Vertical Velocity in Fair-weather Shallow Cumulus over Land: MMCR Observation against Large-Eddy Simulation

November 5th 2013

Yunyan Zhang, Arun Chandra, and Steve Klein

Lawrence Livermore National Laboratory

ASR Atmospheric System Research

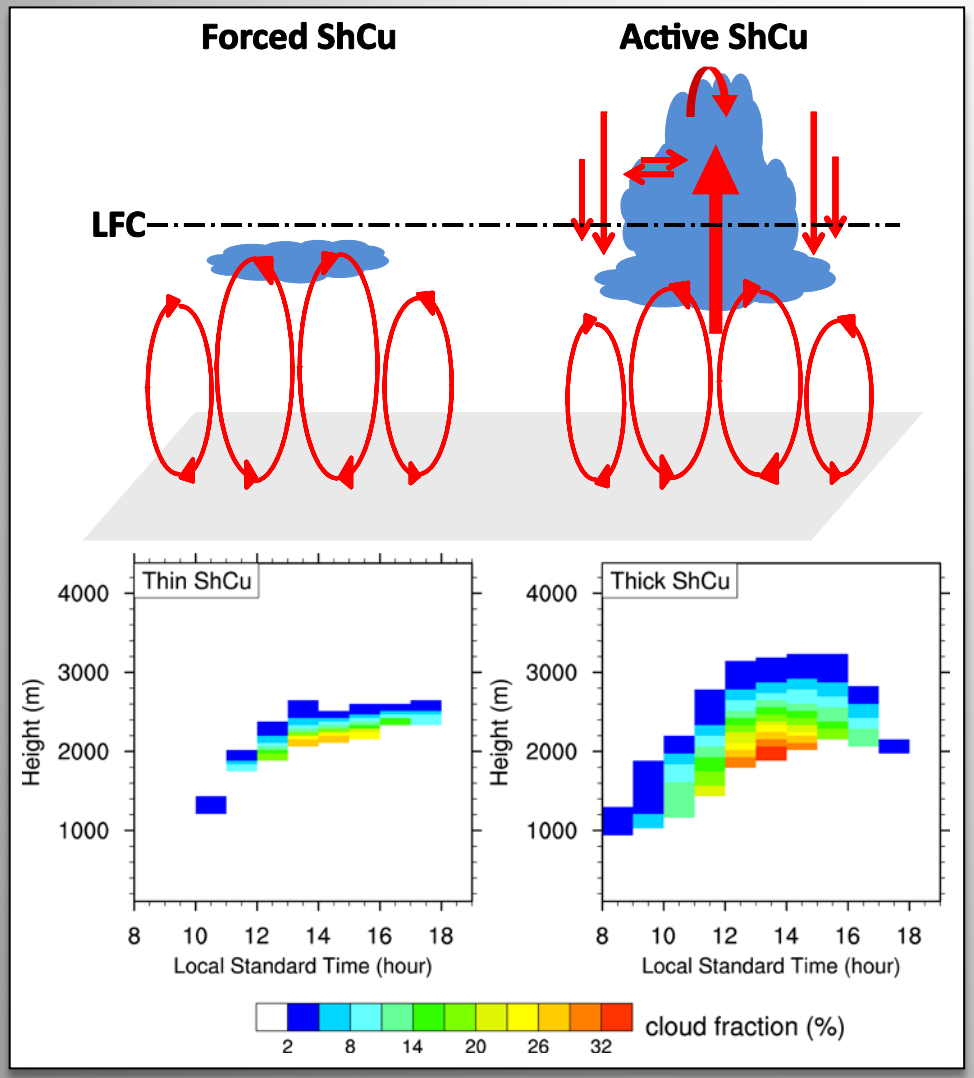
LLNL-PRES-644938

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Outline

- Motivation
- Large-eddy simulation using SAM
  - Model setup details
  - Comparison with some basic observational statistics
- Vertical velocity data details
  - Known problems and fixes
  - Analysis criteria to match between obs and LES
- Compare LES vertical velocity with MMCR observed vertical velocity
  - Uncertainty tests
- Summary and Future work

Motivation



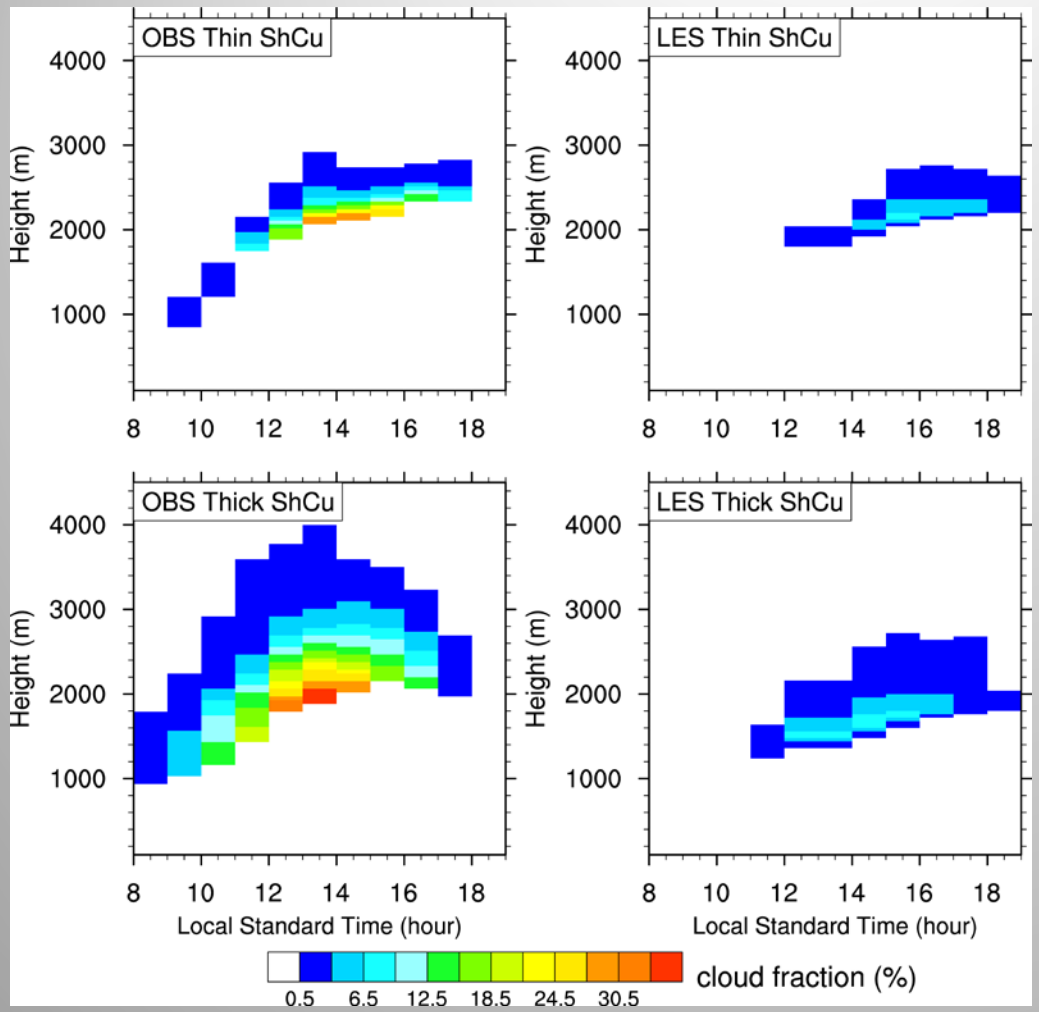
- We have developed long-term observational statistics for forced and active shallow cumulus at SGP and identified that boundary layer humidity and atmospheric stability above cloud top are key factors to affect cloud vertical extent. LES based on observed composite case will help us explain the physical processes in details

- At the same time, we focus on in-cloud vertical velocity and mass flux. We use long-term MMCR 10s retrievals and hope to facilitate an apple to apple comparison to LES results.

LES Setup

- SAM 6.10.4 with1.5-order TKE closure, simple microphysics (temperature partition) and RRTM
- 10 km by 10 km domain with 50 m horizontal and 40 m vertical resolution
- Initial sounding at 5:30 a.m., integrated for 18 hours subject to hourly large-scale forcing and time-varying surface heat fluxes
- Large-scale forcing is the observed selected shcu-day composite constructed from long-term continuous forcing
- Surface heat fluxes are based on both BAEBBR and QCECOR data
- Wind nudging time scale: 2 hours

Simulated Cloud fraction vs. OBS

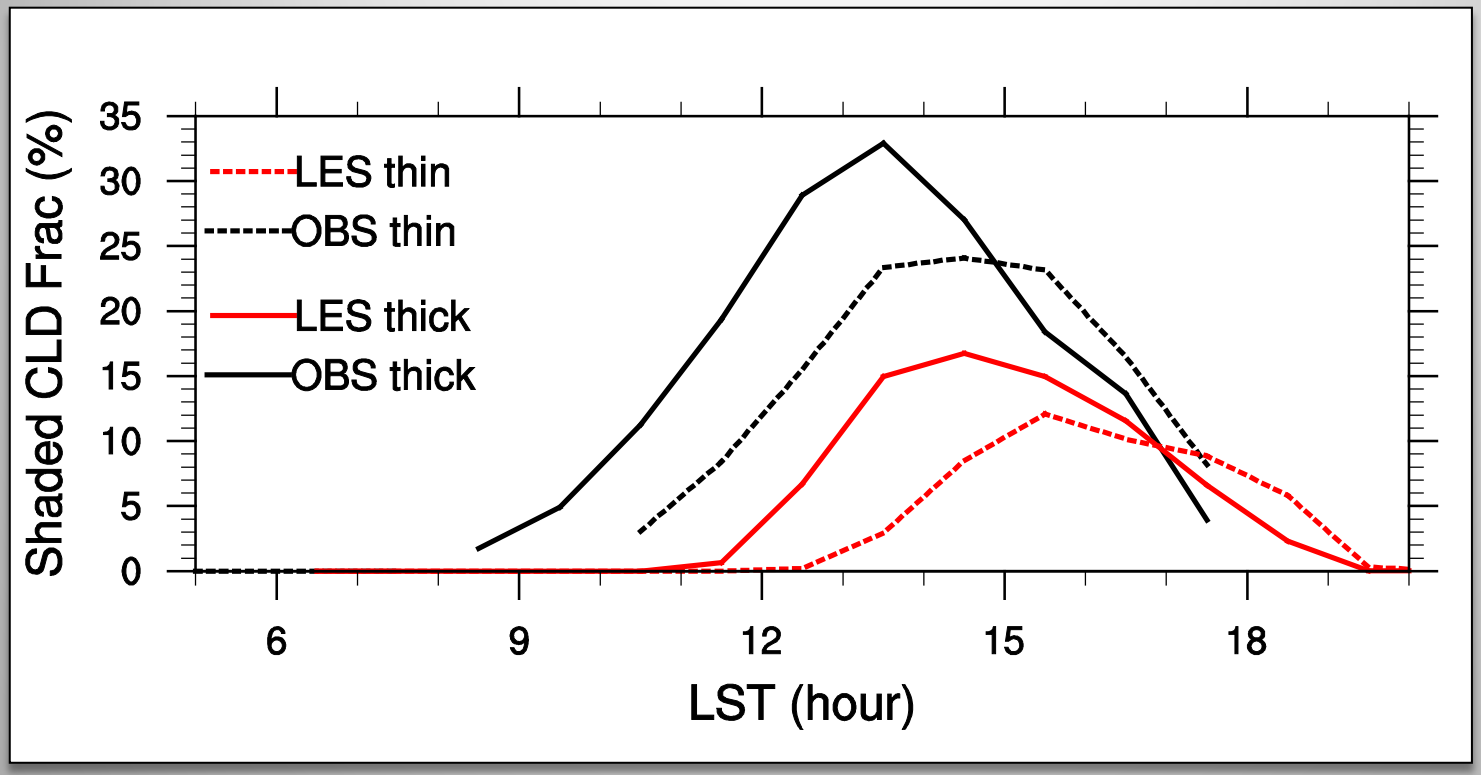


- LES shows diurnal evolution of cloud fraction and cloud base gradually increases with time
- LES shows cloud base difference between thin and thick clouds
- LES shows difference in cloud vertical extent

However

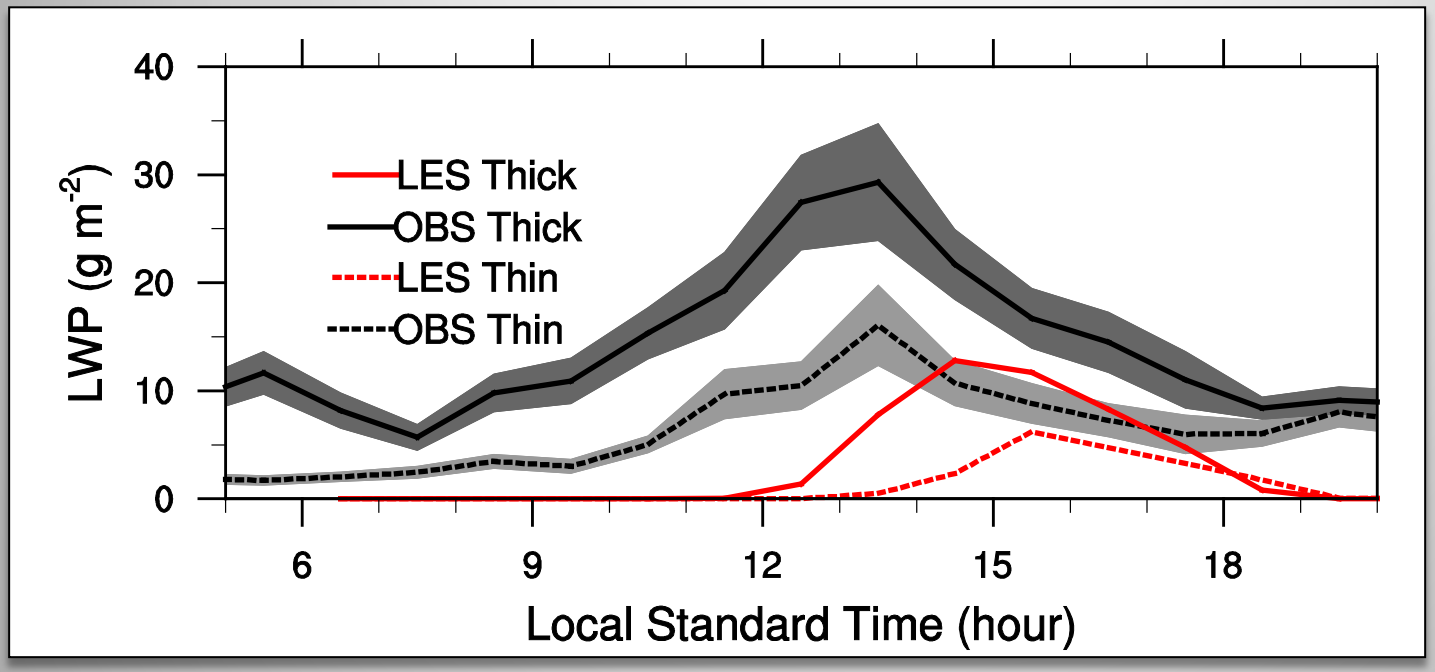
- LES has much less cloud fraction
- LES shows a later onset of clouds

Projected cloud fraction



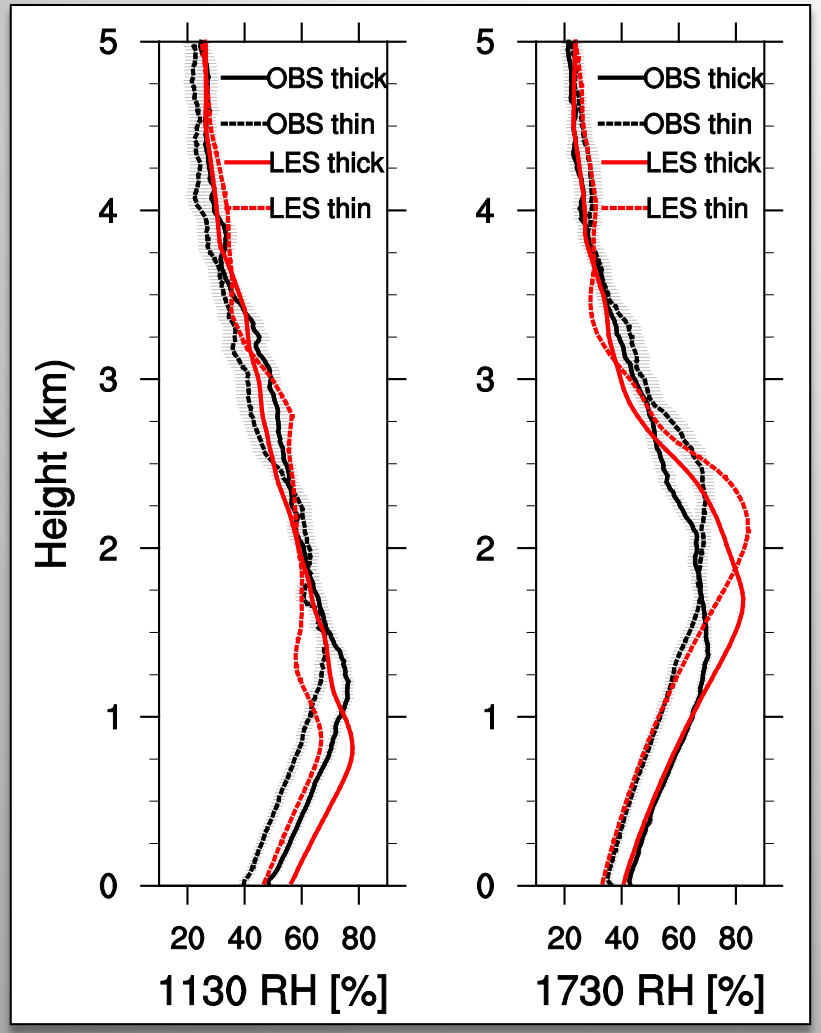
- Simulated projected (or shaded) cloud fraction is almost half of the observation.
- Simulated cloud starts late and diurnal maxima lag one hour.

Liquid water path



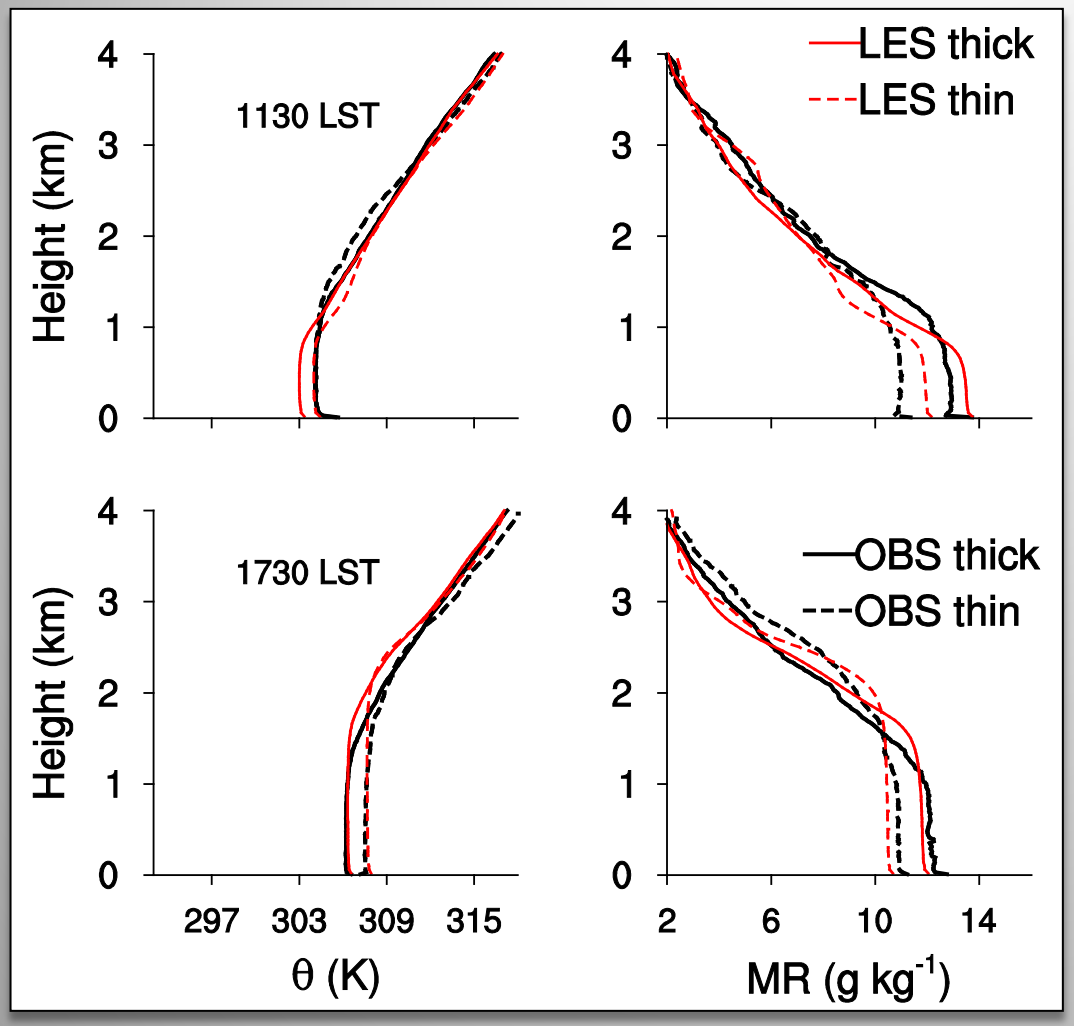
Simulated liquid water path is almost half of obs too. However this is an average of both cloudy and clear cases, thus the in-cloud LWP between LES and OBS should be similar if considering LES shaded cloud fraction is almost half of OBS too.

Domain Average Relative Humidity



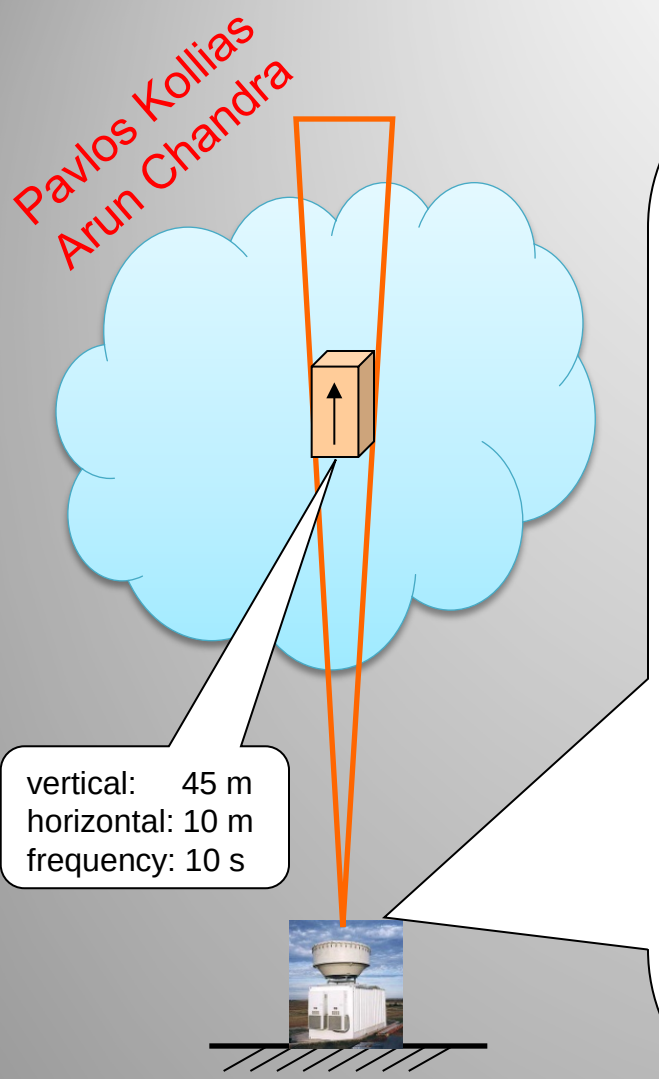
- At 1130 LST, LES boundary layer RH is 10% larger than the observed
- At 1730 LST, the LES boundary layer RH is almost the same as the observations
- Temperature or mixing ratio effect?

Domain Mean Theta and Mixing Ratio



- At 1130 LST, on thick cloud days, LES boundary layer is cooler and moister than OBS, and the mixed layer height is also lower. These suggest not enough turbulence mixing in LES at this time; similar situation for thin cloud case too.
- At 1730 LST, LES mixed layer height is higher, boundary layer is slightly drier than OBS

Vertical Velocity Observation



ARM SGP Millimeter Wavelength Cloud Radar (MMCR)

- Vertical pointing Doppler Radar
- Measure the movement of scattering targets.
  In non-precipitating shallow cumulus, the target is the liquid water cloud droplet
- 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
- In this study, we focus on 10s data

Insects contamination—Fuzzy Logic algorithm

MMCR reflectivity is sometimes contaminated by insect signals. Some contamination has to be removed or filtered out in order to make valid retrieval of vertical velocity.

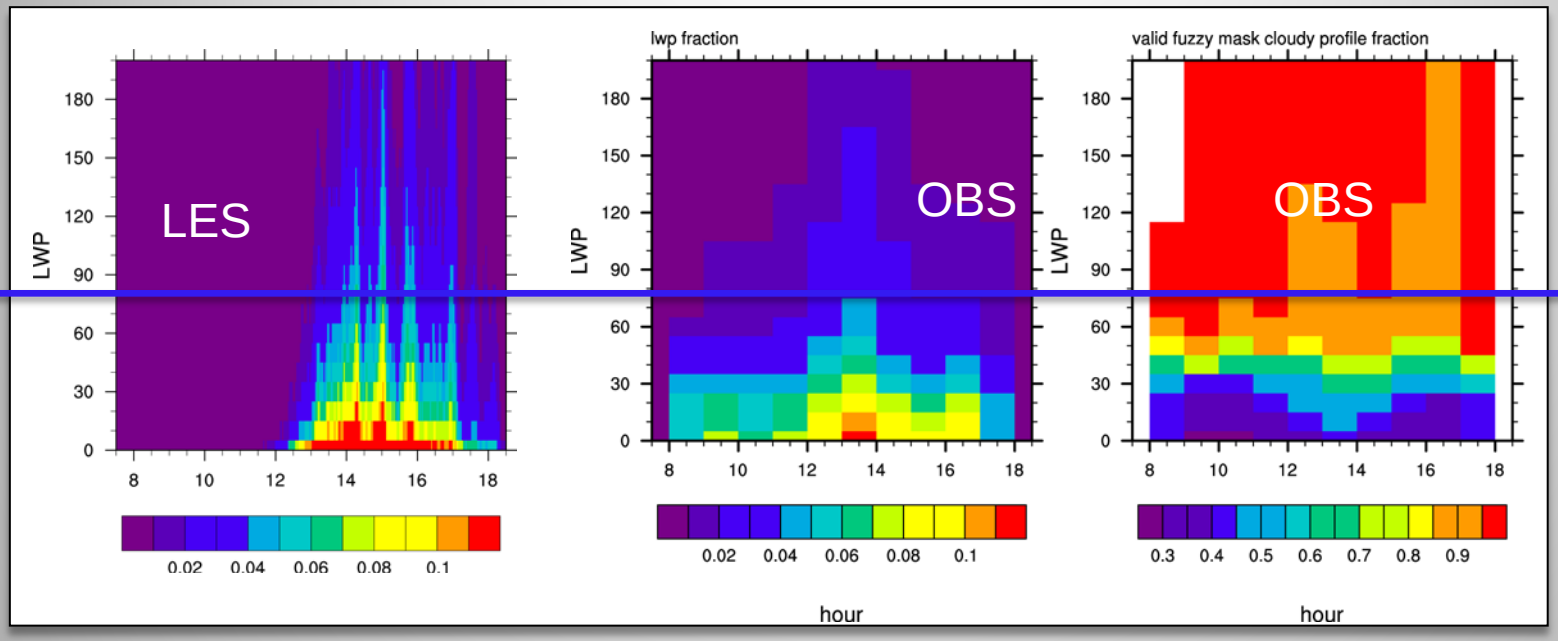
Fuzzy logic algorithm is developed to resolve this problem. (Chandra and Kollias, 2013, JAS)

The membership functions for each decision parameter.

a) Standard deviation of reflectivity values.
b) Median of spectral width values.
c) Cloud Water Path.
d) Ratio of Cloud Water Path to the cloud thickness.

If without radar simulator of LES to simulate the criteria listed above, could we still make a fair comparison between MMCR obs and LES results? Or in other words, could we have a simple or single criterion that can be easily applied to both OBS and LES to make the comparison feasible?

Liquid water path and valid retrieval fraction



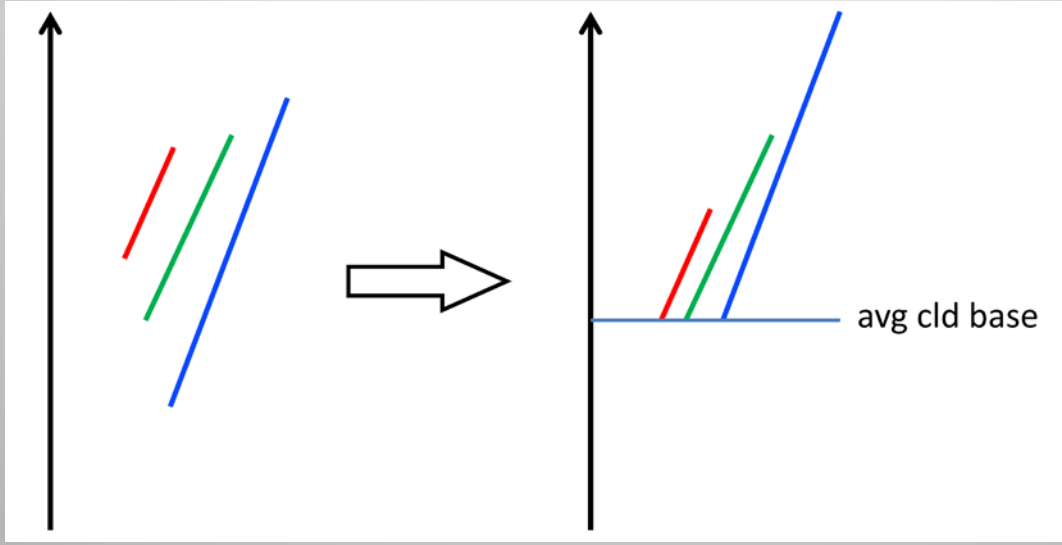
Left two panels: contour shows at each hour, the possibility to observe a LWP > certain Values. Right panel: contour shows that at each hour, when lwp > certain value, the possibility that this profile can pass through fuzzy logic algorithm and give valid VV retrieval.

e.g. at 14 LST, both LES and OBS shows that there is 6% possibility to find a cloudy profile with LWP > 80 g/m^2; at 14 LST, when LWP > 80 g/m^2, the OBS shows that 90% profiles with 80 g/m^2 or more will give valid retrievals of VV.

Thus if we use LWP > 80 as a single criterion, we are making a fair comparison for LES v.s. OBS

Methodology

- For each daytime hour, make composite of 10s valid in-cloud vertical velocity retrievals
- How to average clouds with different cloud base heights and preserve the intrinsic shape of the vertical profiles?

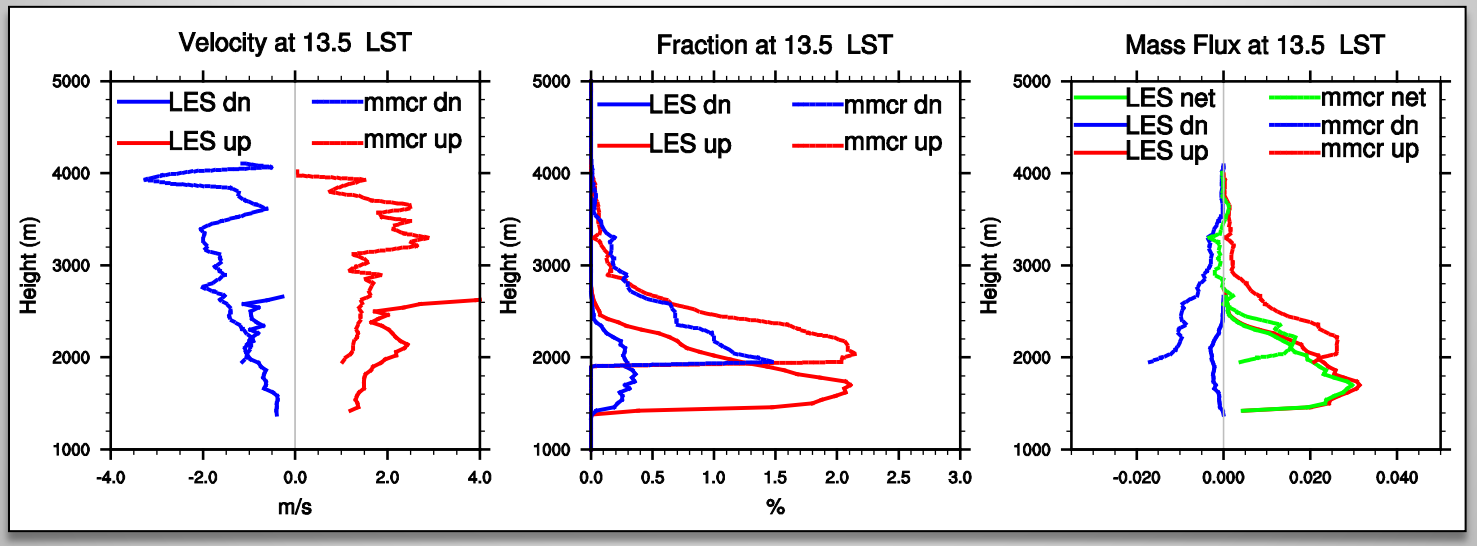


Updraft fraction = cloud fraction * in-cloud updraft fraction

Updraft mass flux = updraft fraction * updraft velocity

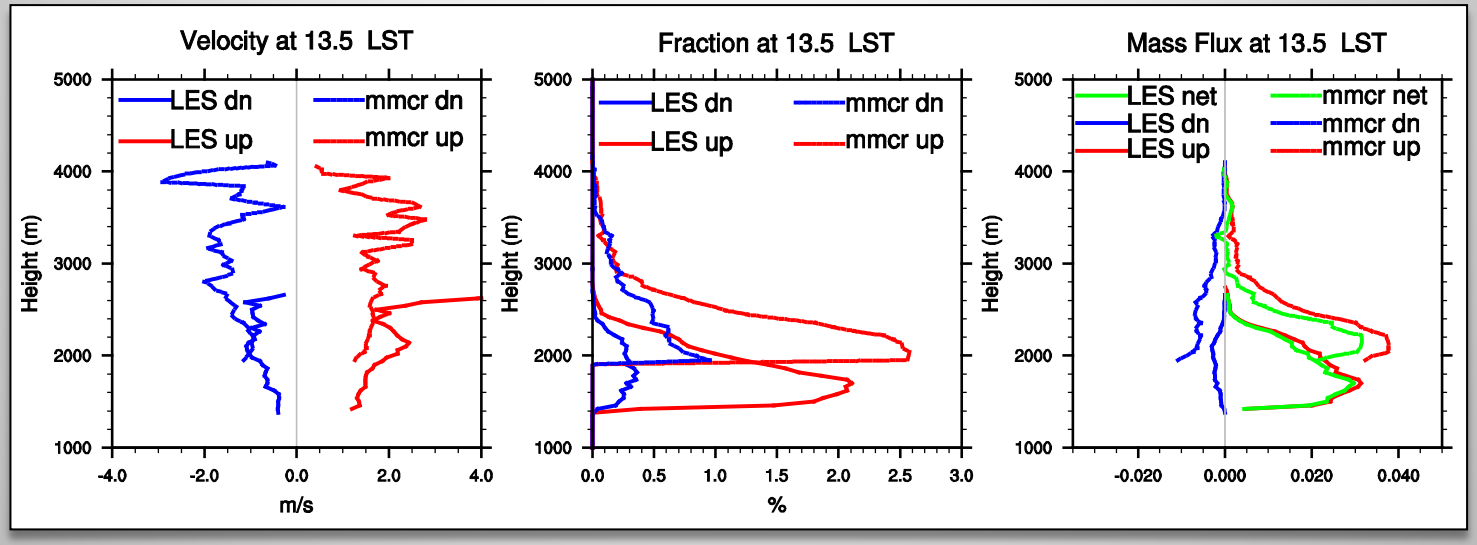
Net mass flux = updraft mass flux- downdraft mass flux

In-Cloud Mass flux: LES against MMCR



- OBS shows similar magnitude of updraft and downdraft velocity
- OBS shows updraft fraction is 33% larger than downdraft fraction, this leads to a positive net mass flux
- Compared with OBS, LES shows stronger updraft and weaker downdraft
- Compared with OBS, LES shows similar updraft fraction, but smaller downdraft fraction
- Compared with OBS, LES shows larger net mass flux, with slightly larger updraft mass flux and smaller downdraft mass flux

What if observed velocity offset by 0.5m/s?



- We treat OBS as “truth”, however there is also uncertainties. If we make an assumption that vertical velocity has a uncertainty of 0.5m/s toward downward motion, that means downward motion is overestimated by 0.5m/s, the results would look much closer to LES
- This is just an ideal assumption from perspective of modelers, however we need more discussion with radar experts on how to quantify such uncertainty.

What's next?

- Sensitivity tests of LES, what factors lead to the best match to OBS? Or what influences the match from LES to OBS?
- Extend vertical velocity analysis to include sub-cloud layer statistics (MMCR and recent Lidar data)