Nature versus nurture in shallow convection

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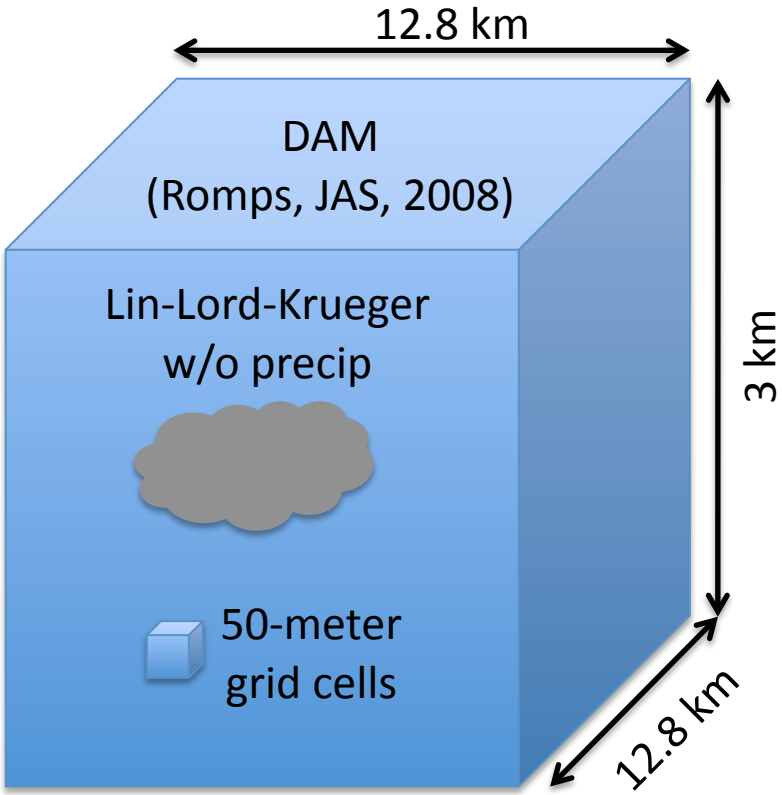
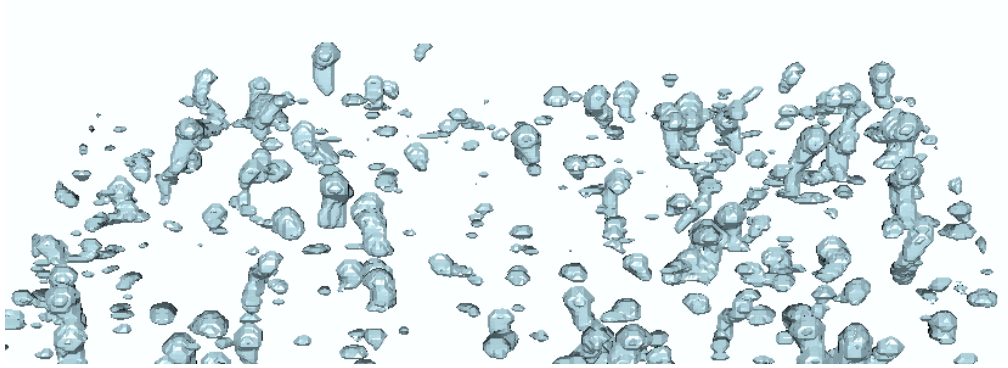
ARM working group meeting

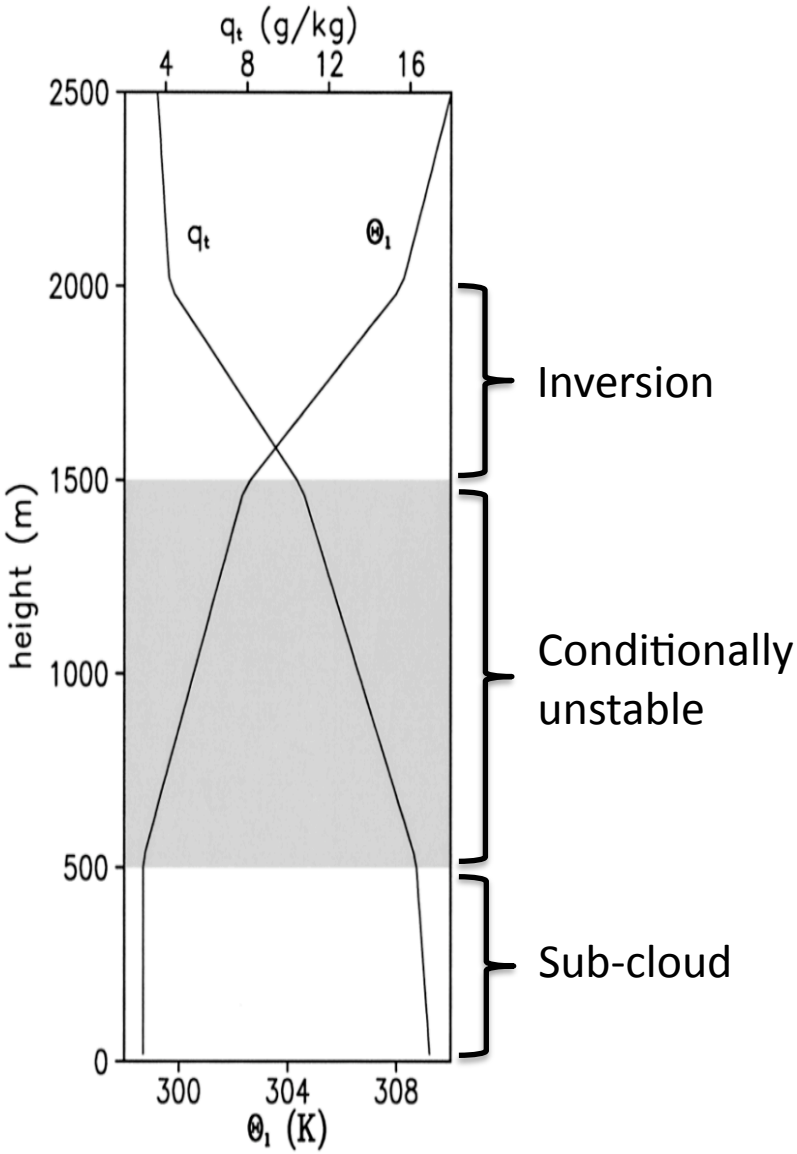
September 29, 2009

LES of BOMEX



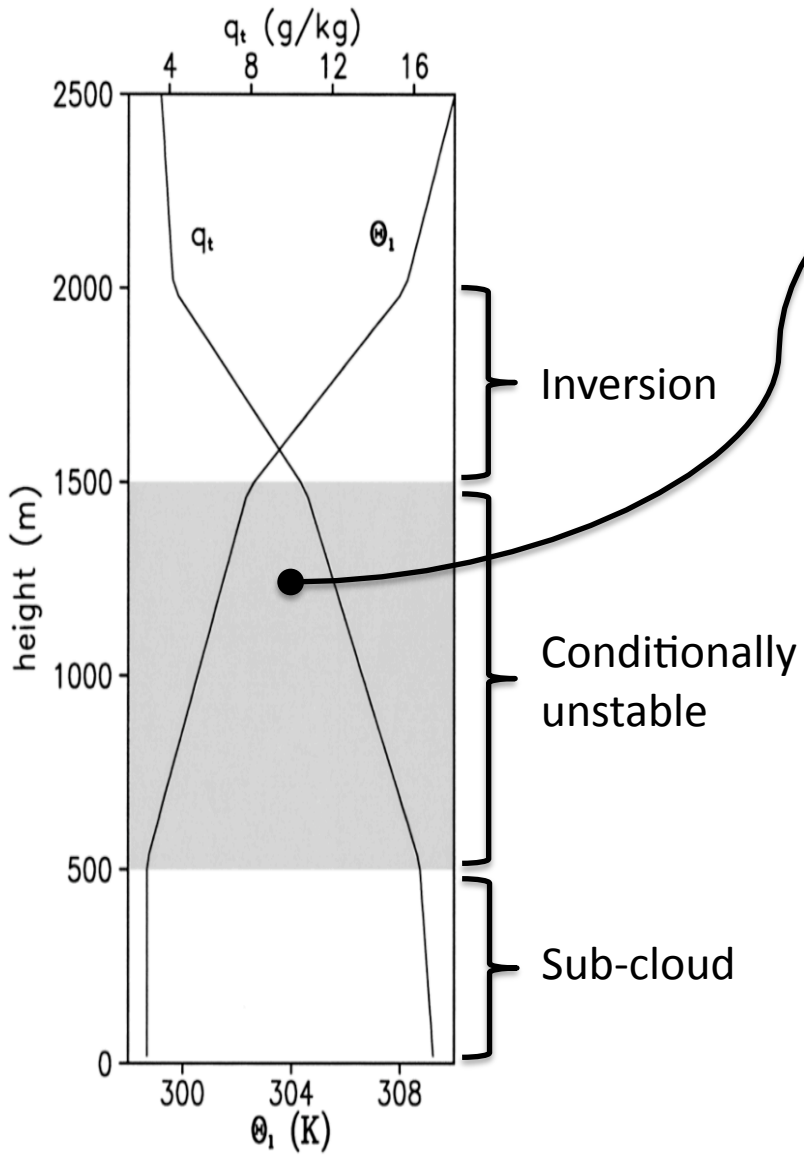
SST = 300.4 K





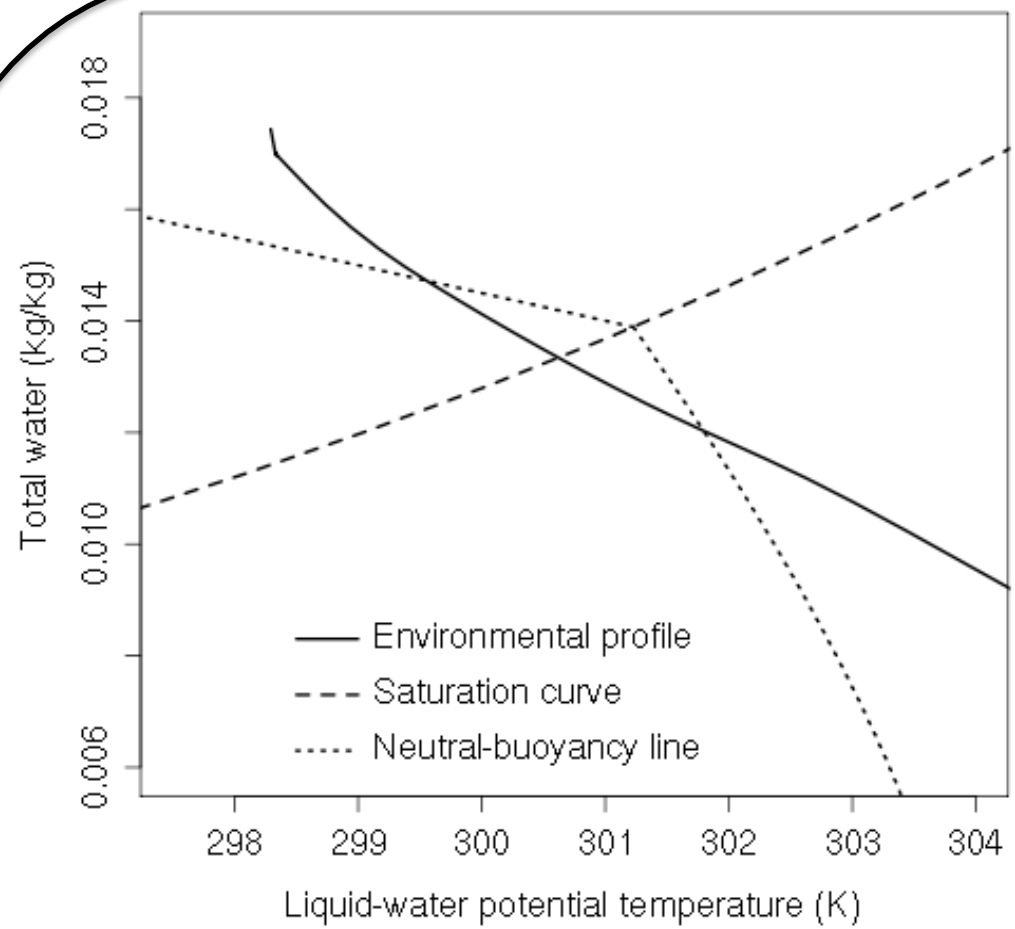
(Siebesma et al., JAS, 2003)

The "Paluch tail"



(Siebesma et al., JAS, 2003)

Paluch diagram at 1275 meters



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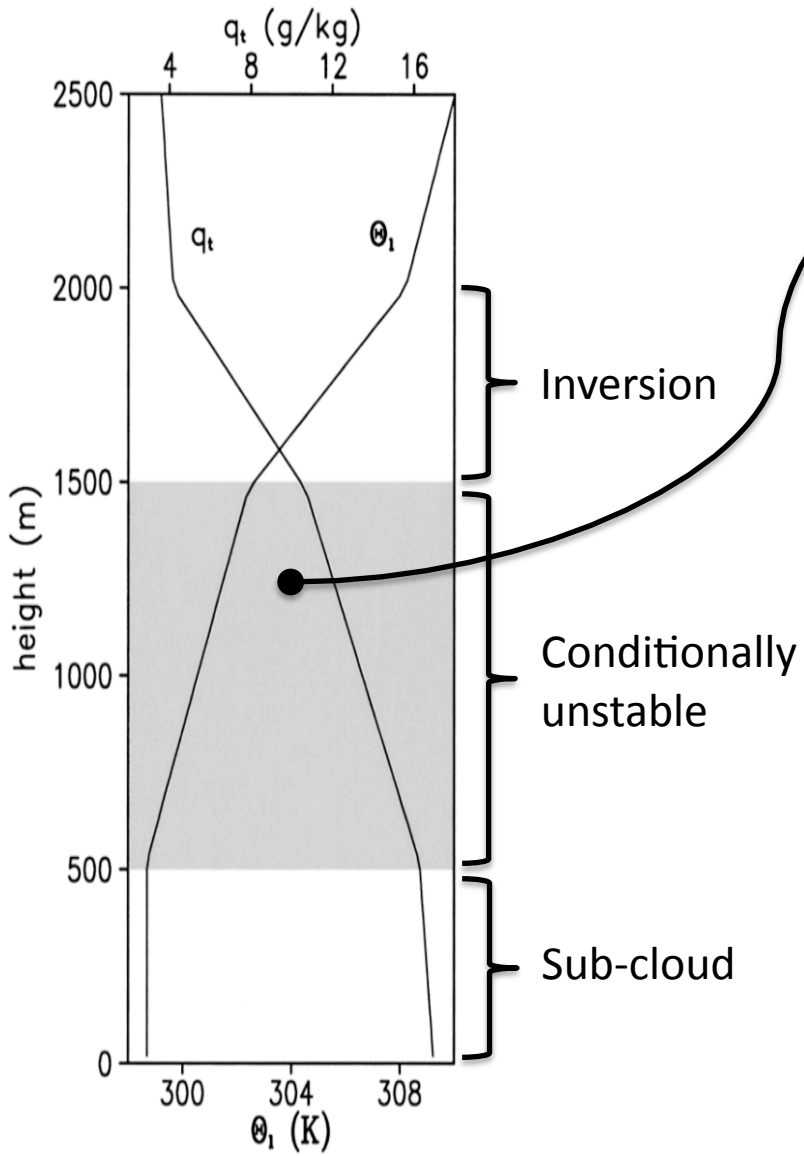

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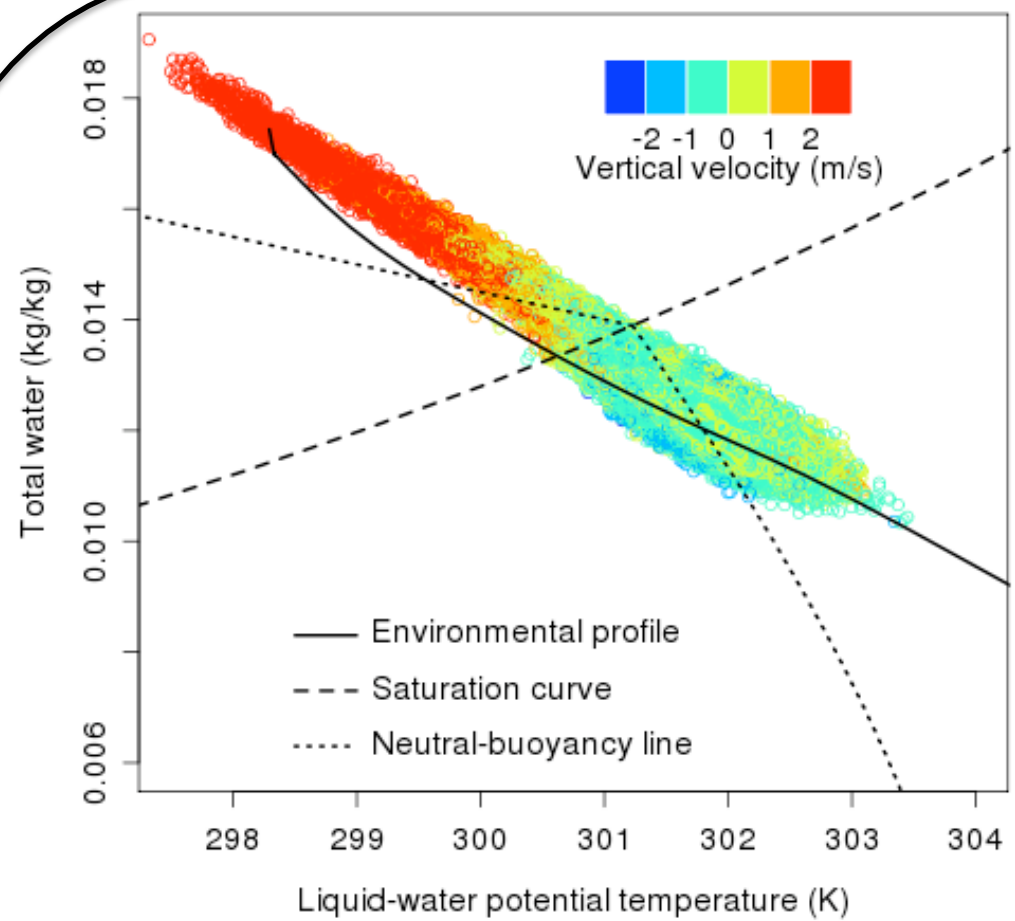


The "Paluch tail"

What explains this variability?

In other words, why is there this "Paluch tail"?

Is it

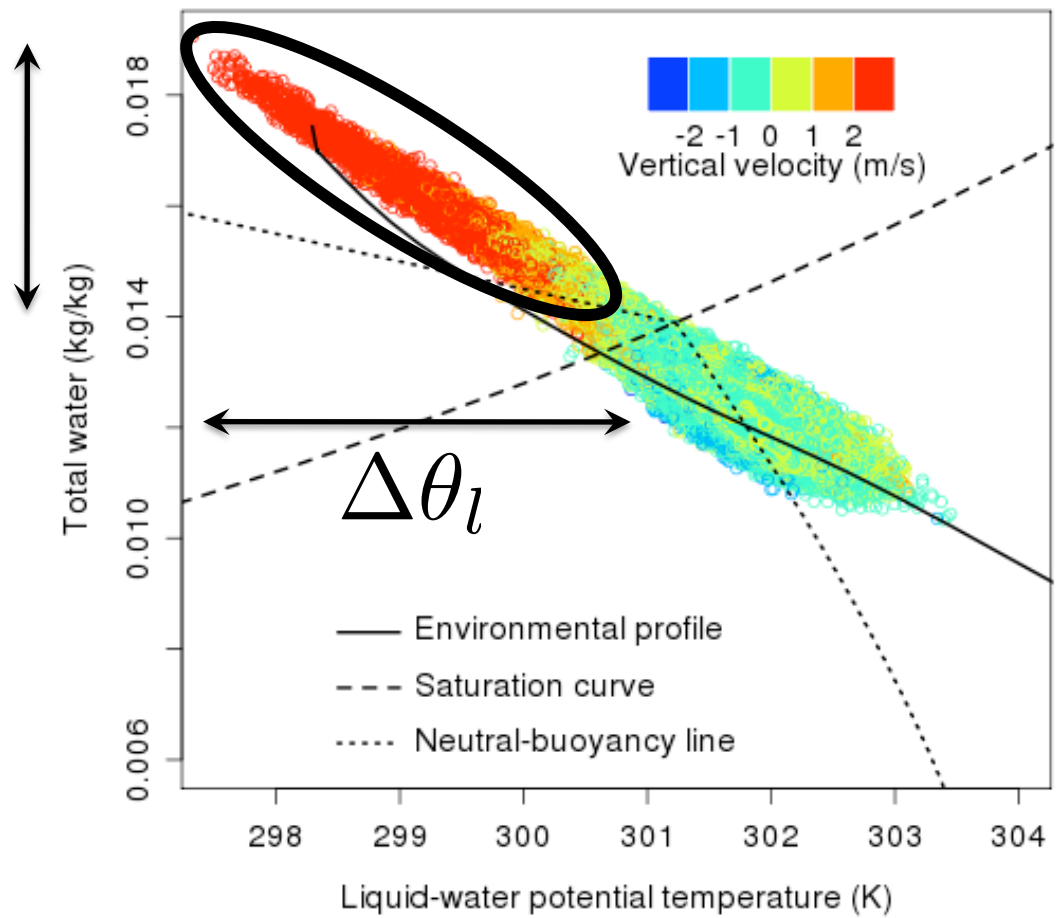
Nature
(variability built in at the cloud base, perhaps amplified)

Or

Nurture
(new variability introduced by stochastic entrainment)

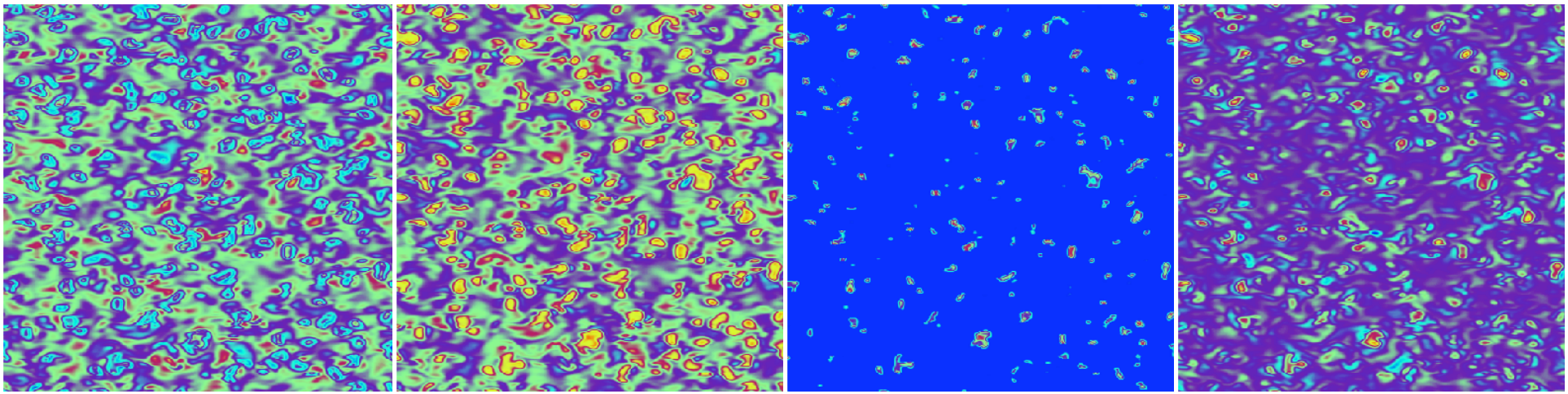
?

Paluch diagram at 1275 meters



Could it be Nature?

Temperature | Water vapor | Liquid water | Vertical velocity

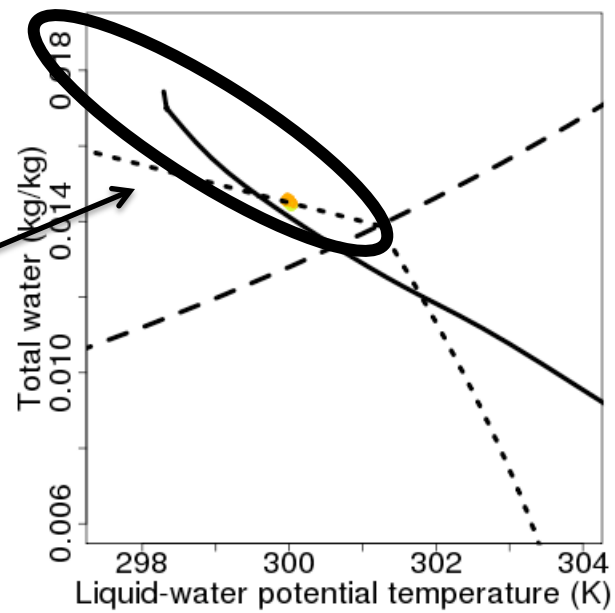


Snapshots of LES cloud-base → Initialize Lagrangian parcel model

If we use a fixed fractional entrainment,

$$\epsilon = \text{constant}$$

No Paluch tail



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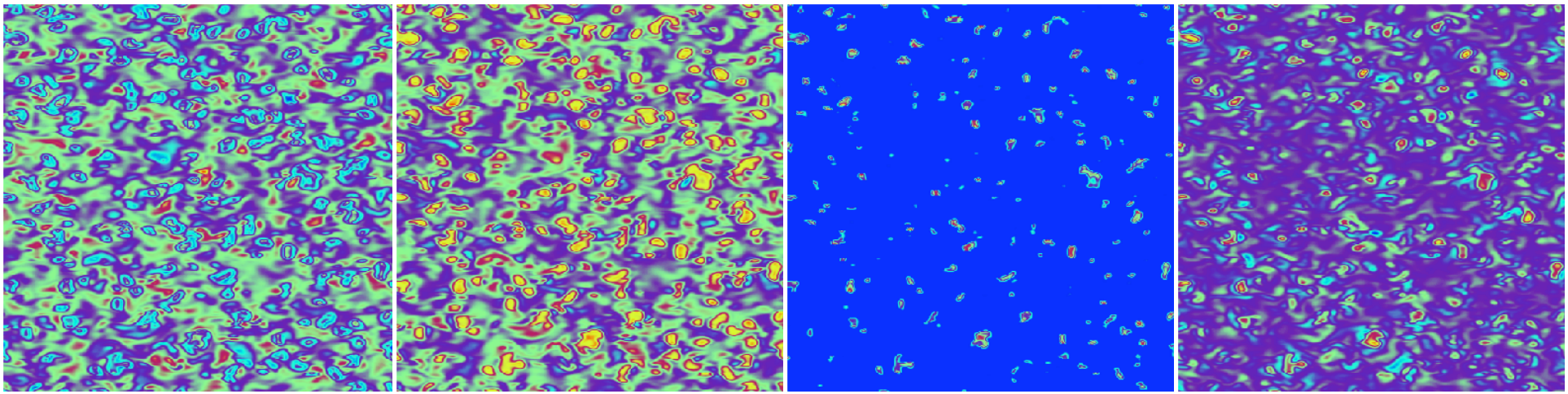


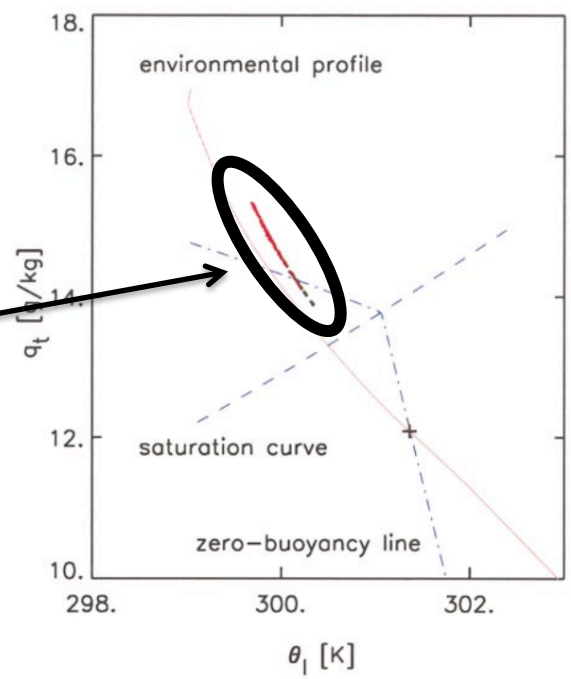
Snapshots of LES cloud-base → Initialize Lagrangian parcel model

What if we amplify the cloud-base variability?

Try $\epsilon \sim 1/w$ (Neggers et al, JAS, 2002)

Yes, a Paluch tail

Implemented in ECMWF
(Neggers et al, JAS, 2008)



(Neggers et al, JAS, 2002)

Is it true that $\epsilon \sim 1/w$? Test with tracers

Prognostic variables: $\vec{u}\,,\ \rho\,,\ T\,,\ q_v\,,\ \ldots\,,\ \phi$

Add "purity" tracer

Is it true that $\epsilon \sim 1/w$? Test with tracers

Prognostic variables: $\vec{u}\,,\ \rho\,,\ T\,,\ q_v\,,\ \ldots\,,\ \phi$

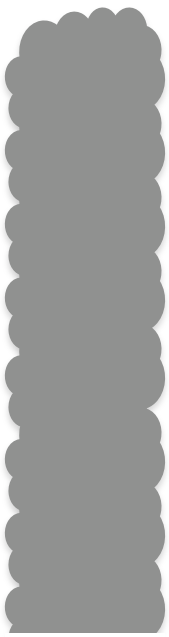
Add "purity" tracer

$$\begin{aligned} \phi &= \text{Fraction of air from cloud base} \\ 1-\phi &= \text{Fraction of entrained air} \end{aligned}$$

Is it true that $\epsilon \sim 1/w$? Test with tracers

Prognostic variables: $\vec{u}\,,\ \rho\,,\ T\,,\ q_v\,,\ \ldots\,,\ \phi\,,\ \zeta$

Now, add a second tracer to record cloud-base θ_e



$$\zeta/\phi \;=\; \text{cloud-base } \theta_e$$

Entrainment reduces ϕ and ζ by same fraction

$$\phi = 1\,,\ \zeta = \theta_e$$

Is it true that $\epsilon \sim 1/w$? Test with tracers

Recap so far

- We ask the following question:

  Is the variability within and between clouds (Paluch tail)

caused by	Nature	(cloud-base variability)
or by	Nurture	(stochastic entrainment) ?

- Neggers says the answer is Nature amplified through $\epsilon \sim 1/w$

- We now have tracers to diagnose cloud-base properties

Is it true that $\epsilon \sim 1/w$? Test with tracers

If $\epsilon \sim 1/w$, then

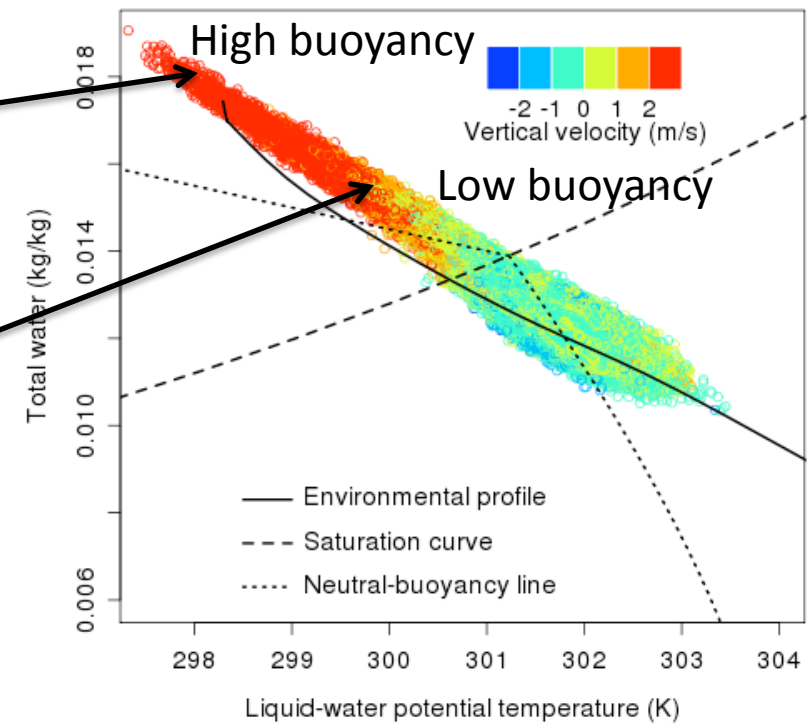
bouyancy, q_t , and θ_l in clouds

will be highly correlated with

the clouds' values of θ_e and w at the cloud base.

High θ_e → High w → Low ϵ

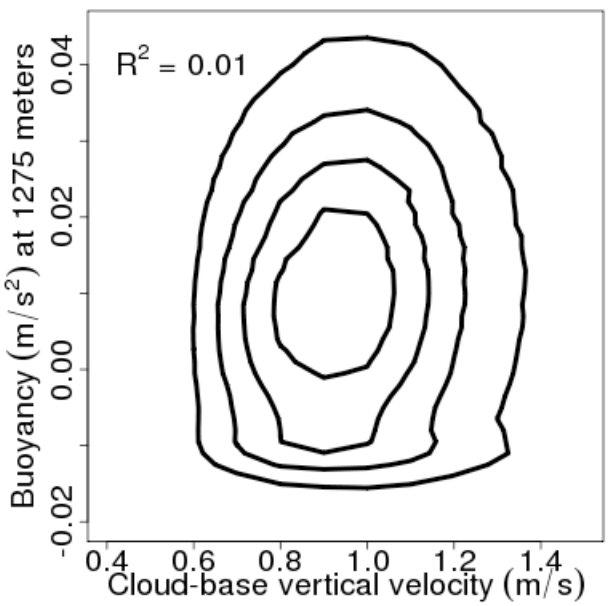
Low θ_e → Low w → High ϵ



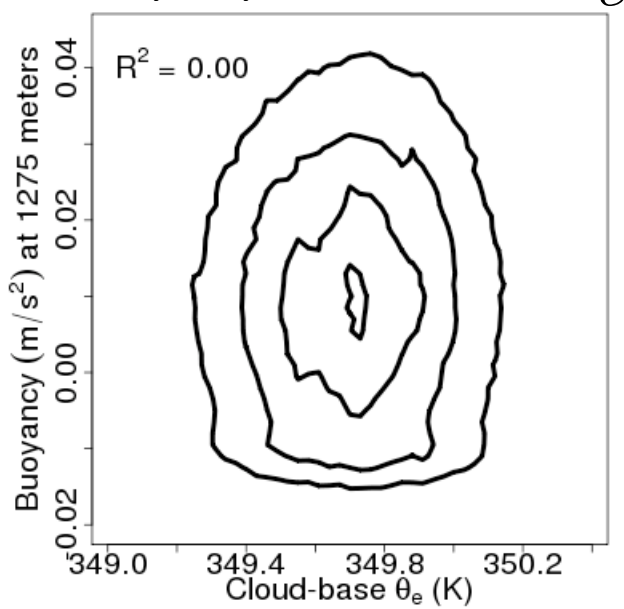
The answer is… Nurture

Correlations at 1275 meters

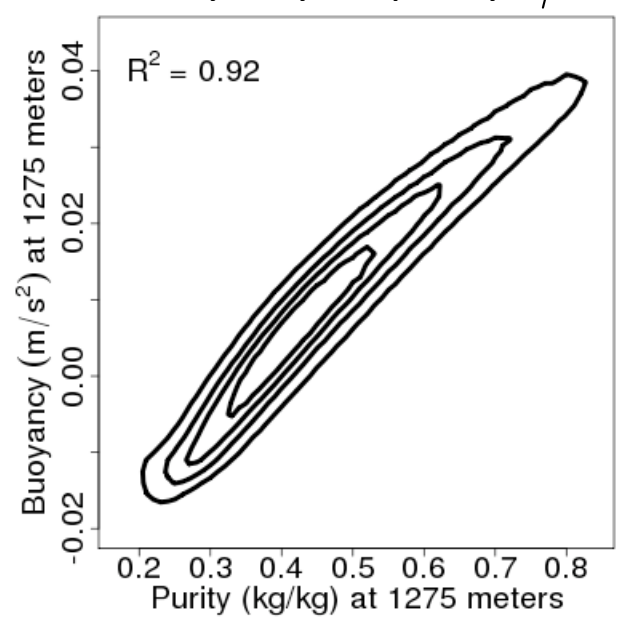
Buoyancy vs. cloud-base w



Buoyancy vs. cloud-base θ_e



Buoyancy vs. purity, ϕ



$\cancel{\epsilon \sim 1/w}$

~~Nature~~

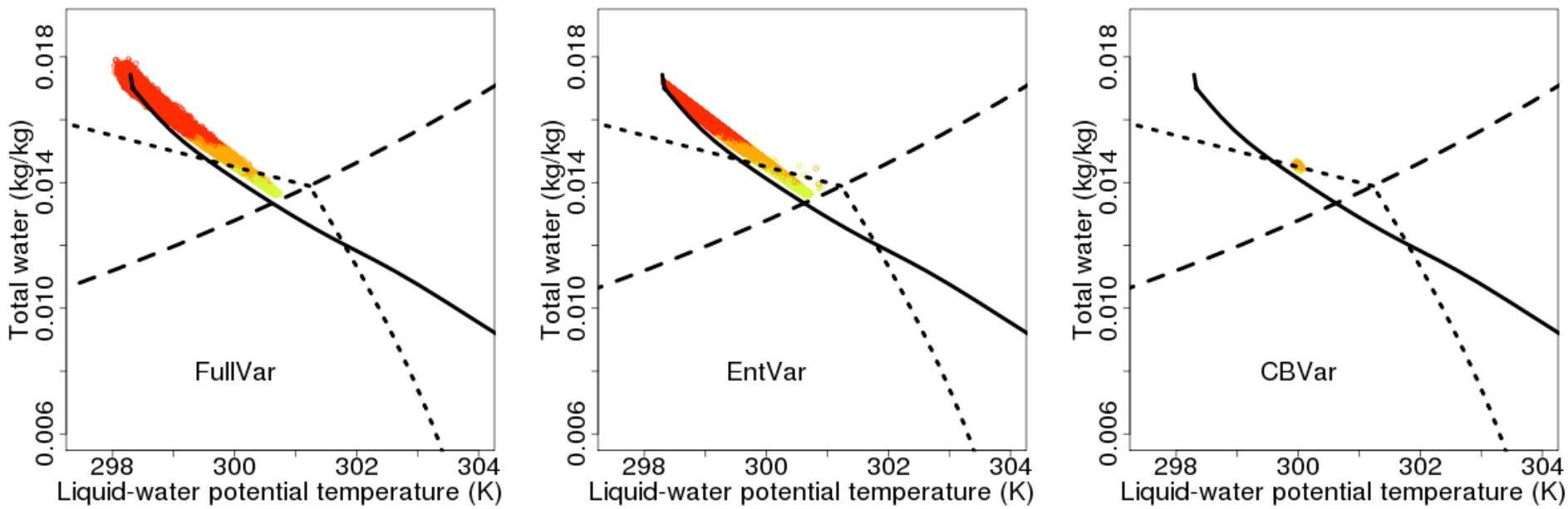
Nurture

Stochastic parcel model

Cloud modeled as a collection of entraining parcels.

(The LNB's of parcels define the cloud's detrainment profile.)

Entrainment occurs only discrete events, modeled using a Monte Carlo method



Cloud-base variability + Stochastic entrainment

Stochastic entrainment only

Cloud-base variability only

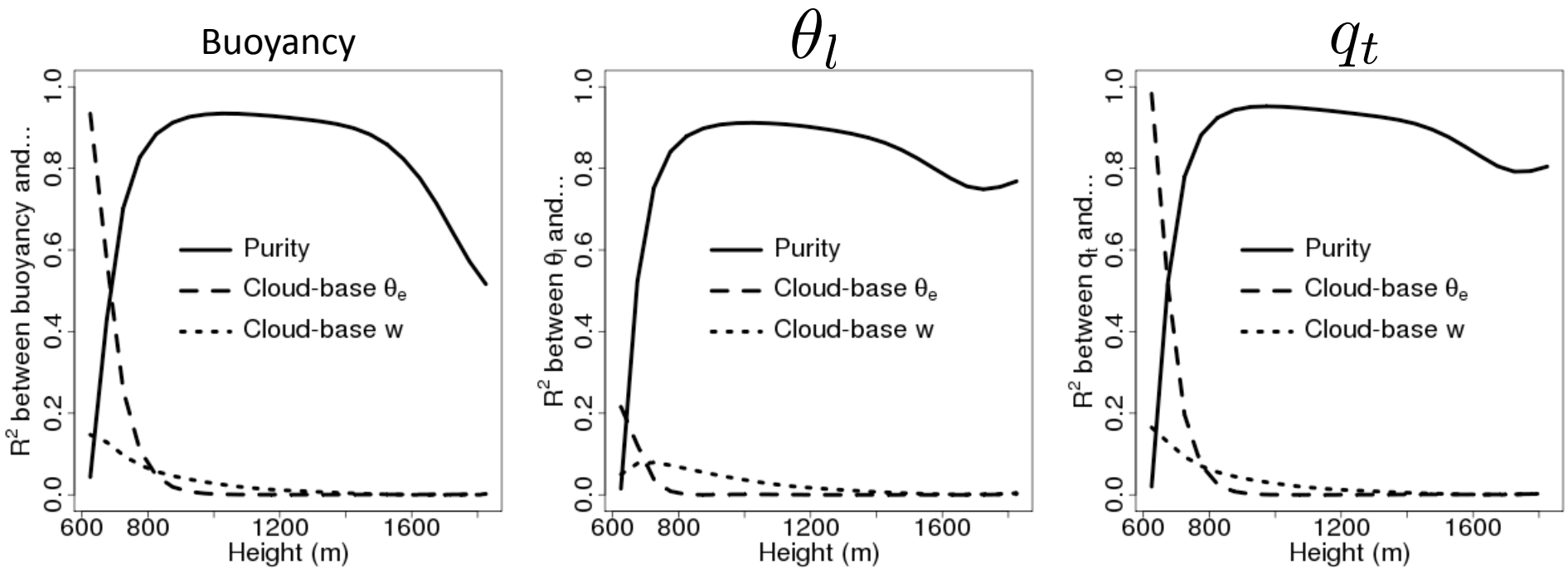
Conclusions

1. Stochastic entrainment is the source of the variability among cloudy updrafts in shallow convection (Nurture, not Nature).

2. Stochastic entrainment coupled to a Lagrangian parcel model is a promising approach to convective parameterization.

The answer is… Nurture

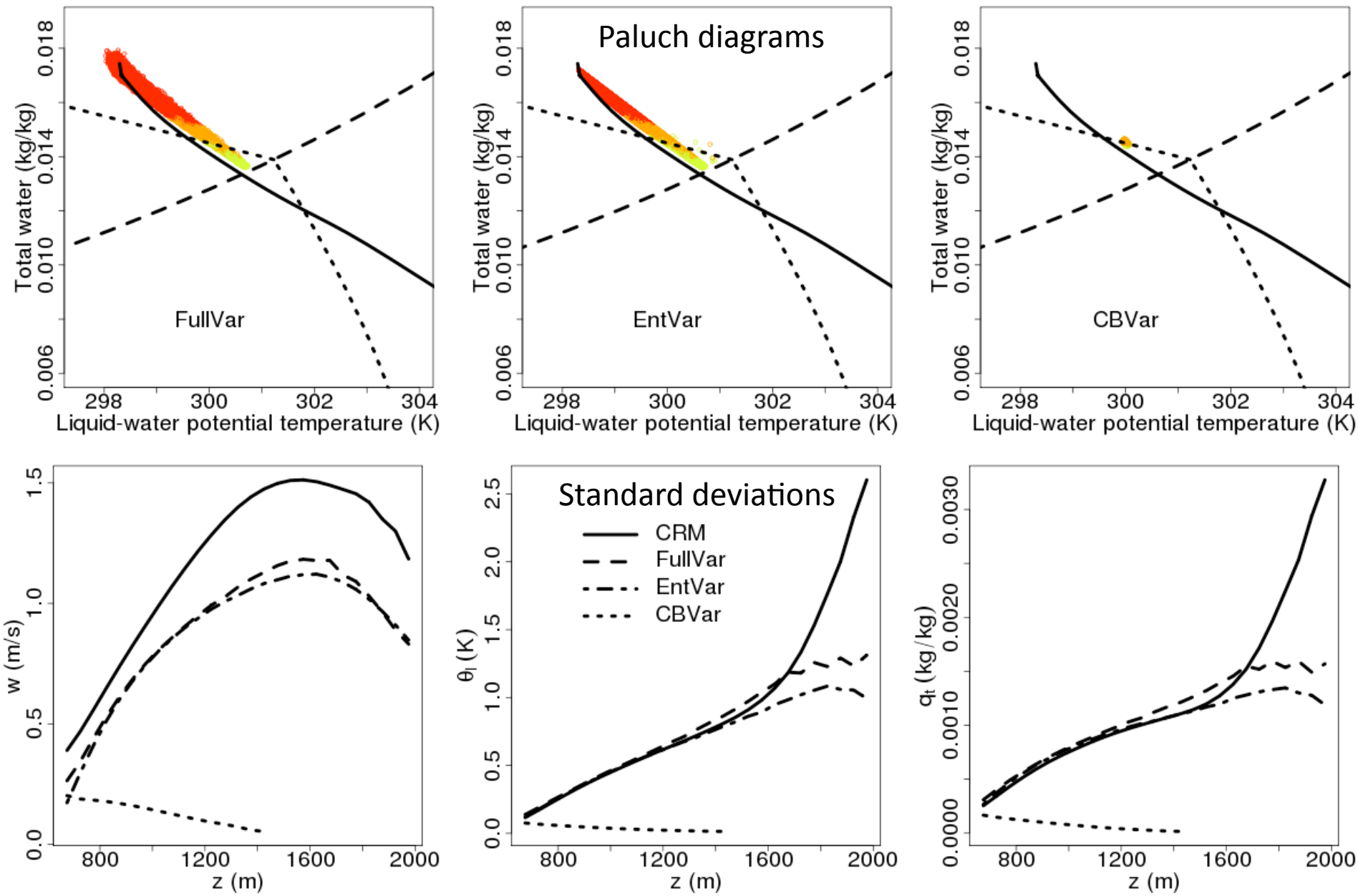
Correlations as a function of height



Parcels are uncorrelated with their cloud-base properties 200 meters above the cloud base

Stochastic parcel model

Lagrangian parcel model with stochastic entrainment



Stochastic parcel model

Cloud modeled as a collection of entraining parcels.

(The LNB's of parcels define the cloud's detrainment profile.)

Entrainment occurs only discrete events, modeled using a Monte Carlo method

Two parameters, λ and σ, define entrainment

In time step δt, the probability of a entrainment event is:

$$P(\text{an entrainment event}) = |w|\delta t/\lambda$$

If there is a mixing event, entrain a fractional amount f:

$$P(\text{entrain fraction } f) = \frac{1}{\sigma} e^{-f/\sigma}$$