Understanding the Relationship between Tropical Cyclone Precipitation and SST Utilizing a CAM Hierarchical Framework

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CESM Workshop 2022

Extreme precipitation-temperature relationship on different timescales

- On short timescales, the extreme precipitation-temperature relationship can depend on storm type, season, and localized convective feedbacks (Fowler et al. 2021)
  - Localized sub-daily increases above the 7% per K baseline (Clausius-Clapeyron) have been observed in certain locations (e.g., Guerreiro et al. 2018)
  - Uncertain how short term relationship (apparent scaling) may relate to the climate change response (climate scaling)

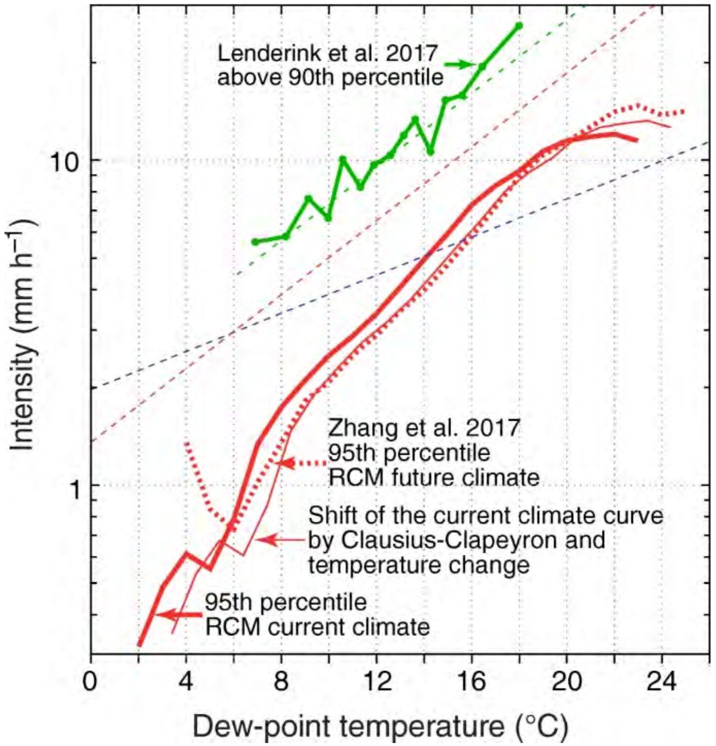


Fig. 2 from Neelin et al. (2022)

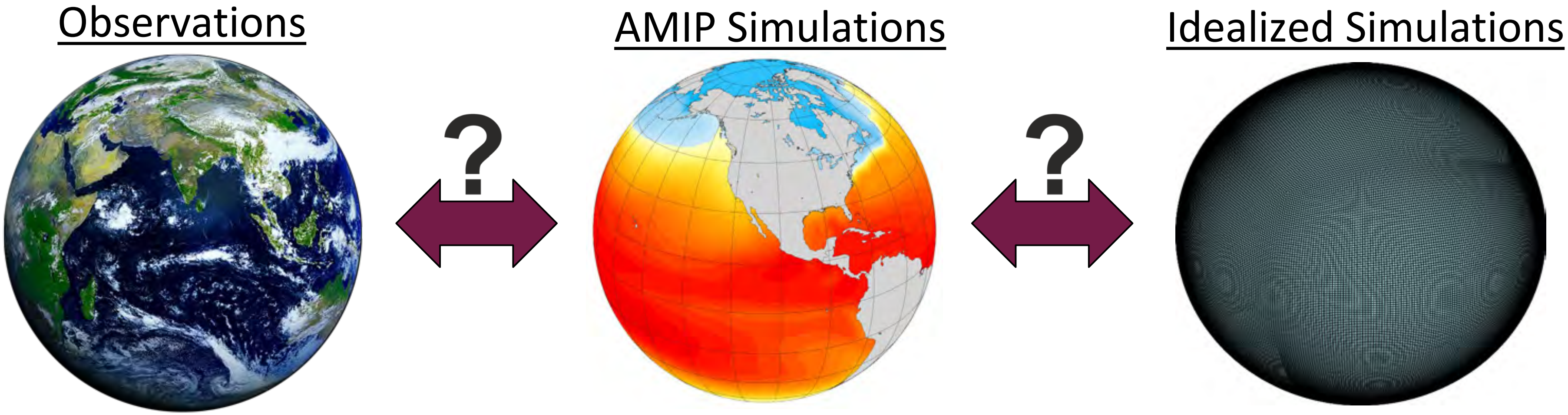
Tropical cyclone (TC) extreme precipitation

Flooding from Hurricane Ida in Mississippi, 8/29/21, Steve Helber

- Precip. observations over tropical oceans in the past have been:
  - Sparse and not frequent → tough to estimate present-day variability
  - Short-duration → tough to estimate climate scale relationship
- For TCs, most interest = how precip. will react to climate warming
  - Most studies compare historical and future GCM simulations
  - Summary assessment (Knutson et al. 2020): near-storm precip. will increase ~14% per 2 K of warming

Research Question

What can idealized simulations tell us about the TC precipitation response to real-world climate change?



Datasets: Idealized Model Simulations

- Model: Community Atmosphere Model (CAM), version 5
  - CESM2, with official RCEMIP compset (Reed et al. 2021)
  - Using protocols of RCEMIP (Wing et al. 2018), except **adding rotation**
- 11 simulations with globally-uniform SST varying from 295-305 K in 1 K increments
  - Simulation length = 2 years
  - Horizontal grid spacing: ~28 km
  - SE dynamical core
- No seasonal or diurnal cycles

- More information on TCs in these simulations: Stansfield, A. M. and K. A. Reed (2021) Tropical Cyclone Precipitation Response to Surface Warming in Aquaplanet Simulations with Uniform Thermal Forcing. *JGR:Atmospheres*, 126, e2021JD035197. https://doi.org/10.1029/2021JD035197

Datasets: Earth-like Model Simulations

- Model: Community Atmosphere Model (CAM), version 5
  - Atmospheric Model Intercomparison Project (AMIP) simulations for 1980-2012
  - Horizontal grid spacing: ~28 km
  - SE dynamical core
  - Used to study TCs in Bacmeister et al. (2018) and Reed et al. (2019)

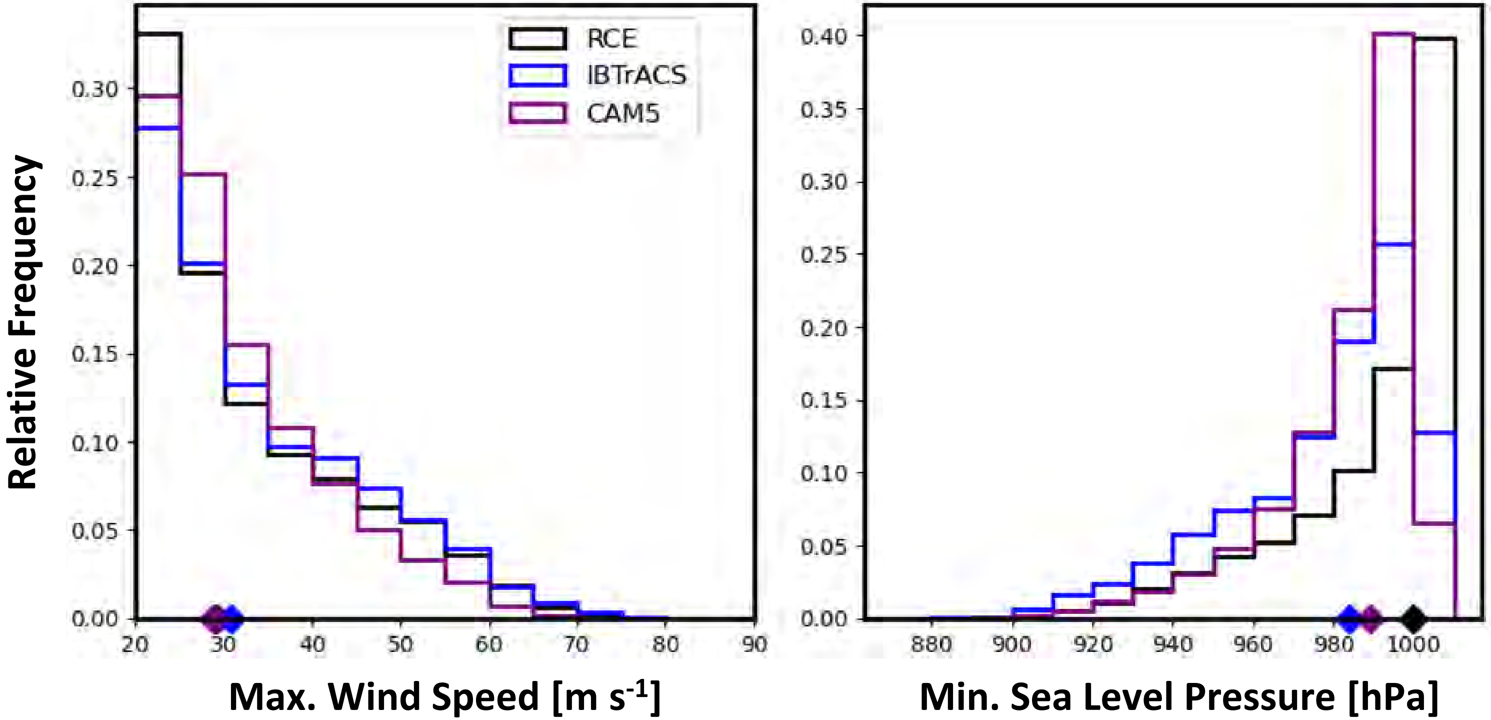
- TCs in models tracked using TempestExtremes software package (Ullrich & Zarzycki 2017; Ullrich et al. 2021)

Datasets: Observations

- Time period for observations: 2001-2020
- International Best Track Archive for Climate Stewardship (IBTrACS) for TC tracks and intensities
- Integrated Multi-satellitE Retrievals for GPM (IMERG) satellite product for precipitation
  - Converted from half-hourly to 6-hourly
  - 0.1° spatial resolution, regridded onto common grid with models for TC precipitation analysis

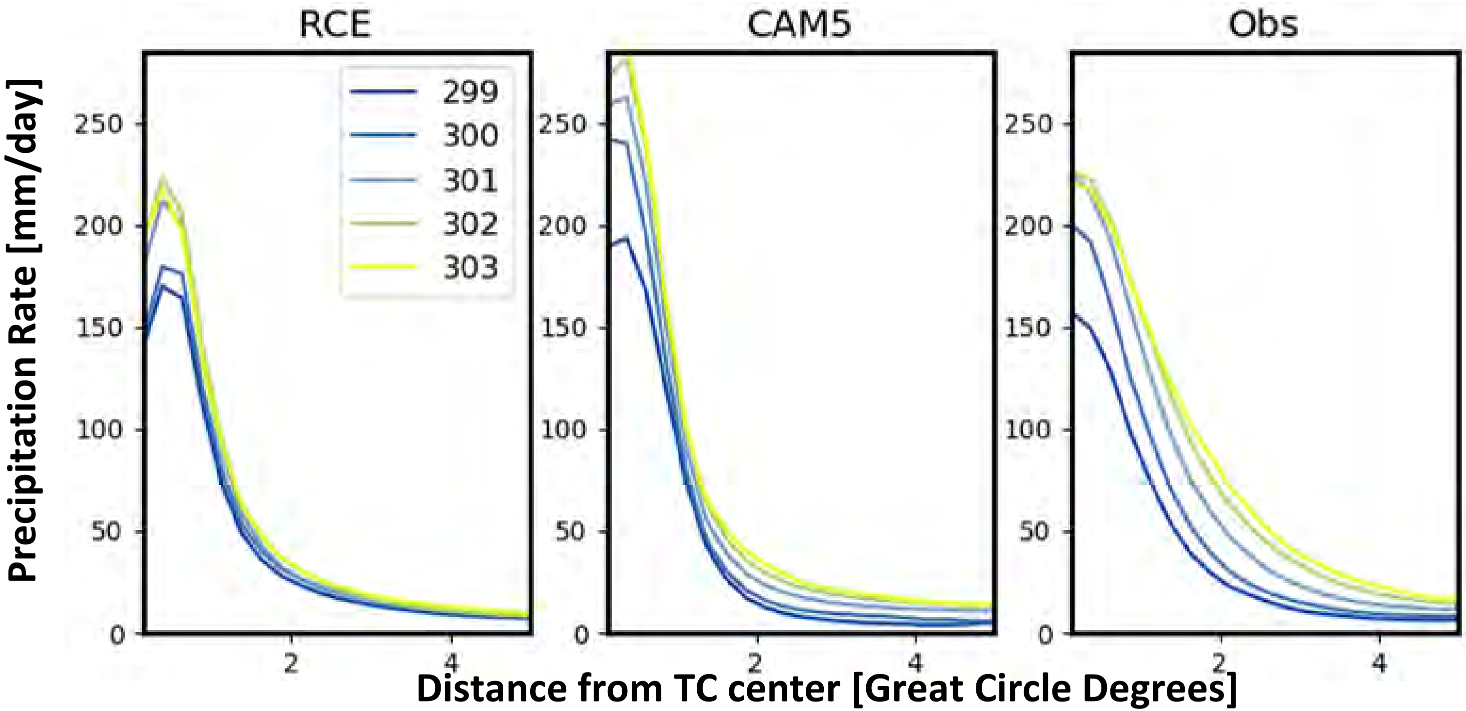
*Only TCs between 5 and 20° latitude in both hemispheres are analyzed in all datasets, to try to focus on the area where the idealized simulations may be most comparable to the real world

TC Intensity



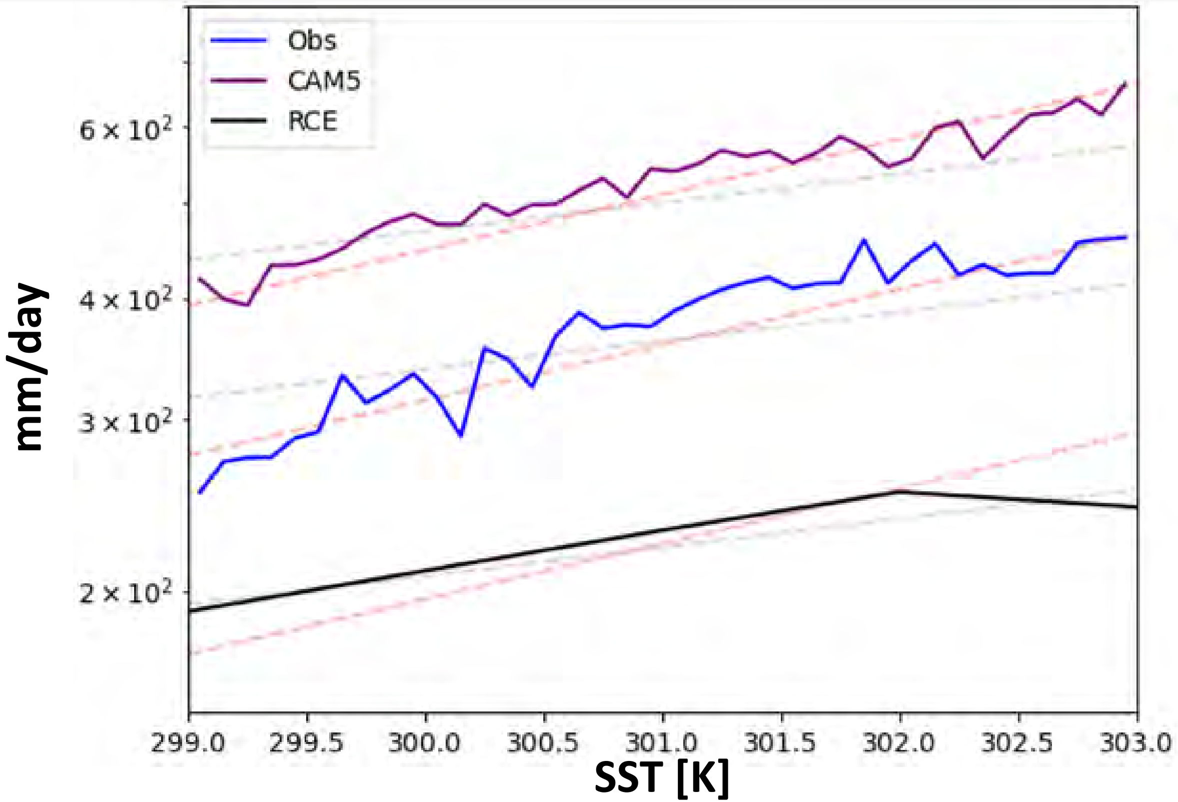
- In general, models underestimate observed TC intensities, more so for MSLP

TC Precipitation Radial Profiles



- Response of profiles to SST increase varies between models and observations

99th Percentile TC Precipitation vs SST



- Grey dashed lines: Clausius-Clapeyron rate
- Red dashed lines: 2 X Clausius-Clapeyron rate
- RCE simulations less sensitive to SST change than CAM5 and observations

**Modeled after Fig. 2 in Neelin et al. (2022)*

Breakdown of thermodynamic vs dynamic factors increasing TC precipitation

Change in TC precipitation = change in moisture available + change in TC intensity (V)

*For more information on equation, see Stansfield & Reed 2021

$$\frac{dP(SST,V,R)}{dSST} \approx \frac{\partial_{V,R}P}{\partial SST} + \frac{\partial_{SST,R}P}{\partial V}\frac{\partial V}{\partial SST}$$

Estimated using exponential regression on raw data

Estimated using Poisson Regression

Estimated with linear regression of changes in V

Thermodynamic vs dynamic breakdown for 99th percentile precipitation

Change in 99th percentile TC precipitation = change in moisture available + change in TC intensity

	Total	Thermo. Contribution	Intensity Contribution
RCE	6.1% per K	82%	15%
CAM5	11.5% per K	99%	~0%
Obs	15.3% per K	78%	~0%

Results

- For apparent scaling, TC precipitation appears to be less sensitive to SST in models than in observations, especially for the RCE simulations
  - Majority of change comes from thermodynamic contribution in both models and observations
  - In CAM5 and observations, TC intensity change with SST is ~0 or negative, leading to negligible contributions from intensity changes
- Still exploring how RCE simulations could relate to climate scaling between TC precipitation and SST in observations
  - Could these RCE simulations be used to project TC precipitation increases as SSTs continue to warm?

For more information:

- Stansfield, A. M. and K. A. Reed (2021) Tropical Cyclone Precipitation Response to Surface Warming in Aquaplanet Simulations with Uniform Thermal Forcing. *JGR:Atmospheres*, 126, e2021JD035197. https://doi.org/10.1029/2021JD035197

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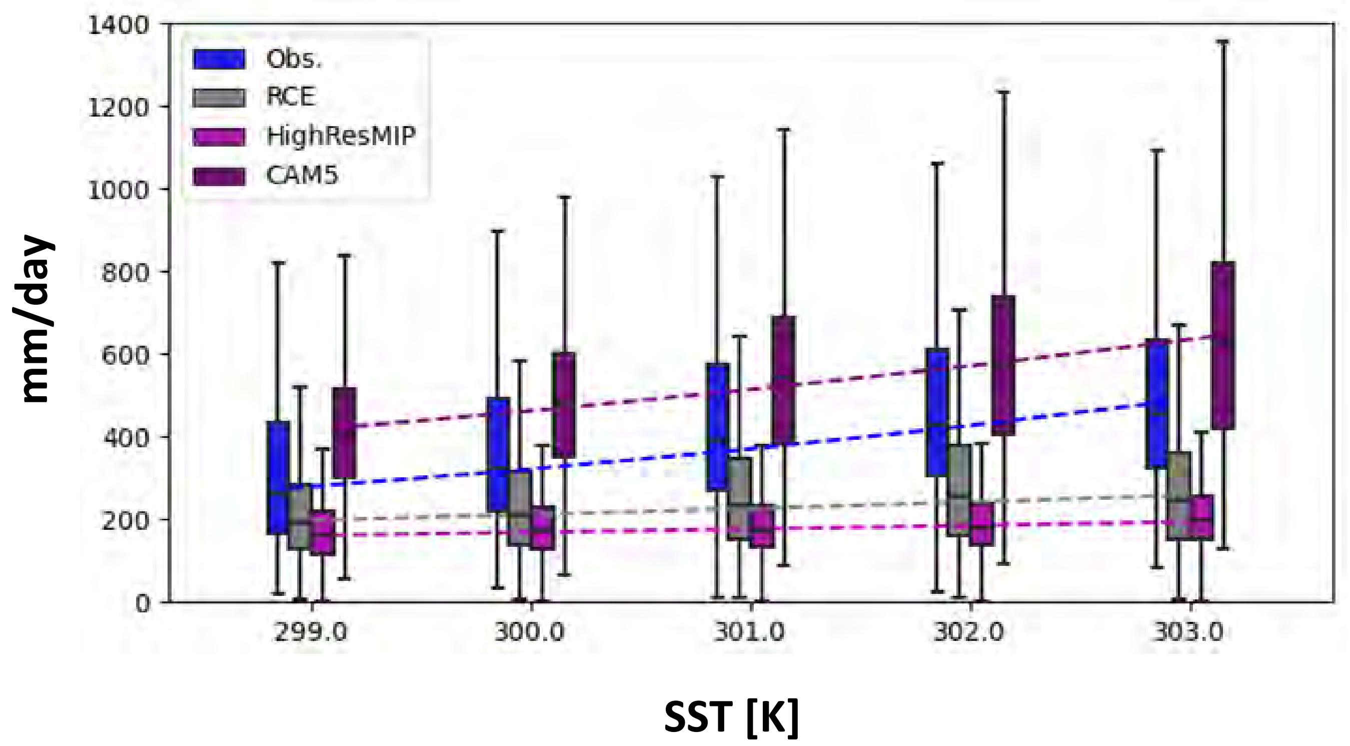
Distributions of 99th Percentile TC Precipitation



Distributions of TC Intensity by SST