Advancing Storm-Scale Forecasts over Nested Domains for High-Impact Weather

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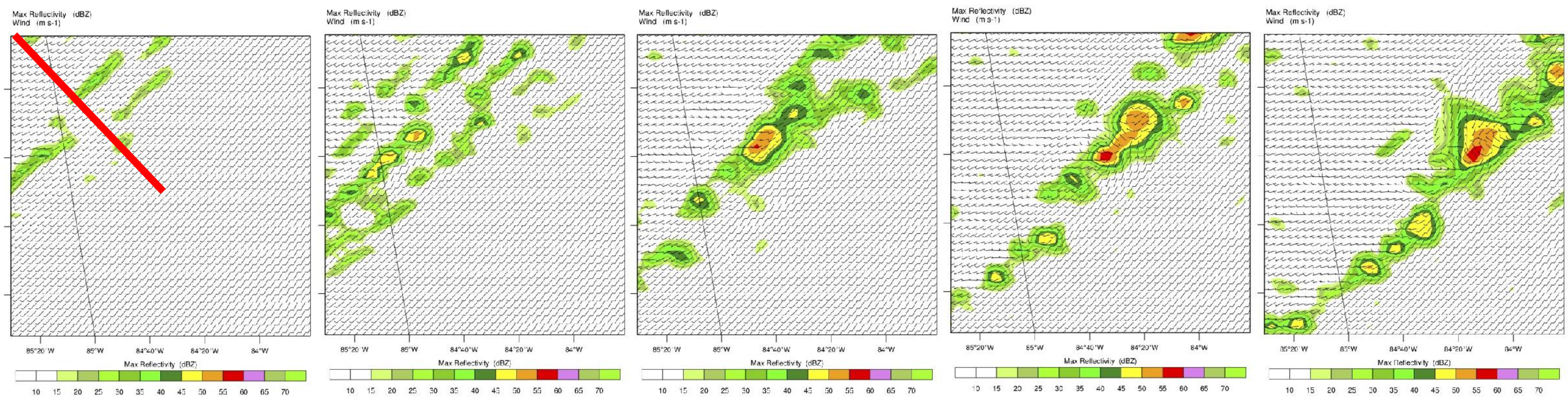
Objectives

- Assess the ability of the North American Model (NAM) 4 km Nest to provide realistic and accurate forecasts of severe convective weather (capability and accuracy)
- Determine if the 1.33 km Fire Wx Nest has added value beyond that provided by the 4 km NAM
- Develop useful diagnostics for forecasters and model developers

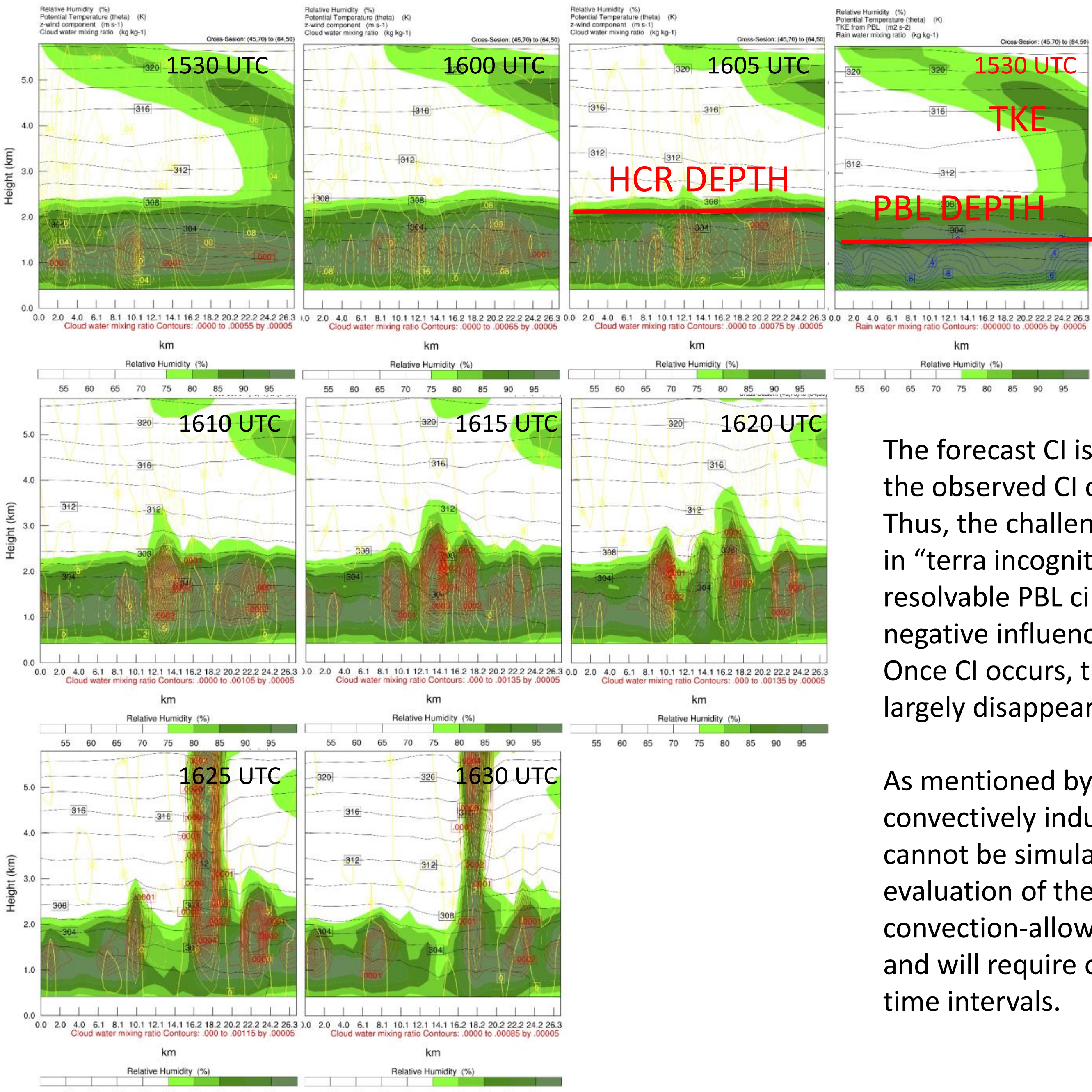
Methods

- Focus evaluation on supercells and convection initiation (CI) as key phenomena
- In-depth study of two cases
- Examine model output every 5 minutes and compare forecast storms and CI with observations (Doppler radar, Mesonet, surface, soundings, satellite, etc)
- Evaluate the ability of the current physical parameterizations to produce realistic storm and CI behaviors

Why?



- WRF/ARW forecast at 4 km grid spacing with prediction of CI on 8 July 2014 over Kentucky. Plots every 30 minutes.
  - Notice linear features in reflectivity and eventual development of deep convection along one of these lines

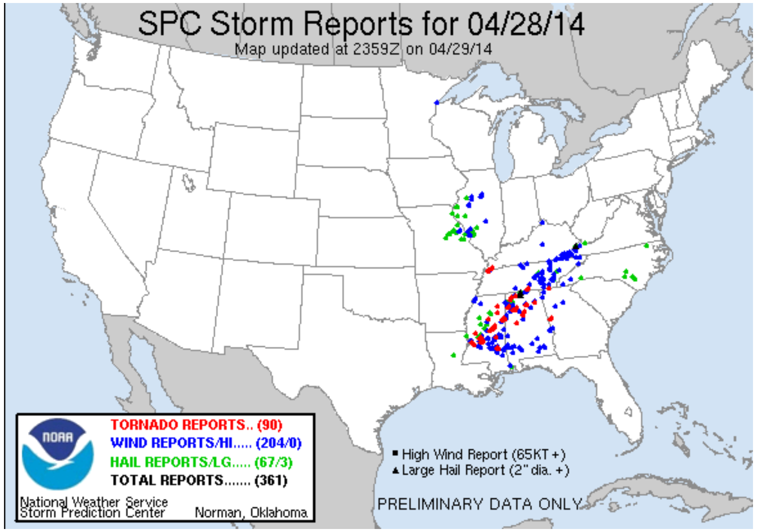


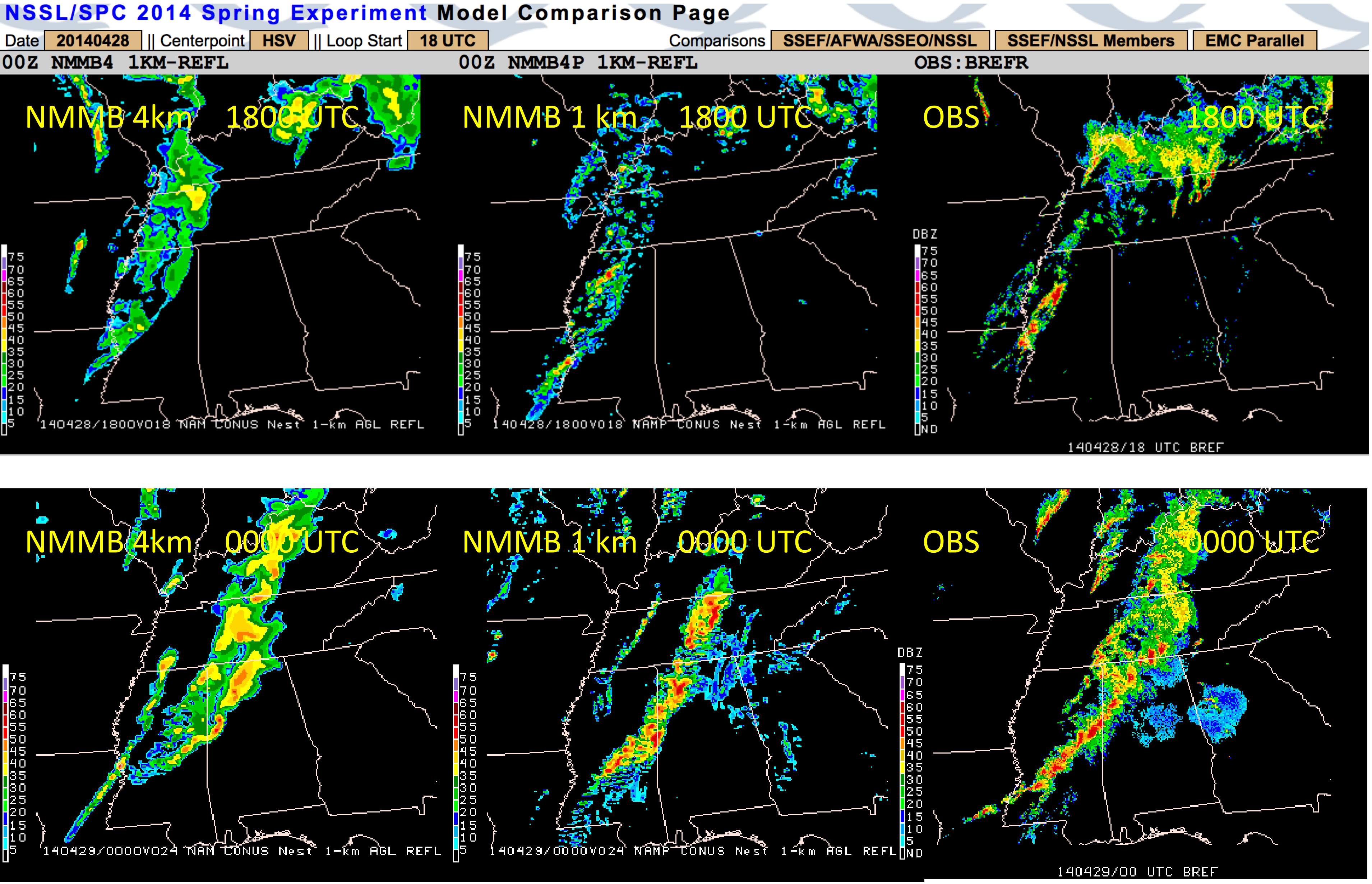
The forecast CI is several hours earlier than the observed CI over northern Kentucky. Thus, the challenges of the MYJ PBL scheme in "terra incognita" that leads to the resolvable PBL circulations may have had a negative influence on the predicted CI. Once CI occurs, these 2 delta-x circulations largely disappear.

As mentioned by Ching et al. (2014), these convectively induced secondary circulations cannot be simulated reliably. More careful evaluation of the ways in which CI occurs in convection-allowing models also is needed and will require output at very frequent time intervals.

Two Cases Selected

- 1) Significant severe weather outbreak:
  - 36 h forecast starting 0000 UTC 28 April 2014 with the nest centered over Mississippi/Alabama
  - CI along frontal boundary
  - Numerous long-lived supercells

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Comparisons SSEF/AFWA/SSEO/NSSL SSEF/NSSL Members EMC Parallel
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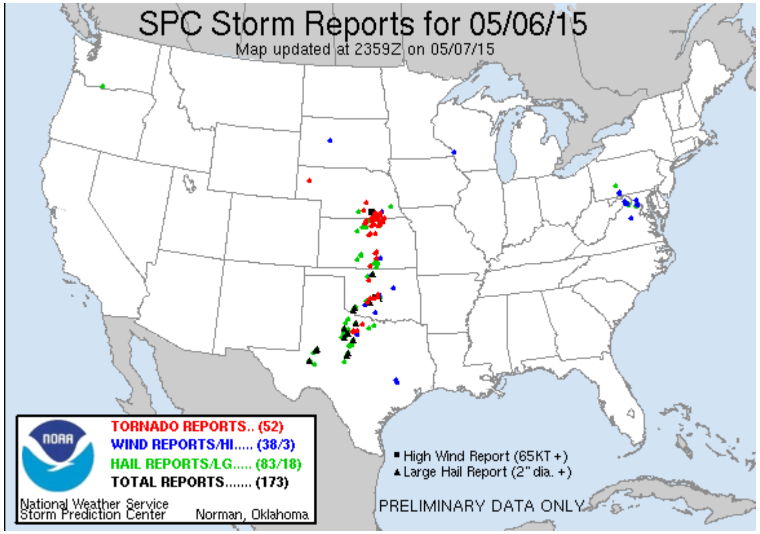
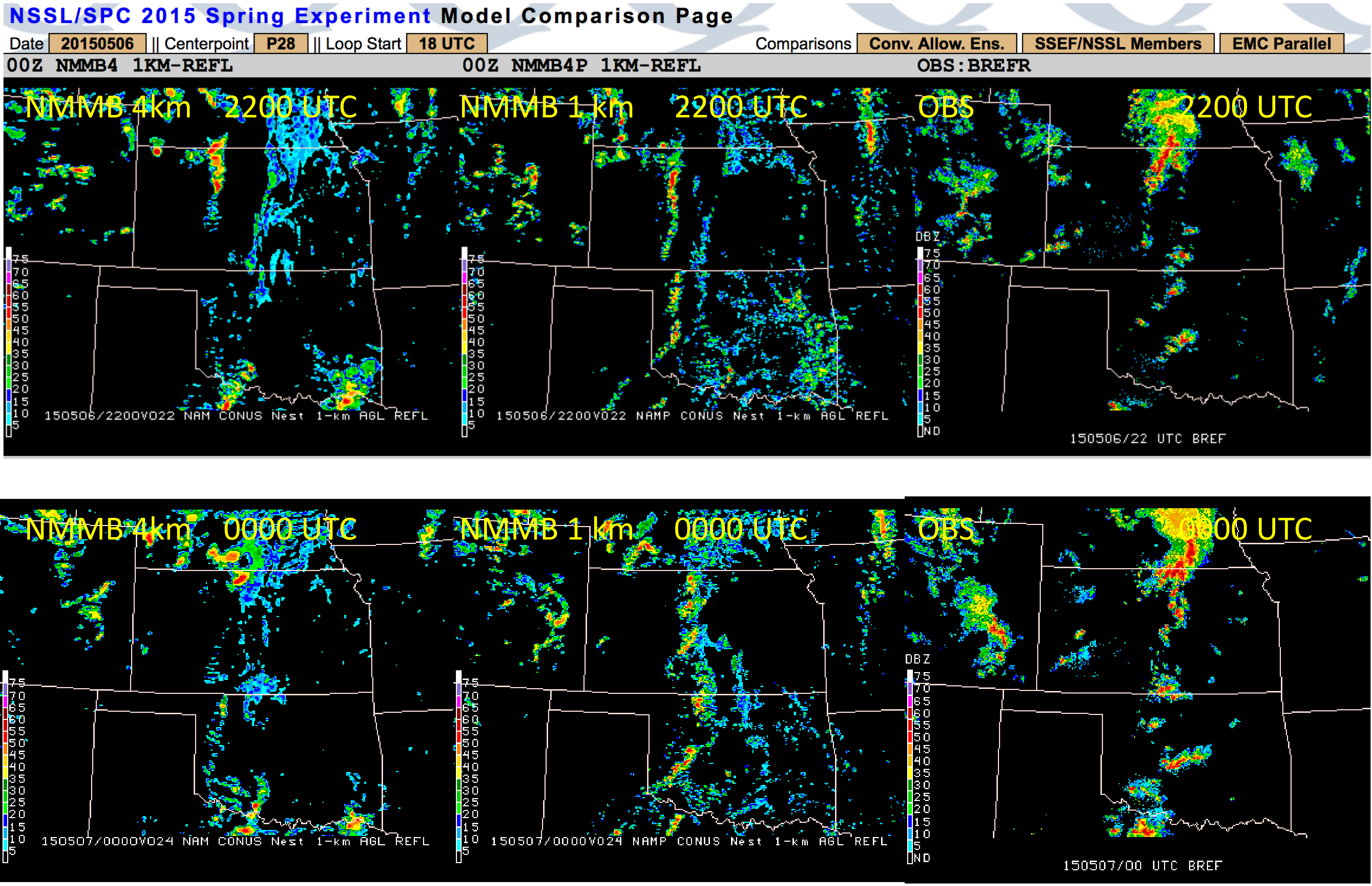
Two Cases Selected

- 2) Modest severe weather event:
  - 36 h forecast starting 0000 UTC 6 May 2015 with the nest centered over Oklahoma
  - CI along dryline
  - Several long-lived supercells

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Status

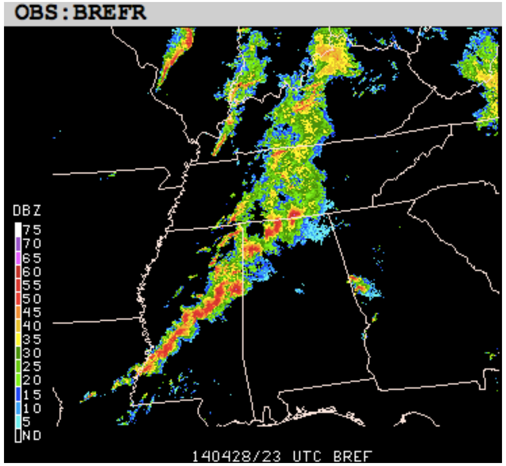
- Selected cases for in-depth study after discussions with EMC and SPC
- Identified graduate students who will work on the supercell and CI components of project
- Worked with EMC on output needs
- Purchasing needed computer equipment
- Beginning to collect observational data for the two cases

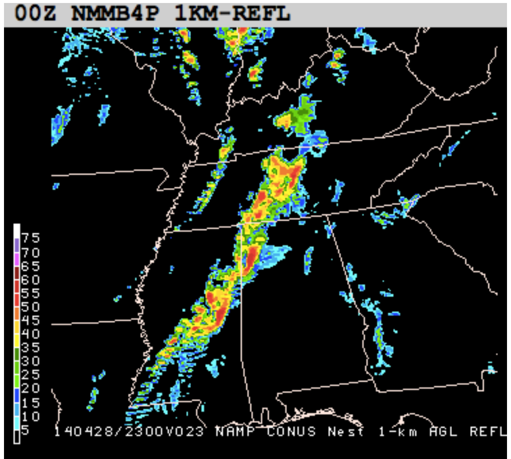
Supercell Evaluation

What differences exist between the precipitation fields of the simulated and observed convection?

What about the three-dimensional kinematic structure of the simulated versus observed convection?

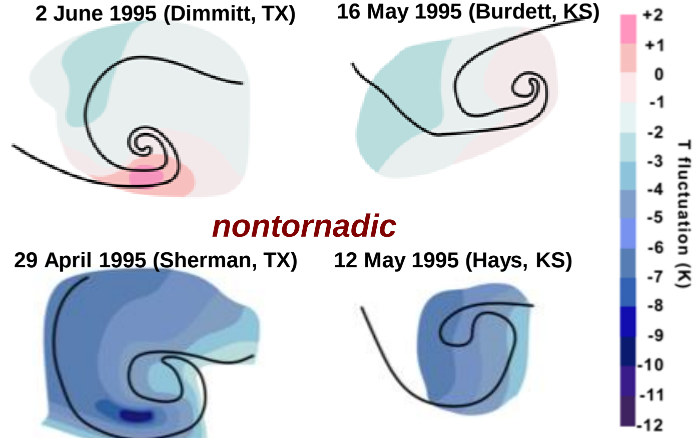
- There are likely to be competing effects
  - As horizontal grid spacing is reduced, total updraft surface area increases (updrafts are narrower and more numerous), which increases entrainment and cloud water evaporation rates and decreases precipitation efficiency
  - Nonhydrostatic processes are better resolved at finer resolutions (which would tend to promote more intense drafts), but turbulence and entrainment are better resolved at finer resolutions (which would tend to weaken drafts)





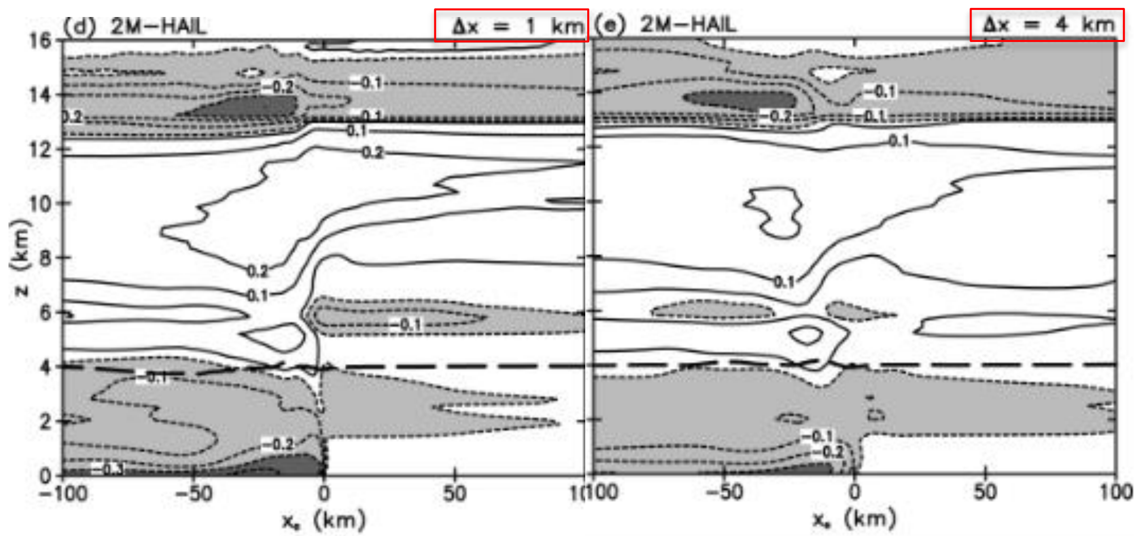
How are the cold pools of the simulated storms different from those observed (and how do the differences depend on grid spacing)?

Low-level buoyancy fields of supercells intercepted in VORTEX1



Adapted from Markowski et al. (2002)

Buoyancy in simulated squall lines

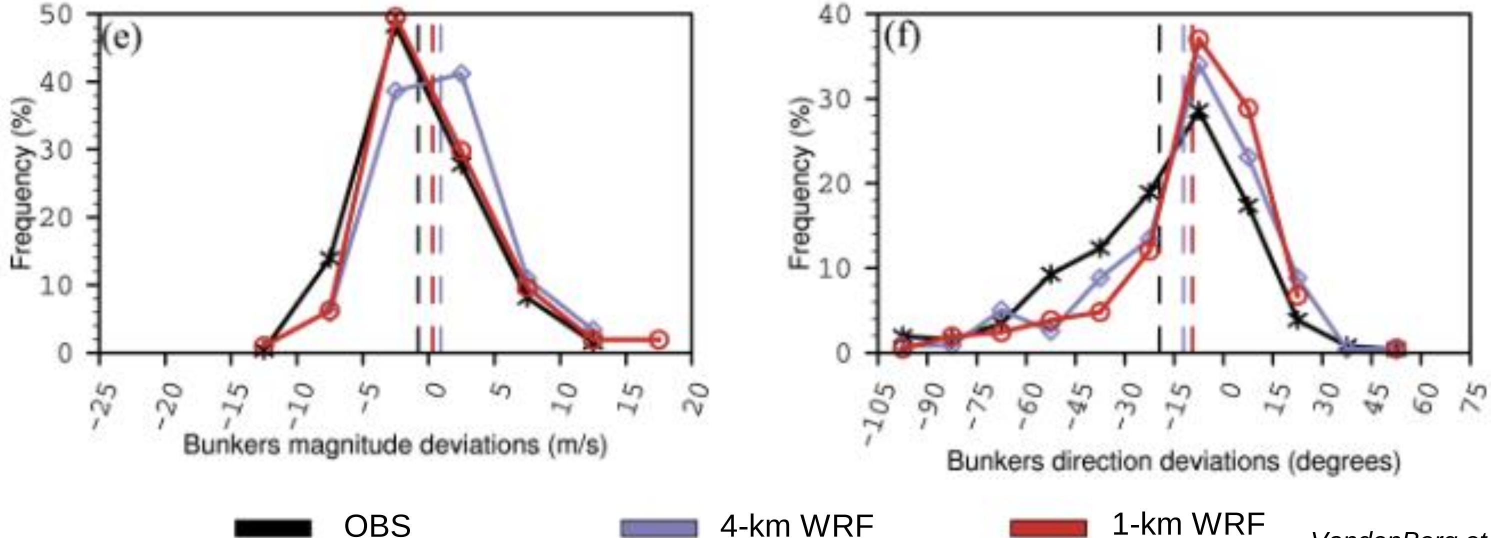


Bryan and Morrison (2012)

- It is essential for a simulation to accurately predict the cold pool characteristics if there is to be any hope for accurately predicting tornadogenesis likelihood; this likely also applies to the development of vortices within some severe MCSs.
- Misrepresentations of cold pool development also would likely lead to misrepresentations of the lifecycle of vortices (e.g., whether the low-level mesocyclones in supercells “cycle,” and the frequency with which it happens) and potential for upscale growth of initially isolated convection into larger-scale convective systems.

How does the motion of the simulated storms differ from the observed motion?

There is good reason to believe the operational simulations utilizing 4-km grids are not properly representing at least some aspects of convective storm dynamics adequately.



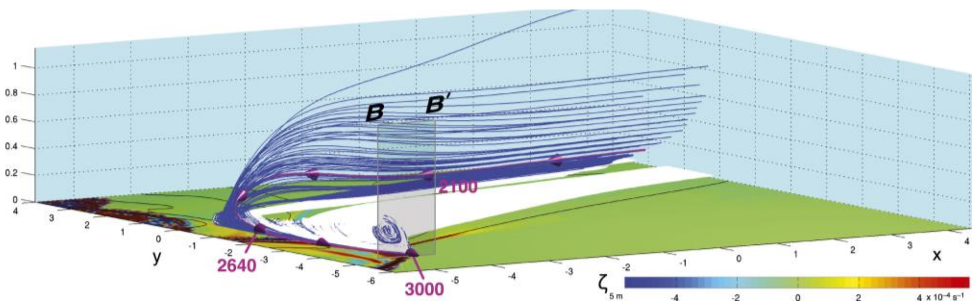
"a reduction from 4- to 1-km grid spacing can potentially improve forecasts of storm motion, but further analysis … is needed to confirm these results and to explore specific hypotheses for their differences."

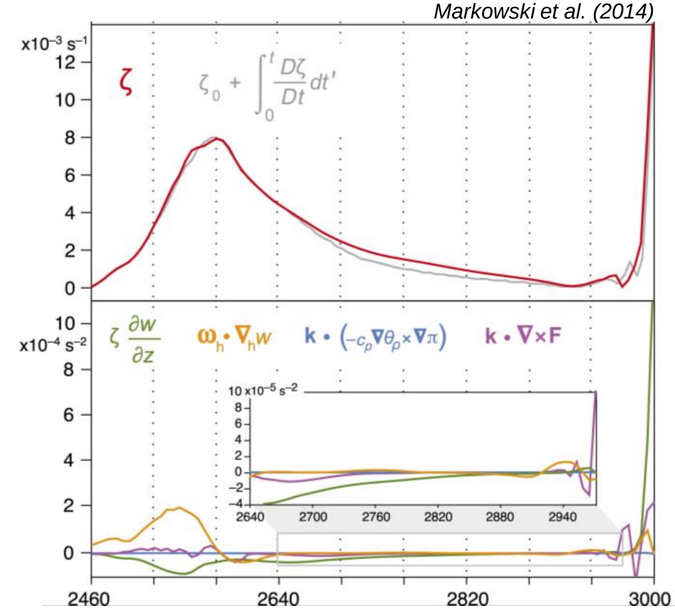
VandenBerg et al. (2014)

- For example, VandenBerg et al. (2014) found differences in supercell propagation between 4-km and 1-km WRF simulations, with the storm motions being more accurate on the 1-km grid than on the 4-km grid
  - This would imply differences not only in the VPPGFs in the simulations, but also in how mesocyclogenesis is represented.
  - Errors in storm motion beget errors in updraft rotation because updraft rotation depends on the degree to which the updraft ingests streamwise vorticity.
  - The amount of streamwise vorticity ingested by an updraft is tied to the strength and veering of the storm-relative winds, both of which depend on the storm motion.

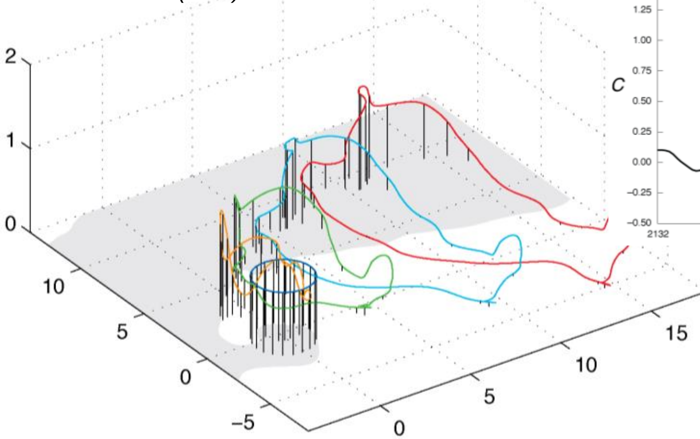
What are the underlying dynamical reasons for the differences between the simulated storms and observed storms?

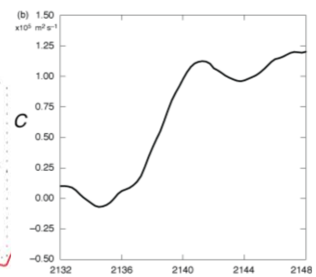
Markowski et al. (2014)

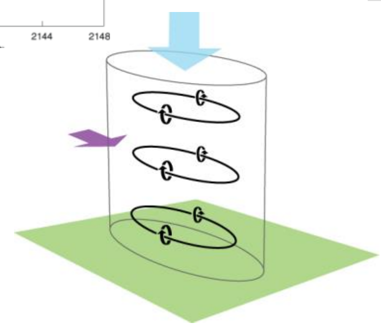




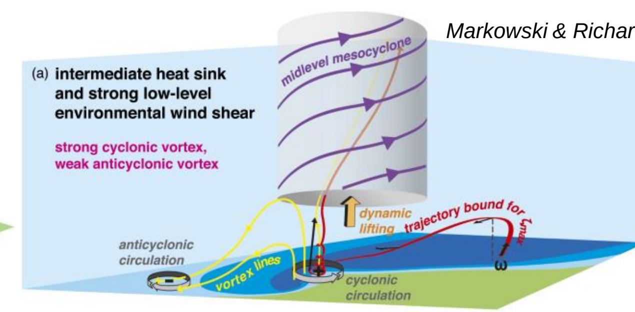
Markowski et al. (2012)







Markowski & Richardson (2014)

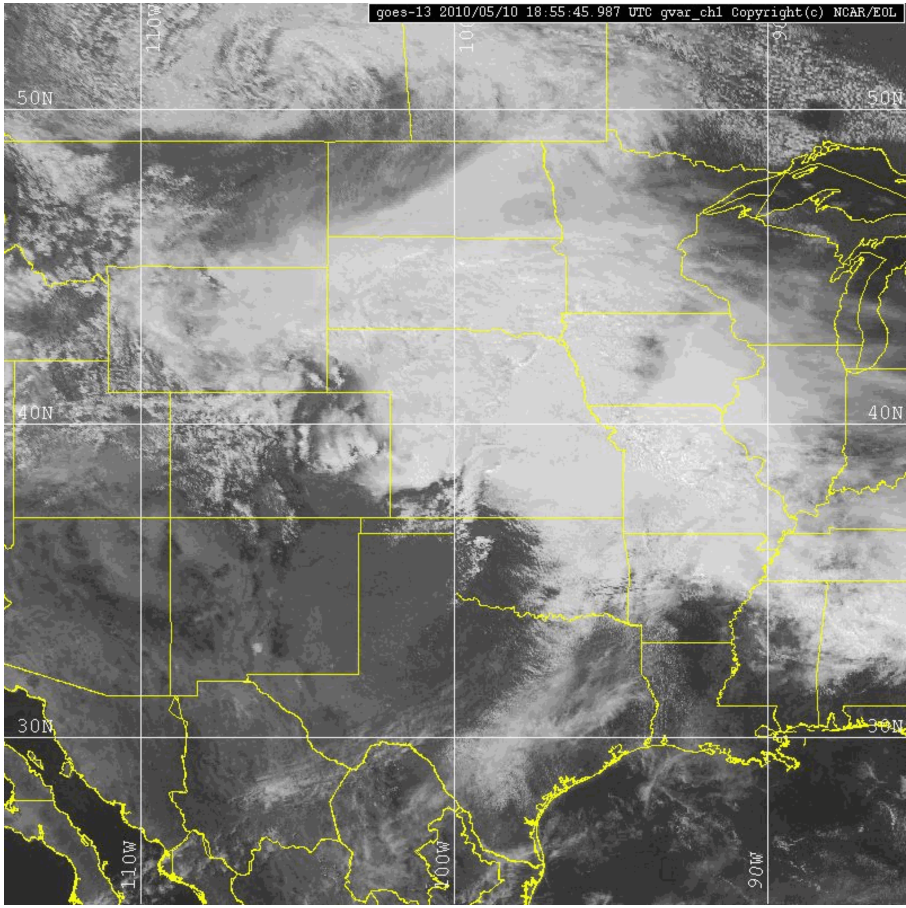


- We will examine momentum and/or vorticity budgets and pressure decompositions (i.e., examining buoyancy and dynamic pressure perturbations, their gradients, and accelerations resulting from their gradients), similar to the types of analyses performed by Markowski et al. (2012, 2014) and Markowski & Richardson (2014).

CI Evaluation

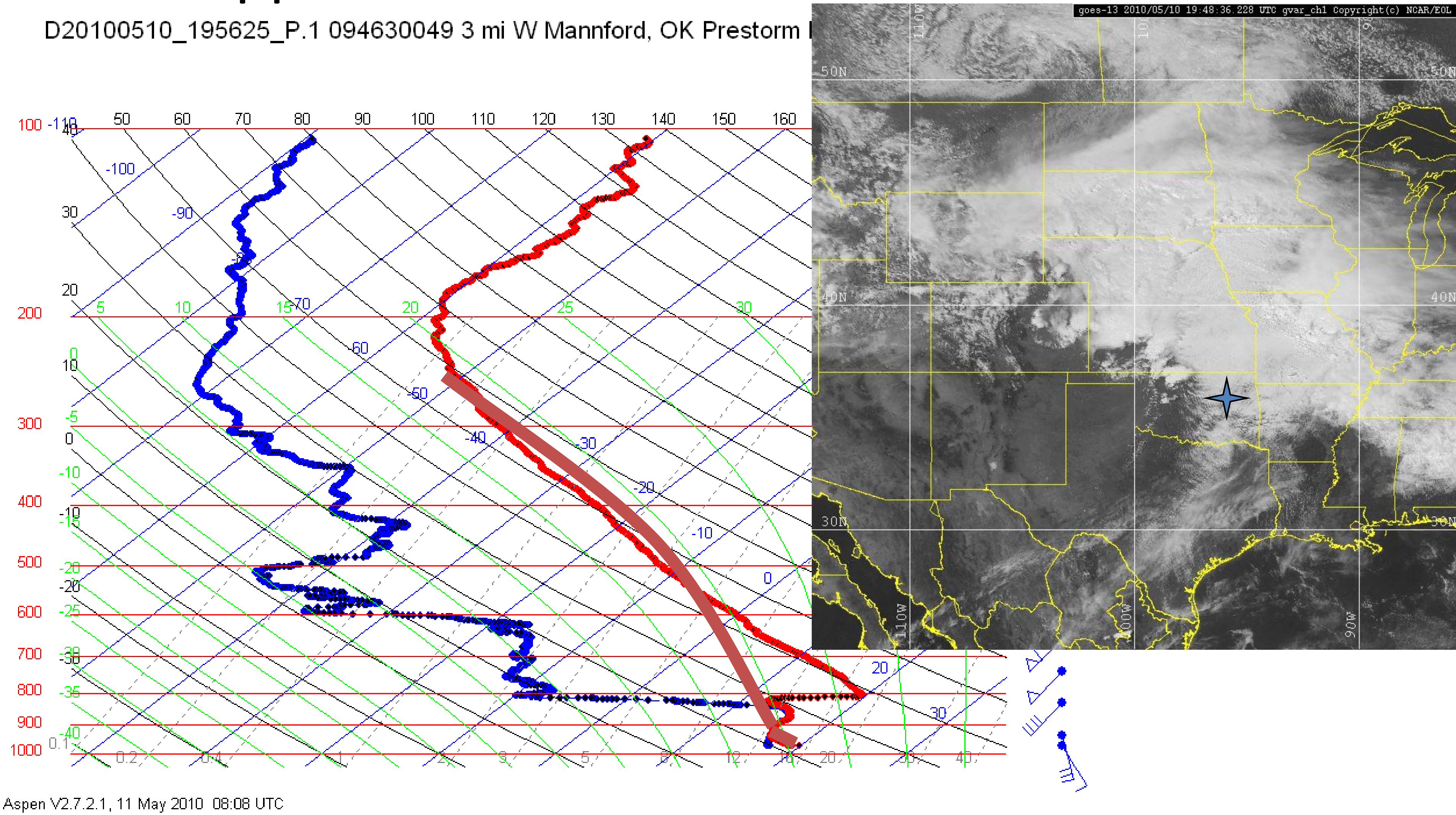
Convection Initiation

- On one hand a very simple idea—parcels of air have to get to a level where they are warmer than their surroundings
- On the other hand, one of the most challenging aspects of storm forecasting
  - Combination of evolving mesoscale environment with more localized forcing for upward motion



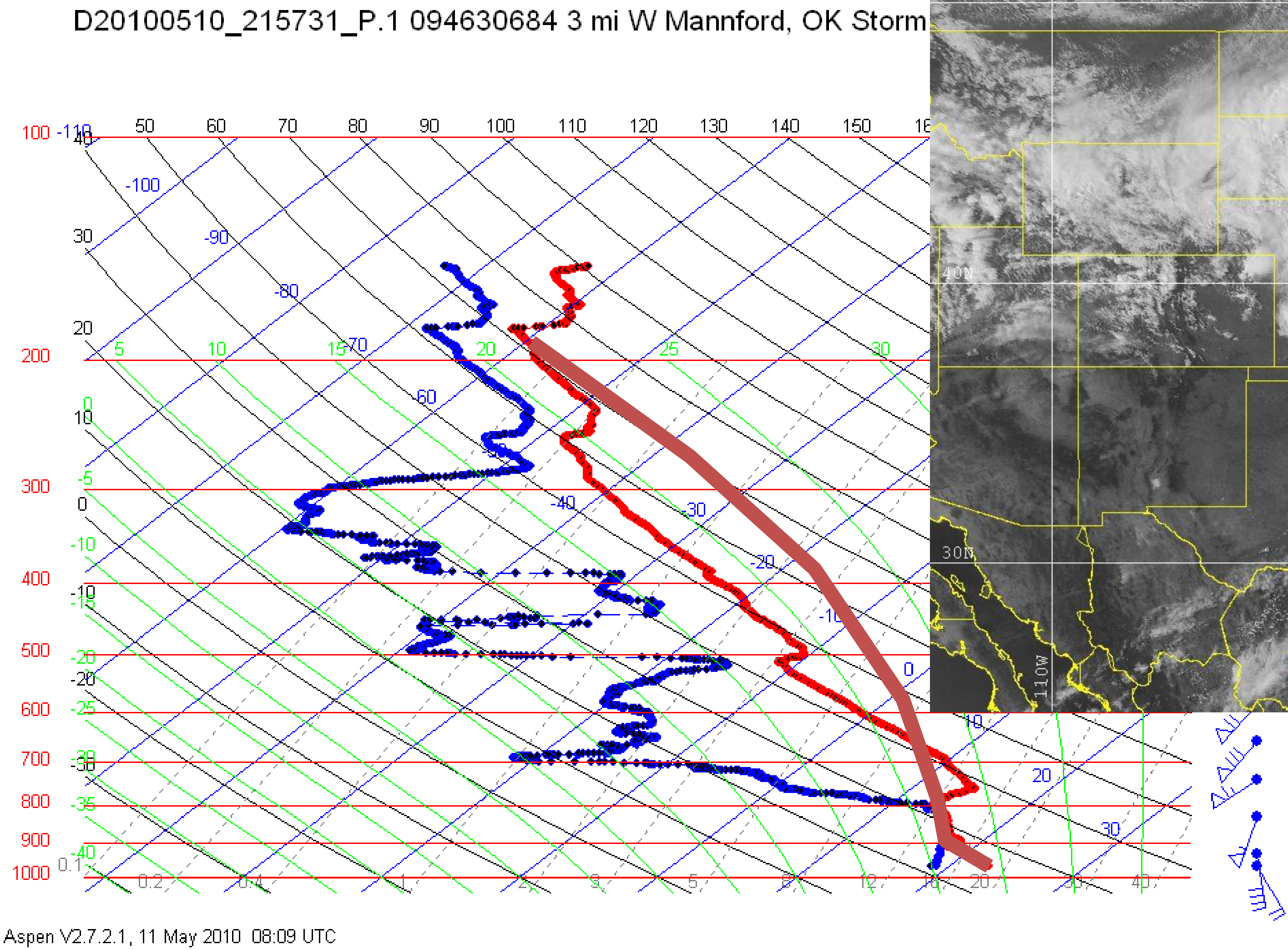
Mesoscale Environment and CI

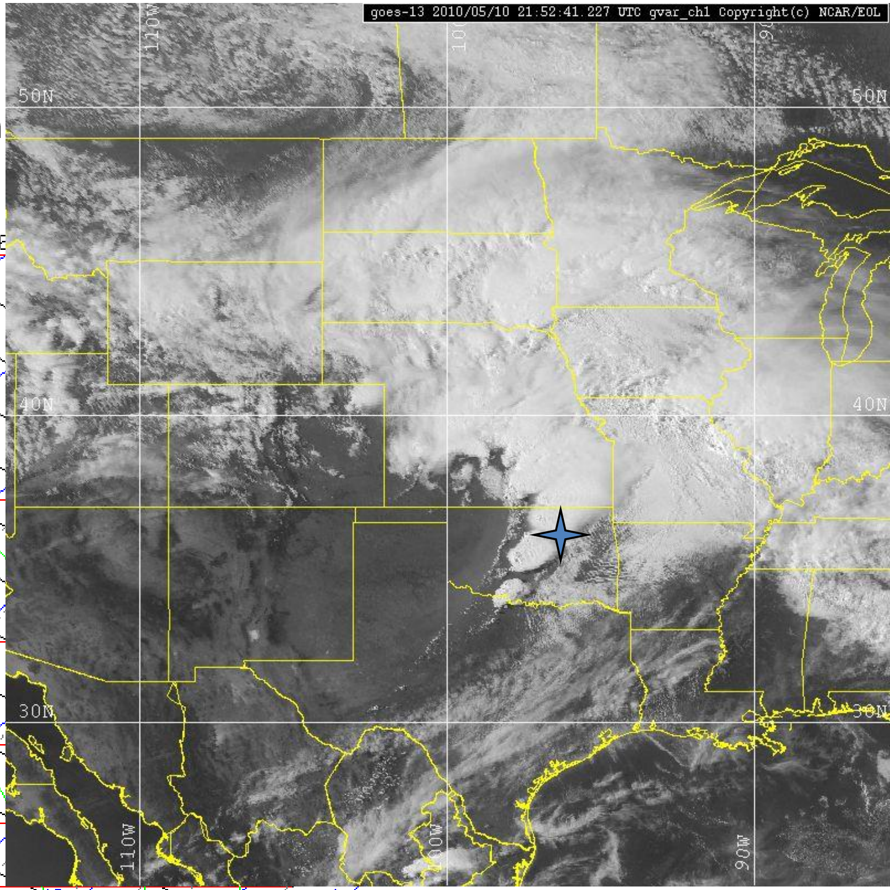
Often involves thin transition layers in the vertical that suppress convection



Evolving Environment

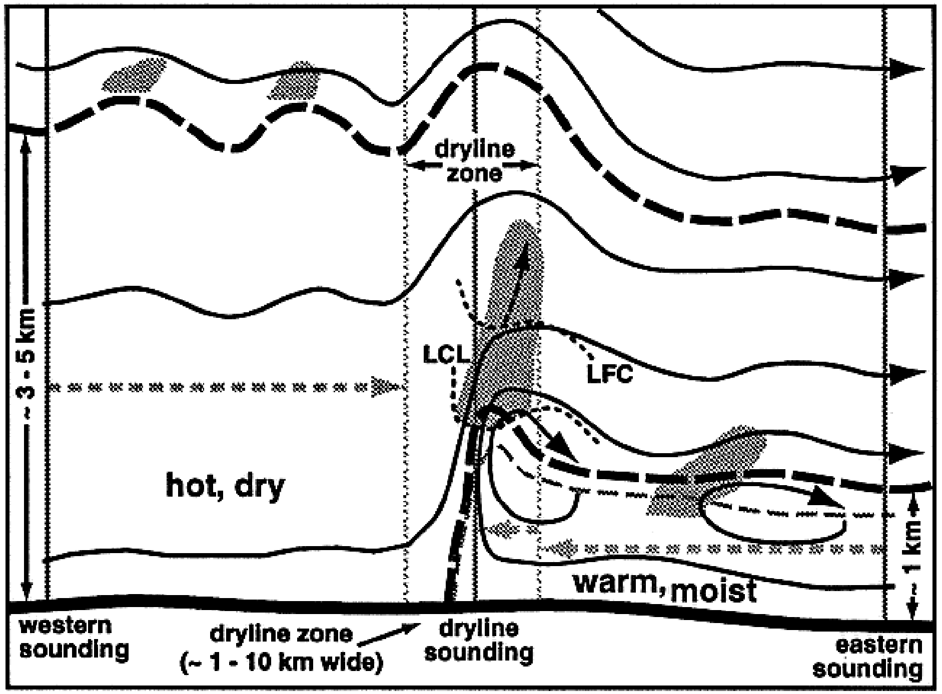
- These layers can evolve quickly
- Two hours later…





Mechanisms by which parcels can be lifted to their LFC

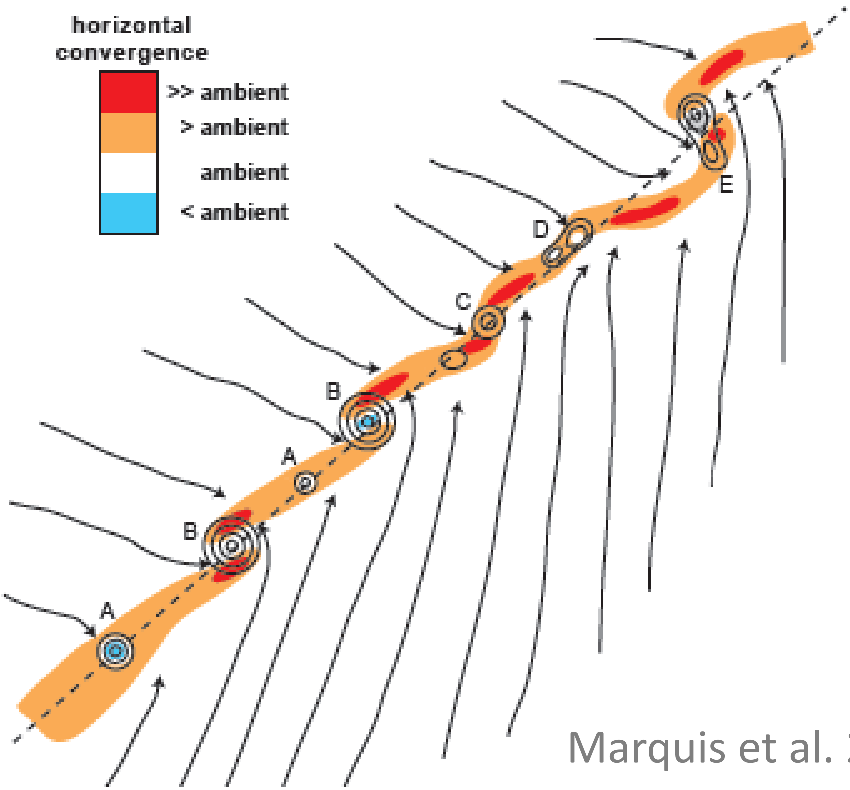
- Fronts
- Drylines
- Outflow boundaries
- Flow over topography
- Gravity waves
- Other mesoscale circulations forced by differential terrain heating (e.g., sea/land breezes, cloud boundaries, etc.)



Ziegler and Rasmussen (1988)

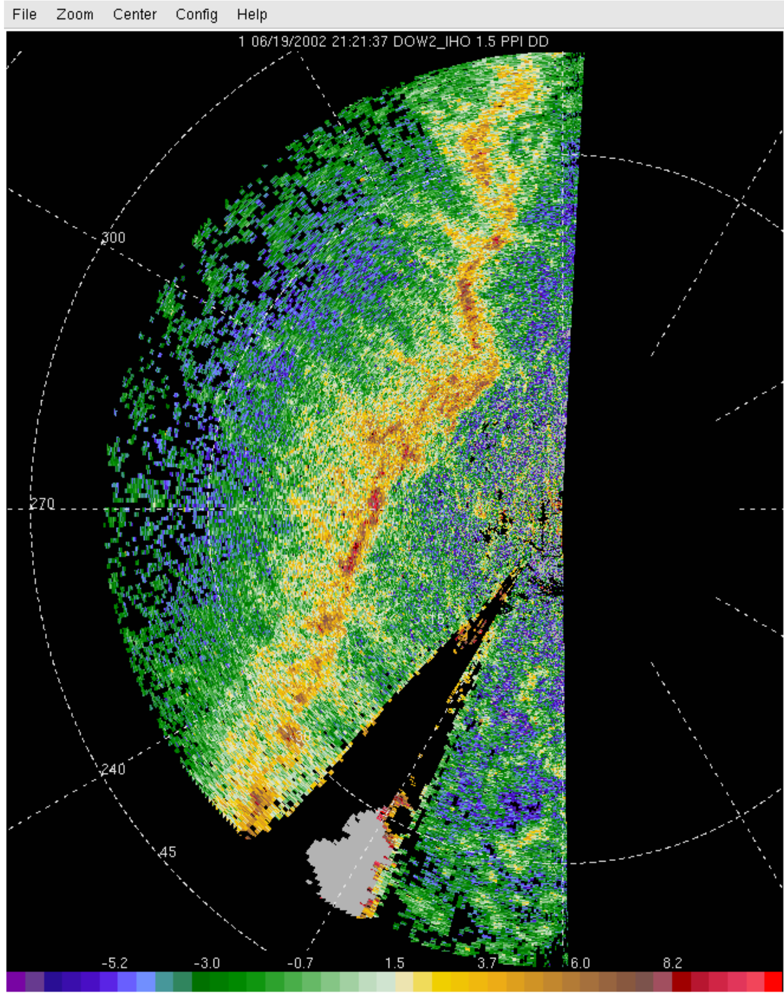
How well do CAMs represent these lifting processes?

Misocyclone Influences on Vertical Motion



Marquis et al. 2007

Vertical velocity field influenced by the presence of misocyclones

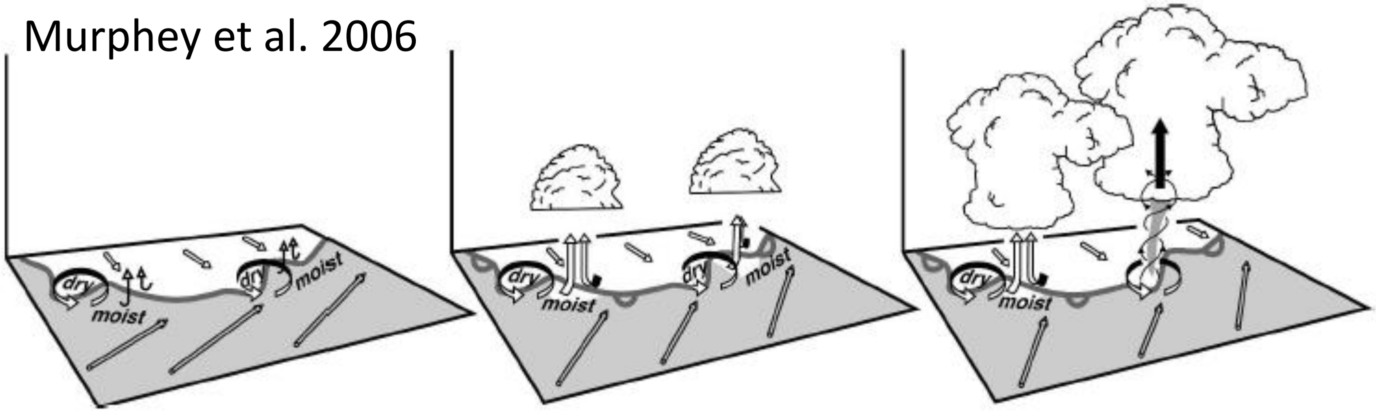


Are CAMs able to reproduce misocyclones?

Misocyclones and CI

Conceptual model based on observational case study

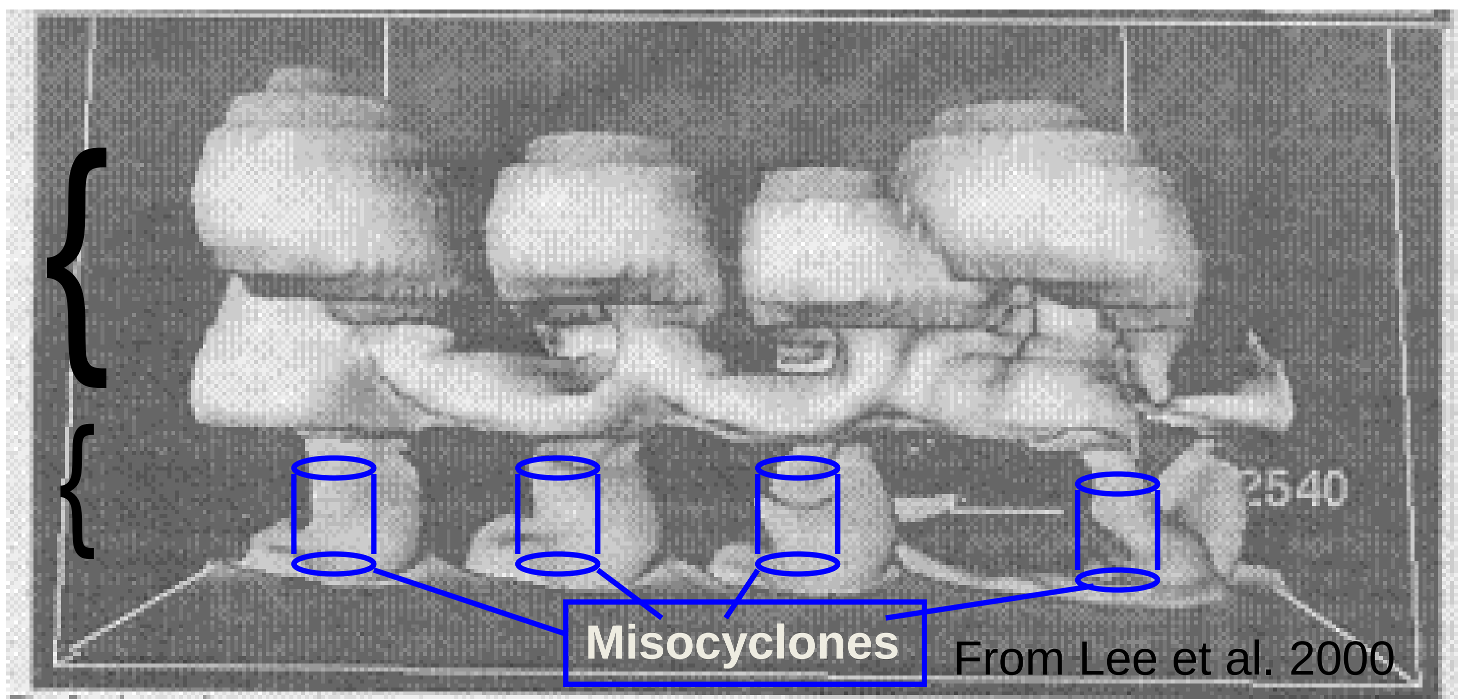
Murphey et al. 2006



High-resolution numerical simulation

Gray: Liq. water mix. ratio = 0.1 g/kg

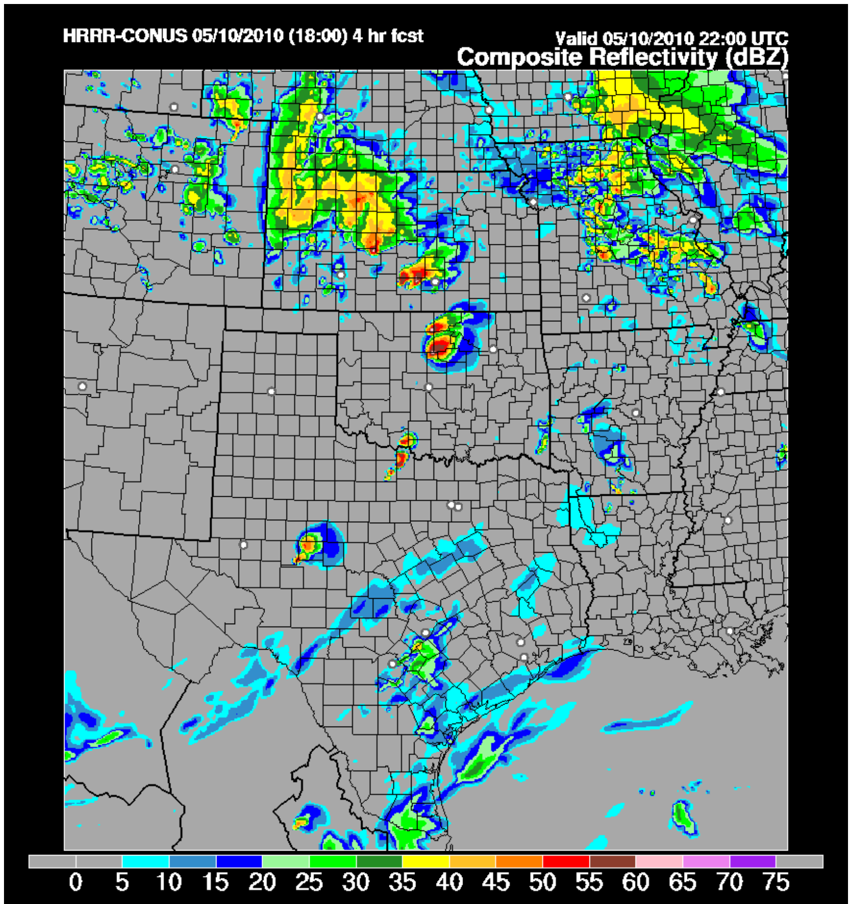
Gray: vap. mix. ratio = 8 g/kg



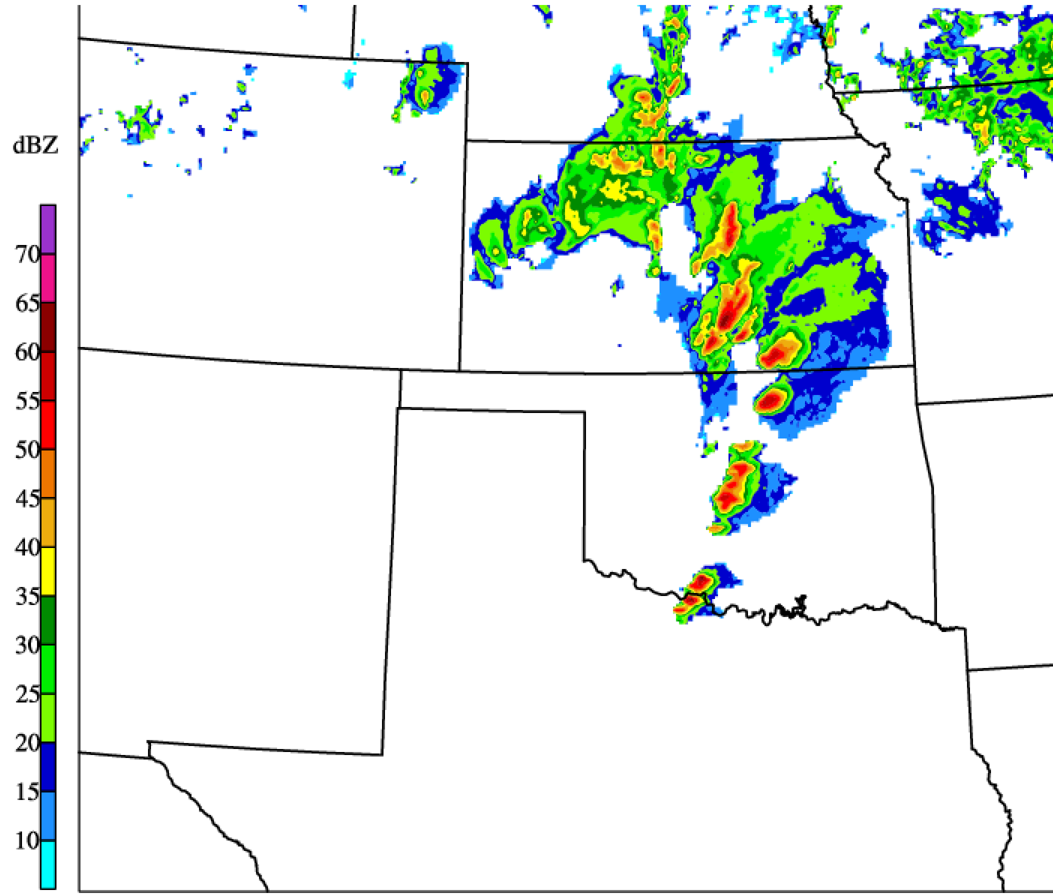
Can 1-km simulations capture these processes?

Model Prediction of CI

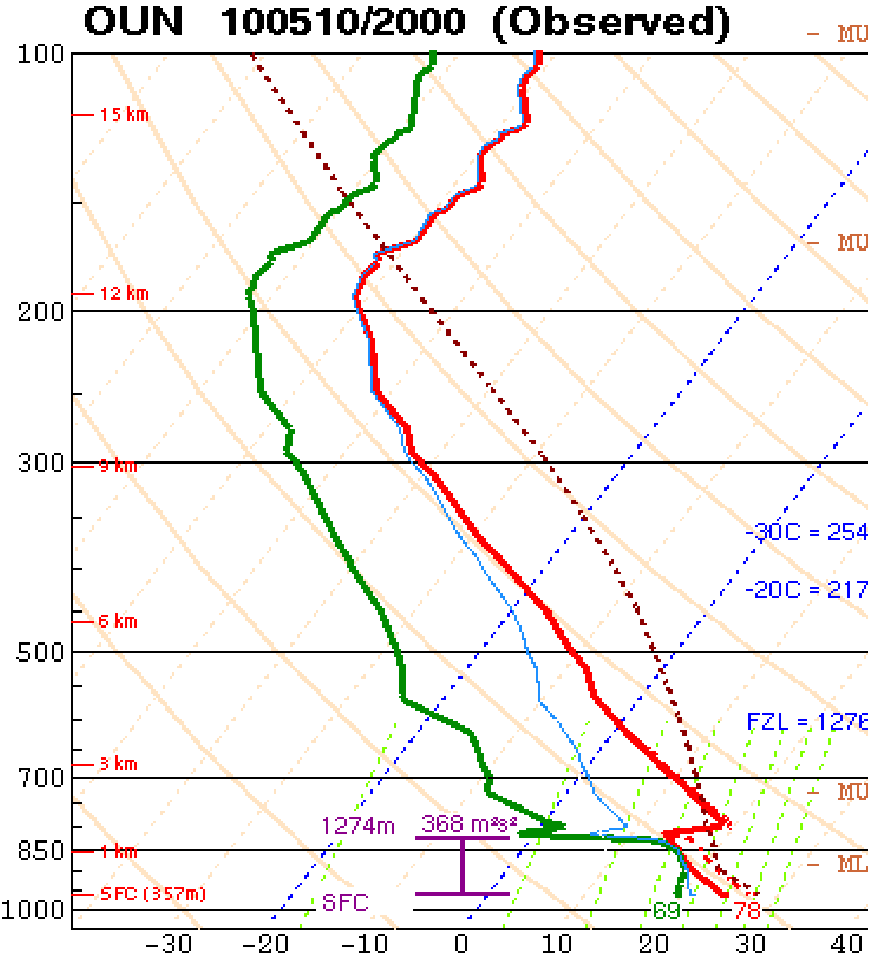
The complex evolution of the mesoscale environment and the more localized forcing for upward motion makes CI difficult to predict

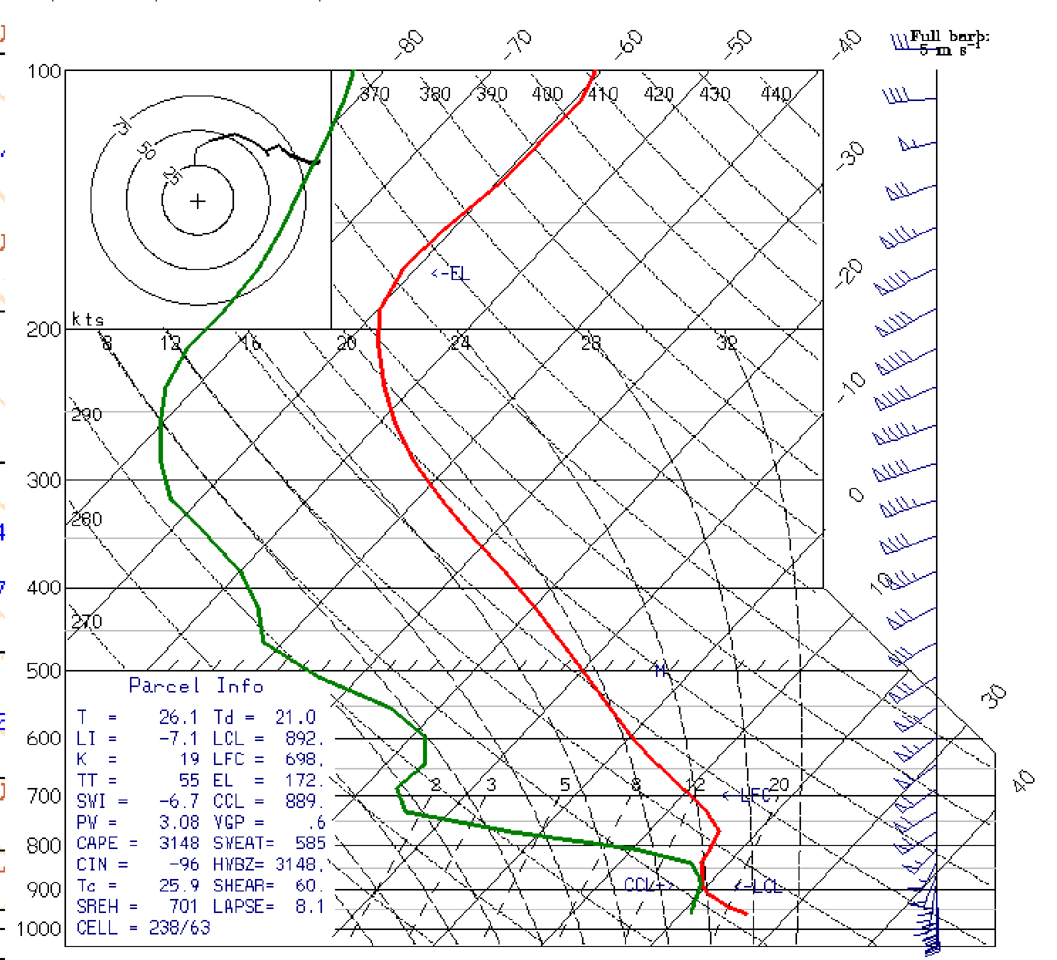


4-hr high resolution precipitation forecast



Radar Observations





How well do CAMs represent the environmental conditions leading up to CI?

Too much overly dry air?

Not enough lifting of low-level parcels?

Vertical structures too smooth?

Large Environmental Variations Based on PBL Parameterization

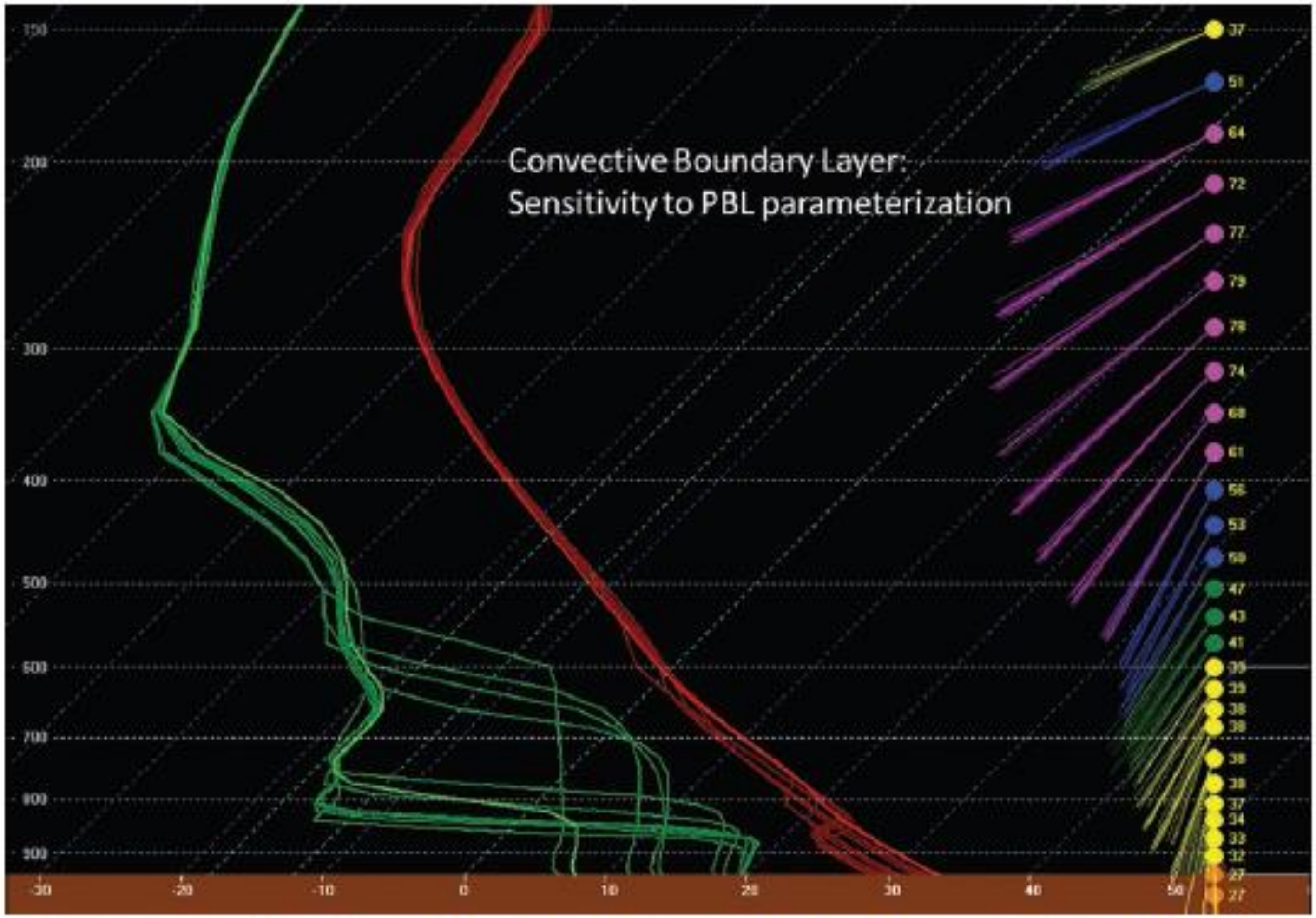


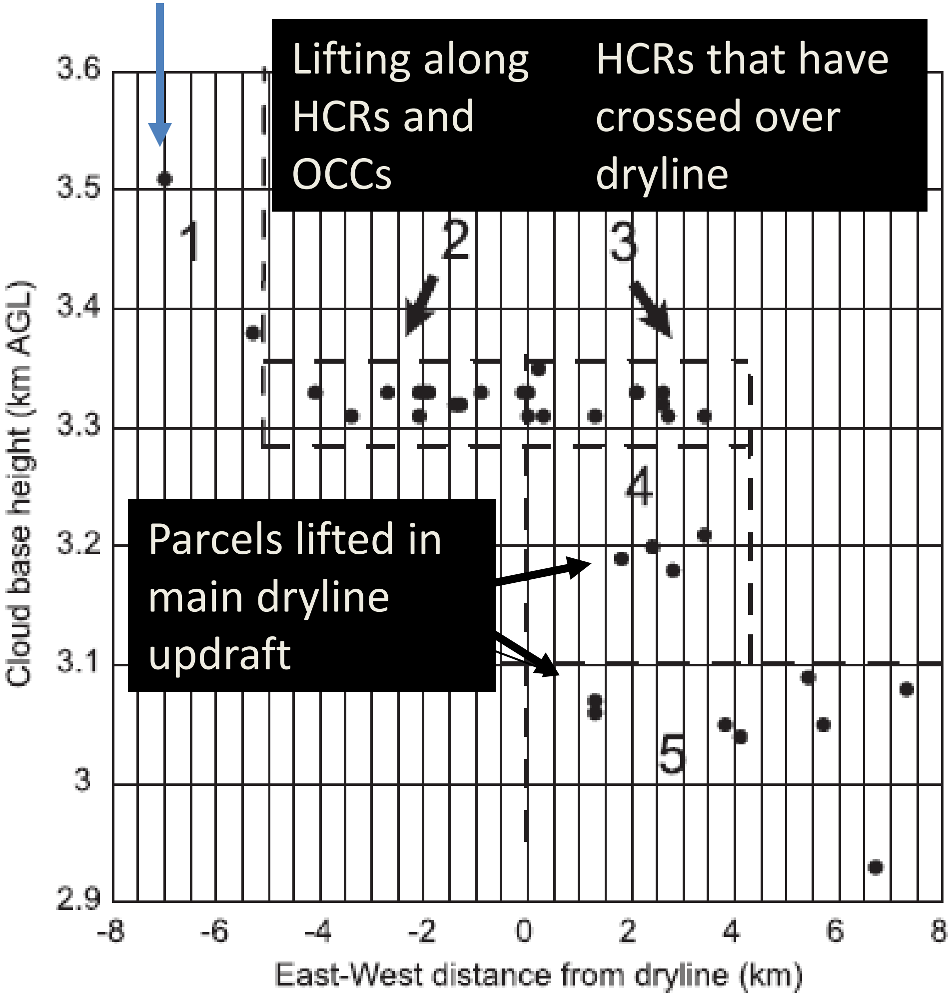
Fig. 6. Forecast soundings valid at a single time and location from each of the PBL members from the CAPS ensemble.

How does the PBL differ between 4-km and 1-km resolution simulations?

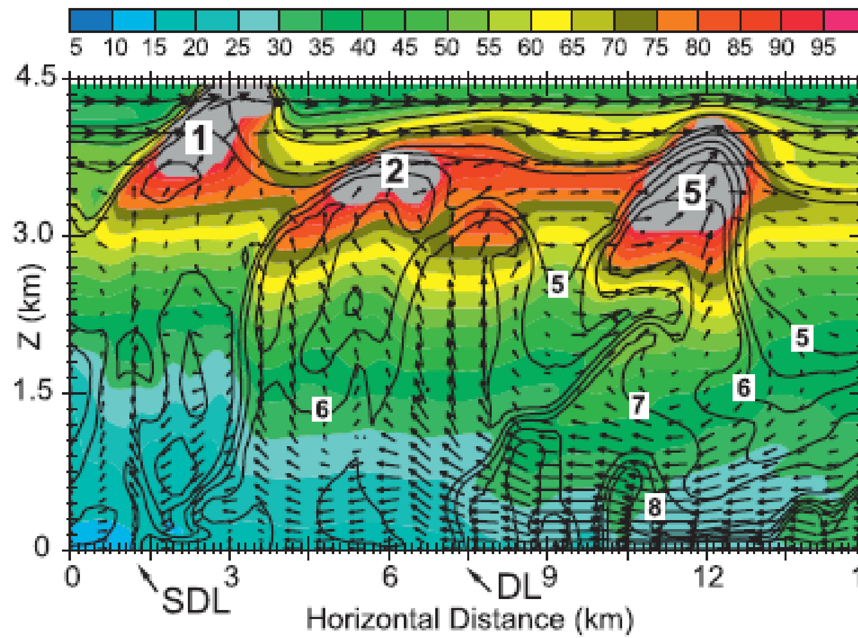
Kain et al. 2013

High Resolution Numerical Simulations of a Dryline

Lifting along secondary dryline



Buban et al. 2012

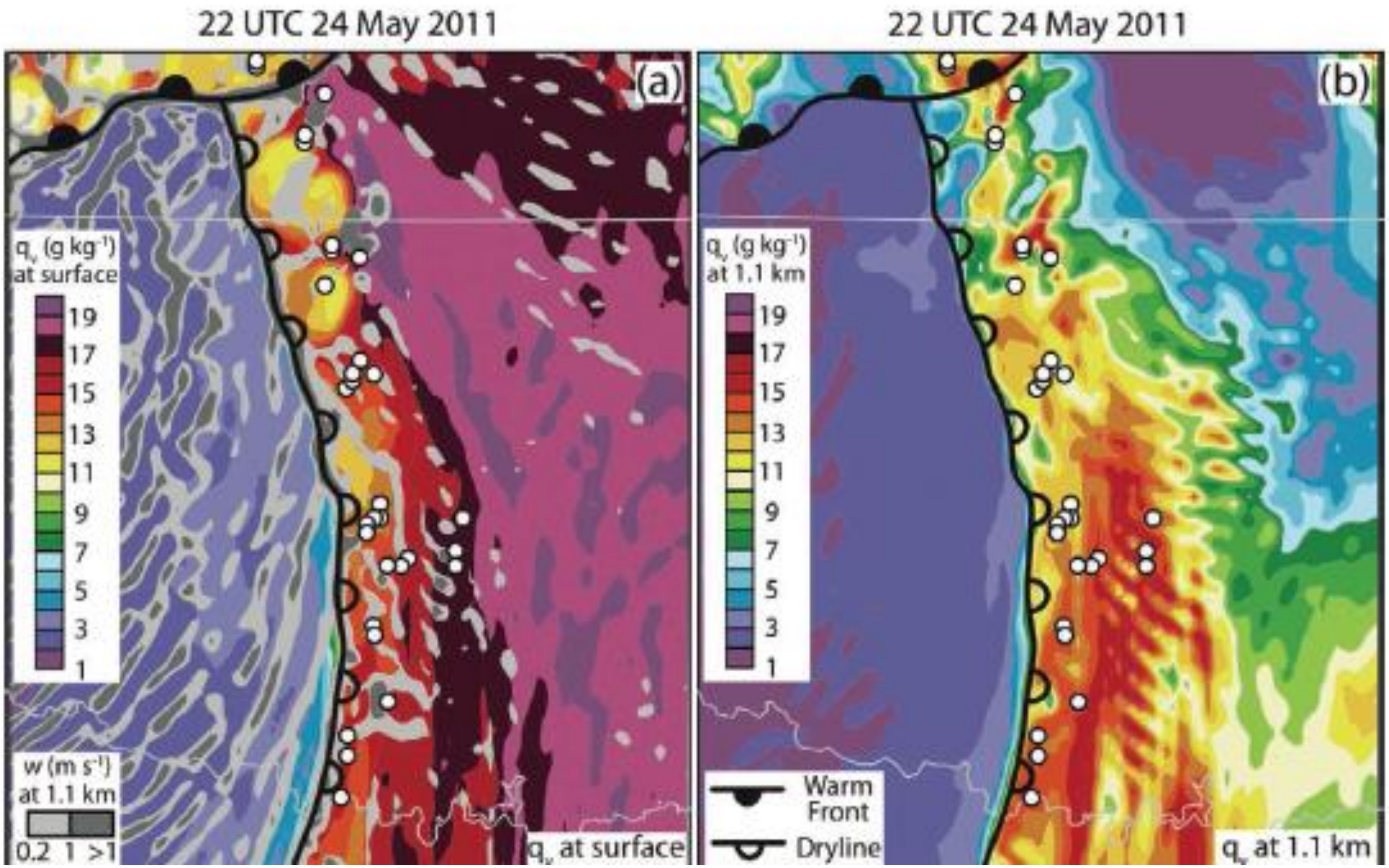


Lower cloud bases as we go from west to east

How well do operational CAMs represent these processes?

HCR-like Features and a Dryline in a 4-km Simulation

Surface | z = 1.1 km



How realistic are these circulations using 4-km resolution?

Are the processes captured much better with 1-km resolution?

Kain et al. 2013

Research Plan

- Study supercells and CI for two cases in both 4-km and 1-km nests
- Compare observed supercells and CI to simulations
- Examine the physical processes of supercells and CI in the model – in line with observations and current knowledge?
- How accurate are the nest predictions? Changes between 4 and 1 km nests?
- Develop diagnostics to help assess supercell and CI behaviors quickly and easily

Questions?