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Using the CAM hierarchy to advance understanding of climate change impacts on hurricanes

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Motivation

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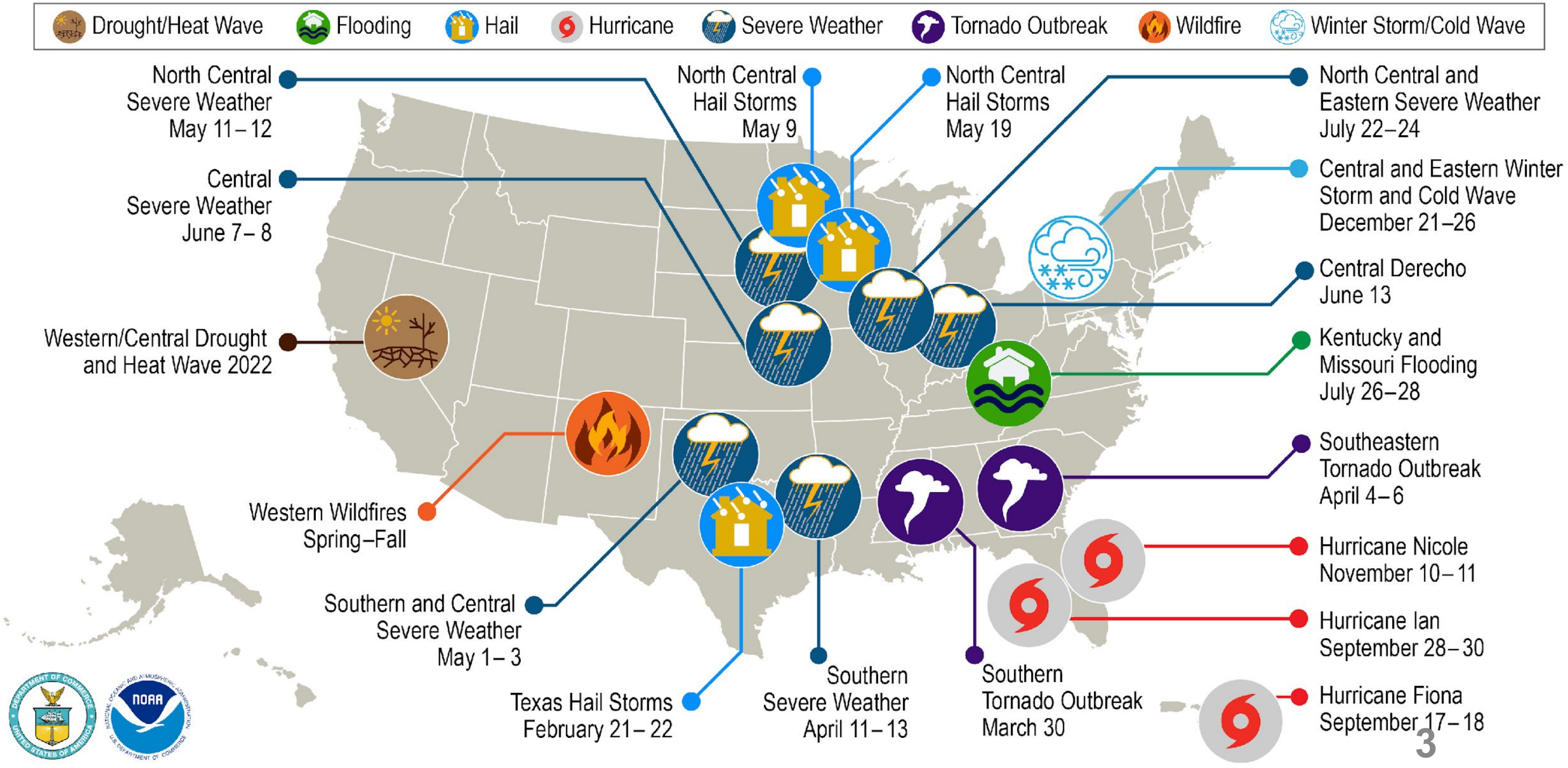
Motivation

U.S. 2022 Billion-Dollar Weather and Climate Disasters



*This map denotes the approximate location for each of the **18 separate billion-dollar weather and climate disasters that impacted the United States in 2022.***

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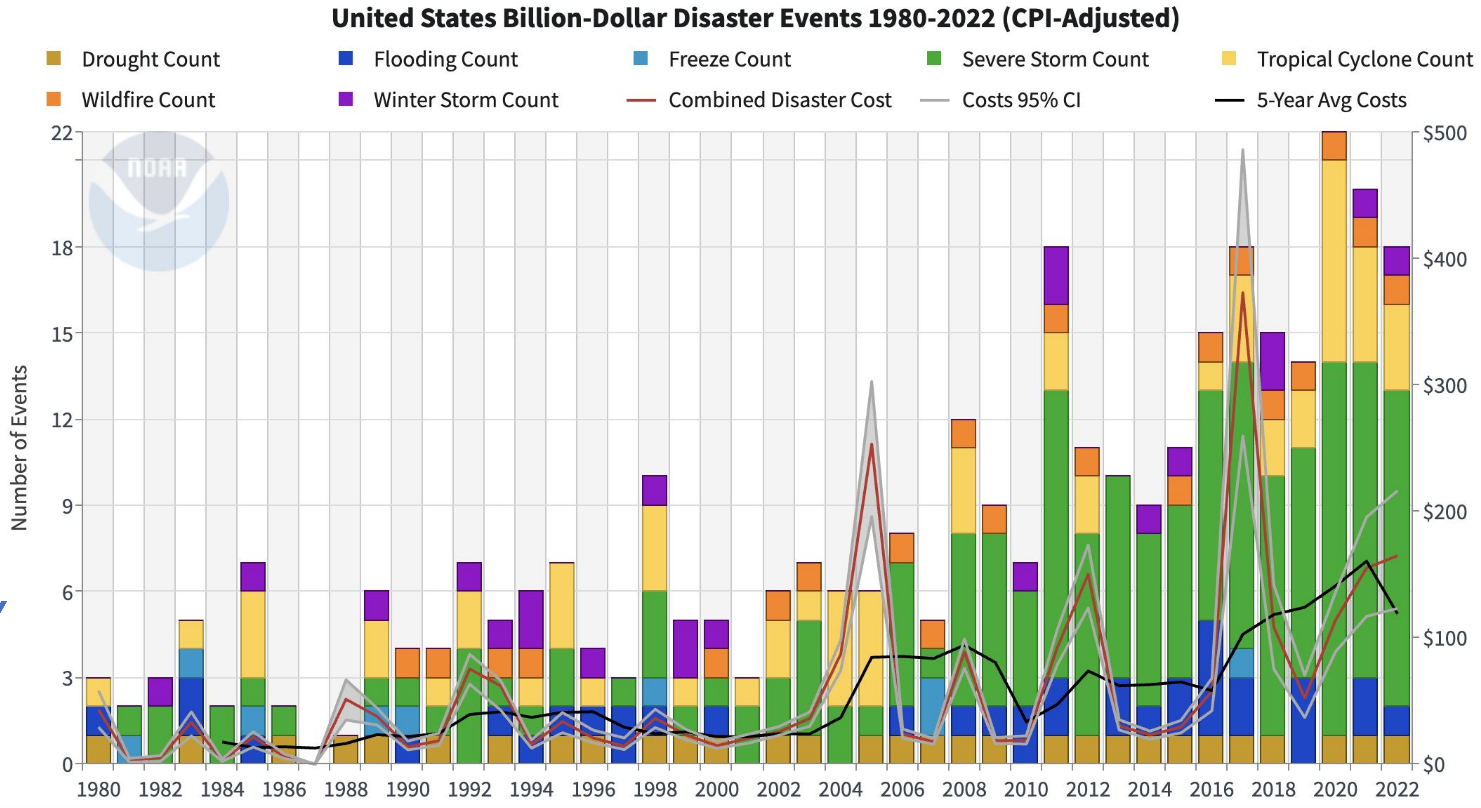
Motivation: Extreme events and climate change

U.S. National Climate Assessment:

"*Changes in* ***extreme weather events*** *are the primary way that most people experience climate change. Human-induced climate change has already increased the number and strength of some of these extreme events.*"



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Motivation:

- We are entering an era where the numerical tools typically used to assess **long-term climate change** are approaching those now used for **short-term weather prediction**.
- Advances in climate modeling has improved our ability to investigate trends in **extreme weather** and to project **regional impacts** of climate change.
- As a result, there are growing possibilities to use the **CAM hierarchy to understand** these changes.

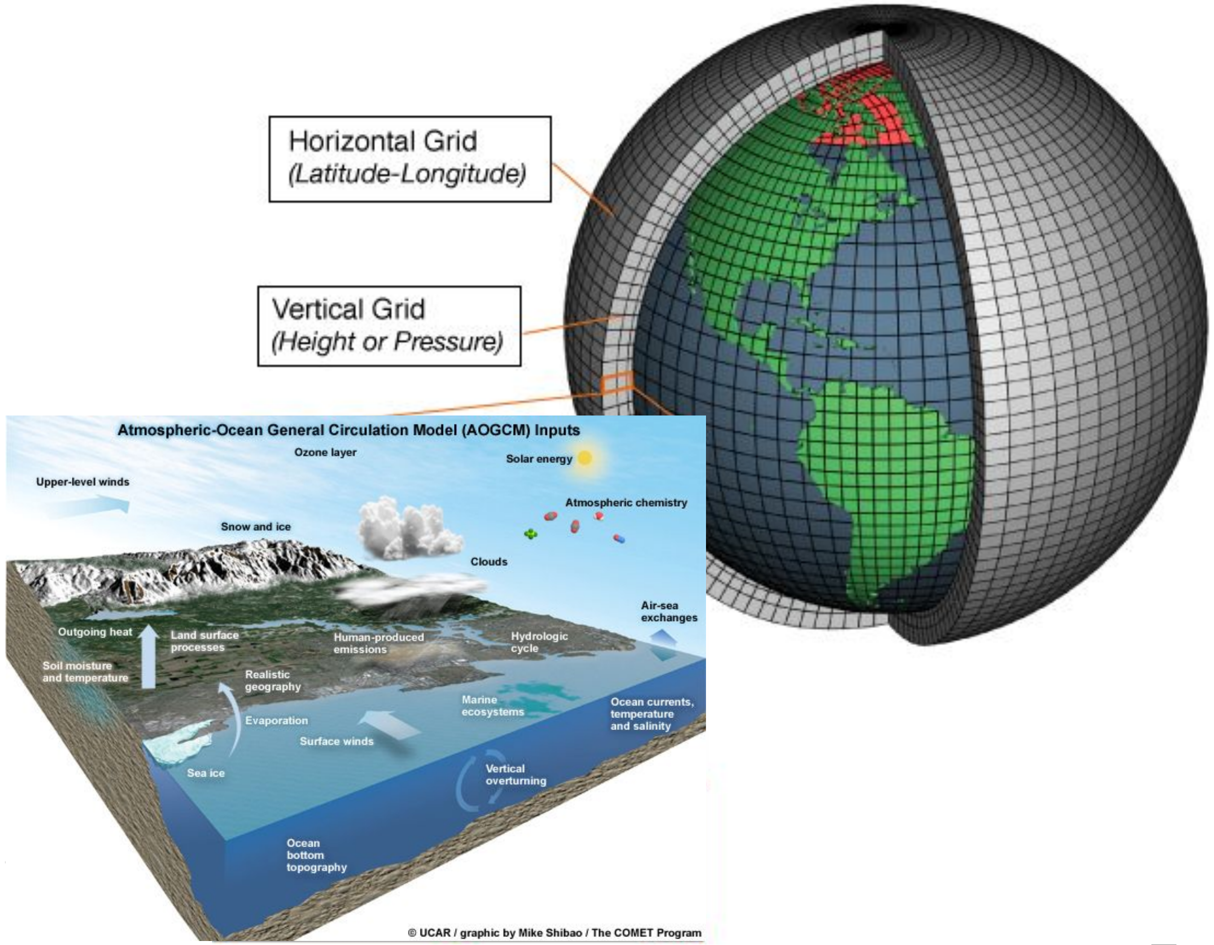
Methodology

Virtual laboratory: numerical model

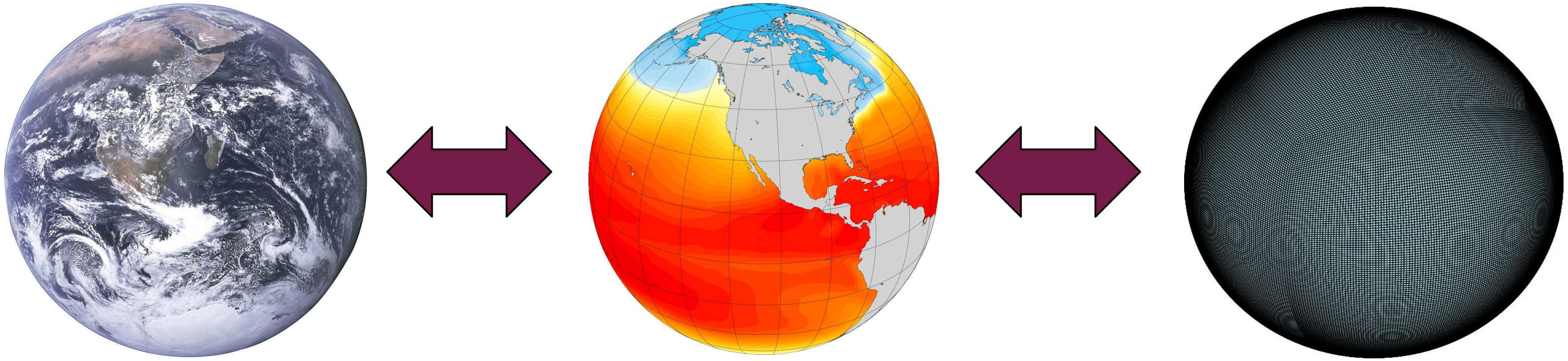
Various versions of the National Center for Atmospheric Research's (NCAR) Community Atmosphere Model version 5 (CAM5).

Generally, we use horizontal resolutions of:

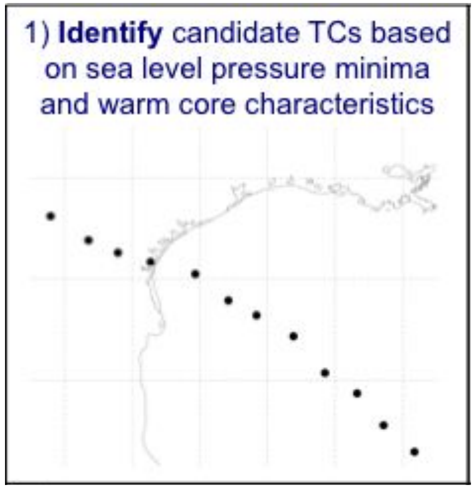
- ~100 km – *current standard*
- ~25 km – *high-resolution*
- All simulations are *atmosphere only* with specified sea surface temperatures.



Utilize a model hierarchy…



We use TempestExtremes to identify, track and analyze Tropical Cyclones (TCs)



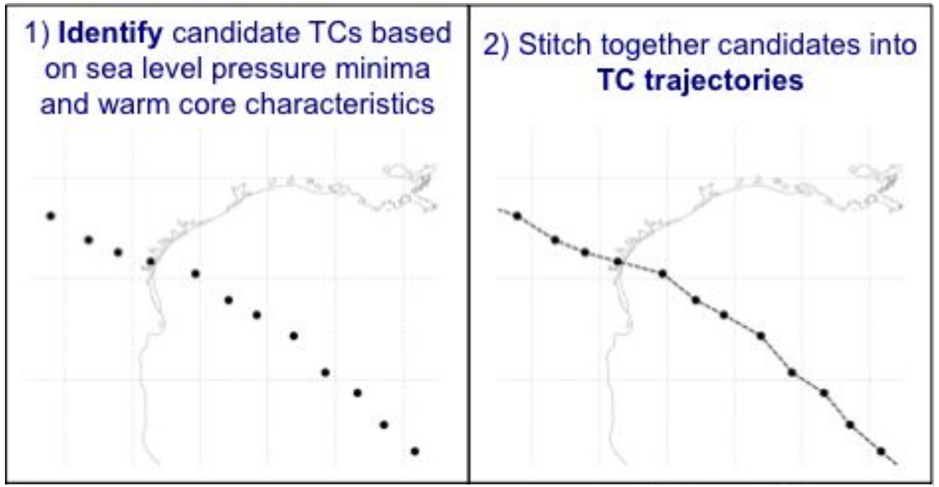
Available on Github:

https://github.com/ClimateGlobalChange/tempestextremes

[Ullrich et al. 2021, GMD]

[Stansfield et al. 2020, JHM]

We use TempestExtremes to identify, track and analyze TCs



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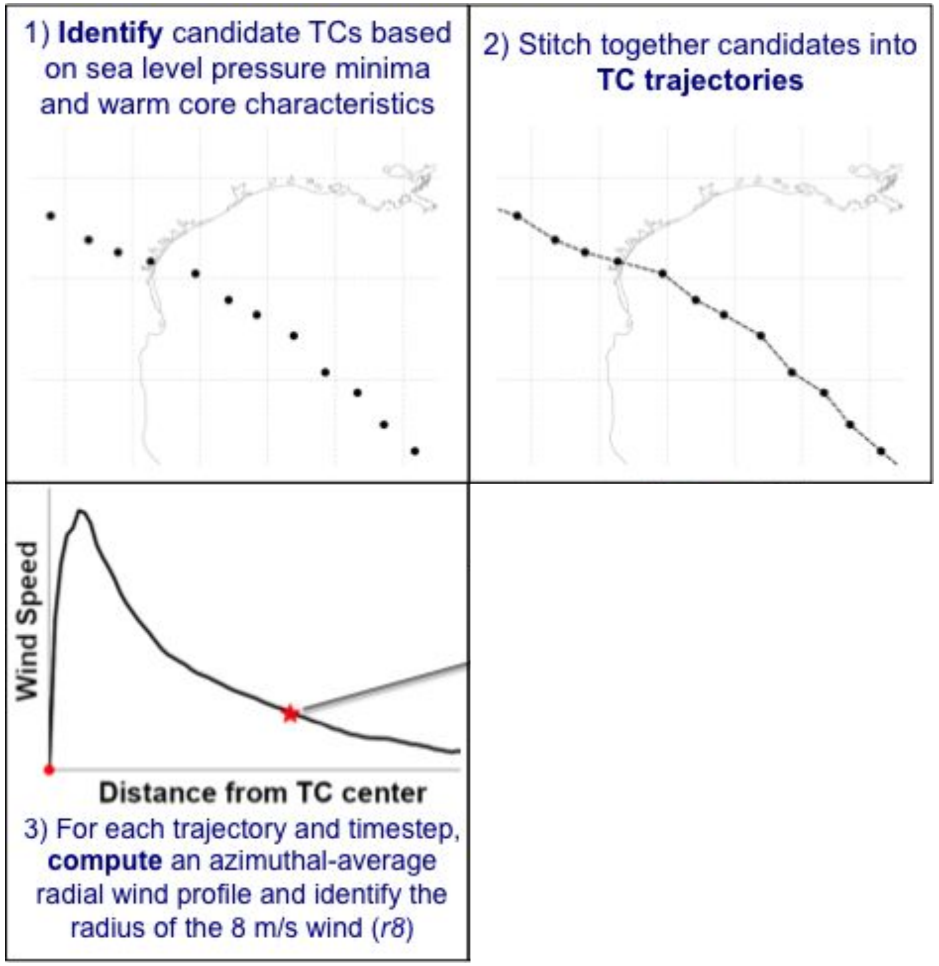

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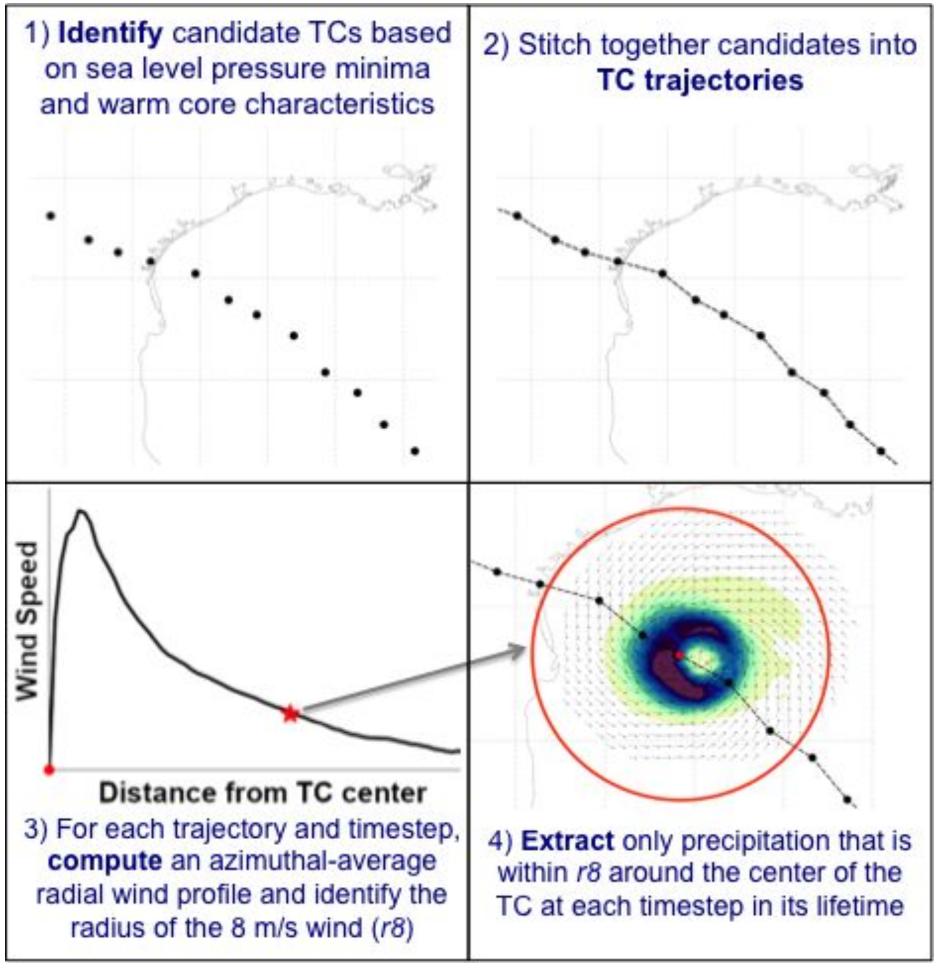

[Stansfield et al. 2020, JHM]

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Conventional Climate Simulations

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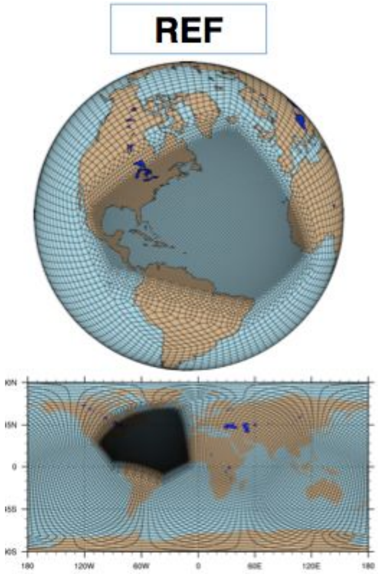
Simulation design

- National Center for Atmospheric Research's (NCAR) Community Atmosphere Model version 5 (CAM5).
- Performed with 30 vertical levels is used at the horizontal resolutions of:
    - ~100 km
    - ~25 km
- Full CAM 5 physics with Atmospheric Model Intercomparison Project (AMIP) protocols (with prescribed aerosol forcing).
- Observed ozone, CO_2, solar forcing, etc. for 1980-2015.
- RCP settings for future scenarios 2070-2100.



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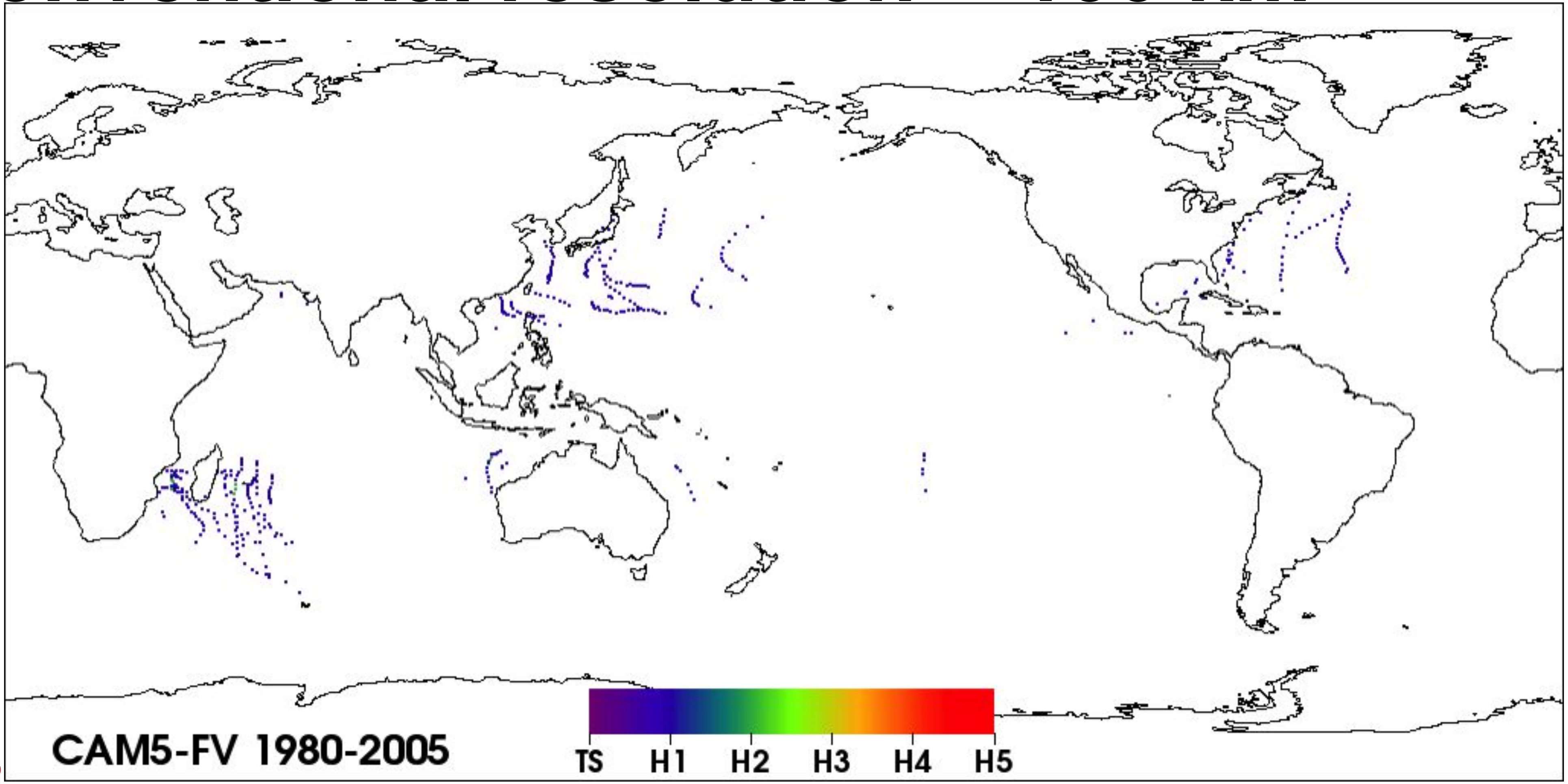
Conventional resolution - 100 km



[Wehner et al. 2014, JAMES]

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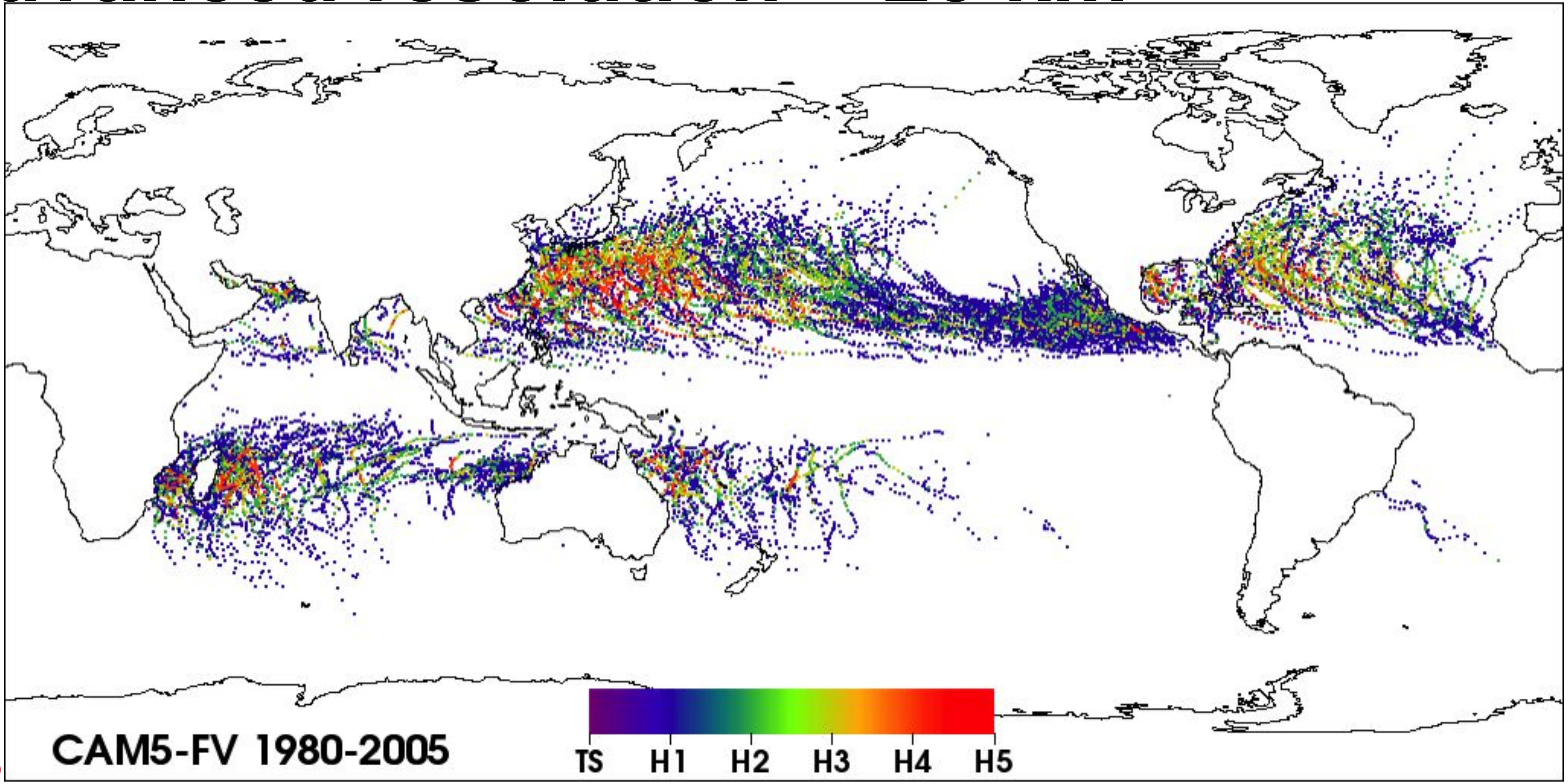
Advanced resolution - 25 km



[Wehner et al. 2014, JAMES]

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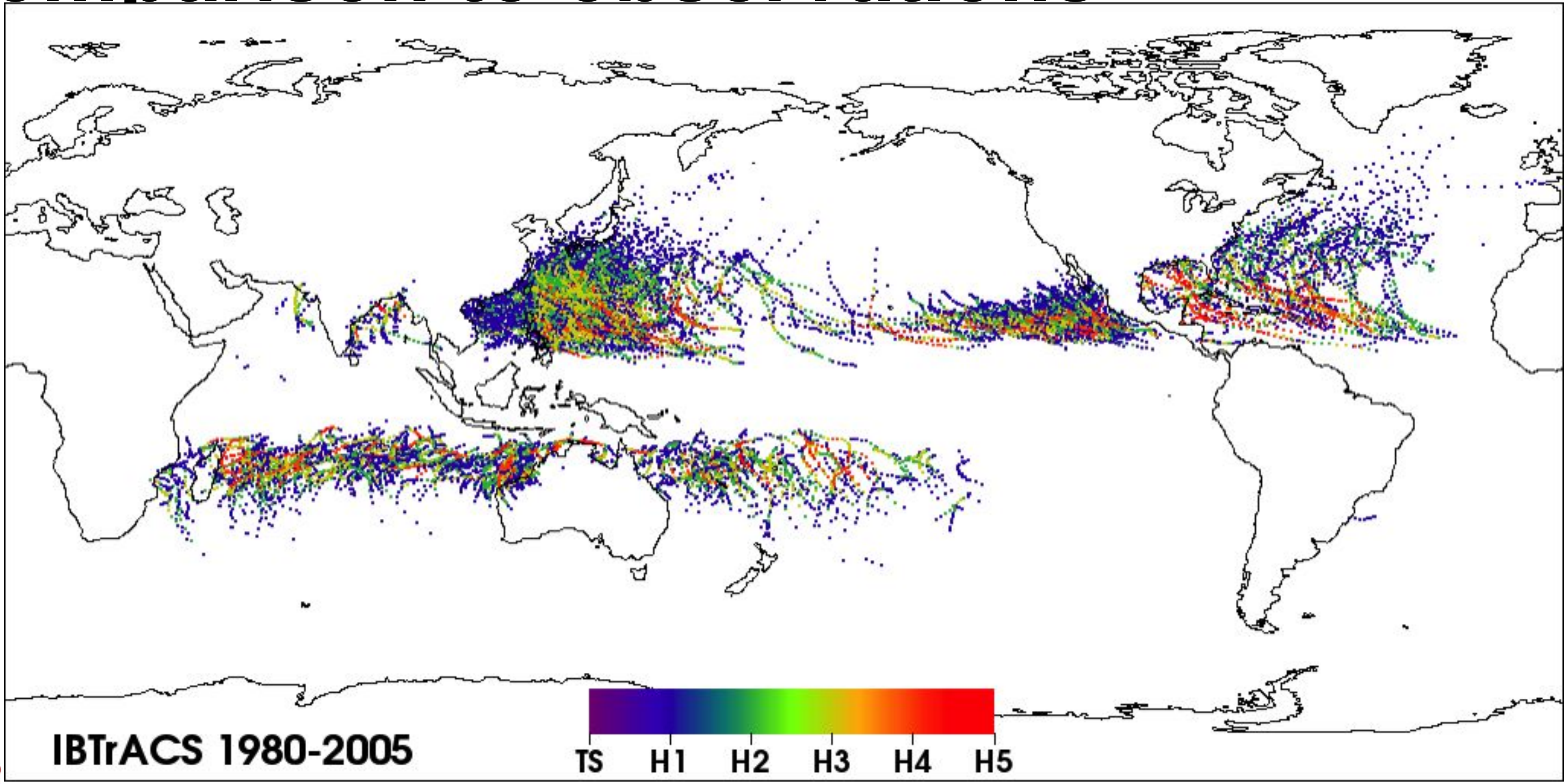
Comparison to observations



[Wehner et al. 2014, JAMES]

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Change in storm hours per year

Storm Hours

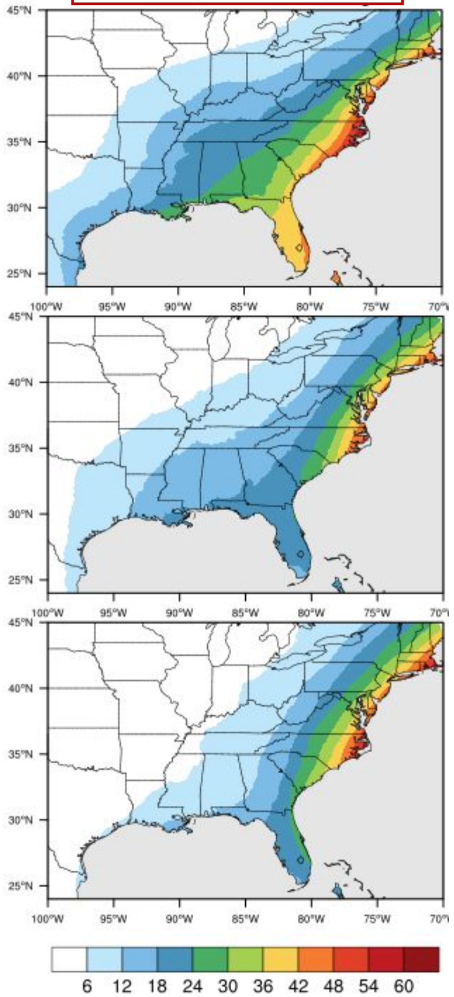
Rainfall

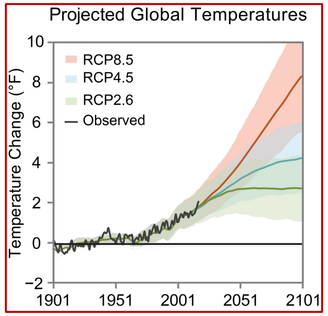
Rainfall per Hour

General decrease in storm hours over land, which is consistent with a decrease in TC frequency.

Present Day

Future Scenarios





[Stansfield et al. 2020, GRL]

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Change in storm rainfall

Projections are mixed when looking at rainfall from TCs.

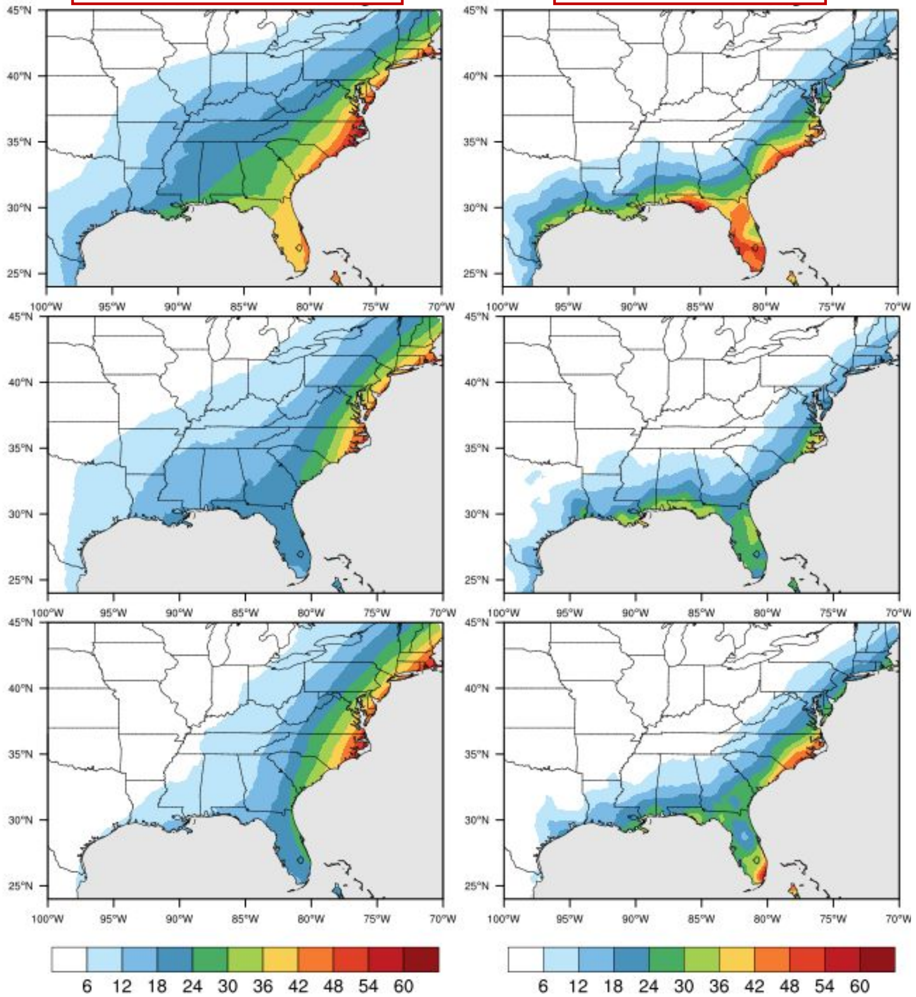
Storm Hours

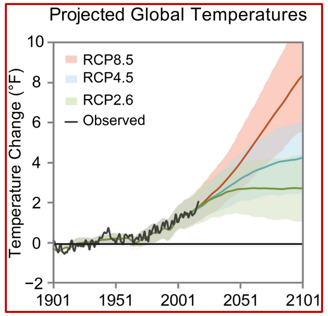
Rainfall

Rainfall per Hour

Present Day

Future Scenarios





[Stansfield et al. 2020, GRL]

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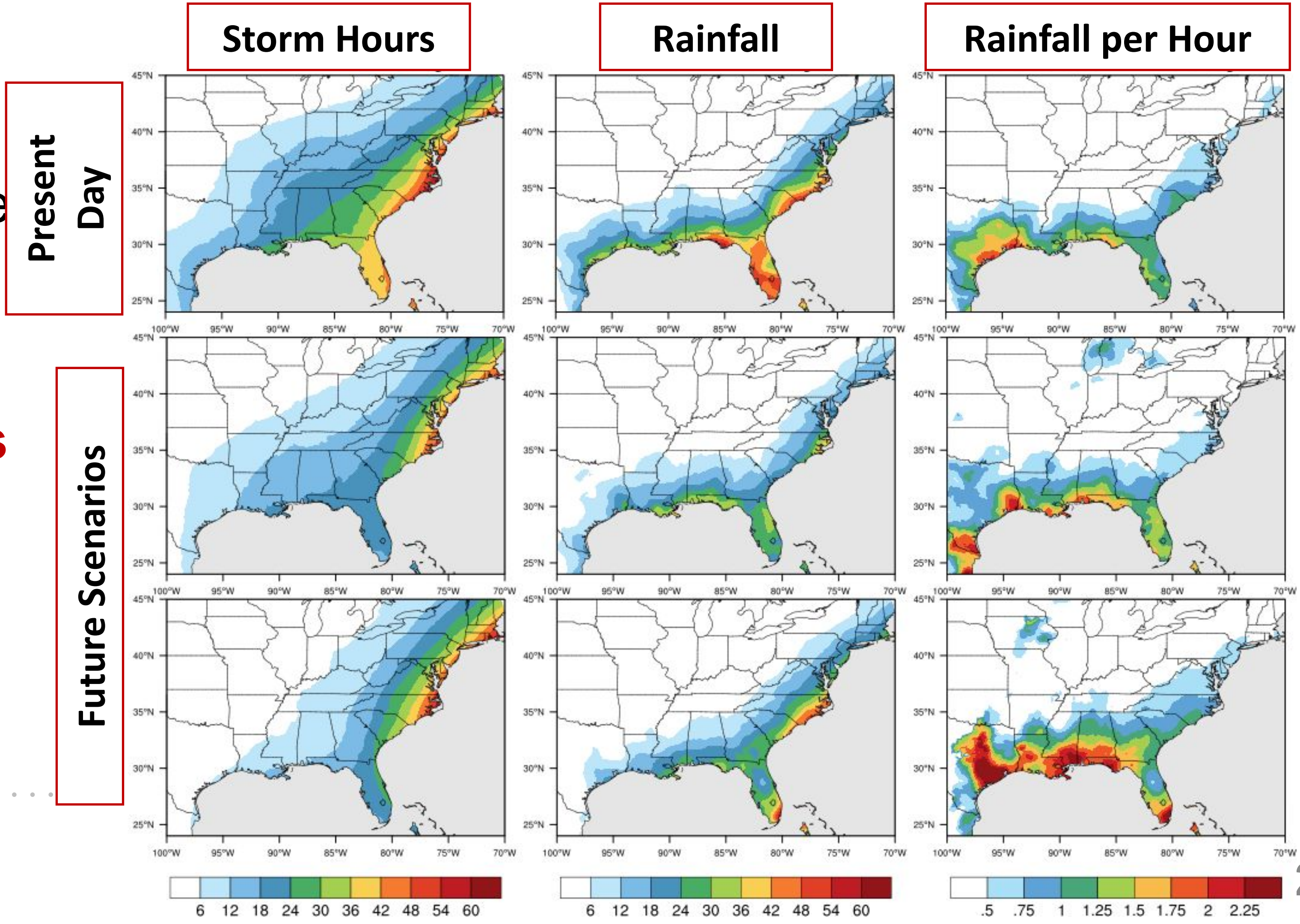
Change in storm rainfall per hour

The amount of TC-related extreme precipitation (and TC-related precipitation in general) **increases per storm**!



[Stansfield et al. 2020, GRL]

Idealized Climate Simulations

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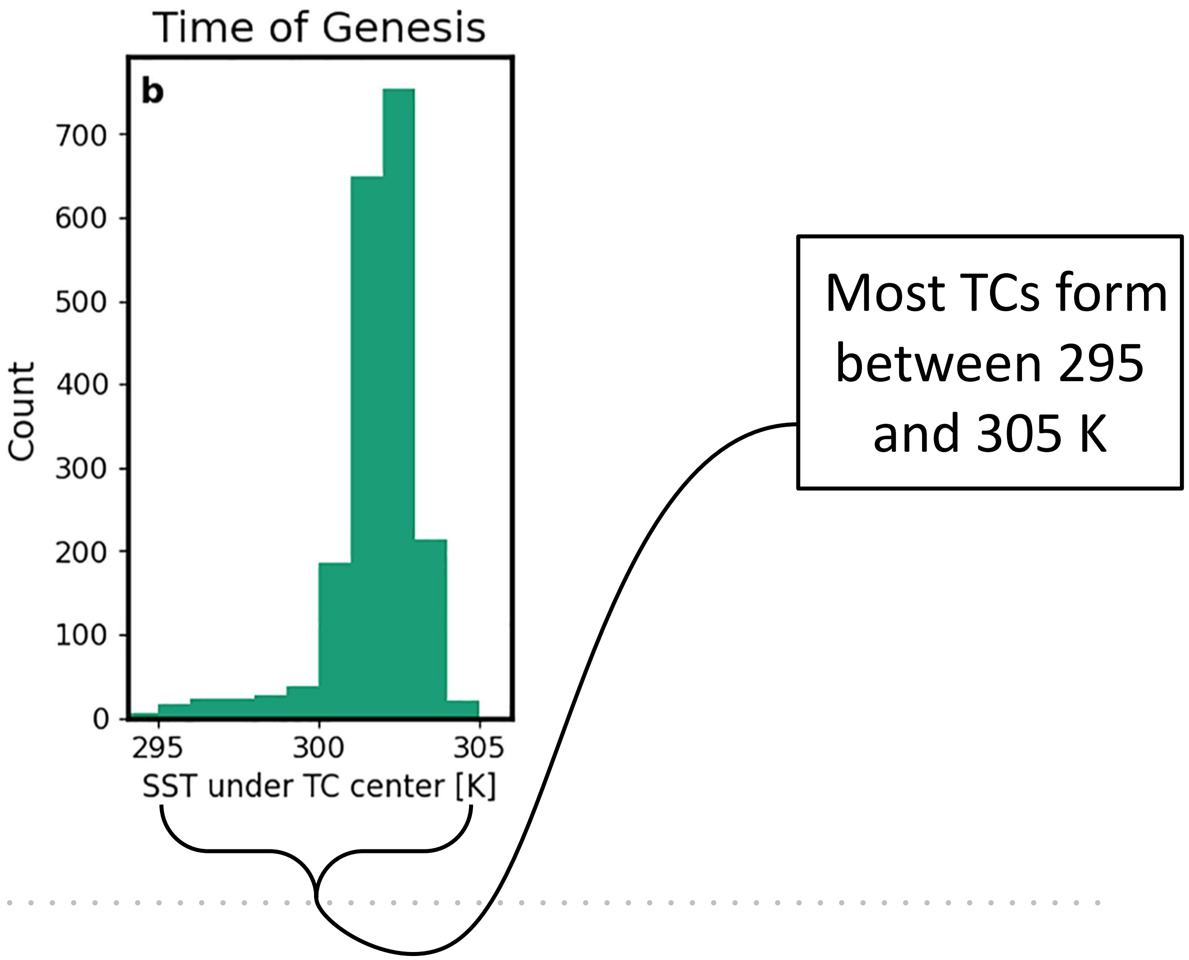
Simulation design

- NCAR's Community Atmosphere Model version 5 (CAM5).
- Run with 30 vertical levels is used at the horizontal resolutions at a resolution of ~25 km.
- Full physics in Aquaplanet mode is used, with a simplified ocean covered Earth and constant surface temperatures.
- Using RCEMIP [Wing et al. 2018] but with rotation effects.
- Diurnally varying, spatially uniform insolation.



[Stansfield and Reed 2021, JGRA]

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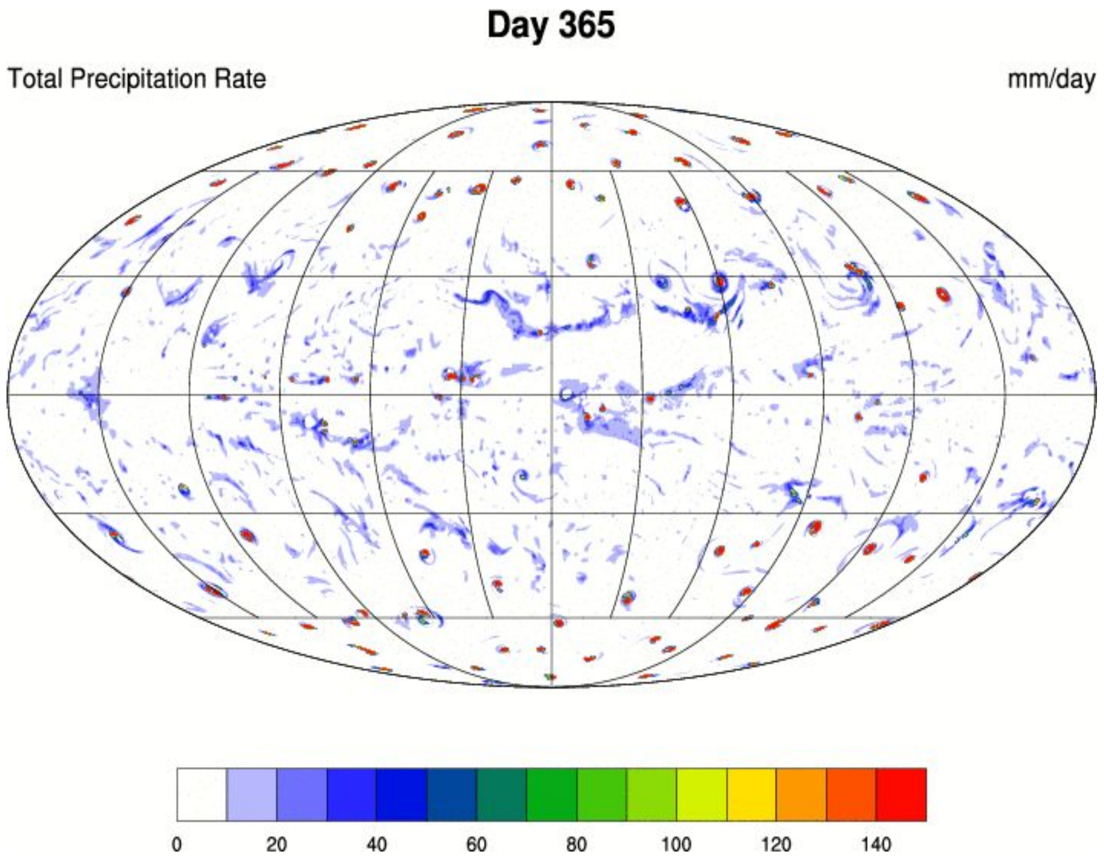

[Stansfield and Reed 2021, JGRA]

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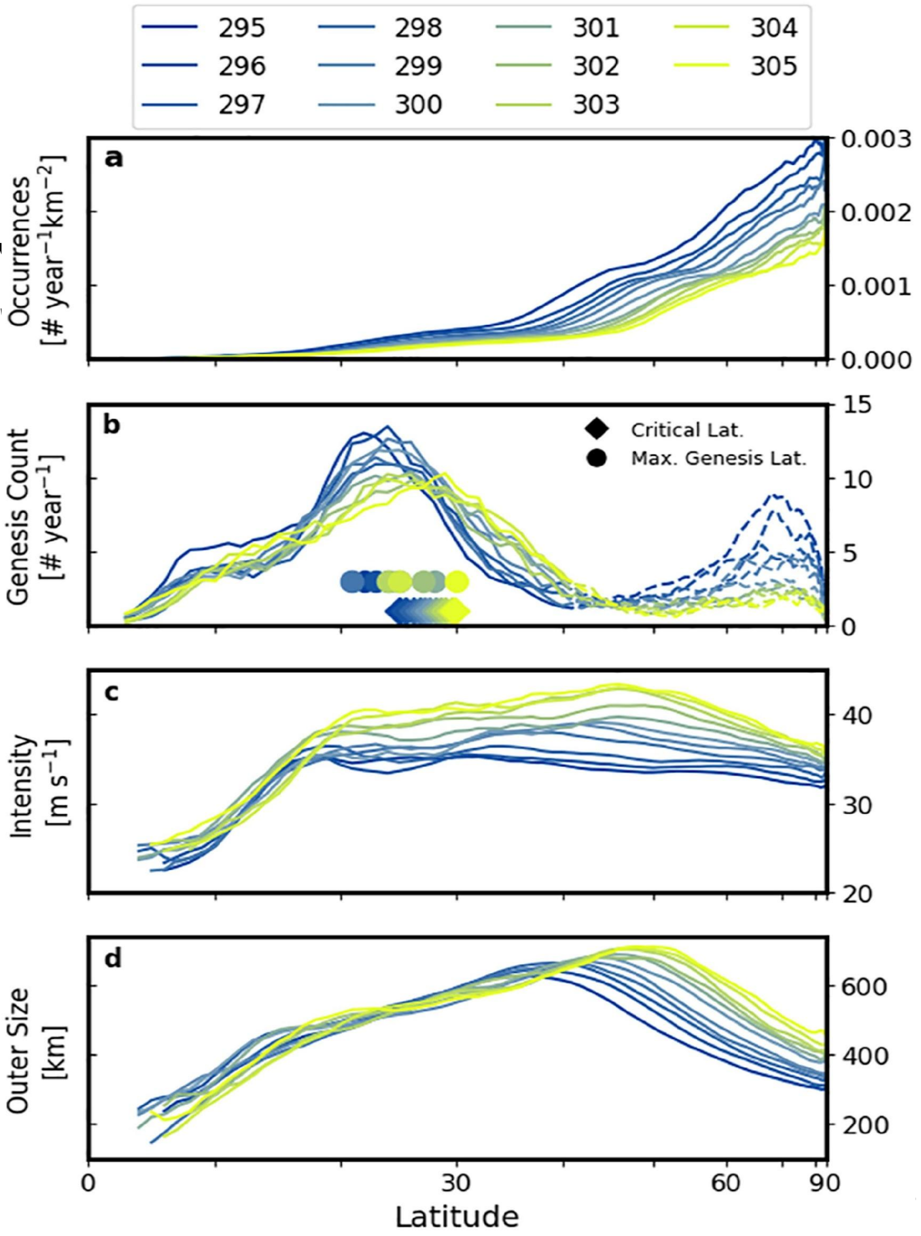
TC climatology



[Stansfield and Reed 2021, JGRA]

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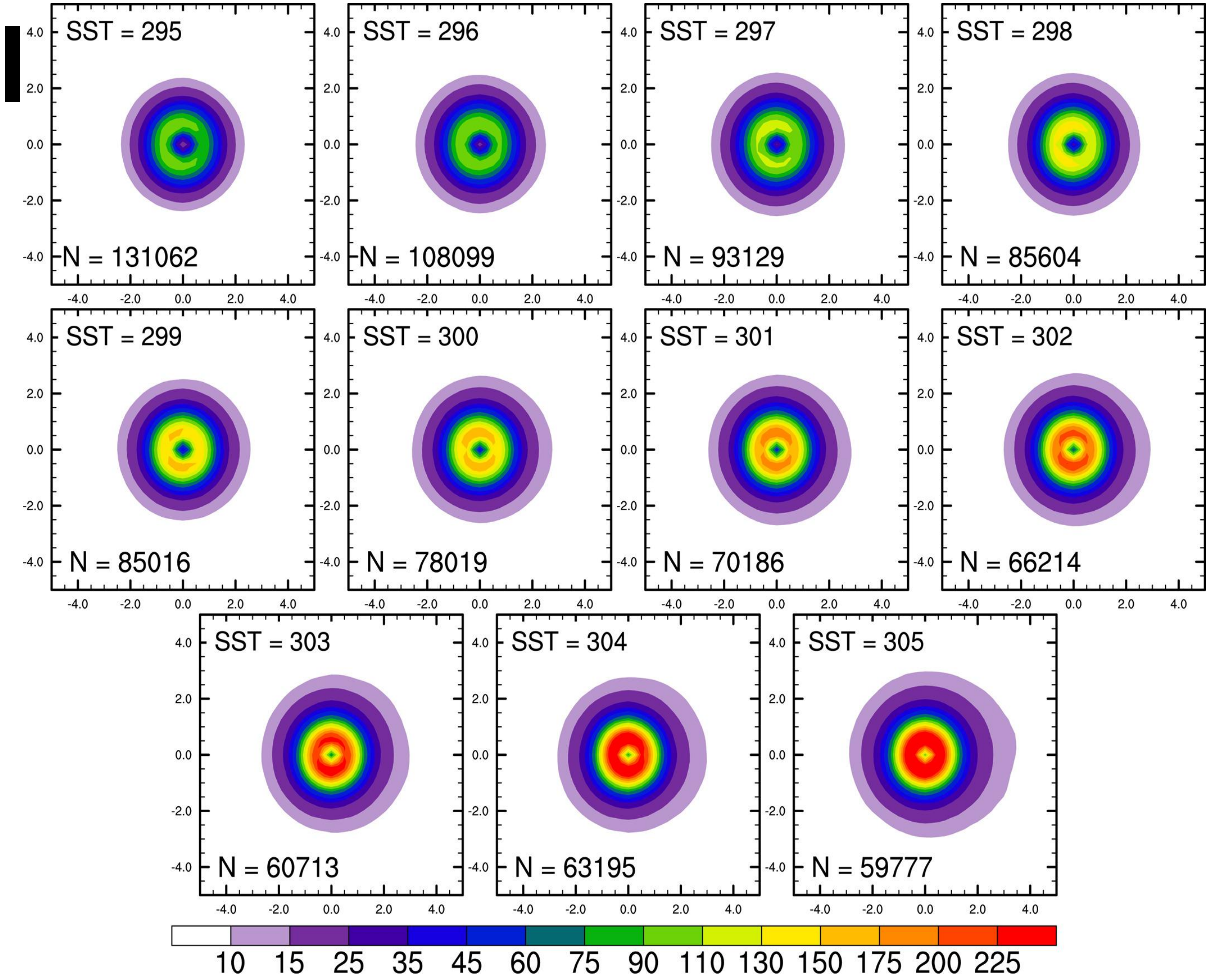
Changes in rainfall

Storm **rain rates increase** with warmer SSTS.

Precipitation field becomes larger.



[Stansfield and Reed 2021, JGRA]

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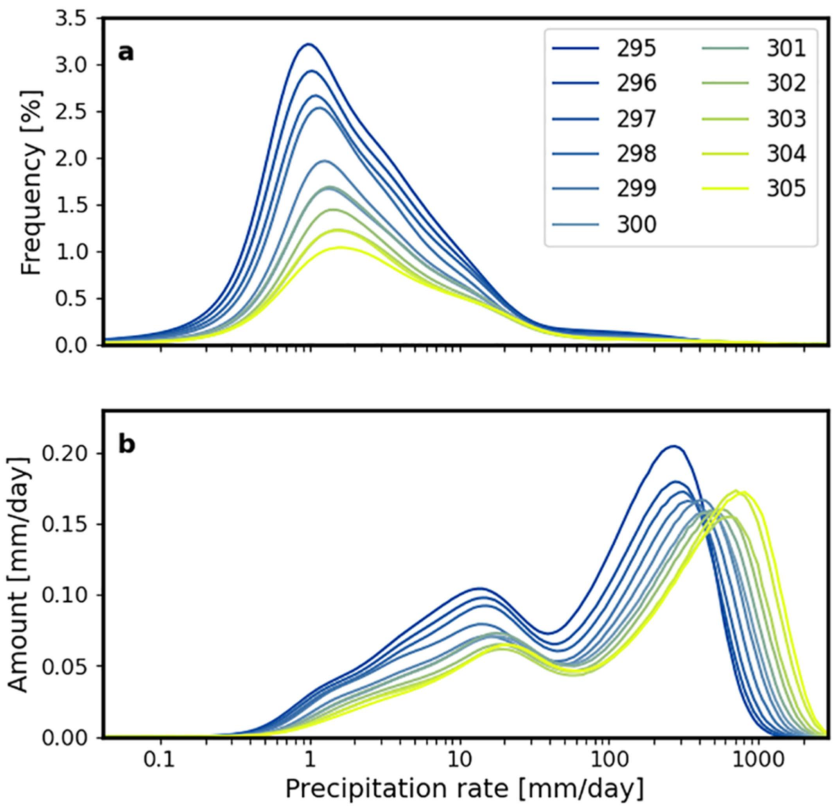
Changes in rainfall

- Robust increase in mean and extreme rainfall.
- **60-80% of increase** in rainfall is from increase SST (thermodynamics).
- **10-20% of increase** is from increasing intensity (dynamics).



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[Stansfield and Reed 2021, JGRA]

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Connecting Models to Observations

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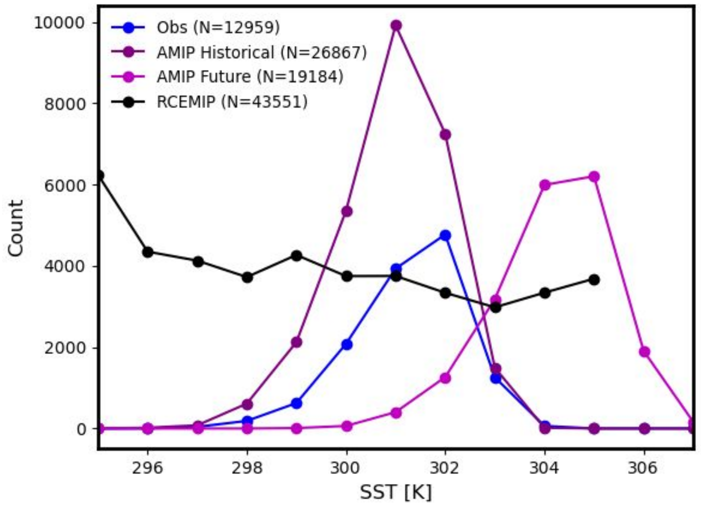
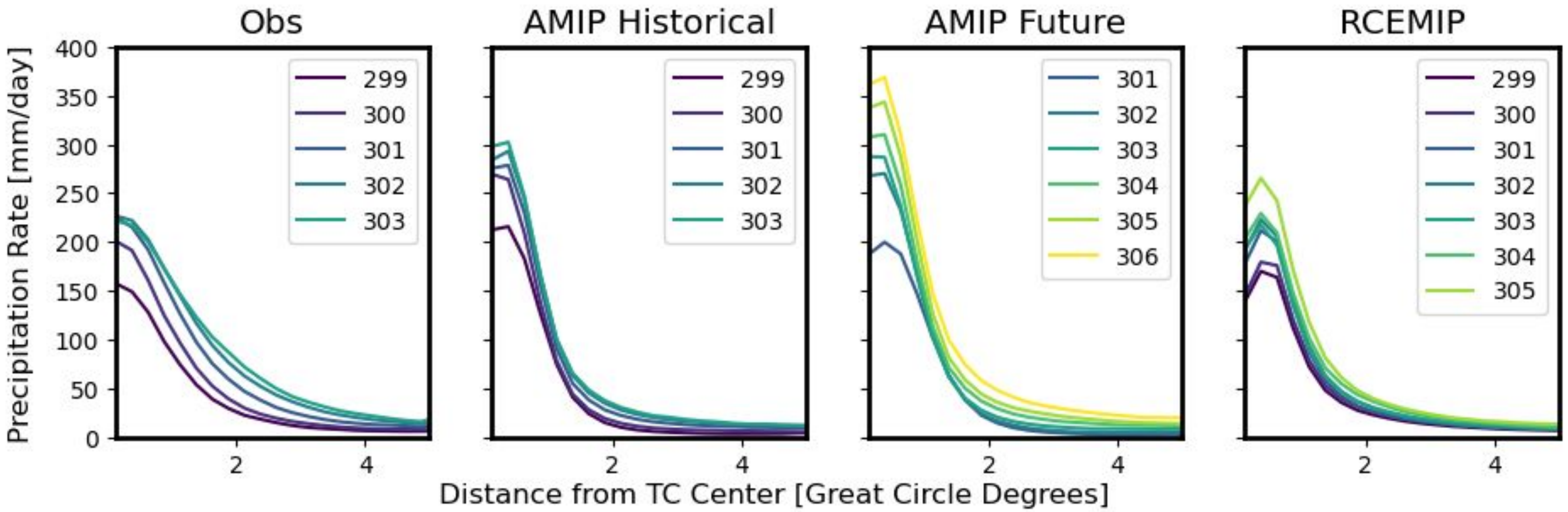
Connection to model hierarchies…





We also use idealize configurations **to better understand precipitation changes** with consistent methodologies.

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[Stansfield and Reed 2023, npj]

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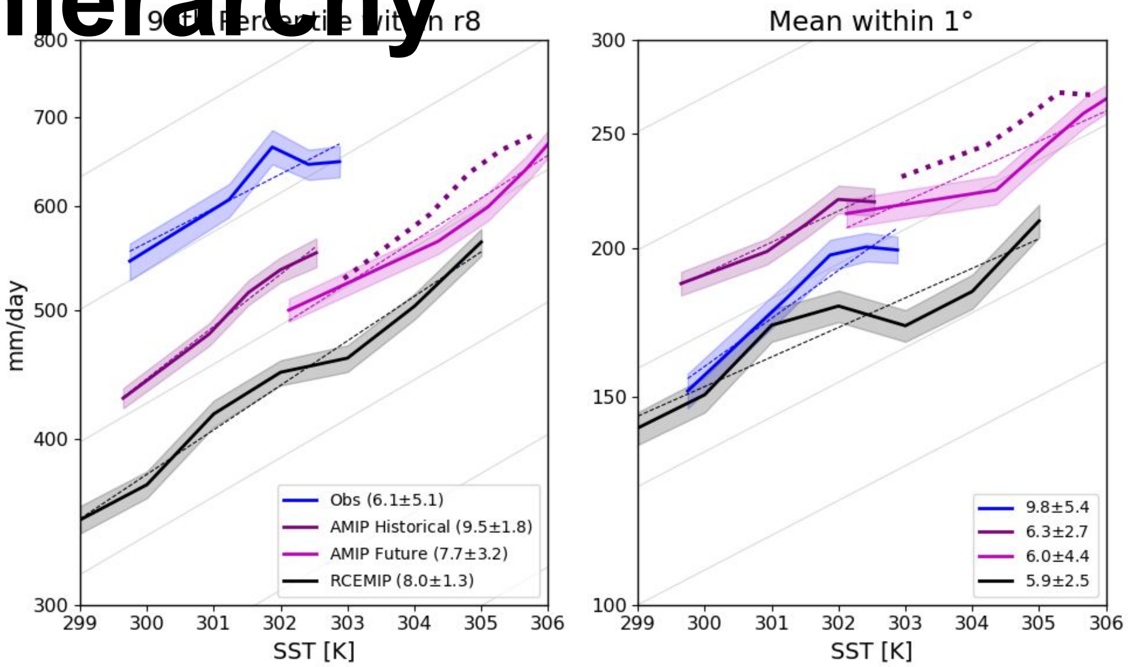
Change in precipitation with warming across the hierarchy



The apparent scaling rates - **6-10% per K** - depending on precip metric.
The climate scaling rate (for AMIP) is smaller at **5% per K.**

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Summary

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Summary

- In idealized and conventional simulations: As surface temperature warms both mean precipitation and extreme precipitation increase in TCs (though storm counts decrease); the **magnitude of extreme precipitation can increase at larger rates** – we are working to better quantify these changes.
- In conventional simulations: Ensemble simulations **start to shed light on regional changes in TC hazards.**
- Hindcast attribution simulations (*not shown*): Demonstrate that human-induced climate change increased the extreme precipitation rates and accumulations in TCs by **5-11%.**

[Reed et al. 2022, Nature Comm.]

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Questions?

To understand changes in extreme precipitation in the future, we need to understand the changes in the events responsible for extreme precipitation.

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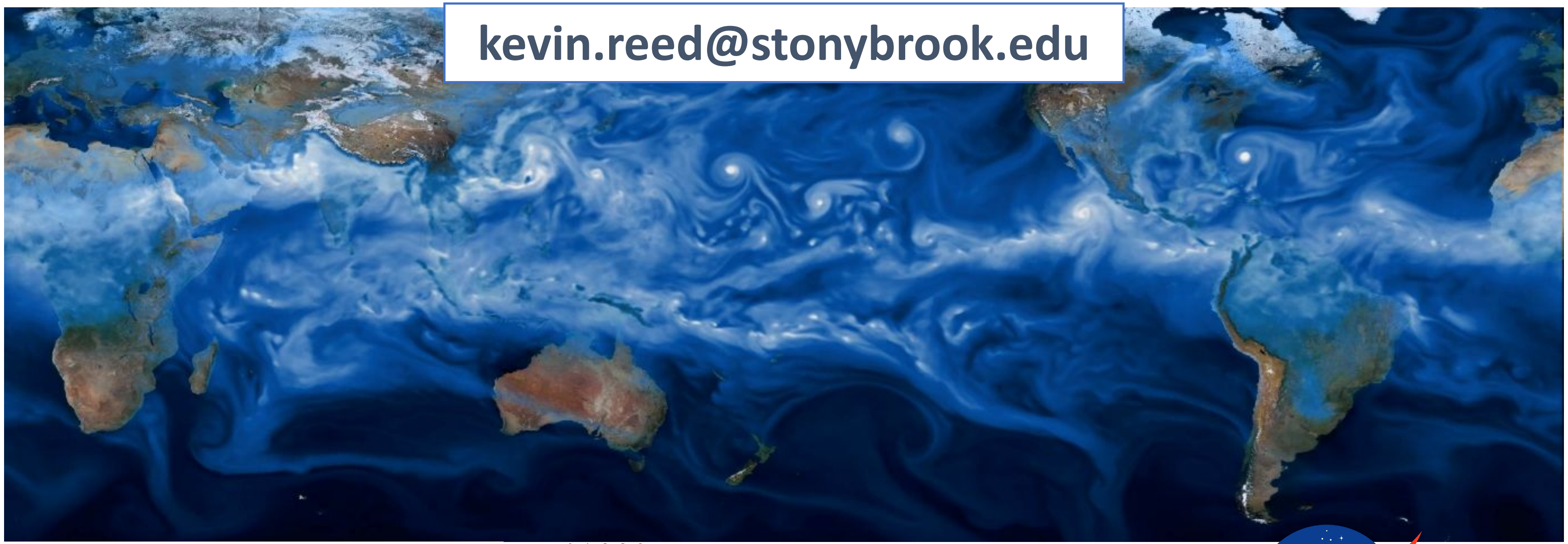

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HYPERFACETS
A Framework for Improving Analysis and Modeling of Earth System and Intersectoral Dynamics at Regional Scales
NASA
NSF
U.S. DEPARTMENT OF ENERGY | Office of Science

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Extra Slides

Climate Change Event Attribution

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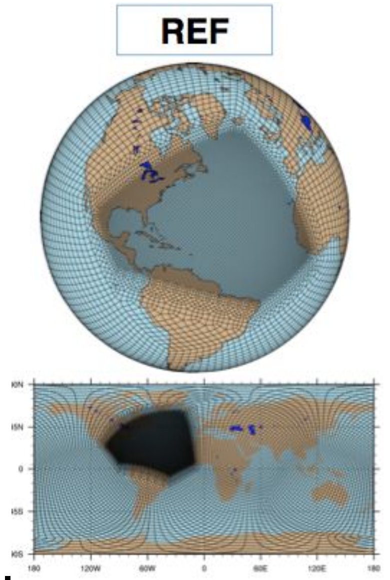
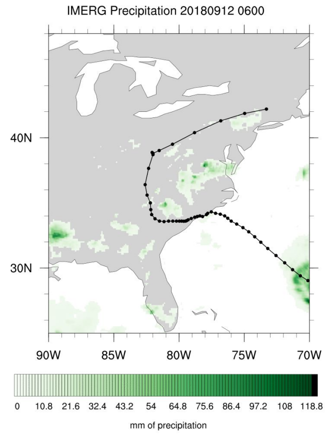
A Storyline Approach

- National Center for Atmospheric Research's (NCAR) Community Atmosphere Model version 5 (**CAM5**).
- Variable resolution is used over region of interest with 30 vertical levels is used at the local horizontal resolution of: Δx = ~100 > ~25 km
- **Actual:** Similar to full physics AMIP simulation, but initialized at specific times in advance of hurricane landfall. Initial conditions taken from operational **NOAA GFS**.
- **Counterfactual:** Temperature, specific humidity, and SST from the observed initial conditions are modified to remove effects of climate change (using CAM5 C20C+ or the CESM Large Ensemble).
- Prescribed observed SSTs, ozone,CO_2, solar forcing.





Courtesy of **Erica Bower**

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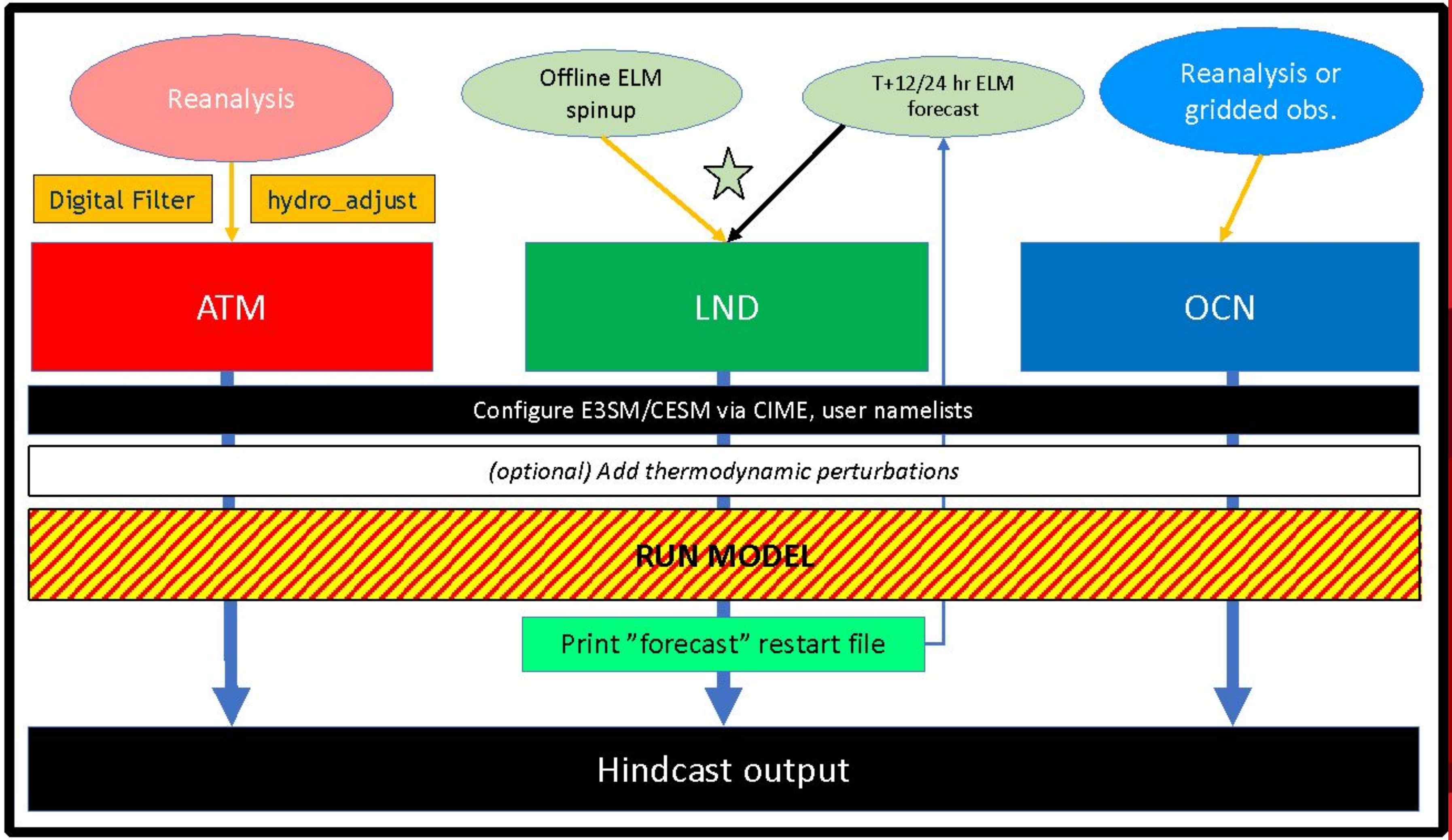
Betacast Implementation

Available on Github:

https://github.com/zarzycki/betacast



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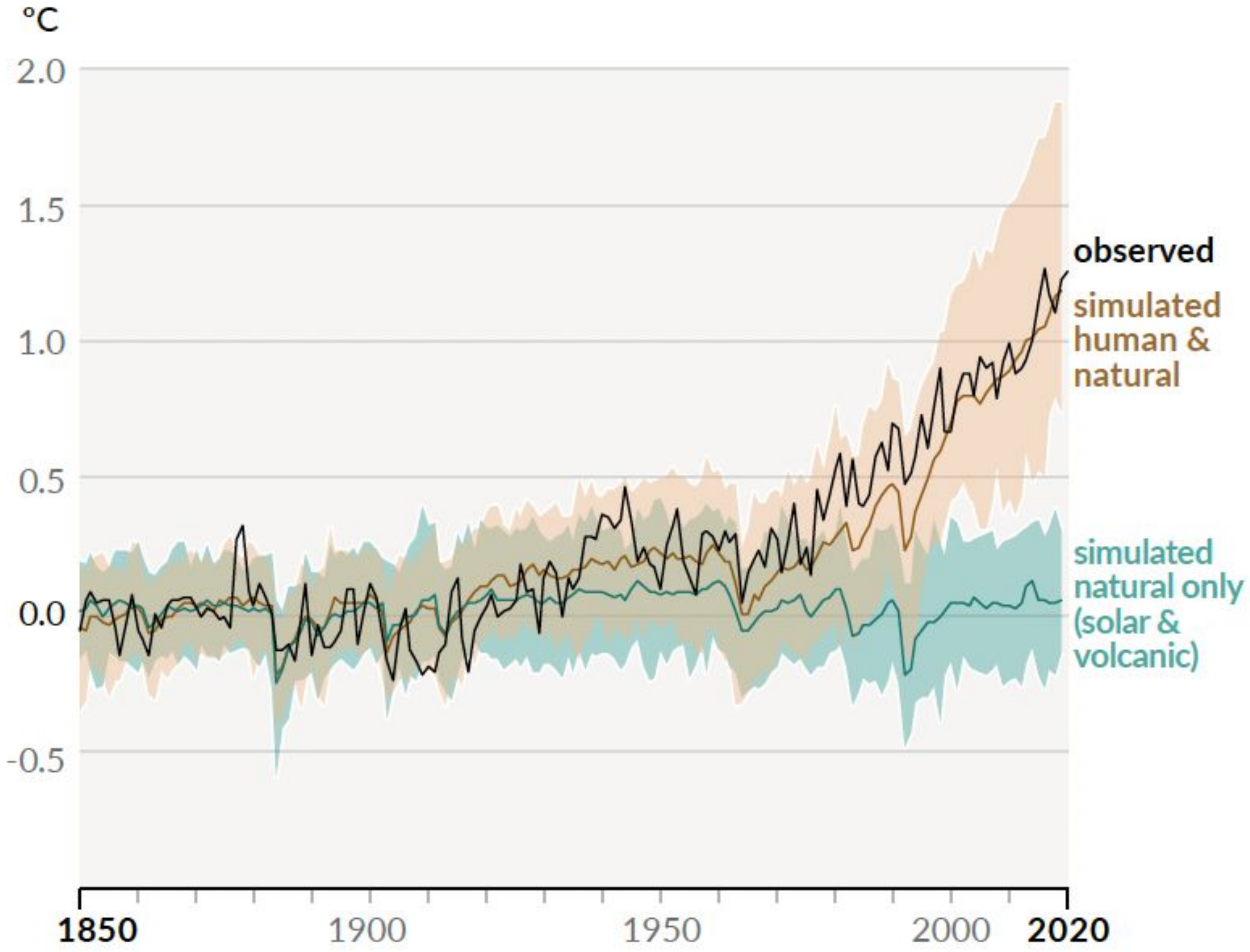
Building a Counterfactual

- Comparing 2020 to 1850
- Without human increases in GHG



[IPCC AR6 WGI]

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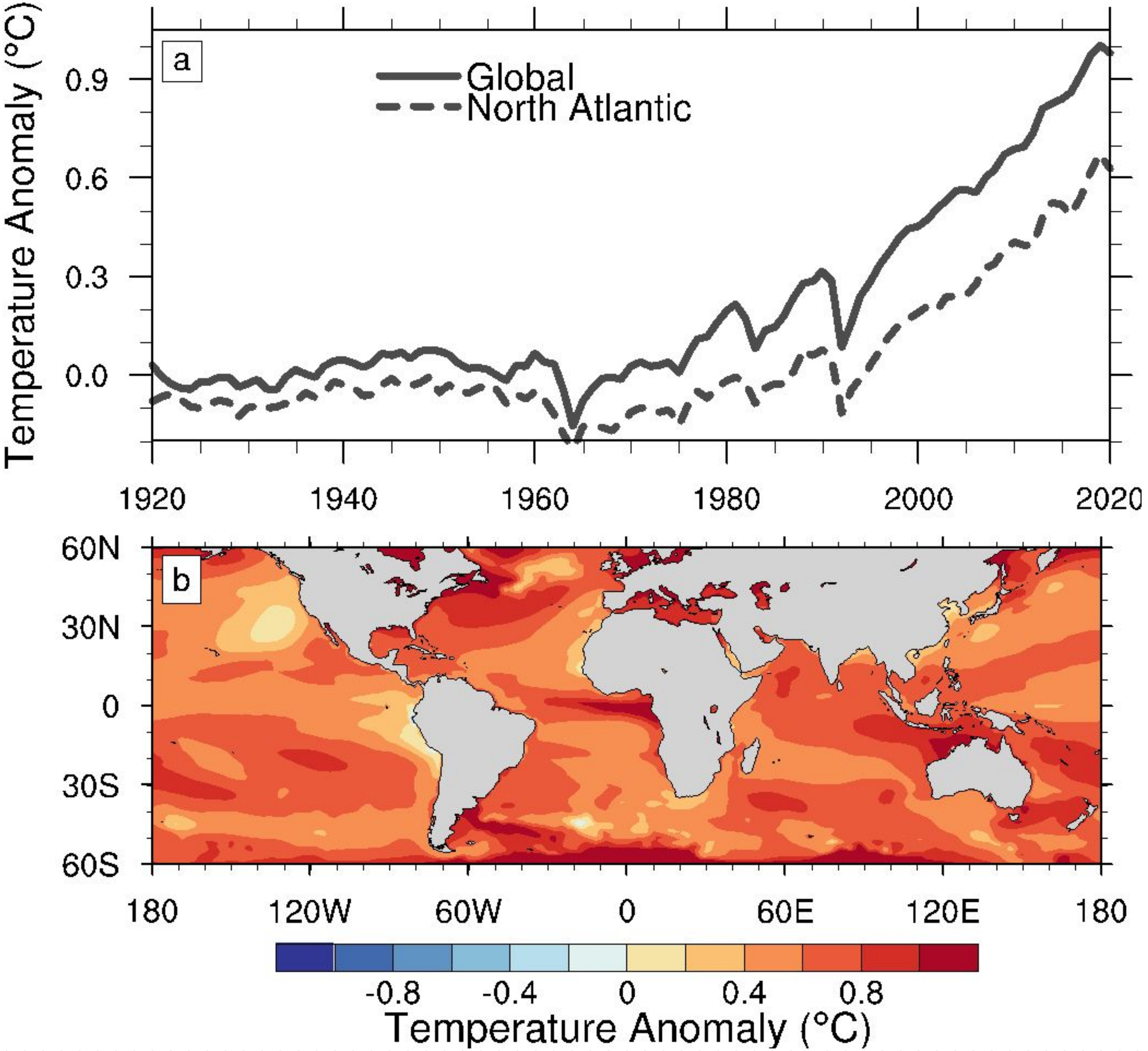
Building a Counterfactual

- Use the 40-member CESM Large Ensemble
- Update T, Q and PS for initial and boundary conditions.



[Reed et al. 2022, Nature Comm.]

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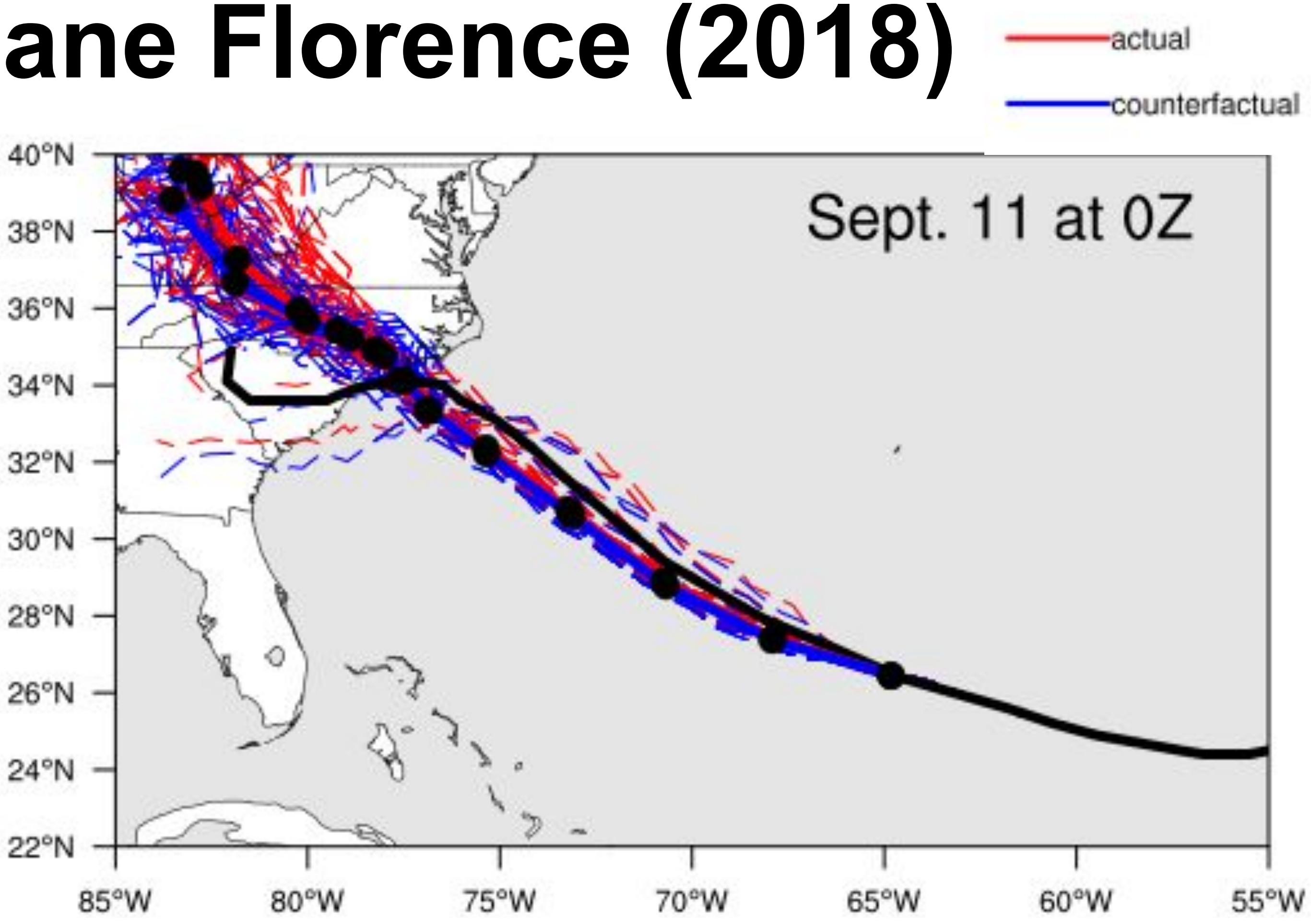
Prototype: Hurricane Florence (2018)

- CAM5 reproduces Hurricane Florence track and landfall location in both landfalls.
- Suggests that the model is **fit-for-purpose**.



[Reed et al. 2020, Science Advances]

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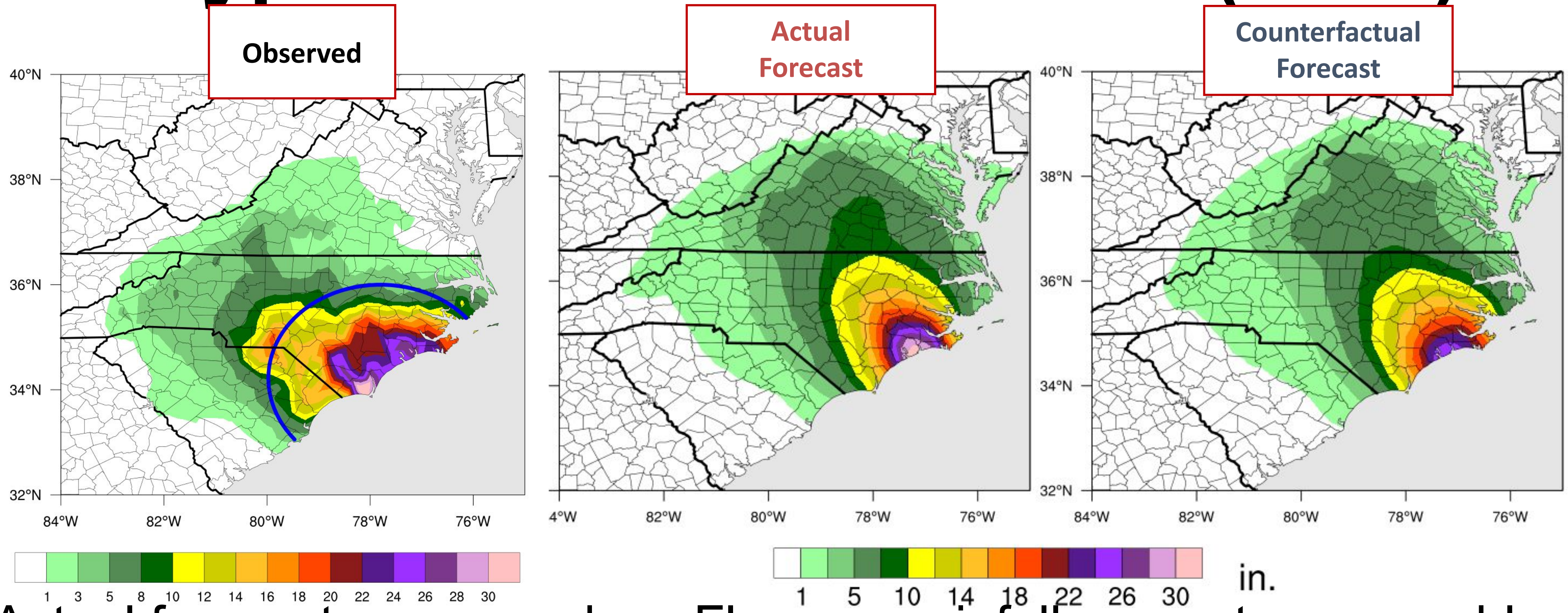

- Actual forecast can reproduce Florence rainfall amounts reasonably well.
- Rainfall is **increased by 5%** due to observed warming.

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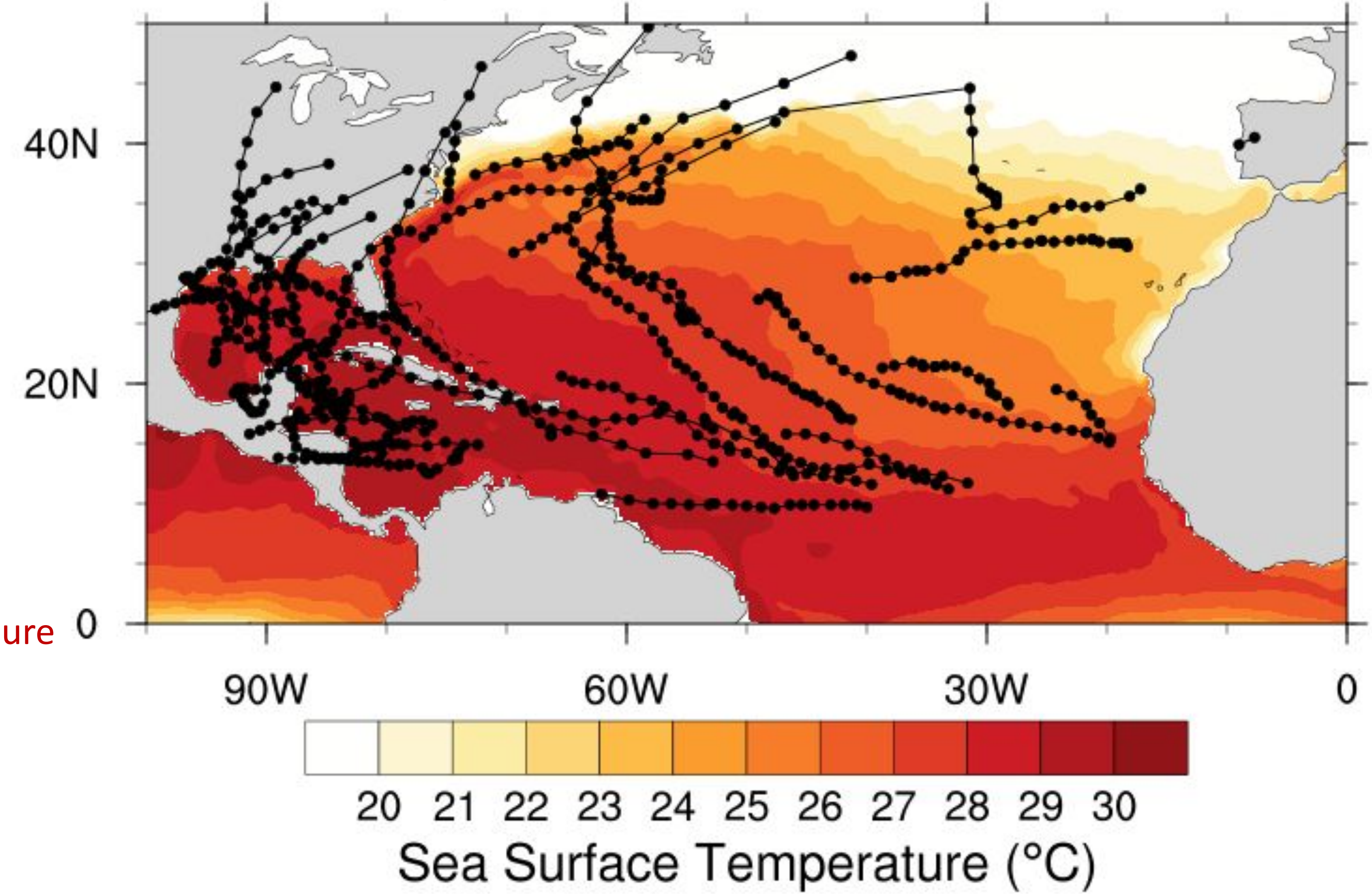
2020 Hurricane Season



[Reed et al. 2022, Nature Comm.]

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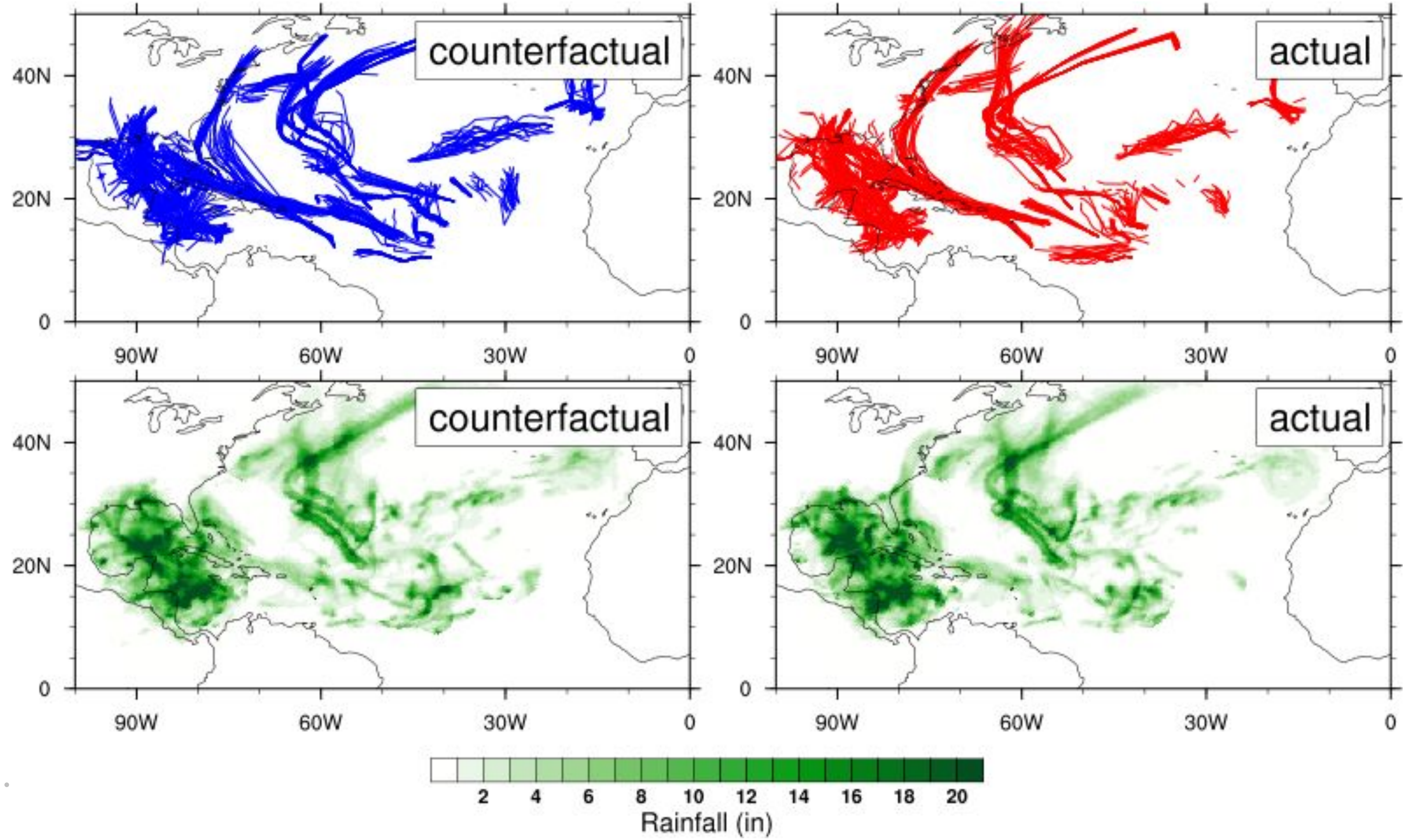
2020 Hurricane Season

Initialize hindcasts every 3 days starting June 1, 2020



[Reed et al. 2022, Nature Comm.]

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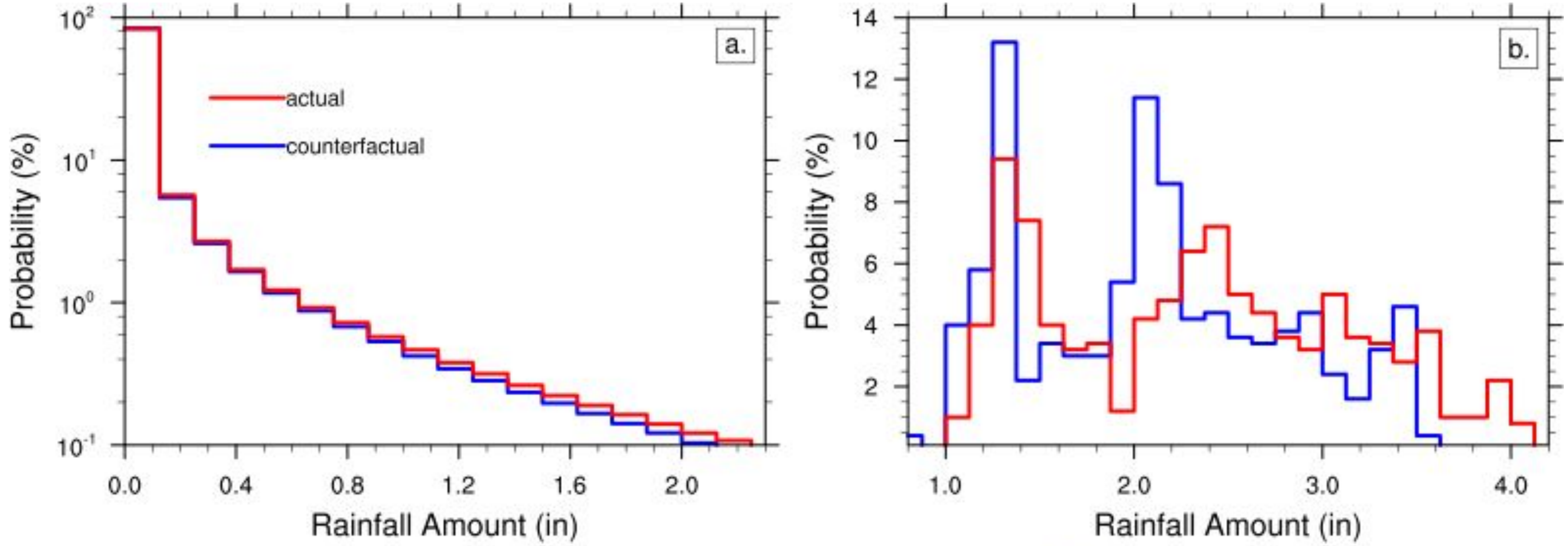
3-Hourly Rainfall Intensity

3-hr Rainfall Amounts

99 percentile
3-hr Rainfall Amounts



- A shift of **~10 ± 5%** in most extreme rainfall rates.

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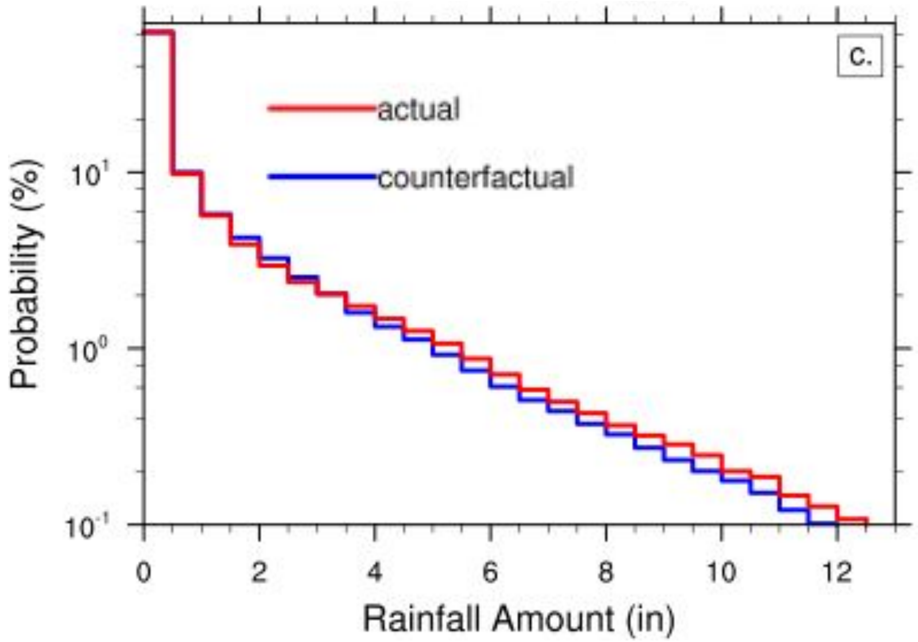
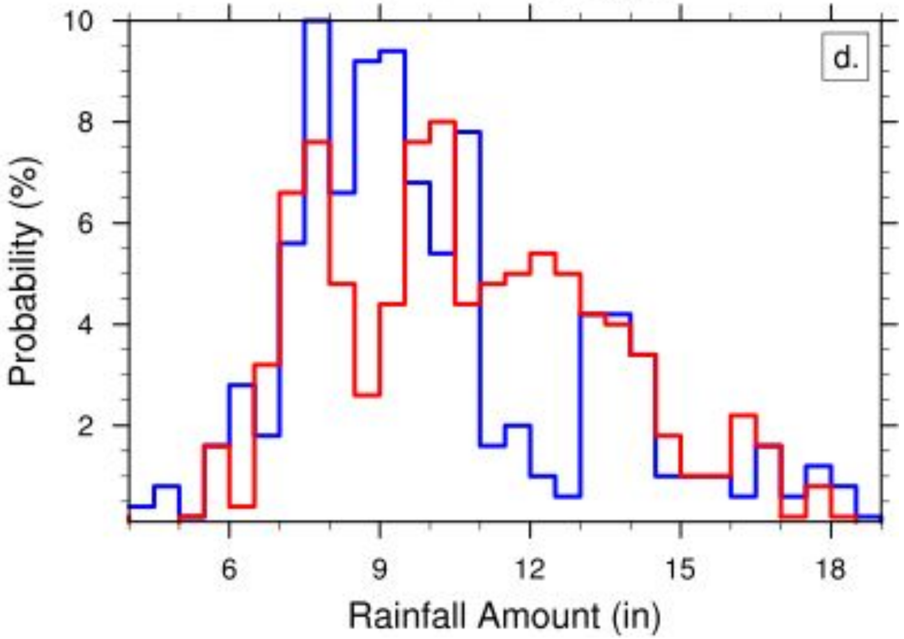
[Reed et al. 2022, Nature Comm.]

Accumulated Rainfall

Accumulated Rainfall



99 percentile
Accumulated Rainfall



- A shift of **~5 ± 5%** in extreme rainfall accumulation.

[Reed et al. 2022, Nature Comm.]