SCALING THE CESM TO ULTRA-HIGH RESOLUTIONS FOR ANALYZING TROPICAL CYCLONE–CLIMATE FEEDBACKS

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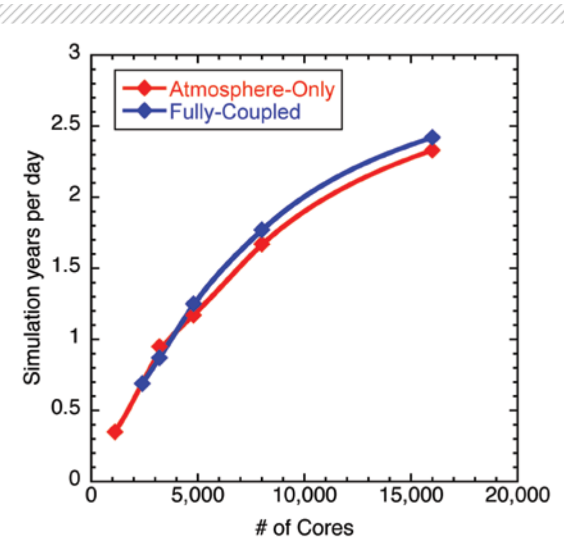
EXECUTIVE SUMMARY:

The goal of this project is to optimize code performance and test the scalability of the Community Earth System Model (CESM) to ultra-high resolutions to examine connections between tropical cyclones and climate. We are conducting benchmarking simulations for different model coupling configurations (atmosphere only, ocean only, and fully coupled) and grid resolutions, including a 0.25° atmosphere and 0.1° ocean. This is the first time the ultra-high resolution version of the coupled model is being tested for studying tropical cyclones. The computational expense of the simulations is considerably outside the capabilities of traditional HPC resources, which is why we are using Blue Waters. Ultimately, this work will provide the critical next step in settling the decade-long debate about the importance of tropical-cyclone-induced feedbacks to Earth's climate.

FIGURE 1: Preliminary scaling results of CESM for the atmosphere-only model (red curve) and the fully-coupled model (blue curve).



INTRODUCTION

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 tropical cyclones depend on large-scale environmental factors, such as tropical ocean temperatures and the structure of atmospheric winds. Changes in these factors due to climate variations can alter tropical cyclone activity on regional to global scales. However, tropical cyclones also actively contribute to the dynamics of Earth's climate system through complex ocean-atmosphere interactions that alter ocean temperature patterns and influence circulations within the atmosphere and ocean. These connections are poorly understood and largely missing from today's generation of Earth system models used to study climate variability, yet they may be fundamentally important to improving projections of future climate change. New earth system modeling strategies utilizing coupled ocean-atmosphere configurations, capable of resolving realistic tropical cyclone circulations and ocean-atmosphere interactions, are critical to developing a complete understanding of the relationship between tropical cyclones and climate.

METHODS & RESULTS

The Community Earth System Model (CESM) 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 energy fluxes between the components [1]. It represents the leading edge of community-wide efforts in global climate modeling and is considered a state-of-the-art earth system model. We are currently testing the scalability of CESM to ultra-high resolutions useful for analyzing tropical-cyclone-induced climate feedbacks (fig. 1). The simulations feature different model configurations, including ocean-only, atmosphere-only, and fully-coupled component sets. We are conducting these benchmarking tests at ultra-fine-scale grid resolutions (0.25° atmosphere coupled to 0.1° ocean) that are capable of simulating realistic tropical cyclones and the associated impacts on the upper ocean. These configurations are not typically used for tropical cyclone studies, due in part to the challenges of computational demand, coupling strategies, and the large volume of information produced by the high-resolution version of the coupled model. This work represents the cutting edge of current earth system modeling initiatives.

Preliminary results from high-resolution CESM simulations [2] have shown that the model generally simulates realistic tropical cyclones with the correct frequency, intensity, seasonality, and spatial distribution on global scales (fig. 2). However, the influence of these small-scale intense events on large-scale climate is largely unexplored, in particular for climate processes related to the ocean. We are using the benchmarking and scalability analysis described above as the basis for new model experiments examining how tropical cyclones affect upper-ocean energy budgets, circulation patterns, and important climate processes such as El Niño, ocean heat uptake and warming (due to enhanced ocean mixing), and large-scale ocean heat transport. In addition, we are running the model using several different grid resolutions to test sensitivities of the climate responses to changes in spatial resolution. This work will provide scientific insight into the effects of tropical cyclones on the upper ocean and will enable better understanding of the feasibility and computational demands of ultra-high resolution coupled modeling approaches to analyze connections between tropical cyclones and climate, as well as feedbacks that can influence our interpretations and projections of future climate change.

WHY BLUE WATERS?

The computational demand of the modeling efforts described above is considerably outside the capabilities of traditional HPC resources. Blue Waters provides unique resources capable of overcoming challenges due to large core-hour demands, high-frequency I/O, and post-processing of model output. Understanding the physical relationship between tropical cyclones and climate and assessing the societal and economic impacts under climate change represent a grand challenge to the Earth system modeling community. Blue Waters may provide the computational resources necessary to solve this problem.

PUBLICATIONS

Hui, L., and R. L. Sriver, Modeled Sensitivity of the Upper-Ocean Response to Tropical Cyclones in the Northwestern Pacific Using a Fully-coupled Climate Model with Varying Ocean Resolution. *Amer. Geophys. Union Fall Mtg.*, San Francisco, Calif., December 15–19, 2014.

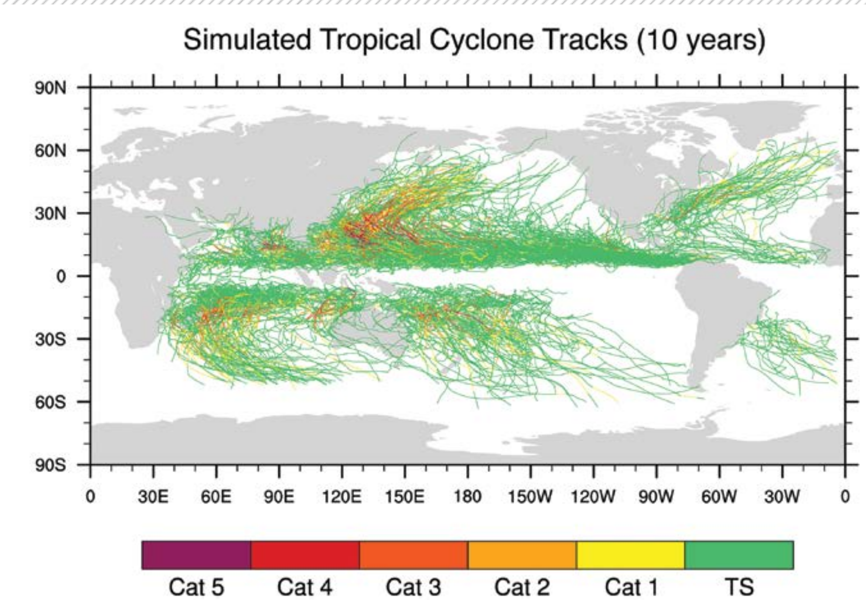


FIGURE 2: Simulated tropical cyclone tracks analyzed from ten years of CESM model output [2]. These tracks are the basis for new runs exploring the impacts of tropical cyclones on the upper ocean and the related climate impacts.