Blue Waters Annual Report 2018

Project Information

Title: Petascale modeling of convective storms under climate change and variability

PI: Robert J. Trapp; Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign

Corresponding author name/contact information: Robert J. Trapp, jtrapp@illinois.edu

Executive Summary

This overarching goal of this research is to address the basic question of how extreme thunderstorm events might be affected both by human-induced climate change and modes of natural climate variability. Three subprojects were pursued in 2018 toward this end. In this summary we focus on the first subproject, in which we selectively varied the vertical profile of temperature, humidity, and wind in the initial/environmental conditions, allowing us to control the updraft width in the resultant storm. Updraft width, in turn, controls downdraft width and thence depth of the surface-based cold pool. We are able to explain this coupling through analyses of the dynamical properties of the convective storm. One key implication of these results is that significant improvements can be made to convective-parameterization schemes by incorporating the effects of environmental vertical wind shear. The second is that, considered in isolation, a projection of weaker vertical wind shear in future climates suggests a corresponding decrease in convective-draft width.

Description of Research Activities and Results

Key challenges: A persistent uncertainty in climate-change assessments regards how the frequency and intensity of local, high-impact thunderstorms 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. This challenge likewise applies to long-term predictions of such phenomena. Modeling approaches such as dynamical downscaling are one way to address this resolution issue. Another approach is idealized modeling, and a final approach is global modeling with grid refinement.

What it matters: Quite simply, tornadoes, hail, damaging "straight-line" winds, lightning, and localized flooding all have high socio-economic impact. Improvements in long-term predictions and projections of these phenomena can help aid decision makers and ultimately reduce human vulnerability.

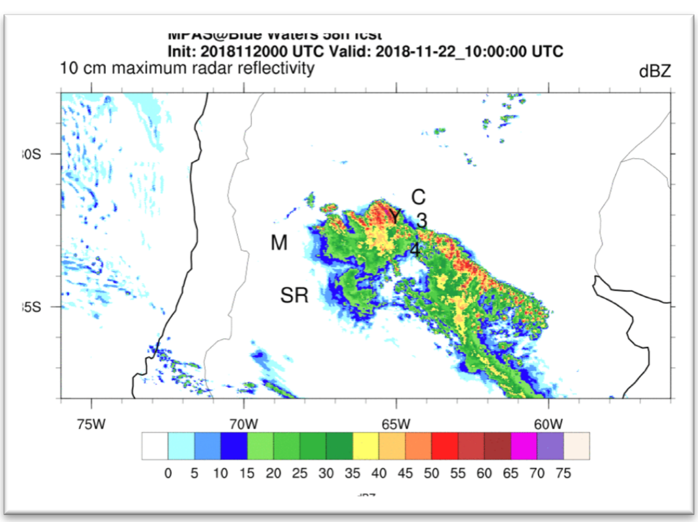
*Why Blue Waters***:** The relatively small size of thunderstorms, coupled with their episodic occurrences, necessitates research approaches that can account for temporal scales from decades to minutes, and spatial scales of thousands of kilometers to hundreds of meters. In other words, we require very large geospatial domains that have fine gridpoint 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.

Accomplishments: As noted**,** three subprojects were pursued in 2018. The first involved a large suite of idealized thunderstorm simulations using Cloud Model 1 (CM1) run at high resolution (125-m grid lengths). The second involved the Weather Research and Forecasting (WRF) model for the study of hail storms. And the third featured an implementation of the Model for the Prediction Across Scales (MPAS) to study the long-range predictability of thunderstorms in Argentina.

The first subproject focused on simulations of supercell thunderstorms, a highly organized convective-storm morphology that most readily allows quantification of the key processes of updraft, downdraft, and surface-based cold pool. By selectively varying the vertical profile of temperature, humidity, and especially wind in the initial (and environmental) conditions, we were able to control the updraft width in the resultant storm. Updraft width, in turn, controls downdraft width and thence the depth of the surface-based cold pool. We were able to explain this coupling of updraft–downdraft–cold pool through analyses of the dynamical properties of the convective storm. There are two key implications of these results. The first is that significant improvements can be made to convective-parameterization schemes by incorporating this effect of environmental vertical wind shear. The second is that, considered in isolation, a projection of weaker vertical wind shear in future climates suggests a corresponding decrease in convective-draft width. Additional experiments and analyses will help us understand how this effect would be modulated by projected increases in temperature lapse rates and associated convective available potential energy.

The second subproject provides a new assessment of the effect of climate change on the frequency and intensity of hail within the U.S. This assessment required a consideration of a range of physical processes and scales, including: the degree of forcing of the hail-generating convective storms and the frequency of their initiation; the storm volume over which hail growth is promoted; and the depth of the lower atmosphere conducive to melting. Here we used high-resolution (convective-permitting) dynamical downscaling to simultaneously account for these effects. We found broad geographical areas of increases in the frequency of large hail (≳ 35 mm diameter) over the U.S., during all four seasons. Increases in very large hail (≳ 50 mm diameter) are mostly confined to the central U.S., during spring and summer. And, although increases in moderate hail (≳ 20 mm diameter) are also found throughout the year, decreases occur over much of the eastern U.S. in summer. Such decreases are clearly promoted by a decrease in convective-storm frequency. Overall, the annual U.S. hail season is projected to begin earlier in the year, be lengthened by more than a week, and exhibit more interannual variability in the future.

The final subproject involves long-range predictions with the Model for the Prediction Across Scales (MPAS), which we are using in part to support the real-time operations of the RELAMAGO field campaign. MPAS is a new global, non-hydrostatic model that also allows for local grid refinement. Because MPAS is a global model, it is well suited for extended range predictions. A configuration detail of particular relevance is the specification of 3-km gridpoint spacing over South America, with 15-km gridpoint spacing elsewhere around the globe. The 3-km spacing is considered to be “convection allowing”, and thus we are effectively able to resolve thunderstorms over large domains. The adjacent figure shows one example, and more can be found at the



following link: http://catalog.eol.ucar.edu/relampago/model/uiuc_mpas

For reference, RELAMPAGO is a major, NSF-sponsored, and UIUC-led campaign to study extreme thunderstorms in Argentina:

https://www.nsf.gov/news/news_summ.jsp?cntn_id=296639&org=NSF&from=news

The project was also featured in a *Nature* news article:

https://www.nature.com/articles/d41586-018-07268-2

The "convection-allowing" forecast guidance from MPAS has been critical in the data-collection decision making. These runs are also being used to understand the extended predictability of severe thunderstorms in regions of complex terrain. Ultimately, the MPAS model runs will be used to aid in my investigations of the connections between thunderstorms and modes of internal climate variability.

List of publications

Trapp, R. J., G. R. Marion, and S. W. Nesbitt, 2018: Reply to "Comments on 'The regulation of tornado intensity by updraft width'". *Journal of the Atmospheric Sciences,* **75**, 4057–4061.

Marion, G. R., and R. J. Trapp, 2018: The dynamical coupling of convective updrafts, downdrafts, and cold pools in simulated supercell thunderstorms. *Journal of Geophysical Research-Atmospheres*, in revision.

Trapp, R. J., K. A. Hoogewind, S. G. Lasher-Trapp, 2018: Projected increases in hail occurrences in the United States determined through convective-permitting dynamical downscaling. *Journal of Climate*, in review.

Plan for Next Year

With the help of NCSA staff, we have invested considerable time and effort in the deployment of MPAS on Blue Waters. The MPAS runs for RELAMPAGO have been hugely successful, and we plan to conduct additional runs in an off-line mode for other periods, to help us understand long-term predictability. Also, MPAS 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. We plan to conduct experiments in which we modify Arctic sea ice extent, and then investigate this effect on the midlatitude circulation and storm forcing. Finally, we will complete the other subprojects initiated in 2018, including the idealized modeling of convective storms, and the investigation of hail (and other severe weather) under climate change; in fact, we will be submitting a grant proposal to the NSF next month to support this research.

My current Blue Waters Professor allocation should be sufficient for all of this proposed work.