CRM tests of PBL-based cumulus mass flux closures

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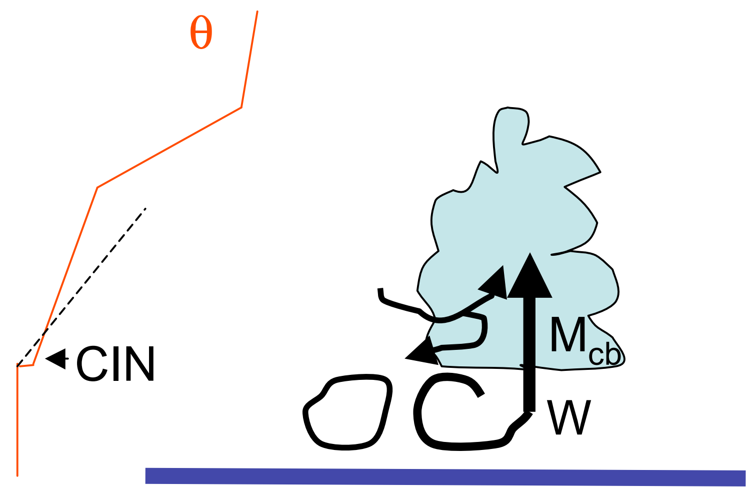
UW Shallow Cu CIN-based mass flux closure

- Cu form above the moistest, strongest boundary-layer updrafts, which have some vertical eddy velocity scale W.
- Convective inhibition (CIN) regulates fraction of these updrafts rising into buoyant Cu:

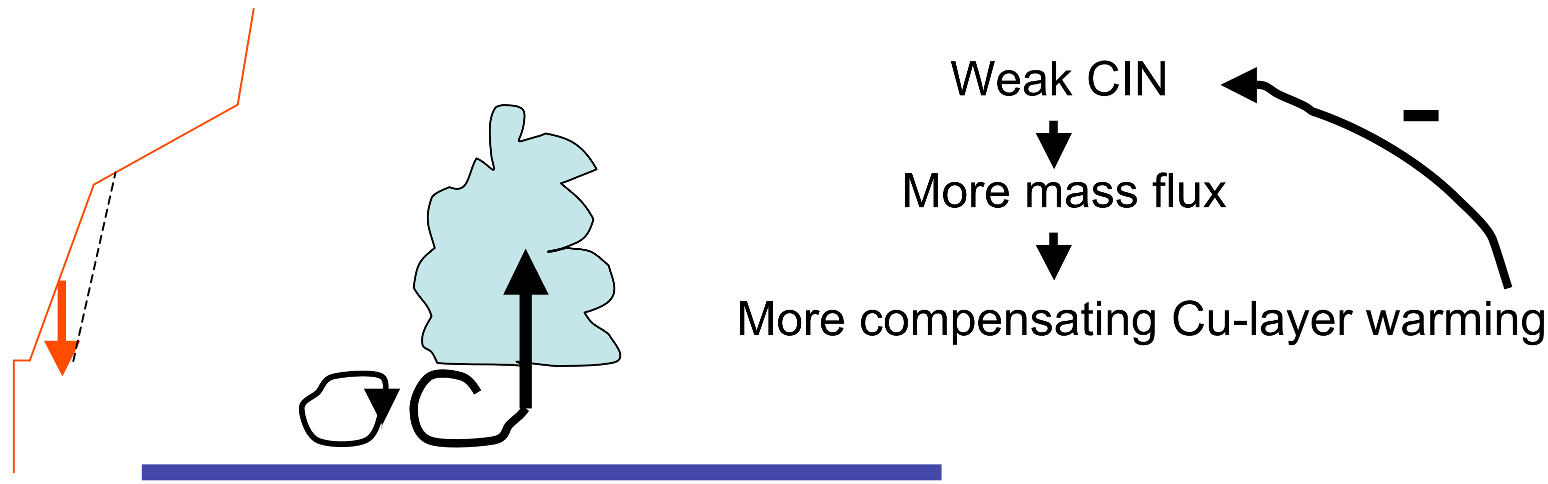
$$M_{cb} = c_1 W \exp(-c_2 \, CIN/W^2)$$

(Bretherton et al. 2004; Mapes 2000)

- Cu vertical structure is separately predicted from Cu-layer thermodynamic profiles.



CIN feedback in cumulus convection

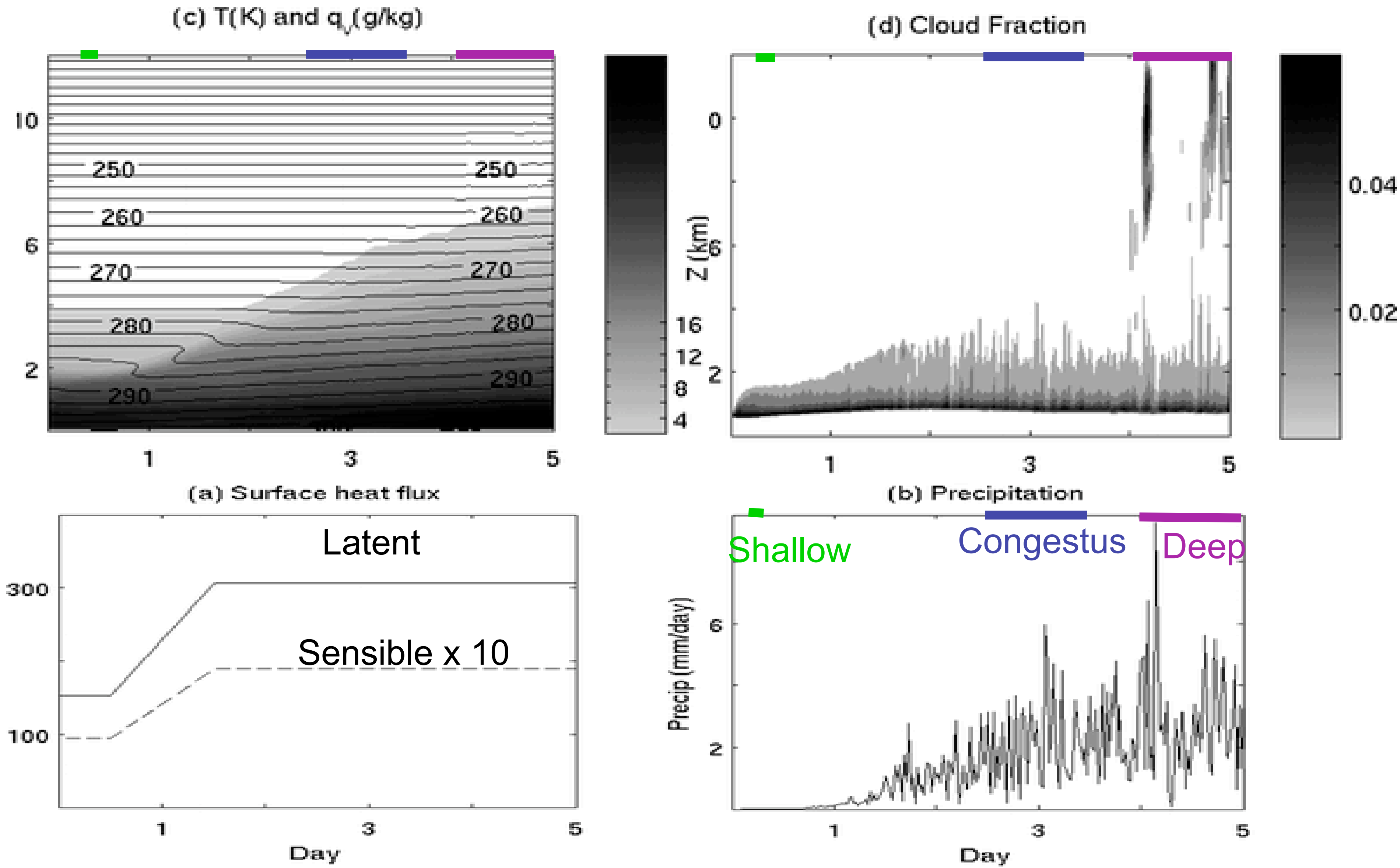


CIN acts as a fast ‘valve’ adjusting cloud base mass flux to keep Cu base near the subcloud layer top.

With slowly-varying surface/large-scale forcings, the Cu-layer thermodynamic and mass flux profiles evolve naturally into a quasi-equilibrium dependent on the cumulus plume model: No need for CAPE closure.

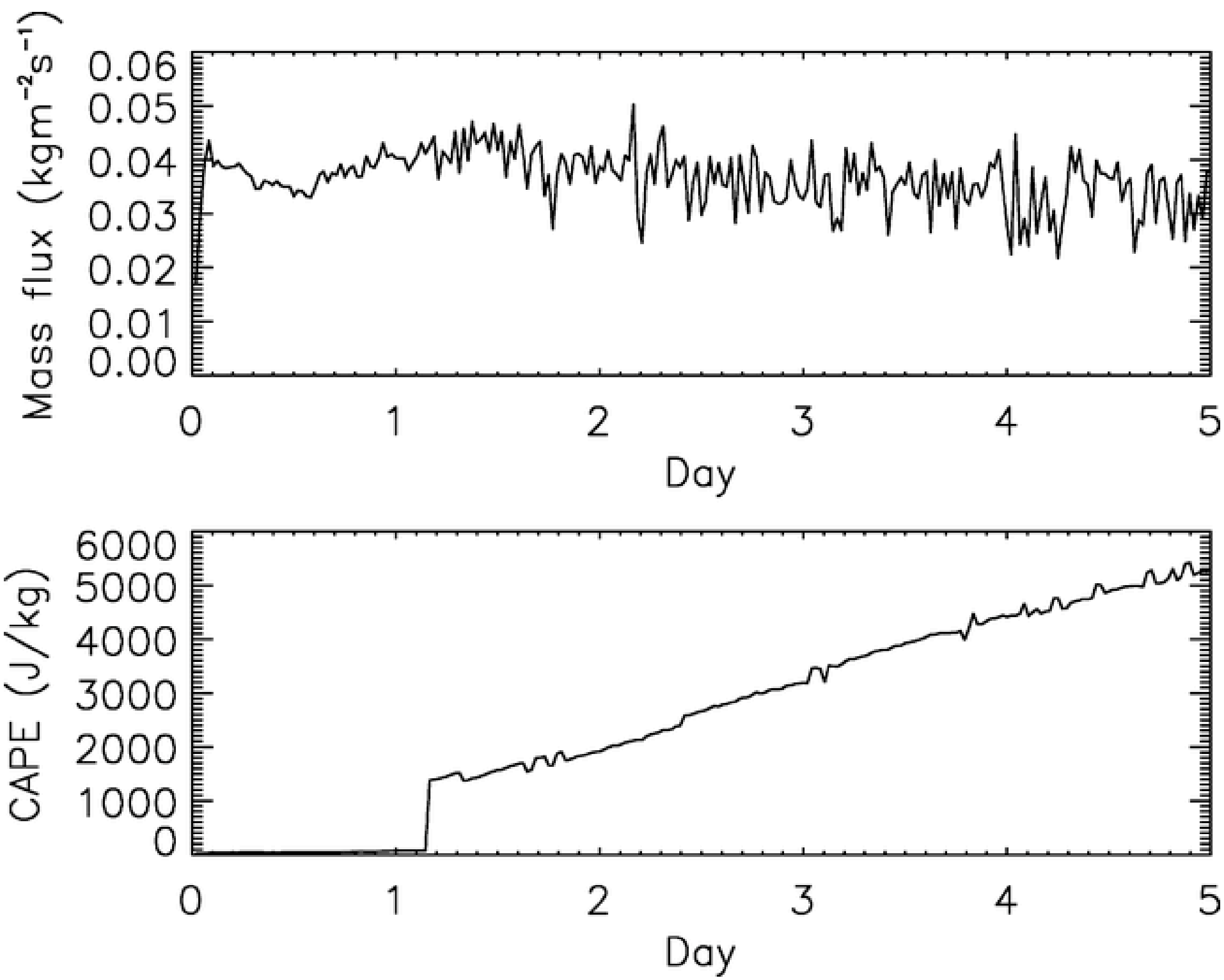
Does this conception work for deep convection?

Kuang and Bretherton (2006): CRM-simulated shallow-to-deep Cu transition



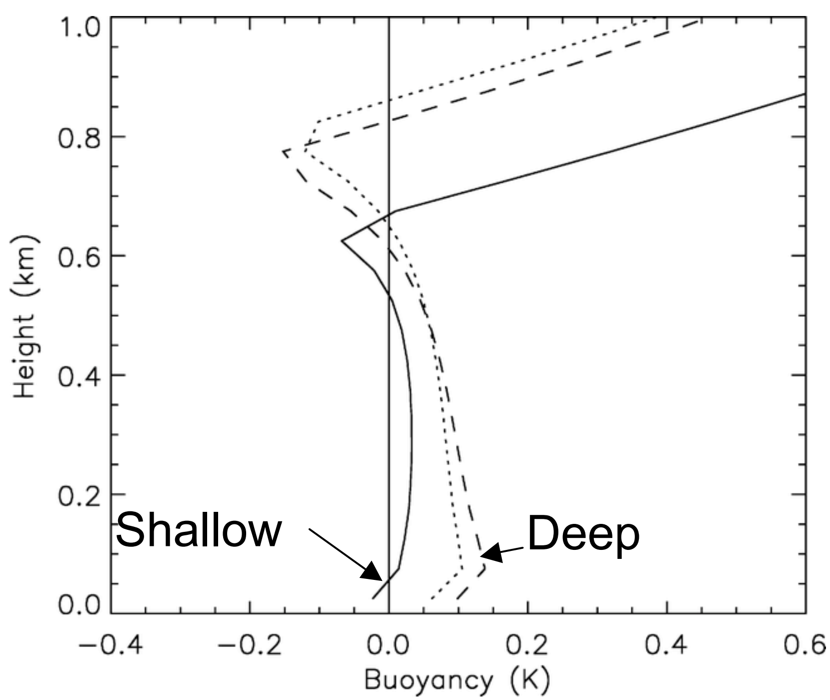
Cloud base mass flux closure

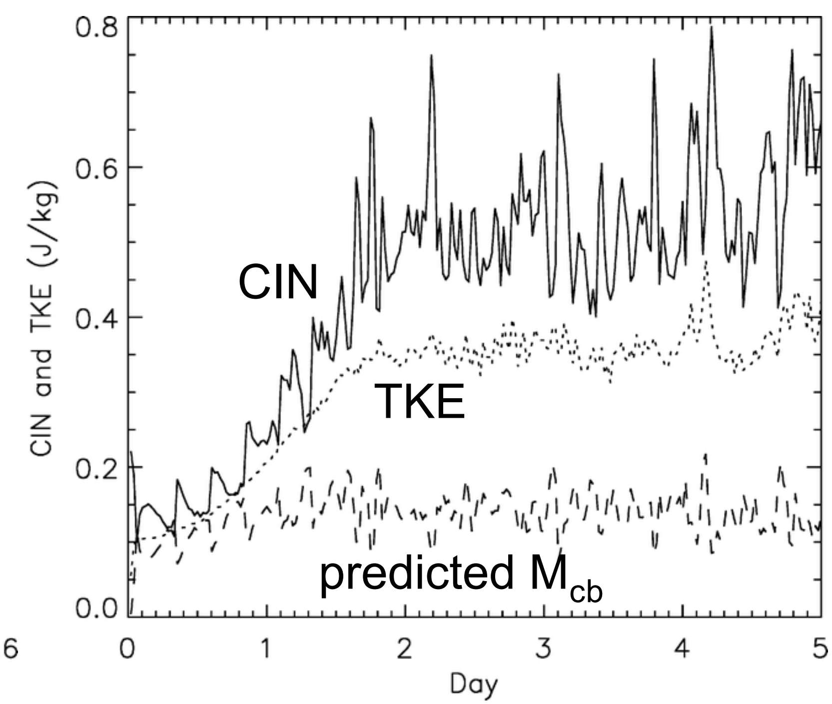
- Mass flux quasi-constant through simulation, but not CAPE.



CIN regulation of mass flux

- CIN present in all 3 regimes (based on mean sounding and adiabatically displacing mean cloud base air parcel).
- Nicely follows $M_{cb} = c_1 W \exp(-CIN/W^2)$, $W^2 = TKE_{PBL}$

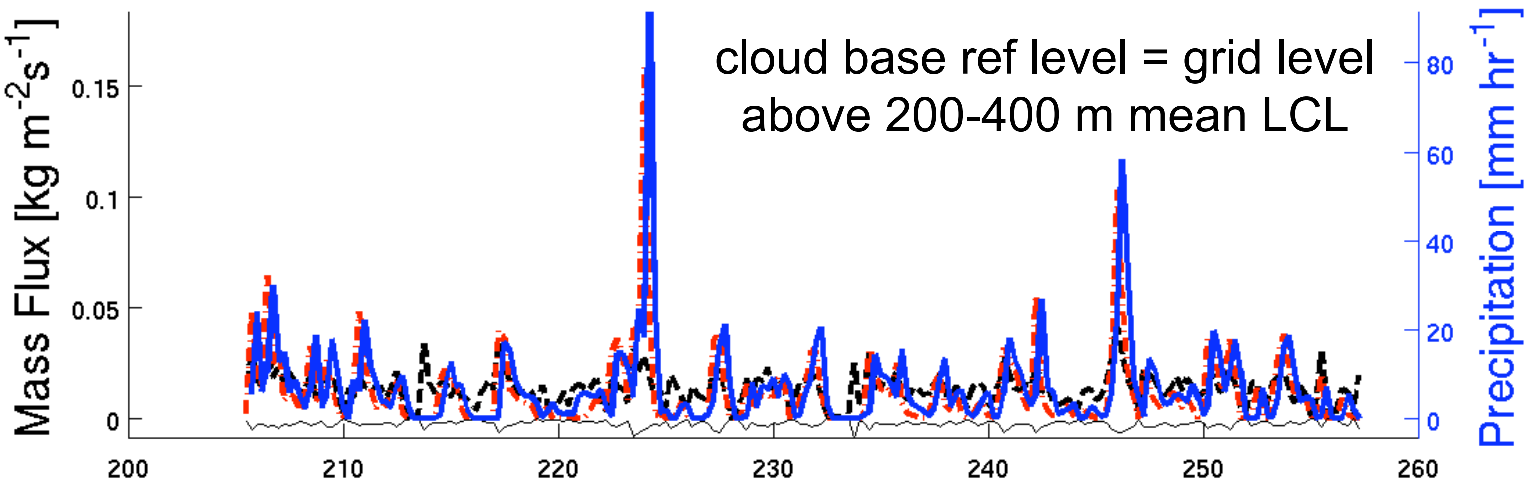




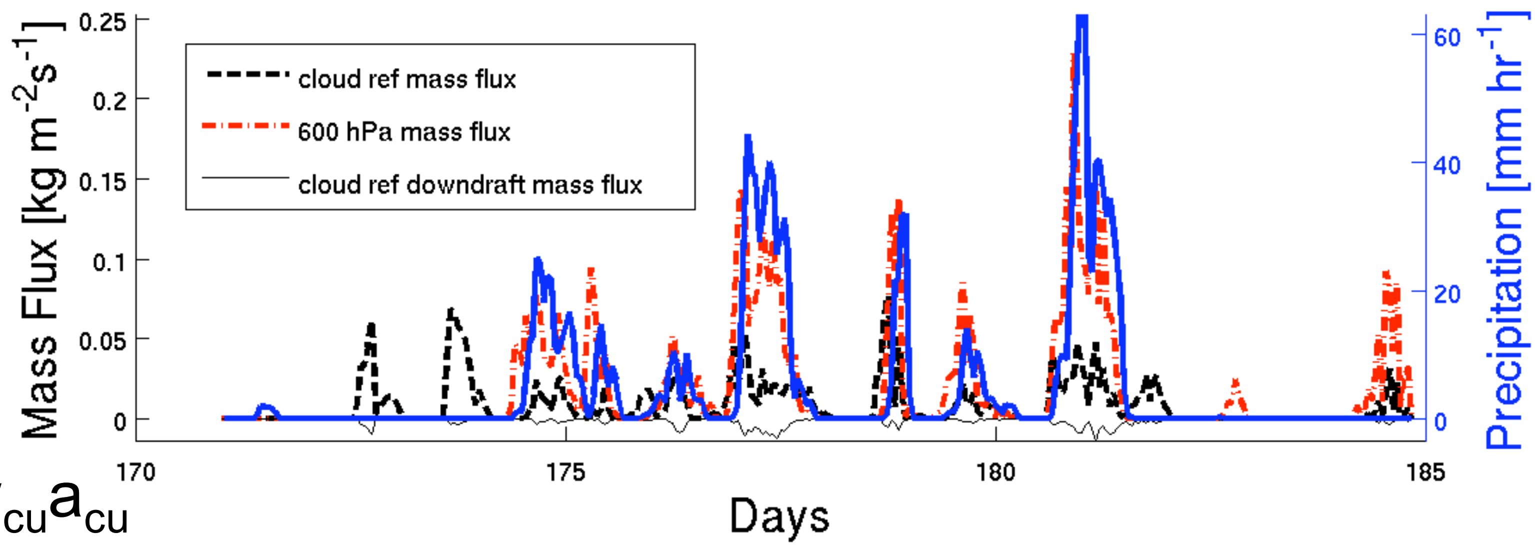
...but convection not that deep or rainy, and case is idealized.

Two CRM-simulated ‘real’ deep Cu cases

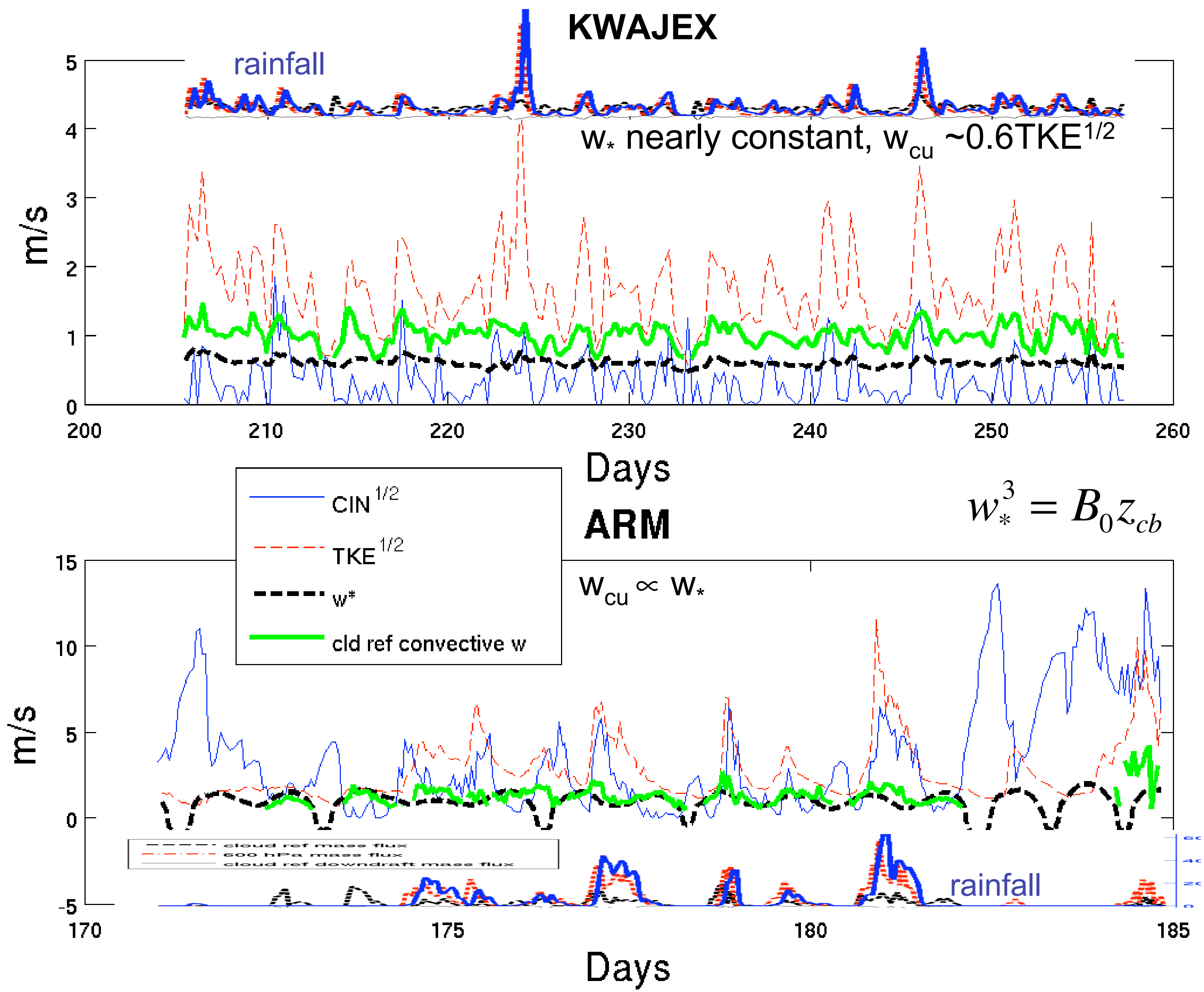
Tropical oceanic KWAJEX 256x256x64, Δx = 1 km



Summertime continental ARM 192x192x96, Δx = 1 km

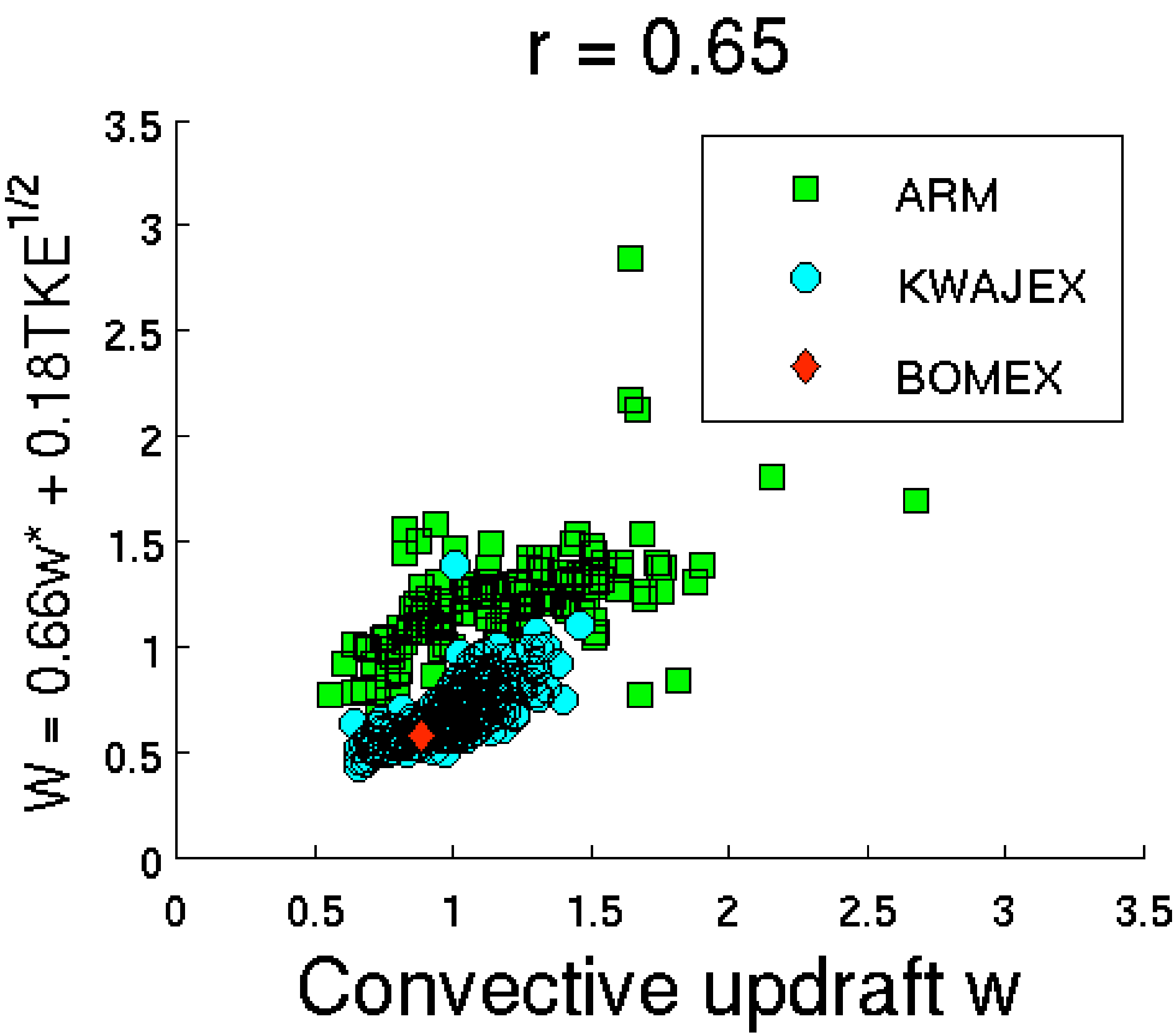


$M_{cu} = w_{cu}a_{cu}$

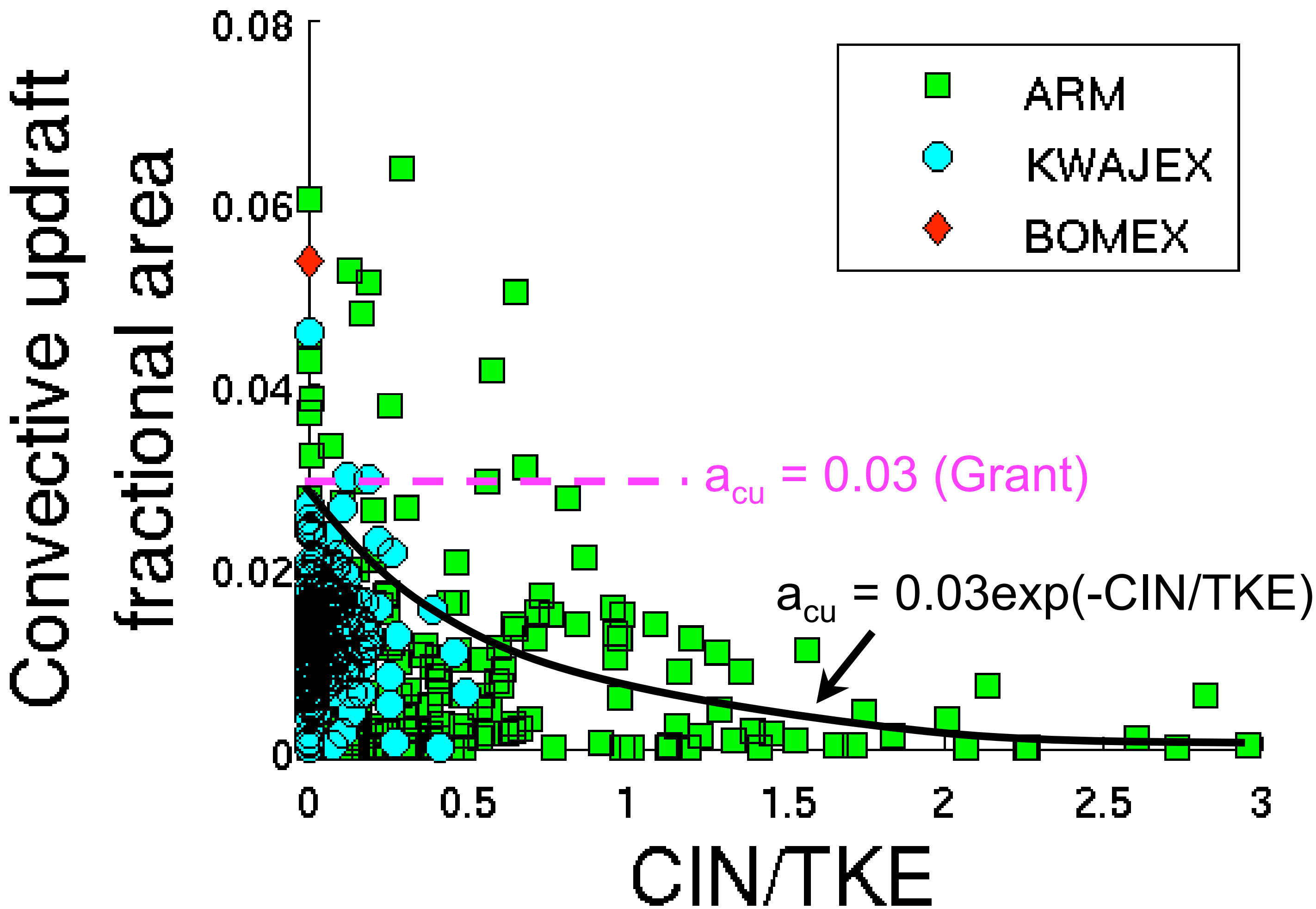


KWAJEX
rainfall
w_* nearly constant, w_{cu} ~0.6TKE$^{1/2}$
m/s
Days
CIN$^{1/2}$
TKE$^{1/2}$
w*
cld ref convective w
ARM
$w_*^3 = B_0 z_{cb}$
$W_{cu} \propto W_*$
cloud ref mass flux
600 hPa mass flux
cloud ref downdraft mass flux
rainfall
m/s
Days

Updraft W best predicted using both w_* and $TKE^{1/2}$



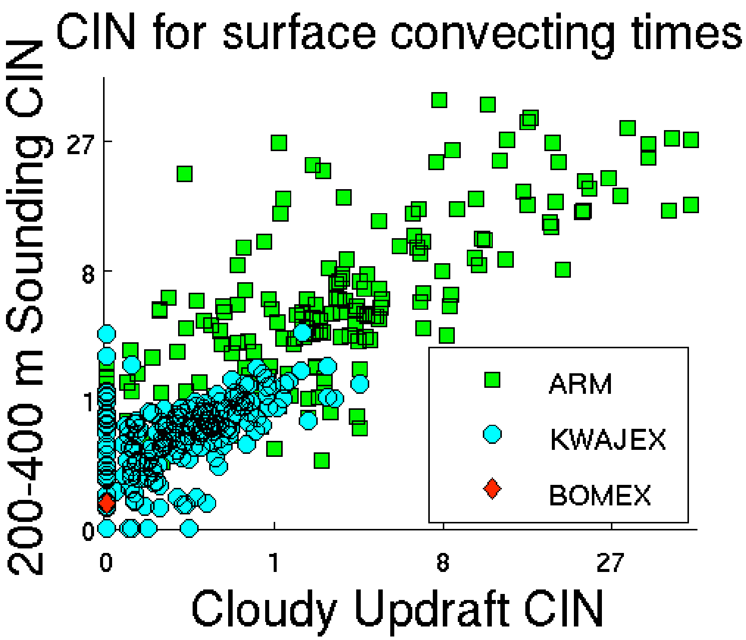
Surface Convection times only

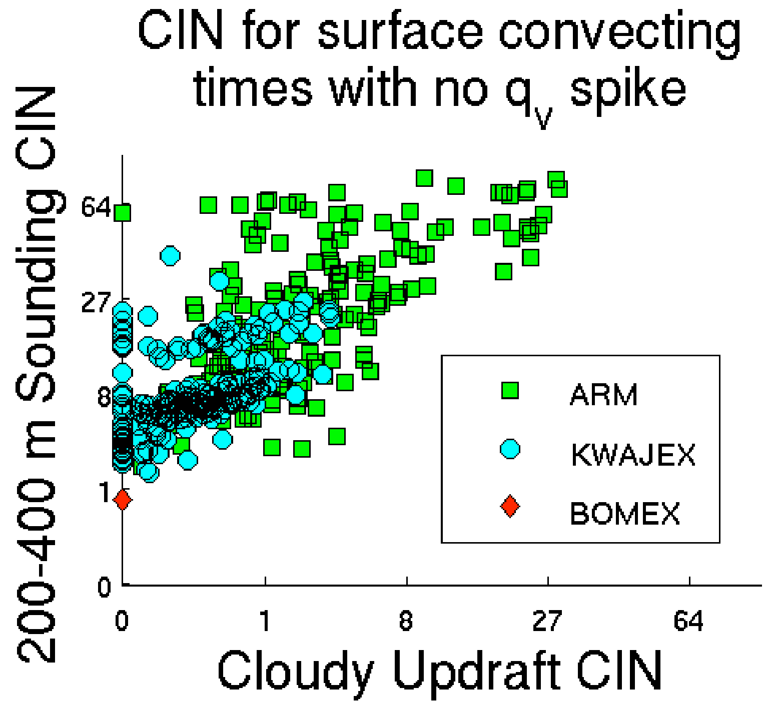


Predicting cloudy updraft CIN

- Empirically, 200-400 m level works better than near-surface air for predicting cloudy updraft properties:

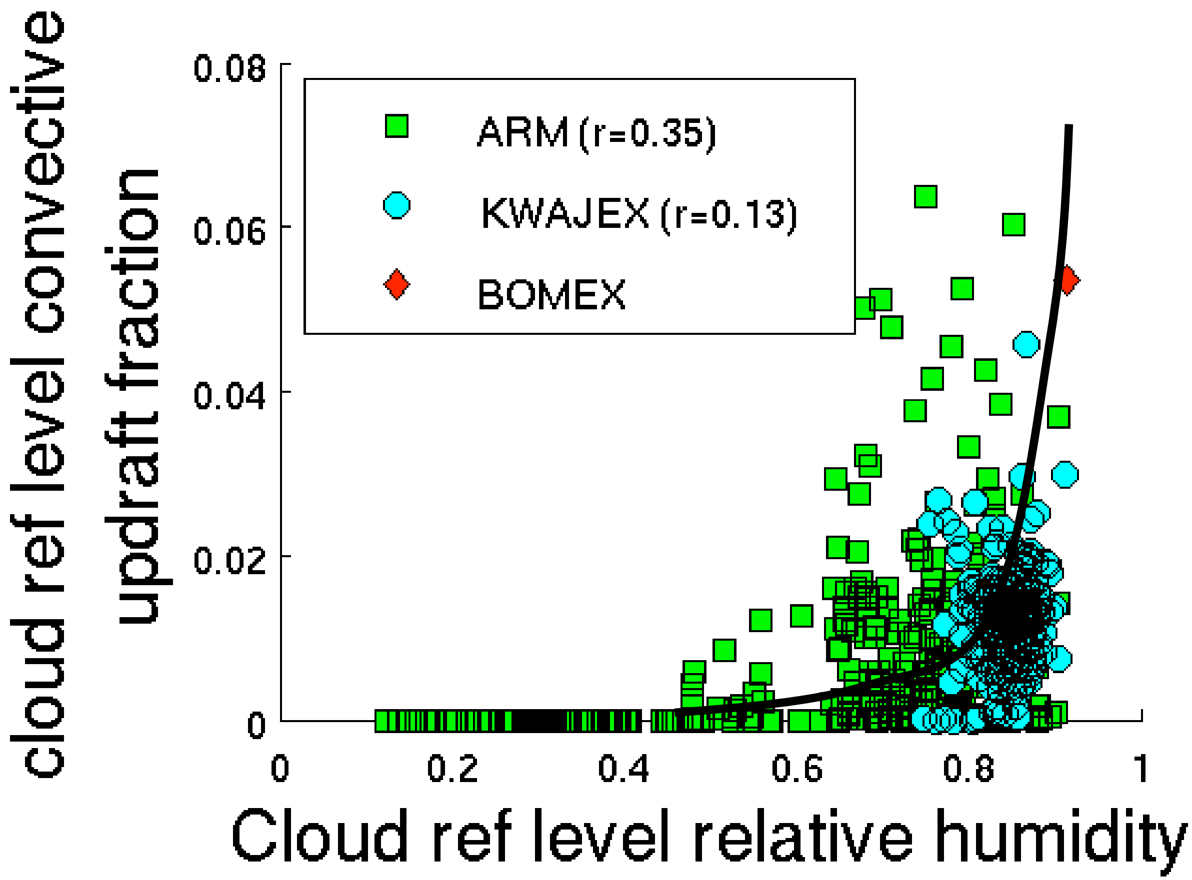
$$\theta_{cu} \sim \theta_{200\text{-}400}, \quad q_{cu} \sim q_{200\text{-}400} + \sigma_q$$





Cloud fraction consistency

Simulated cases show a consistent relation between RH and cloudy updraft area fraction near cloud base.



A typical diagnostic cloud scheme coupled to a CIN-based mass-flux scheme may not enforce this consistency.

Conclusions

- CIN-based closure appears viable for deep convection.
- A plausible approach is:

  $M_{cu} = w_{cu}\, a_{cu}$

  $W_{cu} = b_1 w_* + b_2 TKE^{1/2}$

  $a_{cu} = 0.03 \exp(-c_2 CIN_{cu}/W_{cu}^2)$ or $f(RH_{cb}) \exp(-c_2 CIN_{cu}/W_{cu}^2)$

  UWShCu uses the first of these, with b_1=0, b_2=1, c_2=1.

- Care is required to ensure the computation of cloud fraction is consistent with the computation of cumulus updraft fraction near the cumulus base.