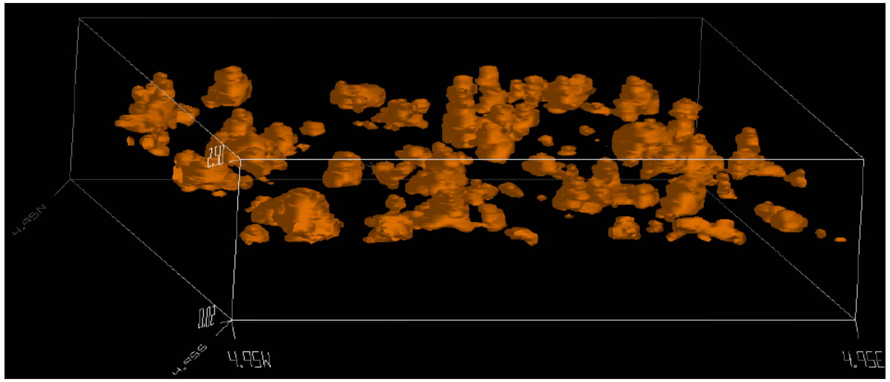
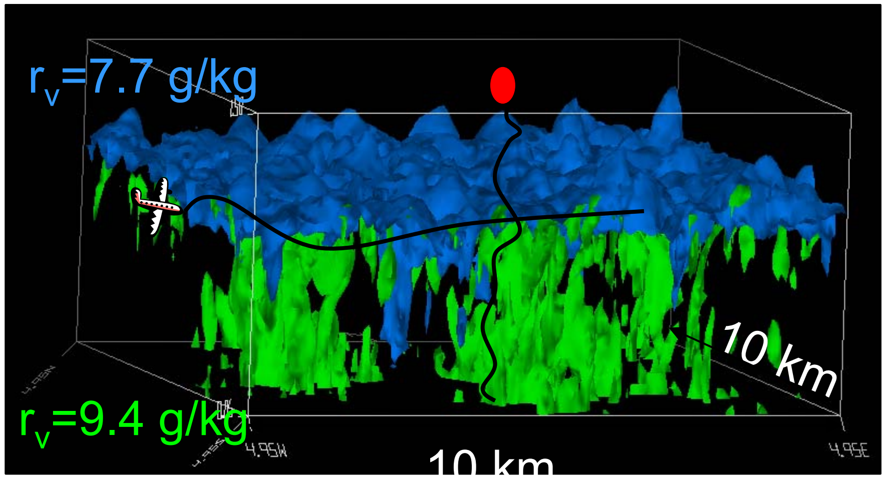
Resolved versus parameterized boundary layer plumes : A parametrization oriented conditional sampling in LES

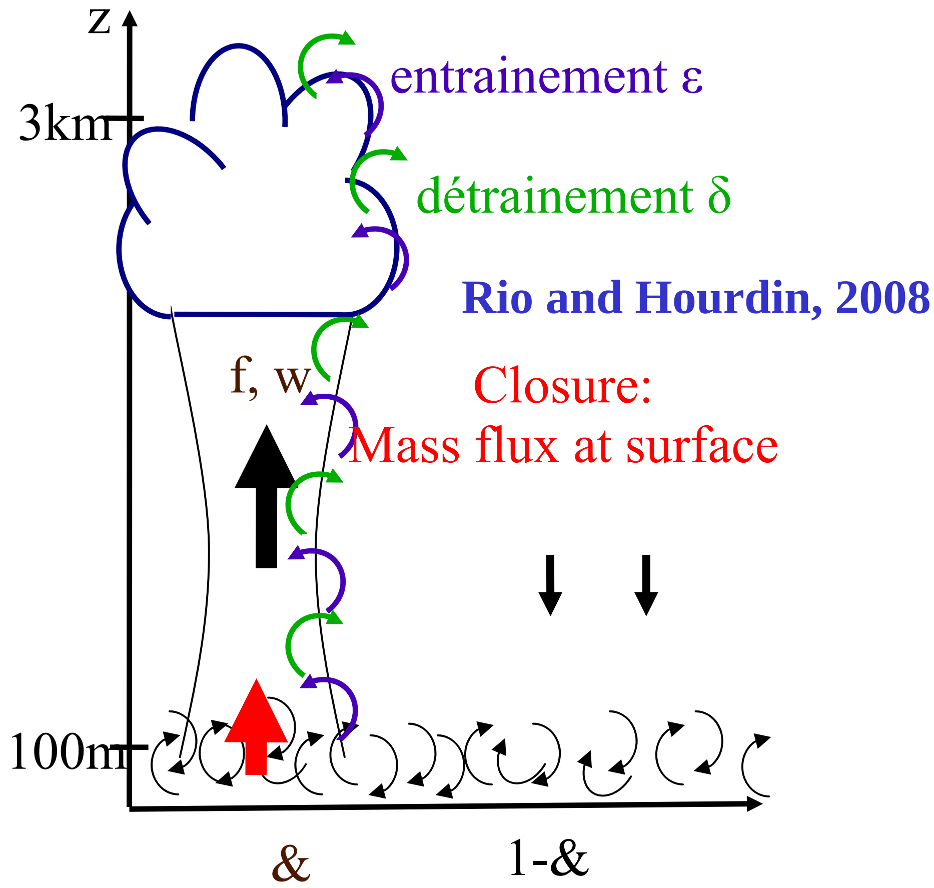
Fleur Couvreux, Catherine Rio, Frédéric Hourdin,
Emilie Perraud, Arnaud Jam



ARM cumulus

IHOP thermals





From resolved thermals … to parametrized thermals

Boundary layer thermals

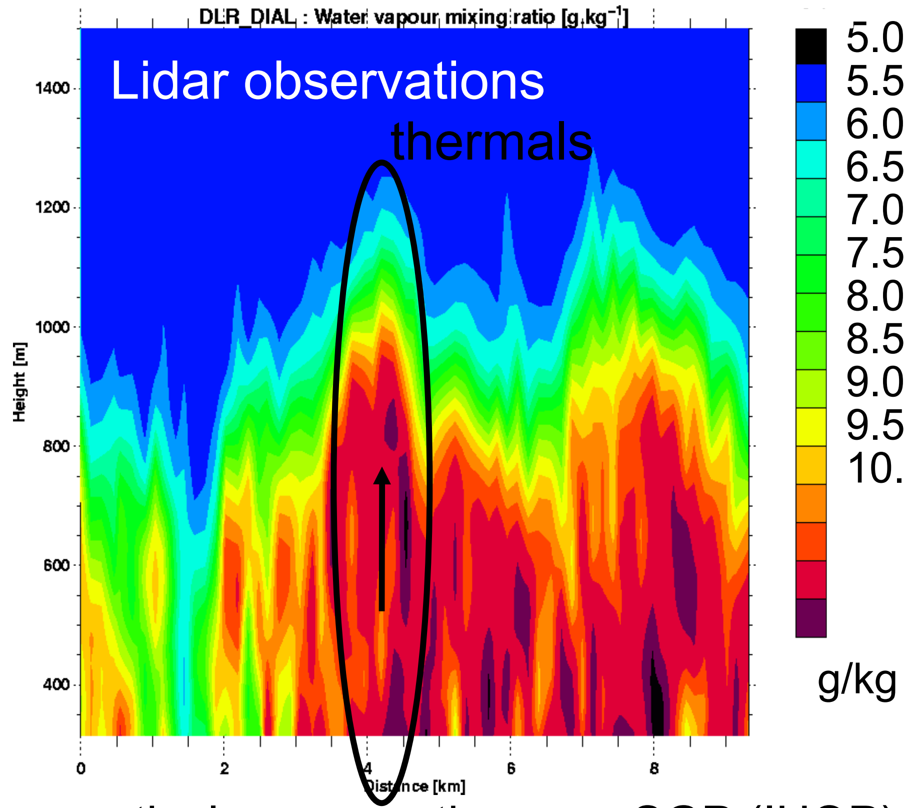
How to isolate clouds and thermals from their environment?

clouds: occurrence of liquid water

dry thermals under 0.6zi: excess of θv

in the transition layer and the upper boundary layer: ?

Can we find a criterion characterizing thermals continuously from the surface to cloud top?



rv vertical cross section over SGP (IHOP)

1. A conditional sampling to select thermals in LES

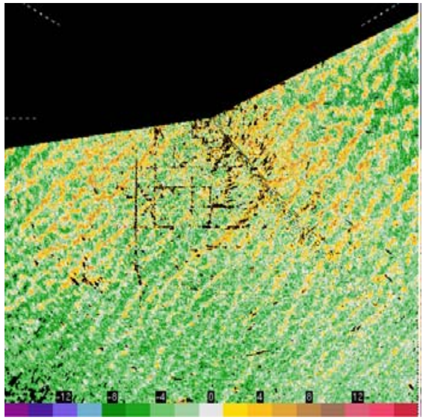
2. How to use this CS to improve EDMF schemes?
   - 2.a entrainment/detrainment definition
   - 2.b cloud scheme

Structures explicitly resolved in LES

Thermals in cloud-free CBL

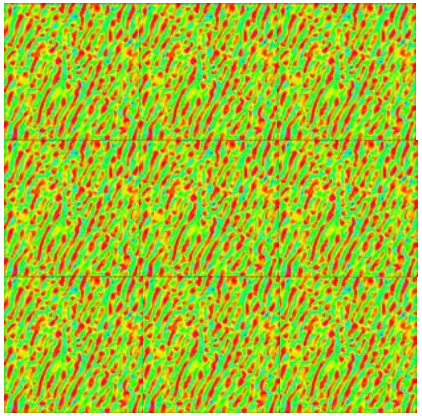
IHOP case, Couvreux et al. (2005)

Radar observations



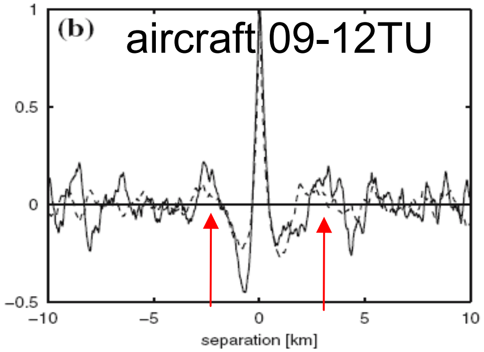
30 km

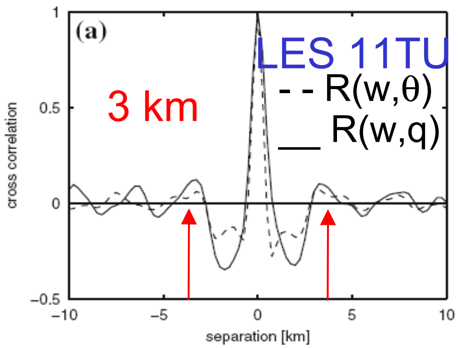
LES



30 km

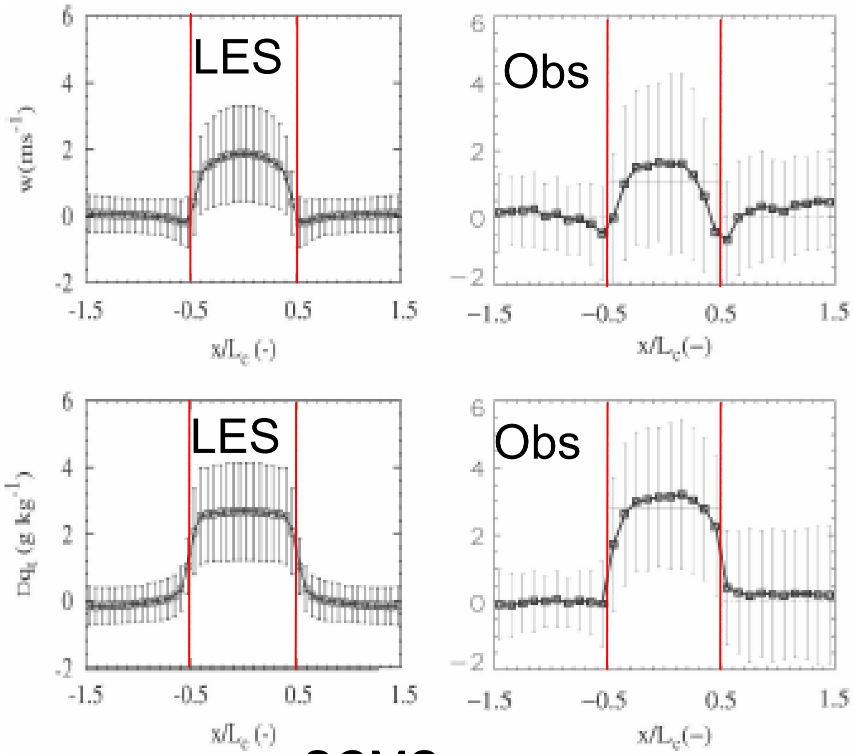
HAPEX Sahel, Lothon et al. (2007)





Cumulus clouds

Horizontal distribution at the cloud-edge
(Heus et al., 2008)



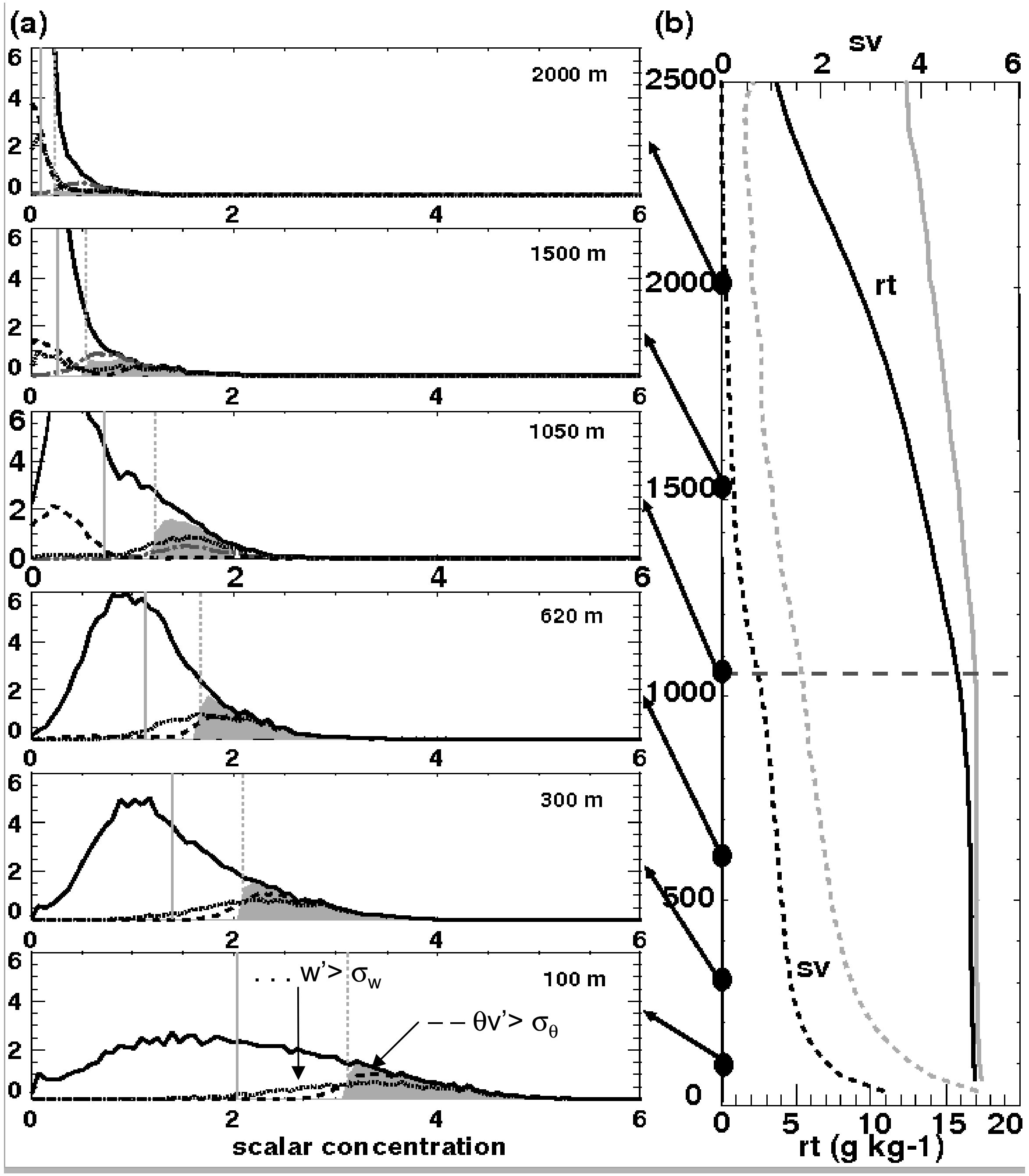
vertical velocity

total water vapour

- ➢ LES: adapted tool to study coherent structures (thermals, clouds)
- ➢ LES: provide 4D variables, low sensitivity to parameterizations

A conditional sampling to characterize thermals continuously from the surface to cloud top

Couvreux et al., 2010

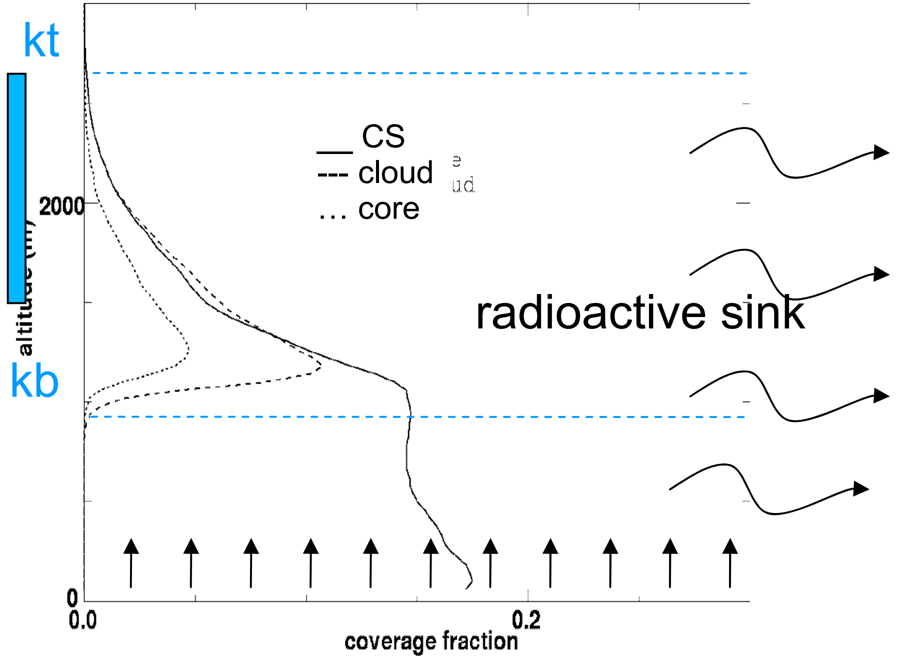


Emission of a tracer at surface
+ radioactive decay

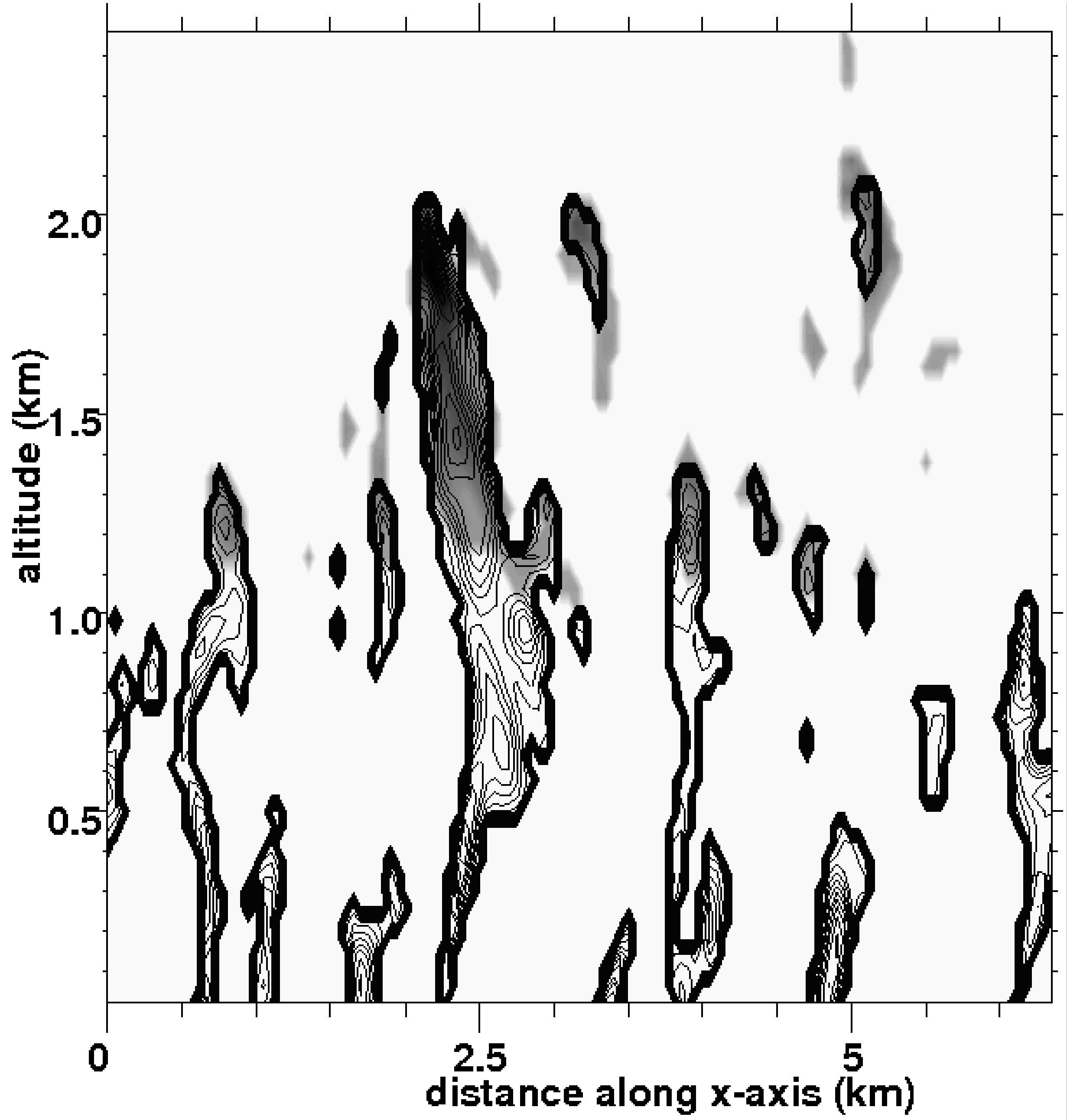
Thermals are selected from following criteria:

$s' > m \times \max(\sigma_{s'}, \sigma_{min}) + w > 0$

+ ql > 0 in the upper part of clouds

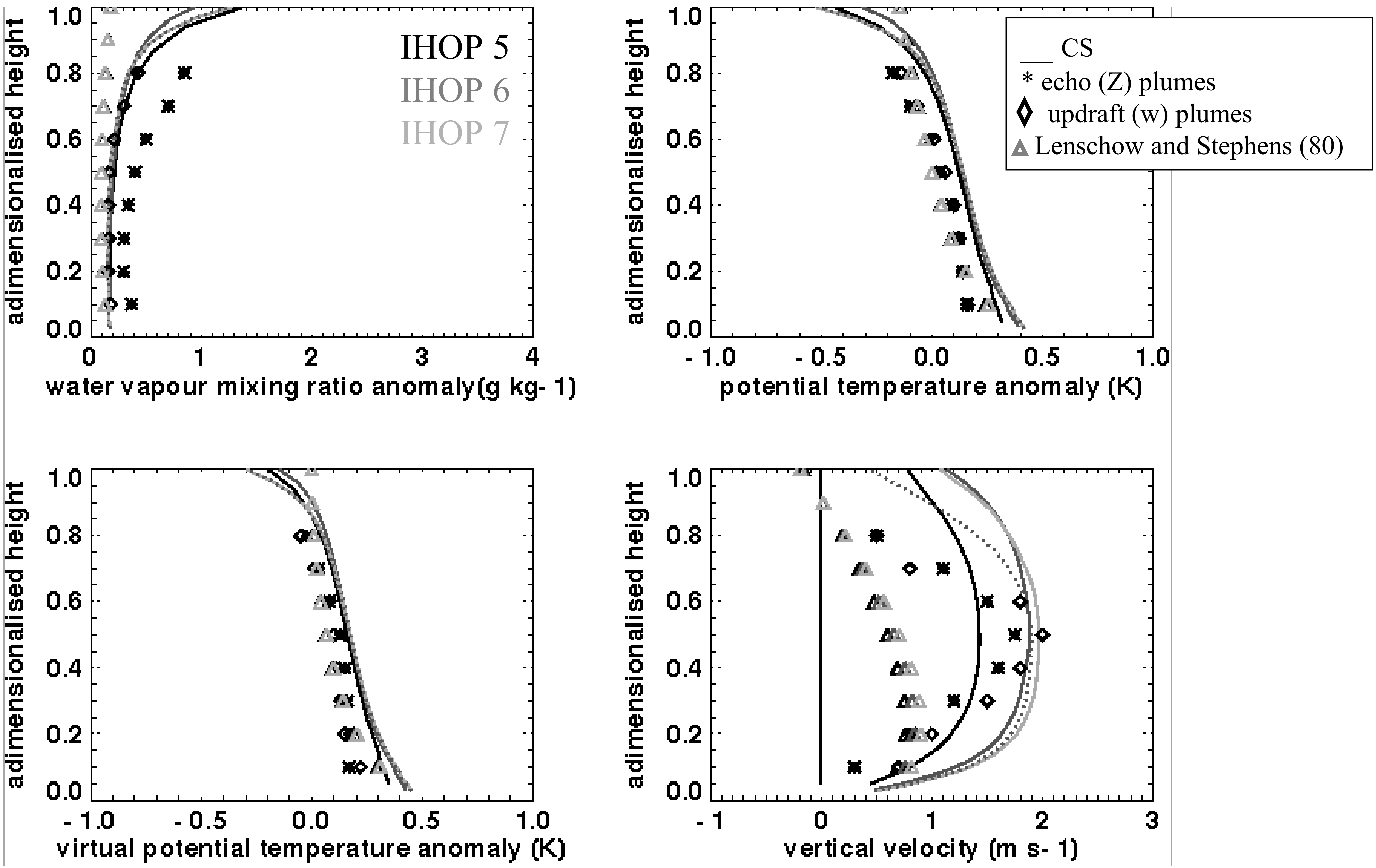


Selected structures in LES

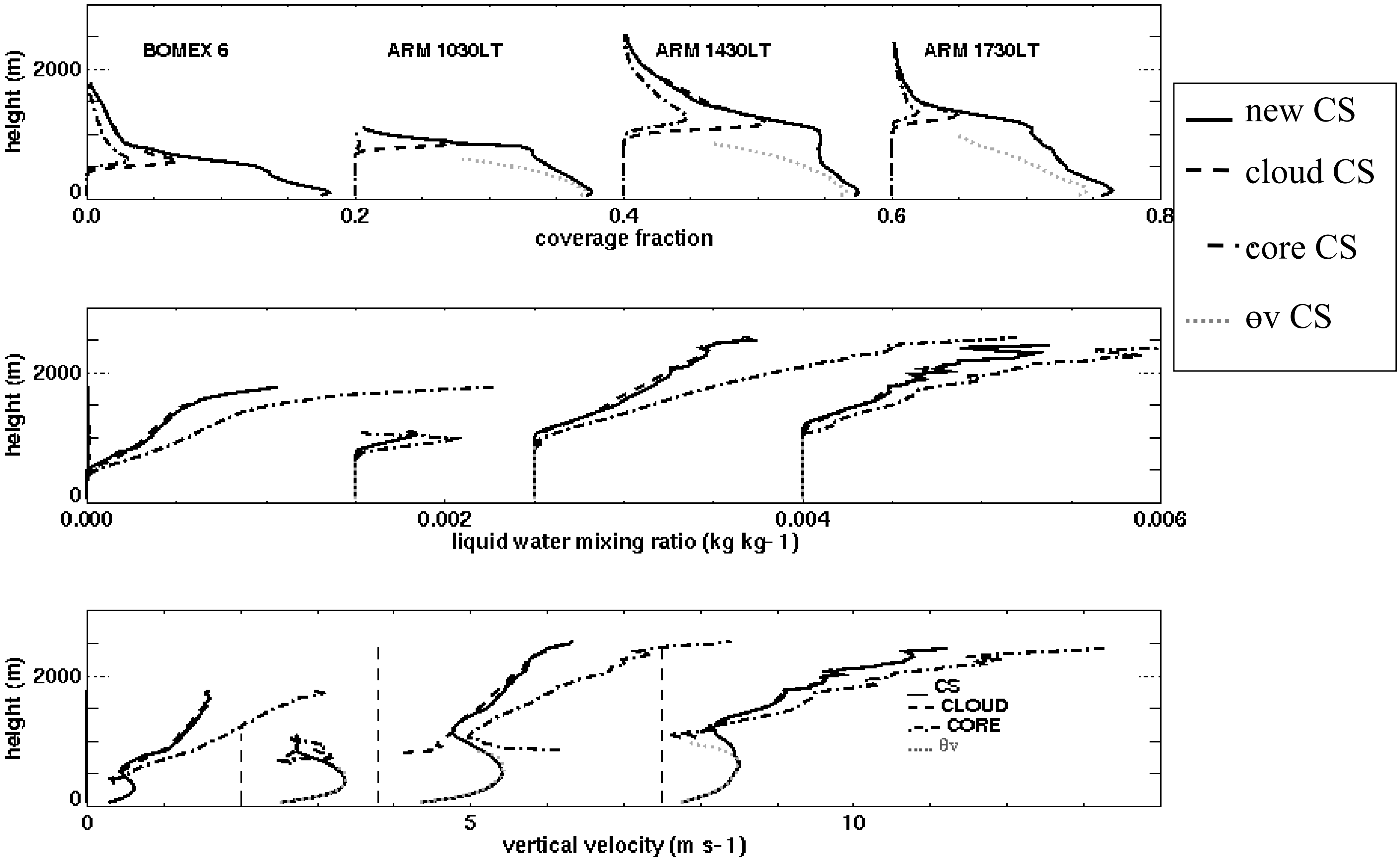


cumulus are the saturated, visible part of updrafts rooted in the subcloud layer… LeMone and Pennell (1976)

Evaluation of the conditional sampling on clear CBL



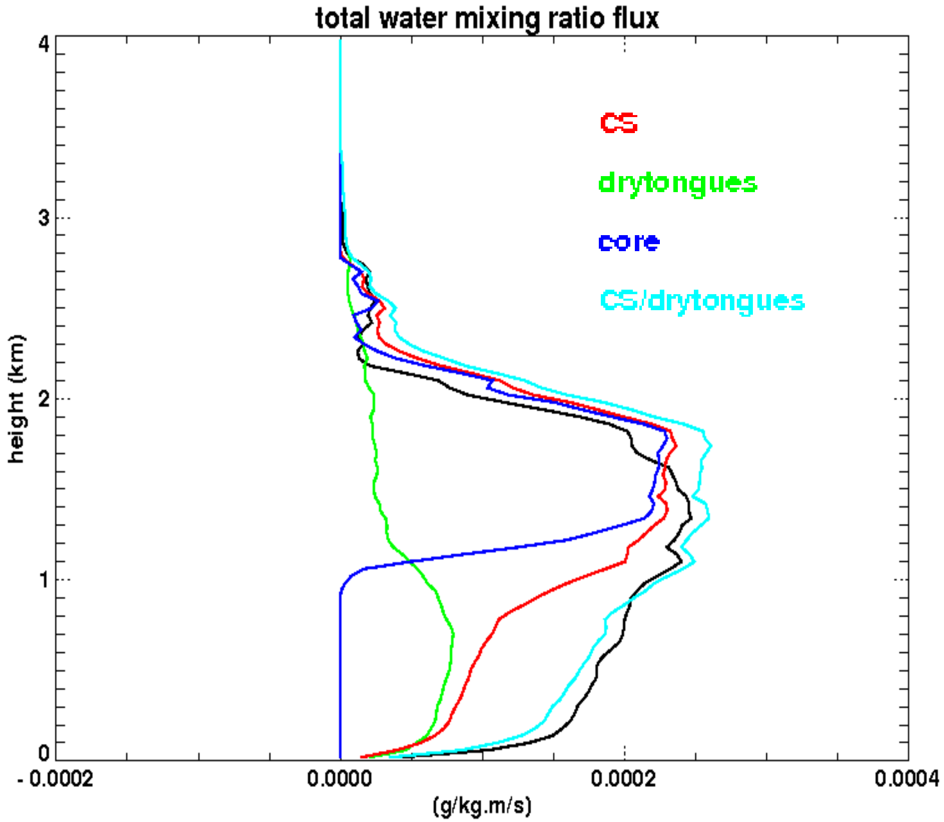
Evaluation of the conditional sampling on cloudy CBL

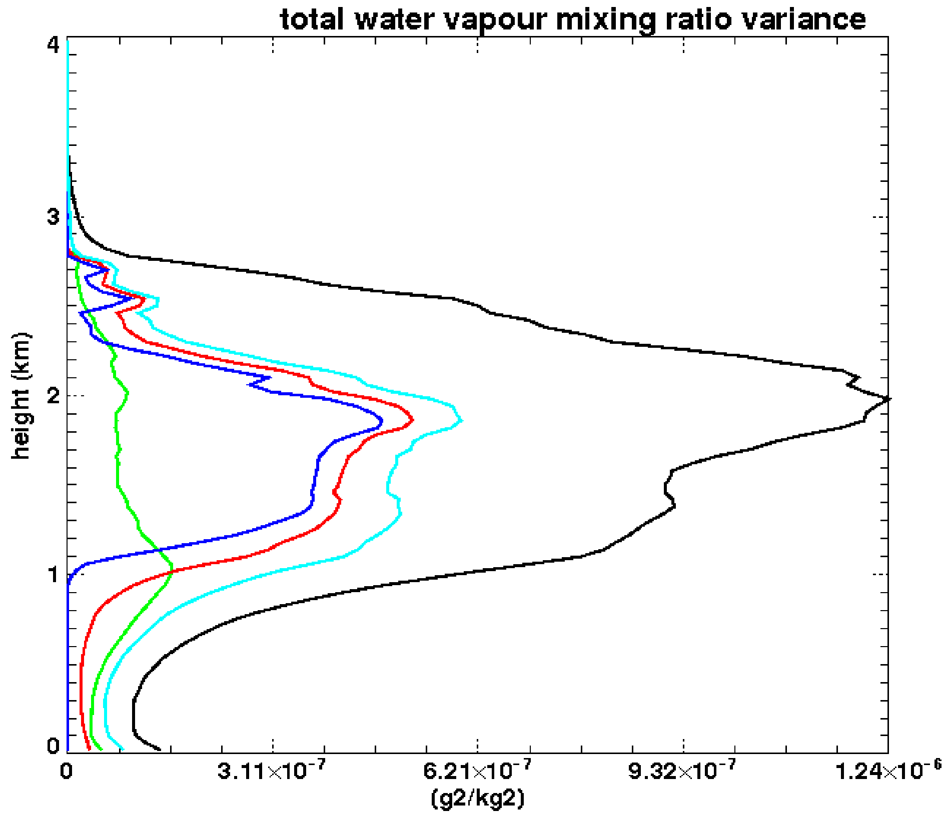


provide thermal characteristics from the surface to the top of the clouds

Application
Contribution of thermals to fluxes and variances

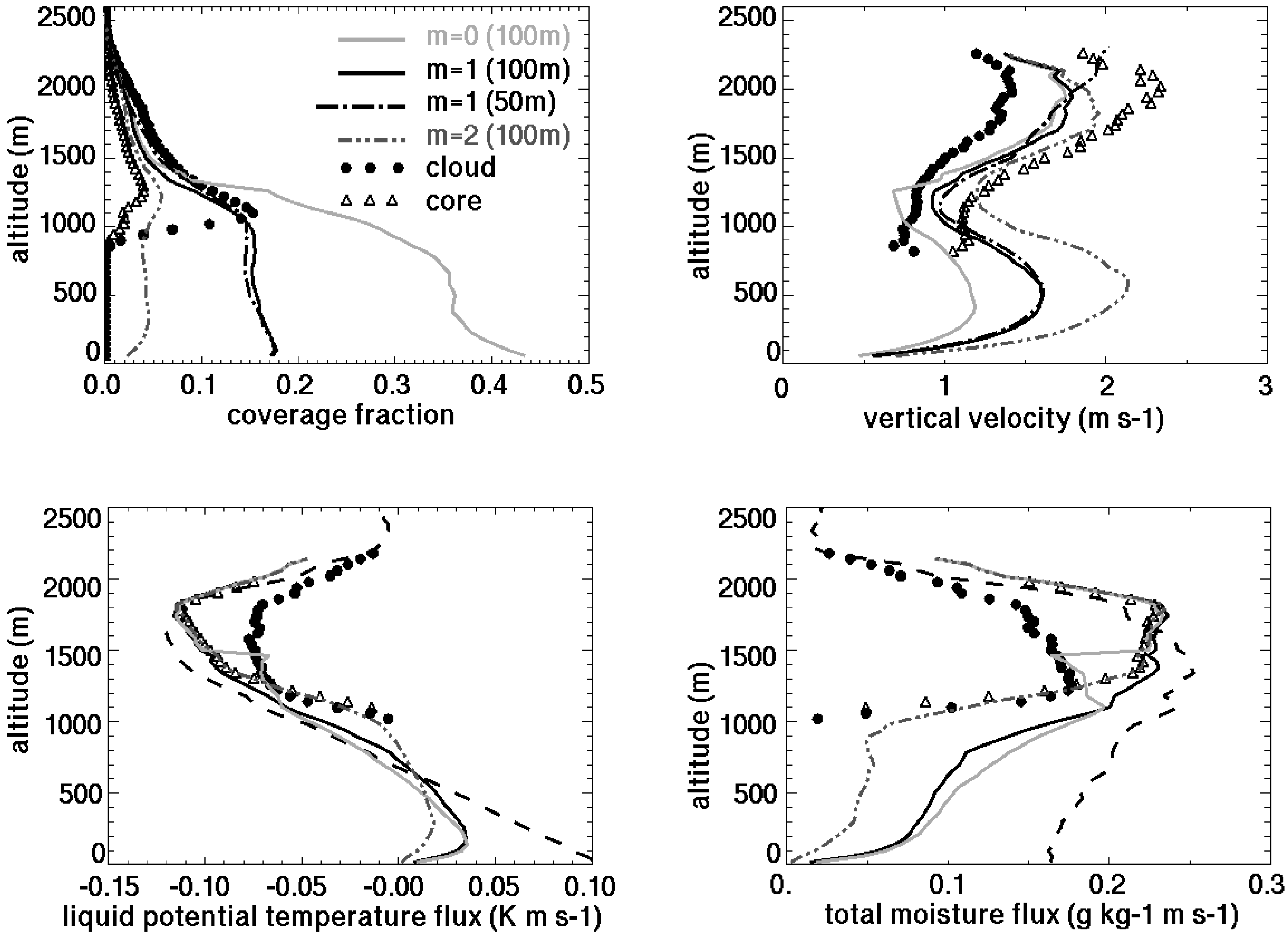
Flux and variance of rt



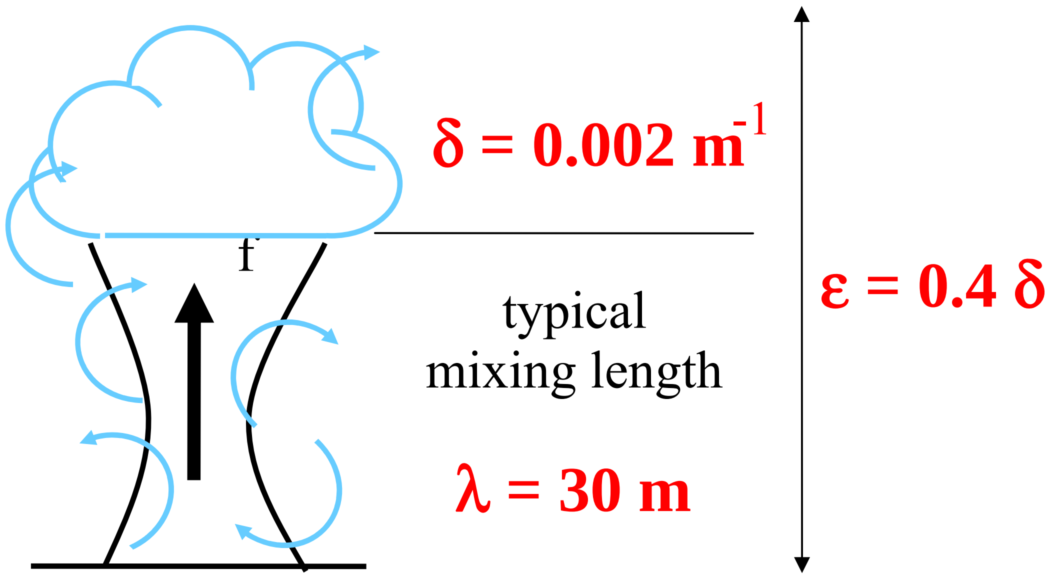


CS explains ~ 100% of the flux in the cloud layer,
~ 60-80% in the sub-cloud layer
~ 30-40% of the variance

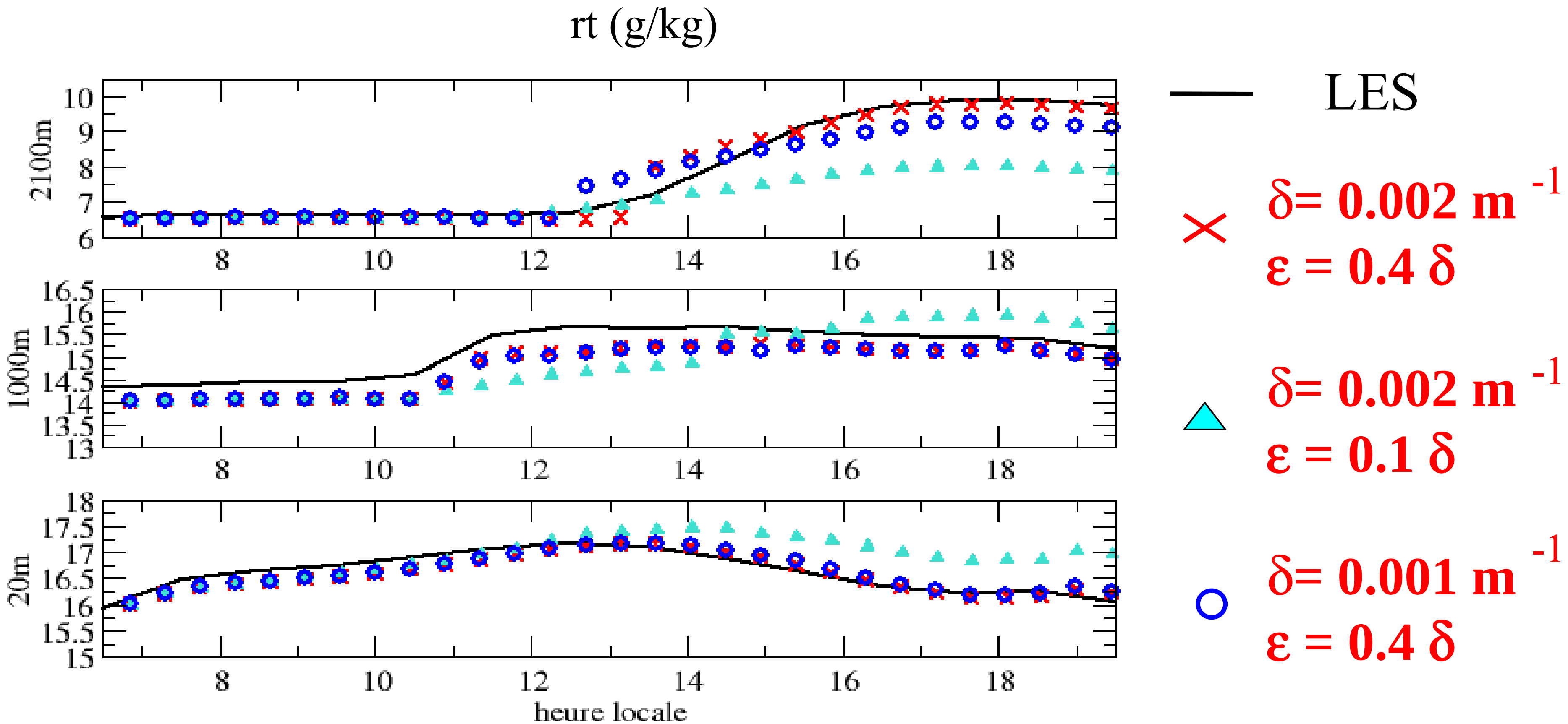
Sensitivity tests to the definition of the conditional sampling



The question of the mixing rates



How to define mixing rates
physically rather than geometrically?



Application
Evaluation of internal variables of parameterizations

Equation for the vertical velocity

Rio and Hourdin 2008

$$\frac{1}{2}\frac{\partial w_u^2}{\partial z} = B - \varepsilon w_u^2$$

modifications

$$\frac{1}{2}\frac{\partial w_u^2}{\partial z} = a_1 B - b w_u^2 - \varepsilon w_u^2$$

A continuous formulation of mixing rates

Rio et al., 2010

Impact of acceleration

ε =0.4 δ

$$\varepsilon = \max(0, \frac{\beta_1}{w_u}\frac{\partial w_u}{\partial z}) = \max(0, \frac{1}{1+\beta_1}(a_1 \frac{B}{w_u^2} - b))$$

moisture contrast

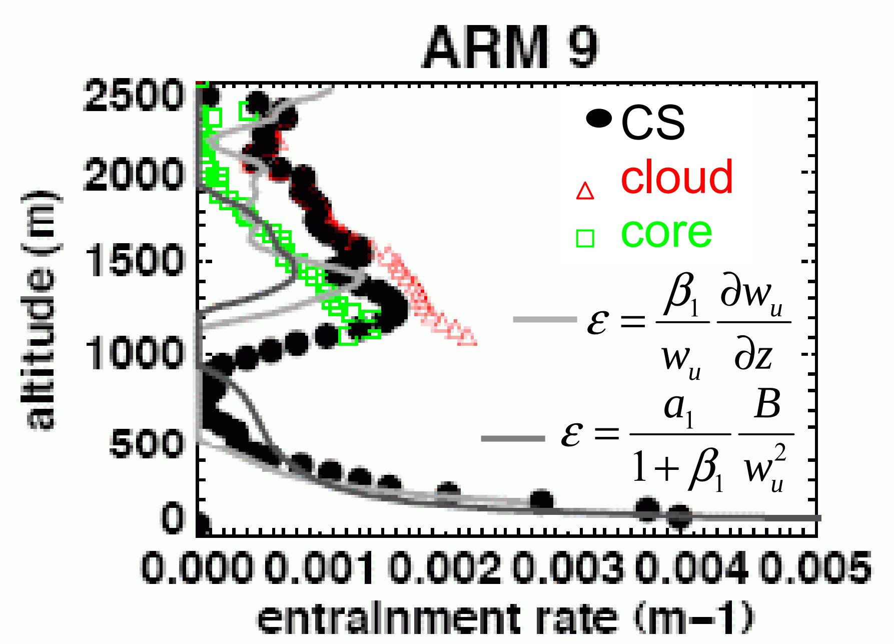
δ=0.002 in cloud

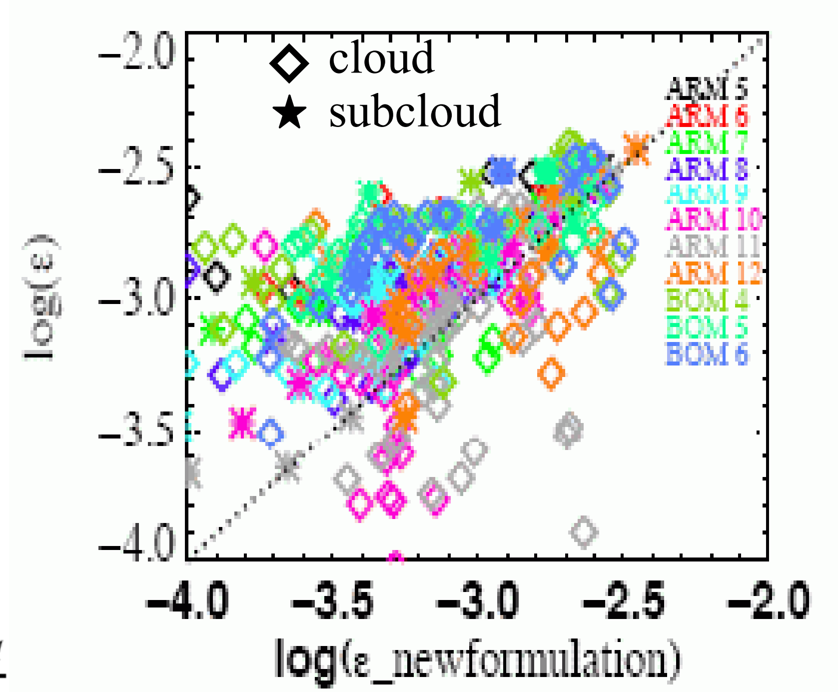
δ geometrical def

$$\delta = \max(0, \frac{-a_1\beta_1}{1+\beta_1}\frac{B}{w_u^2} + c(\frac{\Delta q_t / q_t}{w_u^2})^d)$$

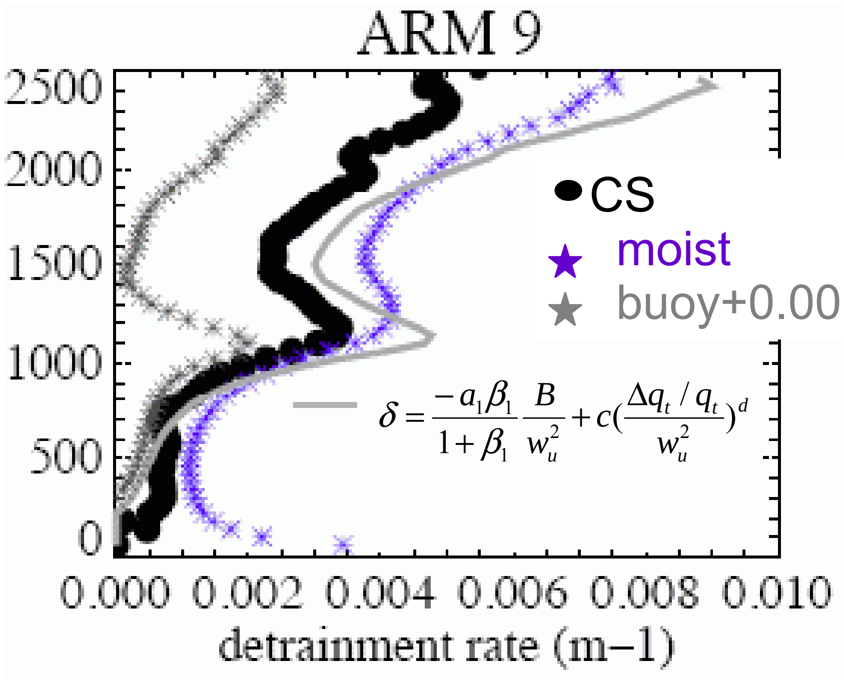
Impact of deceleration

Validation of the formulation in LES

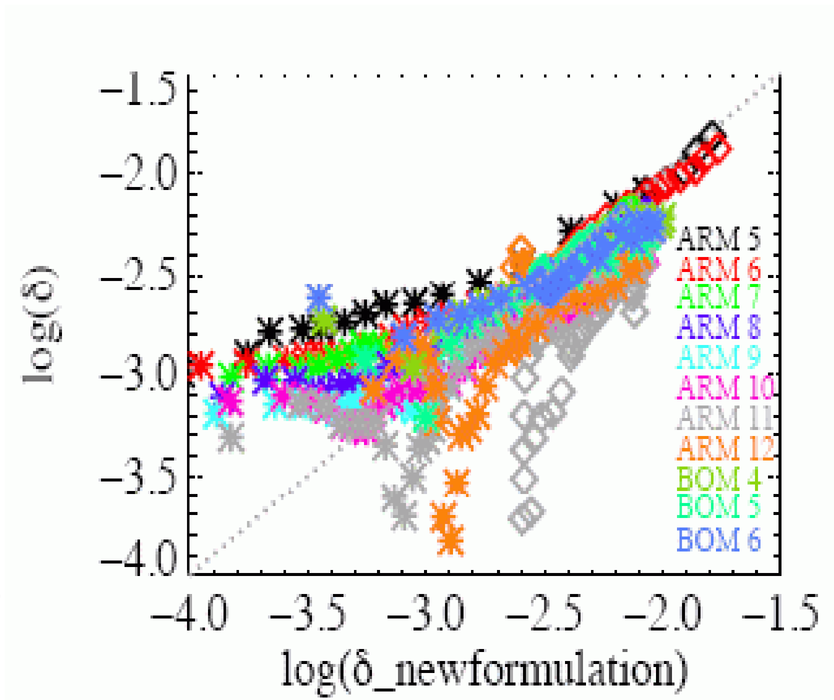




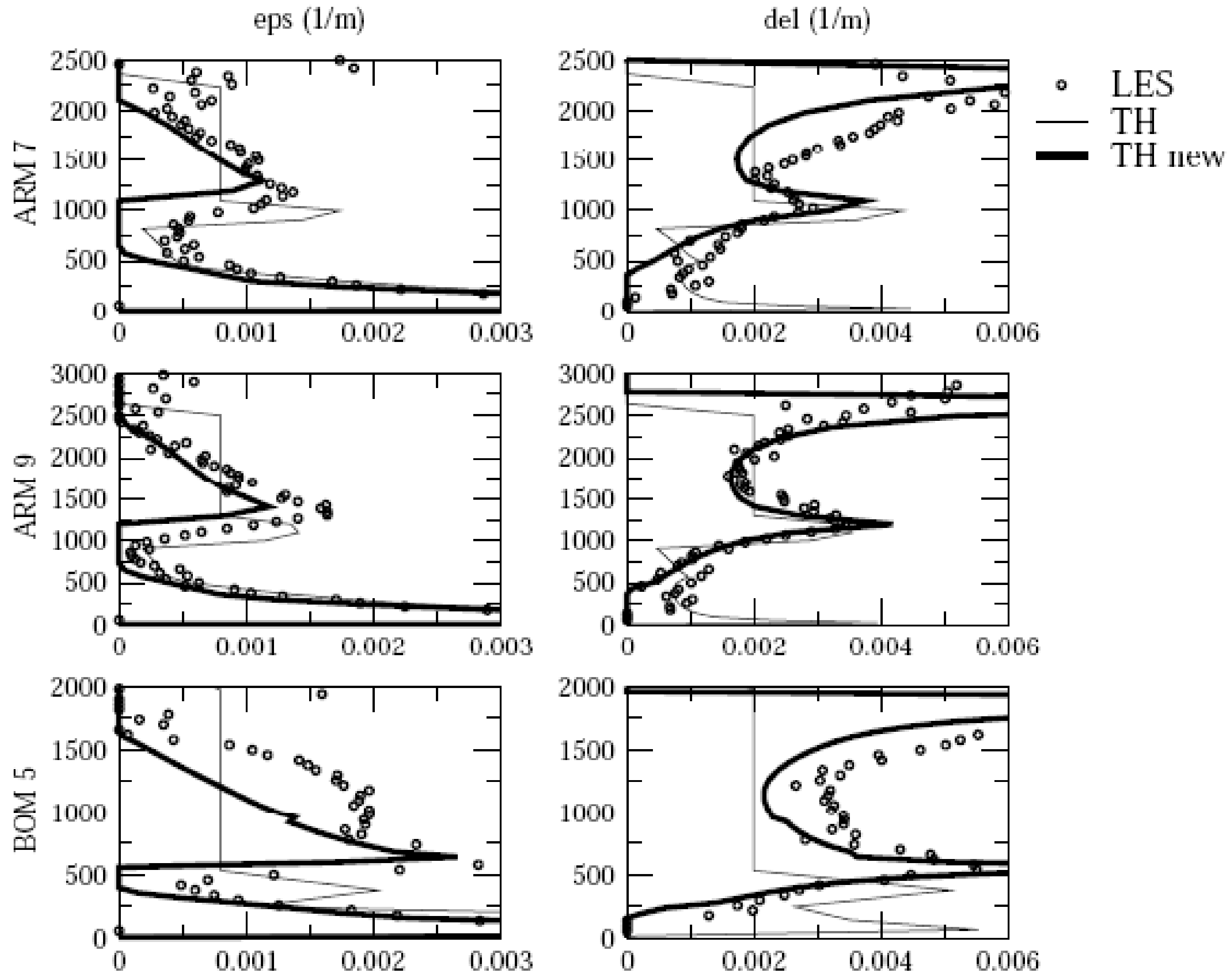
$$\varepsilon = \frac{1}{\psi - \psi_u}\frac{\partial \psi_u}{\partial z}$$



$$\delta = \frac{-1}{f}\frac{\delta f}{\delta z} + \varepsilon$$



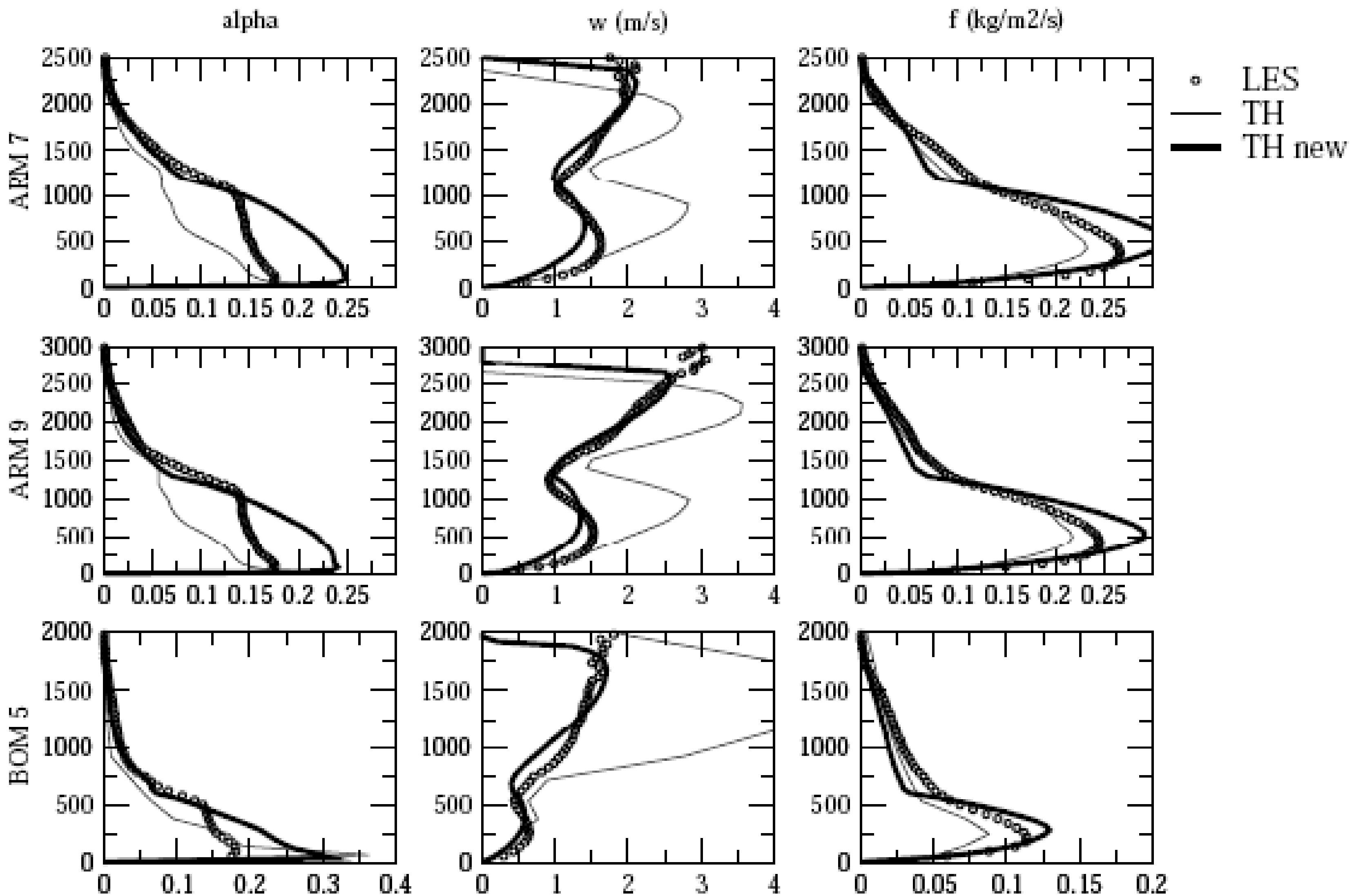
Introduction of the formulation in the thermal plume model



ε (1/m) δ (1/m)

- Entrainment decreases from the surface to the top of the mixed layer and from cloud base to cloud top
- Detrainment increases near cloud base and top

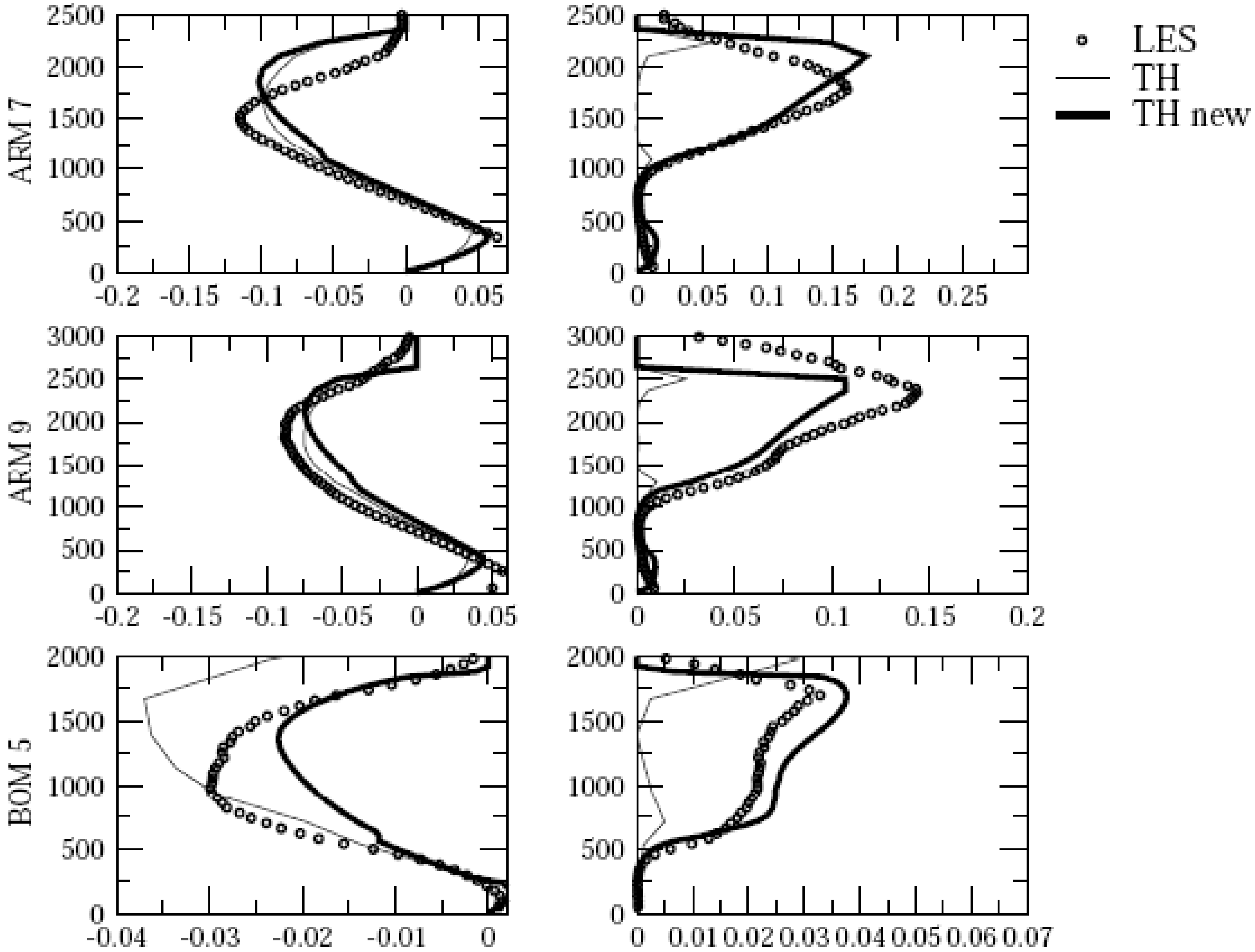
Thermals characteristics



α w (m/s) f (kg/m2/s)

- Better representation of the vertical profile of vertical velocity and thermals coverage

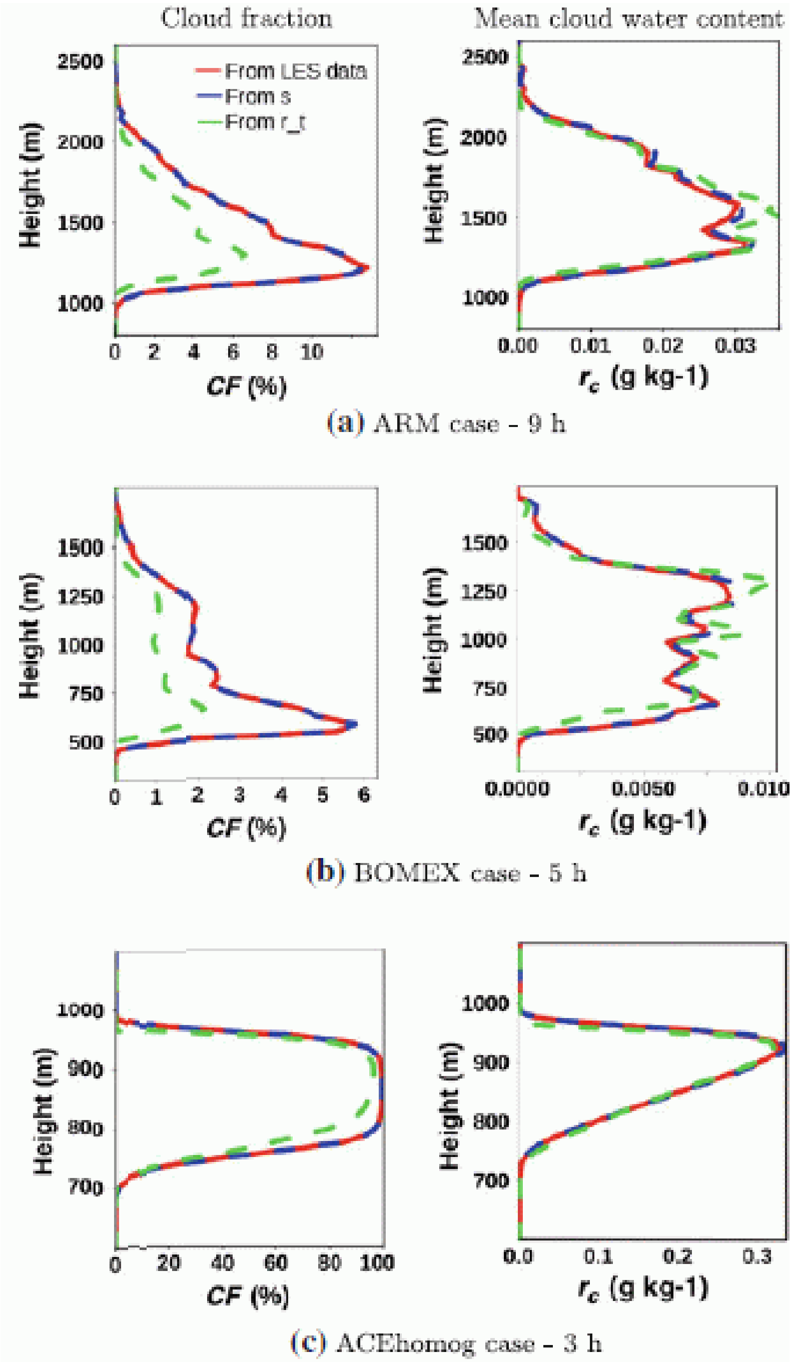
Flux and variance of liquid potential temperature

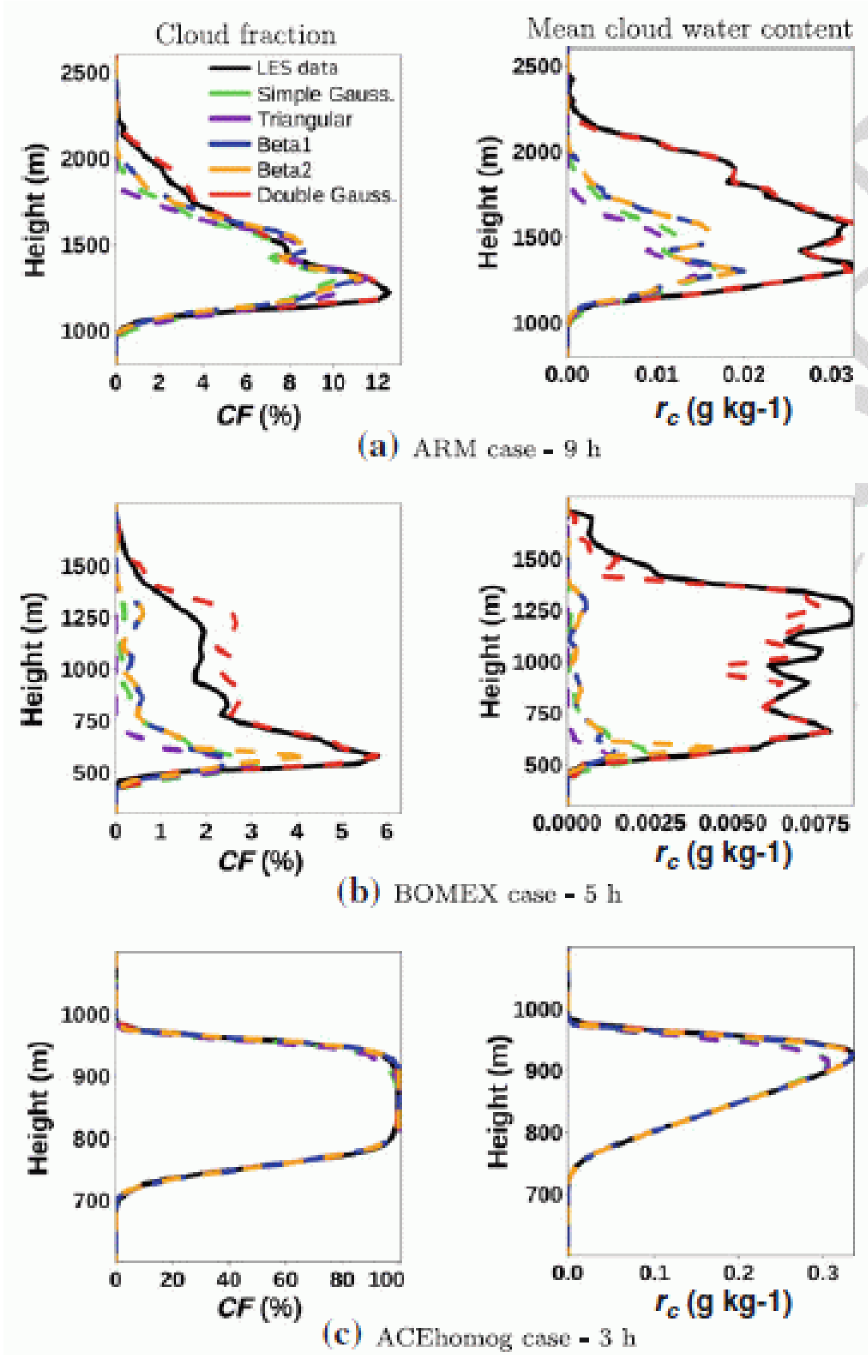


- Flux unchanged
- Better representation of the variance

Concerning the cloud scheme :

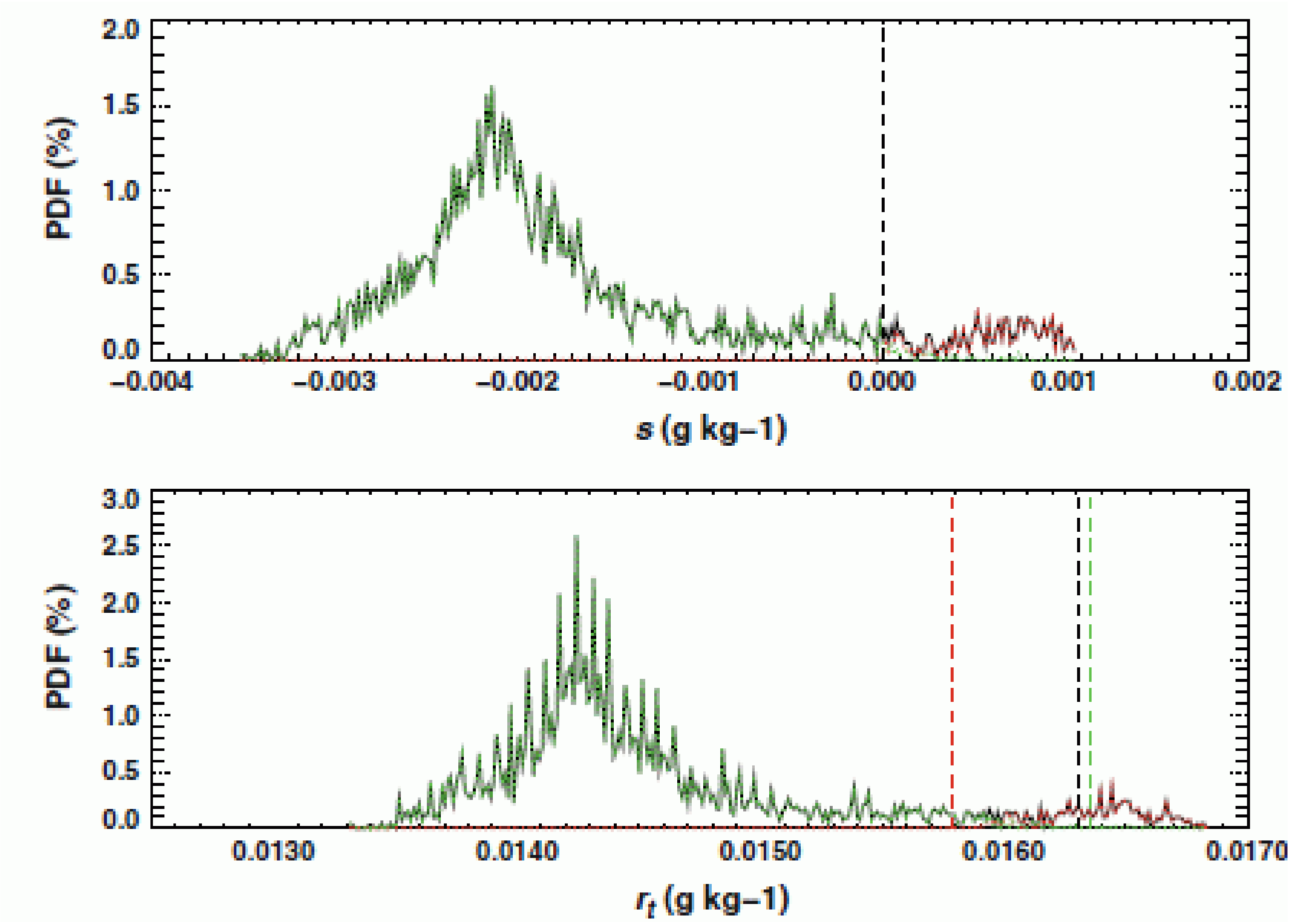
Perraud et al., 2011





- s instead of rt
- Bi-gaussian describes the subgrid variability

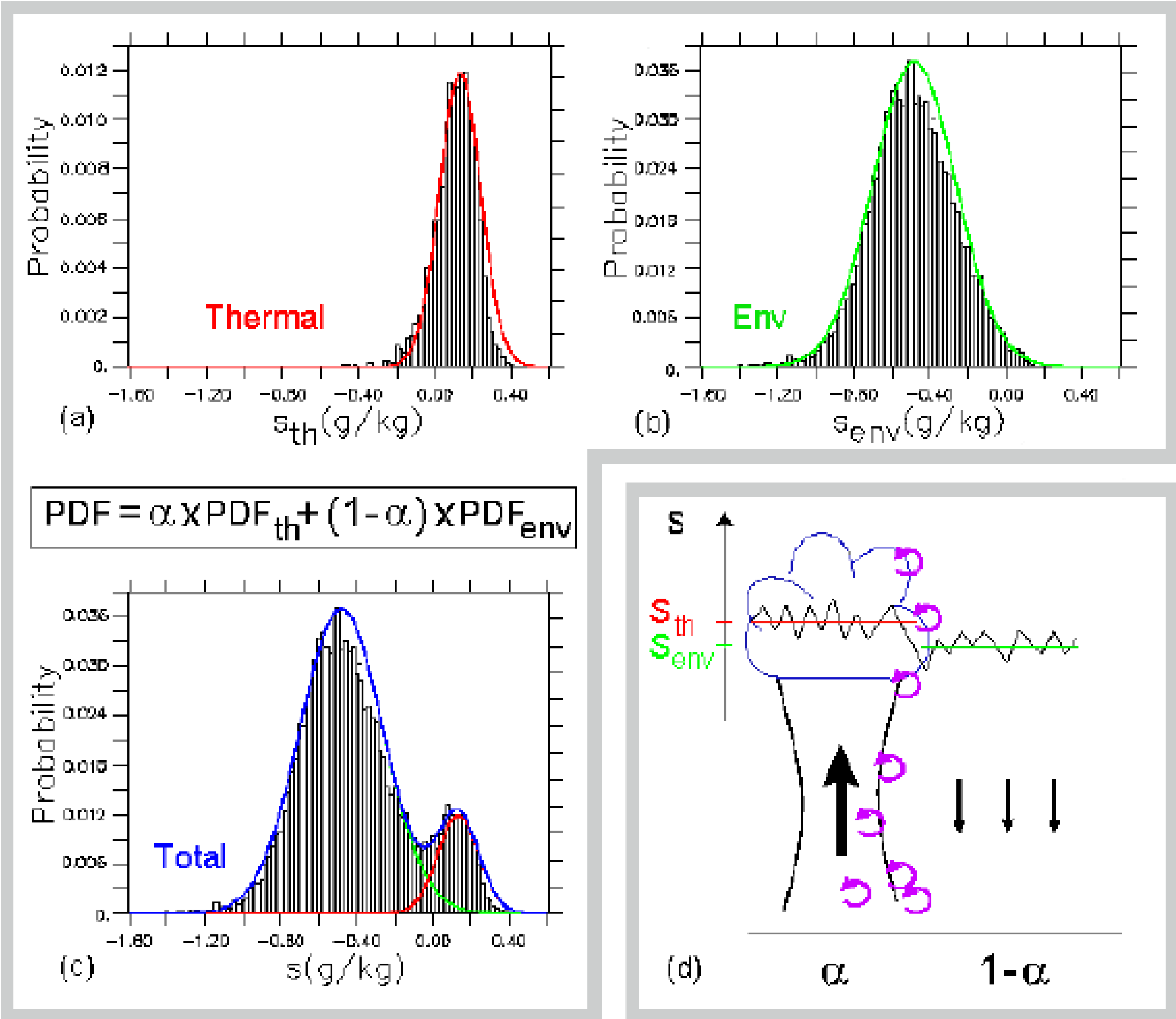
In the bi-gaussian distribution, rt can be the variable



- If one assumes separate saturation threshold for thermals and environment:
  - no need for s, rt is sufficiant

A new cloud scheme coupled to EDMF: determined using the CS

Jam et al., 2011



- A bi-gaussian distribution: environment and thermals

$$\text{PDF}=(1-\alpha)\times f(s,\bar{s}_{env},\sigma_{env})+\alpha\times f(s,\bar{s}_{th},\sigma_{th})$$

$$\text{f}(s,\bar{s},\sigma)=\frac{1}{\sigma\sqrt{2\pi}}\times e^{-\frac{(s-\bar{s})^2}{2\sigma^2}}$$

- &, s_{th}, s_{env} already defined by EDMF

- σ_{th}, σ_{env} must be parameterized

A new cloud scheme coupled to EDMF: Parameterization of the standard deviation

Jam et al., 2011

Hypothesis:

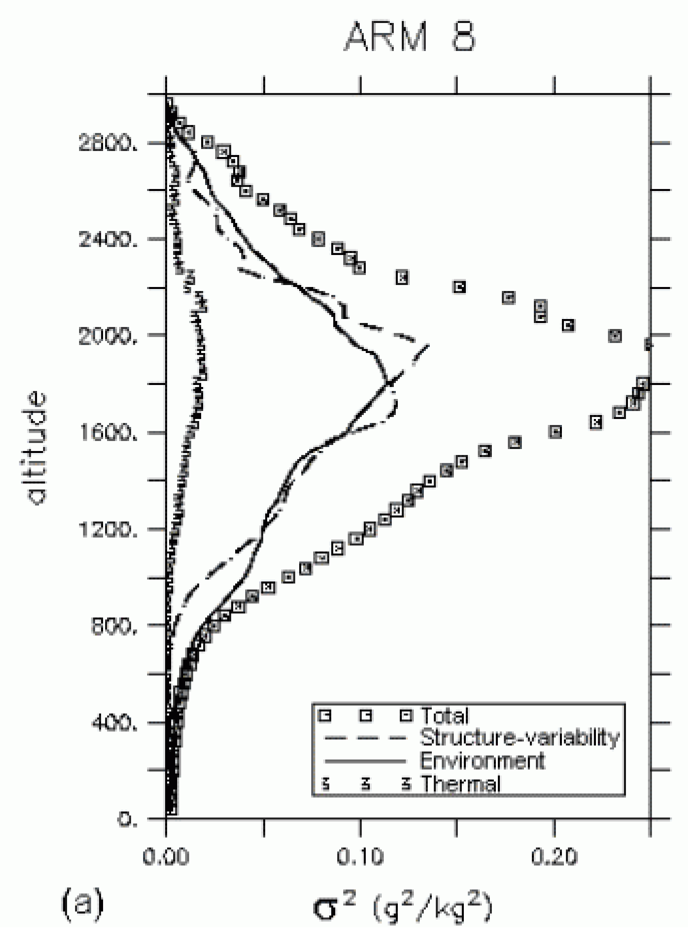
- main source of variance in {thermals} & {environment} is the mixing => σ depends on s_{th}-s_{env}
– σ also depends on the fraction of thermals :

the bigger the thermals, the larger σ_{env} due to detrainment of air from thermals;
the smaller the thermals, the larger σ_{th} due to more impact of entrainment of air from environment

$$\sigma_{s,env} = c_{env} \times \left(\frac{\alpha}{1-\alpha}\right)^{\frac{1}{2}} \times (\overline{s}_{th} - \overline{s}_{env}) + b \times \overline{q}_{t_{env}}$$

$$\sigma_{s,th} = c_{th} \times \left(\frac{\alpha}{1-\alpha}\right)^{-\frac{1}{2}} \times (\overline{s}_{th} - \overline{s}_{env}) + b \times \overline{q}_{t_{th}}$$

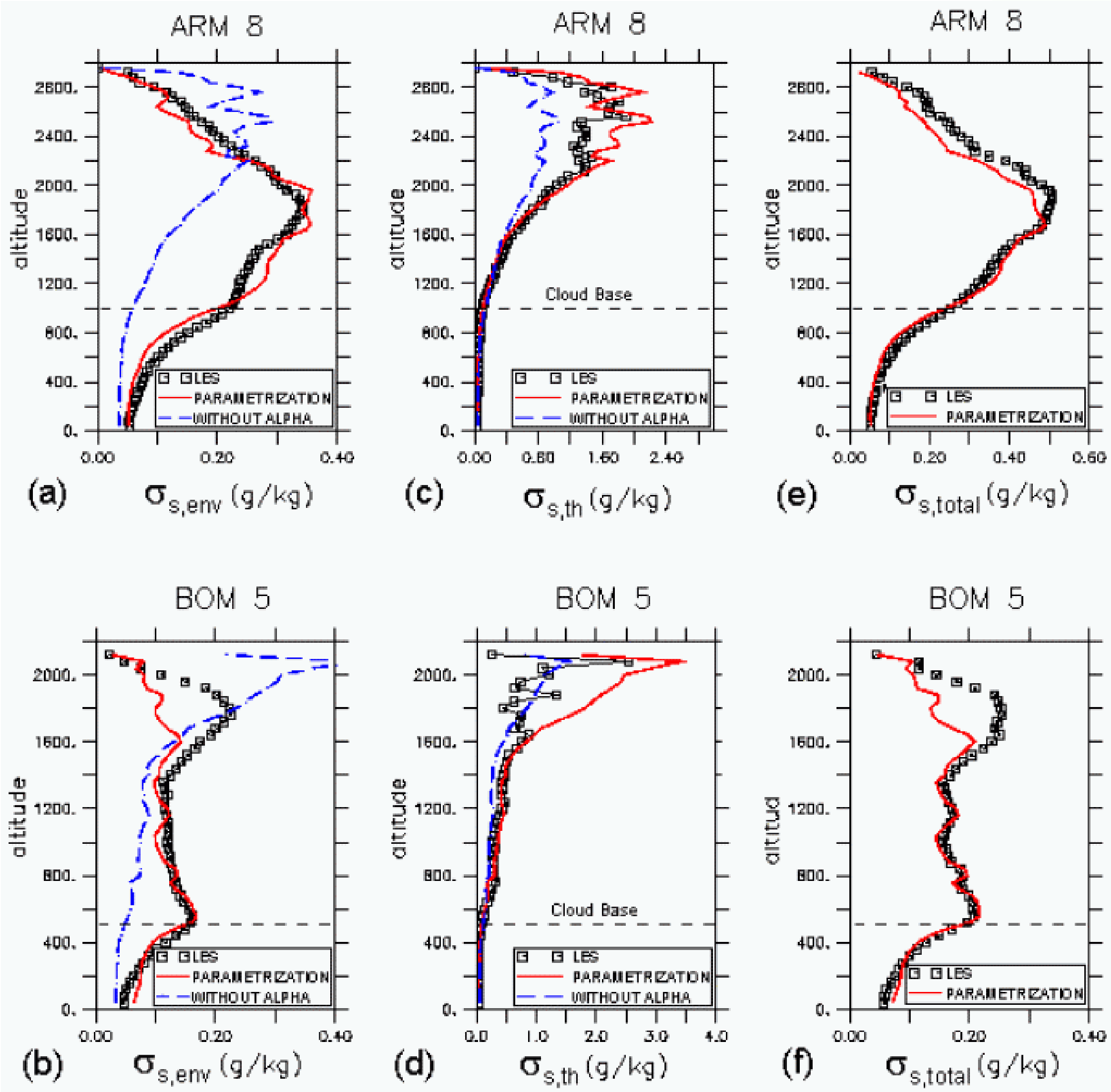
with b=2.10-3, cenv=0.92, cth=0.09

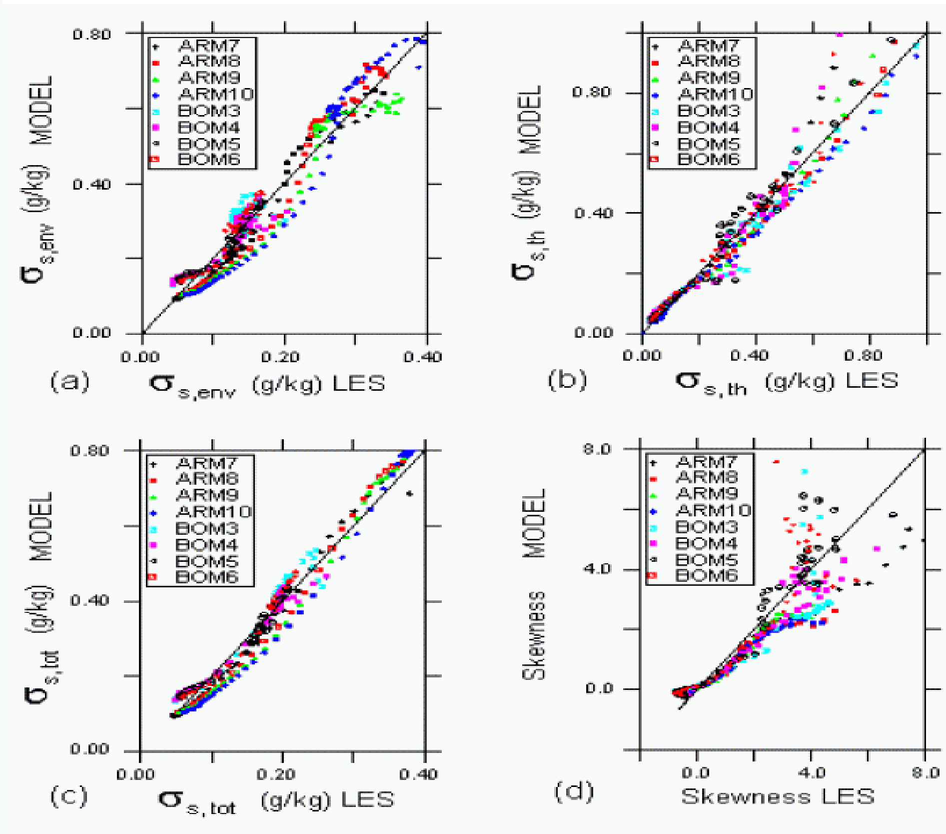


A new cloud scheme coupled to EDMF: Parameterization of the standard deviation

$$\sigma_{s,env} = c_{env} \times \left(\frac{\alpha}{1-\alpha}\right)^{\frac{1}{2}} \times (\overline{s}_{th} - \overline{s}_{env}) + b \times \overline{q}_{t_{env}}$$

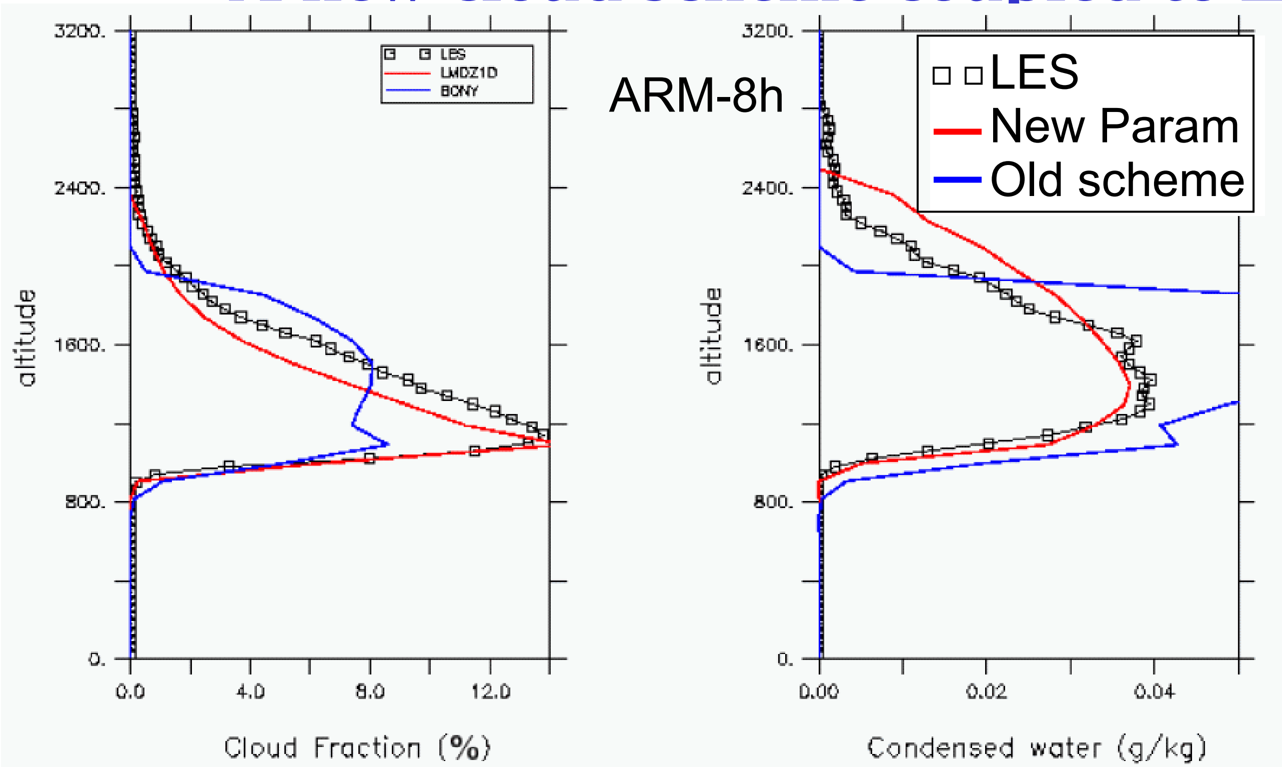
$$\sigma_{s,th} = c_{th} \times \left(\frac{\alpha}{1-\alpha}\right)^{-\frac{1}{2}} \times (\overline{s}_{th} - \overline{s}_{env}) + b \times \overline{q}_{t_{th}}$$

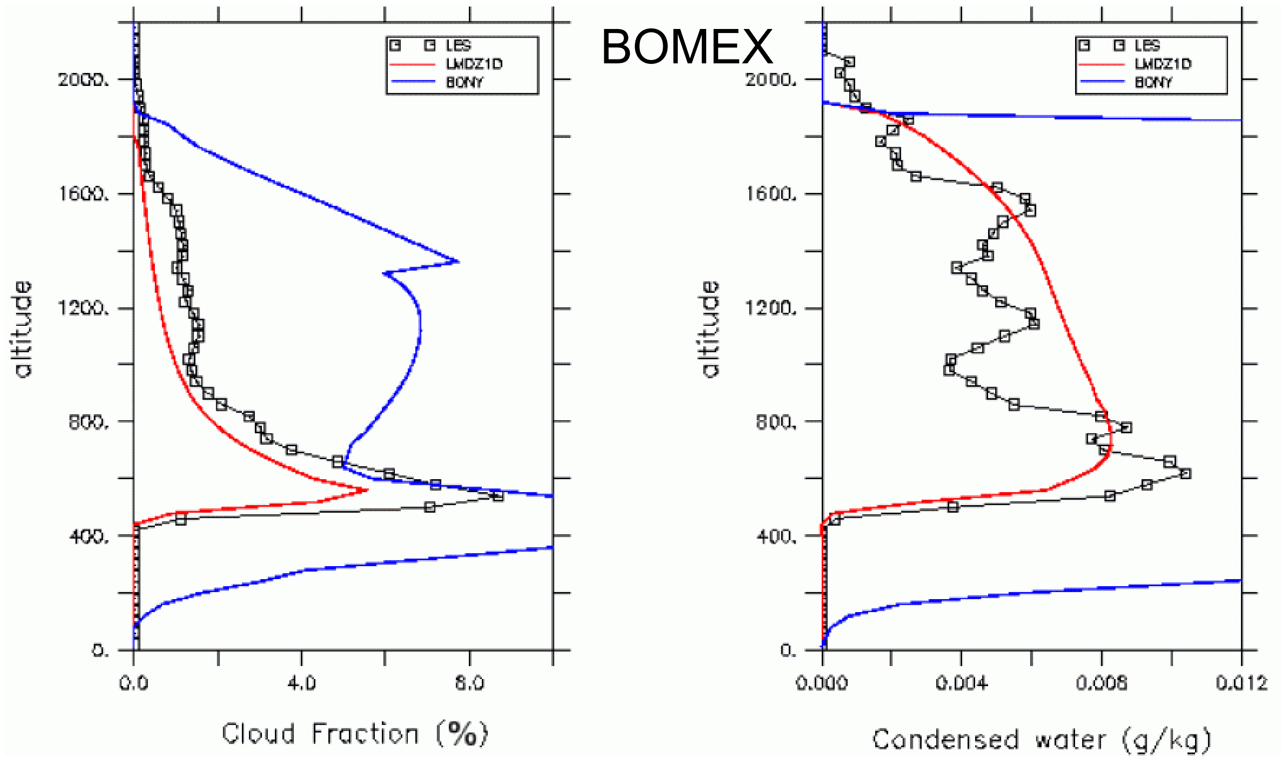




- Importance of & dependency
- Good representation of the variance

A new cloud scheme coupled to EDMF: Test in 1D





- Improvment of representation of cloud fraction and cloud liquid content

Conclusions

- A new conditional sampling to select thermals from the surface to cloud top based on the emission of a passive tracer in LES: a new tool to evaluate and improve parameterizations of boundary layer thermals
  Couvreux et al., blm, 2010

- A continuous formulation of entrainment and detrainment from the surface to cloud top based on physical considerations
  Rio et al., blm, 2010

- A new cloud statistical scheme linked to a thermal plume model, parameterization of the standard deviation in thermals and environment
  Perraud et al, blm, 2011; Jam et al., blm, 2011

A Diagnostic for evaluating the Representation of Turbulence in Atmospheric Models at the Kilometric Scale

R. Honnert, V. Masson, F. Couvreux

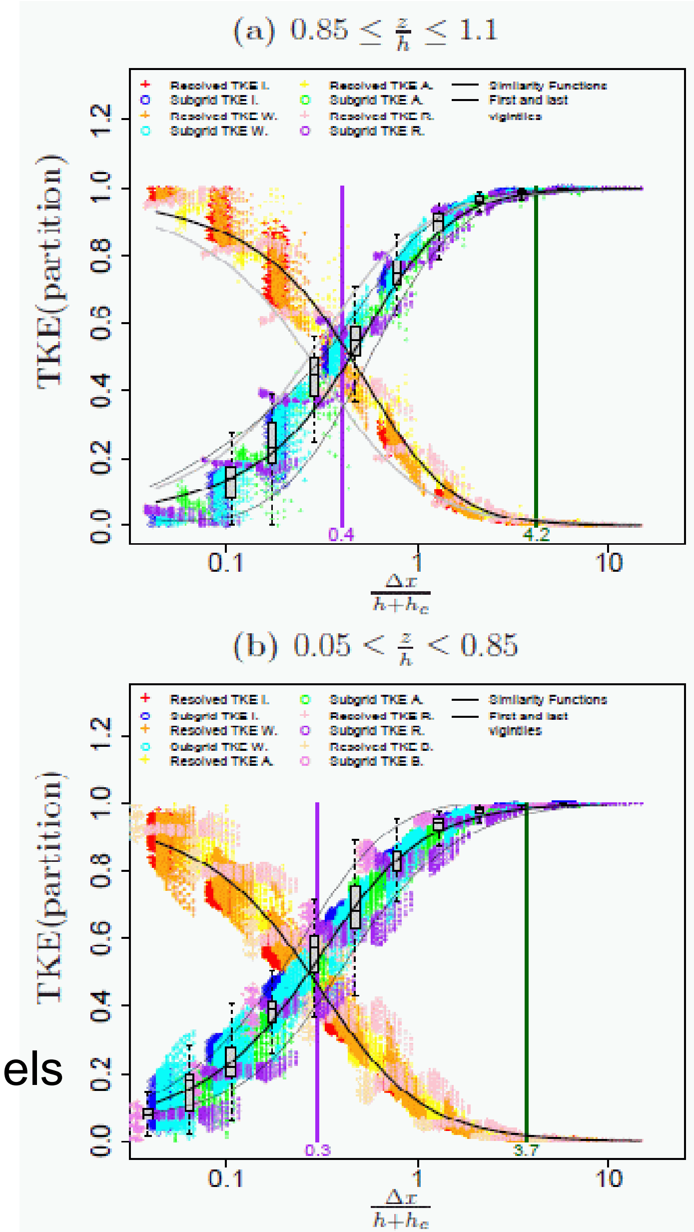
Honnert et al., 2011

- Use LES to determine similarity laws to describe the partitioning resolved / parameterized for moments

- For tke, <w’thl’>, <w’rt’>, <thl’²>, <rt’²>

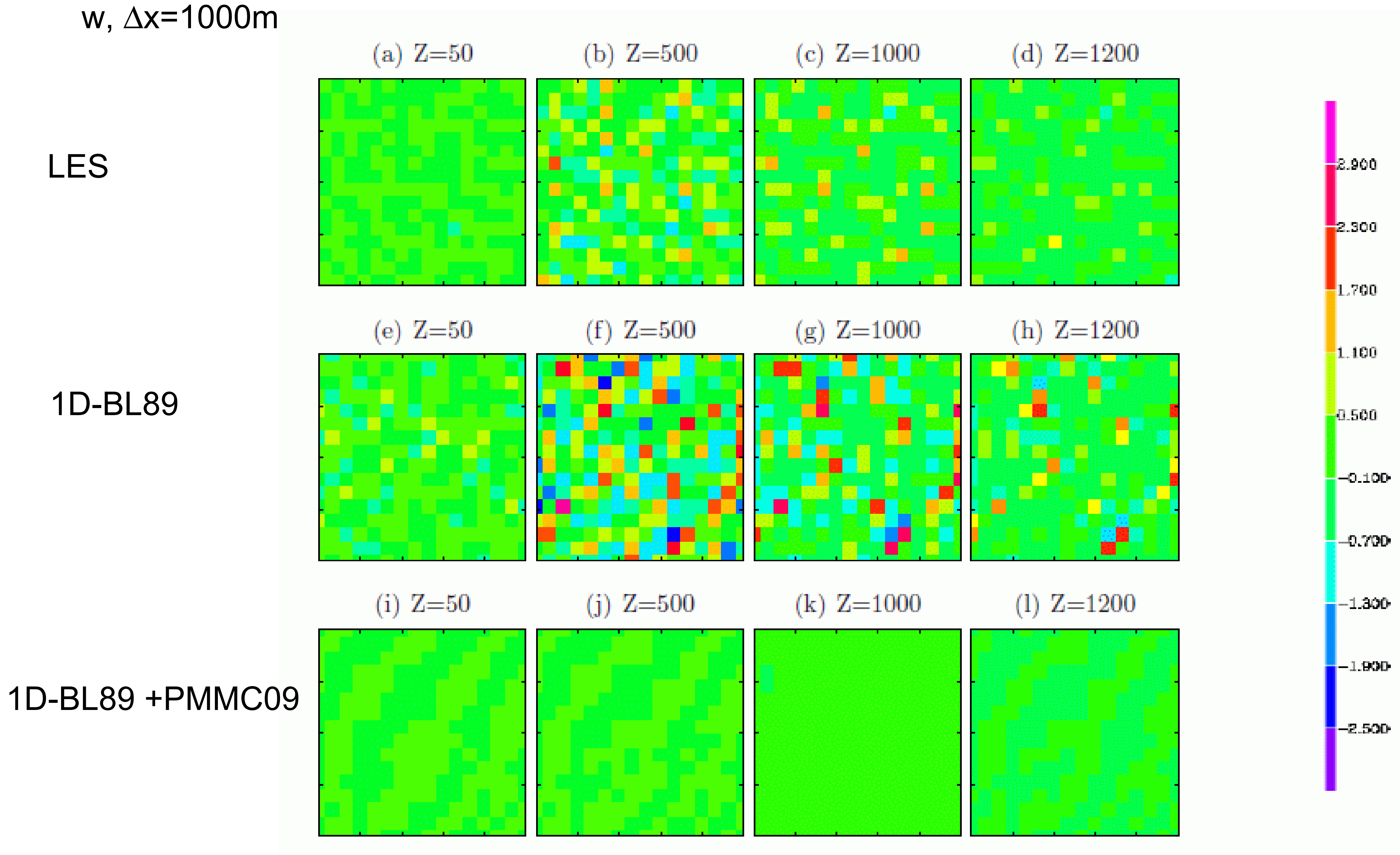
- Hypothesis:
  total moment=f(z/(zi+hc))
  partition=f(Δx/(zi+hc))

- Tested on 5 cases (3 dry CBL, 1 continental cu, 1 oceanic cu)



1/ determination of similarity laws
2/ diagnostic to evaluate the representation of turbulence in models

A Diagnostic for evaluating the Representation of Turbulence at the Kilometric Scale



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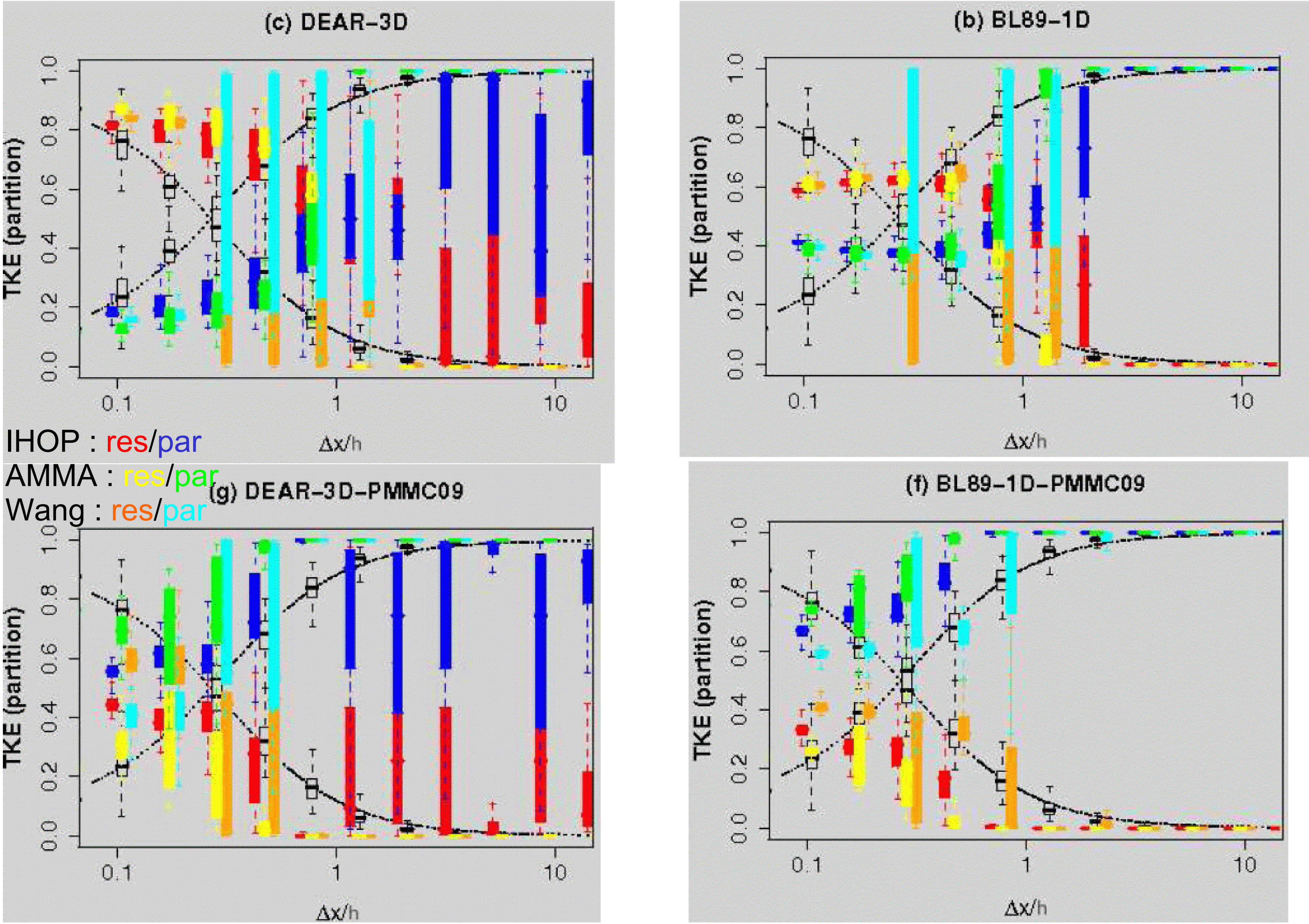
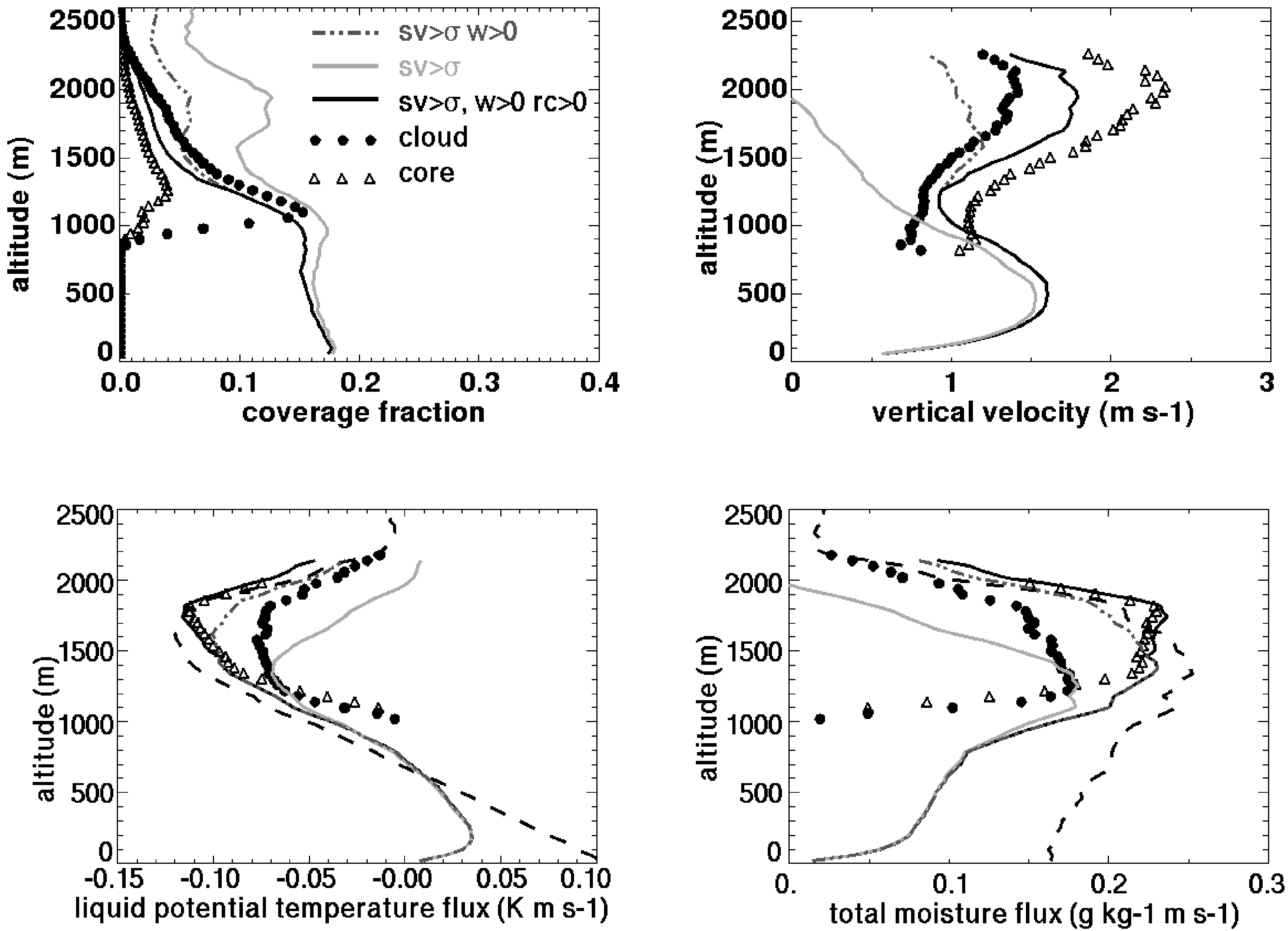


Sensitivity tests to the definition of the conditional sampling



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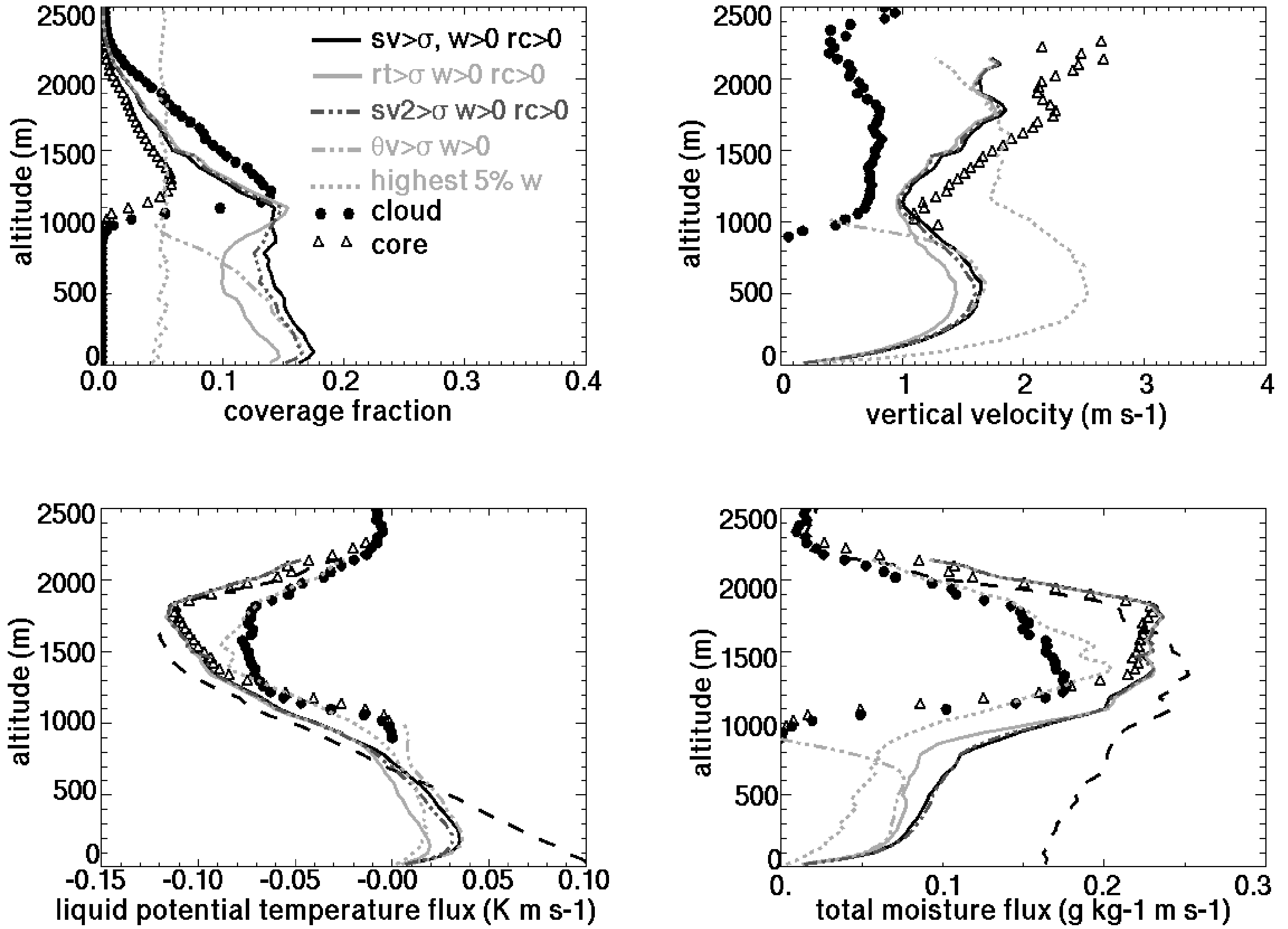
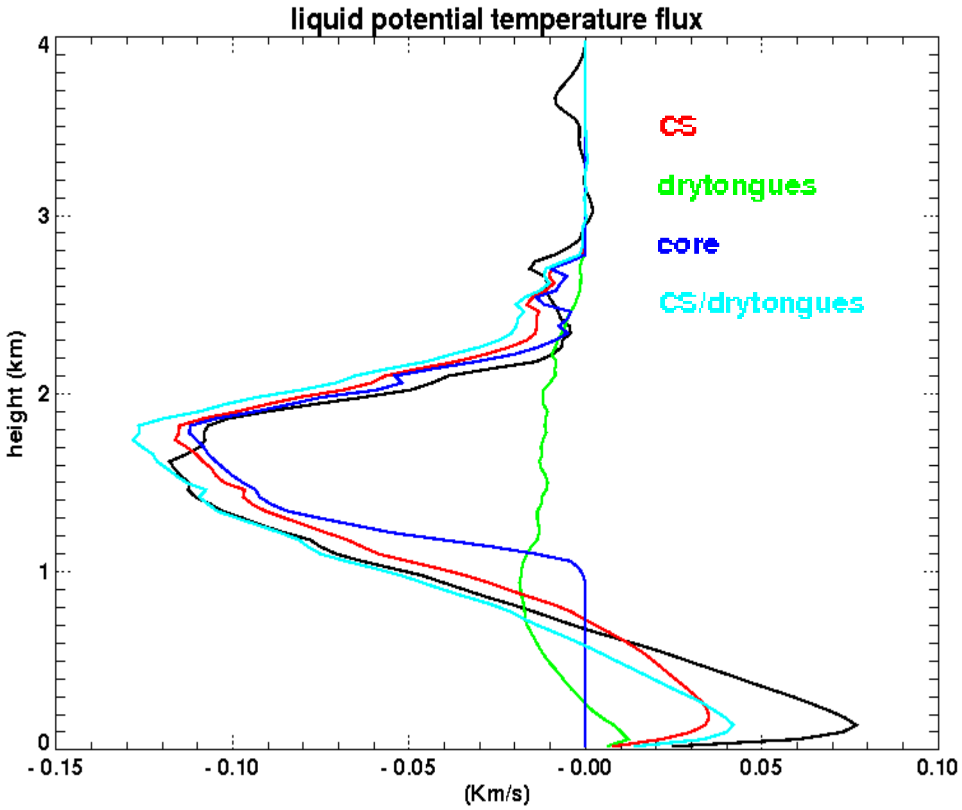
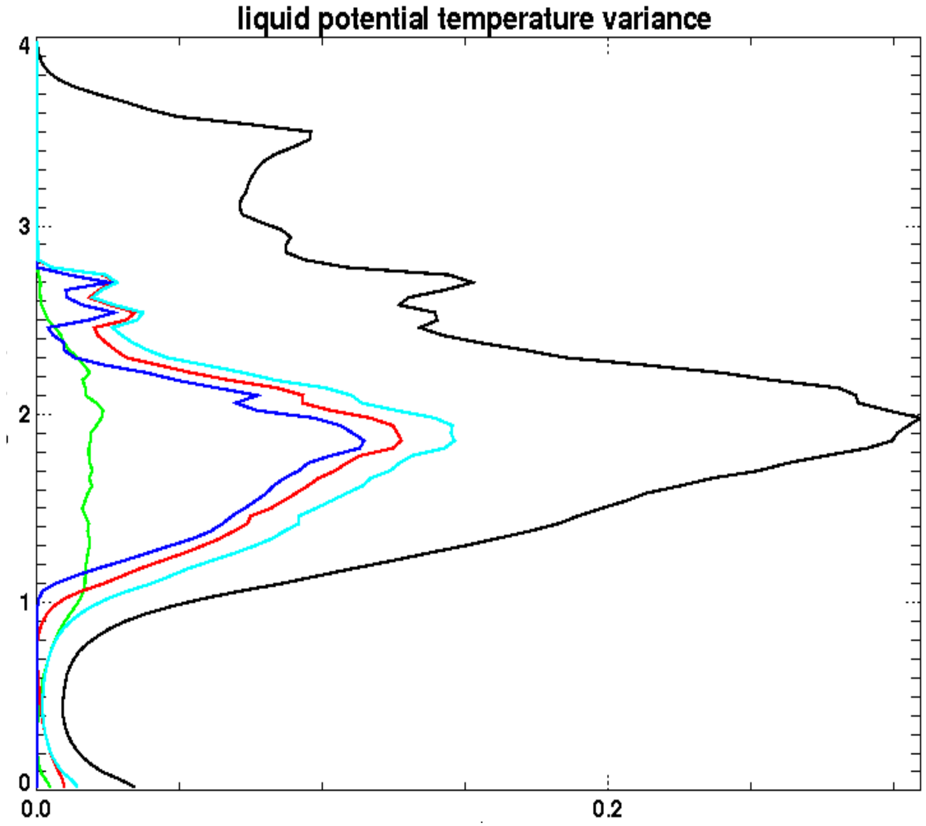


Application
Contribution of thermals to fluxes and variances

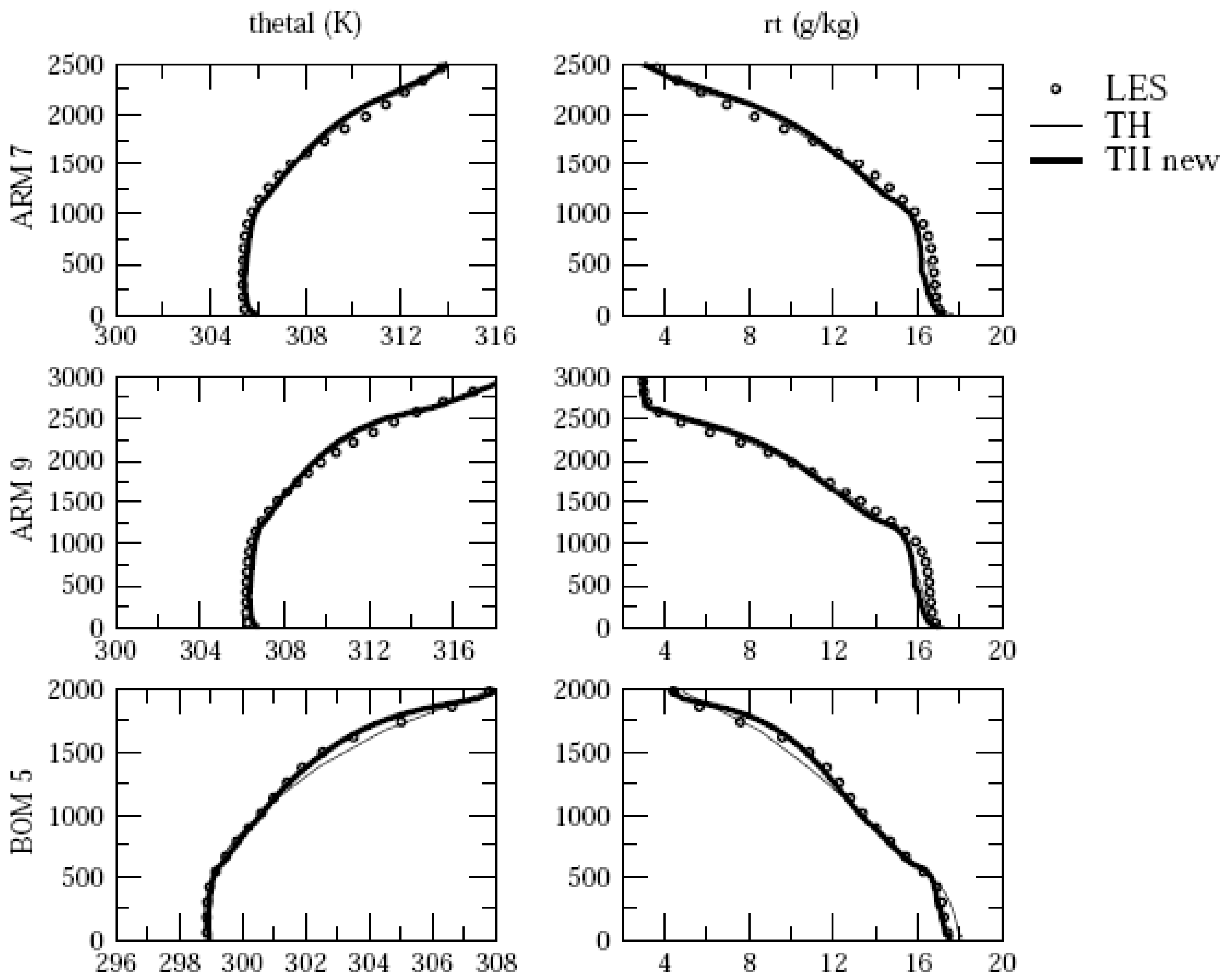
Flux and variance of θl



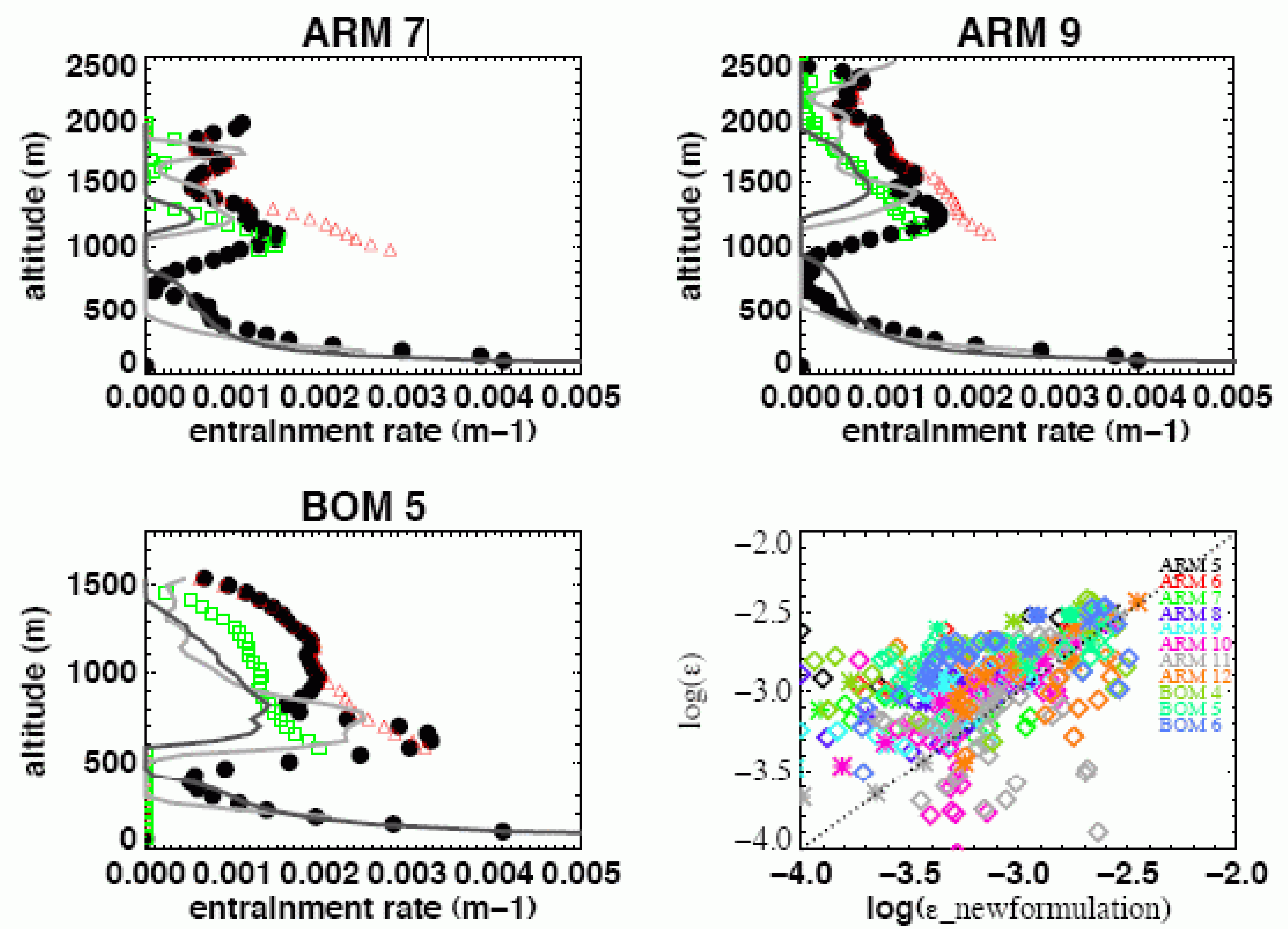


CS explains ~ 100% of the flux in the cloud layer,
~ 60-80% in the sub-cloud layer
~ 30-40% of the variance

Mean profiles of liquid potential temperature and total water



Validation of the formulation in LES



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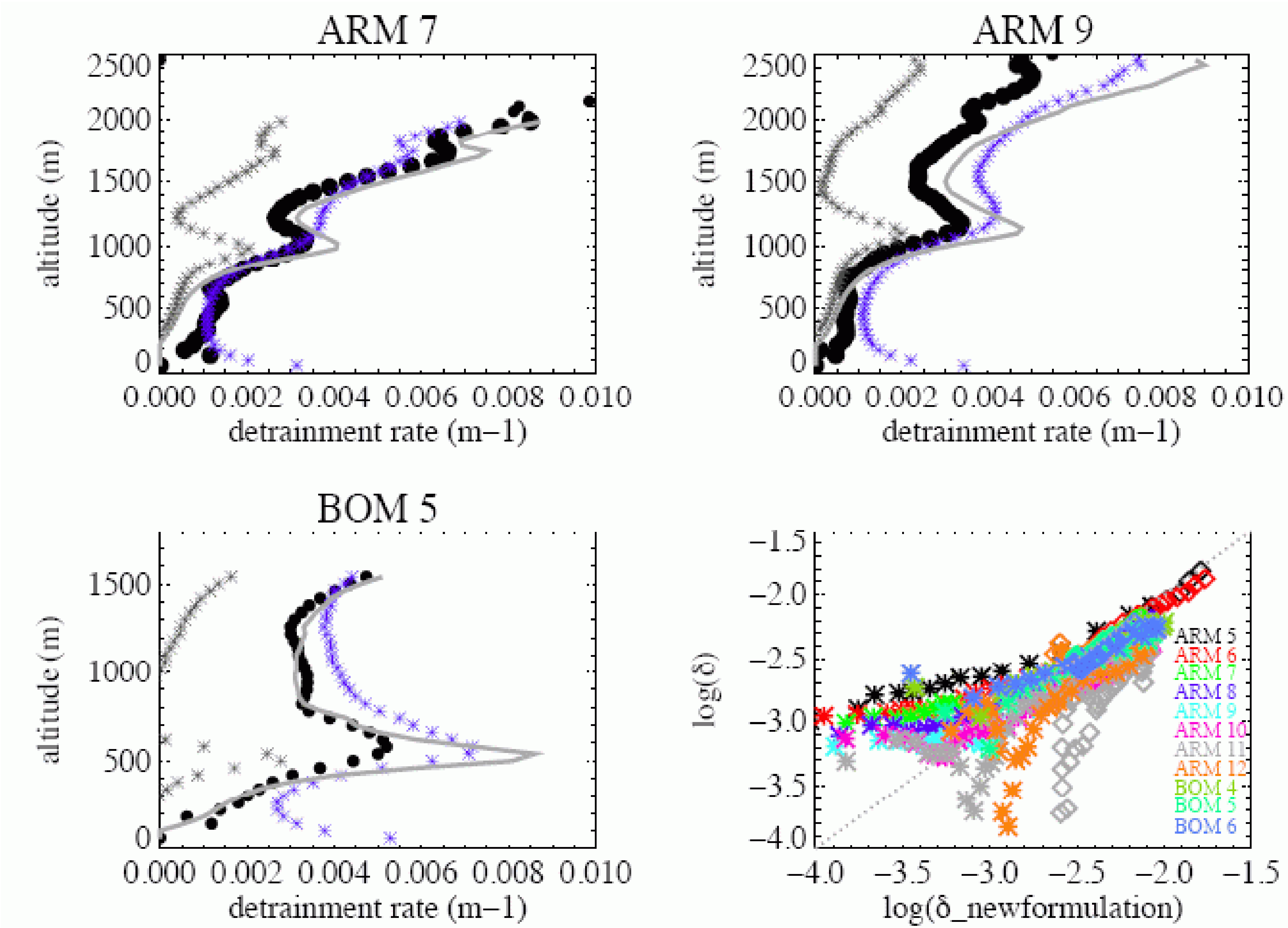
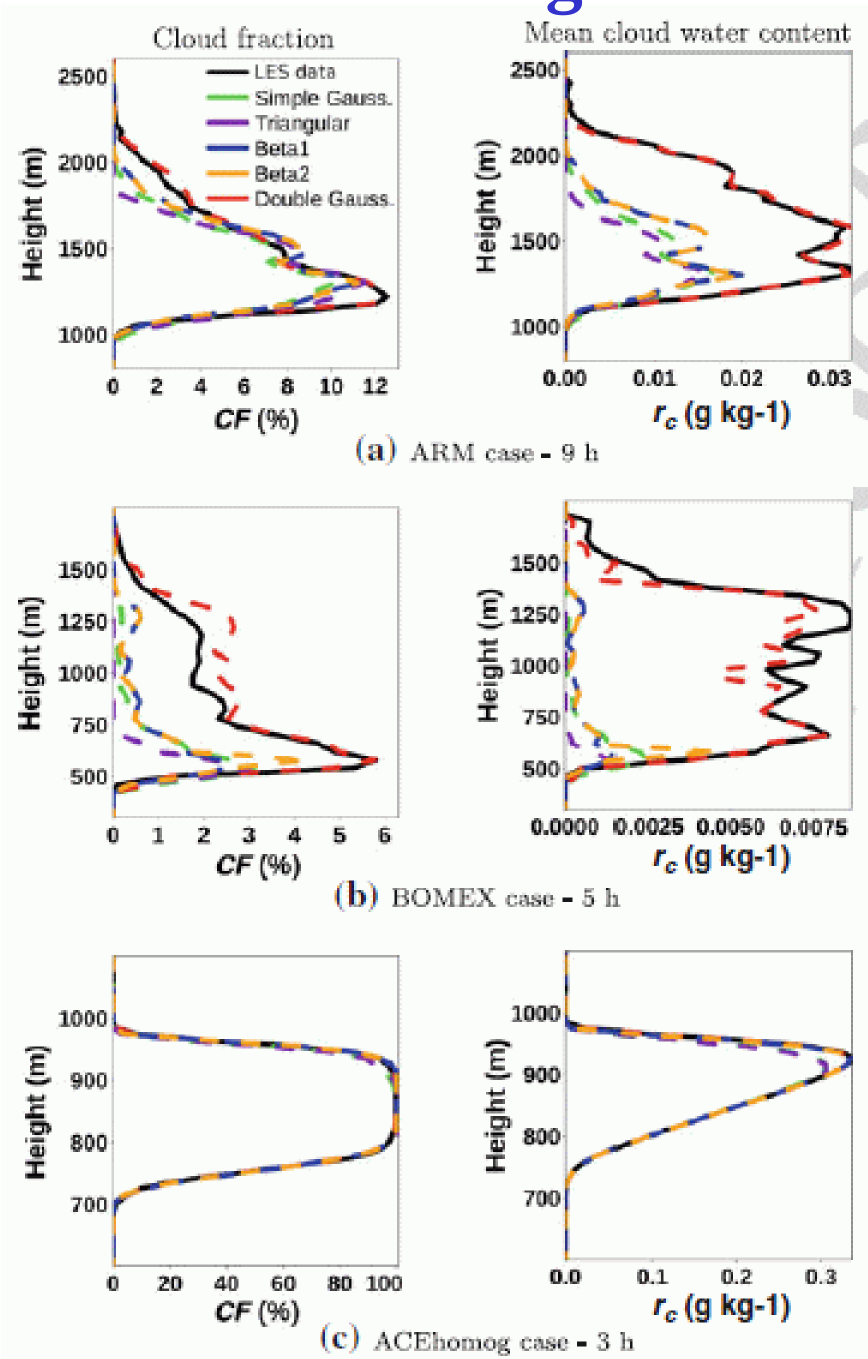
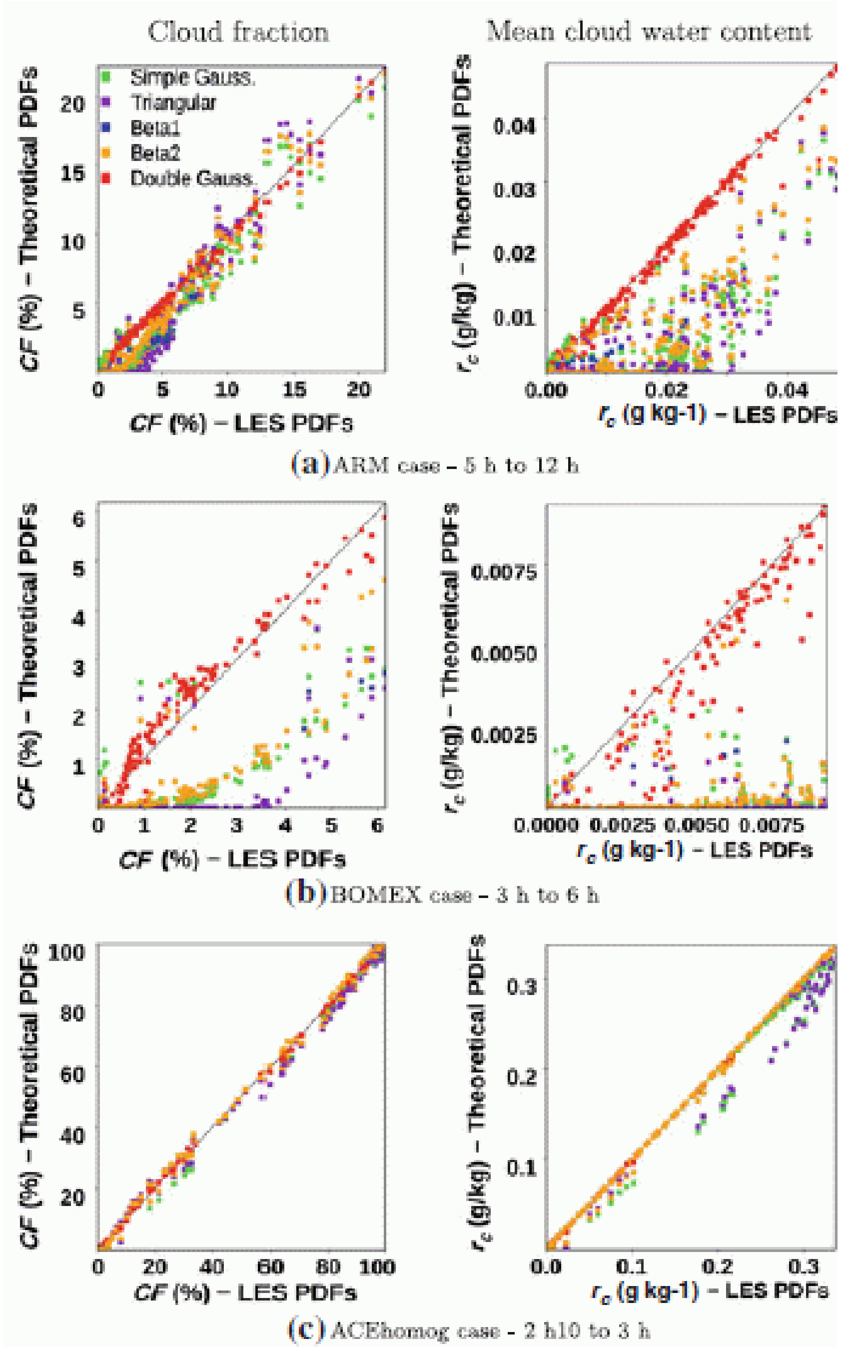


Concerning the cloud scheme :

Perraud et al., 2011





- s instead of rt
- Bi-gaussian describes the subgrid variability

Methods :

Honnert et al., 2011