# Why do GCMs overestimate the aerosol cloud lifetime effect? A comparison of CAM5 and a CRM

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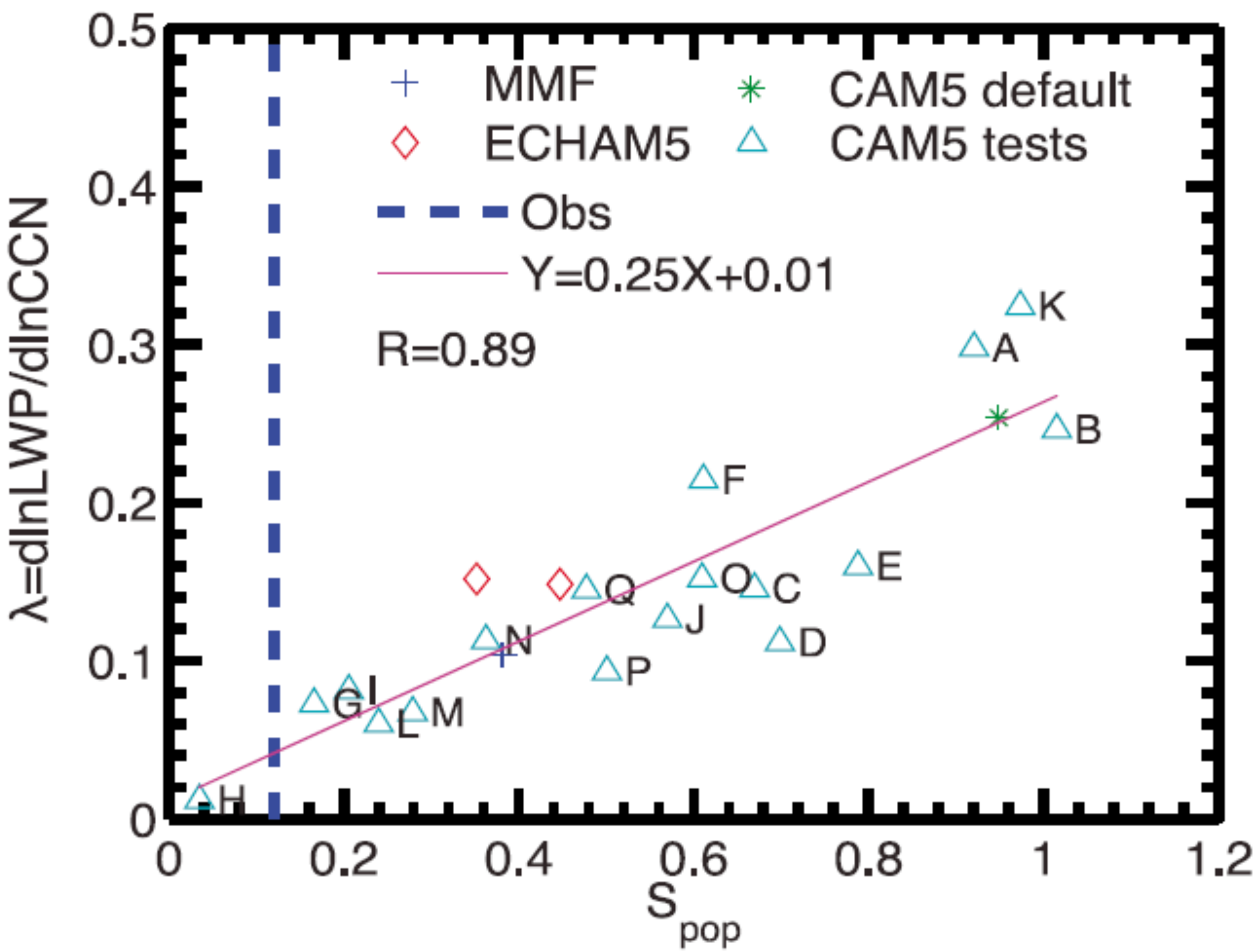
# Constraining cloud lifetime effects of aerosols using A-Train (by Wang et al. 2012)




**$S_{pop}$: precipitation frequency susceptibility, Spop=-dlnPOP/dlnAI**

Spop in marine clouds estimated from CloudSat, MODIS and AMSR-E observations

# Complexities in the First Aerosol Indirect Effect over the Southern Great Plains (Pennypacker and Steiner, ACPD, 2016)

1. There is a decrease of average reff of 20-39% (filtered) and 10-19% (unfiltered) at the four sites with liquid clouds.
2. The response of LWP in all warm clouds over a 5 year period at the SGP site is not clear:
   - At three of the four sites, the filtered average CWP decreases between 25-47%
   - At one site LWP increases.

   This response may be associated with aspects determining the advection of water and temperature into the region.

# Objective of this study

- The objective of this study is to investigate the differences of aerosol second indirect effect (lifetime effect) in a GCM and a CRM.

# Methodology

Use same <u>initial conditions</u> and <u>forcings</u> derived from the MC3E campaign to drive …

The single column version of CAM5.3

CRM:
The NASA GCE model

Compare the results to other ARM observations, e.g., LWP, cloud fraction; explore the dependence of the LWP on aerosol number concentrations.

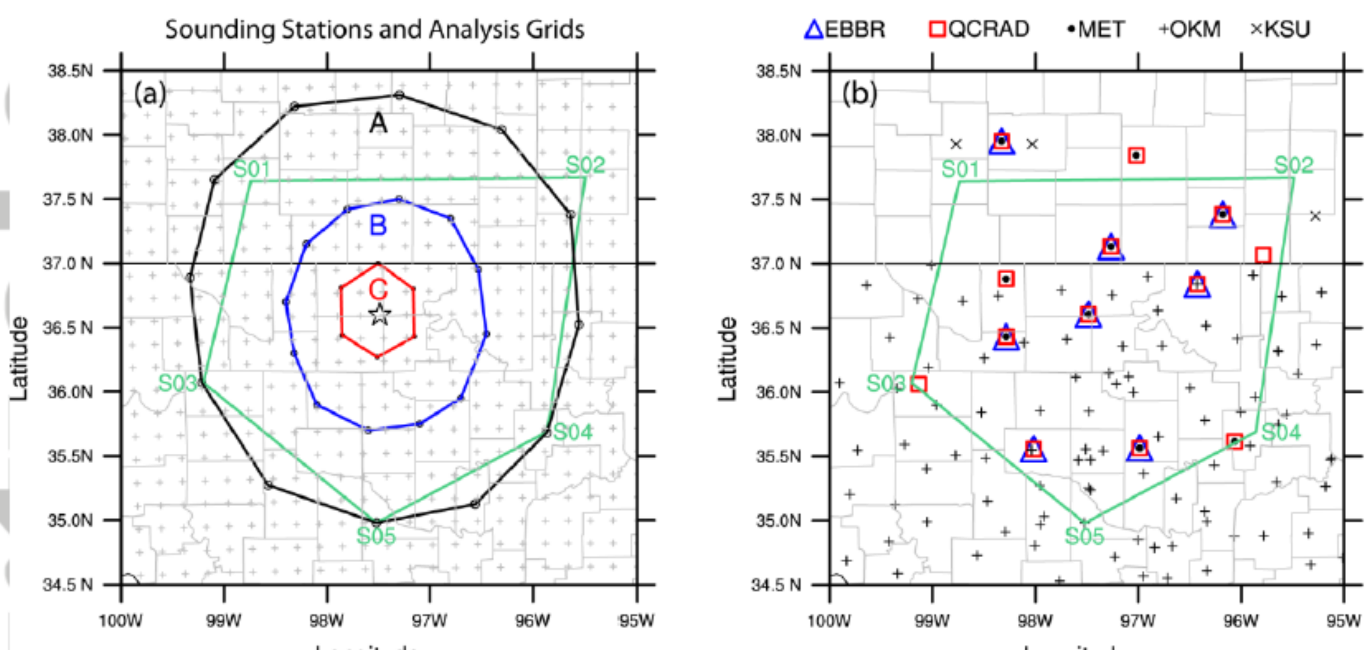
# Comparison of some basic features of the two models

| | Single Colum version of CAM5.3 | CRM (GCE) |
|---|---|---|
| Horizontal resolution | 1 point | 50m, 6.4kmX6.4km |
| Vertical resolution | 30 layers, stretched vertical resolution:<br>• ~100 near surface<br>• ~300m at 2km | 144 layers, stretched:<br>• 30m near surface<br>• ~80-90m at 2km |
| Temporal resolution | 30 min | 0.5 second |
| Sub-grid cloud process parameterization | • Shallow Convection Scheme (Park and Bretherton [2009])<br>• Deep Convection Scheme (Zhang and McFarlane [1995]) | Resolved |
| Microphysics | • Two-momentum scheme (Morrison and Gettelman [2008]), in stratus only<br>• MG1.5 (Version 1.5) | RAMS microphysics, 2-momentum scheme. |
| Aerosol scheme | Prescribed MAM3 aerosols | Prescribed aerosol numbers, look-up table. |

# MC3E: Midlatitude Continental Convective Clouds Experiment

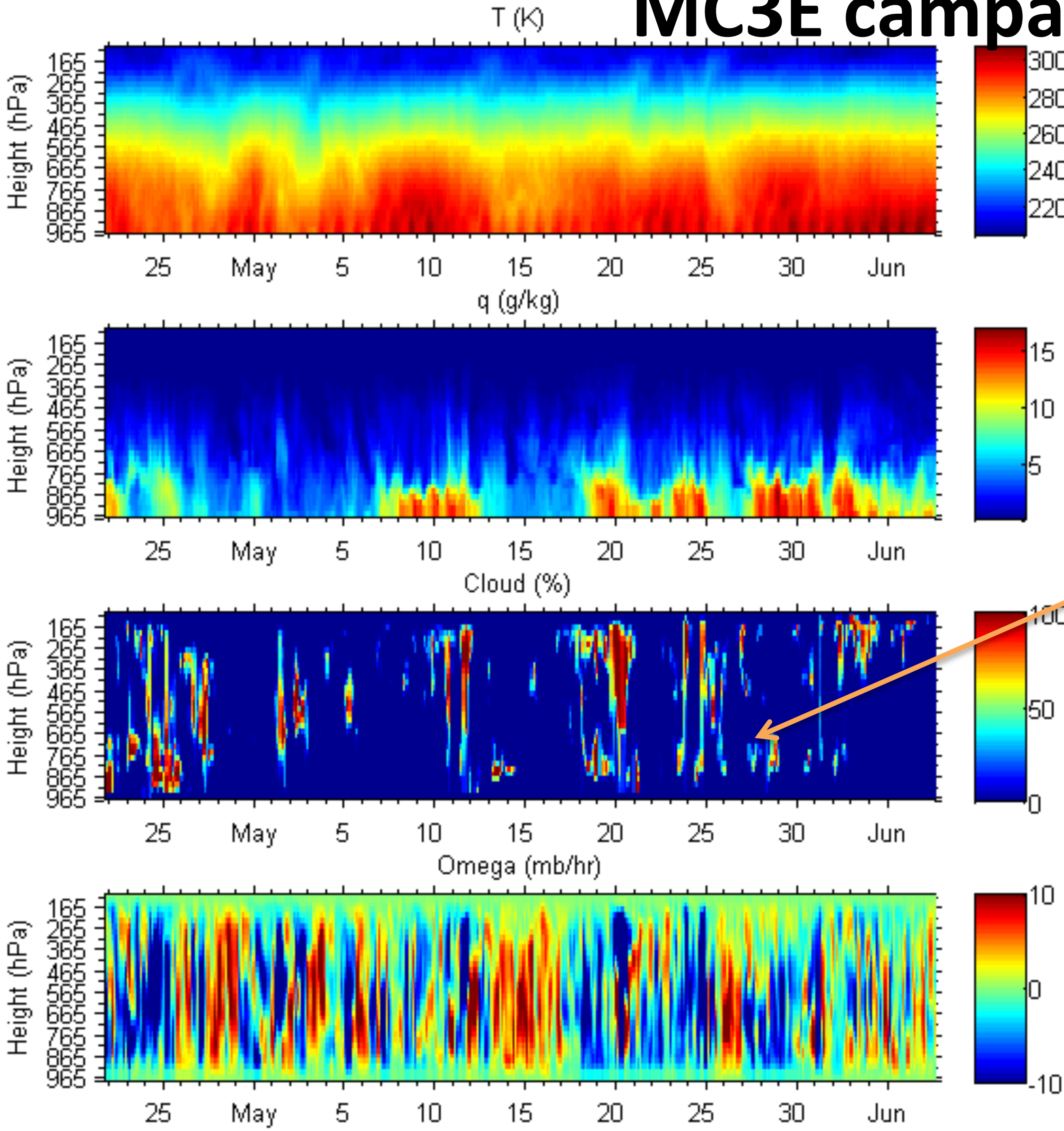
1. Conducted during April to June 2011 near the ARM Southern Great Plains (SGP) site
2. The analysis forcing data cover the period from <u>00Z 22 April - 21Z 6 June 2011</u>.
3. The forcing data represent an average over the 3 different analysis domains centered at central facility with a diameter of 300 km (standard SGP forcing domain size), 150 km and 75 km

The MC3E Ground Observation Network




(From Xie et al. 2014 JGR)

# Observed T, Q, Cloud fractions, Omega from the MC3E campaign




T (K) from soundings

Q (g/kg) from soundings

May 27th,2011
Low level stratocumulus

Cloud (%) from ARSCL

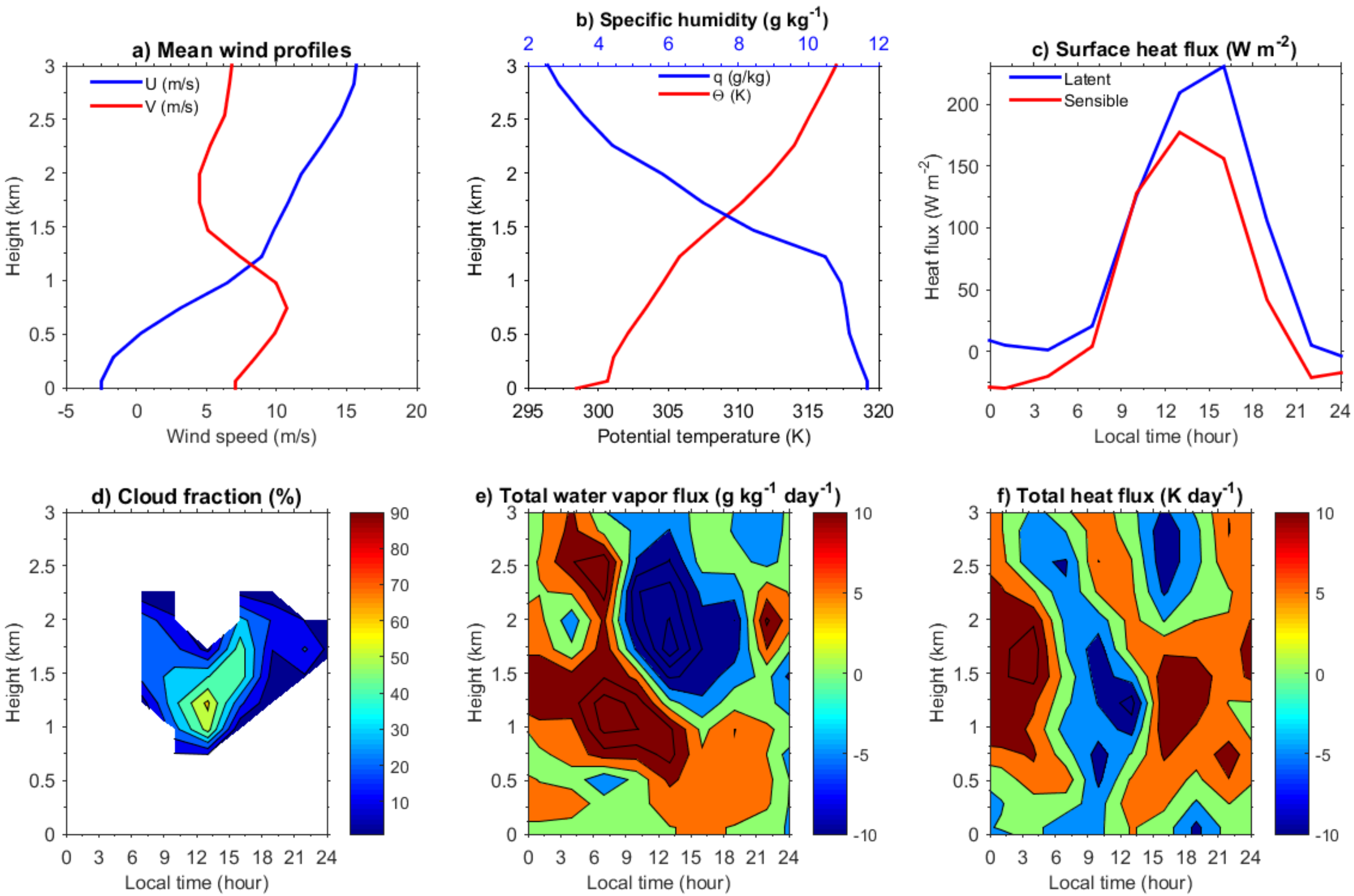
(descending)

Omega (mb/hr) from Soundings +RUC analysis

(ascending)

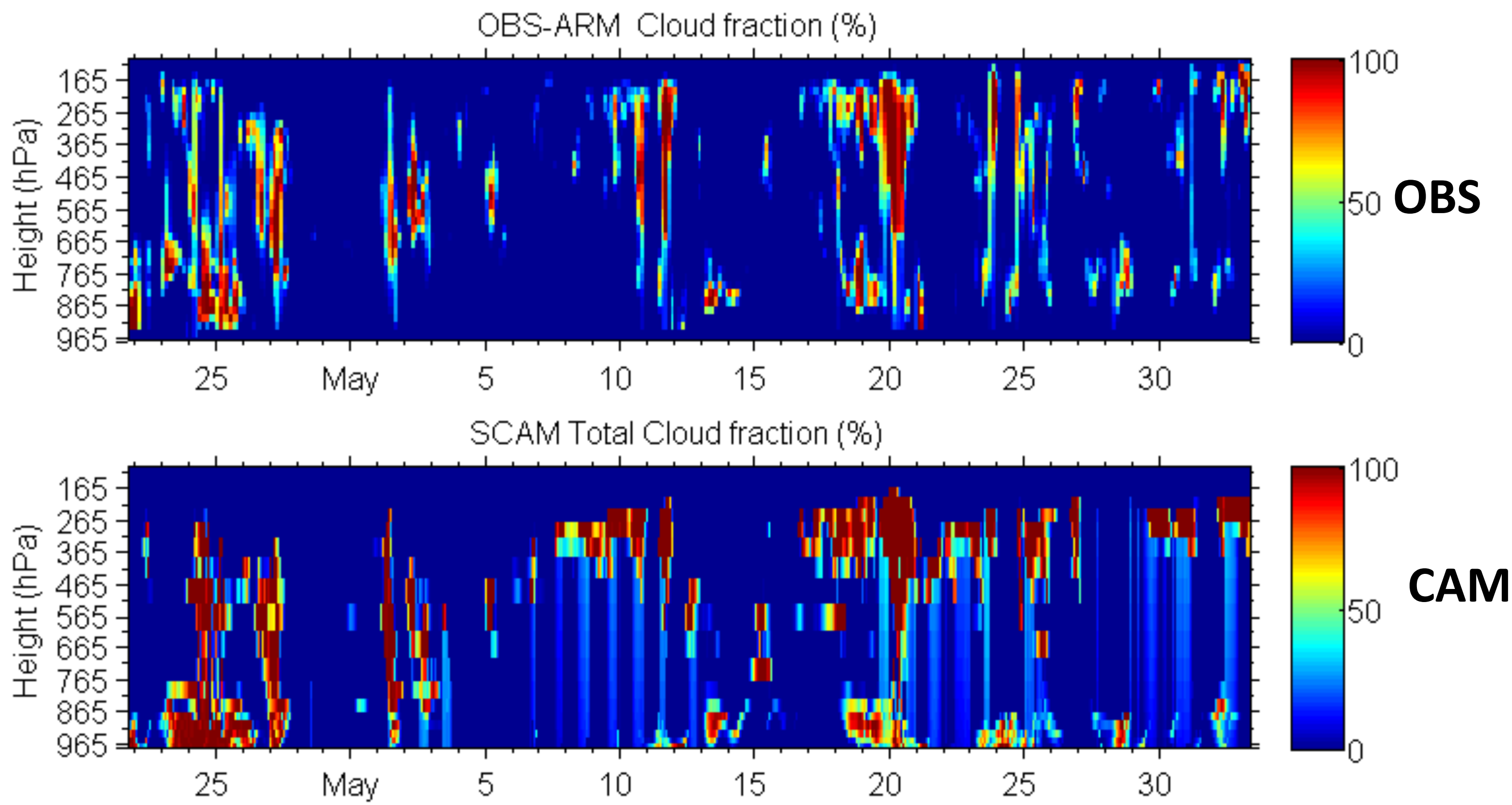
**Deep convective clouds were observed on the majority of the cloudy days. We selected one date, 05/27/2011, in this study as there were only low clouds on this day.**

# Forcing data on 05/27/2011



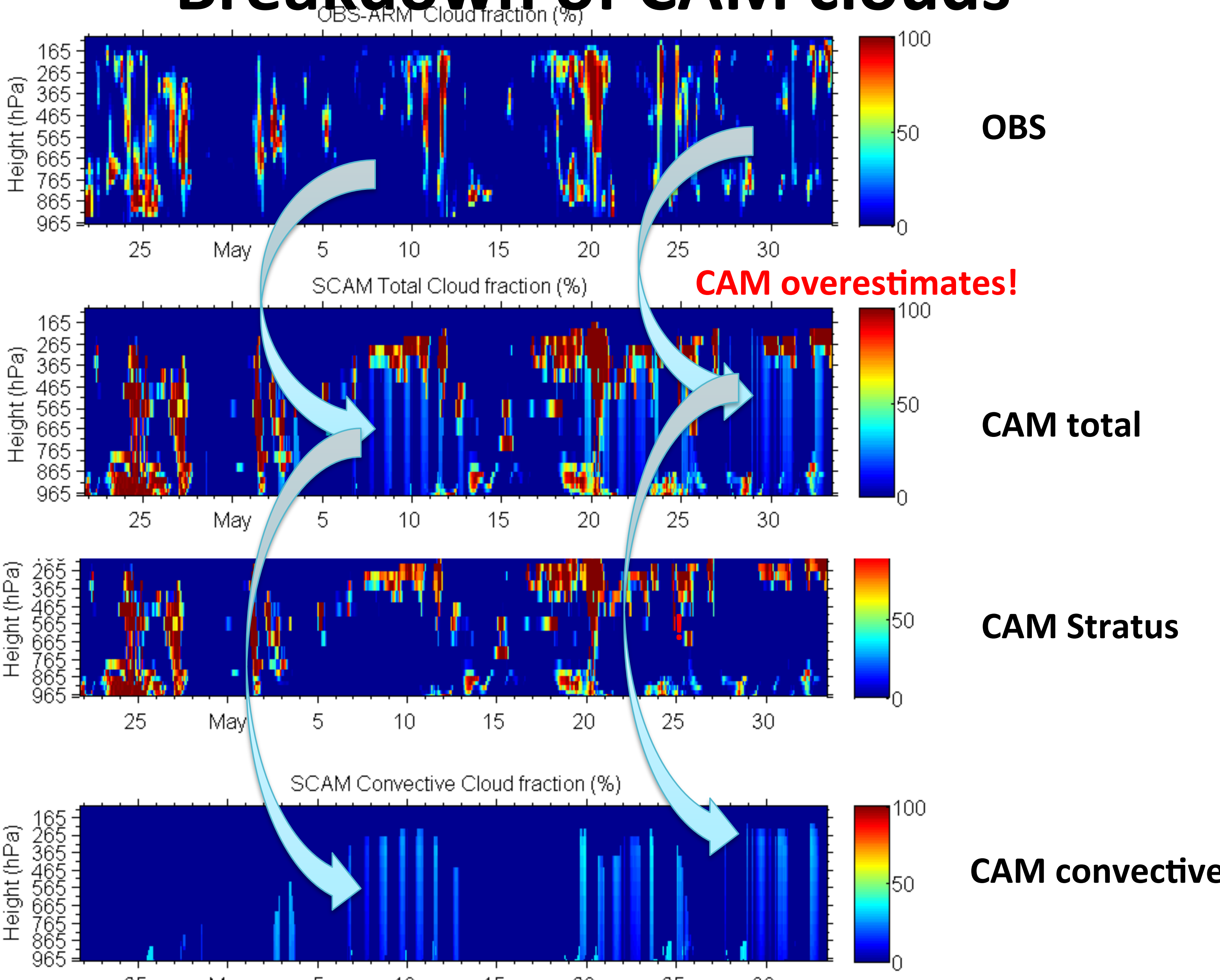

1. Positive water vapor flux and negative heat flux were observed during the growing phase of the clouds before ~14:00 hour.
2. Negative water vapor flux and positive heat flux were observed during the growing phase of the clouds after ~14:00 hour.

# Results from SCM-CAM5.3

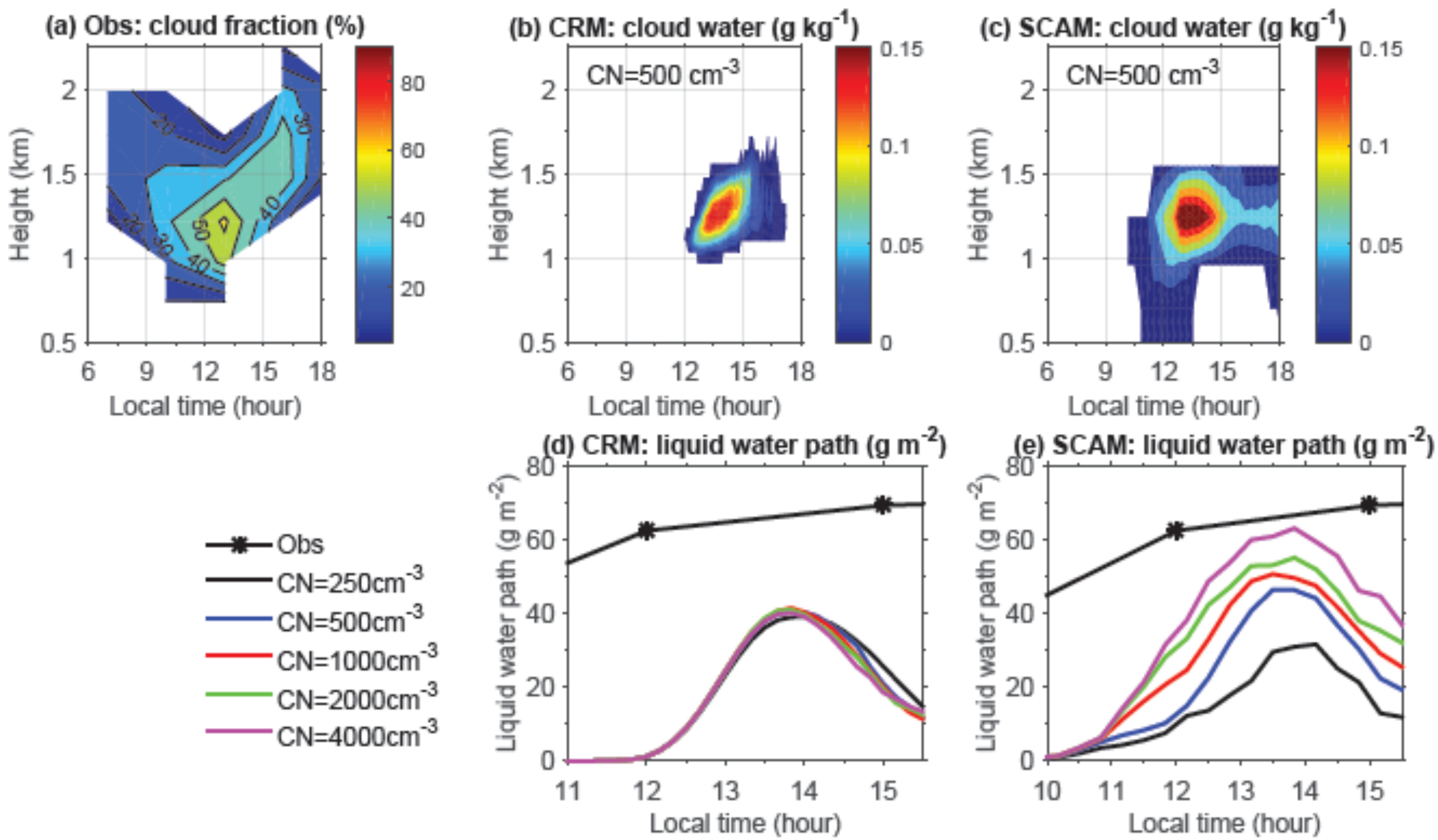



- **CAM overestimates cloud fractions,**
  - **from low clouds to high clouds**
  - **deep convective clouds**

# Breakdown of CAM clouds

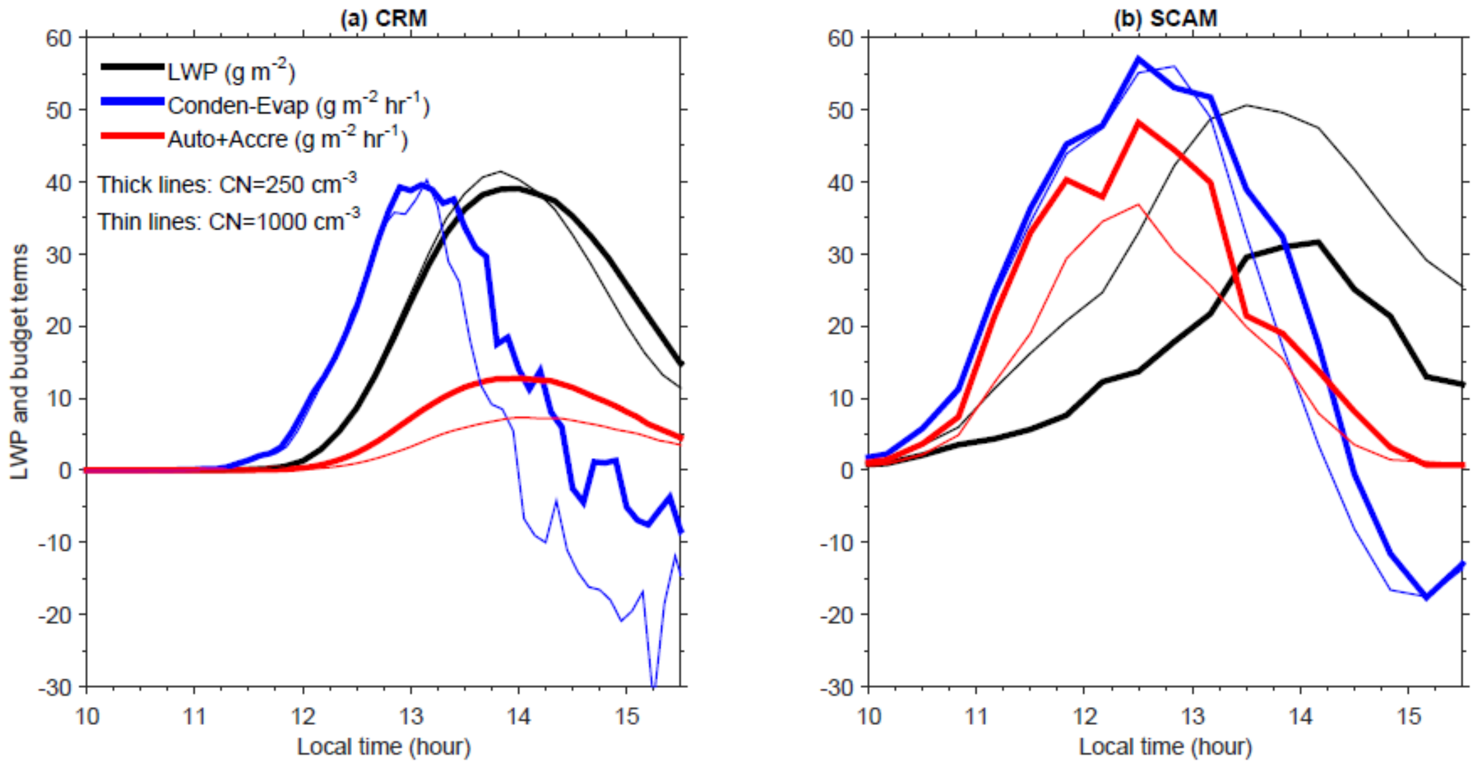


# Results: simulated clouds from the two models




1. **The CRM captures the growth of the cloud top while CAM does not (only has 2 layers of clouds from 1 km to 1.5 km).**
2. **The LWP simulated by CAM increases substantially with aerosol loading while that in GCE does not.**

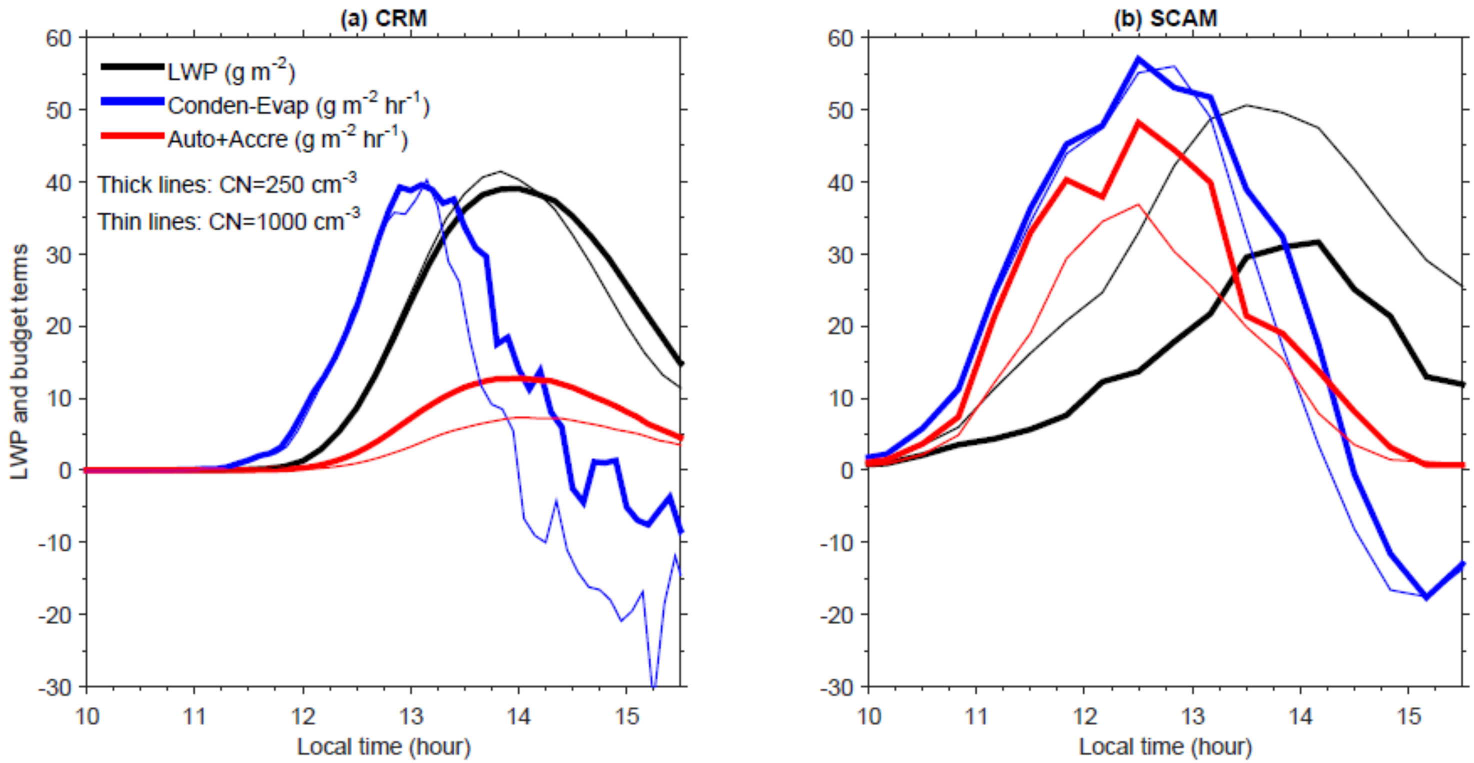
# Budget analysis of the LWP from the two models




**The source term of the LWP in the both models only has condensation.**
**The sink terms include: evaporation, autoconversion and accretion.**

- **Evaporation in CAM is mainly calculated in the macrophysics scheme which does not depend on cloud droplet numbers directly.**
- **Evaporation of falling cloud droplets in its microphysics schemes contributes very little to the total evaporation.**

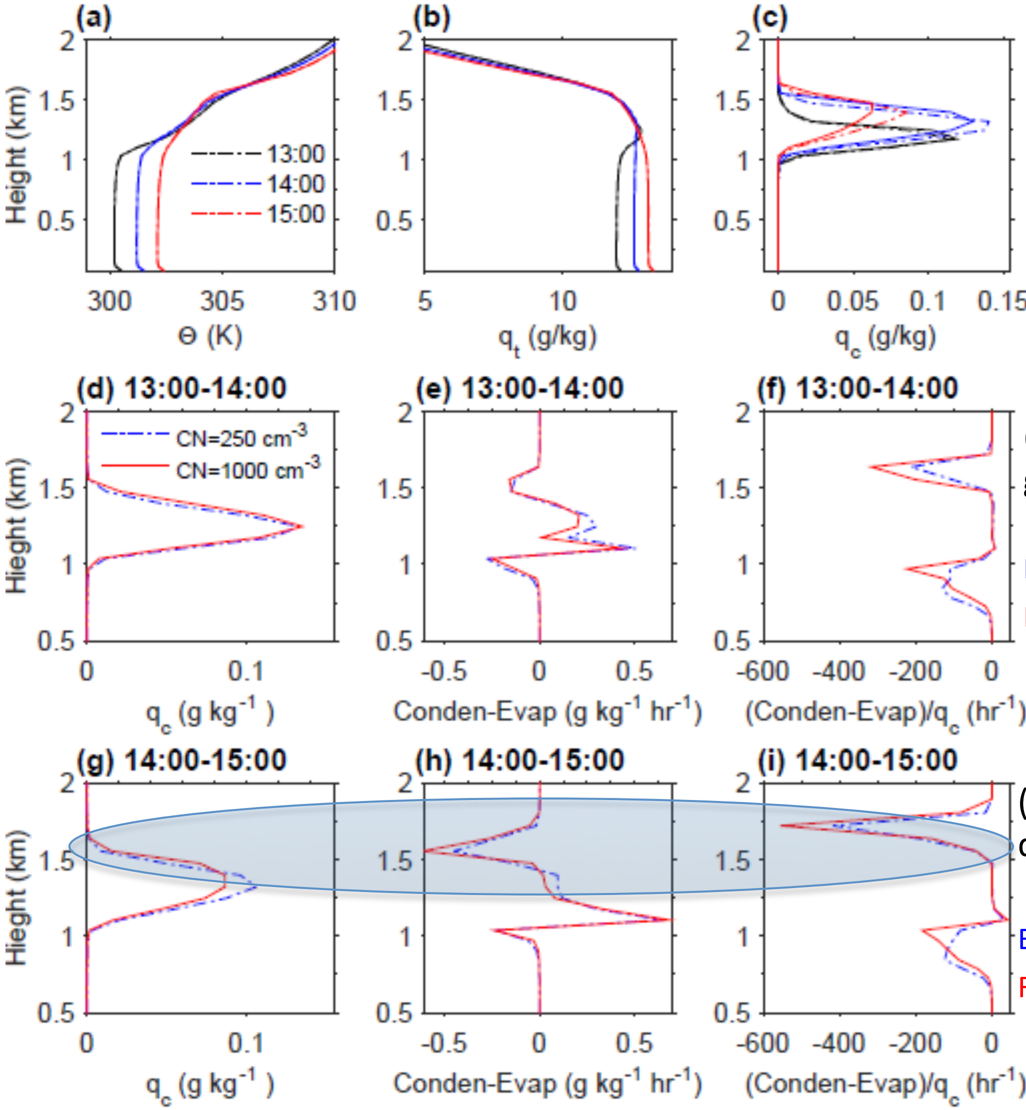
# Budget analysis of the LWP from the two models




**Left: In the CRM model, decreased autoconversion/accretion rate (red curves) is offset or even outweighed by the increased evaporation rate (blue curves).**

**Right: in CAM, the effect from decreased autoconversion/accretion rate dominates (red curves).**

# Where does the increased evaporation occur? Vertical profiles from the CRM model




(a)-(c)Domain averaged potential temperatures, total water specific humidity and cloud water content at three times (13:00, 14:00 and 15:00)

Dash-dotted : CN =250 $cm^{-3}$

Solid : CN =1000 $cm^{-3}$

(d)-(f) One hour means (13:00-14:00) at the growing phase.

Blue dash-dotted : CN =250 $cm^{-3}$

Red solid : CN =1000 $cm^{-3}$

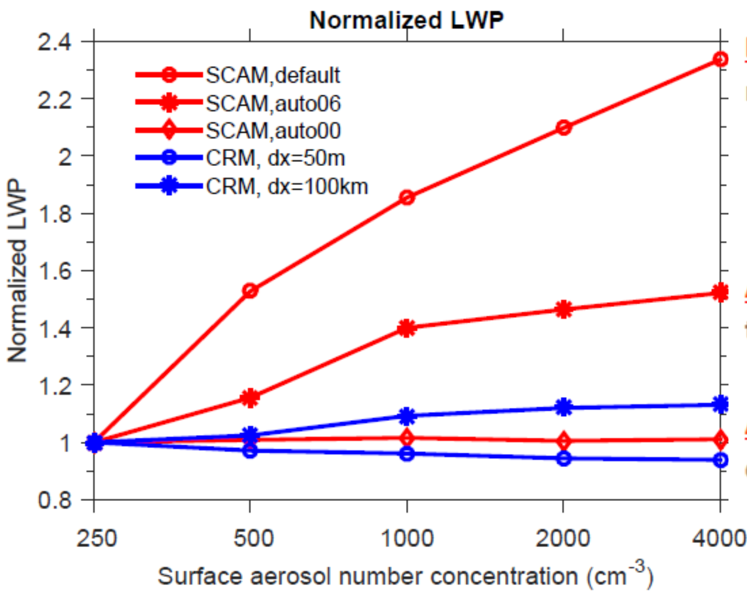
(g)-(f) One hour means(14:00-15:00) at the decaying phase.

Blue dash-dotted : CN =250 $cm^{-3}$

Red solid : CN =1000 $cm^{-3}$

- **Slightly increased cloud top height and PBL height when the aerosol number increases.**
- **Increased evaporation of cloud droplets near the cloud top especially at the decaying phase.**

# Sensitivity tests: Can we decrease the LWP from CAM using Wang et al. 2012 method?



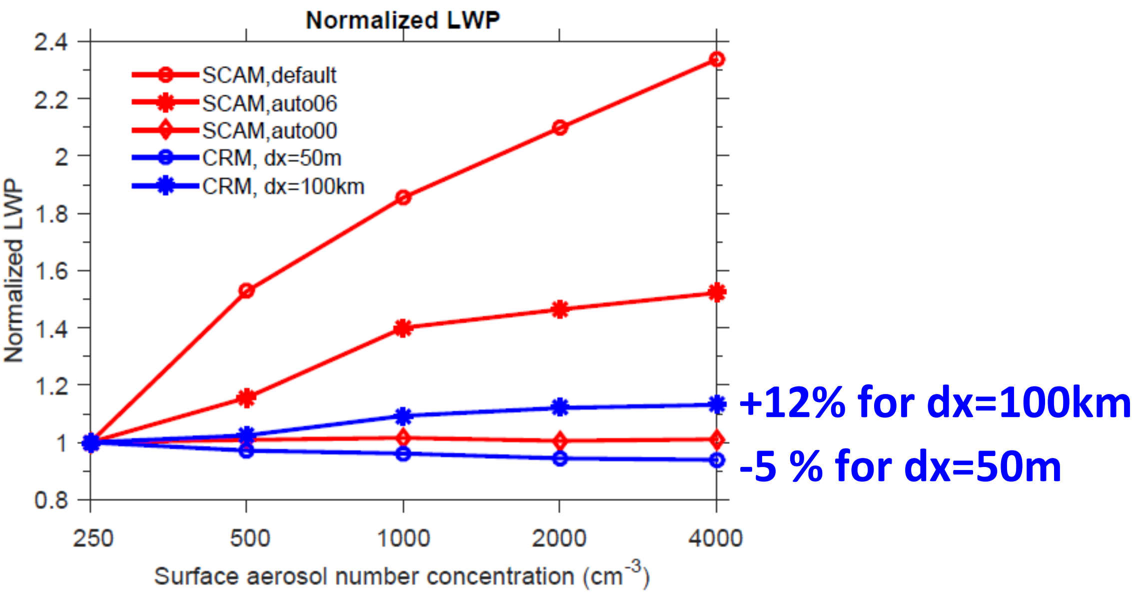

**Default:** The default autoconversion rate is inversely proportional to cloud droplet number (~$N_c^{-1.79}$ where $N_c$ is the in-cloud cloud droplet number).

**Auto06:** modified autoconversion rate now proportional to $N_c^{-0.6}$, scaled to have the same the rate as the default case when $N_c = 100\ cm^{-3}$ .

**Auto00:** fixed autoconversion rate, scaled to have the same the rate as the default case when $N_c = 100\ cm^{-3}$ .

- **Red curves show the normalized LWP from CAM with 3 different autoconversion rates on the cloud droplet number.**
- **The increase of LWP in CAM can be reduced or eliminated when the dependence of the autoconversion rate on cloud droplet number is reduced.**
- **However, CAM could not produce a decreased LWP due to the lack of increased evaporation near the cloud top and increased cloud top height.**

# Sensitivity tests: What if we limit the entrainment/mixing at the cloud top in the CRM?




- Blue curves show the normalized LWP from the CRM for 2 different horizontal grid size, dx=50 m and 100 km.
- We increase the horizontal grid size from 50 m to 100 km to limit the vertical velocities inside the clouds and the cloud top growth.
- When dx=100 km, we also see increased LWP. This result confirms the importance of the enhanced evaporation and cloud top height growth to cause reduced LWP.

# Conclusions

One unique aspect of this study is that the response of the LWP to increase aerosol numbers over the lifetime of the cloud is *negative* in the CRM while it is *positive* in the CAM model for the *same forcing conditions*.

1. The high sensitivity of LWP to aerosol loading in CAM can be decreased somewhat by tuning the autoconversion rate.
2. But the lack of enhanced entrainment/evaporation in CAM is the fundamental cause of *opposite responses* of LWP in the two models.
3. CAM needs to relate the cloud top growth and evaporation to the cloud droplet number.