PETASCALE MODELING OF CONVECTIVE STORMS UNDER CLIMATE CHANGE AND VARIABILITY

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EXECUTIVE SUMMARY

This research seeks to answer the basic question of how present-day extreme storm events might be altered by human-induced climate change. The pseudo-global warming (PGW) methodology has been adapted for this purpose. Modified atmospheric states drawn from global climate model (GCM) output were used to constrain an ensemble of Weather Research and Forecasting (WRF) model simulations of select extreme events. Highly resolved grids allow for process-based analyses of the simulated events; ensembles of such simulations facilitate quantification of uncertainty.

Our most recent work has focused on hail storms and tornadoes spawned by landfalling hurricanes. The severe hail events considered thus far are more intense but generate less-extensive and fewer hail swaths under PGW. Simulations of Hurricane Ivan (2004) are showing that the conditions under PGW promote a relatively more intense hurricane at landfall, and lead to a much higher incident of mesoscale vortices with tornadic potential.

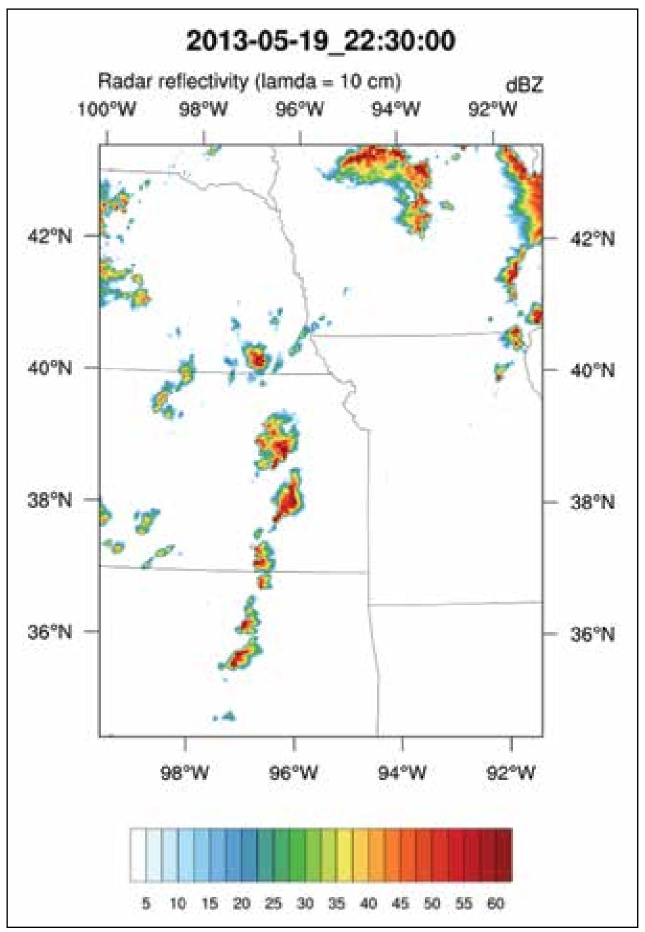

Figure 1: Simulated radar reflectivity from a high-resolution WRF model simulation of the May 19, 2013, outbreak of tornadoes, damaging wind, and hail. The radar reflectivity portrays the structure of the individual hail-producing storms in the CTRL simulation.

RESEARCH CHALLENGE

A persistent uncertainty in climate-change assessments is how the frequency and intensity of local, high-impact thunderstorms, and even large thunderstorm systems including hurricanes, might be affected by human-enhanced greenhouse gas concentrations. Part of the challenge is that such storms—and especially the attendant tornadoes, hail, damaging "straight-line" winds, lightning, and localized flooding—have spatial scales that fall below the effective resolution of typical global models. Modeling approaches such as dynamical downscaling have addressed this resolution issue, but their applications thus far have generally been unconcerned with historical events, and therefore about how these events might be projected in the future.

METHODS & CODES

Drawing on the success of our previously reported work, we have further adapted the PGW methodology to investigate the impact of human-induced climate change on outbreaks of severe hail and on landfalling hurricanes. Modified atmospheric states drawn from GCM output were used to constrain WRF model simulations of these events at high resolution (inner-domain grids with lengths of 333 m). Comparison of an ensemble of these simulations with control simulations (CTRL) is facilitating the assessment of PGW effects. Experimentation with two-moment microphysical parameterization schemes adds to the hailstorm simulation ensemble.

RESULTS & IMPACT

Exemplifying the hailstorm results are the simulations of the May 19, 2013, outbreak of tornadoes, damaging wind, and hail (Fig. 1). Relative to the CTRL experiments, the PGW experiments across the three microphysical schemes (Morrison: MO, Milbrandt-Yau: MY, NSSL: NS), and the three GCM drivers (GFDL, MIROC, and NCAR), the individual hailstorms under PGW tended to be more intense but generated less extensive and fewer hail swaths (Fig. 2). Our analyses thus far are showing that this response is due to the PGW-induced: (1) changes in the thermodynamic environment (e.g., higher convective available potential energy, higher convective inhibition, and higher freezing level), (2) increases in precipitation loading of individual updrafts, and (3) reductions in environmental vertical wind shear. One hypothesis that we are currently exploring is that a reduction in wind shear leads to a reduction in updraft area and thus in the area that accommodates hail growth.

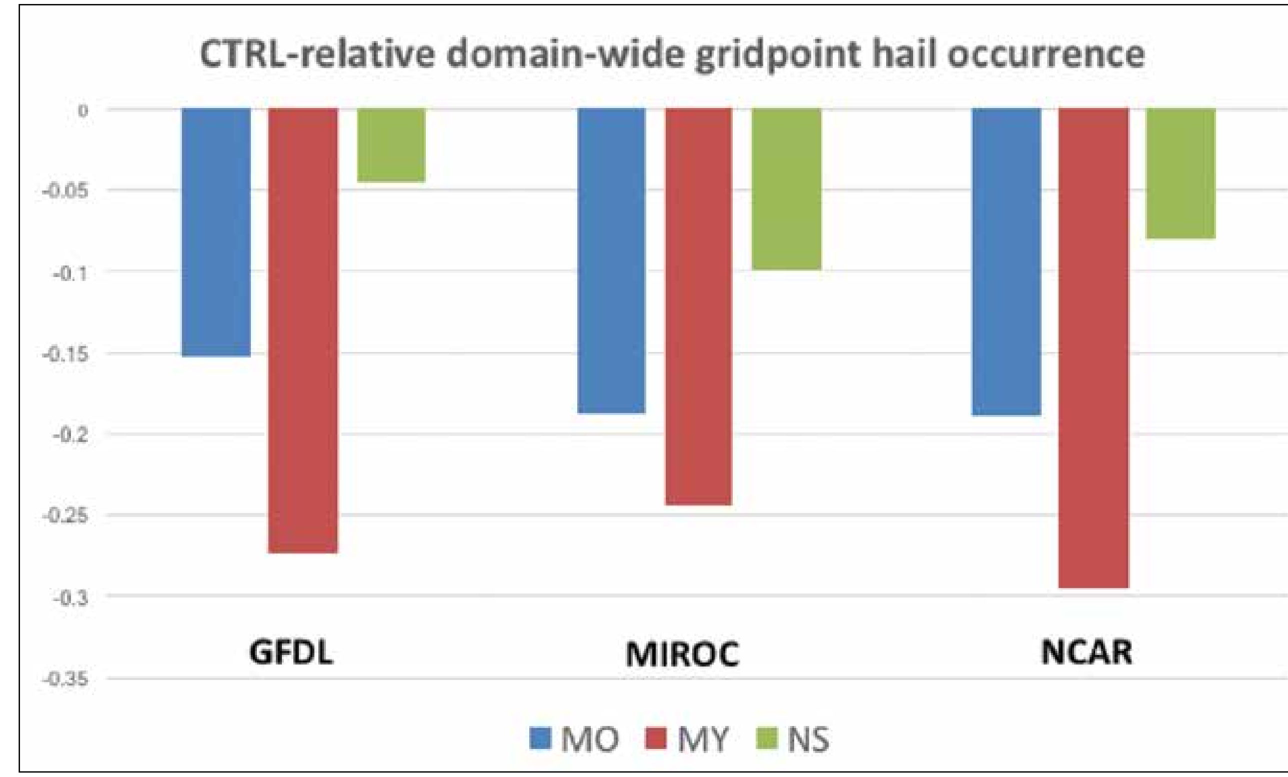

Figure 2: Bar graph showing the domain-wide grid point hail occurrence on May 19, 2013, under PGW. The values represent fractional changes relative to the CTRL simulation. The PGW experiments are across three microphysical schemes (Morrison: MO, Milbrandt-Yau: MY, NSSL: NS) and three GCM drivers (GFDL, MIROC, and NCAR).

The hurricane simulations are of Hurricane Ivan (2004), which spawned a record 118 tornadoes and caused significant damage to inland communities. We are finding that the conditions under PGW promote a relatively more intense hurricane at landfall and lead to a much higher incidence of mesoscale vortices with tornadic potential. The relatively higher convective available potential energy under PGW is one hypothesized physical explanation for this response.

In addition to continued analyses of the hailstorm and hurricane simulations described above, we are currently developing the capability to employ the Model for Prediction Across Scales (MPAS) for studies of convective storms under climate change and variability. MPAS is one of the emerging global atmospheric models with variable-resolution grids and provides us with the ability to isolate effects of low- and high-latitude processes (e.g., from Arctic sea ice and tropical oceans) on deep convective storms that are well resolved in middle latitudes. With the assistance of National Center for Supercomputing Applications personnel, the MPAS model codes have recently been compiled on Blue Waters, and MPAS experimentation is currently under design.

WHY BLUE WATERS

The relatively small size of thunderstorms and the ranges of relevant scales within tropical cyclones, coupled with their episodic occurrence, necessitates a research approach that can account for temporal scales from decades to minutes and spatial scales of thousands of kilometers to hundreds of meters. In other words, we require very large geospatial domains that have fine grid point spacings and long-time integrations with high rates of model output. Moreover, quantifications of uncertainty require that such realizations be repeated over multiple experiments. The Blue Waters allocation is providing us with the resources needed to achieve this unprecedented level of climate simulation.