Understanding the Development and Evolution of Violent Tornadoes in Supercell Thunderstorms

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Blue Waters Symposium
Sunriver, OR
June 5, 2018
The problem

- Supercell thunderstorms produce the strongest tornadoes (Joplin, MO; Moore, OK; Greensburg, KS; El Reno, OK).
- We still don’t understand why a very small subset of supercells produce long-path tornadoes producing surface winds in excess of 200 mph.
- Worse yet, we don’t really understand the processes leading to tornadoes in general; around one quarter of supercells are observed to produce tornadoes at all.
- Overarching goal: To understand the internal workings of nontornadic, weakly tornadic, and strongly tornadic supercell thunderstorms well enough to significantly improve our forecasting of supercell behavior.
Why it matters

- Currently the National Weather Service has a false alarm rate for tornado warnings of about 70%.
- There are cases also where no warnings is given, and yet a tornado occurs.
- Large majority of fatalities occur in EF4-EF5 strength tornadoes, which is why we are first focusing on simulating these rare, powerful storms.
- Despite advances in observational and computational meteorology, why some supercells produce no/weak/strong tornado is not currently understood.
Breakthrough tornado simulations

- Our team first accessed Blue Waters during the friendly user period
- Initially work focused on modifying the CM1 model code to improve I/O performance and an efficient visualization framework
- It was only at the very end of our first allocation in 2013 that we managed to simulate a supercell that produced a long-track EF5
- After some bumps in the road we managed to get good datasets with frequently saved data
Recent work

- We have simulated the 24 May 2011 EF5 tornado producing supercell at 30, 20, and 15 meter grid spacing.
- Along the way I created a file system (LOFS) to manage all this data, utilizing HDF5 files and ZFP lossy floating point compression.
- Our most impressive dataset is 67 TB, containing 32,400 times - saved *every model time step* throughout the entire life of the EF5 tornado.
Recent work

- In addition to saving datasets with up to 1/6 second temporal resolution, we have also done temporal averaging of fields to reveal the persistent flow features, while “averaging out” the more sporadic ones.

- A new theory for tornadogenesis is emerging where no downdraft “trigger” in the rear flank is required, and where there is no real distinction between genesis and maintenance.

- The fantastic simulation, the spatial and temporal resolution of the saved data, and the subsequent visualizations make this “breakthrough” work that only could have happened with long term access to a machine like Blue Waters.
Key challenges

1. Getting the model to create the desired storm
2. Managing data - consider that the datasets we have created will be analyzed for many years
3. Making sense of the simulation - we have thus far focused primarily on 3D visualization to “tell a story” before we decide what quantitative techniques to apply to the storm
Accomplishments/Broader Impacts

- Simulations are having an impact on the severe storms community
- Field programs are being conducted that involve looking for the newly identified streamwise vorticity current (Orf et al. 2017)
- CADENS / AMNH / lots of other PR
- Several journal articles, five grad students working on data
- Hundreds of thousands of views of animations on YouTube

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Vorticity magnitude

SVC

Looking north

Every model time step

shaded by wind speed

shaded by w

10X
Vorticity magnitude

Looking west

shaded by w

SVC

Every model time step
Fields are temporally averaged over 2 min in 1 s intervals.
Vorticity magnitude shaded by zeta

Red = cyclonic
Blue = anticyclonic

Looking north

Forward Flank

Rear Flank
Updrafts can tilt (and stretch) near-surface horizontal vorticity to create intense vertical vorticity.
Comparing simulation data with observations
Multiple vortices
Subtornadic vortices
Parting thoughts

- Blue Waters has enabled breakthrough science in supercell/tornado modeling
- The tremendous amount of cloud model data produced on Blue Waters will be analyzed beyond Blue Waters - providing the motivation to take great care in massaging and curating data
- Our team is working on postprocessing/visualization code utilizing (massively parallel) GPU technology
- The portability of the LOFS data will enable us to do analysis on current and future supercomputers
Acknowledgments

Collaborators on this project: Catherine Finley (Co-PI), St. Louis University; Bruce Lee, High Impact Weather Research and Consulting, LLC; Robert Wilhelmson, University of Illinois; Austin Dixon, University of Wisconsin; Kelton Halbert, University of Wisconsin. This work is supported by NSF grants OAC-1614973, OAC-1663954, OAC-1550405 and the Space Science and Engineering Center (SSEC) at the University of Wisconsin.

This research is part of the Blue Waters sustained-petascale computing project, which is supported by the National Science Foundation (awards OCI-0725070 and ACI-1238993) and the state of Illinois. Blue Waters is a joint effort of the University of Illinois at Urbana-Champaign and its National Center for Supercomputing Applications.
Thank you!

See http://orf.media for more Questions?