ENTRAINMENT AND THE DIURNAL CYCLE OF CONTINENTAL CONVECTION

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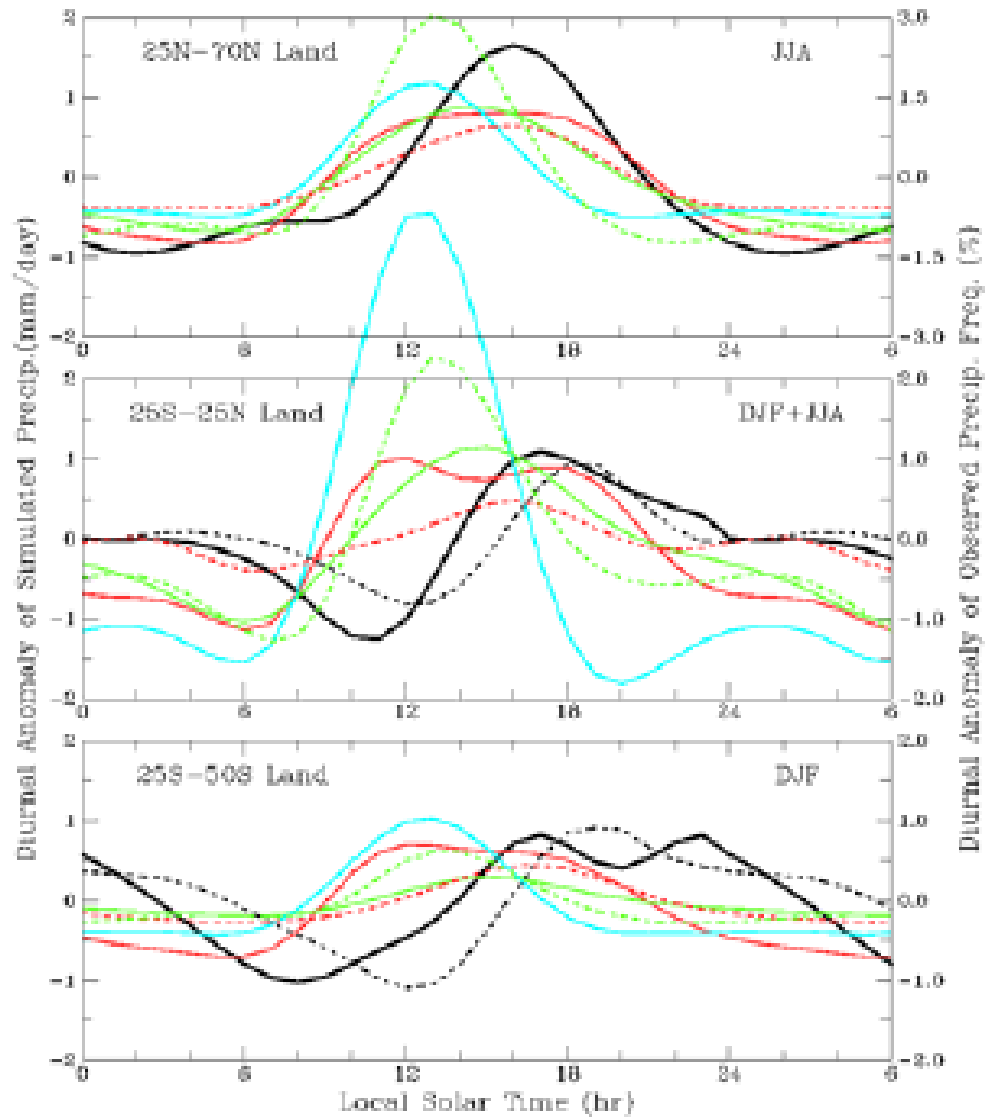
Transition from shallow to deep convection occurs late in the day in real world, but in early afternoon in IPCC AR4 models

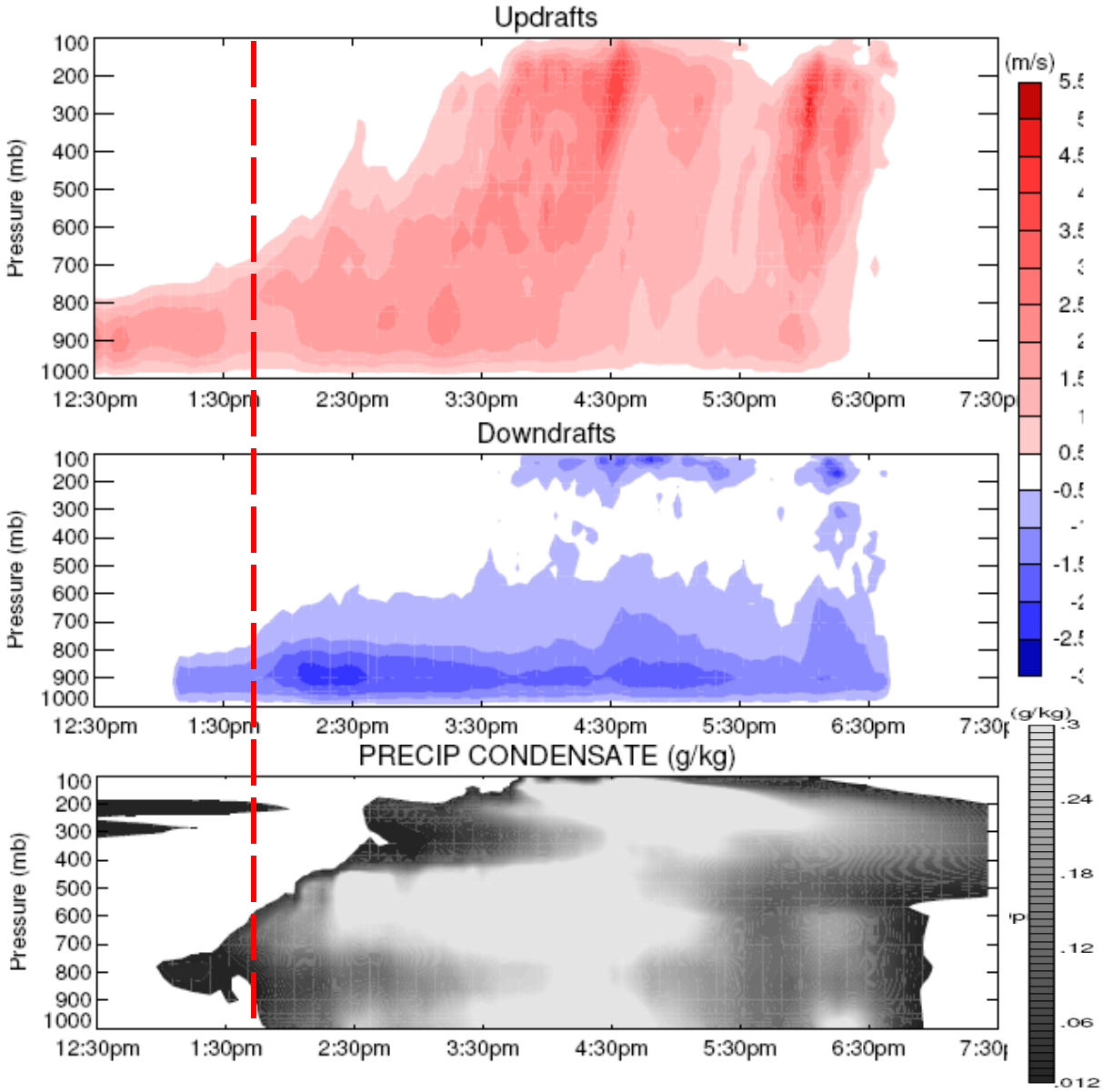
(Dai, 2006)

___ TRMM 3B42 - - - gauge colors = models



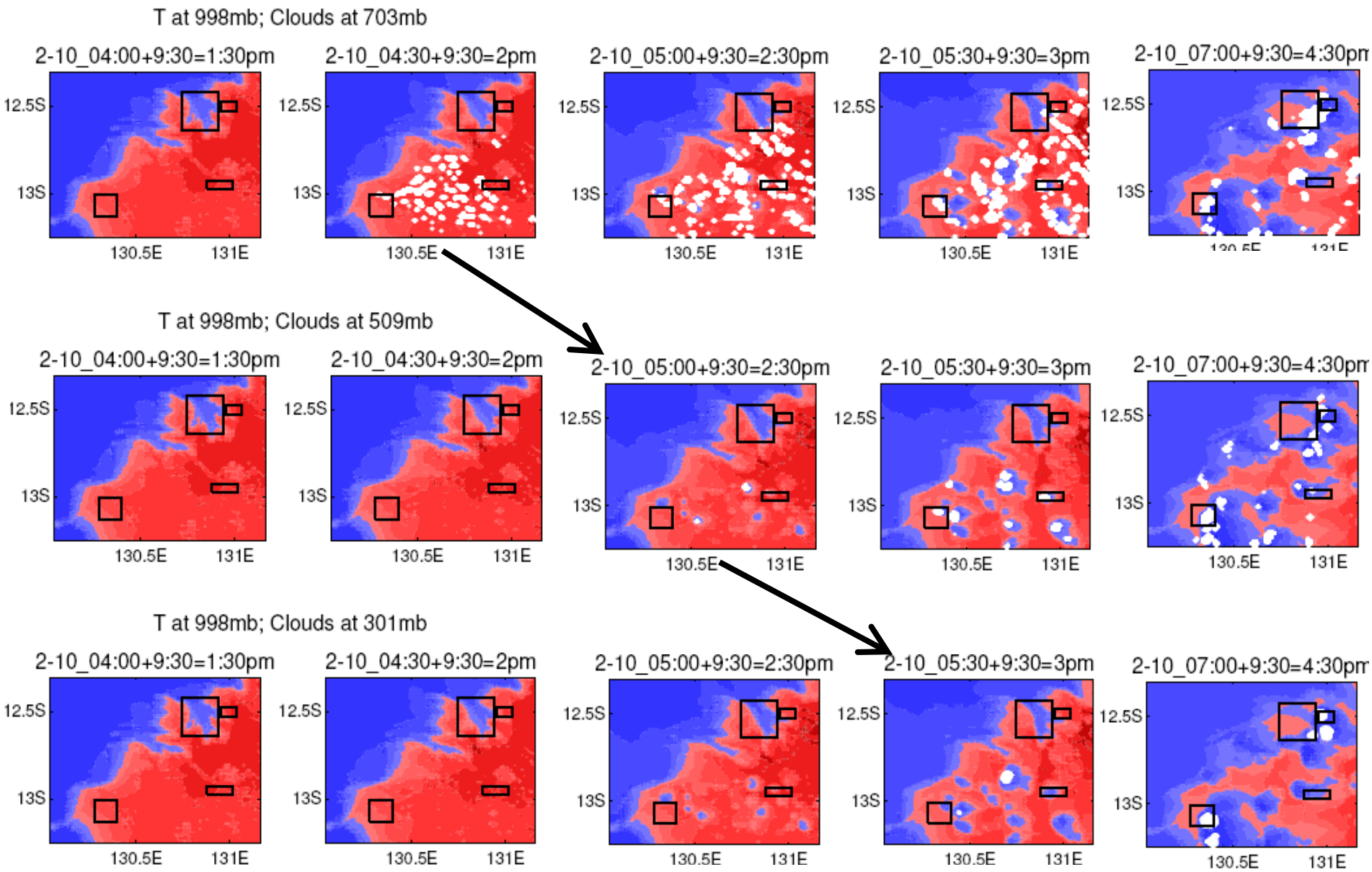
Some recent studies

- Derbyshire et al. (2004): SCMs insensitive to tropospheric humidity
- Grabowski et al. (2006): Need entrainment rate to decrease with time of day
- Kuang and Bretherton (2006): Weaker entrainment rates for deep than for shallow convection - increasing parcel size as cold pools form?
- Khairoutdinov and Randall (2006): Demonstration of downdraft/cold pool role in transition from shallow to deep convection
- Bechtold et al. (2008): Explicit parameterization of entrainment rate as f(RH)

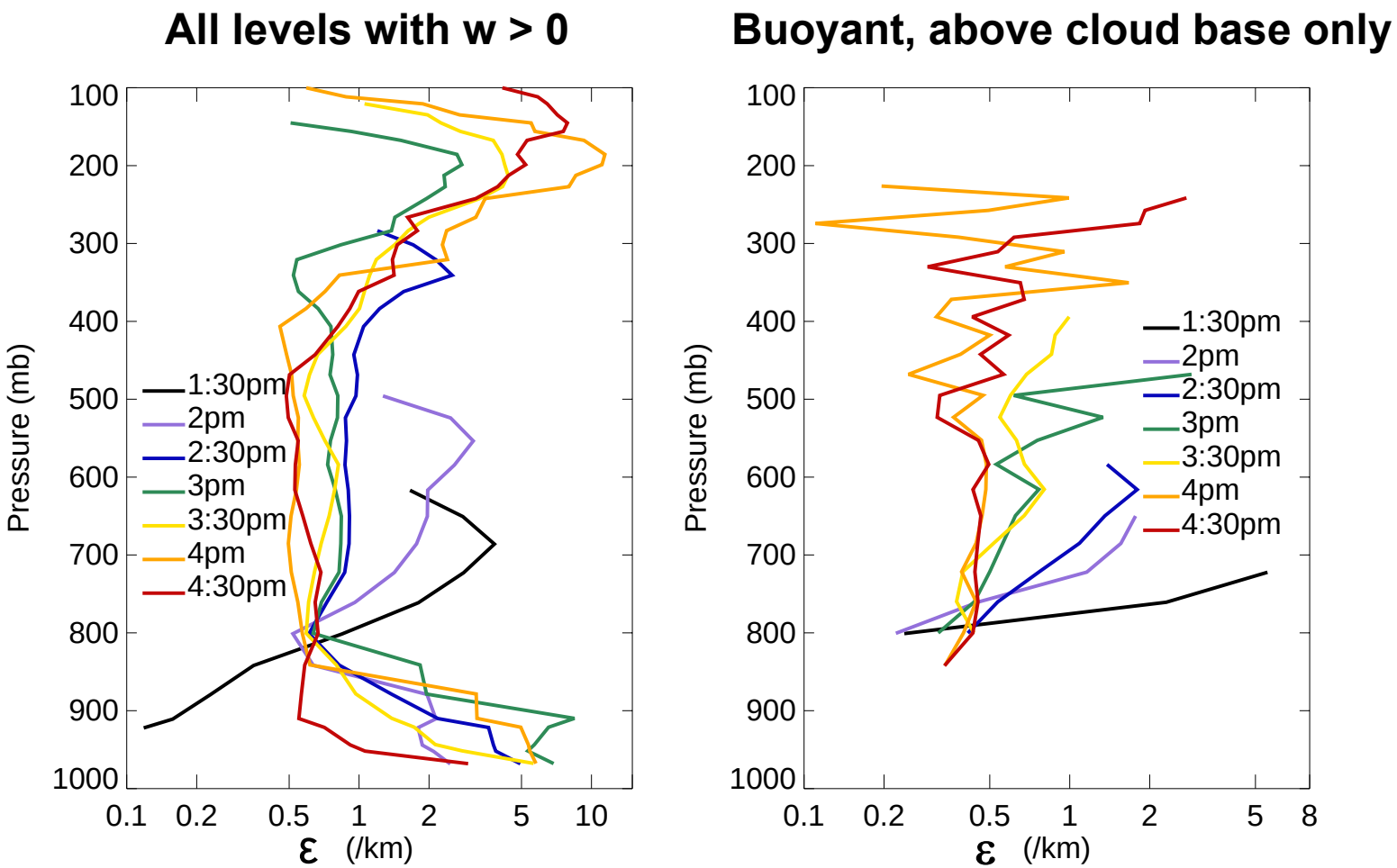


TWP-ICE monsoon "break" period (2/10) simulation of scattered mainland convection with WRF model:

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



Cold pools appear ~ ½ hour later



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):

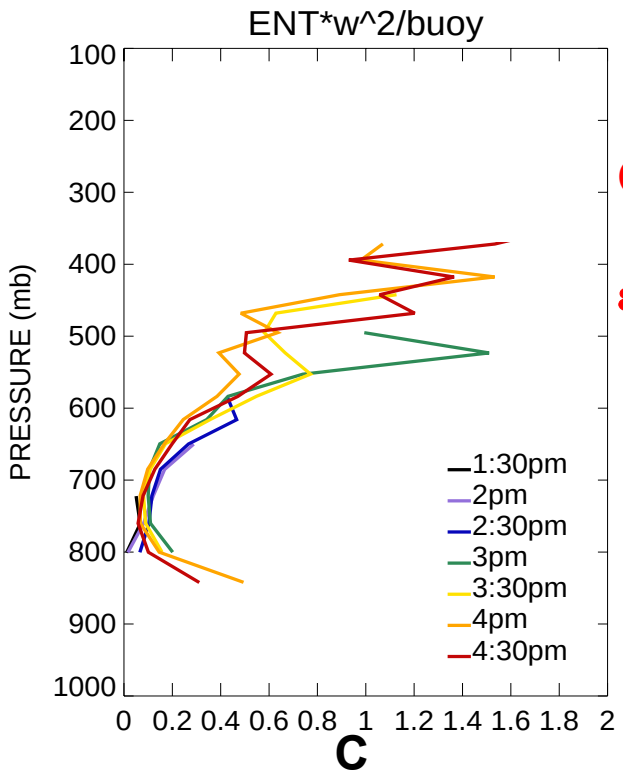
$$\varepsilon(z) = CB / w^2 = Cg\left(\frac{T_v'}{\overline{T_v}} - q_h\right) \Big/ w^2$$

Neggers et al. (2002):

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

(equivalent if $w = B\tau_e$)

WRF evaluation



Gregory (2001)

$\varepsilon(z) = CB/w^2$

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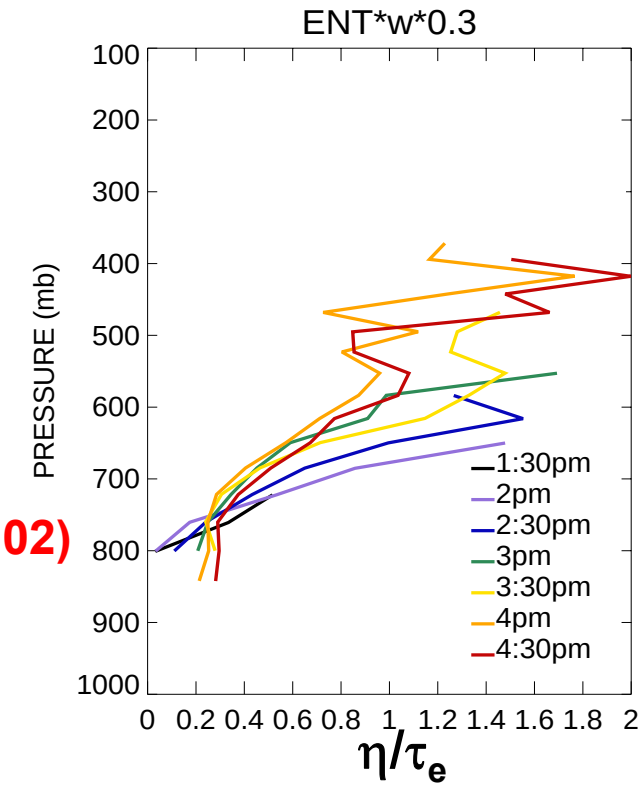


Free parameter in Gregory scheme decreases to top of CBL then increases with height (decreasing/increasing fraction of buoyant energy used by entrainment) – but ~ invariant with time

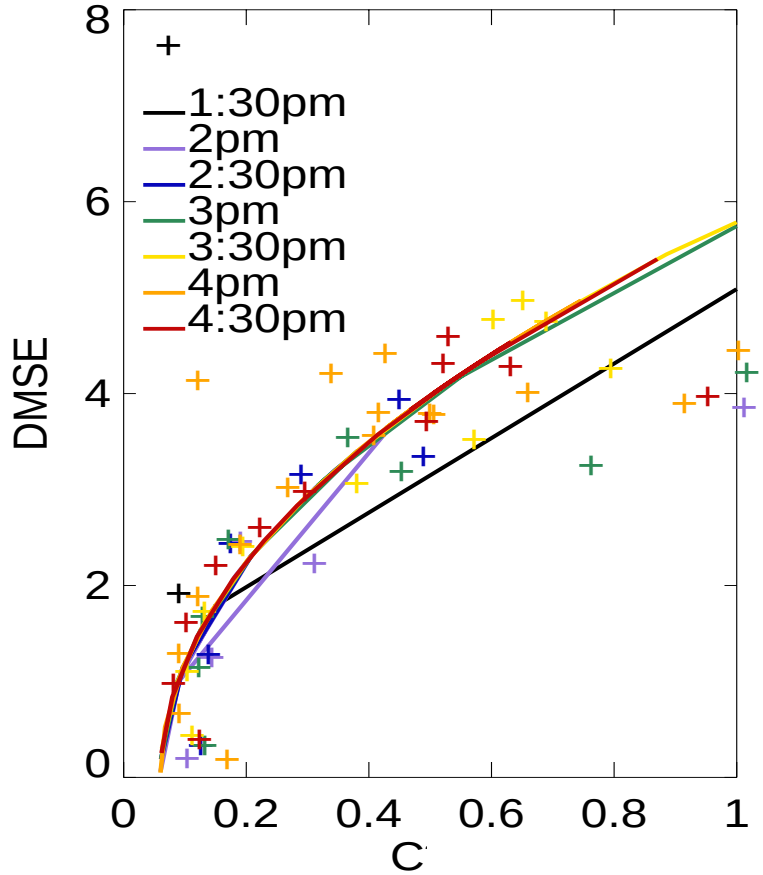
So…key is to get the profile of C, the buoyancy and w correct

Dilution of parcel (undilute minus actual moist static energy) a reasonable proxy for height variation of C

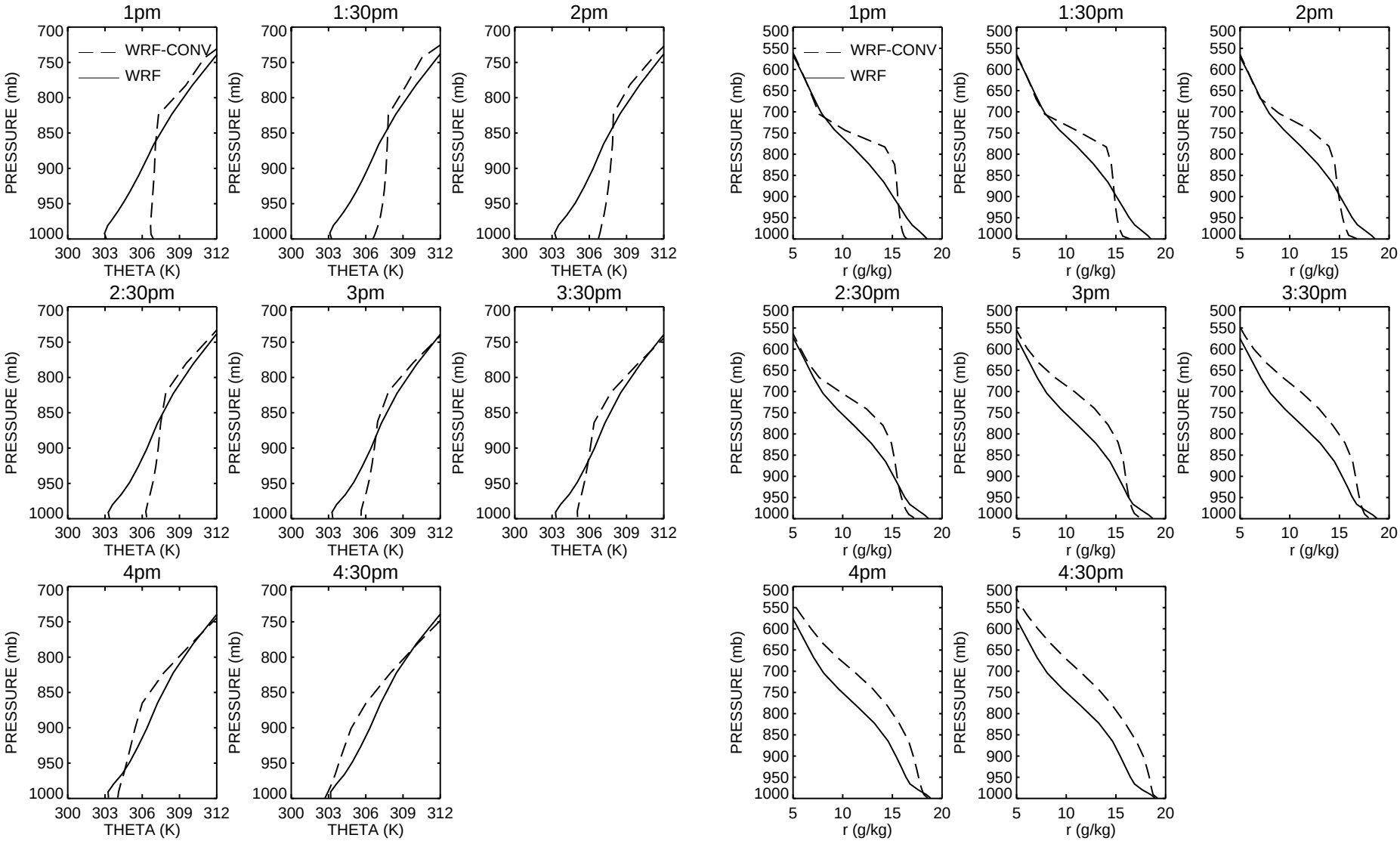
…as anticipated by Gregory (2001) and Grant and Brown (1999)

Greater fraction of buoyant energy given up to entrainment process as parcel dilutes

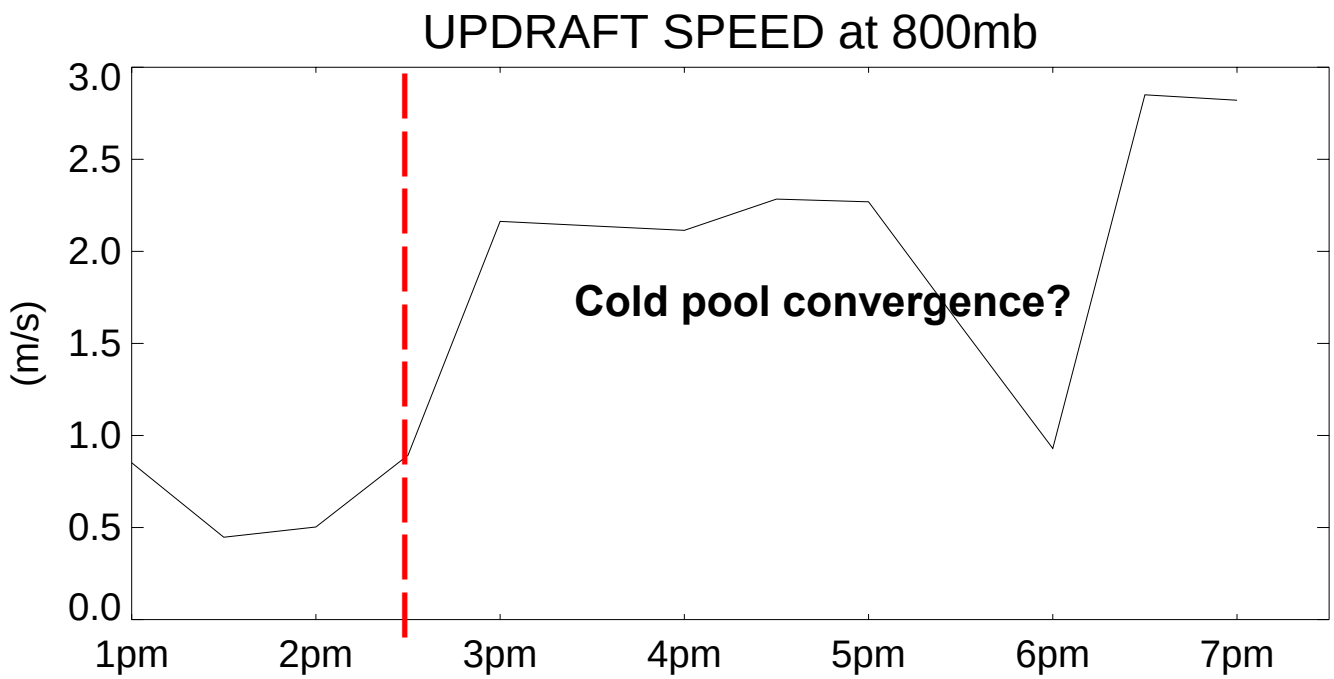
Physical basis for Bechtold et al. (2008) assumption of ε = f(RH)?



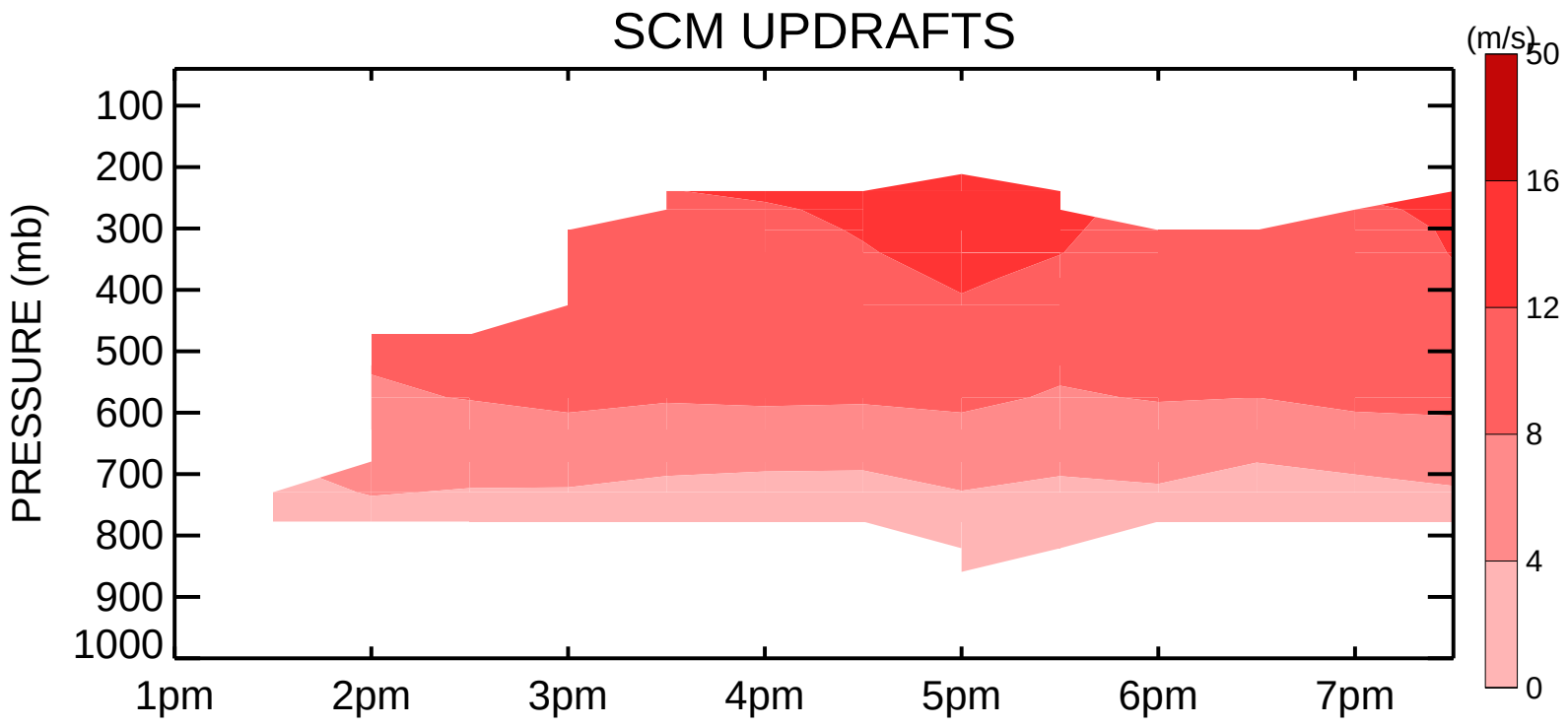
Thermodynamic structure: Domain mean vs. convective gridboxes



Cloud base updraft speed ~0.5/~2 m/s before/after cold pool formation



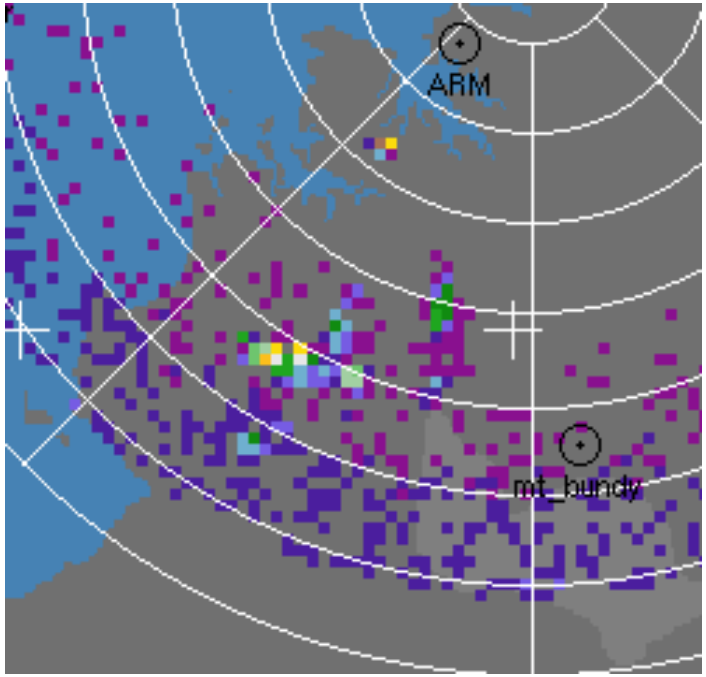
SCM diurnal cycle with Gregory entrainment, C ~ DMSE^2, and initial w enhanced by onset of downdraft

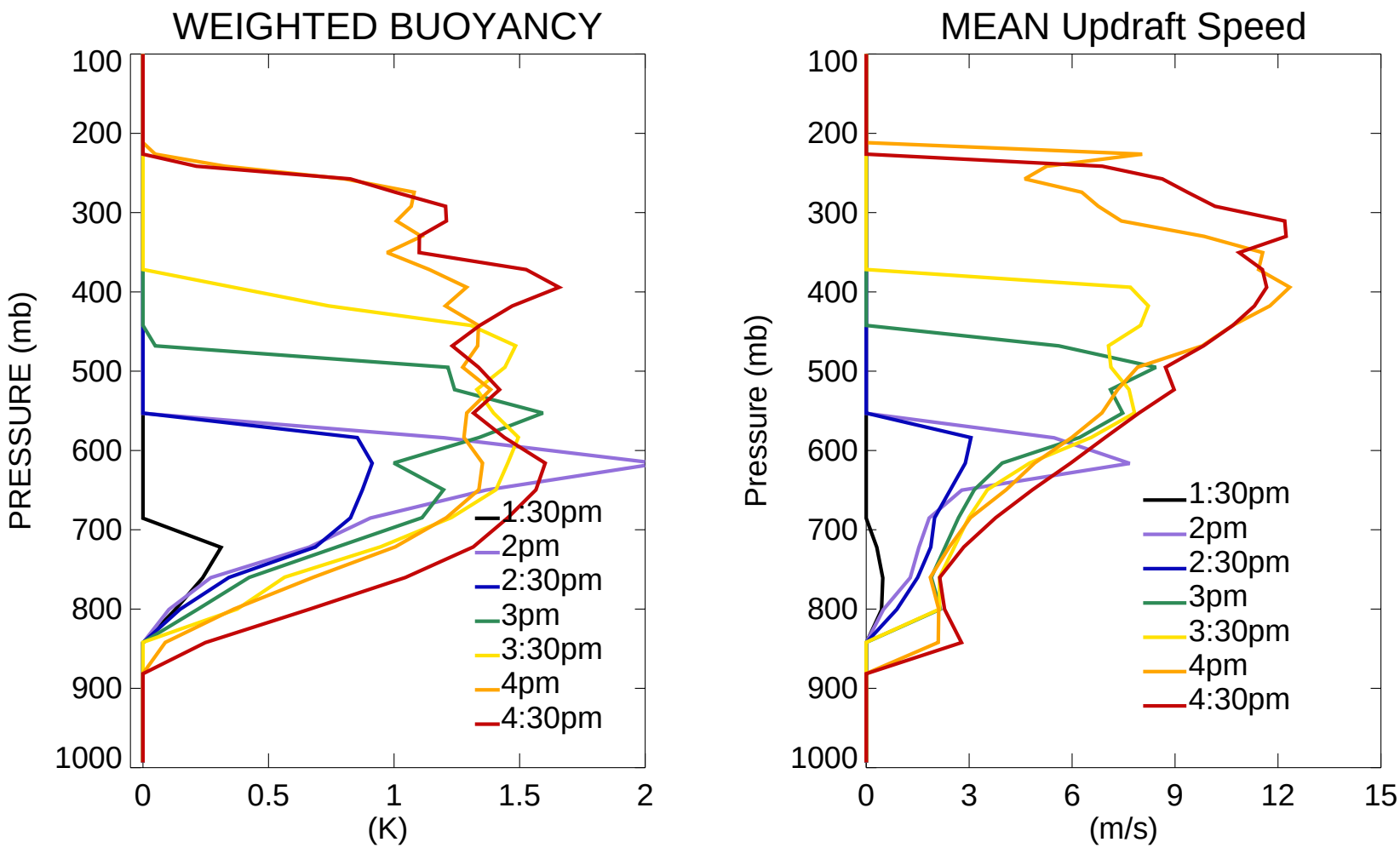


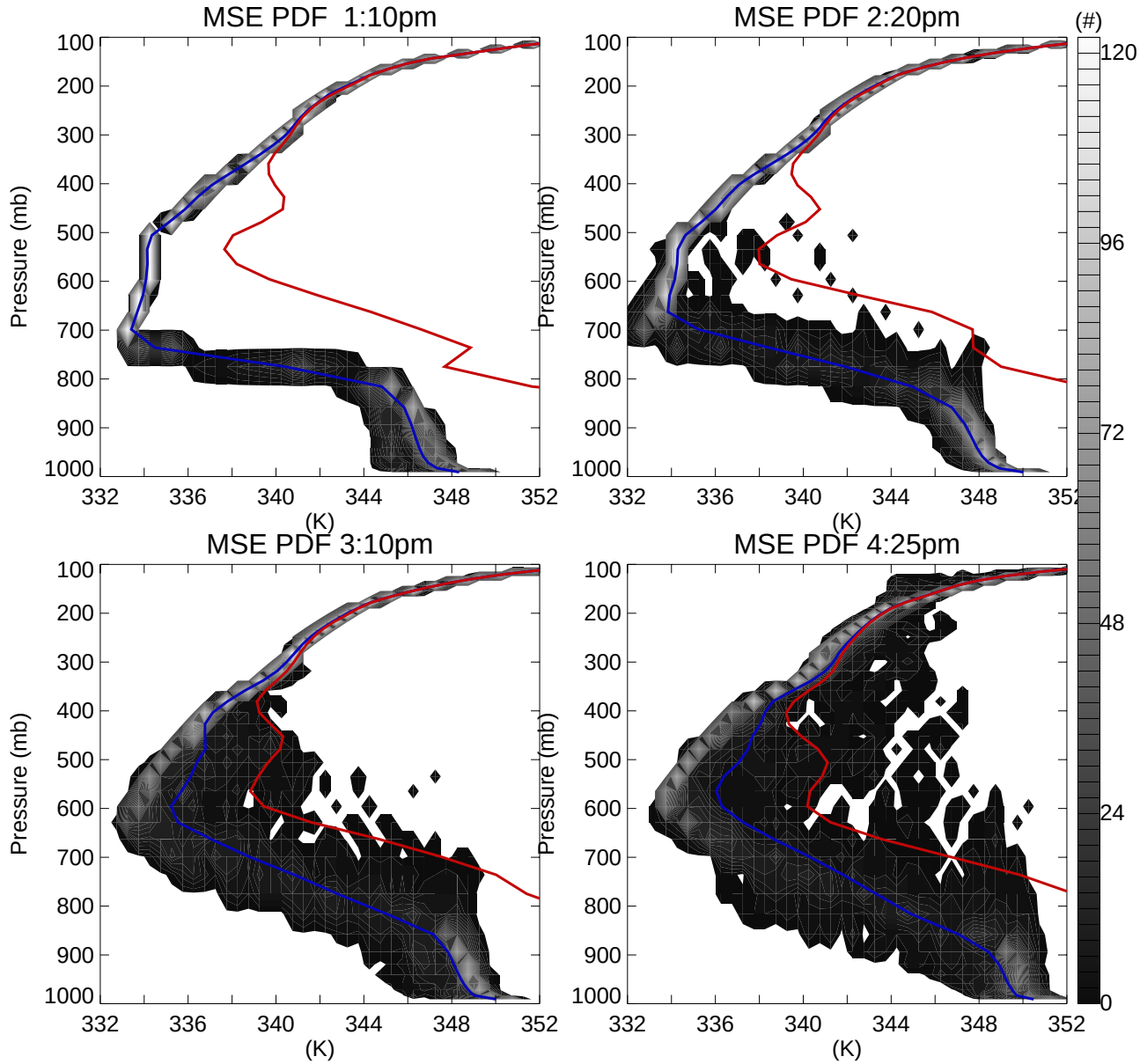
Conclusions

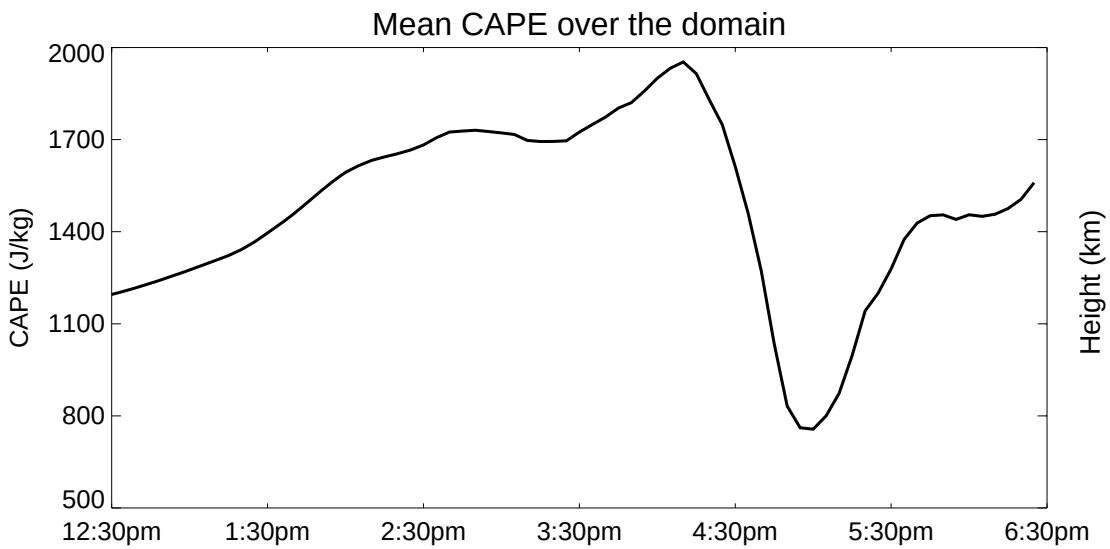
- Gregory (2001) entrainment parameterization appears to simulate TWP-ICE shallow-deep transition well if % of buoyant energy consumed increases with height
- Dilution of parcel moist static energy with height represents this fairly well
- Given correct T, q and initial updraft speed enhanced in presence of downdrafts, SCM appears able to simulate transition at about the right time
- Need to account for MSE pdf broadening by rain evaporation and extrema at cold pool edges
- Neggers et al. (2002) shallow cumulus entrainment approach may also be viable for transition to deep if eddy turnover time allowed to vary

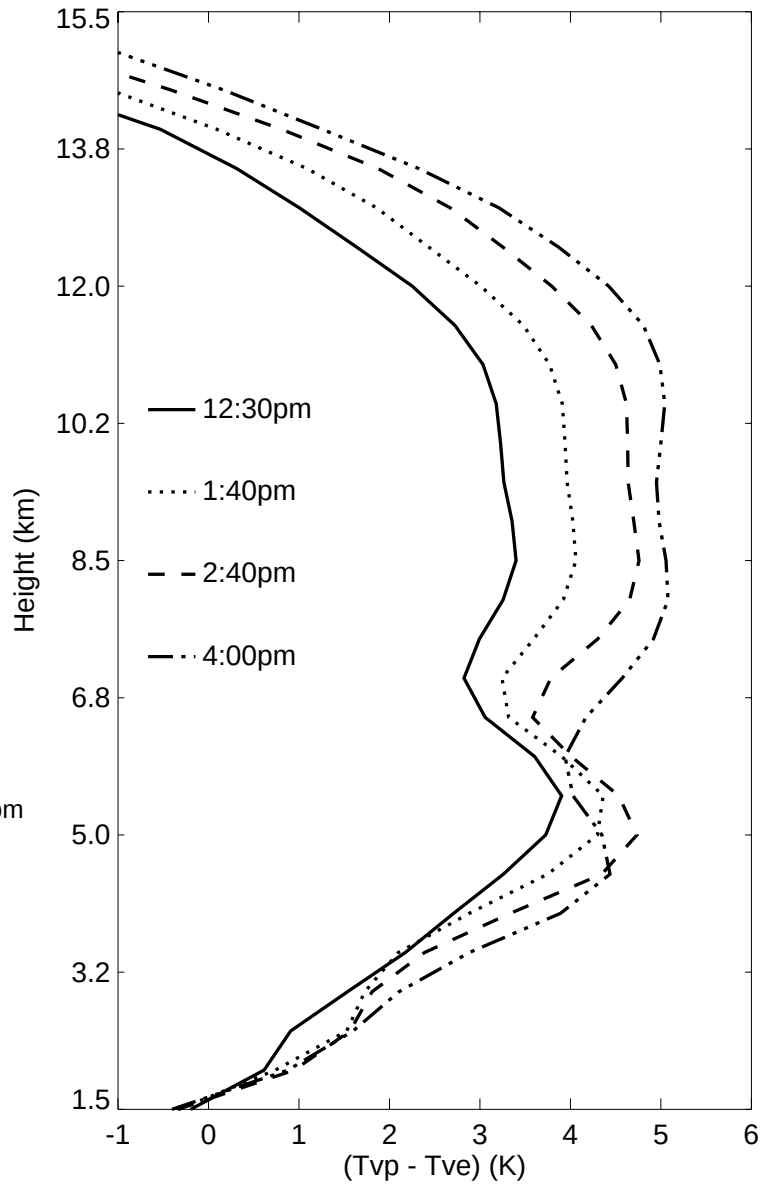
Other slides


ARM
mt_bundy


WEIGHTED BUOYANCY
PRESSURE (mb)
100
200
300
400
500
600
700
800
900
1000
0
0.5
1
1.5
2
(K)
1:30pm
2pm
2:30pm
3pm
3:30pm
4pm
4:30pm
MEAN Updraft Speed
Pressure (mb)
100
200
300
400
500
600
700
800
900
1000
0
3
6
9
12
15
(m/s)
1:30pm
2pm
2:30pm
3pm
3:30pm
4pm
4:30pm


MSE PDF 1:10pm
MSE PDF 2:20pm
MSE PDF 3:10pm
MSE PDF 4:25pm
Pressure (mb)
(K)
(#)
100
200
300
400
500
600
700
800
900
1000
332
336
340
344
348
352
120
96
72
48
24
0


Mean CAPE over the domain
CAPE (J/kg)
2000
1700
1400
1100
800
500
12:30pm
1:30pm
2:30pm
3:30pm
4:30pm
5:30pm
6:30pm


Height (km)
15.5
13.8
12.0
10.2
8.5
6.8
5.0
3.2
1.5
12:30pm
1:40pm
2:40pm
4:00pm
-1
0
1
2
3
4
5
6
(Tvp - Tve) (K)