Une représentation de la dynamique des populations de cumulus, de cumulonimbus et de poches froides dans le GCM LMDZ

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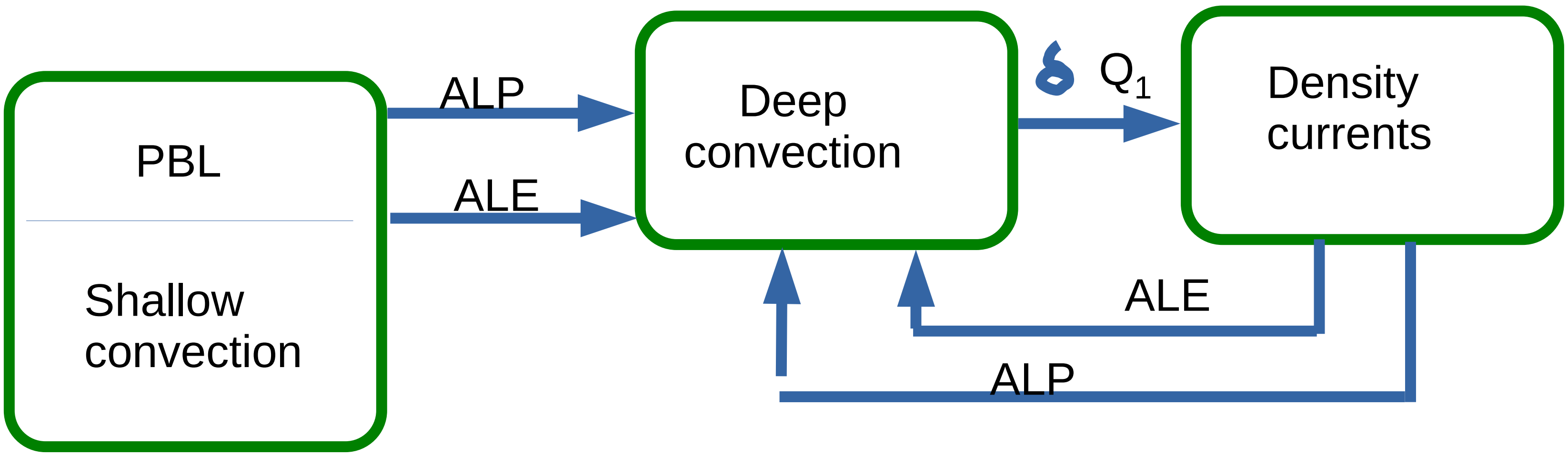
1- The ALP-ALE system: coupling boundary layer thermals, deep convection and density currents. (LMD & CNRM)

- Deep convection trigger given by the Available Lifting Energy (ALE) :

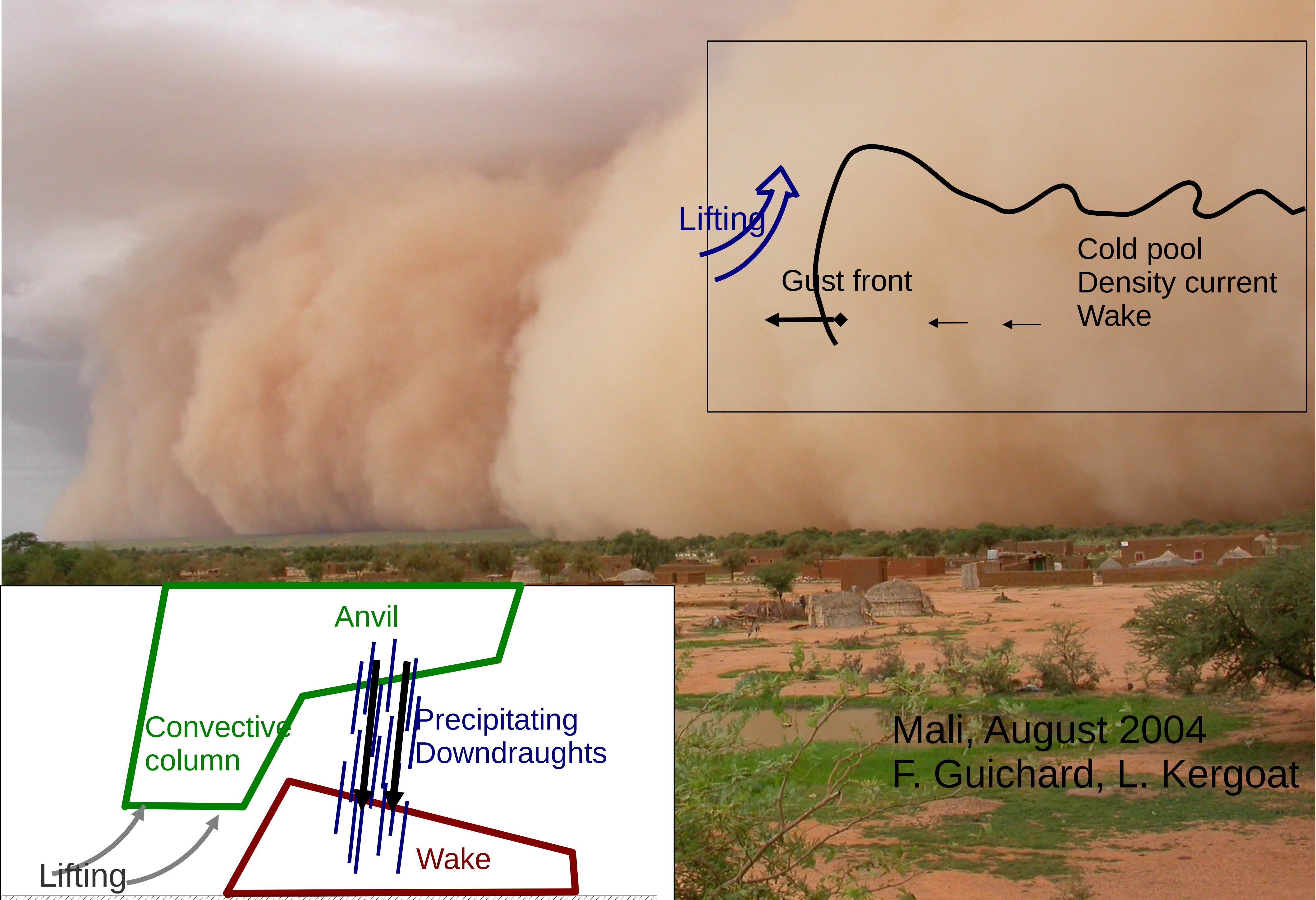
ALE > |CIN| ==> deep convection is triggered

- Closure given by the Available Lifting Power (ALP) :

$M = ALP/(2\,W_B^2 + |CIN|)$;
M = cloud base mass flux; W_B = updraught velocity at LFC



2- Cold pools: the "wake" scheme (LMD & CNRM)

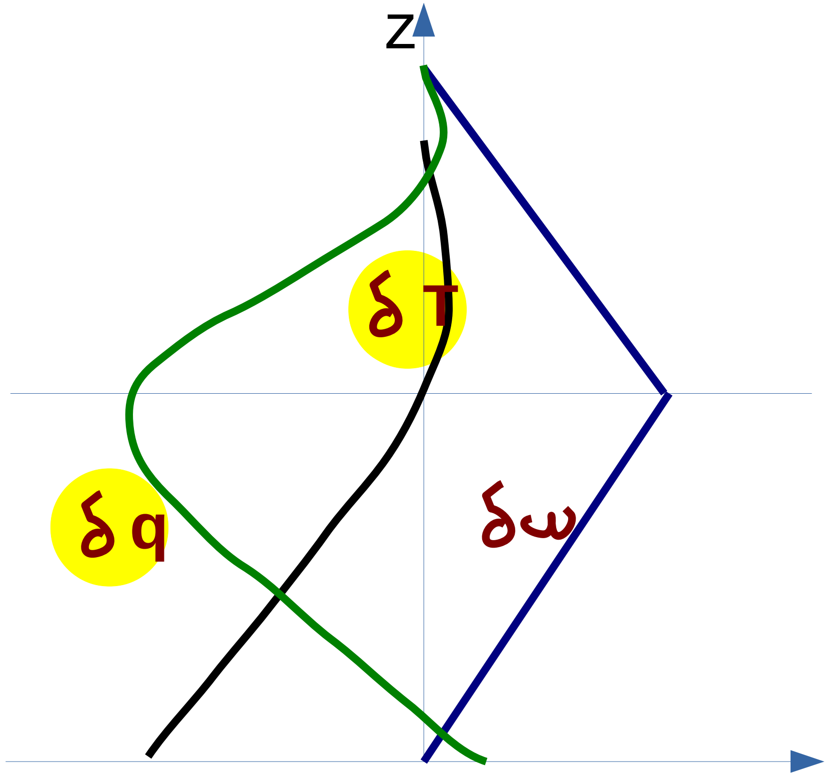


The density current (wake) parametrization

(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 $D_{\rm wk}$.
- State variables : (i) surface fraction covered by the wakes $\sigma_w = \frac{S_w}{S_t}$ ($\sigma_w = \pi r^2 D_{\rm wk}$), (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

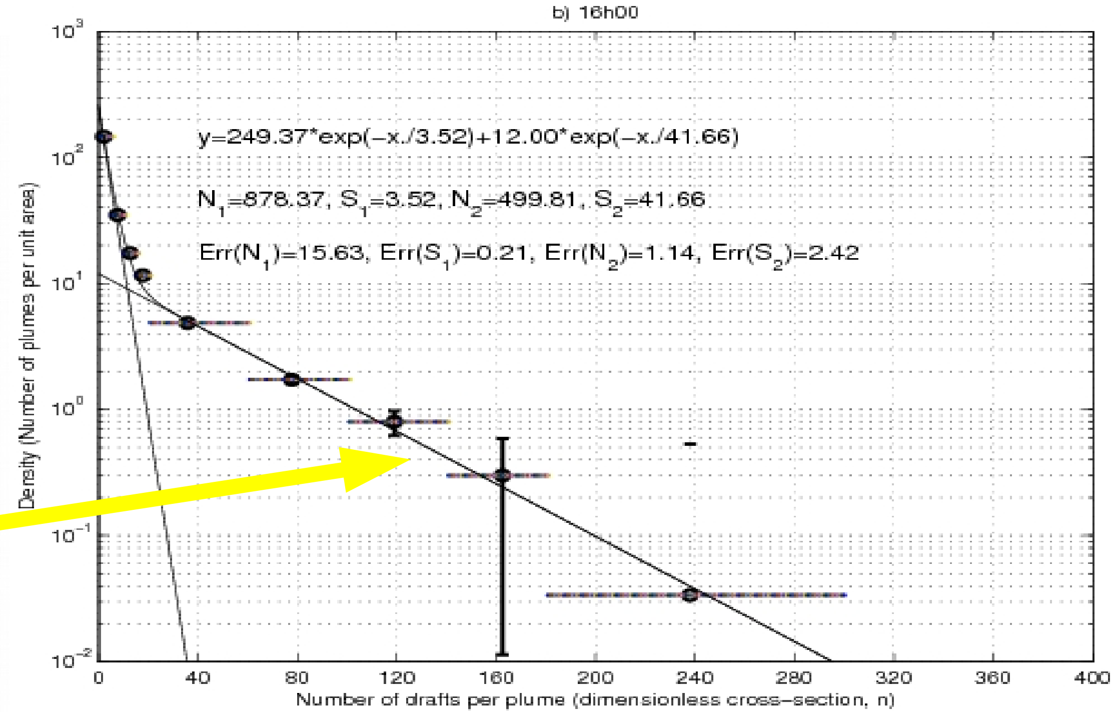


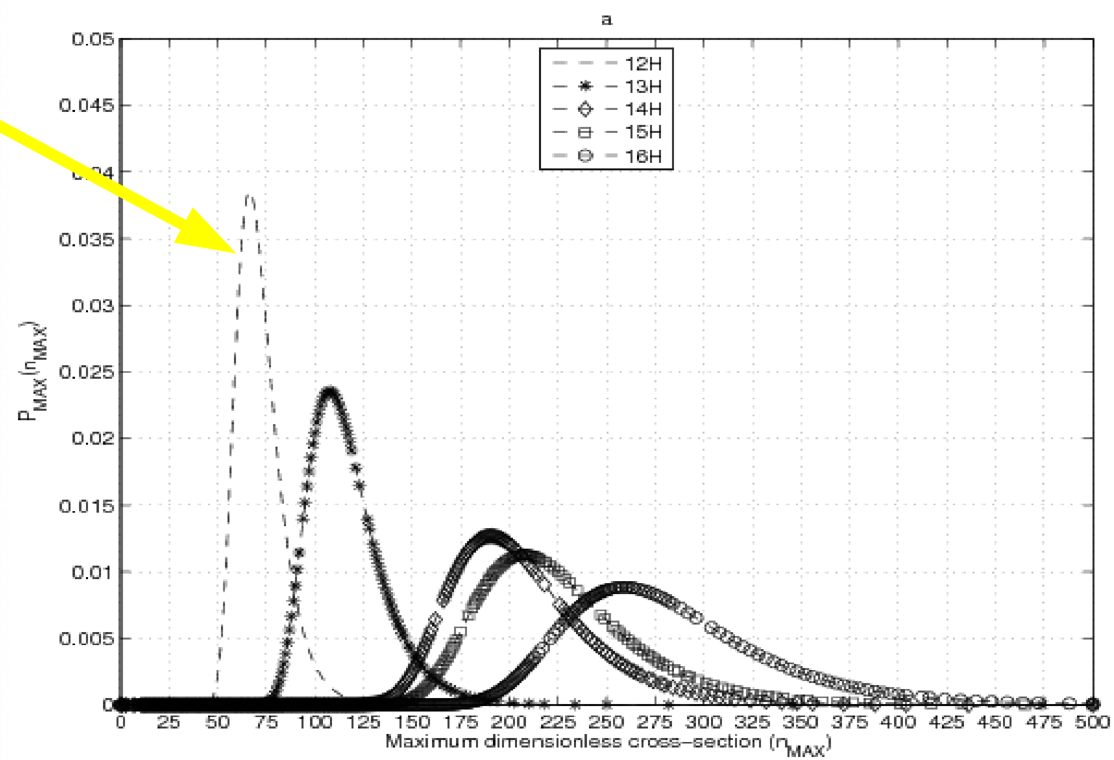
3- Stochastic physics: Deep convection triggering by boundary layer thermals

Stochastic trigger

- Analysis of LES (Large Eddy Simulation" of 10 July 2006 case over Niamey :
  1. PDF of cumulus sizes is exponential.
  2. deep convection triggers when there are large cumulus.
- Trigger = "largest cumulus size exceeds a given threshold"
- From PDF of Cu size ⟶ PDF of largest cumulus size
- From the thermal model ⟶ number of cumulus clouds per unit area
- ⟹ number of cumulo-nimbus per unit area
- ⟹ probability of triggering ; use of a random number generator to implement this probability (no trigger ⇒ ALE set to zero).

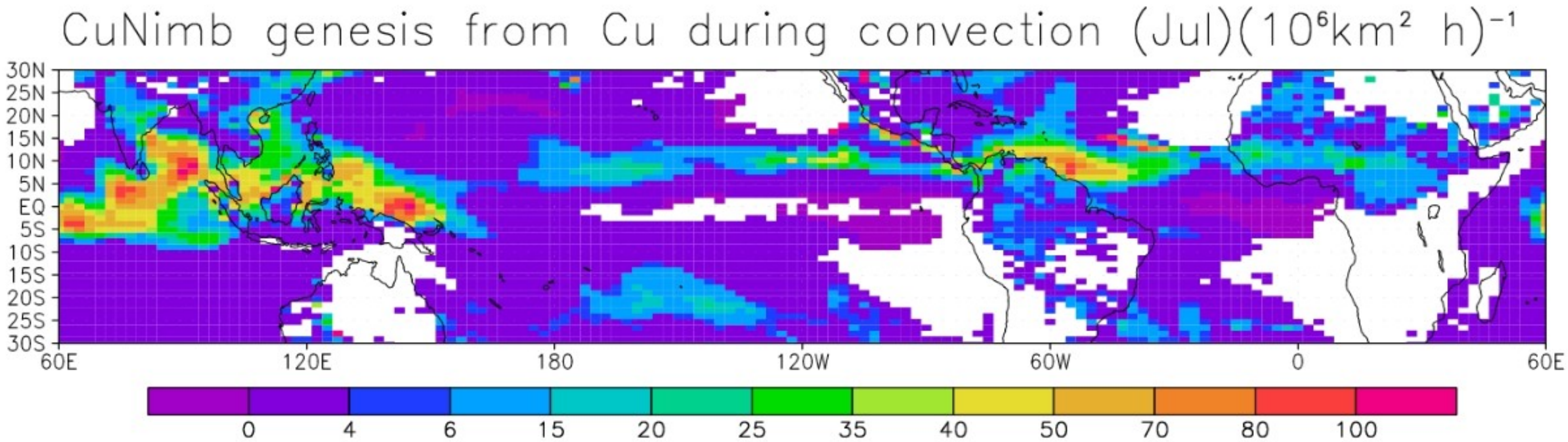
(Rochetin et al, JAS, 2014, I and II)

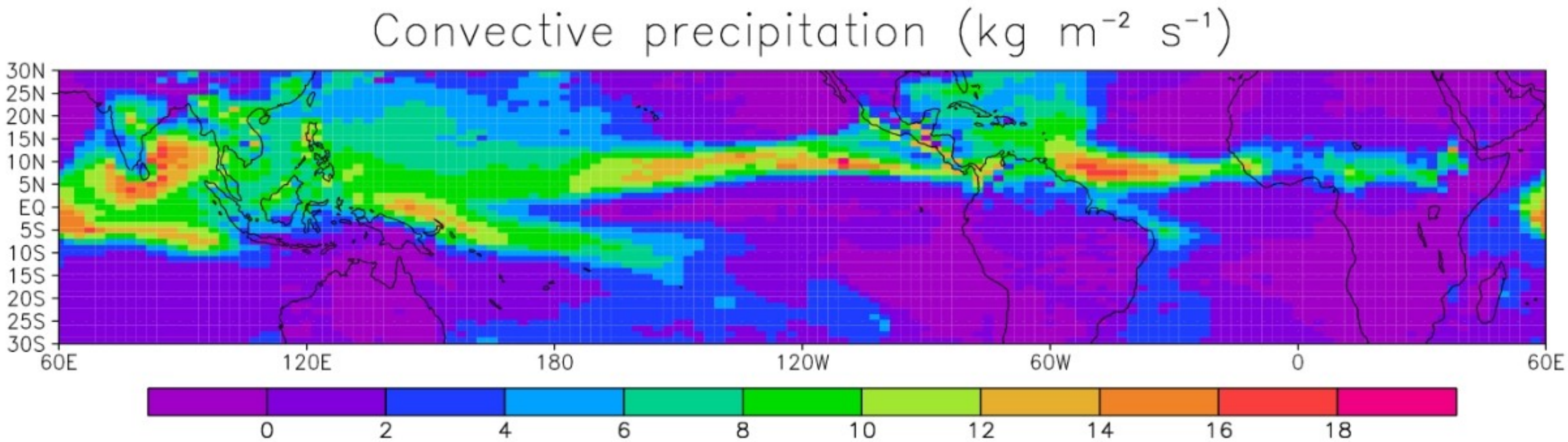




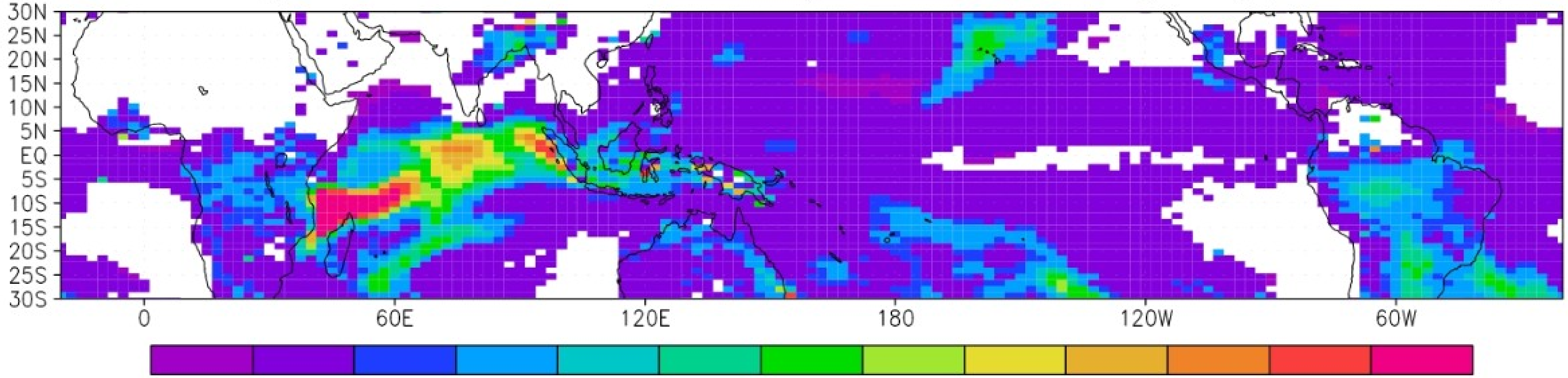
4 -Cumulonimbus & cold pool genesis

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.

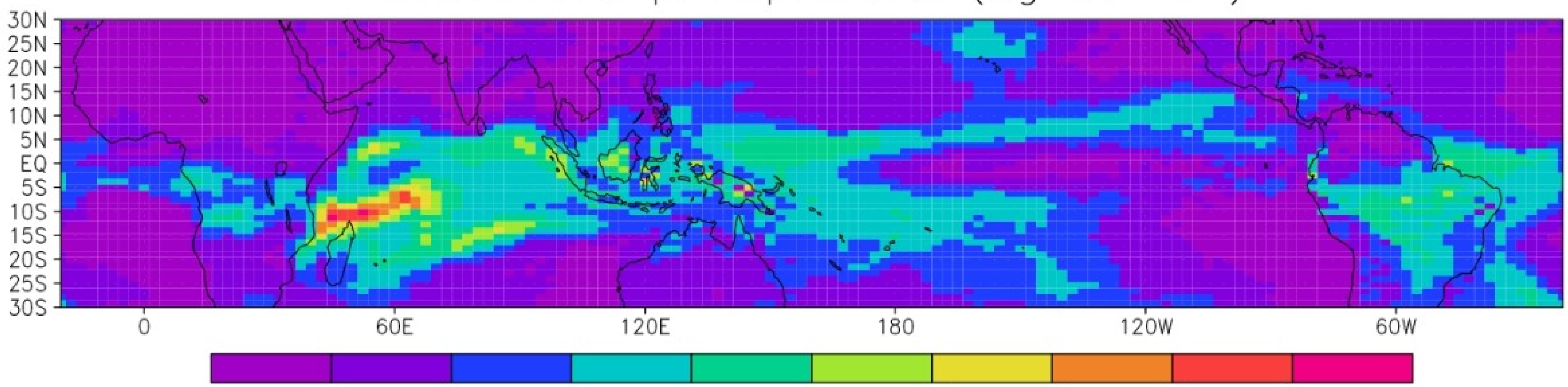




CuNimb genesis from Cu during convection (Feb)$(10^6 km^2\ h)^{-1}$



Convective precipitation $(kg\ m^{-2}\ s^{-1})$



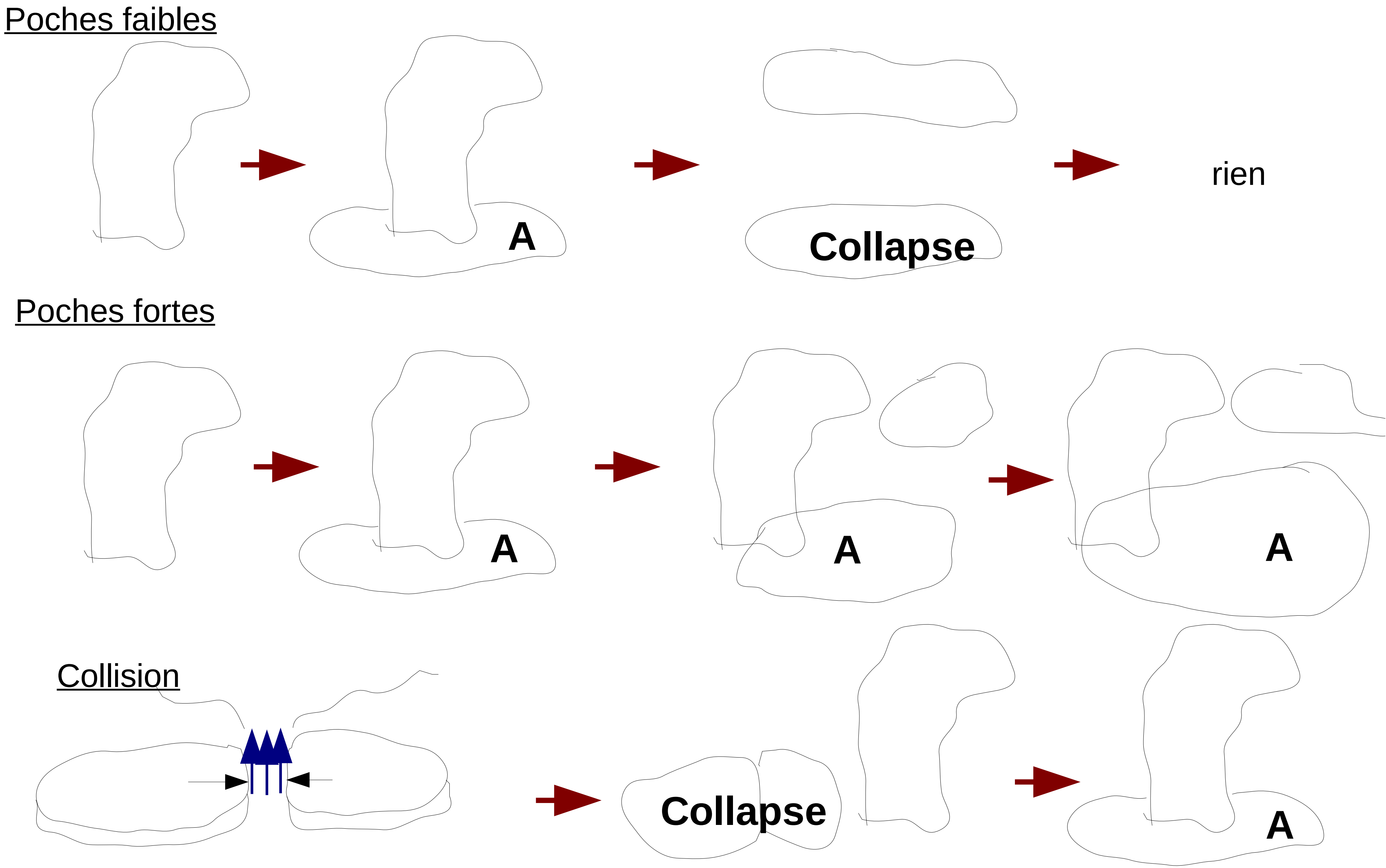
5 - The new scheme

Principle:

The cold pool (or wake) scheme describes a population of identical circular wakes. It is supposed to represent a population of wakes of various sizes and ages, some fed by a cumulonimbus (the “active” ones), others merely collapsing. These wakes may collide or merge. The purpose of the scheme is to describe the evolution of such a diverse population while representing a population of identical wakes.

Structure:

- Two categories of wakes: active (with Cu Nimb) and inactive (collapsing). ***D*** is the number of wakes per unit area and ***A*** the number of active ones. The active wakes become inactive when their attached CNs decay. The inactive ones decay by collapsing.
- The wake radius varies by three mechanisms: (i) spread (speed C*); (ii) genesis (new cold pools are small, hence cold pool genesis induces a decrease of the mean wake area); (iii) coalescence (when colliding wakes merge, yielding a larger wake, the average size increases).


Poches faibles
A
Collapse
rien
Poches fortes
A
A
A
Collision
Collapse
A

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

$$\left\{\begin{array}{lcl}\partial_t A & = & B - \dfrac{1}{\tau_{cv}}(A - \beta D) \\[2ex] \partial_t D & = & B - \dfrac{D - A}{\tau} - 4\pi r D^2 \partial_t r \\[2ex] \partial_t \sigma & = & B a_0 - \dfrac{\pi r^2}{\tau}(D - A) + 2\pi r D C_* \\ & & - \alpha 4\pi r D \partial_t r (2\sigma - D a_0)\end{array}\right.$$

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 ?).**

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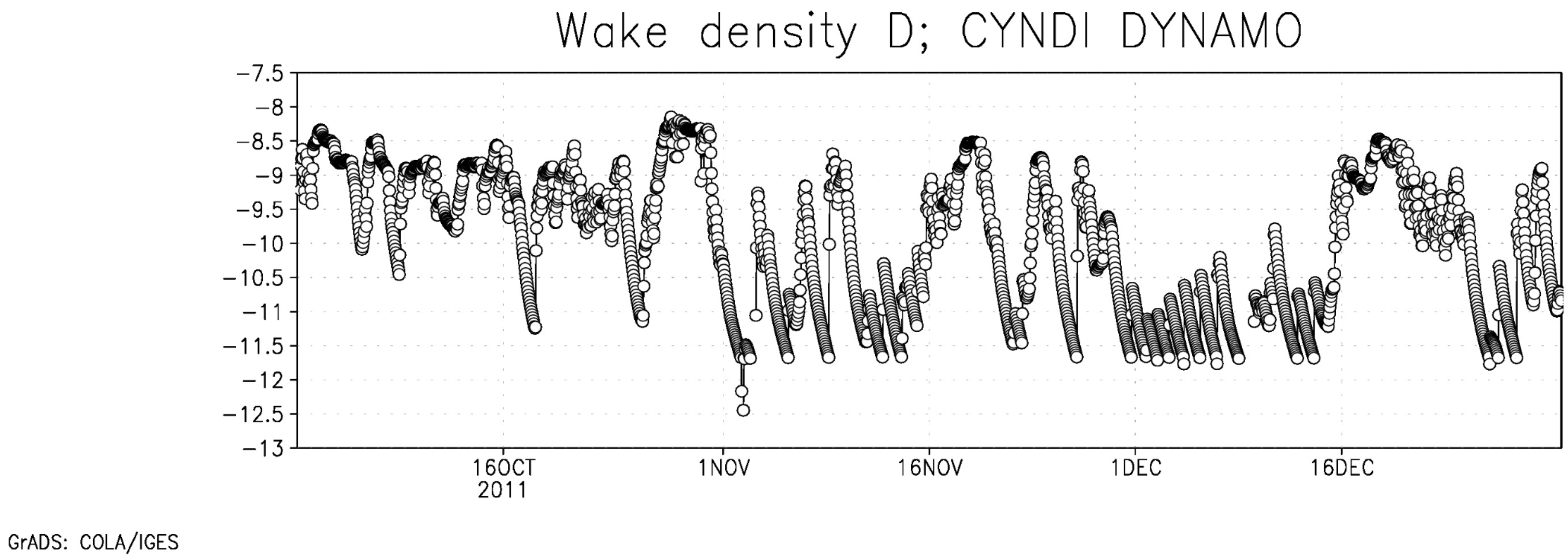
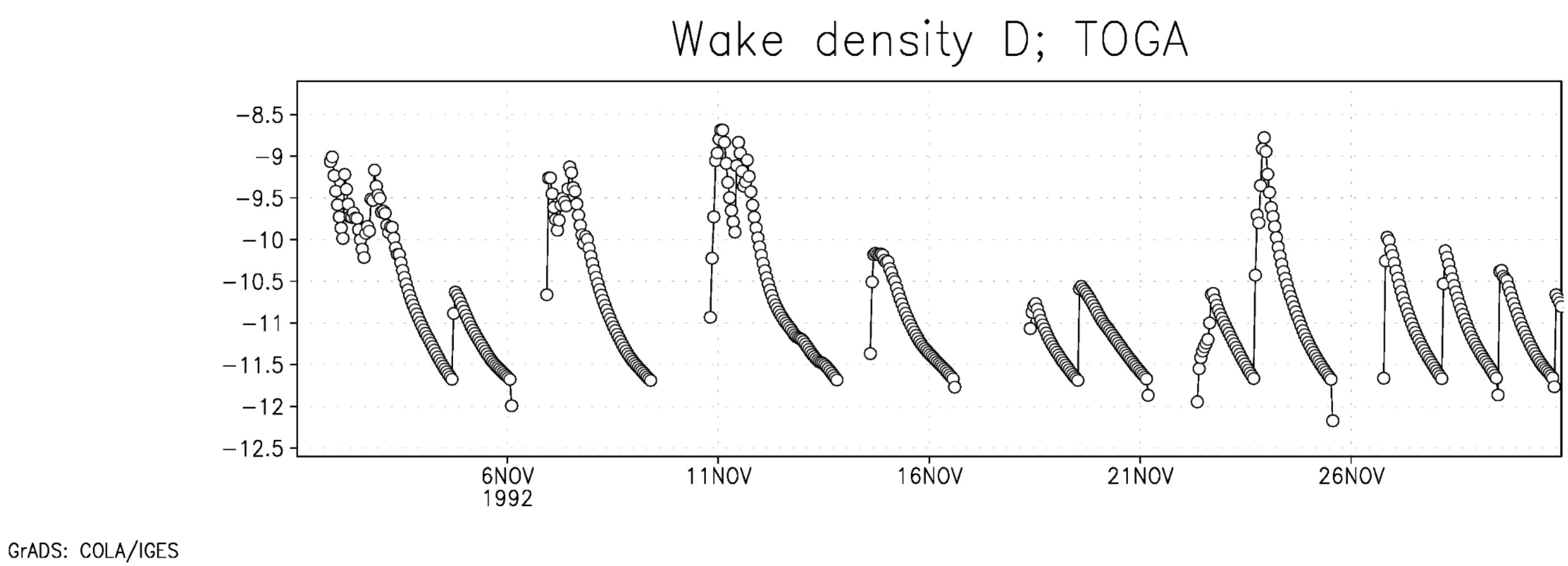
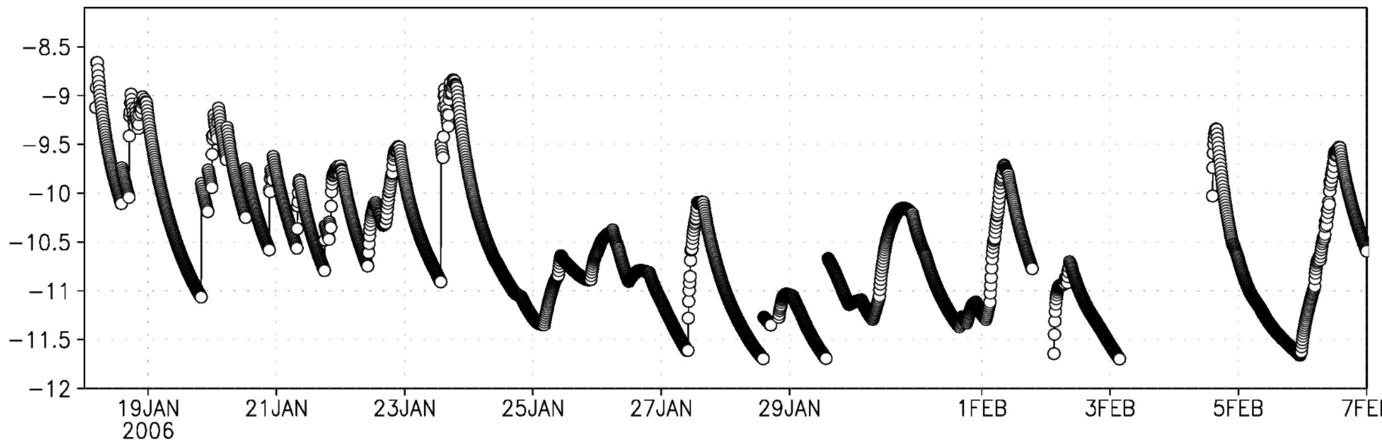
6 - Large variability of D, both short term (few hours) and long term (weeks)



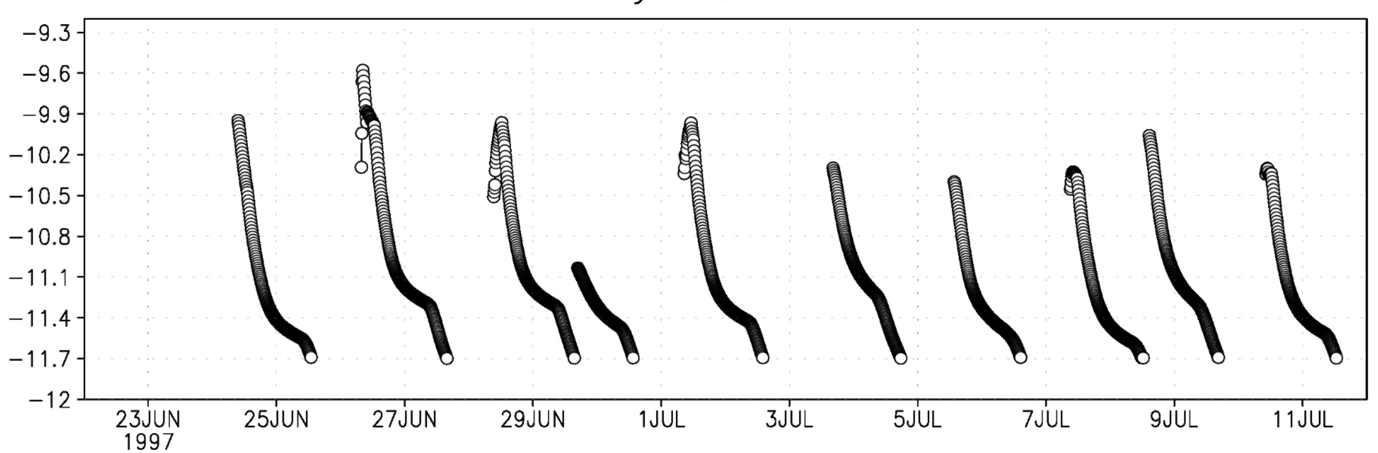


Wake density D; TWPIce



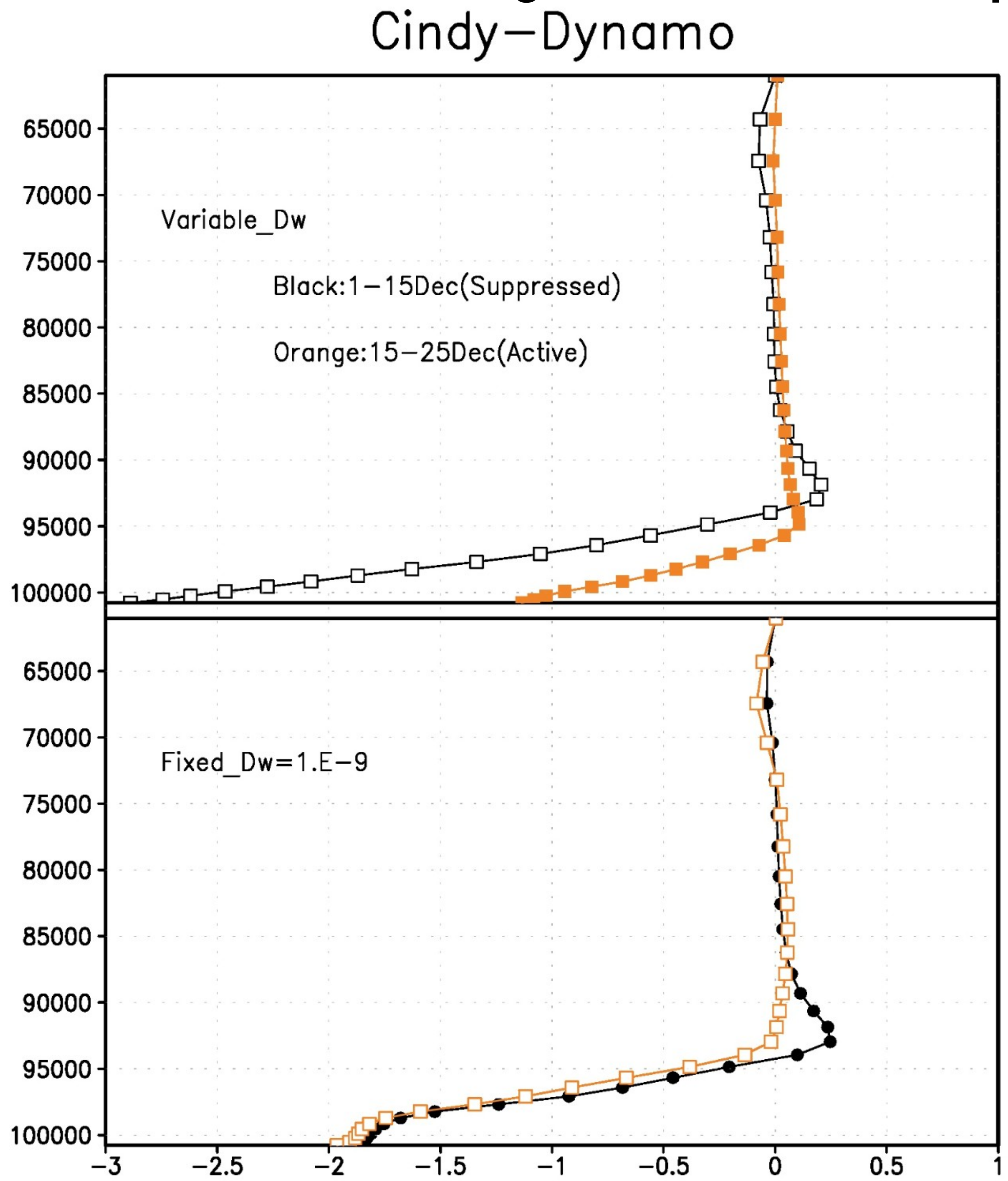
GrADS: COLA/IGES

Wake density D; RCE over land



GrADS: COLA/IGES

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.



Conclusion

- Le modèle de dynamique de la population des poches froides semble raisonable et prometteur.
- Mais résultats très préliminaires : manquent des études de sensibilité et un modéle pour l'activation des poches.
- Impact significatif sur la convection profonde et les poches froides.
- Va permettre d'abandoner les valeurs prescrites de la densité de poches froides fonction de la nature de la surface.
- Constitue un premier pas vers la représentation de l'advection de poches froides de maille en maille.