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

Jean-Yves Grandpeix, LMDZ Team

1- The ALP-ALE system: coupling boundary layer thermals, deep convection and density currents. (LMD & CNRM)
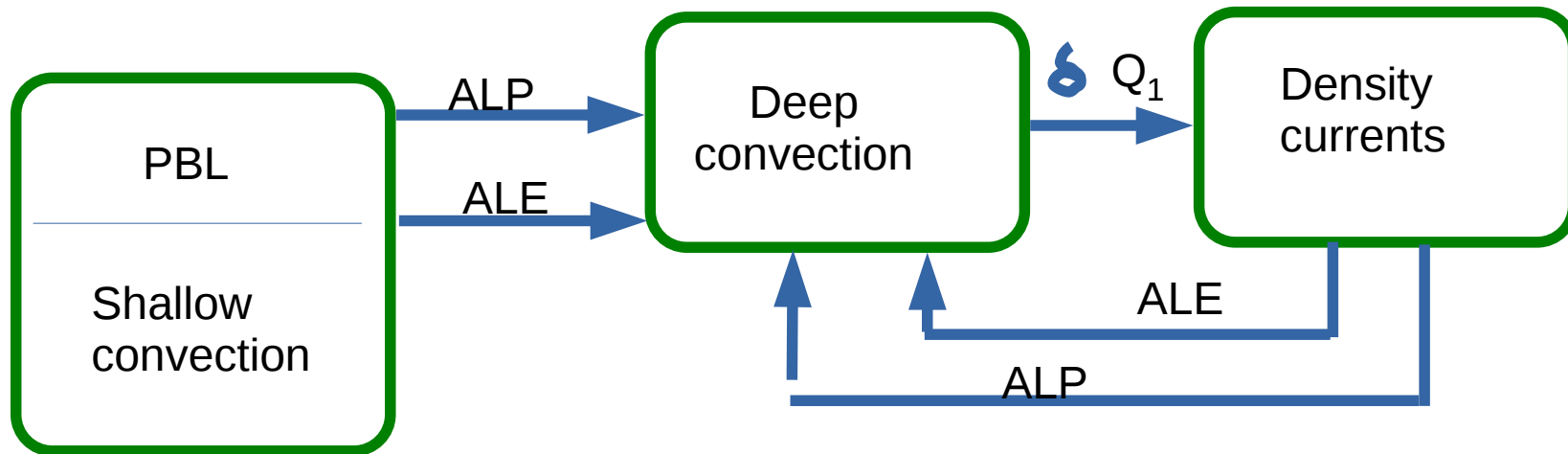
- Deep convection trigger given by the Available Lifting Energy (ALE) :

ALE > |CIN| ==> deep convection is triggered
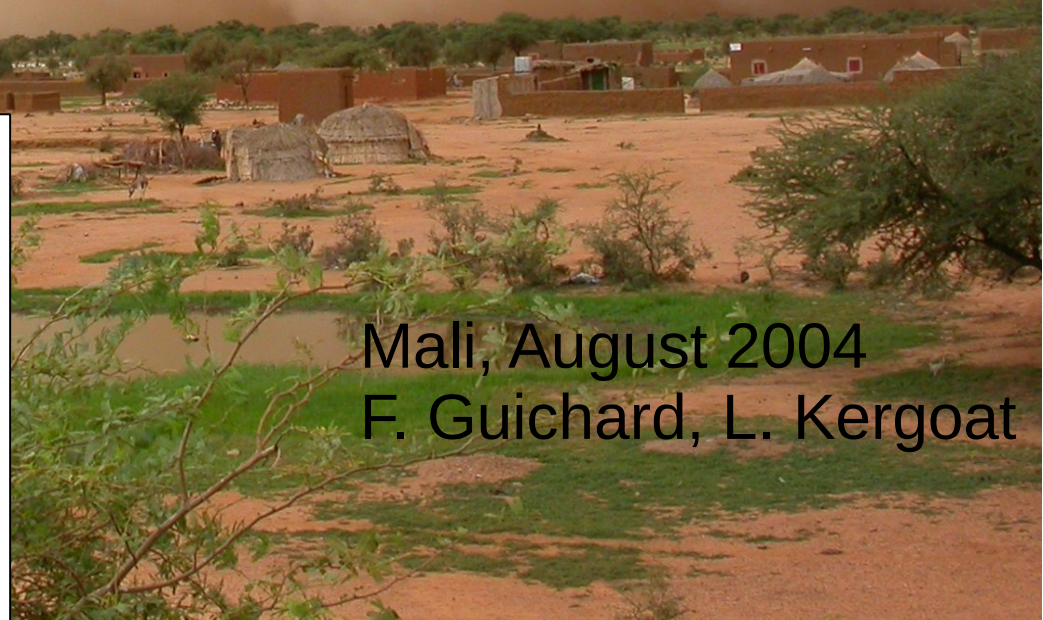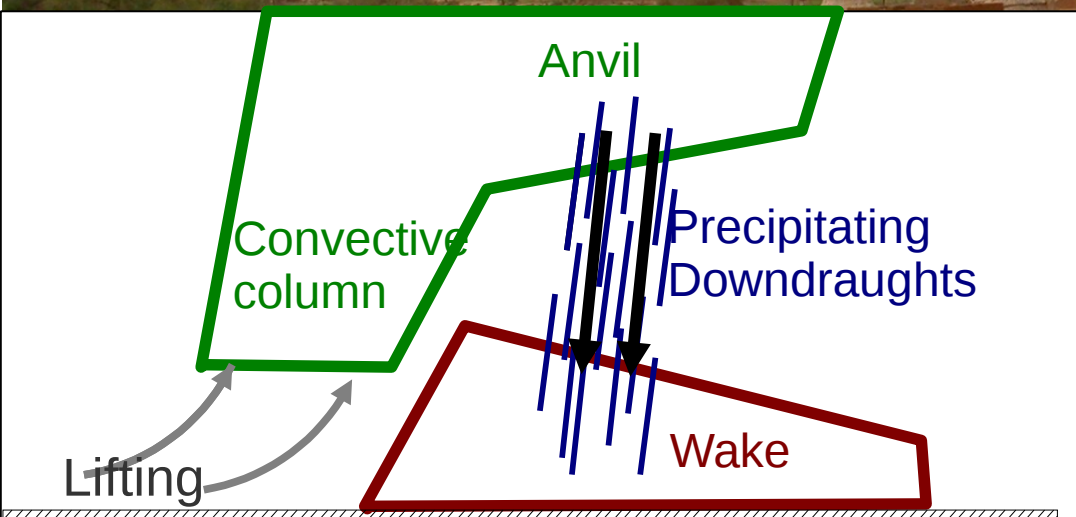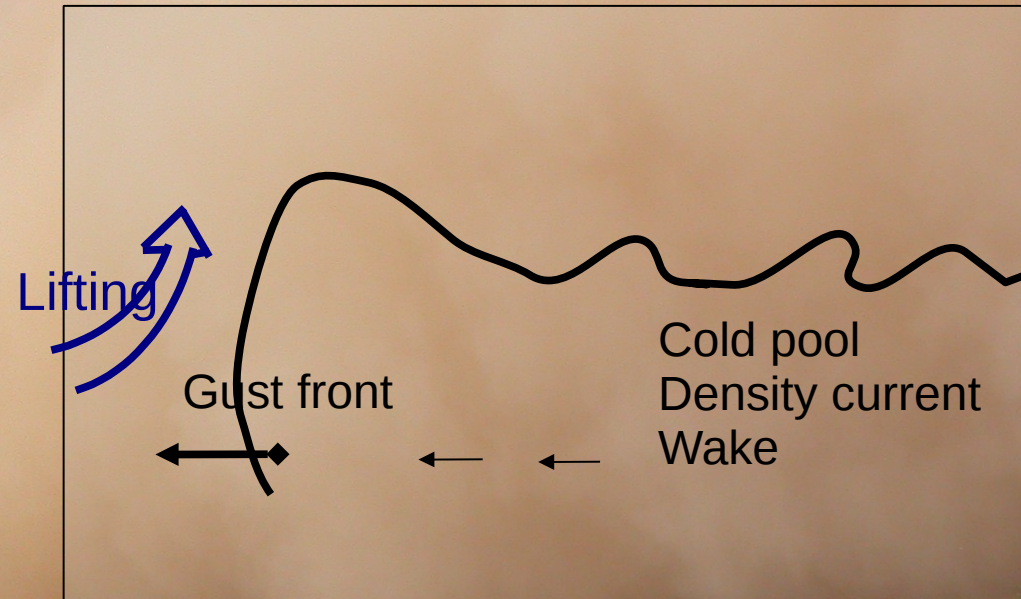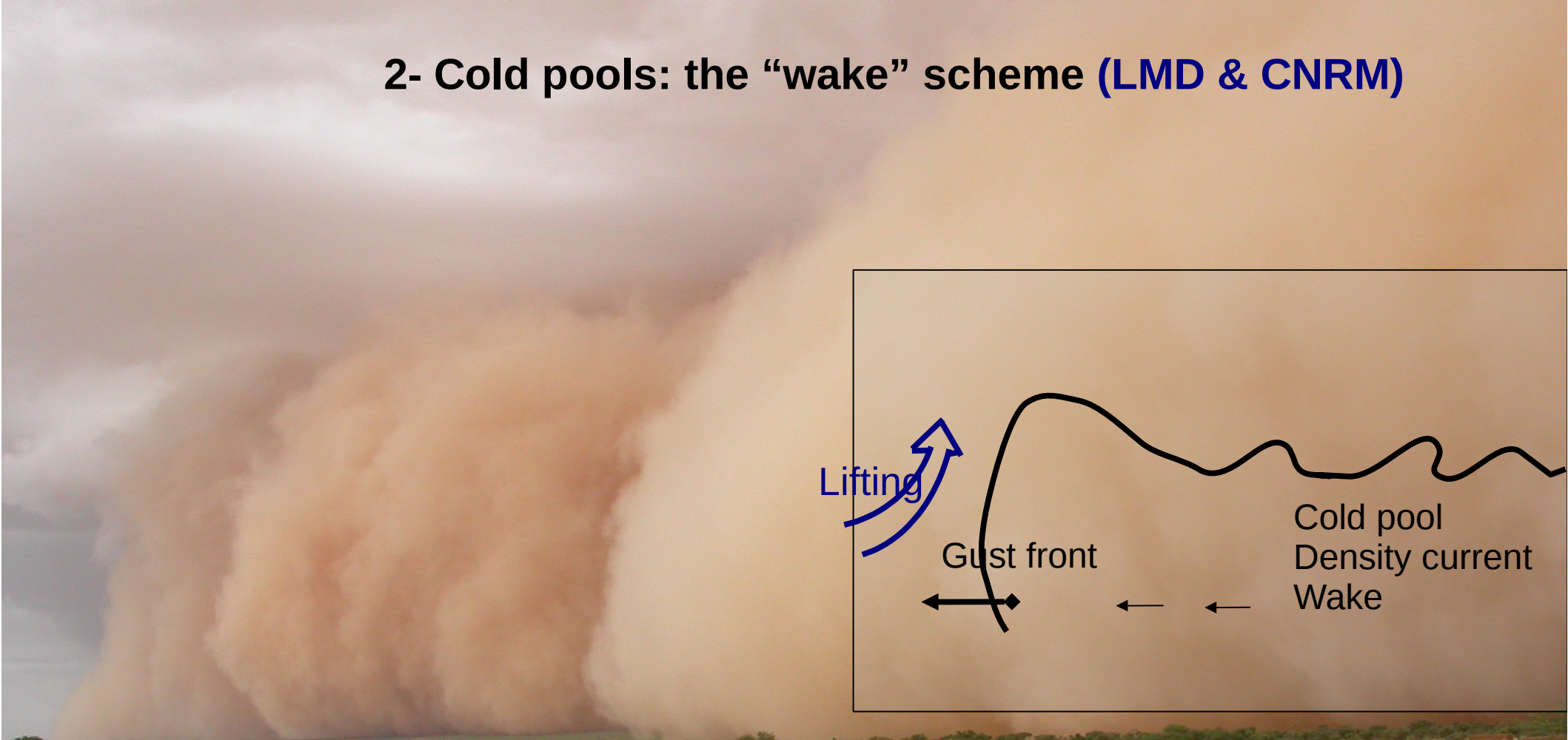
- Closure given by the Available Lifting Power (ALP) :

$$M = ALP/(2\ W_B^2 + |CIN|)\ ;$$

M = cloud base mass flux; W_B = updraught velocity at LFC

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

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_{wk}.
- State variables : (i) surface fraction covered by the wakes $\sigma_w = \frac{S_w}{S_t}$ ($\sigma_w = \pi r^2 D_{\mathrm{wk}}$), (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).
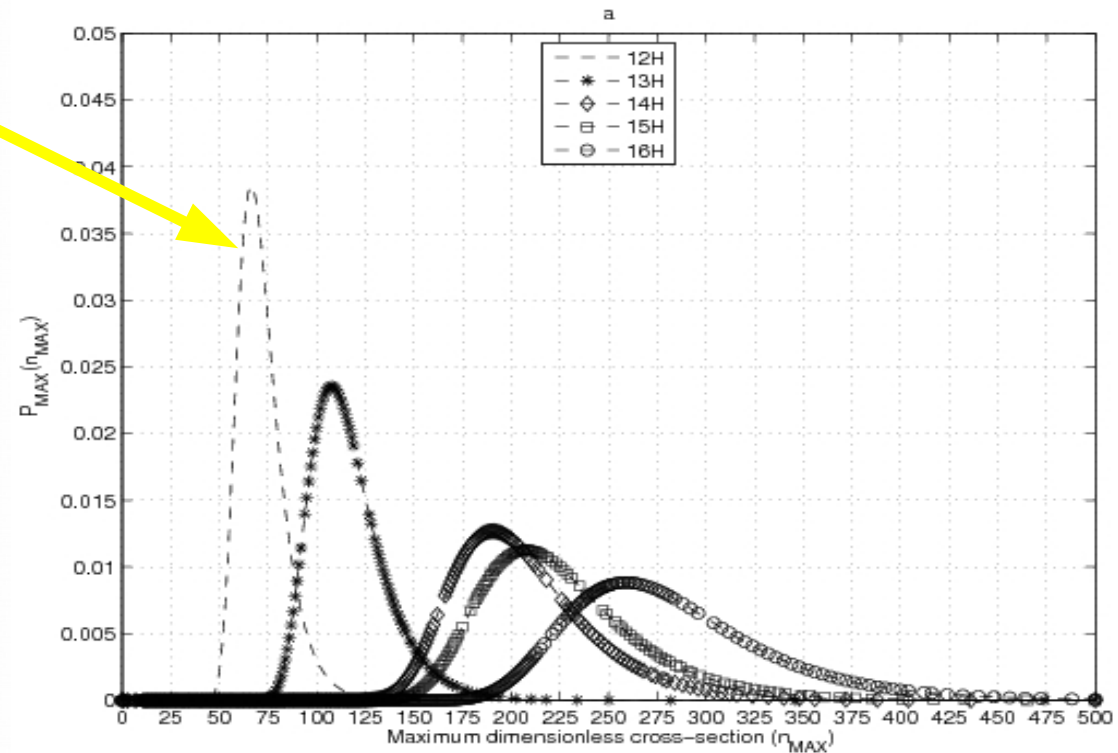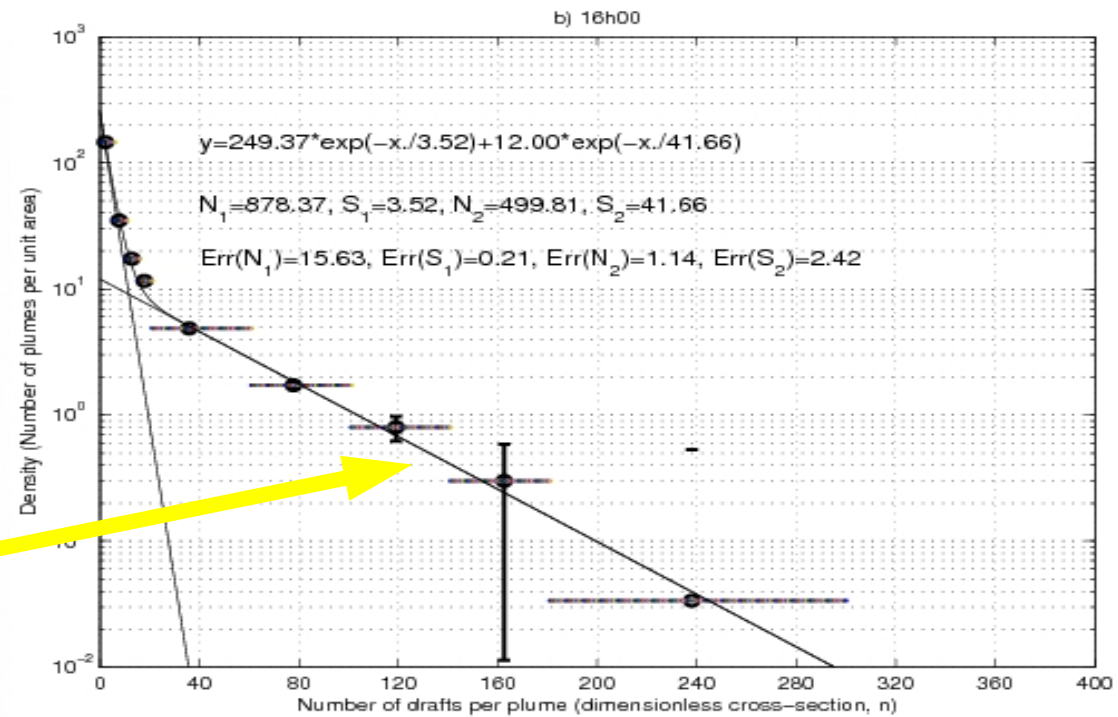
Wake differential profiles
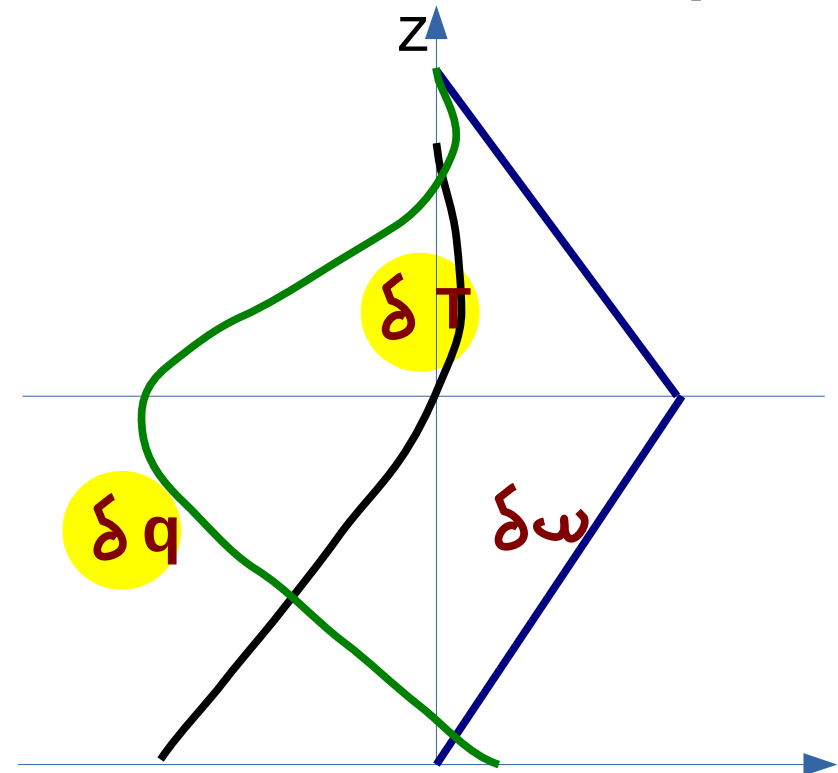
3- Stochastic physics:
Deep convection triggering
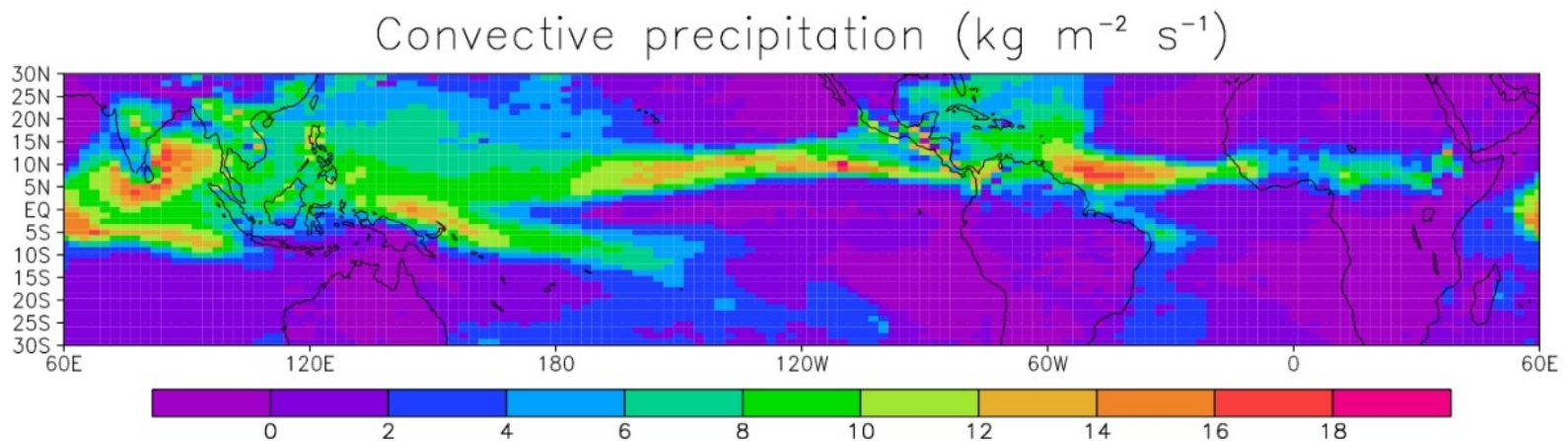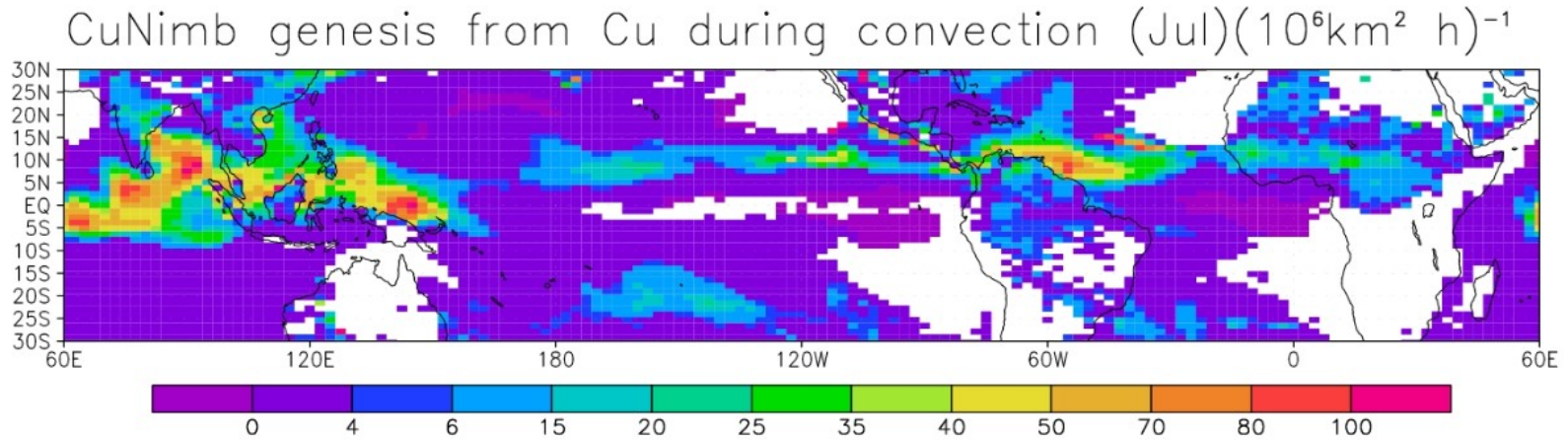# by boundary layer thermals

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 $\longrightarrow$ PDF of largest cumulus size

– From the thermal model $\longrightarrow$ number of cumulus clouds per unit area

– $\Longrightarrow$ number of cumulo-nimbus per unit area

– $\Longrightarrow$ probability of triggering ; use of a random number generator to implement this probability (no trigger $\Rightarrow$ ALE set to zero).

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

b) 16h00

$y=249.37*\exp(-x./3.52)+12.00*\exp(-x./41.66)$

$N_1=878.37$, $S_1=3.52$, $N_2=499.81$, $S_2=41.66$

$Err(N_1)=15.63$, $Err(S_1)=0.21$, $Err(N_2)=1.14$, $Err(S_2)=2.42$

Density (Number of plumes per unit area)

Number of drafts per plume (dimensionless cross–section, n)

a

- – - 12H
- – * – 13H
- – ◇ – 14H
- – ⊟ – 15H
- – ⊖ – 16H

$P_{MAX}(n_{MAX})$

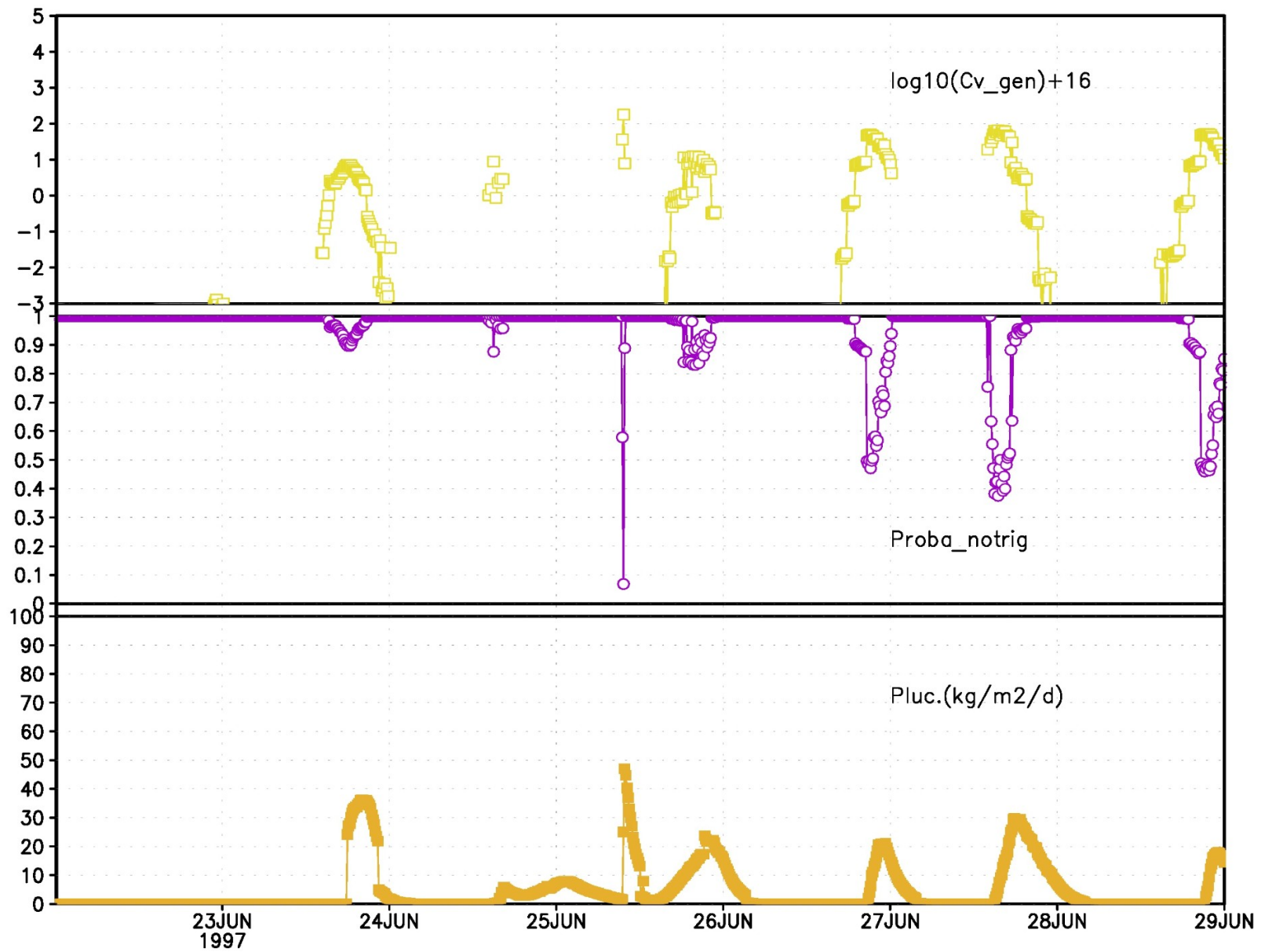Maximum dimensionless cross–section (n_{MAX})

4 -Cumulonimbus & cold pool genesis

CuNimb genesis rate diagnosed from an LMDZ AMIP simulation.
Order of Magnitude : 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 (Jul)$(10^6 km^2\ h)^{-1}$

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

Cas equilibre radiatif-convectif humide

Moist RCE over land

Plot with three stacked panels sharing a time axis from 23JUN 1997 to 29JUN.

- Top panel (yellow squares), vertical axis from −3 to 5: $\log_{10}(C_{v\_gen})+16$
- Middle panel (purple/magenta circles), vertical axis from 0 to 1: Proba_notrig
- Bottom panel (orange), vertical axis from 0 to 100: Pluc.(kg/m2/d)
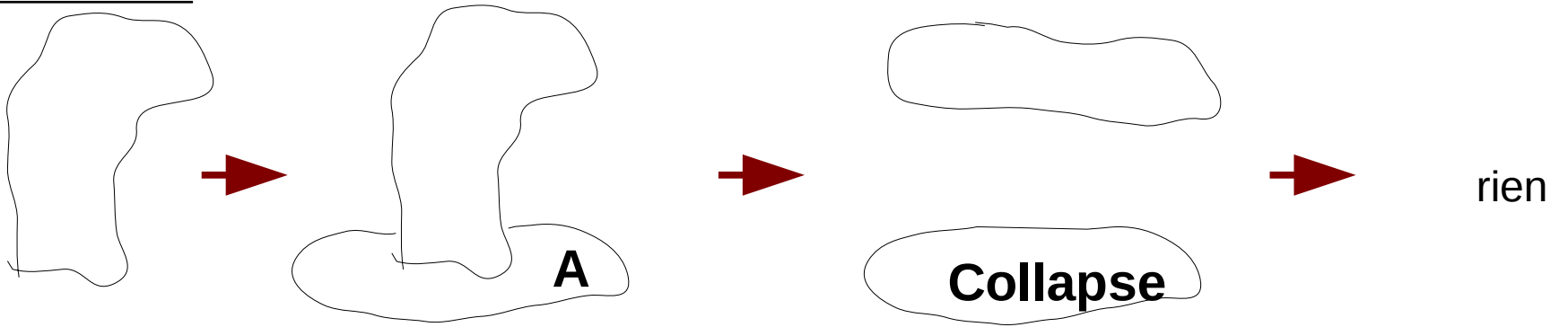
5 - The new scheme

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.
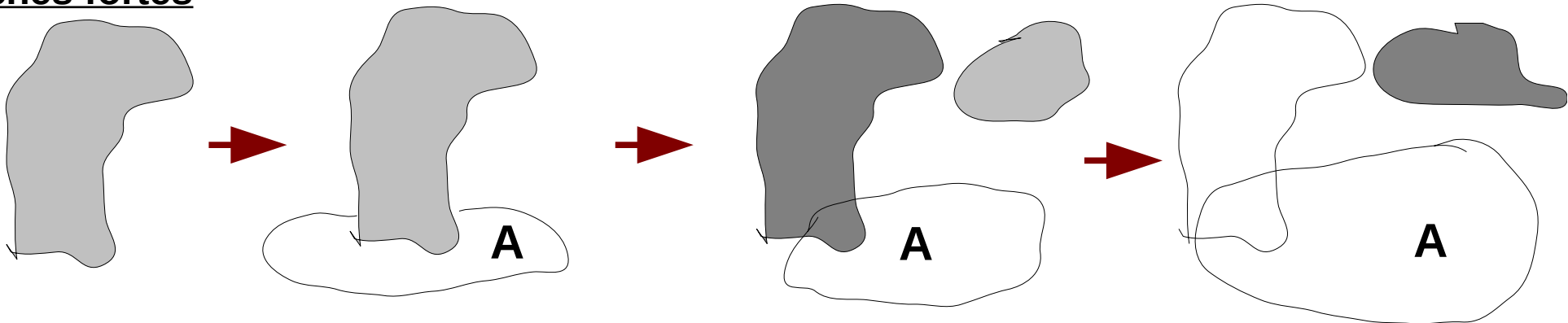
Structure:
- Two categories of wakes: active (with Cu Nimb) and inactive (collapsing). *D* is the number of wakes per unit area and *A* the number of active ones. The active wakes become inactive when their attached CNs decay. The inactive ones decay by collapsing.
- The wake radius varies by three mechanisms: (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).
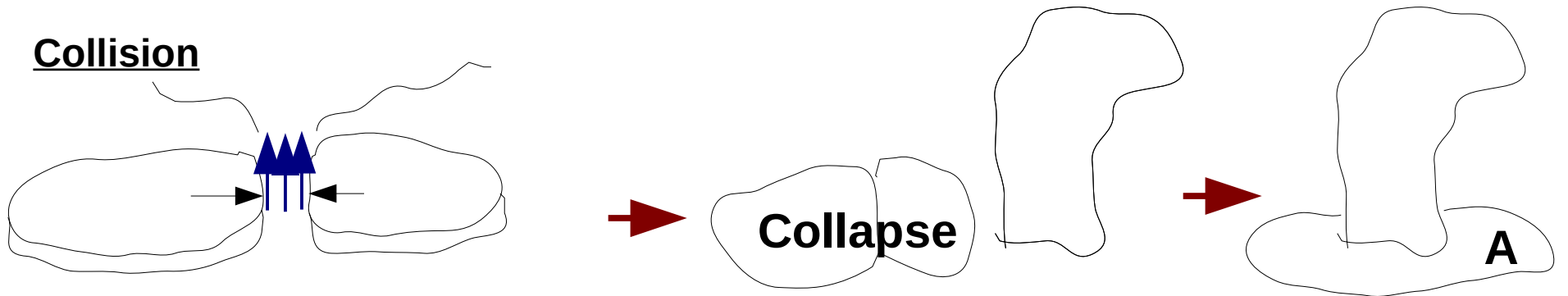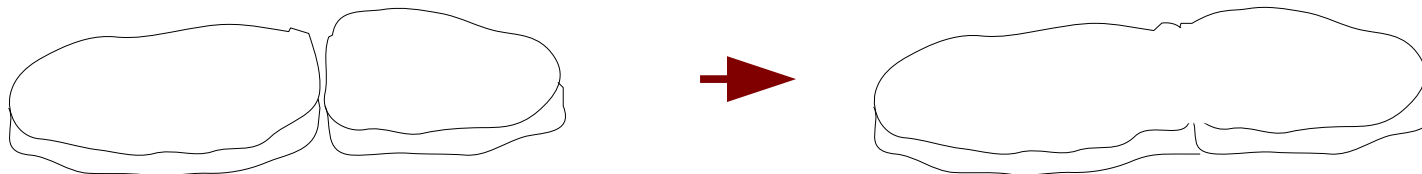
Poches faibles

A

Collapse

rien

Poches fortes

A

A

A

Collision

Collapse

A

Fusion

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

$$
\begin{cases}
\partial_t A = B - \dfrac{1}{\tau_{cv}}(A - \beta D) \\[2mm]
\partial_t D = B - \dfrac{D - A}{\tau} - 4\pi r D^2 \partial_t r \\[2mm]
\partial_t \sigma = B a_0 - \dfrac{\pi r^2}{\tau}(D - A) + 2\pi r D C_* \\[1mm]
\qquad\quad - \alpha 4\pi r D \partial_t r (2\sigma - D a_0)
\end{cases}
$$

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 $\mathrm{ALE_{wk}} < \mathrm{CIN}$.
- 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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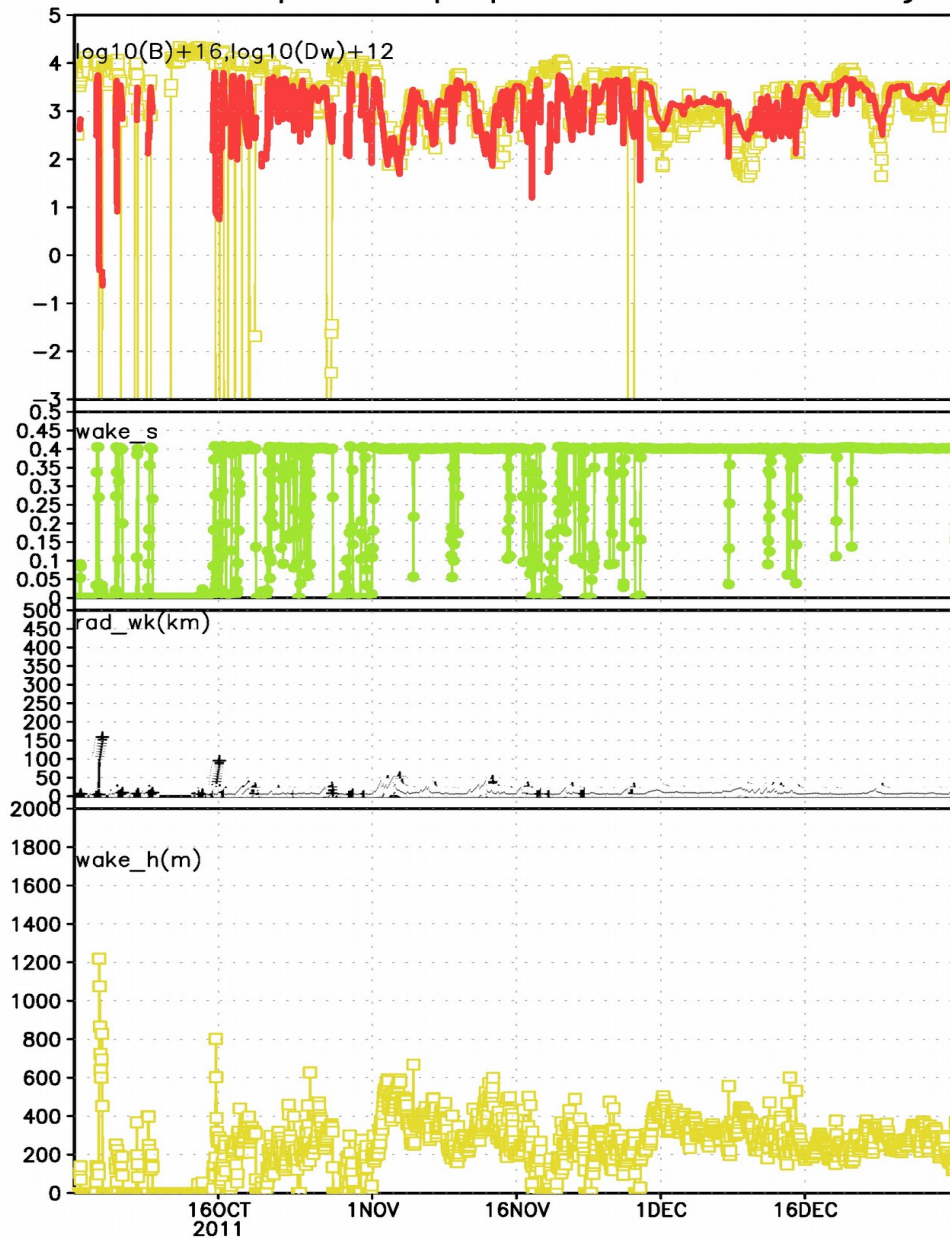
NPv5.70−popd−0L79lmd2 ; cindynamo

log10(B)+16,log10(Dw)+12

wake_s

rad_wk(km)

wake_h(m)

16OCT
2011

1NOV

16NOV

1DEC

16DEC

1
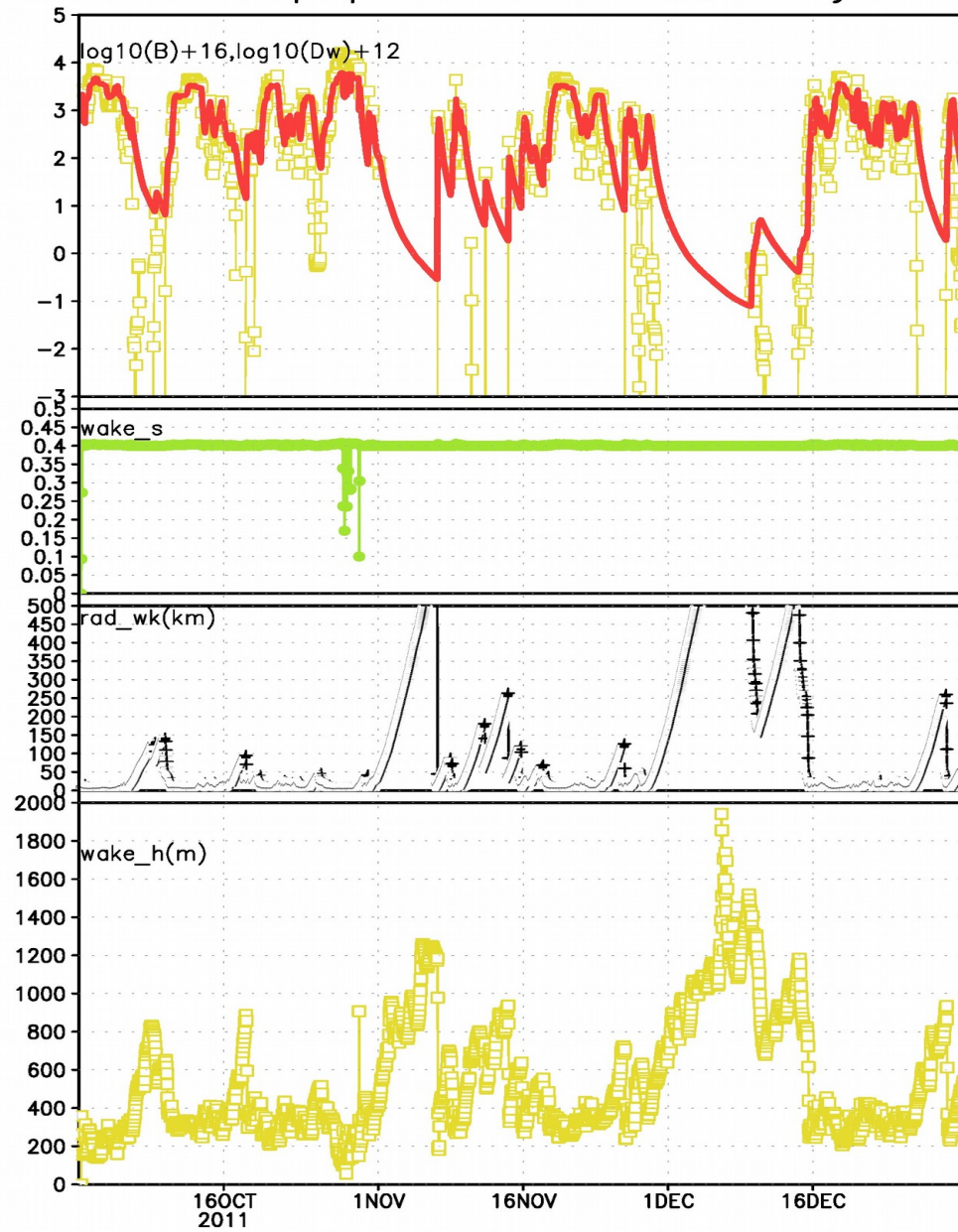
7 - Strong effect of D variability on wake properties:
Fixed D ==> wake profiles unchanged between suppressed and active phase during Cindy ;
Variable D ==> strong difference of wake profiles.
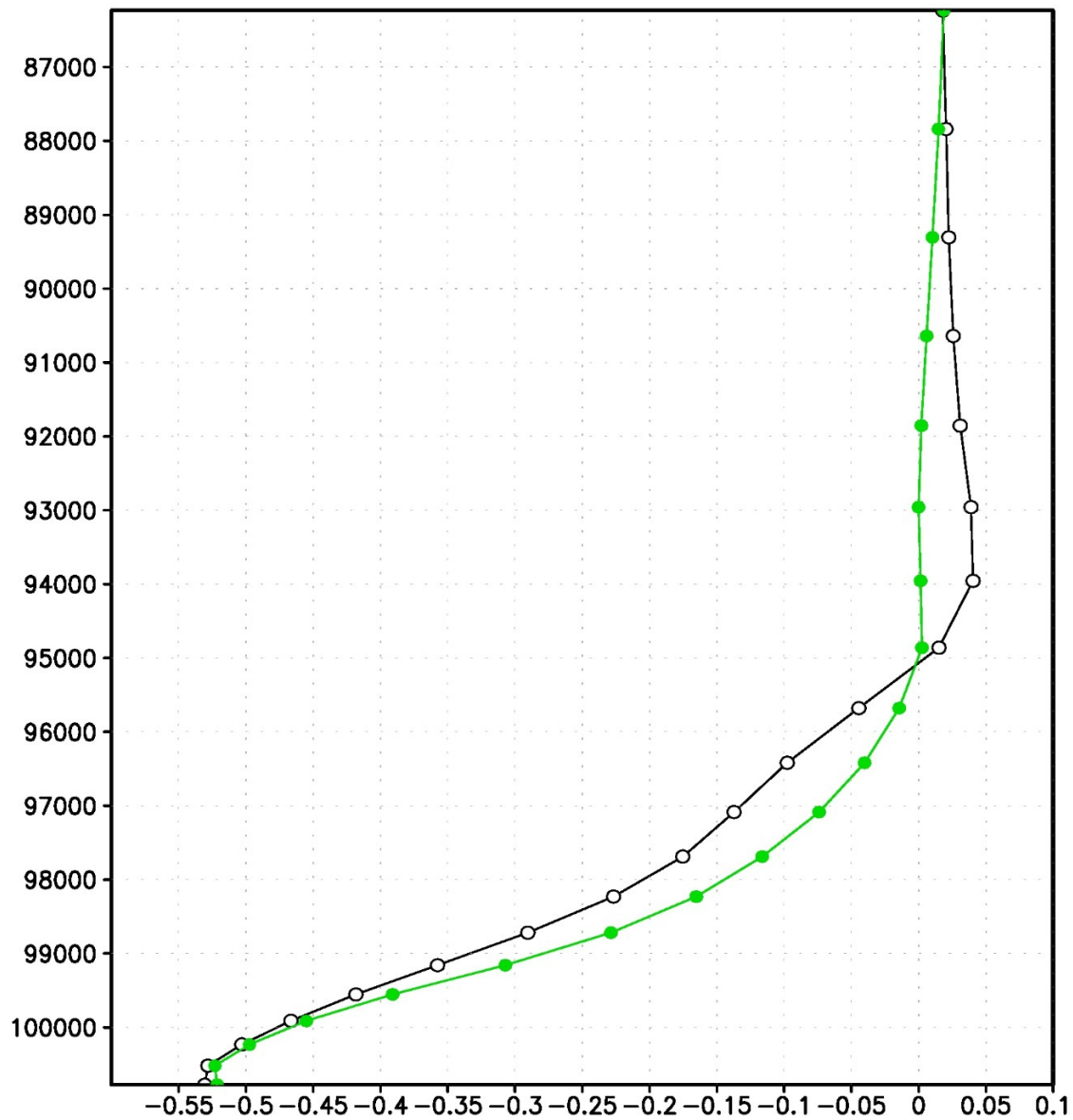

Cindy-Dynamo

Variable_Dw

Black:1-15Dec(Suppressed)

Orange:15-25Dec(Active)

Fixed_Dw=1.E-9
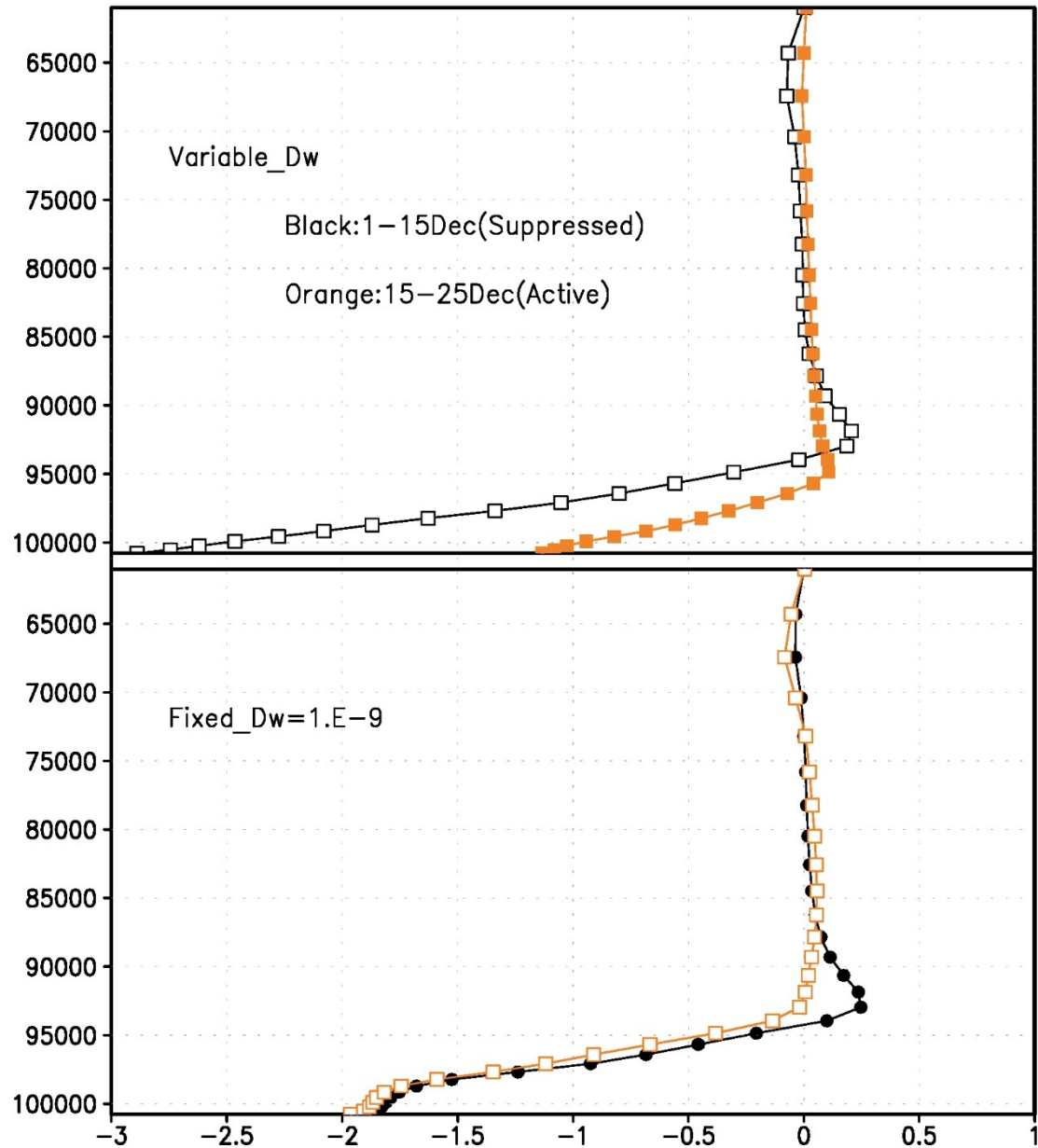
Cindy-Dynamo Beta=1

NPv6.0.14—splith10popdL79lmd2 ; cindynam

Cindy-Dynamo Beta=1

wake_deltat. noir=1-15Dec, vert=15-25Dec

GrADS: COLA/IGES

2018-06-25-14:20

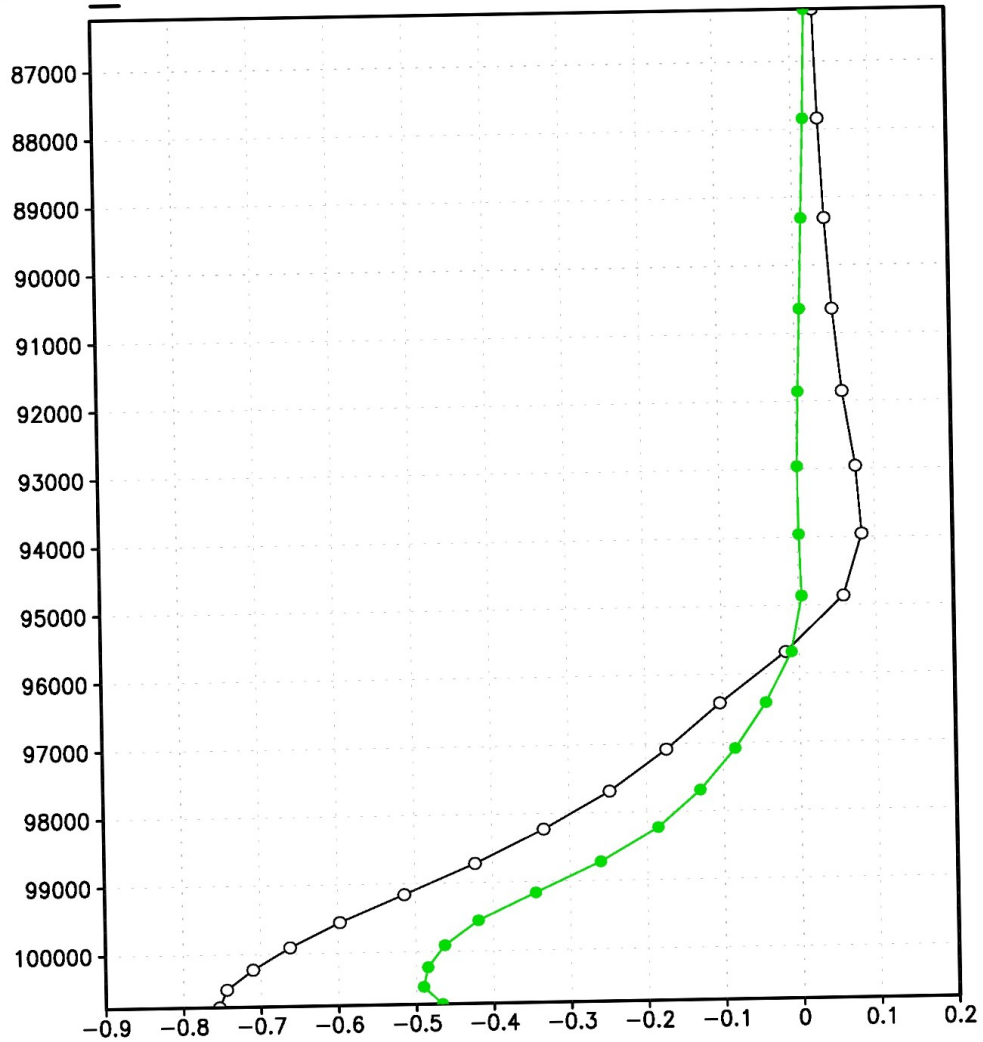# Cindy-Dynamo Beta=0

NPv6.0.14—splith10popdact0L79lmd2 ; cindyna
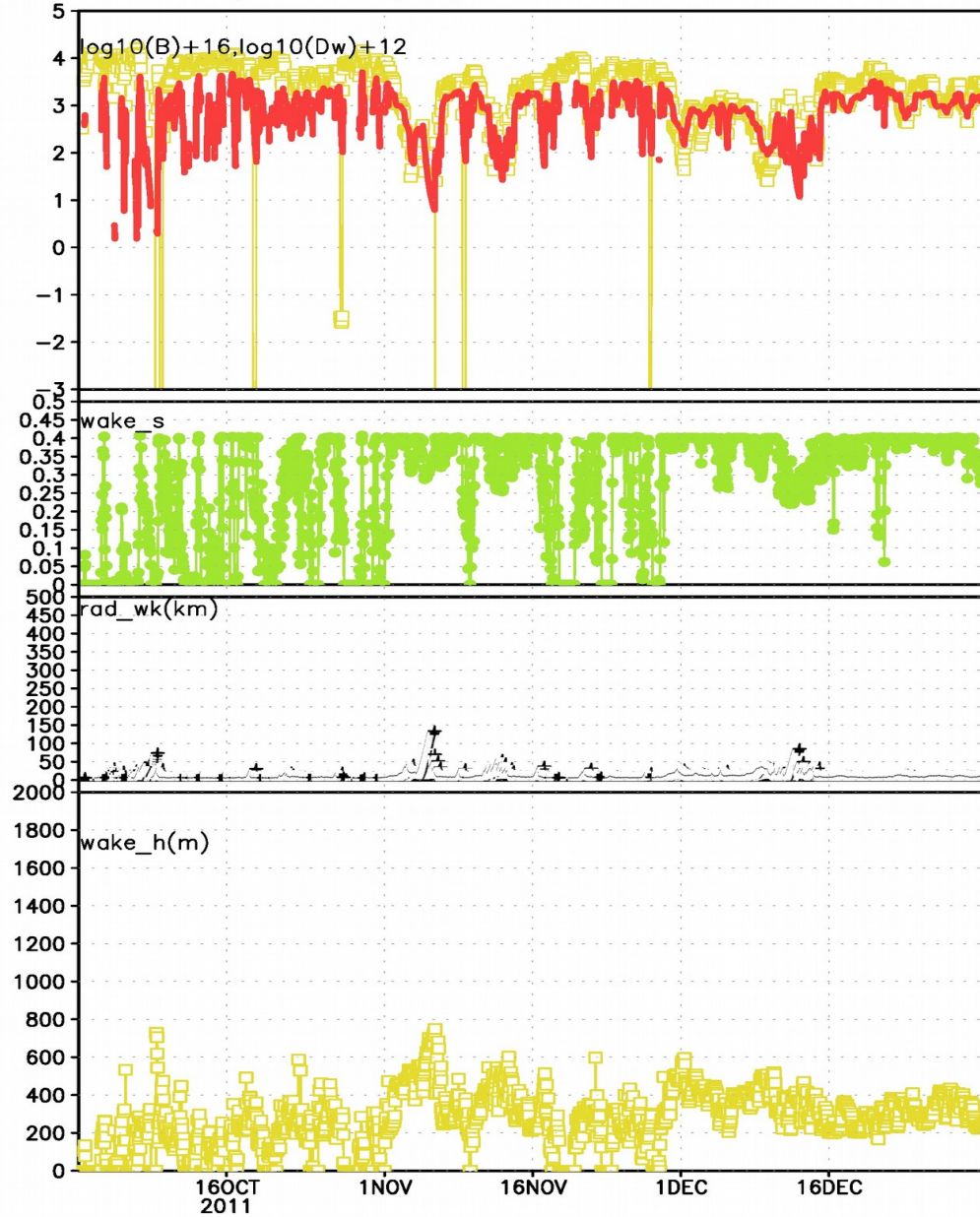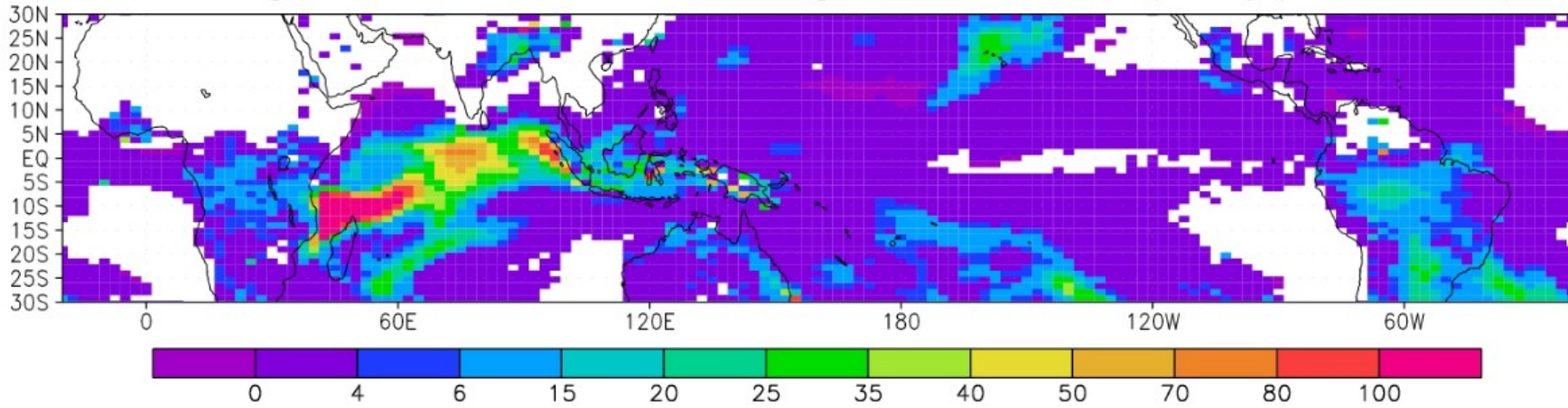
Cindy-Dynamo Beta=0

wake_deltat. noir=1-15Dec, vert=15-25Dec

2018-06-25-14:22

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 en fonction de la nature de la surface.

- Constitue un premier pas vers la représentation de l'advection de poches froides de maille en maille.

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

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