THE ROLE OF ENTRAINMENT IN THE DIURNAL TRANSITION FROM SHALLOW TO DEEP CONVECTION

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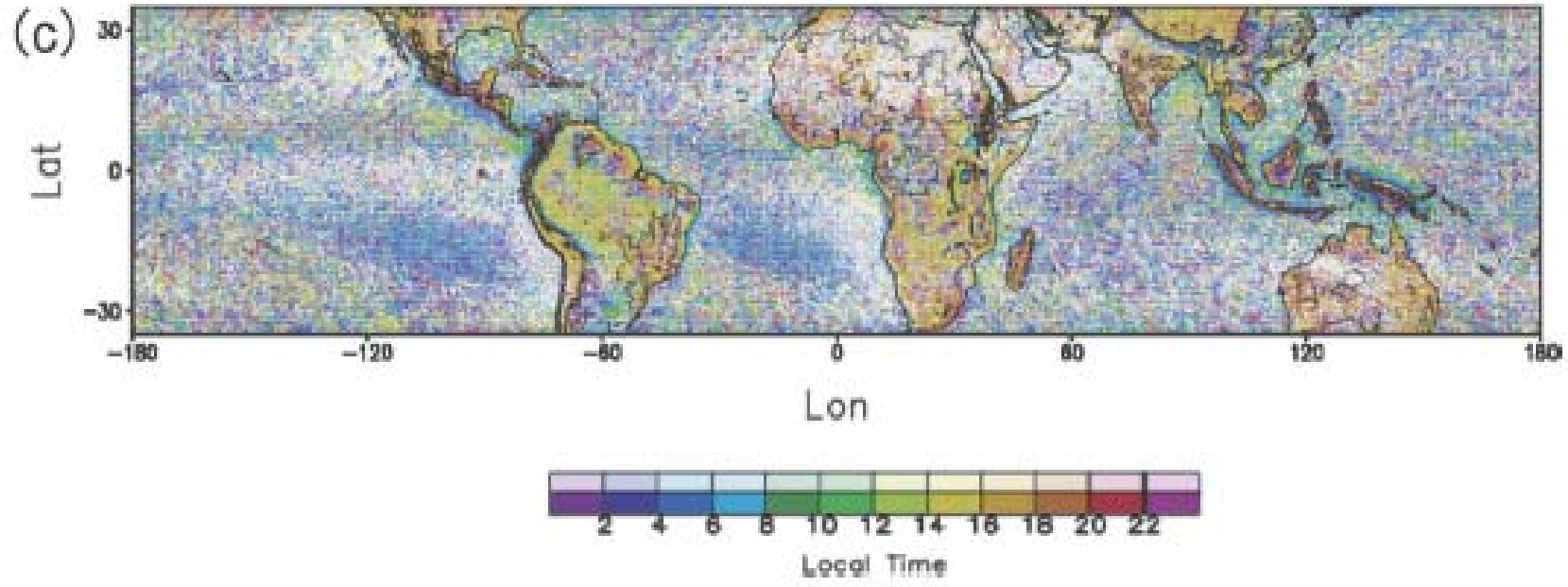
NASA/GISS

ARM Science Team Meeting, 3/31/09

Continental rainfall rates tend to peak in mid-late afternoon or evening

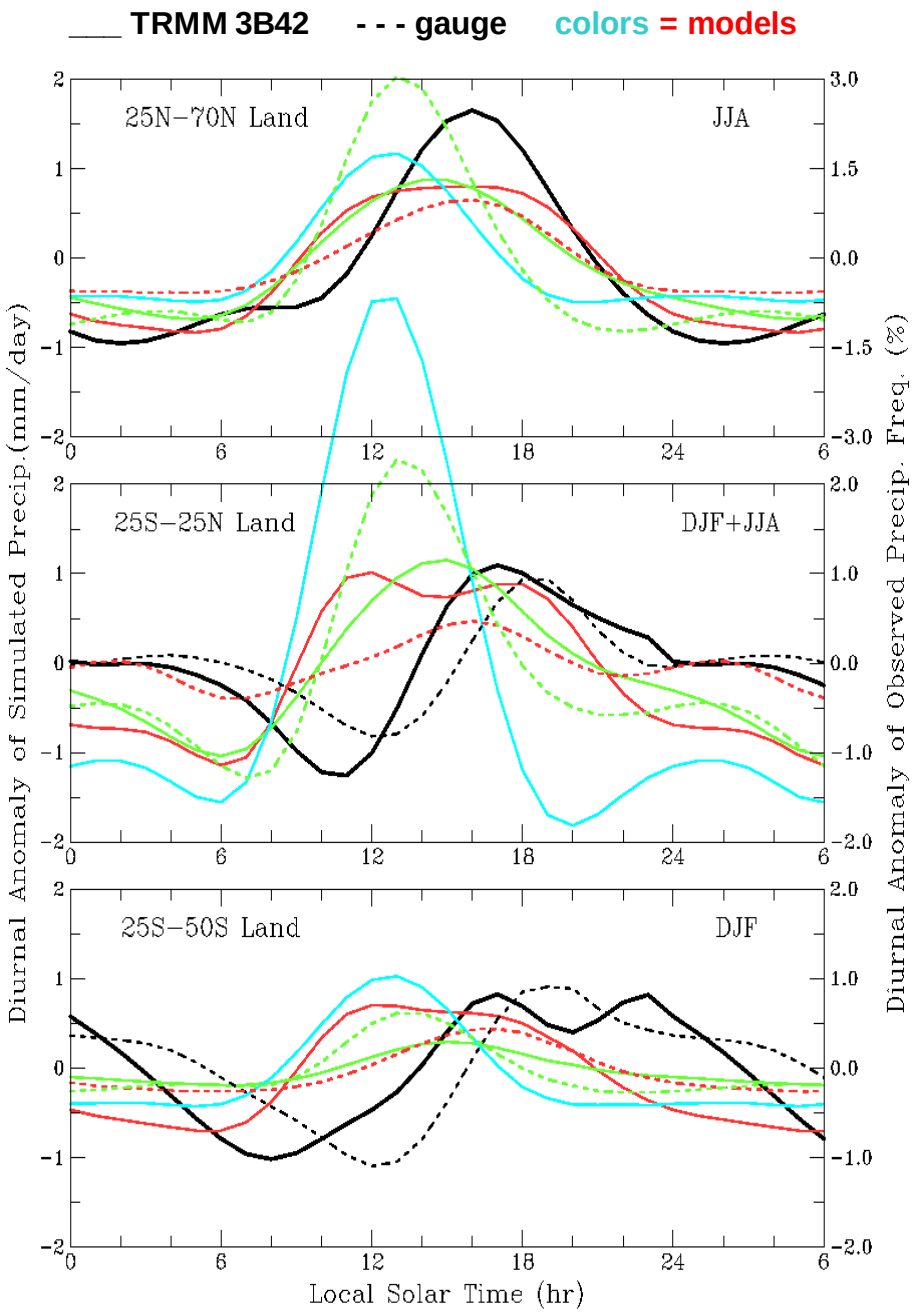
Time of peak rainfall, TRMM PR



Hirose et al. (2008)

But not in GCMs, which like to rain near noon

IPCC AR4 models **(Dai, 2006)**



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(1-RH)***

TWP-ICE monsoon break, Darwin, Australia, 2/10/06

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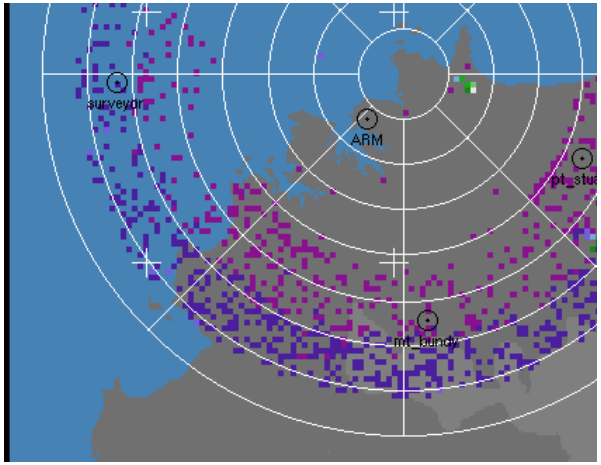

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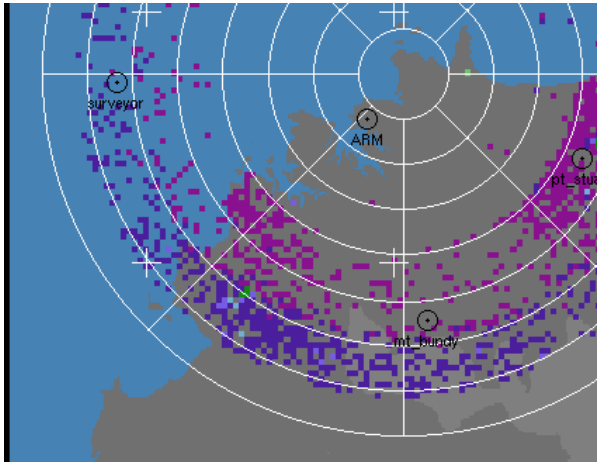

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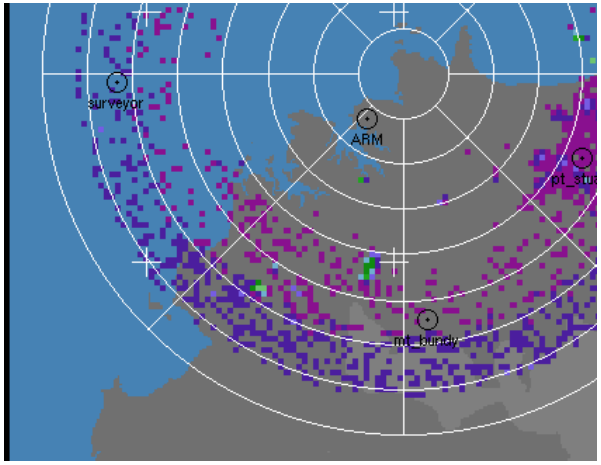

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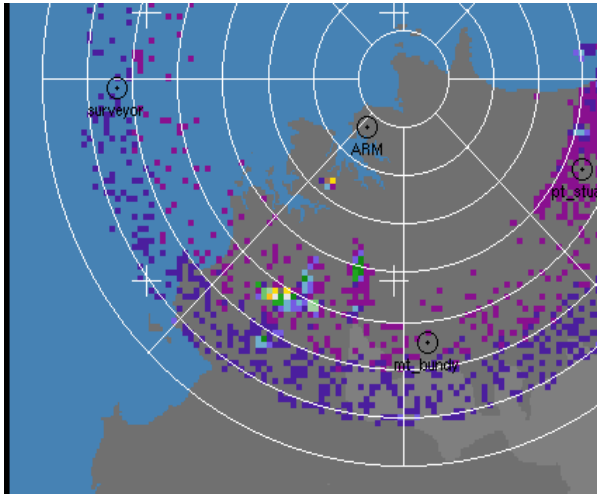

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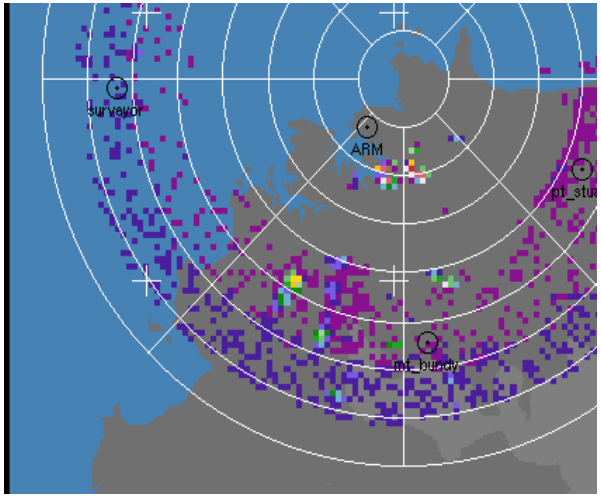

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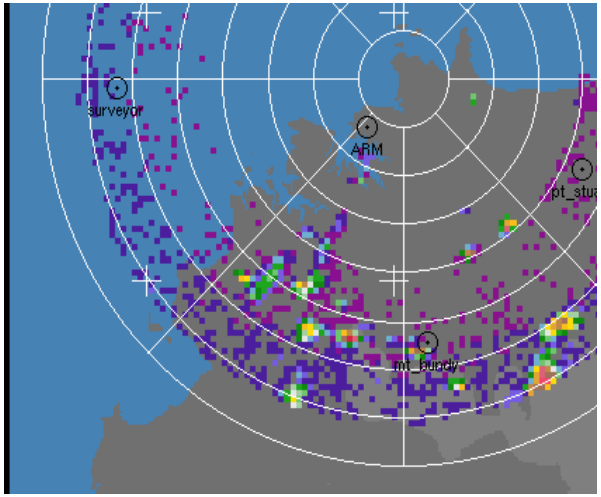
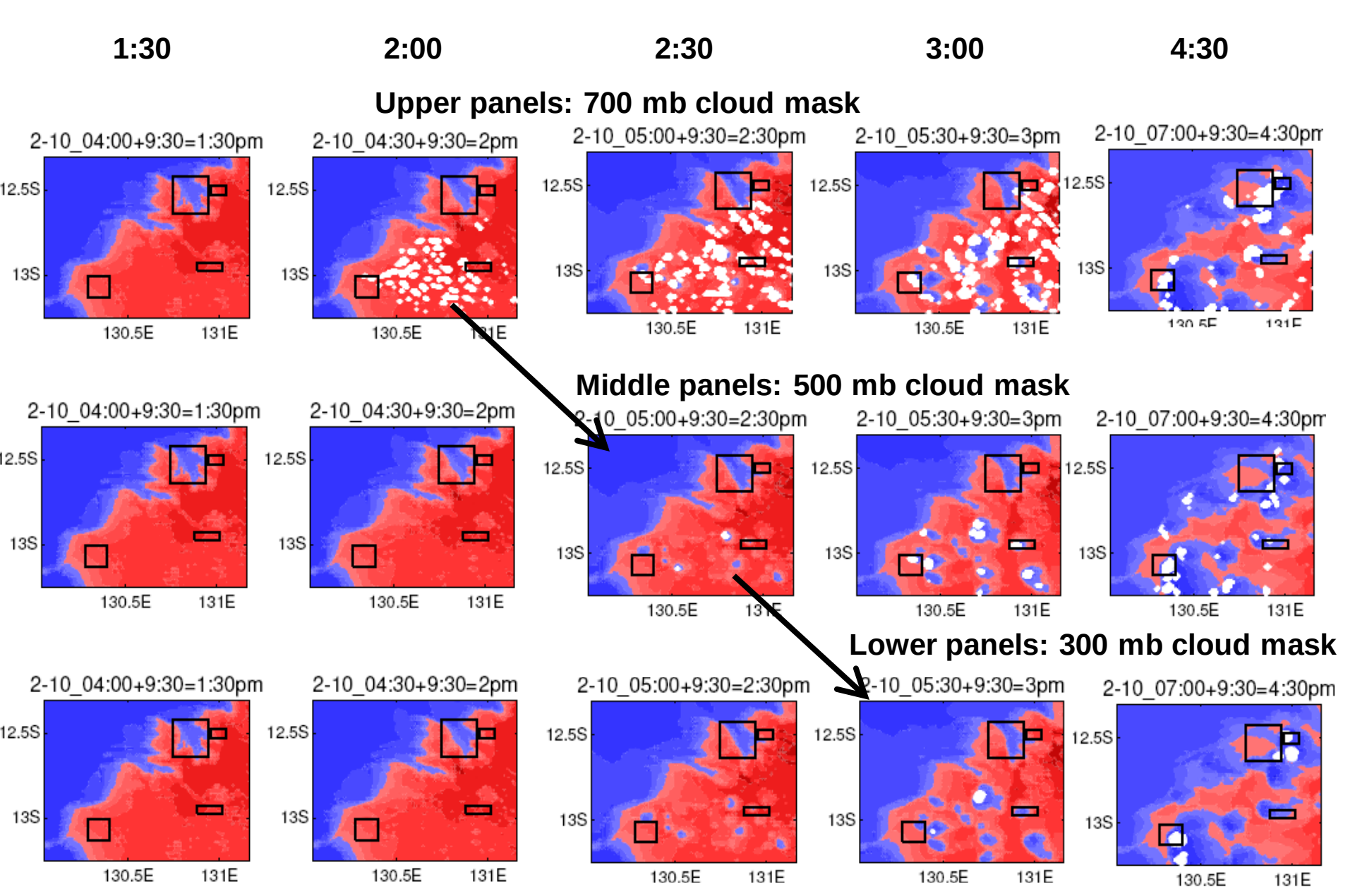
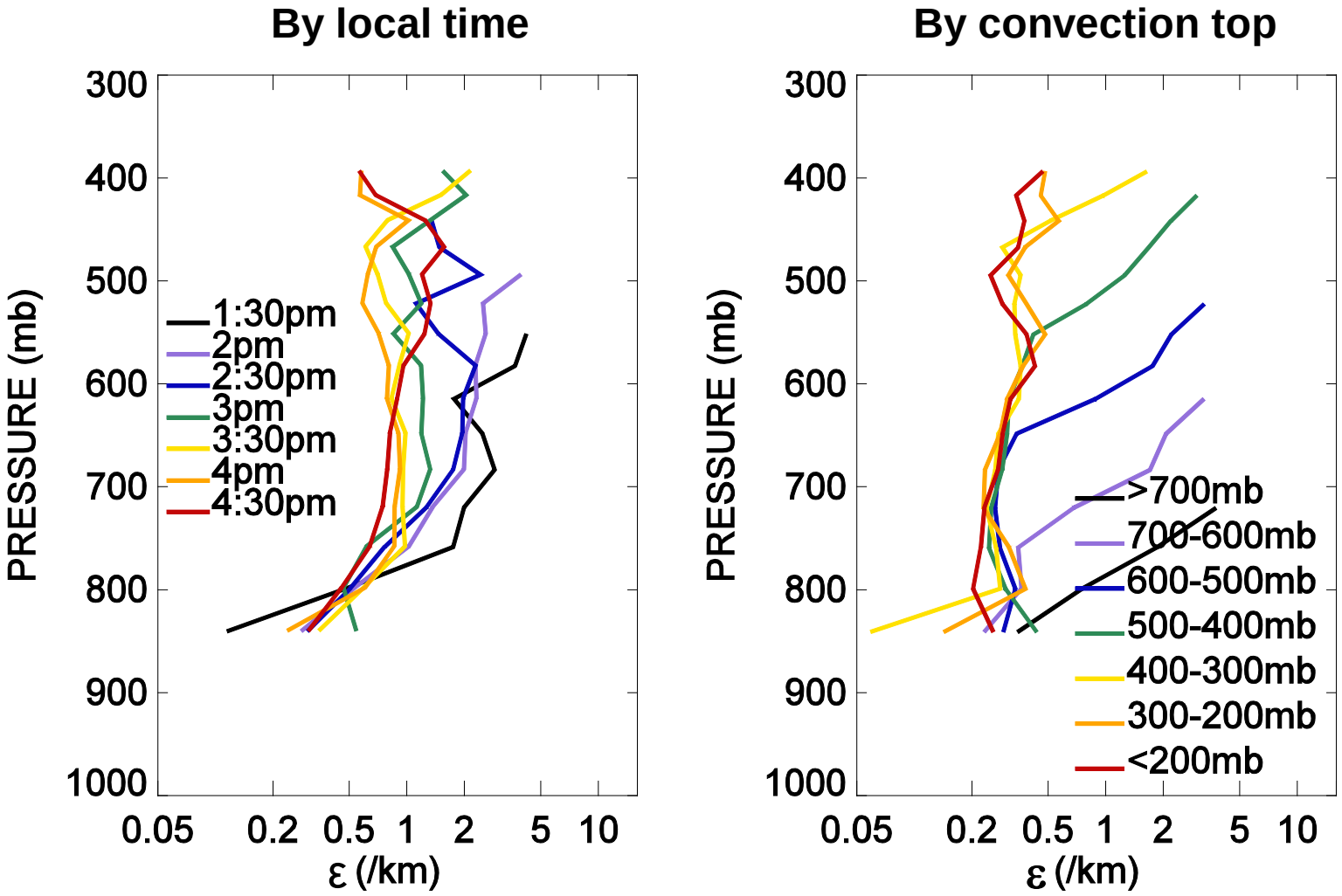


C-POL radar (courtesy Jasmine Cetrone and Bob Houze)

Can we simulate this transition with a cloud-resolving model?


1:30
2:00
2:30
3:00
4:30
Upper panels: 700 mb cloud mask
2-10_04:00+9:30=1:30pm
2-10_04:30+9:30=2pm
2-10_05:00+9:30=2:30pm
2-10_05:30+9:30=3pm
2-10_07:00+9:30=4:30pm
Middle panels: 500 mb cloud mask
Lower panels: 300 mb cloud mask
12.5S
13S
130.5E
131E
Shallow-deep transition simulated well by WRF at 600 m resolution, 50 layers
25 26 27 28 29 30 31 32 33 34 35 36 37 (C)
Surface temperature



Entrainment rate: $dh_u/dz = -\varepsilon (h_u - h_e)$ **(h = frozen MSE)**

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

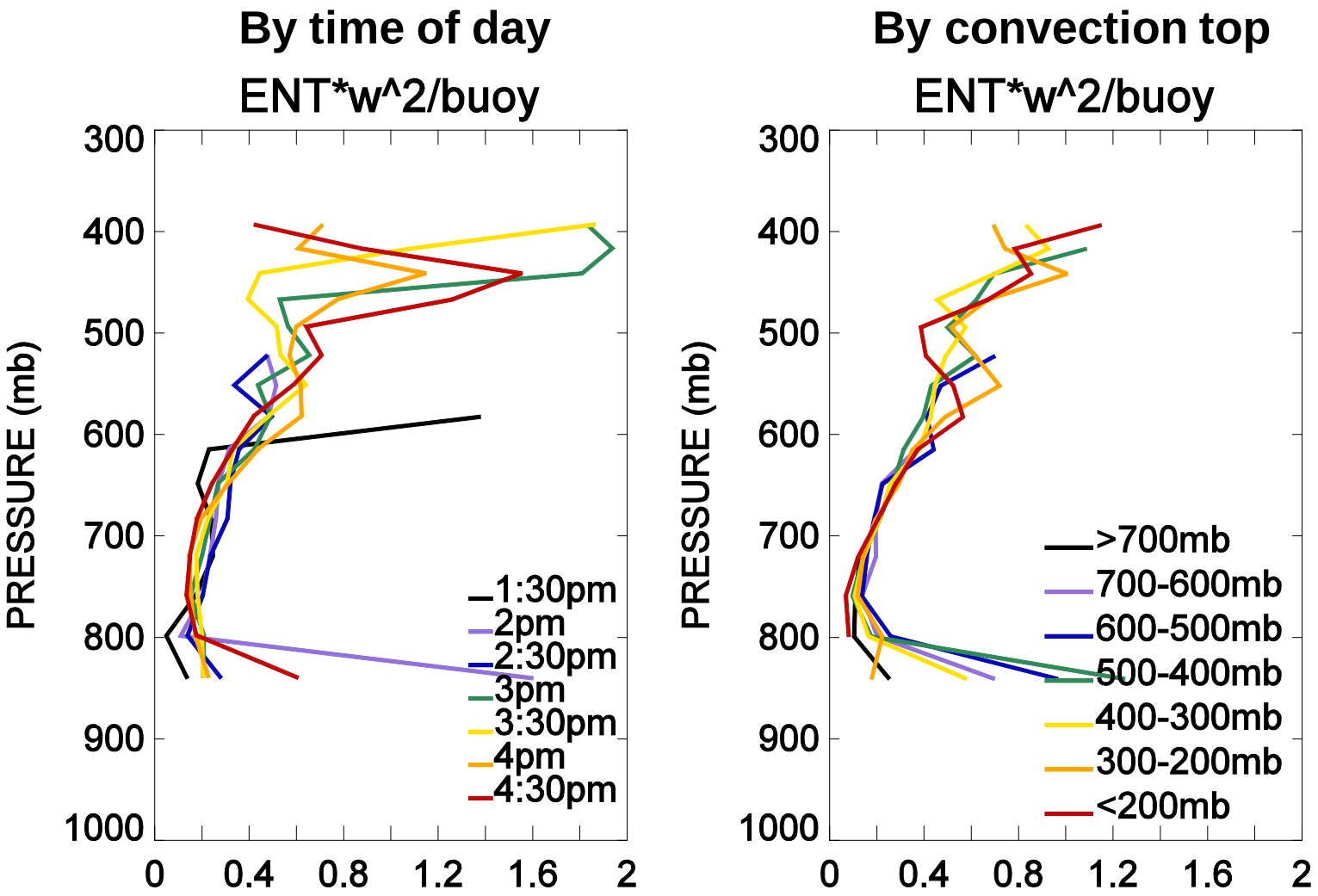
Entrainment rate parameterization:

Gregory (2001):

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

- **Motivated by Grant and Brown (1999) LES study of shallow Cu (but applied here to both shallow and deep convection)**
- **Kinematic view of entrainment**
- **C = fraction of buoyant TKE generation consumed by entrainment**

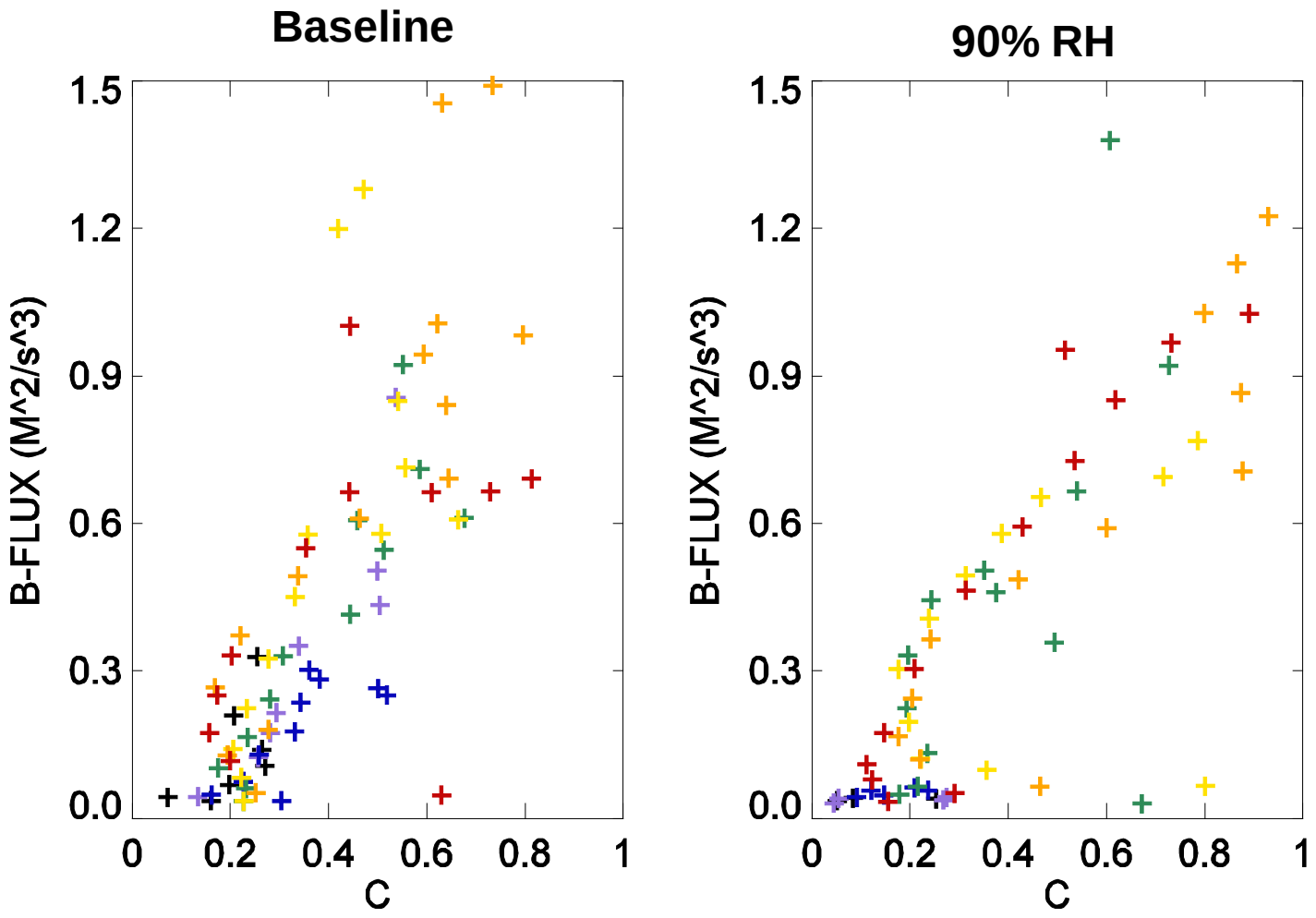
Is it consistent with WRF?

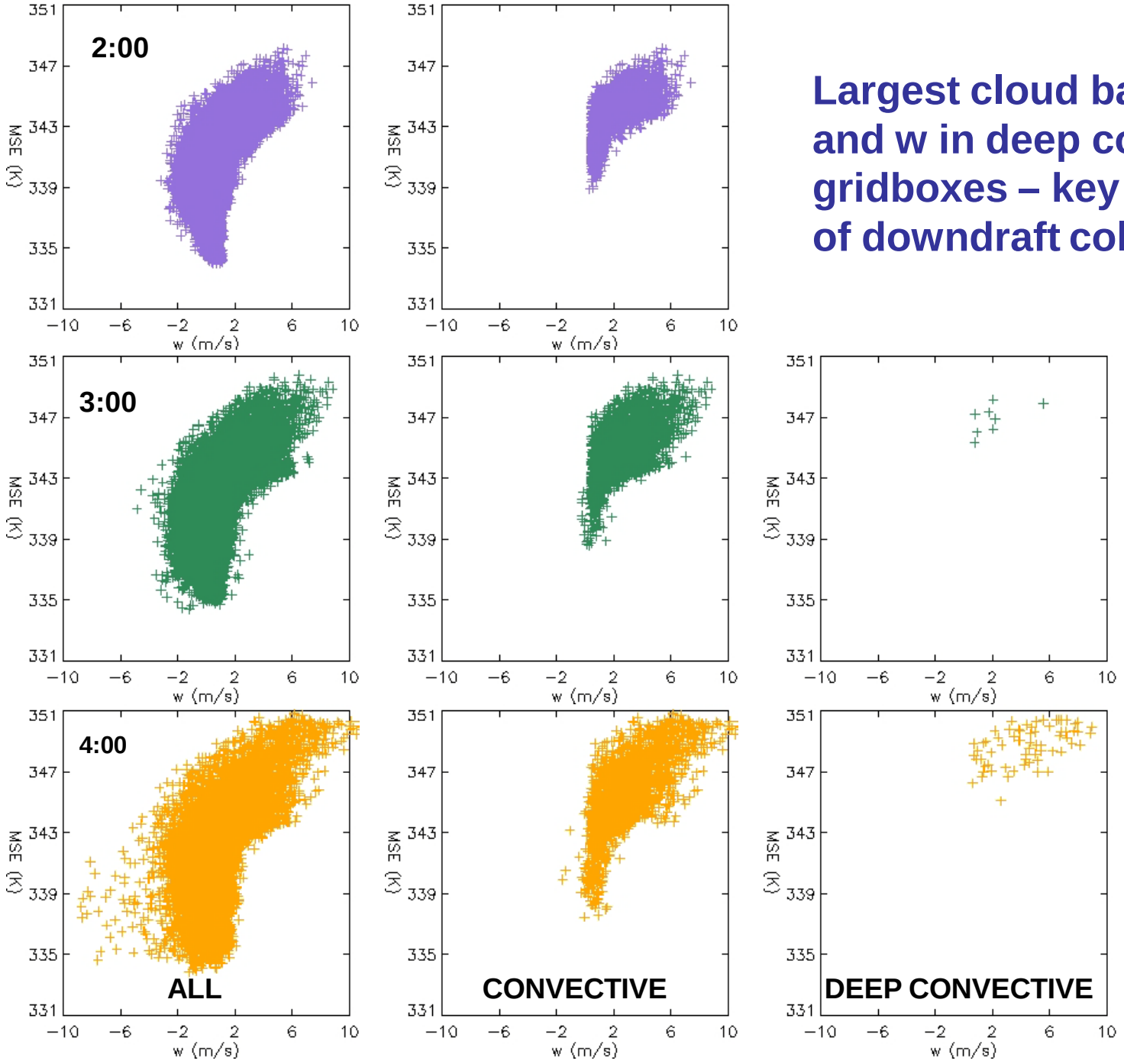


C decreases to top of CBL then increases with height…
but ~ invariant with time or convection depth

What determines C?

C ~linear with buoyancy flux *w'B'* in RH 90% run; smaller C for given buoyancy flux in baseline run – RH effect?

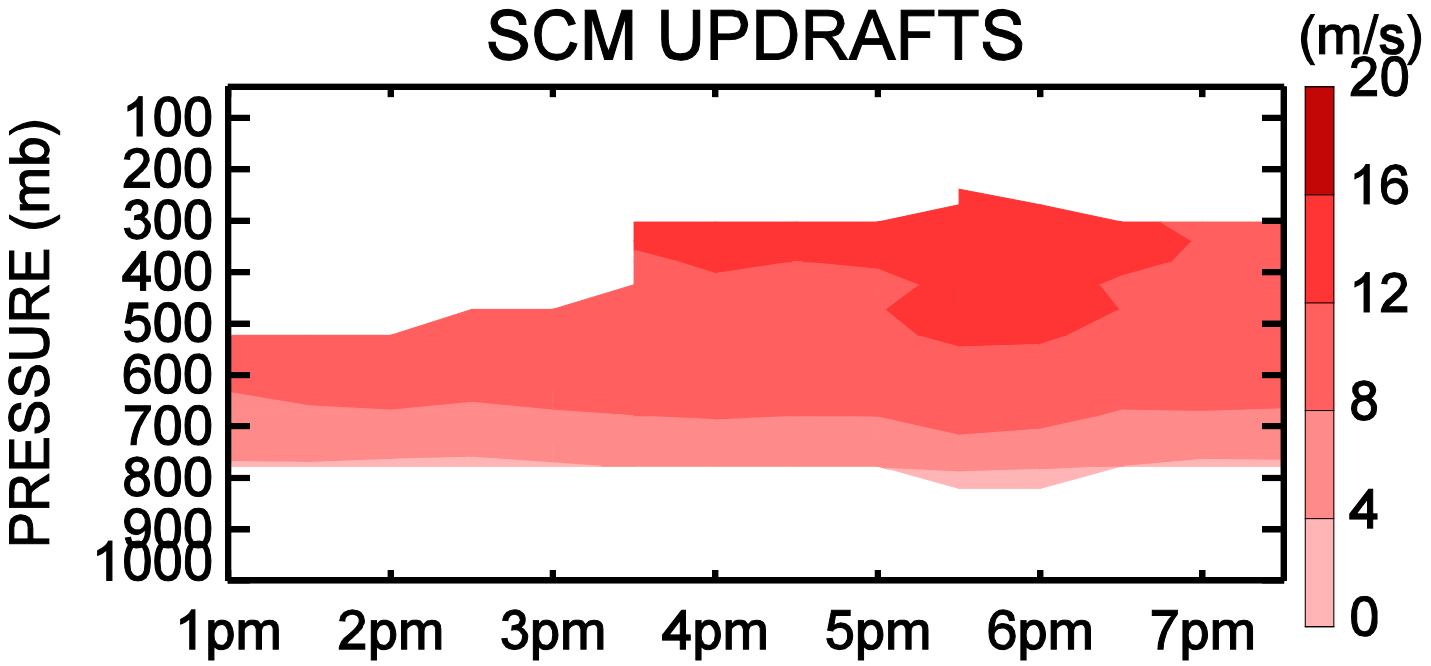




Largest cloud base MSE and w in deep convective gridboxes – key impact of downdraft cold pools?

GISS SCM (initialized with WRF land *T*, convective *q*) with:

- **Gregory updraft speed and entrainment, $C = w'B'/1.8 + 0.4(1 - RH)$**
- **$\delta = \varepsilon - 0.5\, dB'/dz$**
- **Cloud base w increased from TKE-based value to 2.5 m/s by onset of downdraft**



Conclusions

- **Gregory (2001) entrainment parameterization simulates TWP-ICE shallow-deep transition well if % of buoyant energy consumed varies with height**
- **Represented fairly well as function of buoyancy flux, perhaps with *(1 – RH)* correction**
- **Downdraft cold pool effect on cloud base *w* important for smaller entrainment rate of deep convection?**
- **Given realistic *T*, *q*, Gregory entrainment, and cloud base *w* enhanced by onset of downdrafts, SCM simulates transition at about the right time**