Annual Report for Blue Waters Allocation: Sonia Lasher-Trapp, Oct 2015

- **Project Information**
  - ***Simulating Cumulus Entrainment: A Resolution Problem, or Conceptual?***
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- **Executive summary (150 words)**

Deep convective clouds produce the majority of the earth's precipitation, and yet it is difficult to predict if developing clouds will attain the depth and longevity required to produce heavy rainfall. *Entrainment* is the process by which clouds bring dry air from outside the cloud inward. It can initially favor precipitation formation; eventually, it dilutes the cloud and encourages its demise. It is dependent upon the thermodynamic state of the atmosphere, the vertical wind profile, and the spatial distribution of clouds. Entrainment affects cloud strength and longevity, and thus is important to understand for a variety of weather and climate-related problems, including severe weather, the global water cycle, and the radiative balance of the earth. Simulations performed on Blue Waters allow us to represent smaller scales of turbulence in our models, and to study the basic physics of entrainment.

- **Description of research activities and results**
  - *Key Challenges:* A long-standing problem in meteorology has been to reproduce how quickly entrainment dilutes a cumulus cloud. Currently, all models fail. It has long been assumed to be a problem of inadequate spatial resolution, where the smallest scales of turbulence must be parameterized and their effects are improperly represented. It could also result from a fundamental problem in our conceptual understanding of the entrainment process. Our goals are to test both possibilities. In addition, cloud interactions are known to effect entrainment. Thus an investigation of entrainment with respect to cloud spacing is also necessary.
  - *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 will help determine if that underlying conceptual model is adequate or flawed. In addition, even higher-resolution models cannot seem to model the rates of entrainment that are observed, and thus fundamental changes to the underlying conceptual model of entrainment might be necessary. It is anticipated that the results will be used to substantiate a future proposal.
  - *Why Blue Waters:* Our Blue Waters allocation is essential for testing the resolution-dependency of the entrainment process, and in particular for determining the sizes of the eddies that are most critical to represent in

simulations of cumulus entrainment. The Blue Waters supercomputer allows us to push the spatial scale limit much farther than in the past, with its huge number of nodes, its high speed, and its large storage capability for high-resolution model output and analysis. We intend to increase the resolution to as high as 5 m (over domain sizes of 10 km or greater) in order to understand any computational issues related to cumulus entrainment, in addition to improving our knowledge of the underlying physics. The hardware needed to run these kinds of simulations quickly supersedes the limits of most computers.

- *Accomplishments:* We've run simulations at relatively course (50 m) resolution, in order to see how entrainment in a single cumulus cloud differs due to basic physical parameters such as the strength of the cloud forcing, the size (width) of the cloud, and the amount of wind shear (the change in wind speed with height) in the atmosphere surrounding the cloud. We've also developed tools to quantify the entrainment that is occurring in the simulated clouds as they grow in time. As predicted from laboratory and theoretical models of thermals, narrower clouds are diluted by entrainment more quickly, helping to validate the cloud model results. However, contrary to theoretical models, weaker clouds, i.e. having weaker updrafts, also appear to be diluted more quickly than stronger clouds. This finding is perplexing, and we continue to explore related parameter spaces to determine if the result is physically viable or due to a computational artifact in cloud models. In addition, our coarse resolution simulations also suggest that particular spatial orientations of clouds may "shield" some from entrainment effects, allowing them to grow and perhaps precipitate more. Higher resolution runs are needed, however. Future comparison of the simulation results with aircraft observations of real cumulus clouds will also be key to understanding these findings, and are planned in the next year.

• List of publications and presentations associated with this work

None yet to report; a manuscript is in progress.

• Plan for next year

The small usage of my BW allocation over the past year has been primarily due to a lag in rebuilding my research group since moving from Purdue University last fall. I am currently advertising for a postdoc to help expedite progress over the next year, with new graduate students anticipated next summer/fall. I will be able to move one graduate student to using Blue Waters in January 2016. A smaller, but significant stumbling block in the past year has been my inability to produce efficient runs from the model ported from Yellowstone to Blue Waters. I am currently changing to a new model, CM1, (for this and other reasons) which has been run on Blue Waters before, and thus should expedite progress over the next year's allocation.

I thus would like to request a similar allocation as received last year: 240,000 node hours on Blue Waters. This is based on the original calculations I presented last year: the simplest runs at 50 m grid spacing would require only 8.5 node hours on Blue Waters, while the highest resolution runs at 5 m grid spacing would require 8.5 $x10^6$ node hours on Blue Waters. This latter number would actually be smaller, however, because it is likely that only 25% of the entire simulation time would require this high resolution, reducing this amount to 2.1×10^6 node hours on Blue Waters for the most extreme simulation. In reality, most runs will be in between these two extremes, as we incrementally increase the model resolution to the degree sufficient. We may never need to perform the run at 5 m resolution, but it is provided as an upper limit of the computational costs. The default storage quotas should be sufficient. I will scale the anticipated usage schedule according to the timeframe in which I hope to hire additional members to my research group, expressing this per quarter as a percent of the requested allocation: Q1: 5%, Q2: 25%, Q3: 40%, Q4: 30%.