UNTANGLING ENTRAINMENT AND PRECIPITATION IN CONVECTIVE CLOUDS

Allocation: Blue Waters Professor/250 Knh
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EXECUTIVE SUMMARY

Internal cloud circulation patterns introduce dry air inward from outside the cloud, which is called entrainment. Its effects can limit storm development, longevity, and various interdependent microphysical processes that may ultimately produce precipitation. Our understanding of entrainment and precipitation links has been limited in the past by inadequate model resolution. We are using high-resolution 3D simulations of convective clouds and storms, along with our diagnostic entrainment algorithm, to untangle the intricate web of connections between entrainment and its effects upon the generation of precipitation. Our latest results show that closer spacing between storms along a storm line can initially delay and decrease precipitation by competing for air flowing into the cloud bases; decreases in entrainment may not appear until the spacing is so small that the storms' edges are no longer distinct. If ultimately the closer-spaced storms can generate even weak precipitation outflows, they can combine due to their proximity to produce a new generation of stronger storms that precipitate much more.

RESEARCH CHALLENGE

Deep convective clouds produce the majority of the earth's precipitation, and yet it is difficult to predict whether developing cumulus clouds will attain the depth and longevity required to produce heavy rainfall and/or become severe thunderstorms. Entrainment is the term for the process by which the circulations within clouds bring dry air from outside the cloud inward. In time, entrainment not only reduces the cloud buoyancy, limiting its vertical development, but also depletes its liquid water by evaporation, limiting precipitation formation. A long-standing problem in meteorological models has been to understand why they tend to predict rain formation too early and in excessive amounts. While others are researching what details of precipitation processes might be incorrectly represented in models, our approach is to investigate if the under-prediction of entrainment could explain the over-eagerness of the models to produce convective rainfall. 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.

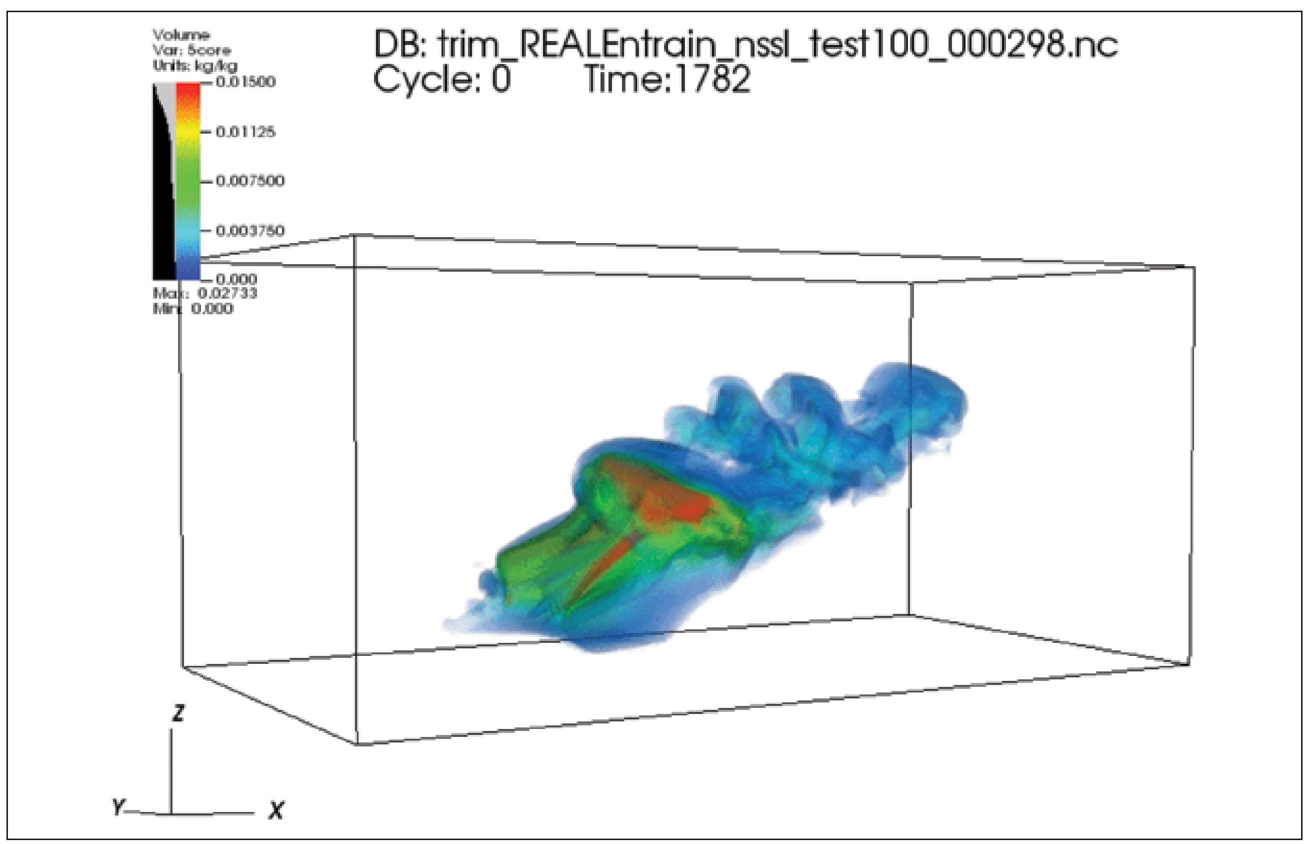

Figure 1: Visualization of the 3D core of a developing thunderstorm. Warm colors (yellow, red) denote areas of greater amounts of precipitation mass; cool colors (green, blue) denote areas with little water mass remaining. We are studying how (likely limited) entrainment resulting from the storm internal motions allows the greater precipitation mass to exist higher in the cloud. Once it falls out (not shown), the upper portions of the cloud exhibit multiple thermal circulations (nodes along the top of the storm).

METHODS & CODES

We are using the National Center for Atmospheric Research's CM1 model [1] to simulate convective clouds and storms at high resolution by employing its MPI capabilities on the many nodes available on Blue Waters. We make use of the National Severe Storms Laboratory microphysical scheme [2] within CM1. The simulations are conducted in both idealized and realistic environments. We evaluate entrainment with our own code [3] that calculates mass fluxes into the user-defined core of the cloud as the clouds and storms evolve and relate this entrainment to the ability of the clouds to produce precipitation and hail. We relate the calculated entrainment to the storm longevity and the amount of precipitation it produces.

RESULTS & IMPACT

Many atmospheric scientists have worked to try to produce parameterizations (larger-scale approximations) for cumulus entrainment, when the models they use for daily weather prediction as well as regional and global climate employ resolutions that are not high enough to represent all the cloud motions explicitly. However, these efforts are greatly hampered when we do not fully understand the process of cumulus entrainment. If more details about entrainment and its effects on precipitation can be discovered, then we will also know how best to represent its effects in larger-scale models.

We are tackling this problem using multiple approaches, including studying the process of entrainment in an individual thunderstorm at its earliest stages (Fig. 1), as well as in a line of thunderstorms.

Our latest results show that closer spacing among storms along a line can initially delay and decrease precipitation by competing for air flowing into the cloud bases; the expected decreases in entrainment for closely spaced clouds may not appear until the spacing is so small that the storms' edges are no longer distinct (and thus the storms engulf cloudy mixtures of air from surrounding storms). If ultimately the closer-spaced storms can generate even weak precipitation outflows, they can combine due to their proximity (Fig. 2) and create focal points for generating new storms that may precipitate much more heavily.

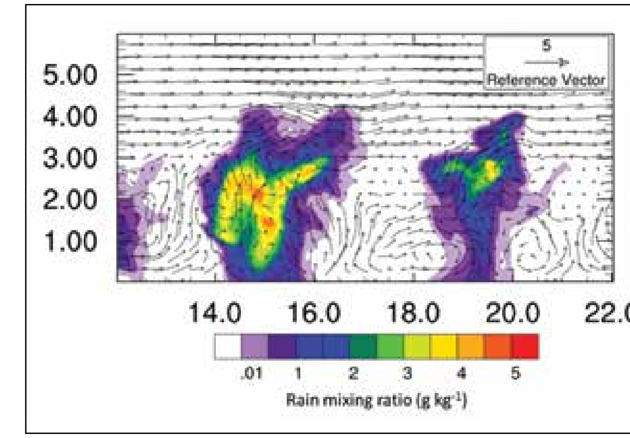

Figure 2: Vertical cross-section through a portion of a line of convective clouds that are precipitating. Rain mass indicated by color bar below; wind motions and strength denoted by direction and magnitude of plotted vectors. Rain precipitating from adjacent clouds form downdrafts that may collide near the ground to form new strong storm updrafts in between the original clouds.

WHY BLUE WATERS

Our Blue Waters allocation is essential for achieving the high resolution required within a given simulation to properly represent the smaller cloud motions that can still be important for entrainment but over the larger domains required for thunderstorms and groups of thunderstorms. Blue Waters, with its huge number of nodes, its high speed, and its large storage capability for high-resolution model output and analysis allows us to push the spatial scale limit much farther than in the past. The hardware needed to run these kinds of simulations quickly exceeds the limits of most computers. Blue Waters staff have helped us to learn new and practical ways to visualize the output for easier analysis.