DOES DEEP CONVECTION MATTER ANYMORE?

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CERES/GERB Team Meeting, 10/28/08

…the simulation of the sensitivity of marine boundary layer clouds to changing environmental conditions constitutes, currently, the main source of uncertainty in tropical cloud feedbacks…

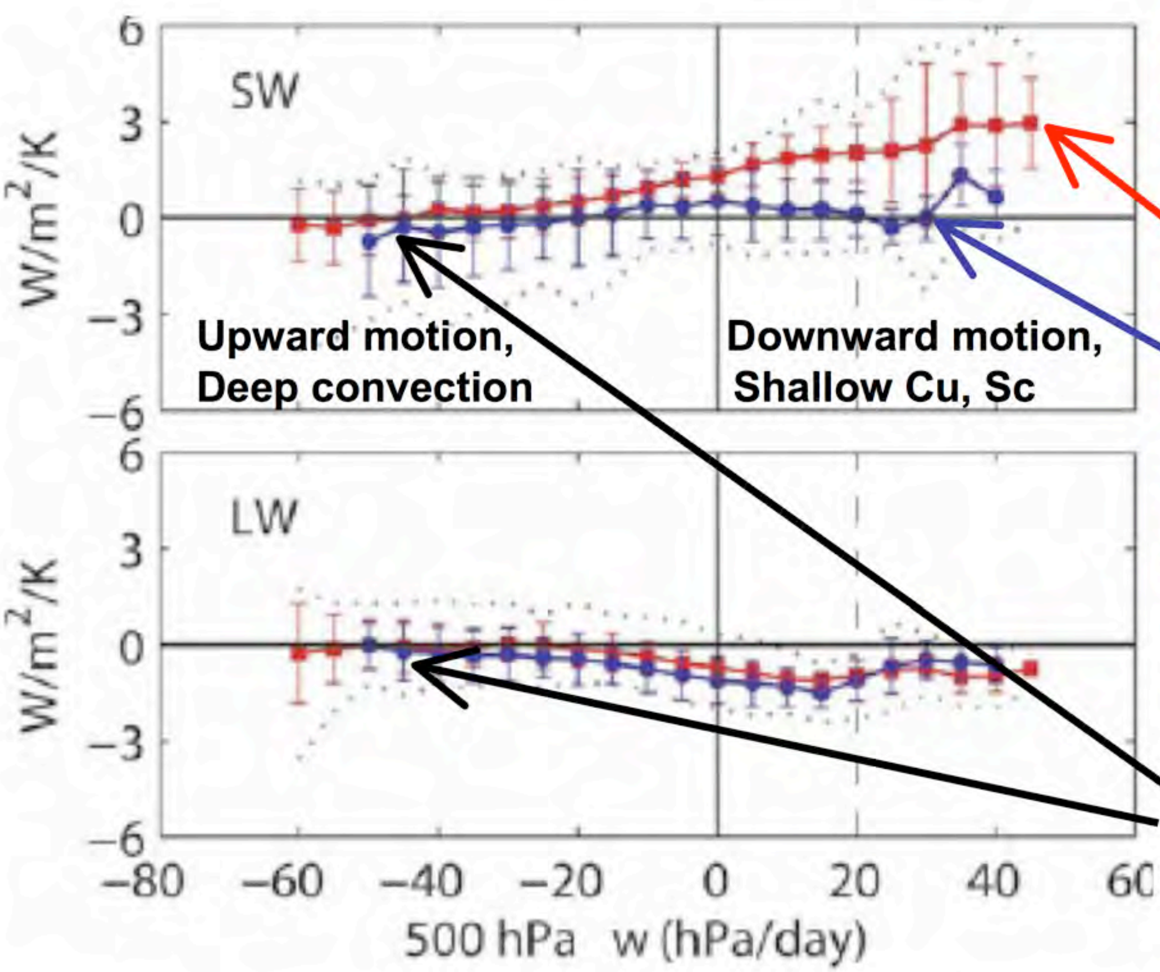
Bony and Dufresne (2005), "Marine boundary layer clouds at the heart of tropical cloud feedback uncertainties in climate models"

…the representation of shallow (trade wind) cumulus convection, which is ubiquitous in the tropics, is largely responsible for differences in the simulated climate sensitivity…

Medeiros et al. (2008), "Aquaplanets, climate sensitivity, and low clouds"

The IPCC AR4 reaffirms the spread in equilibrium climate sensitivity…among current models. The identification of low clouds as the primary (direct) contributor to this spread is one of the signature achievements of the research community as summarized by the AR4.

Bony et al. (2008), CFMIP-2 plan for IPCC AR5



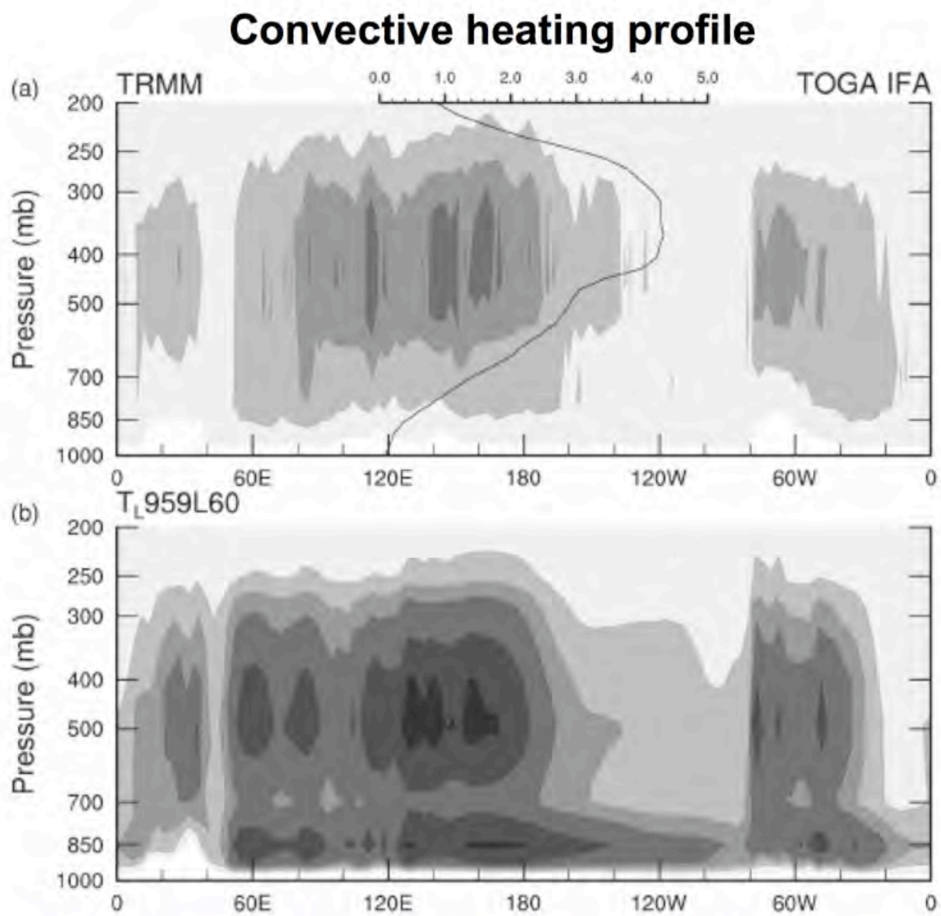
Models with higher sensitivity: Low clouds decrease, more sunlight absorbed

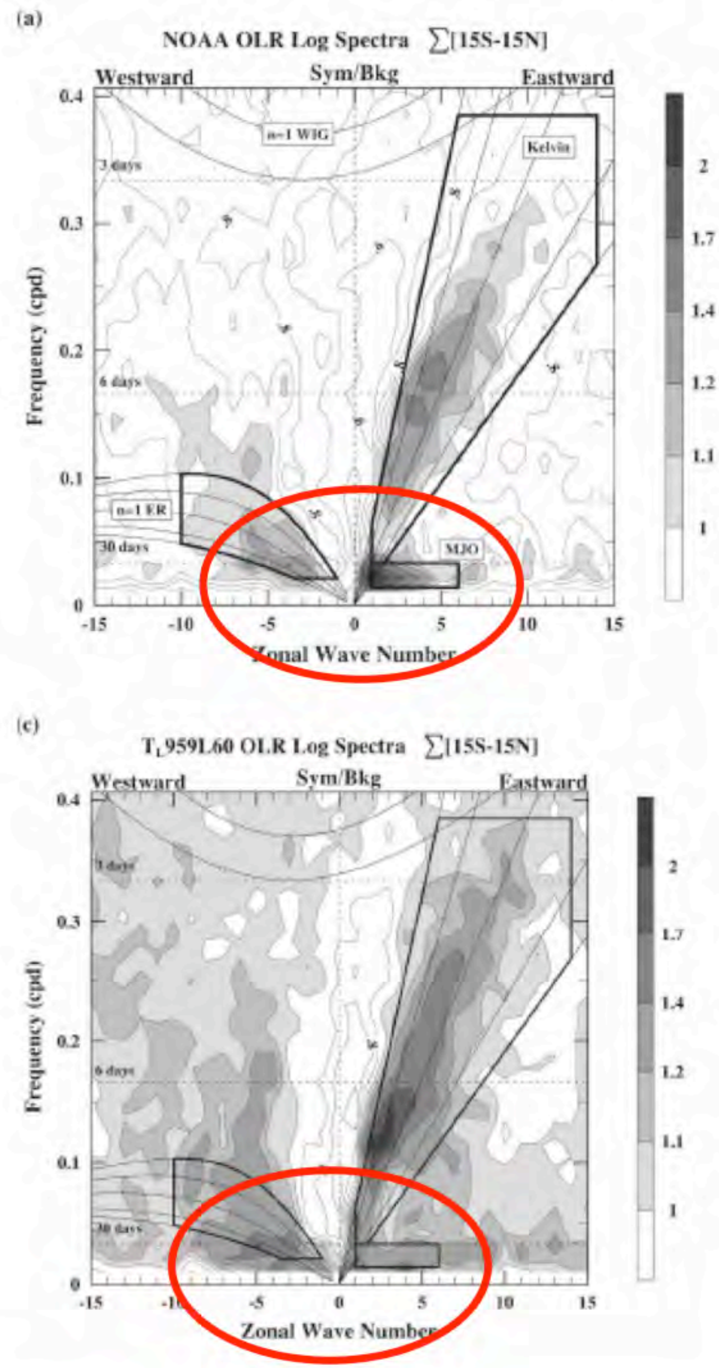
Models with lower sensitivity: Low clouds do not change very much

Deep convective cloud systems: Little change in SW or LW, good agreement among models

But does this mean we are doing well on deep convection?

(Bony and Dufresne, 2005)





MRI/JMA GCM @ 20 km resolution:

Too much low-level convective heating,

little evidence of MJO signal

(Rajendran et al., 2008)

MJO shallow-deep transition controlled by entrainment of dry vs. humid air into rising cumulus clouds

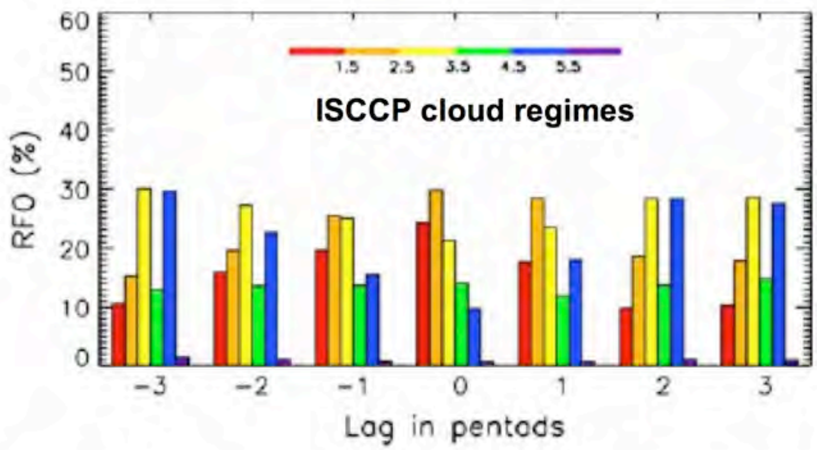
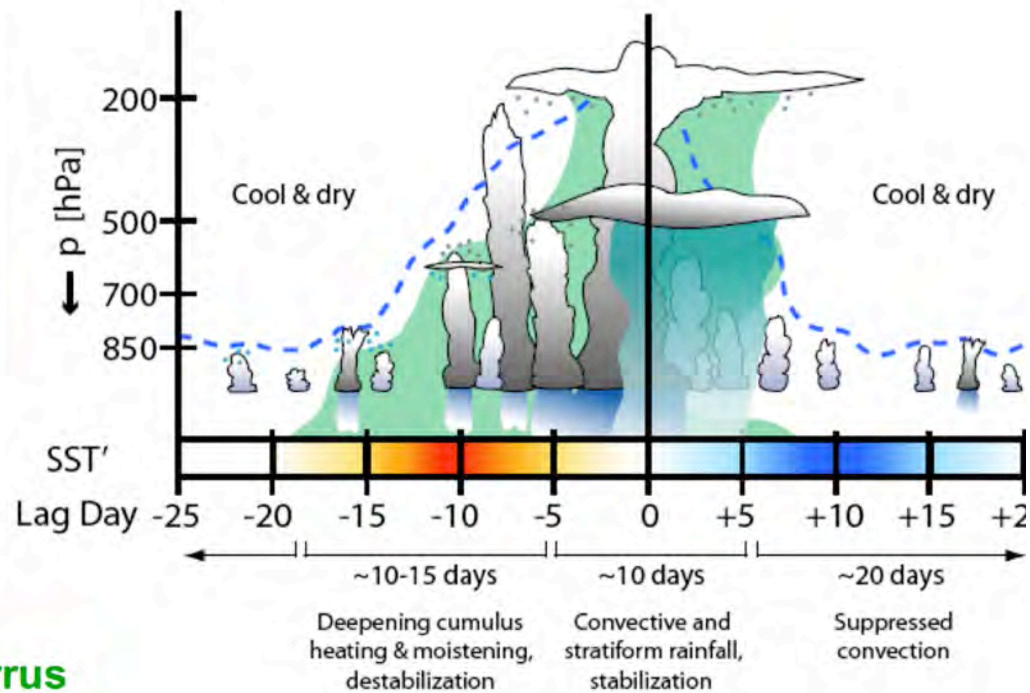


Fig. 10 Relative frequency of occurrence (*RFO*) of each cloud regime at seven lag periods in pentads of eight MJO events in 4 November–April periods from 1999 to 2003. The color scheme for the cloud regimes is the same as in Fig. 9

red = deep convective
orange = anvil
yellow = congestus
green = thin cirrus
blue = shallow Cu
violet = marine Sc

(Chen and Del Genio, 2008)

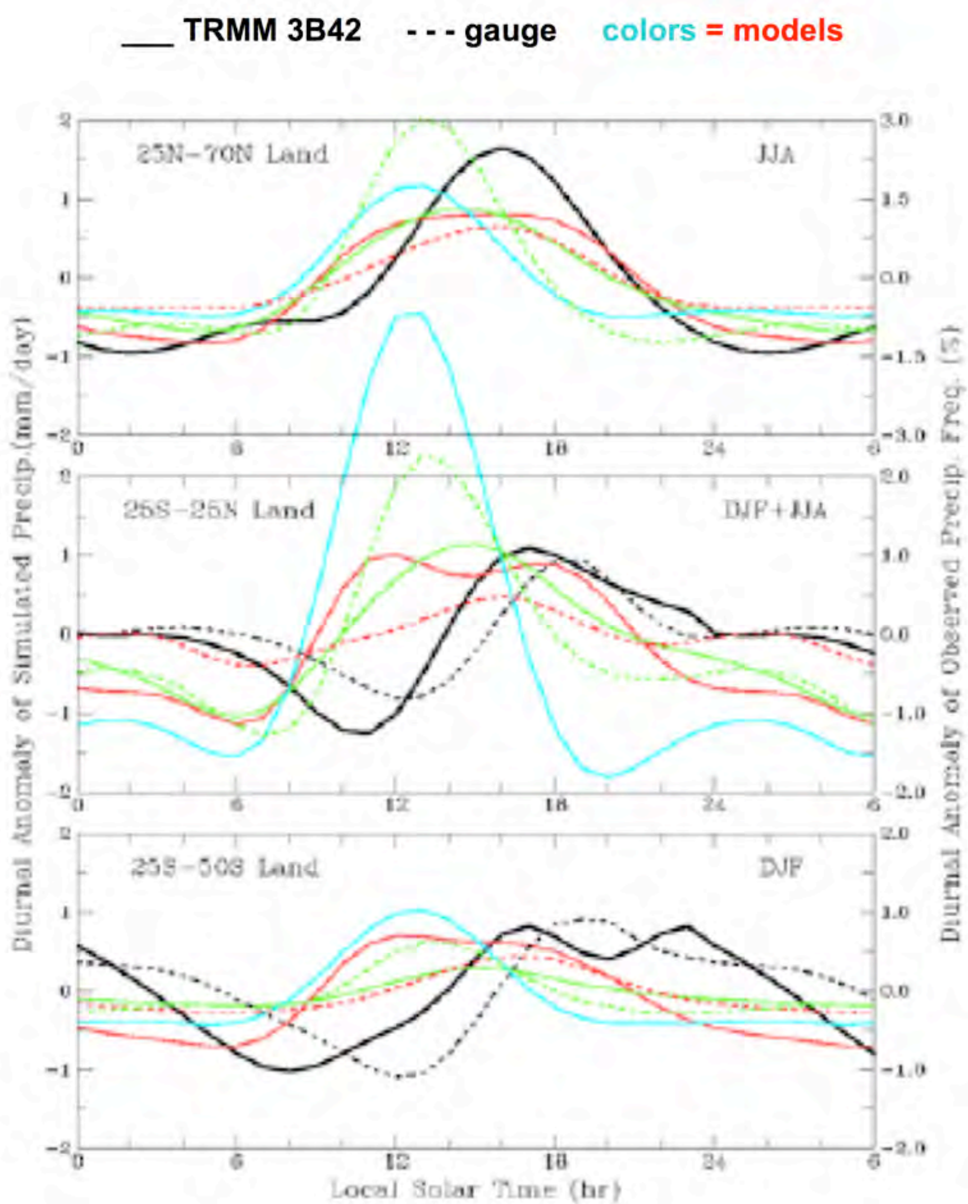


(Benedict and Randall, 2007)

Transition from shallow to deep convection occurs late in the day in real world, but in early afternoon in IPCC AR4 models

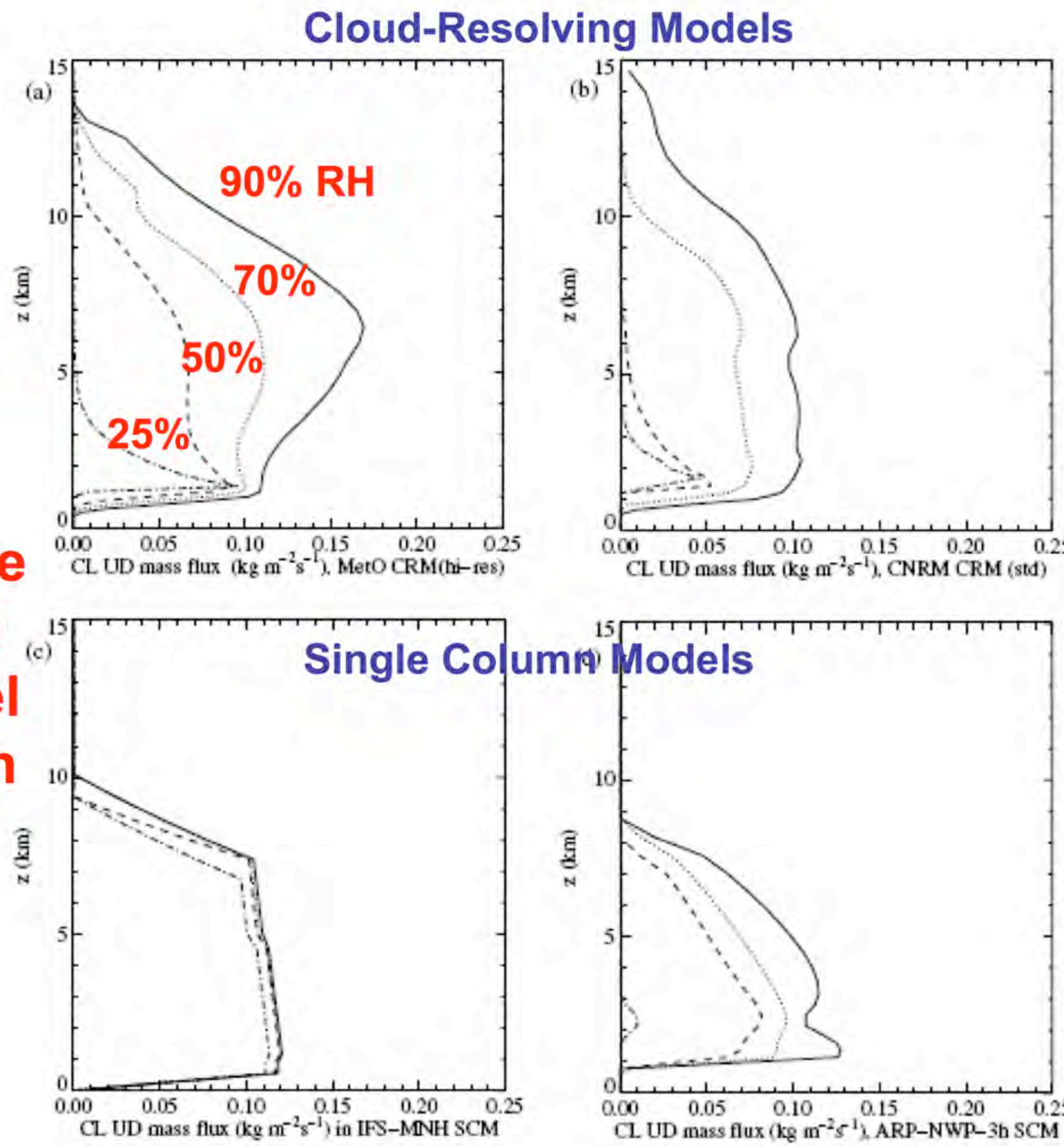
∴GCMs reflect too much sunlight, or reflect the right amount for the wrong reason

(Dai, 2006)

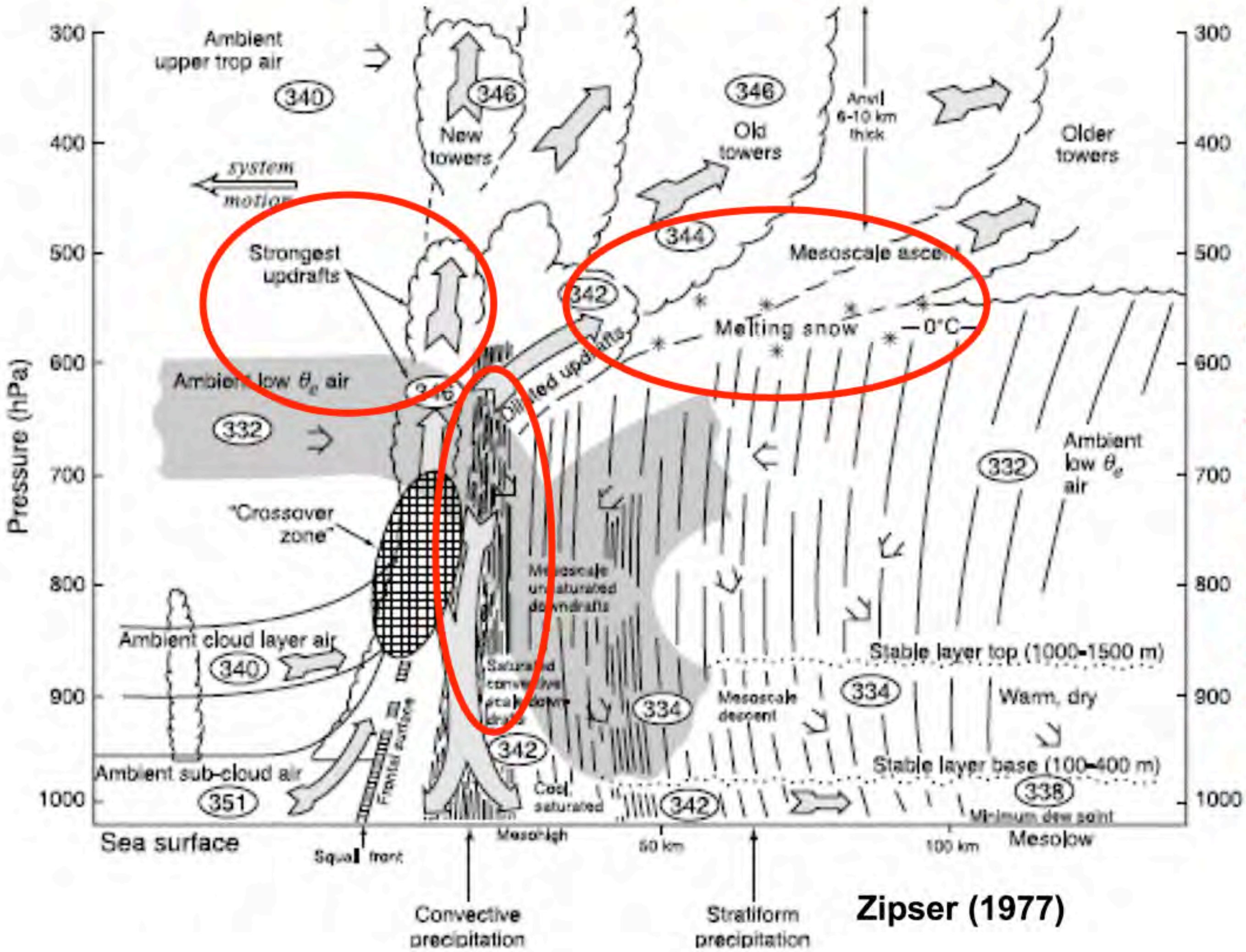


GCM cumulus parameterizations are not sensitive enough to free troposphere humidity to capture the transition from shallow to midlevel to deep convection

(Derbyshire et al., 2004)



Water condensed in updrafts either precipitates (large particles) or is lifted to form anvil cloud and cirrus (small particles) – most GCMs partition these via a "precipitation efficiency" tuning knob



Zipser (1977)

How can we do better? Need to know 3 things:

How strong are the updrafts?

What is the particle size distribution?

How fast do particles of different size, shape, phase fall?

Worth the effort?

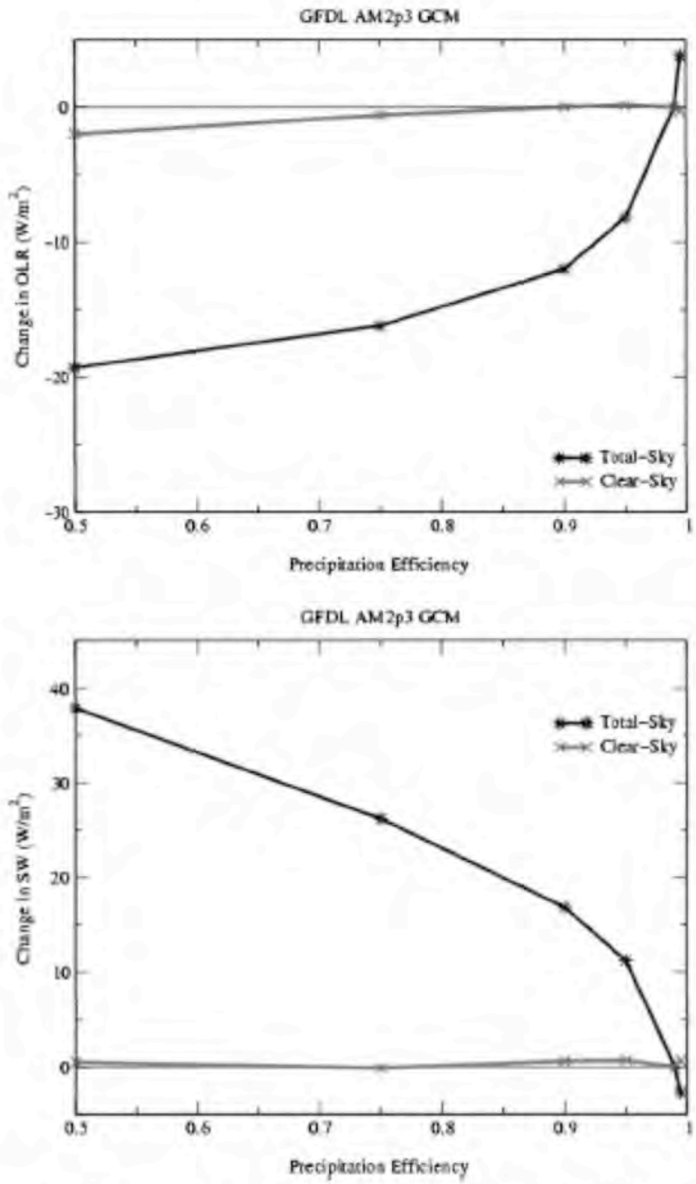


FIG. 7. Changes in tropical-mean (30°N–30°S) (top) OLR and (bottom) reflected SW as a function of the convective precipitation efficiency

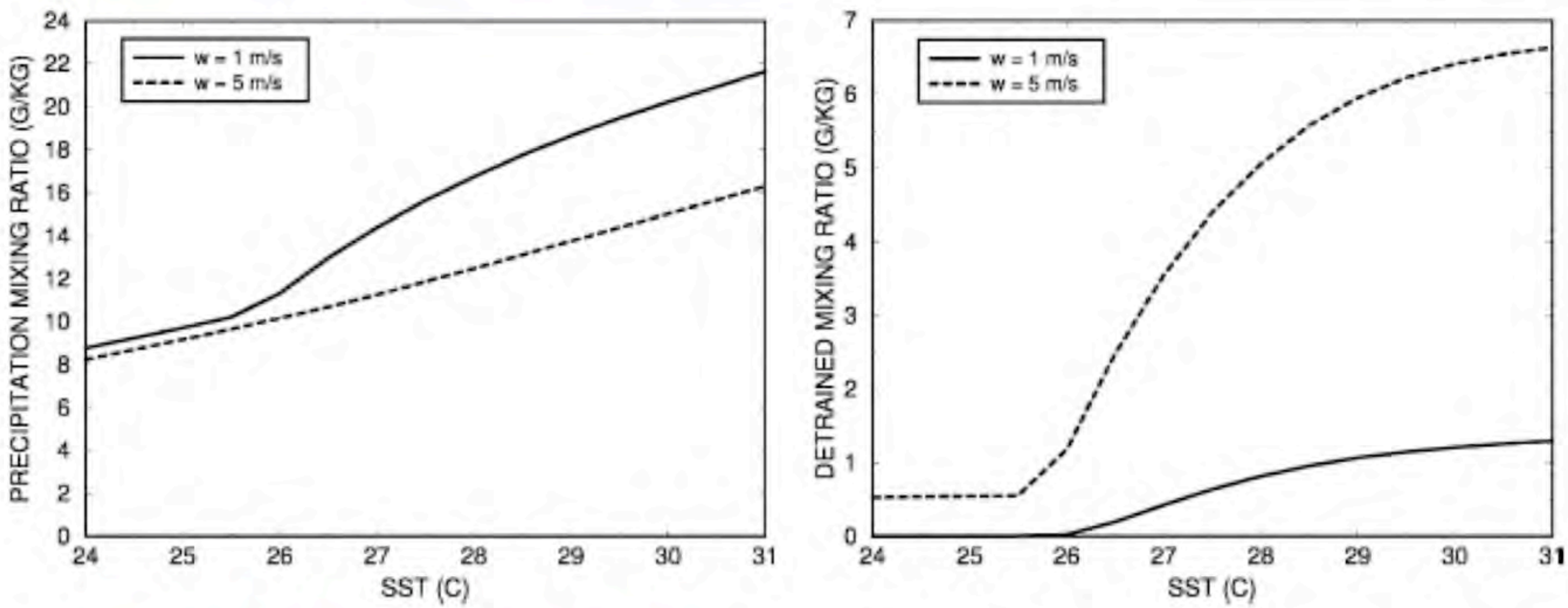
GFDL AM2 GCM:

Tweaking the precipitation efficiency tuning knob can easily change the TOA radiation budget components and even the net radiation balance

(Clement and Soden, 2005)

TRMM TMI convective storms + CERES cloud top T

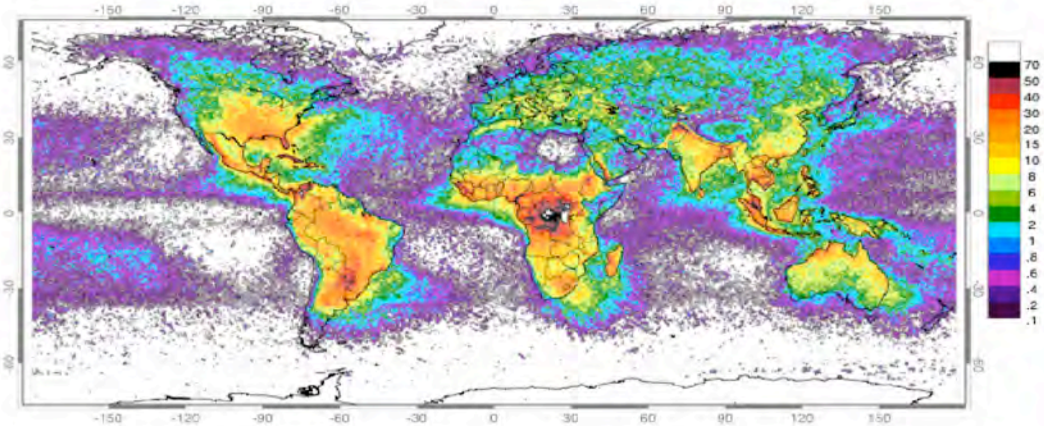
Input to conceptual parcel lifting model, condensate partitioned by updraft speed, Marshall-Palmer DSD, size-fallspeed relationships



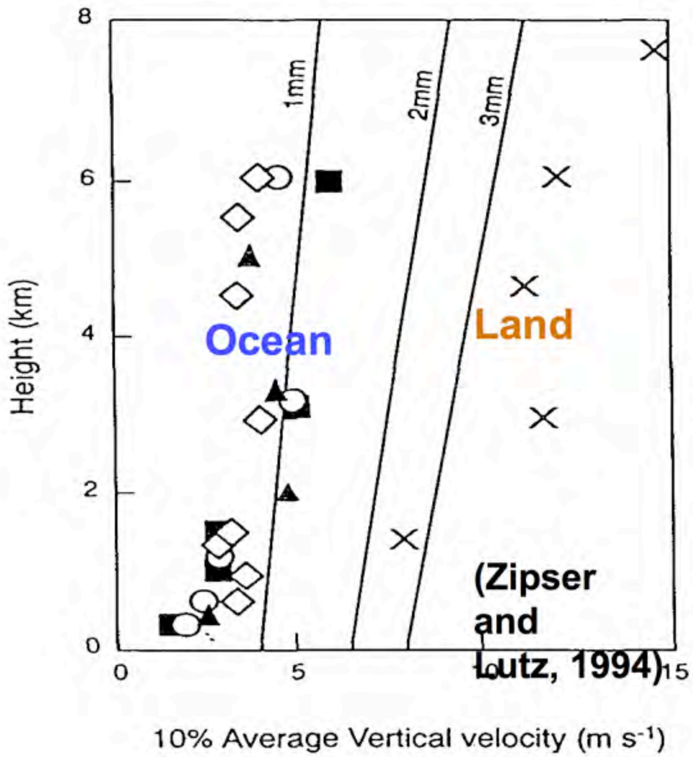
Updraft speed matters!

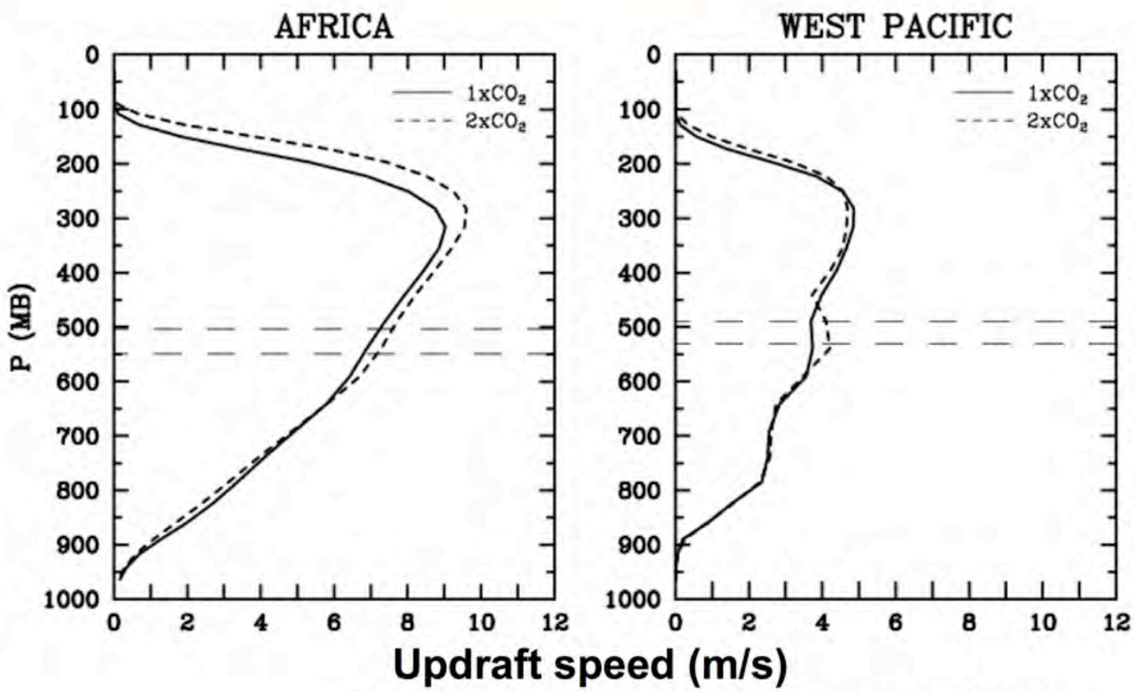
(Del Genio et al., 2005)

TRMM LIS lightning



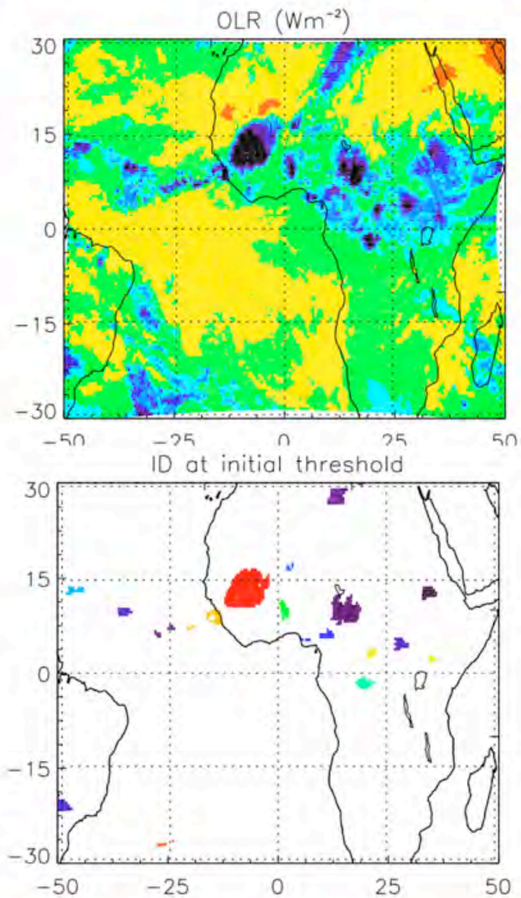
Land-ocean difference in lightning caused by difference in convection strength – can be simulated in GCM but need to predict entrainment rate



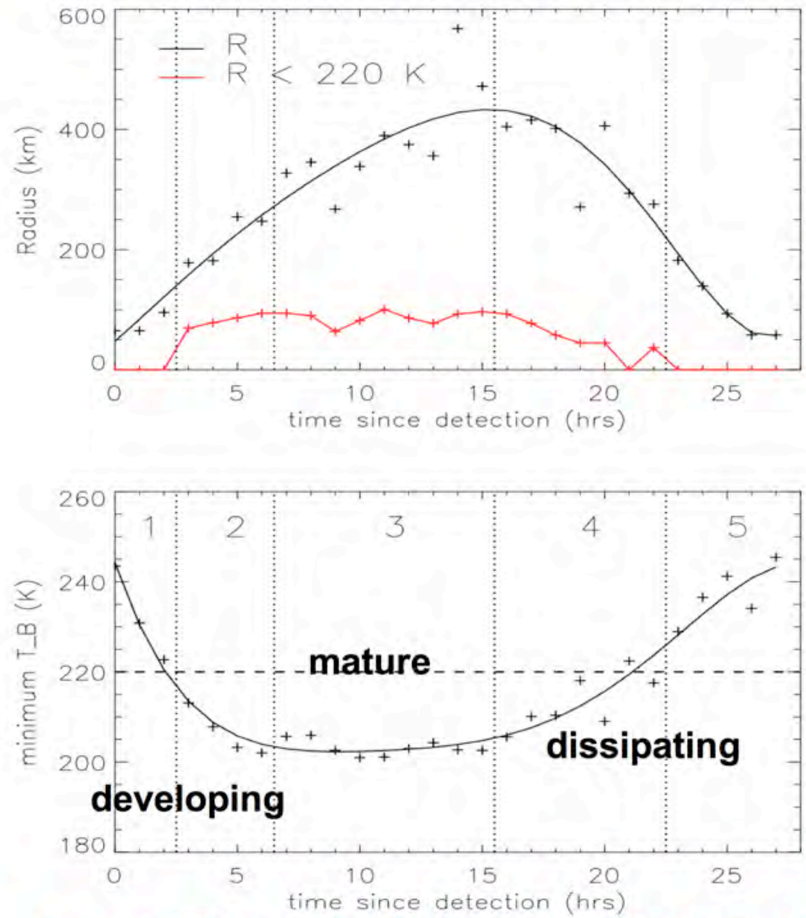


(Del Genio et al., 2007)

Mesoscale clusters: Most of the rainfall, much of the cloud forcing…and not represented in GCMs



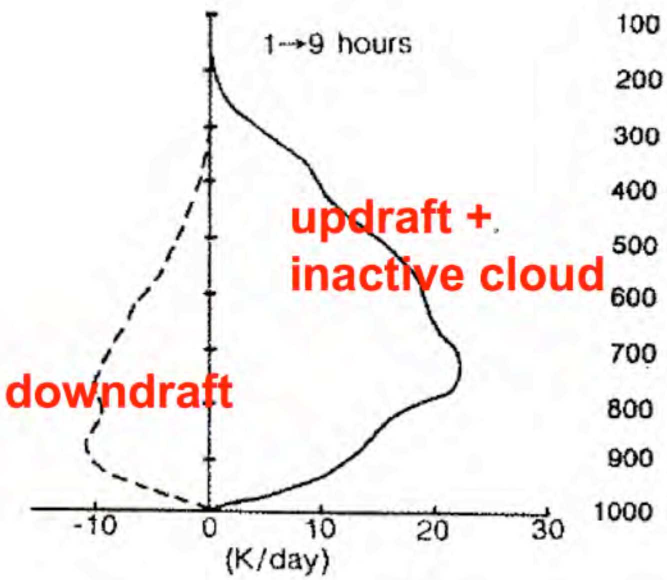
Multiple GERB OLR threshold 'detect and spread' approach; track via maximum overlap



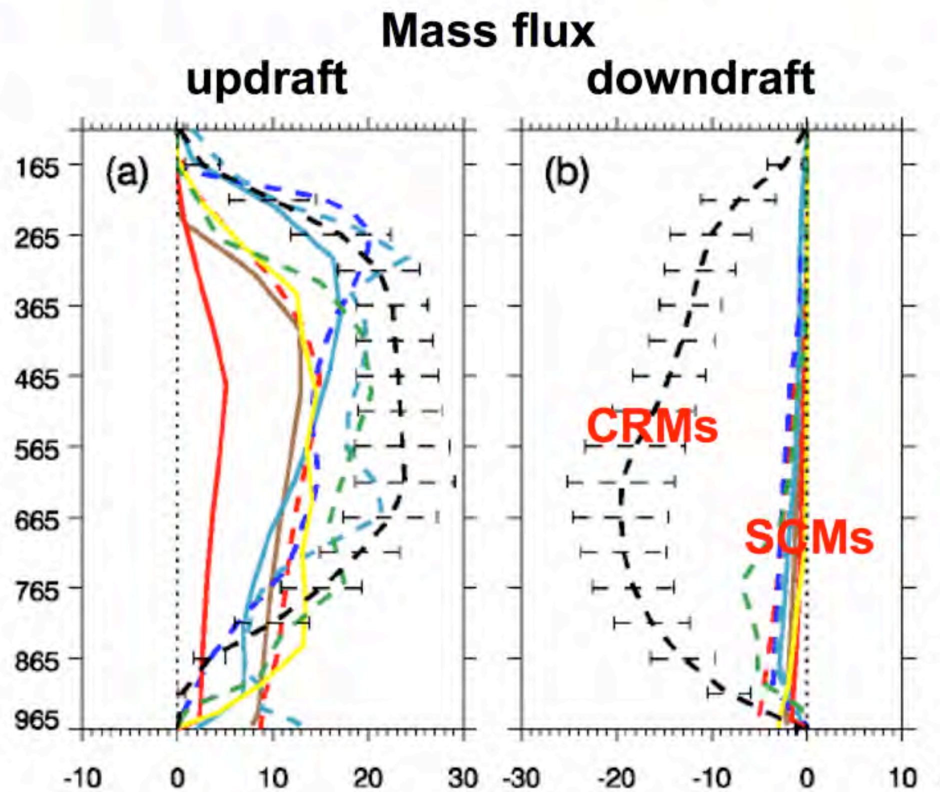
Evolution of cluster radius and height defines lifecycle phases

Futyan and Del Genio (2007)

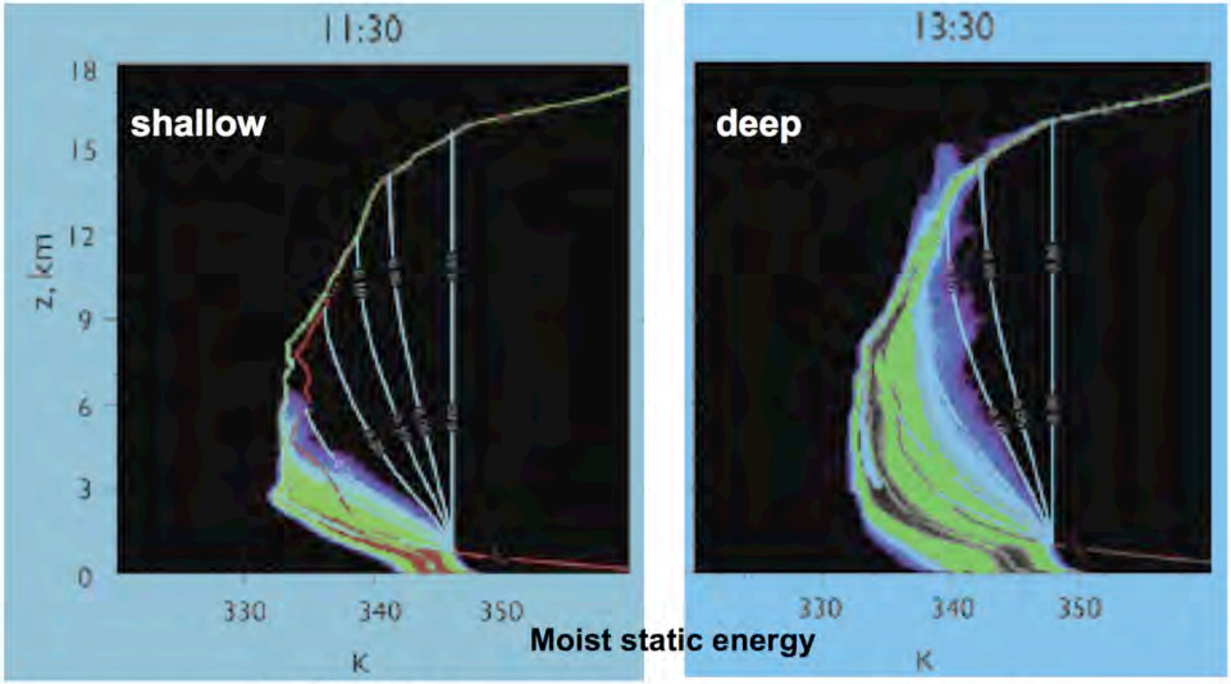
Convective downdrafts affect heating profile and create PBL cold pools, but absent or underestimated by GCMs



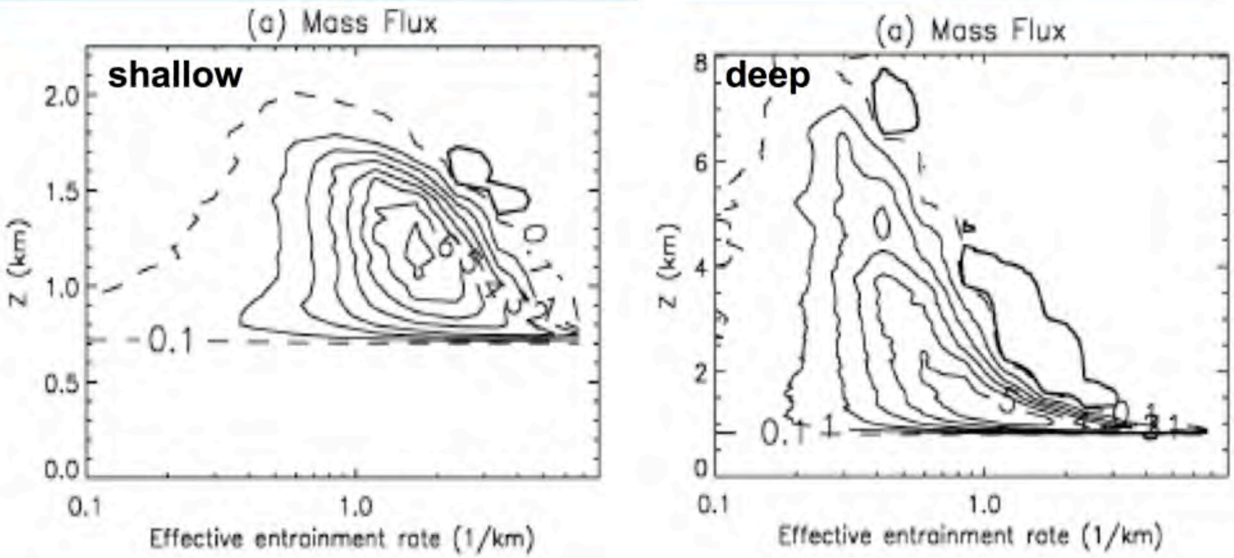
Gregory and Miller (1989)



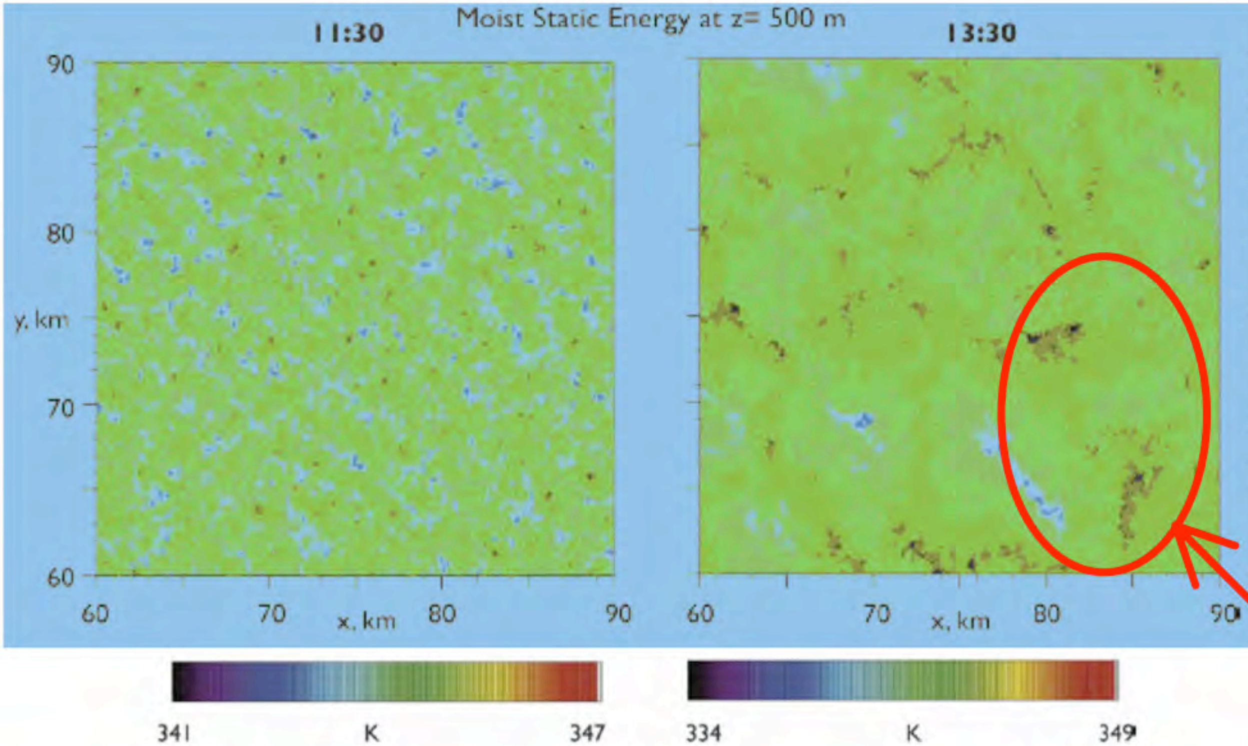
Xie et al. (2002)



Khairoutdinov and Randall (2006): Weaker entrainment after diurnal transition from shallow to deep convection

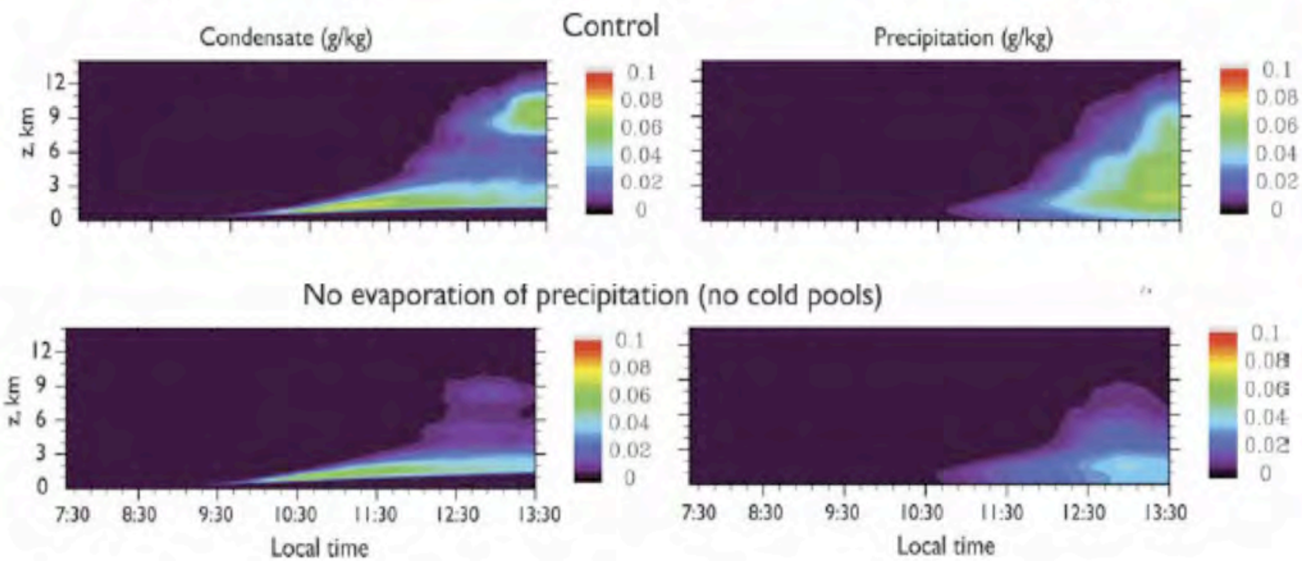


Kuang and Bretherton (2006): Weaker entrainment for deep case than for shallow case

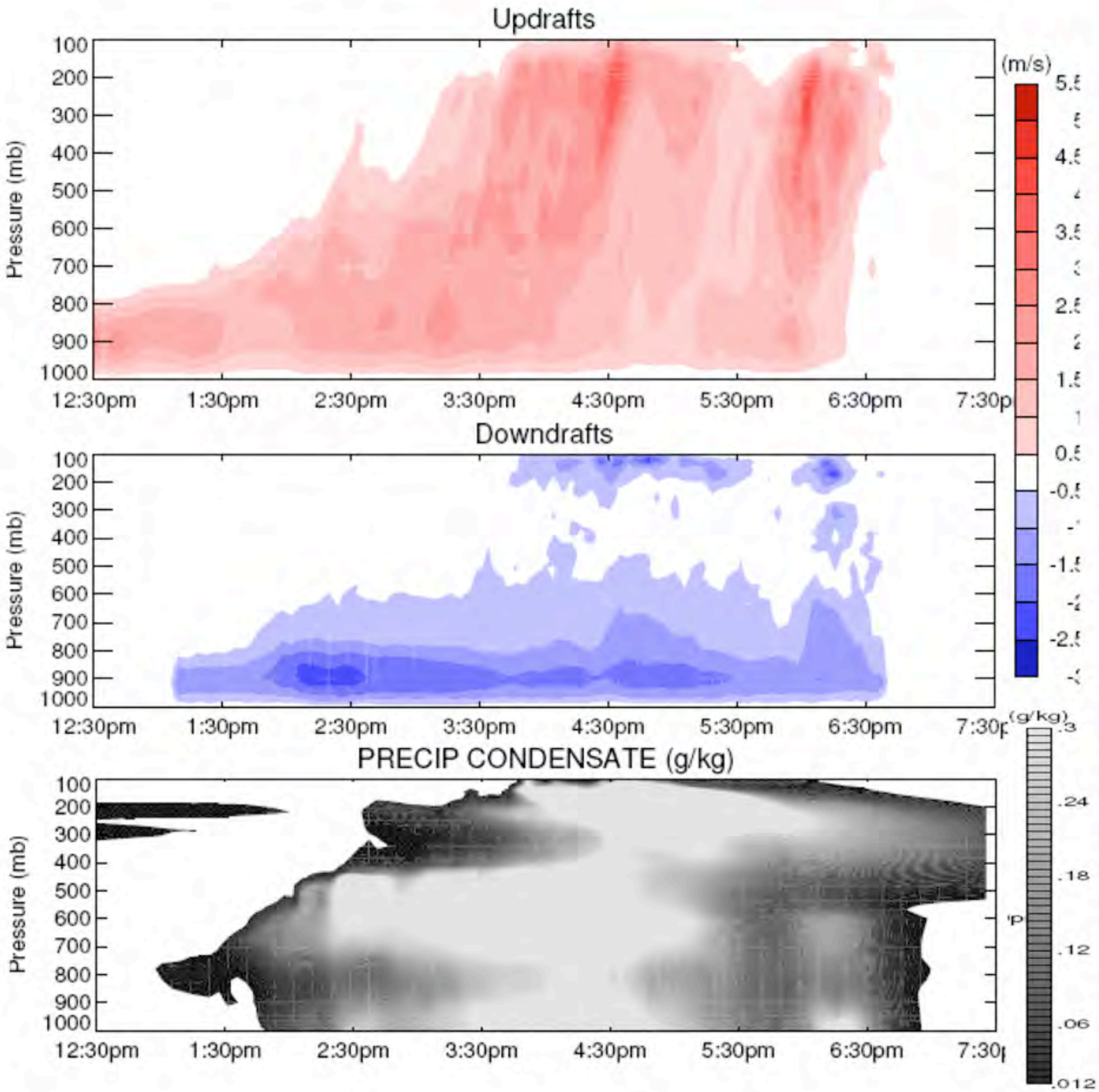


Khairoutdinov/Randall: MSE maxima organized on small scales when convection is shallow and on large scales (at edges of downdraft cold pools) when convection is deep

Stronger MSE extremes at cold pool edge



Transition to deep convection greatly suppressed when evaporation of precipitation is shut off (i.e., no downdraft cold pools)



TWP-ICE monsoon "break" period simulations with WRF model:

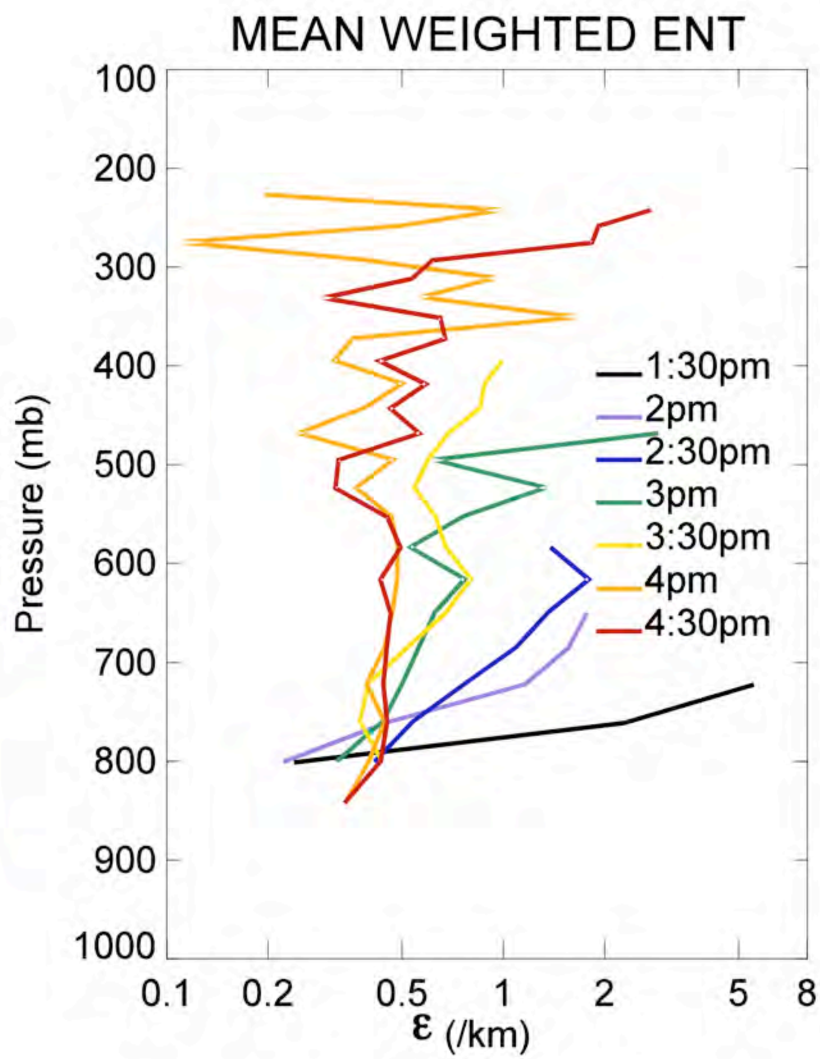
Transition begins at ~2:00-2:30 PM as downdrafts strengthen and rain begins to reach surface

(Wu and Del Genio)

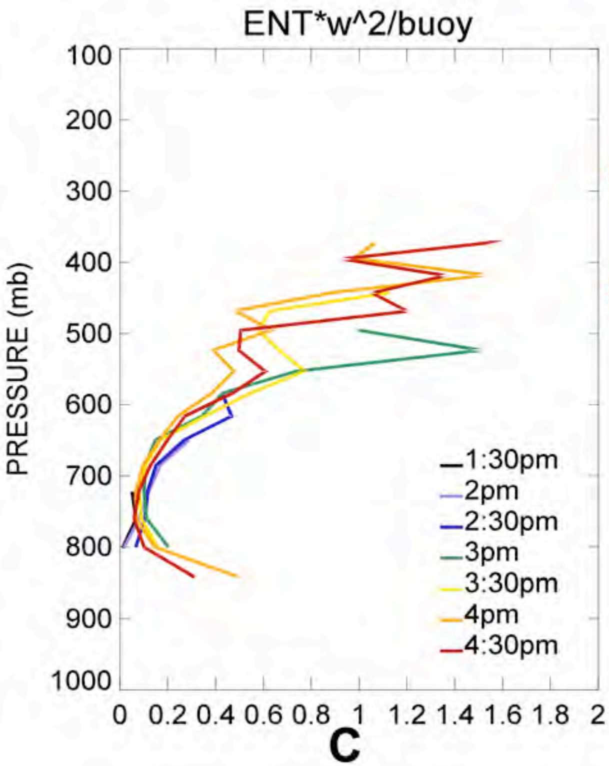
Entrainment rate:

$$dh_u/dz = - \varepsilon \, (h_u - h_e)$$

Weakens as convection deepens…but how to predict that as parcel rises from cloud base?



Entrainment parameterizations

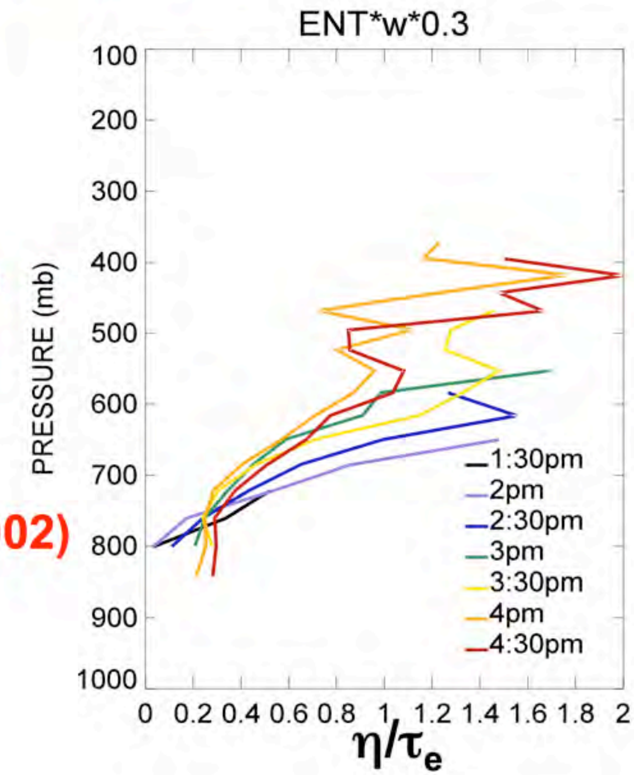


Gregory (2001)

$$\varepsilon(z) = Cg[(T_v' - T_v)/T_v - q_h]/w^2$$

Neggers et al. (2002)

$$\varepsilon(z) = \eta/(\tau_e w)$$



Free parameter in Gregory scheme decreases to top of CBL then increases with height (decreasing/increasing fraction of buoyant energy used by entrainment) – but ~ invariant with time

So…key is to get the buoyancy right

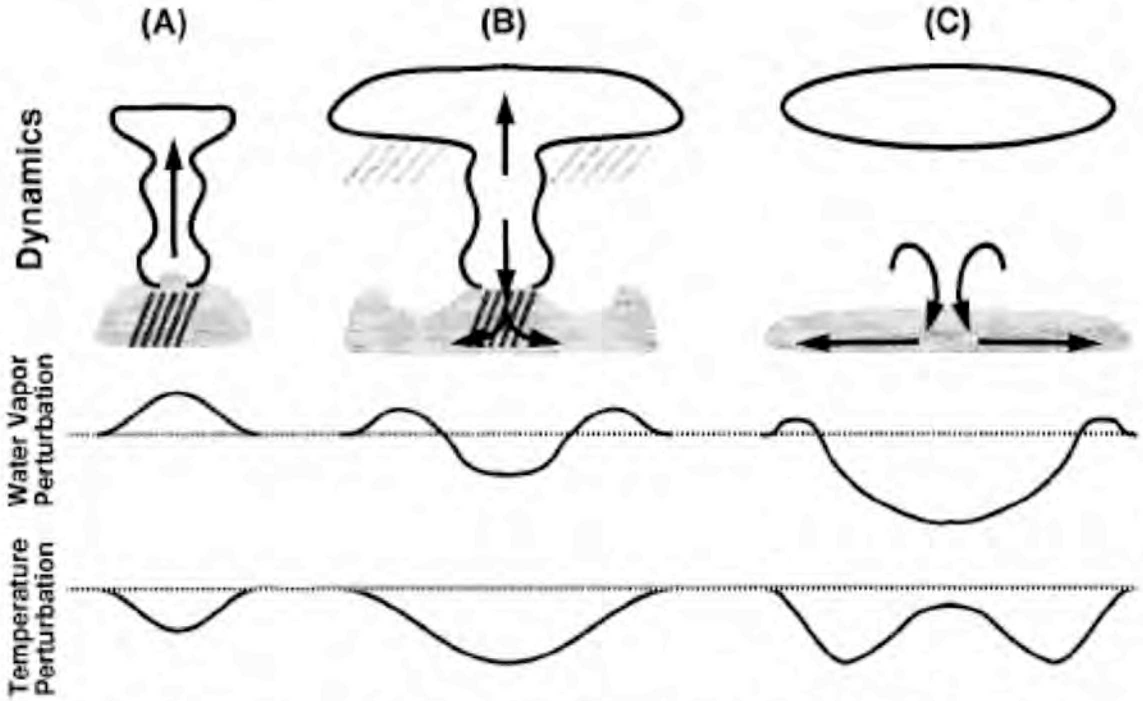


FIG. 14. Schematic diagram of cold pool development. (A) A deep convective tower develops, moistening and cooling the subcloud layer through the evaporation of rainfall, air that already had high θ_e values. (B) As convective tower matures, downdrafts introduce cold, dry air into the boundary layer, and the moist band is advected at the edges of the newly formed cold pool. (C) Convective system dissipates, leaving cirrus remnants. The edges of the cold pool have already recovered in temperature due to the action of surface fluxes, and are able to trigger new convection.

Tompkins (2001)

So perhaps the broadening of the pdf of MSE by cold pools is the missing ingredient in GCMs

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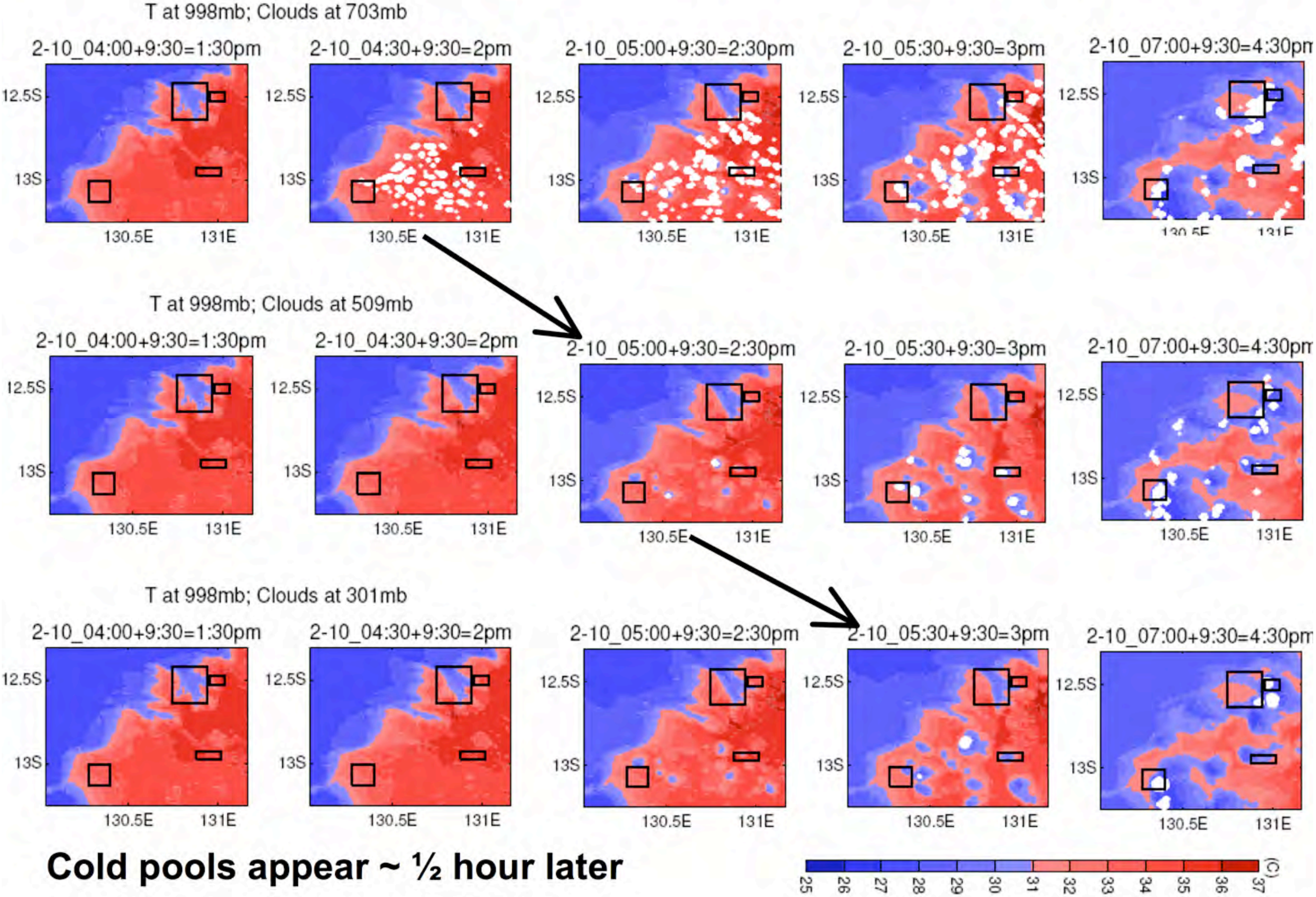
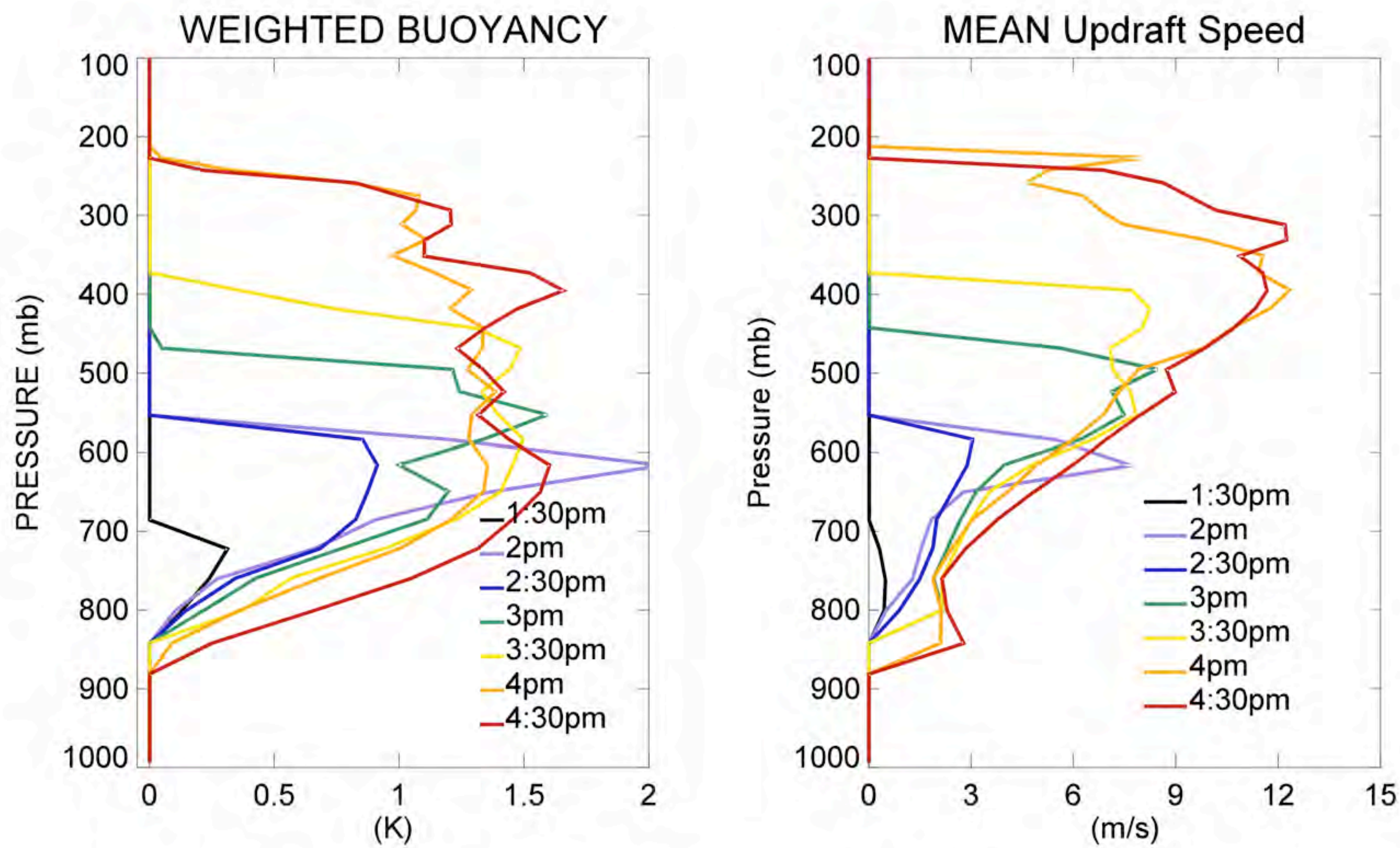
- Need to add height variation of buoyant energy consumption
- Need to account for MSE pdf broadening by rain evaporation and extrema at cold pool edges

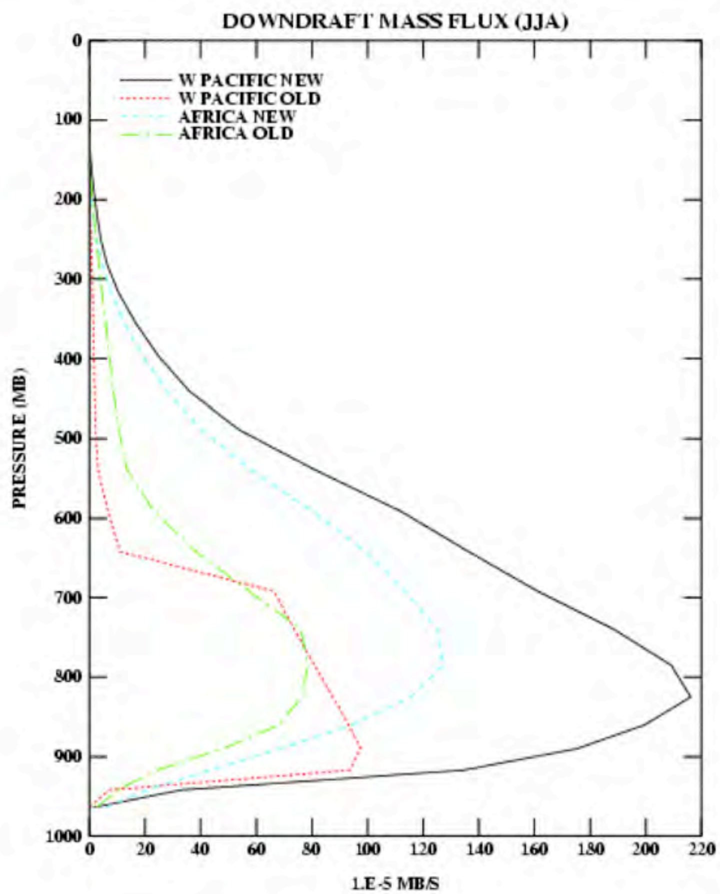
Other slides

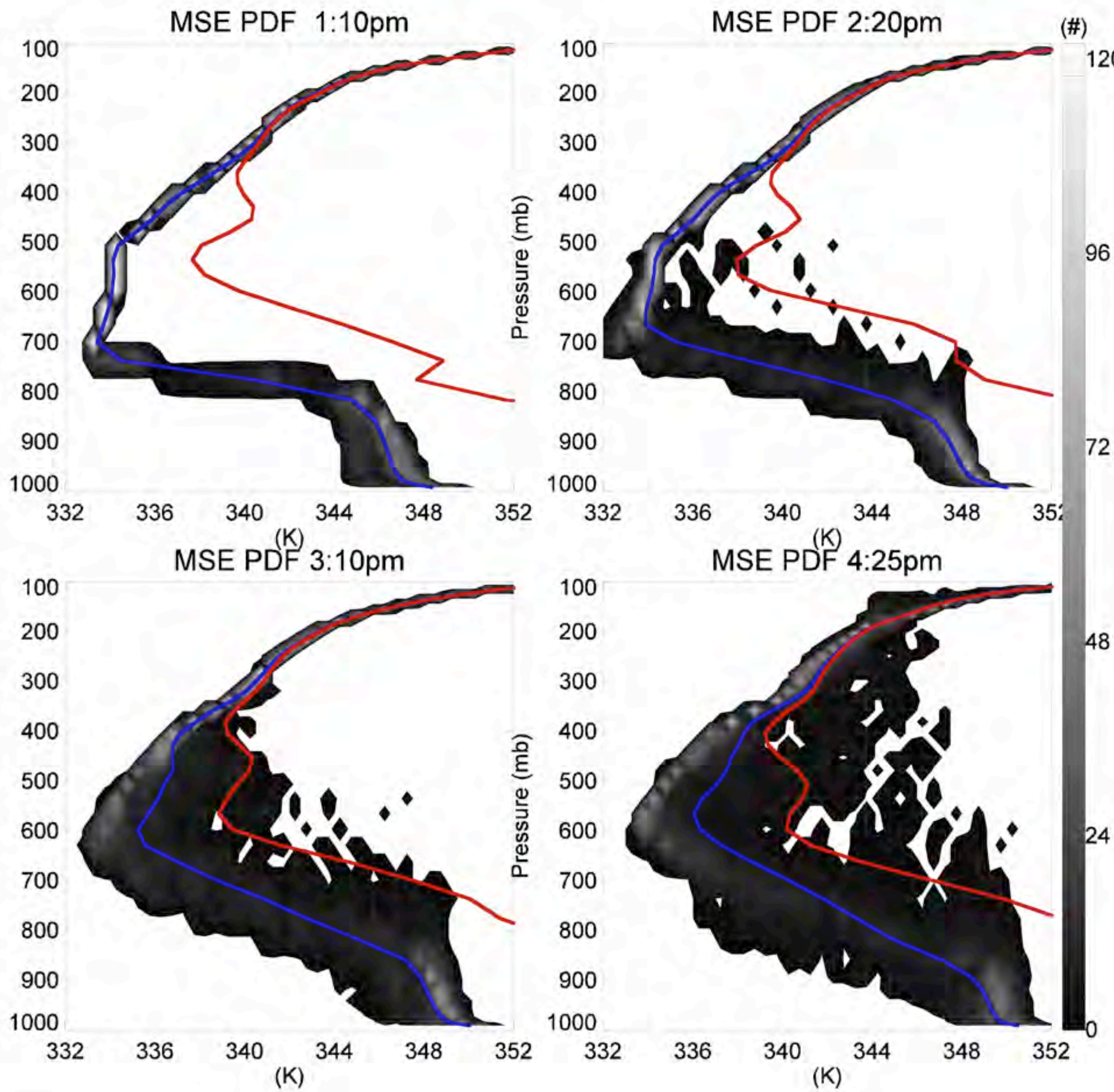


Cold pools appear ~ ½ hour later


WEIGHTED BUOYANCY
PRESSURE (mb)
(K)
MEAN Updraft Speed
Pressure (mb)
(m/s)
1:30pm
2pm
2:30pm
3pm
3:30pm
4pm
4:30pm

Allow multiple downdrafts: ~doubles downdraft mass flux, decreases shallow convection in deep convective regions; also reduces low-level heating





MSE PDF 1:10pm
MSE PDF 2:20pm
MSE PDF 3:10pm
MSE PDF 4:25pm
Pressure (mb)
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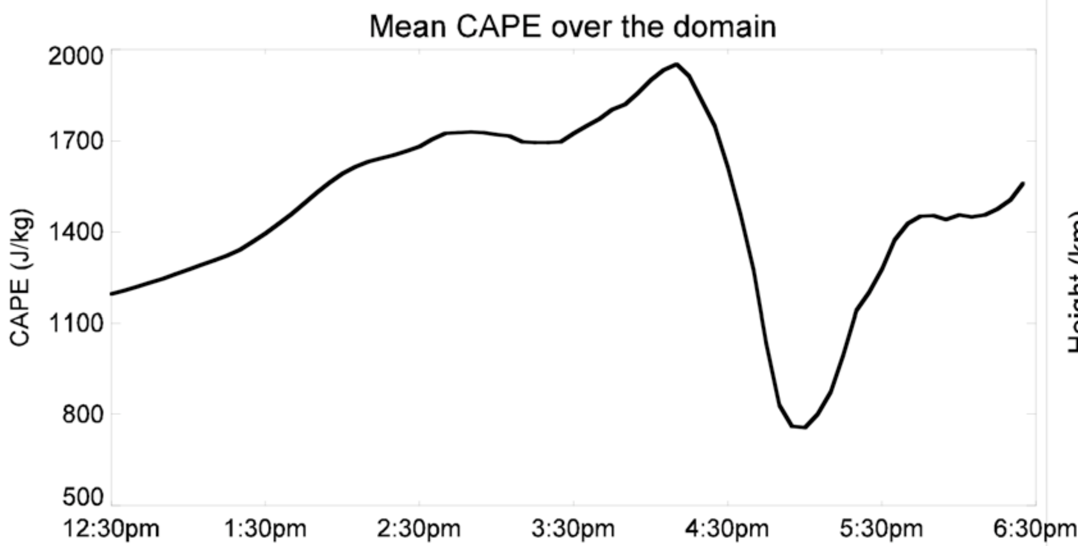
Mean CAPE over the domain
CAPE (J/kg)
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800
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1:30pm
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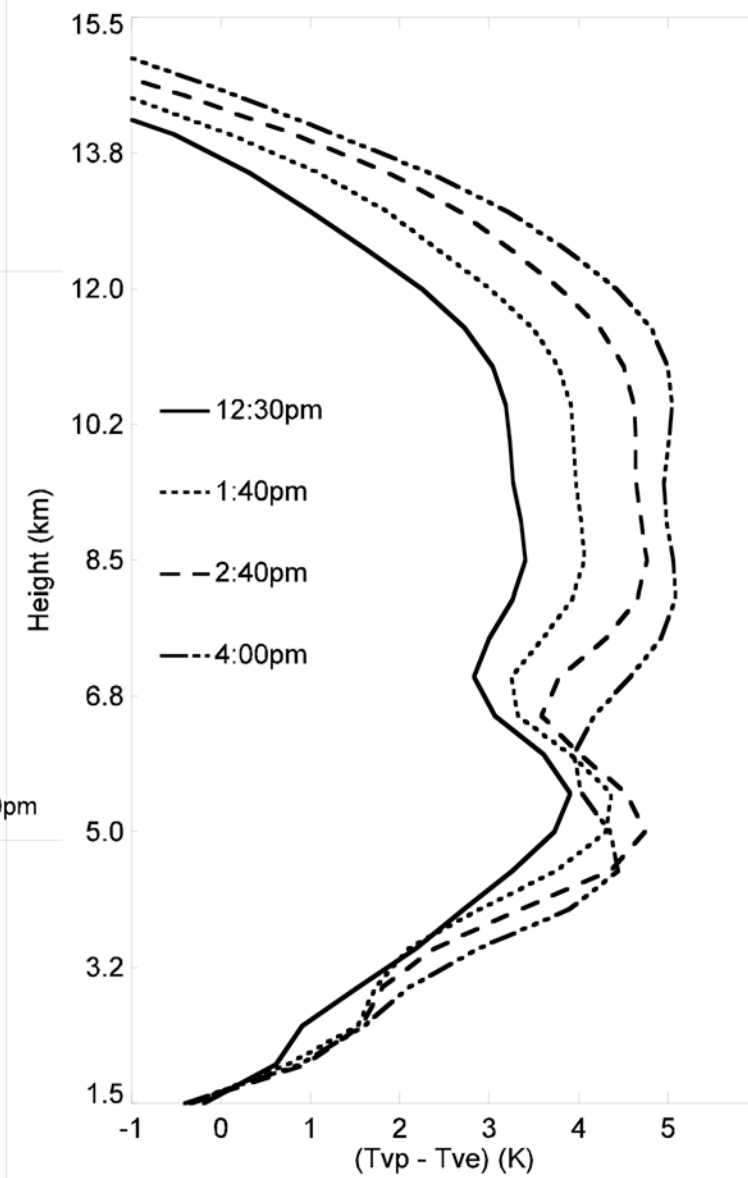
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12.0
10.2
8.5
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12:30pm
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(Tvp - Tve) (K)