Large Eddy Simulation of Mid-Latitude Continental Shallow Cumulus

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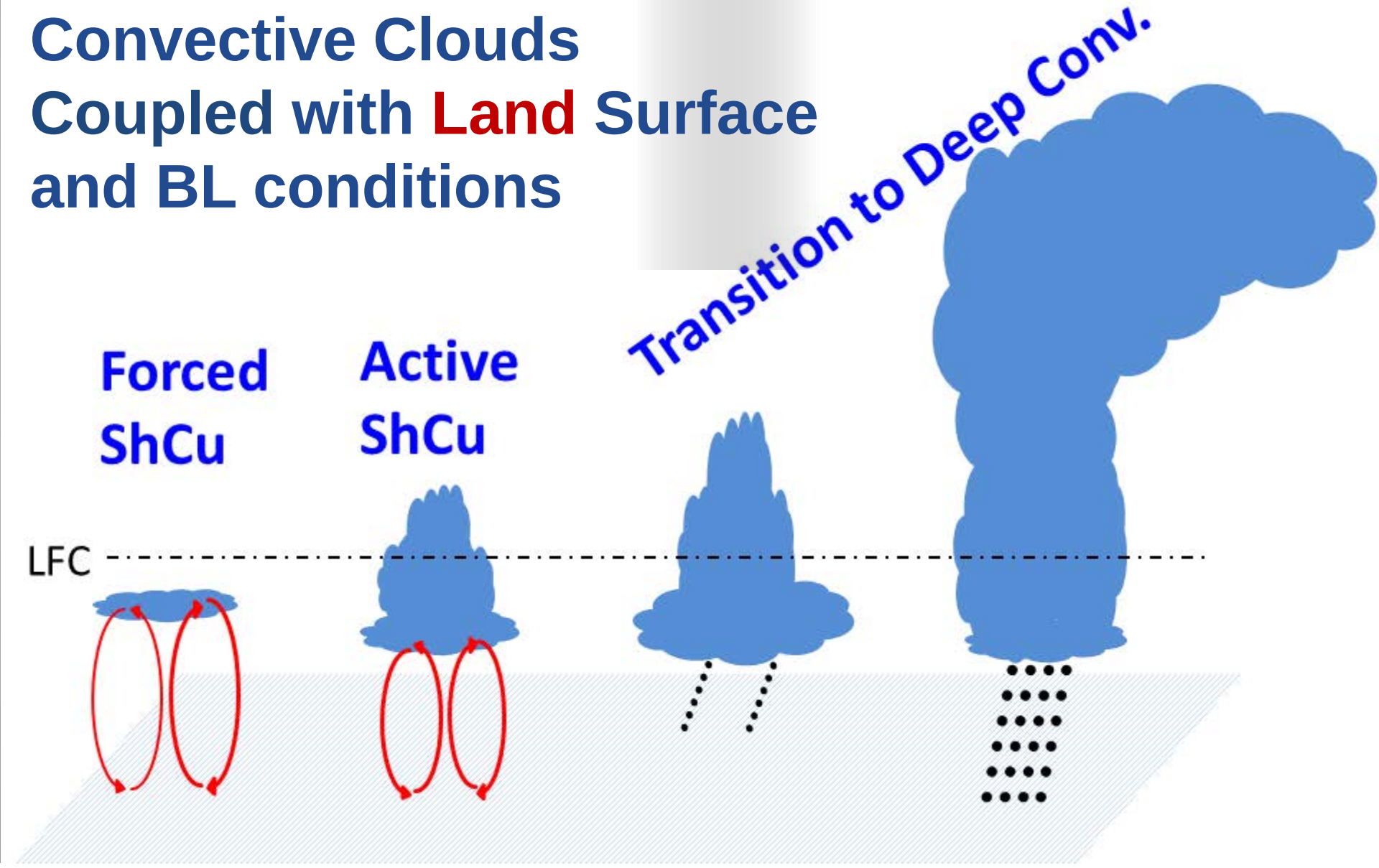
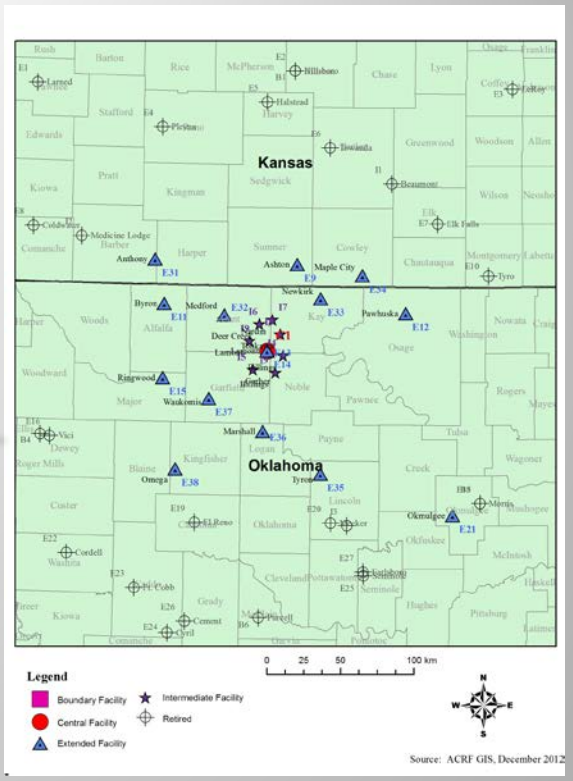
Locally-Generated Convective Clouds Coupled with Land Surface and BL conditions

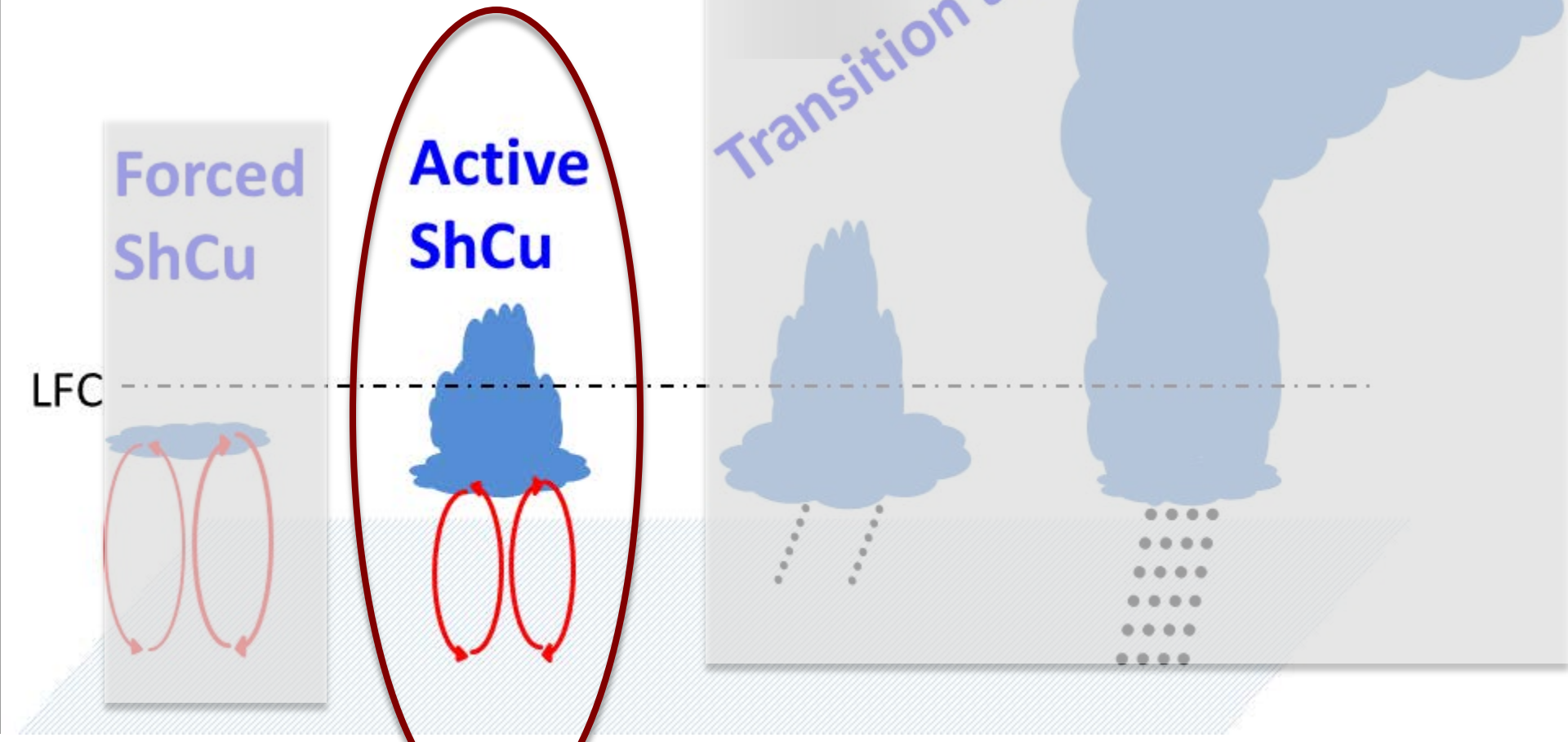


ARM observations --- a test bed

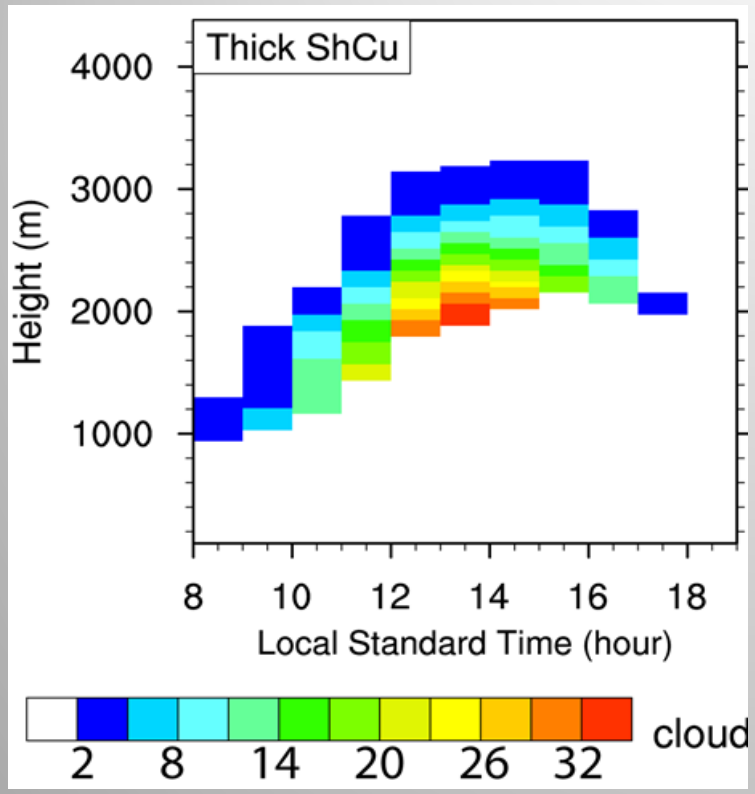


- ARM Oklahoma site provides long-term observations and continues the development of new instrument and data with scanning radar and vertical velocity retrieval capacity
- Our goal is to utilize these observation to characterize clouds for the purpose of a test bed for model developments

Locally-Generated Convective Clouds Coupled with Land Surface and BL conditions



A composite case for active ShCu



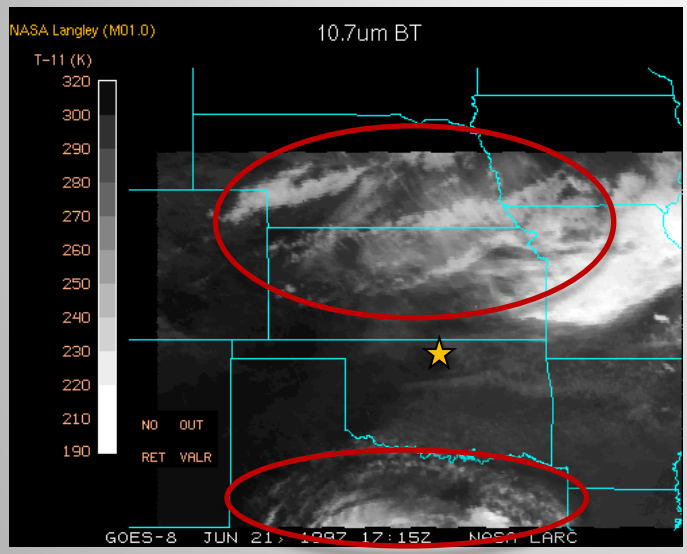
Radar observed avg ShCu cloud fraction @ SGP summer

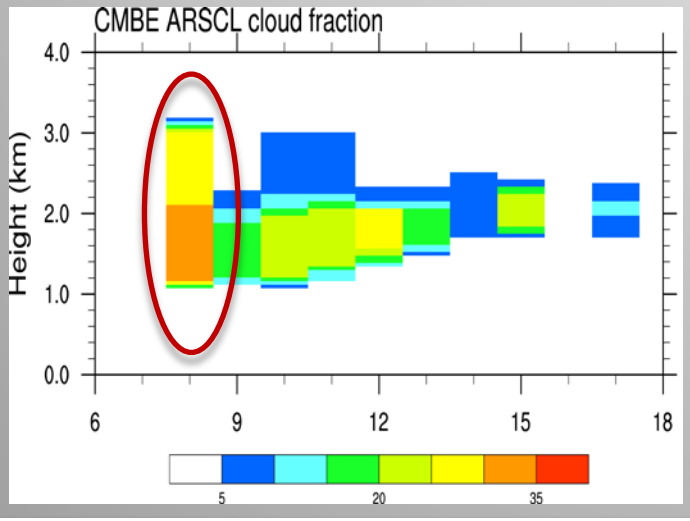
How well can LES of this composite case match the observed cloud statistics of active ShCu convection?

- 70+ active ShCu days with cloud vertical extent > 300 metes
- Reliable observations on cloud base, total cloud fraction and cloud vertical extent
- Cloud radar retrieved vertical velocity data for comparison

Our case: more typically surface-coupled

Brown et al 2002, 06.21.97





- Bowen Ratio:
  - 0.3 (Brown et al 2002)
  - 0.5 to 0.9 (Active ShCu Cases)
- Total surface flux, diurnal maximum
  - 650 Wm^2 (Brown et al 2002)
  - 550 WM^2 (Active ShCu avg)
- Cloud onset time
  - 8 a.m. (Brown et al 2002)
  - 10 a.m. (Active ShCu)

➢ "GCSS ARM ShCu CASE ≠ Purely surface-coupled shallow convection"

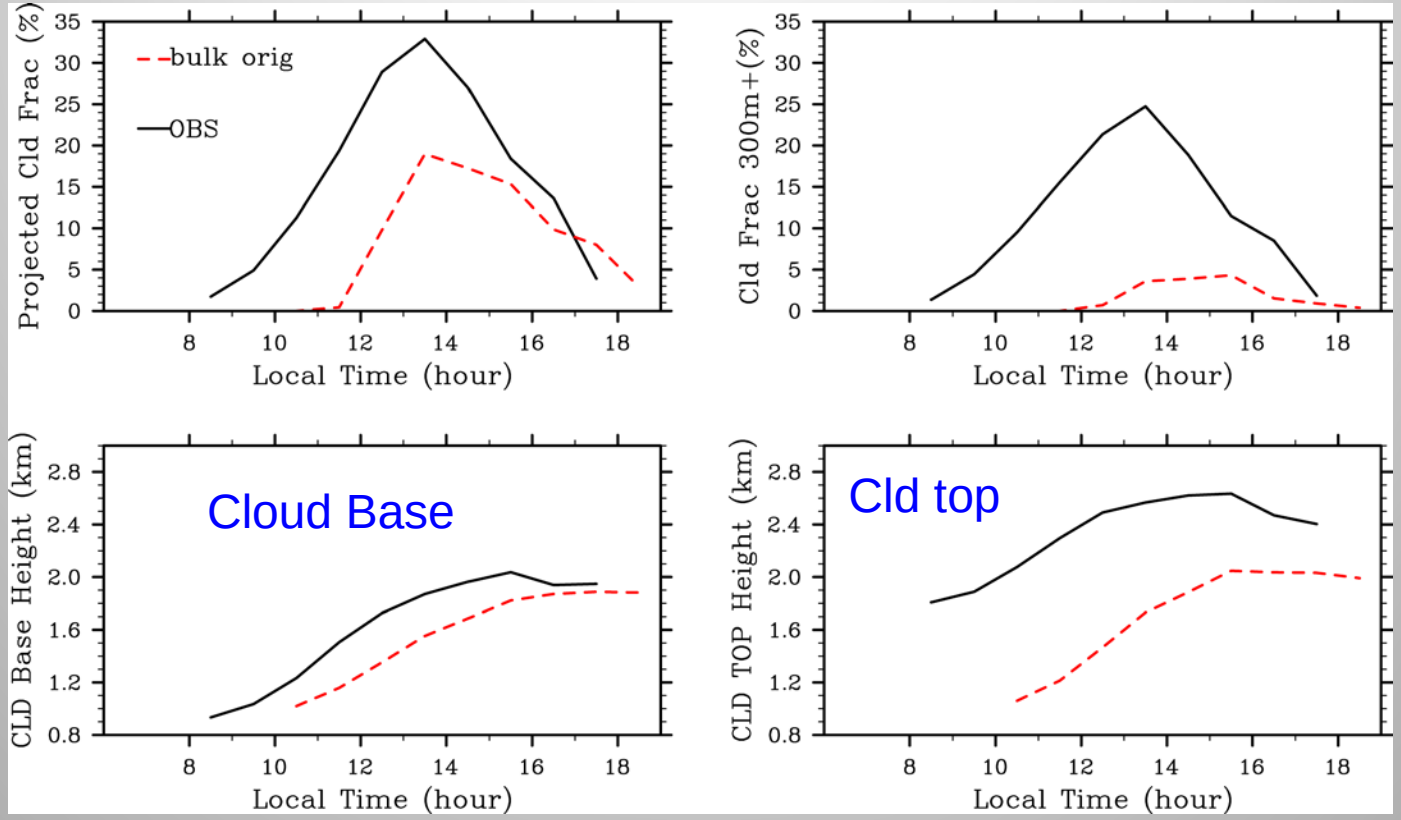
SAM LES Modeling details

- System of Atmospheric Modeling (SAM6.9) (Khairoutdinov and Randall, 2003)
- SGS TKE with 1.5 order closure
- Coupled RRTM, interactive lw/sw radiation
- Bulk microphysics / Spectral Bin microphysics (Khain et al, 2004, Fan et al, 2009)
- 5 km domain with 40 m horizontal and vertical resolution to match the 10s radar retrieval data with gates of 45 m
- 2-h wind nudging
- Initialized at 5:30 a.m. based on average of active shallow cu days' sounding and the run lasts for 14 hours.
- Total large-scale advective tendency, surface fluxes and wind fields are based on continuous forcing (Xie et al, 2004)

LES – bulk microphysics with 40 m

Total Project Cld. Frac.

Cld. Frac for deeper clds



PROBLEMS of LES: Half total cld fraction; not deep enough; lower cloud base and top; later onset time

What we have tried to improve LES

- Forcing
  - Surface flux, a more accurate Bowen Ratio (cloud base, cloud onset, ✓)
  - Initial sounding, residual layer (cloud onset ✓)
- Numerical
  - Resolution (✓, total cloud fraction)
  - Domain size (✗)
- Perturbation
  - Initial perturbation (✗)
  - Wind-speed scaled surface flux (✗)
- Ensemble of days versus one composite day, nonlinearity? (✗)
- Microphysics (✓, total cloud fraction, clouds' depth)

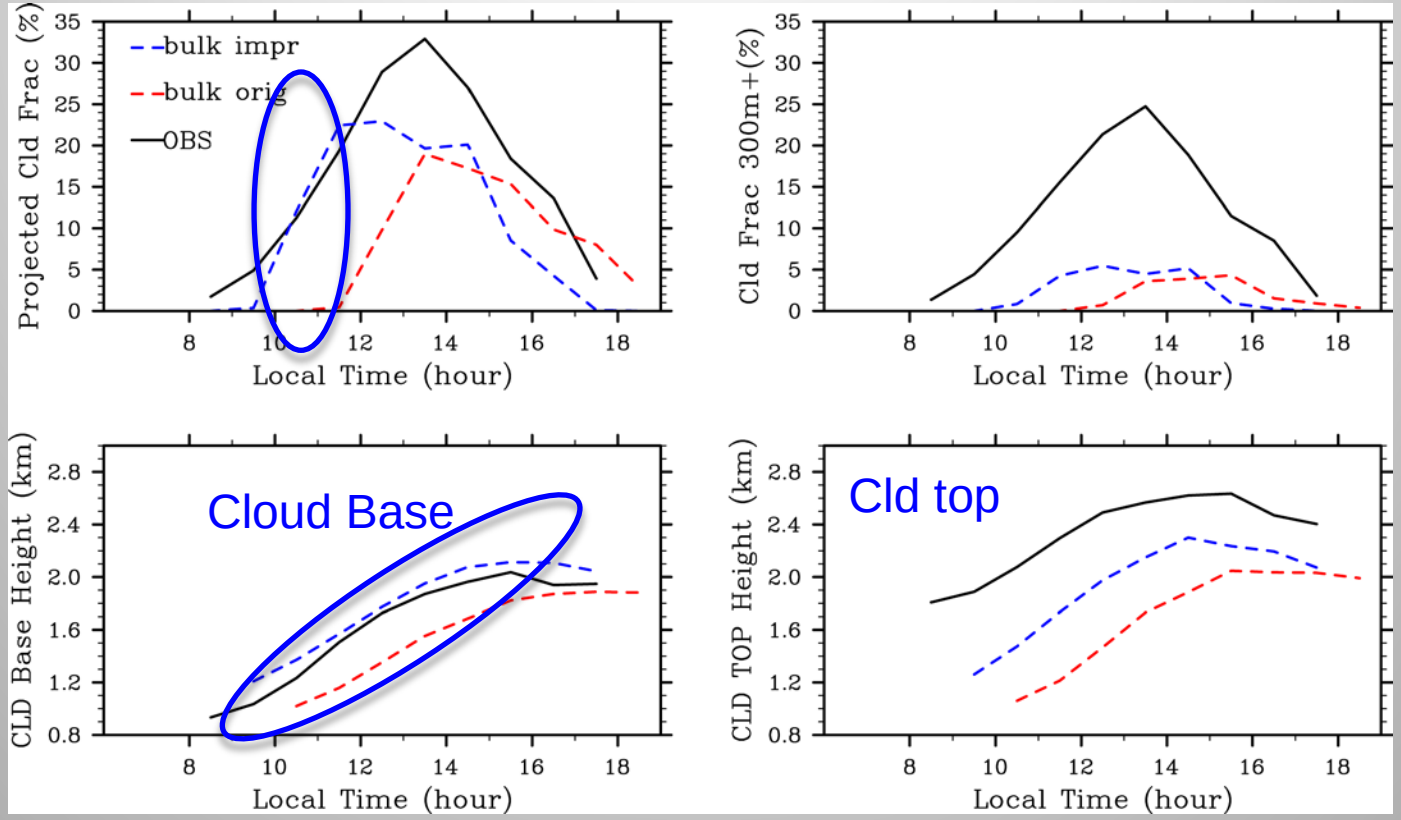
✓ **Sensitive**

✗ **Not sensitive**

Factors that improve onset time and cloud base height

Total Project Cld. Frac.

Cld. Frac for deeper clds

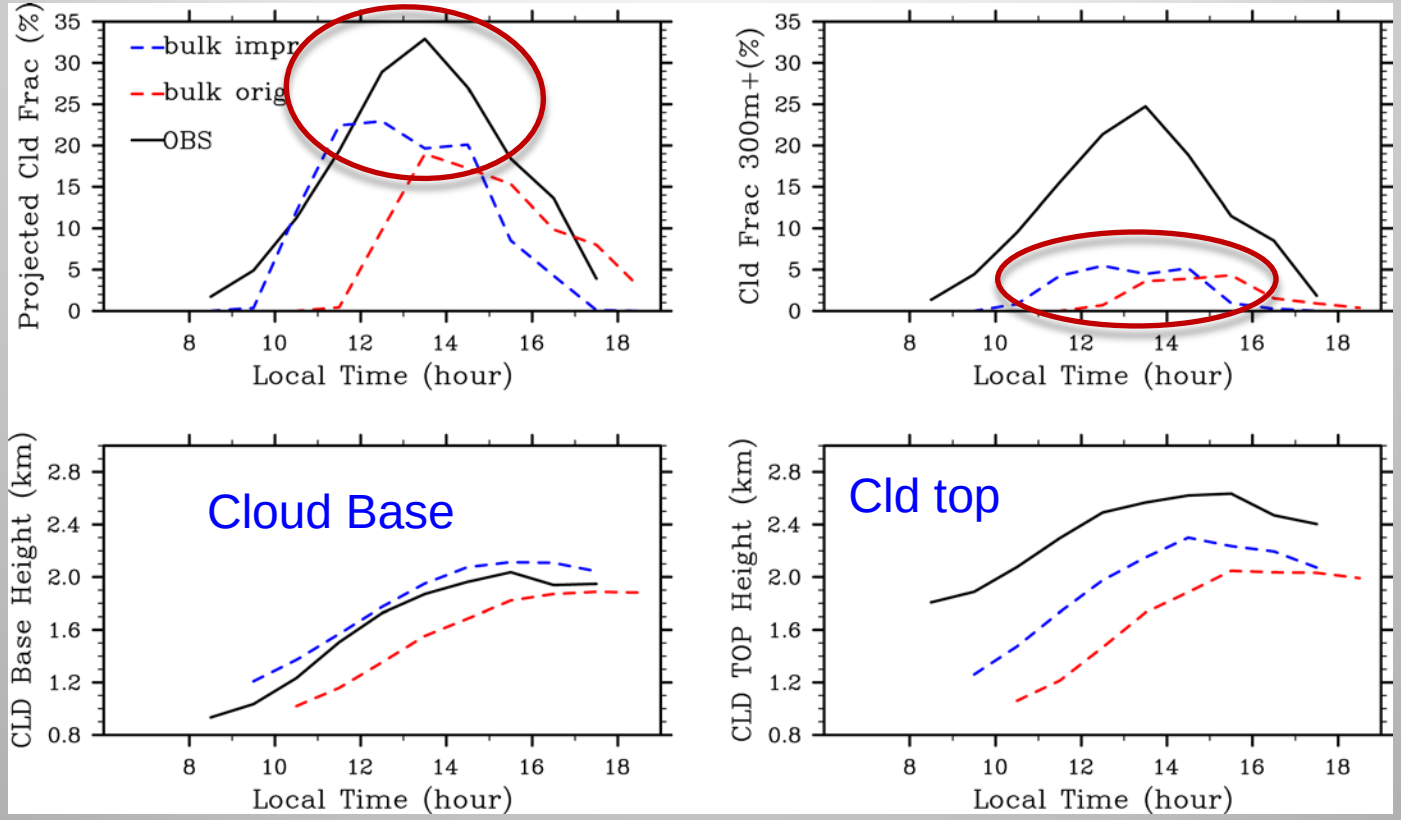


1. More accurate Bowen ratio (from 0.5 to 0.65)
2. Adding to the initial sounding a residual layer of the previous day's mixed layer
3. Increasing resolution to 20 m

Factors that improve onset time and cloud base height

Total Project Cld. Frac.

Cld. Frac for deeper clds

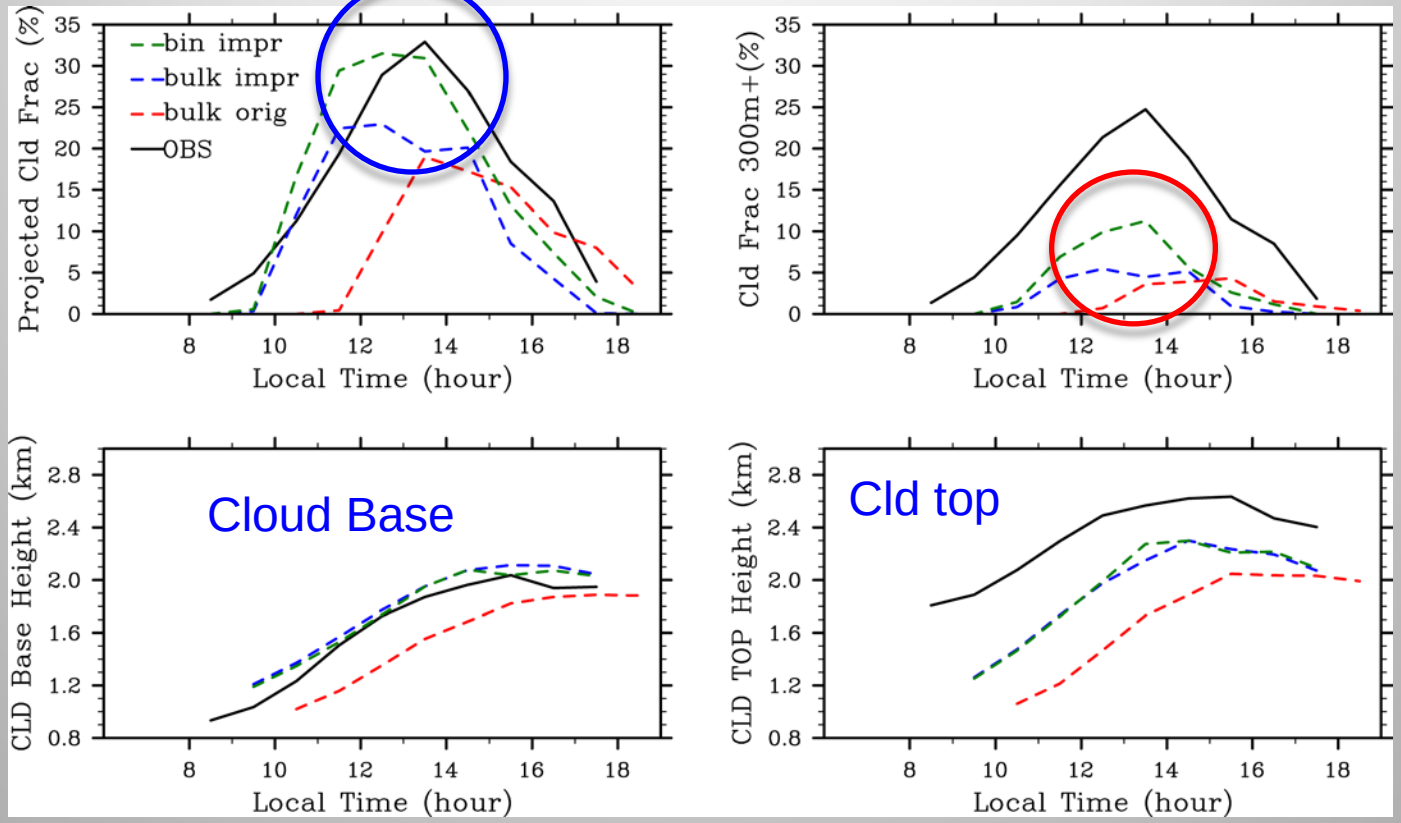


Problems remain for total cloud fraction and clouds still not penetrating deep

Bin microphysics improves total fraction and clouds grow deeper

Total Project Cld. Frac.

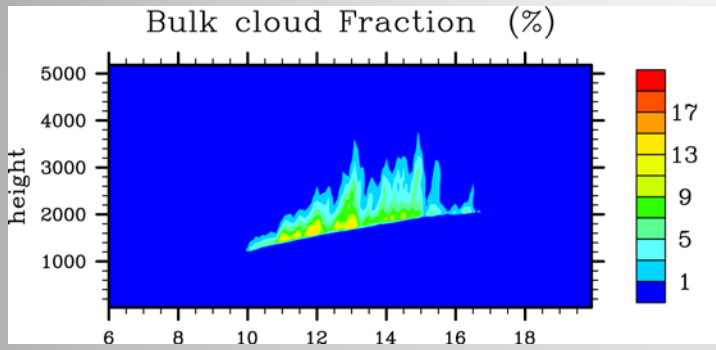
Cld. Frac for deeper clds

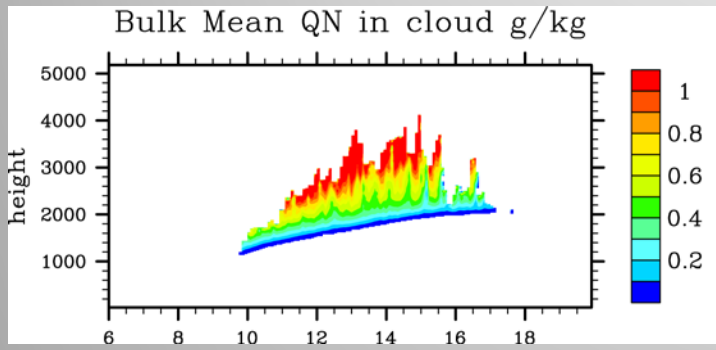


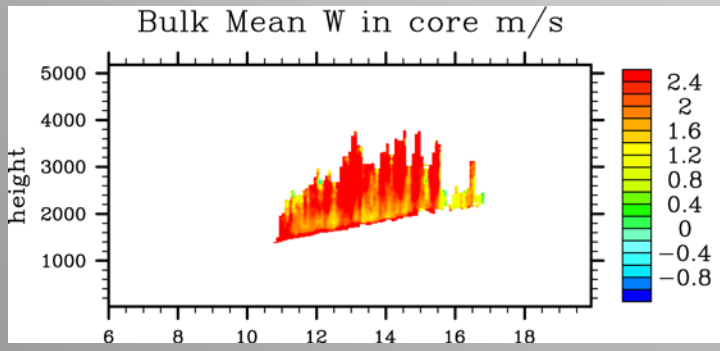
Total cloud fraction looks very nice however just partially fix the deeper cloud problem

Microphysics: Bulk vs. Bin

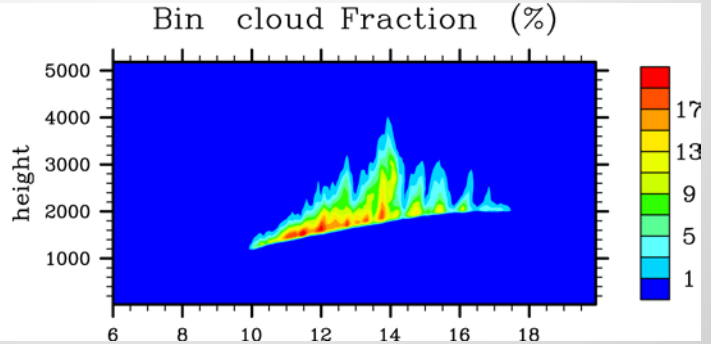
Bulk

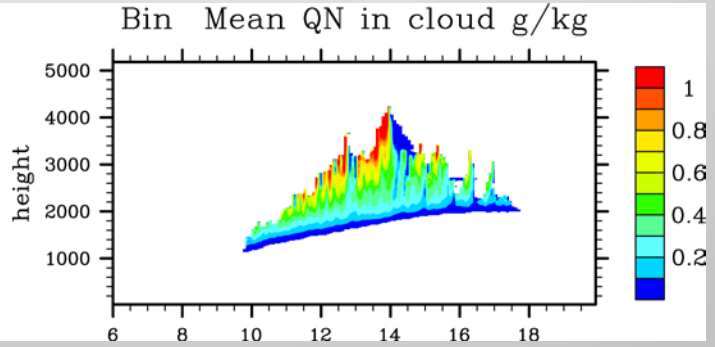


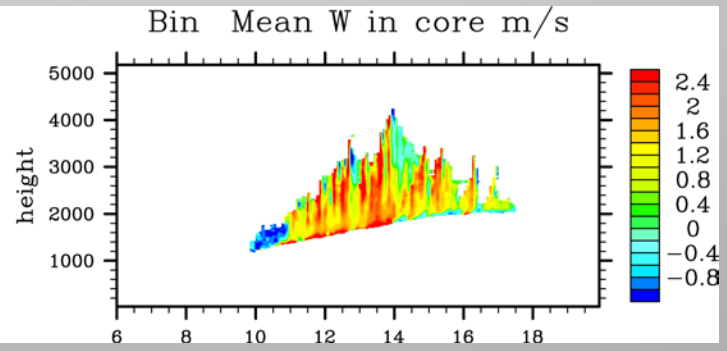




Bin







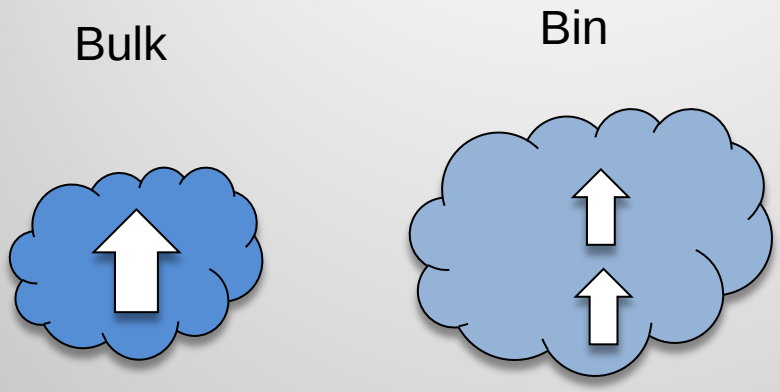
Bin Scheme has

More clouds

Less condensates

Weaker velocity

Why does microphysics matter for non-precipitating shallow cumulus?

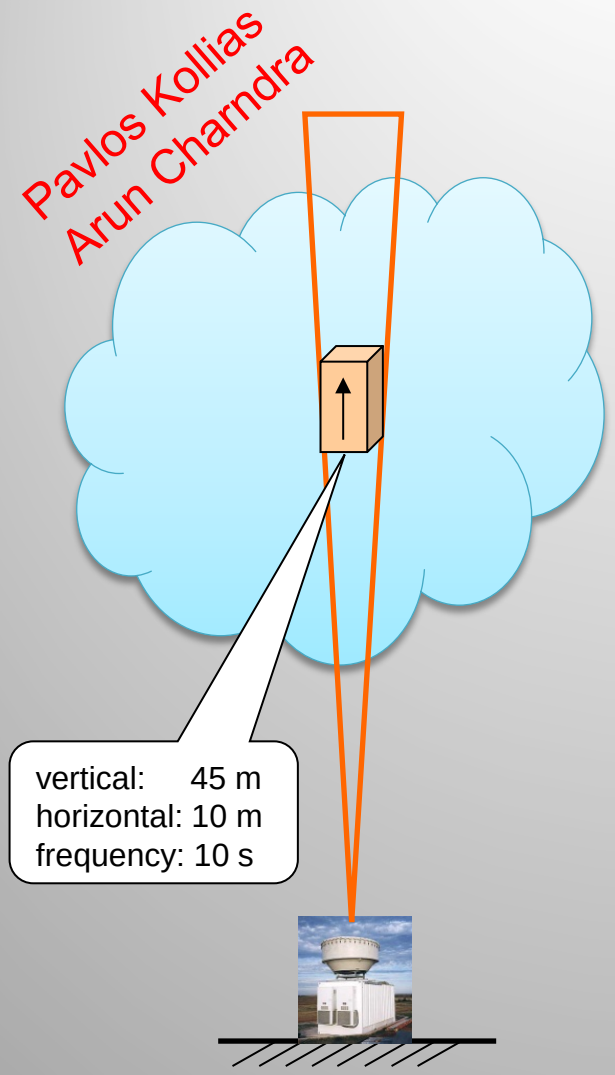


The finite condensation/evaporation time scale in Bin microphysics

Instantaneous condensation/evaporation in Bulk microphysics

- Longer lingering time of cloud?
- Does the larger positive buoyancy area hints at a less vigorous mixing and a smaller entrainment rate? Thus leads to a larger fraction of cloud penetrating deeper.

Vertical Velocity Observation

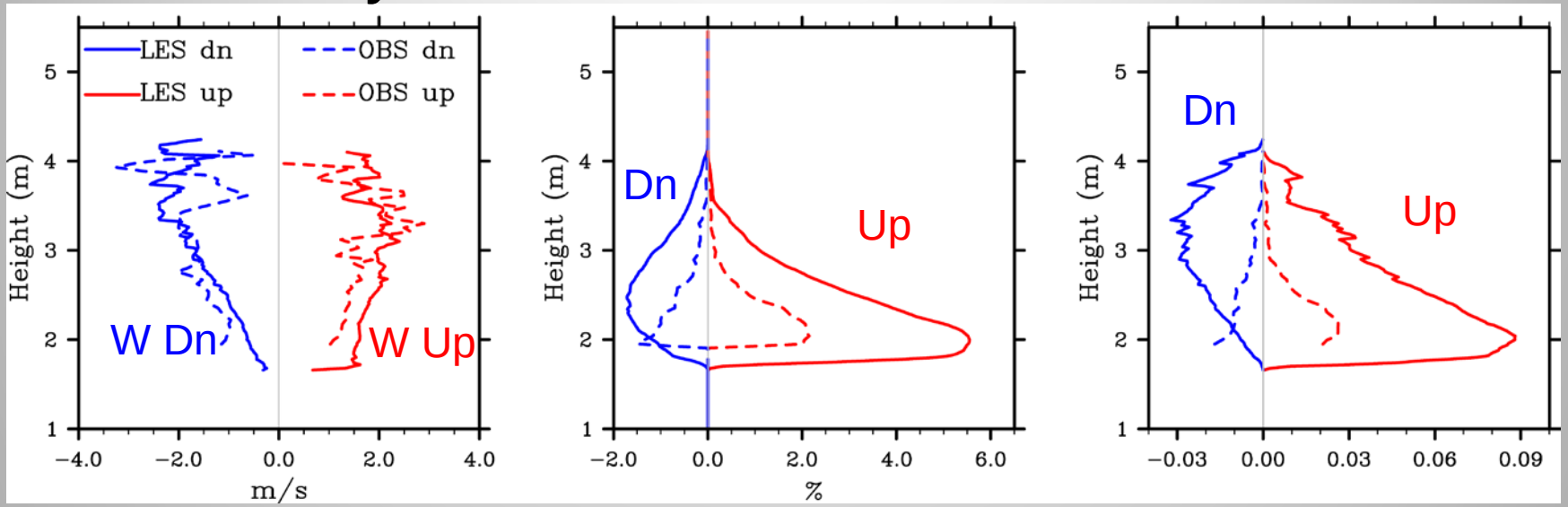


ARM SGP Millimeter Wavelength Cloud Radar

- Usually the terminal velocity of liquid cloud droplet is about ~cm/s, this is much smaller compared to air motion velocity ~ m/s Thus the vertical velocity of cloud droplet is representative of air motion
- 10s data with 45 m vertical resolution
- To make an apple-to-apple comparison, we are limited to sample profiles with LWP > 80 g/m^2 both in OBS and LES.

LES mass flux compared with Radar

Velocity | Fraction | Mass Flux



- Comparable vertical velocity, slightly stronger updraft
- Both show that downdraft occupies a significant in-cloud area, in-cloud downdraft mass flux is not negligible
- Much larger updraft/downdraft fraction in LES results in a larger mass flux compared to OBS

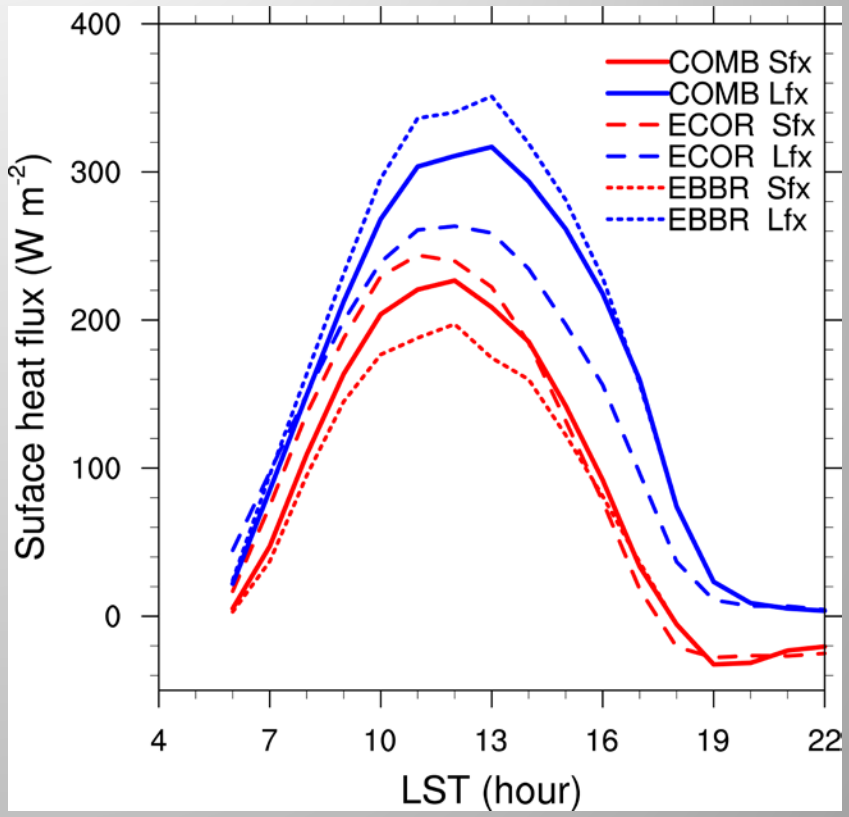
Summary

- We have already created a case of more typically surface-coupled non-precipitating active ShCu day than the previous GCSS case by Brown et al 2002
- With improved surface flux and initial sounding conditions and bin microphysics scheme, LES shows a promising comparison with OBS, especially on the most reliable observed quantities, such as cloud base height, total projected cloud fraction, and cloud onset time.
- Problems still remain with simulating cloud deep enough than 300 meters.
- Such simulation may serve as a future test bed for LES and SCM
- We will then test the environmental controls such as moisture and atmospheric stability on clouds' vertical extent and transition to deep convection

Thank You!

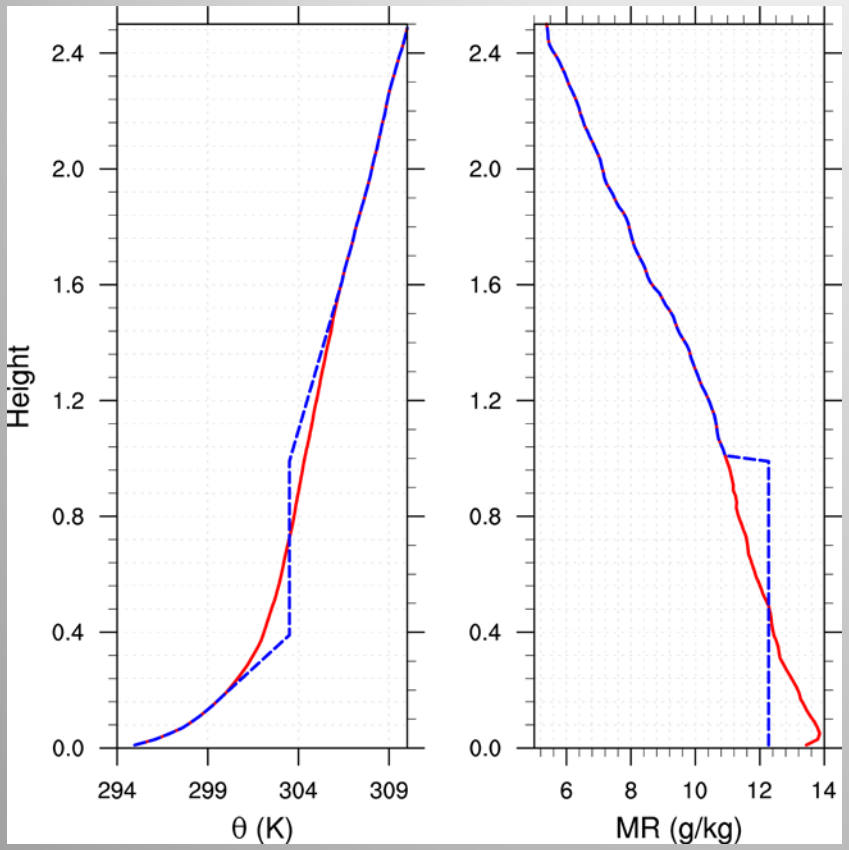
Surface flux fix

- Continuous forcing's surface flux is solely based on EBBR, ECOR data is not include
- Rely on the total flux of EBBR because of the energy balance constrains by radiation
- Partition between sensible and latent heat flux is based on the average of EBBR and ECOR to represent a "domain" average



Initial sounding fix

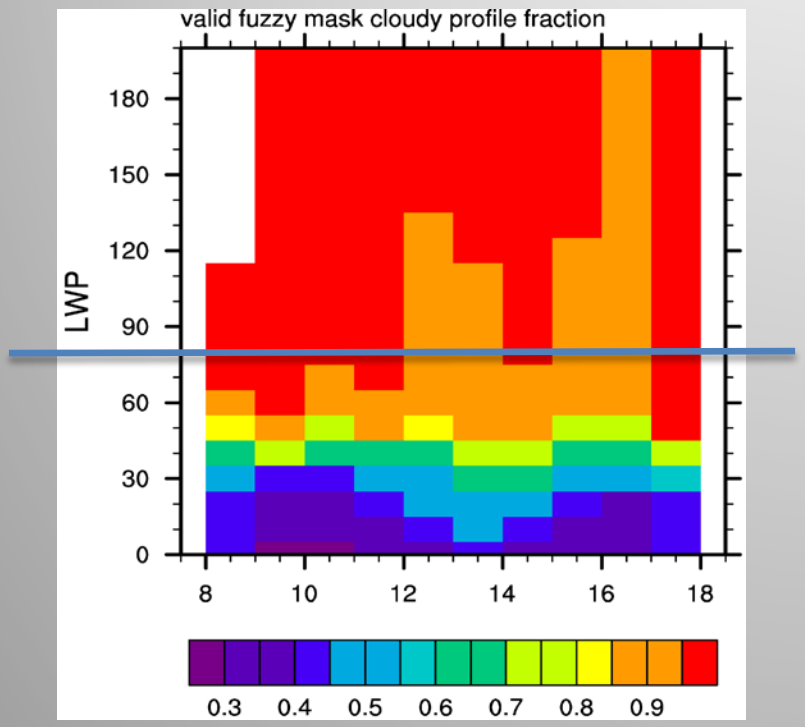
0530 a.m. sounding composite

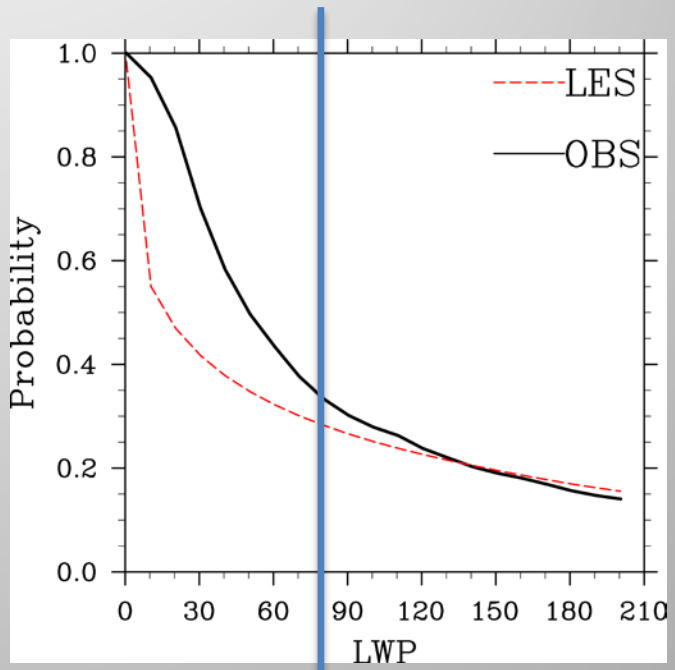


- To address the residual layer often observed in 0530 am sounding of shallow cumulus days, we add a residual layer between 400 to 1000 meters and preserve the total needed energy and moisture for BL growth

Comparison criteria

Are we still comparing the same part of clouds?





Inside cloud, the cumulative probability function of cloudy profile greater than certain value of LWP

LES mass flux: LWP>80 vs. Total