

Annual Report for 2016-2017 Blue Waters Allocation: Robert J. Trapp

- **Project Information**
 - *Petascale modeling of convective storms under climate change and variability*
 - Robert J. Trapp, Department of Atmospheric Sciences, UIUC
 - jtrapp@illinois.edu

- **Executive summary (150 words)** A significant focus of this research regards how current-day hailstorm and land-falling hurricane events might be realized under anthropogenic climate change. The “pseudo-global warming” (PGW) methodology was adapted for this purpose. One preliminary finding is that PGW tends to lead to a decrease in peak hail size and in the occurrence of accumulated hail. Another preliminary finding is that a Hurricane Ivan type-event under PGW has a westward-shifted track, but otherwise is more intense and generates more tornadoes than the actual event. The other focus of this research seeks to gain a better understanding of how basic convective-storm components—updrafts, downdrafts, and cold pools—are regulated by larger-scale atmospheric conditions, and thus how these might change given future changes in these conditions. We find an intrinsic coupling between updraft area, downdraft area, and cold-pool depth, and that this coupling is strongly controlled by vertical wind shear.

- **Description of research activities and results**
 - *Key Challenges:* Our research is motivated by a desire to better understand the morphology, intensity, and spatio-temporal occurrences of severe thunderstorms, tornadoes, and hurricanes. We are particularly interested in determining how the characteristics of these extreme events might change in the future, owing to human-enhanced greenhouse gases as well as to the natural variations of the Earth system. We use numerical models toward this end, but are immediately challenged by the fact that our problem spans multiple orders of magnitude in time and space. In other words, we need to well-represent the convective event (e.g., tornado or hail), the parent convective storm, its regional-scale forcings, and even its planetary-scale forcings. Additionally, to gain confidence in our findings, we need multiple realizations, which include possible uncertainties.
 - *Why it Matters:* As just alluded to, the research addresses atmospheric phenomena that have a significant impact on society. Besides an improved understanding on how convective phenomena connect to climate change and variability, the anticipated results have application towards long term planning and adaptation.
 - *Why Blue Waters:* The episodic nature yet relatively small size of thunderstorms, tornadoes, and hurricane-induced hazards necessitates a research approach that can account for temporal scales that range from decades to minutes, and spatial scales ranging from thousands of kilometers to hundreds of meters. This is illustrated well in **Figure 1**, for the “control” simulation of Hurricane Ivan. The Blue Waters allocation is providing us with the resources needed to achieve this unprecedented level of climate simulation.
 - *Accomplishments:* Given a fully functional WRF-modeling system, the Trapp research group was able to perform high-resolution simulations of

hailstorms and hurricane events under PGW (*Trapp, Carroll-Smith*). One preliminary finding is that PGW tends to lead to a decrease in peak hail size and in the occurrence of accumulated hail. This work is being combined with other regional climate model simulations over longer time periods, and will be submitted for publication in a special issue of the journal *Climate Dynamics*.

A more intense and hazardous hurricane at landfall appears to be another potential effect of PGW. This is illustrated in **Figure 2**, as is the fact that PGW has resulted in a westward shift of the location at landfall and hurricane track. We are working on our methodology to quantify tornado occurrences with these Ivan simulations. The methodology involves the use of a diagnostic parameter known as “updraft helicity,” the details of which will be submitted for publication in the journal *Weather and Forecasting*. Indeed, even though this is ultimately a climate-change study, the research appears to have operational-forecasting implications.

The other significant component of our Blue Waters research is centered on how the basic convective-storm components—updrafts, downdrafts, and cold pools—are regulated by larger-scale atmospheric conditions, and then how these might change given future changes in these conditions (*Marion, Trapp, Malinson*). A tangential track to this research additionally involves tornadoes: we have found through theory and numerical simulations that more intense tornadoes are favored in larger updrafts (for example, see **Figure 3**). This work has been accepted for publication in the *Journal of the Atmospheric Sciences*, and should appear in print in December 2017 or January 2018. The CM1 model is being used for all of this work, and a suite of high-resolution simulations are now being analyzed to expand on our basic finding thus far: updraft area, downdraft area, and cold-pool depth are intrinsically coupled, and that this coupling is strongly controlled by vertical wind shear. A manuscript on this work will hopefully be submitted in January. We note that this research is being supported by a grant from the Department of Energy. The ultimate goal of the research is to provide information that can be used to help improve convective parameterizations in climate models.

Finally, some of our Blue Waters allocation—and considerable effort—has been devoted to develop the means to employ the Model for Prediction Across Scales (MPAS) for studies of convective storms under climate change and variability (*Trapp, Hoogewind*). MPAS is one of the emerging global atmospheric models with variable-resolution grids, and will provide 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 NCSA personnel, especially Ryan Mocos, the MPAS model codes and ancillary software have been built on Blue Waters. We had budgeted 10-15% of the current allocation for MPAS-enabled research, but unfortunately, we still have a final configuration issue that needs to be resolved. Once resolved, we will be able to refine the global model so that grid spacings as small as 3-km can be employed over country-scale regions.

- **List of publications and presentations associated with this work**

Publications in press:

Trapp, R. J., G. Marion, and S. Nesbitt, 2017: The regulation of tornado intensity by updraft width. *Journal of the Atmospheric Sciences*, in press.

Publications in preparation:

Carroll-Smith, D., L. C. Dawson, and R. J. Trapp, 2018: High-resolution WRF modeling and verification of tropical cyclone tornadoes associated with Hurricane Ivan (2004). *Weather and Forecasting*, to be submitted early 2018.

Trapp, R. J., and K. A. Hoogewind, 2017: Hailstorm frequency and intensity under anthropogenic climate change as revealed through convection-allowing dynamical downscaling. *Climate Dynamics*, to be submitted December 2017.

Presentations:

“The regulation of tornado intensity by updraft characteristics.” November 2016, 28th AMS Conference on Severe Local Storms, Portland, Oregon

“Controls on the Widths of Intense Convective Updrafts.” March 2017, 8th Atmospheric System Research (ASR) Science Team Meeting, Vienna, VA,

“Hail occurrence under anthropogenic climate change.” April 2017, Second European Hail Workshop, Bern, Switzerland (keynote)

“Characteristics, controls, and inter-relationships of the convective components of simulated convective storms under current and future climates.” April 2017, Karlsruhe Institute of Technology, Karlsruhe, Germany, 2017 (invited)

“Hurricane-spawned tornadoes under anthropogenic climate change.” June 2017, Blue Waters Symposium, Sunriver, Oregon.

- **Plan for next year**

The Trapp research group now has several members who individually are pursuing computational research related to this project. This research will require an allocation comparable to the 2016-2017 level (in terms of node hours and data storage). The specific research planned for 2017-2018 includes: (1) simulation of hail storms under anthropogenic climate change (WRF); (2) evaluation of land-falling hurricane structure and hazard implication under pseudo-global warming (WRF); (3) simulations of convective updraft and cold pool characteristics under different environmental conditions, to be used as guidance for climate-model parameterization (CM1); and (4) the use the MPAS for the study of the effects of

Arctic sea ice on midlatitude convective storms. Additionally, MPAS will be used for extended-range forecasts in support of field research operations in Argentina, during an international field campaign called RELAMPAGO. This campaign is being led by UIUC scientists, and is supported by the National Science Foundation.

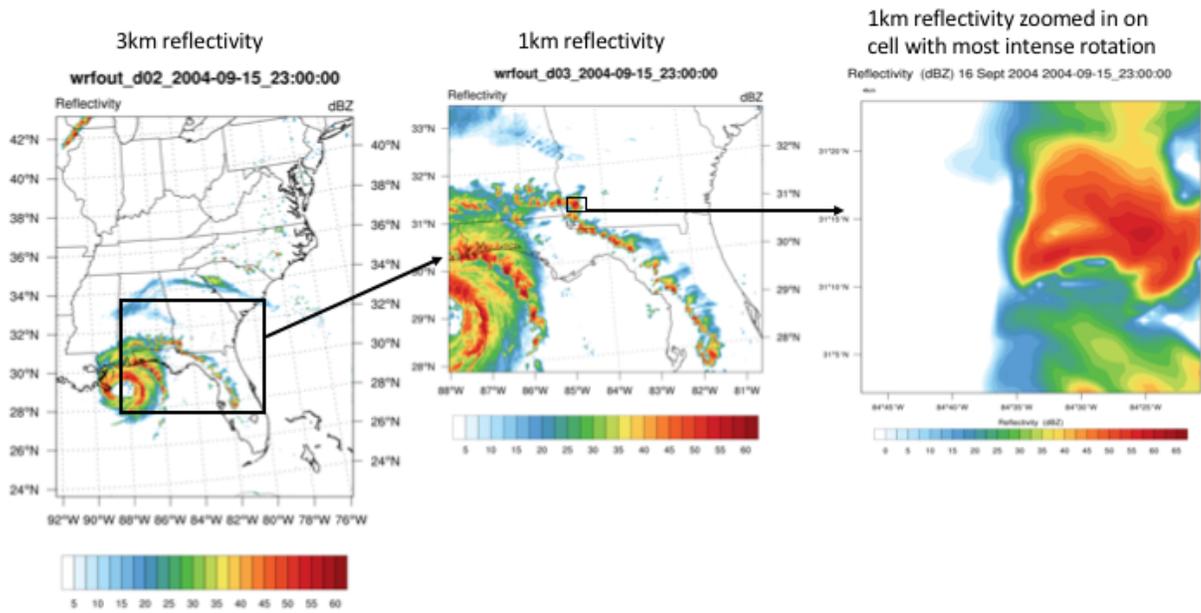


Figure 1. WRF-simulated radar reflectivity of the “control” simulation of Hurricane Ivan. Shown are three perspectives: The near-country-scale domain, the small regional domain, and the storm-scale domain.

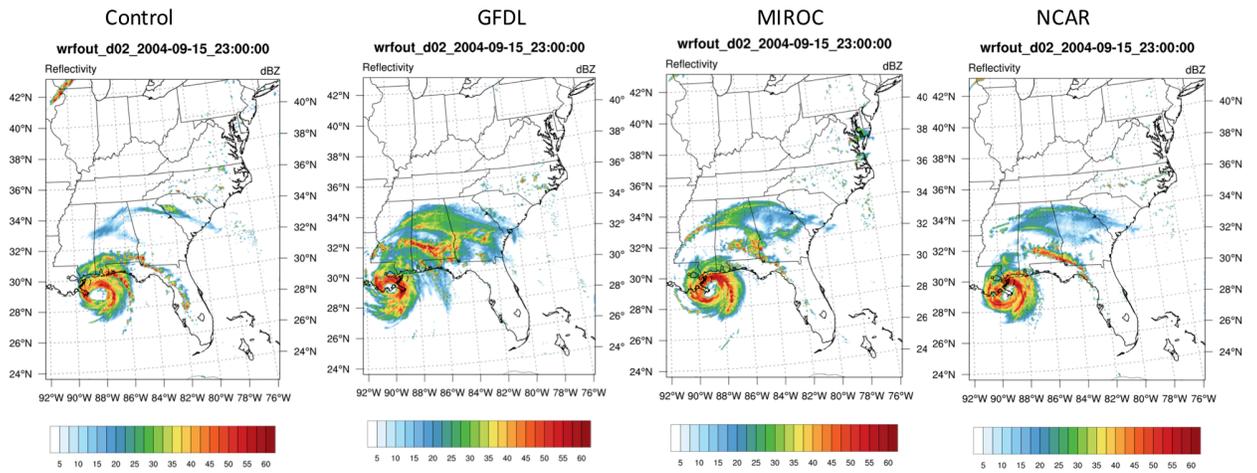


Figure 2. WRF-simulated radar reflectivity of a “control” simulation of Hurricane Ivan, as well as simulations of Ivan under PGW as represented by three different global climate models (GFDL-CM3, MIROC5, and NCAR-CCSM4).

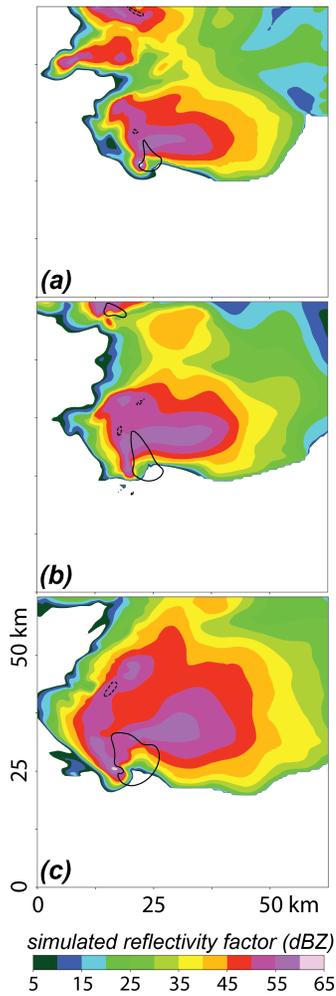


Figure 3. Simulations of three supercell thunderstorms under different environmental vertical wind shear conditions. Color fill is simulated radar reflectivity, and black contour indicates the location and size of the midlevel updraft core. Panel (c) shows the storm with both the largest updraft core area, and the strongest low-level vortex.