2021 Blue Waters Professor Allocation: Sonia Lasher-Trapp

Project: Thunderstorm Entrainment and Cold Pool Effects

- Research accomplished on Blue Waters during 2020

We continue to perform high-resolution 3D simulations of supercell thunderstorms to quantify entrainment (the introduction of dry air from outside the cloud inward by its own motions, and the effects on the precipitation produced. High resolution is required to study the interactions of the small-scale turbulent motions (responsible for entrainment, on the order of tens of meters) and precipitation processes (involving millimeter-scale particles and smaller).

Building on our prior work, we have discovered a new mechanism of entrainment in supercell thunderstorms: “ribbons” of horizontal vorticity that wrap around the counter-clockwise rotating updraft and introduce air periodically into the thunderstorm core (Fig. 1). Graduate student Enoch Jo was awarded the “Audience Choice Best Oral Presentation” of this work during the European Conference on Severe Storms. Current estimates are that this mechanism is responsible for approximately 30% of the air brought into the storm core, and reduces the amount of precipitation that the storm could otherwise produce. We hypothesize that the presence and/or strength of these vorticity ribbons will depend upon the change in the vertical winds with height on a given day. Our remaining allocation for 2020 is being used to evaluate this hypothesis for a variety of different wind profiles in the storm environment.

In 2020, we have also studied the differences in entrainment during the developing stage of thunderstorms (i.e., before the storm cores rotate like seen in Fig. 1), in environments with different wind profiles. As shown in Figure 2, a very clear relationship is evident in that increased changes in the vertical wind with height (called “vertical wind shear”) clearly scale with entrainment during the developing stages of the storms, and helps to explain why some storms never develop on days with very strong wind shear. Graduate student Luke Allen successfully completed this project in Summer 2020 to earn his M.S. degree. A publication is currently in preparation.

We note here that only ~ 50% of our 2020 allocation will likely be used by the end of the calendar year. We understand that Blue Waters computational time is precious, and that some Illinois investigators’ requests had to be declined last year due to limited resources. But I hope the evaluation committee can appreciate that 2020 has not been a normal year. Graduate student morale, mental health, and motivation severely declined once the pandemic struck in Spring 2020, after which time students were isolated in their respective tiny apartments/ dorm rooms with no opportunities for social interaction. The two graduate students who were to use the 2020 allocation, while making some progress, did not nearly accomplish what we had set out to do.

Each of the graduate students who will perform work under the 2021 allocation now have a better support system in place, and are currently being very productive. So I believe this impediment to our progress has now declined significantly, and we are set to have a productive 2021.
Figure 1. Top: Three-dimensional rendering of an interior part of the rotating thunderstorm core (direction of turning denoted by overlaid arrow). Shaded values of rates of entrainment (blue; winds blowing into the core) and detrainment (red; winds blowing out of the core) shown on core surface, in units of kg m$^{-2}$ s$^{-1}$. These “overturning ribbons of air” have never been found before, but may correspond to those striations sometimes seen in pictures of supercell thunderstorms (bottom picture, with direction of storm rotation implied with overlaid arrow). Adapted from Lasher-Trapp et al. (2020; in review). Bottom photo courtesy of NOAA Photo Library.
Figure 2. Top: Vertical cross-sections of the strength of the buoyancy (and thus the rate of rising air in the center of the developing storms) in three different environments: (a) weak vertical wind shear; (b) moderately-strong vertical wind shear; and (c) strong vertical wind shear. Vectors in each plot denote the storm-relative winds, where strong wind motions on the right side increase as the wind shear increases, entraining more air and making it difficult for all but the strongest storms to develop further. Bottom: vertical profiles of entrained mass of air (normalized for differences in developing storm widths) clearly show a strong dependence on the environment in which the storms are growing. The case with no winds in the environment (“NOWND”) clearly has the least entrained air, and cases with increasingly more wind shear all systematically indicate more entrainment. From Allen (2020; M.S. thesis, Univ. of Illinois).
• **Goals for 2021 allocation:**

With our 2021 allocation, we will finish our study of thunderstorm entrainment and its effects by investigating a *variety of environments with different amounts of humidity*. Specifically, we will answer how thunderstorm entrainment depends upon the environment humidity (both throughout the depth of the atmosphere, as well as when dry layers occur within the environment). We will require similar resources for this project as for the others we have already completed.

These new results will help us generalize our previous results, which is essential for understanding the overall scientific importance of entrainment to thunderstorm development and precipitation, as well as how these effects might change in the future in a changing climate.

Generalizing these results will also help improve forecasting of hazardous thunderstorms (and their precipitation), important for personal property and safety, agriculture, and infrastructure.

Our other goal for the 2021 allocation is to complete a study that grew out of our former BW work published in Mallinson and Lasher-Trapp (2019): the effects of aerosol particles in the storm environment upon thunderstorm precipitation that produces *cold pools*, large pools of cold air that can initiate new thunderstorms at their leading edges. A graduate student in our group has been analyzing observations from field work in Argentina over the past 6 months; we now require high resolution numerical simulations to test various hypotheses suggested by the field data to finish this study. We were able to easily estimate the computational resources required based on our former simulations performed on Blue Waters by graduate student Mallinson.

These results will help to improve not only our physical understanding, but also model parameterizations, of the extra thunderstorms initiated by cold pools in both numerical weather prediction models (important for daily weather forecasts) and climate models, and the role that the amount of aerosol particles in the local environment plays in this process.

• **Estimated Blue Waters usage schedule:**

*To complete all of these projects by the end of 2021, we anticipate needing a 120,000 node hour allocation for 2021.*

We have made this estimate by scaling the runs conducted on Blue Waters over the past years to those planned for 2021 (to be run using the same CM1 model), and by considering some new improvements to speed up our code, applied by graduate student Enoch Jo over the last several months.

→ If the unused portion of our 2020 allocation can be “rolled over” (we estimate still having approximately 120,000 node hours by Dec 31 2020), then we would require no additional allocation in 2021.

This allocation will be shared among 2 graduate students and myself.
I will scale the anticipated usage schedule according to the timeframe in which the students within my research group will be most active (barring any additional pandemic-related impediments). Expressing this per quarter as a percent of the requested allocation, we anticipate the following usage: Q1: 20%, Q2: 40%, Q3: 30%, Q4: 10%.

- **Plans for data migration:**

During Q4 of our allocation, we will migrate our data to (a) the NSF/NCAR supercomputer “Cheyenne” for continuation of the work if needed, and/or (b) the Illinois Data Bank for long-term storage and publishing, to share with other researchers.

- **Storage during the 2021 allocation:**

Our current storage usage suggests that 100 TB of storage (without a regular file system purge) should again be sufficient to meet our scientific needs for 2021.