INFLOW AND OUTFLOW FROM THUNDERSTORMS: TRACKING THEIR INFLUENCE ON PRECIPITATION AND FURTHER GROWTH

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EXECUTIVE SUMMARY

"Entrainment" describes how clouds and storms bring dry air from outside the cloud inward by their own turbulent motions. Its effects can limit storm development, longevity, and precipitation. The understanding of entrainment has been limited by inadequate model resolution in past studies. Therefore, the research team is running high-resolution 3D storm simulations on Blue Waters to quantify the interactions among entrainment, precipitation, and the generation of new storms.

The latest results suggest that: (1) The entrainment occurring in developing storms shows a dependency on grid resolution, at least down to scales of 100 meters (m); (2) mature, rotating storms do in fact continue to entrain dry air but intermittently, by features that ascend within the cores of the storms; and (3) the maintenance of thunderstorm outflows is most dependent upon the amount of large ice particles called graupel, but their speed, depth, and strength are more correlated with the amount of evaporating rain beneath the storm.

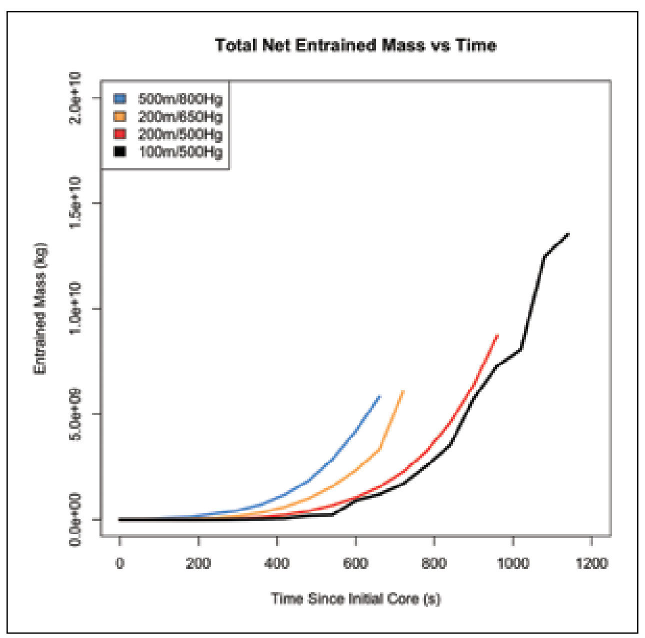

Figure 1: Time series of net mass of air entrained into the core of a developing supercell thunderstorm, for simulations conducted with increasingly smaller grid spacing (resolution) or forcing strengths (labeled). Results have essentially converged between 200-m and 100-m grid spacing, indicating the resolution of the most important turbulent scales.

RESEARCH CHALLENGE

Deep convective clouds produce the majority of the earth's precipitation, and yet it is difficult to predict if developing cumulus clouds will attain the depth and longevity required to create heavy rainfall that can produce flooding in some cases. In addition, strong winds (outflows) from some storms are capable of forcing new storms, leading to thunderstorm outbreaks that can affect society over large geographical areas. "Entrainment" is the term for the process by which the turbulent motions within clouds bring dry air from outside the cloud inward. In time, entrainment can limit storm development and its precipitation, but is not always effective in doing so. Long-standing problems in meteorological models have been to understand why they tend to predict rain formation too early, and/or in excessive amounts, and why they often miss predicting outbreaks of storms. The team's approach here is to create a new understanding of how entrainment operates in thunderstorms, to investigate if deficiencies in past models are related to poor representation of entrainment or simply insufficient resolution, and to investigate the types of precipitation that produce the strongest storm outflows that may generate new storms. This problem affects a broad range of atmospheric science problems ranging from short-term weather forecasts from numerical weather prediction models to climate forecasts from regional and global climate models.

METHODS & CODES

This work uses the National Center for Atmospheric Research's CM1 model [1] to simulate convective clouds and storms at high resolution by employing its Message Passing Interface capabilities on the many nodes available on Blue Waters. The method makes use of the NSSL microphysical scheme [2] within CM1 to model the details of precipitation formation. Simulations are conducted in both idealized and realistic environments. The team evaluates entrainment with its own code [3] that calculates mass fluxes into the core of the storm as it evolves and relates it to the amount of precipitation the storm produces. The team also uses its own code that calculates the most important melting/evaporating precipitation types that can strengthen storm outflows and potentially produce outbreaks of thunderstorms.

RESULTS & IMPACT

The latest results are providing new quantitative information that can assist atmospheric scientists researching ways to represent thunderstorm entrainment, precipitation, and outflows in larger-scale weather and climate prediction models. They will also be of use to weather forecasters. The results suggest:

- The entrainment quantified in developing thunderstorms growing in an environment where the winds increase strongly with height is indeed resolution-dependent (Fig. 1), and the team's calculations suggest that grid spacing of at least 100 m is required for accuracy.
- Although the common thinking is that mature, rotating thunderstorms do not entrain much dry air, the results are showing that they do indeed continue to entrain air (*i.e.* past the developing stage), but that the main entrainment events are transient in time and space (Fig. 2). This is a unique finding, and the team continues to explore the origin of these signatures and to quantify their overall importance to the total amount of air entrained into the storm as well as their possible effect on precipitation.
- Calculations of the contribution of different kinds of precipitation to the storm outflows have revealed that the amount of large ice particles called graupel that fall from the storm appears to be most important in maintaining them, but that characteristics of the outflow (speed, depth, strength) are more influenced by the evaporation of rain beneath the storm bases. This suggests that certain aspects of precipitation production in storms may be critical to forcing thunderstorm outbreaks.

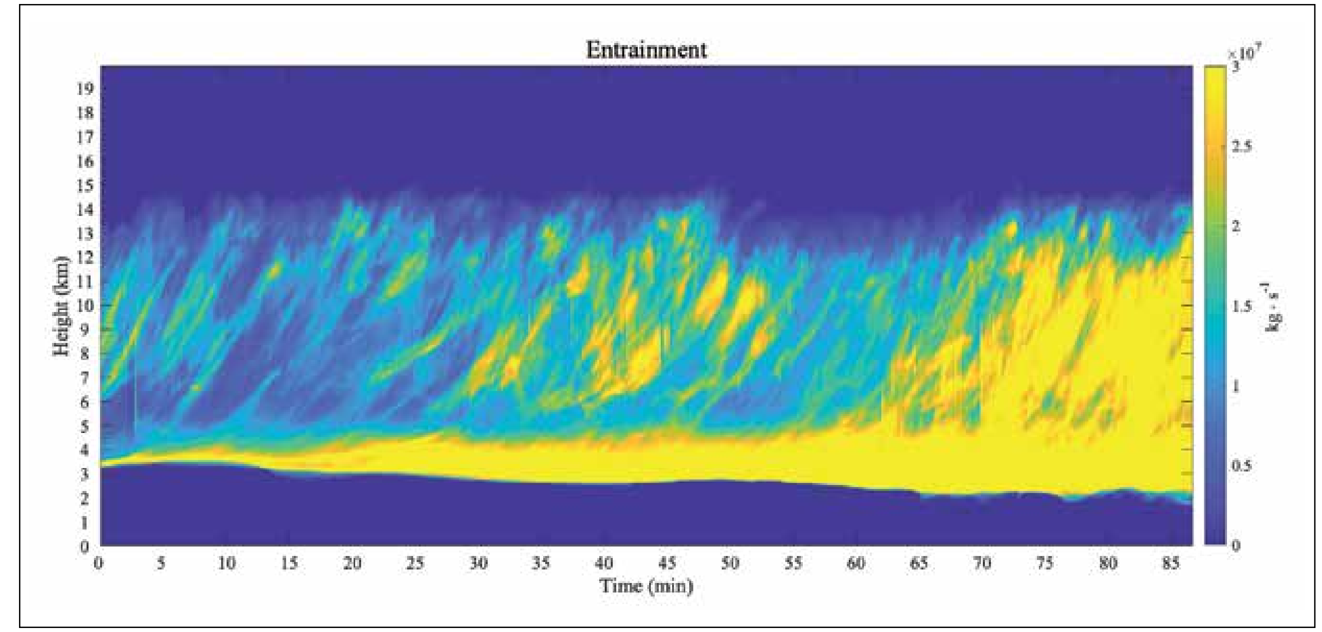

Figure 2: Time series of the rate air is entrained into a mature, rotating thunderstorm as a function of height above the ground. Maxima ascend from the lower part of the storm upward in time, which is an aspect that may contribute to pulselike behavior in its precipitation.

WHY BLUE WATERS

This Blue Waters allocation has been essential for achieving the high resolution required within a given simulation to properly represent the smaller cloud motions that are important for entrainment and precipitation development over the larger spatial and temporal domains required for thunderstorms and their outflows. As a result of its huge number of nodes, its high speed, large memory, and its large storage capability for high-resolution model output and analysis, Blue Waters enables detailed calculations to be conducted over millions of grid points. The hardware needed to run these kinds of simulations quickly supersedes the limits of most computers.

PUBLICATIONS & DATA SETS

H. Mallinson and S. Lasher–Trapp, "An investigation of hydrometeor latent cooling upon convective cold pool formation, sustainment, and properties," *Mon. Wea. Rev.*, vol. 147, no. 9, pp. 3205–3222, Sept. 2019.

D. H. Moser and S. Lasher–Trapp, "Cloud spacing effects upon entrainment and rainfall along a convective line," *J. Appl. Meteor. Clim.*, vol. 57, no. 8, pp. 1865–1882, Aug. 2018.