Towards a dynamical description of the populations of cumulus, cumulonimbus and cold pools in the LMDZ GCM

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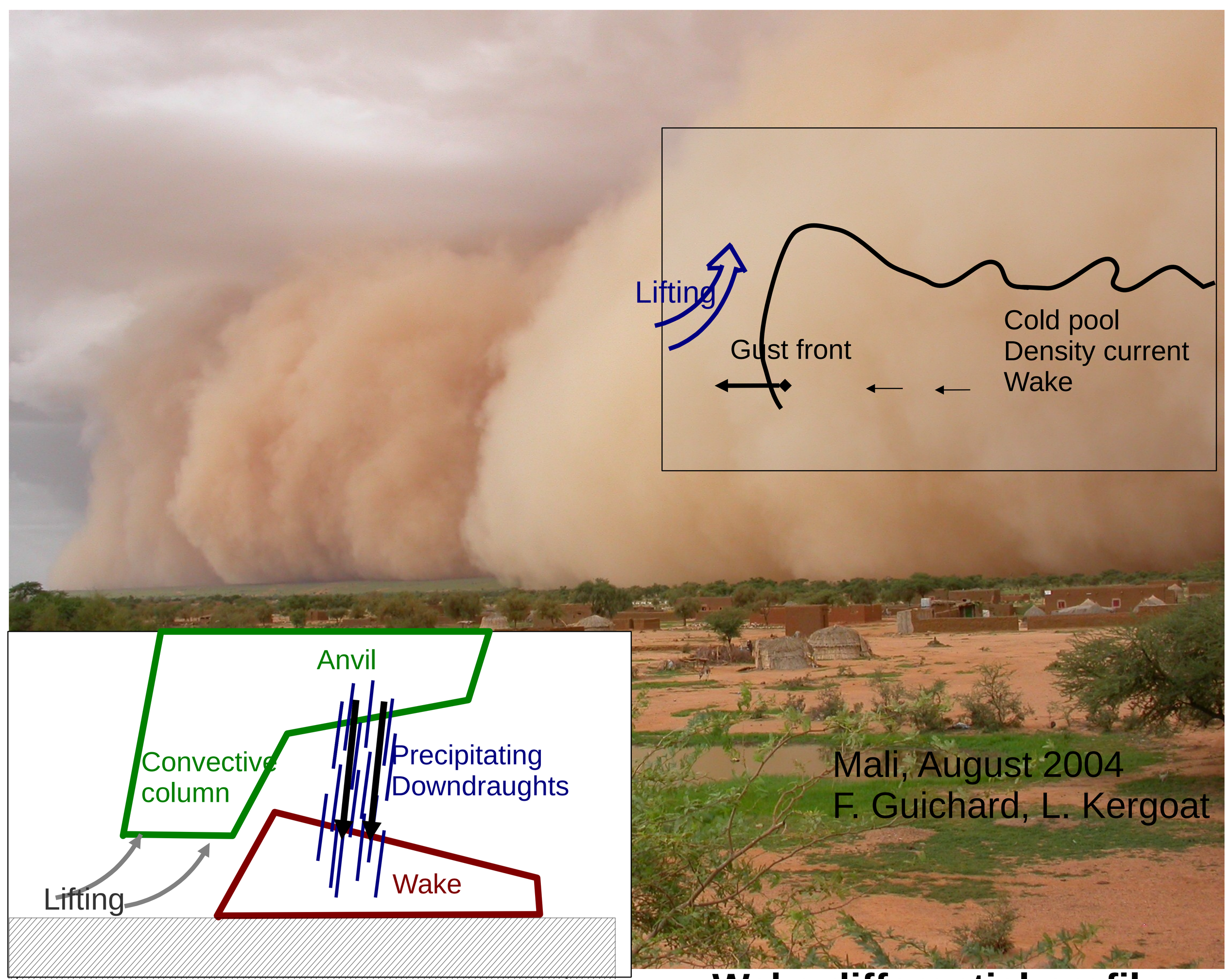
Introduction

In the LMDZ GCM, moist convection is represented by a set of three parametrizations, namely the thermal scheme (representing boundary layer thermals), the wake scheme (representing density currents) and the Emanuel scheme (representing deep convection); the first two parametrizations are coupled with the convective scheme through two variables, the ALE (Available Lifting Energy, used in the convective trigger) and the ALP (Available Lifting Power, used in the convective closure). This set of parametrizations coupled through the ALE/ALP system made it possible to improve largely the simulation of the diurnal cycle of convection over land and of its variability over ocean (Rio et al., 2009, Rio et al., 2012).

The number of cold pools per unit area (the density of cold pools) is an important parameter of the wake scheme. In the LMDZ5B GCM (used in CMIP5), the density was fixed to a single small value typical of semi-arid land conditions (8 wakes per million km2). Presently, two values are used, one over land (same as before) and one over ocean (1000 wakes per million km2).

The purpose of the present study is to design a crude parametrization of the dynamics of a cold pool population. This should bring to an end the present situation where the convection parametrization depends explicitly on the nature of the surface.

I – The representation of density currents

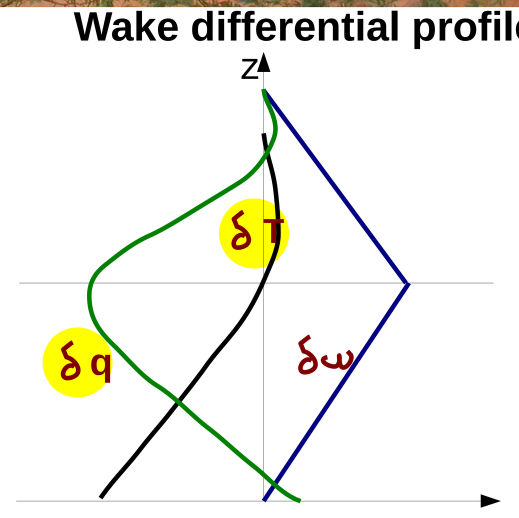


The density current (wake) parametrization

(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



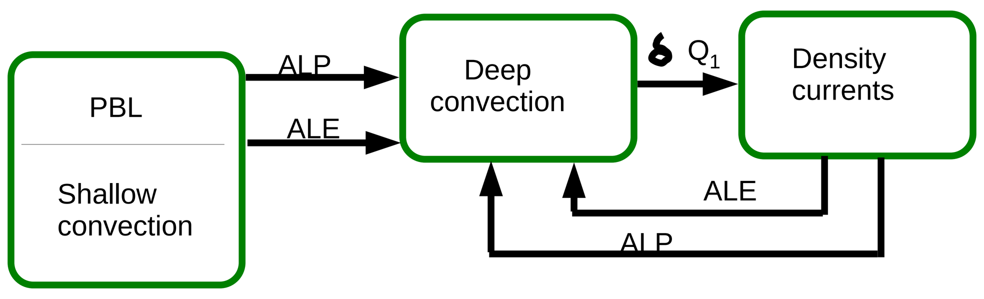
2- The ALP-ALE system: coupling boundary layer thermals, deep convection and density currents. (LMD & CNRM)

- 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

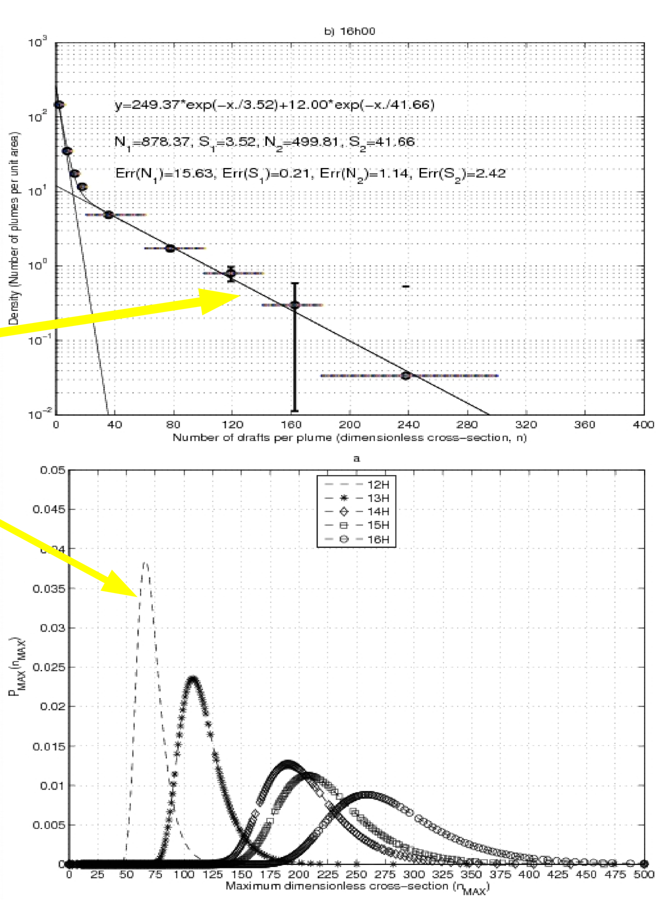


3- Stochastic physics: Deep convection triggering

Stochastic trigger

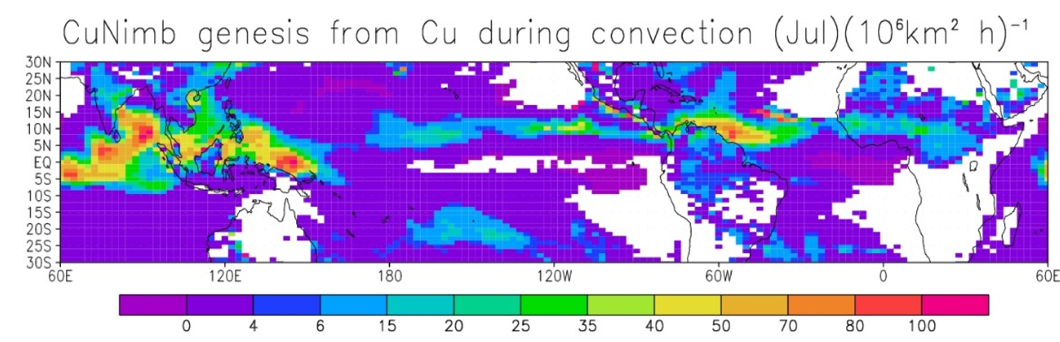
- Analysis of LES (Large Eddy Simulation" of 10 July 2006 case over Niamey :
  1. PDF of cumulus sizes is exponential.
  2. deep convection triggers when there are large cumulus.
- Trigger = "largest cumulus size exceeds a given threshold"
- From PDF of Cu size ⟶ PDF of largest cumulus size
- From the 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).

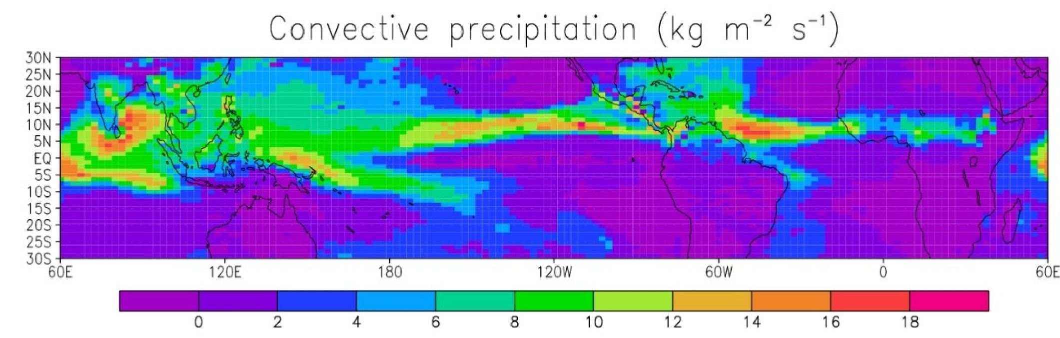
(Rochetin et al, JAS, 2014, I and II)

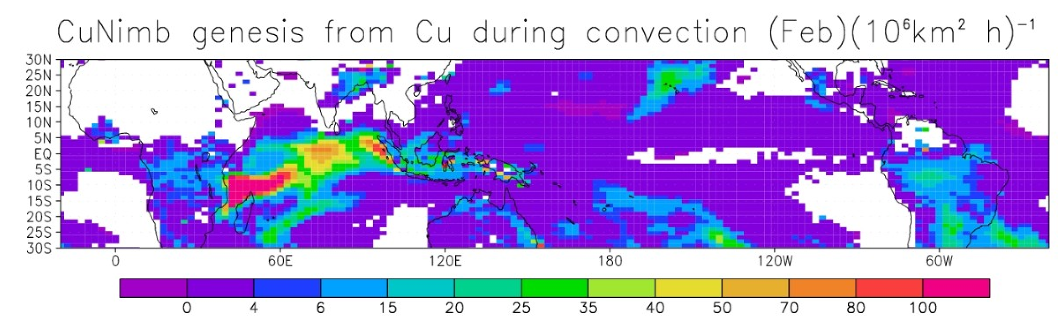


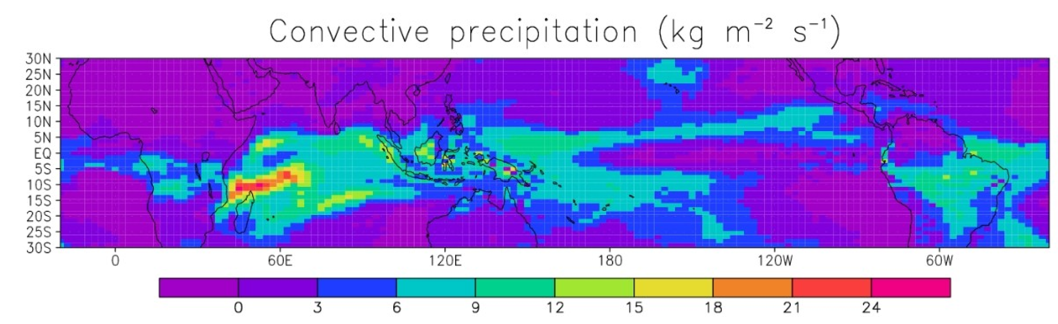
4 -Cumulonimbus & cold pool genesis

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.









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).

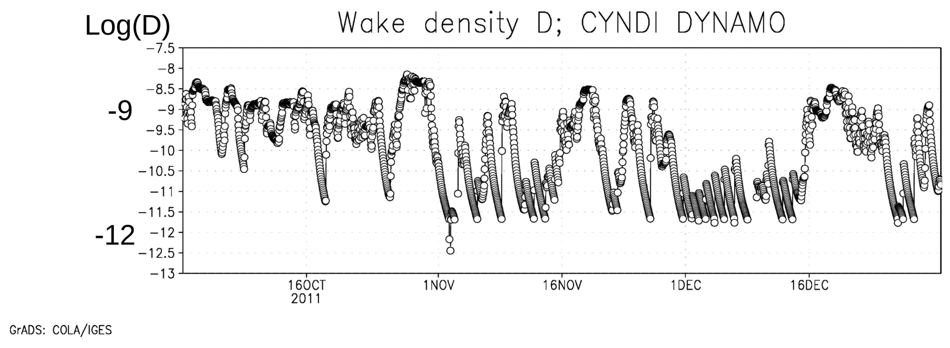
Model equations

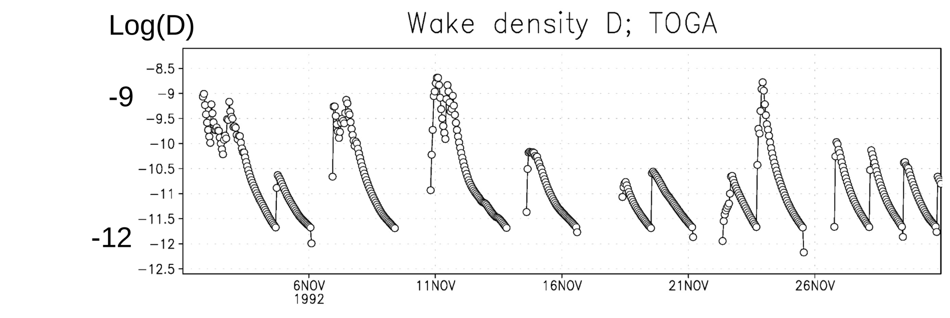
- A : number of active wakes per unit area
- D : number of wakes per unit area
- σ : fractionnal area covered by wakes
- r : wake radius
- B : birth rate of Cumulonimbus (and of wakes)
- a_0 : initial area of newborn wakes
- C_* : gust front velocity
- τ_{cv} : lifetime of convective plumes
- τ : lifetime 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 cold pool that grows while the two others collapse) : should depend on shear. Presently, $\alpha = 1$.

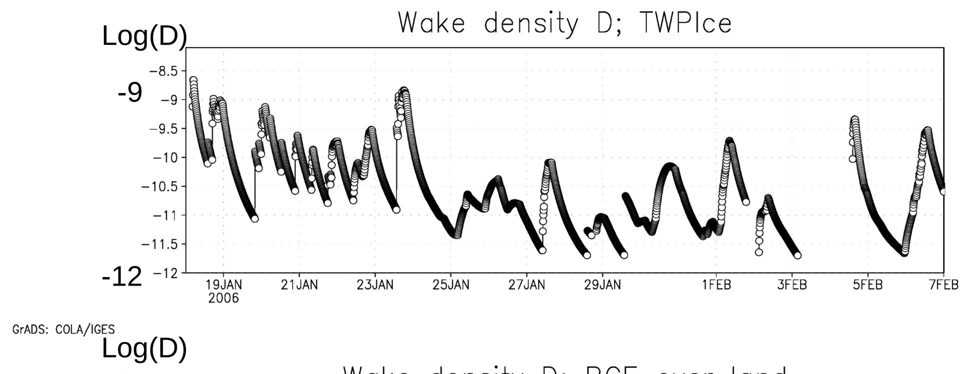
$$\left\{\begin{array}{lcl} \partial_t A &=& B - \frac{1}{\tau_{cv}}(A - \beta D) \\ \partial_t D &=& B - \frac{D-A}{\tau} - 4\pi r D^2 \partial_t r \\ \partial_t \sigma &=& B a_0 - \frac{\pi r^2}{\tau}(D-A) + 2\pi r D C_* - \alpha\sigma 4\pi r D \partial_t r \end{array}\right.$$

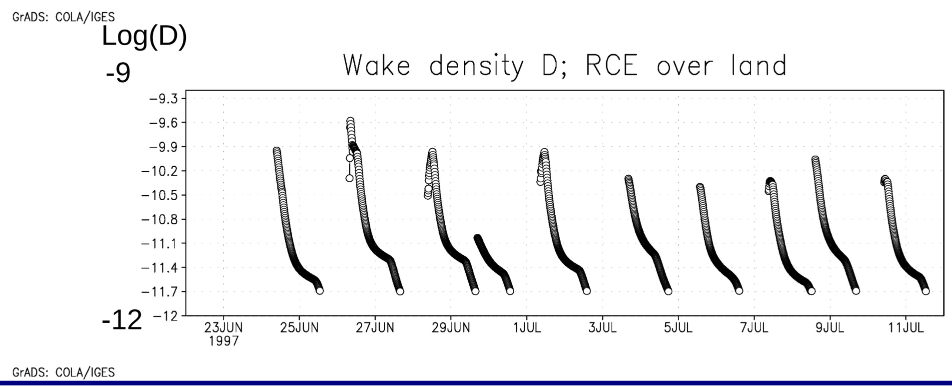
and from $\sigma = \pi r^2 D$: $\partial_t \sigma = 2\pi r D \partial_t r + \pi r^2 \partial_t D$

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

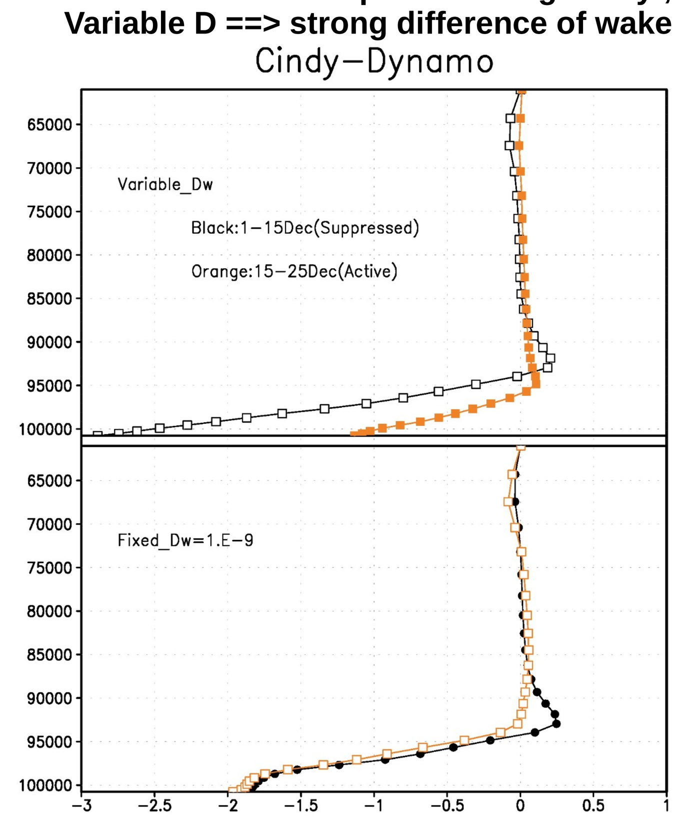




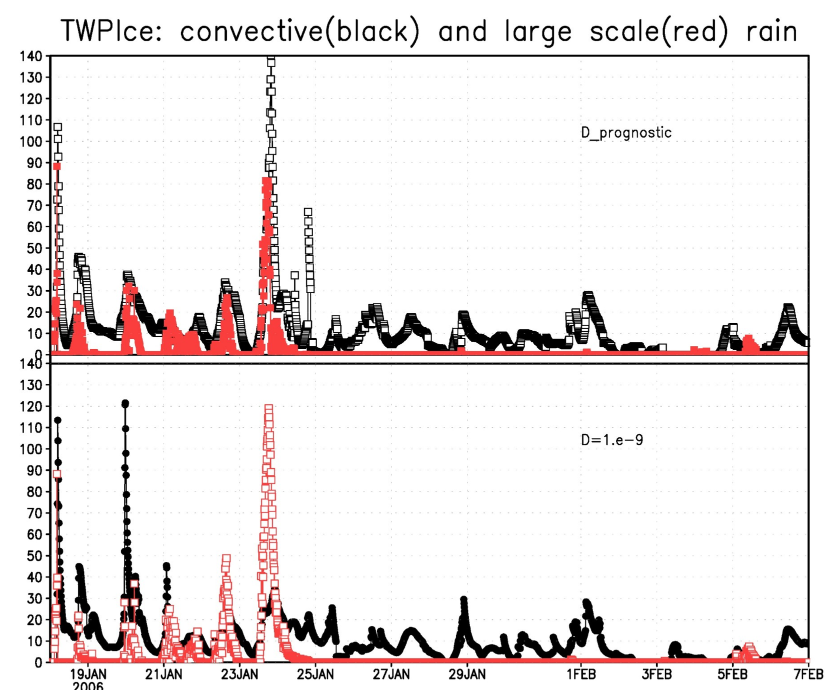




7 - Strong effect of D variability on wake properties: Fixed D ==> wake profiles unchanged between suppressed and active phase during Cindy ; Variable D ==> strong difference of wake profiles.



8 - During TWPIce, convective precipitation differs significantly between the fixed D simulation and the prognostic one.



Also (not shown) the variability of precipitation in a case of radiative-convective equilibrium over land is significantly increased when the wake density D is prognostic.

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.