Do GCM's overestimate the warm cloud aerosol indirect effect?

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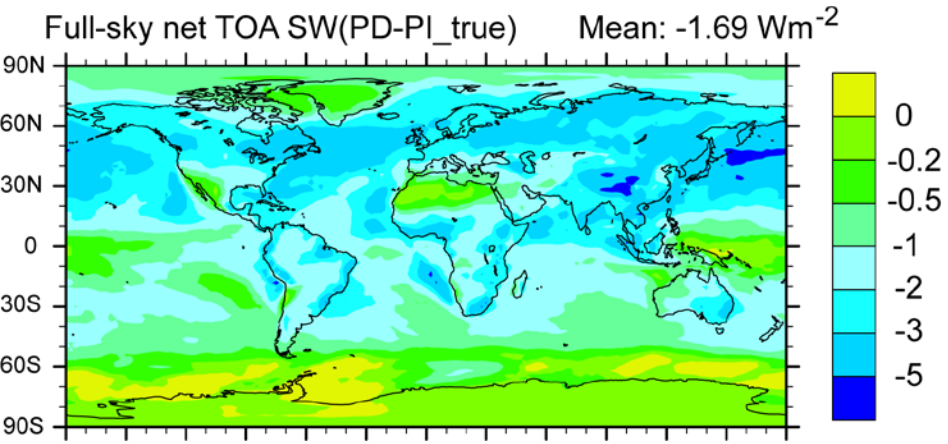
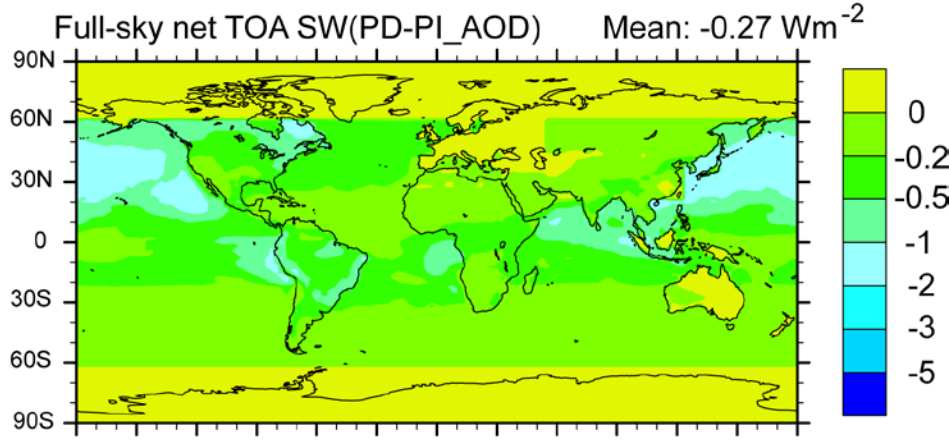
Overview

- AR5 assessed the adjusted total radiative forcing as -0.9 (-1.9 to -0.1) W/m2 with direct radiative forcing as half of this
- Many global model estimates are closer to the high end of this range, so would be judged by the authors of AR5 as being wrong
- Review of relevant results from the literature
- Description of a possible path forward

You cannot use present day ln(N_d)/ln(AOD) to estimate PI N_d and forcing:

$$N_d(PI) = \exp\left(\ln(N_d(PD)) - \frac{\Delta \ln(N_d(PD))}{\Delta \ln(\tau_a(PD))}(\ln(\tau_a(PD)) - \ln(\tau_a(PI)))\right)$$



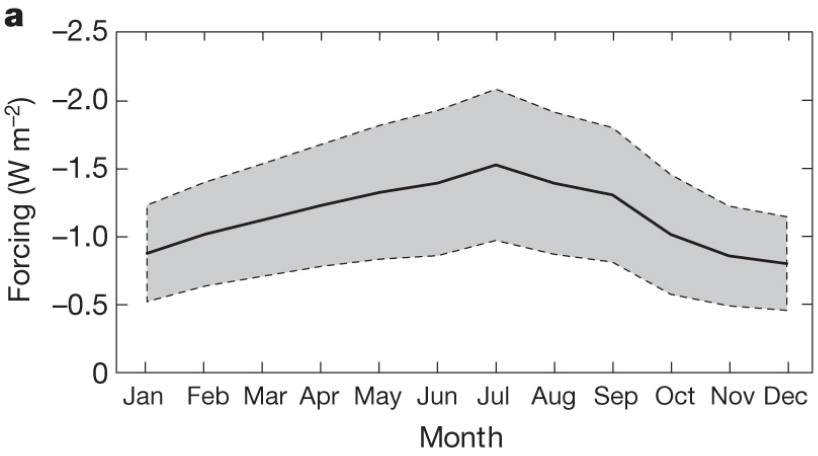


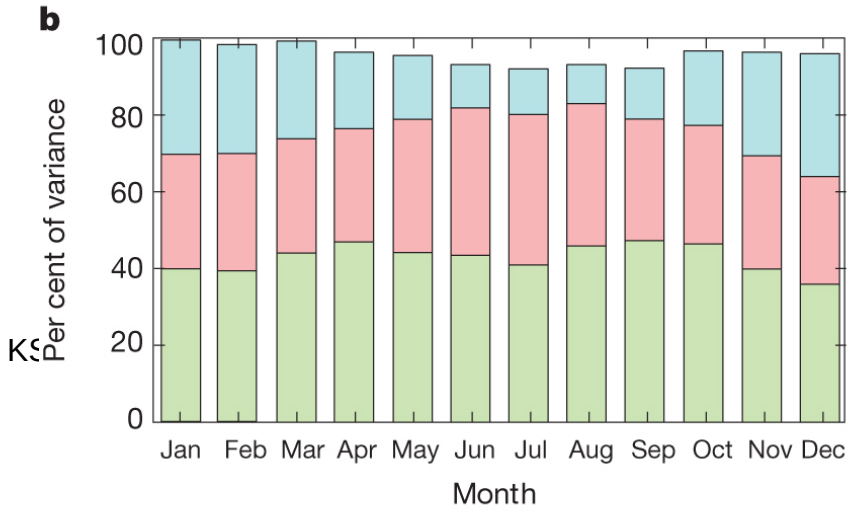
Implication: satellite results based on PD measurements are too small.

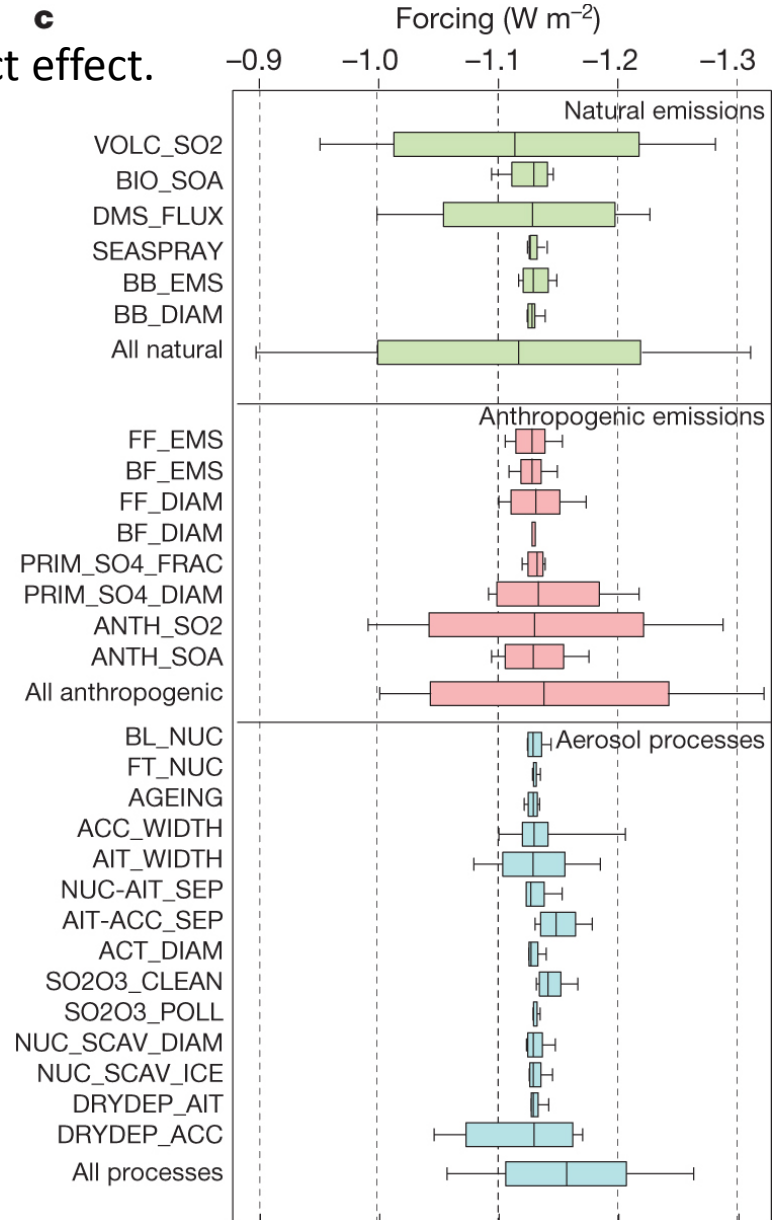
Penner et al., PNAS, 2011

Magnitude and sources of uncertainty in global mean aerosol first indirect forcing: Carlslaw et al., Nature, 2013. But, this leaves the question, how can we proceed to provide better estimates?

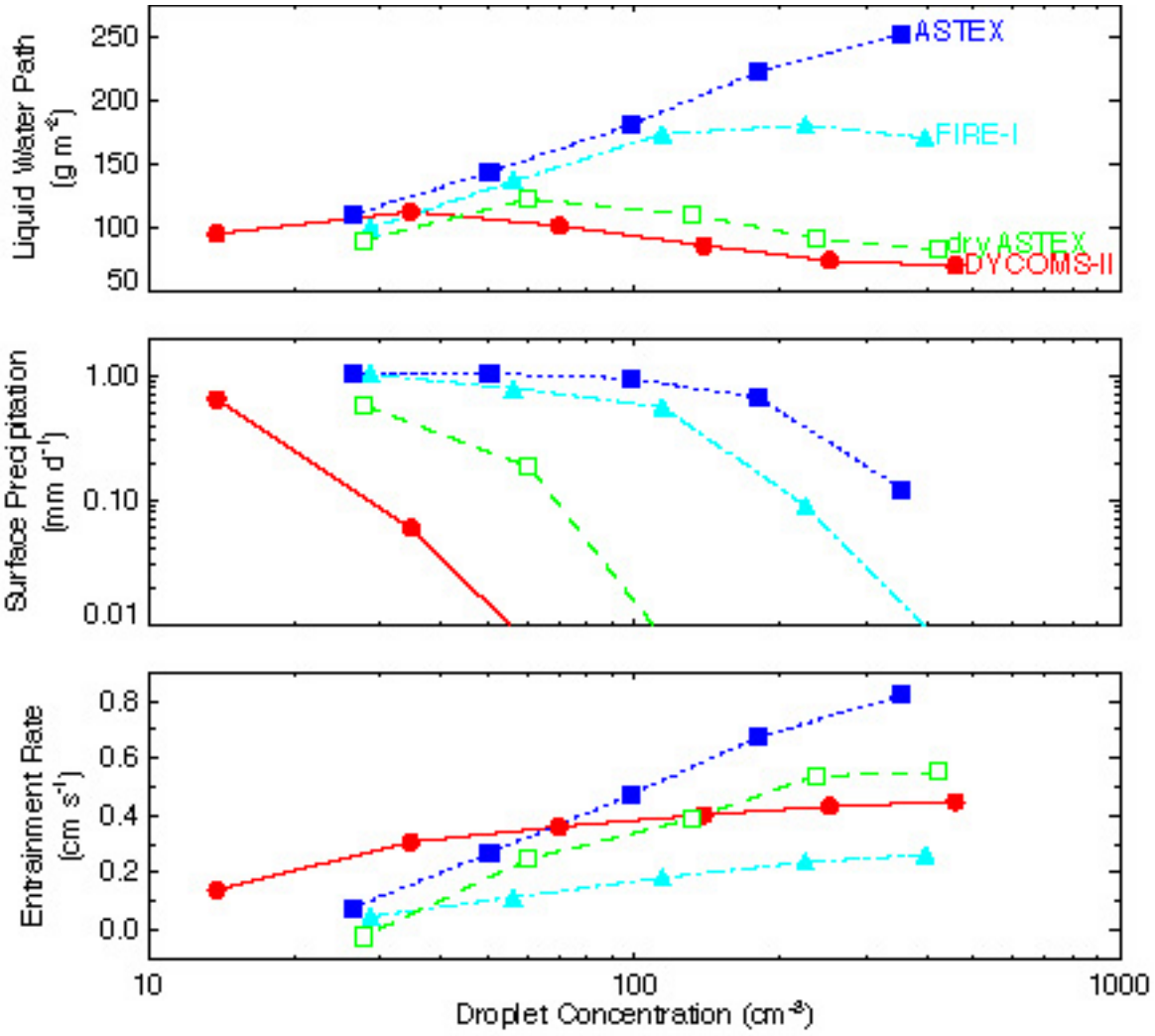
Note: this estimate (-1.2W/m2) is only first indirect effect.







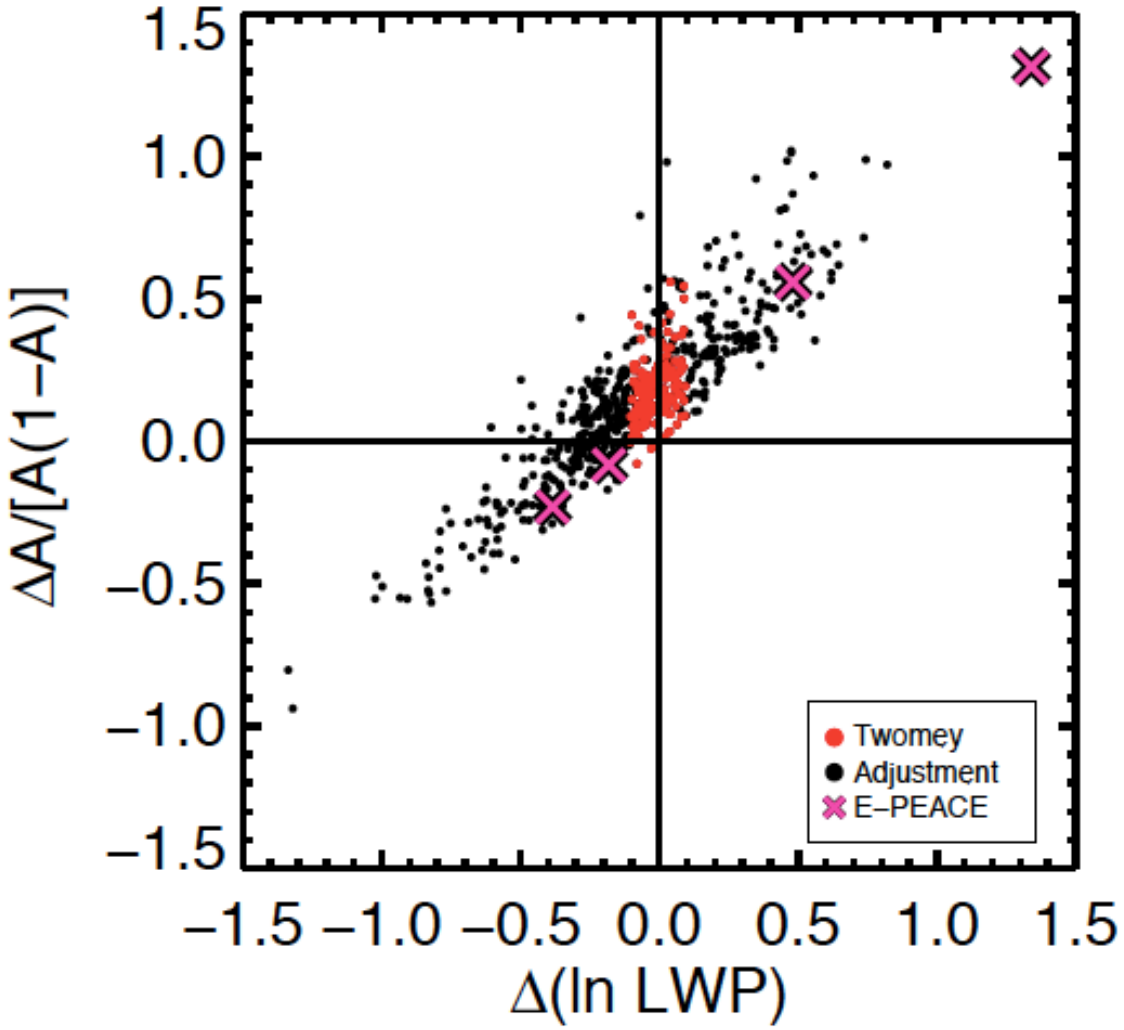
LES models: Ackerman et al. [2004] show that LWP only increases when the surface precipitation rate is high:



Note: decreases in LWP are possible, but not as large as increases

Ackerman et al., 2004

Ship track analogues for marine cloud brightening show response of clouds is mixed



Both decreases and increases in LWP and albedo can occur during ship tracks

Question: how frequently do decreases occur in "normal cloud regimes"?

Chen et al., 2012

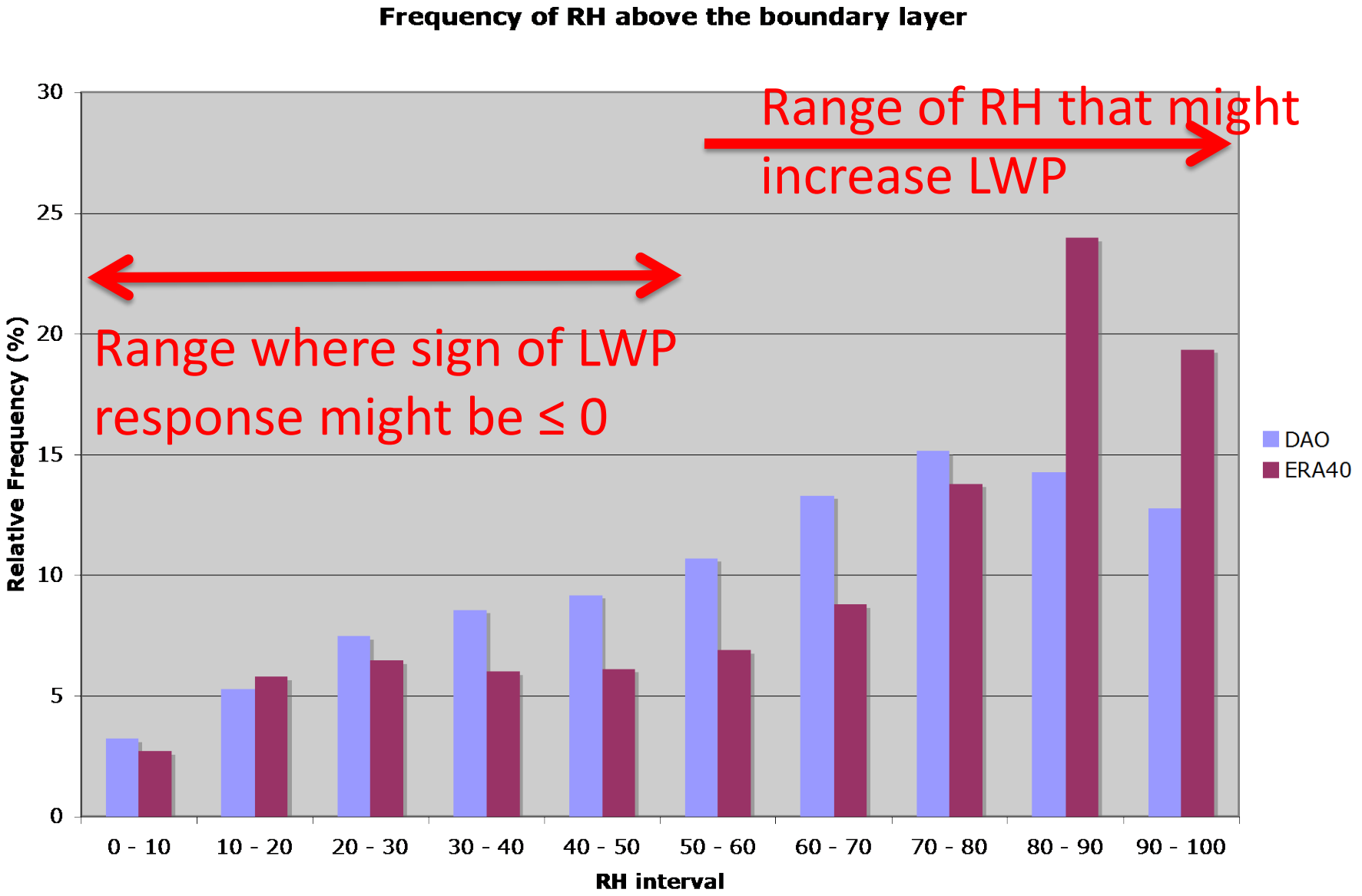
Surface precipitation rates are high when the relative humidity above the boundary layer is high:

Table 1 **Meteorological conditions used for stratocumulus simulations**

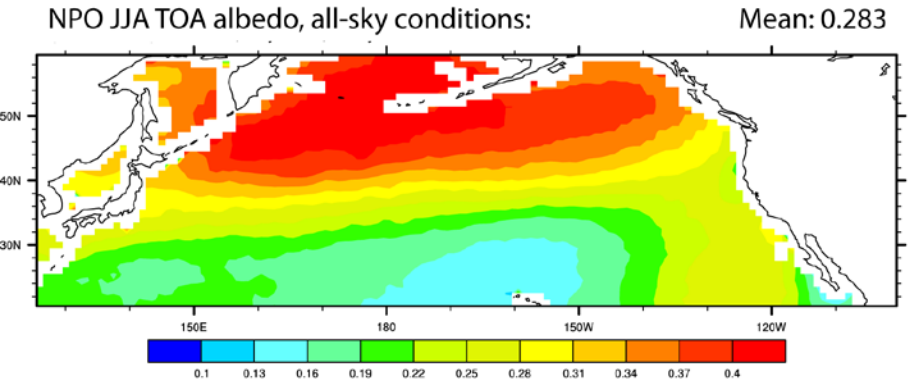
	ASTEX	FIRE-I	DYCOMS-II
Sea surface temperature (K)	290.4	289.0	292.5
Lifting condensation level (m)	340	250	620
Geostrophic wind speed (m s^{-1})	10	6	9
Inversion height (m)	700	600	840
Temperature increase across inversion (K)*	5.5	12	10
Moisture decrease across inversion (g kg^{-1})	1.0	3.0	7.5
Relative humidity above inversion (%)	70	40	25

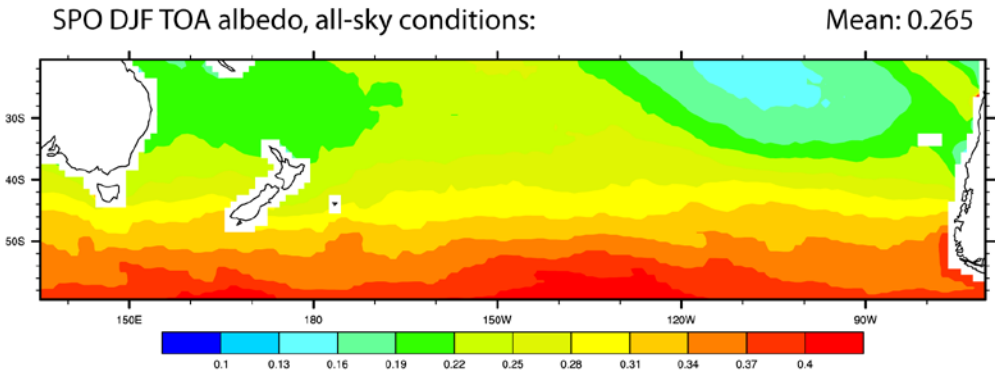
Ackerman et al., 2004

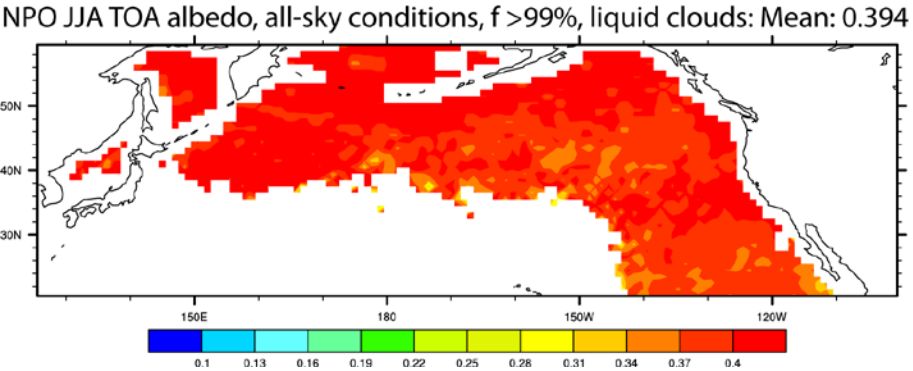
Frequency of high values of RH above boundary layer (0 - 40N; 2000):

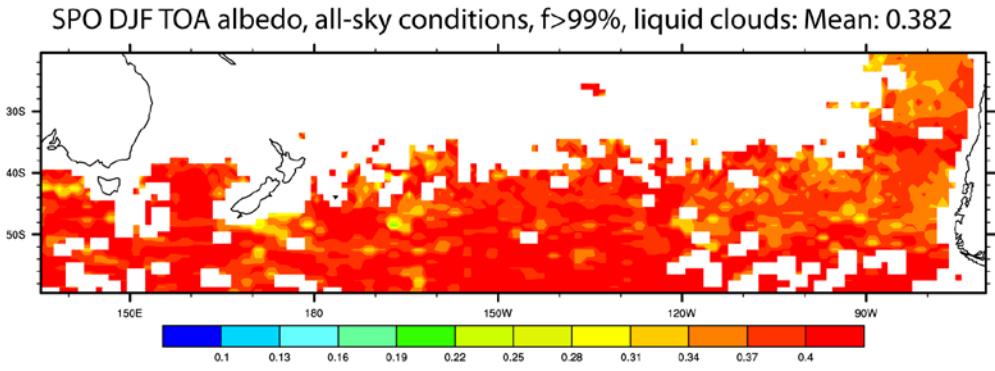


How might we get around the uncertainty in natural background? Use CERES estimates of albedo to compare North Pacific and South Pacific:





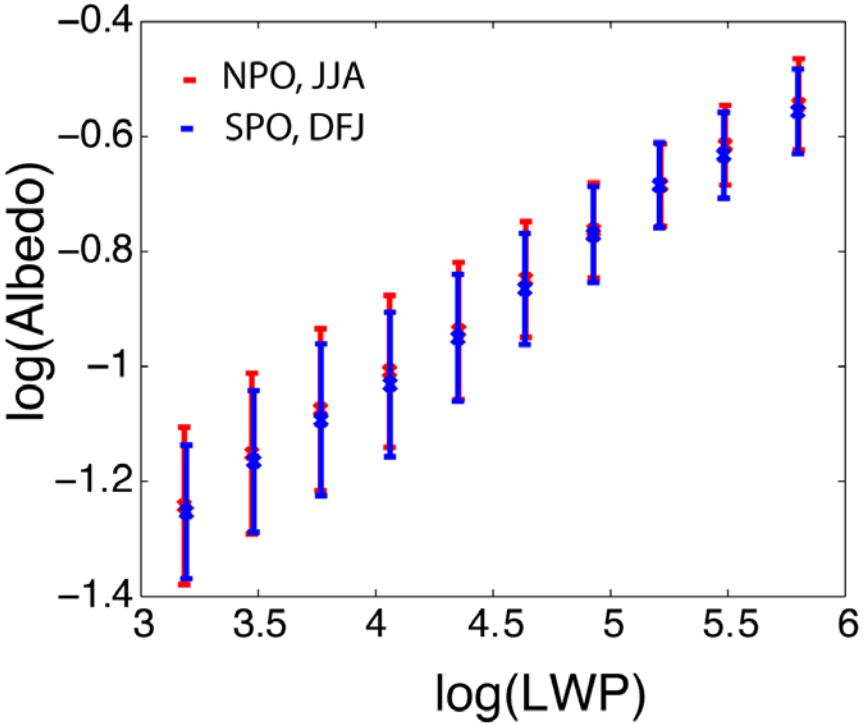


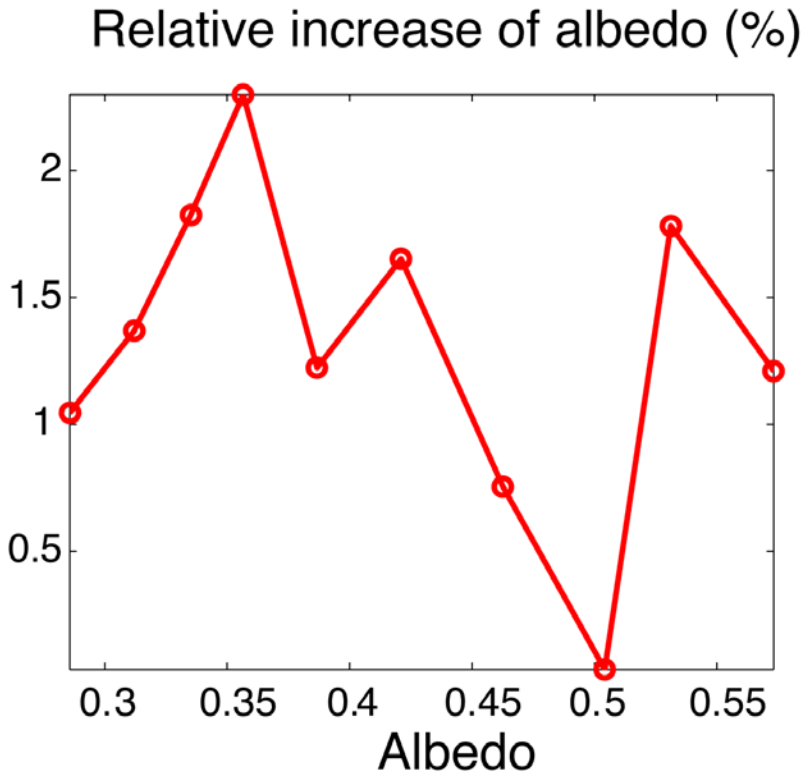


Bottom graphs restrict analysis of albedo change to clouds with f>99%

Penner, Zhou, and Xu GRL 2012

Estimate “albedo effect” by normalizing to fixed LWP:





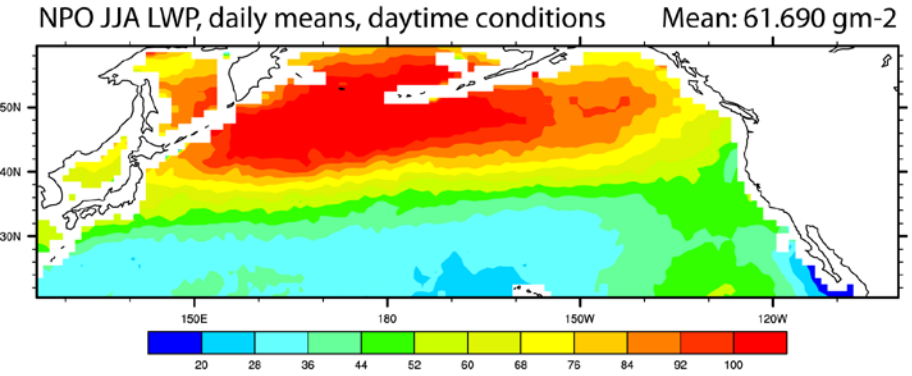
Albedo effect: (first indirect effect):

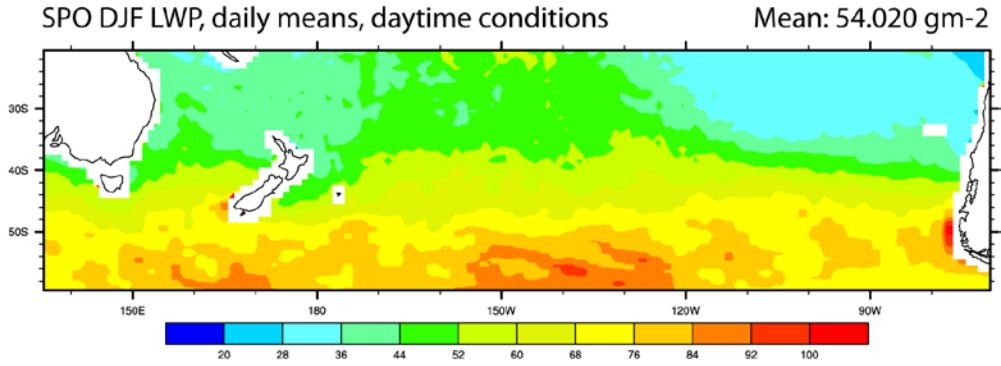
change in cloudy sky albedo × cloud fraction × solar insolation

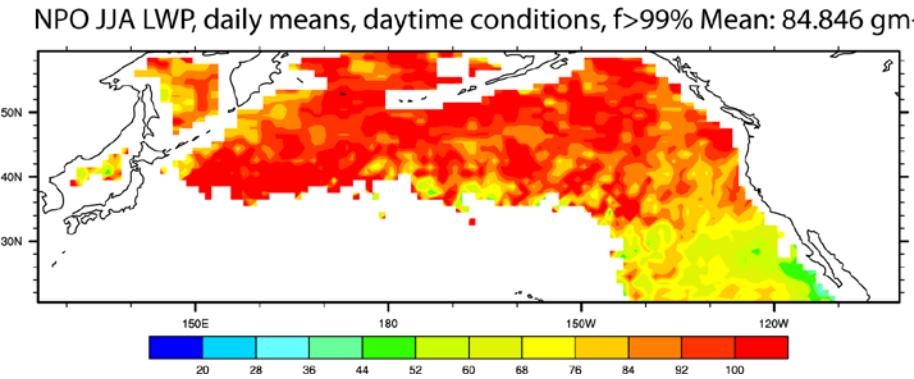
= -1.8 to -2.2 Wm^{-2} (range for f>0.5% to f>0.99%);

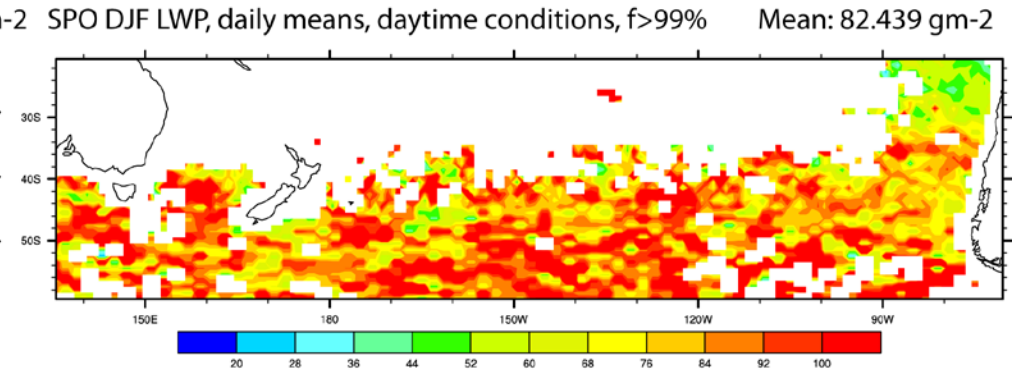
Compare to Model:-2.65 Wm^{-2} or -3.6Wm^{-2} (w/same methodology)

1st + 2nd indirect effect: Increase in LWP and N_d:









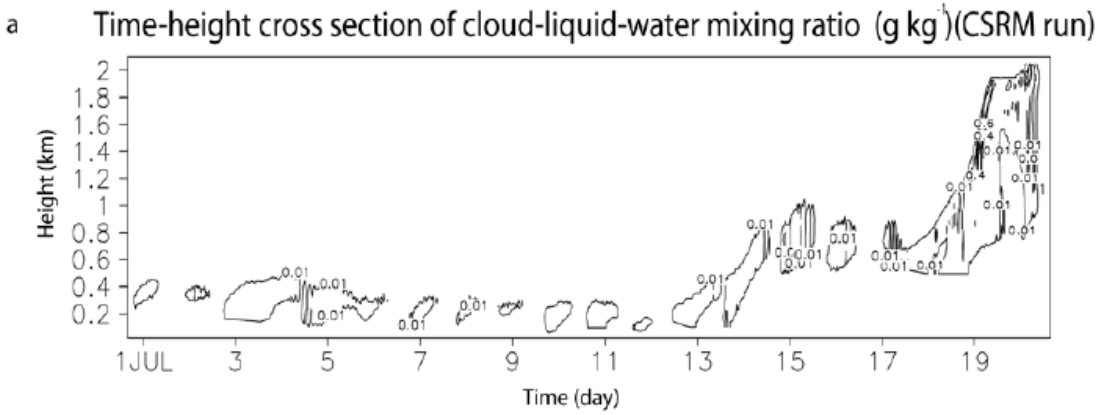
SW TOA change due to changes in LWP+N_d in all clouds : -3.8 Wm^{-2}

Summary and (one) Way Forward

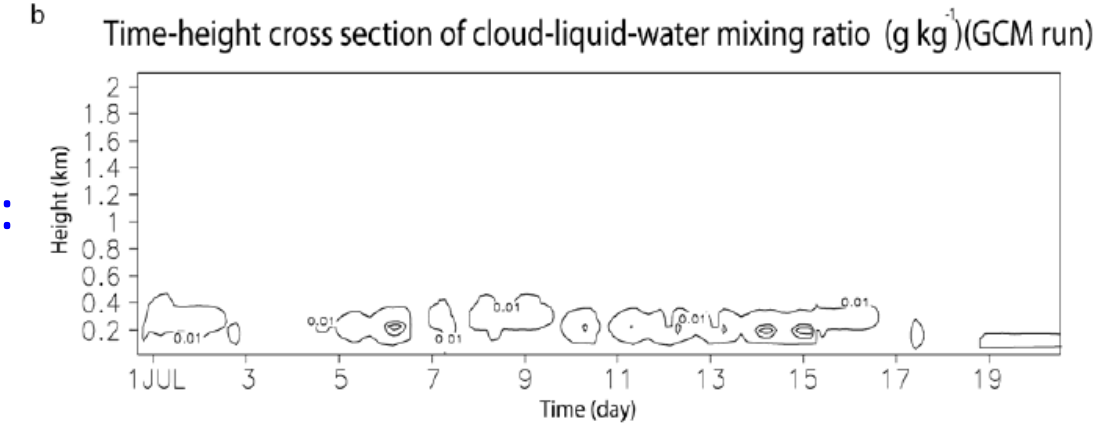
- Some experimental evidence does not support the AR5 small indirect effects
- Changes in LWP in regions where cloud fraction over 1 x 1 degree grid space is > 50% or 99% is > 0. Need to study where these areas intersect with those having RH above cloud > 50%? (Ackerman condition)
- Need to examine indirect effect in warm clouds in climate models in regimes that can be sorted according to specific criteria (i.e. CF > 50% and/or RH > 50% above cloud)
- Next talk (by Cheng Zhou) will examine one method for determining the fidelity of GCM simulations

Background: Lee et al. 2009 compared CAM3 and CRM for thin stratocumulus clouds

CRM LWP:

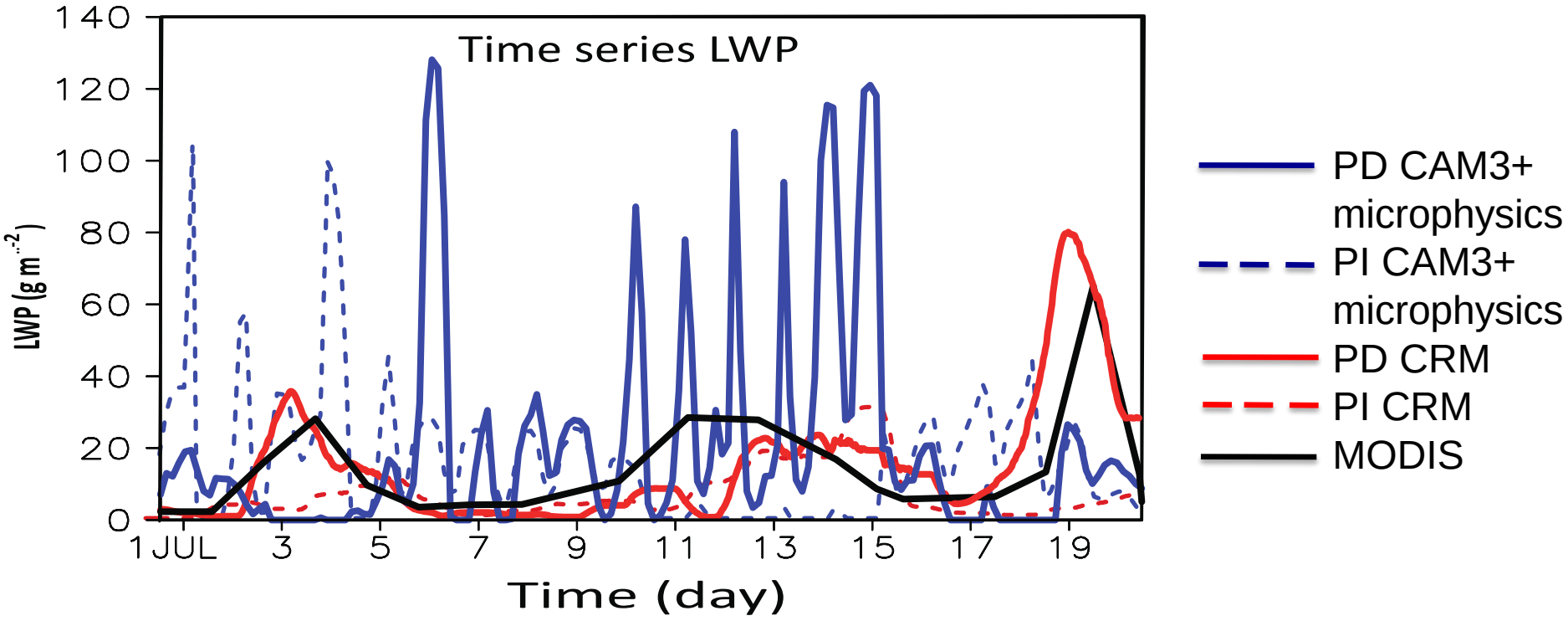


CAM3 LWP:



1. CRM simulated smaller LWP before July 13th.
2. CRM simulated stratocumulus to cumulus transition after July 13th due to the increase surface latent heat flux.

Cheng talk will examine difference between GCM and cloud resolving model:

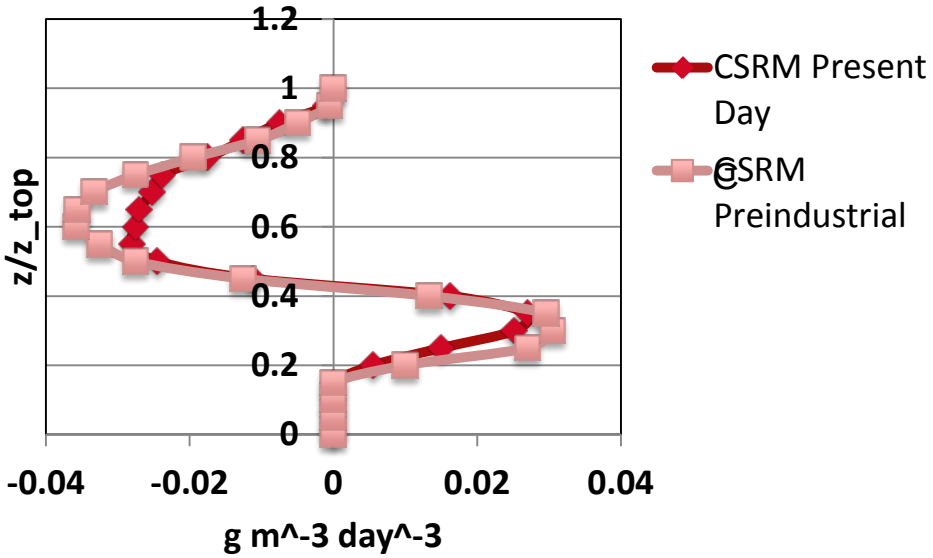


1. CAM3 shows stronger diurnal cycle.
2. CRM compared better with MODIS.

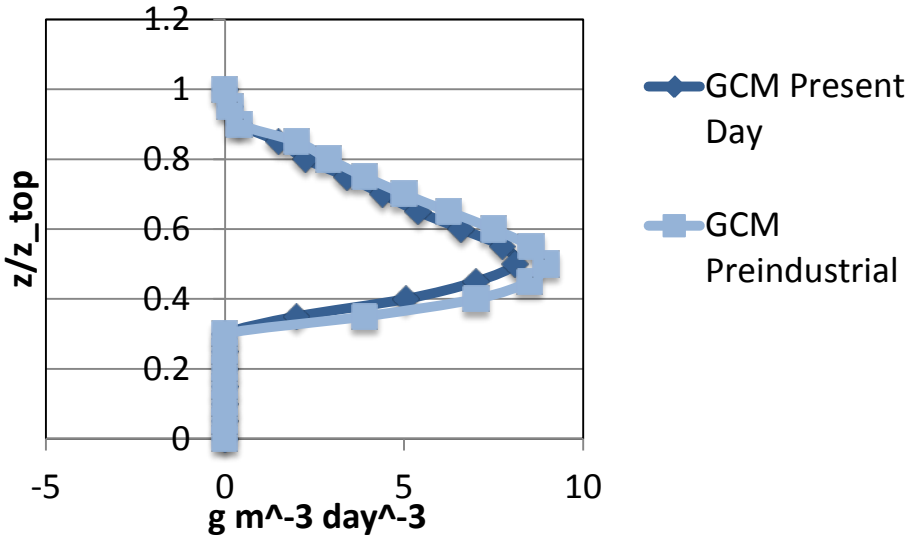
Lee and Penner, 2010

Role of representation of microphysics:

CSRM: Liquid water source/sink:



GCM: loss of cloud liquid to rain



The CSRM includes a 2-bin representation of precipitation size, allowing particles to fall below cloud base and evaporate. This promotes a decoupling between the surface and cloud layer, in part, allowing cumulus clouds to develop near the end of the simulation in the CSRM.

Lee and Penner, 2010