Les paramétrisations convectives dans LMDZ face à la compréhension des processus.

Jean-Yves Grandpeix, LMDZ Team

Ateliers de Modélisation de l'Atmosphère,
12 Mars 2021 ; Toulouse

Les paramétrisations convectives dans LMDZ face à Jean-Luc Redelsperger, Françoise Guichard, Jean-Philippe Lafore

Jean-Yves Grandpeix, LMDZ Team

Ateliers de Modélisation de l'Atmosphère,
12 Mars 2021 ; Toulouse

I - Développements propres au schéma convectif

II - Poches froides (schéma des wakes)

III - Couplage de la paramétrisation des poches avec le schéma de convection profonde

IV - Couplage des poches, de la convection profonde et des thermiques

V - Déclenchement stochastique

VI - Développements en cours ou à venir

- **a/ Dynamique de population des poches**
- **b/ Brises**
- **c/ Splitting des flux de surface**

I - Développements propres au schéma convectif

Schéma d’Emanuel caractérisé par : multiples courants saturés ; une descente insaturée.
Code structuré et vectorisé par Sandrine Bony.

Il y a toujours un fond d'activité portant sur le schéma convectif lui-même

+ **Paramétrisation des probabilités de mélange** pour obtenir une meilleur sensibilité de la convection à l'humidité troposphérique (Grandpeix et al, 2002)

+ **Paramétrisation du transport et du lessivage** des aérosols (Pilon et al, 2014)

+ **Ejection des précipitations liquides** afin de corriger un défaut de LMDZ qui faisait que la majorité des précipitations étaient produites en phase glace, contrairement aux observations (en cours)

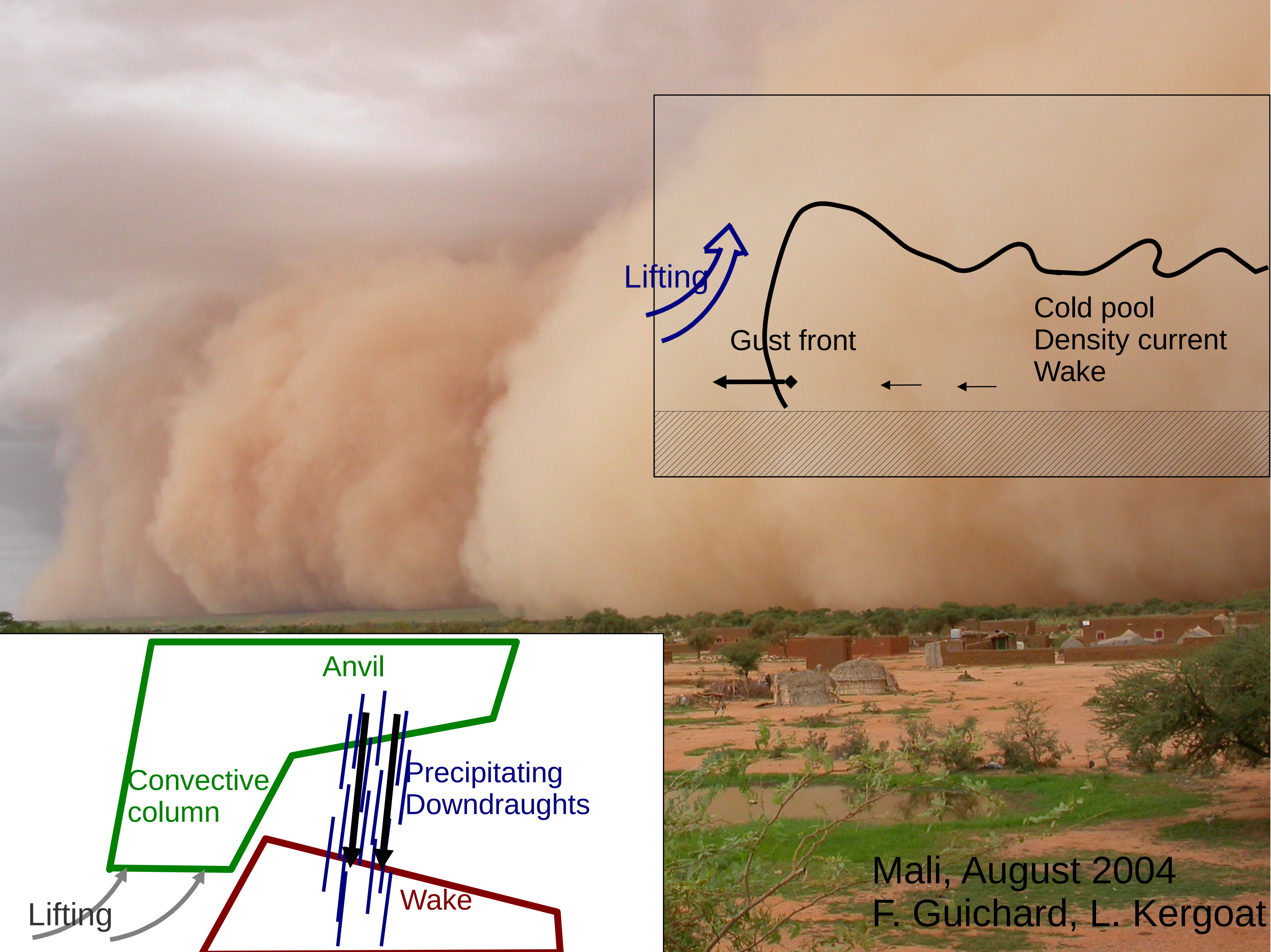
Mais surtout il y a eu les changements clef ayant pour but de coupler le schéma convectif aux poches froides :

+ **séparation des environnements** des courants saturés et insaturés
+ **séparation des tendances** dues aux courants saturés et insaturés
+ **commande du déclenchement et de la fermeture** convective par les variables ALE et ALP afin de représenter le soulèvement au front de rafales.

II - Density current parametrization:

The “wake”model of LMD and CNRM
(Grandpeix, Lafore 2010; Grandpeix et al 2010)

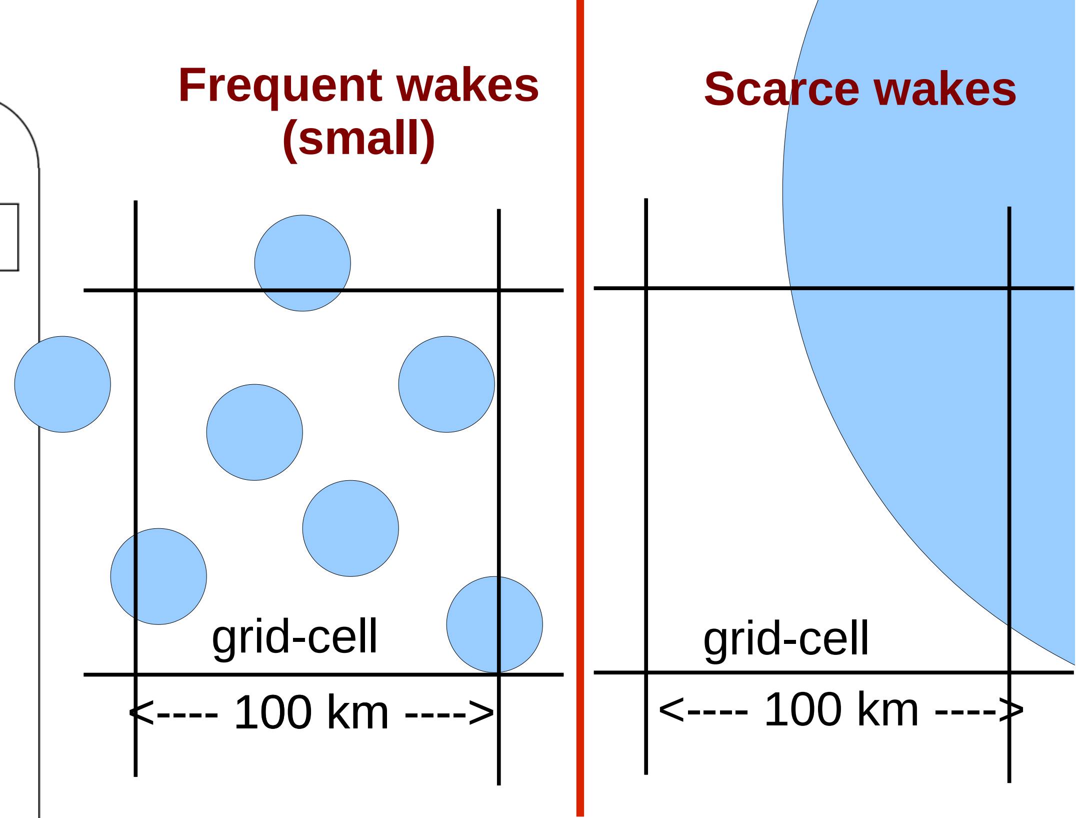

Mali, August 2004
F. Guichard, L. Kergoat


Lifting
Gust front
Cold pool
Density current
Wake
Anvil
Convective column
Precipitating Downdraughts
Wake
Lifting
Mali, August 2004
F. Guichard, L. Kergoat

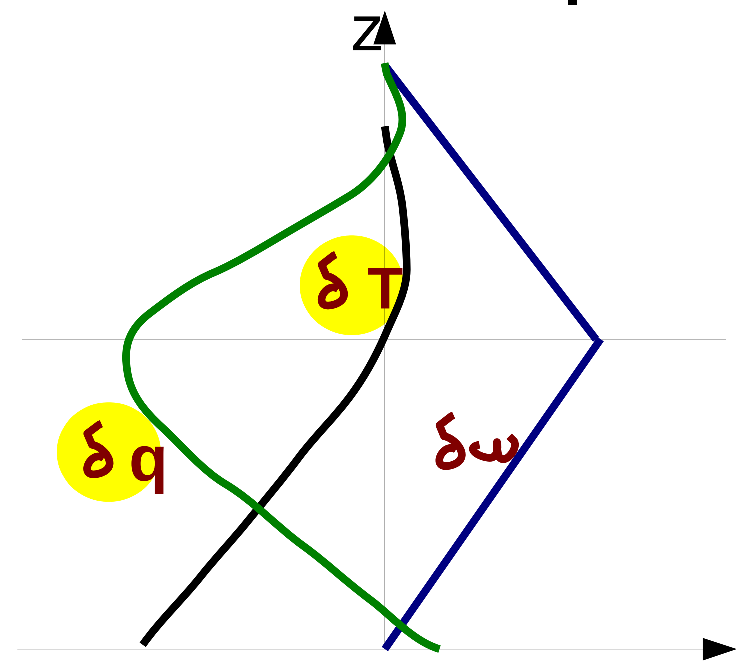
The density current (wake) parametrization

(Grandpeix and Lafore, JAS, 2010 ; Grandpeix et al., JAS 2010)

- Representation of a part of an infinite plane where identical cold pools (radius r, height h) are scattered with an homogeneous density $D_{\mathbf{wk}}$.
- State variables : (i) surface fraction covered by the wakes $\sigma_w = \frac{S_w}{S_t}$ $(\sigma_w = \pi r^2 D_{\mathbf{wk}})$, (ii) temperature and humidity differences (resp. $\delta\theta(p)$ and $\delta q(p)$) between wake and off-wake regions.
- Spreading speed : C_* such that $C_*^2 \simeq$ WAPE (WAke Potential Energy) ; $WAPE = \int_{p_{top}}^{p_{surf}} R_d \delta T_v \frac{dp}{p}$
- Evolutions of $\delta\theta$ and δq profiles are given by conservation equations of mass, energy and water taking into account vertical advection, turbulence and phase changes.
- Turbulence and phase change terms are assumed to be given by the deep convection scheme.
- $\delta\omega$ profile is linear between the surface and the wake top (no mass exchange through the wake boundary) ; it goes back to 0 linearly between the wake top and an arbitrary altitude (about 4000 m).



Wake differential profiles



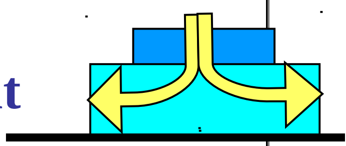
Large scale variable tendencies

Potential temperature :

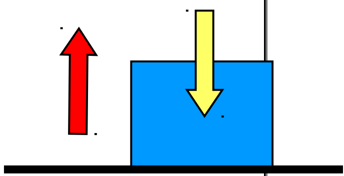
PBL: $Q_1^{\rm bl}$ — KE: $Q_1^{\rm cv}$ — New term: $Q_1^{\rm wk}$

$$\left\{ \begin{array}{rcl} \partial_t \overline{\theta} & = & (\partial_t \overline{\theta})_{LS} + \dfrac{Q_R + Q_1^{\rm bl} + Q_1^{\rm cv} + Q_1^{\rm wk}}{C_p} \\ \dfrac{Q_1^{\rm wk}}{C_p} & = & +(\partial_t \sigma_w - e_w)\ \delta\theta \\ & & -\sigma_w (1-\sigma_w)\ \delta\omega\ \partial_p \delta\theta \end{array} \right.$$

Spreading and entrainment



Differential vert. advection



Specific humidity : idem.

Wake variable tendencies

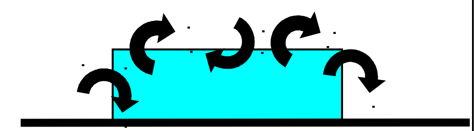
Potential temperature difference :

$$\partial_t \delta\theta = -\overline{\omega}\, \partial_p \delta\theta + \frac{\delta Q_1^{cv} + \delta Q_1^{wk}}{C_p} - \frac{k_{gw}}{\tau_{gw}}\, \delta\theta$$

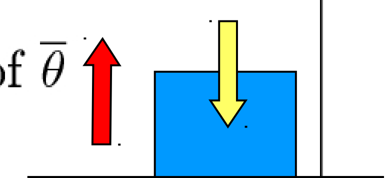
where $\tau_{gw} = \frac{\sqrt{\sqrt{\sigma_w}(1-\sqrt{\sigma_w})}}{4Nz\sqrt{D_{wk}}}$

is the damping time by gravity waves

$$\frac{\delta Q_1^{wk}}{C_p} = -\frac{e_w}{\sigma_w}\, \delta\theta \qquad : \text{Entrainment}$$



$$-\delta\omega\, \partial_p \overline{\theta} \qquad : \text{differential advection of } \overline{\theta}$$



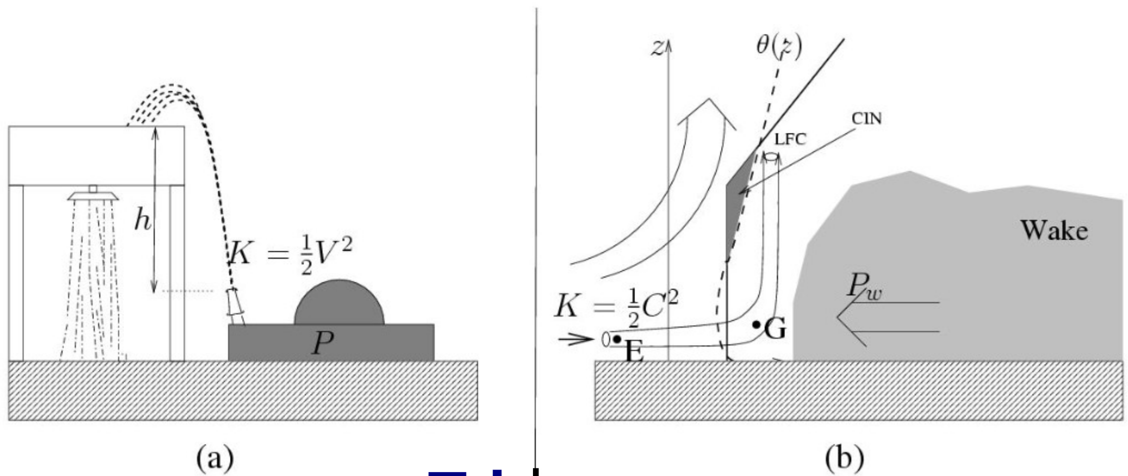
$$-(1 - 2\sigma_w)\, \delta\omega\, \partial_p \delta\theta \qquad : \text{differential advection of } \delta\theta$$

Specific humidity difference : idem (except for the gravity wave term).

III - Coupling wakes and deep convection:

The Available Lifting Energy (ALE) and Available Lifting Power (ALP) interface variables

Coupling convection with sub-cloud processes: ALE & ALP; 1



At least two variables:

- the **Available Lifting Energy (ALE)**
- the **Available Lifting Power (ALP)**.

Trigger

The **shower is triggered** when K > gh (K = ALE = Available Lifting Energy).

Convection is triggered when the maximum kinetic energy K (K = ALE) of air impinging on the gust front exceeds the convective inhibition: **ALE > |CIN|**

Closure

The pump (power P) yields a mass flow rate M. A fraction k (the engine efficiency) of P is used by the stream.

Closure: stream power M K = k P (= ALP)

The wakes provide a power P_W. A fraction k (the wake lifting efficiency) of P_W is used to lift draughts with mass flow rate M:

- overcoming inhibition => power M |CIN|
- velocity at LFC = w_B => power ½ M w_B^2
- dissipation => power 3/2 M w_B^2

Closure: **$M (|CIN| + 2 w_B^2) = k P_W$ (= ALP)**

Coupling convection with sub-cloud processes: ALE & ALP

More generally, the convection parametrization is coupled to sub-cloud processes through the two variables: ALE (for the trigger) and ALP (for the closure).

ALE = sup(ALE_{PBL}, ALE_{ORO}, ALE_{WK})

ALP = ALP_{PBL} + ALP_{ORO} + ALP_{WK}

ALE (Available Lifting Energy) (J/kg)

ALE = order of magnitude of the kinetic energy of the strongest updraughts (scale $\simeq$ km).

- Boundary layer : $ALE \simeq (\frac{1}{2}w^2)_{max}, \simeq (\frac{1}{2}w^2)_{Thermals}$.
- Orography thermal effect : ALE estimated from the potential energy of the surface layer.
- Density currents : $ALE = \frac{1}{2}C_*^2$ (C_* = gust front velocity).

ALP (Available Lifting Power) (W/m^2)

- PBL :

$$\mathrm{ALP} = \frac{1}{2}\overline{\rho w^3} \quad (\simeq \text{ qq } 0.01 \text{ W/m}^2)$$

- Density currents :

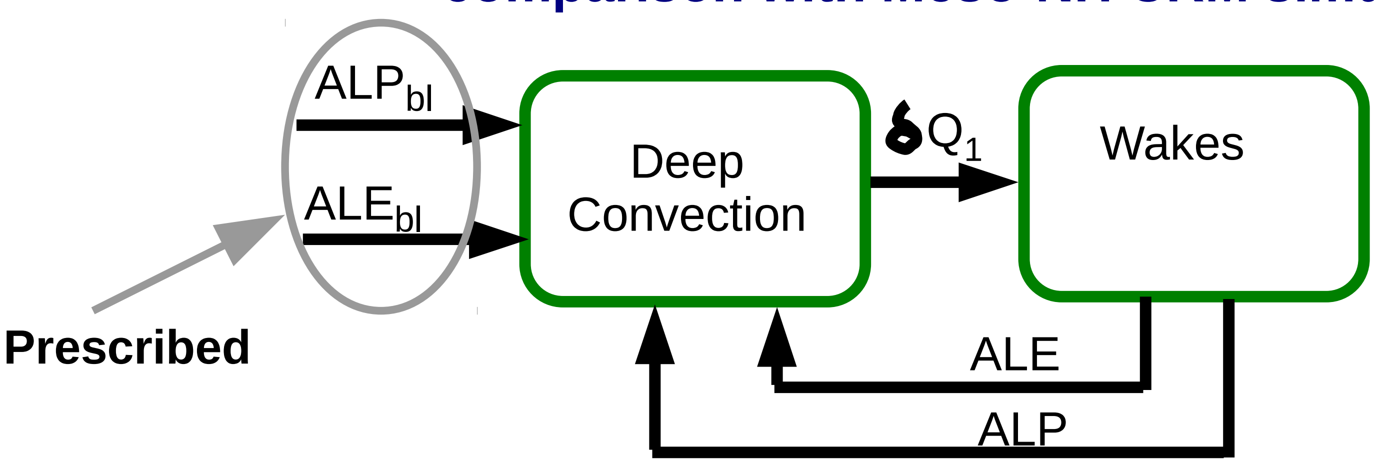
$$\mathrm{ALP} = h_w \Gamma_w \frac{1}{2}\rho c^{*3} \quad (\Gamma_w = \text{gust frt lgth / unit area}) \quad (\simeq \text{ qq } 0.1 \text{ W/m}^2)$$

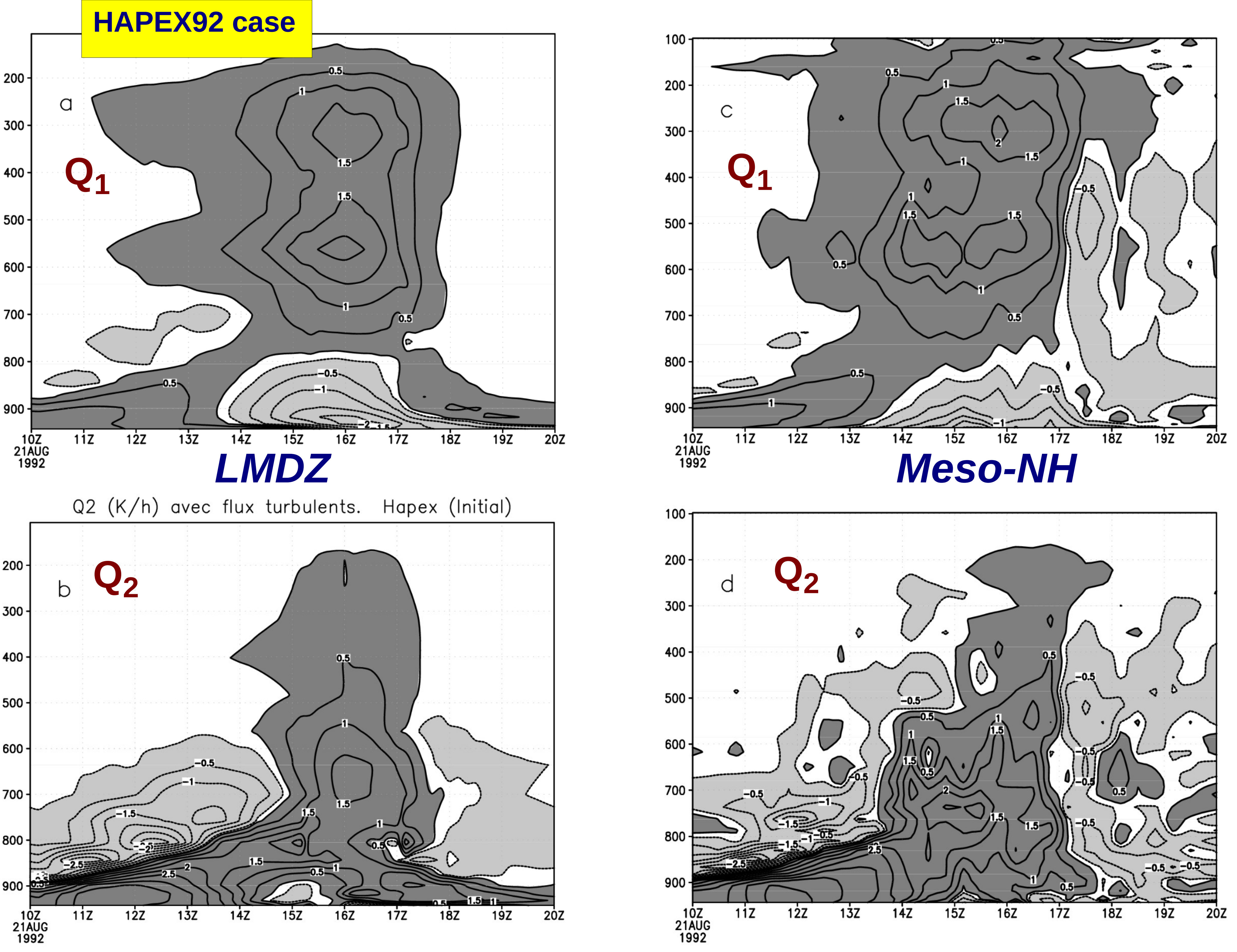
- Orography :

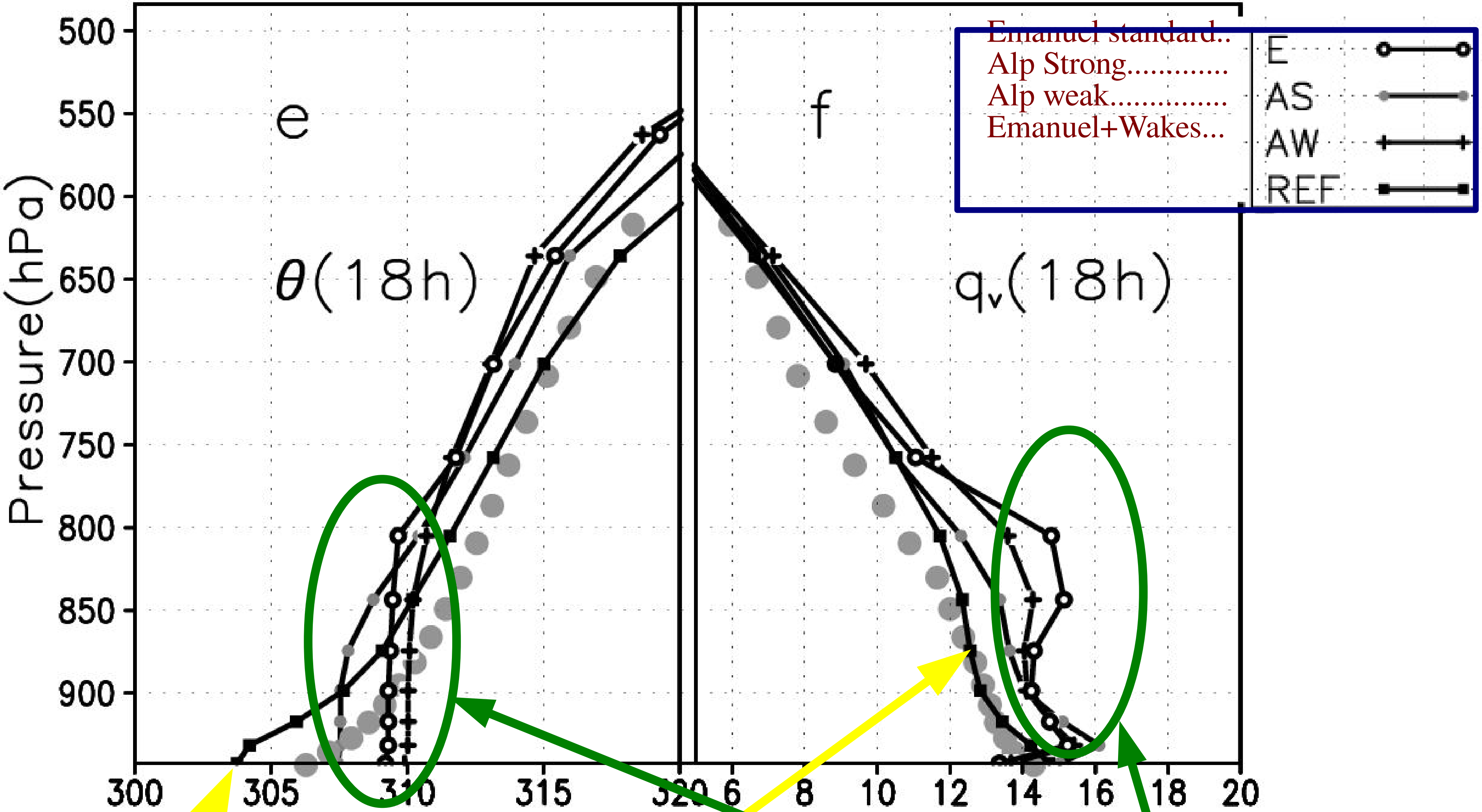
$$\mathrm{ALP} = -\int_{top}^{base} \vec{D}.\vec{V} dp \quad (\simeq \text{ qq } 0.1 \text{ W/m}^2)$$

Coupling wakes and deep convection:

Simulations of a Hapex92 case; “wake” scheme is the sole source of Ale and Alp; boundary layer Ale and Alp are prescribed; comparison with Meso-NH CRM simulations




HAPEX92 case
a
Q_1
LMDZ
Q2 (K/h) avec flux turbulents. Hapex (Initial)
b
Q_2
c
Q_1
Meso-NH
d
Q_2
10Z 21AUG 1992
11Z
12Z
13Z
14Z
15Z
16Z
17Z
18Z
19Z
20Z

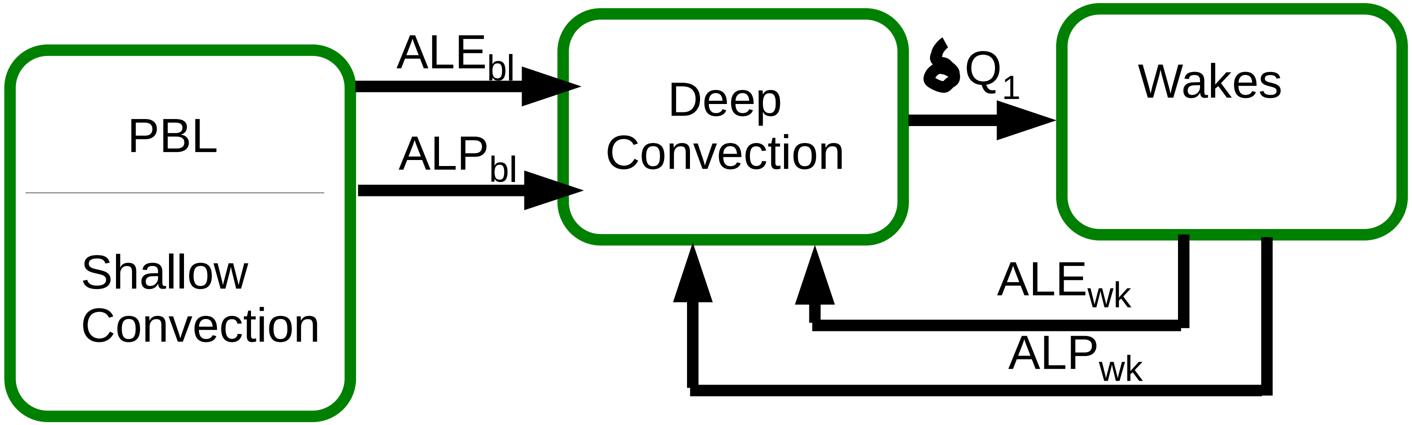


Only the simulation using "wake" yields a stratification in agreement with CRM results.

The other simulations yield a well mixed boundary layer.

IV - Coupling wakes, thermals and deep convection:

Thermal plumes,
The “Thermals” model and the trigger and closure of
The deep convection scheme.
(Rio et al 2008)



PBL
Shallow Convection
ALE$_{bl}$
ALP$_{bl}$
Deep Convection
δQ_1
Wakes
ALE$_{wk}$
ALP$_{wk}$

$\mathrm{ALE_{bl}}$ (Available Lifting Energy due to thermal plumes) (J/kg)

$$\mathrm{ALE_{bl}} = \frac{1}{2} w_{max}^2$$

where w_{max} is the maximum thermal plume vertical velocity over the vertical.

$\mathrm{ALP_{bl}}$ (Available Lifting Power due to thermal plumes) (W/m^2)

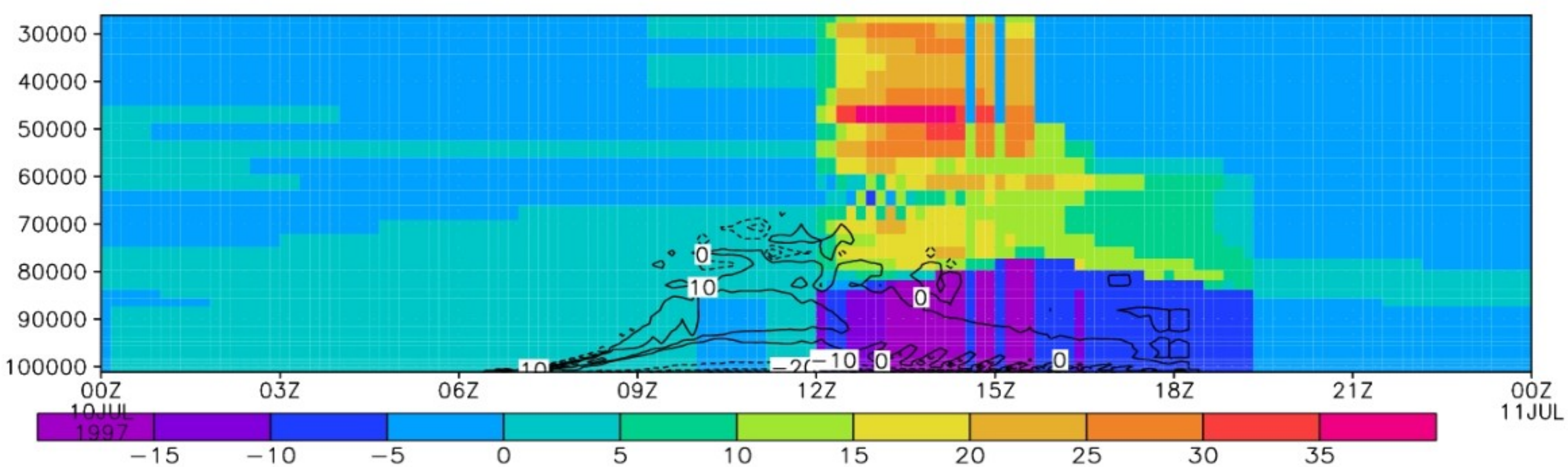
Averaging $1/2 \rho w^3$ horizontally at cloud base one gets :

$$\mathrm{ALP_{bl}} = \frac{3}{2} \rho w_0^3 \frac{\alpha(1 - 2\alpha)}{(1 - \alpha)^2}$$

where α is the fractionnal area covered by thermal plumes at cloud base and w_0 is the thermal plume vertical velocity at cloud base.

GrADS: CC

RCE case
Over land



GrADS: COLA/IGES

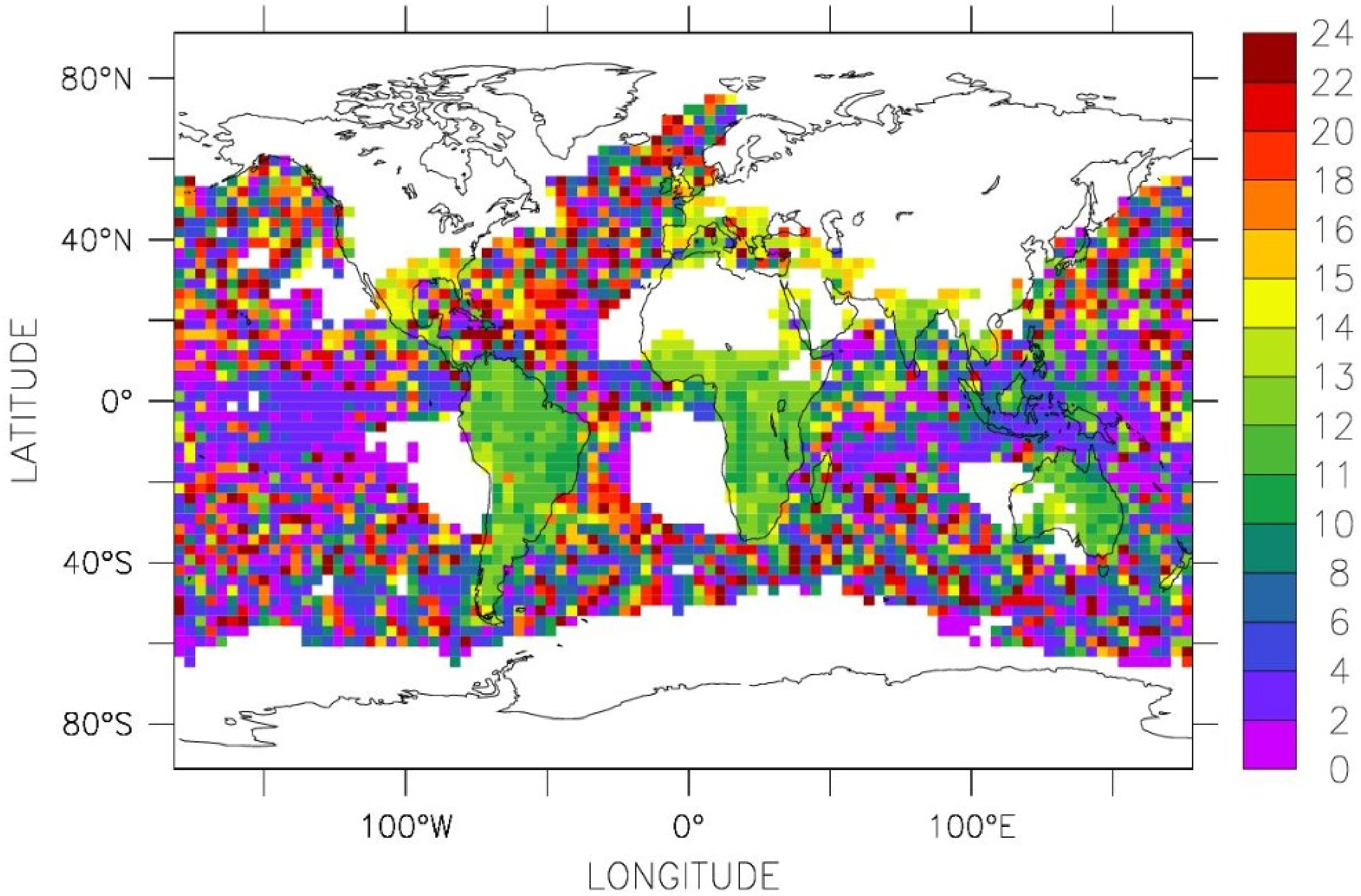


Figure 1: Simulated time of maximum convective precipitation in January; LMDZ4/AR4 physics.

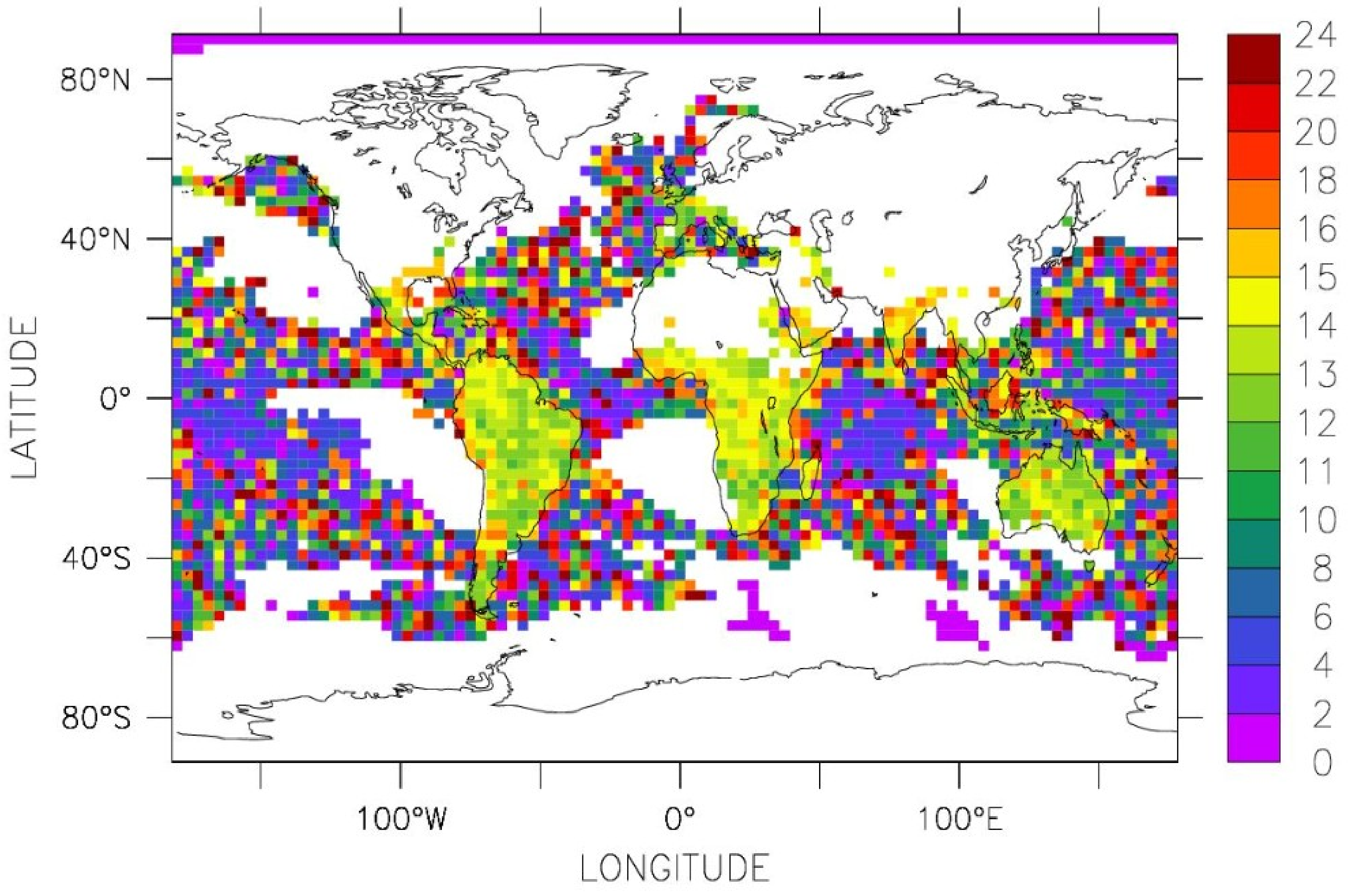


Figure 2: Simulated time of maximum convective precipitation in January; LMDZ4/new physics.

Diurnal cycle is improved.
However, it rains almost every day almost everywhere in the tropics.
The trigger has to be more constrained.

V – Stochastic trigger:

The "Thermals" model and the stochastic triggering of
The deep convection scheme.
LES analysis
(Rochetin et al 2014)

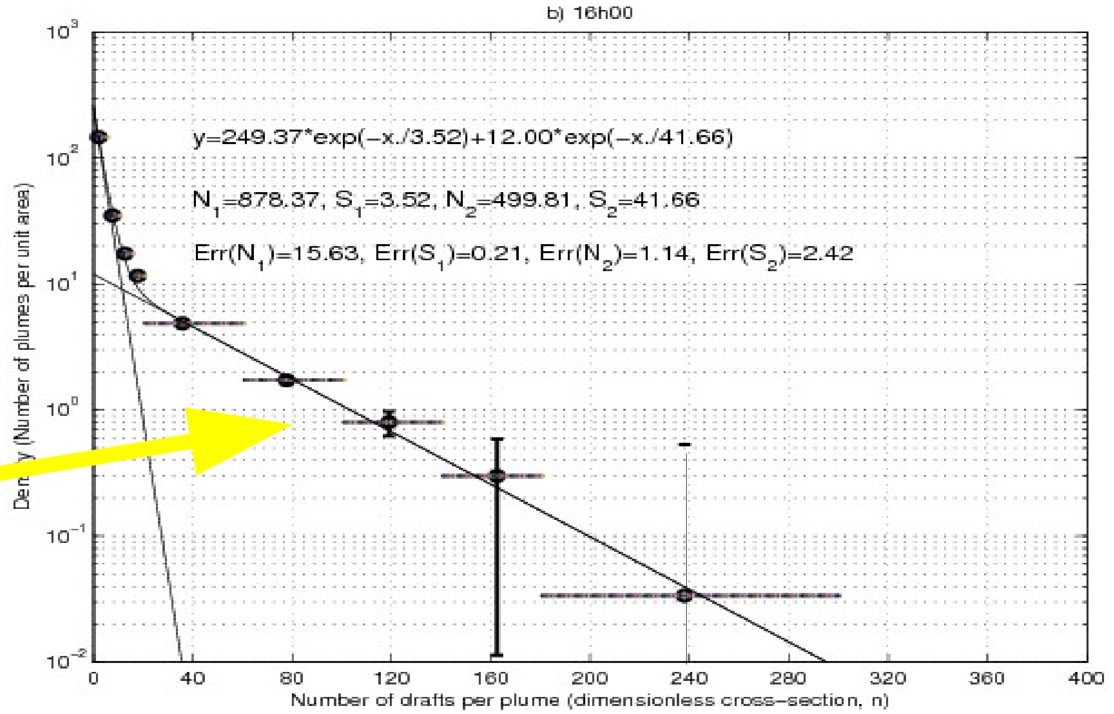
Statistical properties of plumes

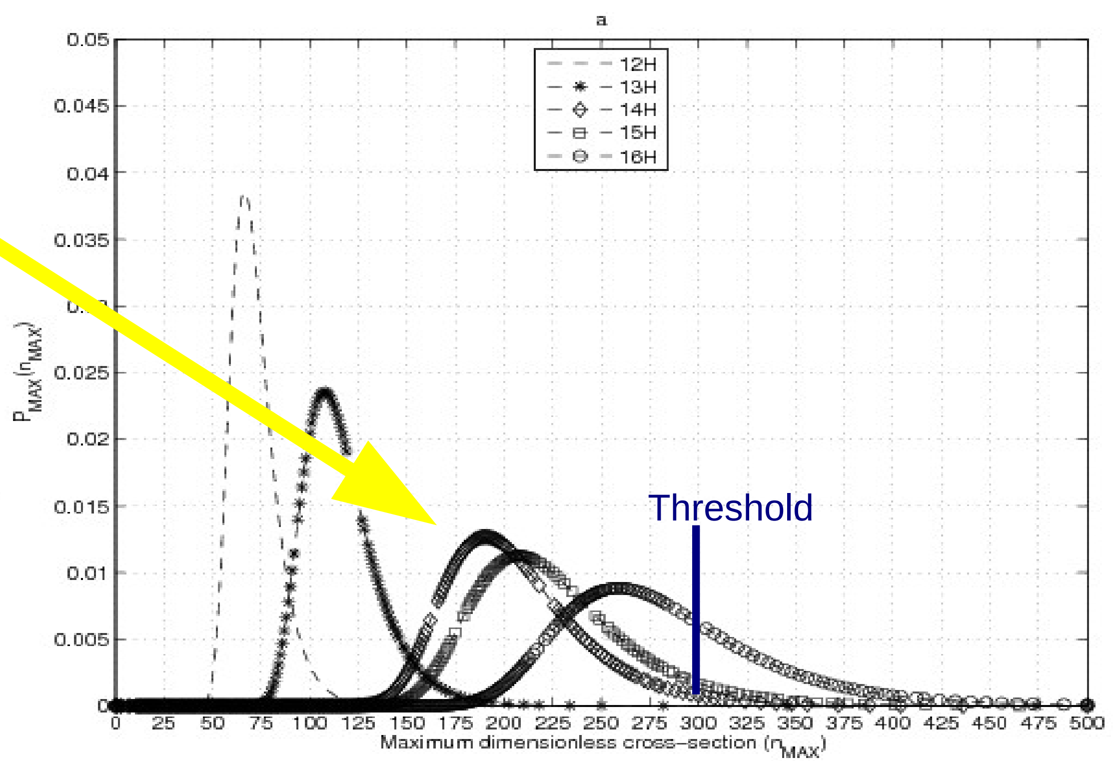
-I- Cross-sections

- Two plume populations with exponential PDF of cloud base cross-section s :

$$\mathcal{N}(s) = \frac{N_1}{s_1} \exp\left(\frac{-s}{s_1}\right) + \frac{N_2}{s_2} \exp\left(\frac{-s}{s_2}\right) \qquad (1)$$

- Triggering is concerned only with population 2.
- **The PDF of the maximum of s shifts towards larger s with time :** the median S_{med} increases with time.





$\mathrm{ALP_{bl}}$ (Available Lifting Power due to thermal plumes)

Averaging $1/2\rho w^3$ horizontally at cloud base one gets :

$$\mathrm{ALP_{bl}} = \frac{3}{2}\rho w_0^3 \frac{\alpha(1 - 2\alpha)}{(1 - \alpha)^2}$$

where α is the fractionnal area covered by thermal plumes at cloud base and w_0 is the thermal plume vertical velocity at cloud base.

$\mathrm{ALP_{bl}}$ conditionned on the presence of convection

The stochastic trigger provides a probability that deep convection is triggered in the grid cell. The above formula provides the **expection value of the $\mathrm{ALP_{bl}}$**. In order to conserve this expectation value, we divide, at each time step, the ALP by the trigger probability P_τ :

$$\mathrm{ALP_{bl,eff}} = \frac{\mathrm{ALP_{bl}}}{P_\tau}$$

If, for instance, $P_\tau = 0.1$ then convection will trigger every tenth step with an ALP ten times larger, so that the average ALP is unchanged.

Stochastic trigger

Basis

- First trigger criterion (as before) : ALE $>$ |CIN|.
- Additionnal criterion concerning plume sizes : trigger only if there exists a plume with $s > S_{\rm trig} \simeq 12\ 10^6\ m^2$
- Scenes separated by time intervals $> \tau \simeq$ 1200s are independant.

Implementation

- Computation of the probability $\widehat{P}_\tau$ that $S_{\rm max} < S_{\rm trig}$ (no-trigger probability) :

$$\widehat{P}_\tau = \left(1 - \exp\left(\frac{-S_{\rm trig}}{S_2}\right)\right)^{N_2 \frac{\delta t}{\tau}} \tag{2}$$

- Generation of a random number R uniform over $[0\ ,\ 1]$.
- Trigger if $R > \widehat{P}_\tau$

Summing up :

Trigger condition $=$

- **Cloudy** convective boundary layer
- **ALE $>$ |CIN|**
- Random number $R > \widehat{P}_\tau$.

AMMA case simulation; stochastic triggering leads to:

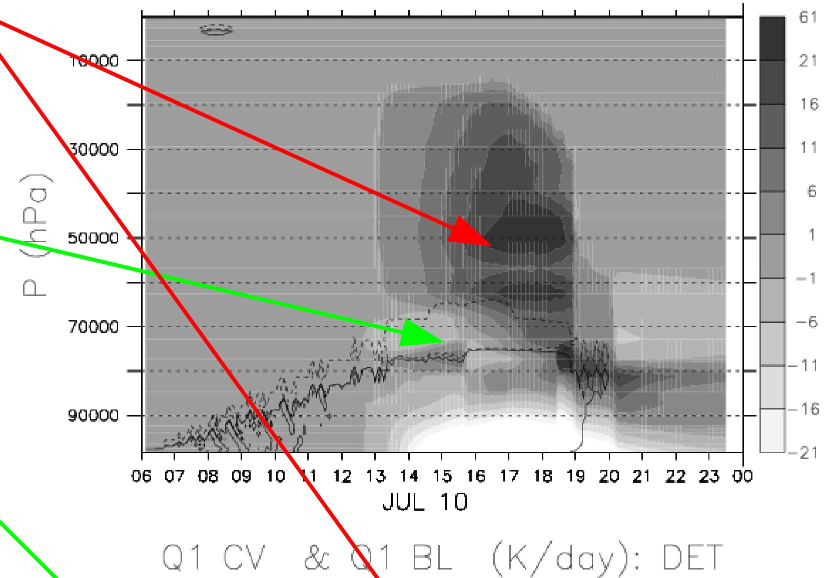
- ***Delay of deep convection triggering.***
- ***Larger growth of cumulus clouds.***

Heating by deep convection

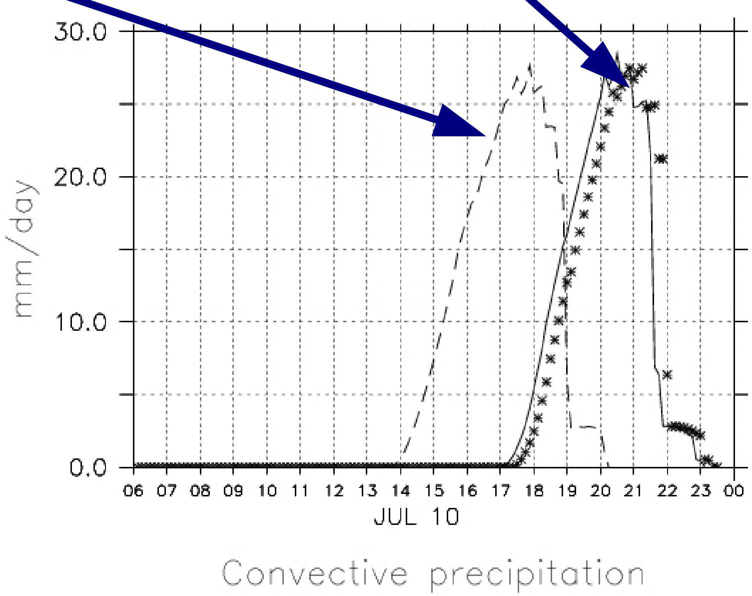
Cooling by cumulus

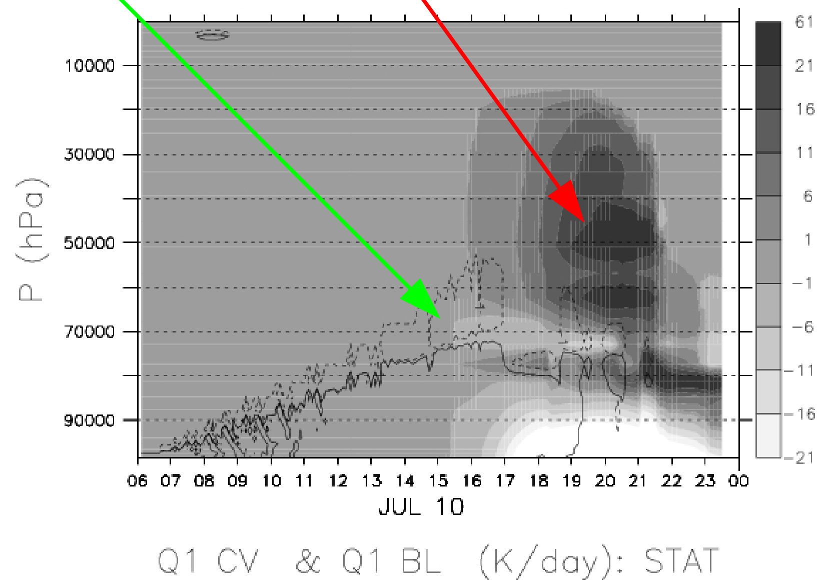
Two realizations with the stochastic trigger

Standard (deterministic) trigger



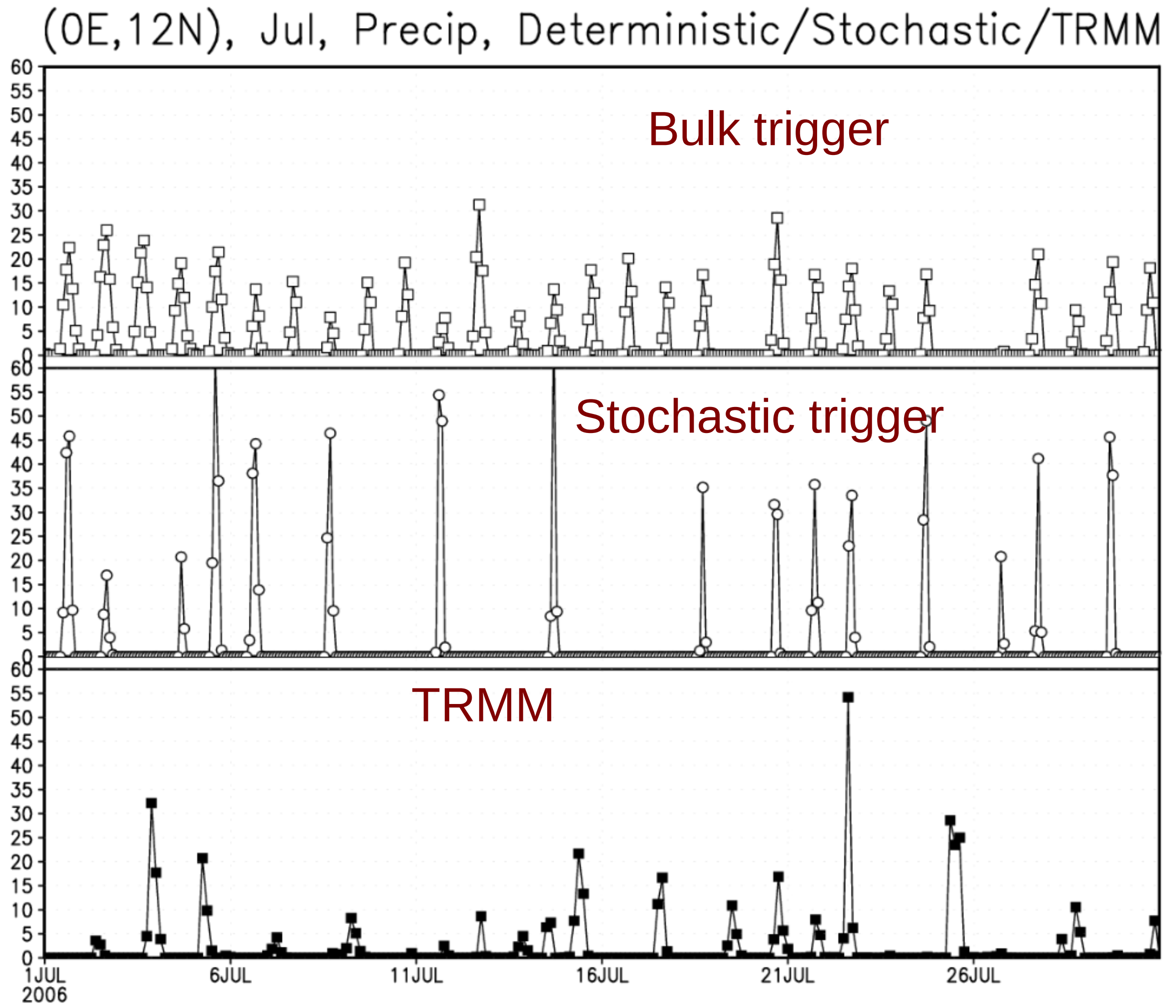
AMMA case
10 July 2006



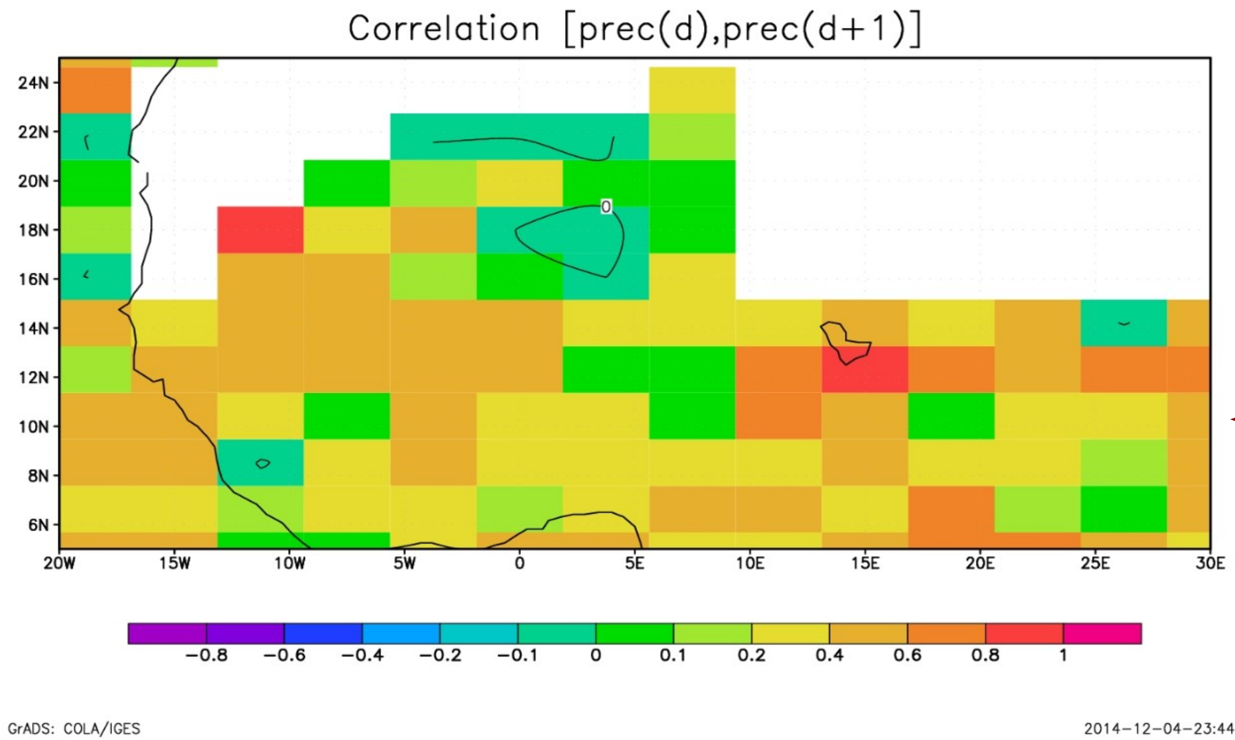


Stochastic triggering yields back precipitation intermittency

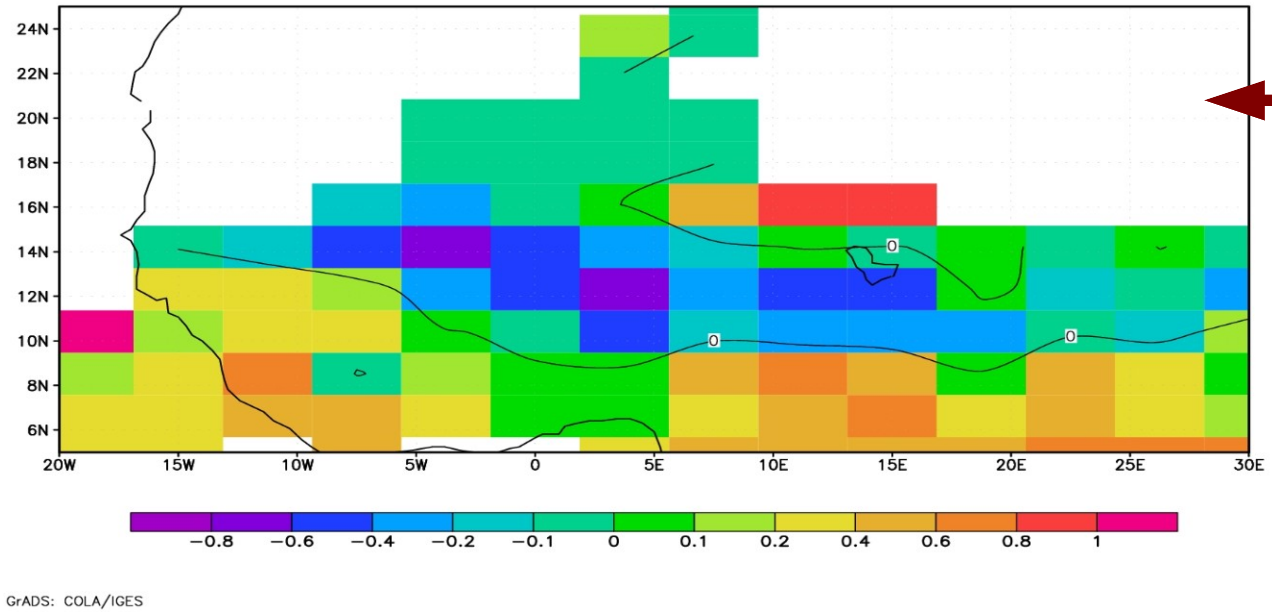
Precipitation at Niamey in July



Intermitence - 2



Declenchement standard



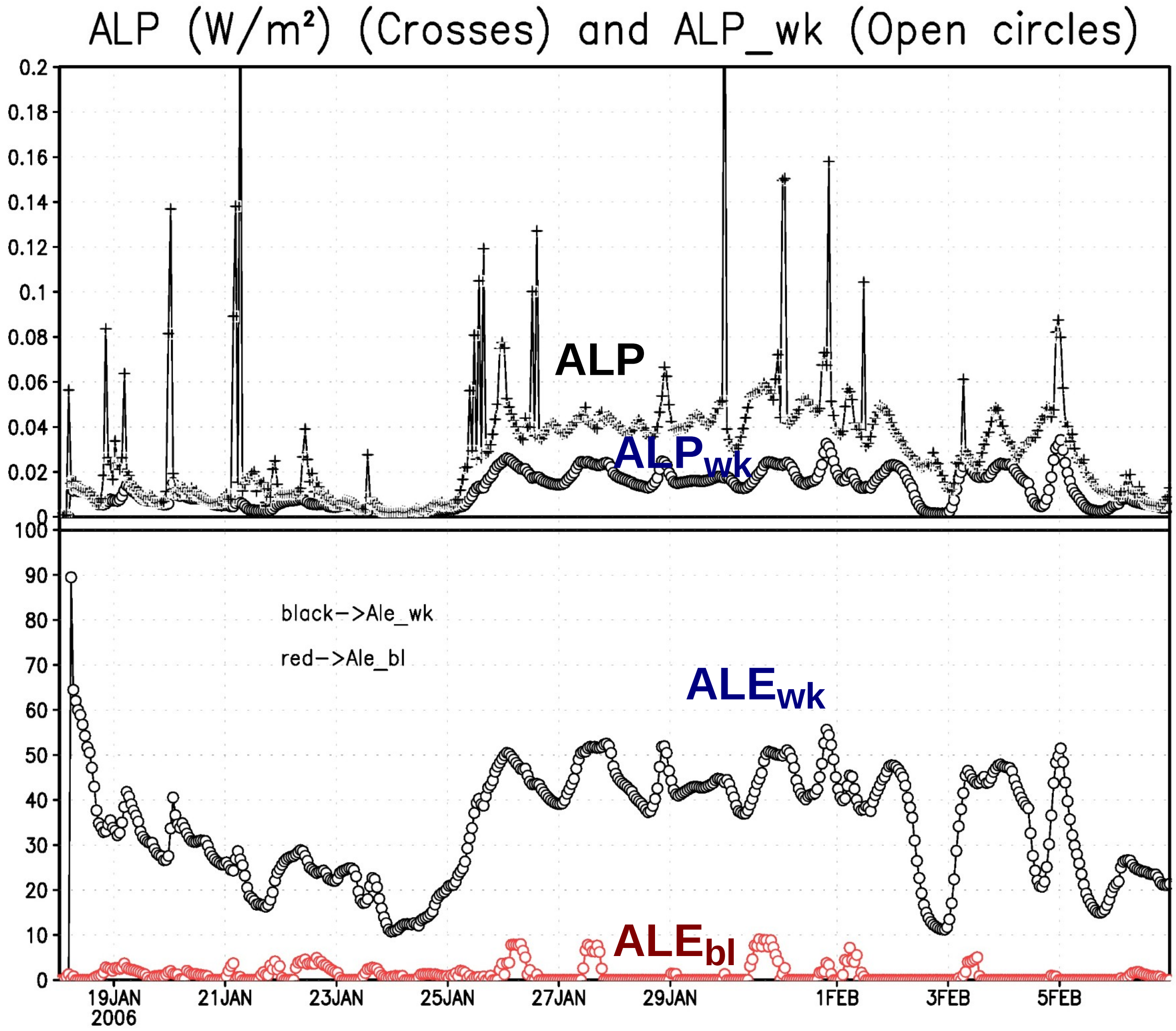
Declenchement stochastique

Over ocean

TWPICE case

The trigger is dominated by the wakes.
→ problem over oceans: Cold pools are always present and convection is almost always active.

The convective intensity is equally fed by wakes and Thermals.



VI – Ongoing or future developments:

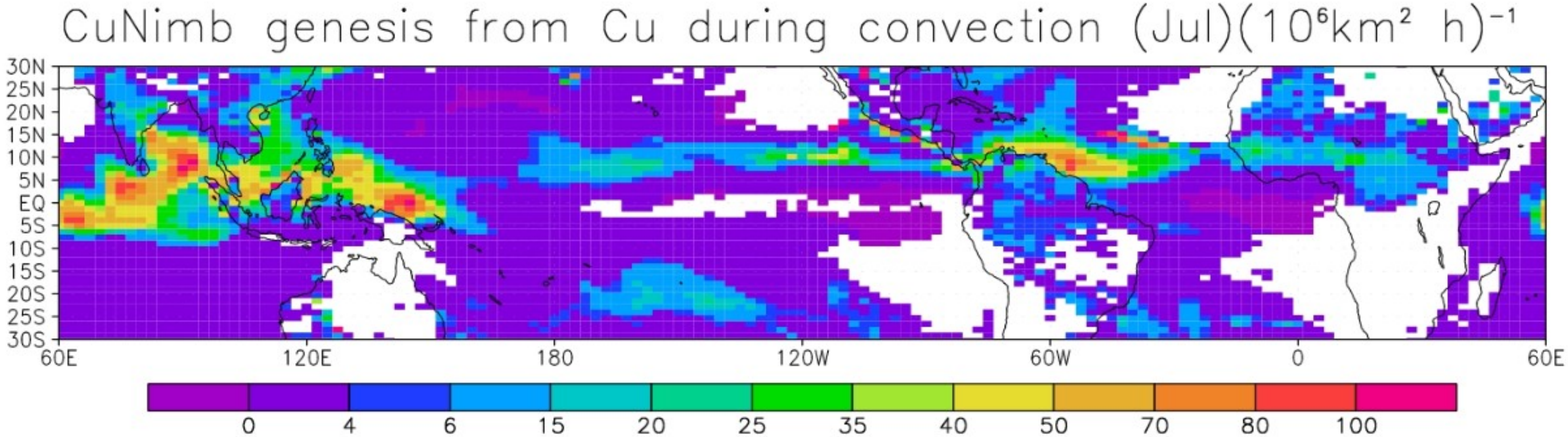
Developments concerning the surrounding of deep convection: breeze, splitting of surface fluxes, cold pool population dynamics

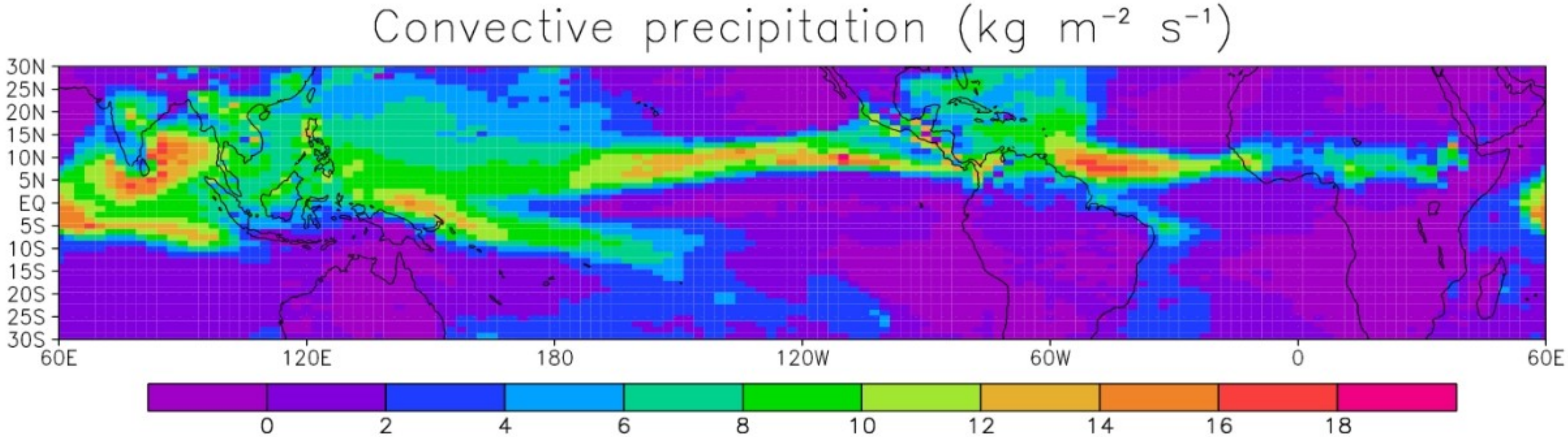
VI.1Representing the population dynamics of cumulus, cumulonimbus and cold pools:

From stochastic trigger to birth rate of CB
And to cold pool population dynamics

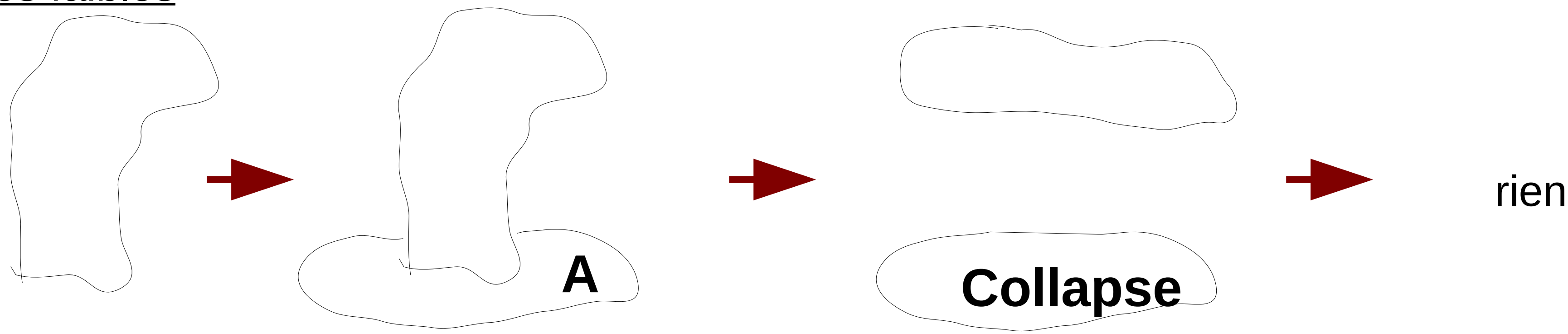
4 -Cumulonimbus & cold pool genesis

CuNimb genesis rate diagnosed from an LMDZ AMIP simulation. The order of Magnitude looks reasonable: up to a hundred per million km2 and per hour over ocean; half a dozen over Sahel in July.

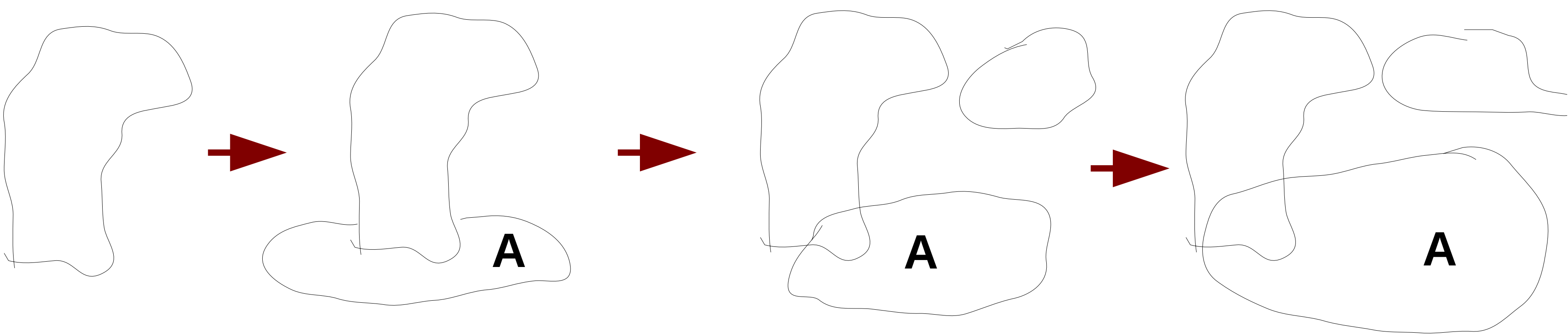




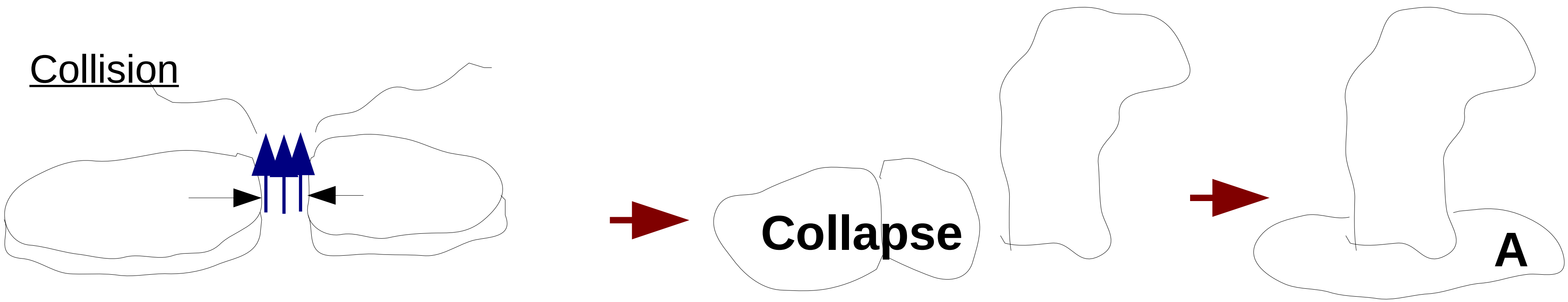
Poches faibles



Poches fortes



Collision



Model equations

- A : number of active wakes per unit area
- D : number of wakes per unit area
- σ : fractionnal area covered by wakes
- r : wake radius
- B : birth rate of Cumulonimbus (and of wakes)
- a_0 : initial area of newborn wakes
- C_* : gust front velocity
- τ_{cv} : lifetime of convective plumes
- τ : lifetime of collapsing wakes
- β : fraction of wakes that are active
- α : factor going from zero (colliding wakes merely merge, whithout wake area loss) to 1 (colliding wakes induce a new one that grows while the two others collapse) : should depend on shear. Presently, $\alpha = 1$.

collisions

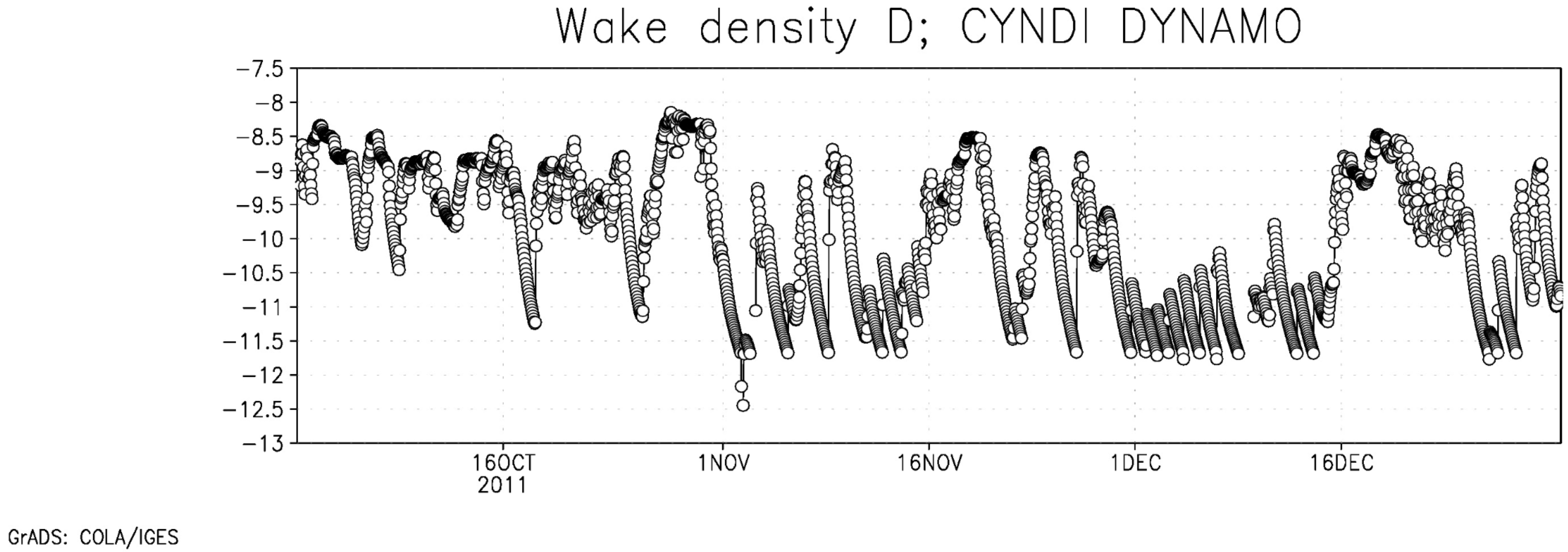
$$
\left\{
\begin{aligned}
\partial_t A &= B - \frac{1}{\tau_{cv}}(A - \beta D) \\
\partial_t D &= B - \frac{D-A}{\tau} - 4\pi r D^2 \partial_t r \\
\partial_t \sigma &= B a_0 - \frac{\pi r^2}{\tau}(D-A) + 2\pi r D C_* \\
&\quad - \alpha 4\pi r D \partial_t r (2\sigma - D a_0)
\end{aligned}
\right.
$$

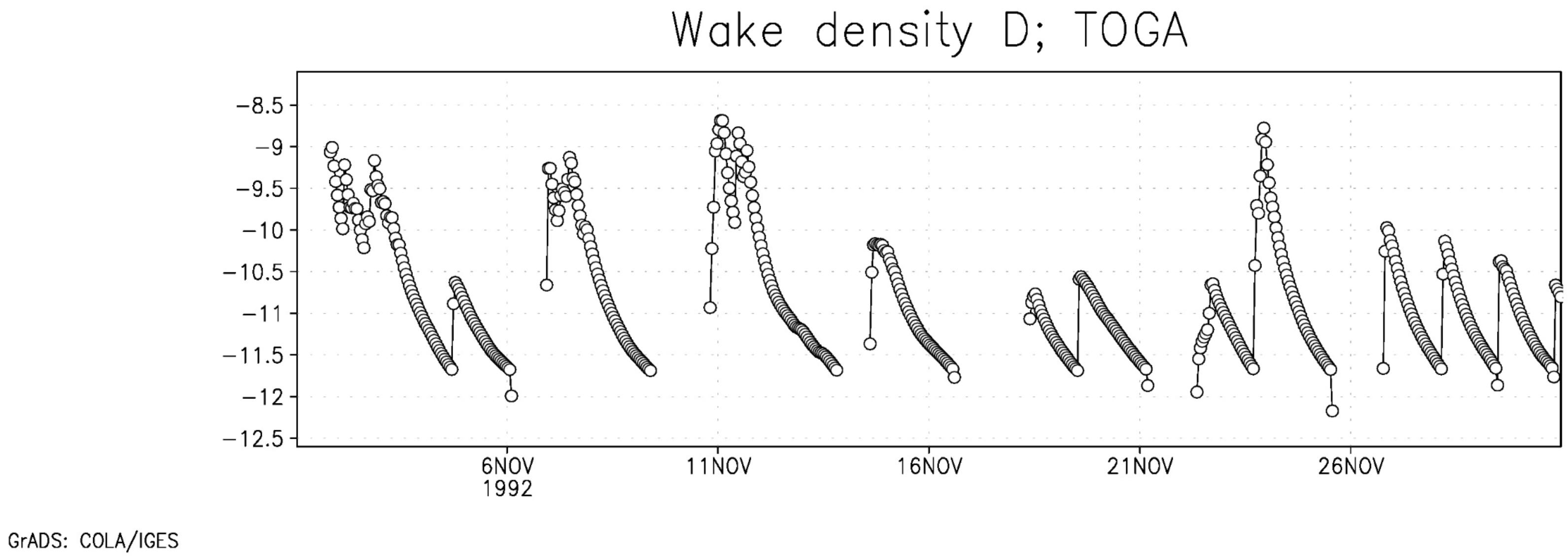
and from $\sigma = \pi r^2 D$: $\partial_t \sigma = 2\pi r D \partial_t r + \pi r^2 \partial_t D$

Le terme βD apparaît comme un rappel vers une fraction β de poches actives.

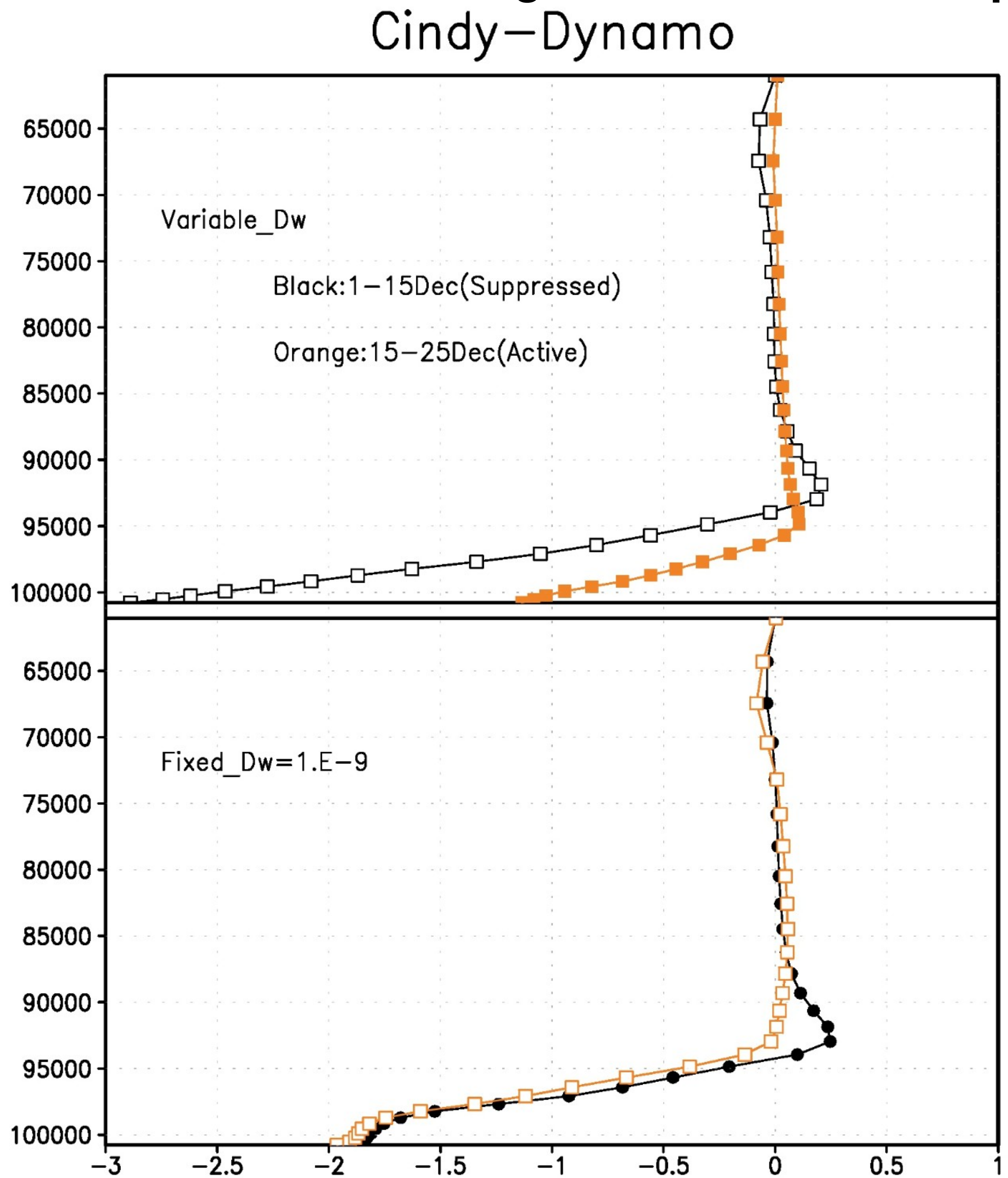
- l'activation ou la réactivation des poches par la convection profonde qu'elles induisent doit apparaitre comme un terme source proportionnel à D.
- $\beta = 0$ lorsque $ALE_{wk} < CIN$.
- la fraction de poches (ré)activées dépend de la granularité de la convection profonde. S'il il y a des thermiques, alors [ALP, B] $\longrightarrow$ "taille" d'un cumulonimbus. Mais que faire en l'absence de thermiques ?
- **Besoin d'une estimation de la "taille" des cumulonimbus (e.g. flux de masse, ALP, section ?).**

6 - Large variability of D, both short term (few hours) and long term (weeks)





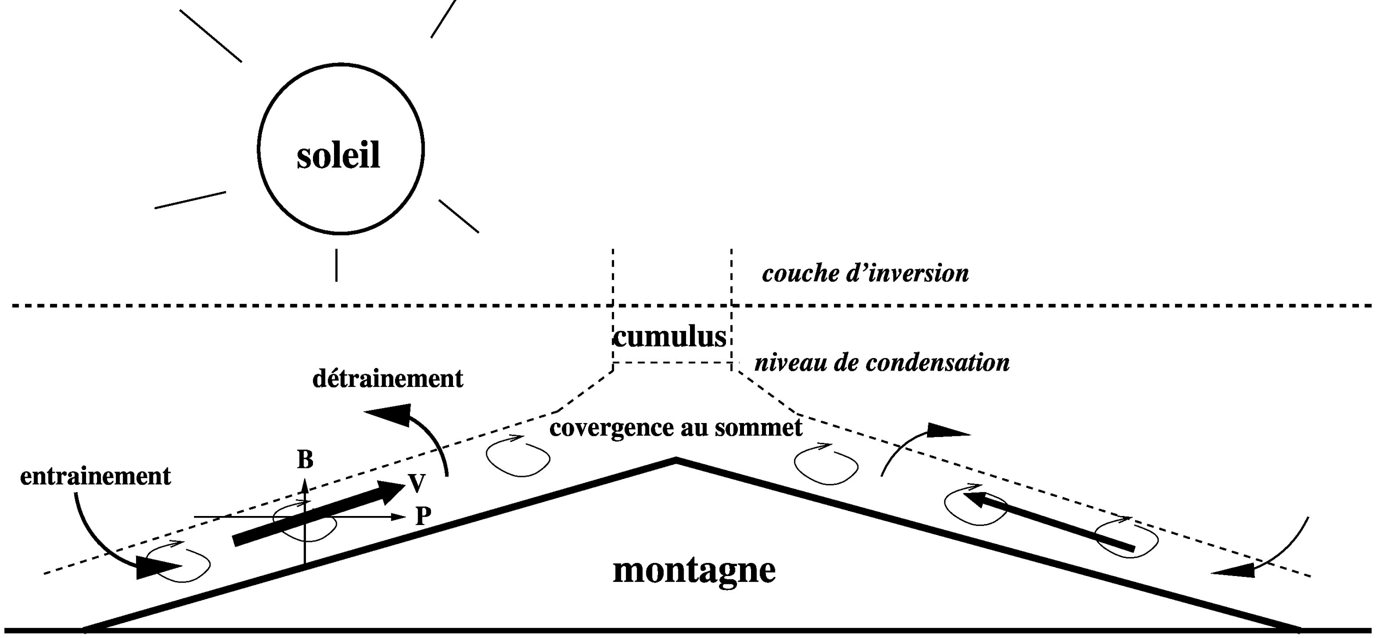
7 - Strong effect of D variability on wake properties:
Fixed D ==> wake profiles unchanged between suppressed and active phase during Cindy ;
Variable D ==> strong difference of wake profiles.



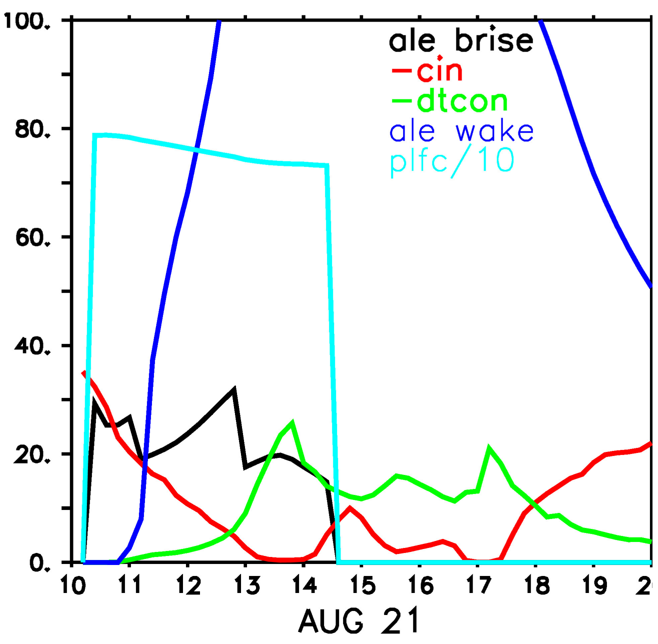
VI.2 Brises:

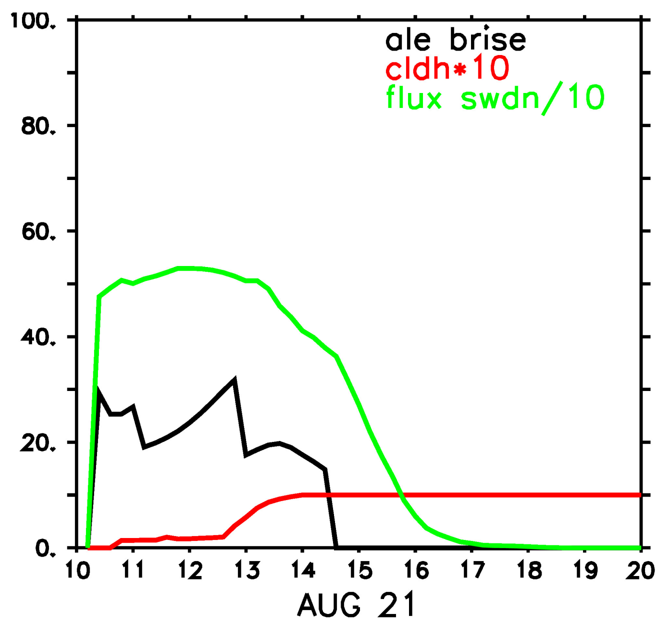
Brises cotières : à poursuivre
Brise de vallée : à reprendre

Jingmei Yu (2010) : modèle de brise anabatique Couplé à un modèle de sol à chaque niveau.



HAPEX92 case





VI.3 Splitting of surface fluxes:

Should reduce cold pools life time over ocean and to a lesser extent over land.

Modele de changement de temperature de surface associe aux poches froides

Passage d'une poche froide $\Longrightarrow$ refroidissement du sol (i.e. flux de chaleur négatif $\delta\Phi_g$) $\Longrightarrow$ variation négative de température de surface δT_s :

$$\delta T_s = \frac{\sqrt{\tau}}{I}\delta\Phi_g \qquad (2)$$

(τ : temps pour parcourir le rayon r des poches ($\sigma_w = \pi r^2 D_w$) avec la vitesse C_* d'étalement : $\tau = (1/C_*)\sqrt{\sigma_w/(\pi D_w)}$; I : inertie du sol).

$$\underset{}{\delta\Phi_g} = \underset{\text{sensible}}{\delta\Phi_s} + \underset{\text{latent}}{\delta\Phi_l} + \underset{\text{rayonnement net}}{\delta R_n} \qquad (3)$$

- **Flux latent** : $\delta\Phi_l = L_v\rho C_d||V||\beta[\delta q_a - \partial_{T_s} q_{sat}\delta T_s]$
  Approx. : $\delta q_a \simeq 0$
- **Rayonnement net** : $\delta R_n = \delta R_{Sn} + \delta R_{Ld} - 4\sigma T_s^3\delta T_s$
  Approx. : $\delta R_{Sn} \simeq 0$ et $\delta R_{Ld} \simeq 4\epsilon_1\sigma T_1^3\delta T_1$

Alors :

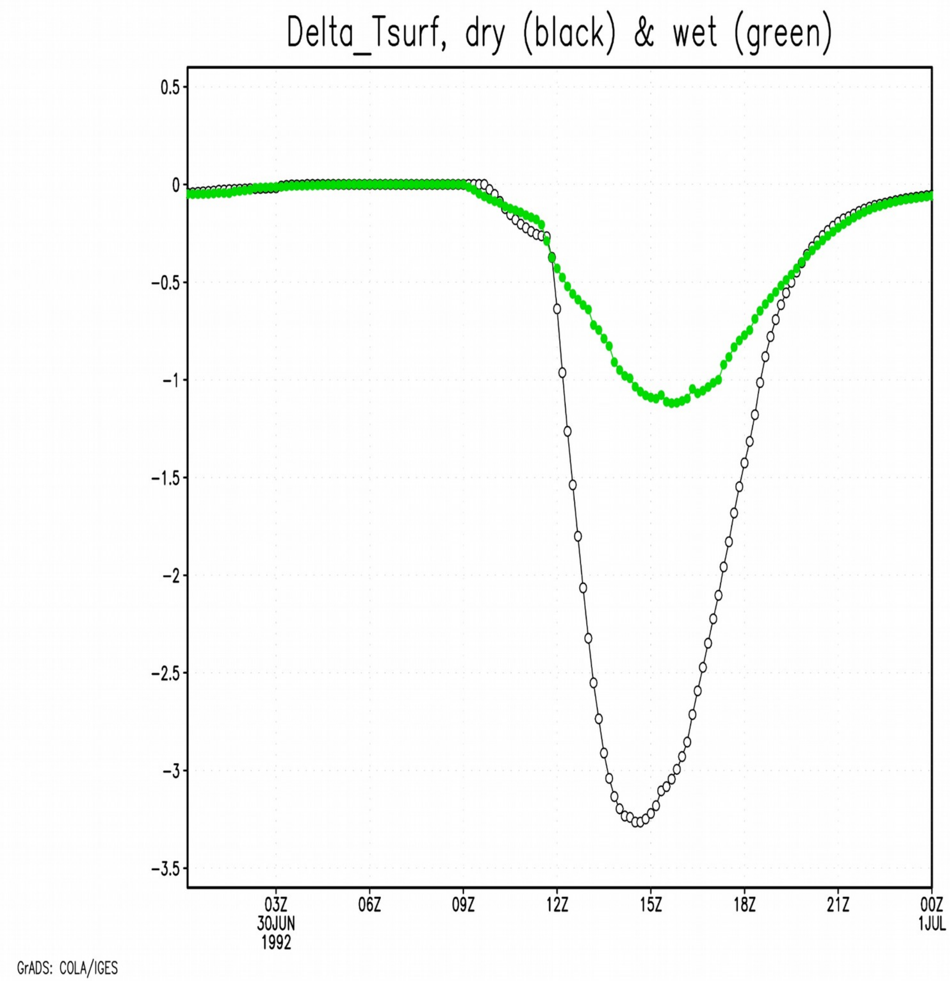
$$\delta T_s = \frac{\sqrt{\tau}}{I}[\delta\Phi_s - L_v\rho C_d||V||\beta\partial_{T_s}q_{sat}\delta T_s + 4\epsilon_1\sigma T_1^3\delta T_1 - 4\sigma T_s^3\delta T_s$$

soit : $C_p\ \delta T_s = a_h\ C_p\ \delta T_1 + b_h\ \delta\Phi_s$, avec :

$$\begin{cases} a_h = \dfrac{\frac{\sqrt{\tau}}{I}4\epsilon_1\sigma T_1^3}{1 + \frac{\sqrt{\tau}}{I}(L_v\rho C_d||V||\beta\partial_{T_s}q_{sat} + 4\sigma T_s^3)} \\ \\ b_h = \dfrac{\frac{\sqrt{\tau}}{I}C_p}{1 + \frac{\sqrt{\tau}}{I}(L_v\rho C_d||V||\beta\partial_{T_s}q_{sat} + 4\sigma T_s^3)} \end{cases} \qquad (4)$$

Ordre de grandeur:

Tau ~ qq heures, Inertie ~ 1000 a 2000
beta ~ 0.1 a 1, epsilon1 ~0.1 a 1,
ah ~ 0.01 a 0.1, bh~ qq 10 a qq 100.



Récapitulation

Trois éléments constitutifs des processus convectifs, représentés par trois paramétrisations :

Cumulus	Modèle du thermique nuageux
Cumulonimbus	Schéma d'Emanuel
Courants de densité	Modèle des wakes

Ces trois éléments interagissent de deux façons :

1/ Espace divisé en deux zones :
(w), l'intérieur des poches, contient les descentes précipitantes.
(x), l'extérieur des poches, contient les thermiques et les courants saturés de la convection profonde.

2/ Paramétrisations des wakes et des thermiques ==> Ale et Alp
==> controle du déclenchement et de l'intensité de la convection.

Perfectionnement indispensable : différencier les flux turbulents dans (w) et dans (x).

Deux manques combler :
+ un ou des modèles de brise pour la génération de convection sur les cotes et sur les reliefs.
+ parametrer l'advection de populations de poches de maille en maille.