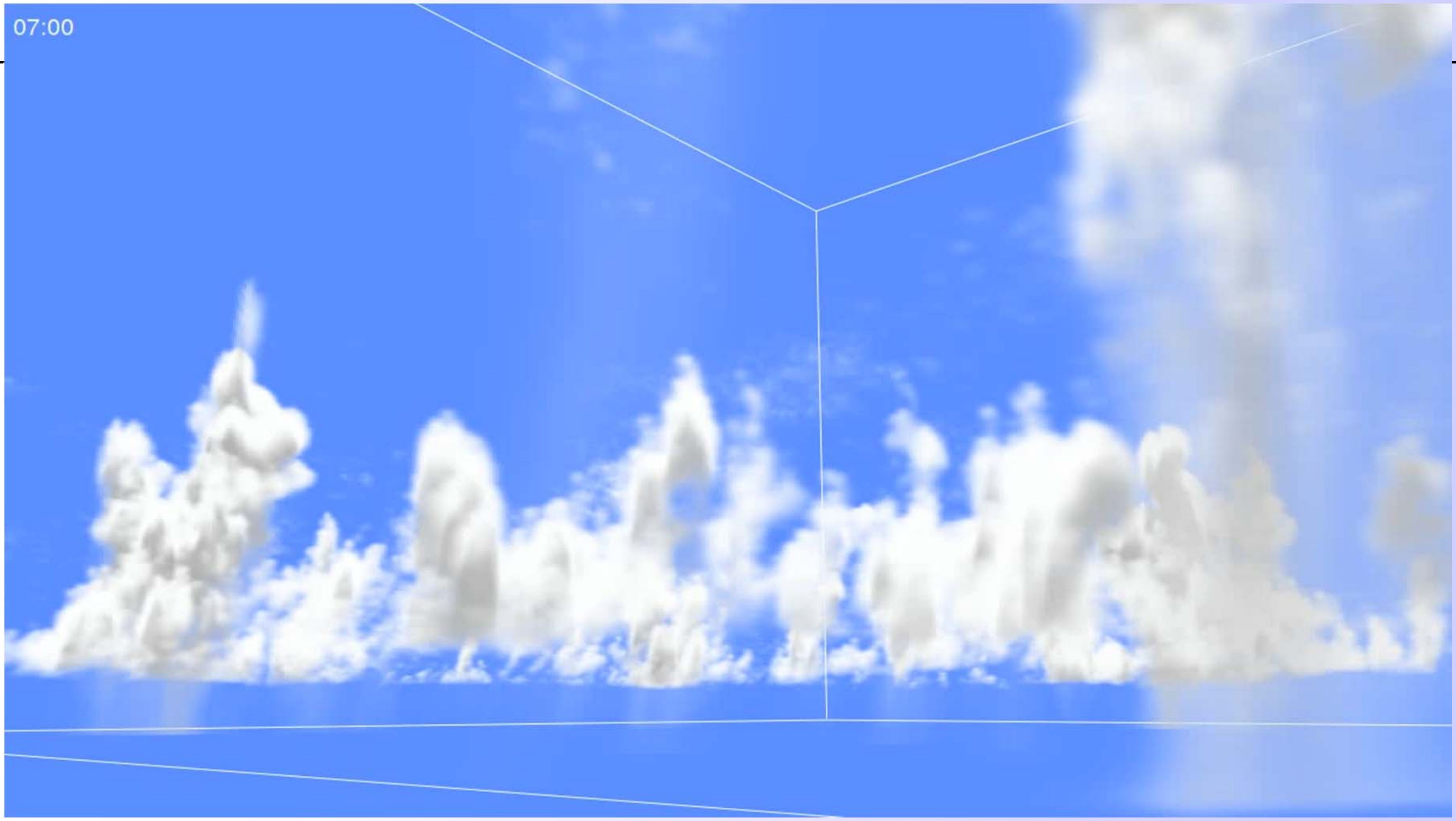
The role of tropospheric humidity and stability on the detrainment of deep convection.
"Entrainment, but what about Detrainment?"



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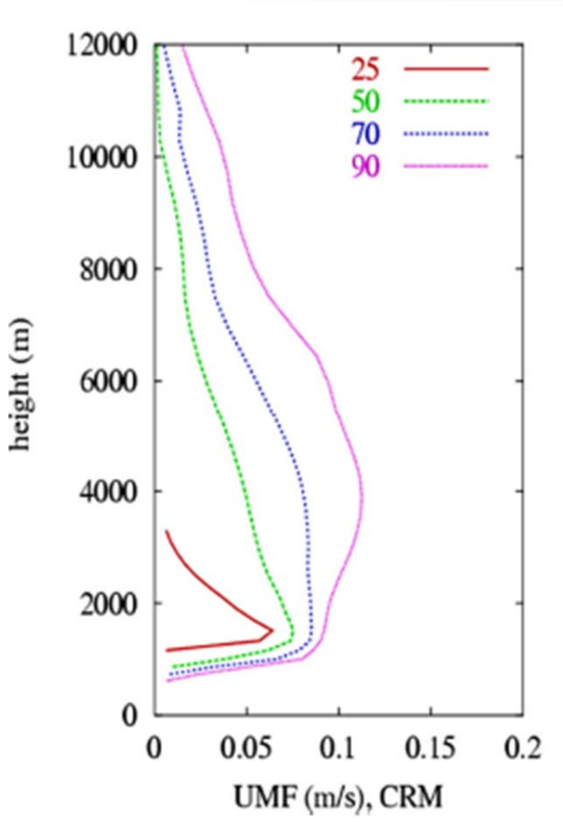
Delft University of Technology

KNMI

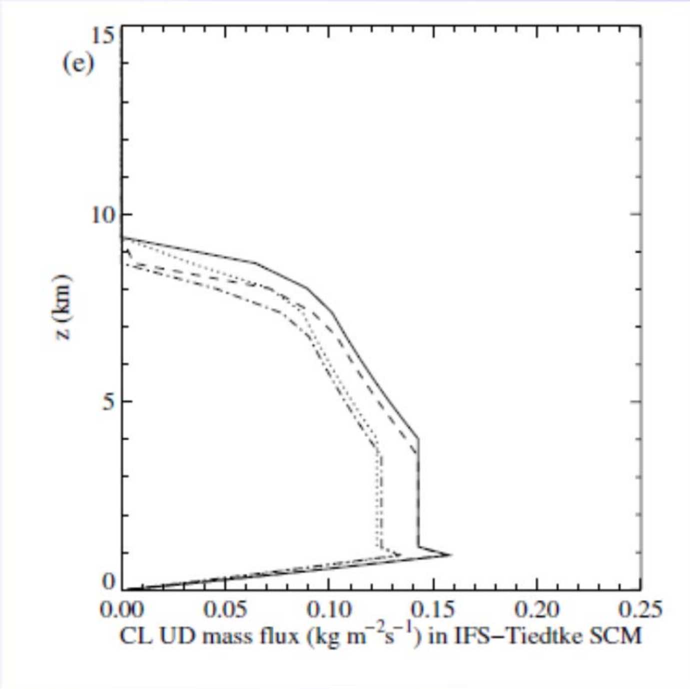
Motivation

Derbyshire et al. QJRMS (2004)

CRM



Single Column Model
(ECMWF) 2004



New ECMWF entrainment parameterization (Bechtold 2008 QJRMS)

$$\varepsilon = \varepsilon_0 \left(1.3 - RH(z)\right) f_{scale}$$

Larger entrainment rates: lower cloud top height.

Is this justified?

Kain_Fritsch mixing (1) (Kain Fritsch JAS1990)

$$\frac{\partial}{\partial z}\ln M = \epsilon - \delta$$

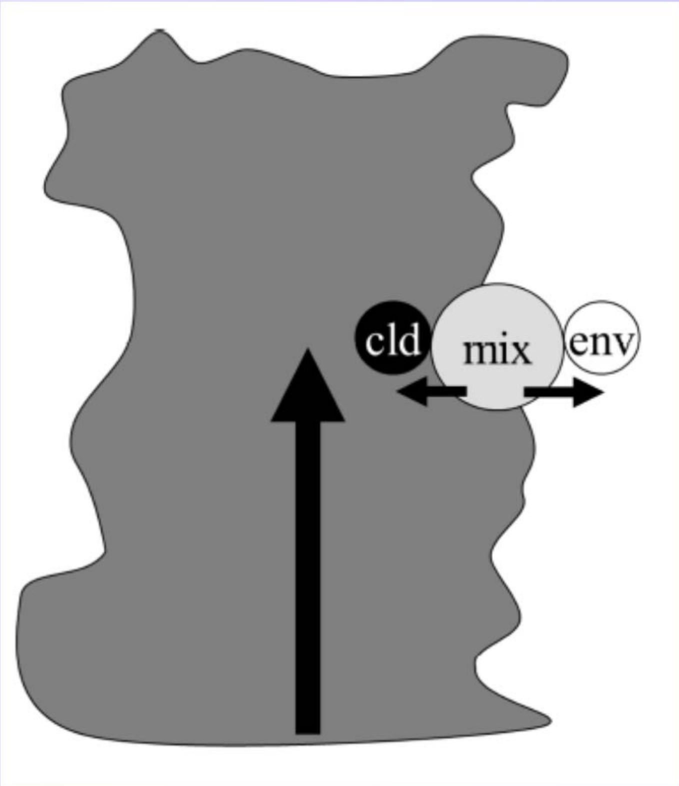
- Fractional inflow rate ε_0

- Assume uniform distribution of all possible mixtures

(Bretherton et al. MWR 2004,

Raymond & Blyth JAS 86)

- Entrainment/Detrainment rate dependent on buoyancy

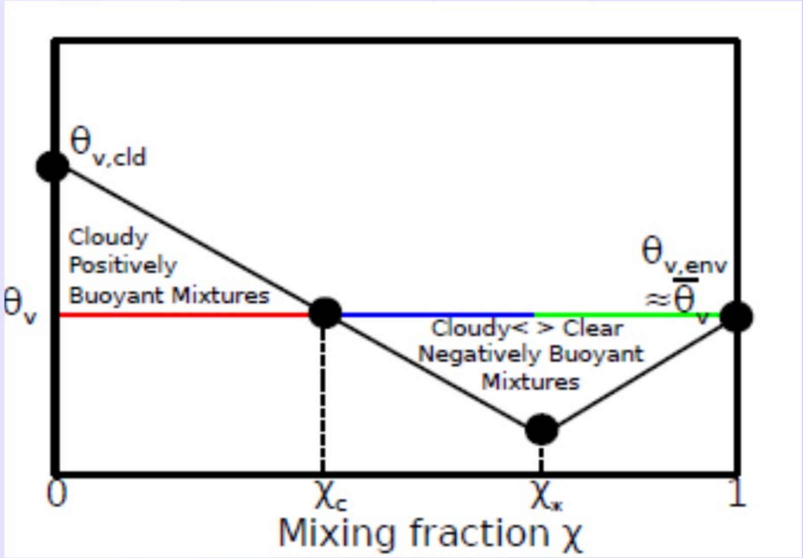


Kain_Fritsch mixing (2) (Kain Fritsch JAS1990)

$$\epsilon = 2\int_0^{\chi_c} \chi p(\chi) d\chi = \epsilon_0 \chi_c^2$$

$$\delta = 2\int_{\chi_c}^{1} (1-\chi) p(\chi) d\chi = \epsilon_0 (1-\chi_c)^2$$

$$\frac{\partial}{\partial z} \ln M = \epsilon_0 (2\chi_c - 1)$$



$$\chi_c = (c_p \pi / L) \frac{\Delta\theta_v}{q_{se}(\beta - \alpha)(1 - RH) - \alpha q_{\ell u}}$$

$\Delta\theta_v \uparrow \;=>\; \chi_c \uparrow$

$RH \uparrow \;=>\; \chi_c \uparrow$

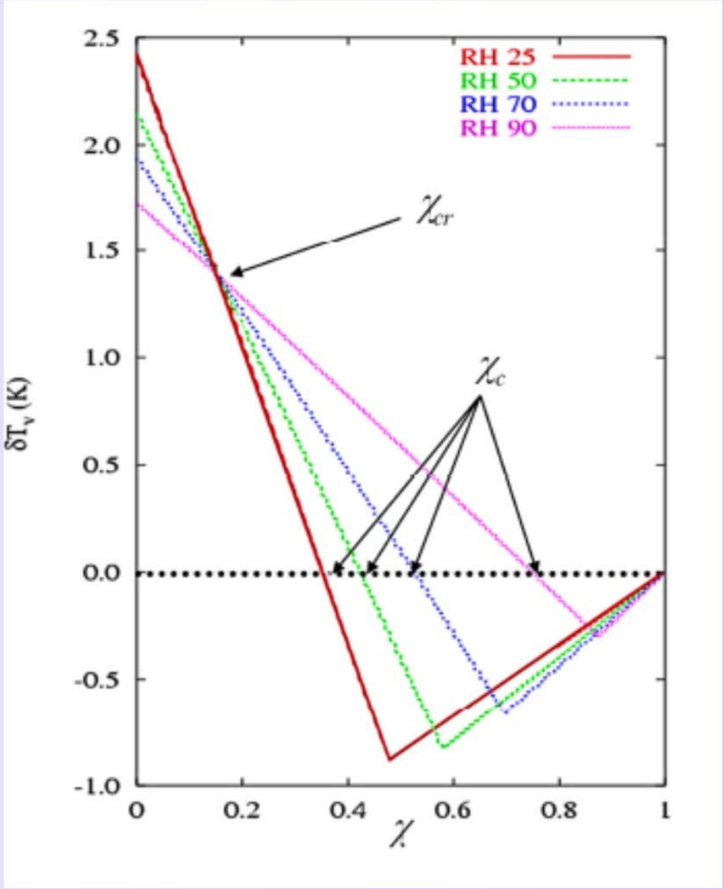
De Rooy and Siebesma MWR 2008

Incorrect sensitivity for entrainment in plume models

- ~~$\epsilon = \epsilon_0 \chi_c^2$~~

Larger RH => larger χ_c => higher entrainment => lower cloud top

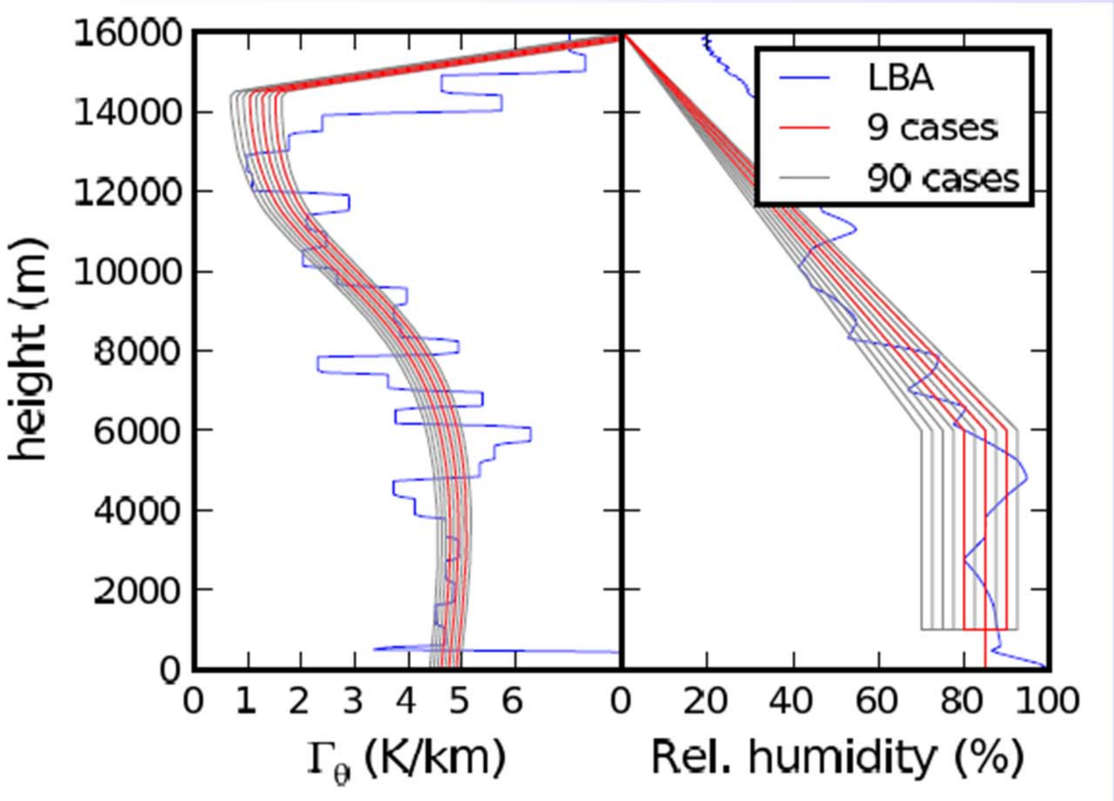
But what about detrainment...?



Msc thesis Sander Jonker (2004)

Deep Convection: the case

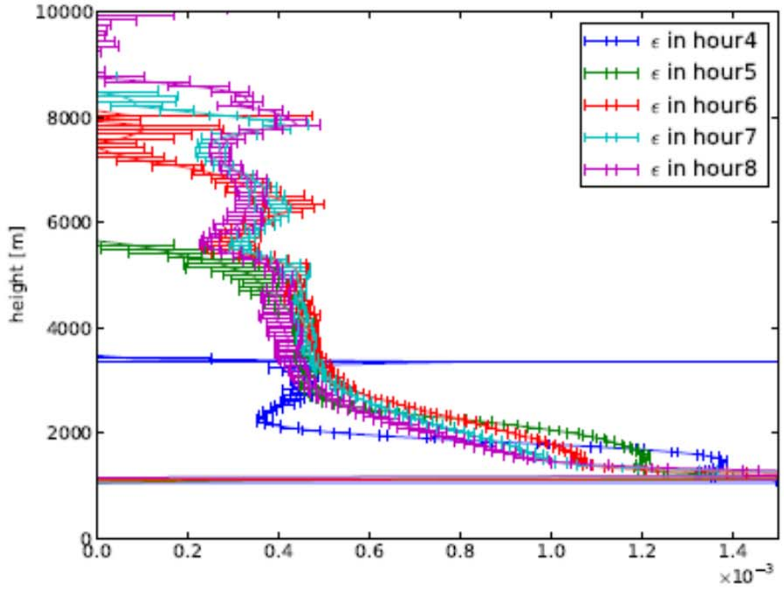
Similar set up as in: Wu, Stevens, Arakawa JAS 2009



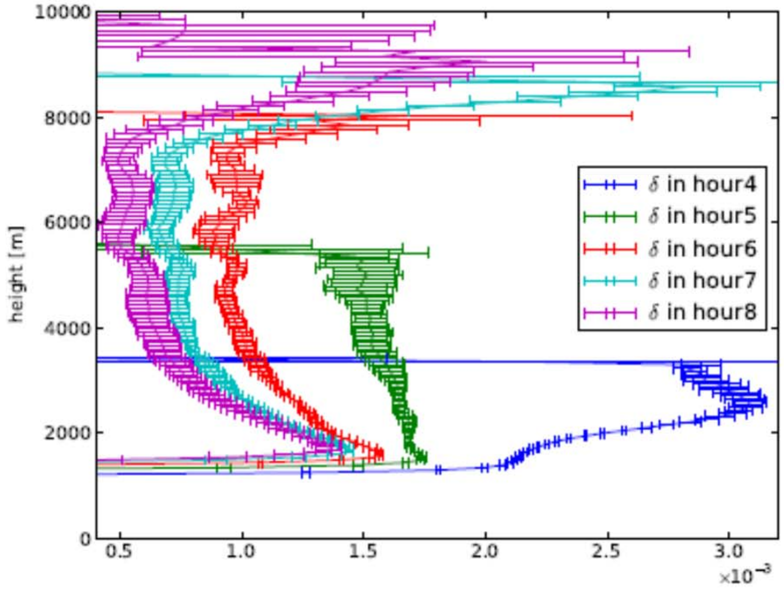
- Domain Size 75X75X25km
- $\Delta x = \Delta y = 150m$ $\Delta z = 40 \sim 190m$
- Fixed surface fluxes:
  - LHF ~350W/m2
  - SHF ~150W/m2
- No windshear
- No radiation

Most cases repeated 5 times with different random initialisation (200 similations)

Time evaluation of entrainment and detrainment



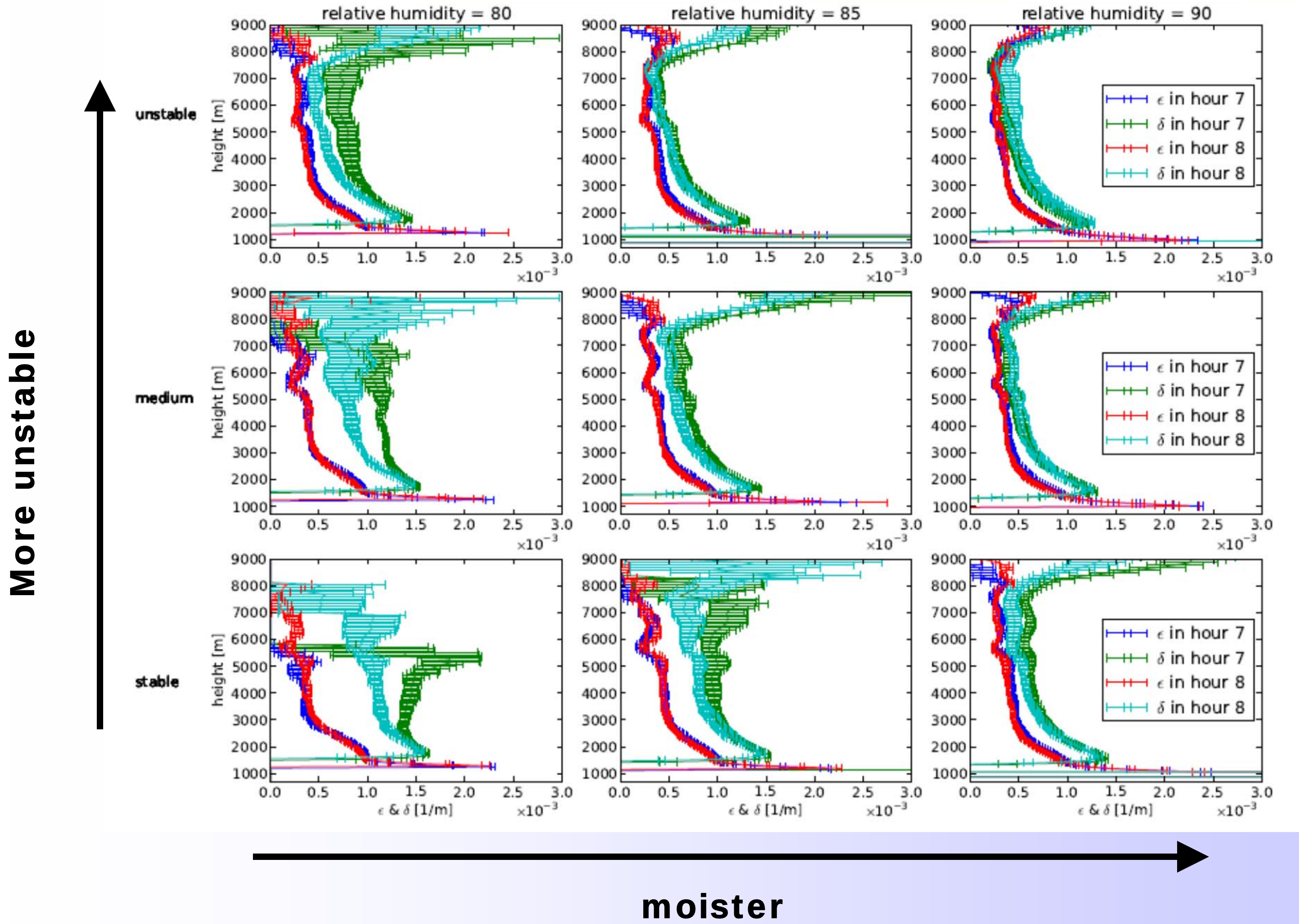
(a) entrainment



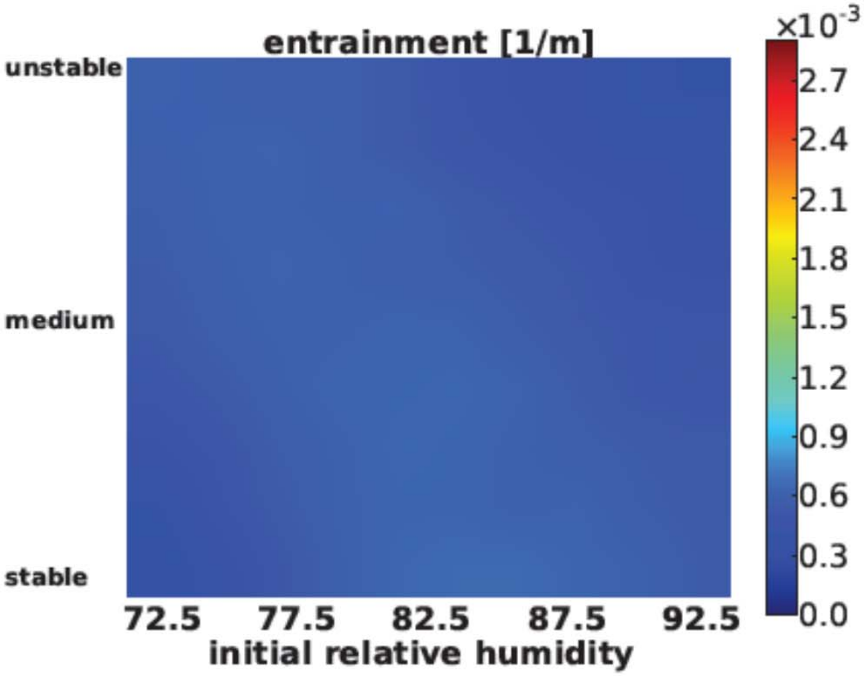
(b) detrainment

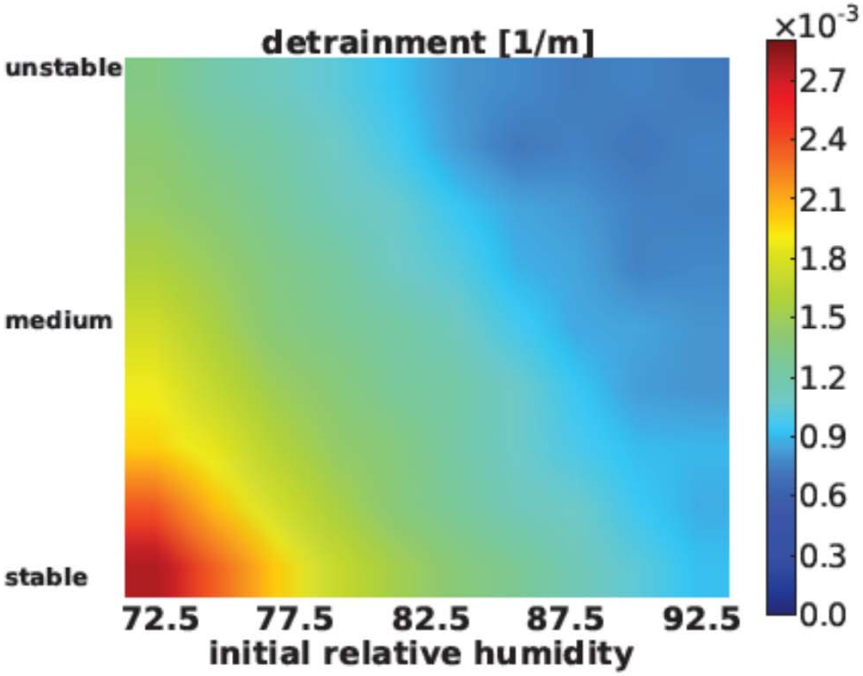
Concentrate on 7th and 8th hour

entrainment and detrainment (hour 7 & 8)



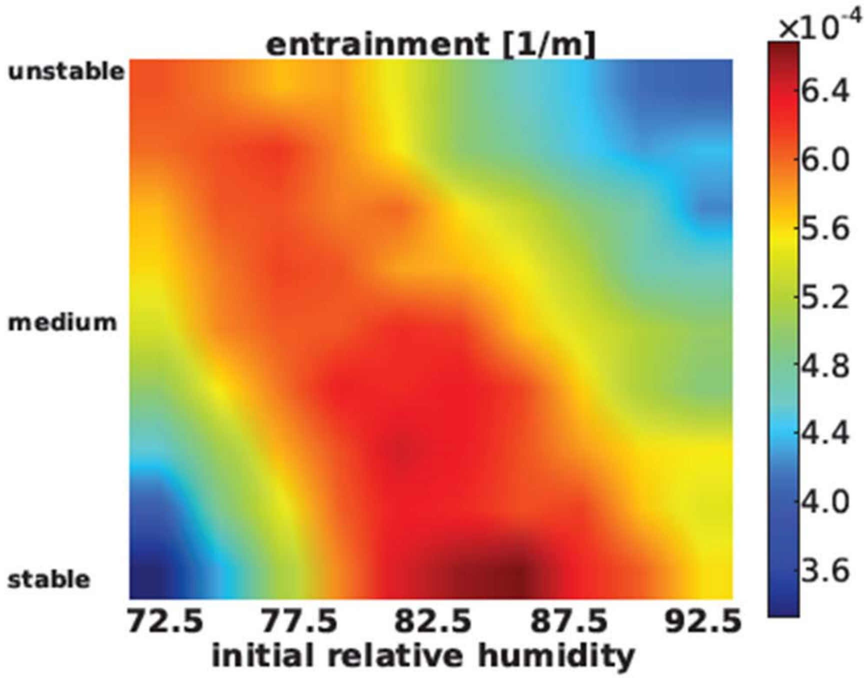
entrainment and detrainment (2000~3000m)

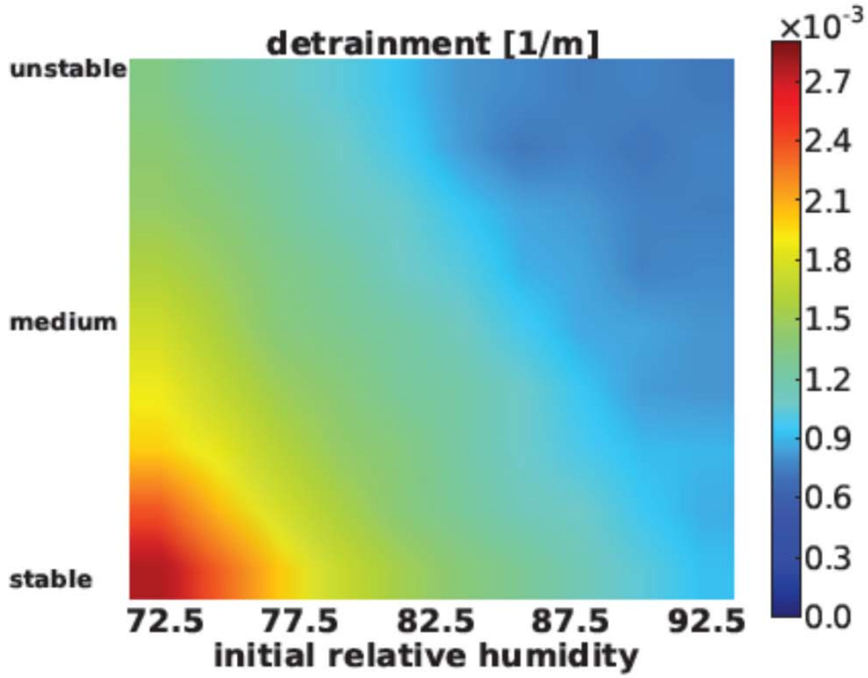




- Detrainment decreases with increasing humidity
- Detrainment decreases with increasing instability
- Variations of Entrainment small……..compared with the variations of detrainment

entrainment and detrainment (2000~3000m)

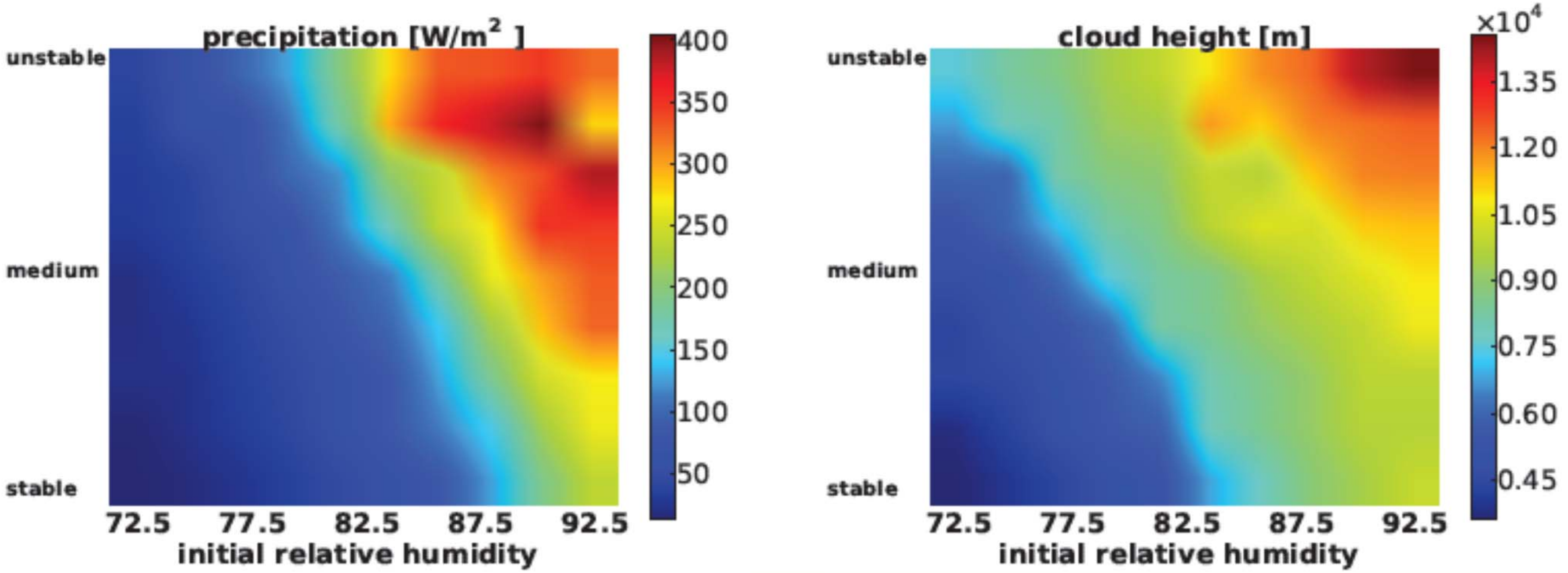




•Entrainment decreases with increasing RH, instability …. But differences are much smaller

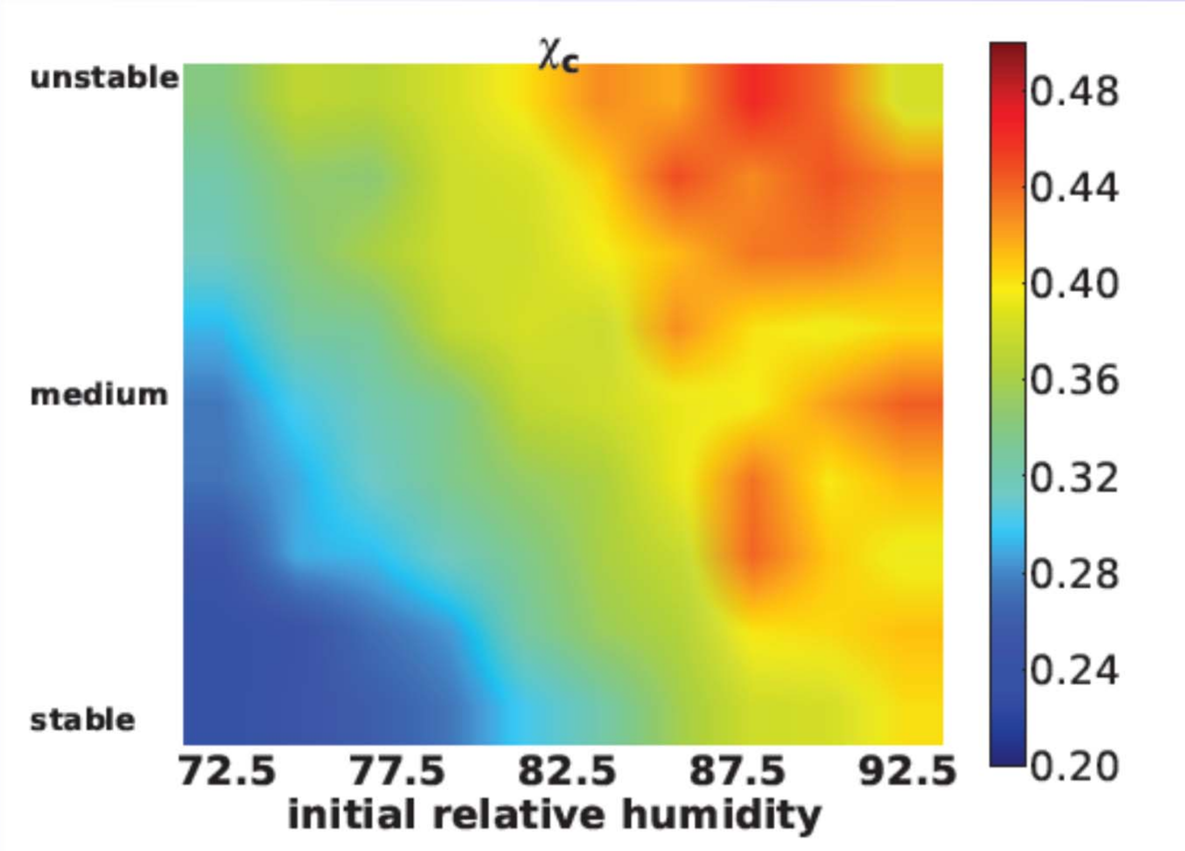
precipitation and cloud top height

Cloud height ~ 0.01 M_{max}



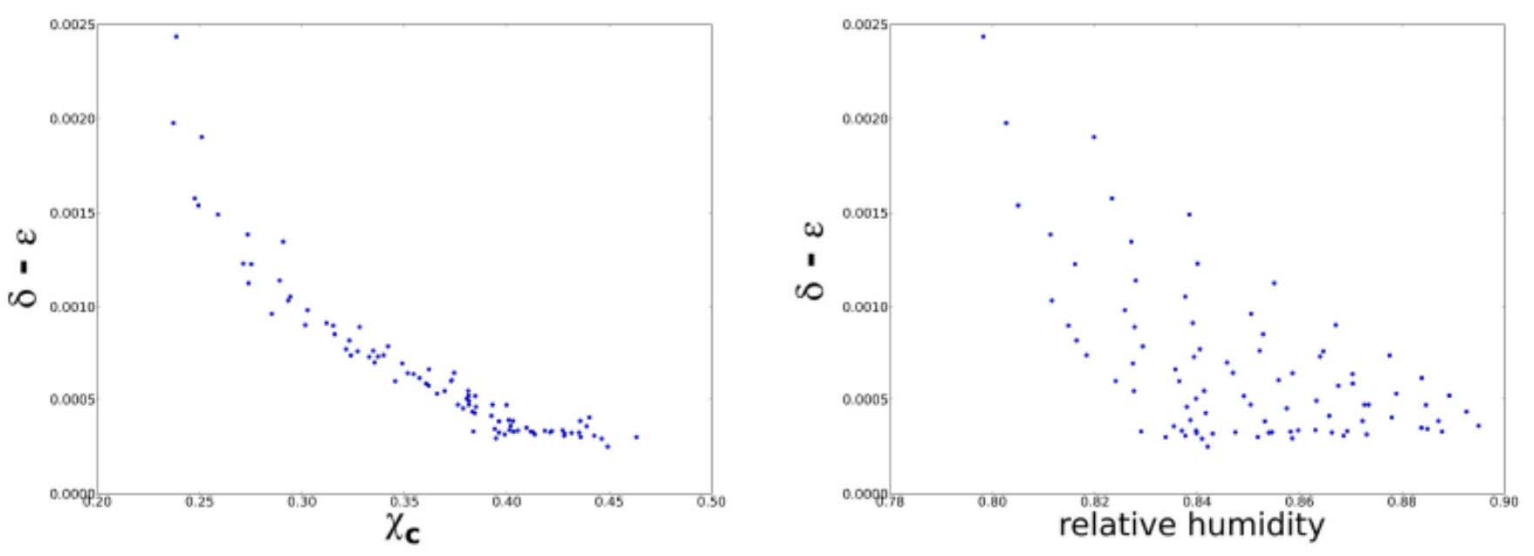
Precip , cloud top height increase with increasing RH, instability

How about χ_{crit} (2~3km)?



χ_{crit} as the key parameter (2~3km)

$$\frac{\partial}{\partial z} \ln M = \epsilon - \delta$$

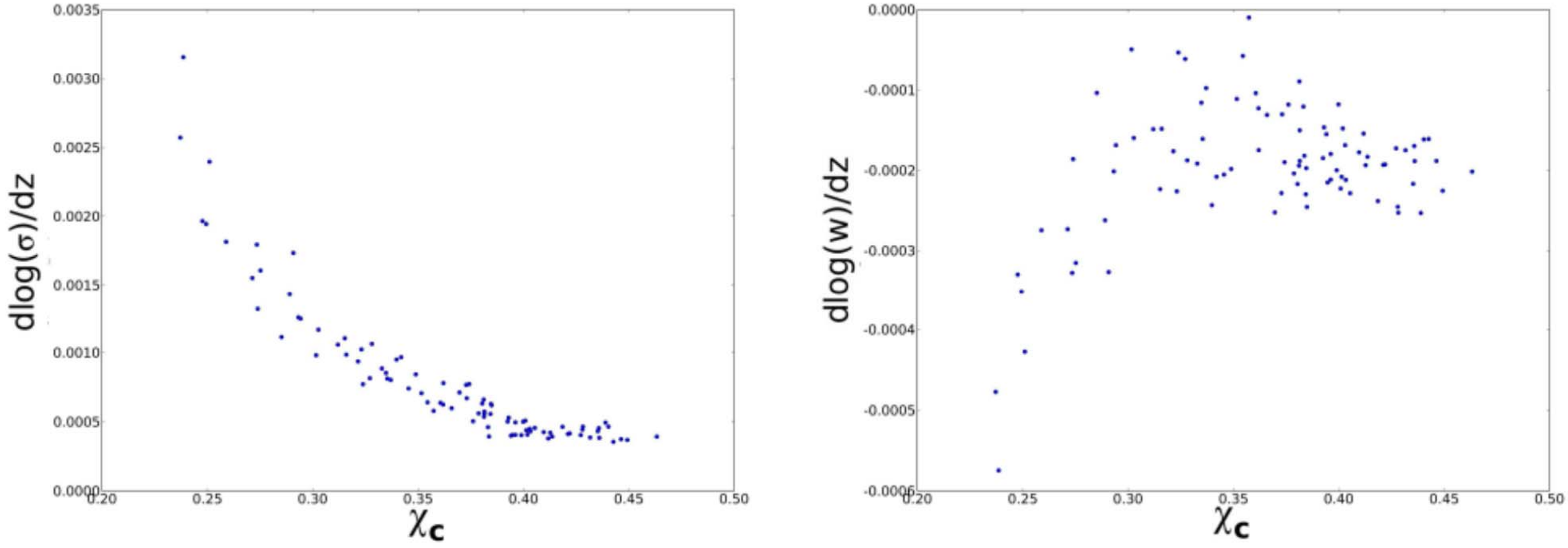


$$M \equiv \rho_0 \sigma w_c$$

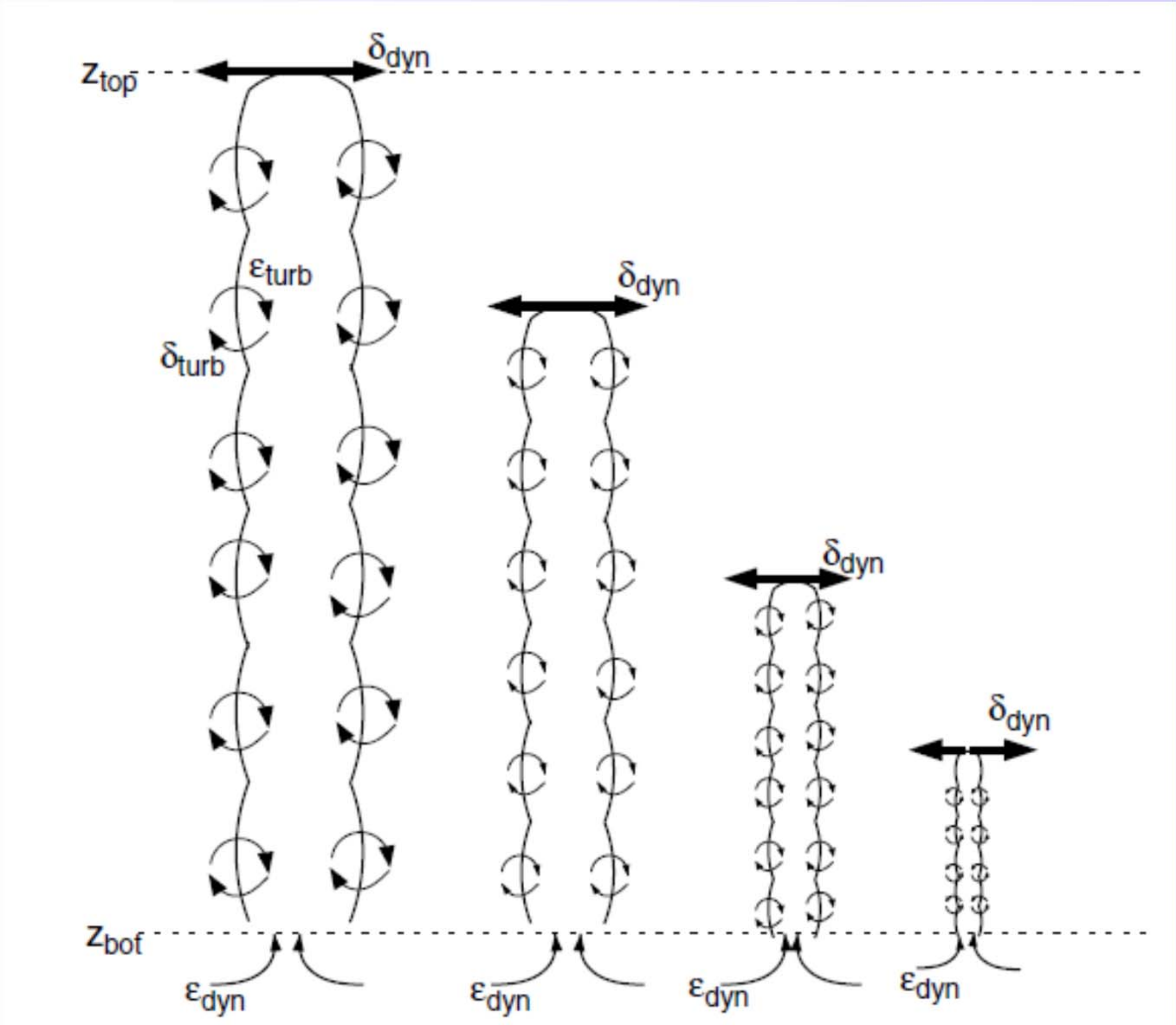
Variation due to cloud core fraction or due to incore vertical velocity?

Cloud fraction and vertical velocity

$$\frac{\partial}{\partial z}\ln M = \frac{\partial}{\partial z}\ln\sigma + \frac{\partial}{\partial z}\ln\rho_0 + \frac{\partial}{\partial z}\ln w_c$$

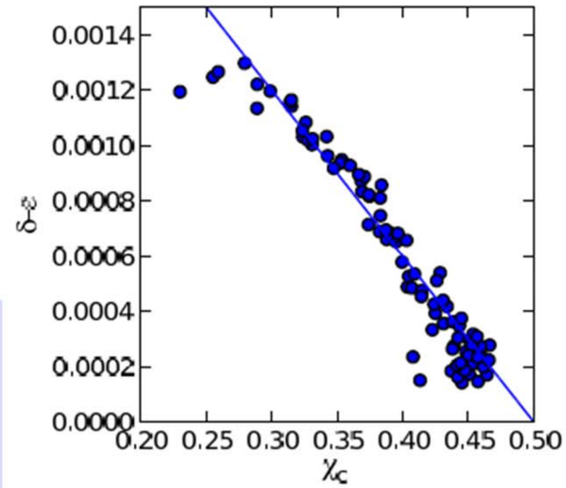


Simplified Physical Picture

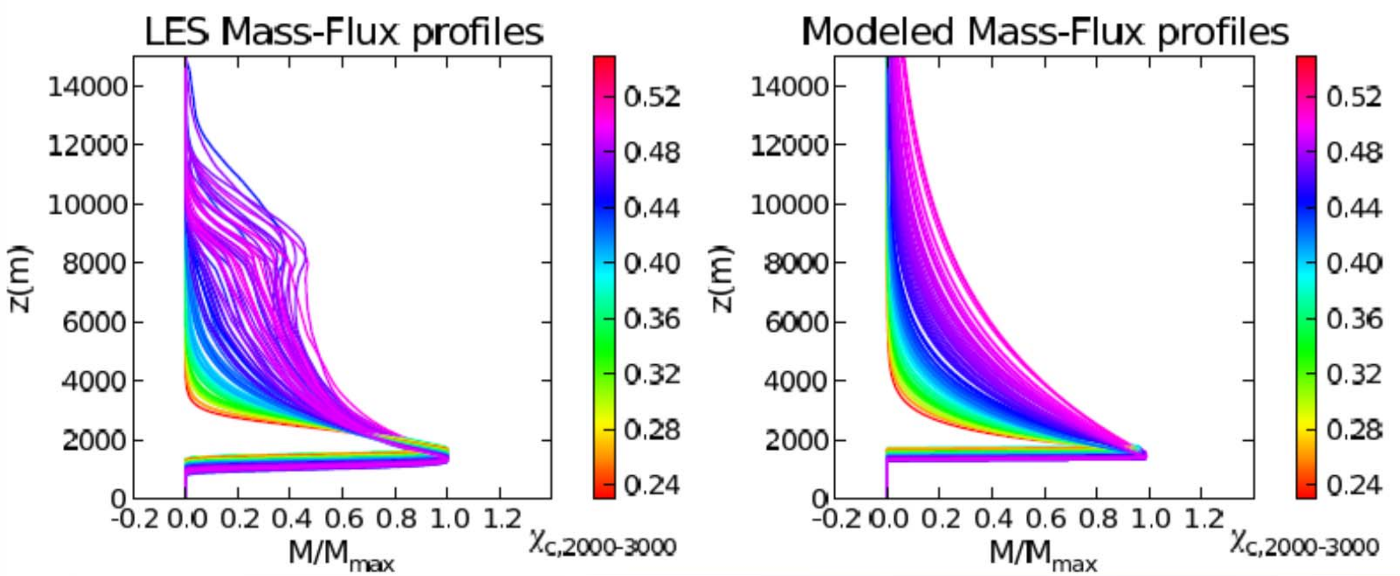


The simplest mass flux parameterization

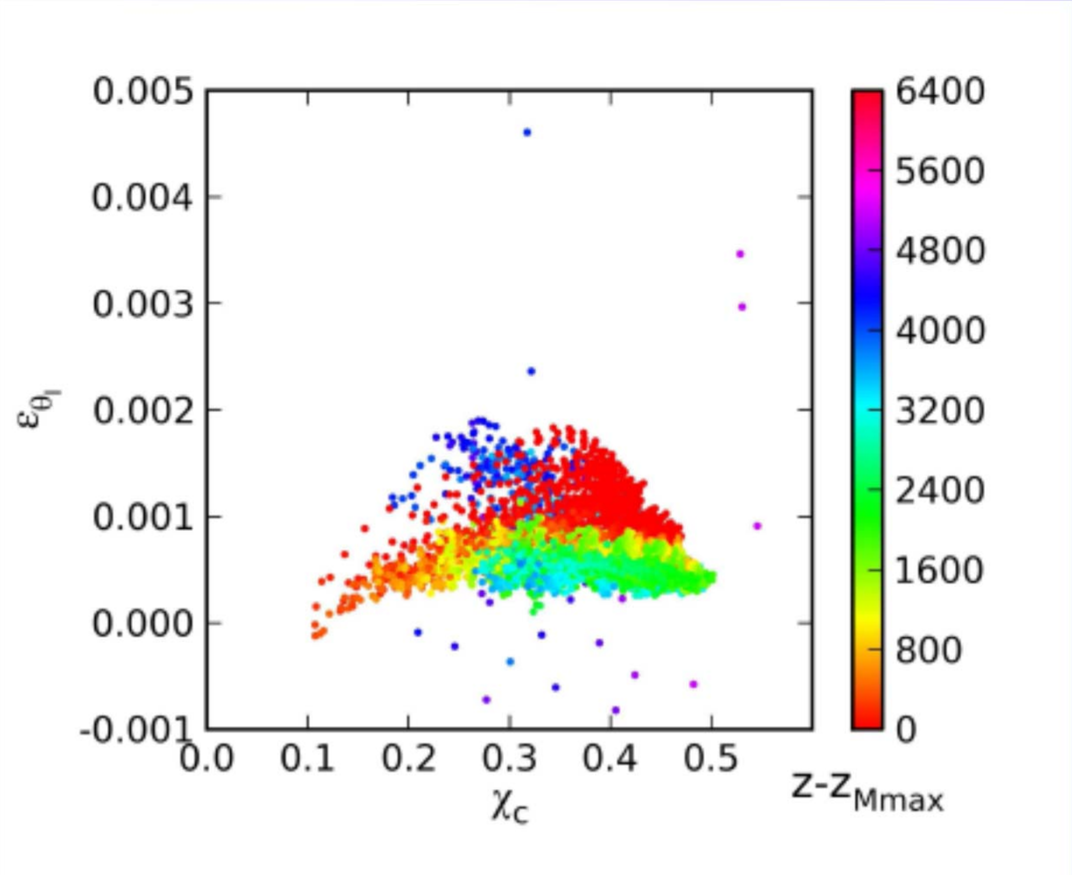
- Directly parameterize $\frac{\partial}{\partial z}\ln M = \epsilon - \delta$ as a function of χ_c
- Use χ_c between 2 and 3 kilometers
- Fit: using relation between χ_c and $\epsilon - \delta$ below $z/z_{top} = 0.5$
- Cloud top requires separate parameterization



- Fit: $\delta - \epsilon = 0.003 - 0.006\chi_c$



What about entrainment?



Conclusions and outlook

- Strong dependency of moist convection on tropospheric relative humidity and stability
- Mostly related to detrainment and due to the cloud height distribution
- Allows for simpler and more realistic convection parameterization (get around detrainment)
- No need to seperate shallow and deep convection
- We are only beginning to constrain deep convection parameterizations
- More systematic exploration of the phase space is needed (and can be done)

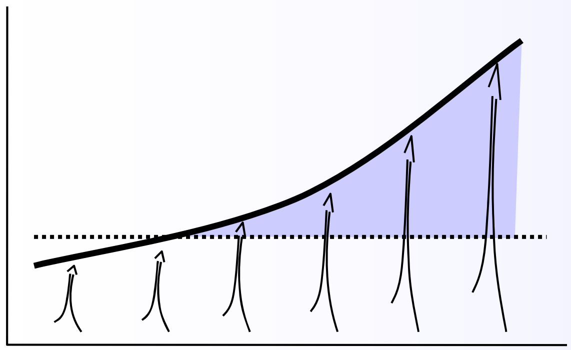
Outlook

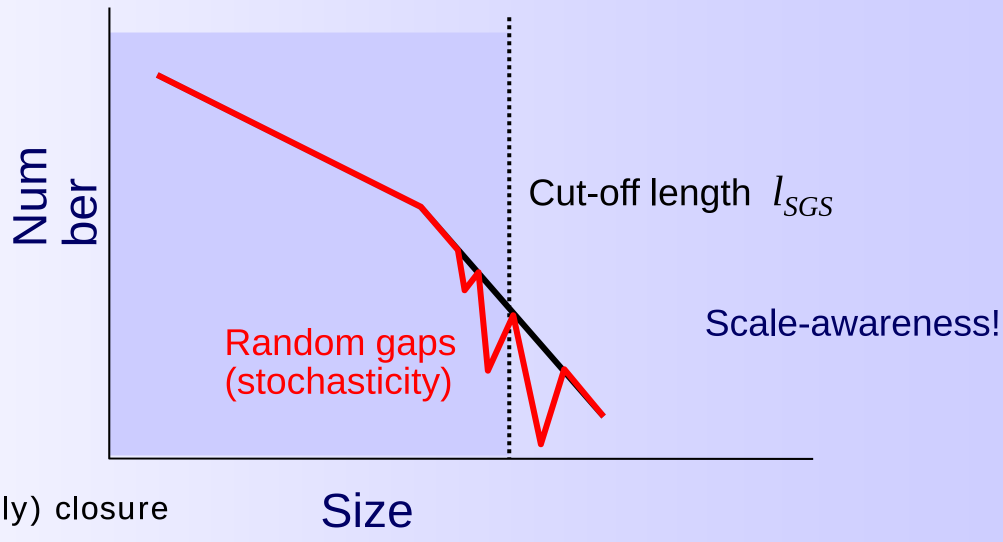
- Bulk parameterizations of Mass flux

$$\overline{w'\phi'} = -K\frac{\partial\overline{\phi}}{\partial z} + M(\phi_c - \overline{\phi})$$

- Multiplume parameterizations

$$\overline{w'\phi'} = -K\frac{\partial\overline{\phi}}{\partial z} + \sum_{i=1}^{I} M_i\left(\phi_i - \overline{\phi}\right)$$





Use cloud size distribution shape as (only) closure

- HOC?