Effects of under-resolved convective dynamics on squall line evolution

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1. Background

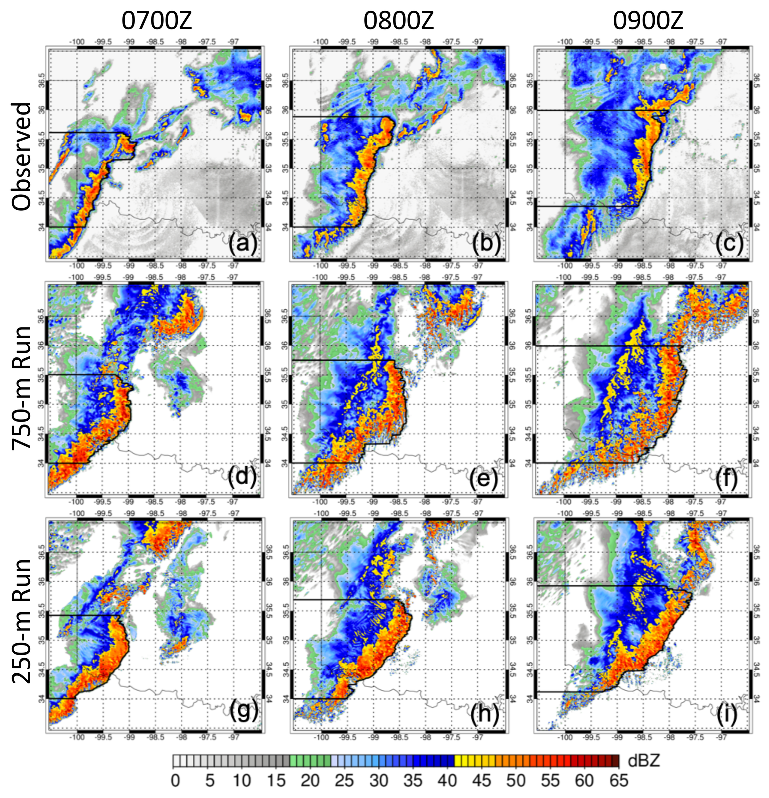
Despite all of the successes of past observational and modeling research that have led to the current advanced understanding of squall lines, a remaining question is how well cloud system resolving models (0.5-5 km) horizontal grid spacing reproduce real world sensitivities of mesoscale convective system (MCS) evolution to environmental thermodynamic and kinematic conditions. This question has become increasingly important because large domain cloud system resolving models are now being used in short-range weather forecasting, and model biases at these scales are therefore now directly impacting weather forecasts. They are also important from a climate prediction standpoint since regional climate models are now being used to anticipate how "extreme" weather such as severe deep convective events will change with the climate. At the same time, recent studies have highlighted that convective updrafts are not resolved for 0.5-km or greater horizontal grid spacing. This study seeks to begin understanding potential impacts of under-resolved deep convection on MCS evolution.

2. Methodology

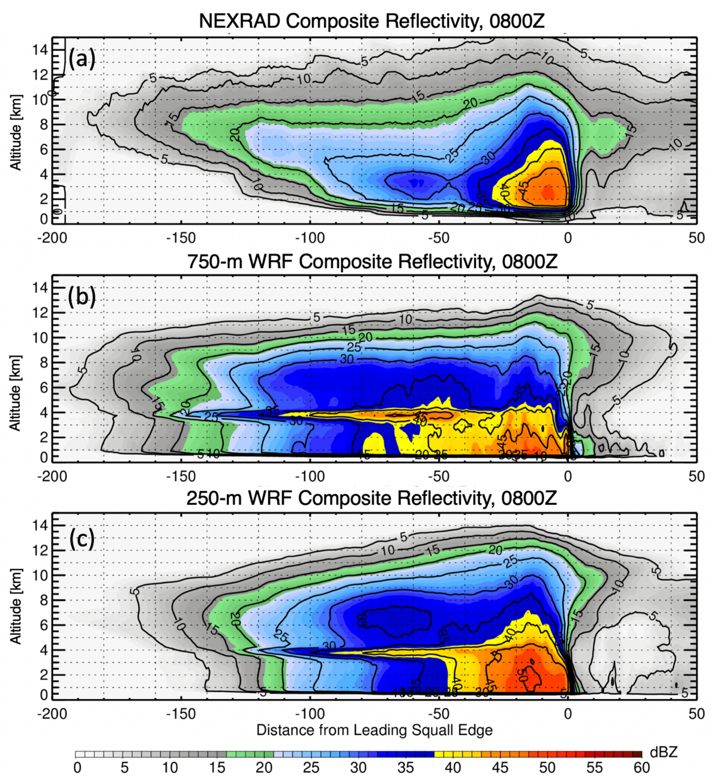
1. We evaluate the representation of precipitation structure in two WRF simulations of the 20 May 2011 squall line event during the Mid-Latitude Continental Convective Clouds Experiment (MC3E) in Oklahoma using NEXRAD radar observations. The simulations are the same apart from one having 750-m horizontal grid spacing and the other have 250-m grid spacing.
2. Biases and differences in simulated precipitation structure are then connected to differences in observed and simulated mesoscale circulations that begin during the initial stages of the squall line formation.
3. Simulated convective draft (contiguous areas with $|w| > 2$ m s^{-1} and condensate > 0.1 g m^{-3}) properties during the first few hours of deep convective growth prior to squall line formation are then compared, highlighting key contrasts between the two simulations that cause differences in the squall line evolution.

3. Comparison of Observed and Simulated Squall Line Evolution

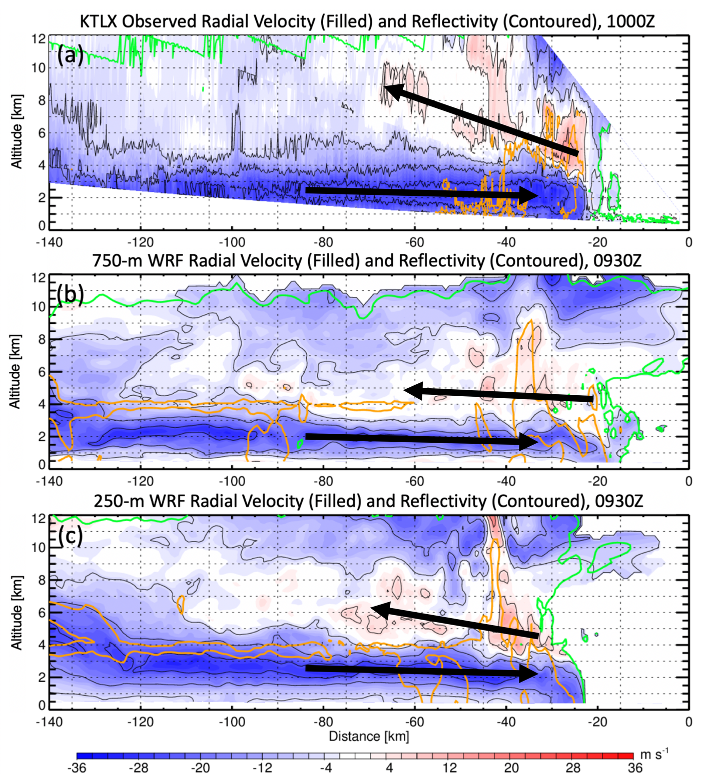
Both simulations struggle to reproduce the observed squall line orientation but the 250-m run better reproduces the observed reflectivity vertical structure, rear inflow strength and altitude, and front-to-rear (FTR) flow height.



2.5-km altitude NEXRAD observed and WRF simulated radar reflectivity evolution between 0700 and 0900Z



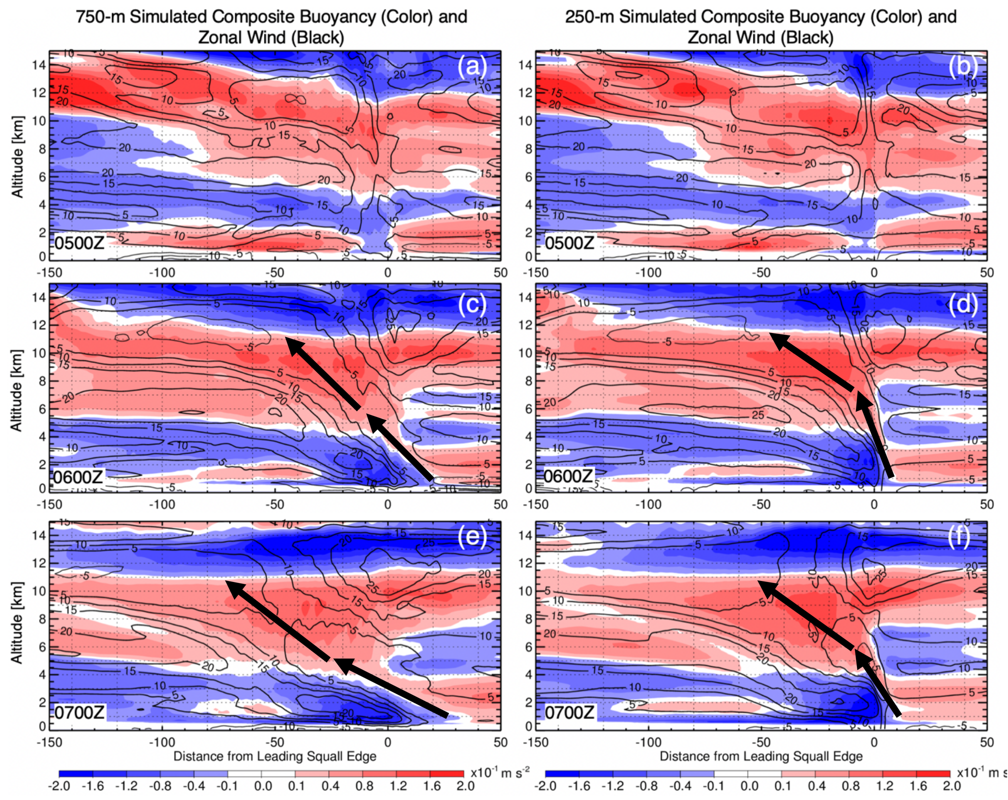
0800Z composite NEXRAD observed and WRF simulated radar reflectivity vertical structure



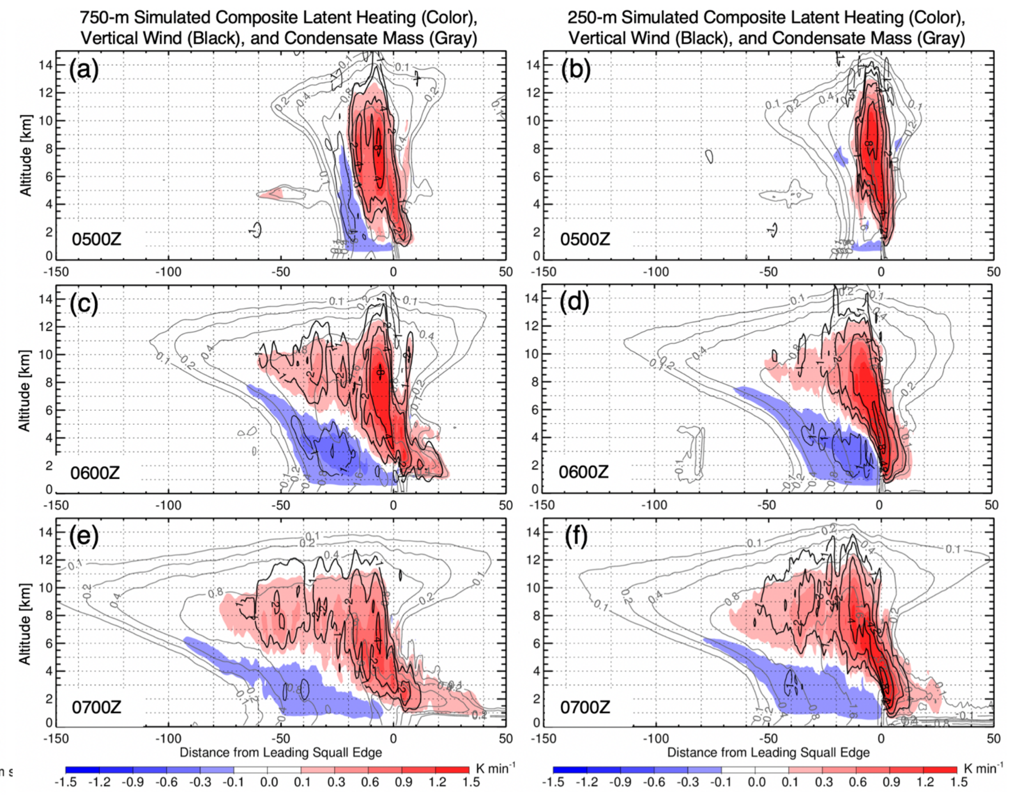
1000Z KTLX observed and 0930Z WRF simulated radar radial velocity vertical structure directly westward through the squall line

4. Contrasting Simulated Squall Line Thermodynamic and Kinematic Evolution

The 750-m run forms a cold pool that is reinforced by zonal winds transported further downward than in the 250-m run, which leads to more upshear tilted deep convective cores and differing rear inflow and FTR circulations

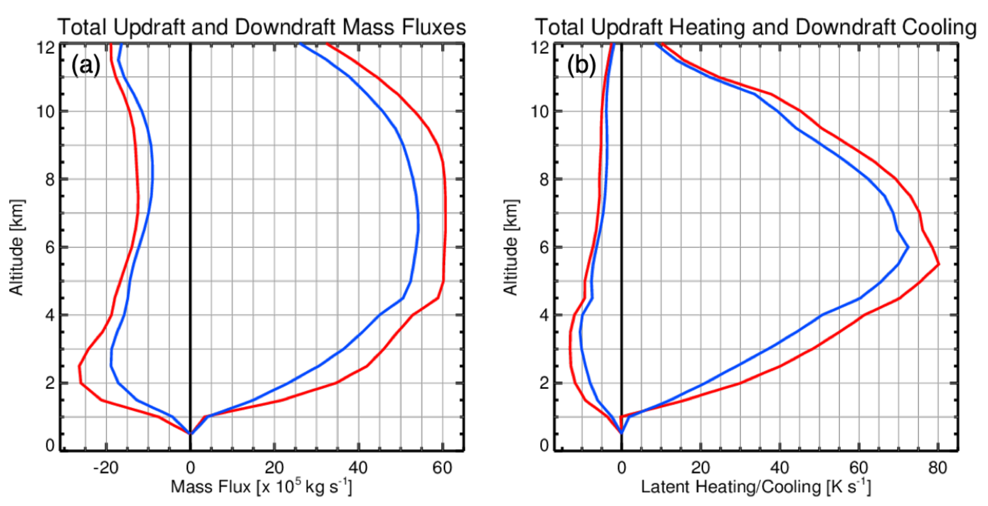


Evolution of composite WRF simulated buoyancy (fill) and zonal wind (contour) vertical structure between 0500 and 0700Z

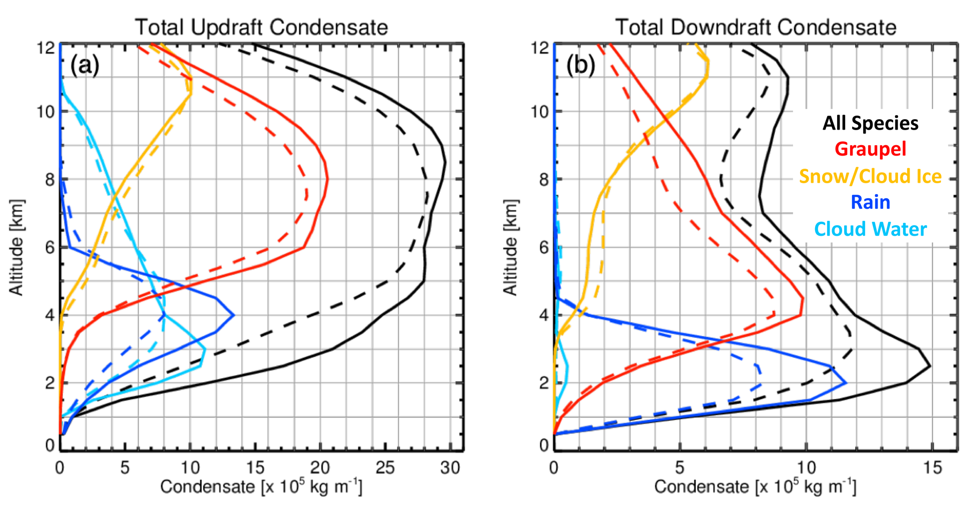


Evolution of composite WRF simulated latent heating (fill), vertical wind (black), and condensate mass (gray) vertical structure between 0500 and 0700Z

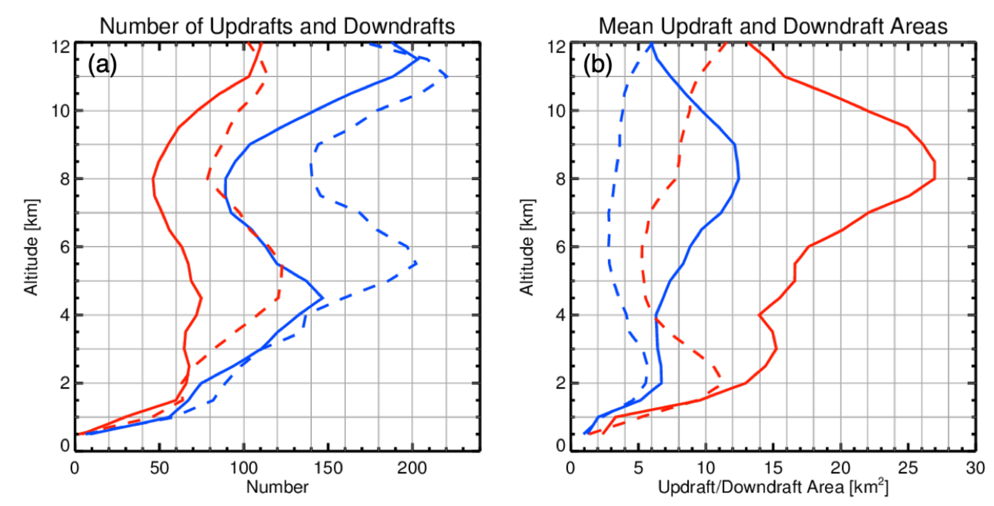
5. Linkage to Differing Simulated Convective Draft Properties



Total updraft (+) and downdraft (-) mass fluxes (left) and latent heating/cooling rates (right) averaged between 0400 and 0600Z in the 750-m (red) and 250-m (blue) runs.

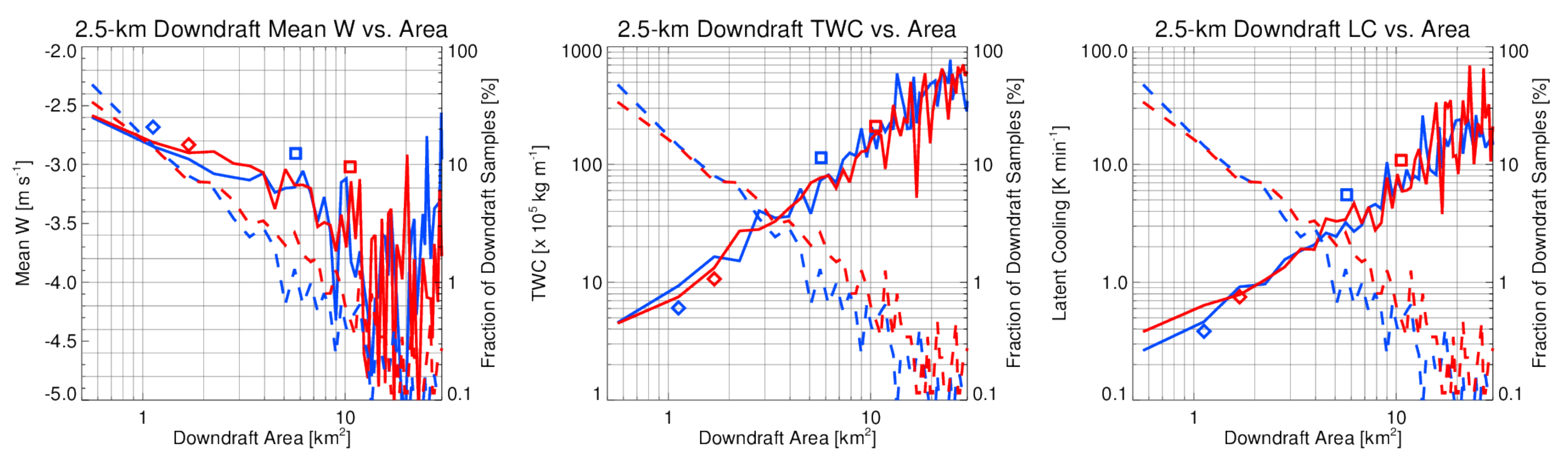


Total updraft (left) and downdraft (right) condensate mass averaged between 0400 and 0600Z in the 750-m (solid) and 250-m (dashed) runs.

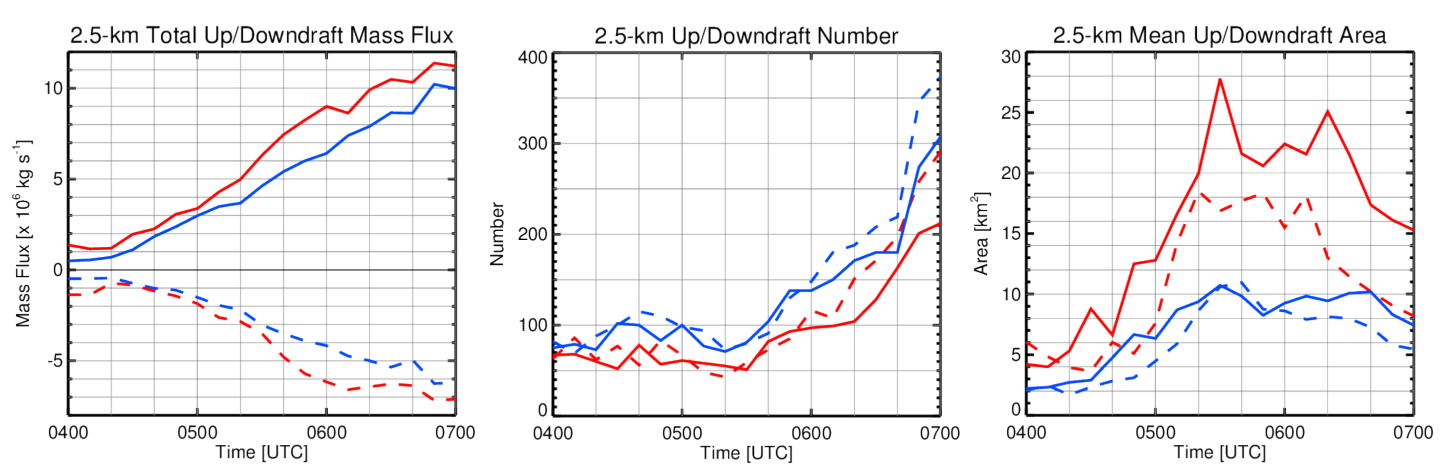


(Left) Number of updrafts (solid) and downdrafts. (Right) Updraft (solid) and downdraft (dashed) areas averaged between 0400 and 0600Z in the 750-m (red) and 250-m (blue) runs.

The greater downward transport of mid-level dry air and zonal momentum in the 750-m run is associated with greater convective downdraft (updraft) mass flux, latent cooling (heating), and condensate mass than in the 250-m run. The 750-m run has convective drafts that are on average twice as large as those in the 250-m run. This difference, rather than differences in draft properties for a given draft size, causes the 750-m run downdrafts (updrafts) to have greater vertical wind speeds, condensate masses, and latent cooling (heating) rates with downdraft sizes correlating in time with updraft sizes. This difference in typical convective draft size produces greater vertical transport in the 750-m run, which leads to the biased mesoscale circulations relative to the 250-m run and observations that negatively impact the squall line evolution.



2.5-km altitude 0400-0600Z mean downdraft mean vertical wind (left), total condensate mass (middle), and total latent cooling (right) as functions of downdraft area in the 750-m (red) and 250-m (blue) runs. The downdraft size distribution is dashed. Overall mean (squares) and median (diamonds) values are also shown.



2.5-km altitude updraft (solid) and downdraft (dashed) total mass flux (left), number (middle), and area (right) as a function of time between 0400 and 0700Z in the 750-m (red) and 250-m (blue) runs.

Conclusions

We have highlighted a pathway by which under-resolved simulated deep convective updrafts produce biased simulated mesoscale system evolution:

1. Under-resolved deep convective updrafts are too wide.
2. Wider updrafts have greater mass fluxes and carry more condensate than narrower updrafts.
3. Wider updrafts are associated with wider downdrafts that have greater mass fluxes and condensate than narrower downdrafts.
4. A greater number of relatively wide downdrafts more efficiently transport dry mid-level air downward than relatively narrow downdrafts, accelerating the development of cold pools and downward transport of horizontal momentum.
5. In the case of a squall line, the altered post-squall cold pool and vertical wind shear structures resulting from under-resolved convective drafts interact differently with the pre-squall vertical wind shear, affecting deep convective tilt, front-to-rear detrainment, and convective line propagation.

More research is needed to determine how under-resolved convective drafts affect mesoscale system evolution in models with grid spacing of 0.5-5 km including how effects vary as a function of environmental conditions.

For more information on the science you see here, please contact:
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