Cold pools and the boundary layer

Ian Glenn

ATMOS 6220 Boundary layer guest lecture

10/20/2015

Outline

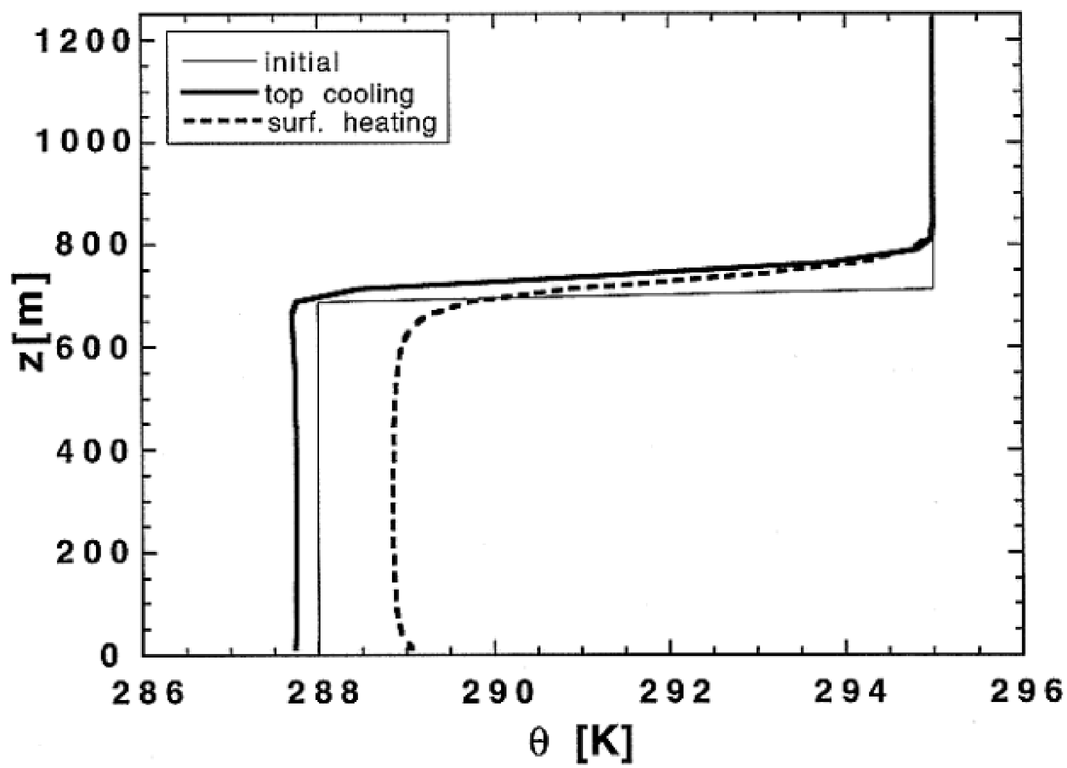
- Non-local transport: EDMF
- EDMF(n)
- Cold pools in cu. Param.

Non-local transport

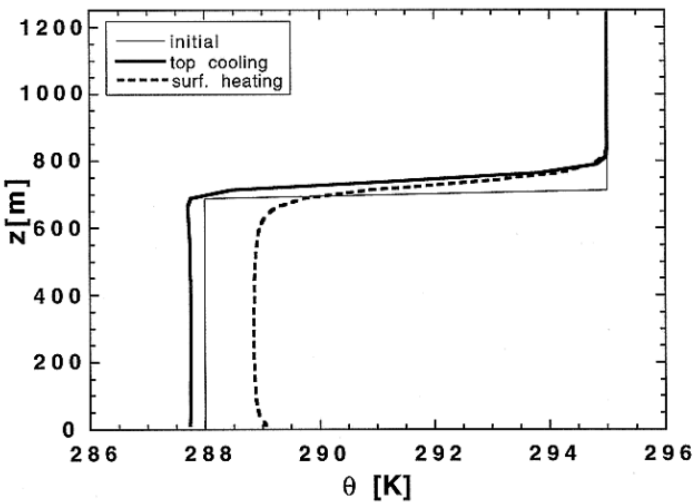
- EDMF approach (or any non-local approach) is attempting to represent the effects of the large eddies or plumes that cannot be represented very well by a down-gradient approach that does work well when the eddies are small compared to the BL depth.

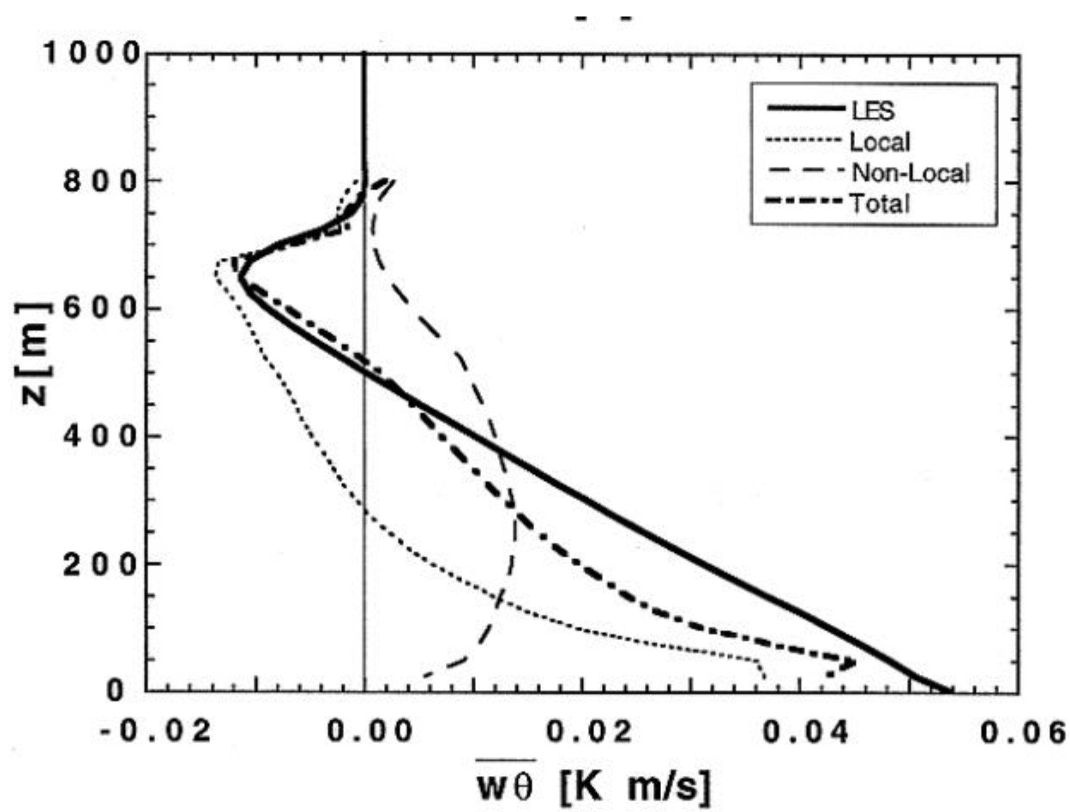
Non-local transport

Observations and LES of surface-heated dry convective BLs (e.g. dashed line in Fig. 9.1) show that over much of the upper half of the boundary layer ($0.4 < z/z_i < 0.8$), the θ gradient is very slightly positive even though the heat flux is also upward, opposite to the expectation from downgradient turbulent diffusion. Nonlocal schemes account for this effect by adding a correction term to scalar fluxes in convective boundary layers.



Non-local transport





Non-local transport

BL parameterizations handle the nonlocal term somewhat differently. In one class of 'gradient-correction' methods, the turbulent flux of an advected scalar a is modelled using a K-profile with a nonlocal correction γ_a added for advected scalars in convective boundary layers

$$\boxed{\overline{w'a'} = -K_a\left(\frac{\partial a}{\partial z} - \gamma_a\right), \quad 0 < z < h} \tag{9.6}$$

The nonlocal term on the right is interpreted as being due to boundary-layer filling convective eddies which distribute the surface flux of a upward regardless of the local gradient of a. If the surface flux of a is positive, the nonlocal term produces a BL within which a decreases less with height than if pure first-order closure were used.

Eddy Diffusivity – Mass flux

A related nonlocal approach for convective boundary layers, EDMF (Eddy Diffusion-Mass Flux) parameterization (Siebesma et al. 2007), is used in the ECMWF weather forecasting model. In a dry-convective boundary layer, the vertical velocity has a positively-skewed pdf, implying that updrafts tend to be narrower and more intense than downdrafts, hence presumably more vertically organized. Siebesma et al. separated out vertical fluxes associated with these strongest updrafts, covering a horizontal area fraction $A \sim 0.05$-0.1 of the horizontal area They treated these fluxes using a 'mass-flux' term in which the scalar flux is represented using the mean updraft velocity $w_u(z)$ and mean scalar value $a_u(z)$ in these updrafts and compensating uniform downward motion across the remaining fraction 1 - A of the domain:

$$\overline{w'a'}_{MF} = Aw_u(a_u - \overline{a}) + (1-A)w_d(a_d - \overline{a})$$

$$= Aw_u(a_u - \overline{a}) + (1-A)\frac{-Aw_u}{(1-A)}\frac{-A(a_u - \overline{a})}{(1-A)} \approx Aw_u(a_u - \overline{a}) \quad \text{if } A << 1.$$

Eddy Diffusivity – Mass flux

Other eddies are assumed to be lesss vertically organized and are treated using eddy diffusion. Thus, the overall turbulent transport is assumed to have the form:

$$\overline{w'a'} = -K(z)\frac{d\overline{a}}{dz} + M(z)\left\{a_u(z) - \overline{a}(z)\right\}$$

Eddy Diffusivity – Mass flux

The mass flux and the value of a_u are

calculated from a differential equation describing turbulent mixing into the organized updrafts, again using ideas transferred from cumulus parameterization:

$$\frac{da_u}{dz} = \varepsilon(z)(\overline{a} - a_u)$$

$$(1-2\mu)\frac{d}{dz}\left(\frac{w_u^2}{2}\right) = B - b\varepsilon w_u^2$$

where $\mu = 0.15$ accounts for pressure forces, $b = 0.5$.

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B is the updraft buoyancy, and based on LES, the lateral entrainment rate

$$\varepsilon(z) = 0.4\left(\frac{1}{z} + \frac{1}{h-z}\right)$$

and h is determined as the height at which w_u goes to zero. Initial updraft

EDMF(n)

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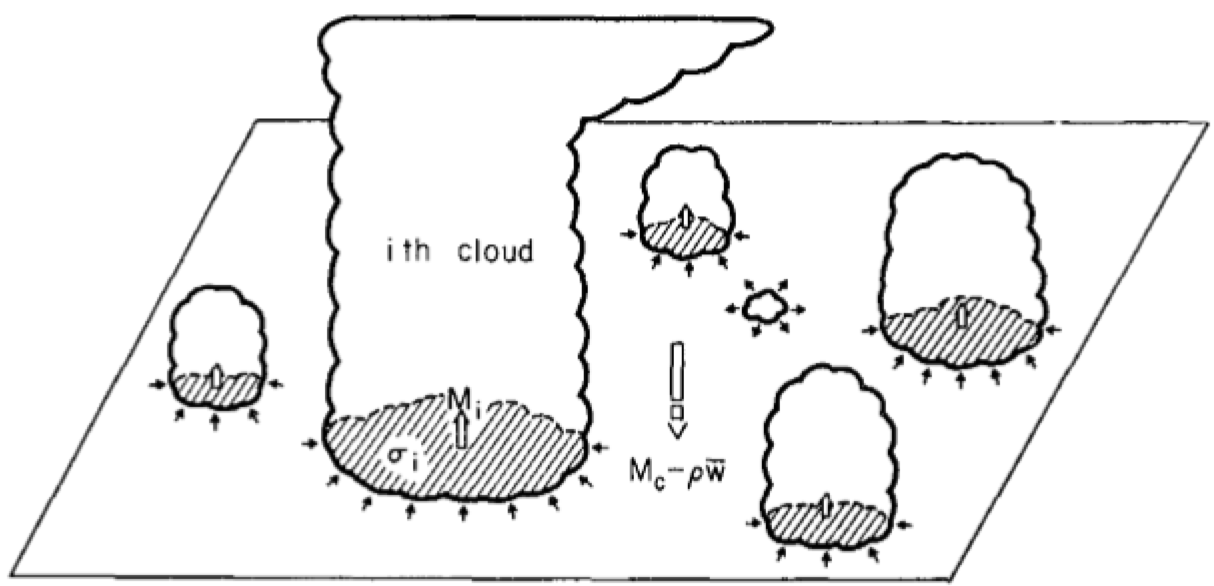
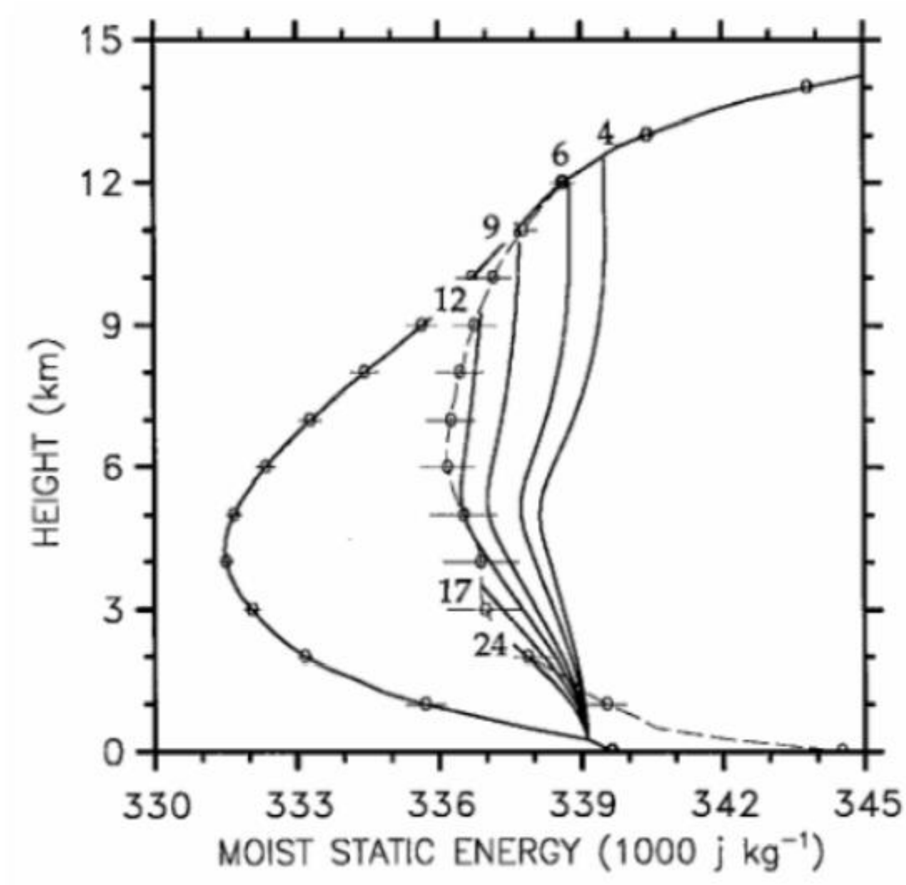
Cumulus parameterization for climate modeling

- Heat and moisture fluxes due to unresolved moist convection

APRIL 1974 AKIO ARAKAWA AND WAYNE HOWARD SCHUBERT

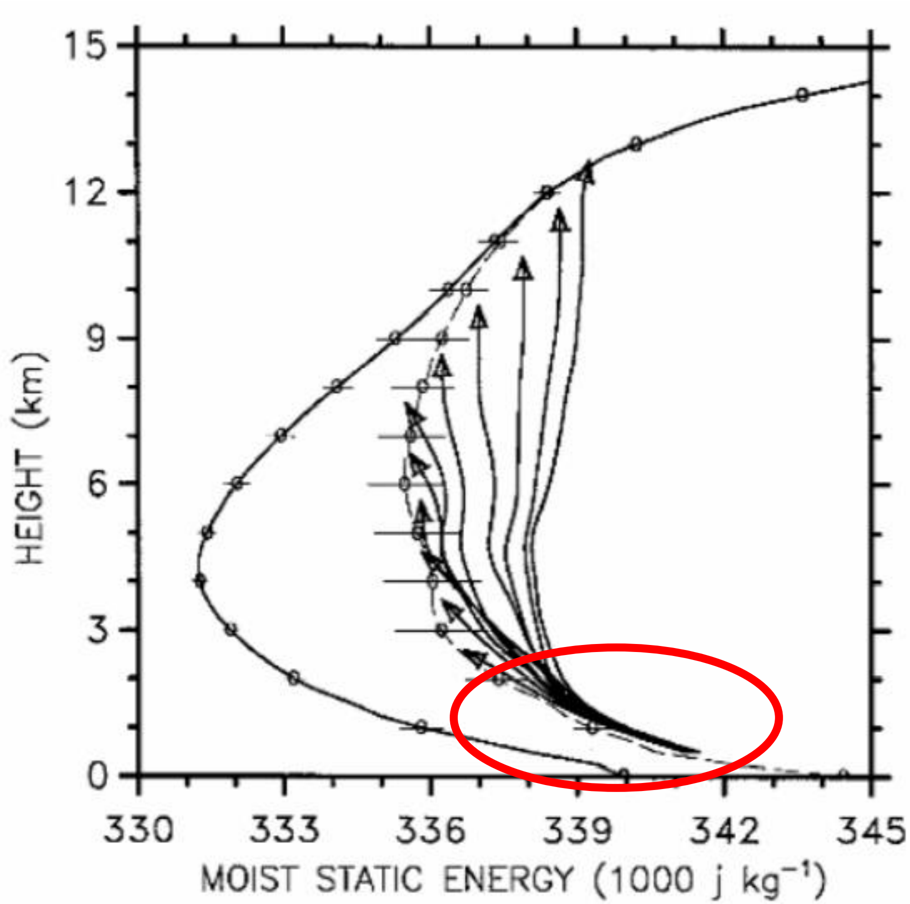


AS Parameterization



Lin and Arakawa (1997)

2D CRM



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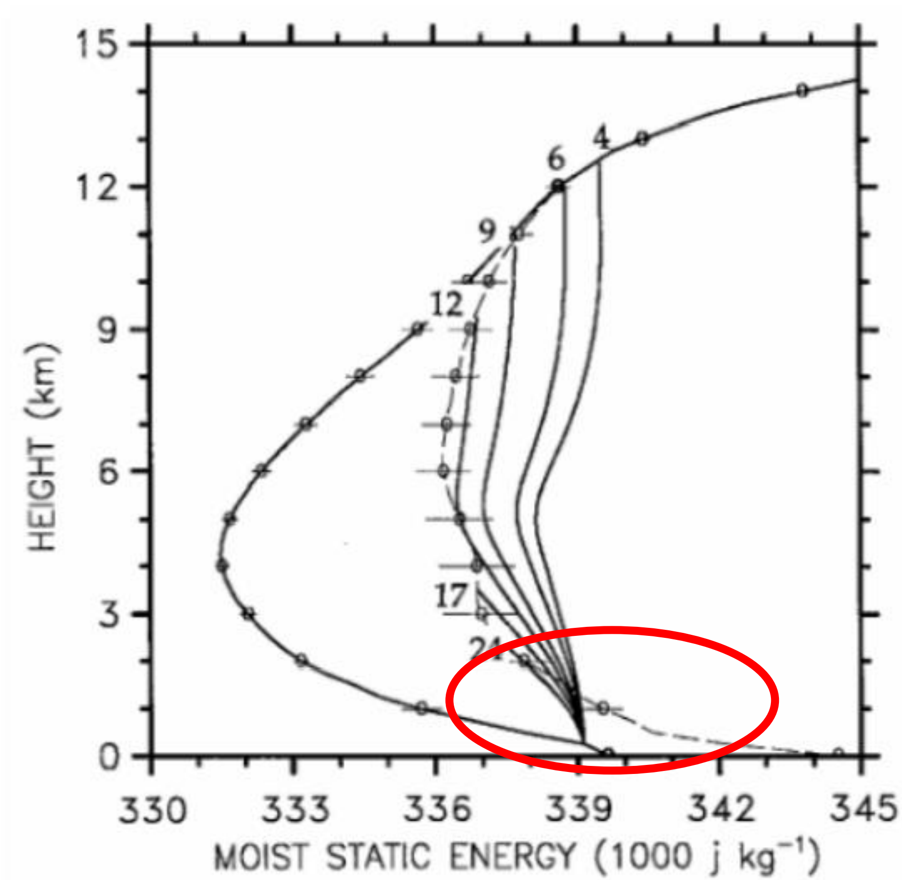
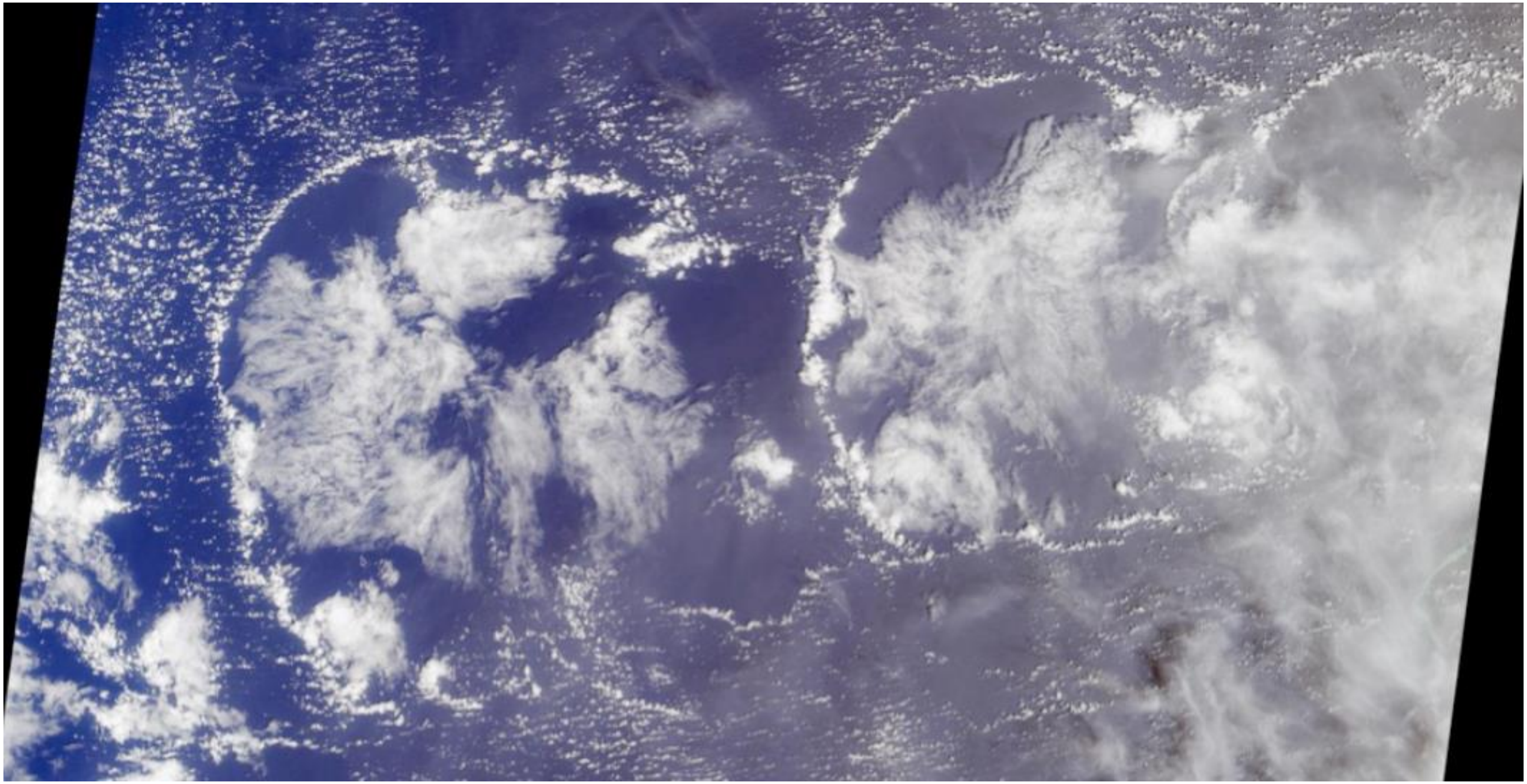
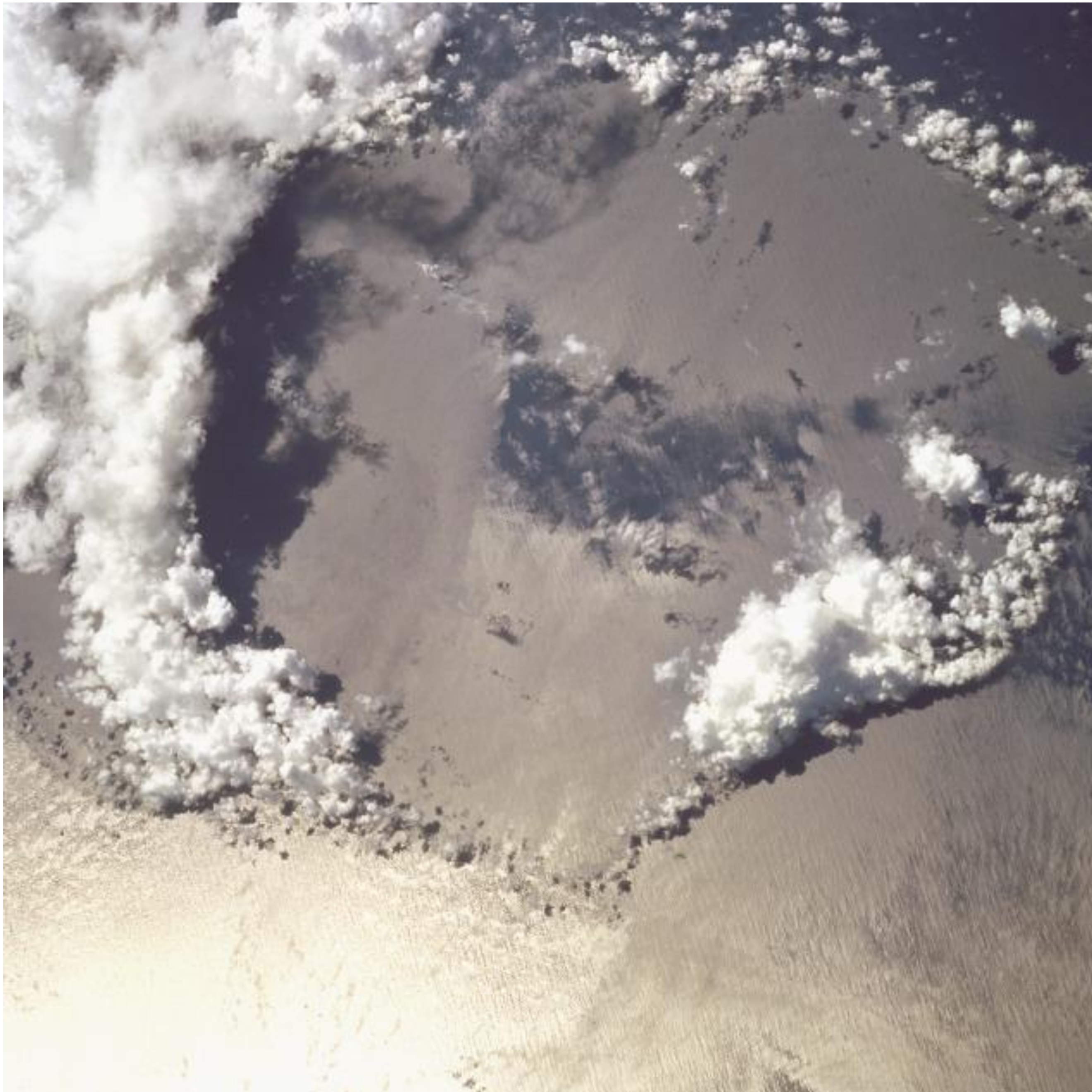
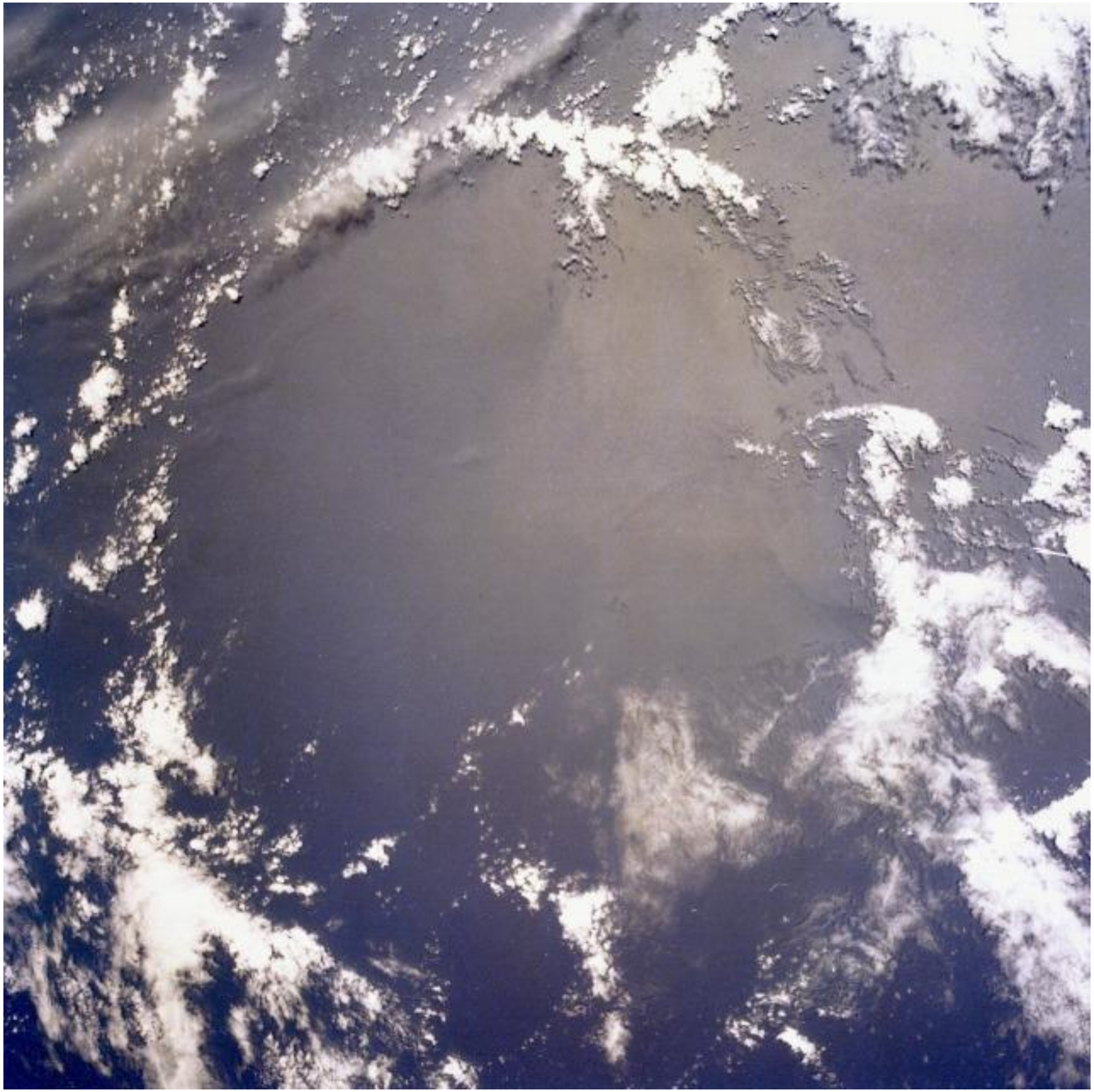


Lin and Arakawa (1997)

Cold pool organization





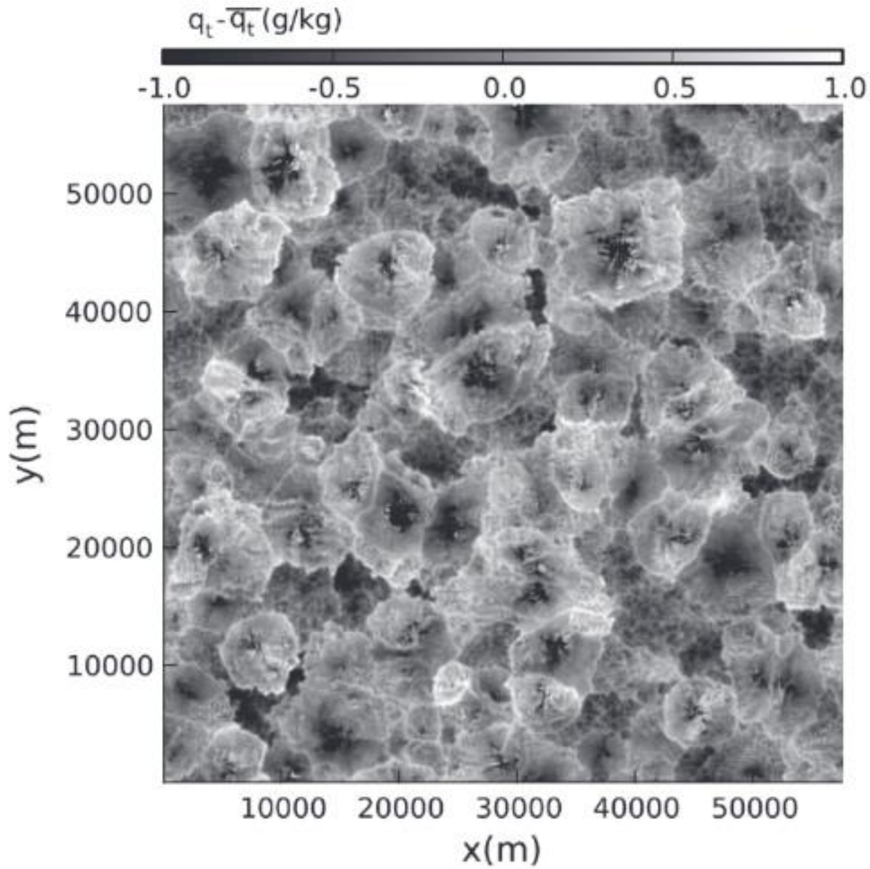


Boing et al. 2012

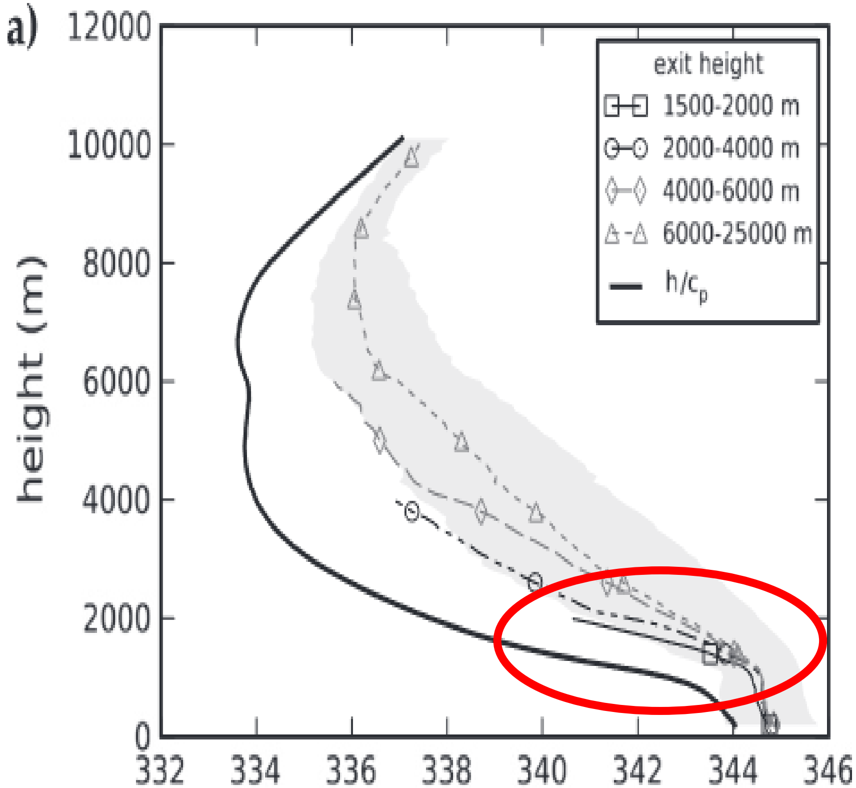
Large eddy simulation (LES)

Study cold pool structures formed by rain evaporation and loading

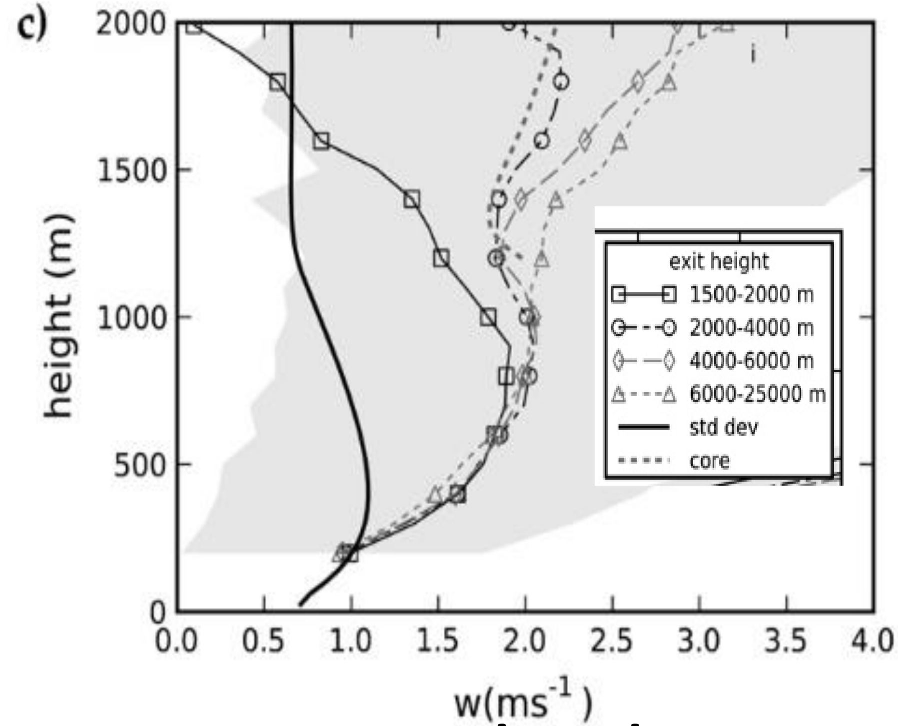
Total water anomaly



3D LES



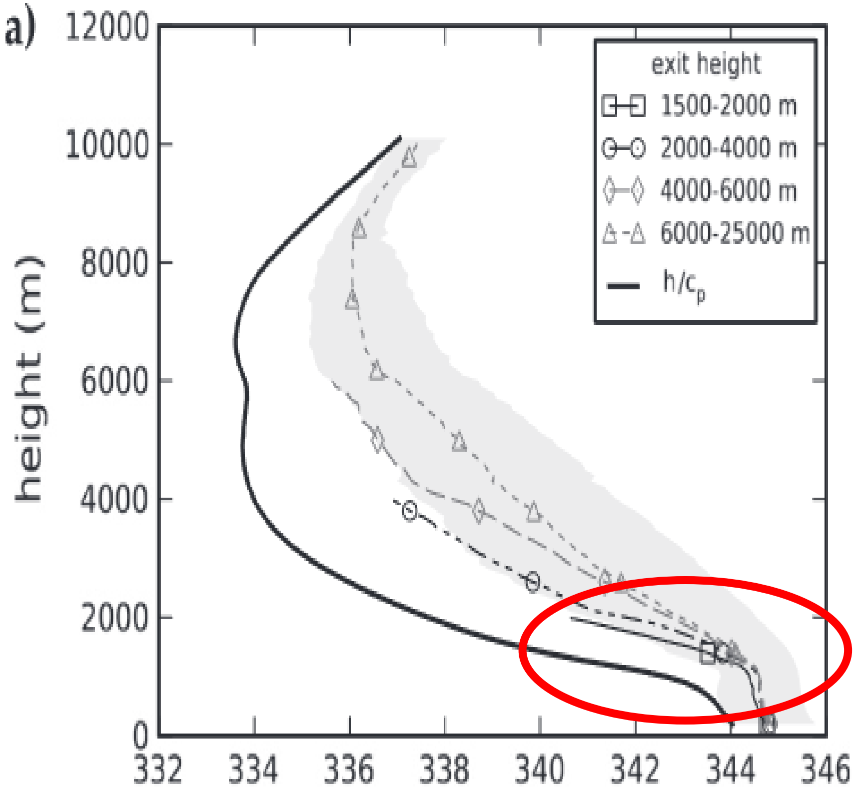
MSE



Vertical velocity

Boing et al. (2012)

3D LES



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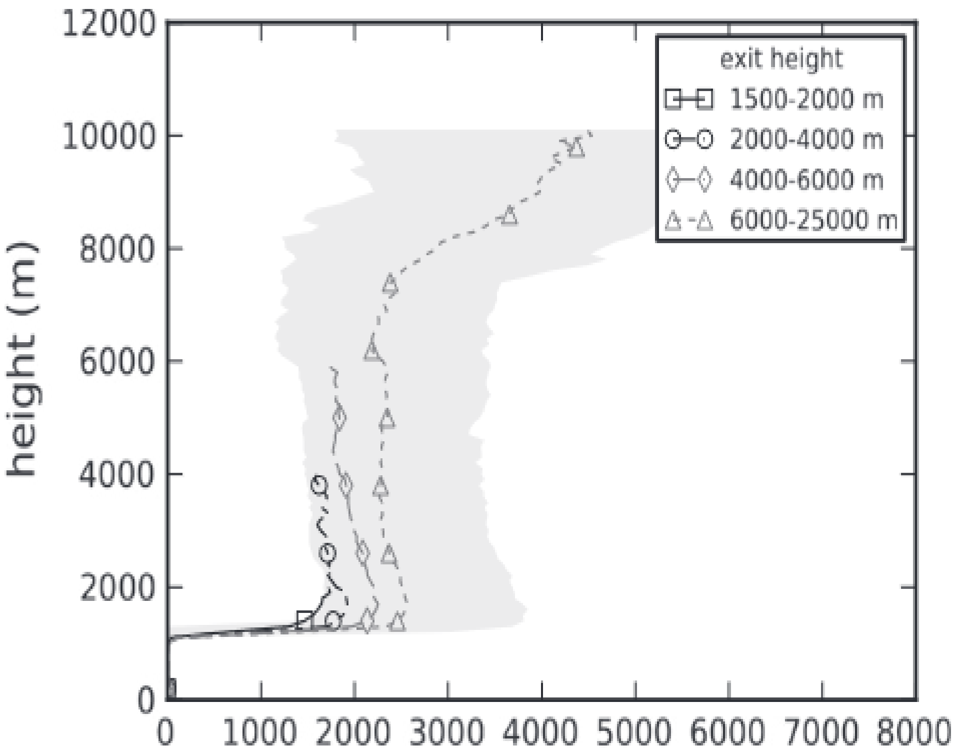
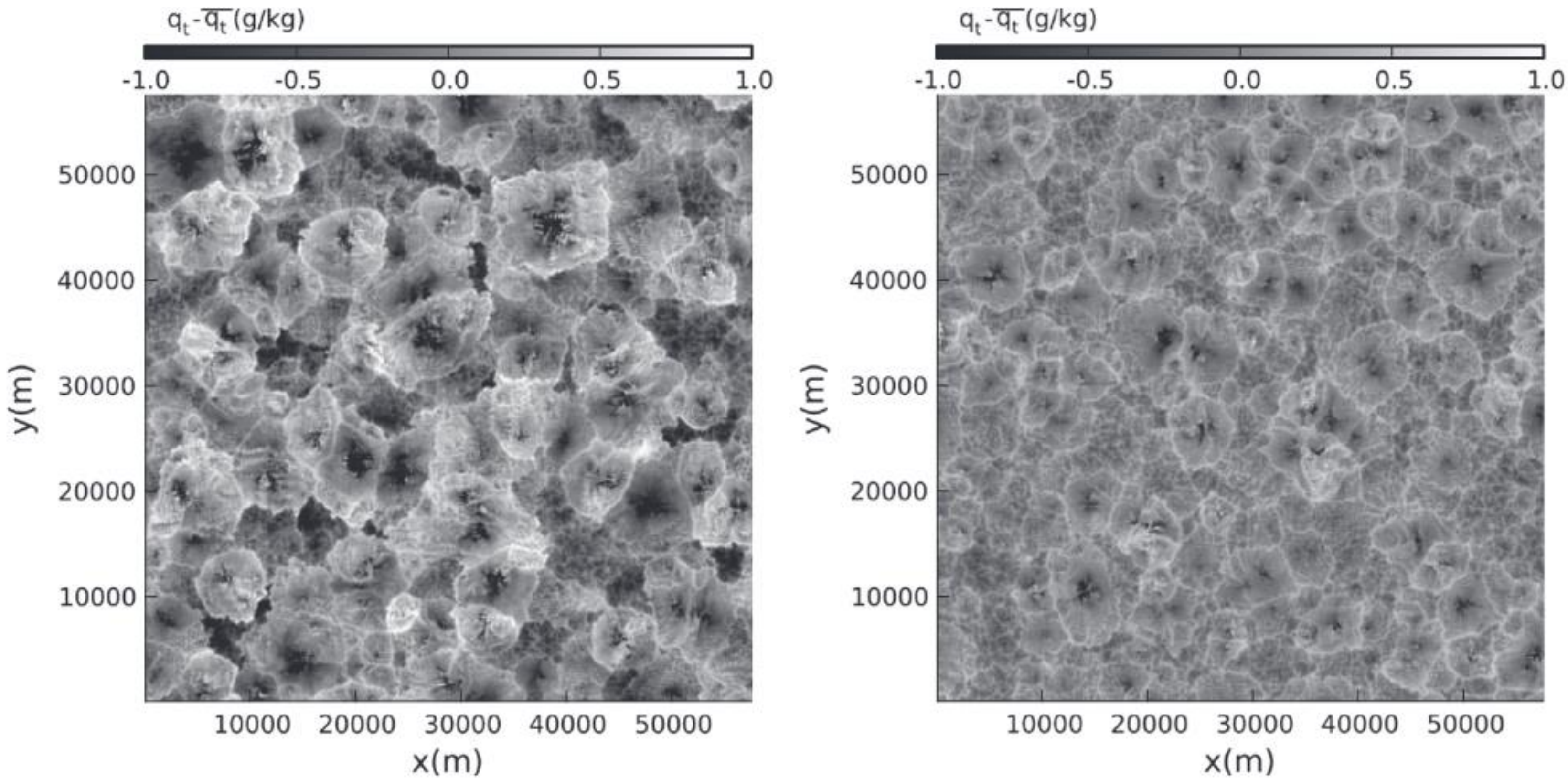


Cloud base radius

Boing et al. (2012)

Boing et al. 2012

Positive feedback: “cold pools promote deeper, wider, and more buoyant clouds with higher precipitation rates”

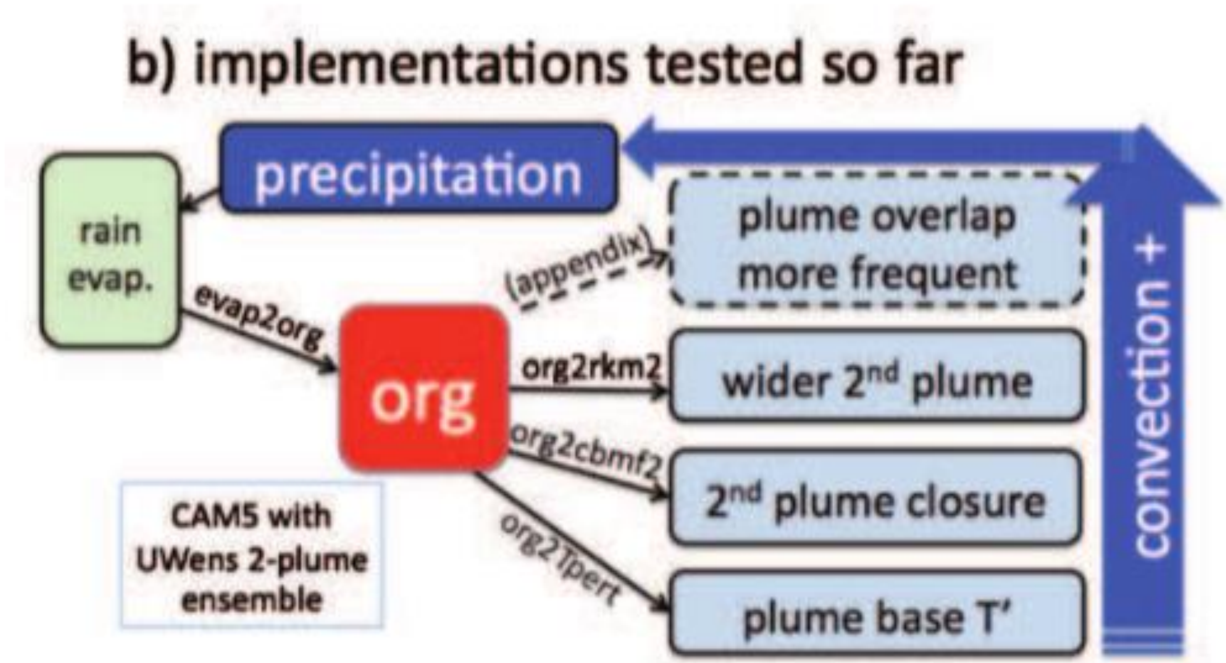


Practical applications

- So what if properties of convection vary with cold pool organization?
- Variability is what cumulus parameterizations are struggling to represent

Mapes and Neale (2011) “ORG”

- Vary plume properties by an order of magnitude according to amount of “organization”



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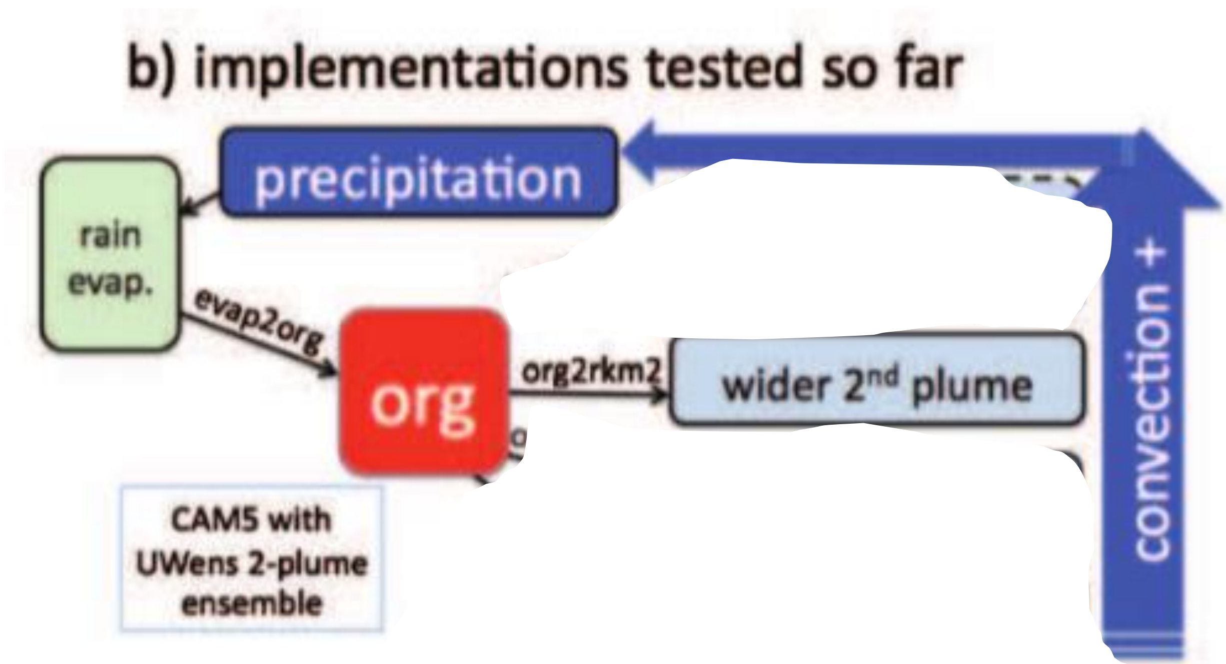
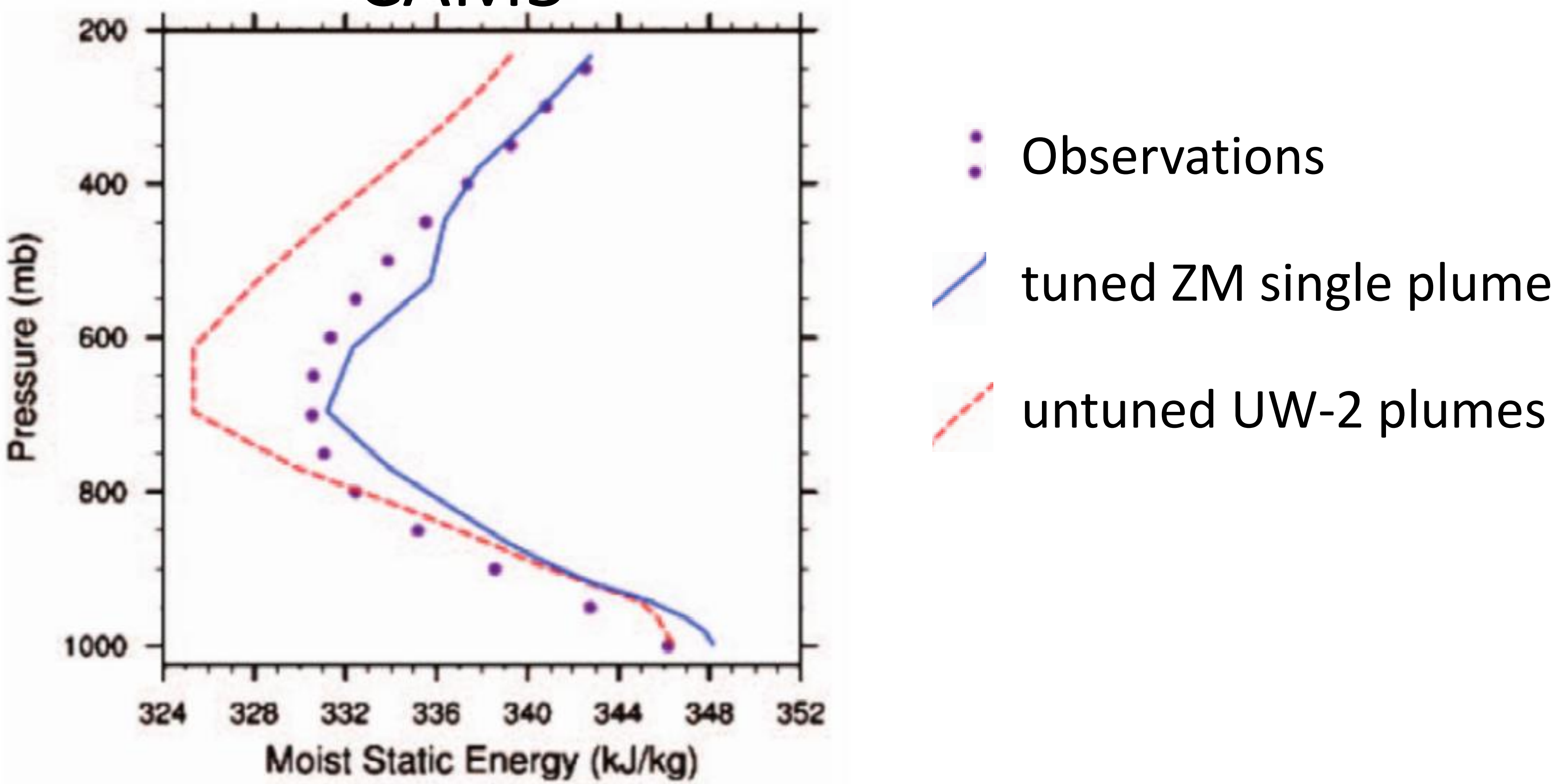
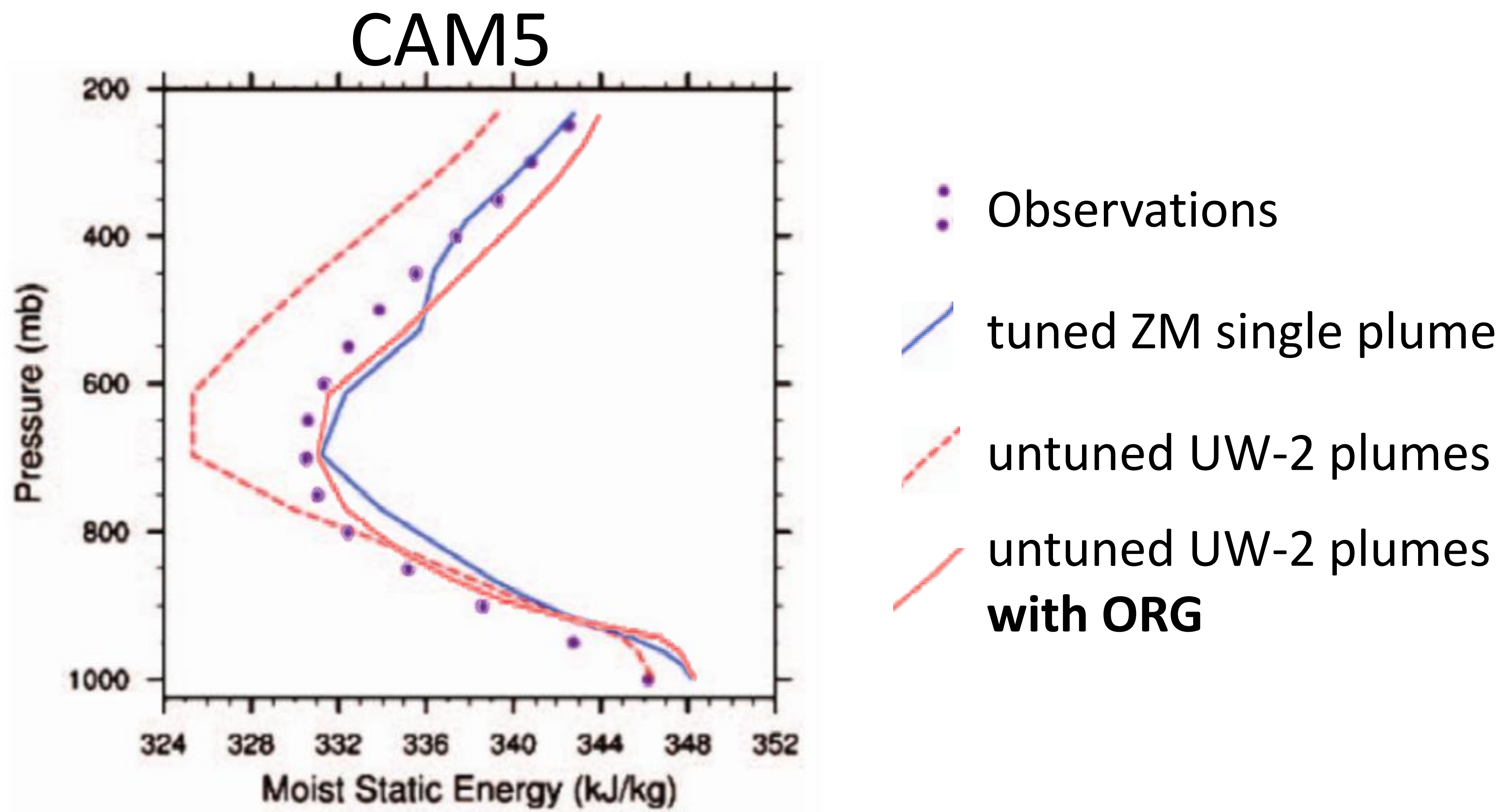


CAM5

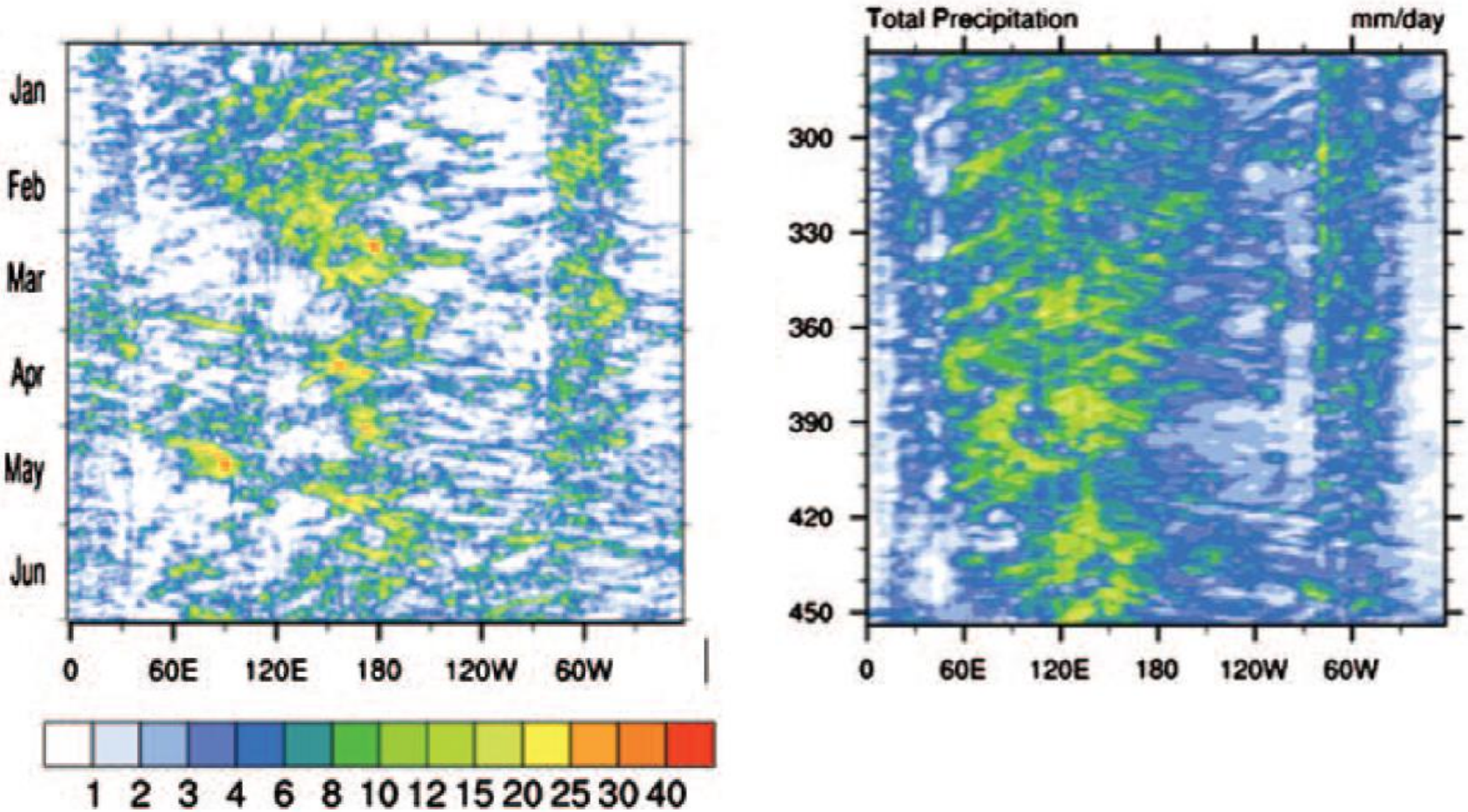


Vertical structure in convective tropical West Pacific



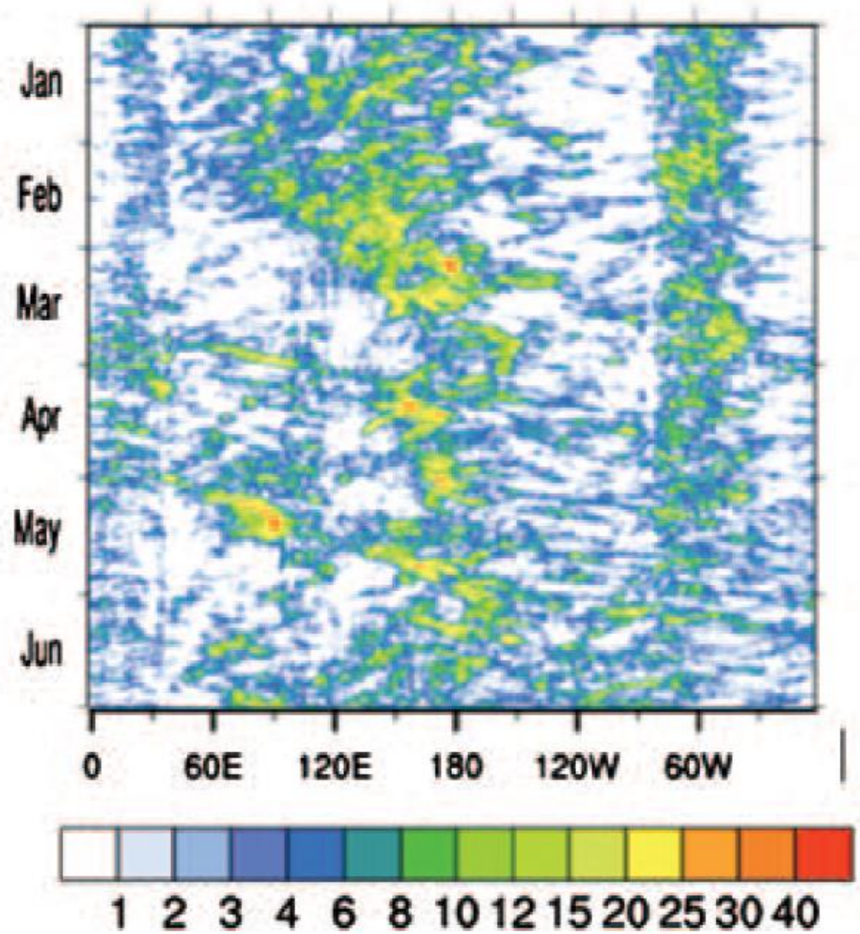
Vertical structure in convective tropical West Pacific

Satellite Derived (GPCP) CAM5 - ZM

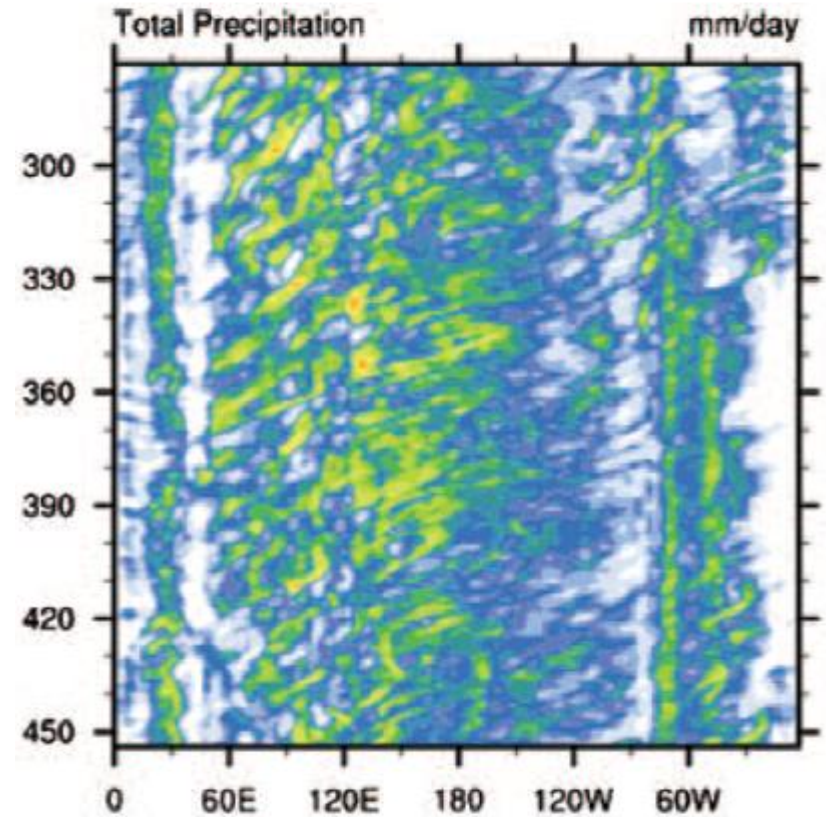


Precip variability improved

Satellite Derived (GPCP)



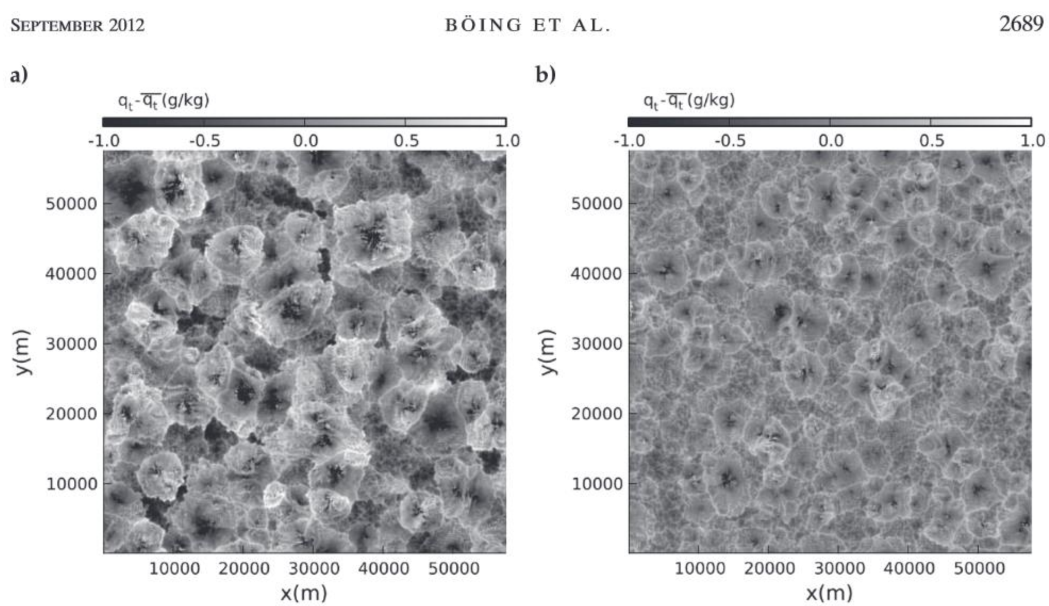
CAM5 - ORG



Precip variability improved

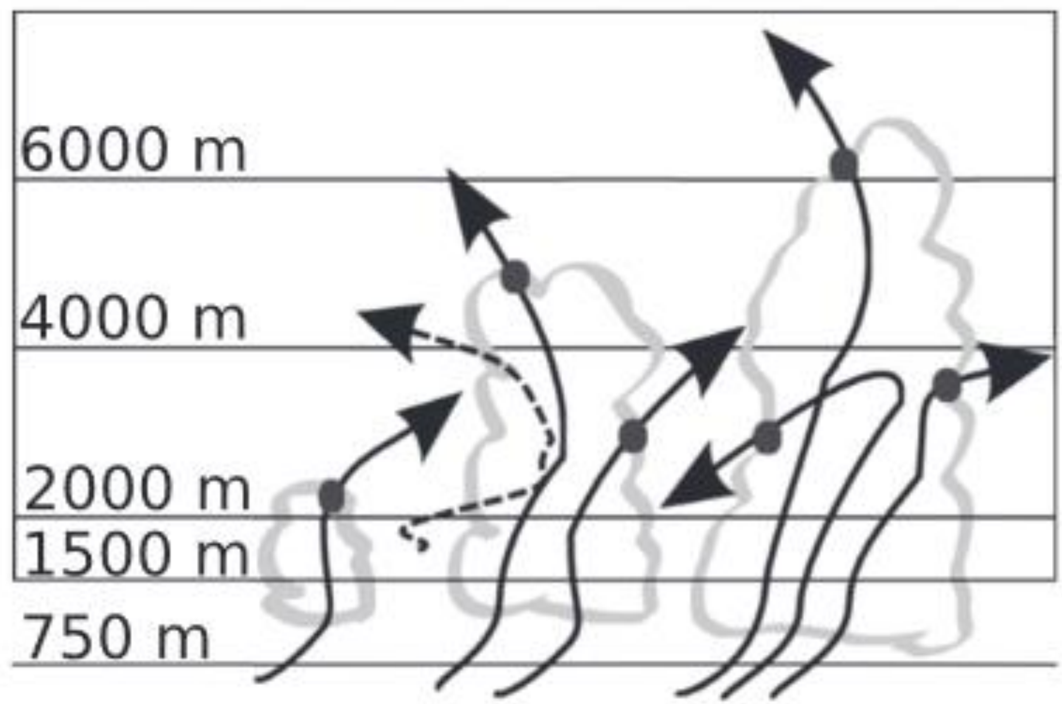
Cold pool organization studied in LES

- Why does cold pool organization promote deep convection?
- What did Boing et al. (2012) find in their study?



Boing et al. 2012

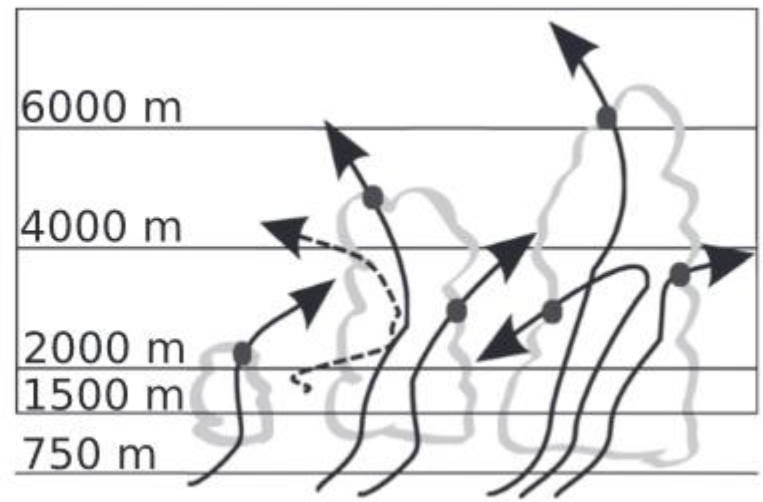
Lagrangian particle trajectories (LPT)



Boing et al. 2012

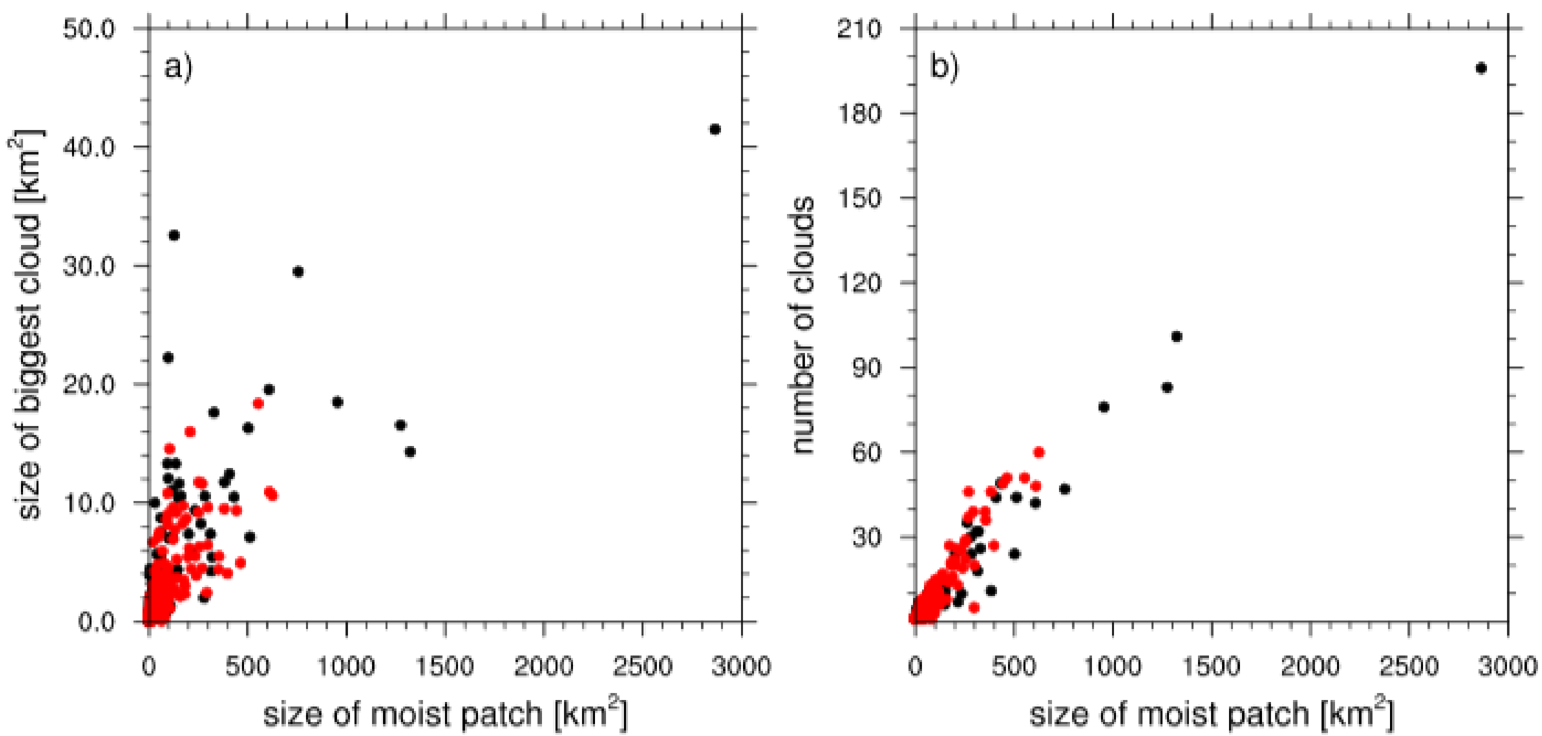
- Poor correlation between exit height and subcloud layer thermodynamic properties of LPTs (like Romps and Kuang 2010)
- Strong correlation for exit height and cloud base size
- Why do cold pools form larger clouds?

Lagrangian particle trajectories (LPT)



Cold pool organization studied in LES

- **Wider cloud bases** correlated with gust front lifting and extra moist patches at cold pool intersections. (Schlemmer and Hohenegger 2014)

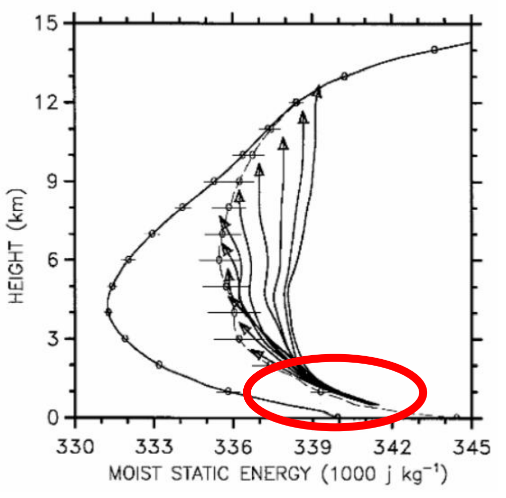


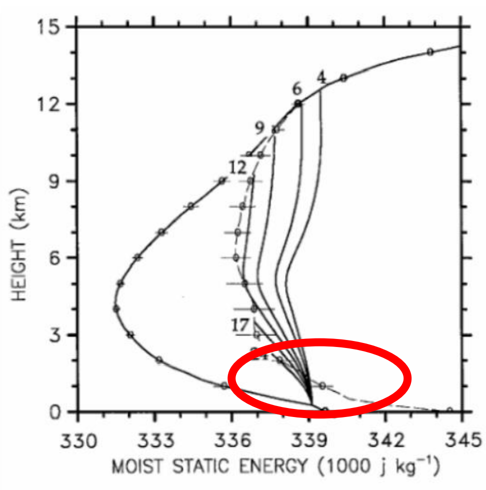
Cold pool organization studied in LES

- **Wider cloud bases** correlated with gust front lifting and extra moist patches at cold pool intersections. (Schlemmer and Hohenegger 2014)
- **Reduced cloud spacing**, stronger updraft velocity, and more deep convection correlated with intersecting cold pools (Feng et al. 2015)

Cold pool organization studied in LES

- Do wider bases exist from the start? Why is entrainment rate initially so large?
- Hypothesis: Merging of cloudy updrafts is promoted by cold pools. The increase in size from merging reduces entrainment.





My proposed research questions stated simply

1. Does reduced cloud spacing really affect cloud development?

2. Does merging occur in deep convective development?

3. How does merging affect development?

Other people's research

1. What is the importance of gustiness at cold pool gust front? (Langhans and Romps paper, Steve's gustiness slides)
2. Cold pools / Downdrafts (KTK slides)