A parametrization of the dynamics of cold pool population in the LMDZ GCM

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UTCC - PROES ; 22-24 October 2018

Some LMDZ GCM present issues

LMDZ GCM :

- deep convection driven by boundary layer cloudy thermals and by cold pools (wakes).
- No propagation nor transport of deep convection

Problems among others :

- it rains every day over tropical oceans.
- poor variability (e.g. MJO)

Unsatisfactory feature : The number density of cold pools is prescribed (10^{-9} wakes per m^2 over ocean and $8\ 10^{-12}$ over land).

Objectives :

- Get rid of prescribed wake density
- Variability of precipitation
- Represent aggregation
- Farther : represent propagation.

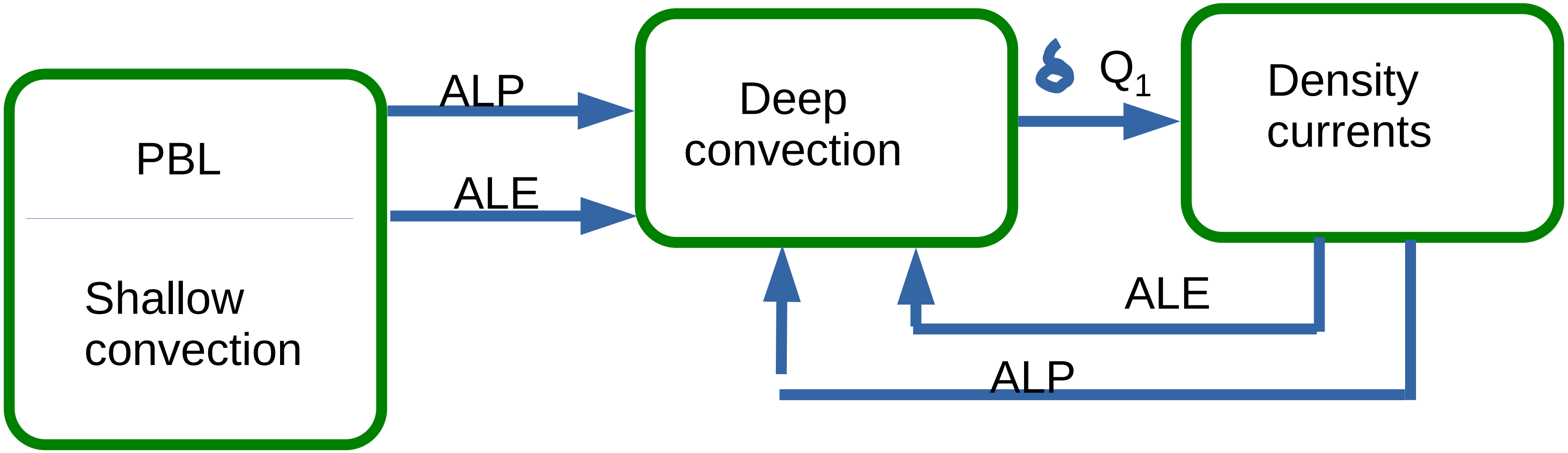
1- The ALP-ALE system: coupling boundary layer thermals, deep convection and density currents. (LMD & CNRM)

- 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



PBL

Shallow convection

ALP

ALE

Deep convection

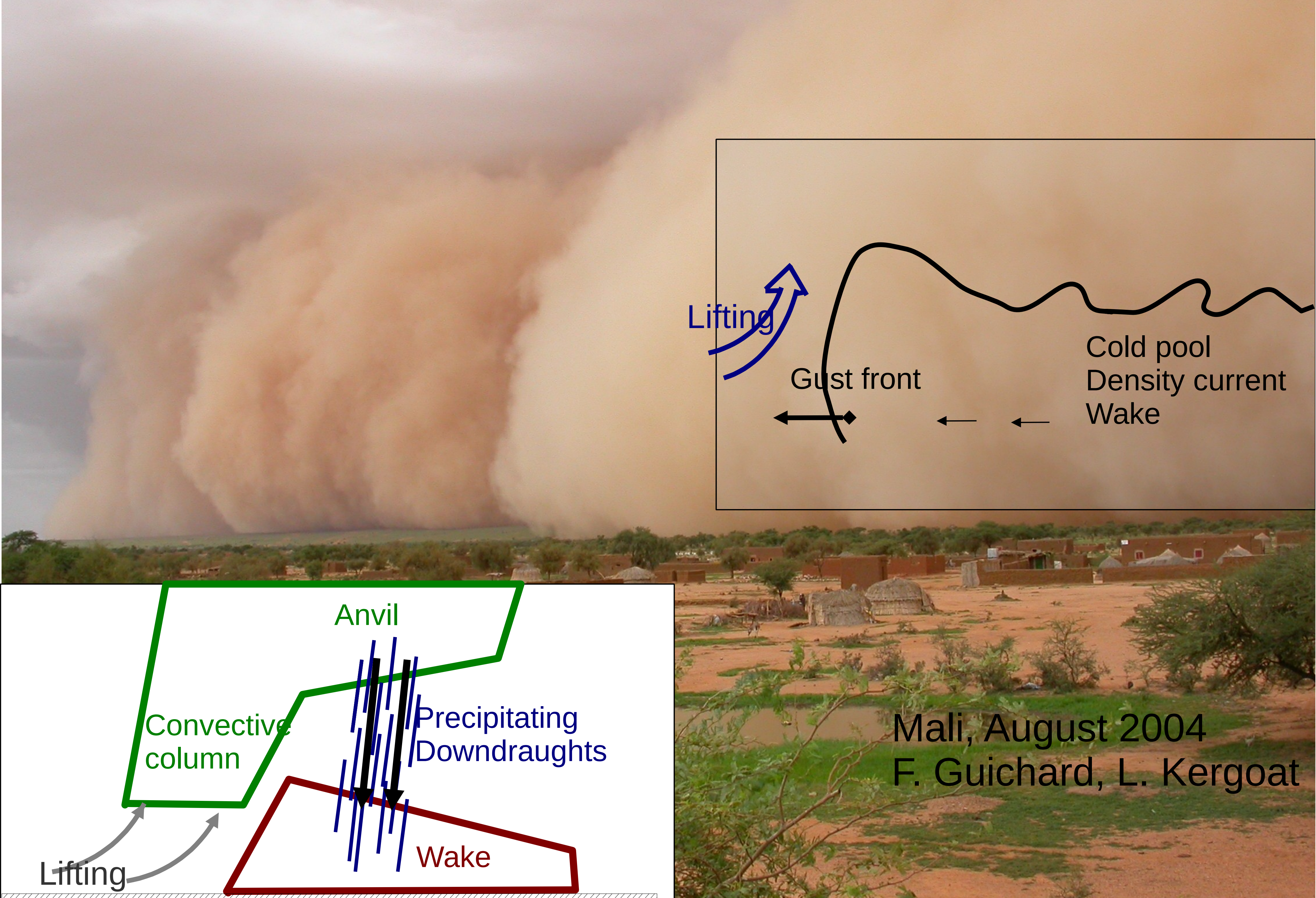
δQ_1

Density currents

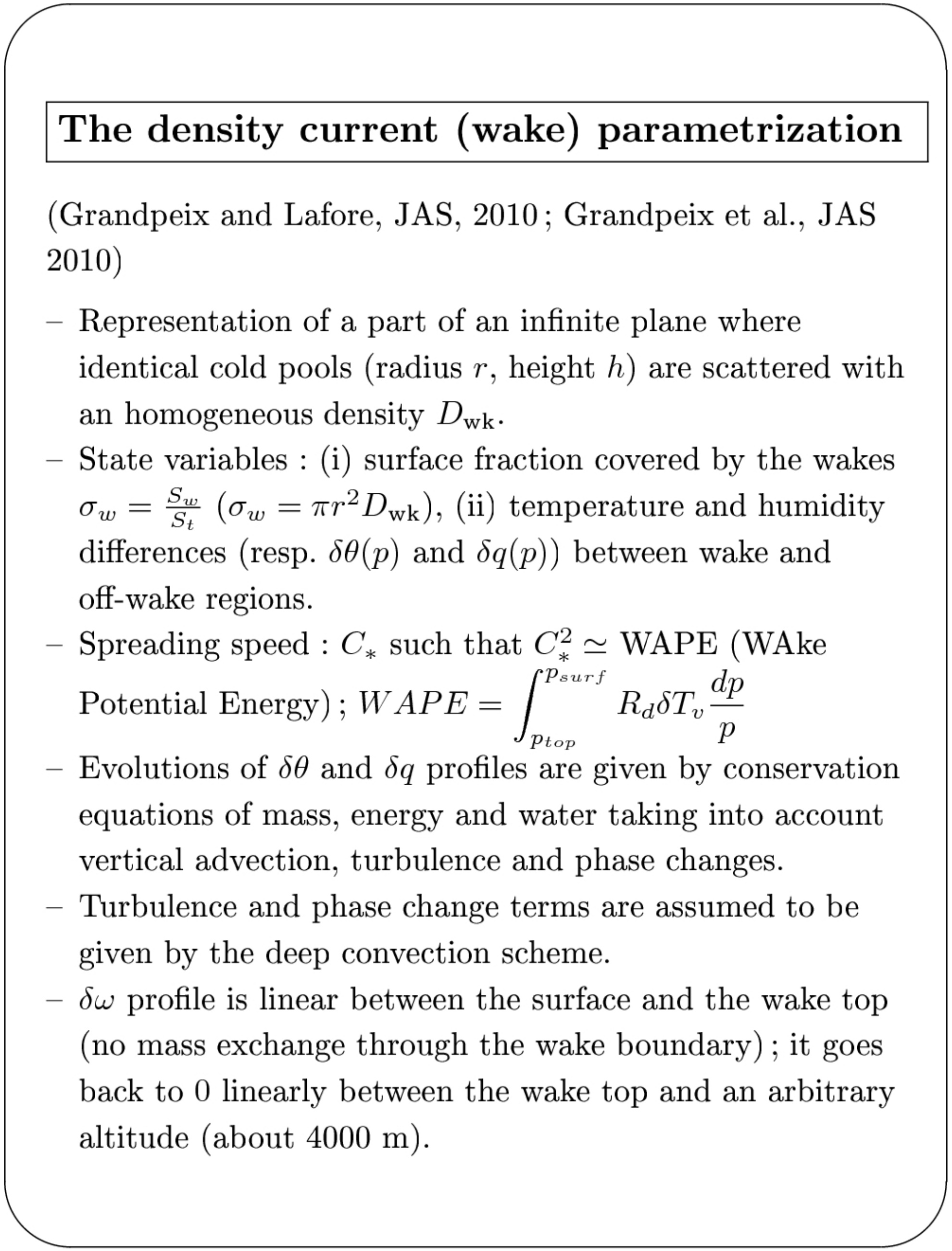
ALE

ALP

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



Mali, August 2004
F. Guichard, L. Kergoat

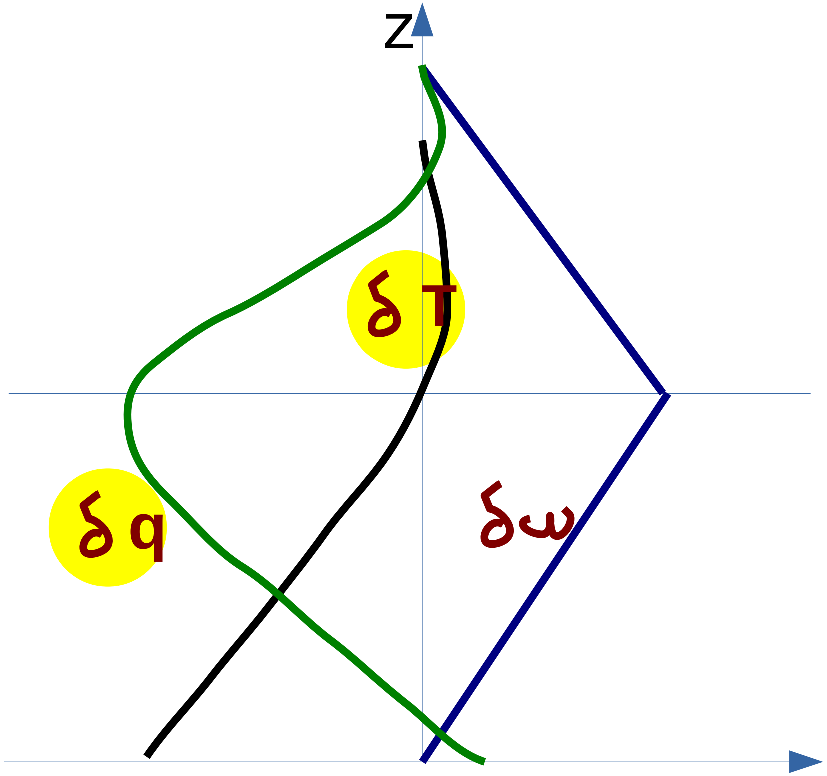


The density current (wake) parametrization

(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).

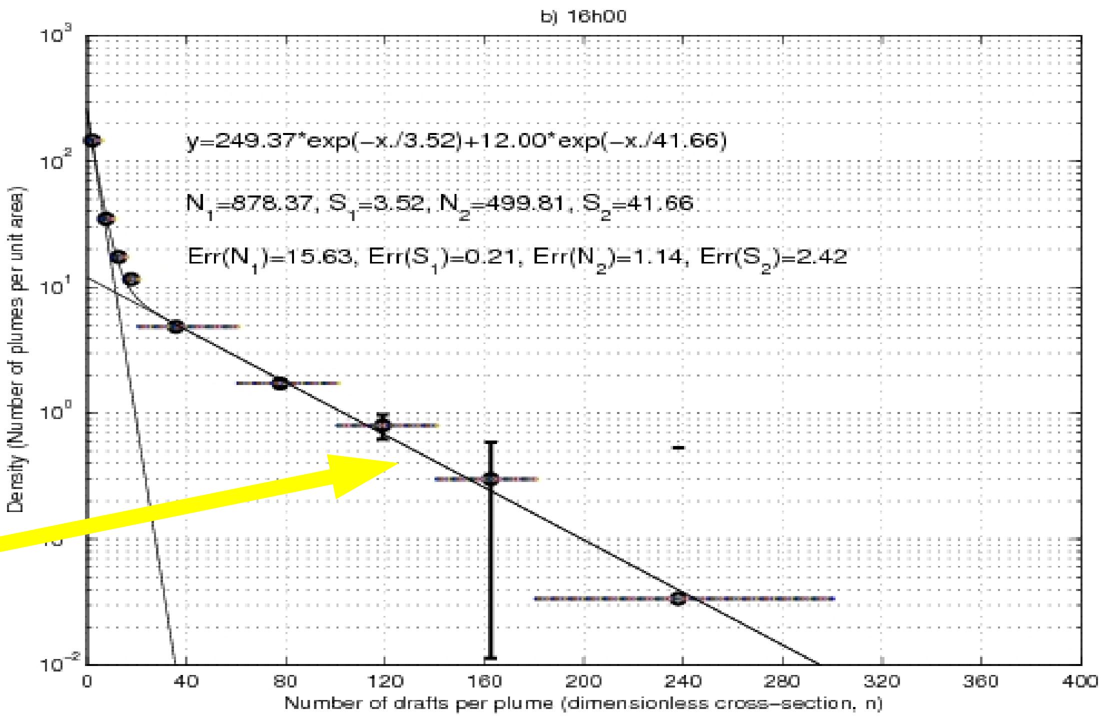
Wake differential profiles

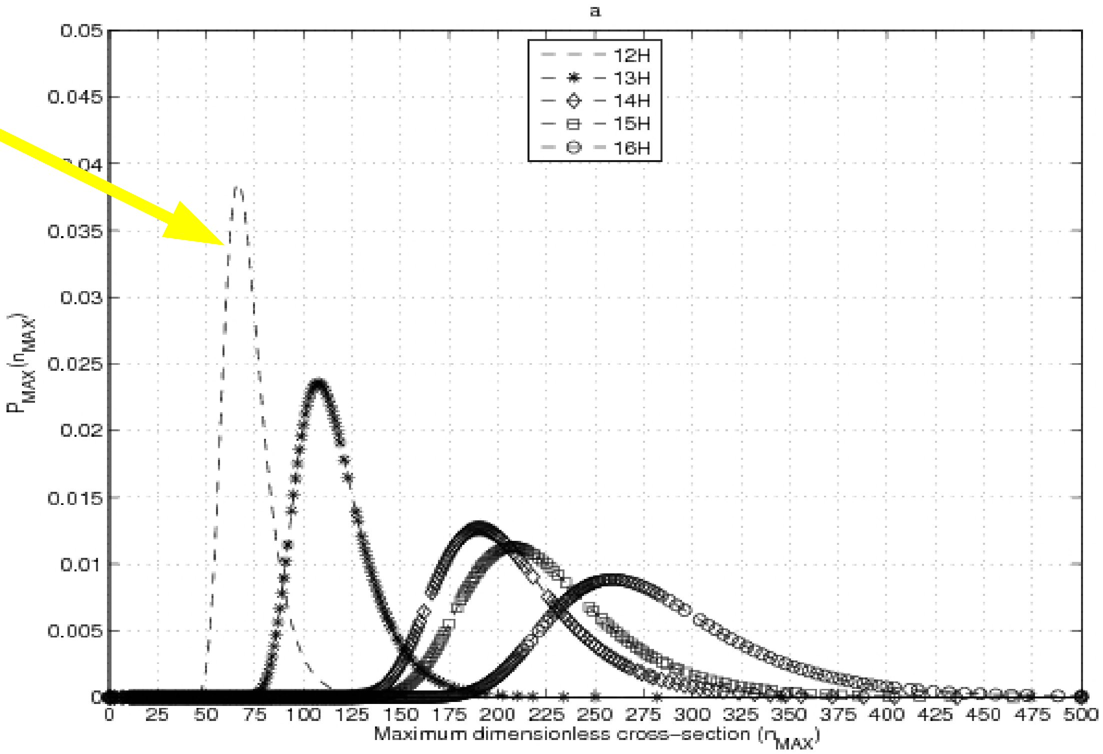


3- Stochastic physics: Deep convection triggering by boundary layer thermals

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 ⟶ 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).

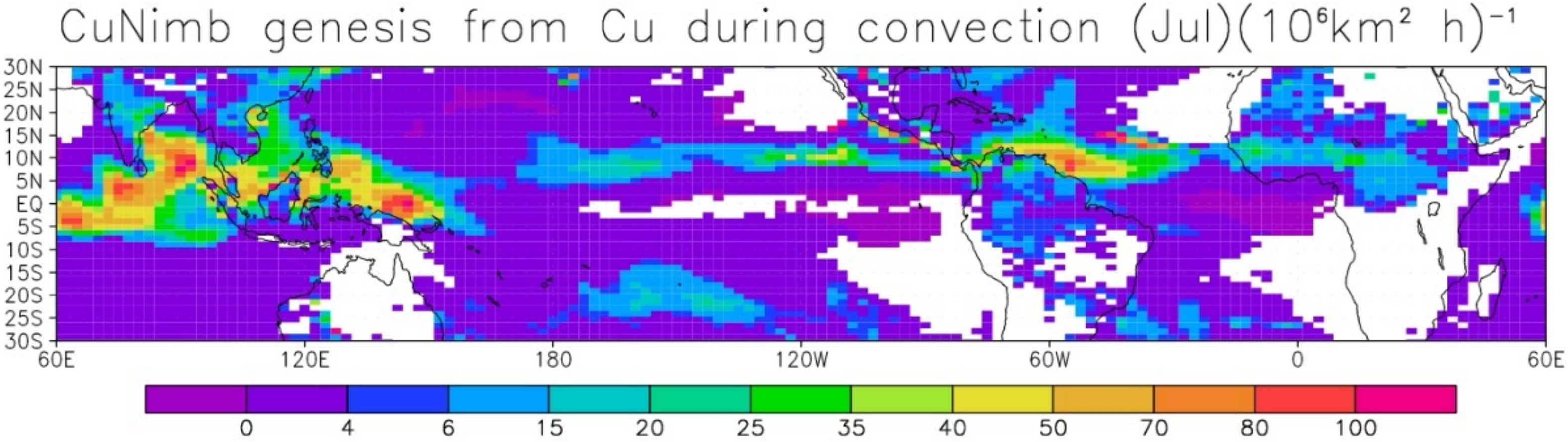




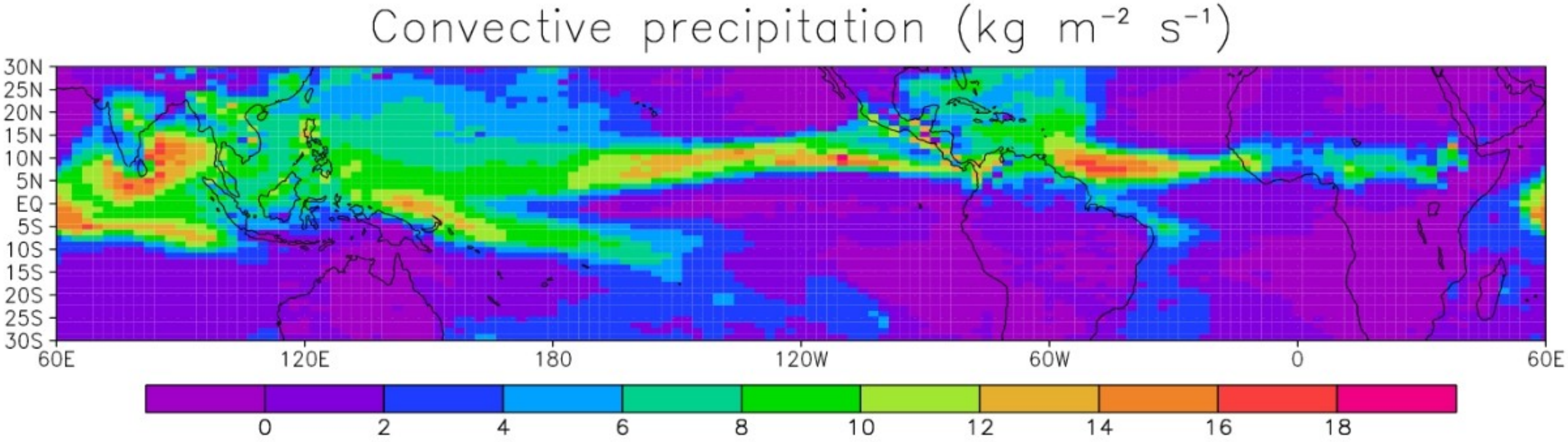
(Rochetin et al, JAS, 2014, I and II)

4 -Cumulonimbus & cold pool genesis

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

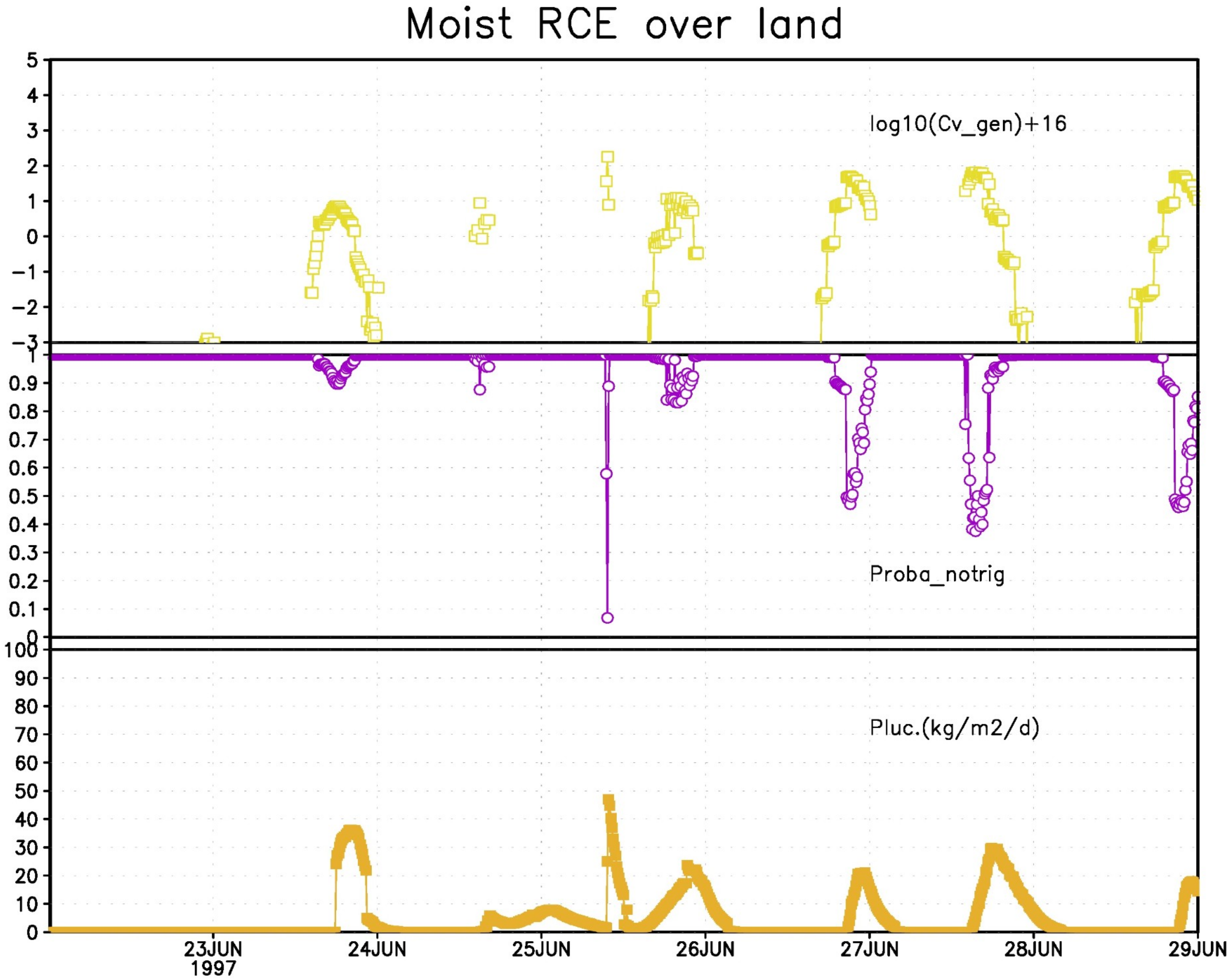


CuNimb genesis from Cu during convection (Jul)$(10^6 km^2\ h)^{-1}$



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

Moist radiative-convective equilibrium case



5 - The new scheme

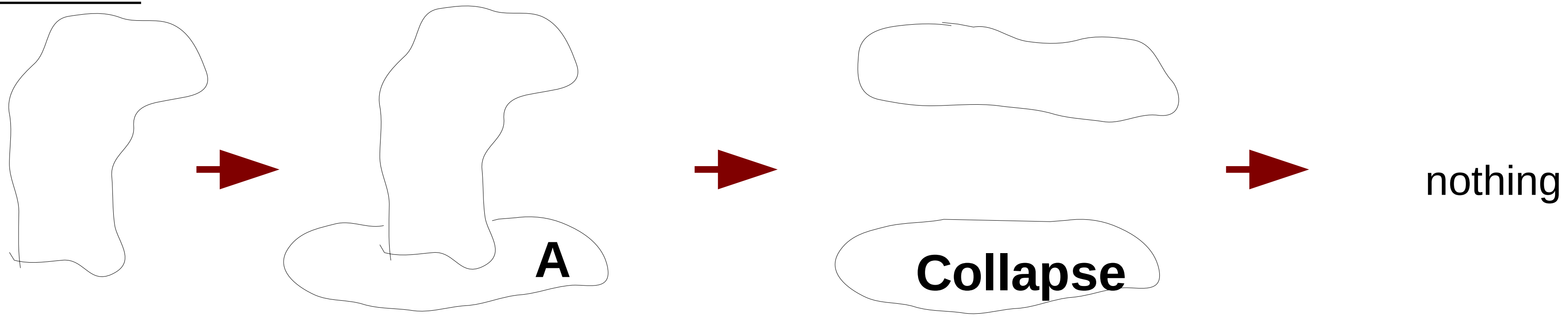
Principle:

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.

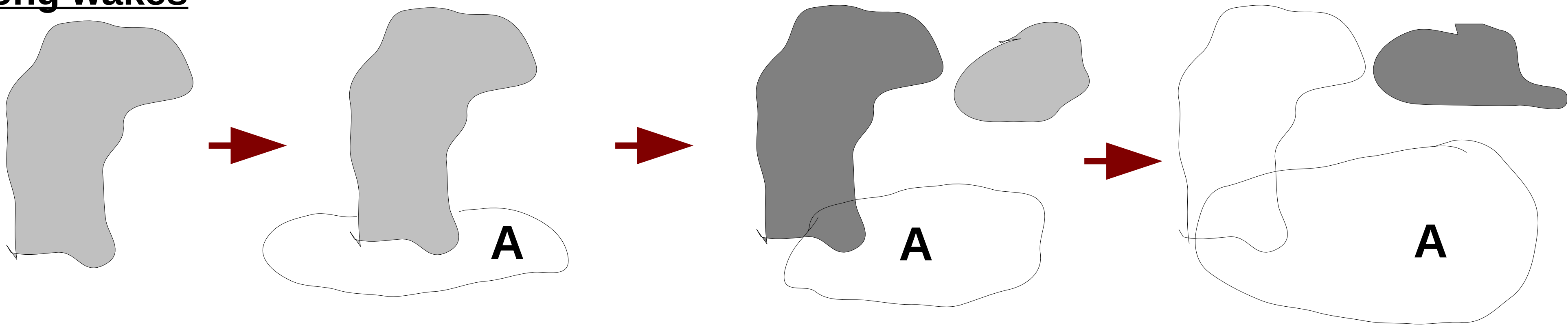
Structure:

- Two categories of wakes: active (with cumulonimbus) 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 Cb's 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).

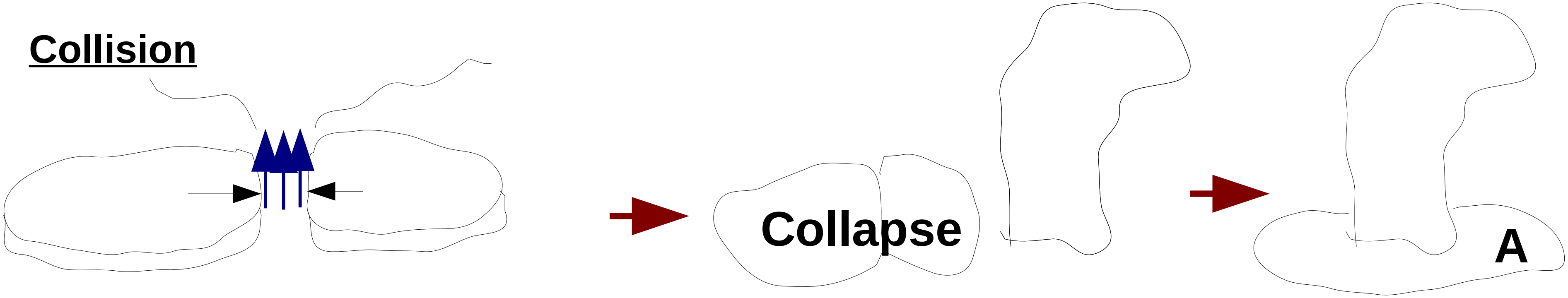
Weak wakes



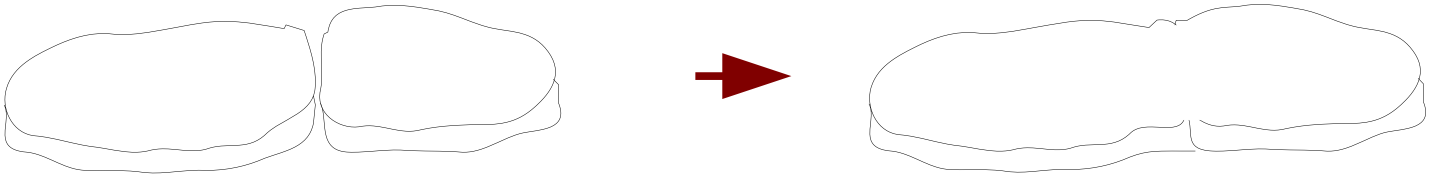
Strong wakes



Collision



Merging



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

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

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

Two ways of understanding the βD term :

- It is a nudging of the active wake density A towards a fraction β of the wakes.
- The activation or re-activation of wakes by wake-induced Cb's should appear as a source term proportional to D.

When cold pools are too weak, they cannot induce deep convection at their gust front :

$\beta = 0$ when $\mathrm{ALE}_{\mathrm{wk}} < \mathrm{CIN}$.

However, LES seem to indicate that even when $\mathrm{ALE}_{\mathrm{wk}} > \mathrm{CIN}$ there are no Cb appearing at cold pool boundaries.

Need for a better parametrization of the ability of cold pools to induce dynamicaly deep convection.

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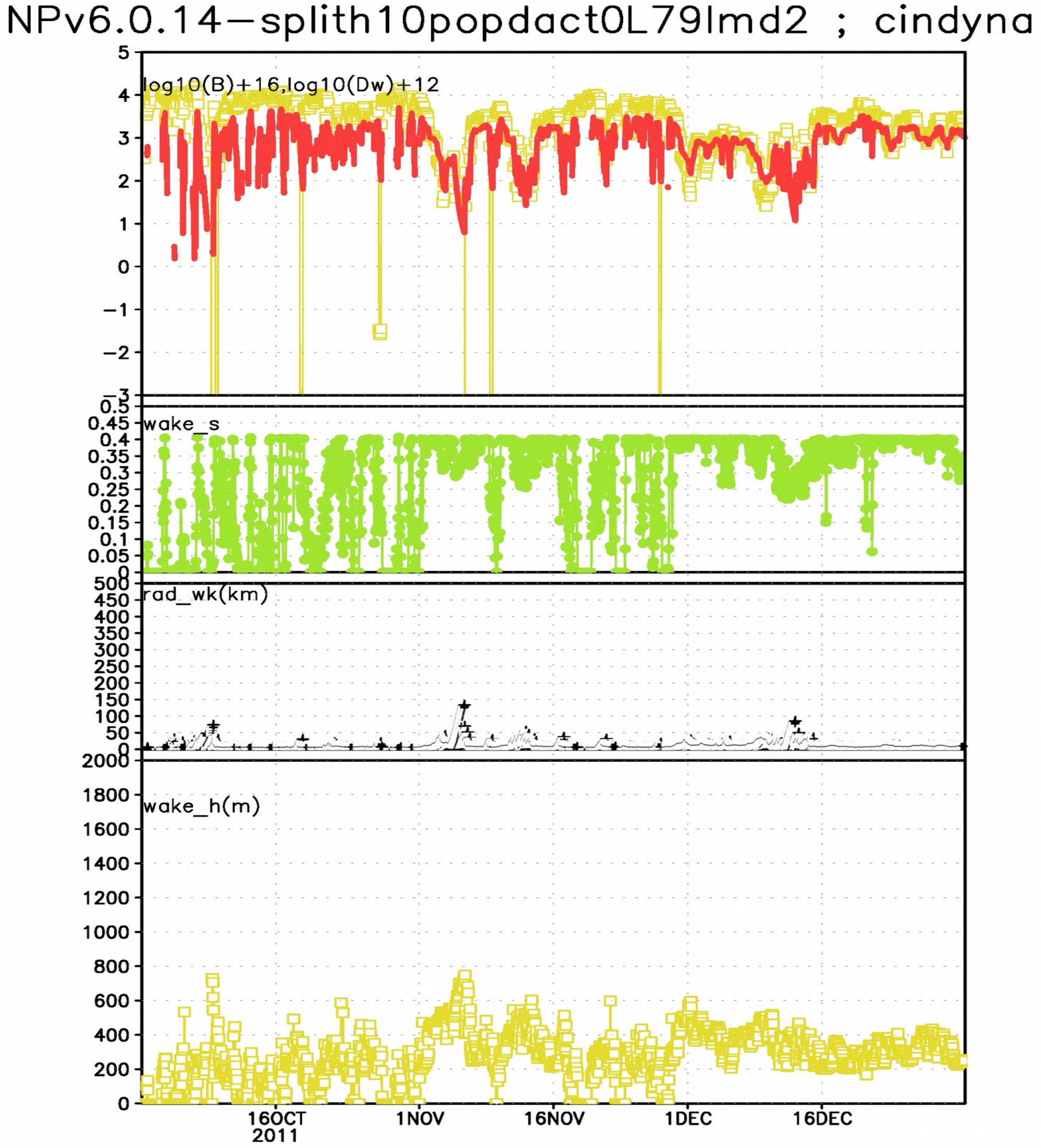
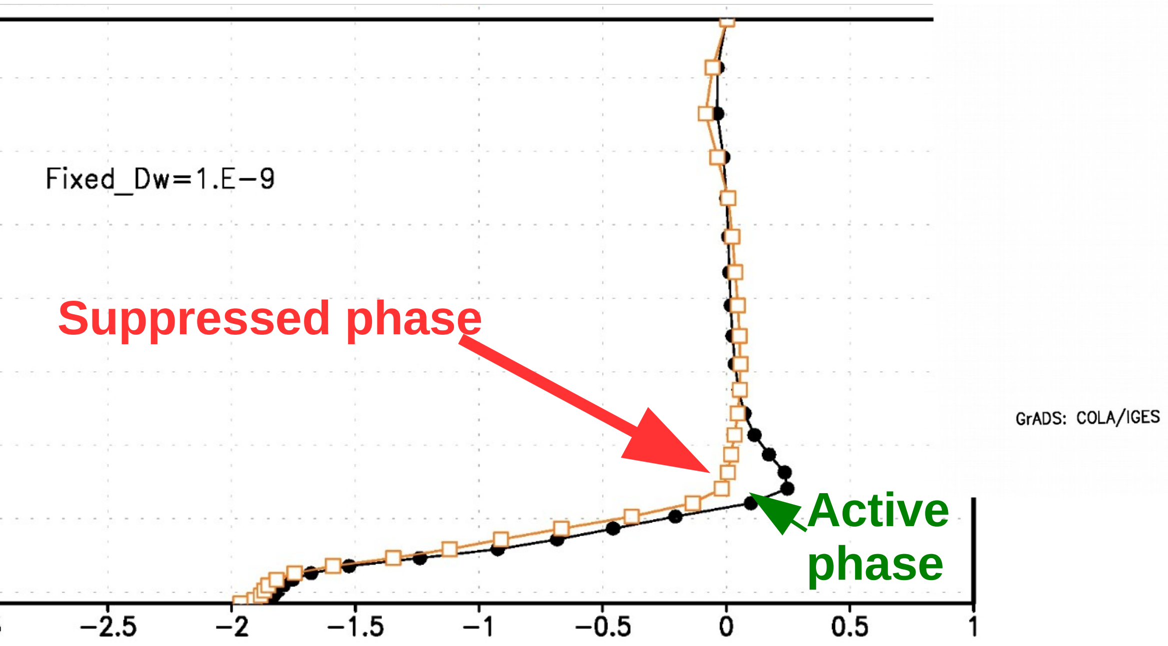
Cindy-Dynamo Beta=0



Cindy-Dynamo

Temperature difference between wake and off-wake regions

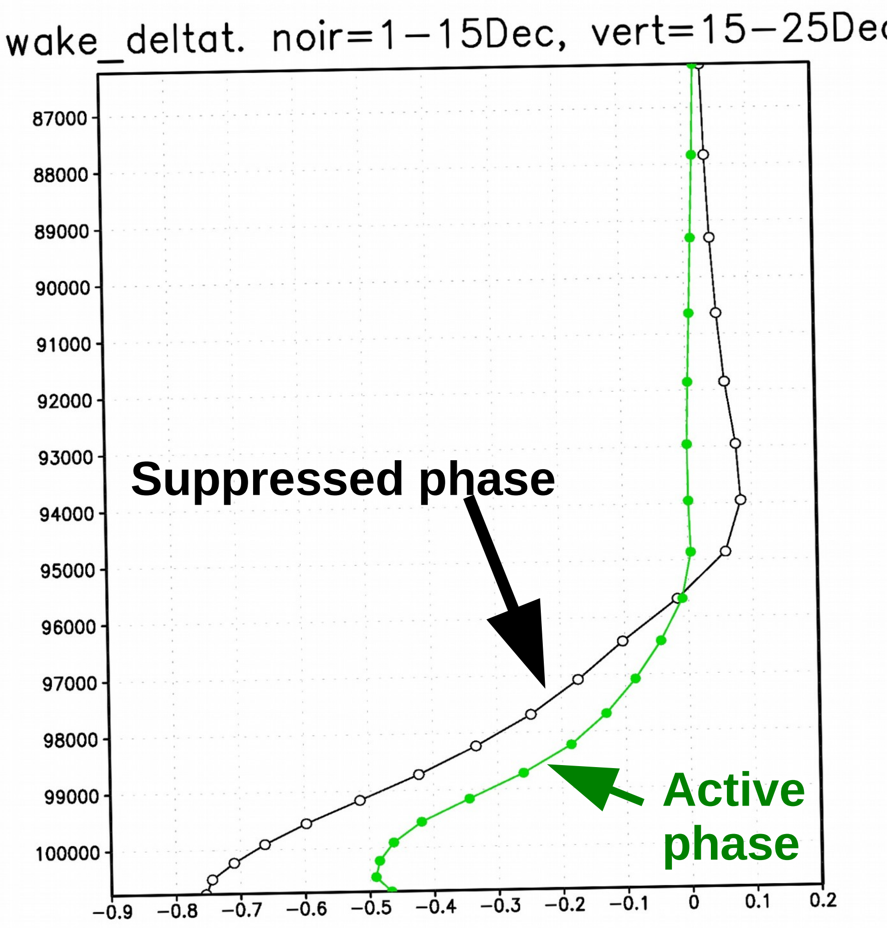
Prescribed D_W



Suppressed phase

Active phase

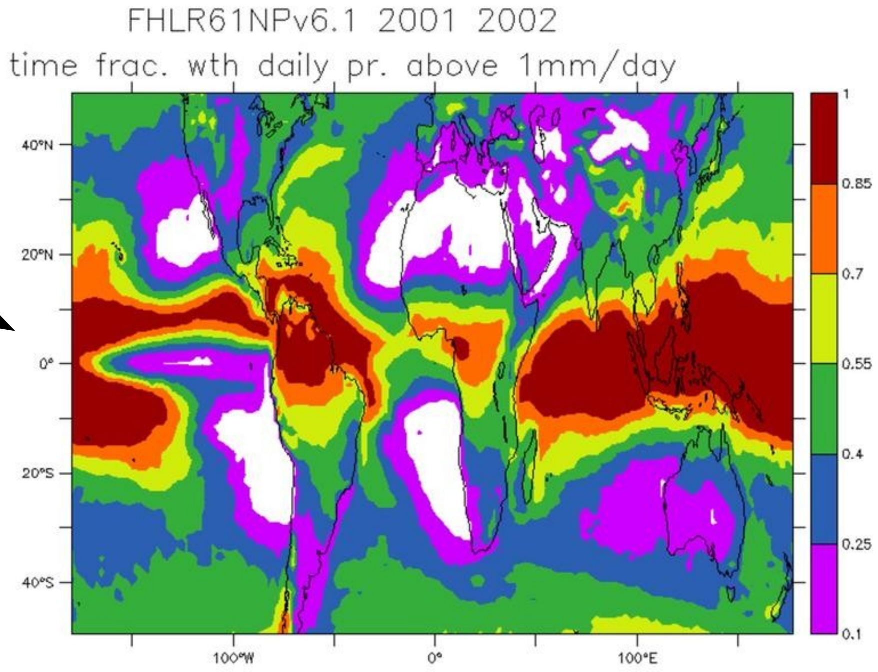
Pop. Dyn. With beta=0



Suppressed phase

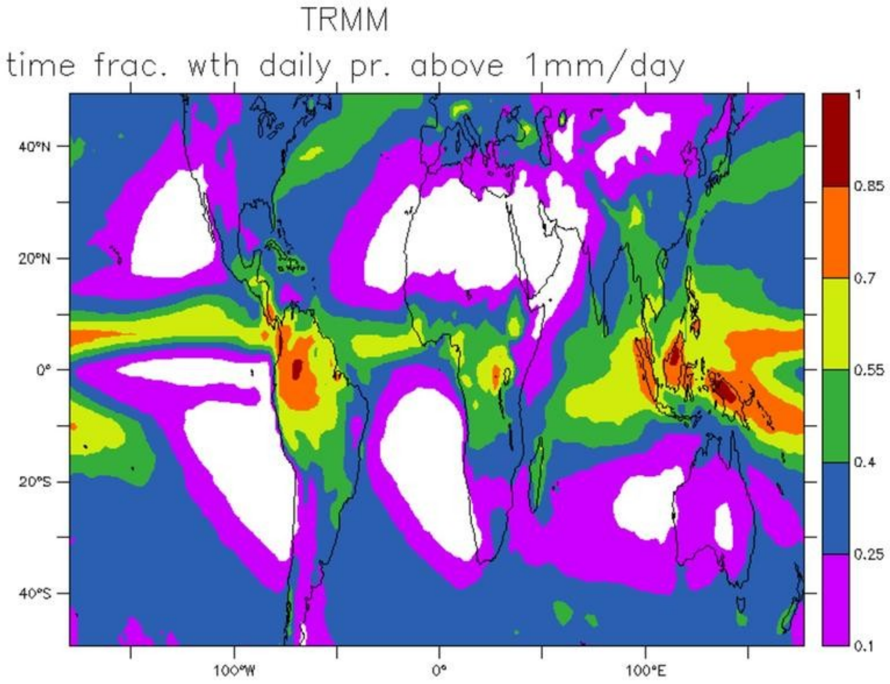
Active phase

Prescribed D_W



FHLR61NPv6.1 2001 2002

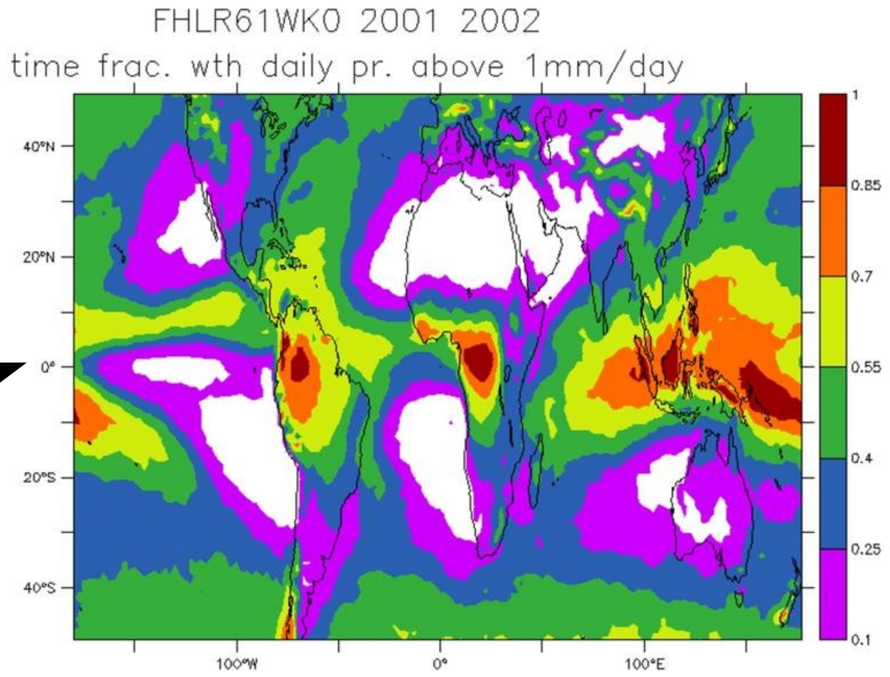
time frac. wth daily pr. above 1mm/day



TRMM

time frac. wth daily pr. above 1mm/day

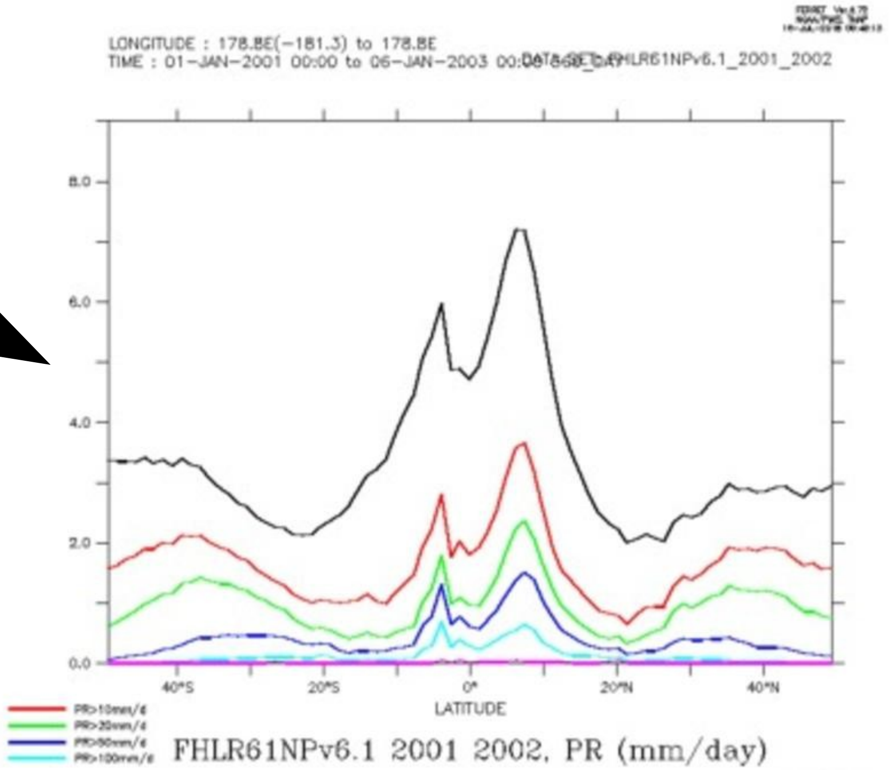
Population dynamics



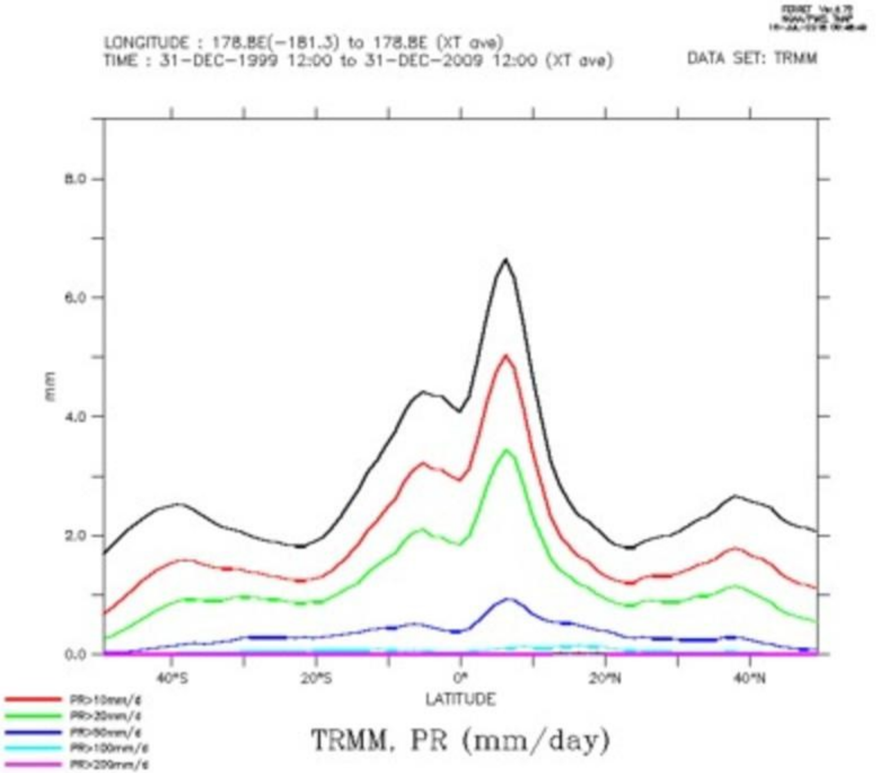
FHLR61WK0 2001 2002

time frac. wth daily pr. above 1mm/day

Prescribed D_W

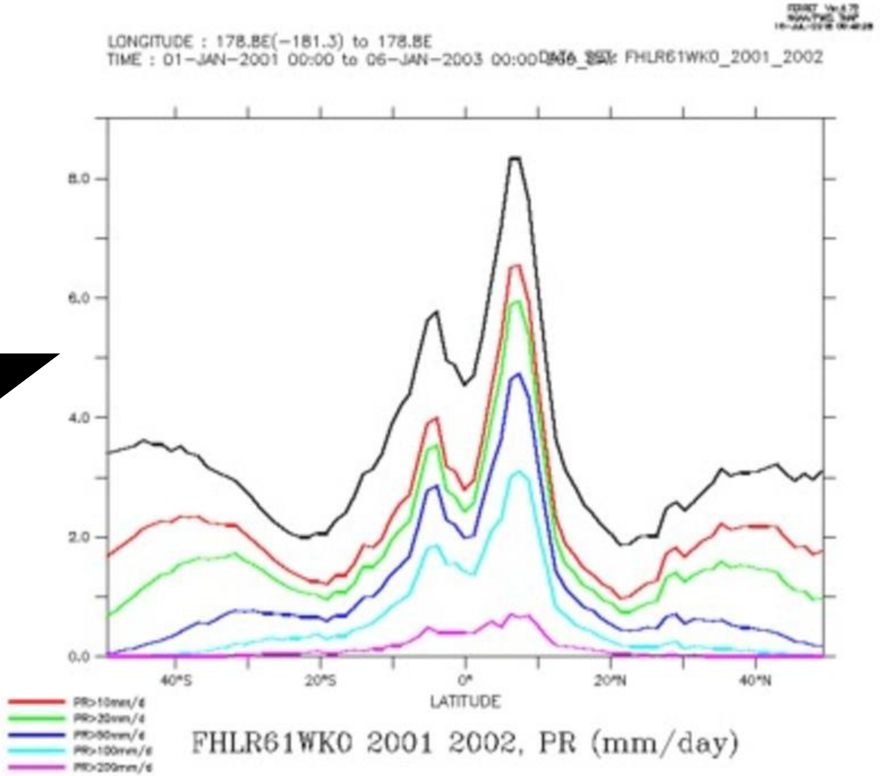


FHLR61NPv6.1 2001 2002, PR (mm/day)



TRMM, PR (mm/day)

Population dynamics



FHLR61WK0 2001 2002, PR (mm/day)

Conclusion

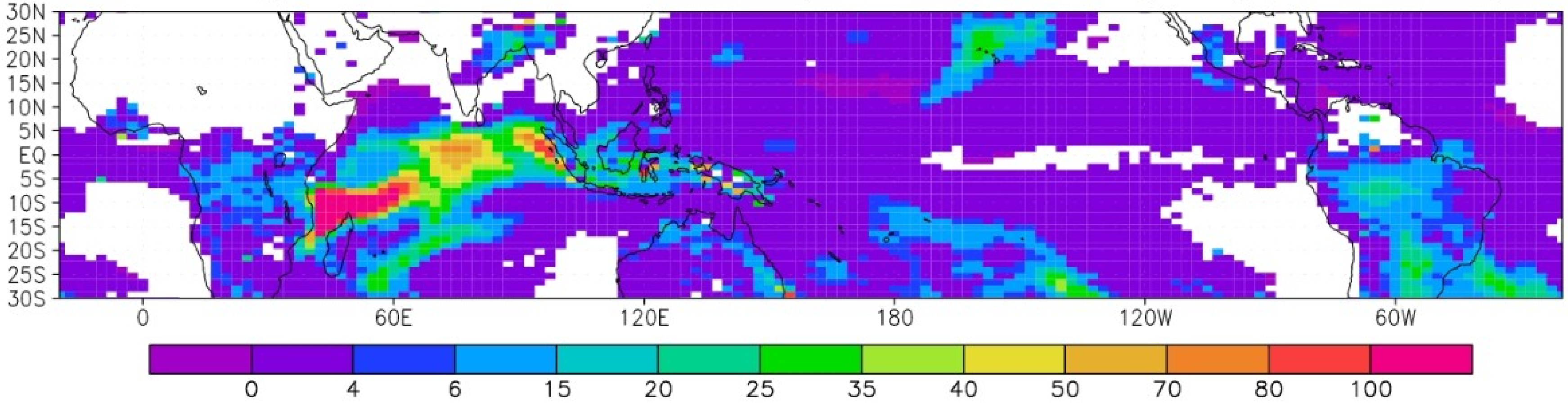
- Although all these results are very preliminary, the model of cold pool population dynamics appears reasonable and promising.

- It has a significant impact on the behaviour of deep convection and cold pools.

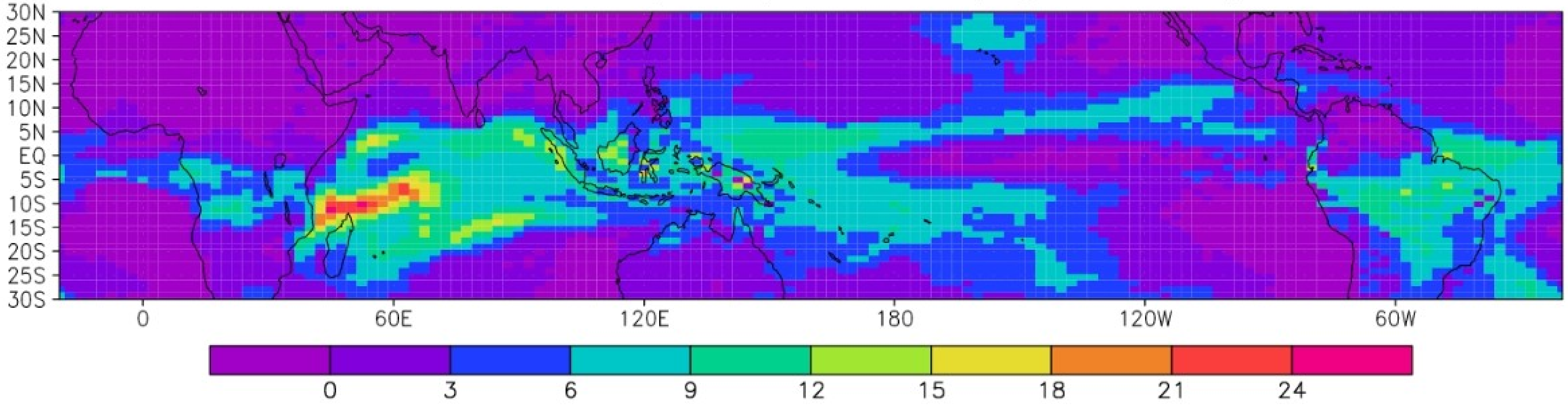
- It will make it possible to abandon the prescribed values of the wake density depending on the surface type.

- It is a first step towards the representation of the advection of cold pools from one grid cell to the other.

- Obviously much work remains to be done before we understand the behaviour of the wake density D.



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



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