Revisite de l'ajustement des paramétrisations de nuages dans LMDZ à l'aide d'émulateurs.

Frédéric Hourdin, Arnaud Jam, Fleur Couvreux, Catherine Rio, Binta Diallo,
Daniel Williamson, Victoria Volodina, Marie-Pierre Lefebvre.

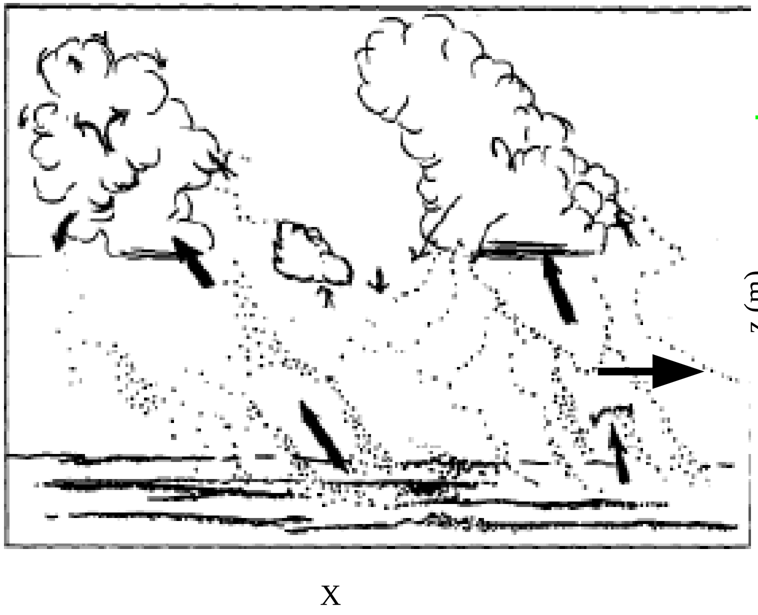
I. Parameterization de nuages dans LMDZ

II. Revisite à l'aide d'émulateur (processus gaussien) et refocalisation itérative

The thermal plume model and associated clouds

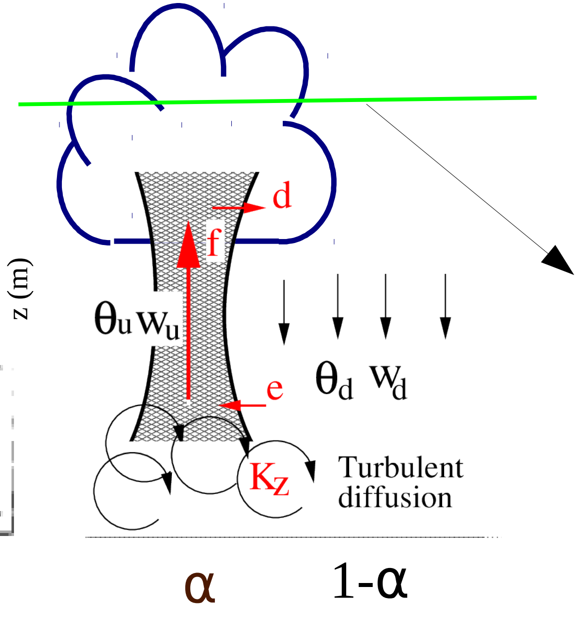
Hourdin et al., JAS, 2002; Rio et Hourdin, JAS, 2008, Rio et al., 2010, Jam et al., 2013

LeMone and Pennell, MWR, 1976



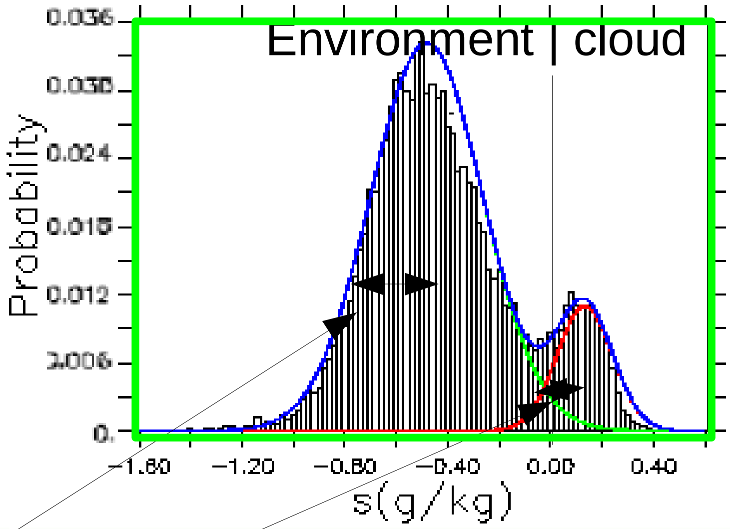
Internal variables

- w: mean vertical velocity within thermals
- α: fractional coverage of thermals
- e: entrainment rate within thermals
- d: detrainment rate from thermals
- qa: concentration of q within thermals



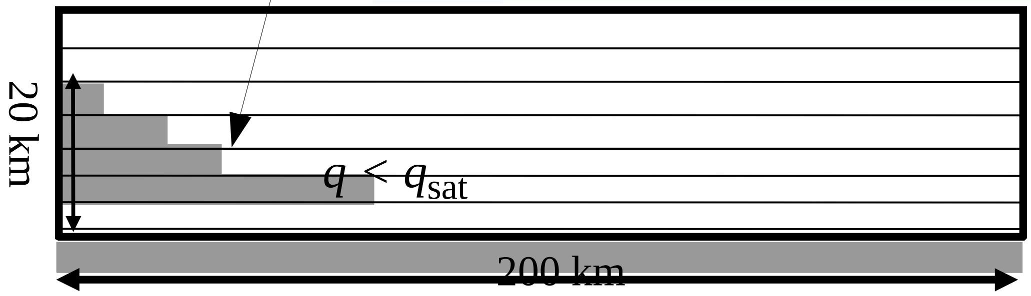
Parameterization of the subgrid-scale distribution of s=q-qsat
Jam et al., 2010

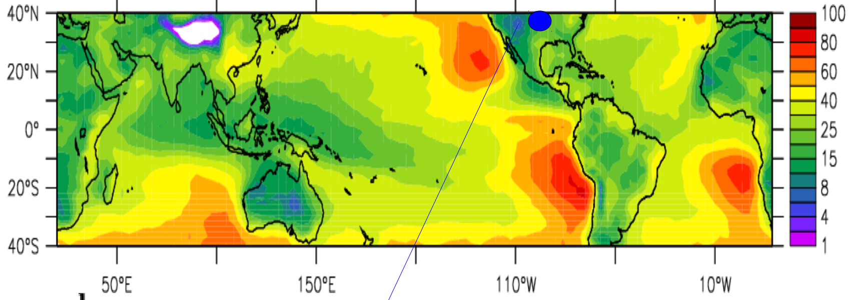
$\overline{s}_{env}=\overline{s}$ $\overline{s}_{th}=\overline{s}_u$



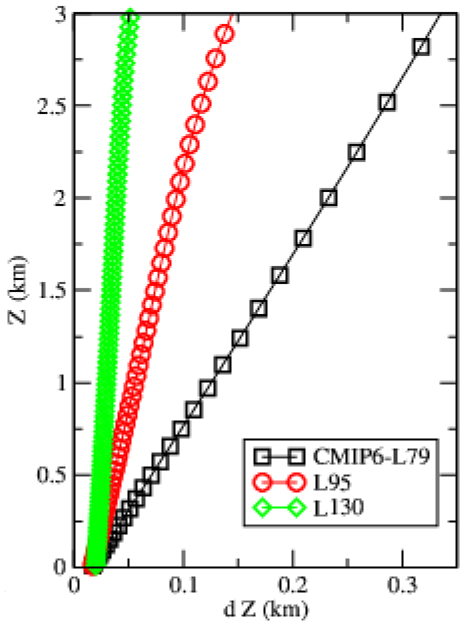
$$\sigma_{s,env} = c_{env} \times \left(\frac{\alpha}{1-\alpha}\right)^{\frac{1}{2}} \times (\overline{s}_{th} - \overline{s}_{env}) + b \times \overline{q}_{t_{env}}$$

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

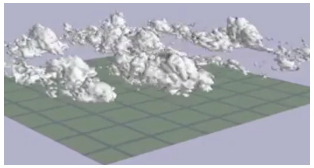


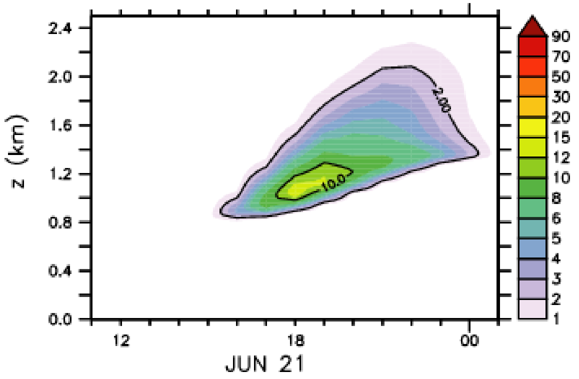


ARM cumulus case

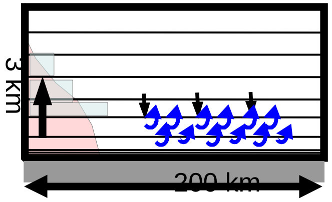


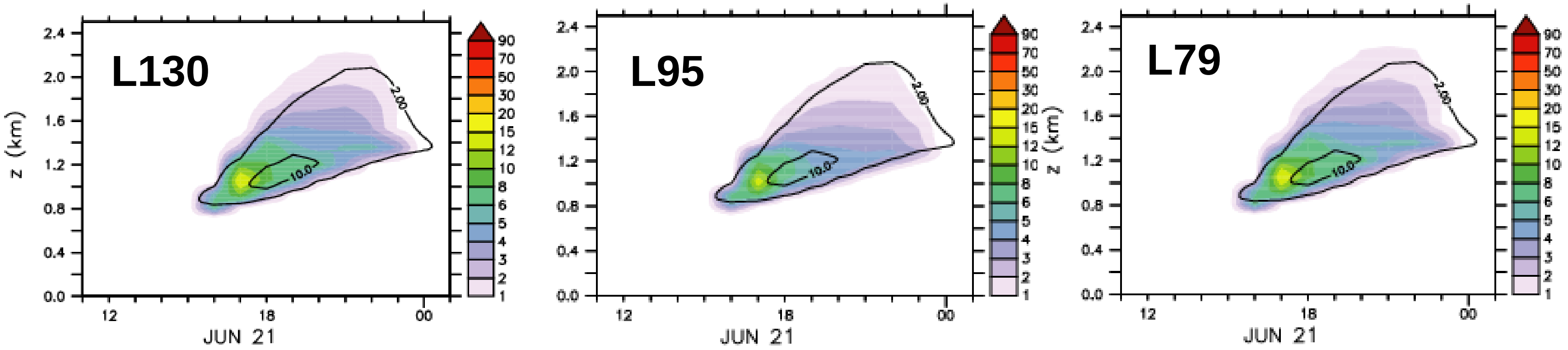
LES



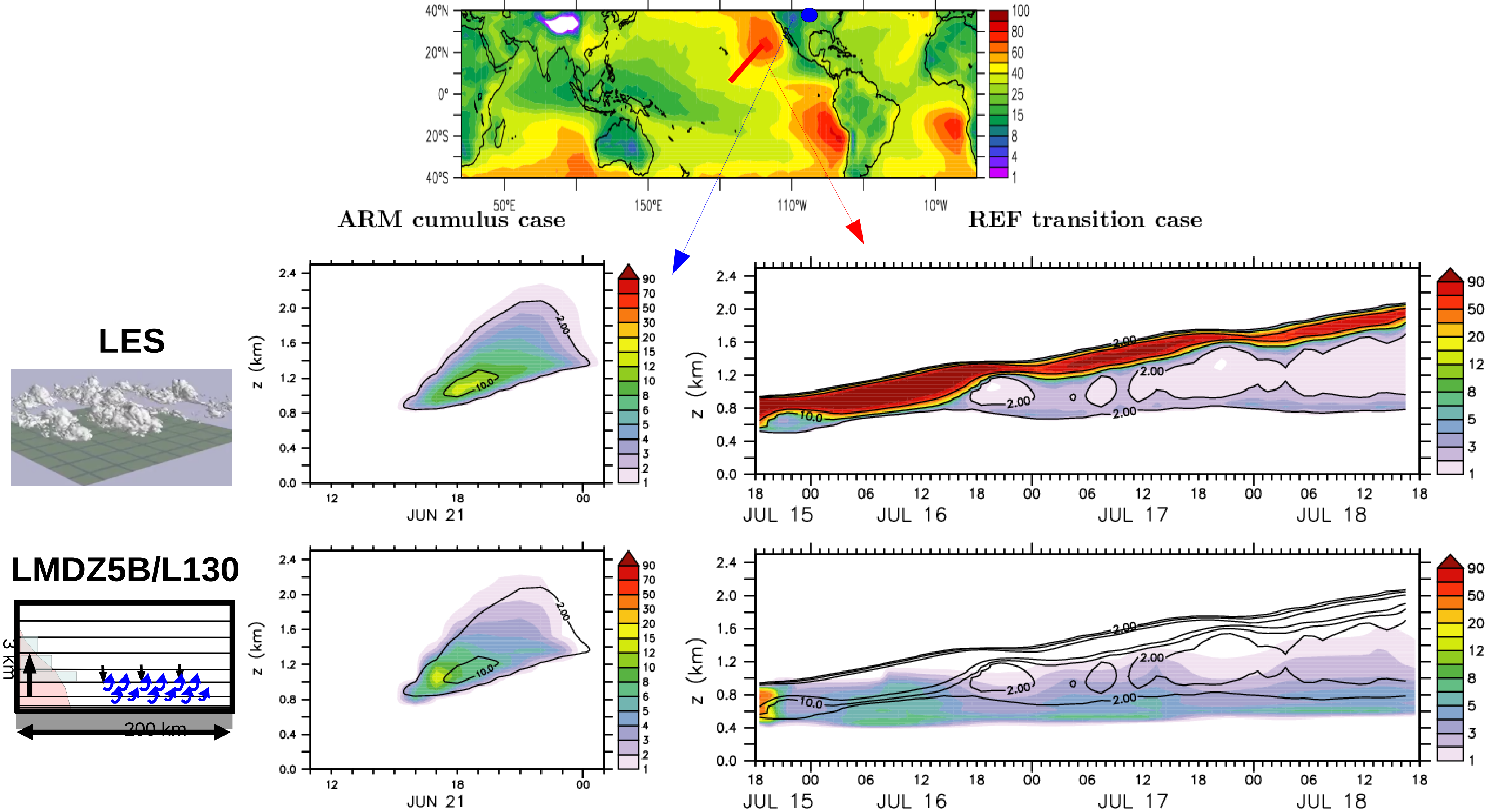


LMDZ5B





SCM/LES comparison, LMDZ5B version = thermal plume model with bigaussian distribution
→ **Reasonable representation of cumulus clouds**



ARM cumulus case

REF transition case

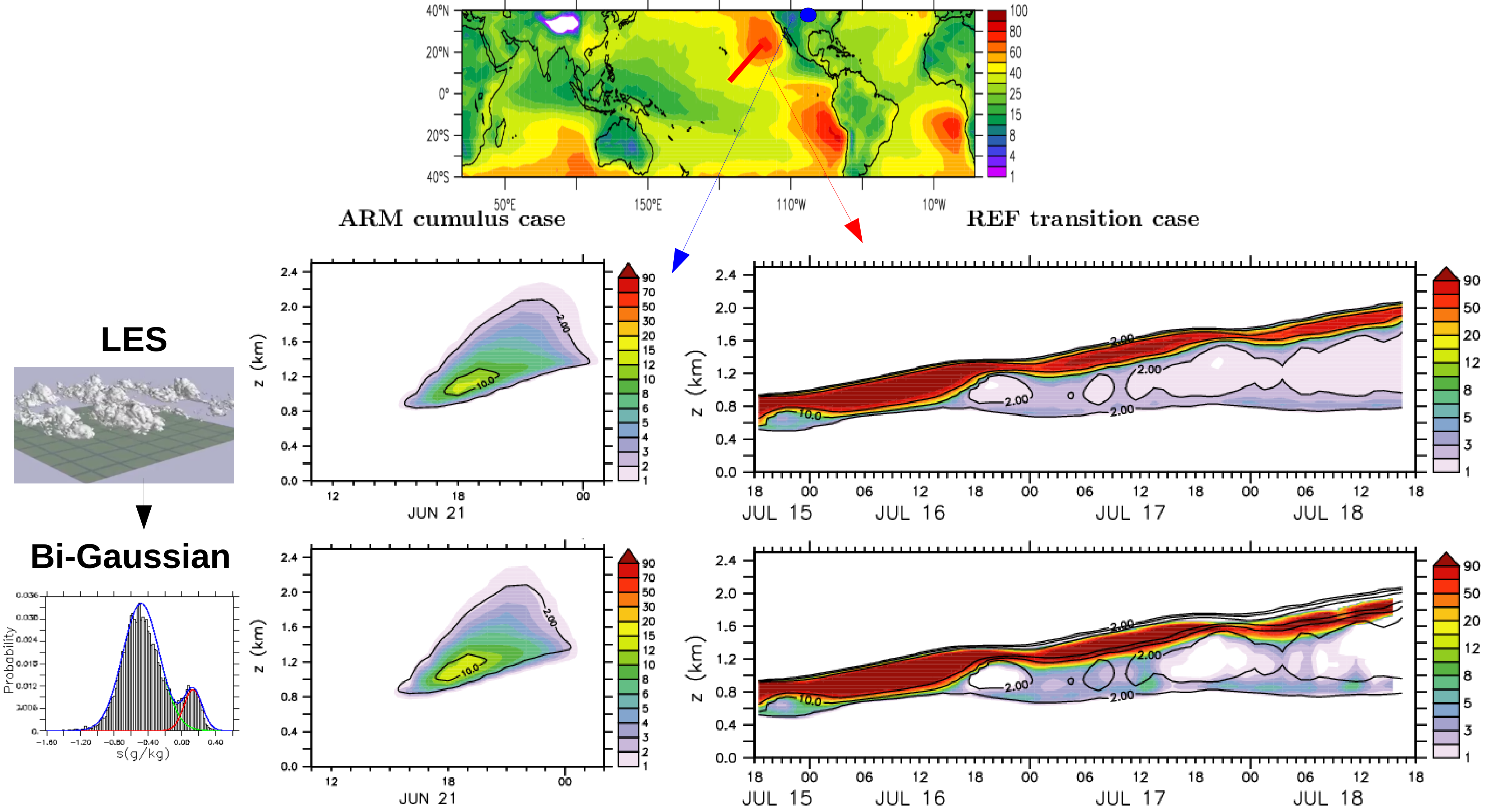
LES

LMDZ5B/L130

SCM/LES comparison, LMDZ5B version = thermal plume model with bigaussian distribution

→ **Reasonable representation of cumulus clouds**

→ **But not the stratocumulus clouds nor the transition from cumulus to stratocumulus**

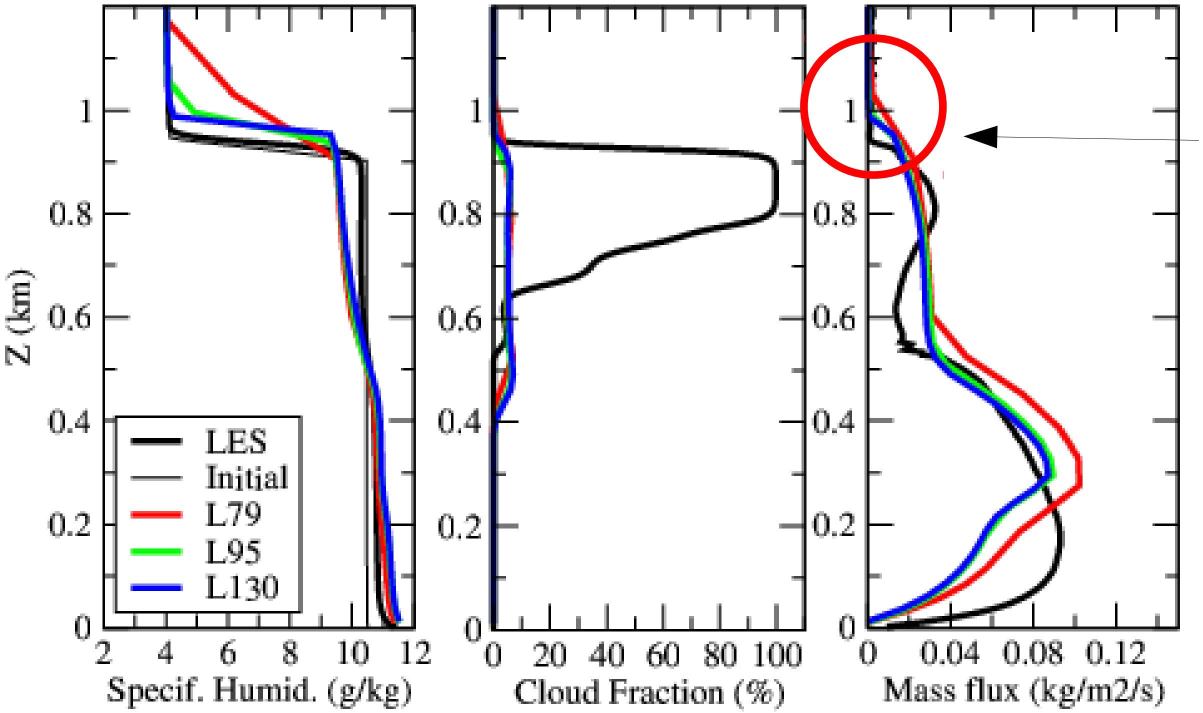


SCM/LES comparison, LMDZ5B version = thermal plume model with bigaussian distribution

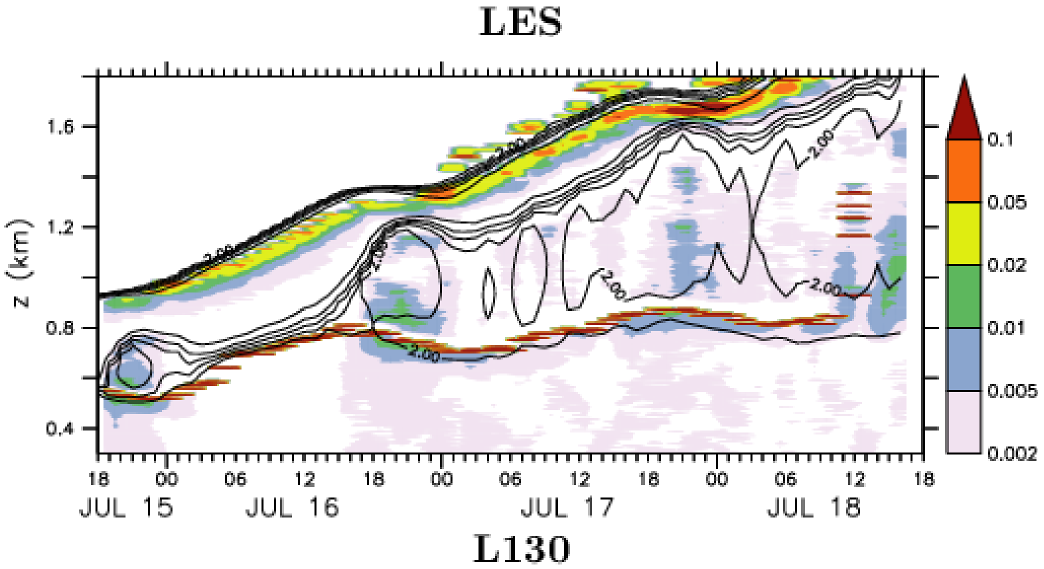
→ **Reasonable representation of cumulus clouds**

→ **But not the stratocumulus clouds nor the transition from cumulus to stratocumulus**

→ **Bi-gaussian cloud schemes works fine when applied to the LES sampled variables**



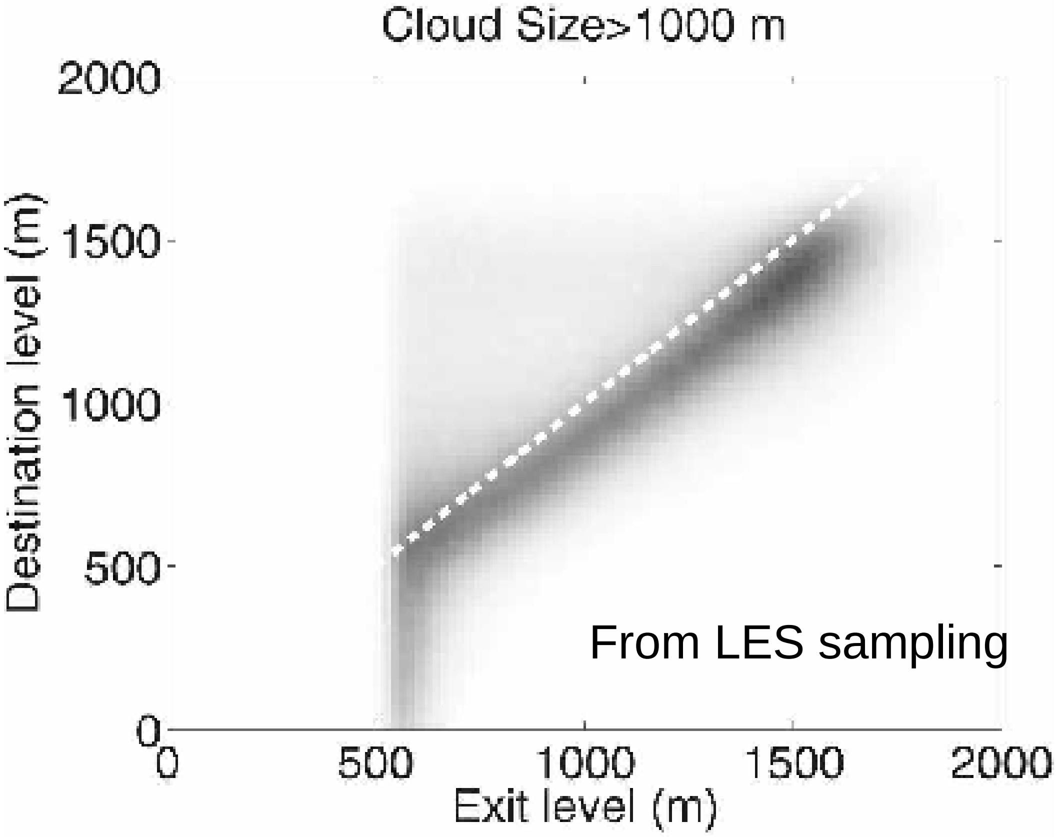
Vertical profiles after 3 hours.
The mass flux overshoots two far above inversion



LES : detrainment (colors) and cloud cover (contour)
All the air should be detrained below cloud top.

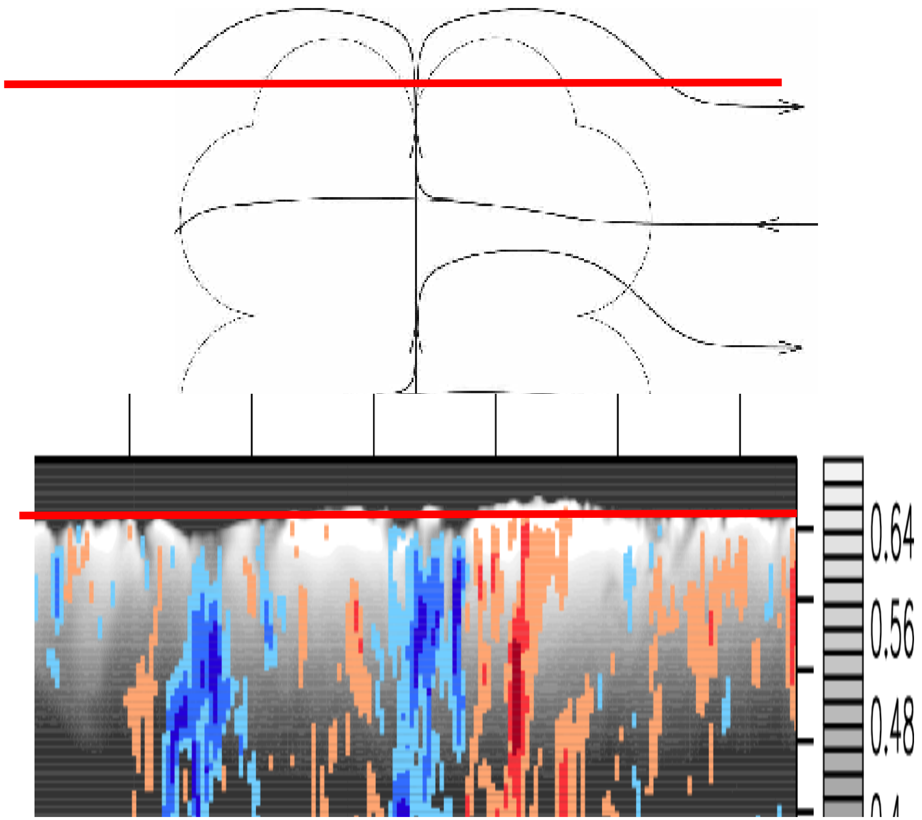
Origine of the disapearance of stratocumulus :
The thermal plume model overshoots and mixes too much dry air from above inversion with the cloud top layer.

Mixing in Shallow Cumulus Clouds Studied by Lagrangian Particle Tracking Heus et al, Jas, 2017



From LES sampling

Fig 14c : Destination level versus exit level



Sandu LES (w, colors) and cloud water (grey)

→ **Modified detrainment**

$$d = f \max\left(0, -\frac{a_1\beta_1}{1+\beta_1}\frac{B^*}{w^2} + c\left(\frac{(q_a - q)/q_a}{w^2}\right)^d\right)$$

$$B^*(z) = g\,\frac{\theta_{v,th}(z) - \theta_{v,env}(z+h)}{\theta_v(z)}$$

Destination level : z

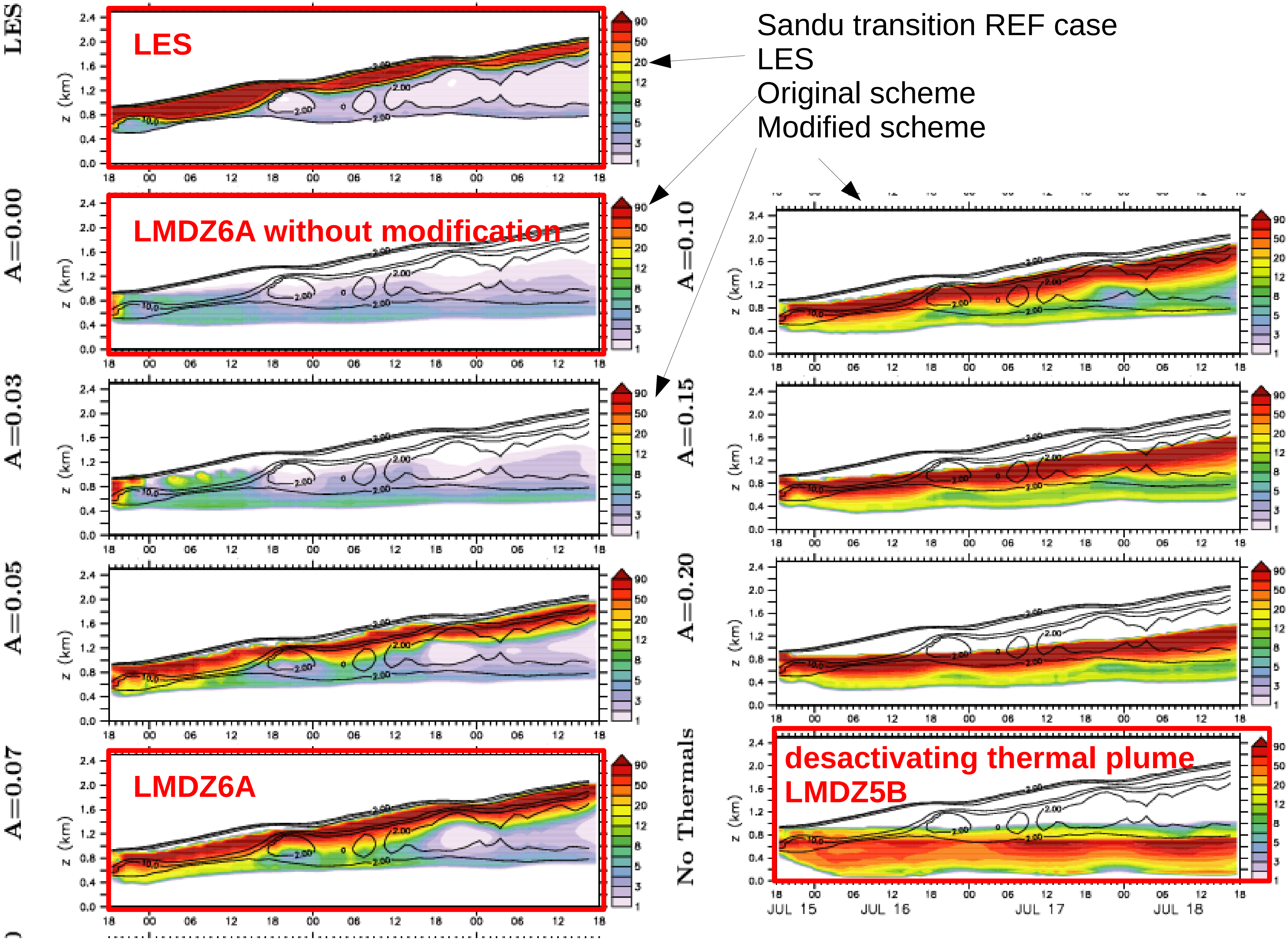
Exit level : z+h with h = A z

Sandu transition REF case

LES

Original scheme

Modified scheme



LES

LMDZ6A without modification

LMDZ6A

desactivating thermal plume LMDZ5B

Does not affect too much the cumulus cases

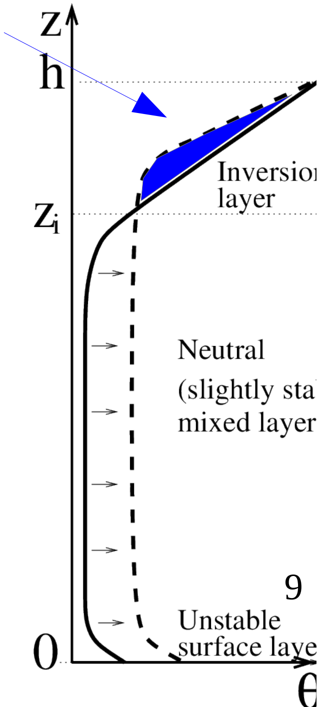
II : Revisite avec émulateur (processus gaussien) et méta modèle

The modified scheme with A ~ 0.7-1.2 seems to work fine.
Questions to be revisited with UQ :
→ **Is there a range of parameters acceptable for all cases ?**
→ **Is the choice of the A parameter dependent of the choice of other parameters ?**
→ **Is it possible to define a range of acceptable values for A for further 3D GCM tests ?**

History matching for 10 metrics based on 4 cases

Cumulus to stratocumulus transition case
SANDU : nebzave, hour: 55-60 — average cloud height — $\int f^{\cdot}\, dz / \int f^{\cdot}\, dz$
neb4zave, hour: 55-60 — height of max cloudiness — $\int f^4 z\, dz / \int f^4\, dz$

case of dry convection over continents
IHOP : Ay-theta, hour: 9-9 — Boundary layer top entrainment



Continental cumulus case
ARMCU : Ay-theta, hour: 7-9
nebzave, hour: 7-9
neb4zave, hour: 7-9
nebmax, hour: 7-9 — Max (z) cloud cover

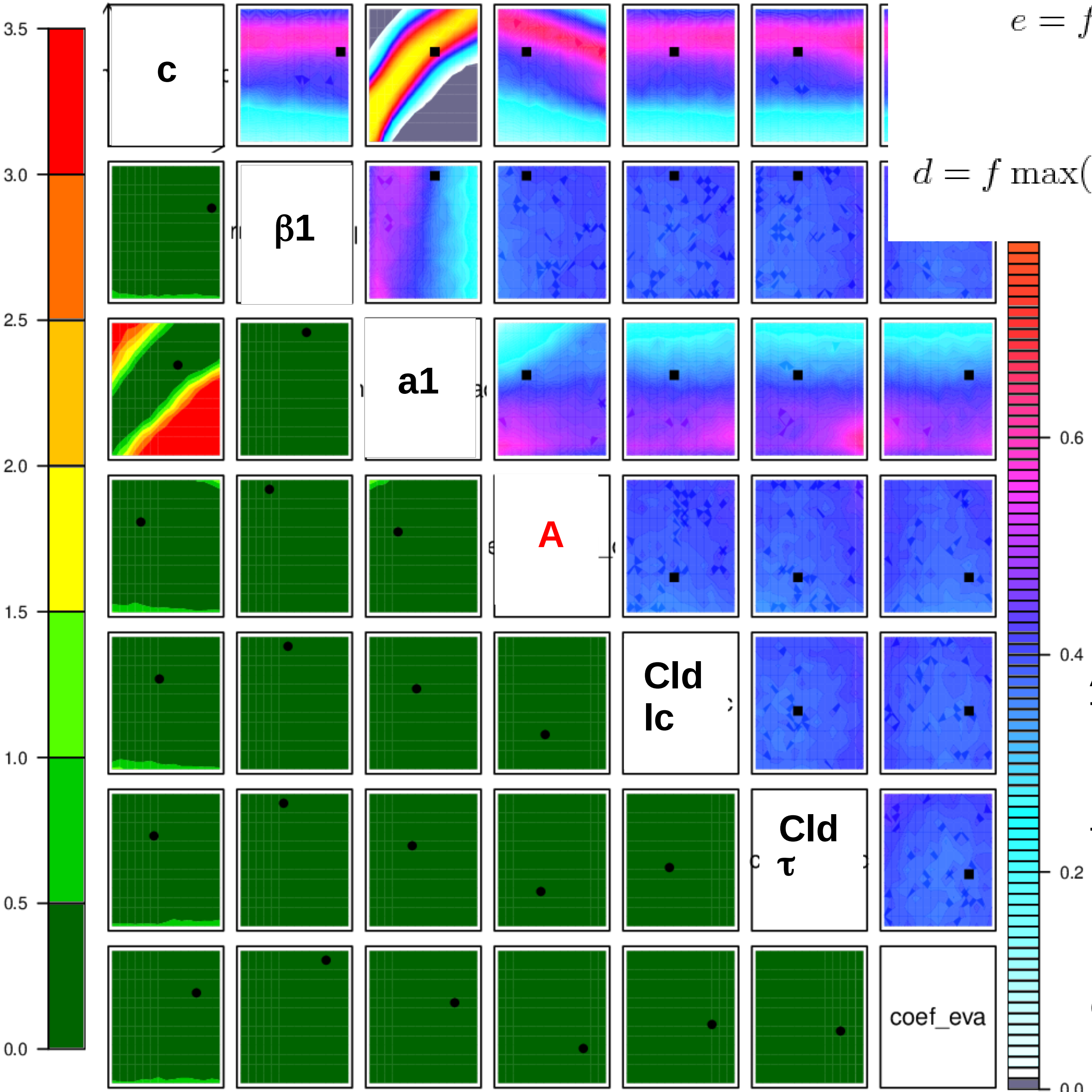
Marine cumuls case
RICO : nebmax, hour: 7-9
nebzave, hour: 7-9
neb4zave, hour: 7-8

« Obs » errorrs : average / 10

HIOP top entrainment alone : same parameters dominate as in Diallo's presentation

$$e = f\,\max\left(0, \frac{\beta_1}{1+\beta_1}\left(a_1\frac{B}{w^2} - b\right)\right)$$

$$d = f\,\max\left(0, -\frac{a_1\beta_1}{1+\beta_1}\frac{B}{w^2} + c\left(\frac{(q_a - q)/q_a}{w^2}\right)^d\right)$$

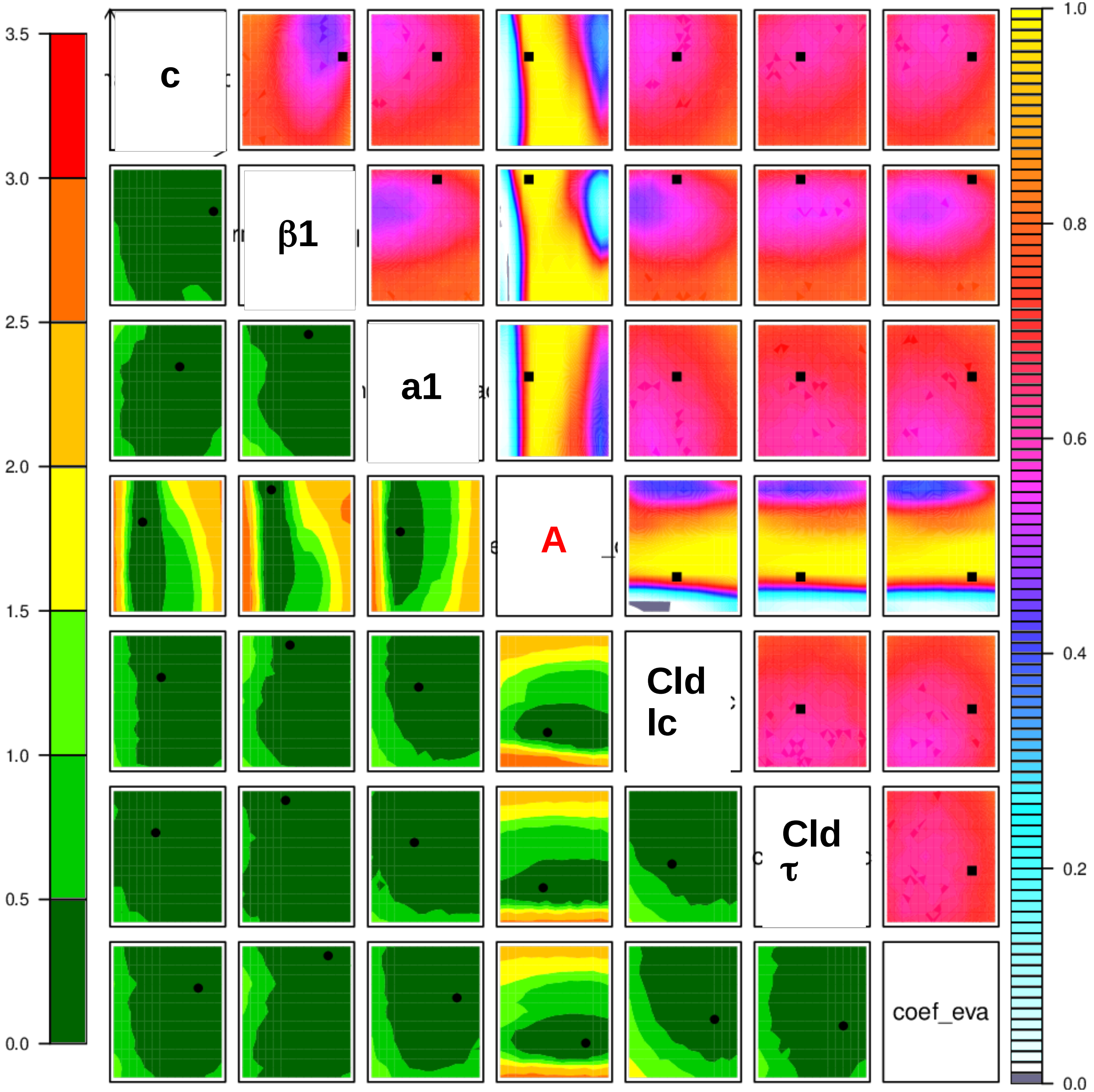


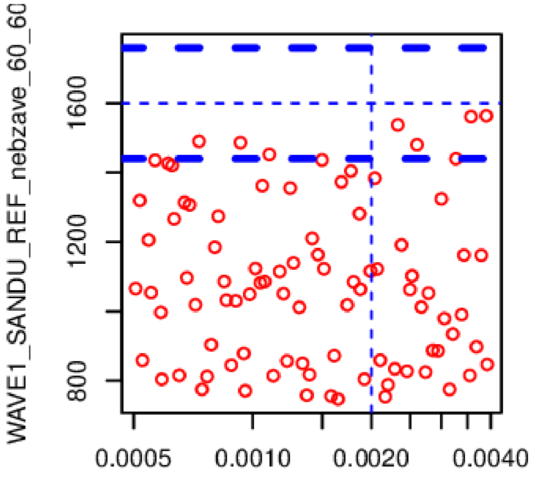
Autoconversion cloud → rain
Threshold

Time constant

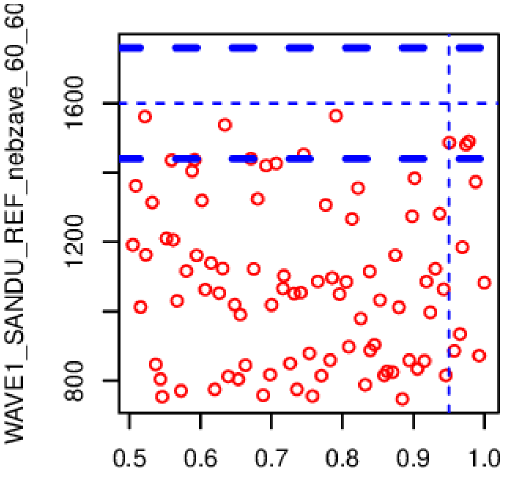
Coef for rain reevaporation

SANDU case. 1/2 of the points removed in one wave

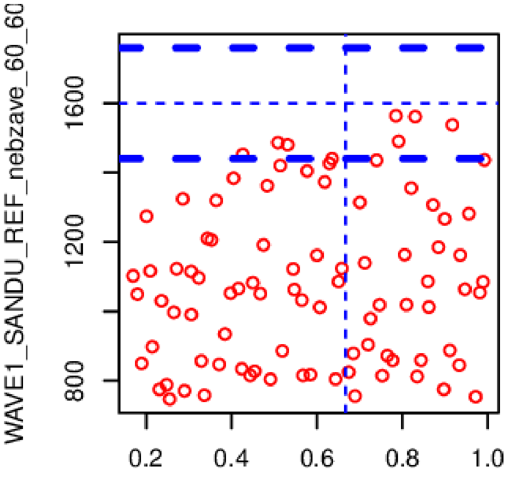




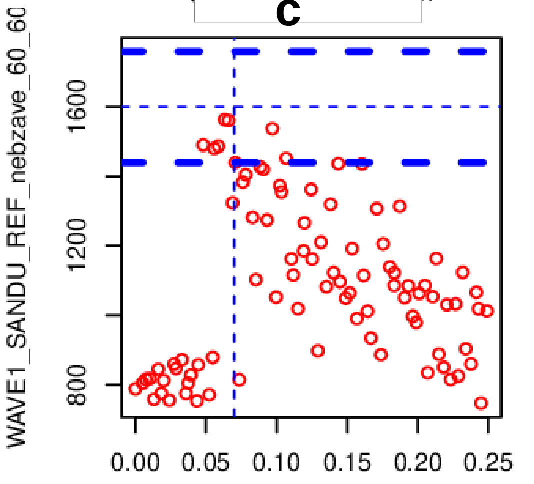
c



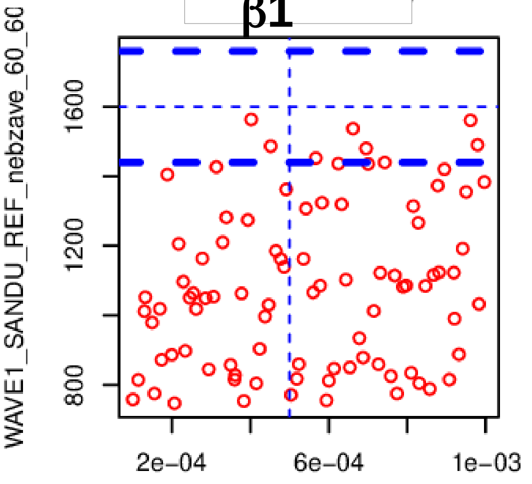
β1



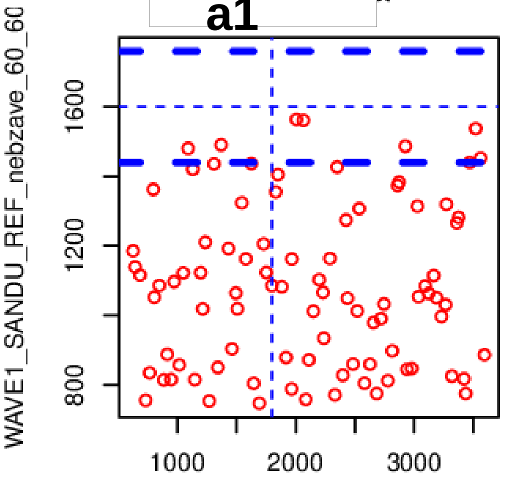
a1



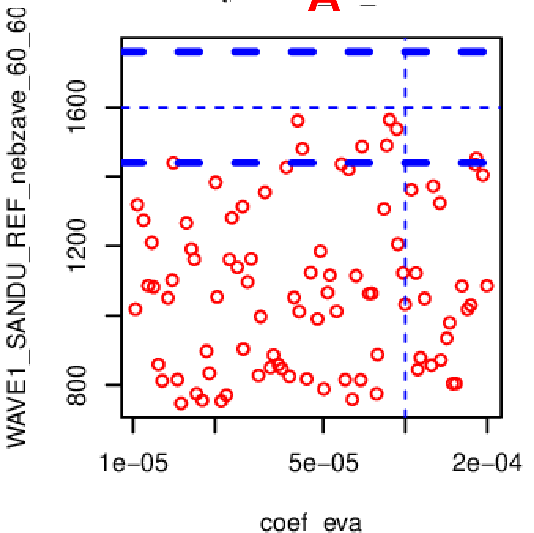
A

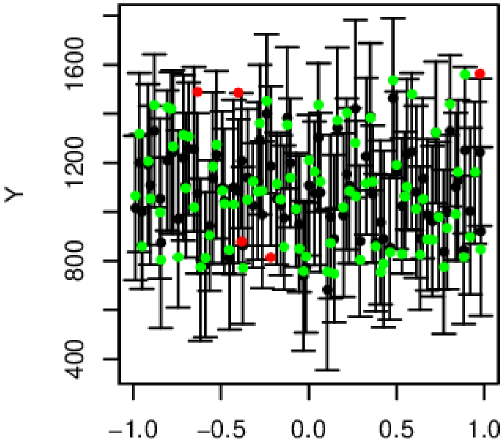


Cld lc

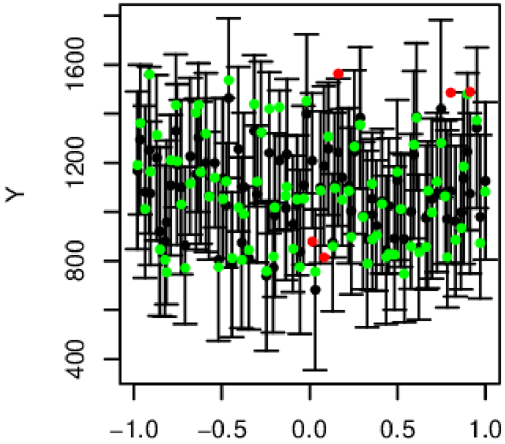


Cld τ

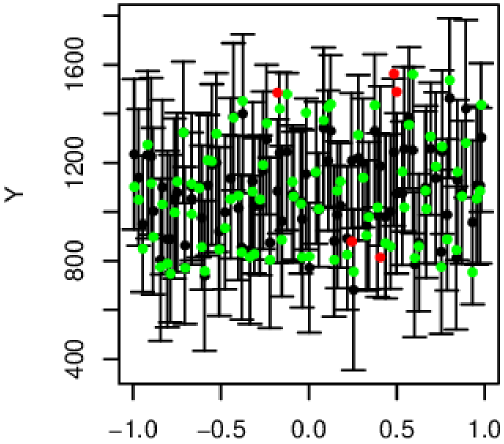




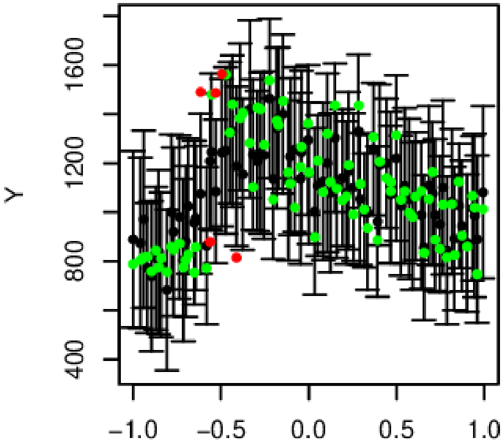
c



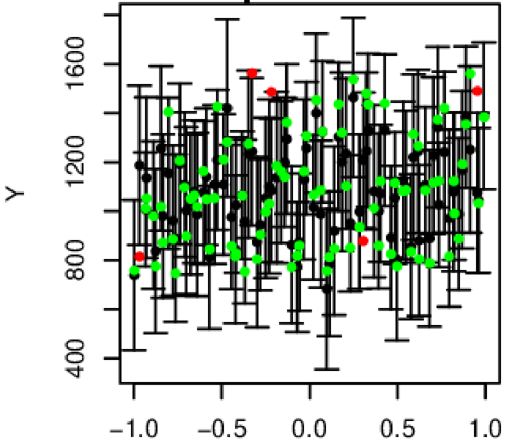
β1



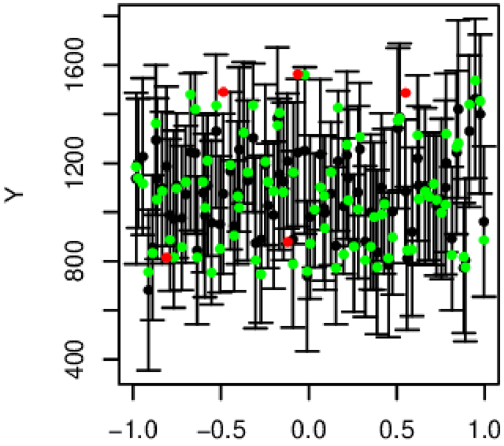
a1



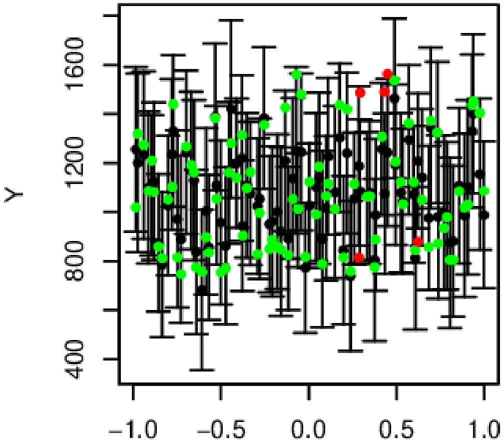
t **A** _



Cld
lc



Cld
τ



coef eva

Error bars : leave one out

Multi-wave history matching for 10 metrics based on 4 cases

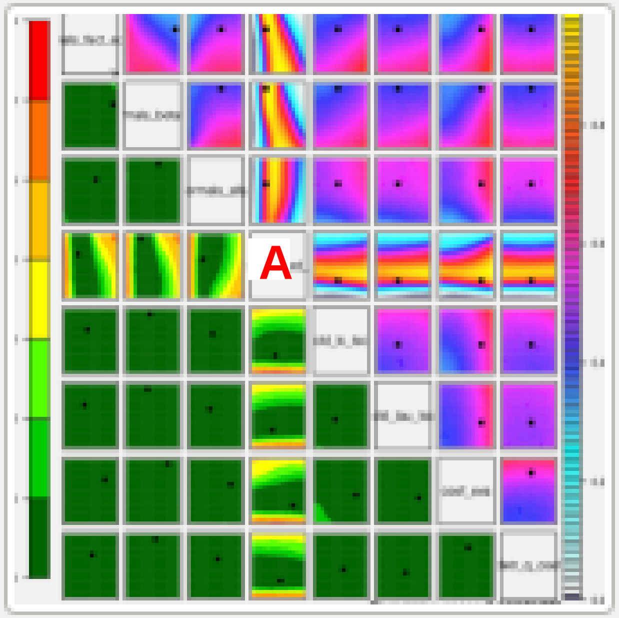
Cumulus to stratocumulus transition case
SANDU : nebzave, hour: 55-60
neb4zave, hour: 55-60

case of dry convection over continents
IHOP : Ay-theta, hour: 9-9

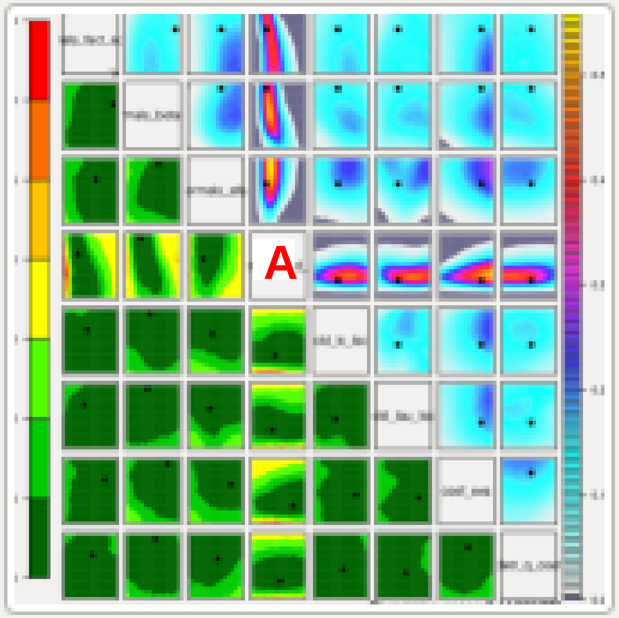
Continental cumulus case
ARMCU : Ay-theta, hour: 7-9
nebzave, hour: 7-9
neb4zave, hour: 7-9
nebmax, hour: 7-9

Marine cumuls case
RICO : nebmax, hour: 7-9
nebzave, hour: 7-9
neb4zave, hour: 7-8

average cloud height
height of max cloudiness
Boundary layer top entrainment
Max (z) cloud cover

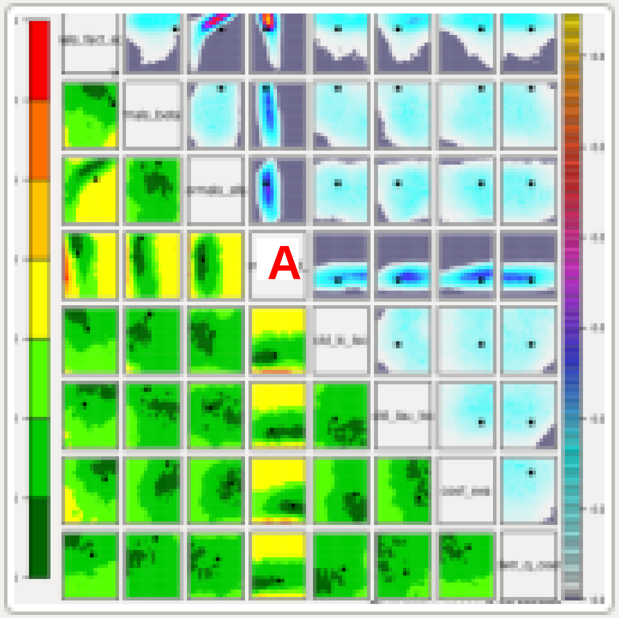


InputSpace_wave1.png

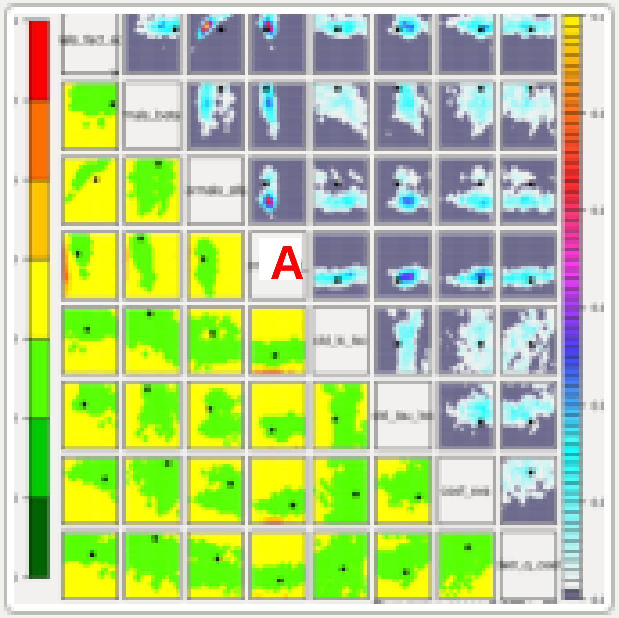


InputSpace_wave2.png

Remaining space after
Wave1: 0.503
Wave2: 0.113
Wave3: 0.0069
wave4: 3.35e-06
wave5: 3.5e-07

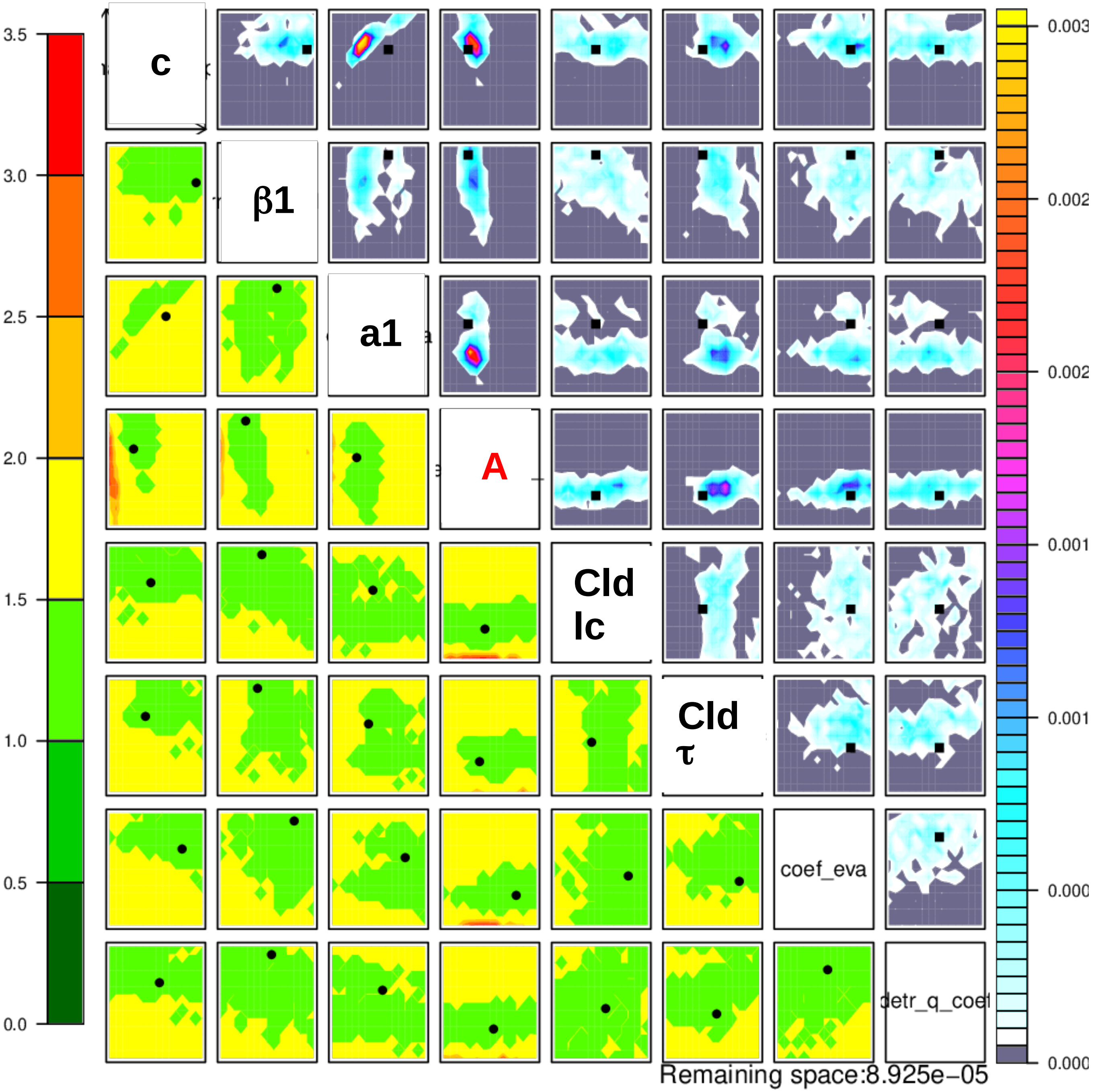


InputSpace_wave3.png

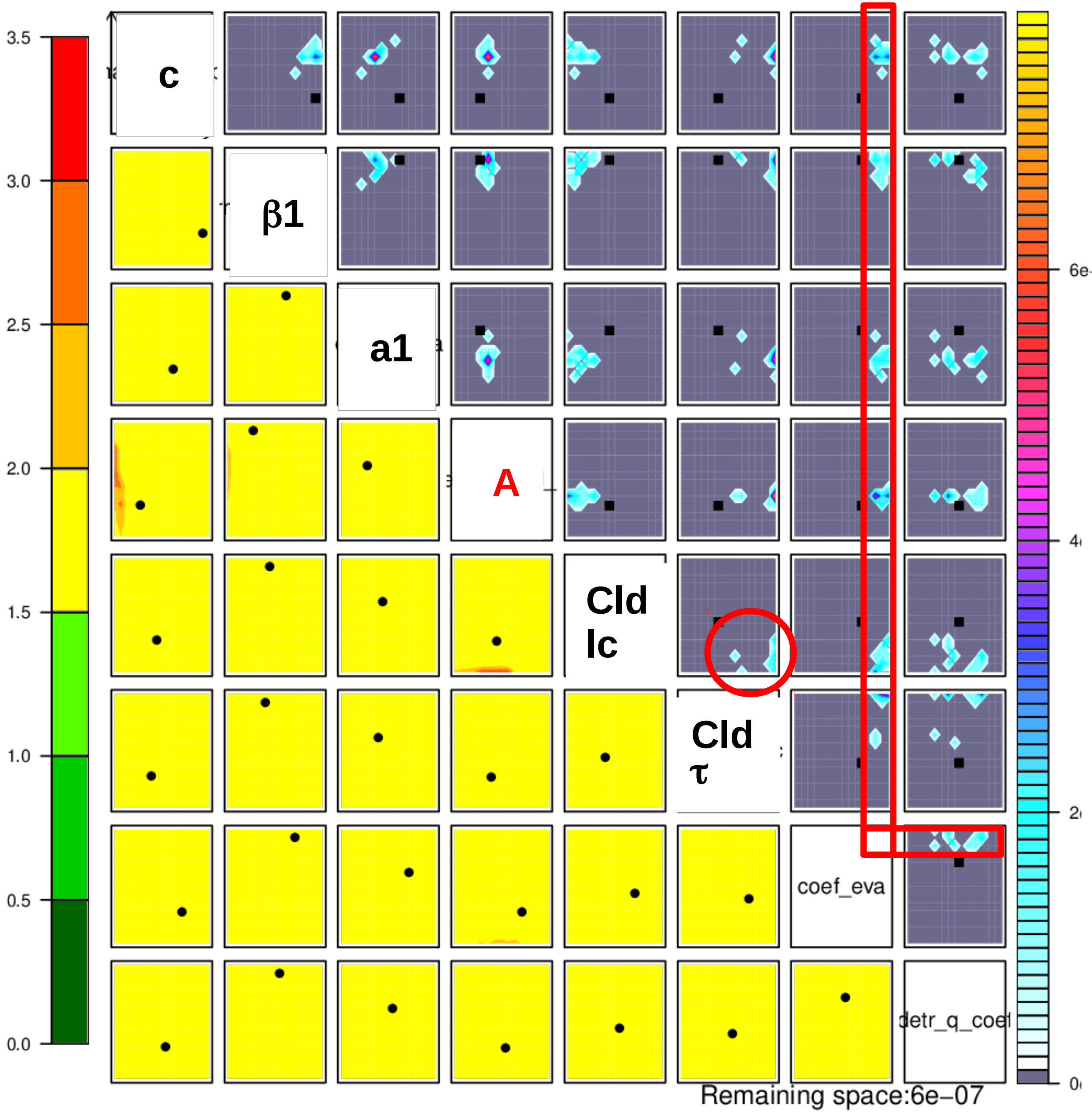


InputSpace_wave4.png

WAVE 4

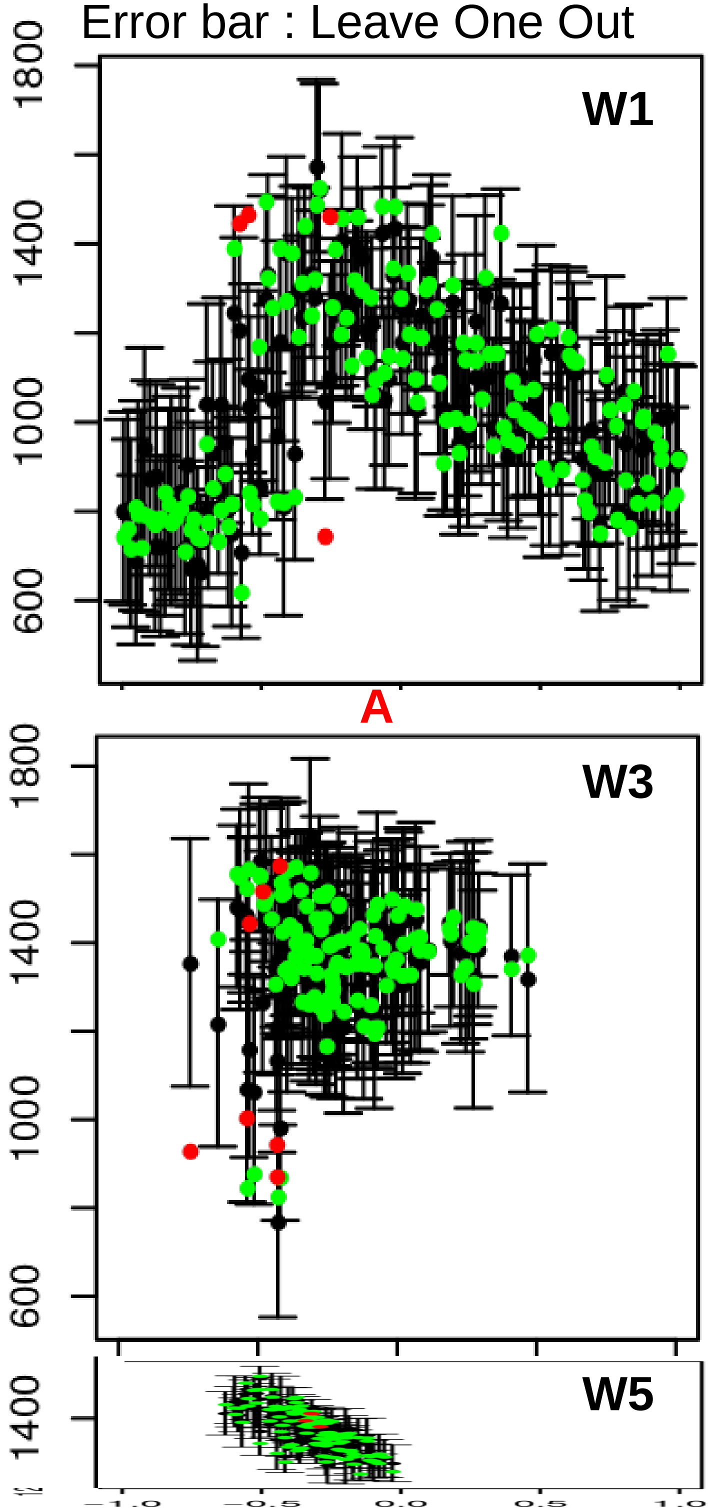

3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
c
β1
a1
A
Cld
lc
Cld
τ
coef_eva
detr_q_coef
0.003
0.002
0.002
0.001
0.001
0.000
0.000
Remaining space:8.925e−05

WAVE 5 (adding Rico)



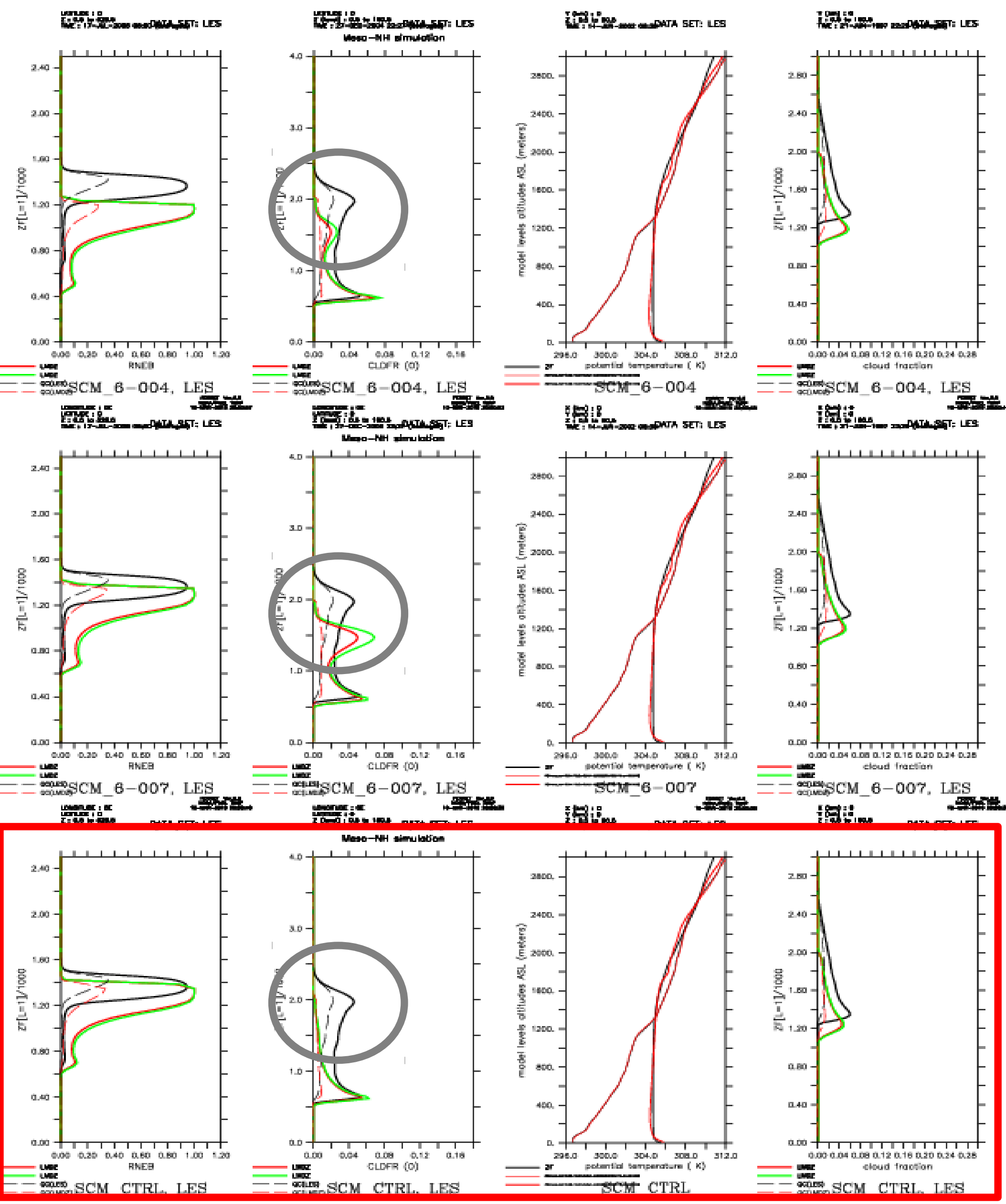
Remaining space:6e−07

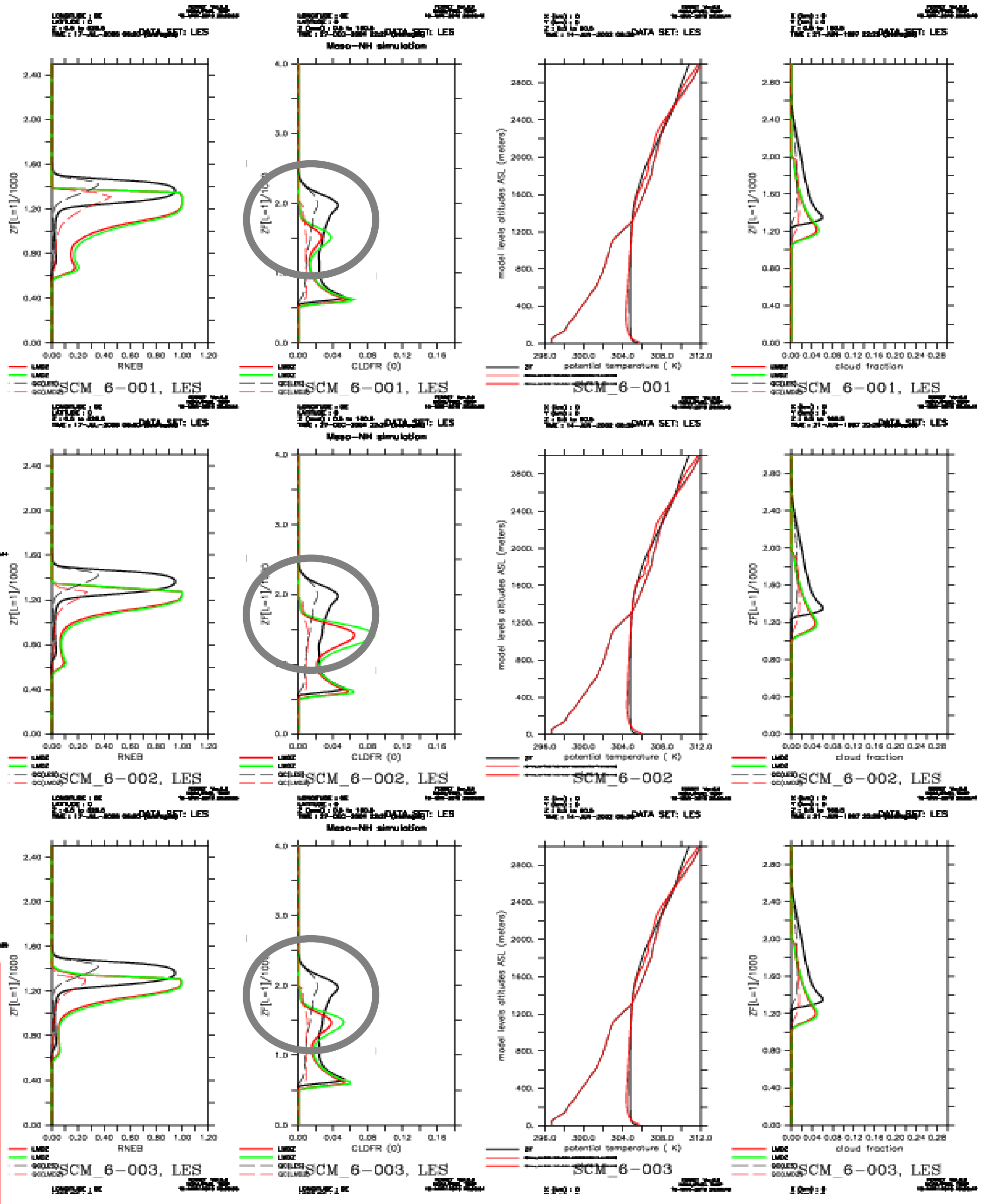
Height of max cloudiness, Sandu
Error bar : Leave One Out



5 simulations chosen randomly in NROY #6

Sandu Rico Hiop Armcu





NPv6.1, Control

Improved Rico case. Stratocumulus a little bit to low but consistant with given error bars.

Conclusion

Exeter tools work fine !!!!! Tanks !

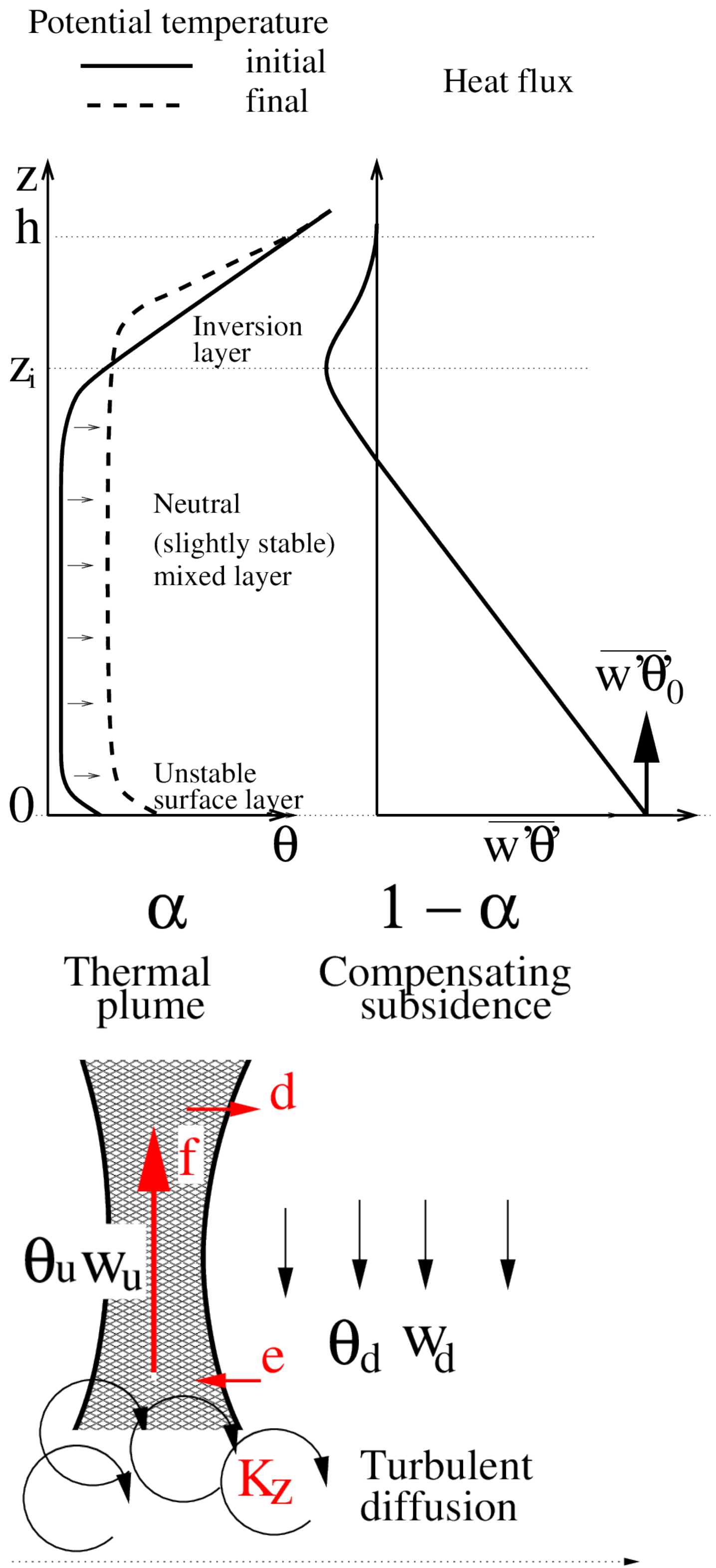
→ Is there a range of parameters acceptable for all cases ?
Not too bad
→ Is the choice of the A parameter dependent on the choice of other parameters ?
Not too much !
→ Is it possible to define a range of acceptable values for A for further 3D GCM tests ?
Yes ! 0.07 – 0.1
+ privilege larger τ and smaller theshold for cloud → rain conversion
+ use larger values of coef_eva

Automatic tuning on average as good as the control case.
Possibility to improve Rico case without regrading too much the others
Stratocumulus a bit too low (error bar should be refined).

To be noticed :

Importance of having a robust setup for SCM/LES
With a reduction of a factor 10^7 of the parameter space, requires samples of 10^9, a bit too much for the current version of HighTune script

Next step : use EOFs on the time evolution of cloud height, top entrainment ...



Conservation de la masse :

$$\frac{\partial f}{\partial z} = e - d \qquad \text{avec} \quad f = \alpha\rho w$$

Conservation de la masse du composant q

$$\frac{\partial f q_a}{\partial z} = e q - d q_a$$

Equation du mouvement

$$\frac{\partial f w}{\partial z} = -dw + \alpha\rho B$$

B **étant la poussée d'Archimède**

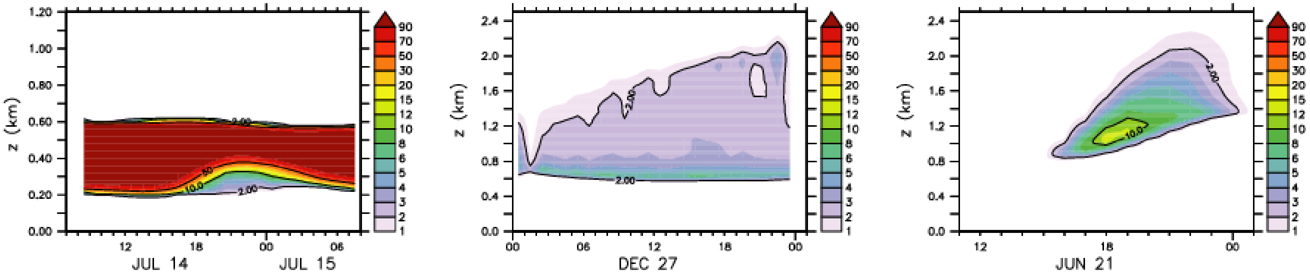
$$B = g\frac{\theta_{va} - \theta_v}{\theta_v}$$

$$e = f \max\left(0, \frac{\beta_1}{1+\beta_1}\left(a_1\frac{B}{w^2} - b\right)\right)$$

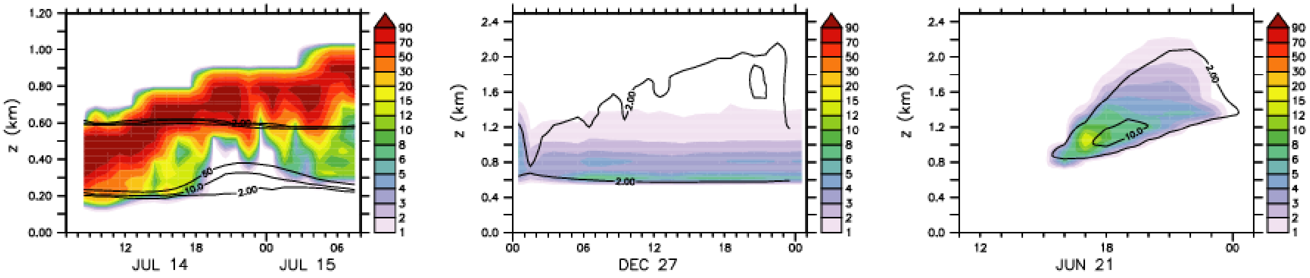
$$d = f \max\left(0, -\frac{a_1\beta_1}{1+\beta_1}\frac{B}{w^2} + c\left(\frac{(q_a - q)/q_a}{w^2}\right)^d\right)$$

FIRE RICO ARM CU

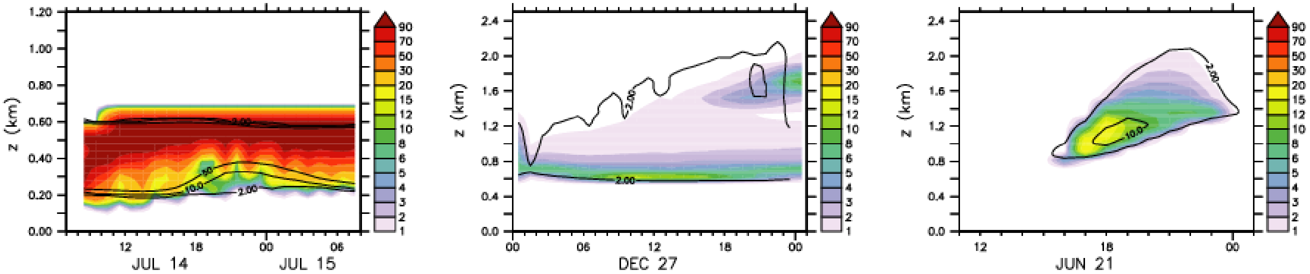
LES



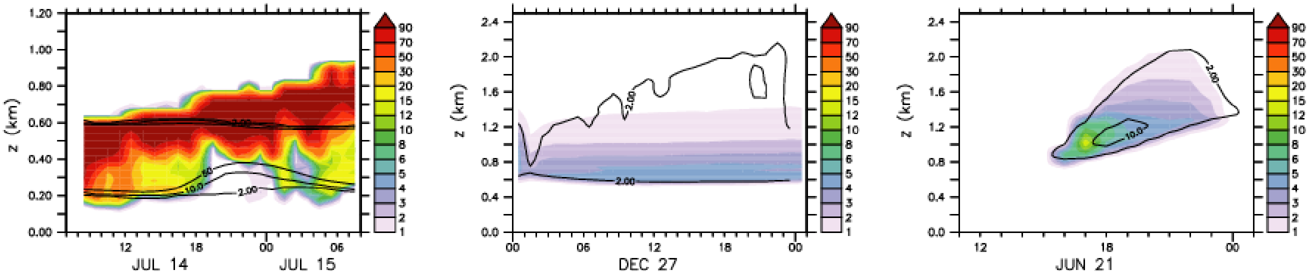
A=0, L79



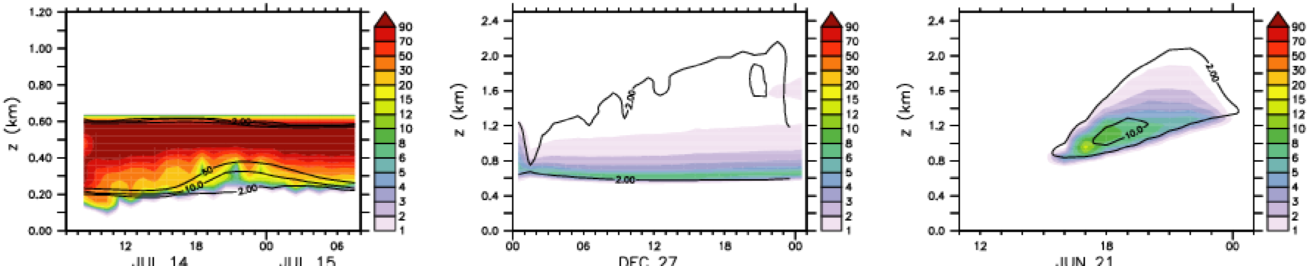
A=0.07, L79



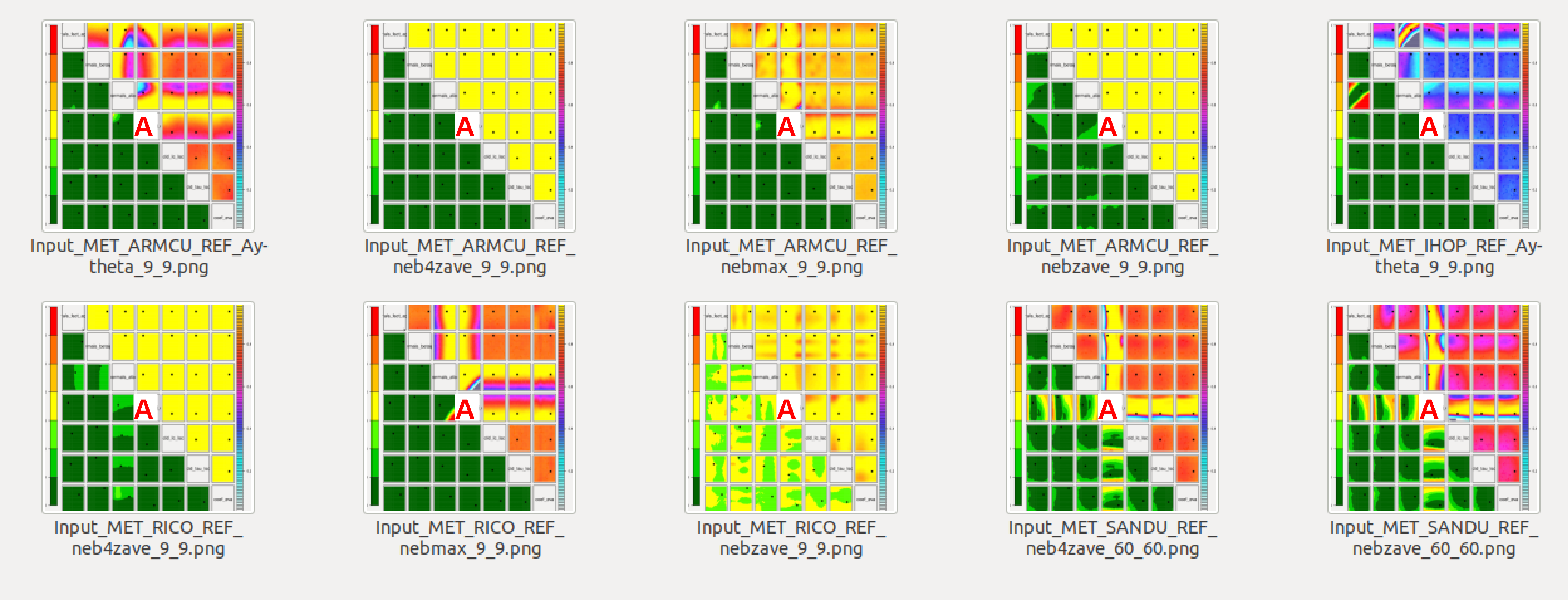
A=0, L95



A=0.07, L95



One wave : one metrics each time



Input_MET_ARMCU_REF_Ay-theta_9_9.png

Input_MET_ARMCU_REF_neb4zave_9_9.png

Input_MET_ARMCU_REF_nebmax_9_9.png

Input_MET_ARMCU_REF_nebzave_9_9.png

Input_MET_IHOP_REF_Ay-theta_9_9.png

Input_MET_RICO_REF_neb4zave_9_9.png

Input_MET_RICO_REF_nebmax_9_9.png

Input_MET_RICO_REF_nebzave_9_9.png

Input_MET_SANDU_REF_neb4zave_60_60.png

Input_MET_SANDU_REF_nebzave_60_60.png

A : varying from 0 to 0.25

Tuning :
Métriques utilisées
Barres d’erreur

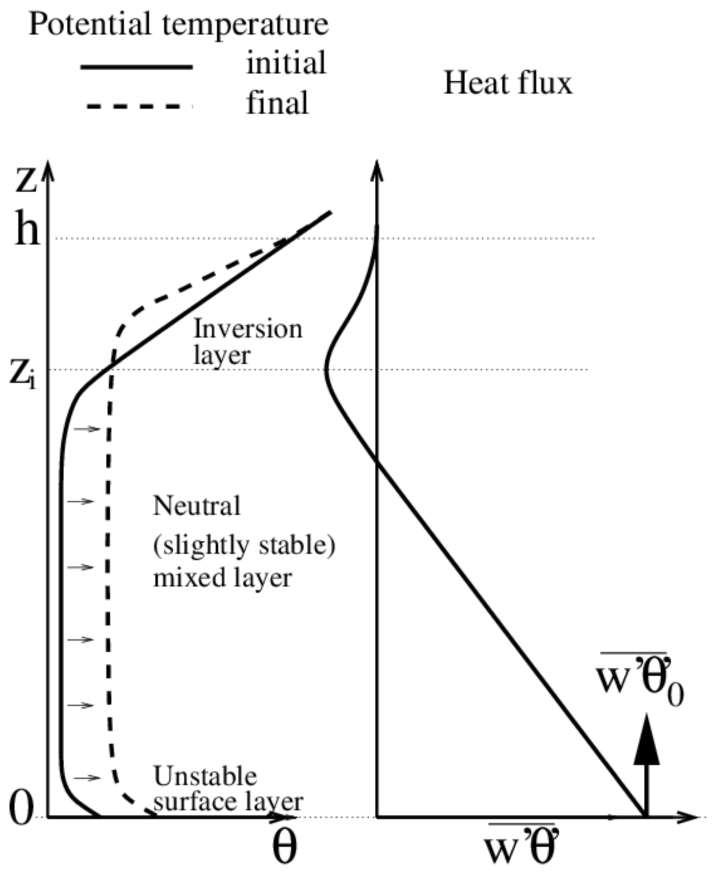
ONE BY ONE

Série

```
[1] "Remaining space after wave1: 0.5036888"
[1] "Remaining space after wave2: 0.1131553"
[1] "Remaining space after wave3: 0.00695575"
[1] "Remaining space after wave4: 3.35e-06"
[1] "Remaining space after wave5: 3.5e-07"
```

Limitations of turbulent diffusion

Idealized view of the dry convective boundary layer.



In the mixed layer

- Diffusive formulation

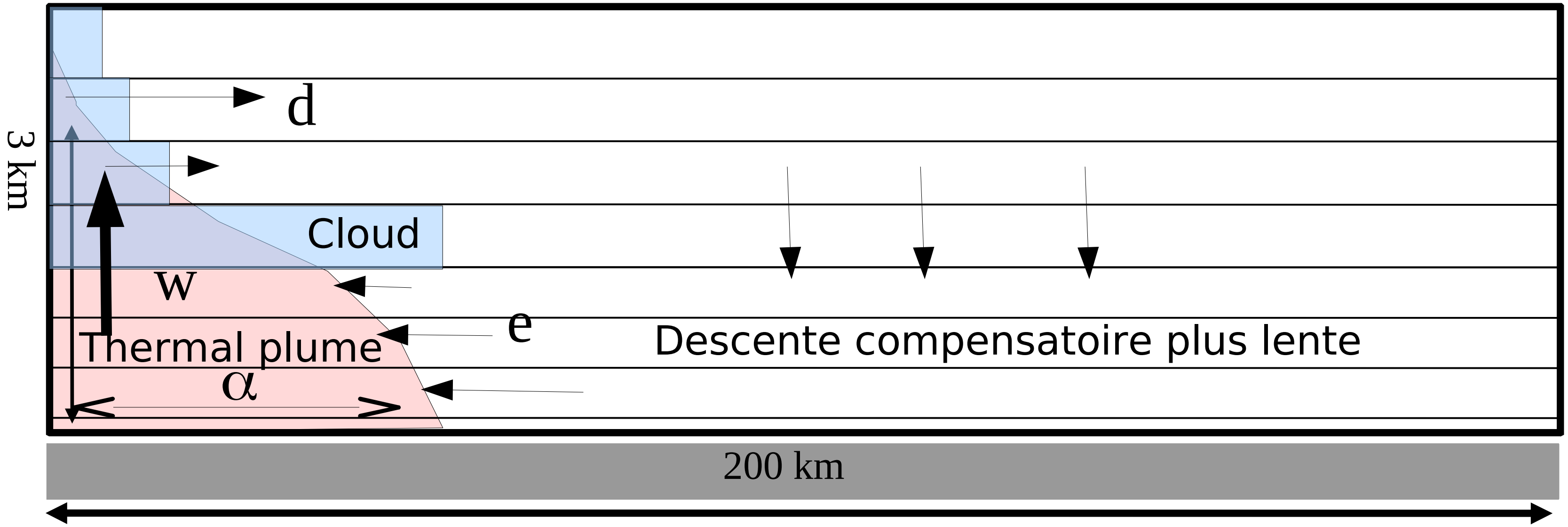
$$\overline{w'\theta'} = -K_z \frac{\partial\theta}{\partial z} = 0 \quad \text{or slightly} \; < 0$$

- Uniform heating by the surface

$$\frac{\partial\theta}{\partial t} \simeq \frac{\overline{w'\theta'}_0}{z_i} (\text{Cste} > 0)$$

$$\overline{w'\theta'} \simeq \frac{z - z_i}{z_i} \overline{w'\theta'}_0 > 0$$

II.1 Thermal plumes and clouds



Variables internes de la paramétrisation :

w : vitesse moyenne des panaches ascendants

α : fraction de la surface couverte par les ascendances

e : taux d'entrée latérale d'air dans le panache (entrainement)

d : sorties d'air depuis le panache (détrainement)

q_a : concentration du composant q dans l'ascendance

Terme source pour les équations explicites

$$S_q = -\frac{1}{\rho}\frac{\partial}{\partial z}\rho\overline{w'q'} = -\frac{1}{\rho}\frac{\partial}{\partial z}\rho K_z\frac{\partial q}{\partial z} + -\frac{1}{\rho}\frac{\partial}{\partial z}\left[\rho\alpha w(q_a - q)\right]$$

Diffusion turbulente

Transport par le modèle de panache

4 Paramètres libres :

$a_1 = \frac{2}{3}$, $\beta_1 = 0.9$, $b = 0.002$, $c = 0.012 m^{-1}$, $d = 0.5$

Conservation de la masse :

$$\frac{\partial f}{\partial z} = e - d \qquad \text{avec} \quad f = \alpha\rho w$$

Conservation de la masse du composant q

$$\frac{\partial f q_a}{\partial z} = eq - dq_a$$

Equation du mouvement

$$\frac{\partial f w}{\partial z} = -dw + \alpha\rho B$$

B étant la poussée d'Archimède

$$B = g\frac{\theta_{va} - \theta_v}{\theta_v}$$

$$e = f\max\left(0, \frac{\beta_1}{1+\beta_1}\left(a_1\frac{B}{w^2} - b\right)\right)$$

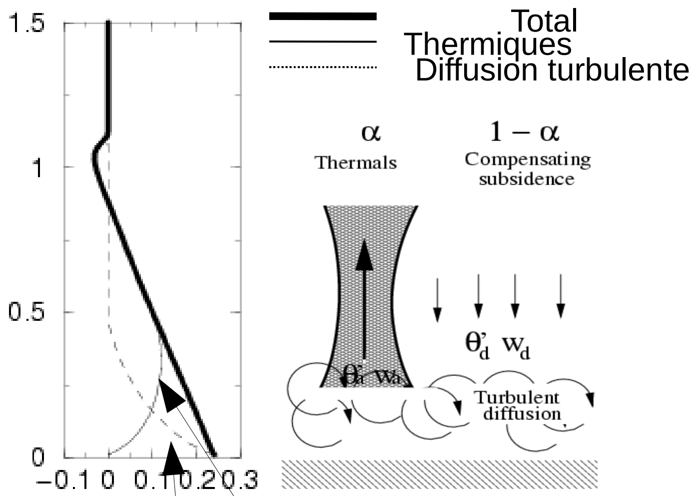
$$d = f\max\left(0, -\frac{a_1\beta_1}{1+\beta_1}\frac{B}{w^2} + c\left(\frac{(q_a - q)/q_a}{w^2}\right)^d\right)$$

Etc ...

II – Paramétrisation des nuages bas : principes et méthodologie

Thermiques : transport convectif

Décomposition du flux de chaleur
dans le cas MY+thermiques



M&Y+**Thermiques**

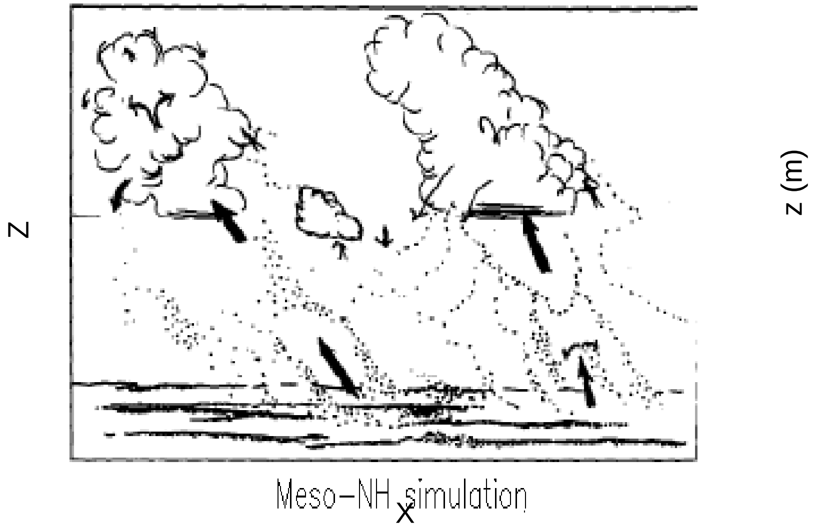
$$\rho\overline{w'\phi'} = -\rho K_\phi\left(\frac{\partial \phi}{\partial z} - \Gamma_\phi\right) + \hat{f}\left(\phi_a - \phi\right)$$

Hourdin et al., 2002

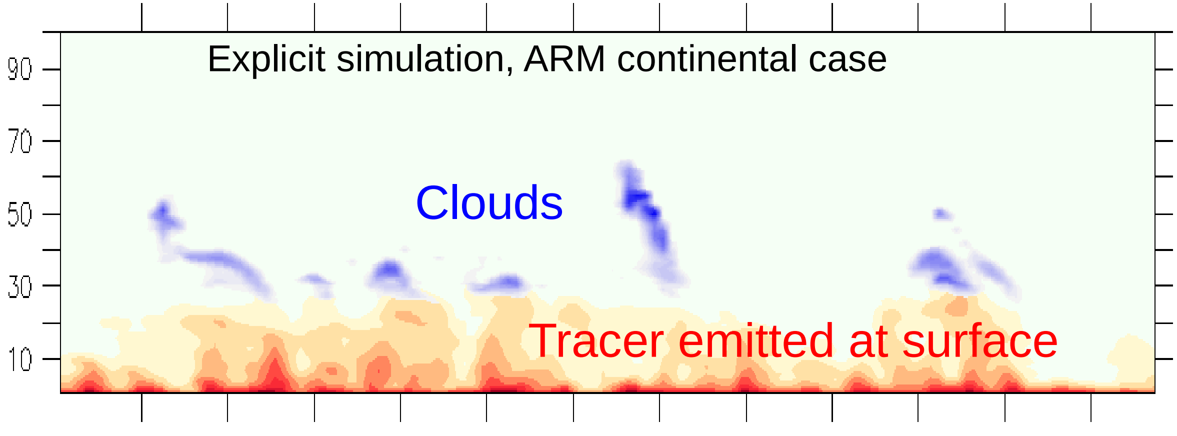
Thermiques et cumulus

Cumulus : partie condensée des panaches thermiques
Rio et Hourdin, 2008, Hourdin et al., 2012

LeMone and Pennell, MWR, 1976



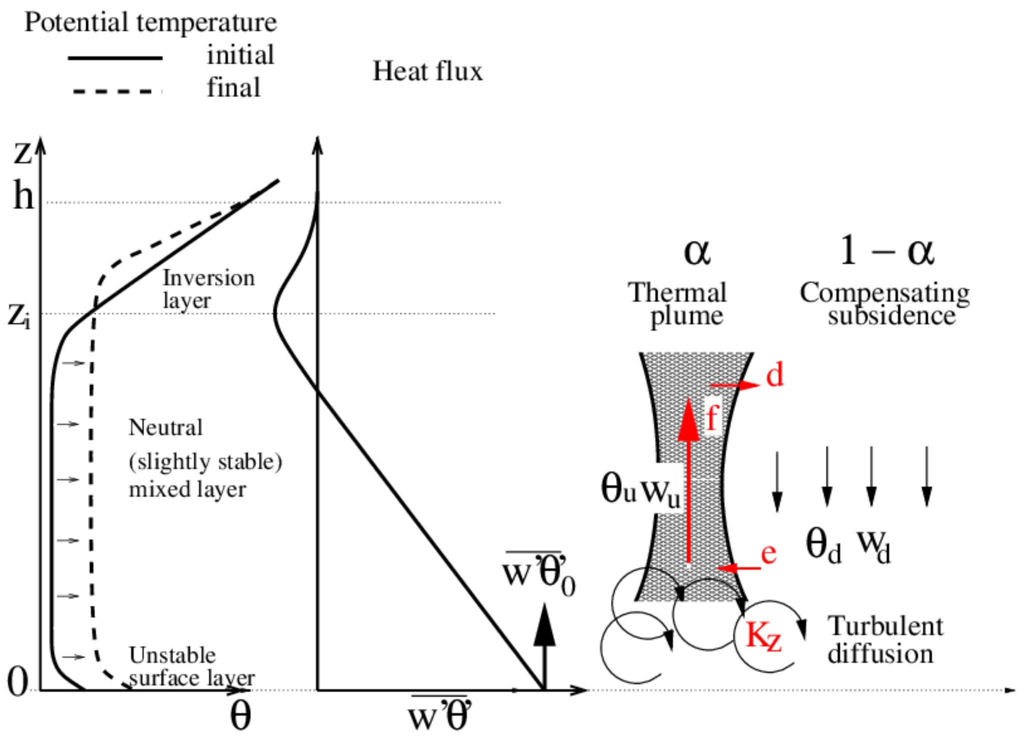
Meso-NH simulation



*Couvreux, et al., **2010**, Rio et al., 2010*

15 ans de collaboration MOANA (CNRM) / LMD

Mass flux schemes combined with turbulent diffusion



Separation into 2 sub-colums :

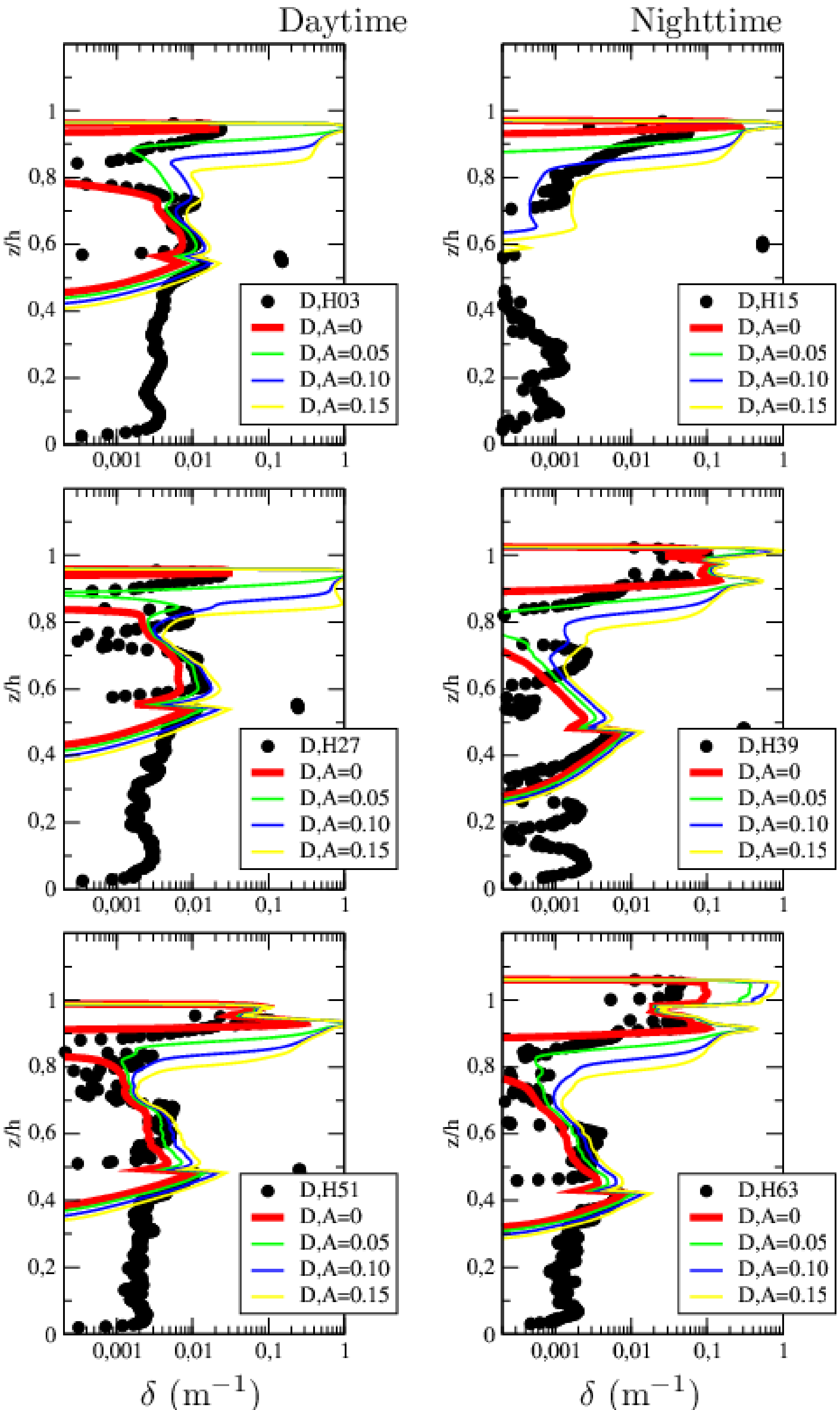
$$X = \alpha X_u + (1-\alpha) X_d$$

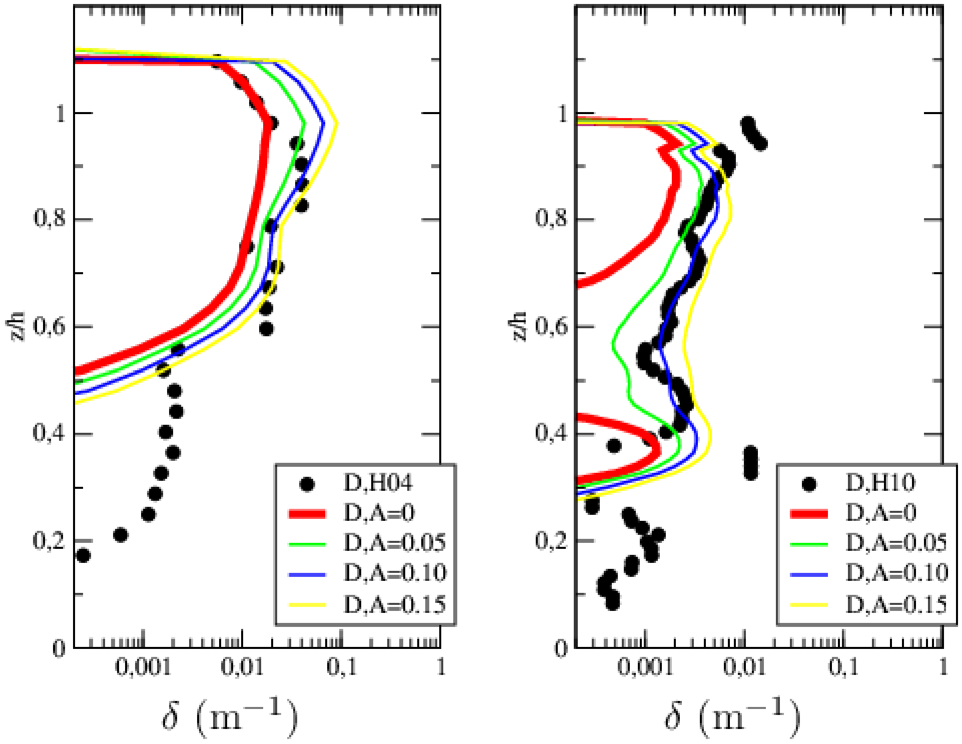
ascending plume of mass flux

$$\begin{aligned} f &= \alpha \rho w_u \\ \frac{\partial f}{\partial z} &= e - d \\ \frac{\partial f c_u}{\partial z} &= e c_d - d c_u \end{aligned}$$

$$\rho \overline{w'c'} = -\rho K_z \frac{\partial c}{\partial z} + f \left(c_u - c_d \right) \qquad (1)$$

Chatfield and Brost, 1987, Hourdin et. al., 2002, Siebesma, Soarez et al, 2004


Daytime
Nighttime
z/h
0
0,2
0,4
0,6
0,8
1
0,001
0,01
0,1
1
D,H03
D,H15
D,H27
D,H39
D,H51
D,H63
D,A=0
D,A=0.05
D,A=0.10
D,A=0.15
δ (m⁻¹)


z/h
0
0,2
0,4
0,6
0,8
1
0,001
0,01
0,1
1
D,H04
D,H10
D,A=0
D,A=0.05
D,A=0.10
D,A=0.15
δ (m⁻¹)