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SIMULATING THE MOST DEVASTATING TORNADOES EMBEDDED WITHIN SUPERCELL THUNDERSTORMS

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EXECUTIVE SUMMARY

Supercell thunderstorms produce the strongest, longest-lived tornadoes, ranked EF4 or EF5 on the Enhanced Fujita Scale. While such tornadoes are uncommon, they cause the vast majority of fatalities and damage. Forecasting such tornadoes requires a deeper understanding of supercell thunderstorms. We have simulated several EF5 tornadoes embedded within supercell thunderstorms at resolutions up to 15 meters, revealing flow features that greatly enhance our current understanding of tornado formation and maintenance. Interactions between the storm's cold pool and updraft create and reorganize vorticity (spin and shear) in such a way as to concentrate it into streams and sheets that help initiate and maintain the EF5 tornado.

RESEARCH CHALLENGE

Tornadoes embedded within supercell thunderstorms create the strongest winds found in nature at the earth's surface. Accurate forecasting of tornado behavior is of great benefit to millions of people who live in tornado-prone regions, such the Great Plains of the United States. However, the process of tornado formation, maintenance, and decay remains elusive to scientists. Our work aims to explore the factors involved in the creation within supercell thunderstorms of the strongest, most long-lived tornadoes.

METHODS & CODES

We used the CM1 model, developed at the National Center for Atmospheric Research. We modified the output driver of the model in order to enable efficient, memory-buffered, high-frequency, lossily compressed floating point HDF5 output, and wrote middleware to read, convert, and visualize raw model output utilizing techniques that included volume rendering and trajectory clouds. We explored different environmental conditions, and the most promising environments were simulated at extremely high resolution, resulting in EF5 tornadoes.

Model data are not currently published online; however, several scientific talks in video format, including model visualizations, may be found at http://orf.media. The code written thus far is on a private github server; we intend to make the code available to the public toward the end of this allocation.

RESULTS & IMPACT

Every year Americans die from tornadoes, despite attempts to warn the public of severe weather before it occurs. Our ability to forecast tornado behavior is limited by our current knowledge of how tornadoes form, are maintained, and decay in supercell thunderstorms. The focus of our research is on the most devastating, long-lived tornadoes embedded within supercell thunderstorms. We have simulated dozens of supercells at ultra-high resolution, and some of these supercells form long-lived EF5-strength tornadoes. These simulations have revealed newly identified flow features such as the streamwise vorticity current (SVC), a primarily horizontally oriented, helically flowing "tube" of rain-cooled air that is tilted vertically into the supercell's updraft. The SVC helps maintain the updraft's vigor near the ground, which appears to force tornado formation and assist in its maintenance.

WHY BLUE WATERS

In order to capture flow features that are critical to tornado formation, maintenance, and decay, the atmosphere must be resolved at extremely high resolution. As the resolution of the model is doubled, it requires approximately 16 times more computing resources. Our highest-resolution simulations (at 15-meter grid spacing) utilized 360,000 Blue Waters cores, or roughly half of the machine. Further, extremely high memory, communication, and I/O bandwidth were essential in these simulations, something which is not currently sufficient with XSEDE resources, much less cloud resources.

PUBLICATIONS AND DATA SETS

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.

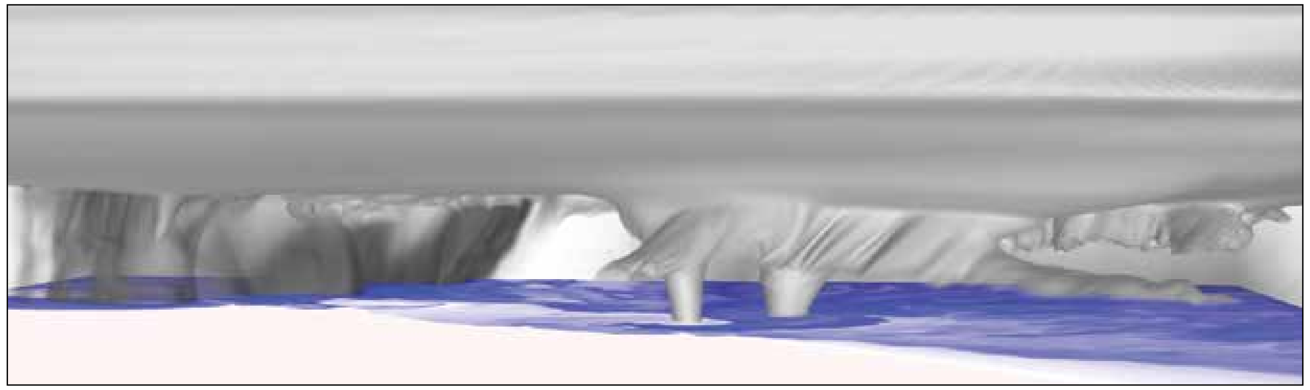

Figure 1: A short-lived anticyclonic tornado (left) adjacent to the long-lived cyclonic EF5 tornado (right), as seen in the volume-rendered cloud field of a 15-meter resolution simulation. The cloud field also reveals a wall cloud and tail cloud, features commonly observed in the field. Rain is visible as a dark grey field and is most prominent in the rear flank of the supercell (left half of image). The cold pool is represented by the surface buoyancy field where the coldest air is dark blue.