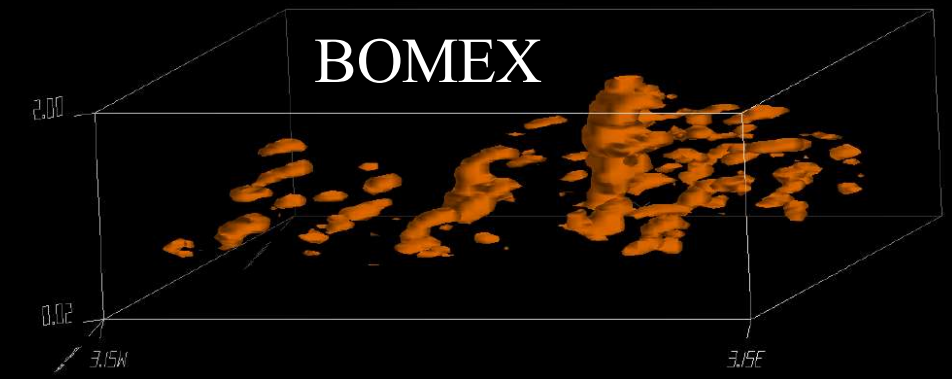
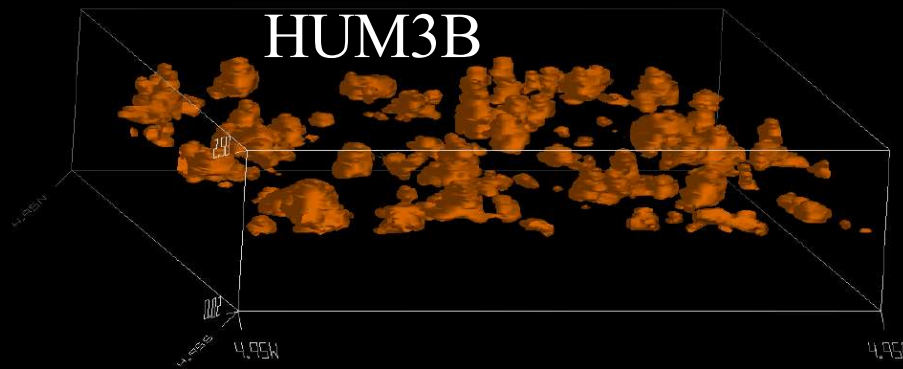
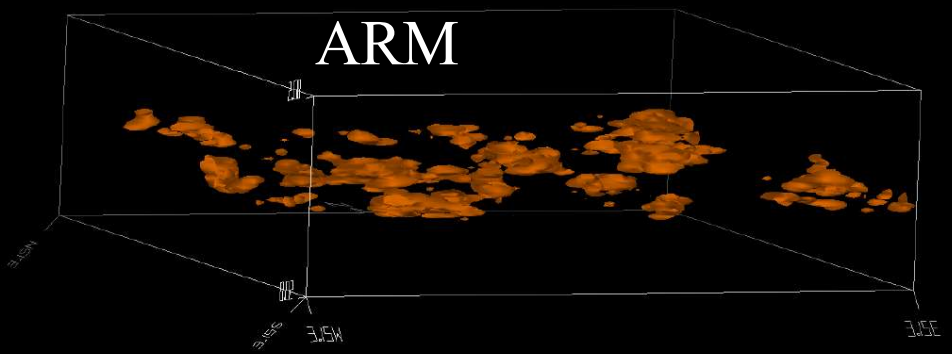
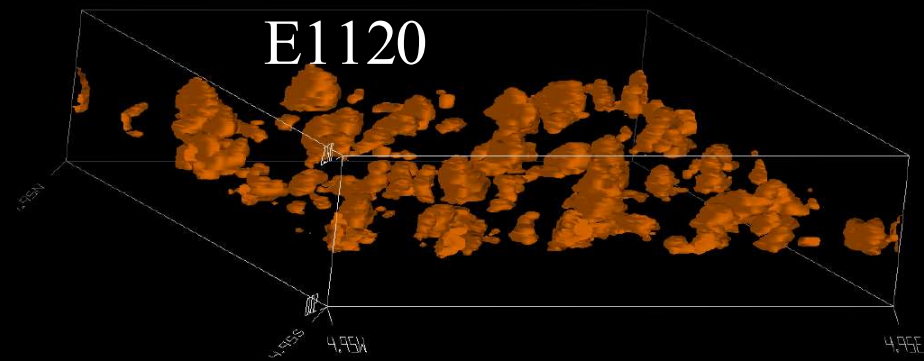
Shallow cumulus : cloud-subcloud layer interaction and the role of water vapour

Fleur Couvreux, Phil Austin







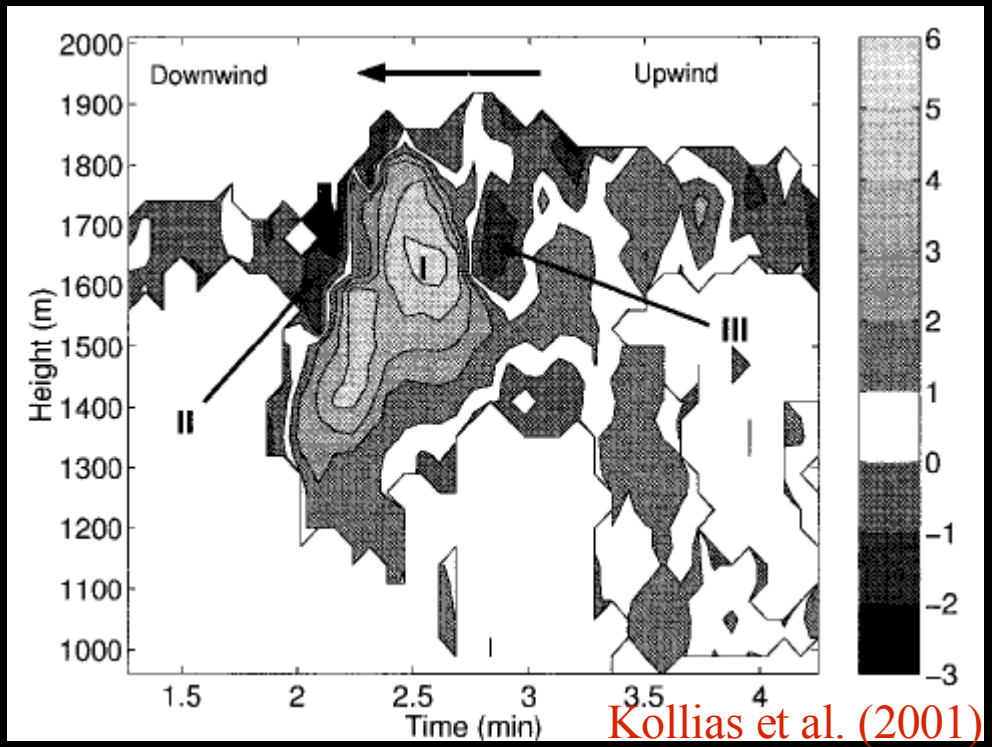


Cumulus characteristics

Inferred from observations :

- Stommel 1947 : significant mixing with environment
- Squires 1958: evidence of downdrafts
- Austin et al. 1985: strong heterogeneity in the cloud

radar



Kollias et al. (2001)

Updraft=5 m/s, downdraft=-3 m/s

spectral width: turbulence

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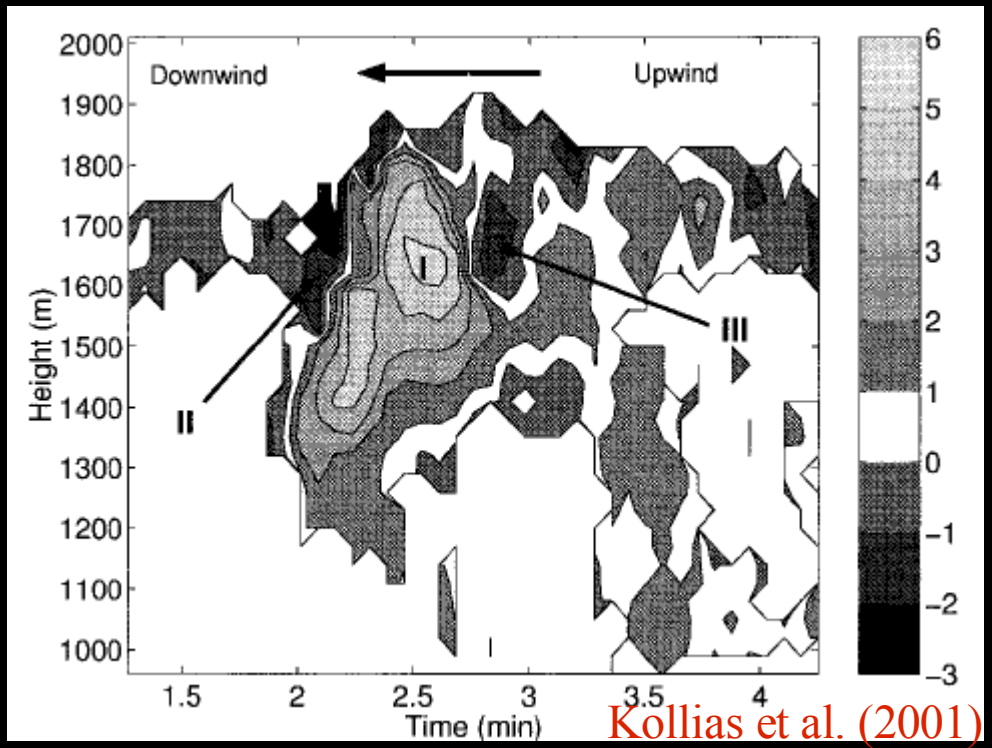


Kollias et al. (2001)

Updraft=5 m/s, downdraft=-3 m/s

spectral width: turbulence

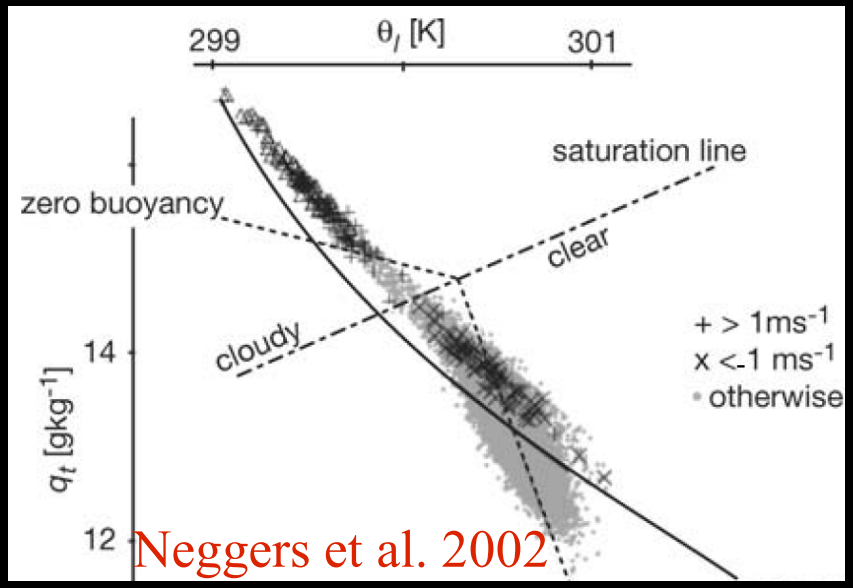
→ No observation of initiation (small spatial and temporal scales)

→ No observation to study the interaction between the cloud layer and the subcloud layer

Cumulus characteristics

Inferred from LES:

- Constraint for the entrainment rate (Siebesma and Cuijpers 1995) ~10^{-3}
- Understanding cloud characteristics (Neggers et al. 2002)
- Description of transport inside cumulus (Zhao and Austin 2005) : pulsating, indirect transport, life cycle (dissipation)



Neggers et al. 2002

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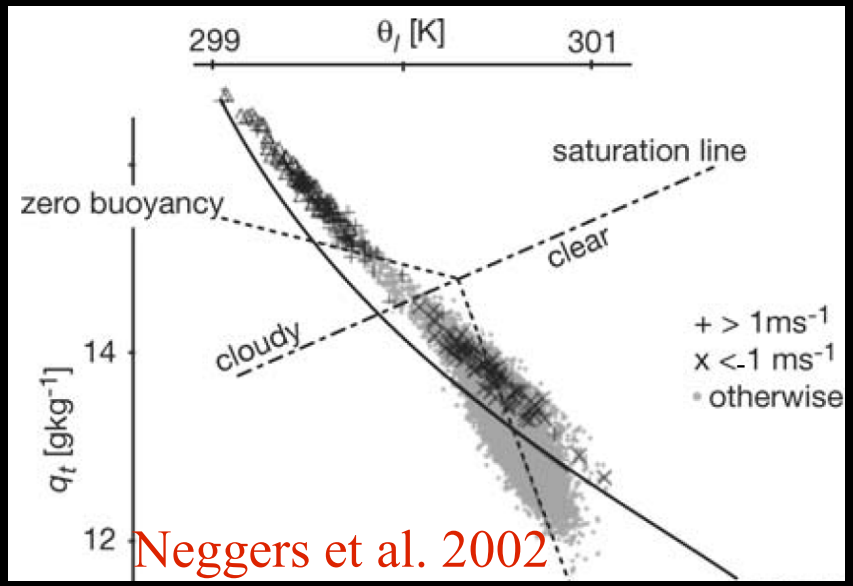

Neggers et al. 2002

→ A look at individual clouds : to study the life cycle of the cloud

→ A closer look at the relation between the subcloud layer and the cloud layer

Importance of humidity variability

Boundary layer humidity :

Mahrt 1976: LCL sensitivity to small changes in humidity

Crook 1996: sensitivity of cloud initiation to Δqsfce

Weckwerth et al. 2000: CIN threshold if wv variability taken into account

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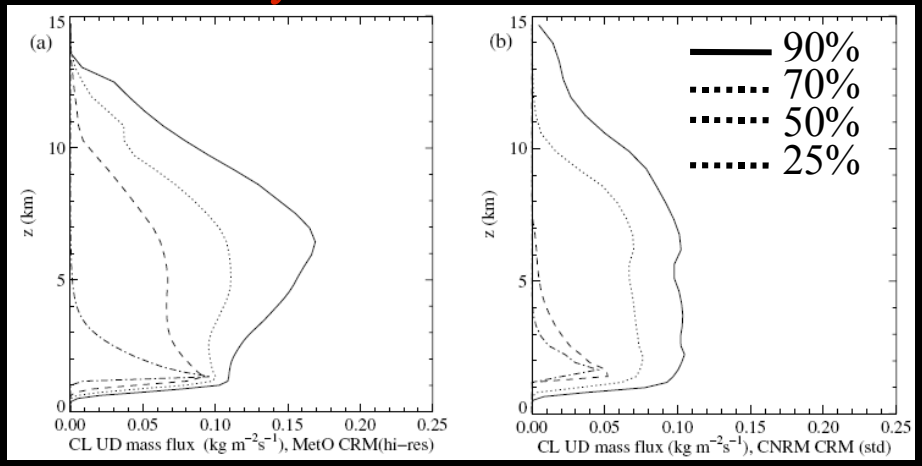
Tropospheric humidity:

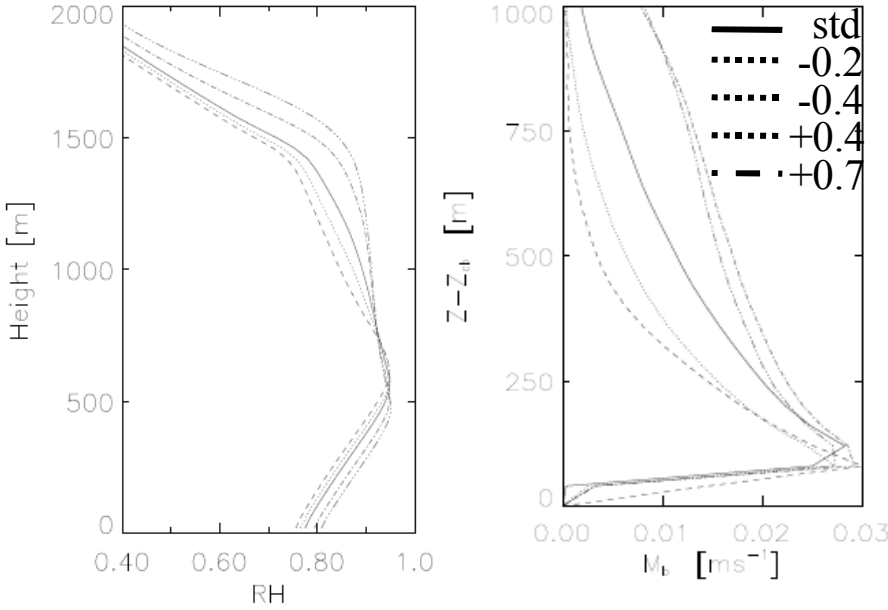
Derbyshire et al. 2004: sensitivity to rh of mass flux profiles -> deep

Loijen, de Roode 2005: shallow

Derbyshire et al. 2004



Loijen & de Roode 2005



→ water vapour role evident but need to be better understood

Our focus

Questions :

- What controls cloud initiation?
  - What is the relevance of the water vapour variability in the BL?
- What are the interactions between clouds and the subcloud layer?
- What controls cloud organisation (not looking at wind as for rolls) ?
- How does the cloud environment impact the cloud ? -> humidity

Methodology :

LES simulations : individual clouds and then total domain

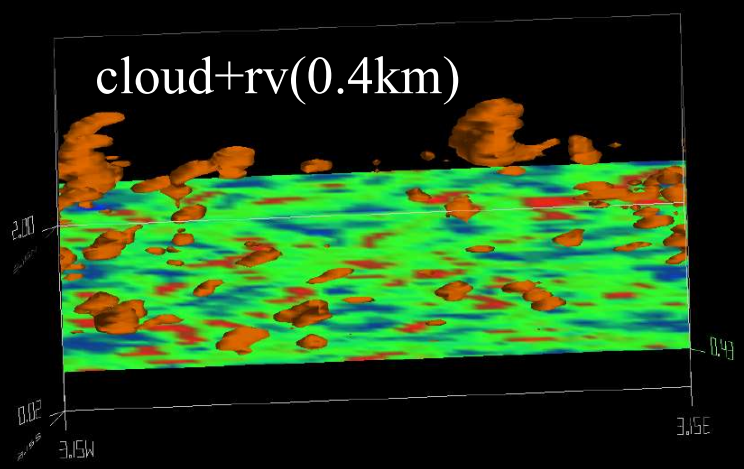
Overview :

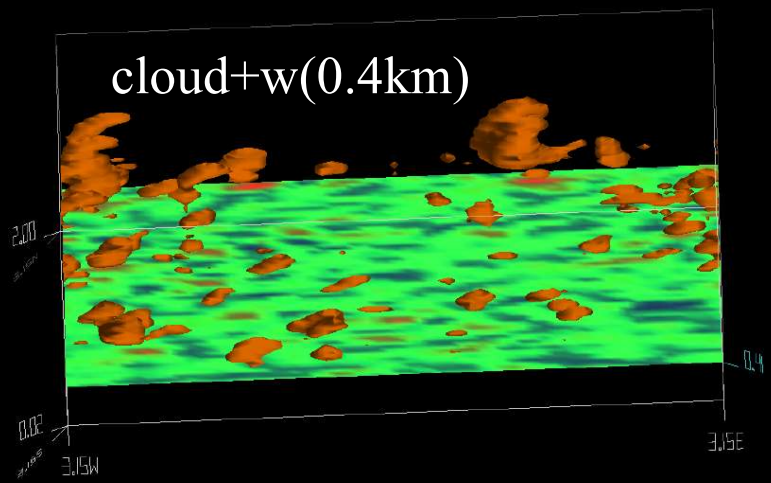
- Cloud base characteristics through the cloud life cycle
- Subcloud layer characteristics at initiation
- Modification of subcloud layer during the cloud life cycle
- Role of water vapour

Methodology : LES

Advantages :

- to address the lack of observations (cloud-subcloud layer interaction)
- cloud realism : fractal dimension, cloud size distribution
  (Siebesma and Jonker 2000, Neggers et al. 2003)
- simultaneous 3D fields of different variables at high resolution





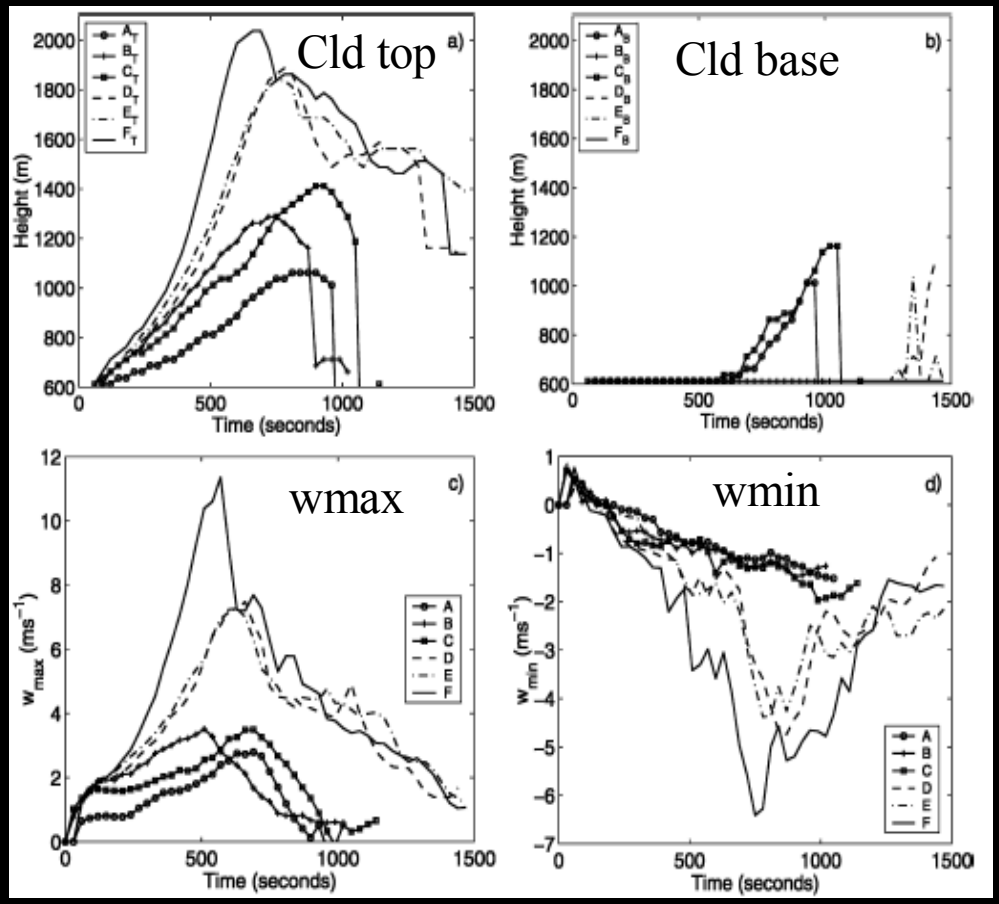
Available simulations :

- six isolated clouds in BOMEX simulation (Zhao and Austin, 2005)
- ~6 cases : LES BOMEX, ARM and IHOP cases (modification of initial profiles, stability and humidity, in order to get different cloud cover)

The six clouds (Zhao and Austin 2005)

3 small clouds and 3 large clouds : same cld base, diff. cld top

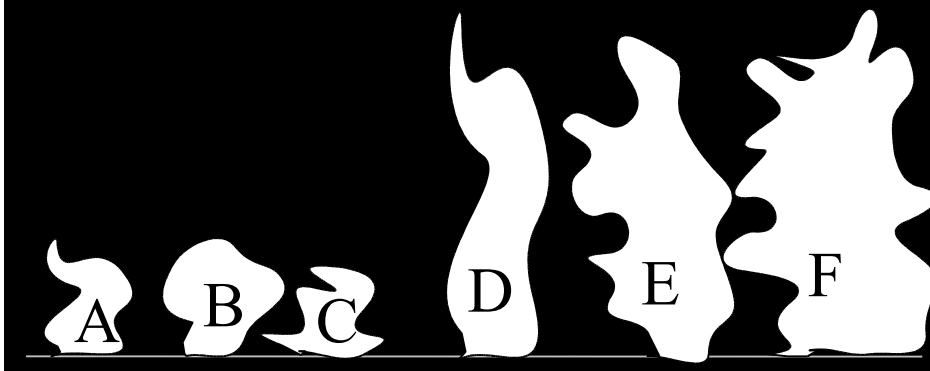
spatial and temporal resolution Δx=25m, Δt=1.5s



Zhao and Austin (2005)

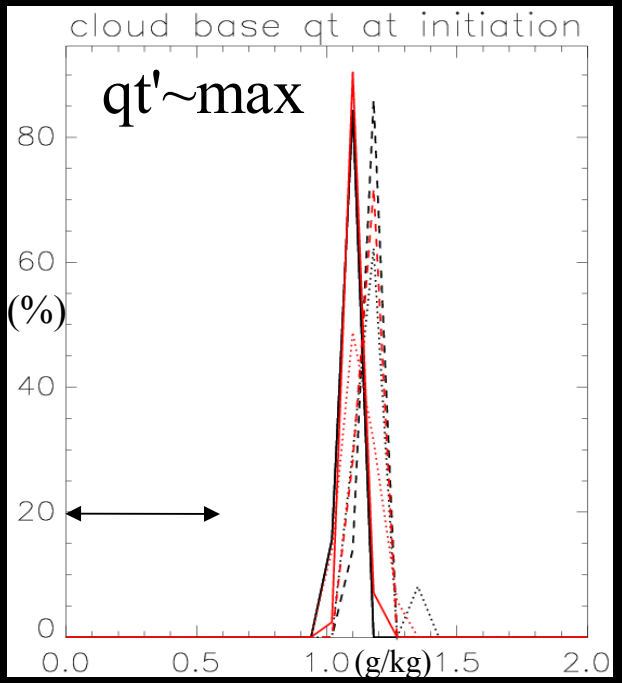
<u>small clouds:</u>
height ~ 500 m
hal L< 200 m
1 updraft
life time~1000s

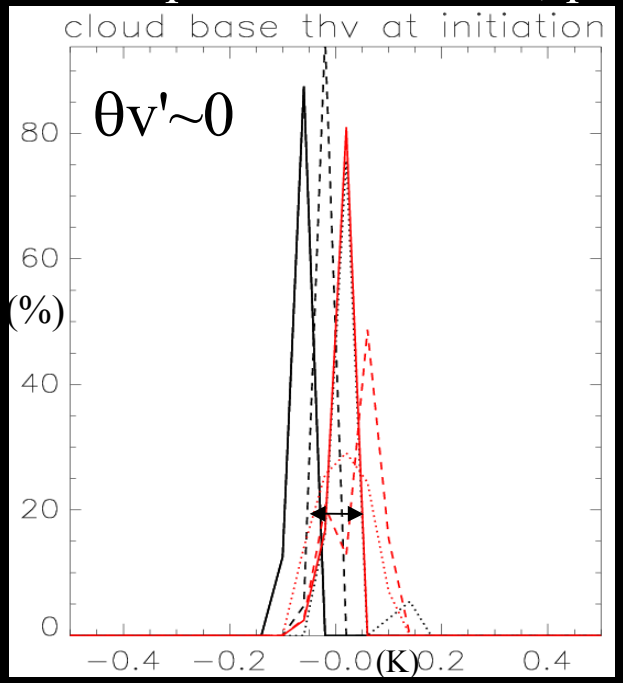
<u>large clouds:</u>
height ~ 1000 m
hal L~ 400 m
2-3 pulse-like updrafts
life time ~ 1500s

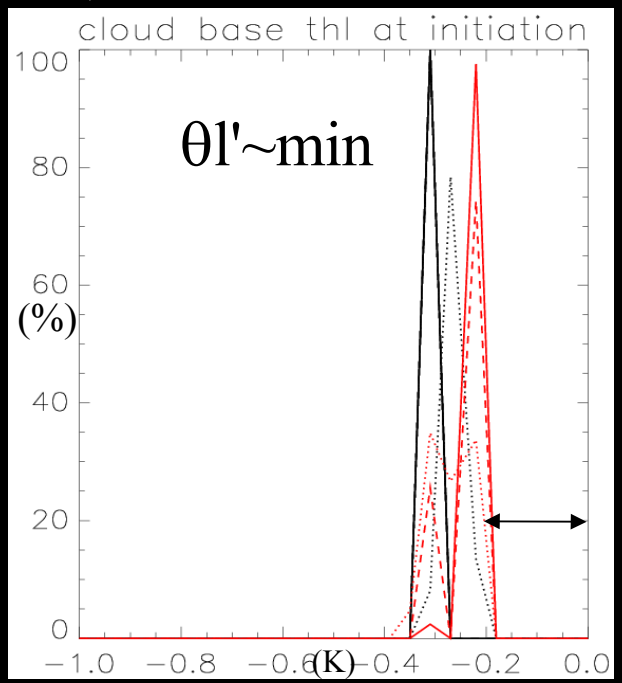


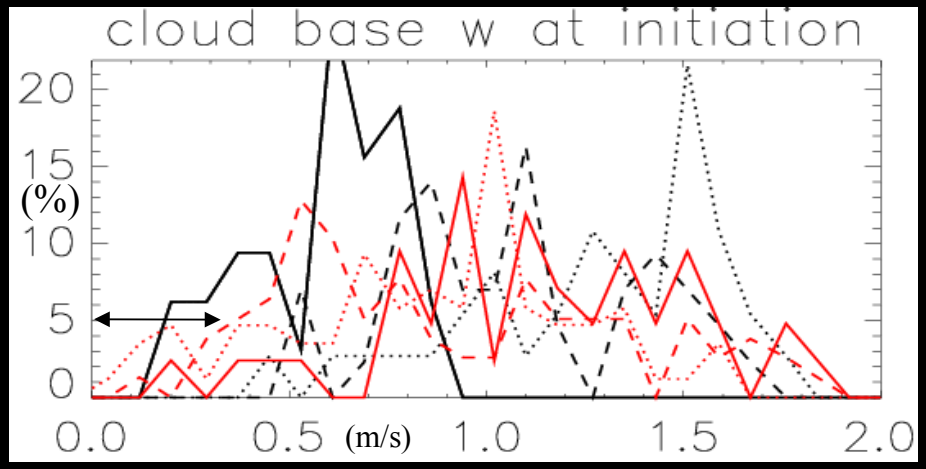
Cloud base caracteristics at initiation

Narrow distribution at initiation except for w': θl'~min,qt'~max, θv'~0





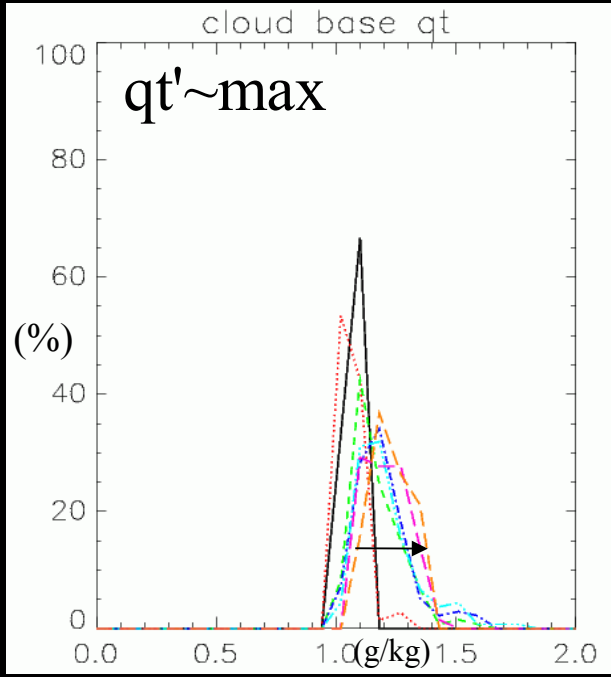


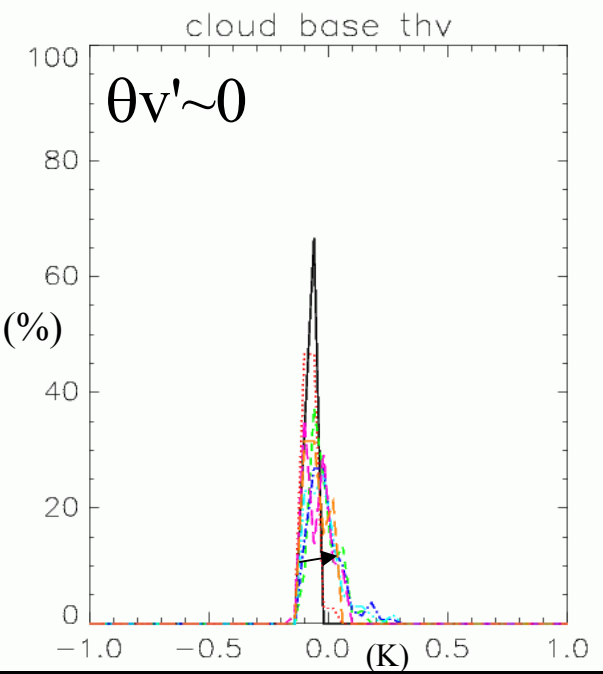


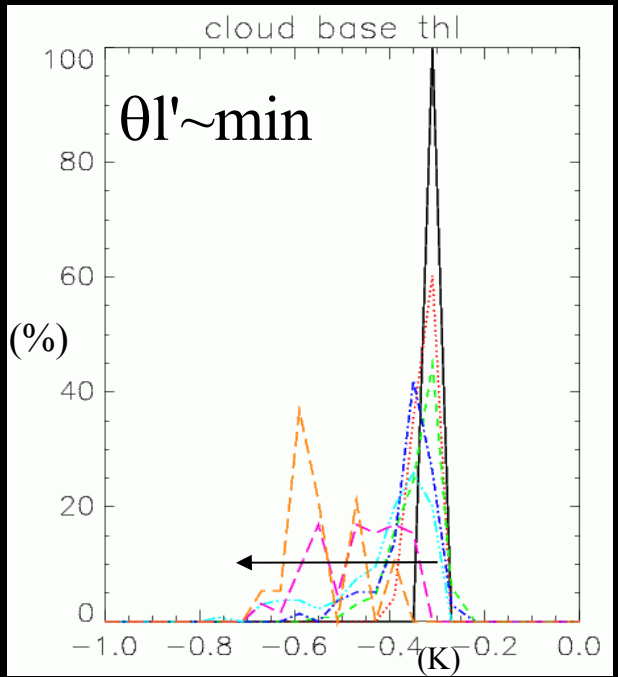
cloud A
cloud B
cloud C
small clouds
cloud D
cloud E
cloud F
large clouds
Standard deviation

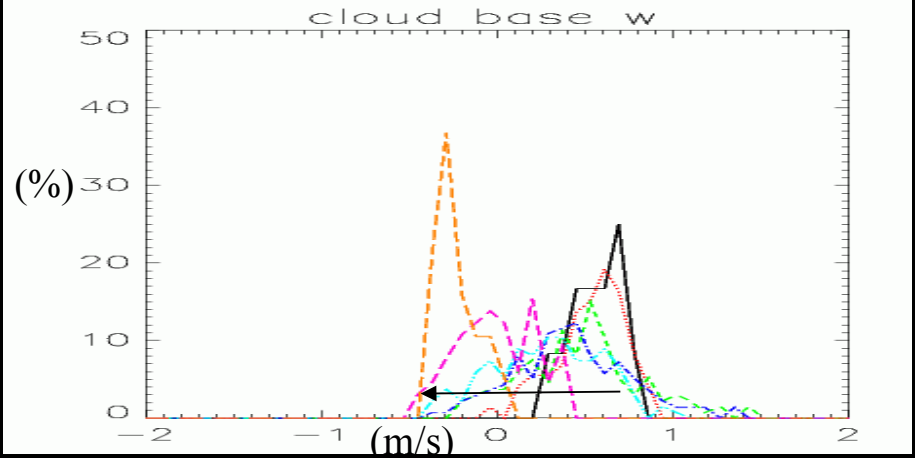
Cloud base characteristics after initiation

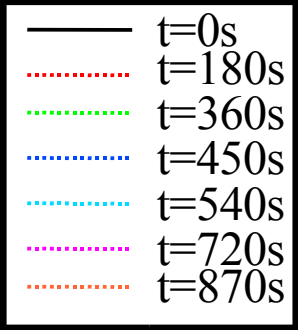
Variation of the distribution through the life cycle of the clouds: ex: cloud A







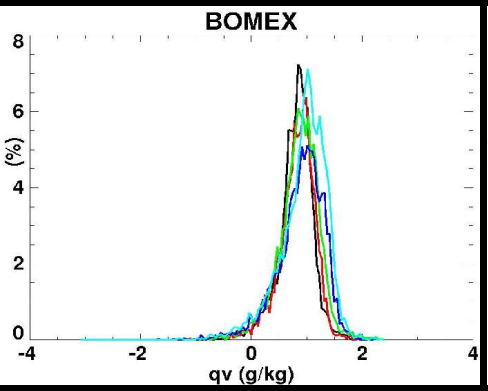




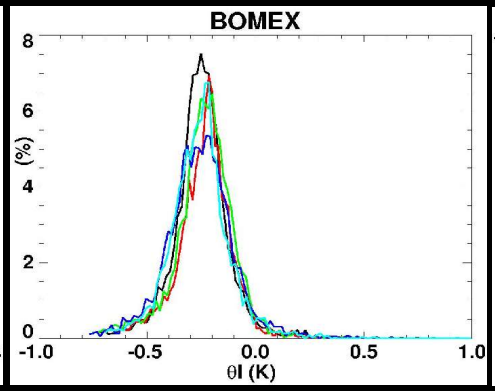
same results for other clouds

Cloud base characteristics in LES

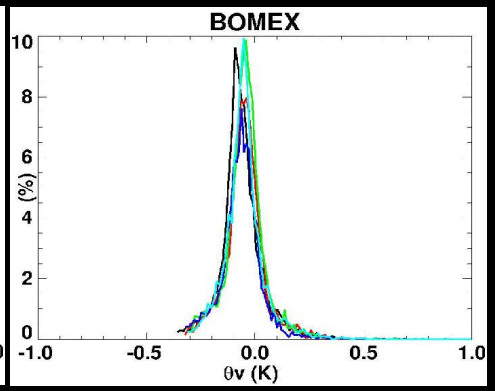
Wider distribution but similar characteristics : θl~min,qt~max, θv'~0



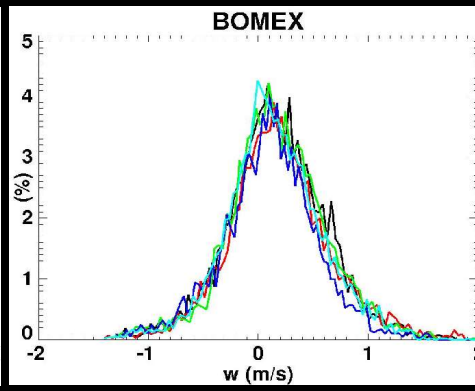
σ=0.8 g/kg



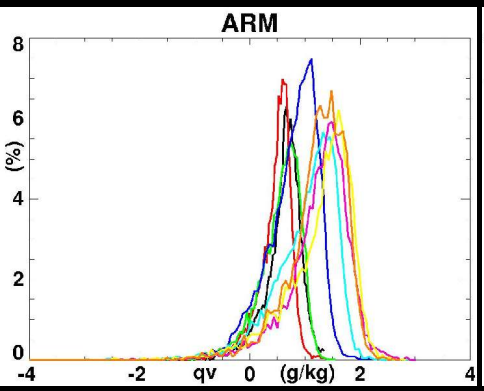
σ=0.1 K



σ=0.05 K

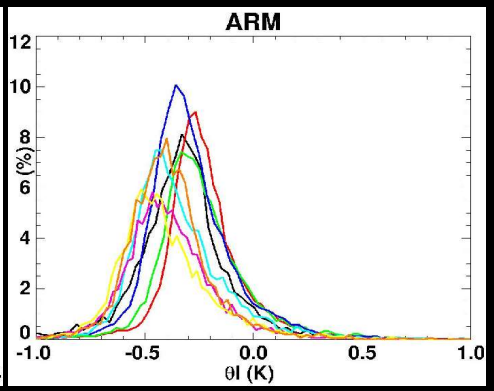


σ=0.3 m/s



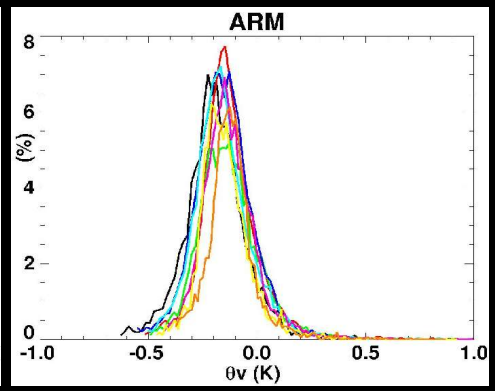
σ=1 g/kg

rv'>0



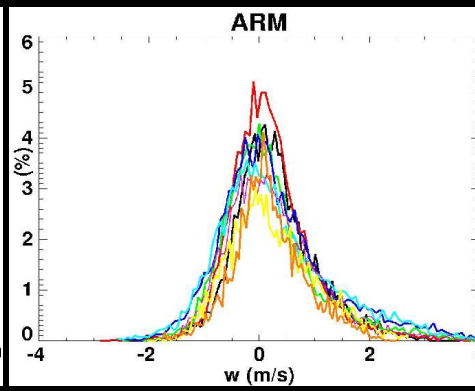
σ=0.2 K

θl'<0



σ=0.06 K

θv'~0

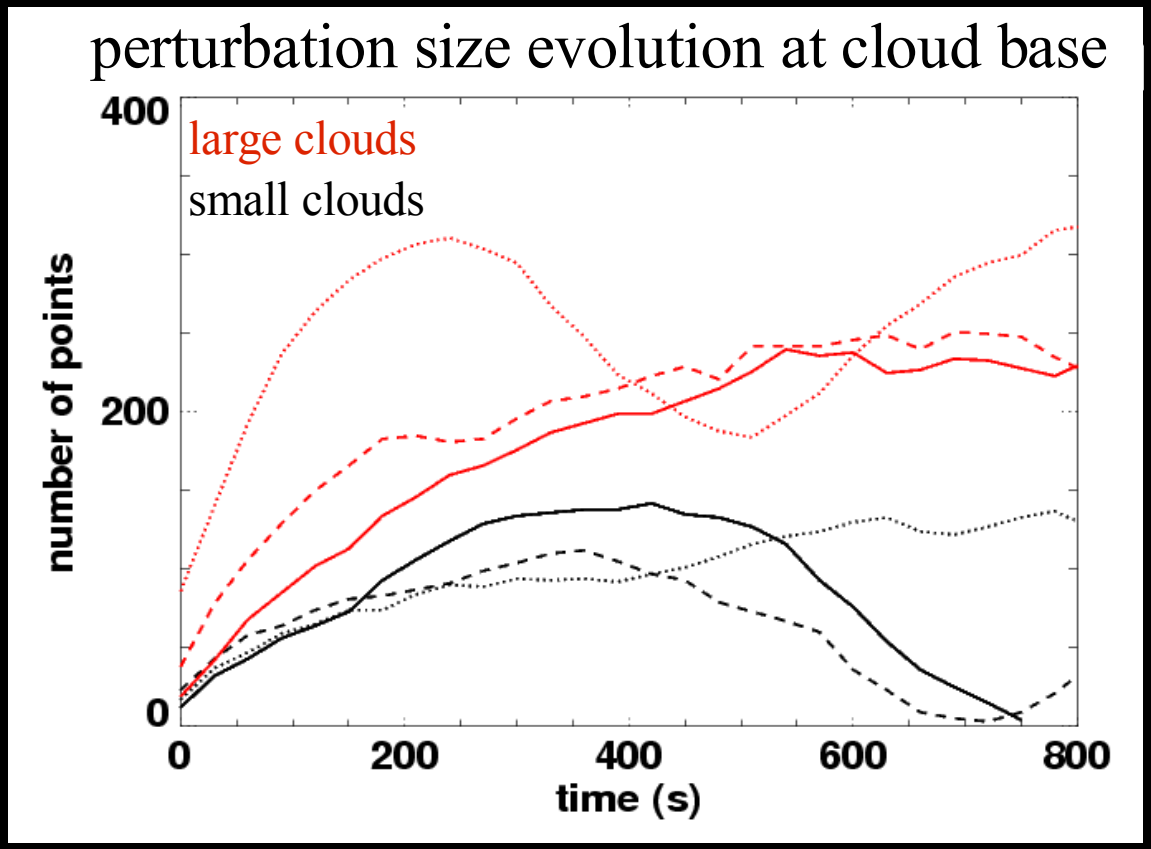


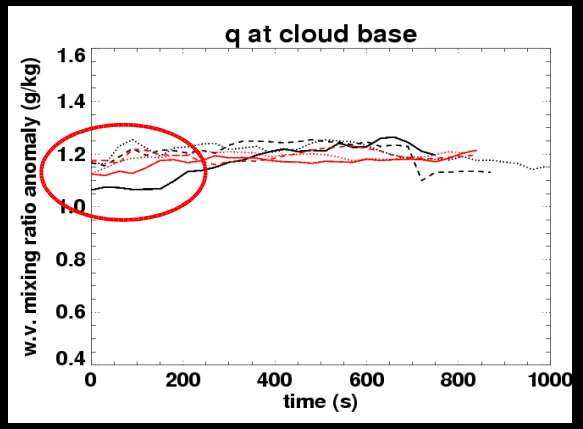
σ=1 m/s

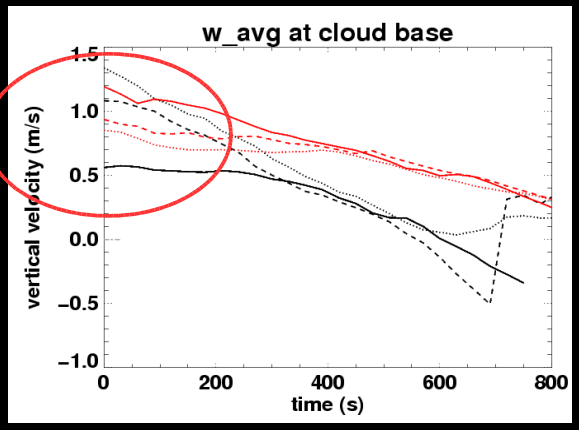
w'>0

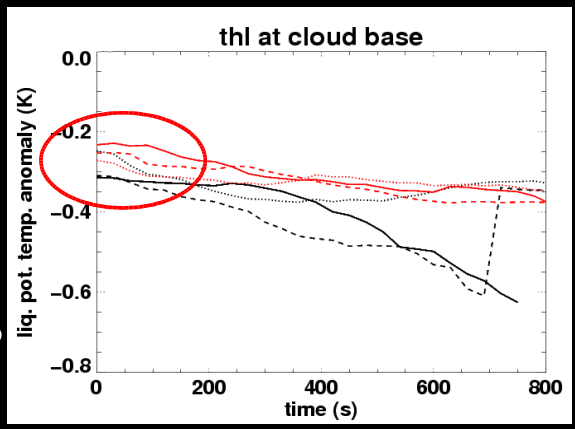
Cloud base characteristics at initiation

Cloud D,E,F -> larger clouds have wider perturbations but same intensity at initiation



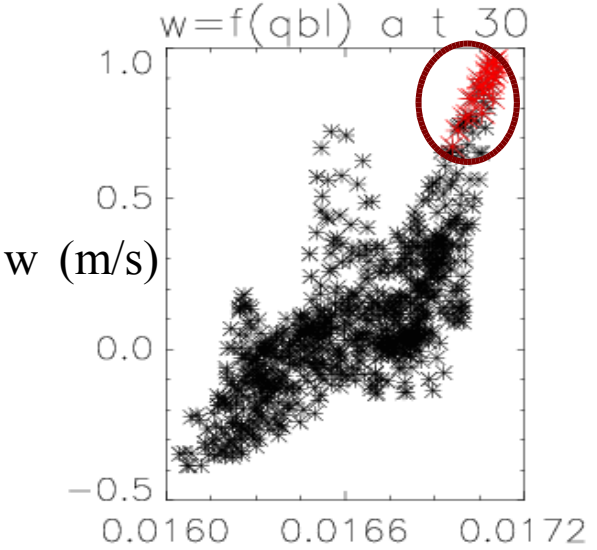


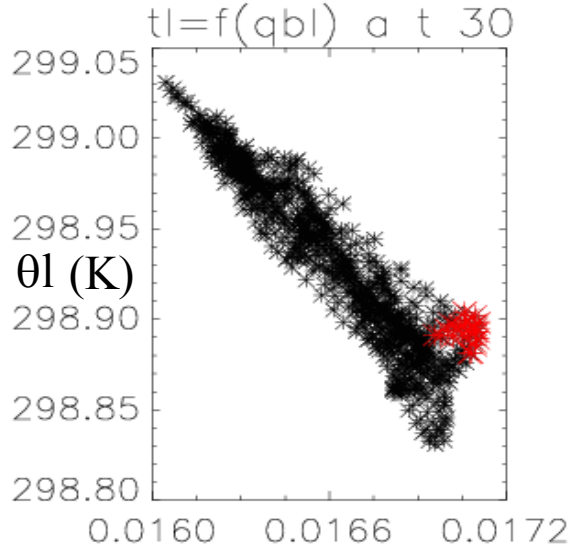




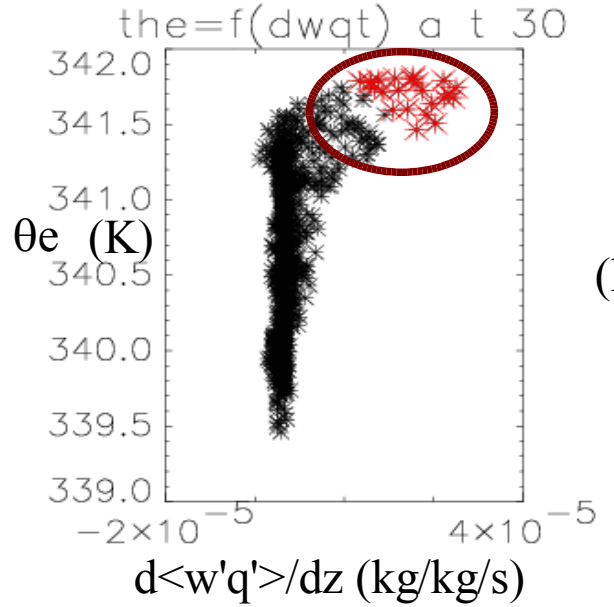
→ Determination of the height of cloud from initiation?

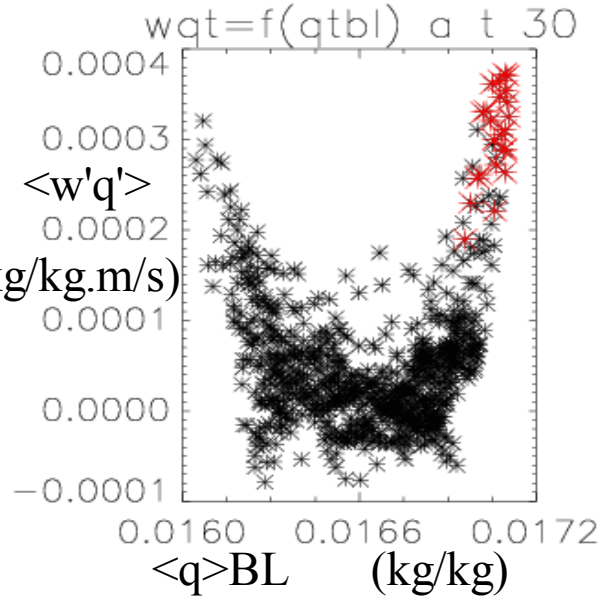
Subcloud layer characteristics





Cloud C





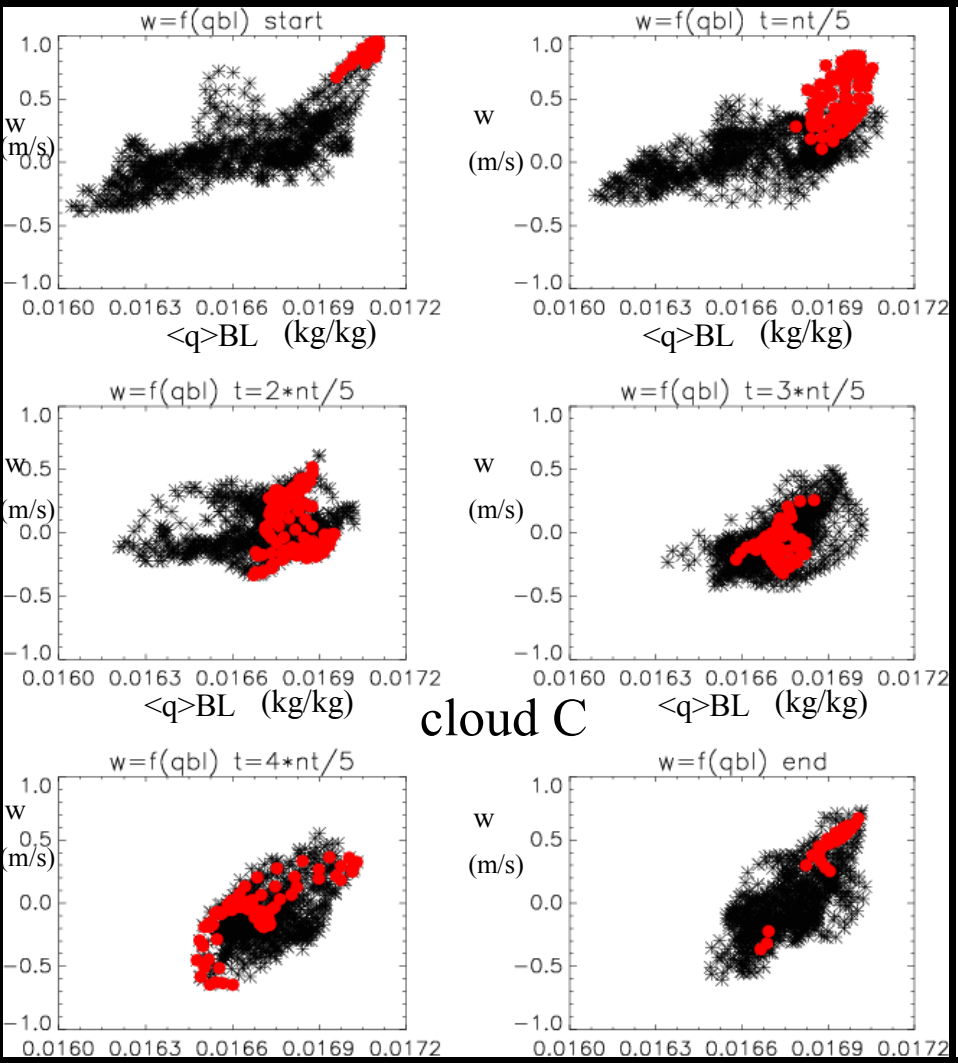
Characteristics at cloud initiation

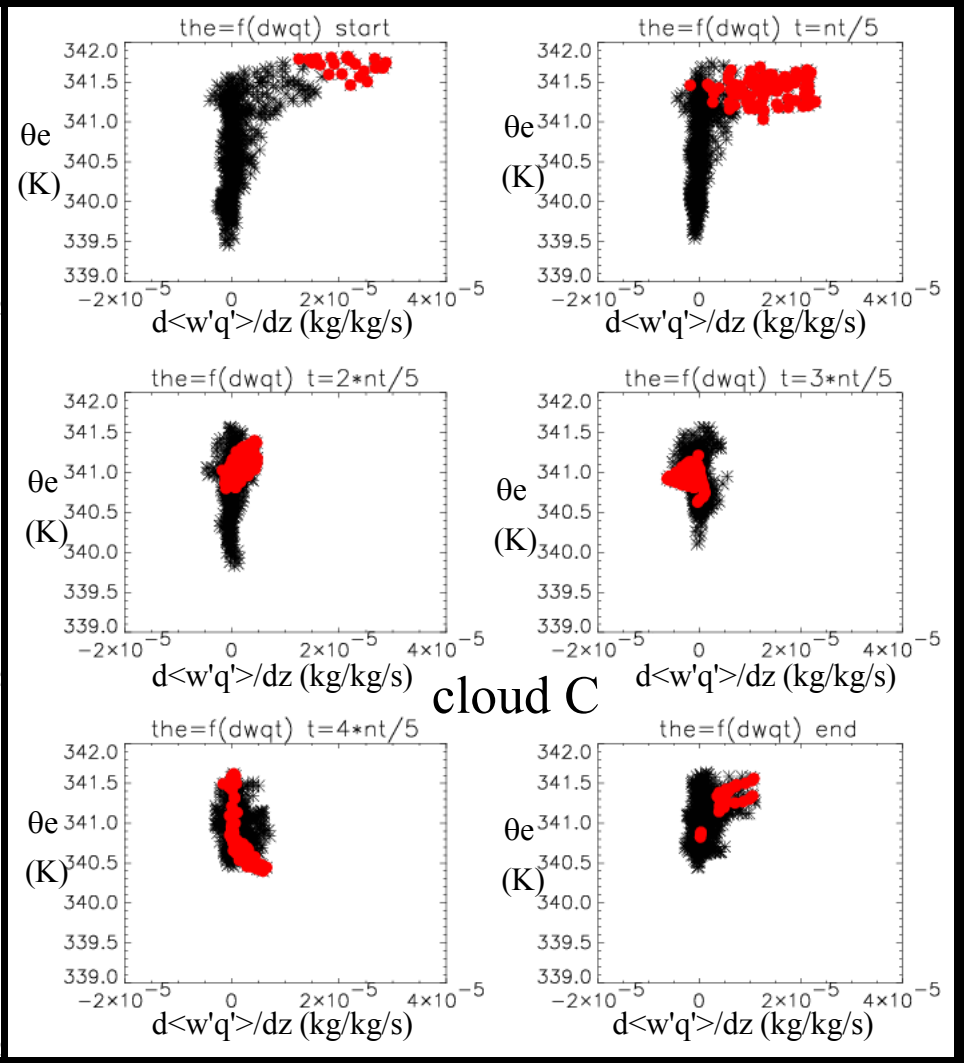
* every column
*cloudy column

<u>Criteria:</u>
moist and ascending
positive div(wqt)

Subcloud layer characteristics

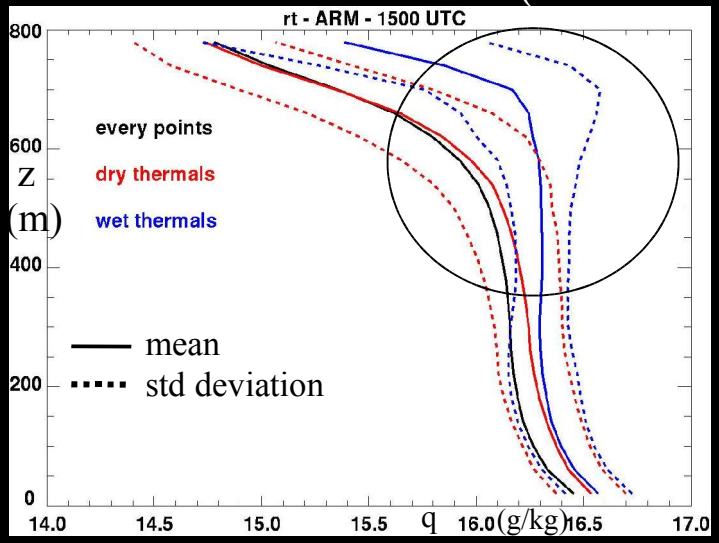
Evolution with time: criteria of initiation only during the first 3-4 minutes

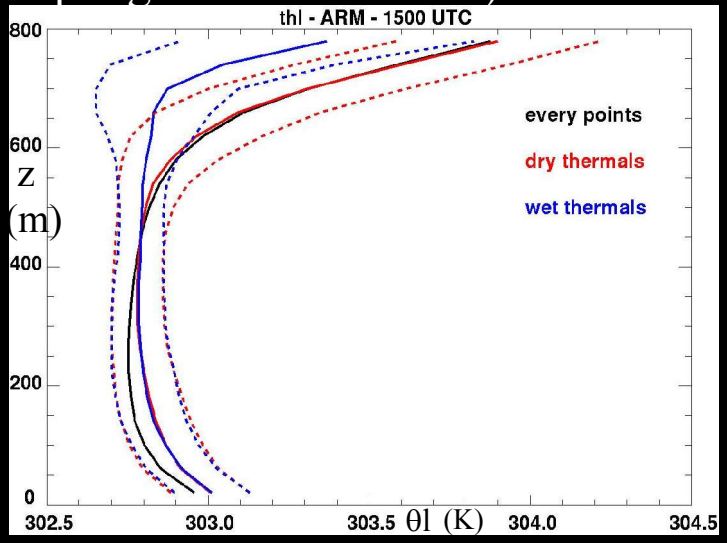


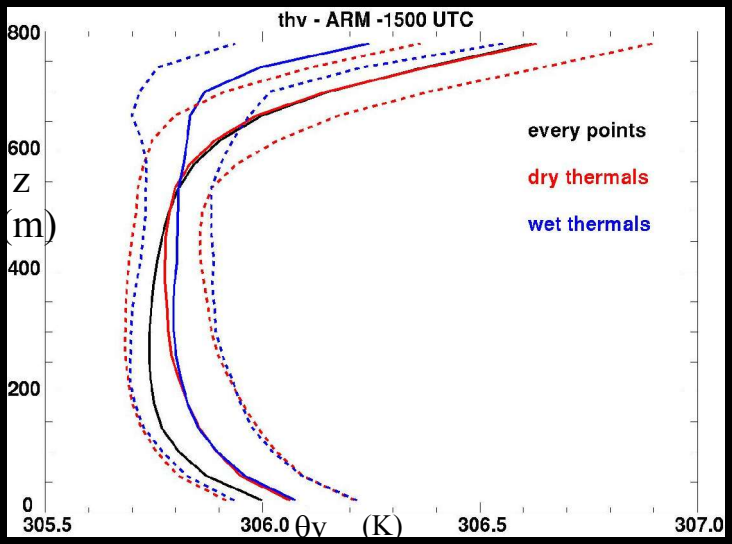


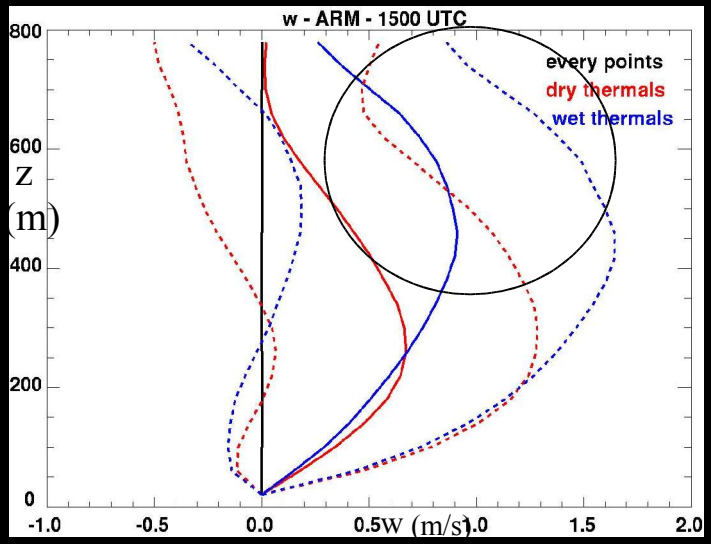
Dry thermals/"cloudy" thermals

Thermodynamical properties of the dry thermals versus cloudy thermal
(conditional sampling on w' and cld col)





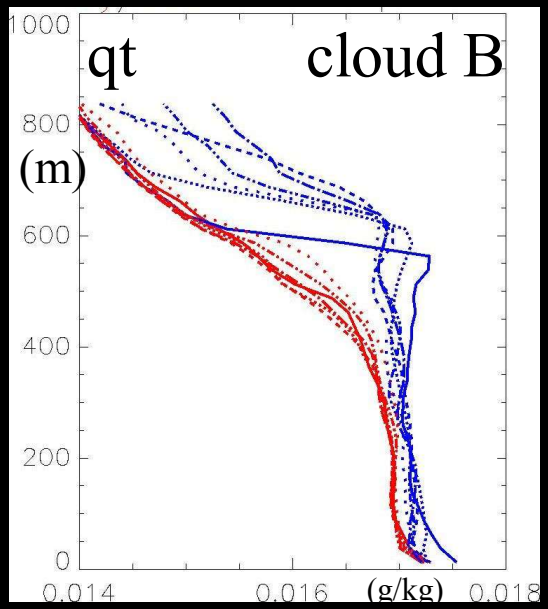


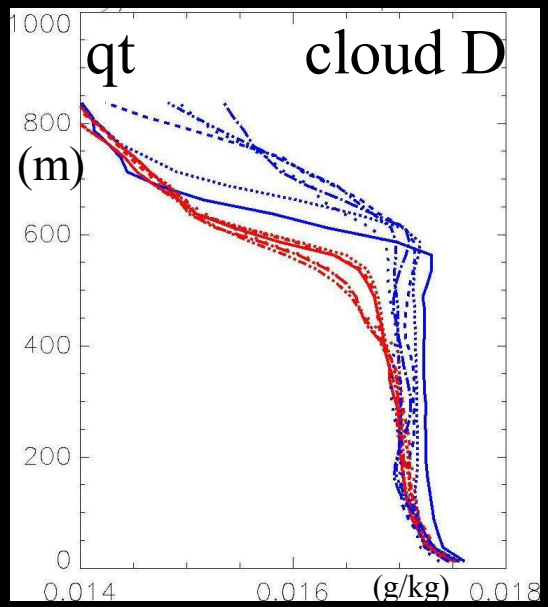


A(cld thermals)~0.1
A(dry thermals)~0.3

"Cloudy" thermals moister and faster in the upper half of the boundary layer

Dry thermals/cldy thermals: ind. clds

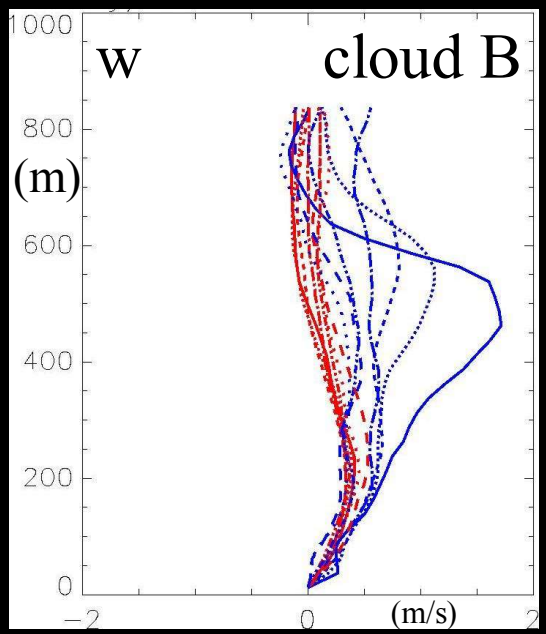


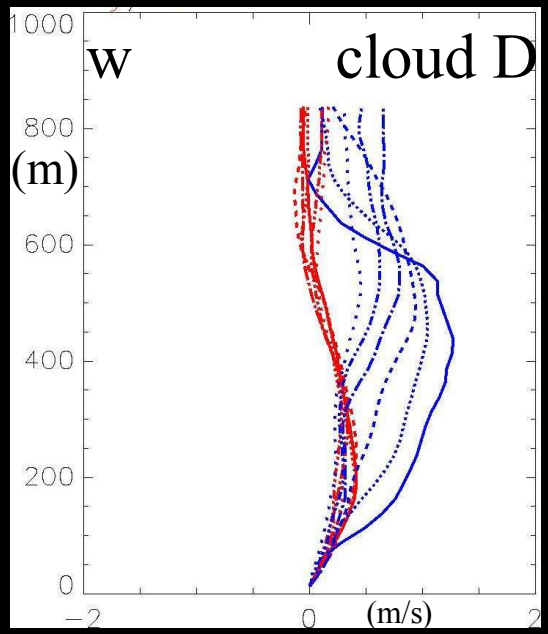


Same conclusions:
moister and faster in the upper boundary layer
+ evidence of vertical transport of moisture

dry thermals
cld thermals

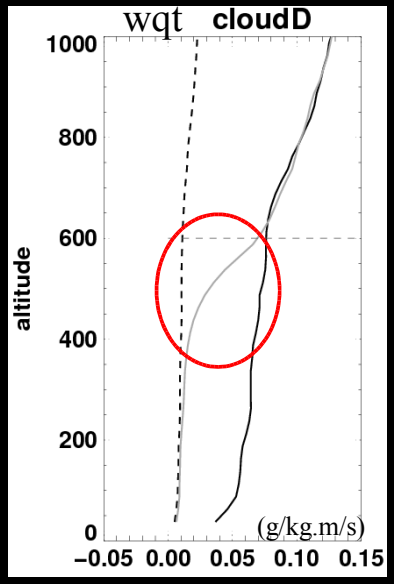
- 0
- 2'
- 4'
- 6'
- 8'
- 10'

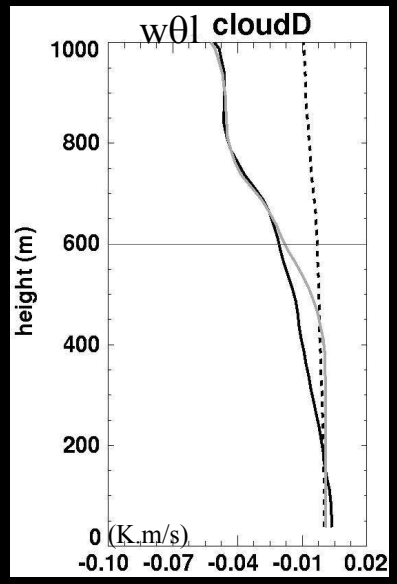


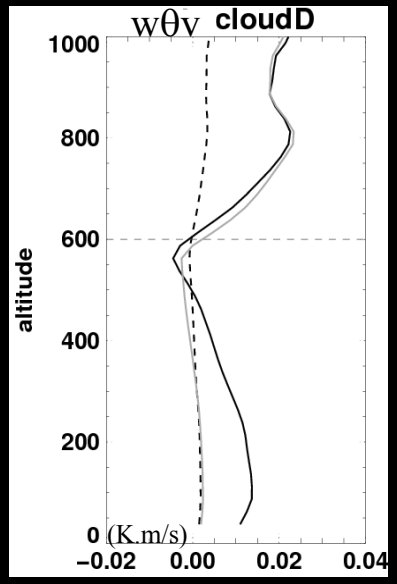


Moisture flux enhancement under clouds

Enhancement of water vapour flux in the 1/3 upper BL







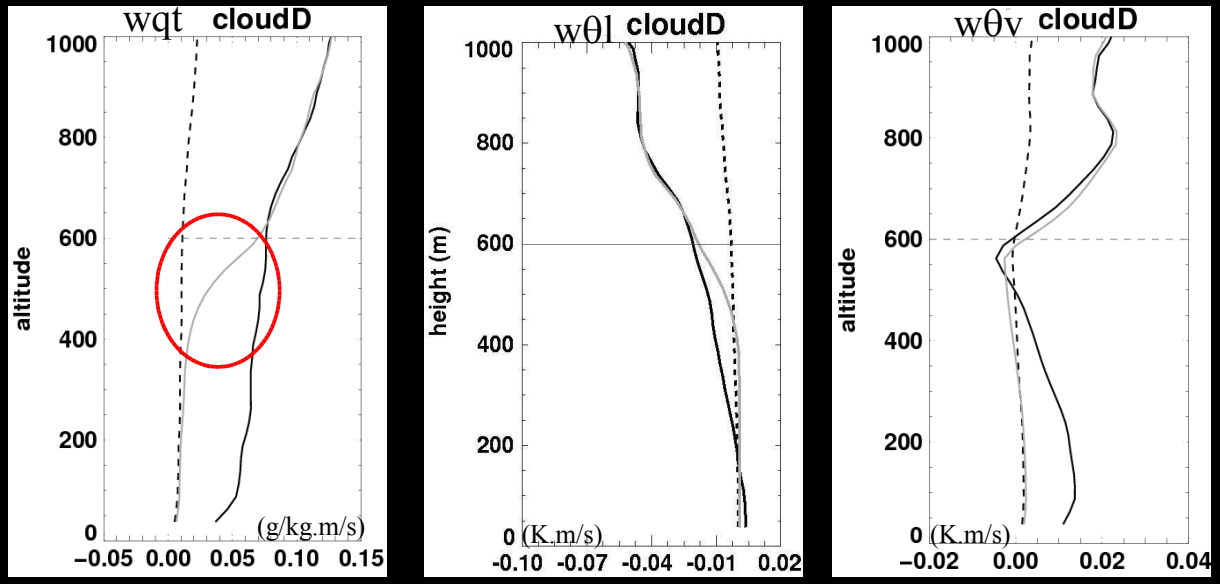
BOMEX: cloudD

- mean profile
- contribution according to cloud fraction
- under cld contribution

assymetry between moisture and temperature

Moisture flux enhancement under clouds

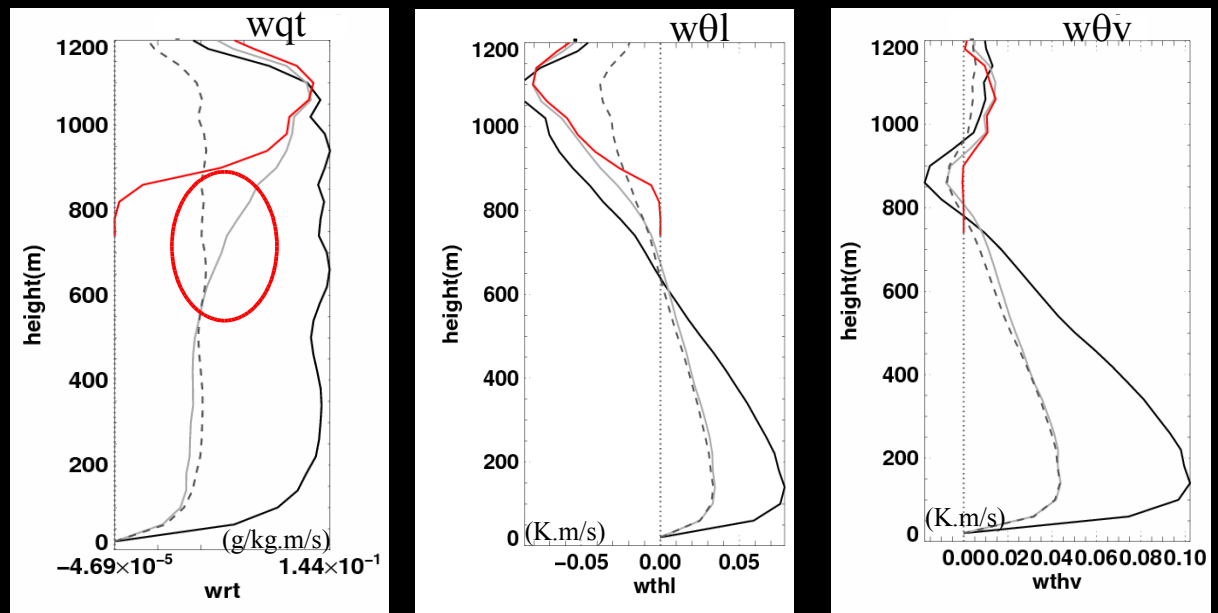
Enhancement of water vapour flux in the 1/3 upper BL



BOMEX: cloudD

- mean profile
- contribution according to cloud fraction
- under cld contribution

assymetry between moisture and temperature



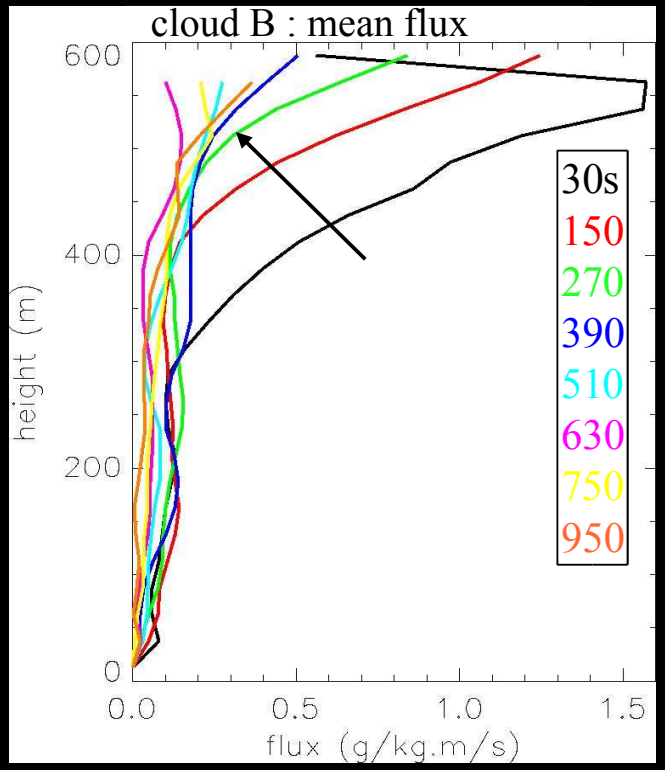
LES: ARM 6h

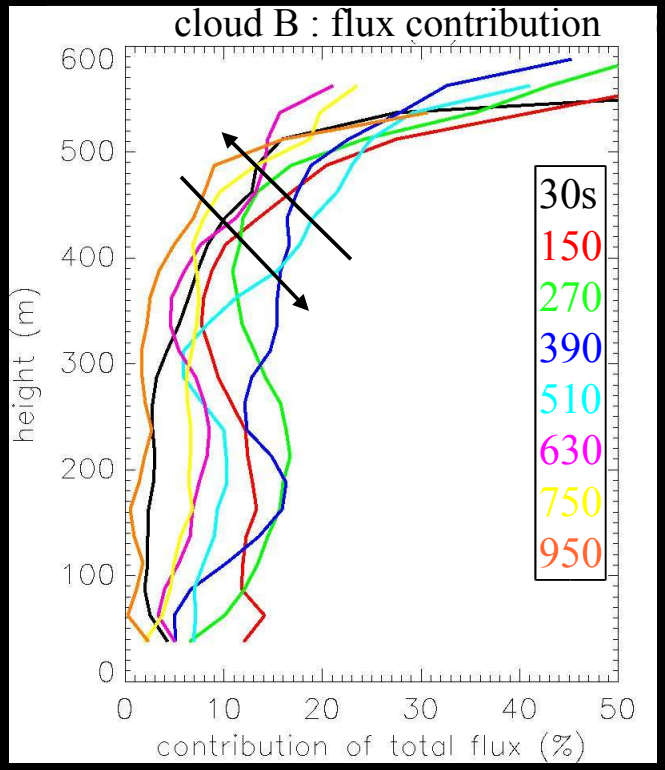
- mean profile
- contribution according to cloud fraction
- under cld contribution
- cld contribution

~no impact on temperature flux (wθl and wθv)

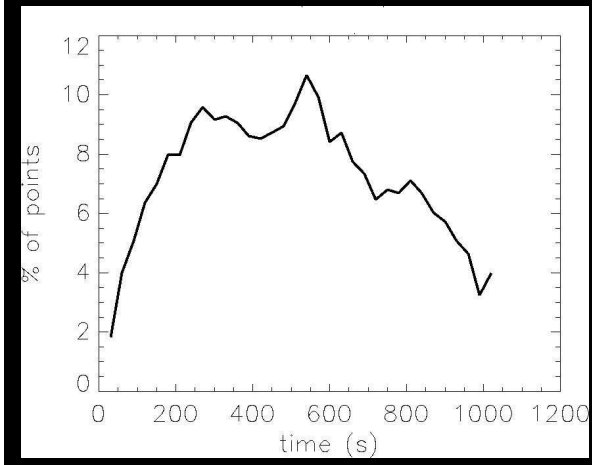
Evolution of the moisture flux below ind. clds

Mean flux under clouds / Flux contribution from under clouds





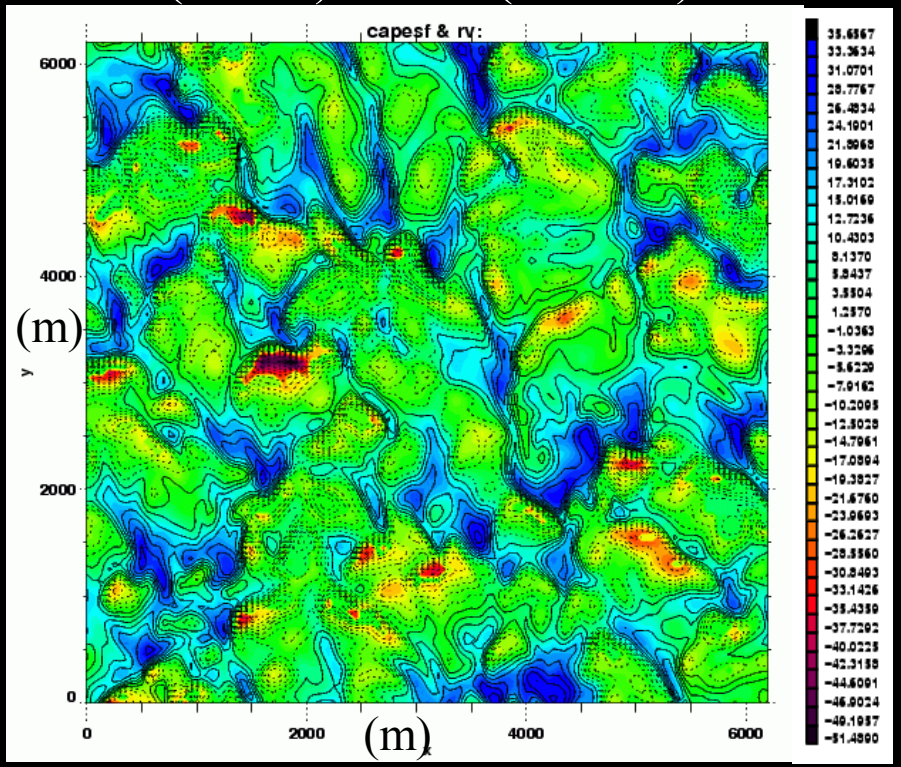
evolution of the area that feeds the cloud



at initiation, maximum of moisture transport but small area covered by updrafts
afterwards this area increases but less and less vertical transport

Role of humidity

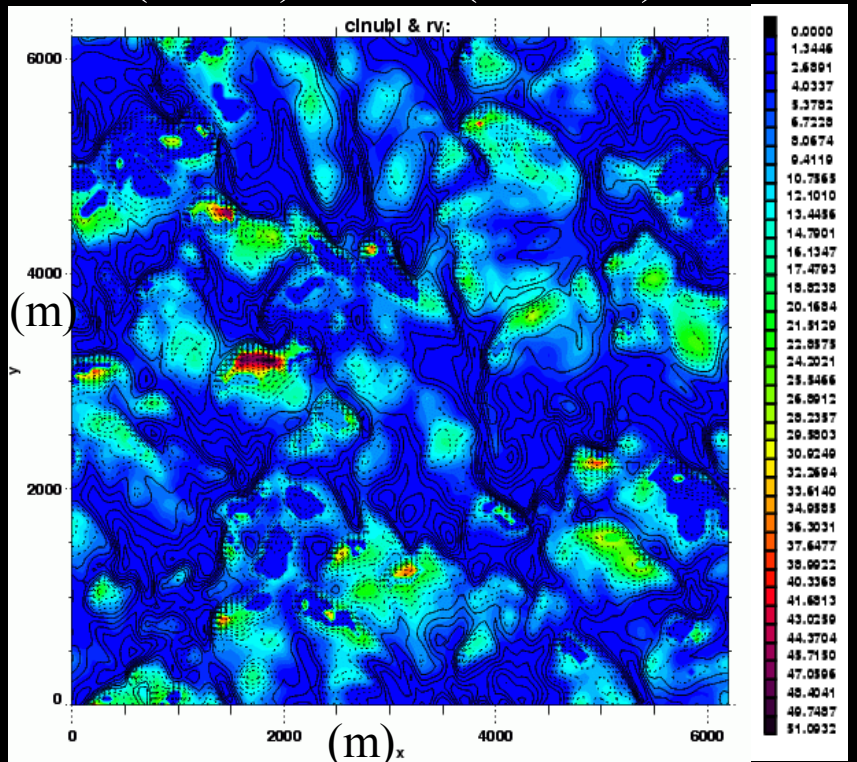
CAPE (colors) and rv (isolines) at surface



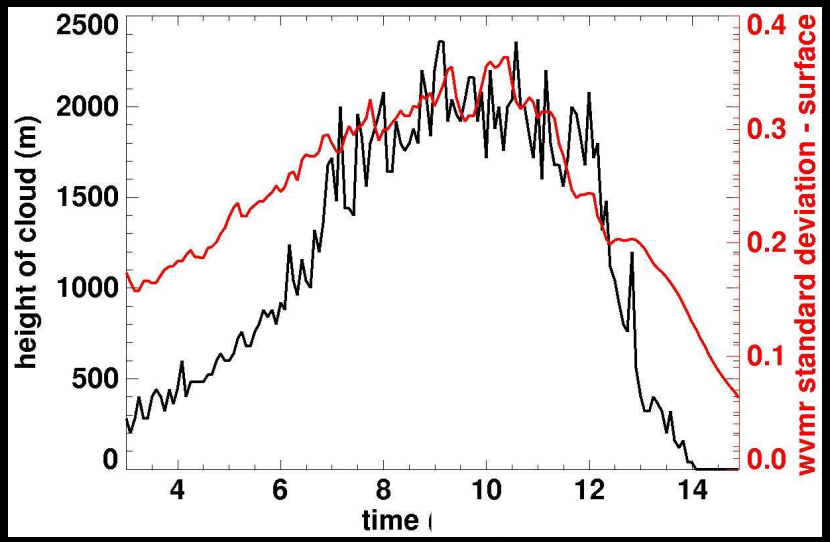
ARM – 16 UTC

Evidence of a strong impact of water vapour variability on stability indexes for CAPE and CIN

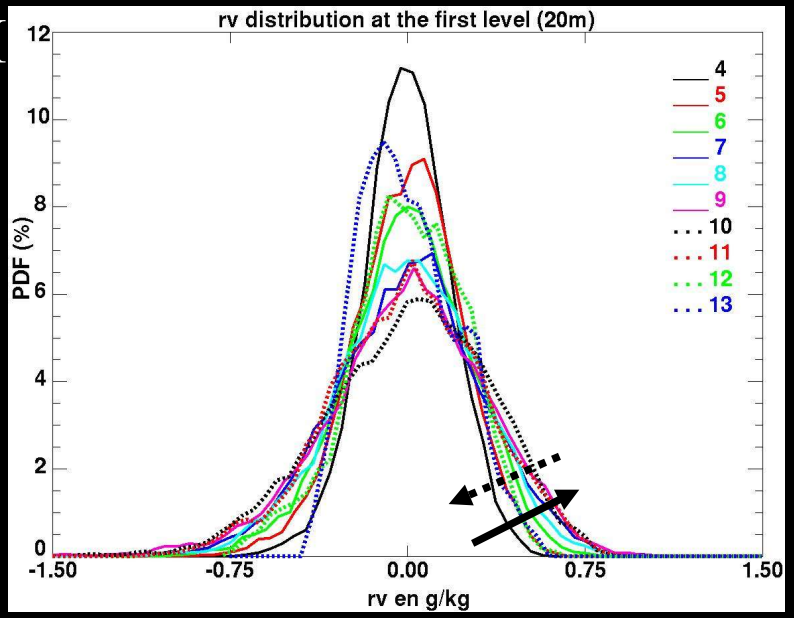
CIN (colors) and rv (isolines) at surface



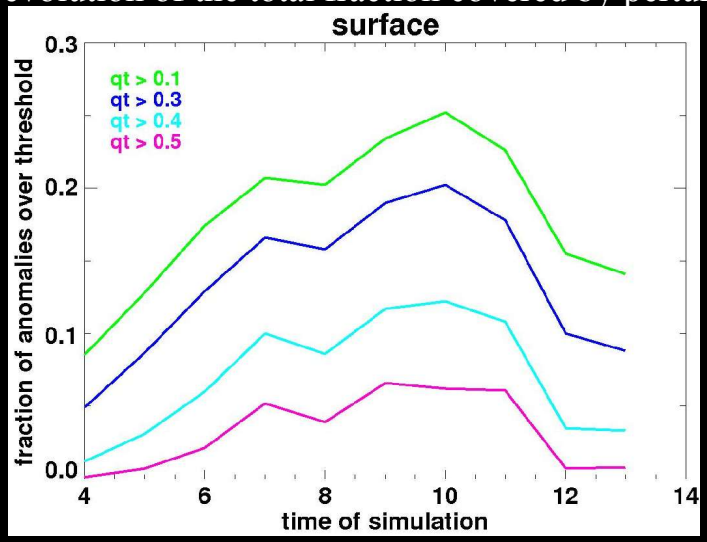
Role of water vapour



ARM

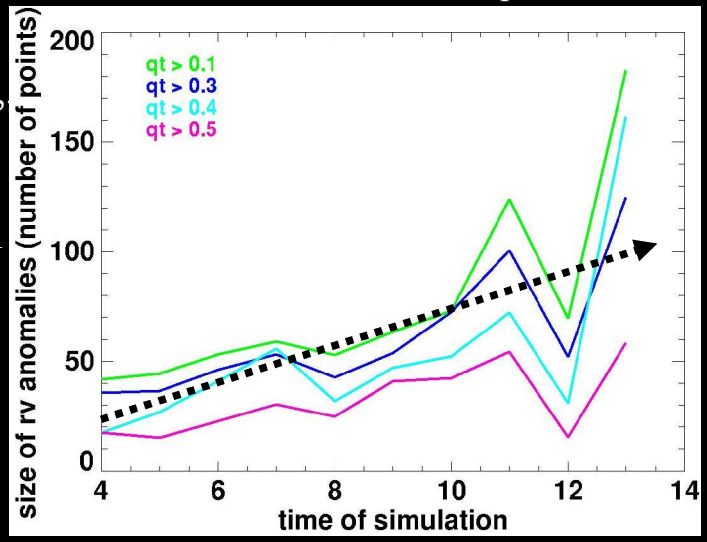


evolution of the total fraction covered by perturbations

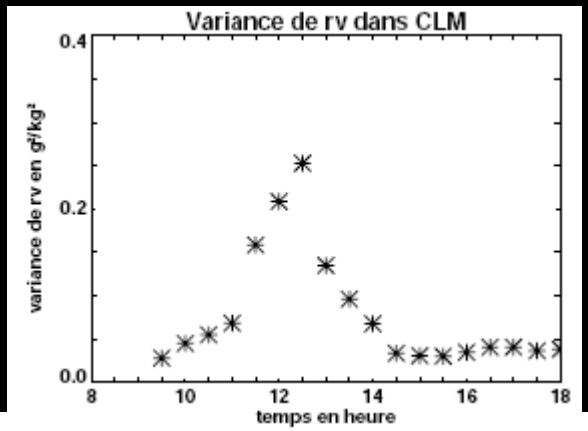


relationship between clouds and the "intensity" but not the size of the moisture perturbation

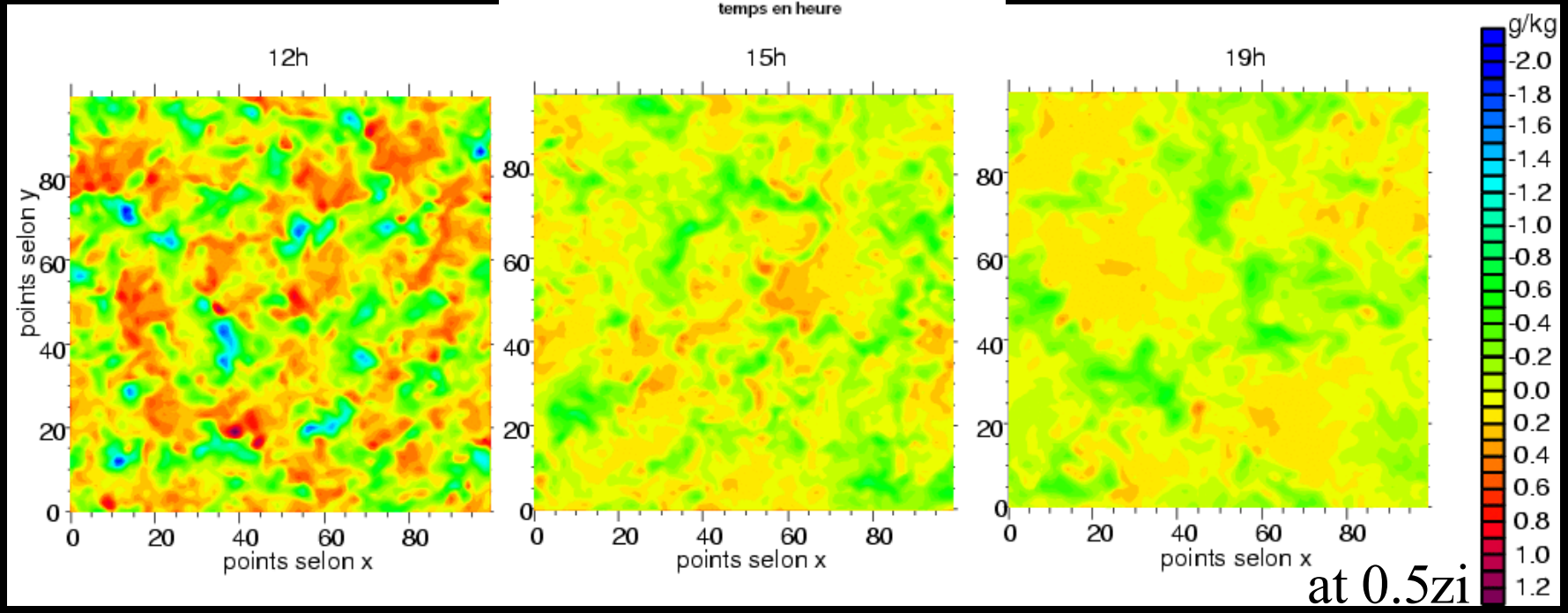
evolution of the mean size of perturbation



Transitory aspect of the water vapour in the dry boundary layer – IHOP simulation



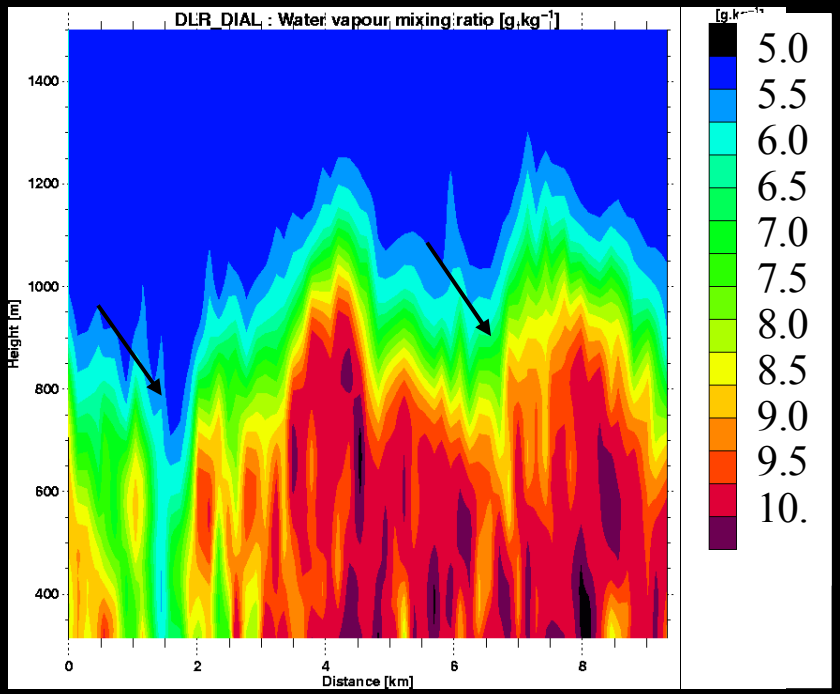
Couvreux (2005)



At the end of the day large scale of variability is still present but smaller intensity

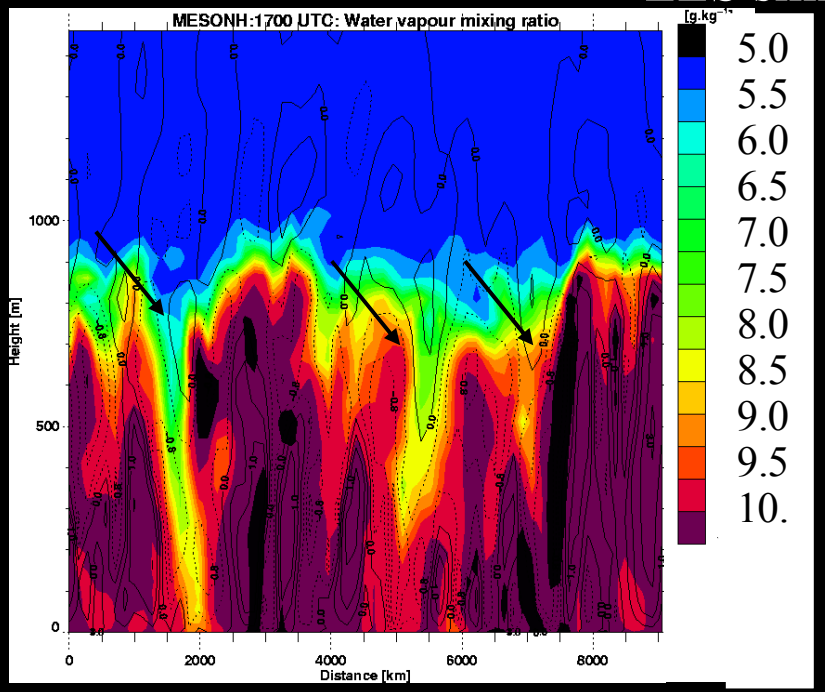
Water vapour variability in dry BL

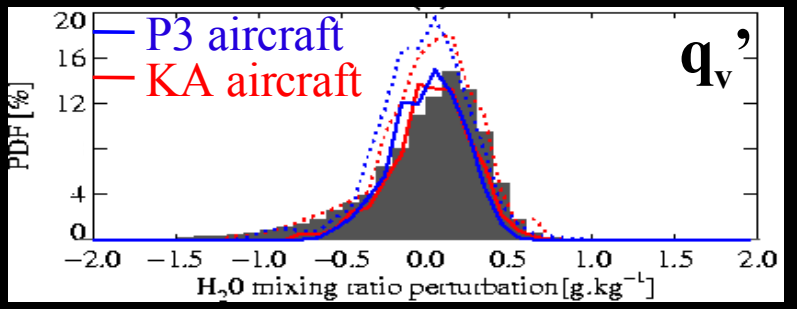
Lidar observations



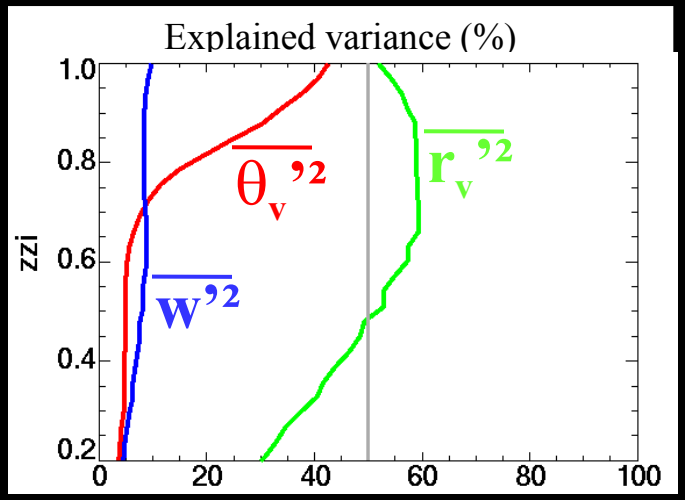
at 12 local time

LES simulation



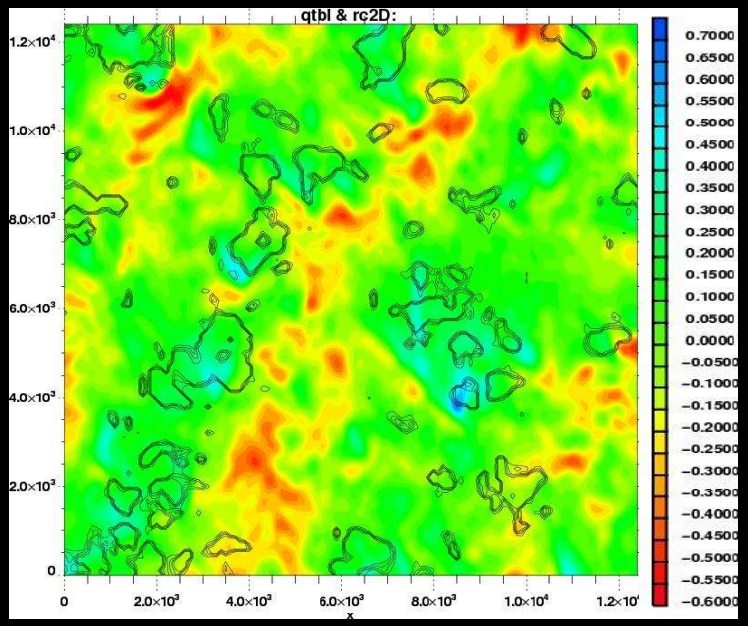


Couvreux et al. 2005

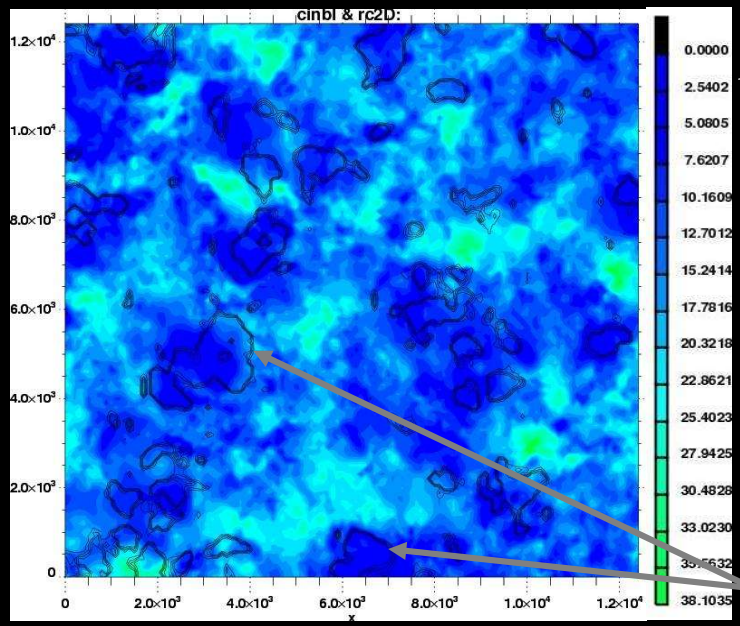


dry tongues largely responsible for the water vapour in the dry boundary layer

Can the dry tongues play a role in organisation ?



qt(BL) & cloud

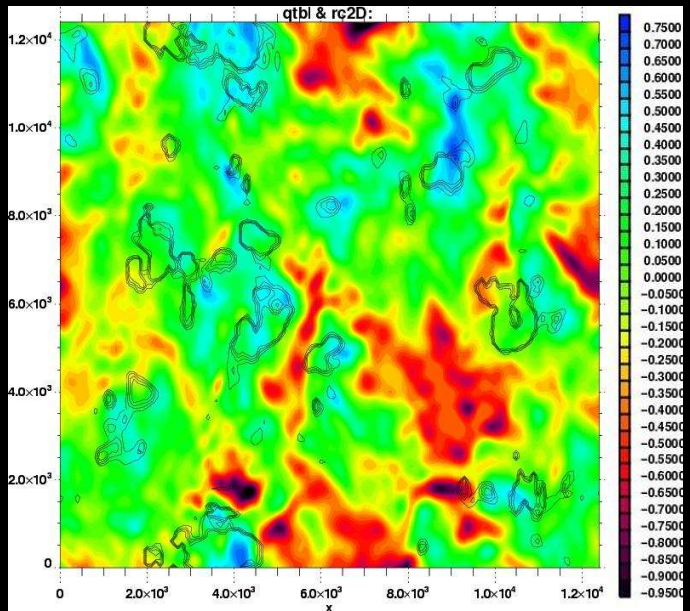


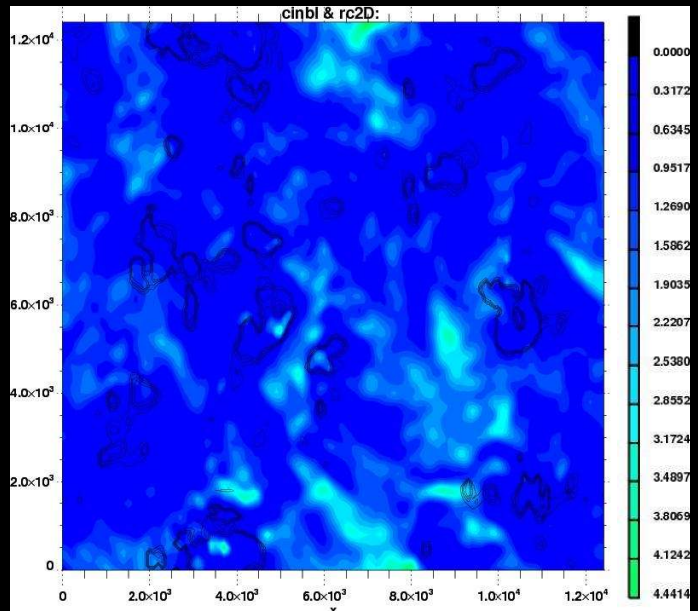
CIN & cloud

ARM – 16 UTC

need to investigate possible role of dry tongues in the organization of clouds

clouds

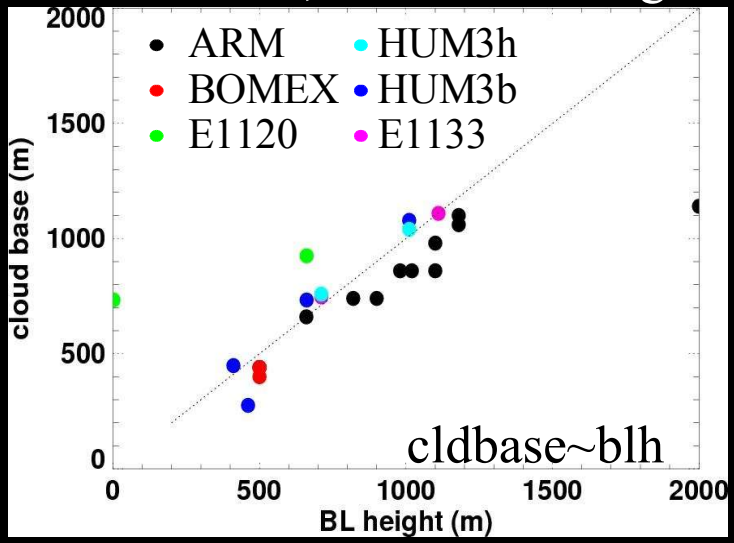


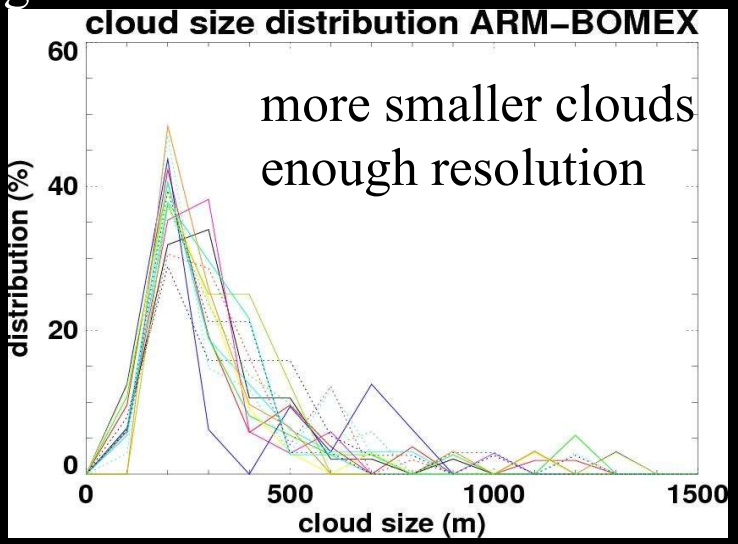


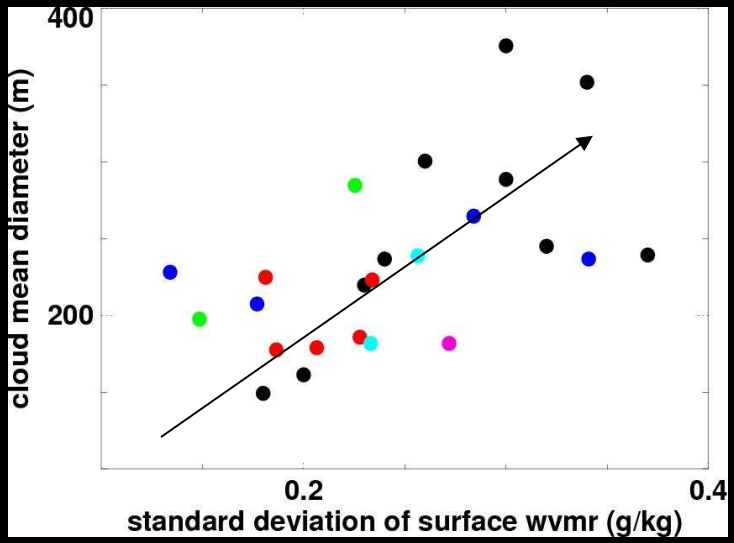
BOMEX

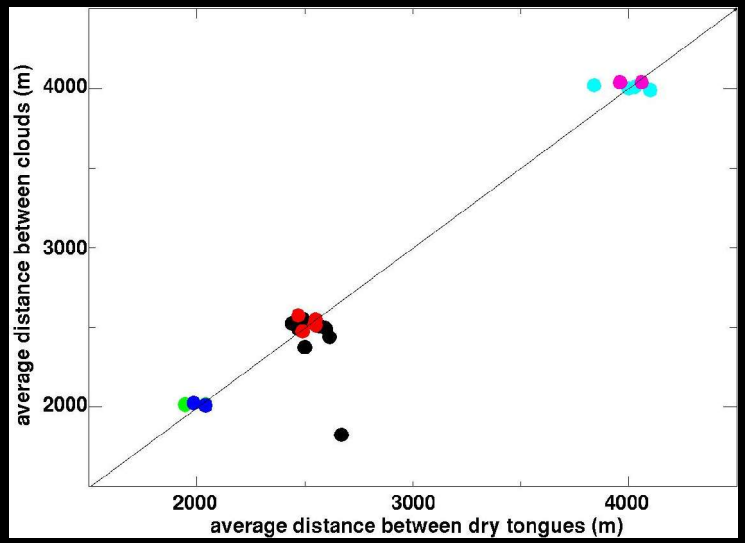
Cloud organisation

variations of size, distance to neighbour, height: links with subcloud variables ?









relationship with dry tongues need to be more investigated ...

Preliminary conclusions

Summary :

- at cloud base: narrow distribution at initiation
  wider distribution during the cloud life cycle
  width of cloud base at initiation discriminates small/large clouds

- in subcloud layer : w' max, qt' max , θe' max, dwqt/dz max at initiation

- enhancement of moisture flux under cloud

- importance of the qt distribution (more “intensity” than size of perturbation)

Future work:

- pursue the study of the link between the qt distribution in BL and clouds

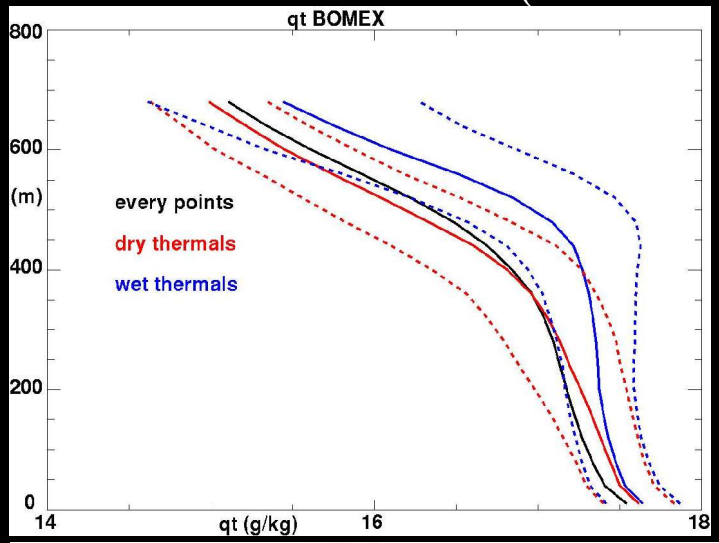
- look more in details at the exchange at cloud base through the cloud life cycle

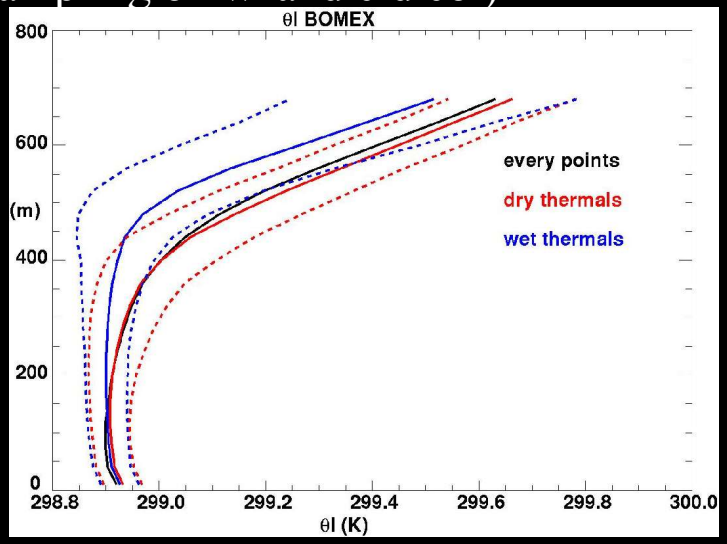
- application to parameterization

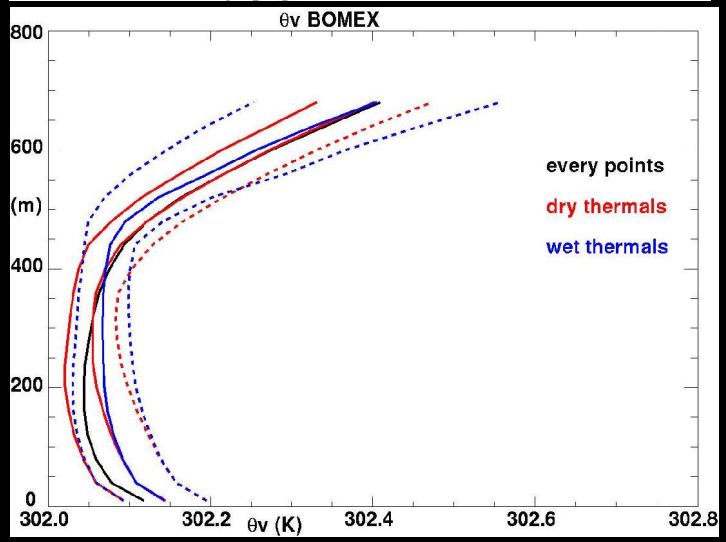
Thanks for
your attention

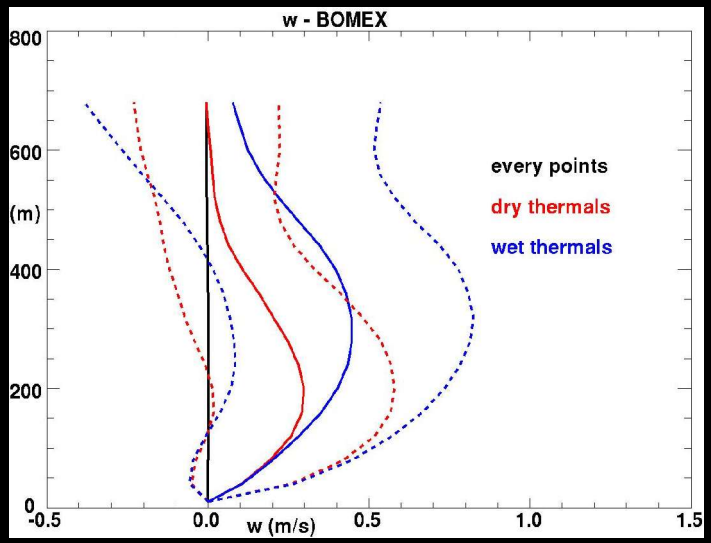
Dry thermals/wet thermals

Thermodynamical properties of the dry thermals versus cloudy thermal
(conditional sampling on w' and cld col)







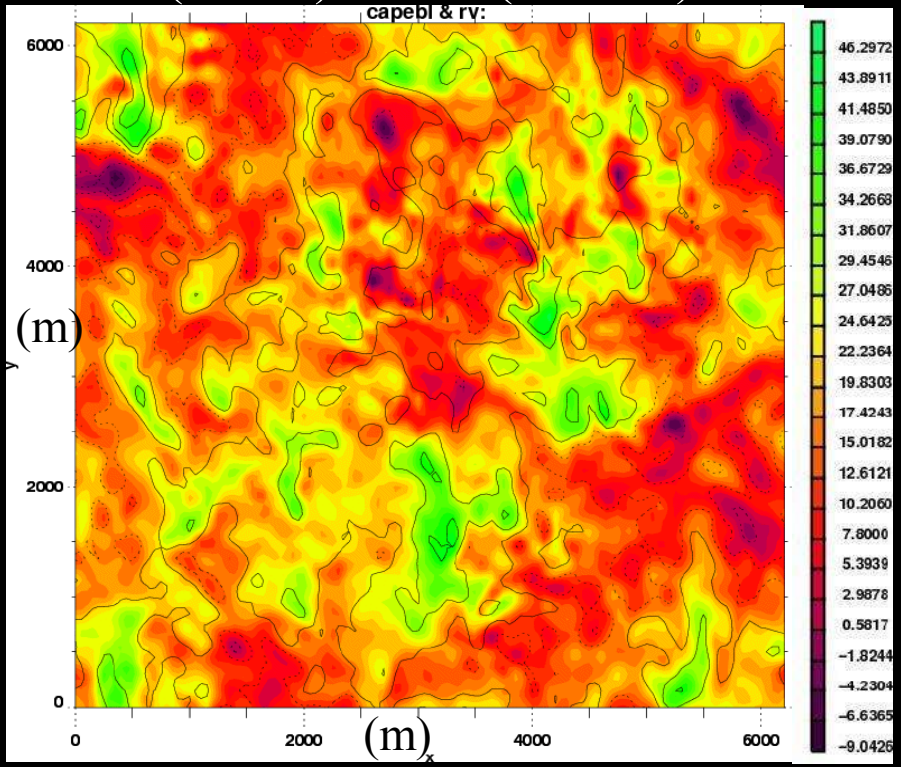


A(wet thermals)~0.2
A(dry thermals)~0.2

Wet thermals moister and faster in the upper half of the boundary layer

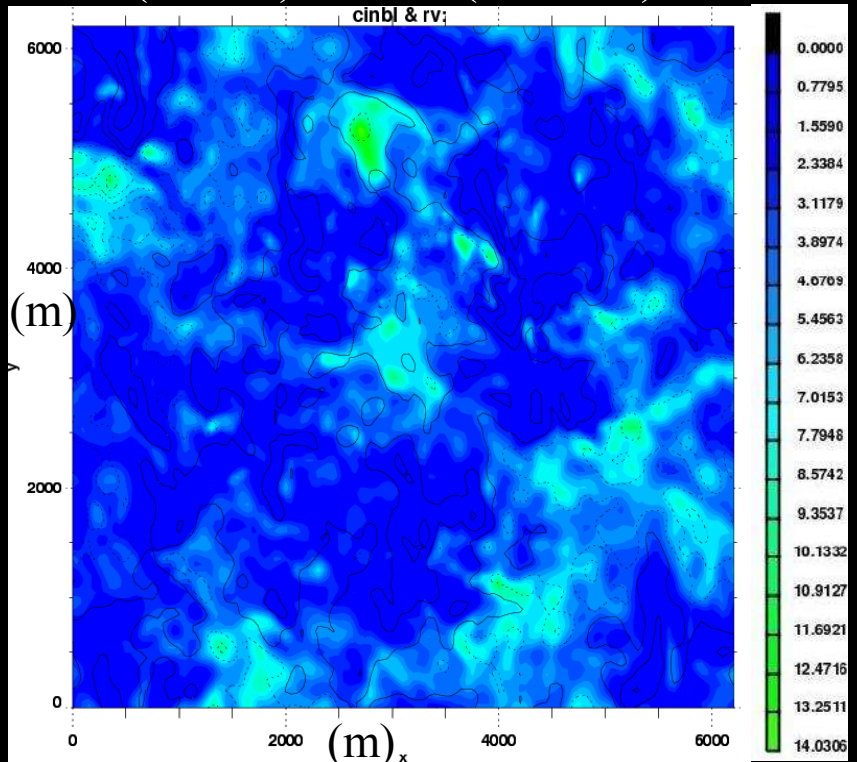
Role of humidity

CAPE (colors) and rv (isolines) in BL

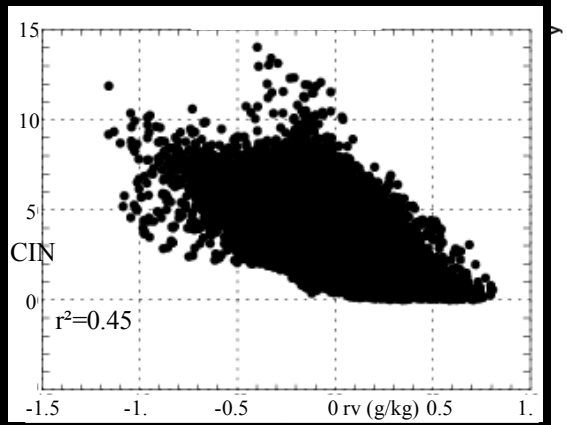


Evidence of a strong impact of water vapour variability on stability indexes for CAPE and CIN

CIN (colors) and rv (isolines) in BL

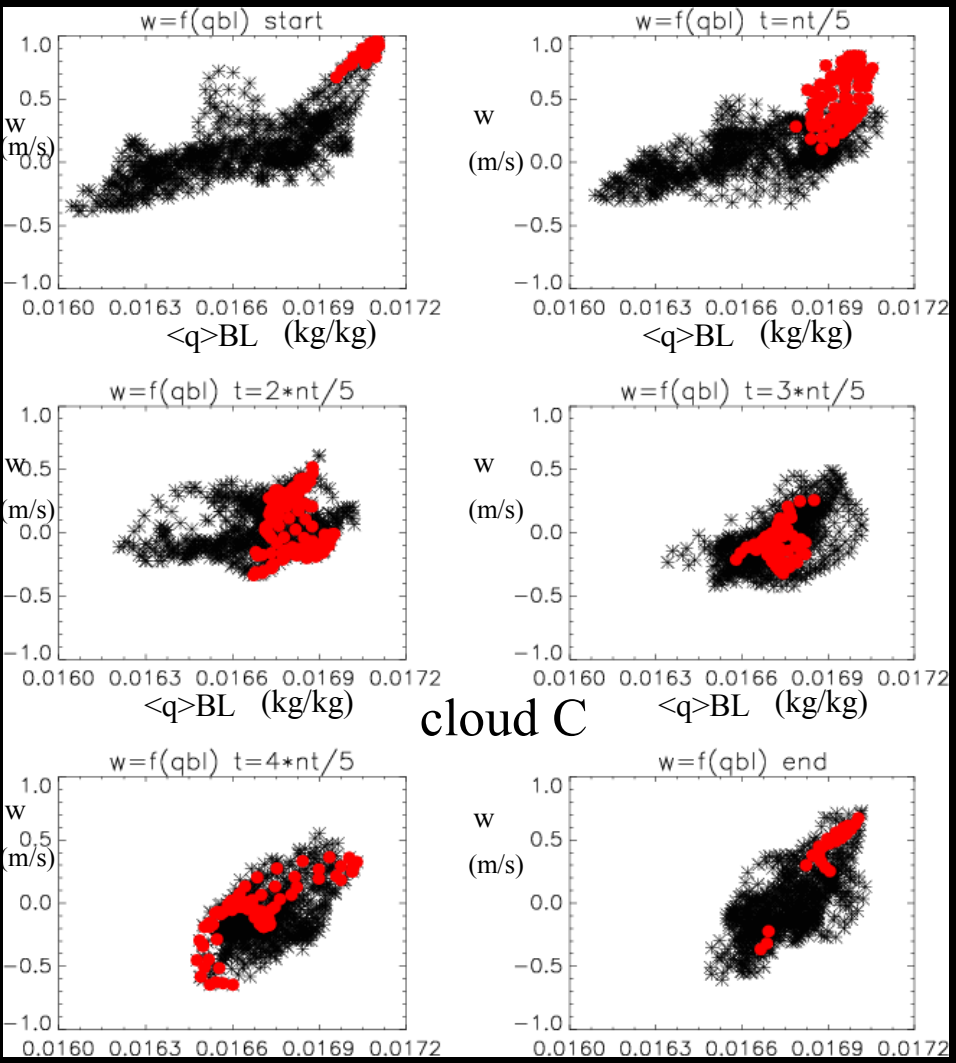


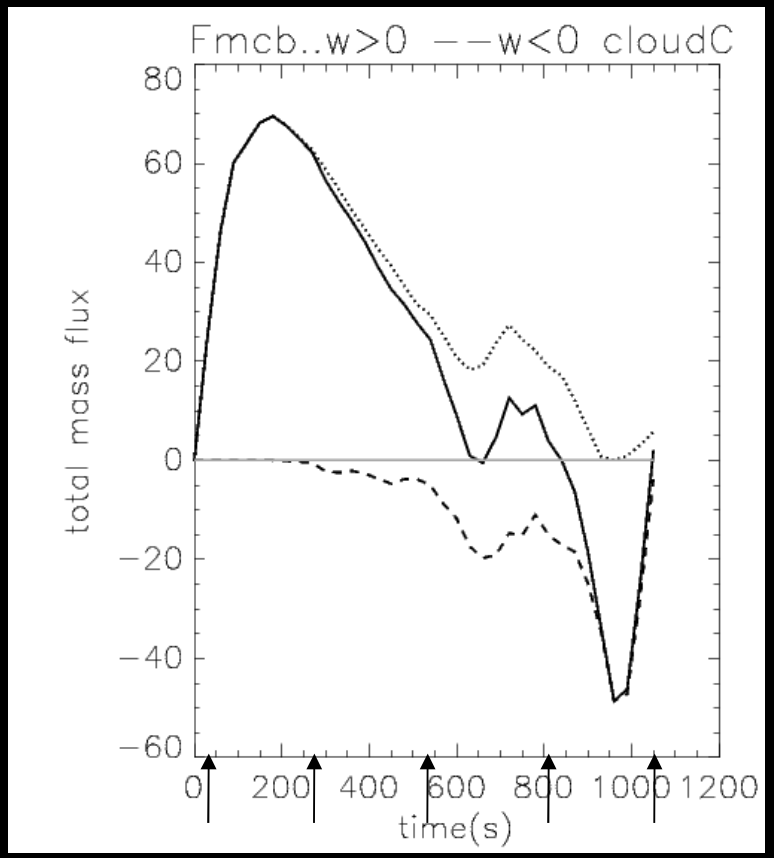
ARM – 20 UTC



Subcloud layer characteristics

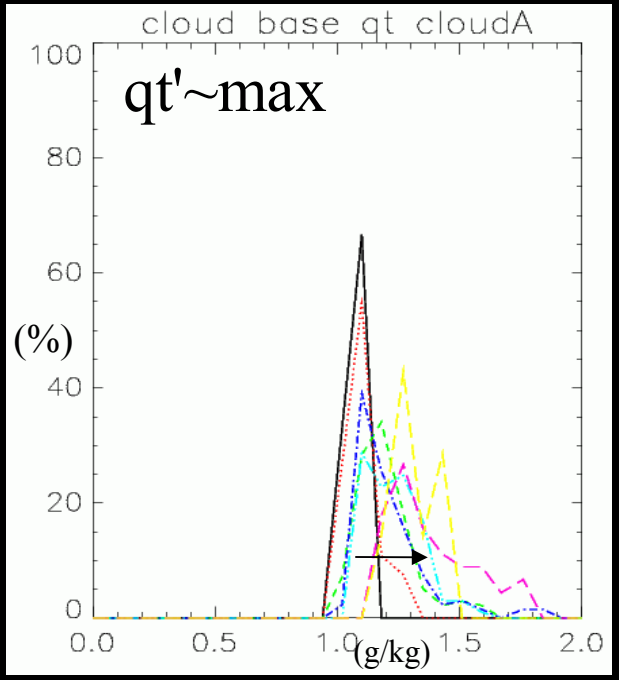
Evolution with time: criteria of initiation only during the first 3-4 minutes

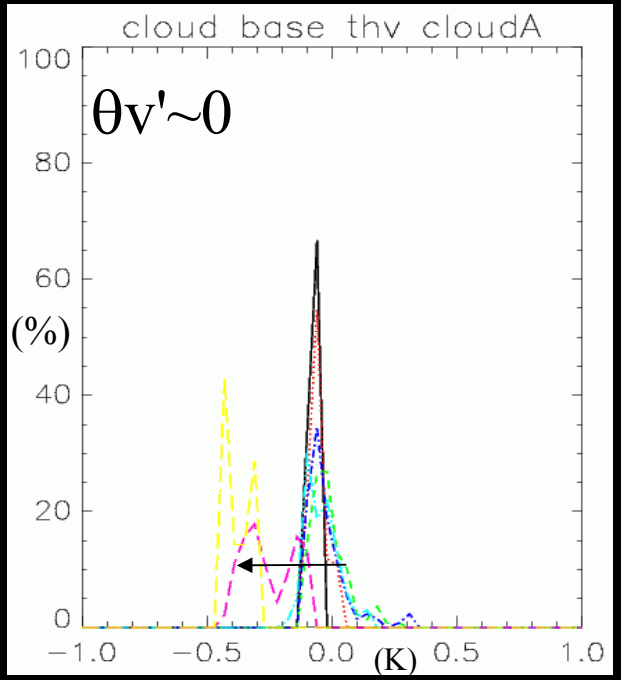


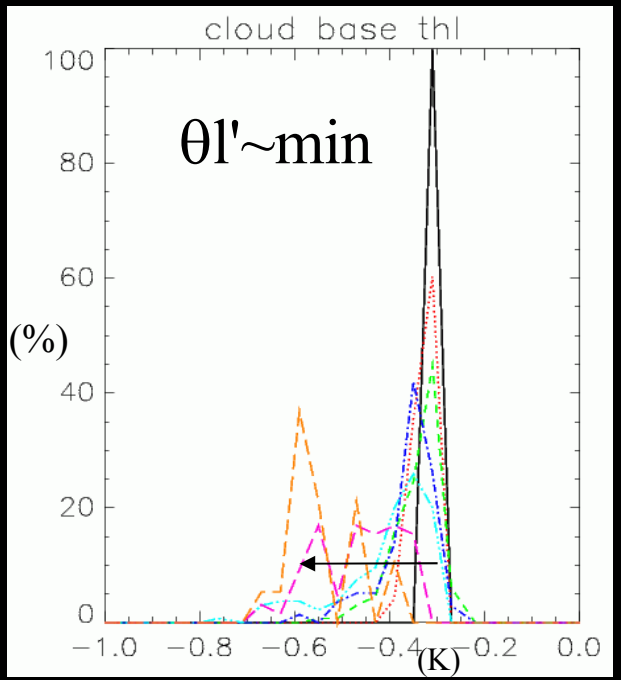


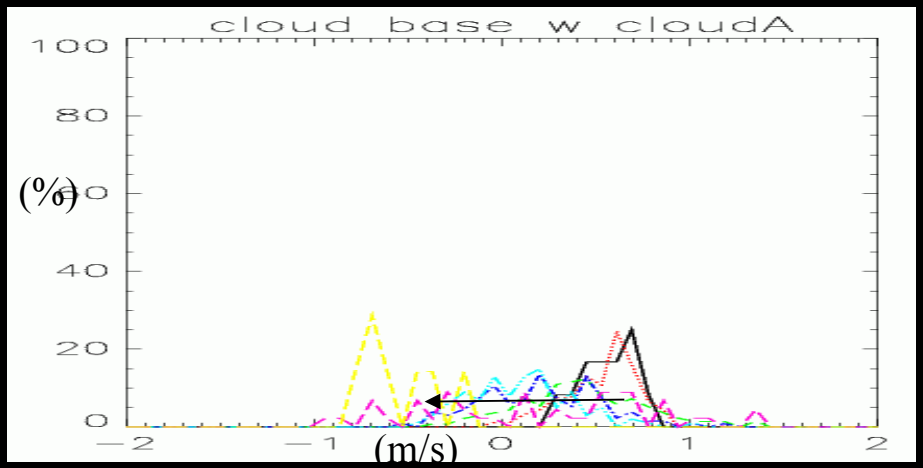
Cloud base characteristics after initiation

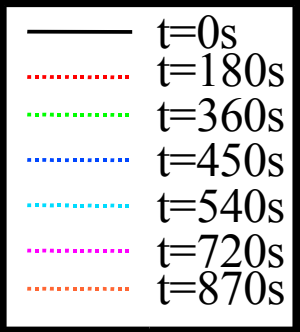
Variation of the distribution through the life cycle of the clouds: ex: cloud A











same results for other clouds