DI

TN

CI

FS

BI

SIMULATING THE MOST DEVASTATING THUNDERSTORMS: BIG TORNADOES AND BIG DATA

Allocation: NSF PRAC/3,630 Knh
PI: Leigh Orf[1]
Co-PI: Catherine Finley[2]
Collaborators: Bruce Lee[3], Robert Wilhelmson[4]

[1]University of Wisconsin-Madison
[2]St. Louis University
[3]High Impact Weather Research and Consulting, LLC
[4]University of Illinois at Urbana-Champaign

EXECUTIVE SUMMARY

Tornadoes are among the most violent atmospheric phenomena, creating winds that can exceed 300 miles per hour. Supercells, long-lived rotating thunderstorms that often track across the Central/Midwest/Southeastern United States in the spring and fall, produce the strongest tornadoes. Currently, very little is known about what causes and supports the strongest tornadoes. In our work on Blue Waters, we have simulated several supercell thunderstorms that produce long-lived EF5 (the strongest category on the Enhanced Fujita scale) tornadoes. Data from these simulations, which will take years to fully analyze, have been saved as frequently as every model timestep, allowing for novel postprocessing and analysis approaches. Results thus far indicate features embedded within the storm's cold pool (including the newly identified streamwise vorticity current) help strengthen the storm's updraft very near the ground, supporting the formation and maintenance of long-lived tornadoes.

RESEARCH CHALLENGE

Tornadoes kill many people every year across the world, but the strongest, longest-lived tornadoes occur in the United States, where hundreds of fatalities and serious injuries can result from a single tornado such as in Joplin, Missouri, in 2011, which was also the costliest tornado in U.S. history. Currently, forecasters are unable to predict with any skill these kinds of tornadoes in advance. Our research aims to understand the inner workings of the most powerful tornado-producing thunderstorms in order to better forecast their behavior. The long-term goal of our work is to provide accurate forecasts of these types of storms (as well as less damaging storms) in order to provide ample time for the public to find shelter, and to reduce the high tornado-warning false alarm rate (about 70%) that currently plagues the National Weather Service in the United States.

METHODS & CODES

We used the CM1 cloud model developed at the National Center for Atmospheric Research, a model designed from the ground up to run efficiently on massively parallel distributed memory supercomputers. However, the PI rewrote the I/O driver completely in order to facilitate the frequent saving of large amounts of model output data. This process resulted in a file system (LOFS) and associated tools to read back and convert data to widely supported formats such as netCDF.

RESULTS & IMPACT

The breakthrough supercell thunderstorm simulations we have conducted on Blue Waters are the first of their kind, containing devastating tornadoes lasting over an hour and a half. The PI has created hours of high-definition visualizations of model data, much of which has been shared on a YouTube channel dedicated to this research.

The identification of the streamwise vorticity current (SVC) in model data has had a big impact in the field of mesoscale meteorology. Efforts are underway to identify the SVC in field studies of supercells. The formation of the tornado, and its subsequent tracking for over an hour and a half, appears to be supported by the SVC and other features in the storm's cold pool along its forward flank. The LOFS file system has enabled us to save data as frequently as every model timestep, and we have saved 90 minutes of data every 1/6 second covering the formation, maintenance, and dissipation of the tornado in one of our simulations. Saving every model timestep to disk opens the door to novel ways of postprocessing and analysis that normally require the model to be running at full scale on a supercomputer. Our approach allows such analysis to be conducted "offline" on much more modest hardware. We are going to use GPU technology to trace millions of particles throughout the saved data and to visualize the data in novel ways. We have recently begun experimenting with creating temporally averaged data from saved 1-second data that reveals the scientifically important persistent forcing features while "smoothing out" the more transient features. The PI uploads "live" video presentations of his research to YouTube and these talks have collectively received tens of thousands of views. Other videos involving the PI and his research have received hundreds of thousands of views.

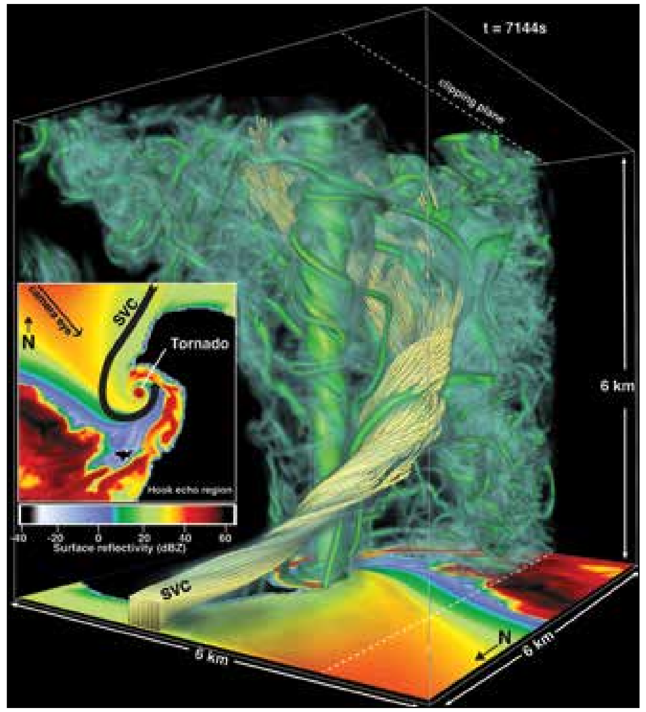

Figure 1: The streamwise vorticity current is comprised of cool air embedded within the storm's forward flank cold pool. It is associated with a drop in pressure 1-2 km above ground that results in a very strong low-level updraft that appears to initiate and maintain a long-lived EF5-strength tornado.

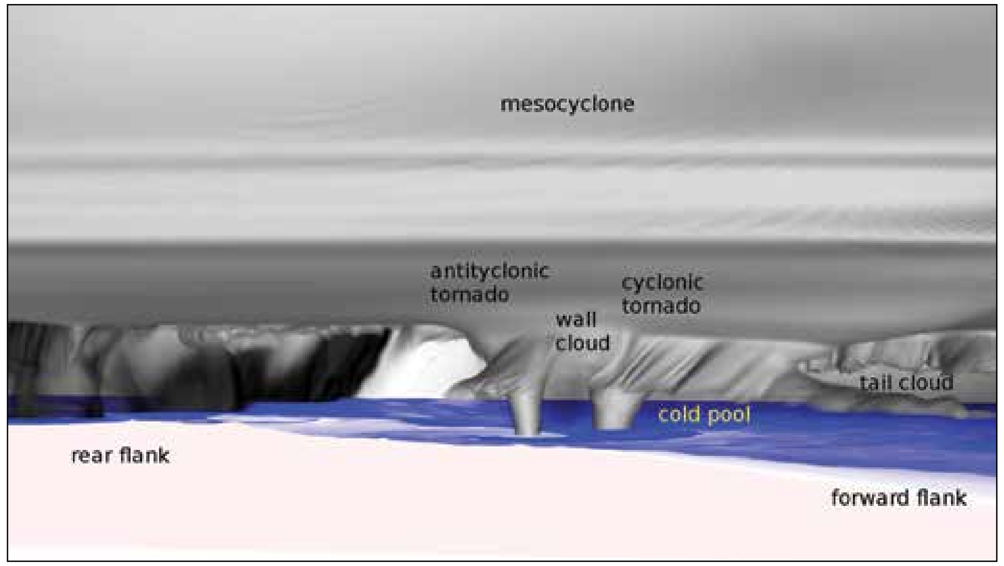

Figure 2: Volume rendered cloud and rain fields for a 15-meter simulation. At this time, two counter-rotating tornadoes descend from the wall cloud beneath the storm's mesocyclone. The storm's cold pool, crucial to the storm's morphology, is indicated at the surface by shades of blue.

WHY BLUE WATERS

In order to simulate thunderstorms at resolutions where features such as tornadoes are properly resolved, a machine like Blue Waters is needed. Our most modest simulations (30-meter grid spacing) contain over 1.8 billion individual grid elements to resolve the storm, and simulations using 15-meter grid spacing required more than 18 billion elements. Beyond having the computational power to conduct a given simulation, dozens of simulations were conducted in order to get a feeling for the sensitivity of simulation results to initial conditions and model parameters. Finally, the amount of data produced by these simulations is astounding—each simulation producing on the order of 50–100 TB, with the highest-resolution simulations creating closer to half a petabyte of data.

PUBLICATIONS & DATA SETS

Shapiro, A., S. Rahimi, C.K. Potvin, and L. Orf, On the Use of Advection Correction in Trajectory Calculations. *J. Atmos. Sci.*, 72 (2015), pp. 4261–4280.

Orf, L., R. Wilhelmson, and L. Wicker, Visualization of a simulated long-track EF5 tornado embedded within a supercell thunderstorm. *Parallel Comput.*, 55 (2016), pp. 28–34.

Orf, L., et al., Evolution of a Long-Track Violent Tornado within a Simulated Supercell. *Bull. Am. Meteorol. Soc.*, 98 (2017), pp. 45–68.

Li, S., et al., Spatiotemporal Wavelet Compression for Visualization of Scientific Simulation Data. *2017 IEEE International Conference on Cluster Computing (CLUSTER)*, pp. 216–227.

Frank, L.R., V.L. Galinsky, L. Orf, and J. Wurman, Dynamic Multiscale Modes of Severe Storm Structure Detected in Mobile Doppler Radar Data by Entropy Field Decomposition. *J. Atmos. Sci.*, 75 (2017), pp. 709–730.

Orf, L., The use of ZFP lossy compression in tornado-resolving thunderstorm simulations. *2017 AGU Fall Meeting* (New Orleans, La., December 11–15, 2017).