Annual Report for Blue Waters Allocation: Sonia Lasher-Trapp, Oct 2018

Project Information: Untangling Entrainment-Precipitation Interactions in Deep Convective Clouds

- Sonia Lasher-Trapp, UIUC, slasher@illinois.edu

- Executive summary (150 words)

New high-resolution 3D simulations of convective storms run on Blue Waters are being used to untangle the intricate web of connections between entrainment (the introduction of dry air from outside the cloud inward by its own motions), precipitation, and the associated storm outflow that can force new storm generation. High resolution is required to study the interactions of the small-scale turbulent motions (responsible for entrainment), precipitation processes, and the latent heating/cooling they provide.

Our latest results suggest: (i) Storms growing in an environment where the winds increase strongly with height entrain ~3 times more dry air than storms growing in an environment with weak winds; and (ii) the precipitation-generated storm outflows are most dependent upon the amount of “graupel” (large ice particles) that sublimate or melt (cooling the air in the outflows), which also potentially increases rainfall and its evaporative cooling of the outflows.

Description of research activities and results

- Key Challenges: As our work has evolved from studying entrainment in single cumulus clouds, to now in individual storms or groups of storms, we have had to expand our model domains to much larger sizes, while trying to keep grid spacing small (200 m and less) to properly represent the smaller turbulent eddies in the cloud motions responsible for entrainment. Thousands of processors are required to divide up the calculations into manageable segments. These deeper storms also have more competing precipitation processes that must be represented in greater detail, thus requiring more memory to store these additional variables while the model is run, and more disk space to output and analyze the high-frequency model data output.

- Why it Matters: Large-scale weather and climate models have inadequate spatial and temporal resolution to model cumulus entrainment, and thus rely on parameterizations that assume a particular underlying conceptual model of entrainment. Our work is helping to acquire fundamental knowledge to improve this conceptual model of how entrainment operates in storms, and its effects upon the precipitation they produce, and the ability of the storm outflows to generate new storms. Our results can then form the basis for improved parameterizations used in larger scale models to predict weather and climate.

- Why Blue Waters: The Blue Waters architecture, speed, and storage is essential for resolving and analyzing the turbulence and precipitation processes at the heart of these fundamental problems. Blue Waters is allowing us to push the spatial and temporal scale limits much farther than in past studies in the formal literature, with
its huge number of nodes, its high speed, and its large storage capability for high-resolution model output and analysis. The hardware needed to run these simulations quickly supersedes the limits of most computers. A variety of data analysis tools for the large data sets we create are available and easy to use with Blue Waters, and the support staff is quickly responsive and supportive of users having any issues with their computational work on Blue Waters.

• **Accomplishments:**
  - We have simulated developing and mature supercell thunderstorms to study how their entrainment differs in the early versus mature stages (Fig. 1), and in environments with different vertical wind structures. Developing thunderstorms growing in an environment where the winds increase strongly with height (called vertical wind shear) entrain more dry air than storms developing in an environment with no wind shear (Fig. 2). When integrated over the entire developing stage, the total entrainment is over 3 times greater in the environment with vertical wind shear. Although weather forecasters have often observed that storm development is initially slower in an environment with wind shear, this is the first study to quantitatively show the inhibiting effects of entrainment on the initial storm development. The graduate student performing these simulations completed his M.S. in Summer 2018, and is gainfully employed in the private sector.

*Figure 1. A 3D snapshot of a supercell thunderstorm simulated on Blue Waters using VisIt. Brighter colors (greens, aqua) represent greater amounts of water/ice in the storm. The high resolution of the BW simulations (here run at 100 meters) enable the direct representation of more turbulent motions that are responsible for the entrainment.*
Figure 2. Comparison of the horizontally averaged, instantaneous, vertical profiles of entrainment at 4 different cloud top heights (~3.5 km upper left; ~5 km upper right; ~6 km lower left; ~6.5 km upper right) during the developing stage, for a storm environment with no wind shear (blue), and one with strong vertical wind shear (red). When integrated over all heights and all times up to when the cloud tops reach 6 km, the entrainment is more than 3 times greater in the storm developing in the environment with strong vertical wind shear.

- We have also simulated isolated thunderstorms to investigate what latent cooling process (e.g. evaporation of rain, melting of graupel and/or hail, and sublimation of graupel and/or hail) contribute most to the thunderstorm outflows that generate “pools” of cold air at the ground (Fig. 3) that can promote new generations of thunderstorms on their boundaries. As opposed to other studies run at coarser resolution and only having analyzed the lower parts of the storms, we have found that graupel appears to be most important for producing and maintaining the cold pool (Fig. 4). However, the rate of propagation of the cold pool outflow appears to be more correlated with the
amount of rain evaporating in the lowest part of the outflow (correlation coefficient = 0.94). These results are being written for publication in the peer-reviewed literature, and have implications for understanding longer-period outbreaks of thunderstorms. The graduate student performing these simulations completed her M.S. in Summer 2018, and has decided to stay at the University and pursue a Ph.D., to follow up on related topics and increase her experience with high-performance scientific computing.

Figure 3. Simulated radar reflectivity at 1 km above the ground (top) and cold pool at the surface (bottom; in units of °C) for the control simulation.
Figure 4. The contribution of various precipitation latent cooling terms to the cold pool, for the control run (top) and 9 other simulations with small variants on different precipitation processes (relating to the amount of rain, graupel or hail produced). In all cases, the sublimation of graupel (conversion from ice to vapor state) dominated in the downdraft forming the cold pool, as opposed to previous studies in the literature.

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

**Presentations:**


Microphysical Influences on Cold Pools. Holly Mallinson, Department of Atmospheric Sciences, University of Illinois, Urbana, IL, May 1 2018.

An Investigation of Entrainment in Developing Thunderstorms with High-Resolution Numerical Simulations. Bryan Engelsen, Department of Atmospheric Sciences, University of Illinois, Urbana, IL, April 17 2018.

Publications:


Other products:

The results of our Blue Waters simulations are also being used in Prof. Lasher-Trapp’s undergraduate and graduate courses on Clouds and Precipitation Physics.

- Plan for next year

I am requesting an approximately 10% larger allocation to that received last year: 300,000 node-hours on Blue Waters, due to an increased number of runs needed to
explore a larger parameter space to continue our project: Untangling Entainment-Precipitation Interactions in Deep Convective Clouds

Executive Summary: Entainment describes how clouds bring dry air from outside the cloud inward, by their own motions. Its effects can limit storm development, longevity, and various interdependent microphysical processes that ultimately govern the precipitation produced. Our understanding of the connections between entrainment and precipitation has been limited by inadequate model resolution in past studies. New high-resolution 3D simulations of convective storms in environments spanning a range of thermodynamic and wind conditions will be run on Blue Waters, along with our entrainment quantification algorithms, to untangle the interactions between entrainment and precipitation processes, with the ultimate goal of increasing our fundamental knowledge of this interaction that can be used to improve forecast models of thunderstorms and the precipitation they produce. In our second year of funding from an NSF grant to study this topic using Blue Waters, we have made significant progress as discussed above in the past year, but continue to require a computer like Blue Waters to expand this work and explore a larger parameter space.

Scaling the runs conducted on BW over the past year to those planned for this project (to be run using the same CM1 model, with similar resolution but over a much wider parameter space thus necessitating many more simulations), we anticipate needing a 10% higher allocation than last year. The few (less than 10), highest resolution runs will require over 10,000 node-hours to run, but the majority of the runs will require on the order of 5000 node hours or less. This allocation will be split among 3 graduate students (2 new students will be trained to work on Blue Waters this fall), and myself, to study the details of how entrainment of dry air into the storm alters the microphysical processes within it, ultimately affecting precipitation at the ground.

We also require an increase (doubling) in our storage quotas on Nearline, as we cannot yet clear off some of the older simulation results that are needed for comparison to the new simulations. I will scale the anticipated usage schedule according to the timeframe in which the students will be “ramping up” within my research group. Expressing this per quarter as a percent of the requested allocation, we anticipate the following usage: Q1: 15%, Q2: 25%, Q3: 35%, Q4: 25%.