A New Composite Case for Continental Shallow Cumulus: Details and Sensitivity Tests

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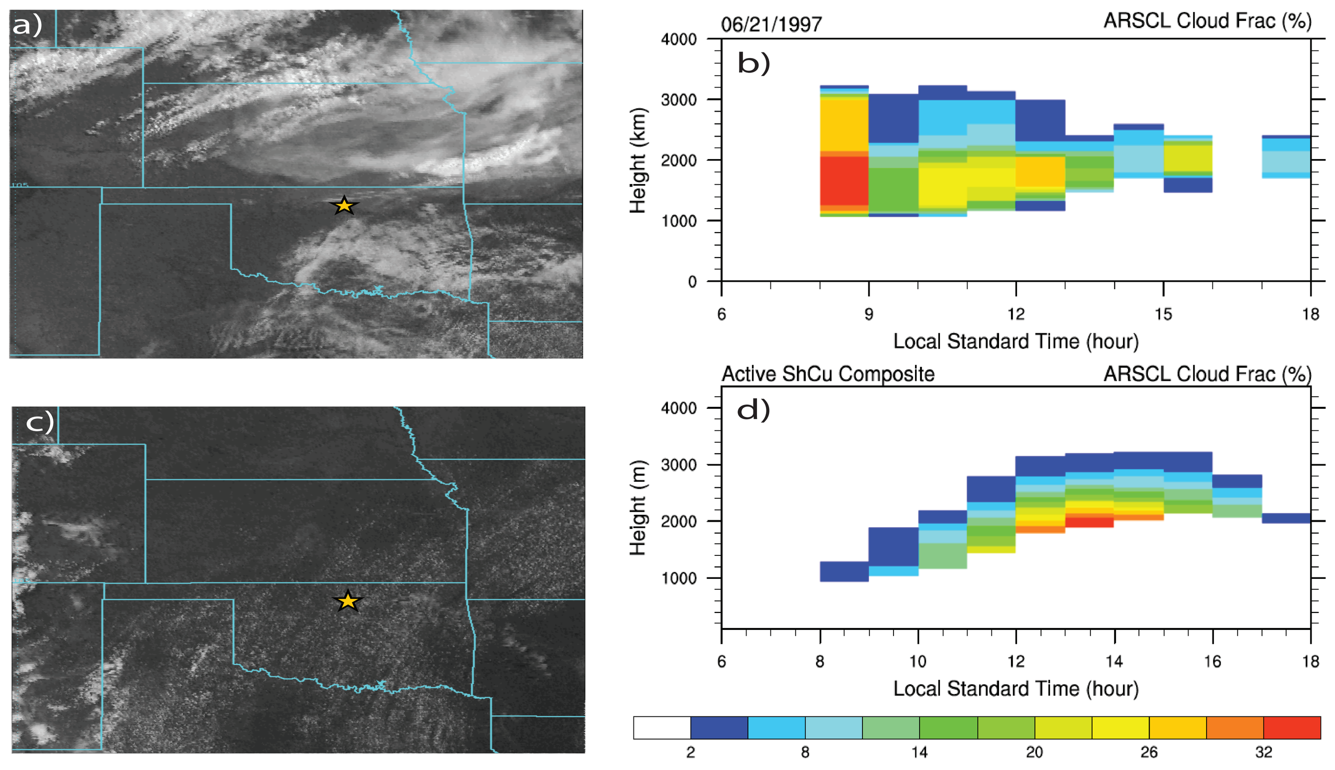
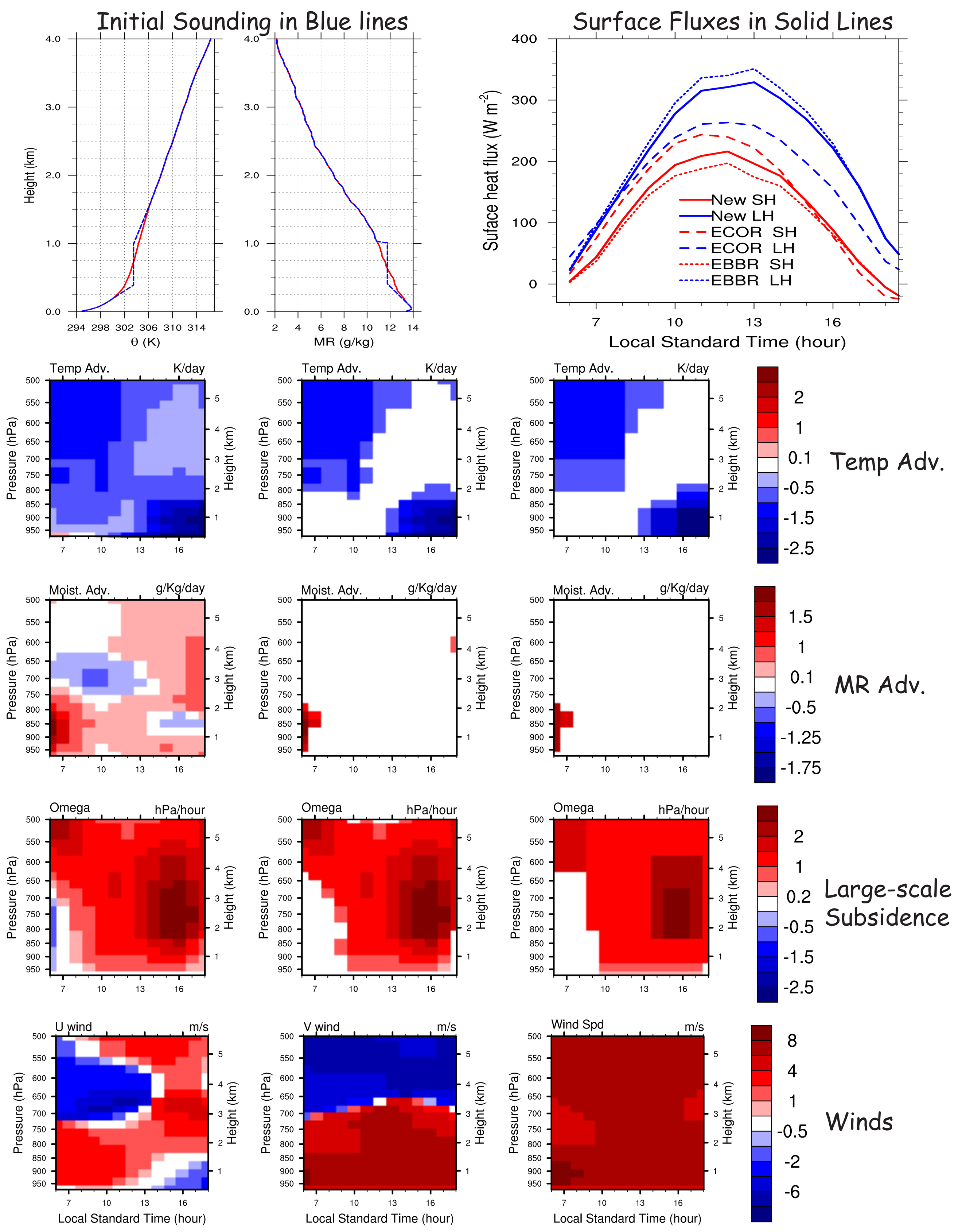
Motivation

Global climate models usually have difficulties in simulating correct diurnal cycle of clouds and precipitation due to the lack of shallow convection development (Guichard et al 2004). Widely-used GCSS-ARM97 SGP case (Brown et al, 2002) may not be a typical representation of land-surface-forced shallow convection. Based on 76 SGP active shallow cumulus days, we build a new composite case to serve as a robust testbed of continental shallow cumulus for LES and single-column model for evaluations of large-scale model parameterizations.



Top left (a): reflectance by GOES-8 at 08:15 Local Standard Time (LST) on 6/21/1997 over ARM SGP site (b): Diurnal cycle of vertical cloud fraction (%) based on ARSCL. X-axis is the Local Time. (c): same image but for 2001/05/14 at 13:15 LST, one of the shallow cumulus days. (d): observed ARSCL cloud fraction for our new composite case.

Forcing data

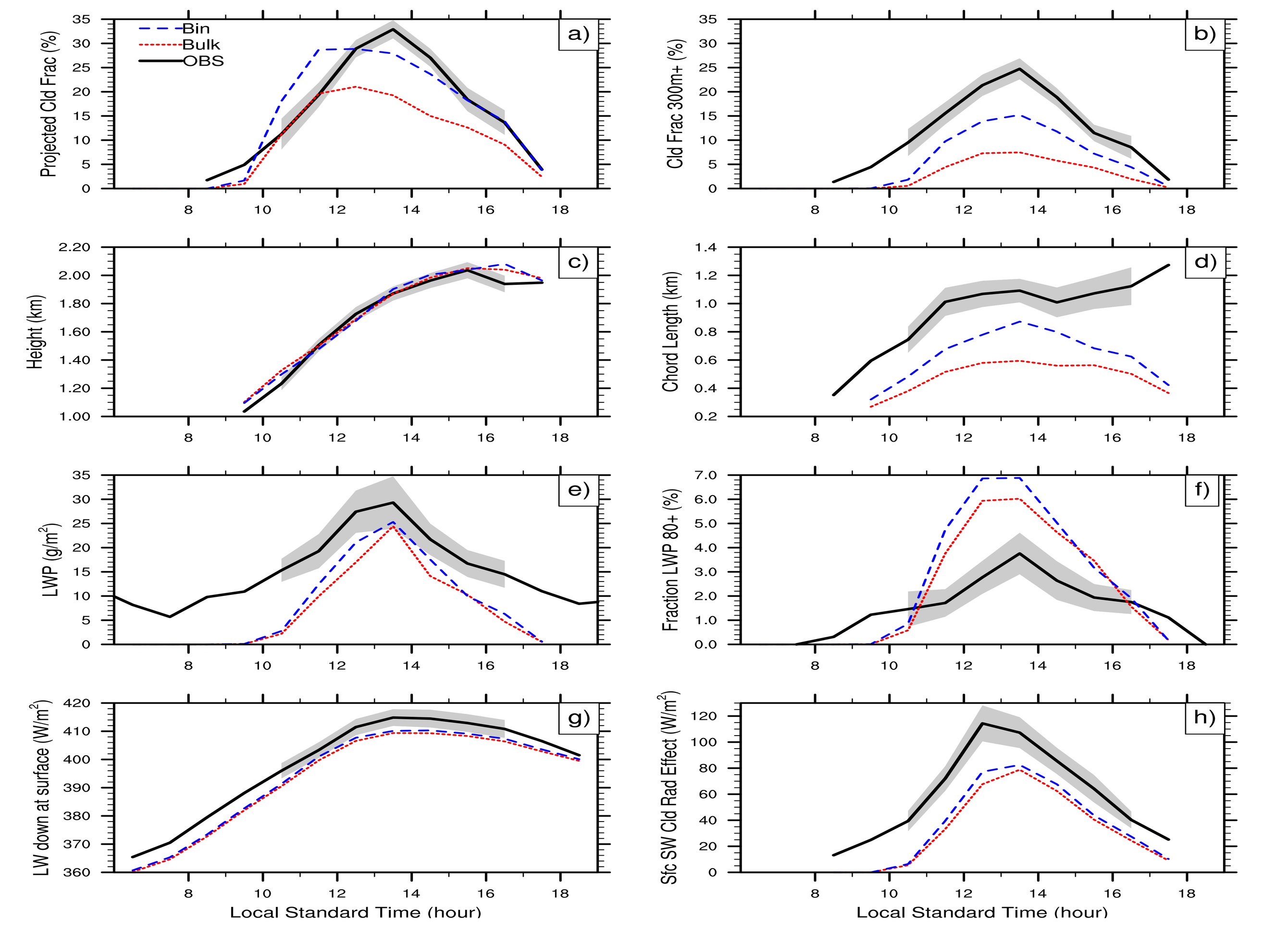


Time-Height composite mean large scale horizontal advective tendency based on long-term continuous forcing data from variational analysis. In the first three rows, the left figures are the original composite values; the middle figures show the data passing the significance test that values are statistically different from "zero"; and the right figures show our idealization of the forcing used in composite case run.

Model details

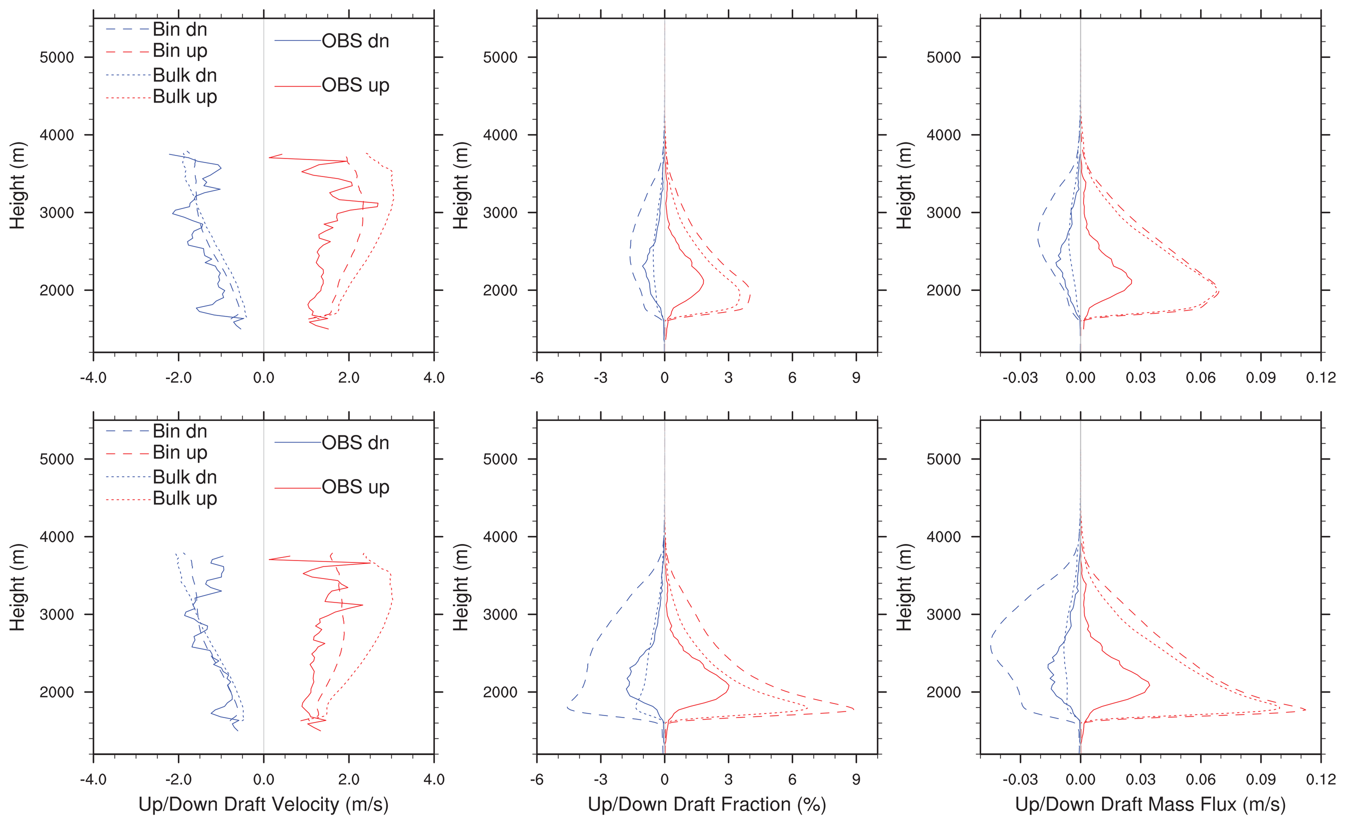
- System of Atmospheric Modeling (SAM6.9) (Khairoutdinov and Randall, 2003)
- Two microphysics packages: one-moment Bulk SAM default; Spectral Bin microphysics (Khain et al, 2004, Fan et al, 2009)
- Subgrid scale TKE with 1.5 order closure
- Coupled RRTM, lw/sw radiation calculation every 60s
- 28 km by 28 km domain, 1-s time step, 12-hr run from sunrise
- 50 m horizontal and 20 m vertical resolution. Stretching vertical grids above 6 km for radiation.
- 1-hour wind nudging at all levels towards forcing wind fields
- 1-hour T and Q nudging above 6 km for radiation purpose
- Samples collected every 30s, 2D and 3D statistics are averaged and output every 5 minutes.
- Large-scale horizontal advective tendencies, subsidence, winds are based on composite mean of continuous forcing data;
- Initial sounding includes a residual layer behavior
- Surface fluxes based on both ECOR and EBBR
- Subsidence was reduced to 70% due to ECOR's correction

Bulk vs Bin Microphysics



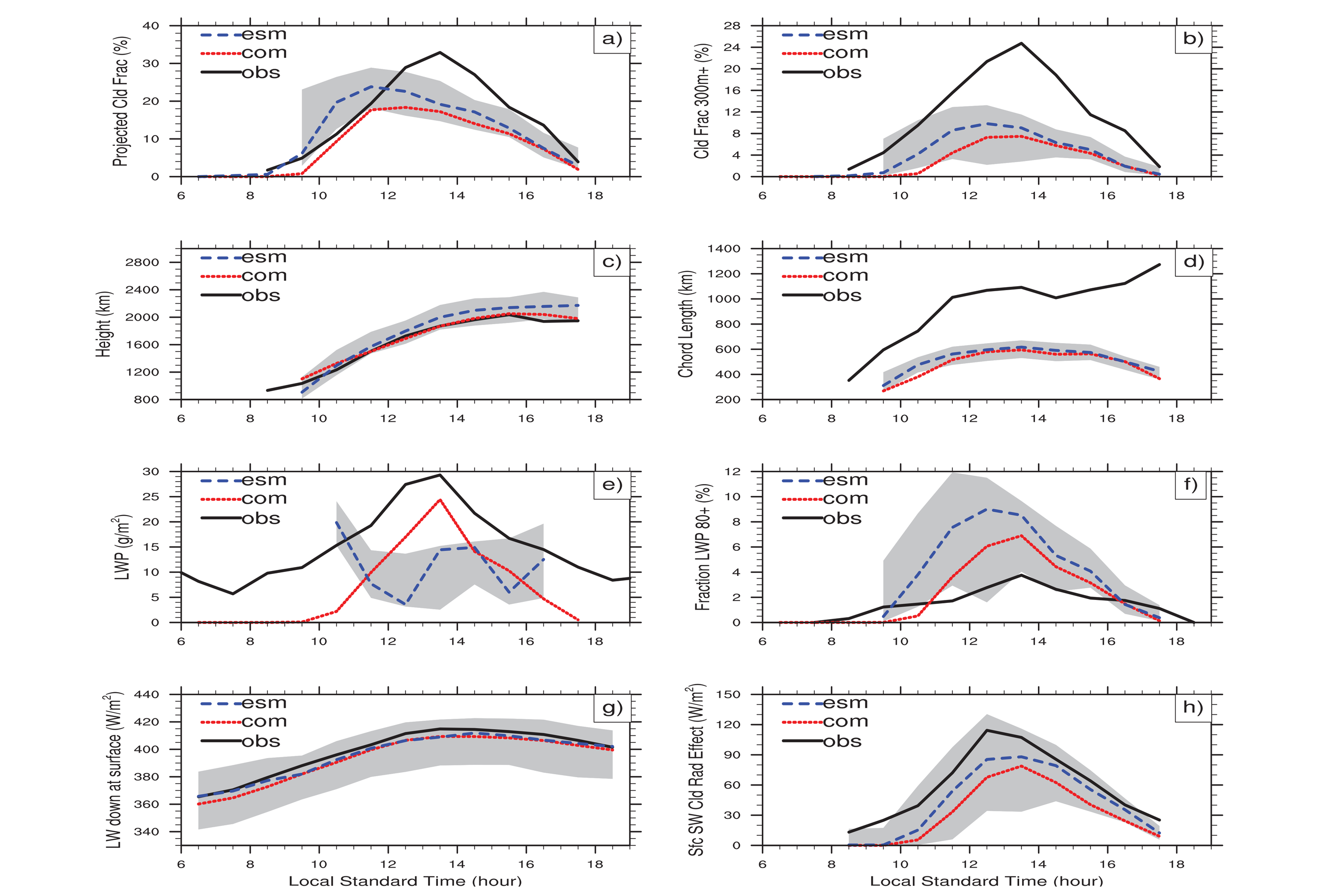
The width of shading on either side the observed composite mean value denotes one standard error of the mean across all the sample days. The shading is only shown for hours with sample days greater than 30 for the purpose of statistical significance.

Mass Flux Comparison



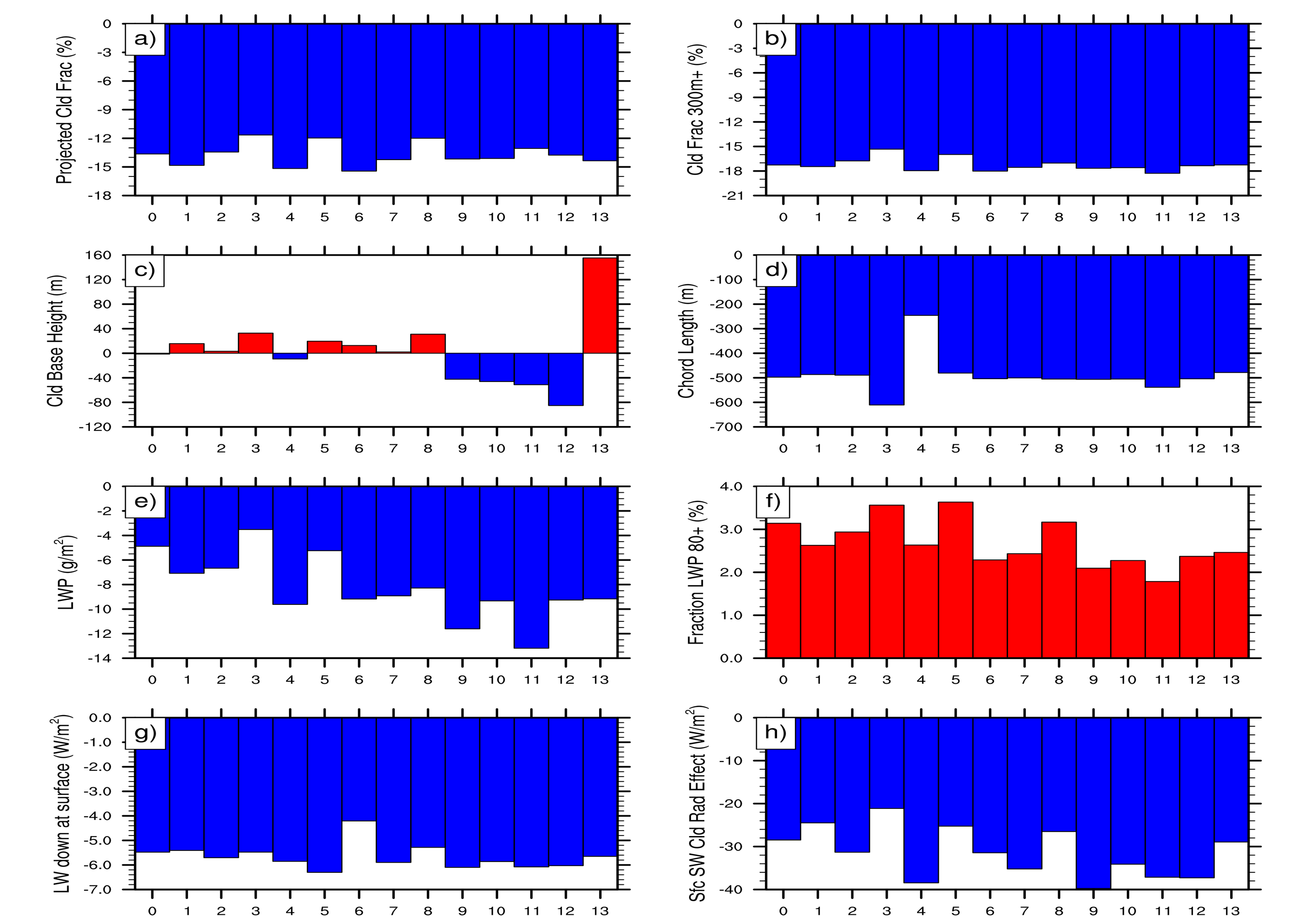
Comparison at 1330 LST between LES with bin (dashed lines) and bulk (dotted lines) microphysics and radar retrievals (solid lines): The comparison (top row) is limited to cloudy profiles with liquid water path greater than 80~g/m2 in both LES and valid observations. Bottom row is the comparison for all the cloud profiles in LES and all the valid retrievals.

Composite case vs. Ensemble



The shaded area denotes the quatile spread of the 40 ensemble runs which produce shallow cumulus clouds, the blue long dashed line denotes the ensemble median.

Sensitivity to Configuration



0, control run; 1, quarter domain; 2, quadrupled domain; 3, double horizontal resolution; 4, half horizontal resolution; 5, double vertical resolution; 6, half vertical resolution; constant geostrophic winds 10m/s; 7, wind nudging 10 hours; 8, subsidence without ECOR correction; 10, initial sounding without residual layer; 11, forcing without significance test; 12, EBBR surface fluxes; 13, ECOR surface fluxes

Summary

LES set up and configuration,
- LES with spectrum bin microphysics generates a better comparison with data in total cloud fraction.
- LES do not produce enough cloud deeper than 300 meters, however may overpredict much deeper clouds with LWP > 80 g/m^2.
- LES is not sensitive to other particular configurations
- Ensemble mean behavior of individual LES shcu days is very comparable to our composite case, although with large spread

Mass flux comparison with long-term Radar retrieval of in-cloud vertical velocity
- Comparable vertical velocity, stronger LES updraft
- Downdraft is not negligible in clouds
- Mass fluxes are larger from LES compared with data

Reference: Zhang et al, 2017, Large-eddy simulation of shallow cumulus over land: A composite case based on ARM long-term observations at its Southern Great Plains site. JAS, in review

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