The difference between thin and thick fair-weather shallow cumulus inferred from ACRF observations over the Southern Great Plains

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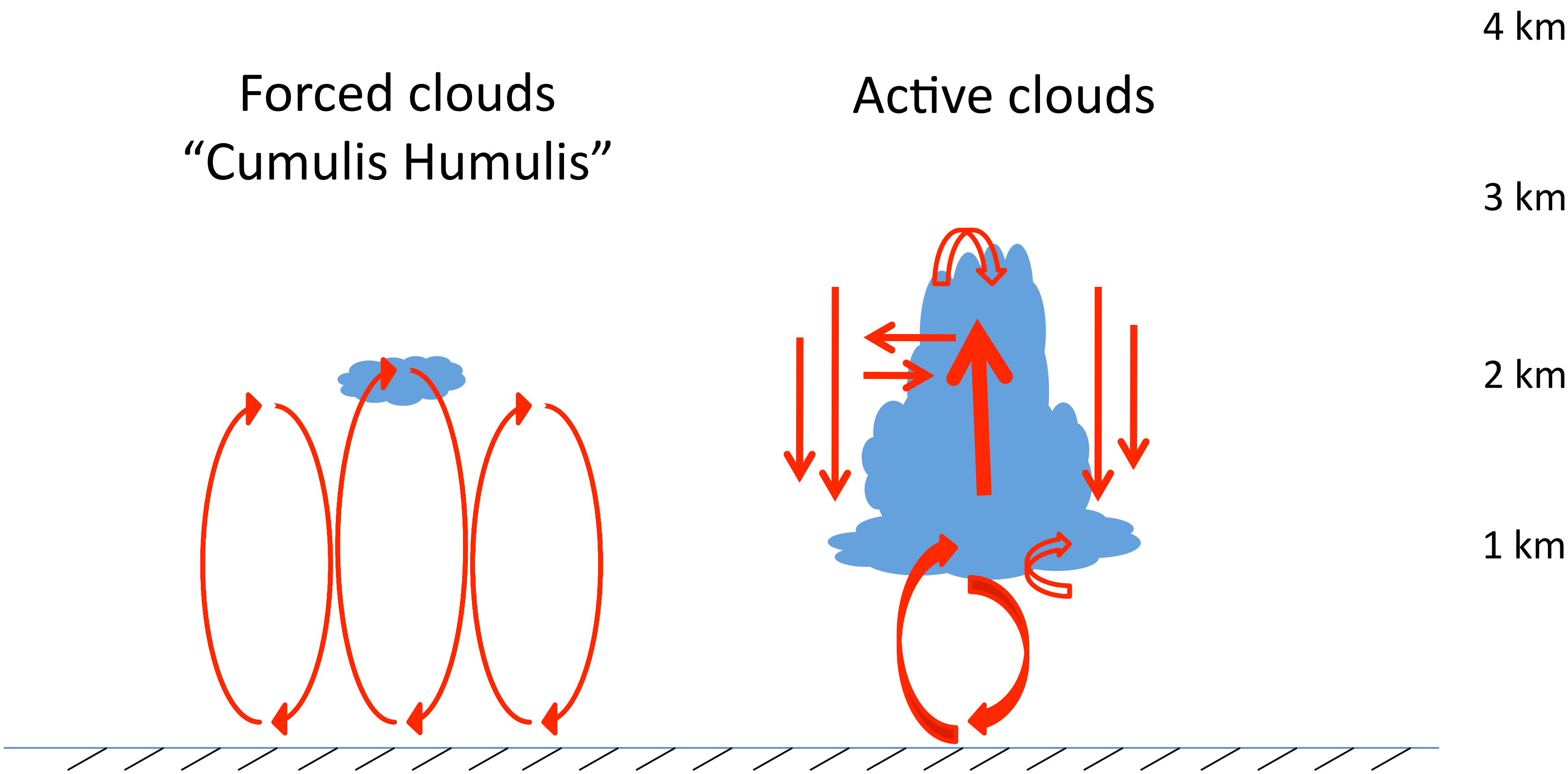
Thanks to Larry Berg (PNNL) and Pavlos Kollis (McGill Univ.)

PCMDI

Program for Climate Model Diagnosis and Intercomparison

LLNL-PRES-459096

Motivation



•We expect that dynamic and thermodynamic cloud properties to be different between forced and active clouds

•On some days one observes only forced clouds whereas on other days active clouds are present either alone or in combination with forced clouds

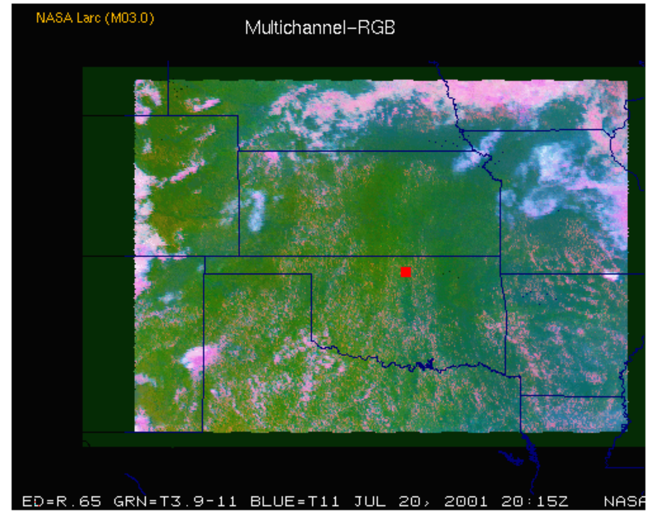
Questions

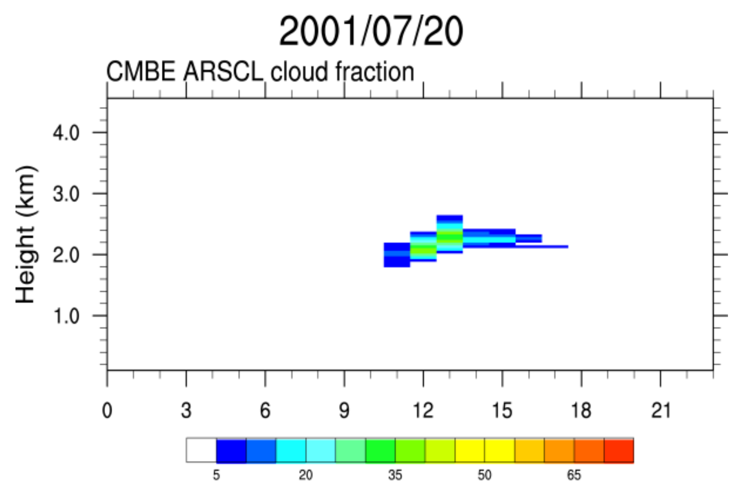
- We use 13 years of ACRF SGP observations of daytime shallow cumulus to ask the following questions:
  - How different are cloud properties and their radiative impacts between days with “thin” versus “thick” clouds?
  - How do environmental conditions differ between days with thin and thick clouds and do the differences provide any clues as to what controls the vertical extent of shallow cumuli?

Selecting Fair-Weather Shallow Cumulus

Days with shallow cumulus are selected from 13 summers (May – August 1997 – 2009) by consulting satellite images and ARM CMBE ARSCL cloud fractions

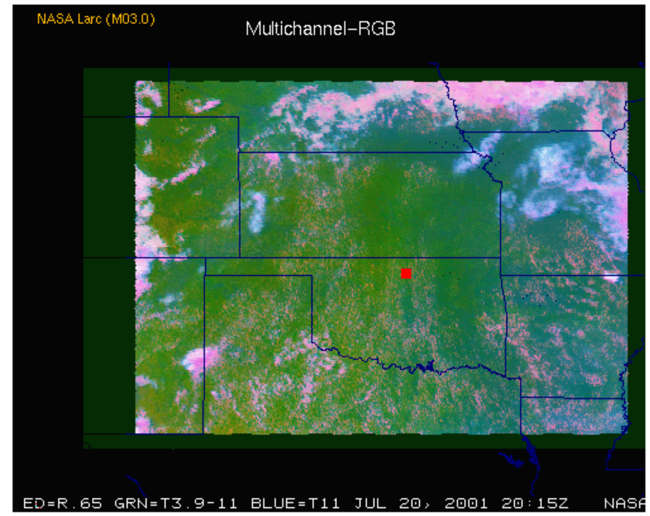
We also consult with a shallow cumulus index developed by Berg and Kassianov (2008) for the years 2000 to 2007

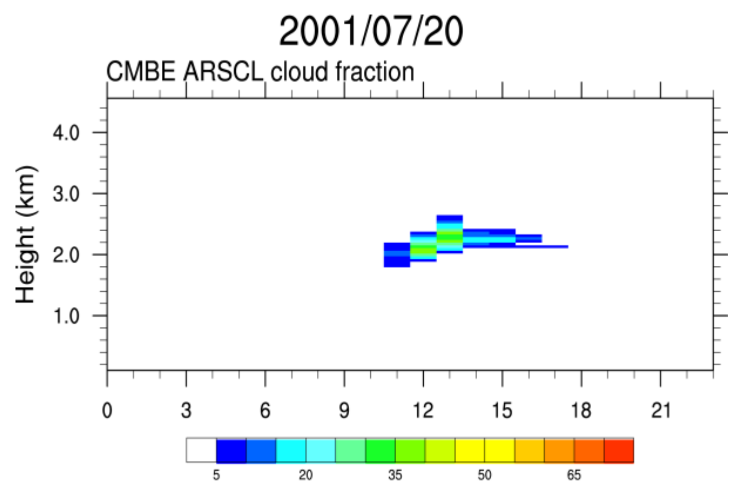




Case Selection Criteria

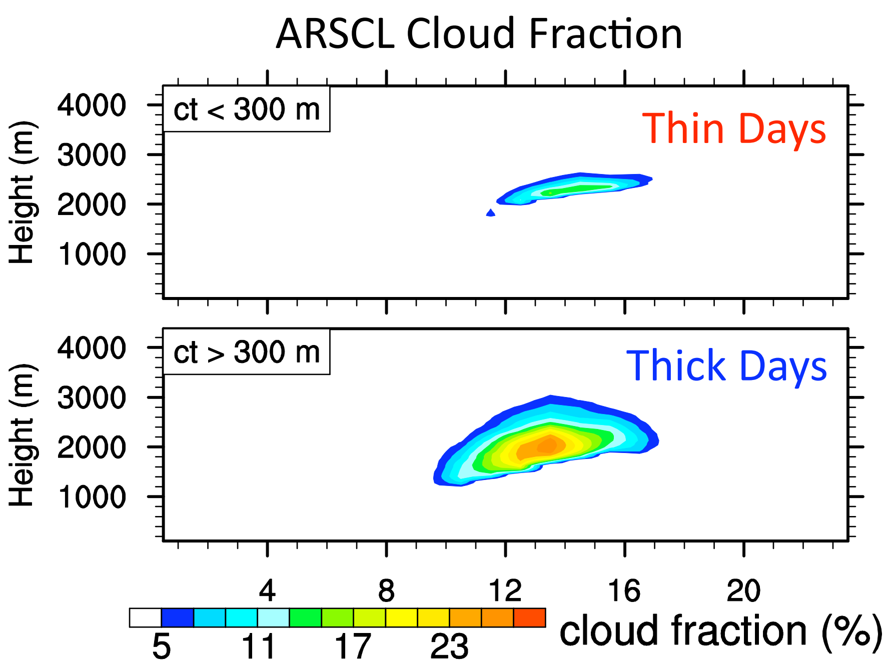
1. No precipitation
2. Cloud development is limited to less than 4 km
3. Gradually rising cloud base ← indicates that clouds have their "roots" in the convective boundary layer
4. Diurnally varying cloud fraction and thickness following a characteristic pattern
5. No boundary layer clouds during the previous nighttime
6. No clear influence of larger-scale weather phenomena based on satellite data images ← indicates that cumulus clouds are locally forced

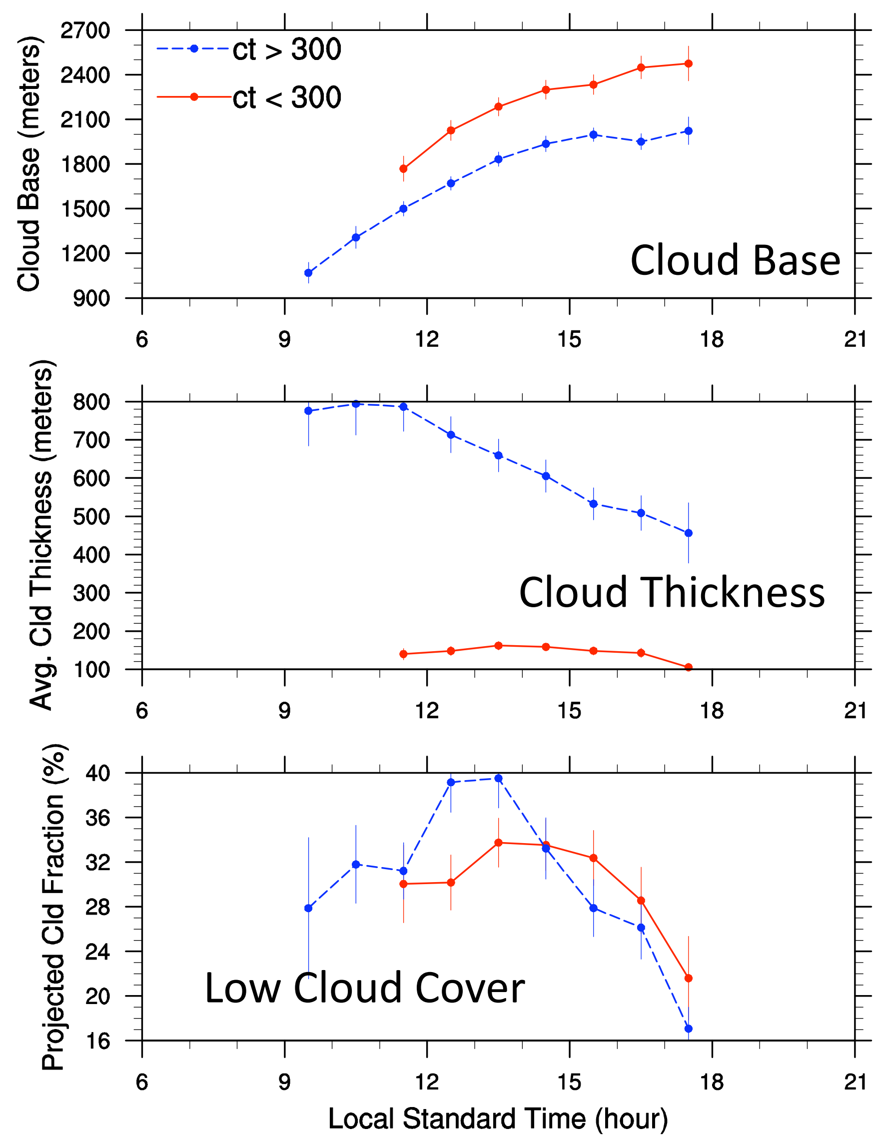




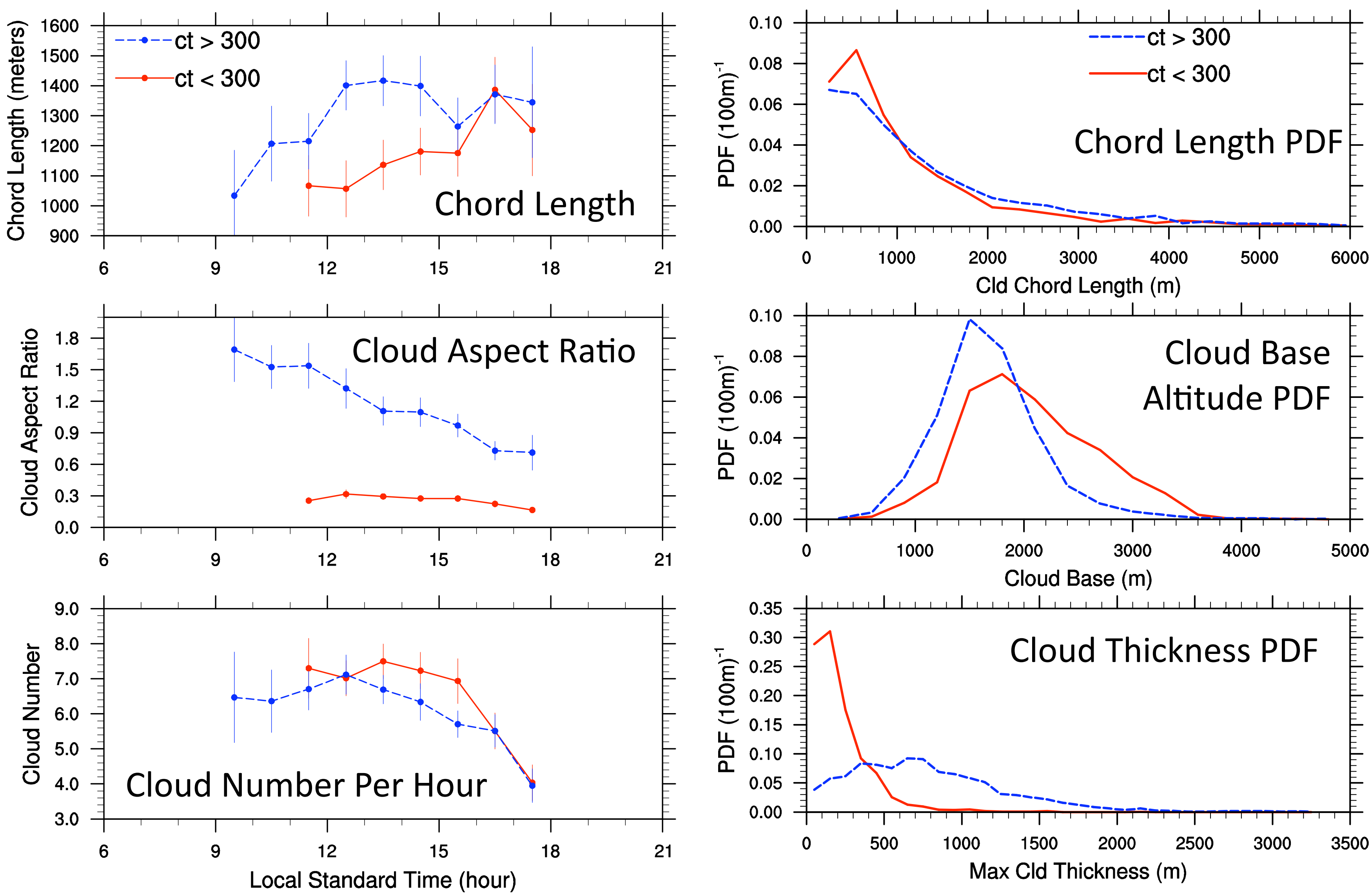
End result is 146 days which are divided into two groups according to whether the daytime mean cloud thickness less or greater than 300 meters

Cloud Macrophysics Statistics (1)





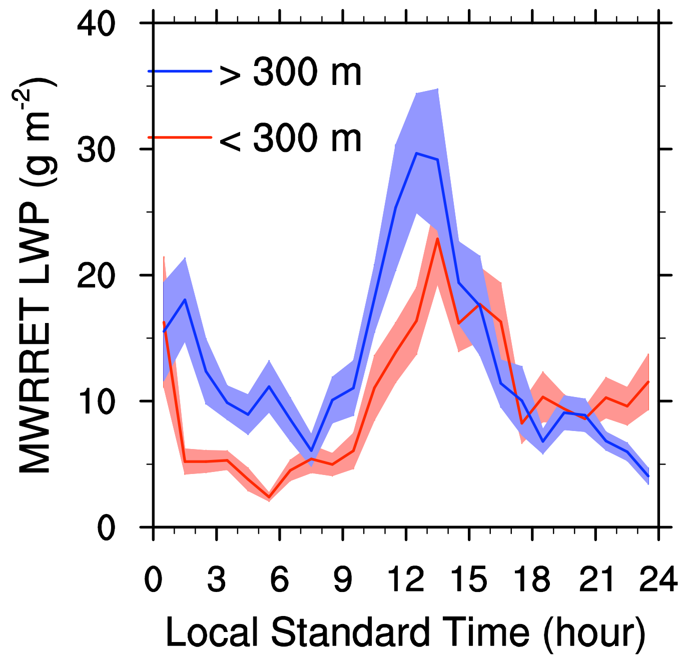
Cloud Macrophysics Statistics (2)



Liquid Water Path

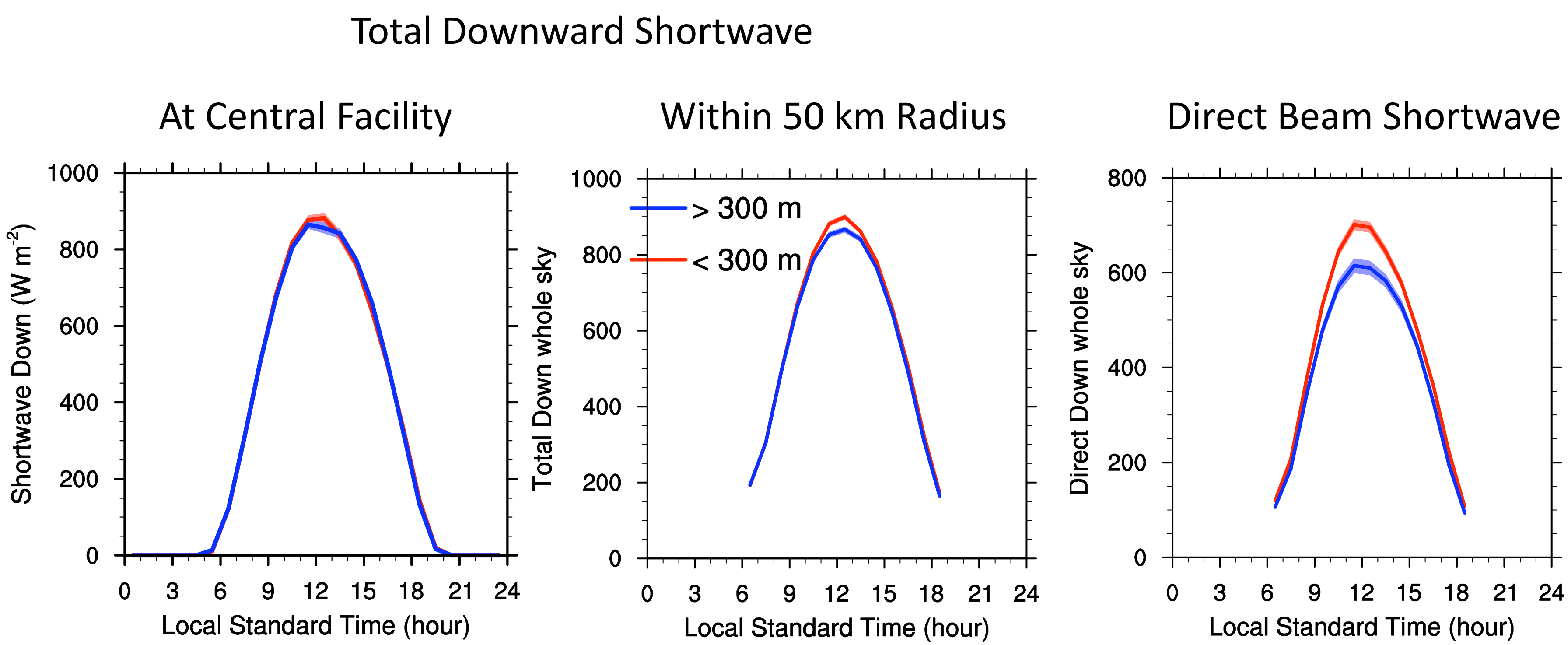
- MWRRET time-mean LWP composite shows a surprising small difference between thick and thin days
- Estimate in-cloud LWP of 50 g m^{-2} for thin days and 75 g m^{-2} for thick days
- Given mean cloud thicknesses of 150 and ~500 m for thick days, this implies average liquid water contents of 0.33 g m^{-3} for thin days and 0.15 g m^{-3} for thick days

  Is this believable?



- Adiabatic water contents would be ~3 times larger for clouds which are 3 time thicker, and yet the opposite is found
- Adiabatic water contents for a 150 m thick cloud is less than 0.33 g m^{-3} (?), so perhaps the measurements (either LWP or ARSCL cloud tops) are not correct
- If they are correct, is this the result of greater mixing in the thicker cloud days?

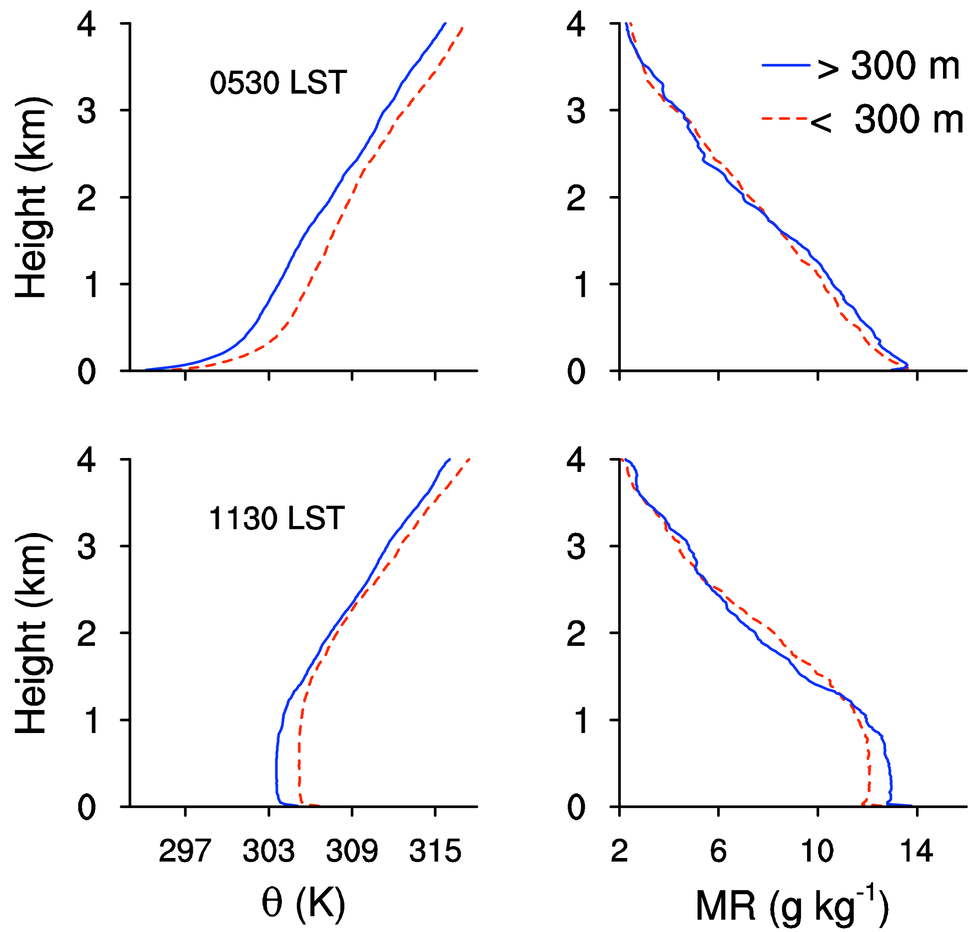
Surface Radiation From QCRAD



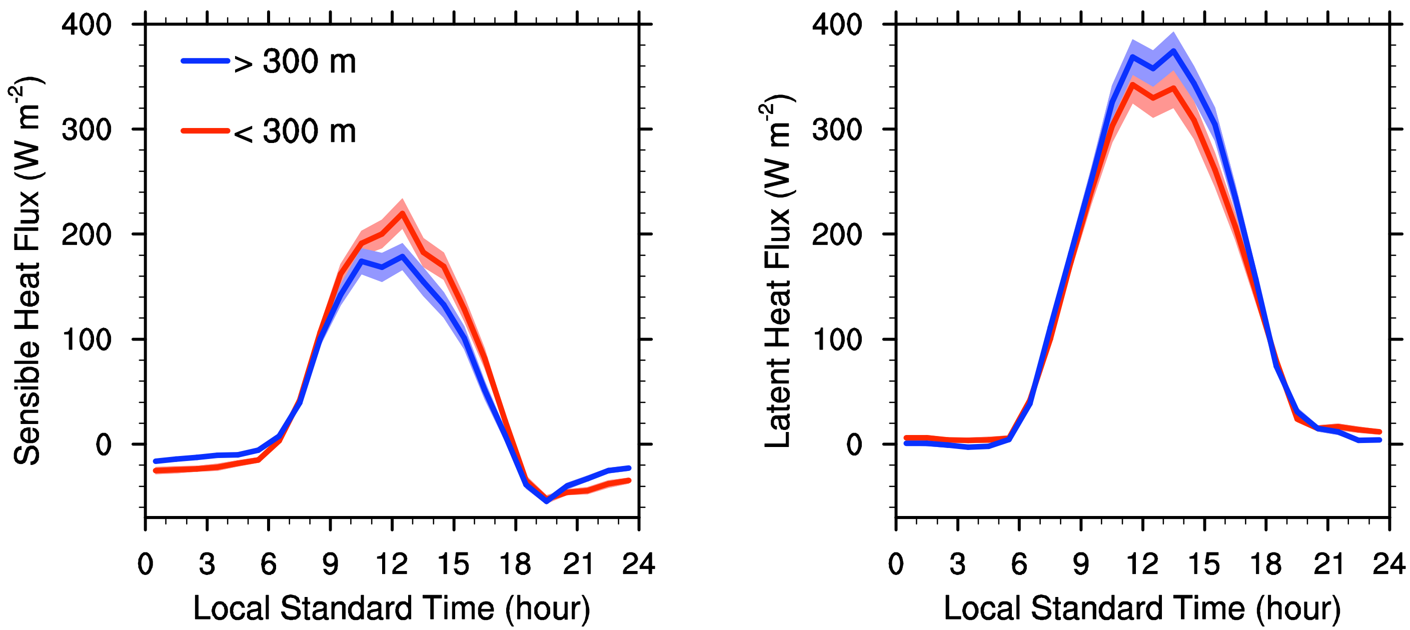
- Consistent with the LWP, the difference in downward shortwave is also surprisingly small

Environmental Parameters

- Early morning sounding shows that days with thicker clouds start out a few degrees colder but with the same mixing ratio
- Mid-morning sounding shows colder and moister boundary layer but with the nearly the same temperature and moisture at the cloud level (~2000 m)
- The greater relative humidity in the boundary layer is consistent with the earlier start and lower cloud base to clouds on days with thicker clouds



Surface fluxes

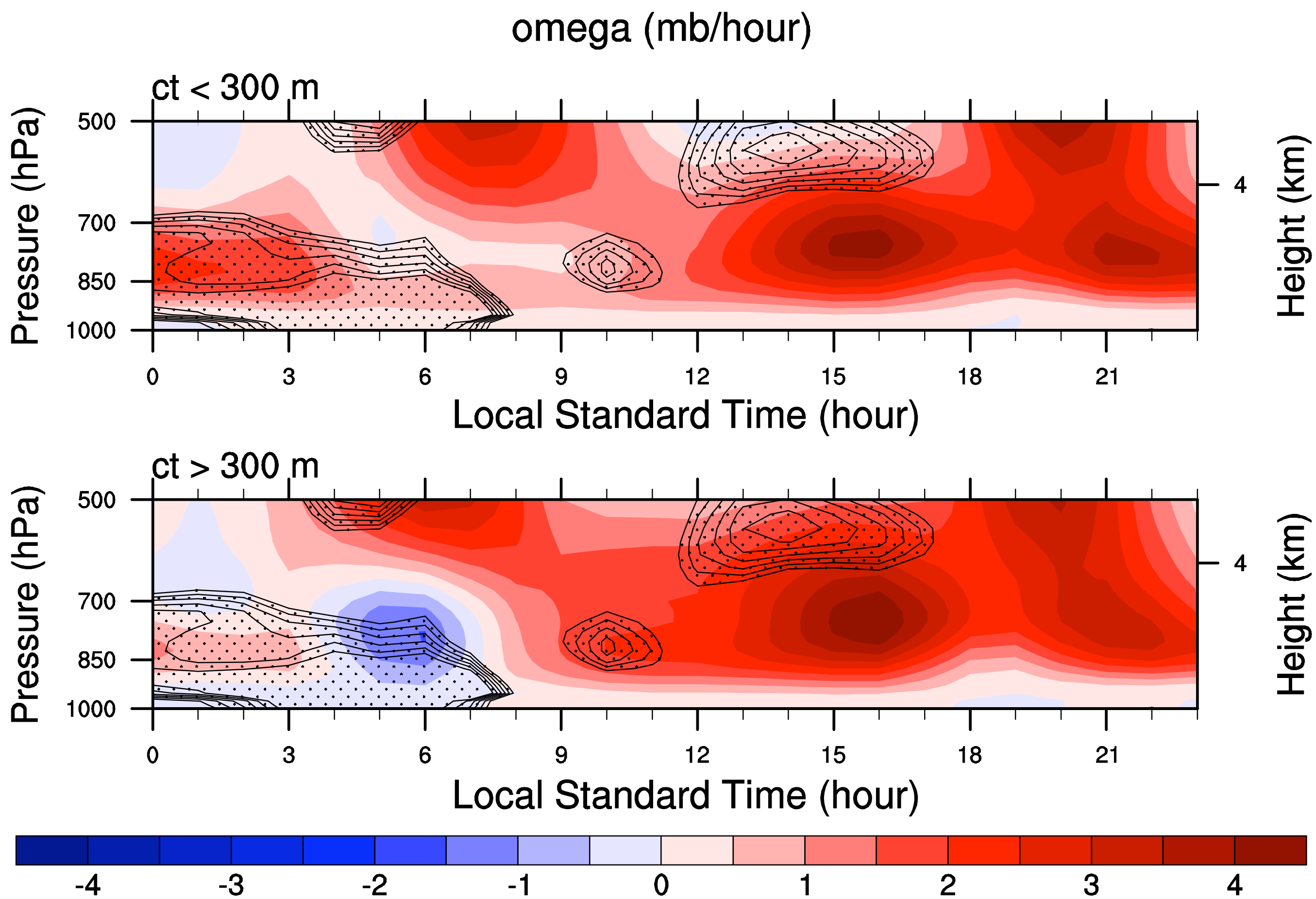


- Central Facility surface fluxes (from BAEBBR) suggest only small differences in the surface buoyancy driving between the two categories
- Does this suggest that cloud-base velocities are similar?
- But if cloud base velocities are the same as well as the moisture and thermodynamic sounding at the cloud level, then why are clouds thicker? Is it due to some other external parameter, we haven't examined?

Large-Scale Dynamics (1)

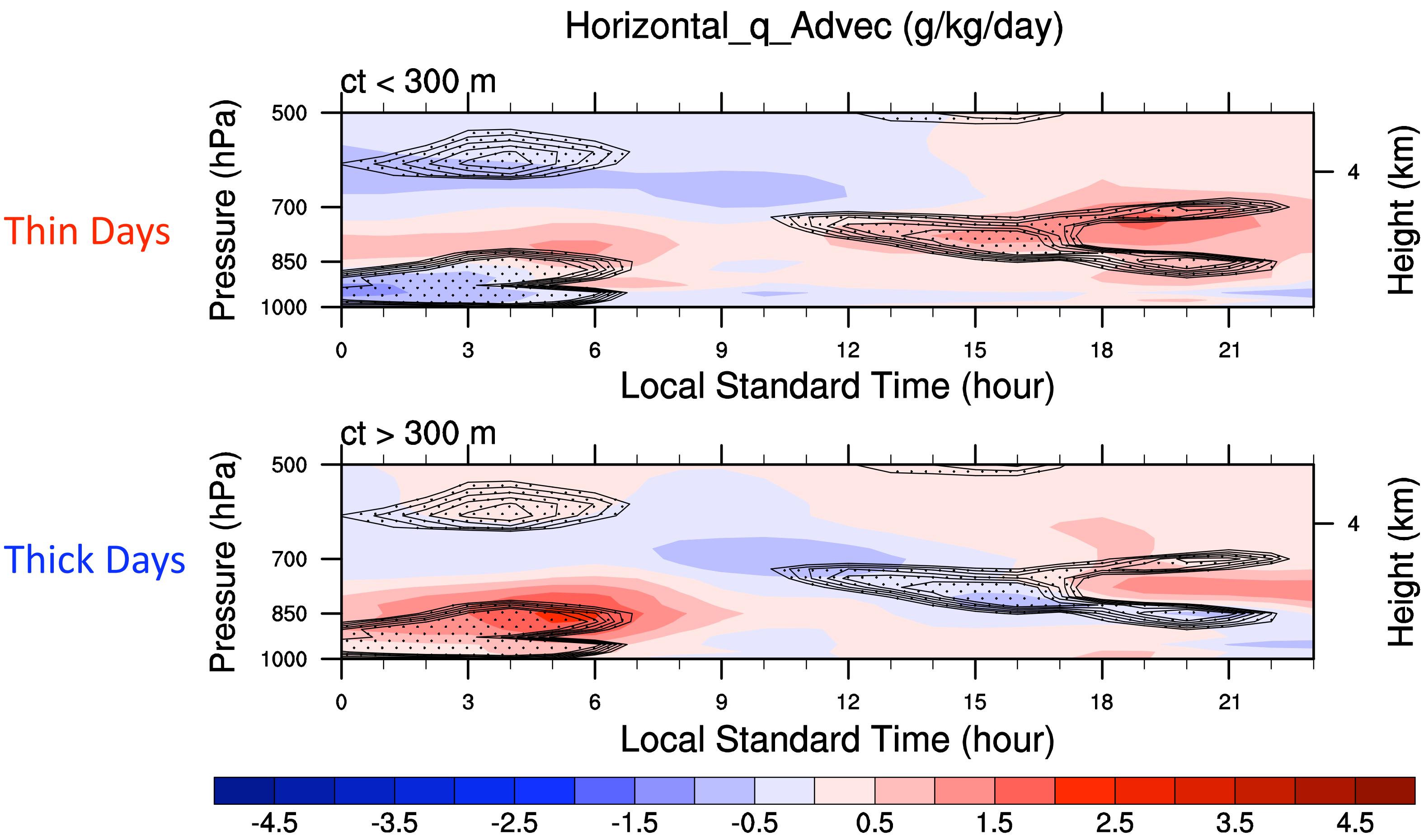
Thin Days

Thick Days



- From the new continuous forcing (1999-2009), the daytime large-scale subsidence rate is similar between the two categories
- Biggest difference is less subsidence the night before

Large-Scale Dynamics (2)



- Horizontal moisture advection is greater the night before
- This is consistent with the greater relative humidity at sunrise

Conclusions (1)

- We have examined statistics of daytime fair-weather cumuli in an attempt to understand what controls shallow cumuli cloud thickness
- Some surprising results include a smaller than expected difference in liquid water path and surface shortwave when days are stratified by cloud thickness
- Does this suggest that thicker clouds have lower liquid water contents due to greater mixing?

Conclusions (2)

- With regard to environmental parameters, surface buoyancy fluxes are similar but the initial value of relative humidity is higher on days with thicker clouds.
- While greater relative humidity may explain the earlier onset and lower cloud base, the physical mechanism for greater cloud thickness is not yet clear to us
- In contrast to our just published work that attempts to determine the conditions that cause late-afternoon deep convection to grow from daytime shallow cumulus, we don't see a major change in the relative humidity of the cloud layer

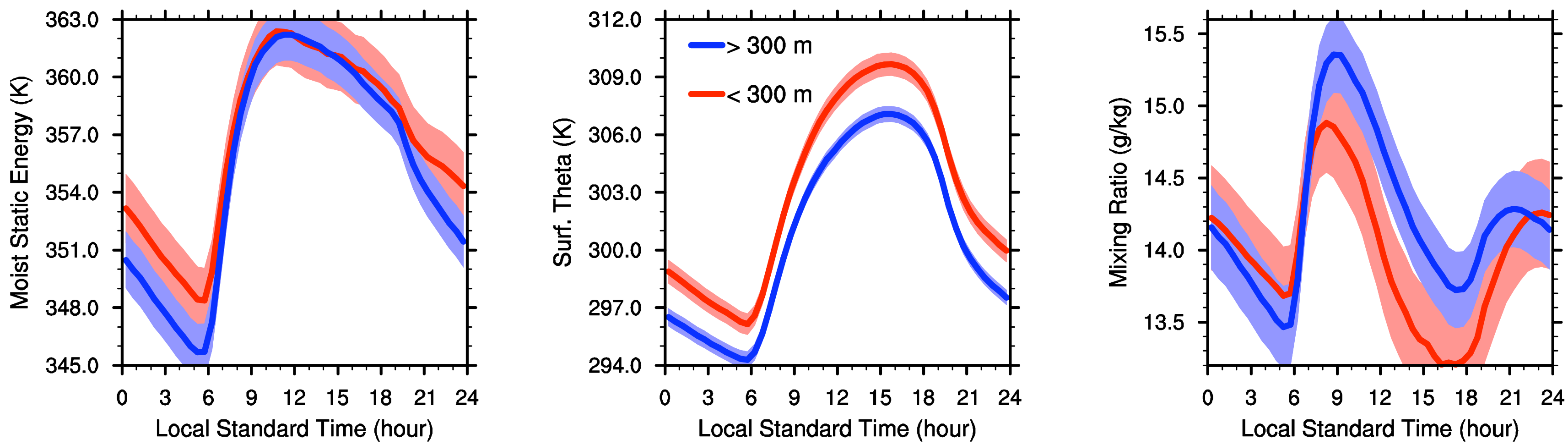
Future work

- We wish to examine updated cloud-scale vertical velocity from Pavlos Kollias and Arunchandra Chandra (McGill U.) stratified by cloud-thickness
  - Surprisingly, our initial analysis suggests that cloud updraft vertical velocity is lower on days with thicker clouds (0.7 m s^{-1}) relative to days with thicker clouds (1.0 m s^{-1})
  - The difference exceeds that that might be explained by the slightly greater surface buoyancy flux on days with thin clouds
- Modeling: Composite LES and SCM cases will be constructed from this data as a means to test both types of models with observations

The End

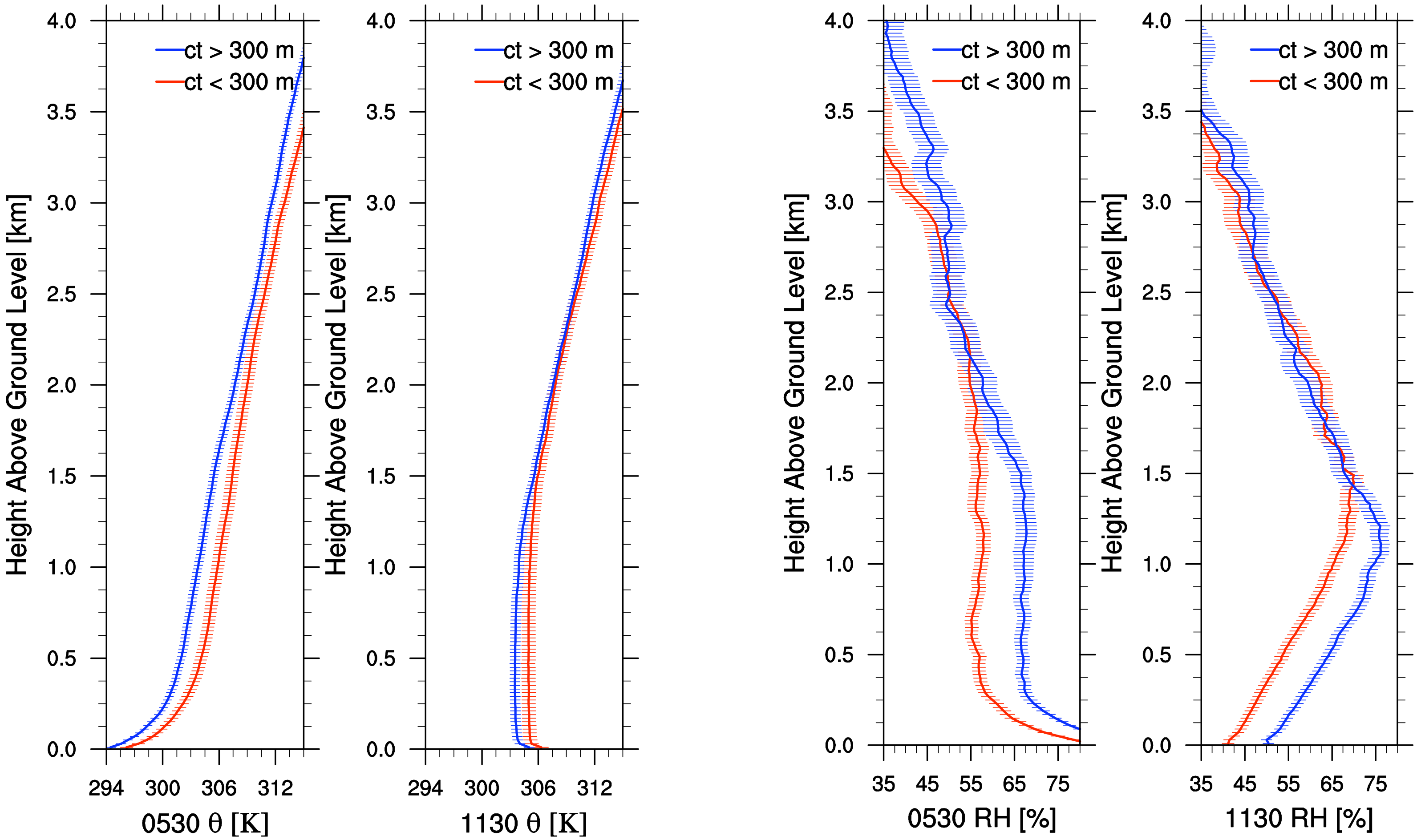
Extra Slides

Surface conditions



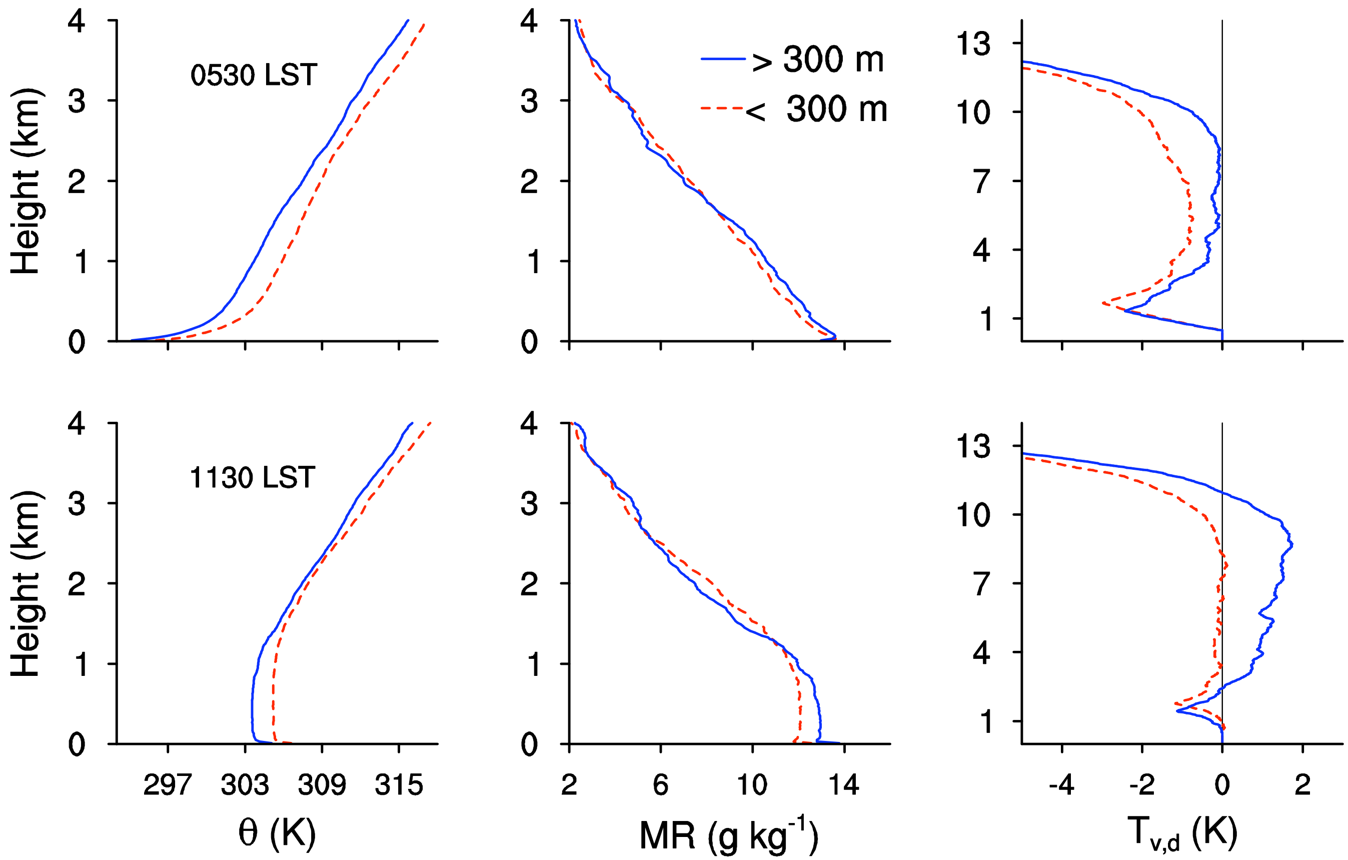
Based on SMOS and OK Mesonet data within 50 km radius of central facility

Sounding data



Composites are based on LSSONDE

Buoyancy



Composites are based on LSSONDE

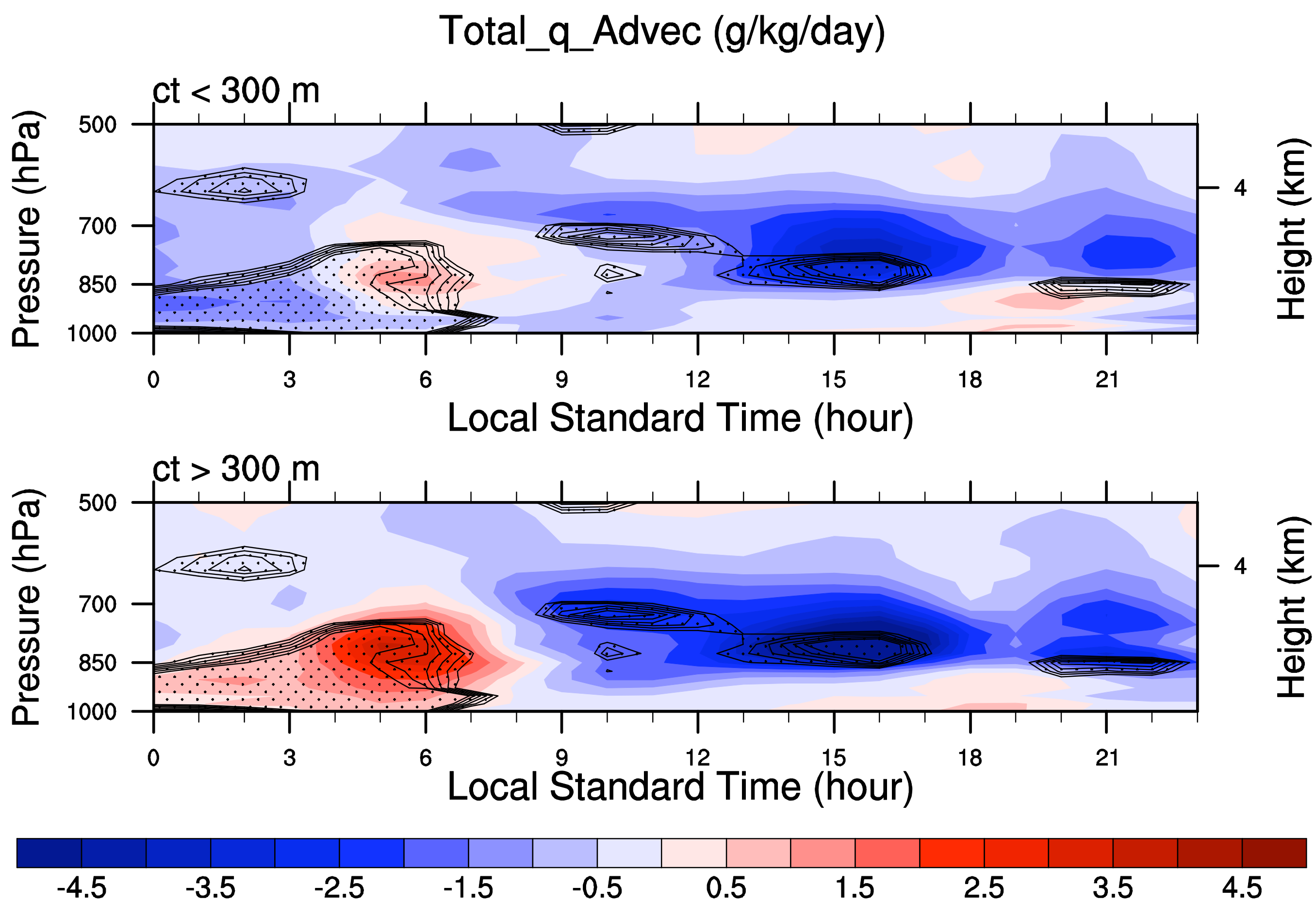
Tv,d is the virtual temp. difference between air parcel and environment

Is there greater buoyancy on the thicker days? – not a big difference

No stronger capping inversion…a little less stable for deeper days above cloud base (1000-3000 m)

Cloud thickness = LNB – LCL ???

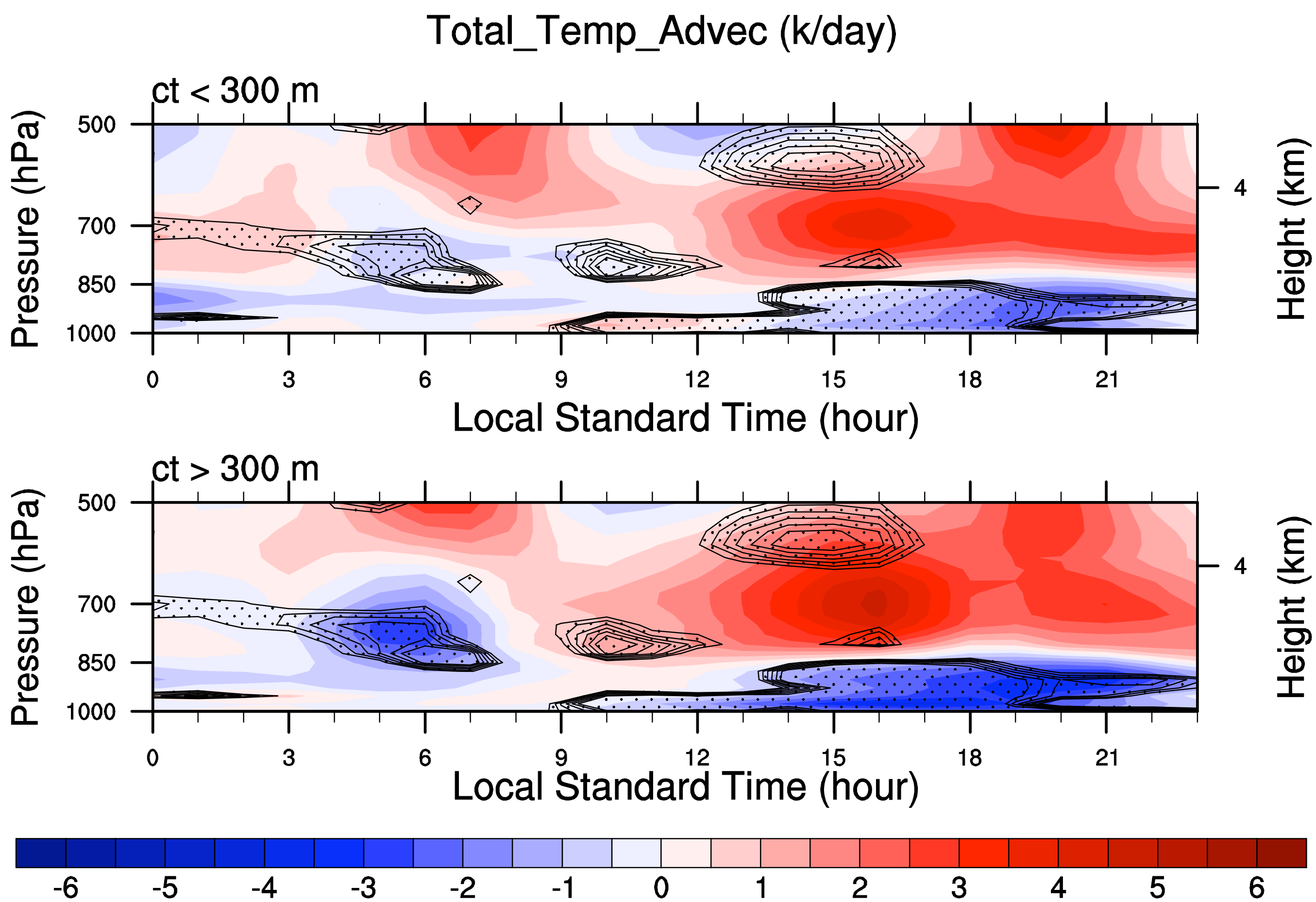
Large-scale moisture advection



Based on newly developed extended long-term continuous forcing

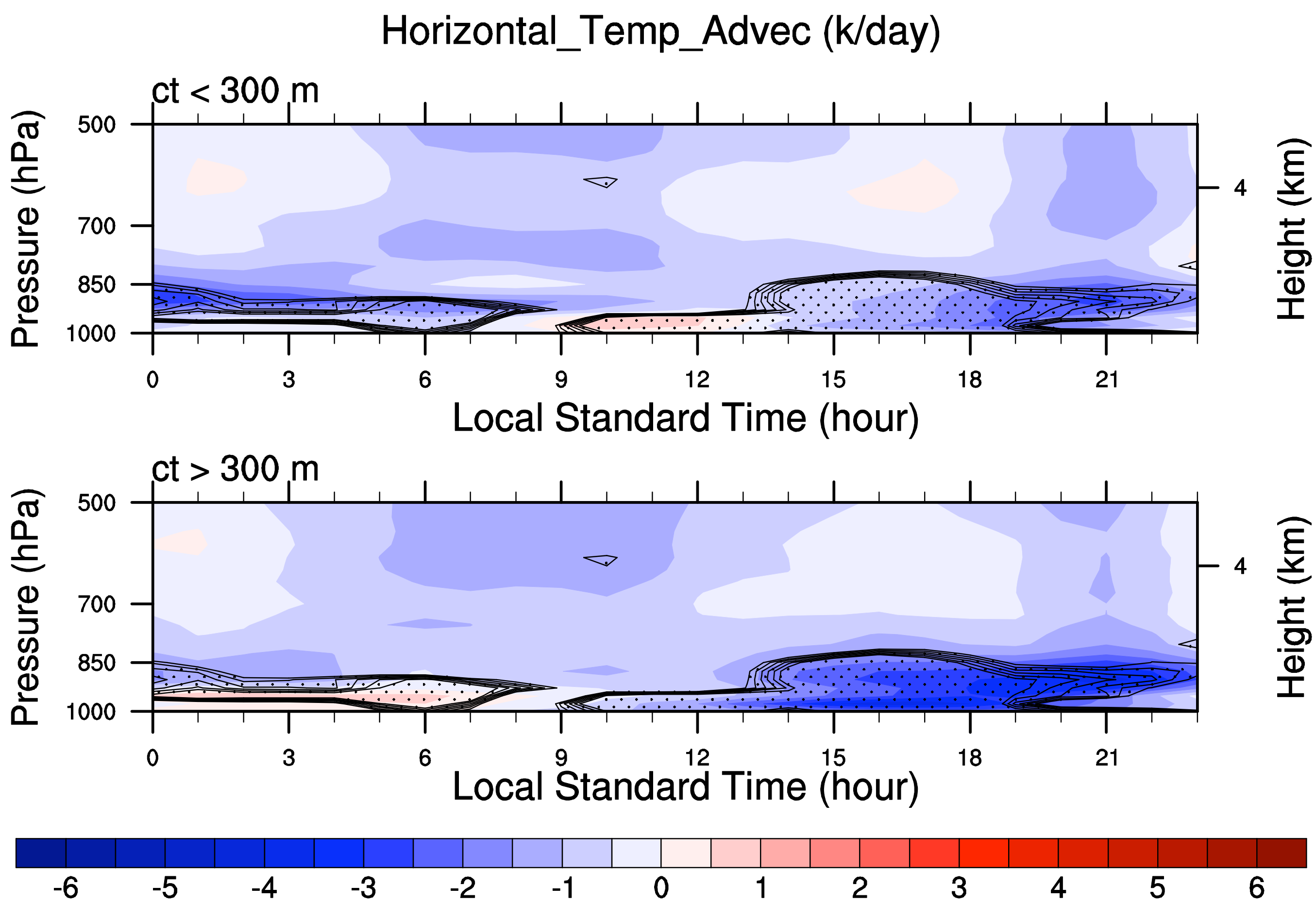
Stippled area is where the forcings are statistical significantly different

Large-scale heat advection



Based on newly developed extended long-term continuous forcing
Stippled area is where the forcings are statistical significantly different

Large-scale heat advection (horizontal)



Based on newly developed extended long-term continuous forcing
Stippled area is where the forcings are statistical significantly different

Future work (1)

- Vertical Velocity data: updated version by removing insects contamination and incorporating missing data flags is on the way of delivery by Pavlos's group

1130 LST

1430 LST