Evaluating similar large-eddy simulation representations of cloud-regime transitions against DOE ARM observations

ASR Atmospheric System Research

ARM CLIMATE RESEARCH FACILITY

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Introduction and motivation

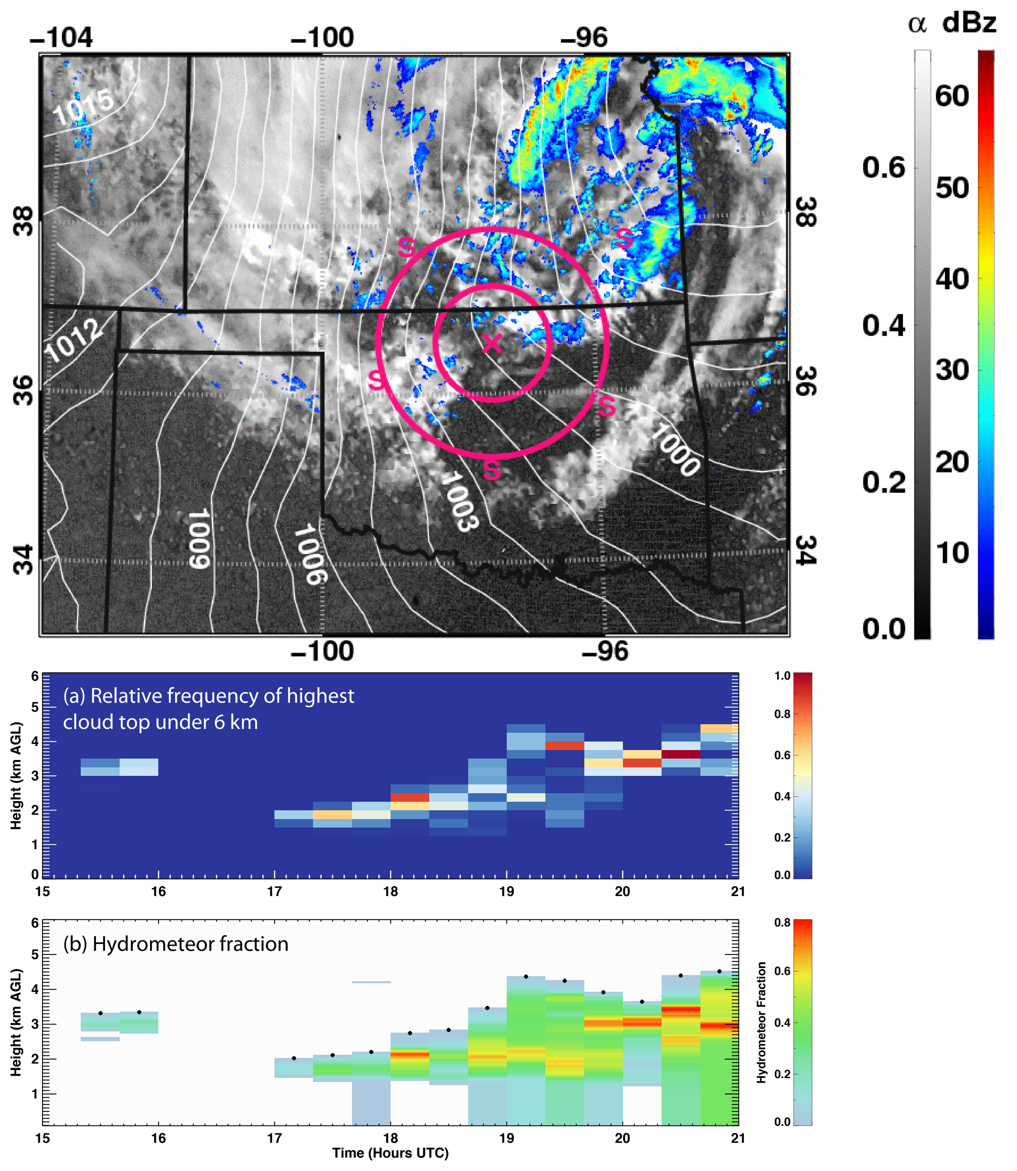
Difficulty in representing cloud and cloud transitions extends to high-resolution cloud process models that are used to construct datasets employed for formulating and evaluating GCM cloud dynamical and microphysical process parameterizations. This research aims to systematically examine the sensitivity of cloud and precipitation properties to differences in forcing. We are particularly interested in the sensitivity of physical mechanisms governing the transition from shallow to deeper clouds, and how these physical mechanisms are manifested across broad differences in forcing.

We employ our previously studied case of extensive cumulus and precipitating congestus sampled over the ARM Climate Research Facility (Southern Great Plains) during the MC3E field campaign (Mechem et al. 2015; M2015) to serve as a testbed for comparisons between high-resolution LES and a wide array of high-resolution radar observations. We employ the SAM LES (Khairoutdinov and Randall 2003) running bulk microphysics based on the M2015 setup. Although the simulation results in M2015 matched reasonably well with observations, here we conduct a number of sensitivity experiments (nudging) to bring the model more in line with observed precipitation onset time.

Our objective is to take the simulations best matching the observed precipitation onset and compare them against independent measures of precipitation accumulation, echo area coverage, and cloud-top height distribution to evaluate whether the model accurately represented precipitation onset for an appropriate reason.

This experimental framework also allows us to evaluate hypotheses on the role of stability controls on cloud-regime transitions.

Synoptic configuration on 25 May 2011

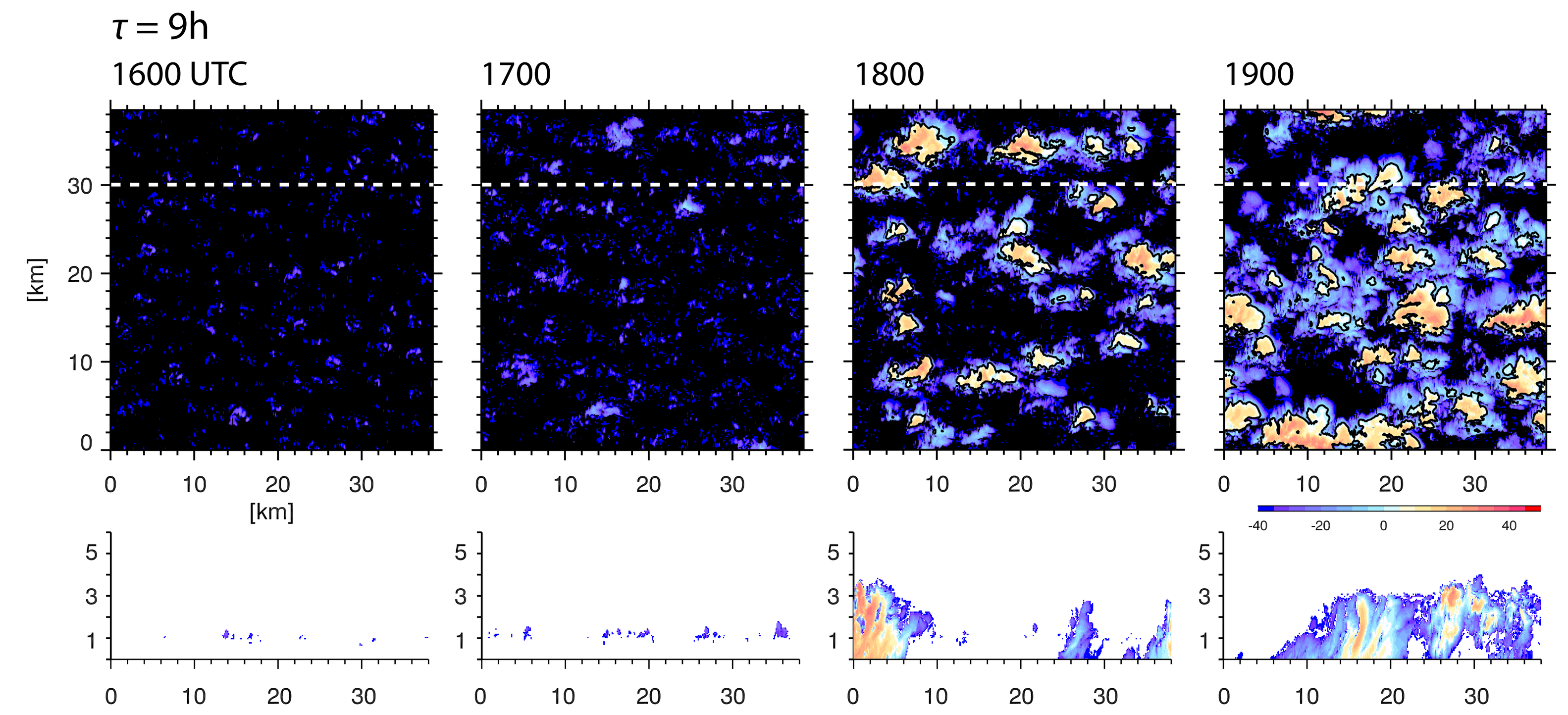


- This time period was characterized by post-cold-frontal cold advection but positive moisture advection, and a vertical motion field dominated by weak ascent
- From 1500 to 1700 UTC, the KAZR does not capture the isolated shallow cumulus visible in the TSI (not shown). However, starting at 1700 UTC, the radar does sample a cloud layer that deepens and increases in cloud fraction over the next 2 h.

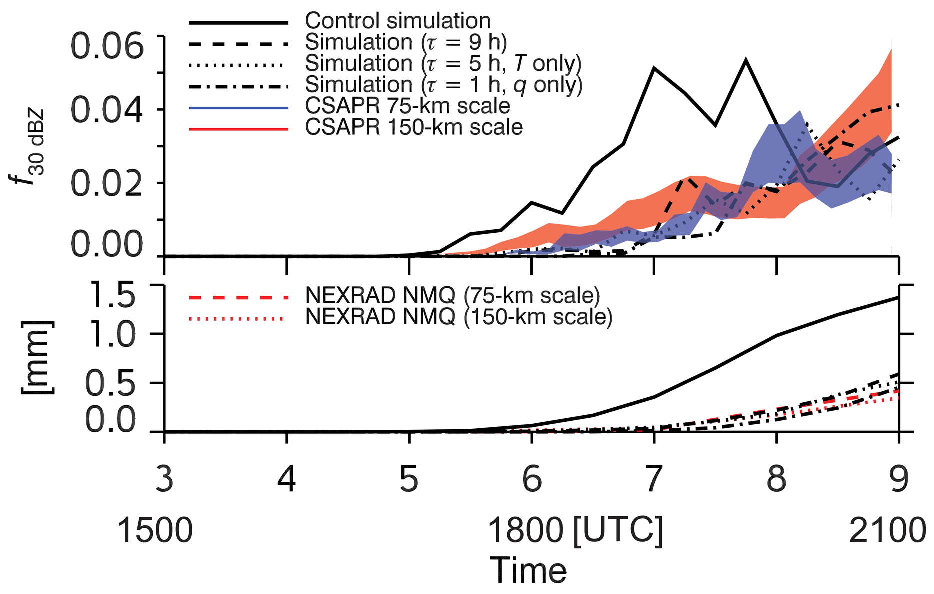
Model configuration

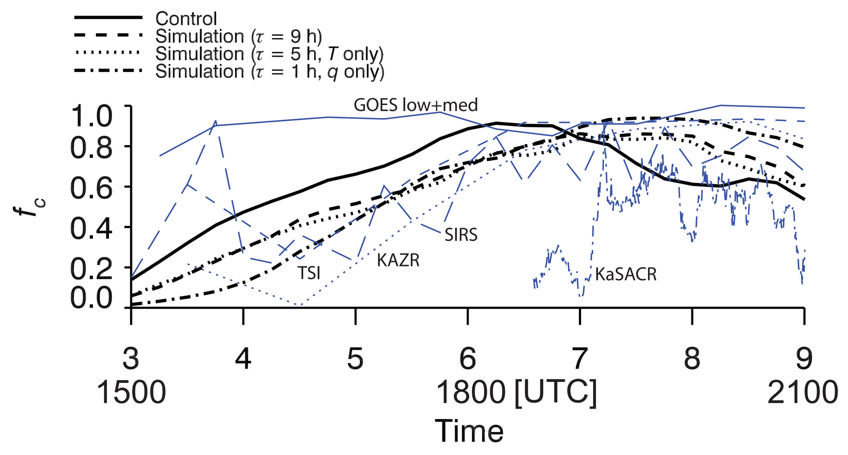
- Initial conditions and large-scale forcings taken from M2015
- Control simulation plus sensitivity simulations relaxing (nudging) the simulation temperature and moisture values to those from the variational analysis
- Relaxed at timescales of 1, 2, 3, 5, and 9 h
- Relaxing to temperature and moisture profiles, as well as each separately, for a total of 15 sensitivity runs

Horizontal and vertical cross sections of model-derived radar reflectivity for the t=9 h simulation show cloud layer deepening over time:



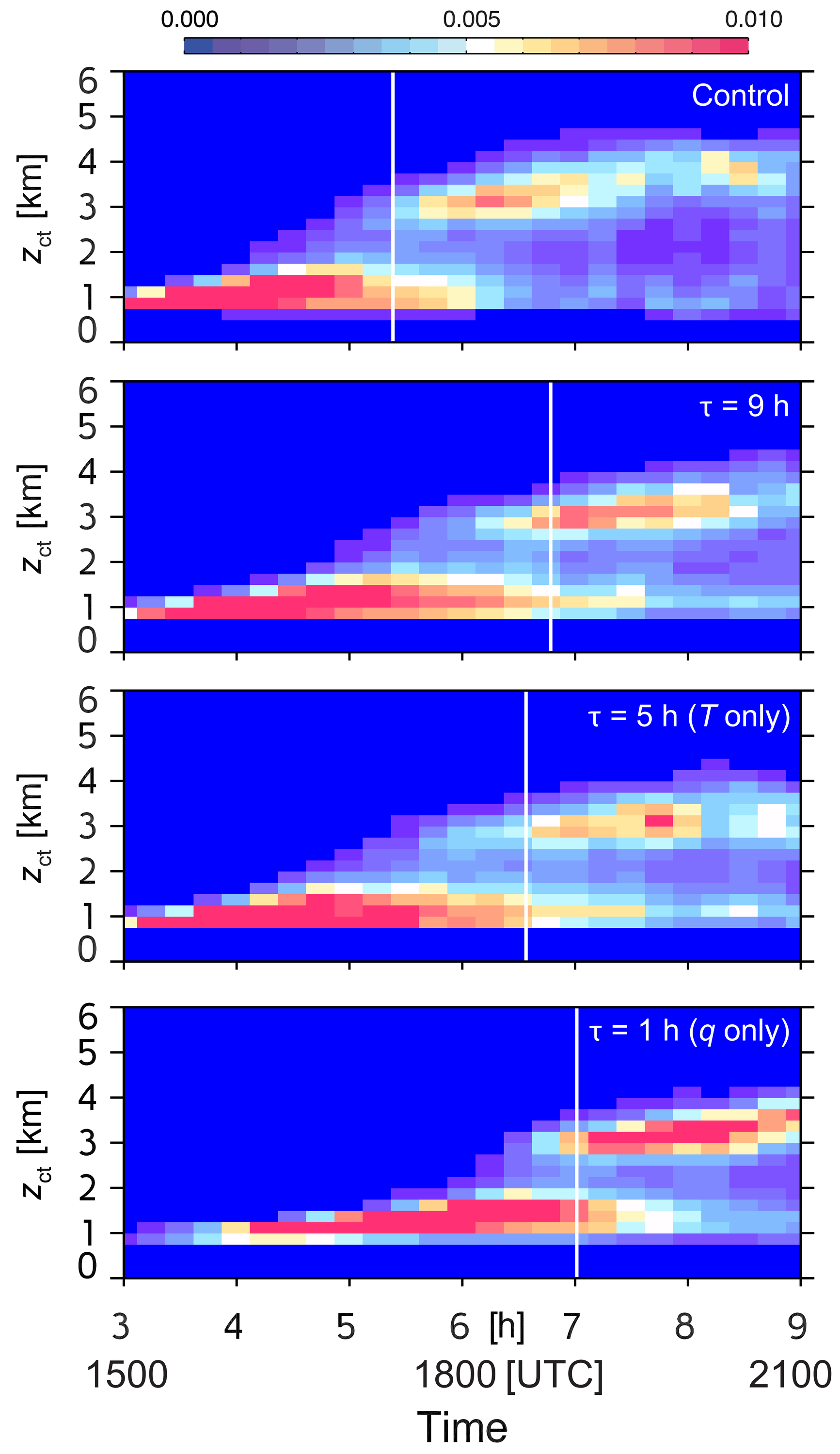
Comparison of runs that produce best precip onset



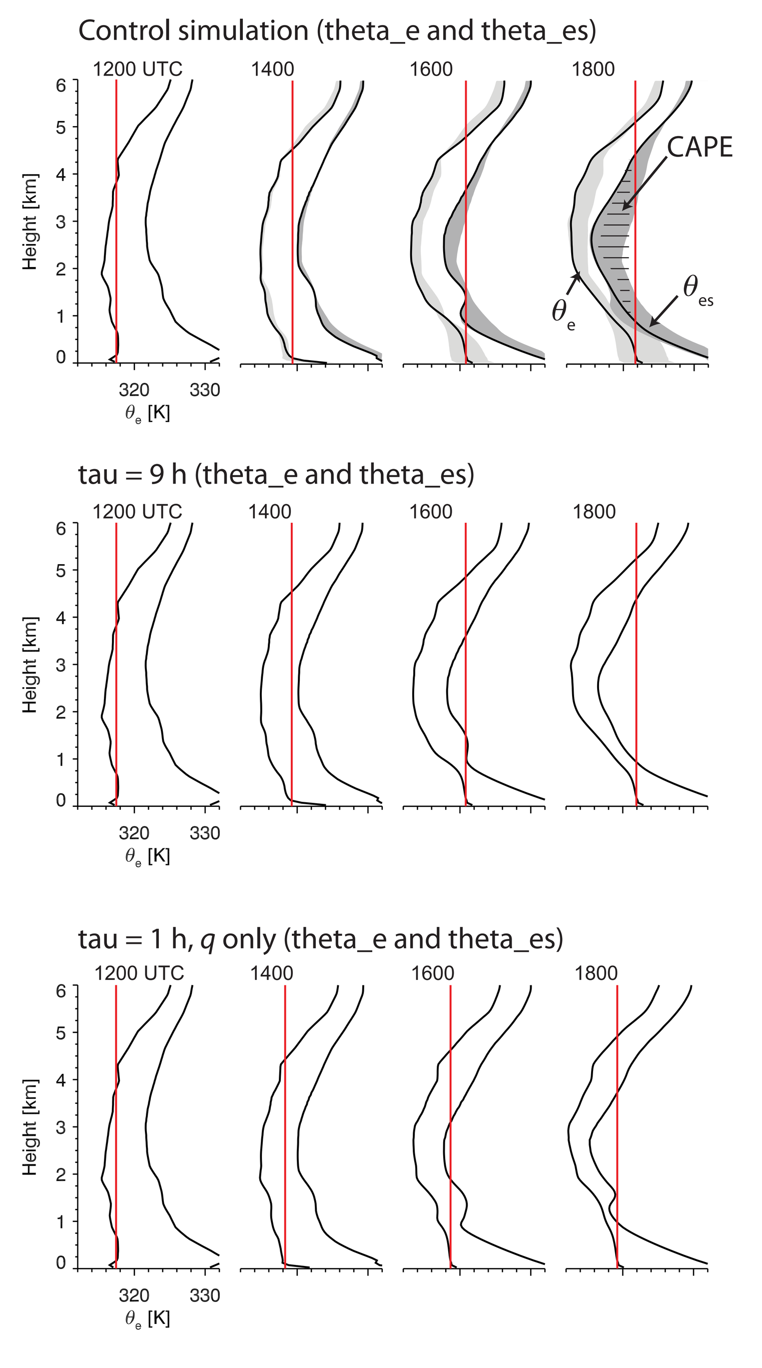


- Of the 15 sensitivity simulations, we picked the three which best capture observed accumulated precipitation and echo area coverage.
- The evolution of cloud fraction in the sensitivity runs is improved over the findings of M2015, capturing the increase in cloud fraction over time. However, we maintain cloud fraction, while radiatively important, is a poor metric for identifying behaviors in model pathologies.
- Relative to the control simulation, each of these three also better reproduced the later observed precipitation onset (each within a half hour of each other).
- The evolution of the cloud structures differs substantially across the simulations. For example, the 1-h *q*-only run remains shallow until after 1800 UTC and then rapidly transitions to predominantly congestus. This is not consistent with the observations.

Cloud-top PDFs from the simulations that best match the observed total precipitation and onset

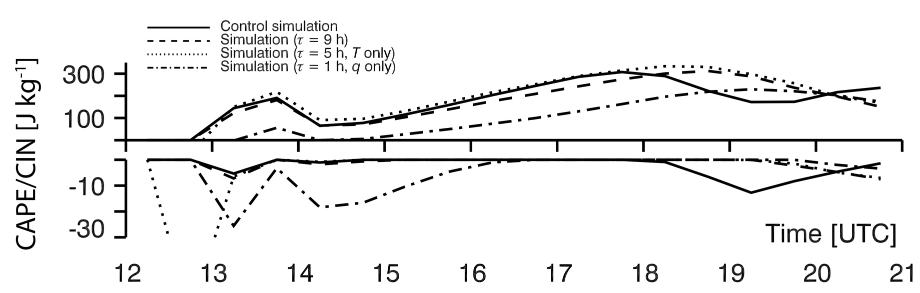


Evolution of LES thermodynamic profiles



- Evolution of profiles of equivalent potential temperature and saturation equivalent potential temperature show destabilization of the model environment.
- CAPE differs across the runs and develops with slightly different timescales.
- The relation to precipitation onset is not obvious.

Time series of CAPE and CIN



Summary

- Cloud fraction/cover is difficult to constrain observationally and provides very little diagnostic guidance to identify model pathologies.
- Area-mean behavior is the first step in evaluating models, but simulations with similar 'bulk' measures may have substantially different behavior underlying them.
- Models should be constrained with higher-order statistical information such as cloud-top height distribution, distribution of cell-sizes, and cell evolution. Need spatial and temporal information to capture behavior over cell lifetimes

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