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# THE RESPONSE OF TROPICAL CYCLONE ACTIVITY TO GLOBAL WARMING IN THE COMMUNITY EARTH SYSTEM MODEL

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## EXECUTIVE SUMMARY

This research aims to advance our understanding about the interactions between tropical cyclones (TCs) and climate using the high-resolution Community Earth System Model (CESM) with 0.25° horizontal resolution in the atmosphere and 1° horizontal resolution in the ocean. The high-resolution CESM can generate TCs within the modeled climate, providing a valuable platform for TC climate research. This project builds on the PIs' recent Blue Waters allocation, analyzing tropical cyclones in high-resolution configurations of CESM under constant present-day climate conditions for different coupled and uncoupled configurations. Here, we expand these simulations into a more comprehensive climate change experiment, investigating the response of global TC activity to changing greenhouse gas forcing (e.g., atmospheric carbon dioxide concentrations) using idealized 4×$CO_2$ experiments. Results provide insights into the model behavior and potential response in global TC activity to changes in anthropogenic global warming.

## RESEARCH CHALLENGE

Tropical cyclones are rare weather events, yet they consistently rank among the world's deadliest and costliest natural hazards. The frequency, intensity, and spatial distribution of TCs can vary with climate. In addition, recent research suggests TCs actively contribute to the dynamics of Earth's climate system through complex ocean–atmosphere interactions that can alter ocean temperature patterns and influence circulations within the atmosphere and ocean. These cyclone–climate connections are poorly understood and largely missing from today's generation of Earth system models, yet they may be fundamentally important to understanding the mechanisms influencing climate variability and to improving projections of future climate change.

## METHODS & CODES

The Community Earth System Model is a comprehensive global climate model that consists of atmosphere, land, ocean, and sea ice components that are connected via a central coupler that exchanges state information and fluxes between the components [1,2]. It is used by scientists and researchers worldwide from universities, national laboratories, and other institutions for climate, weather, atmospheric, oceanic, and land surface research. It represents the leading edge of communitywide efforts in global climate modeling, and it is considered a state-of-the-art Earth system model.

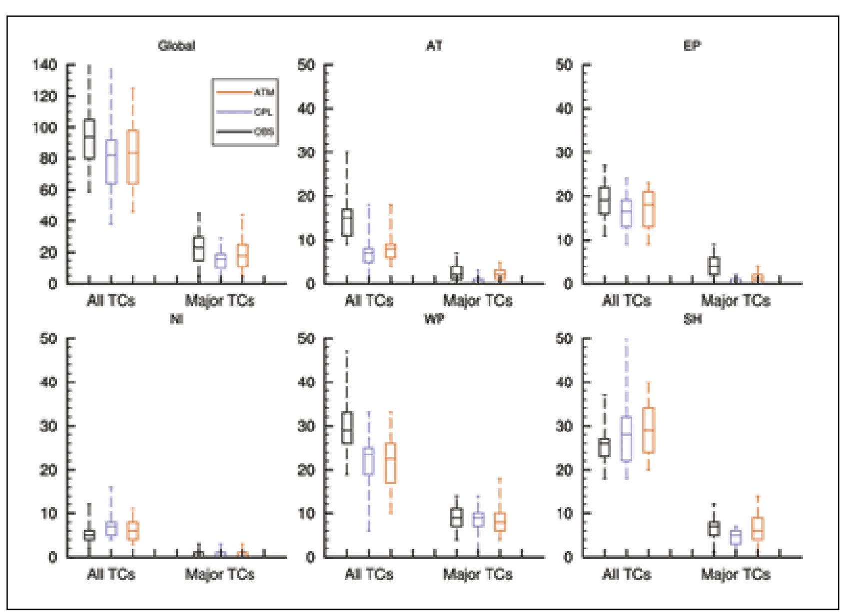


Figure 1: Box-whisker plot of global tropical cyclone number in different basins for observations (black), coupled CESM (steel blue), and atmosphere-only CESM simulations (salmon). Basin abbreviations: AT (Atlantic), EP (Eastern Pacific), NI (Northern Indian), WP (Western Pacific), and SH (Southern Hemisphere).





The atmosphere component of CESM is the Community Atmosphere Model (CAM5.3) with the spectral element (SE) dynamic core [3]. CAM5 has improved microphysics and cloud properties, and the prognostic modal aerosol package is activated in the current experiments. The SE version of the CAM model has a higher scalability than the finite volume version, making it suitable for high-resolution implementation on parallel computing clusters. The atmosphere is configured with 0.25˚ (~25 km) horizontal resolution and the standard 30 vertical layers. The land model is the Community Land Model version 4 and uses the same grid resolution as the atmosphere.

The dynamic ocean component of CESM is the Parallel Ocean Program version 2 (POP2), and the ice component is the Los Alamos Sea Ice Model. POP2 solves the three-dimensional primitive equations with the Boussinesq and hydrostatic approximations. We use the nominal 1˚ horizontal resolution on the displaced pole grid, which has a uniform zonal grid spacing of 1.125˚ and a varying meridional grid spacing that increases from 0.27˚ at the equator to a maximum grid spacing of 0.64˚ (northwestern Pacific). The model has 62 vertical levels, with layer thickness increasing from 10 m at the near-surface to 250 m at a depth of 6,000 m.

## RESULTS & IMPACT

In this research project, we are building on our recent work analyzing the relationship between TCs and climate using a high-resolution, state-of-the-art CESM. We are introducing time-varying changes in $CO_2$ through an idealized ramped forcing experiment, in combination with the extension of the control simulations with constant pre-industrial forcing. We are analyzing potential sensitivities in cyclone activity and damage metrics to $CO_2$-induced changes in large-scale environmental factors, and we are assessing potential biases based on model-data comparisons for current climate conditions. These simulations are also being used to explore the potential for cyclone-induced climate feedbacks within the coupled Earth system.

These runs are orthogonal to our ongoing Blue Waters CESM simulations, in which we are testing the sensitivity of TCs to ocean–atmosphere coupling (Figs. 1 and 2). The preliminary model sensitivity results are very promising, and we are now conducting the climate change component of the experiment. The new simulations will provide enough years to assess statistically significant changes in regional-to-global TC activity under increased carbon dioxide scenarios in CESM.

The comprehensive suite of model experiments have provided us with thousands of simulated cyclone tracks for different climate conditions and coupling configurations using a dynamically consistent Earth system modeling framework, enabling robust assessment of cyclone activity and variability in response to changes in climate. A key outcome of these simulations is gridded fields of cyclone tracks, winds, and other useful cyclone metrics that can be used to assess potential changes in cyclone-related damages under future global warming. These data products and model outputs are freely available upon request.

## WHY BLUE WATERS

TC climate research falls at the interface between weather and climate modeling, requiring high-resolution grid spacing to resolve weather-scale TC features, as well as global-scale coverage and decades of integration time. Blue Waters provides the unique capabilities of handling the computational demand associated with running the model at ultra-high resolutions, including scalability to over 15,000 cores, high frequency input and output, and postprocessing and visualization of model results.

Understanding the physical relationship between tropical cyclones and climate, and assessing the societal and economic impacts of climate change, represents a grand challenge to the Earth system modeling community. Blue Waters provides the unique capability to solve this problem.

## PUBLICATIONS & DATA SETS

Bock, D., H. Li, and R.L. Sriver, Simulation and visual representation of tropical cyclone-ocean interactions. *International Conference for High Performance Computing, Networking, Storage and Analysis (SC17)* (Denver, Colo., 2017).

Li, H., and R.L. Sriver, Tropical cyclone activity in the high-resolution community earth system model and the impact of ocean coupling. *Journal of Advances in Modeling Earth Systems*, 10 (2018), DOI:10.1002/ 2017MS001199.

Li, H., and R.L. Sriver, Impact of Tropical Cyclones on the Global Ocean: Results from Multi-decadal Global Ocean Simulations Isolating Tropical Cyclone Forcing. *Journal of Climate*, in review (2018).

Li, H., and R.L. Sriver, Impact of air-sea coupling on the simulated global tropical cyclone activity in the high-resolution Community Earth System Model (CESM). *Journal of Geophysical Research-Atmospheres*, in preparation (2018).

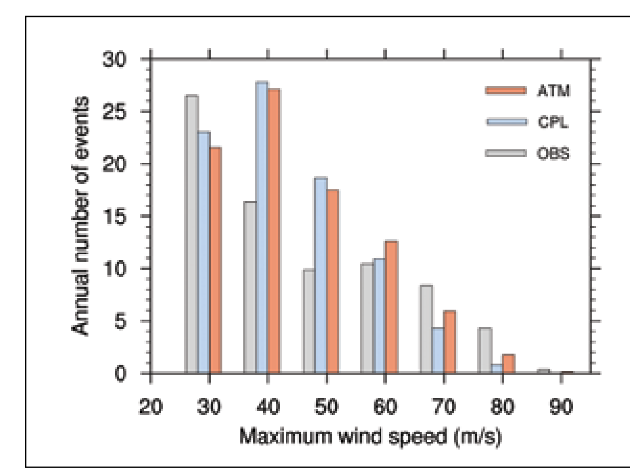


Figure 2: Binned frequency distribution of global annual average number of tropical cyclones for different maximum wind speeds from observations (grey), coupled CESM (steel blue), and atmosphere-only CESM (salmon).