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

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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 $8 \times 10^{-12}$ 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):
  \[ ALE > |CIN| \implies \text{deep convection is triggered} \]

- Closure given by the Available Lifting Power (ALP):
  \[ M = \frac{\text{ALP}}{2 W_B^2 + |CIN|} ; \]
  \[ M = \text{cloud base mass flux; } W_B = \text{updraught velocity at LFC} \]
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 $\sigma_w = \frac{S_w}{S_t}$ ($\sigma_w = \pi r^2 D_{wk}$), (ii) temperature and humidity differences (resp. $\delta \theta(p)$ and $\delta q(p)$) between wake and off-wake regions.
- Spreading speed: $C_s$ such that $C_s^2 \approx WAKE$ (WAPE, WAke Potential Energy); $W A P E = \int_{p_{top}}^{P_{sat}} R_d \delta T_v \frac{dp}{p}$
- Evolutions of $\delta \theta$ and $\delta q$ 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).
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)
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.
Moist radiative-convective equilibrium case

Moist RCE over land

log10(Cv_gen)+16

Proba_notrig

Pluc.(kg/m^2/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 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
- $\sigma$ : fractional 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
- $\tau_{cw}$ : lifetime of convective plumes
- $\tau$ : lifetime of collapsing wakes
- $\beta$ : fraction of wakes that are active
- $\alpha$ : factor going from zero (colliding wakes merely merge, without wake area loss) to 1 (colliding wakes induce a new one that grows while the two others collapse): should depend on shear. Presently, $\alpha = 1$.

\[
\begin{align*}
\partial_t A &= B - \frac{1}{\tau_{cw}} (A - \beta D) \\
\partial_t D &= B - \frac{D - A}{\tau} - 4\pi r D^2 \partial_t r \\
\partial_t \sigma &= B a_0 - \frac{\pi r^2}{\tau} (D - A) + 2\pi r D C_* \\
&\quad - \alpha 4\pi r D \partial_t r (2\sigma - Da_0)
\end{align*}
\]

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 $\beta D$ term:
- It is a nudging of the active wake density $A$ towards a fraction $\beta$ 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 $\text{ALE}_{wk} < \text{CIN}$.

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

**Need for a better parametrization of the ability of cold pools to induce dynamically deep convection.**
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However, LES seem to indicate that even when \( \text{ALE}_{wk} > \text{CIN} \) there are no Cb appearing at cold pool boundaries. **Need for a better parametrization of the ability of cold pools to induce dynamically deep convection.**
Cindy-Dynamo Beta=0
NPv6.0.14—splith10popdact0L79lmd2 ; cindyna
Cindy-Dynamo

Temperature difference between wake and off-wake regions

Pop. Dyn. With beta=0

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

Prescribed $D_w$

Fixed $D_w=1.E-9$

Suppressed phase

Active phase

Suppressed phase

Active phase
Prescribed $D_w$

Population dynamics
Prescribed $D_w$

Population dynamics
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) \((10^6 \text{km}^2 \text{ h})^{-1}\)

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