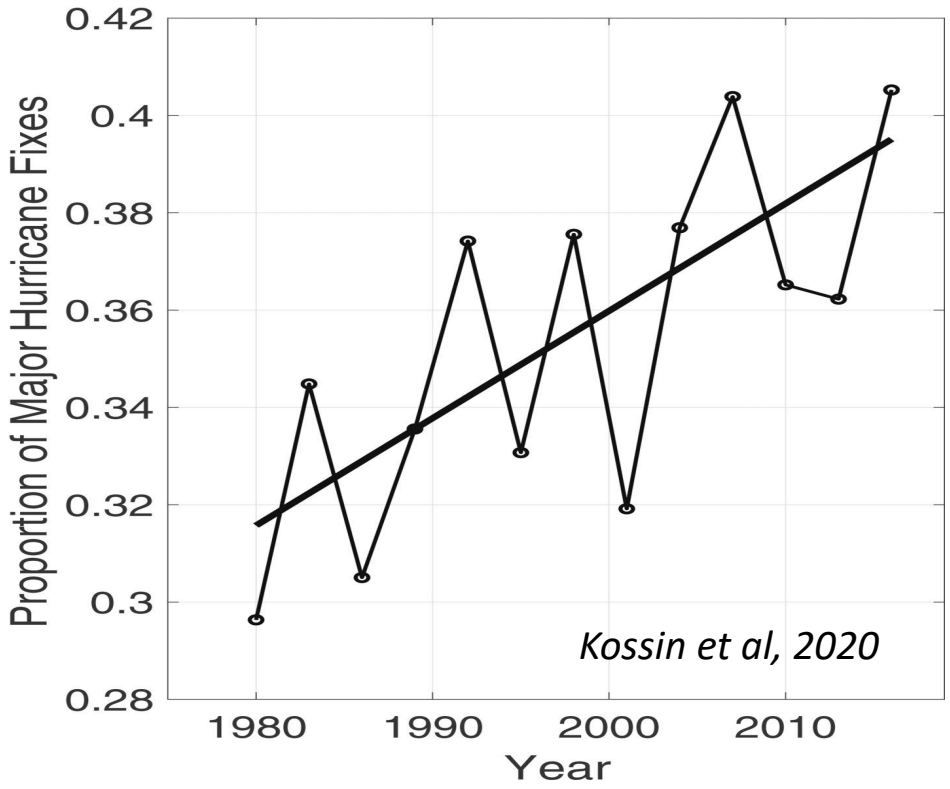
Hurricane Harvey 2017 Houston rain rate (van Oldenborgh et al, 2017). Harvey rain totals 15% more intense, or ~3 times more likely in current climate than pre-industrial climate.

TC Intensity: Consensus on increases for strongest storms.

11) Detectable increase in the global proportion of TCs reaching category 4 or 5 intensity in recent decades **(all agree)**; and anthropogenic forcing has contributed to this increase **(73% agree)**. *Knutson et al, 2020*



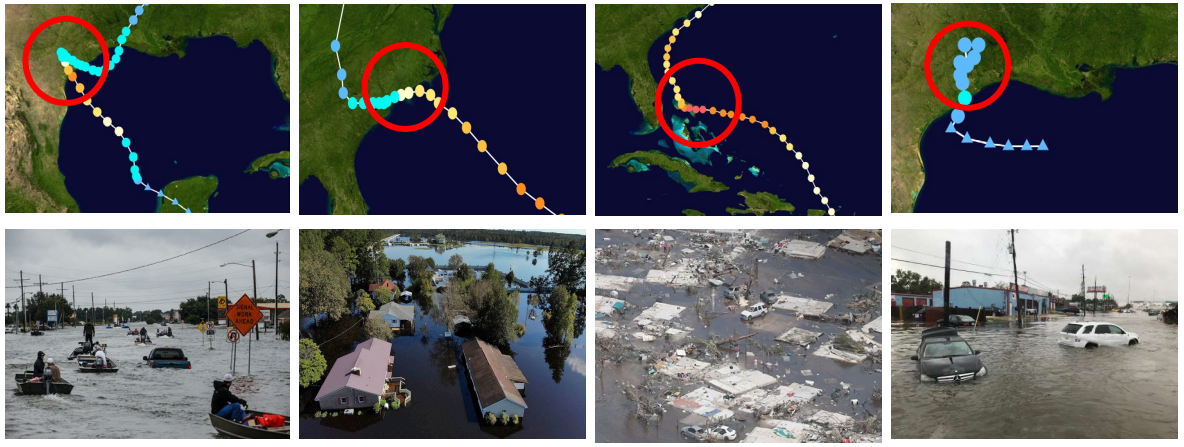
PI from GCM simulations with and without historical aerosol and GHG forcing. Until 1970s, aerosol and GHG impacts canceled. After, reduced aerosols let GHG impact be realized and PI increases.



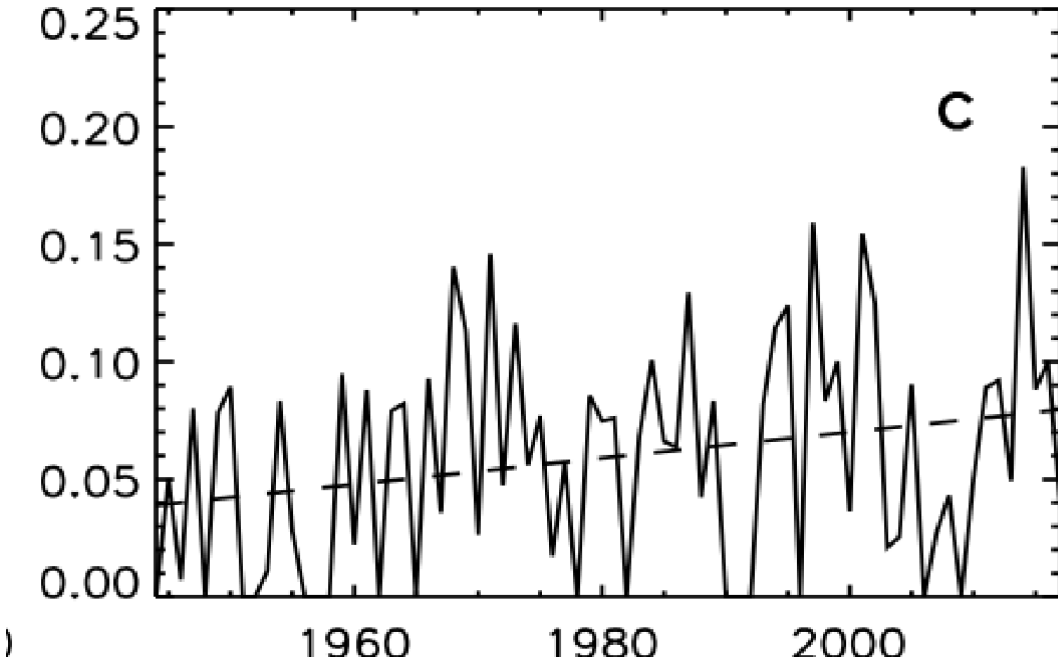
Positive trend in fraction of hurricanes reaching "major" status now visible in historical record.

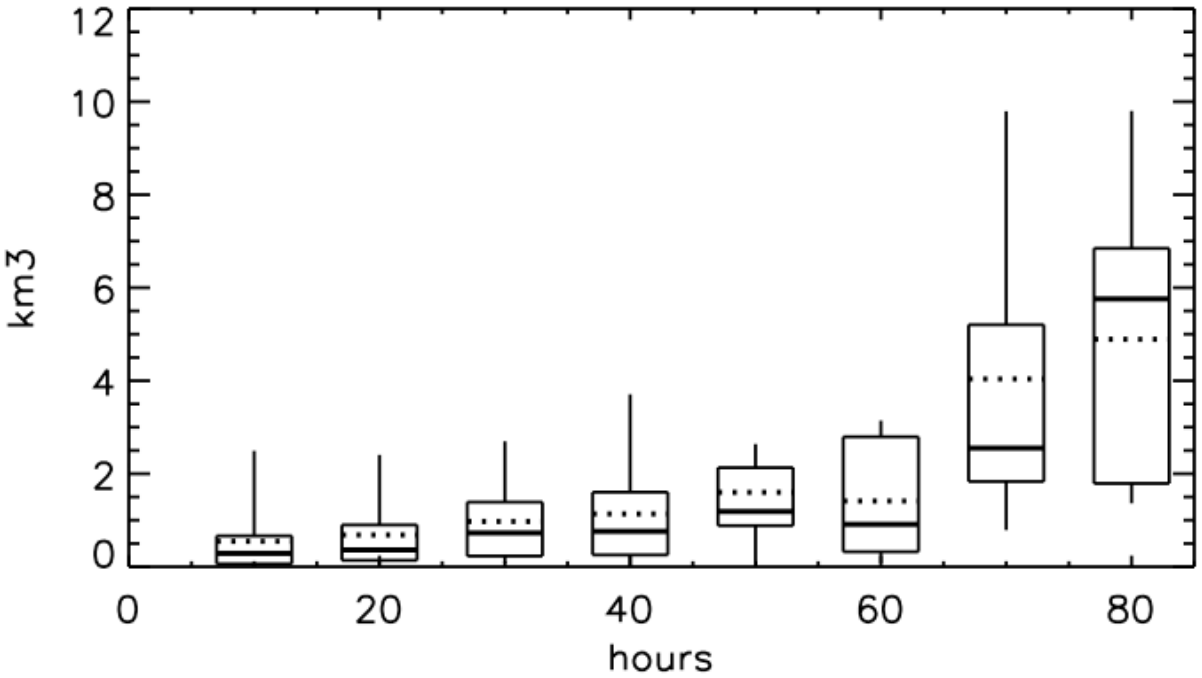
Propagation: TCs Stall More Often

Uncertainty, but potential high impact on regional scales



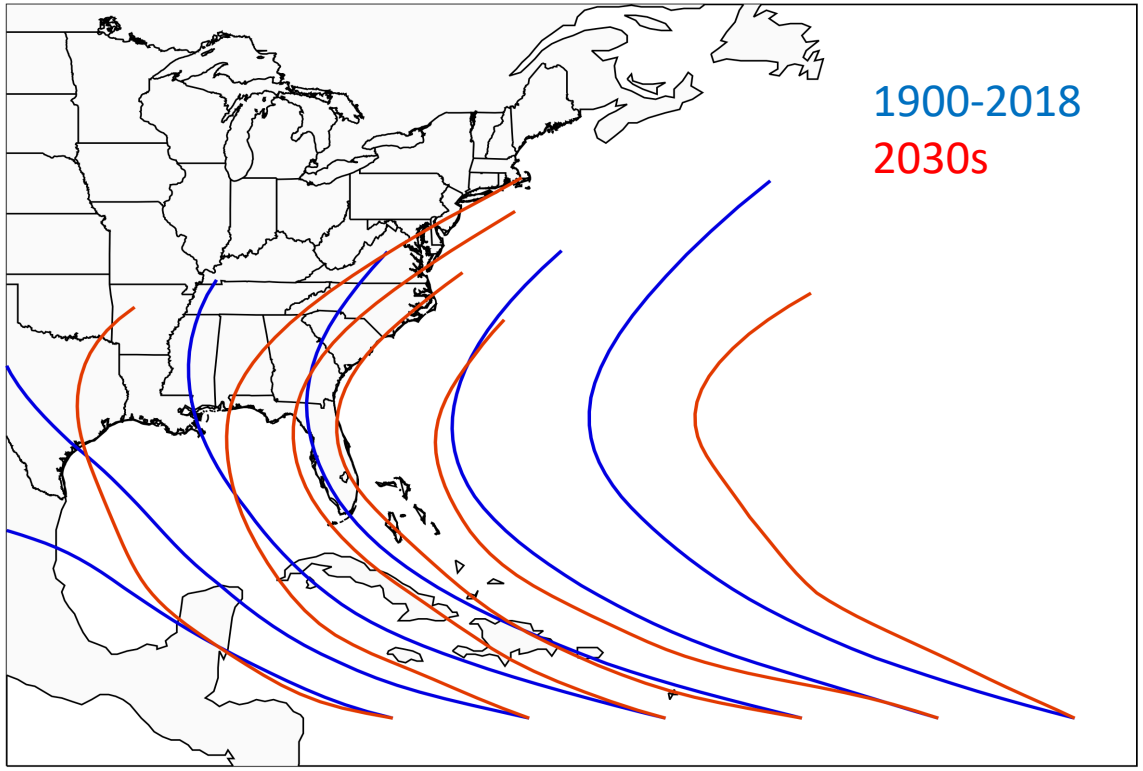
Harvey 2017 | Florence 2018 | Dorian 2019 | Imelda 2019





Annual fraction of TCs that pass through specified coastal 200km-radius regions that spend at least 48 hours in those regions (Hall and Kossin, 2019). Increased stalling → increased rain accumulation.

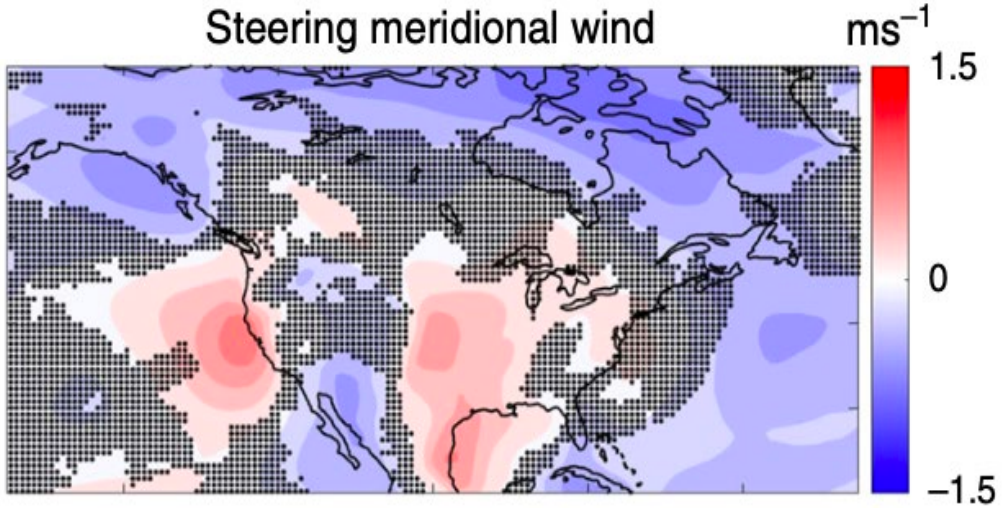
Propagation: Changes in Direction



Mean TC tracks from statistical model holding formation and intensity fixed (Hall et al, 2021)

Large uncertainty, but potential high impact on regional scales.

Corroboration by independent study of projected change in wind patterns that steer TCs.



Hassanzadeh et al (2020) find northward steering wind anomaly projection across set of CMIP5 model projections

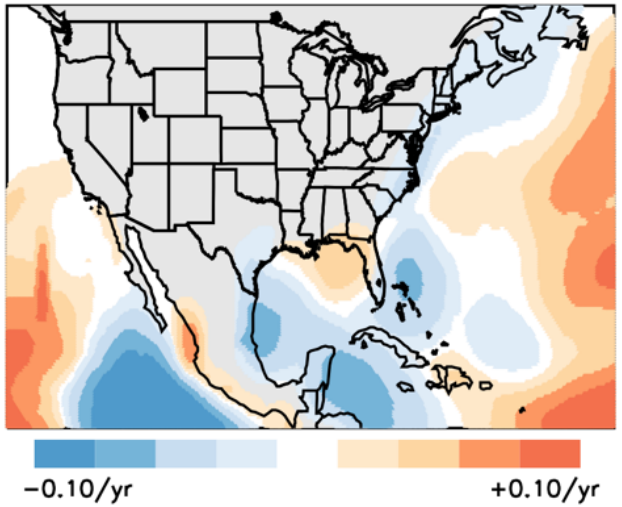
Northeastward track anomaly in Gulf. Possibly due to steering-wind changes from enhanced Atlantic subtropical pressure high due to differential land-ocean heating.

Impact on Gulf states: shifts TC hazard away from Texas and towards west Florida.

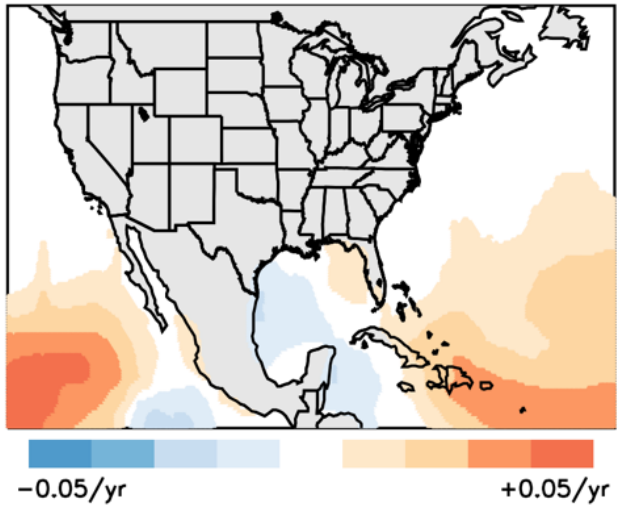
Putting it together: Projected Changes in TC Activity 2040s compared to 1900-2018 baseline

Complex signal, multiple factors varying simultaneously (formation, intensity, track) at different rates in different regions with different signs.

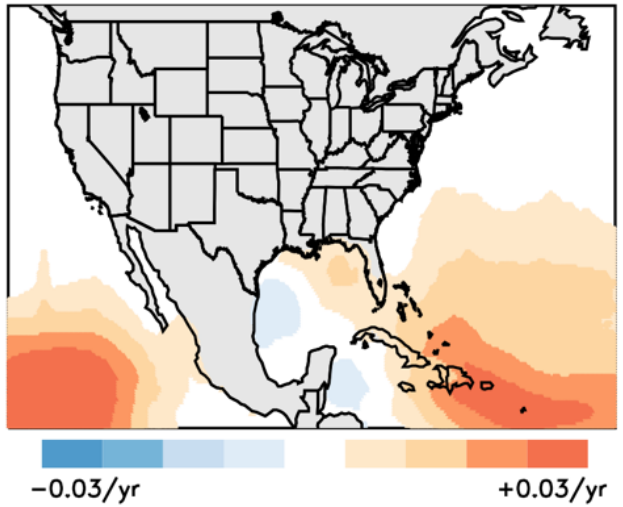
All tropical cyclones



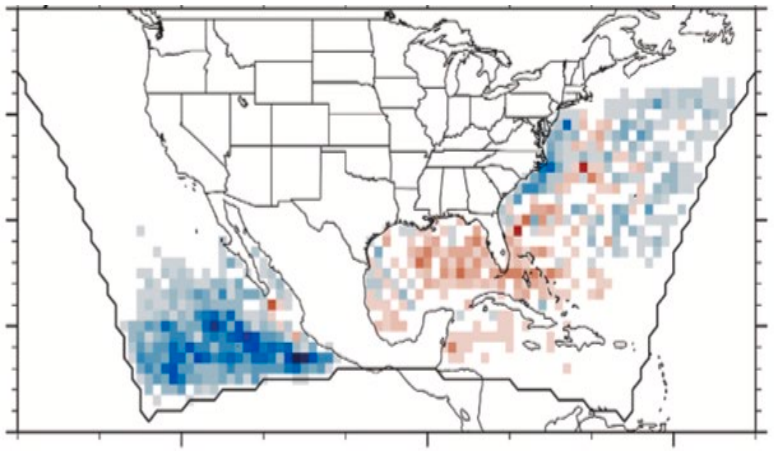
Category 3-5



Category 4-5



All tropical cyclones



Comparison to independent estimate (Rendfrey et al, 2021) shows some agreement.

But across a range of studies, wide range of regional changes. Most show mixed picture: regions of increased and decreased activity for moderate TCs, weak agreement on geographic patterns.

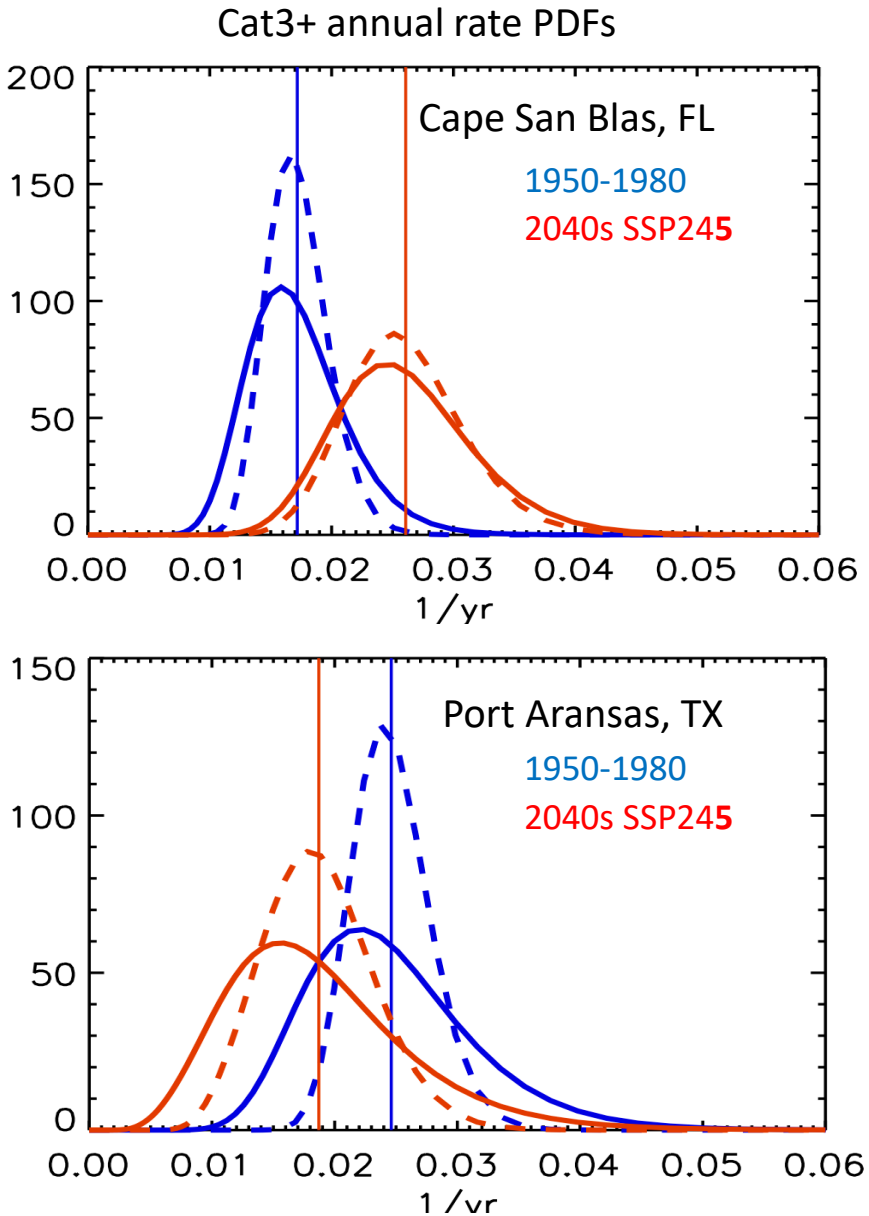
Better agreement: wide regions of increases for strongest TCs.

Probabilistic analysis on two US locations

Uncertainty due to:

- Range of mean climate projections (SST).
- Unforced climate variability (e.g., El Nino)
  Model sampling error from finite training data.

What is distribution of mean rates in a given year?



Summary

- Climate-change signals in current TC climatology are most relevant for Florida-Commission cycles; potential for biases if significant change signals are neglected in historical record.
- Strong evidence for climate-change signature in TC rainfall and intensity.
- Some evidence for signals in TC propagation.
- Changes in each TC characteristic leaves a distinct signature on activity, resulting in complex change signals.
- Currently, no single best method for incorporating climate-TC signals. A range of tools are available, each with strengths and weaknesses.