Simulating and Visualizing Hurricane-Ocean Interactions using High-Resolution CESM

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Tropical cyclones (e.g. hurricanes) pose serious risks

Photo: Pool/Reuters News

Photo: Mike Groll

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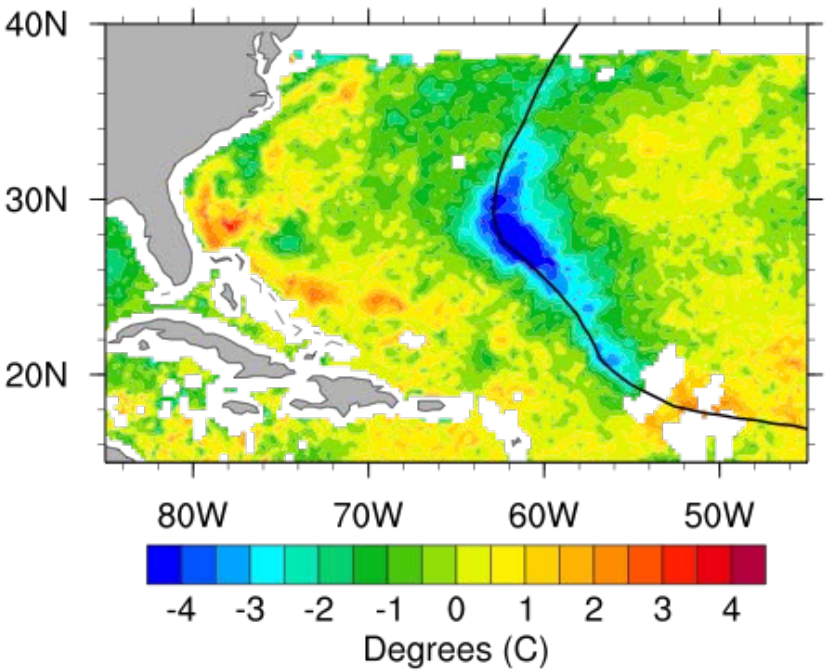
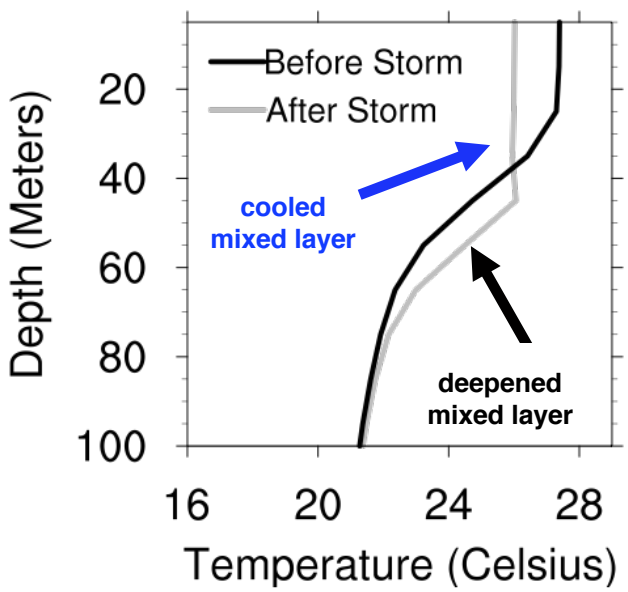
Slide contributed by Hui Li, UIUC

Effects of Tropical Cyclones (TC)s on the Upper Ocean

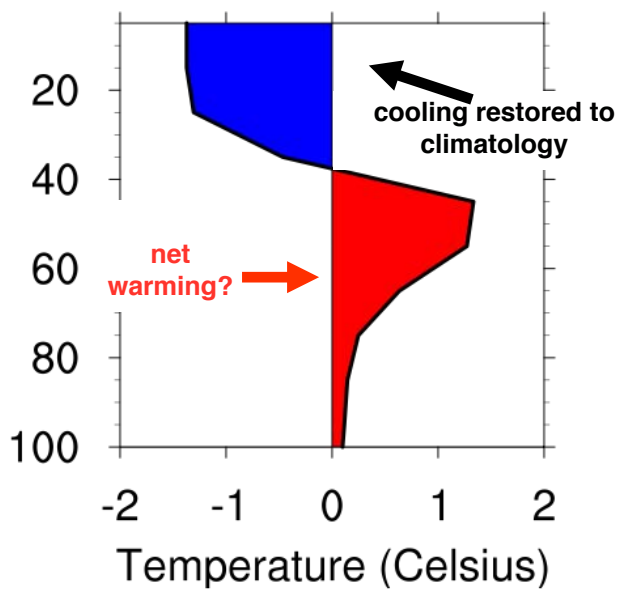
- Leave pronounced cold wakes behind storms (60-85% of cooling due to entrainment through base of mixed layer)
- Mix warm surface water down into the thermocline
- Result is redistribution of ocean heat content (OHC) in region affected by storms
  - potential climate impacts on ocean/atmosphere heat transport and energy budgets

Hurricane Gert, 1999





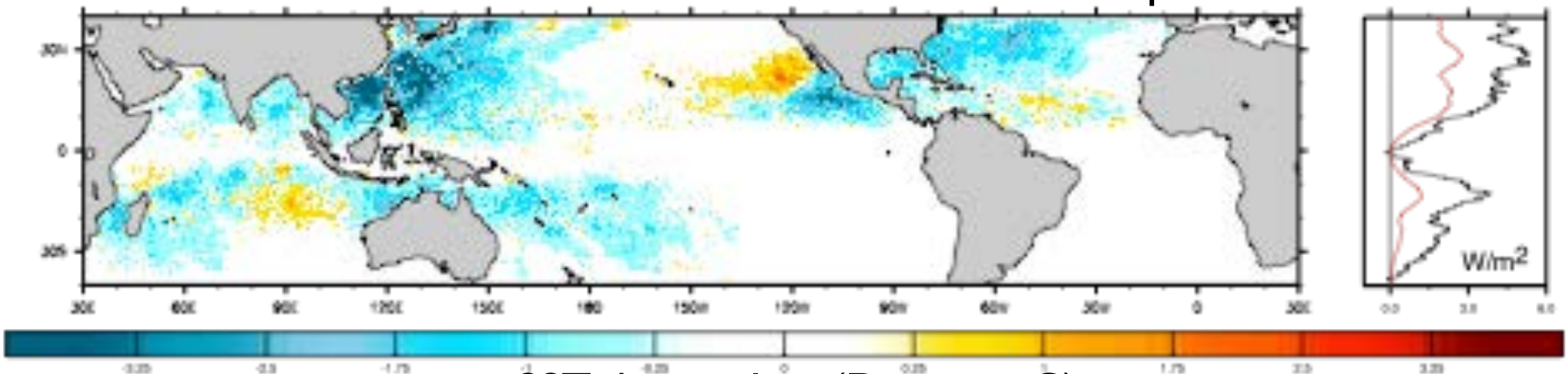
post-storm minus pre-storm



Does TC mixing matter on the global scale?

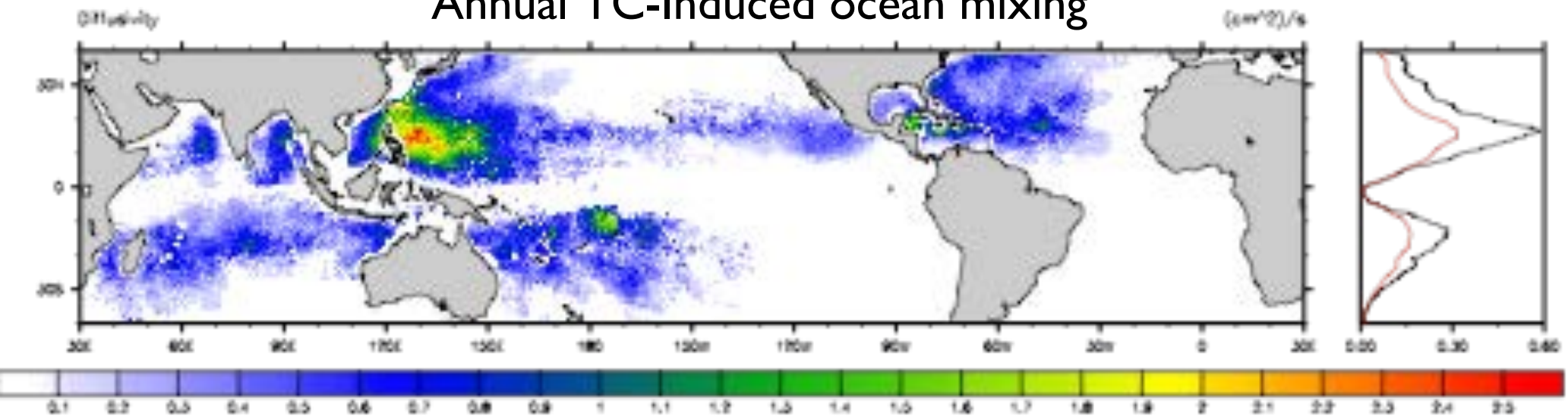
Sriver, 2013

Annual TC-Induced anomalous surface temperature



SST Anomalies (Degrees C)

Annual TC-Induced ocean mixing

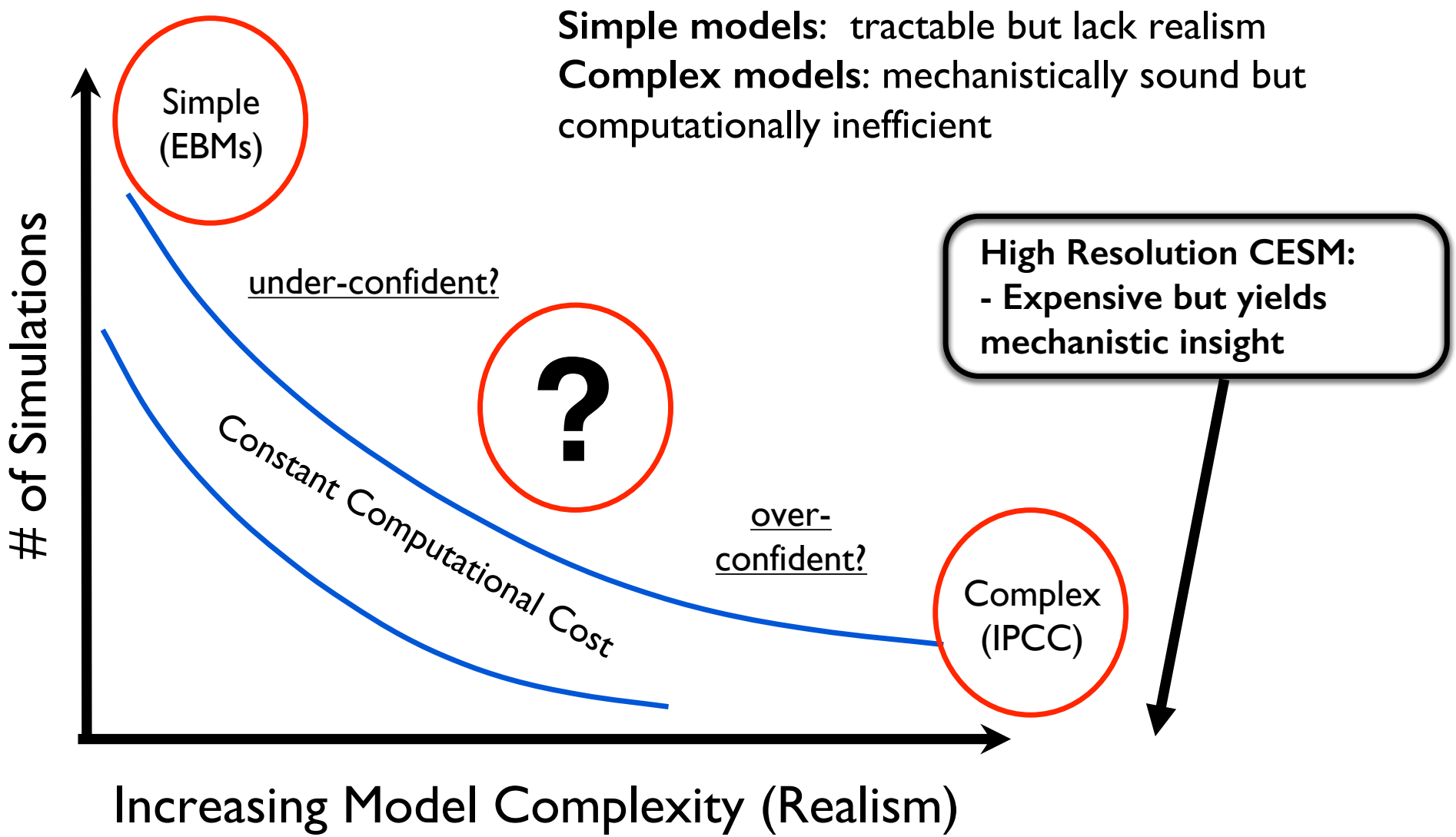


Diffusivity (cm^2/s)

There is strong observational evidence for TC-climate interactions that can influence ocean heat/energy budgets. Can we model these processes?

Sriver et al., 2008

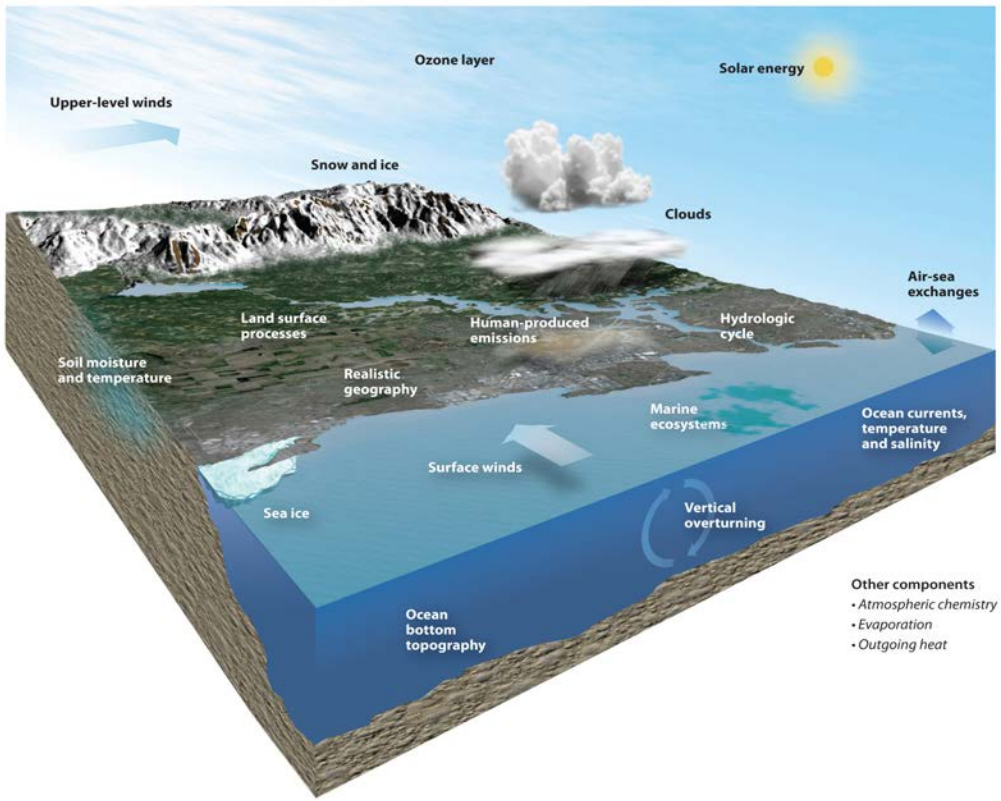
Tradeoff between model realism and computational tractability



Tropical Cyclone-Climate Connections using the High-Resolution CESM

We use high-resolution configurations of the Community Earth System Model (CESM) to investigate the relationship between tropical cyclones, the upper ocean, and Earth's climate.

What is CESM?



Numerical, deterministic global climate model that simulates the physics, dynamics, and interactions between:

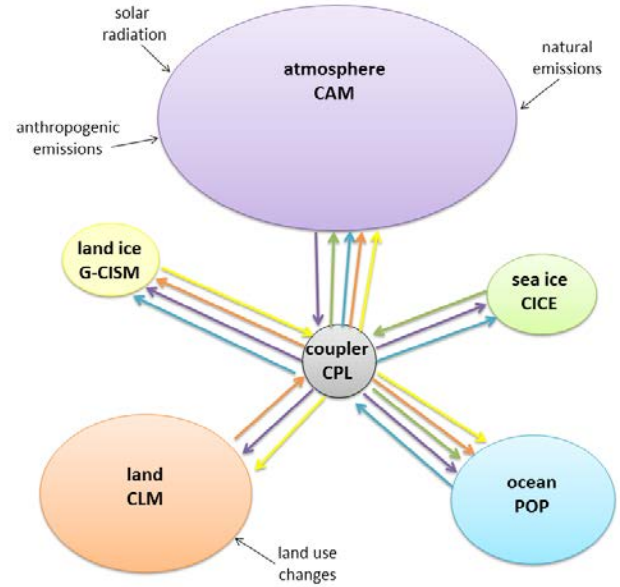
- **atmosphere (optional chemistry)**
- **ocean (optional chemistry)**
- **land surface**
- **glaciers**
- **polar land ice (almost!)**

www.cesm.ucar.edu

High Res CESM Experiment

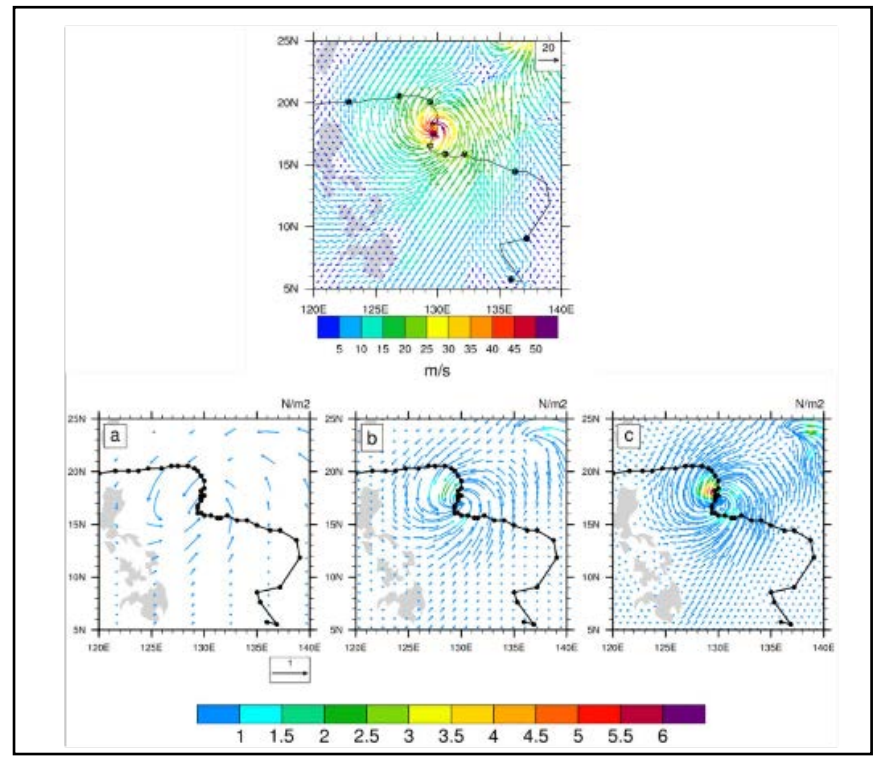
3 multi-decadal pre-industrial control simulations using the 25 km atmosphere:

- **Uncoupled with specified ocean**
- **Partially coupled with ocean-atmosphere heat fluxes but no dynamics**
- **Fully-Coupled with 1 degree ocean general circulation model with full dynamics**



Both resolution and coupling are important for exploring TC-climate connections

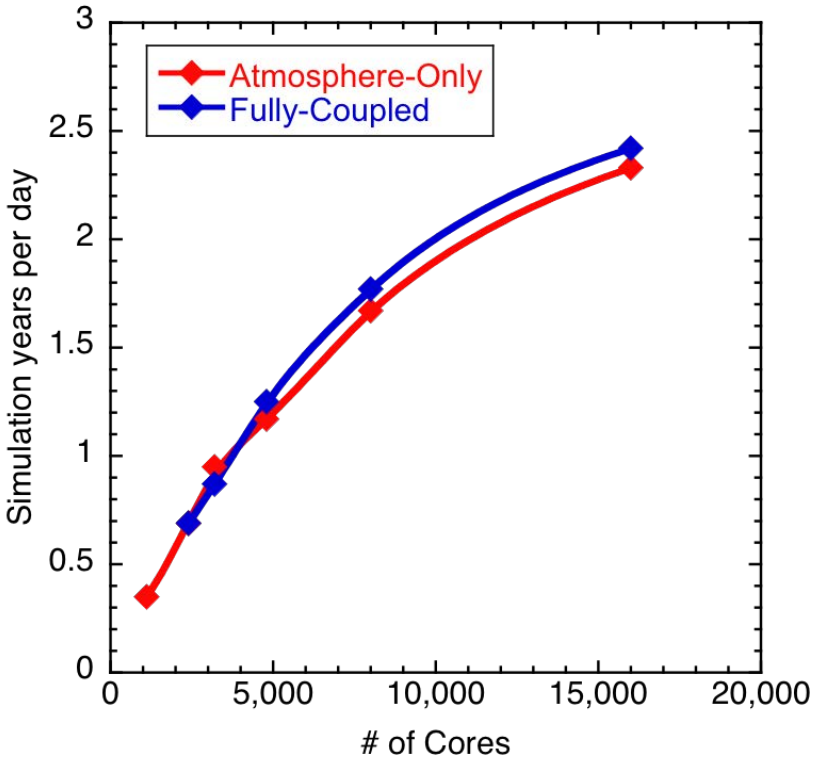
- Very computationally intensive
- Requires petascale HPC resources like Blue Waters



Li and Sriver (2017)

Why Blue Waters?

- CESM scales well on Blue Waters to ~15,000 cores
- High-resolution versions of the model were recently ported and tested on Blue Waters — Don Wuebbles (UIUC) and Susan Bates (NCAR)



Main Challenges

- Updating surface exchange parameterizations for high-wind conditions
- Saving/Archiving Output (sub-daily atmosphere ocean fields)
- Developing a reliable tracking algorithm for TCs in the model

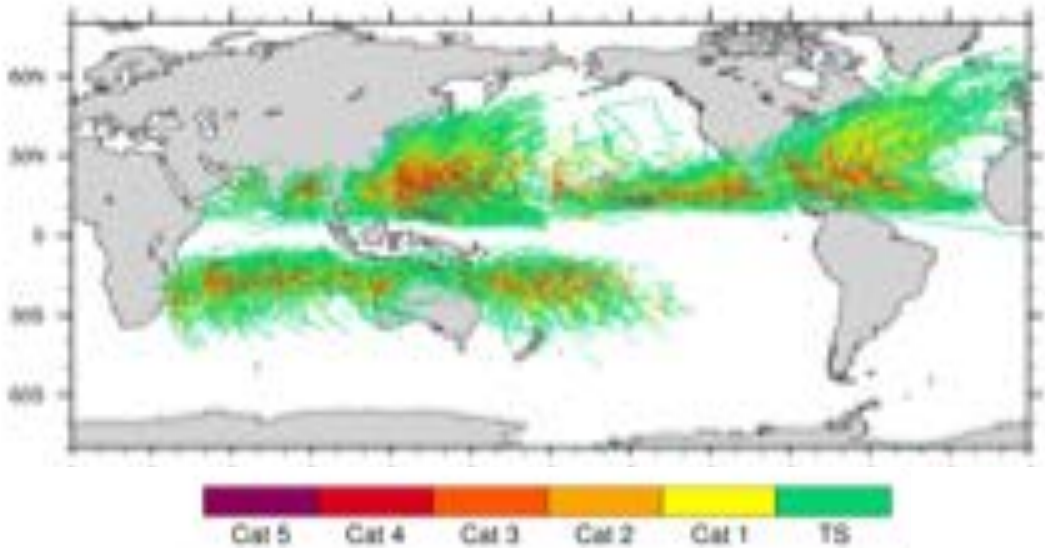
Current Project Status:

~ 100 total simulation years (30 years each + short spinup)

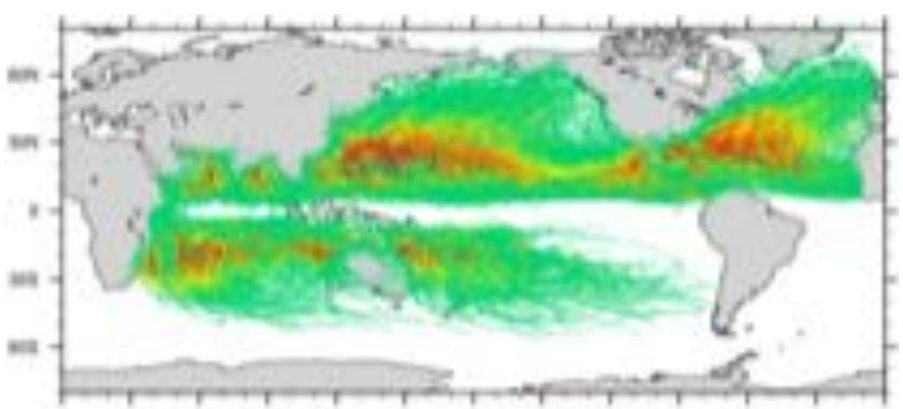
~ 100-150 TB of model output

Some Preliminary Results

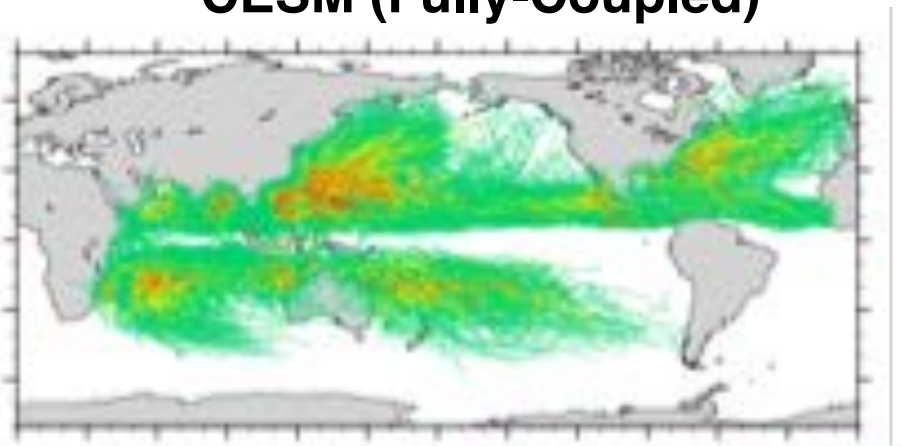
Observed TC tracks and intensities (1981-2010)



CESM (Atm-Only)

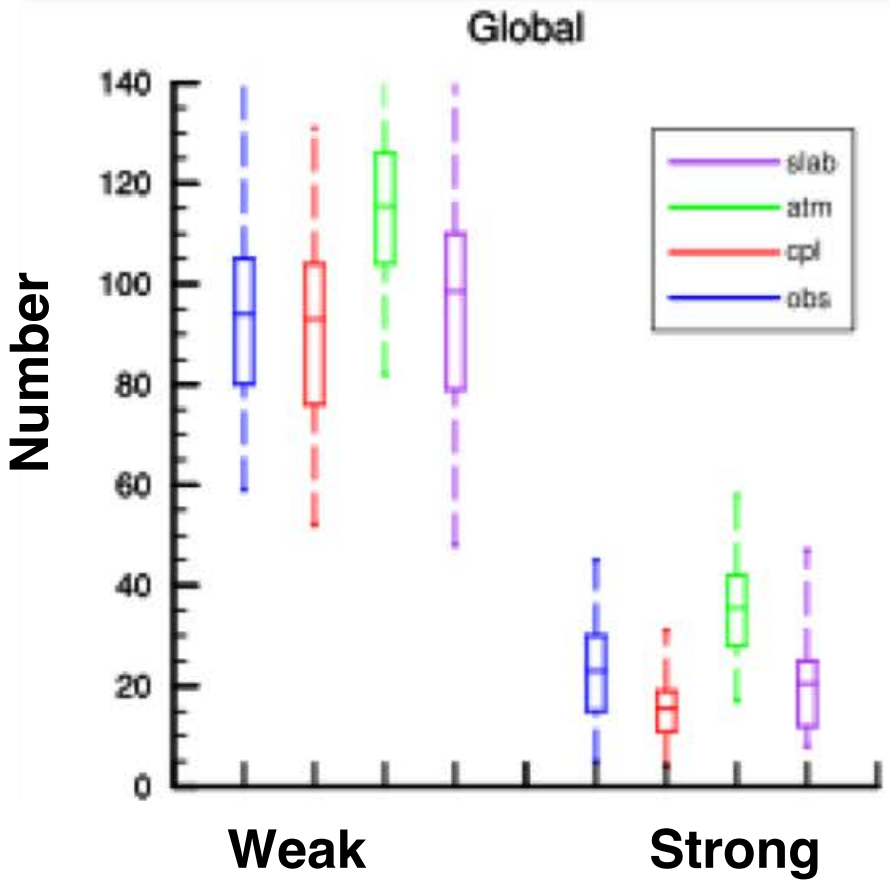


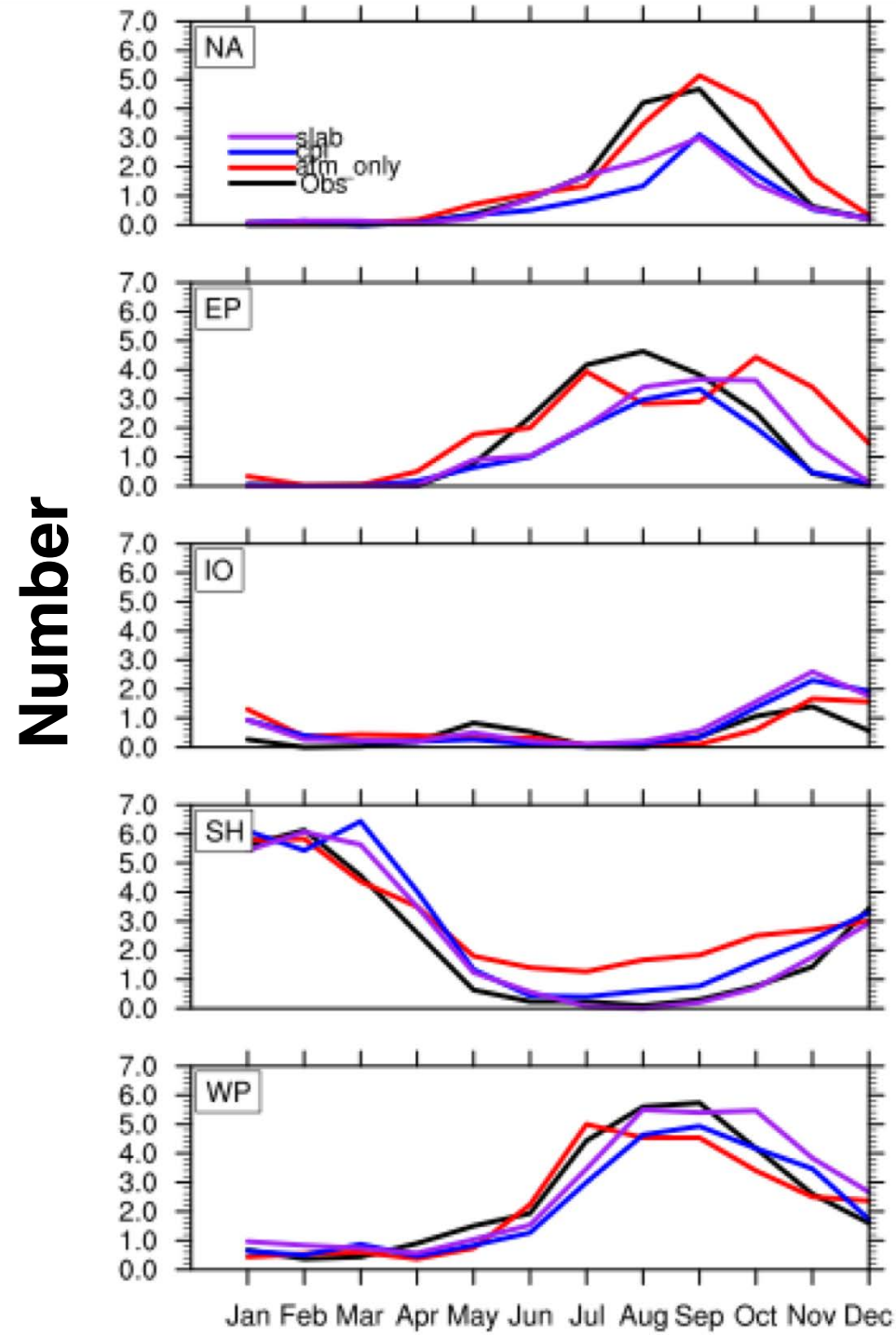
CESM (Fully-Coupled)



- Both coupled and uncoupled versions of CESM simulate realistic spatial reason

Simple Sensitivity Analysis



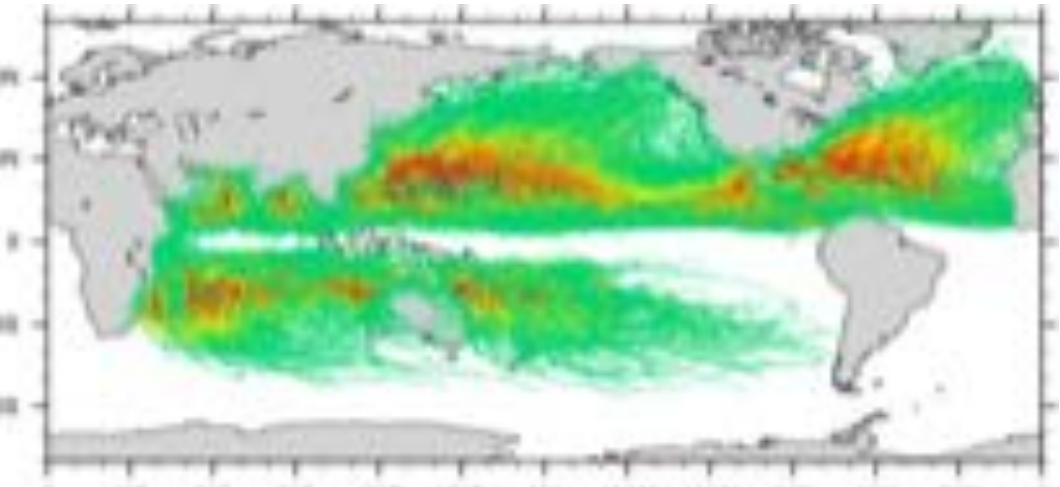


Key Points:

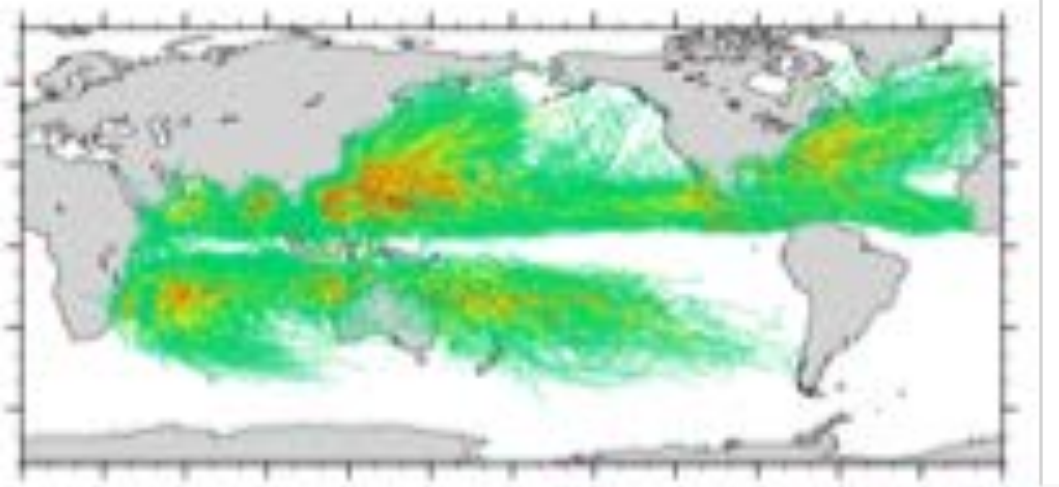
- CESM reasonably captures key features of observed TC activity
  - number, seasonal cycle, intensity
- We find strong sensitivity in number and intensity to ocean coupling
  - Why?

Coupled ocean-atmosphere interactions influence tropical cyclone representation in CESM

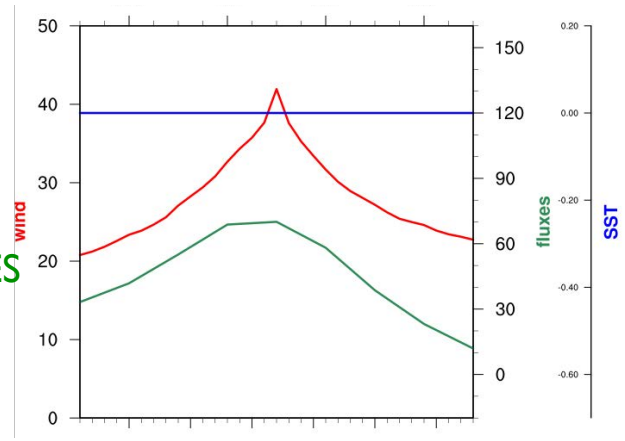
CESM (Atm-Only)



CESM (Fully-Coupled)

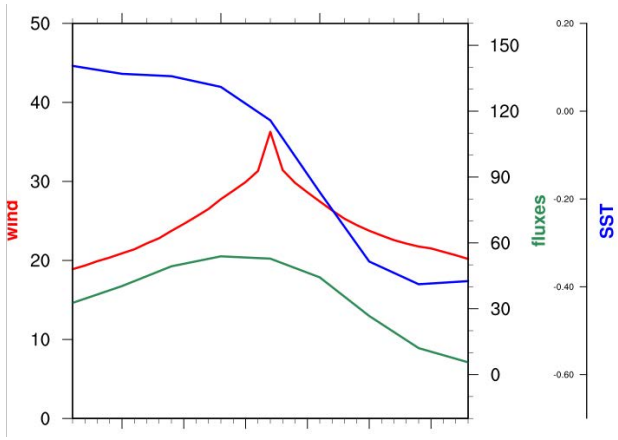


SFC TEMP
SFC WIND
SFC FLUXES



Time

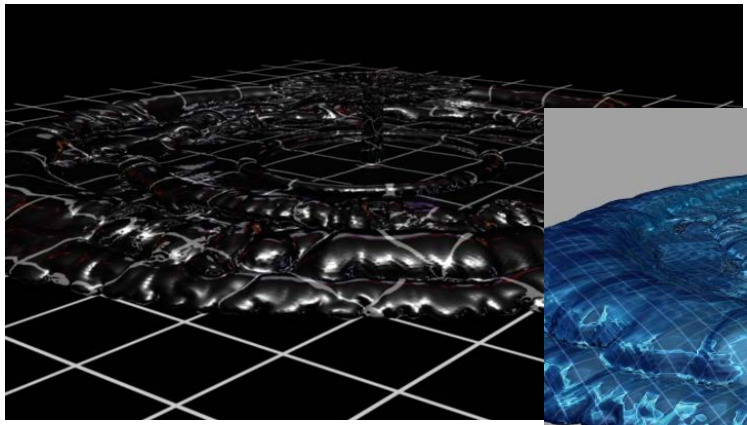
Time evolution of average modeled storm conditions

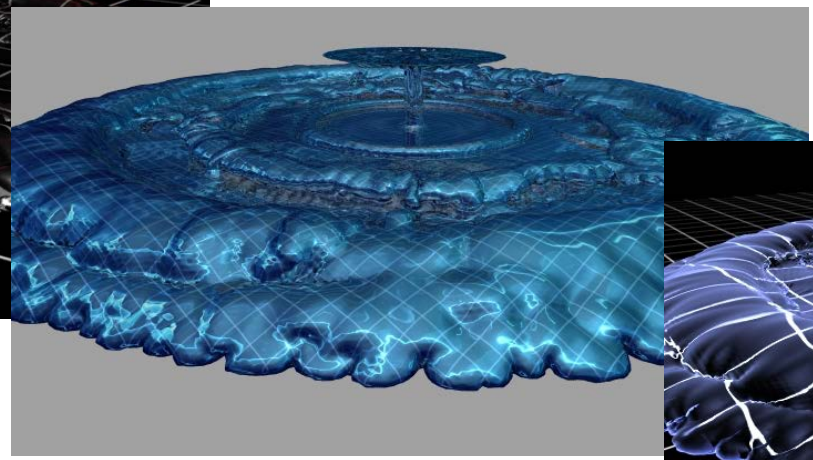


Time

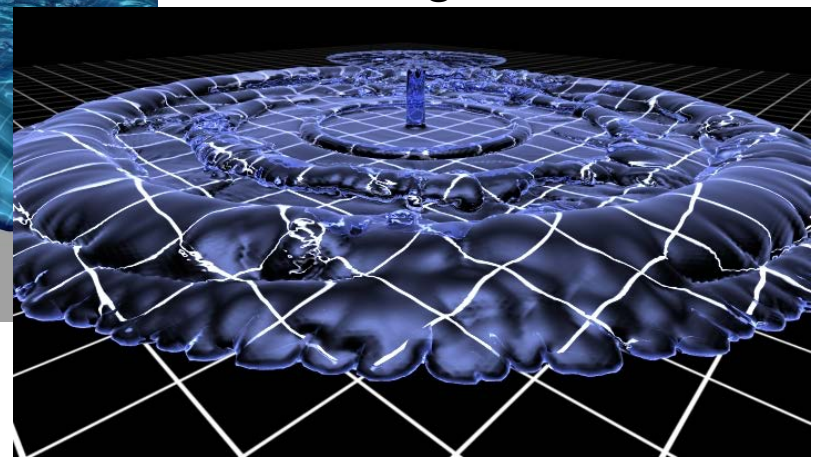
- Coupled interactions can modulate TC intensity, evolution, activity and variability
- Models with fixed ocean conditions are missing these feedbacks

We are working with the NCSA Data and Visualization Group to explore new ways to visualize big climate data (with a focus on TC-ocean interactions)

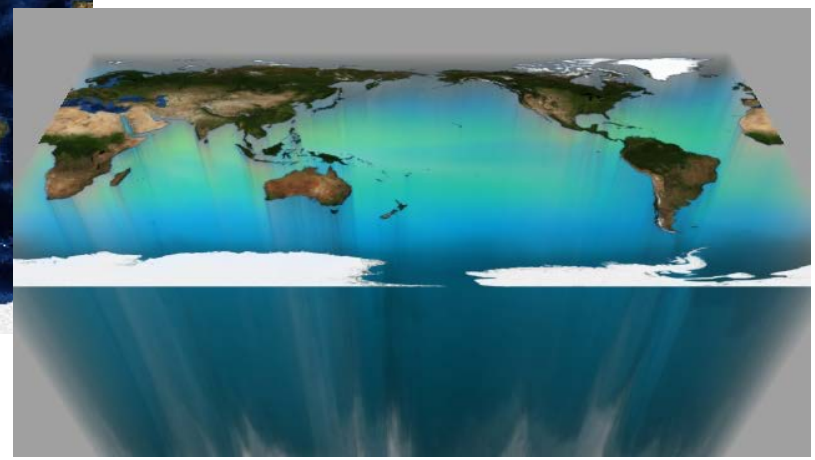




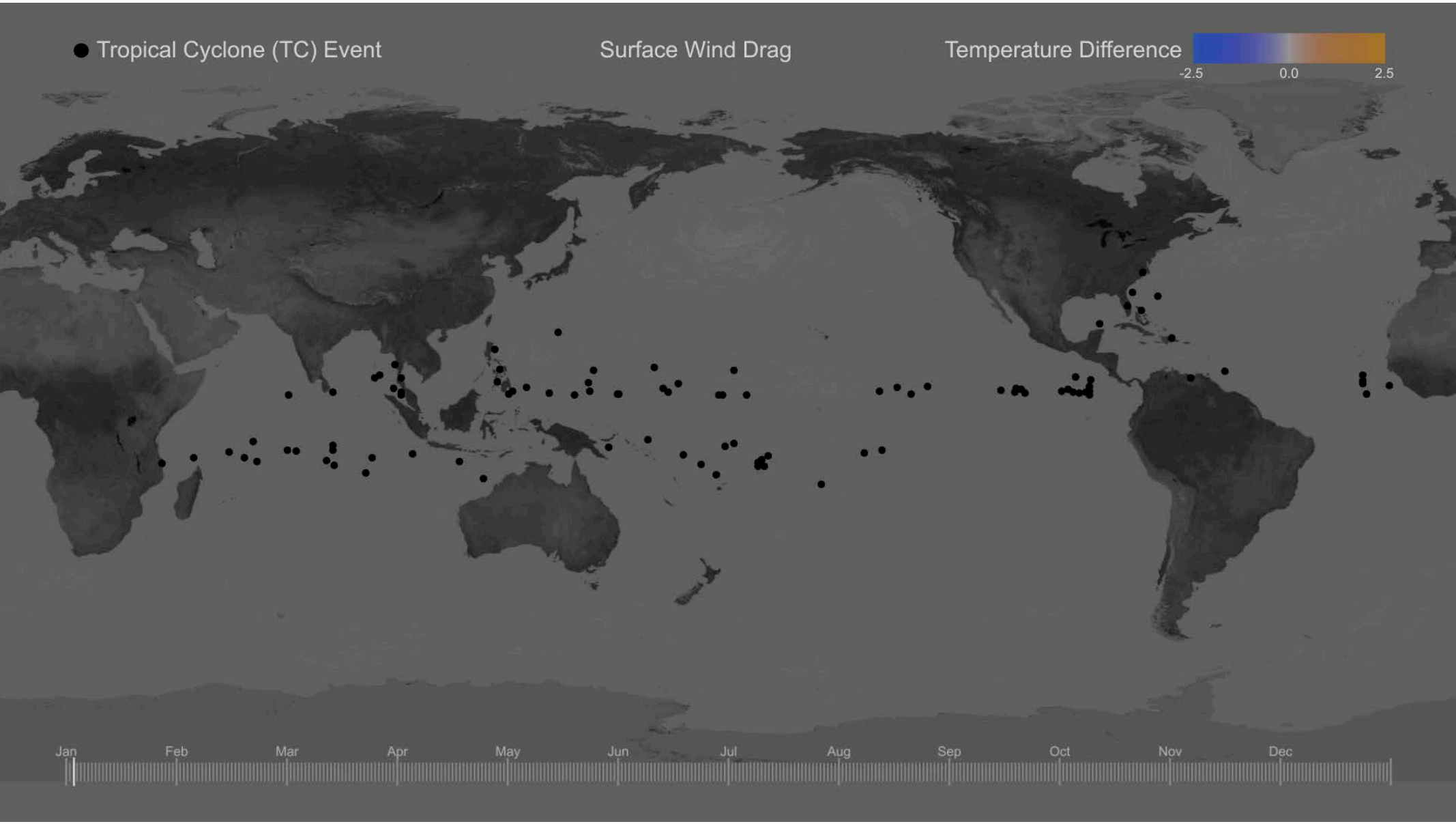
Visualizing Water Surfaces



Volume Rendering of the Ocean



Preliminary Animation of the Coupled System Response



David Bock and Rob Sisneros (NCSA)

Conclusions:

- This study uses high-resolution configurations of the Community Earth System Model (CESM) to investigate the relationship between tropical cyclones and climate.

- We conducted a series of multi-decadal sensitivity experiments highlighting the importance of coupled ocean-atmosphere interactions in simulating realistic TC characteristics and basin-scale activity.

- Ocean-Atmosphere coupling significantly influences TC activity and the feedbacks could be important for large-scale ocean and atmosphere energy budgets and circulations.

- Results point to the importance of coupled interactions in understanding the relationship between tropical cyclones and climate and paves the way for coupled modeling approaches exploring how tropical cyclone activity may change under anthropogenic global warming.

Next Steps:

- **Climate Change Experiment**
  - **Model sensitivity experiments to changing atmospheric CO2**
- **Atmosphere-Only Simulations with SSTs from coupled model**
  - **Diagnosing Feedbacks**
- **Coastal Impacts and Resiliency**
  - **Interfacing Physical Models with Economic Impact Models**

Papers produced by the project:

Li, H., Sriver, R. L., and Goes, M. (2016), Modeled sensitivity of the Northwestern Pacific upper-ocean response to tropical cyclones in a fully-coupled climate model with varying ocean grid resolution, Journal of Geophysical Research-Oceans, 121, doi:10.1002/2015JC011226

http://onlinelibrary.wiley.com/doi/10.1002/2015JC011226/full

Li, H. and Sriver, R. L. (2016), Effects of ocean grid resolution on tropical cyclone-induced upper ocean responses using a global ocean general circulation model, Journal of Geophysical Research-Oceans, 121, 8305-8319, doi:10.1002/2016JC011951. ***(Received Editor's Highlight)***

http://onlinelibrary.wiley.com/doi/10.1002/2016JC011951/full

Huang, A., Li, H., Sriver, R. L., Fedorov, A. V., and Brierley, C. M. (2017), Regional variations in the ocean response to tropical cyclones: Ocean mixing versus low cloud suppression, In Press at Geophysical Research Letters.

http://onlinelibrary.wiley.com/doi/10.1002/2016GL072023/full

Li, H. and Sriver (In Review), Impact of ocean coupling on simulated tropical cyclone activity inn the high-resolution Community Earth System Model, Journal of Advances in Modeling Earth Systems