HIGH-RESOLUTION EARTH SYSTEM MODELING USING BLUE WATERS' CAPABILITIES

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EXECUTIVE SUMMARY

This work contributes to a larger body of ongoing research aimed at using high-resolution climate and weather forecast models to better understand high-impact events in the present day and future warmer scenarios. Simulations completed this year include those using the Community Earth System Model (CESM) at the highest resolution currently feasible for long climate scenarios (0.25° atm/land – 1° ocn/ice) as well as the highest resolution currently possible (0.25° atm/land – 0.1° ocn/ice). For both resolutions, the simulations contribute to a set of control, climate sensitivity, twentieth-century transient, and future scenarios. In addition to ongoing studies of tropical cyclones and midlatitude storms, we also investigated atmospheric rivers and regional extreme temperatures in the northwest Atlantic Ocean. Using low-resolution global climate model (GCM) output to force the higher resolution Weather and Research Forecasting (WRF) model (~12 km) allows for dynamical downscaling over the contiguous United States to investigate extreme temperature and precipitation.

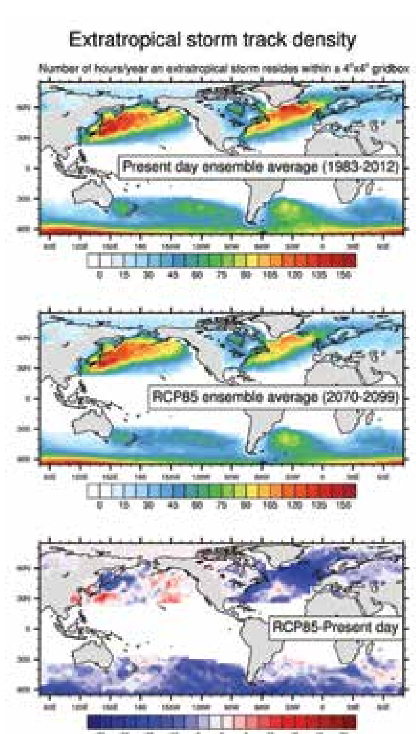

Figure 1: The total number of hours per year in which a storm is located within a 4°x4° gridbox calculated in the present day simulations (top panel), the future scenario (middle panel) and the difference between the two (future minus present day, bottom panel).

RESEARCH CHALLENGE

Our current PRAC project employs global climate models at the highest resolution feasible for simulating multiple centuries of Earth's climate and a high-resolution regional model for informing changes in extremes over the United States, providing a leading research environment for the immediate needs in climate science, informing the upcoming national and international climate assessments, and building the avenue to scientific discovery in the next five to ten years. These analyses will be a significant contribution to the coordinated international special computational studies and model intercomparison to be done to analyze past and projected future changes in the earth's climate system. In addition, the results of these studies will be fully available to the scientific community for further analyses and resulting insights into the processes, mechanisms, and consequences of climate variability and climate change. Such high-resolution modeling studies are likely to produce important findings for other scientists, social scientists, and policymakers to achieve further understanding of climate change science, the resulting societal and ecosystem impacts, and insights for adaptation and mitigation analyses. The nature of simulating climate processes at high resolution makes this work a grand challenge. As we move to higher and higher resolution, we must rethink the need for model parameterizations for various physical processes, and from a technical standpoint we must scale the model to larger node counts.

METHODS & CODES

For long climate integrations we use the Community Earth System Model (CESM), a coupled climate model for simulating the earth's climate system. Composed of six component models that simulate Earth's atmosphere, ocean, land surface, sea ice, land ice, river transport, and one central coupler component, the CESM allows researchers to conduct fundamental research into the earth's past, present, and future climate states.

For regional downscaling over the contiguous U.S., we use output from three GCMs—Community Climate System Model (CCSM4); Geophysical Fluid Dynamics Laboratory Earth System Model (GFDL-ESM2G); and Hadley Centre Global Environment Model, version 2-Earth System (HadGEM2-ES)—to force the Weather and Research Forecasting (WRF) version 3.3.1.

The TempestExtremes [1] and TSTORMS [2] packages were used to track midlatitude storms and tropical cyclones, respectively.

RESULTS & IMPACT

Building on our research from the previous year, we expanded storm tracking into the midlatitudes to investigate potential changes in storm number and strength over the current century. As found with tropical cyclones, the total number of midlatitude storms decreases in the future in all ocean basins (Fig. 1). The atmosphere tends to be more stable in the future in the midlatitudes, contributing to fewer storms. Atmospheric rivers (ARs), a subcategory of midlatitude storms that are able to transfer moisture from the tropics to the midlatitudes, had not previously been analyzed in the 0.25° atm/lnd-1° ocn/ice version of the CESM. Higher model resolution allows for better representation of counts and frequency of ARs. Results indicate that future changes in ARs depend on changes in the atmospheric jets and therefore respond differently in the different ocean basins.

Certain regional processes within the ocean may be much better represented by the high-resolution ocean (0.1°) simulations. An observed hotspot of localized warming in the Gulf of Maine is much better represented in this high-resolution simulation compared to the nominal 1° simulations. Such extremes in ocean temperatures can have a significant economic impact on fisheries.

Investigations of extreme temperature and precipitation change over the contiguous United States reveal startling realities for future climate. Two future climate scenarios were simulated: a moderate warming scenario (RCP4.5) and a strong warming scenario (RCP8.5). Fig. 2 shows the change in the number of days exceeding 95°F for the late twenty-first century under each forcing scenario. Some regions, such as the Northeast, will not experience much change due to the relative rarity of events in that region, while other areas, such as the middle part of the country, are projected to experience large changes in both scenarios. For much of country, there is an additional one to two months each year that will exceed 95°F with the RCP8.5 scenario as compared to RCP4.5. This is significant because in historical simulations, the vast majority of 95°F days take place only during June–July–August (JJA) for these regions. An additional 30–50 days per year means the "summer" months will span more than just JJA, which would have significant energy and agriculture impacts.

WHY BLUE WATERS

Multiple century-long simulations are needed in order to quantify CESM model characteristics and sensitivity and to produce a sufficiently long, stable preindustrial control simulation, followed by historical and numerous future scenarios. Furthermore, multi-member ensembles are needed to quantify and reduce uncertainty. The climate modeling community has refined horizontal resolution to 0.25° for the atmosphere and 0.1° for the ocean, allowing for a full eddy-resolving ocean simulation within the modeling system. These simulations and analyses, at high resolution, at a minimum require petascale computing resources and cannot be completed without a computational platform like Blue Waters. Because these simulations use a modest number of nodes for long periods of time, our project requires the help of the Blue Waters staff to achieve good throughput.

PUBLICATIONS AND DATA SETS

Bacmeister, J. T., et al., Projected changes in tropical cyclone activity under future warming scenarios using a high-resolution climate model. *Climatic Change* (2016), DOI: 10.1007/s10584-016-1750-x.

Reed, K. A., et al., Impact of the dynamical core on the direct simulation of tropical cyclones in a high-resolution global model. *Geophys. Res. Lett.*, 42 (2016), pp. 3603–3608.

Zarzycki, C. M., et al., Impact of ocean coupling strategy on extremes in high-resolution atmospheric simulations. *Geosciences Model Development*, 9 (2016), pp. 779–788, DOI: 10.5194/gmd-9-779-2016.

Zobel, Z., J. Wang, D. J. Wuebbles, and V. R. Kotamarthi, Evaluations of high-resolution dynamically downscaled ensembles over the contiguous United States. *Climate Dynamics* (2017), pp. 1–22, DOI: 10.1007/s00382-017-3645-6.

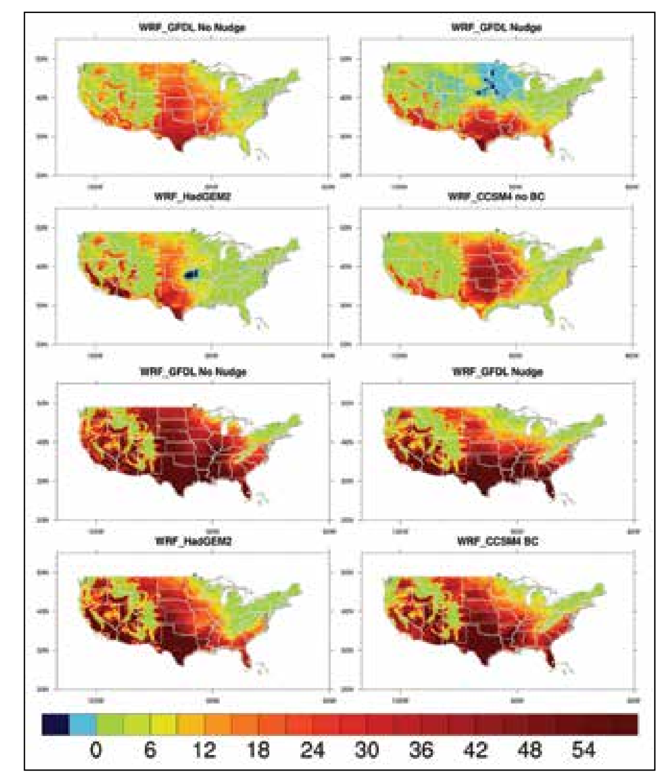

Figure 2: The change in the number of days that exceed 95°F between a moderate warming scenario and present day (top four panels) and a high warming scenario and present day (bottom four panels). The four panels show results from four different configurations of WRF using different boundary forcing (from either a global climate model or observations).