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

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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 initial conditions and forcings derived from the MC3E campaign to drive …

The single column version of CAM5.3

CRM:
The NASA GCE model

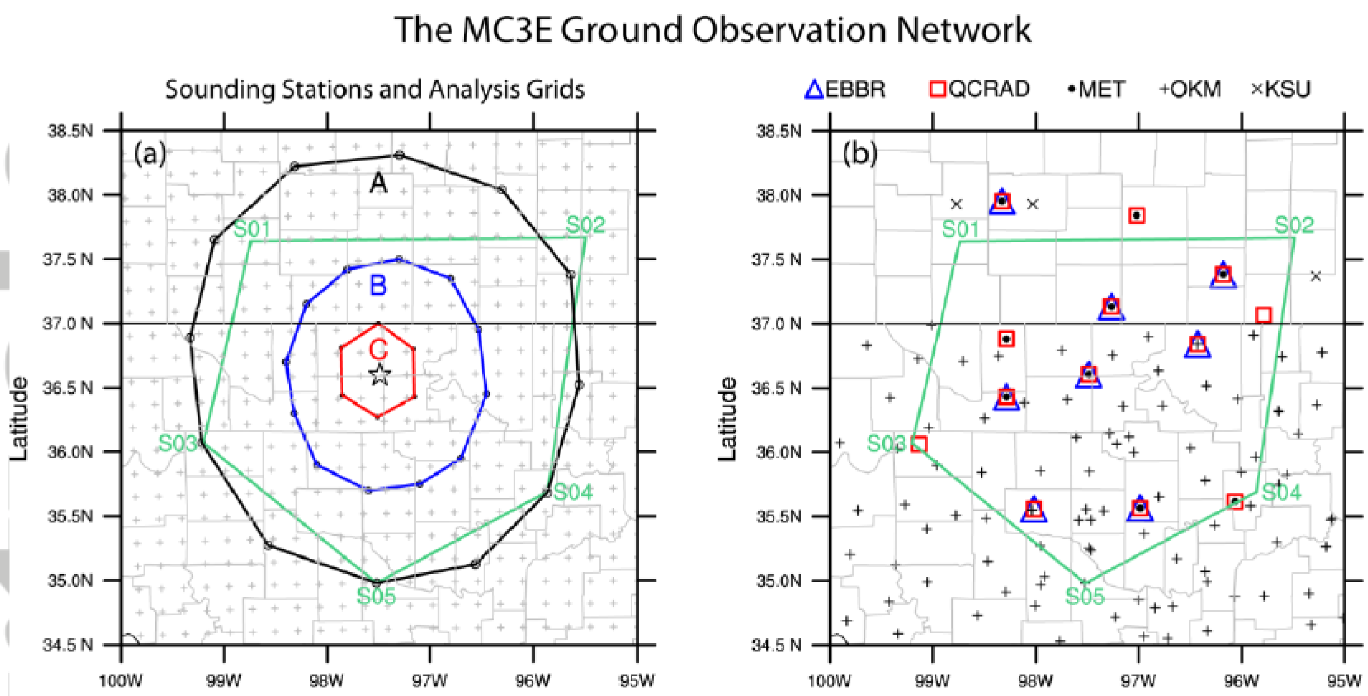
Compare the results to other ARM observations, e.g., LWP, cloud fraction; explore the dependence of the LWP on aerosol number concentrations.

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: • ~100 near surface • ~300m at 2km	144 layers, stretched: • 30m near surface • ~80-90m at 2km
Temporal resolution	30 min	0.5 second
Sub-grid cloud process parameterization	• Shallow Convection Scheme (Park and Bretherton [2009]) • Deep Convection Scheme (Zhang and McFarlane [1995])	Resolved
Microphysics	• Two-momentum scheme (Morrison and Gettelman [2008]), in stratus only • MG1.5 (Version 1.5)	RAMS microphysics, 2-momentum scheme.
Aerosol scheme	Prescribed MAM3 aerosols	Prescribed aerosol numbers, look-up table.

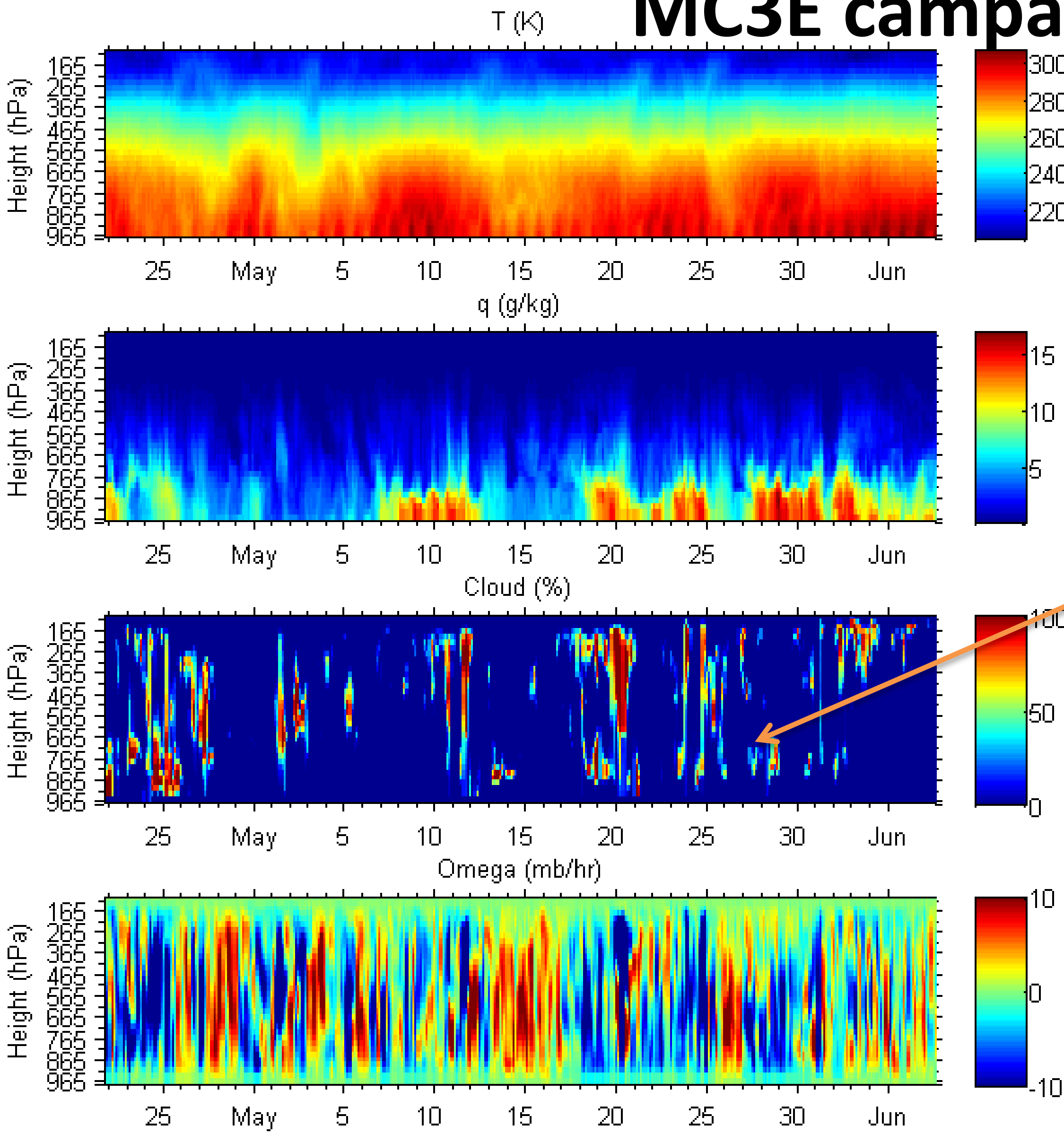
MC3E: Midlatitude Continental Convective Clouds Experiment

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**



(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

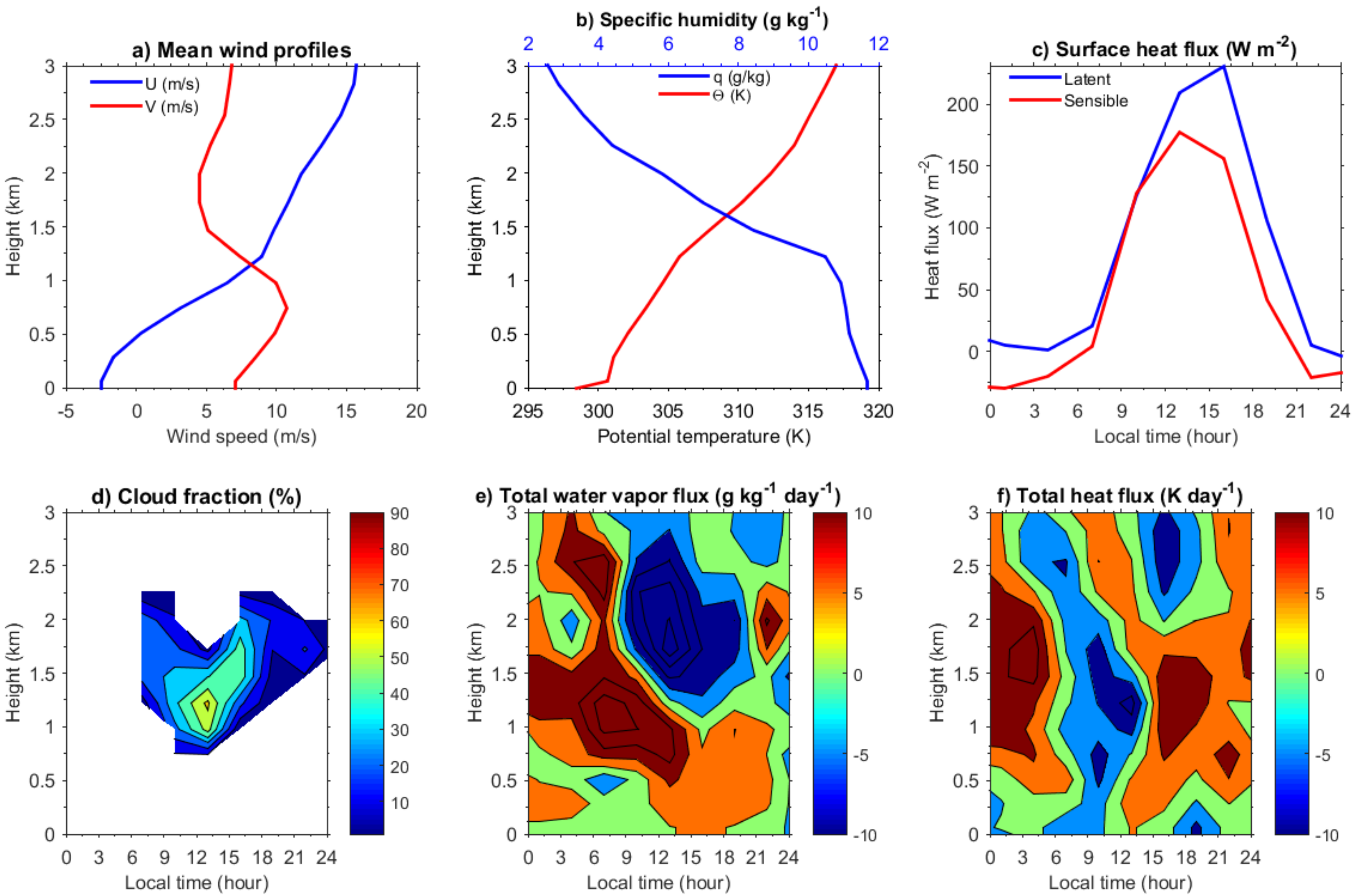
(descending)

Omega (mb/hr) from Soundings +RUC analysis

(ascending)

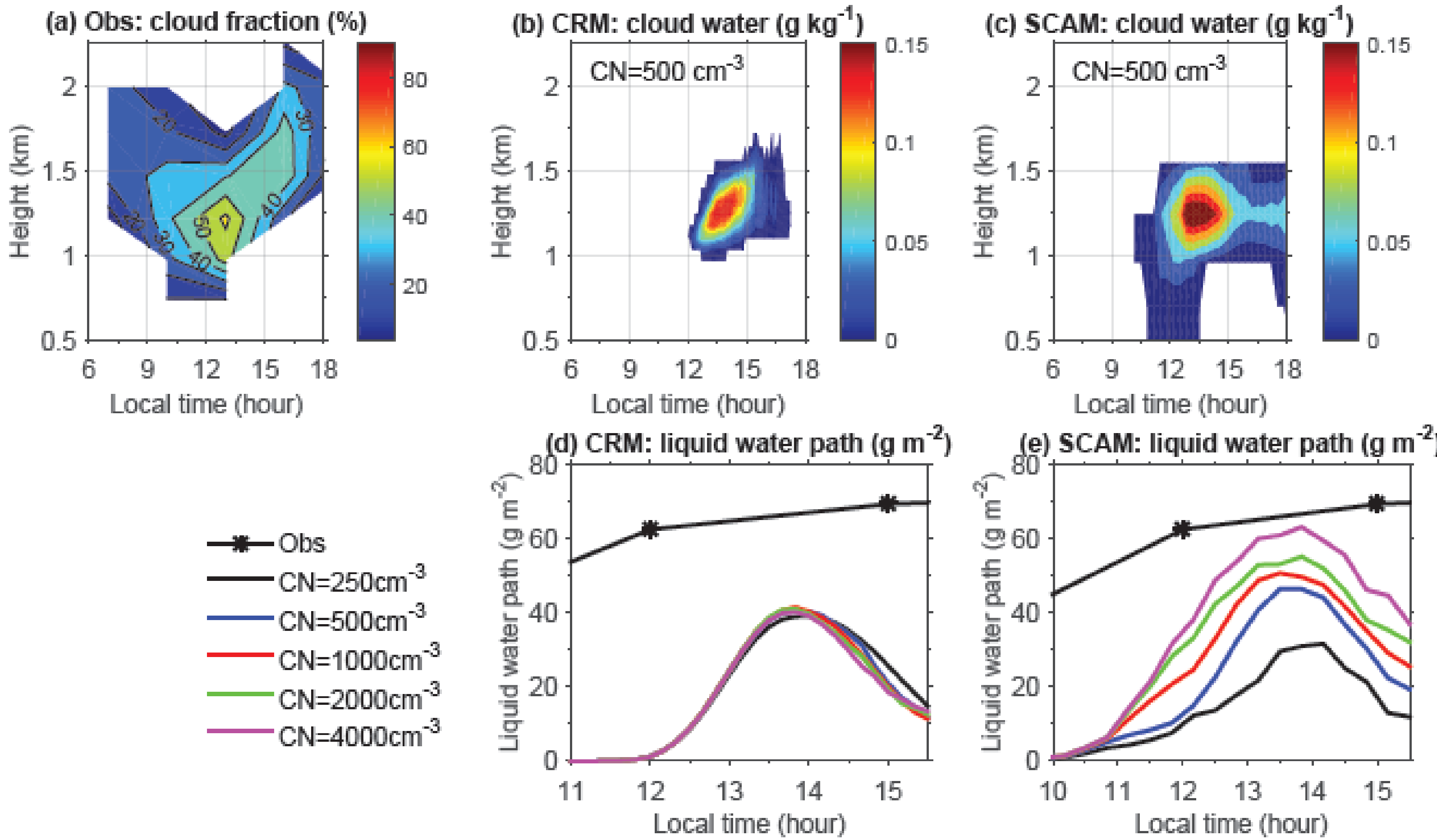
Deep convective clouds were observed on the majority of the cloudy days. We selected one date, 05/27/2011, in this study as there were only low clouds on this day.

Forcing data on 05/27/2011



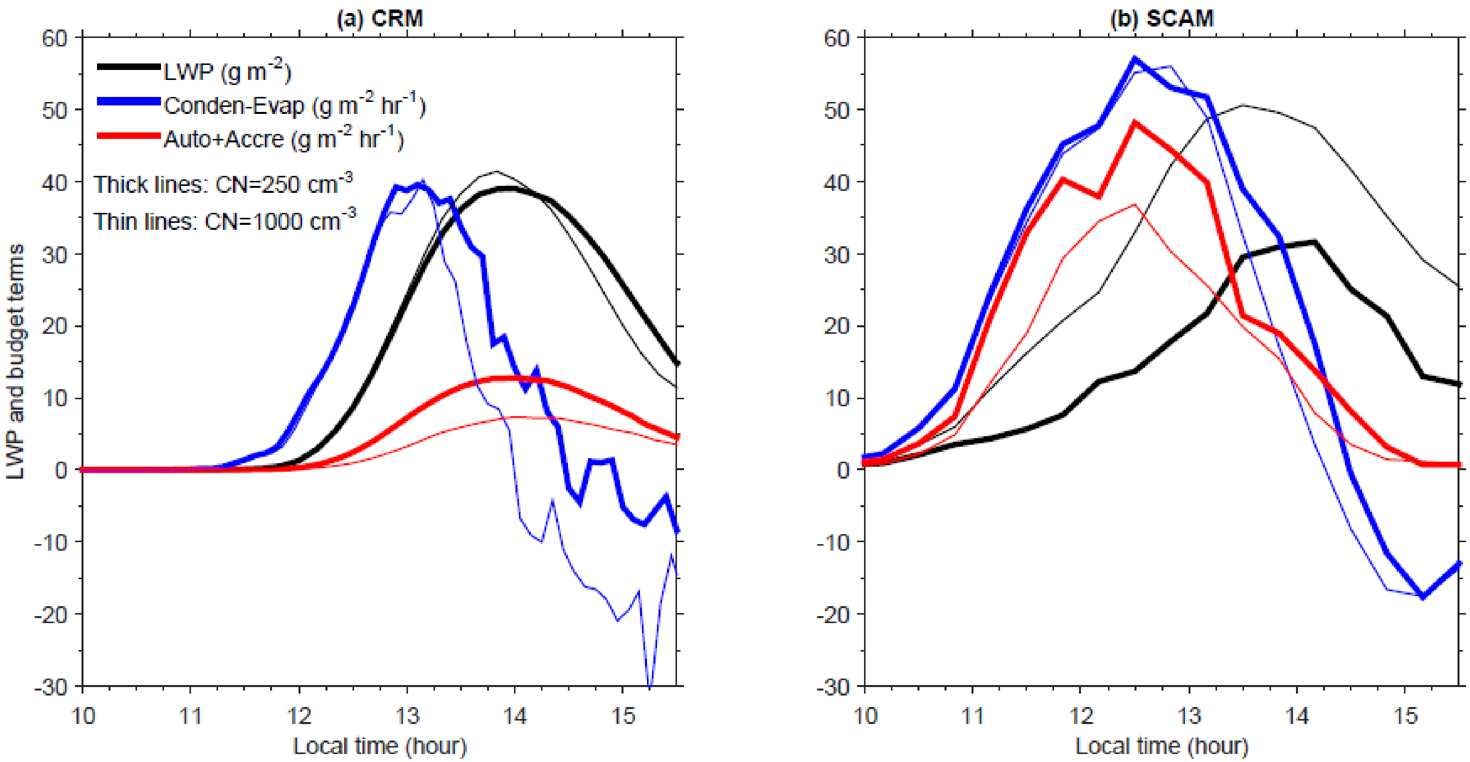
1. Positive water vapor flux and negative heat flux were observed during the growing phase of the clouds before ~14:00 hour.
2. Negative water vapor flux and positive heat flux were observed during the growing phase of the clouds after ~14:00 hour.

Results: 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.**

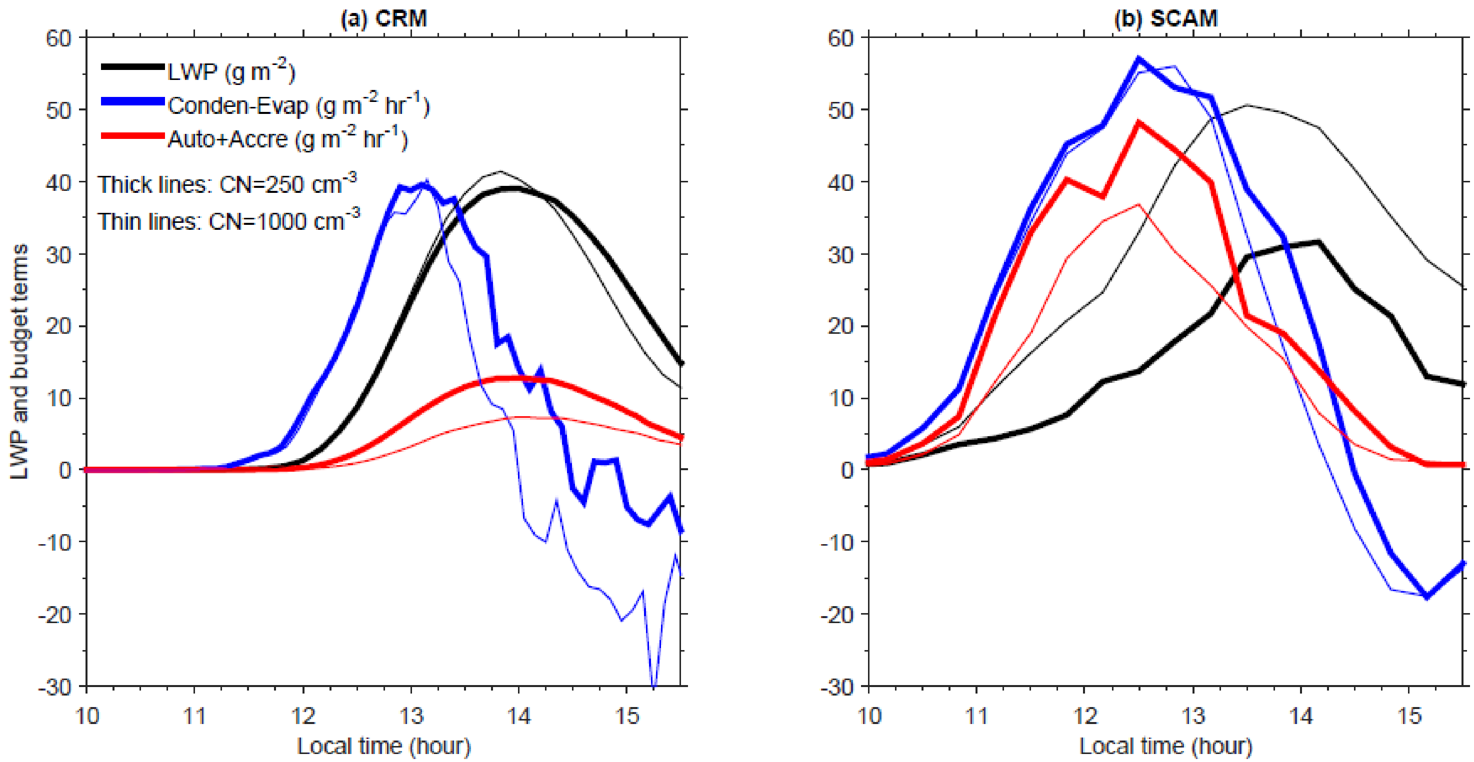
Budget analysis of the LWP from the two models



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.**

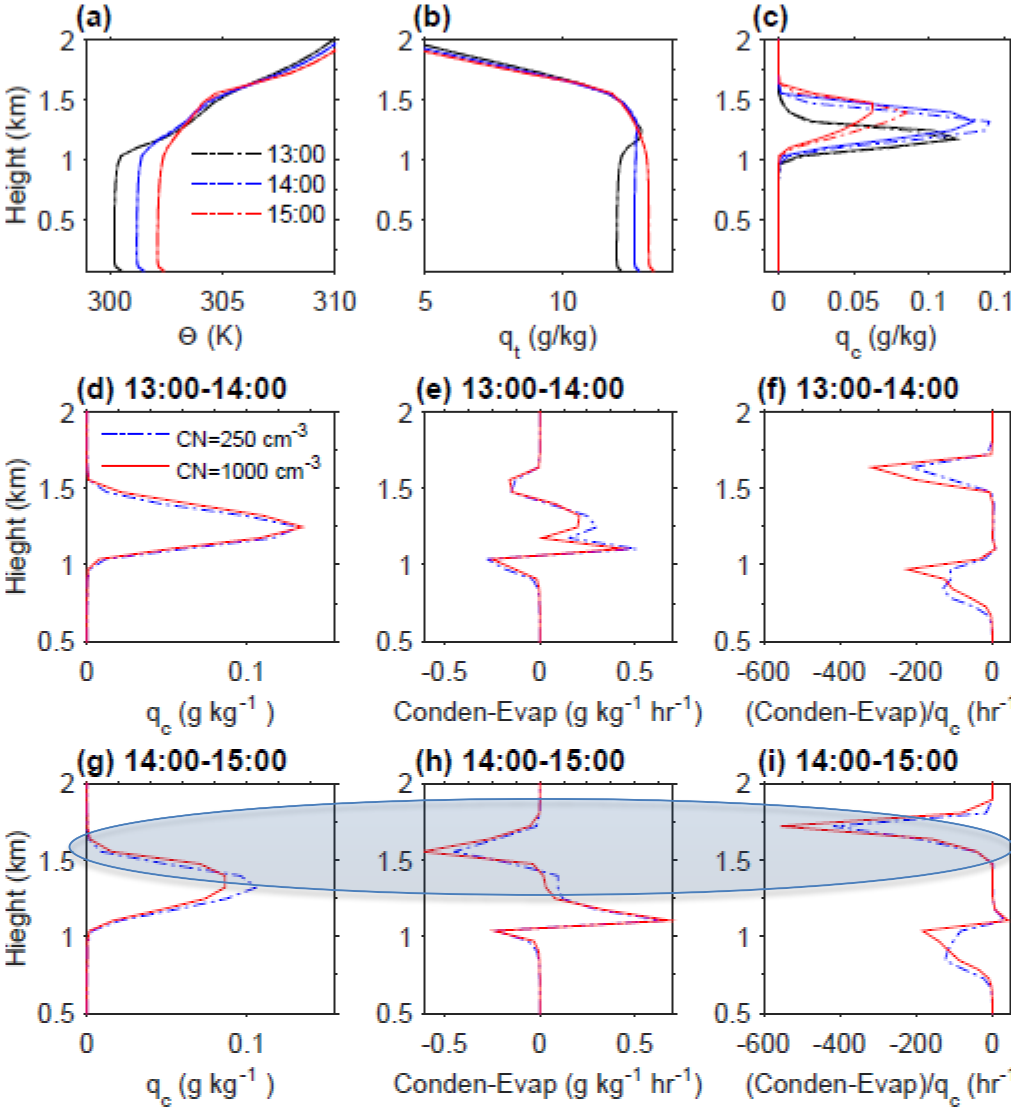
Budget analysis of the LWP from the two models



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}

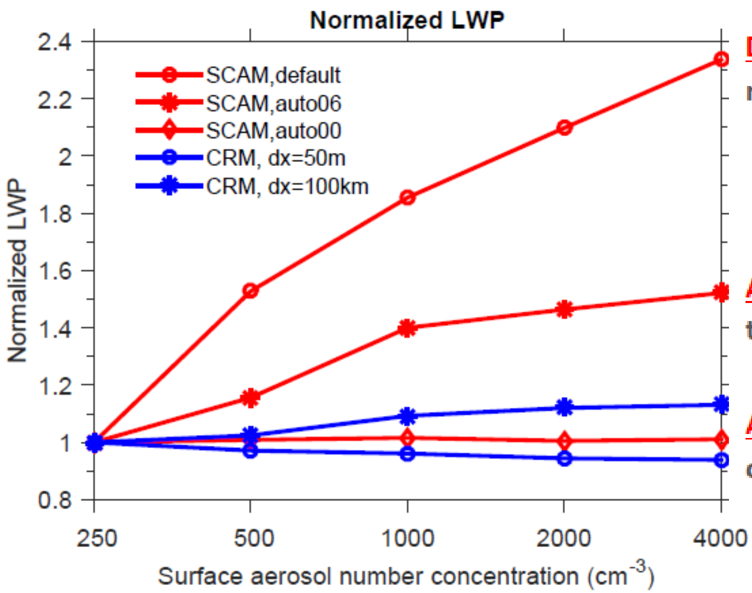
(g)-(f) One hour means(14:00-15:00) at the decaying phase.

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: Why is the LWP from CAM so sensitive?



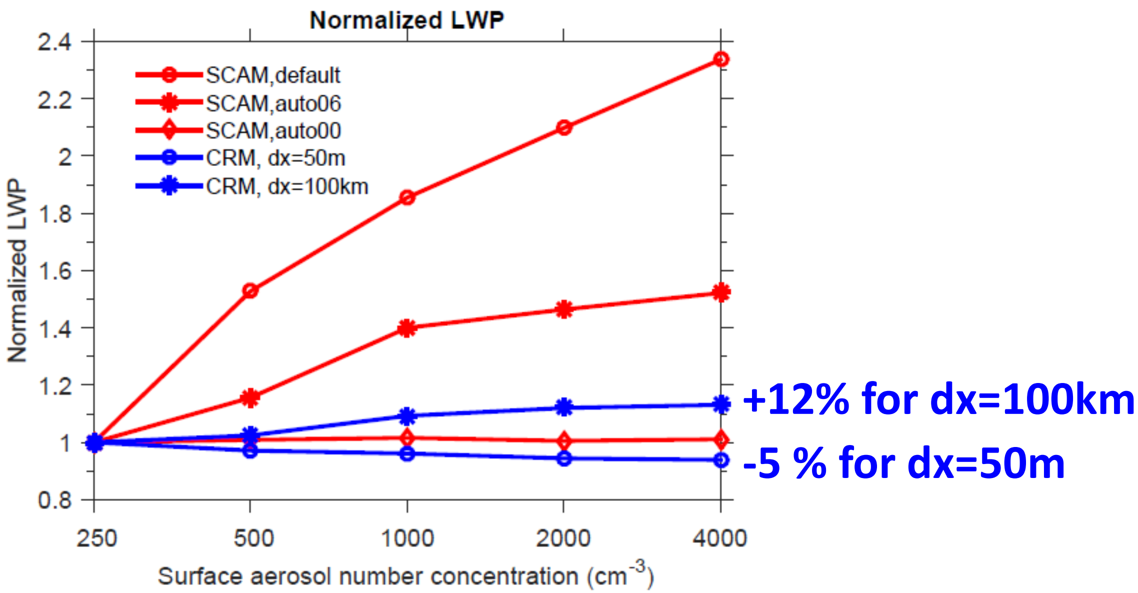
Default: The default autoconversion rate is inversely proportional to cloud droplet number (~$N_c^{-1.79}$ where N_c is the in-cloud cloud droplet number).

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.**

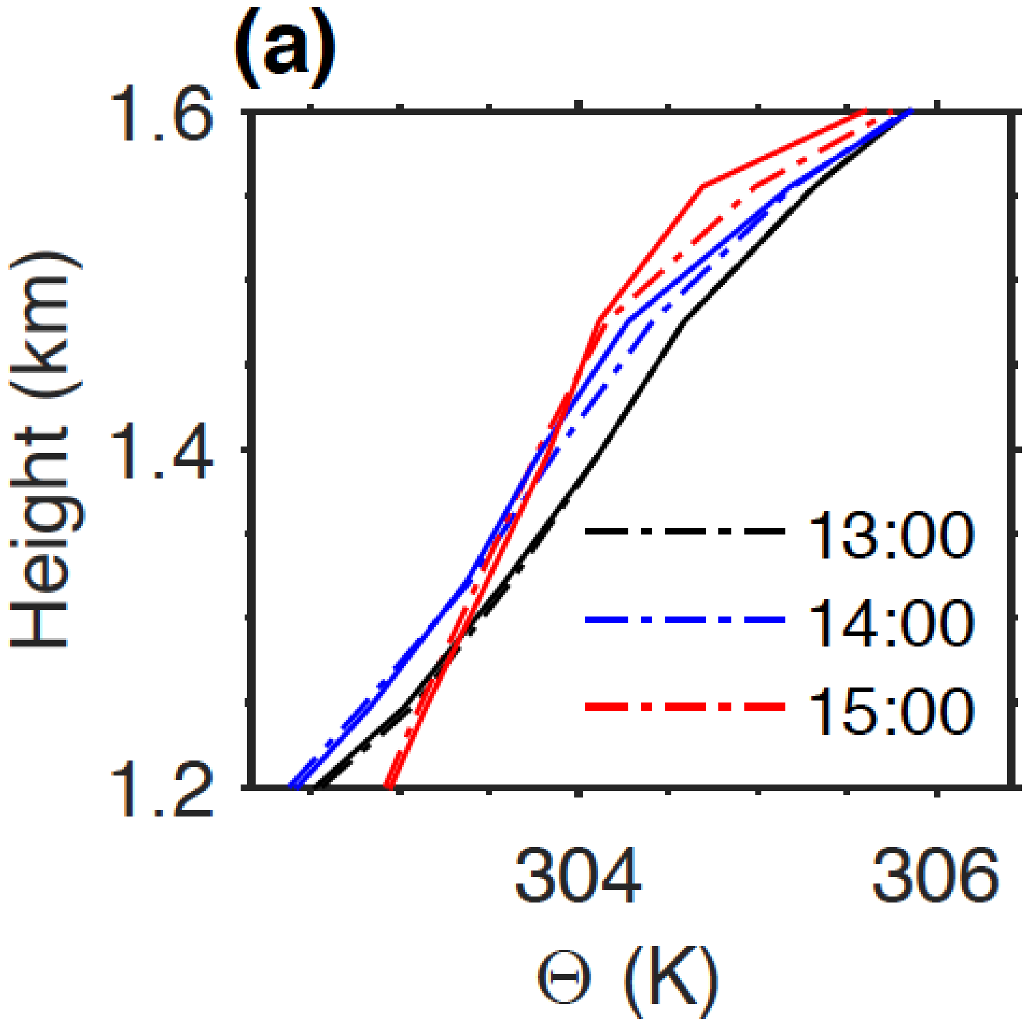
Conclusions

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*.

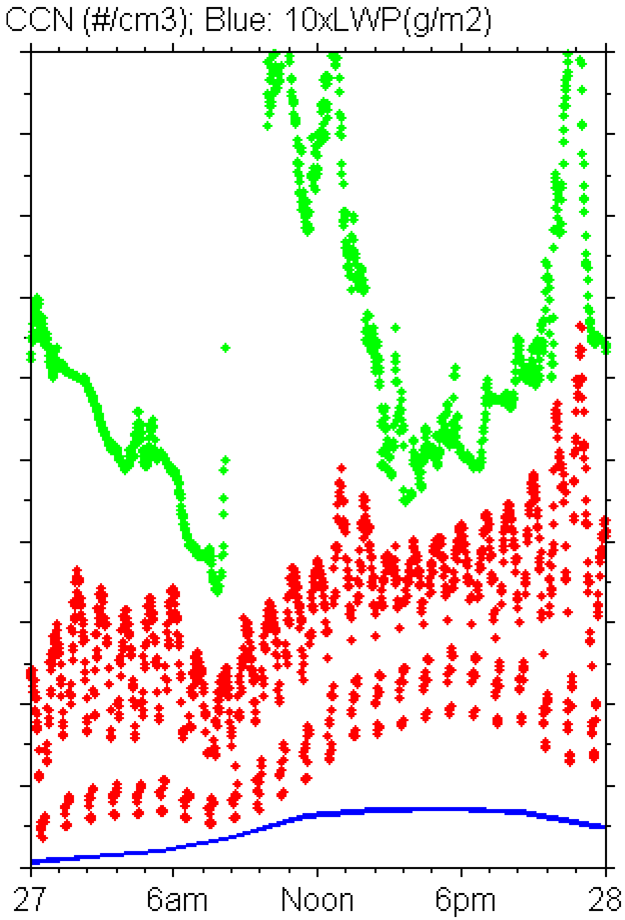
1. The high sensitivity of LWP on aerosol loading in CAM is due to its large dependence of the autoconversion rate on cloud droplet number. The increase of LWP can be reduced or eliminated when the dependence of the autoconversion rate on cloud droplet number is reduced.
2. But the lack of enhanced entrainment/evaporation 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.

THANK YOU!

A zoom in plot of the potential temperatures



Observed CN/CCN/LWP on May, 27th



Source of OBS

LWP: MWR

CN : AOS TSI model 3010 Condensation Particle Counter

CCN: AOS DMT CCN: Condensation Nuclei Counter

- **Note that LWP (g/m2) is timed by a factor of 10 to use the same y-axis.**
- **Relevant CN (green) number is from 4000 to 8000 on May 27th.**
- **Relevant CCN (red) number is 2000-4000 at 1%ss on May 27th**
- **CCN:CN ~ 1:2 at ~1% super saturation.**

Results on 05/27/2011

OBS

CRM: cloud water

SCAM: cloud water