Density current parametrization at LMD and CNRM.

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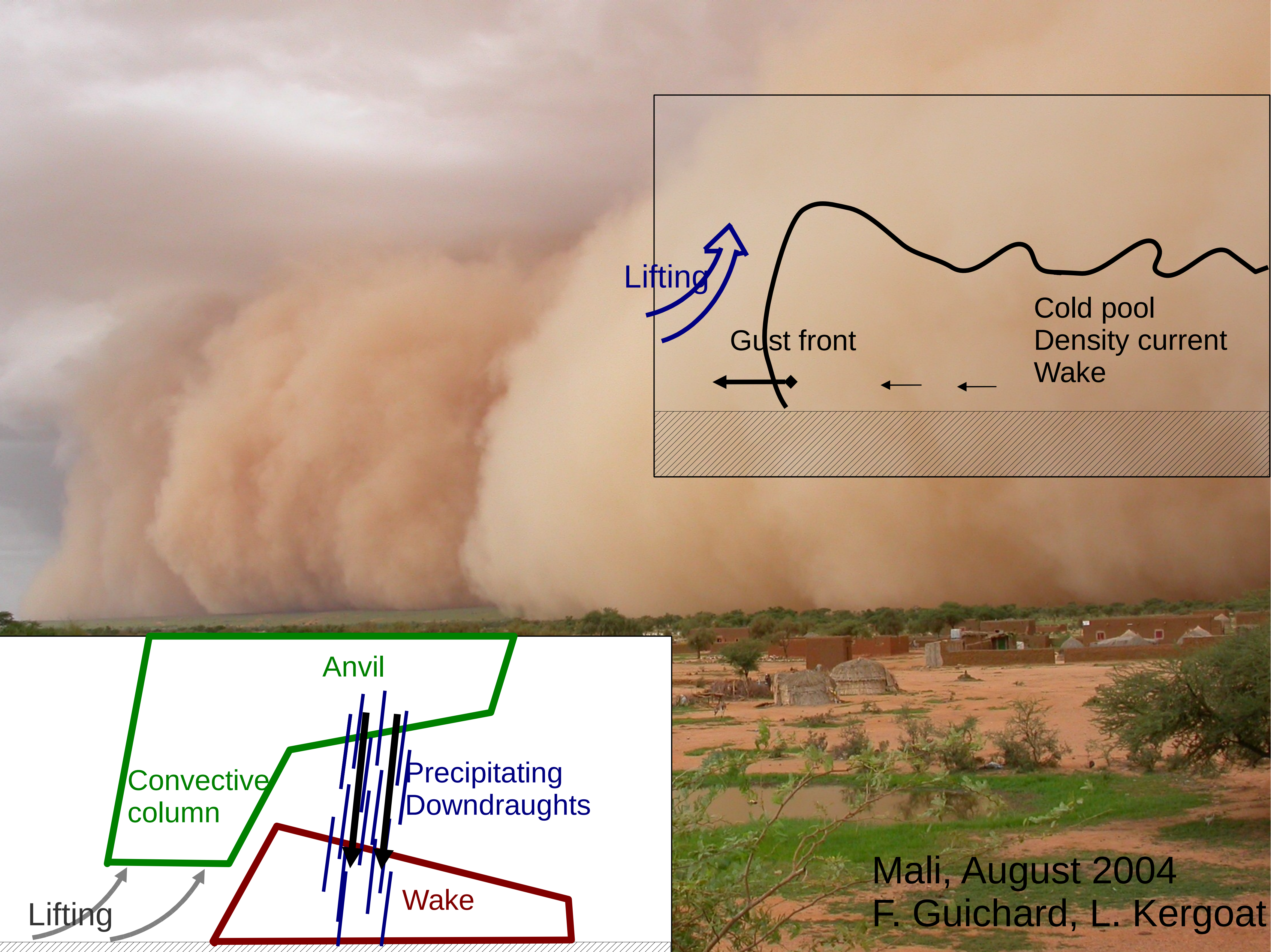
Layout

- 1- Why parametrize density currents?
- 2- The LMD/CNRM density current (wake) parametrization.
- 3- Wakes in the LMDZ5 model.
- 4- LMDZ5 developments and present status.

Why parametrize density currents?

- In most GCMs deep convection is function only of Large Scale variables (quasi-equilibrium hypothesis) ==> elementary convective structures (Mesoscale Convective Systems, Squall Lines) do not exist in climate simulations.
- Observed self-sustaining behaviour of deep convection (diurnal cycle and propagation) shows that there is a memory somewhere.
- **Key hypothesis**: **wakes (= cold pools = density currents) are the key elements of this memory.**
- **LMDZ:** explicit representation of cold pools.

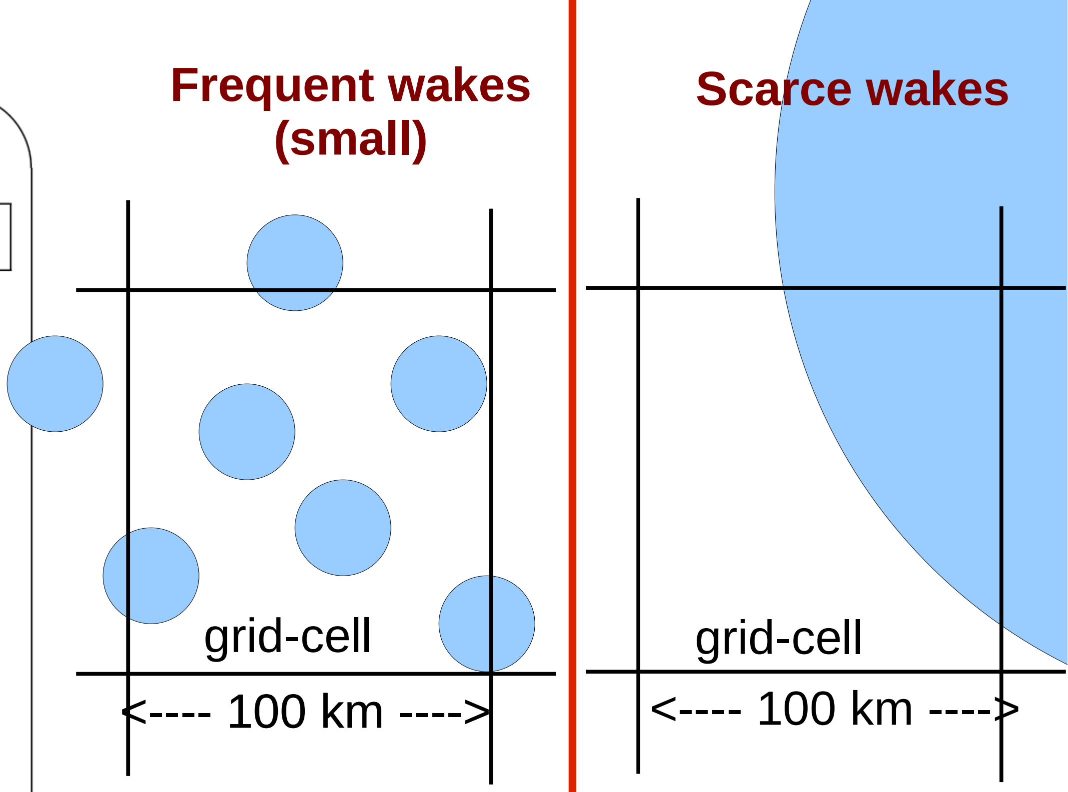


Mali, August 2004
F. Guichard, L. Kergoat

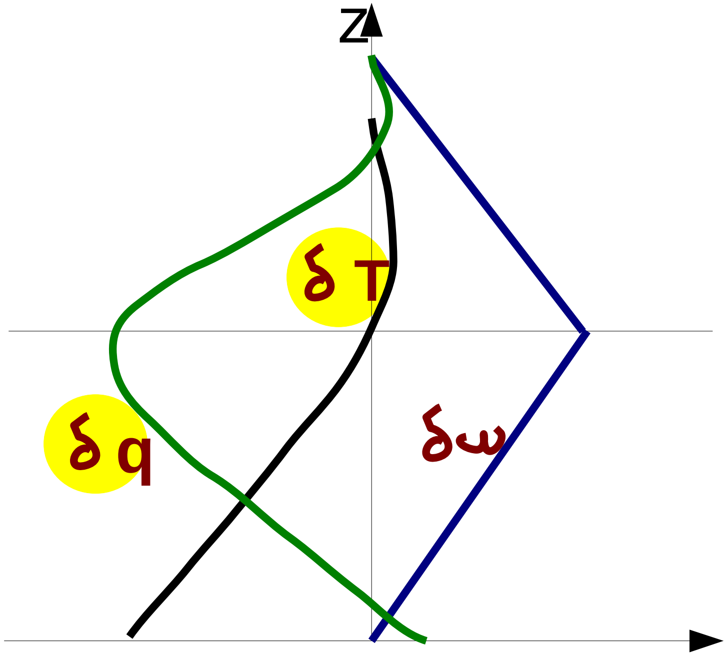
The density current (wake) parametrization

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



Wake variable tendencies

$$\left\{\begin{array}{lll}
\partial_t \delta\theta & = & -\overline{\omega}\,\partial_p \delta\theta + \dfrac{\delta Q_1^{\mathrm{cv}} + \delta Q_1^{\mathrm{wk}}}{C_p} - \dfrac{k_{\mathrm{gw}}}{\tau_{\mathrm{gw}}}\,\delta\theta \\
 & & \text{where } \tau_{\mathrm{gw}} = \frac{\sqrt{\sqrt{\sigma_w}(1-\sqrt{\sigma_w})}}{4Nz\sqrt{D_{\mathrm{wk}}}} \\
 & & \text{is the damping time by gravity waves} \\
 & & \\
\dfrac{\delta Q_1^{\mathrm{wk}}}{C_p} & = & -\dfrac{e_w}{\sigma_w}\,\delta\theta \qquad\qquad\qquad\qquad : \text{Entraînement} \\
 & & \\
 & & -\delta\omega\;\partial_p \overline{\theta} \qquad\qquad\qquad\qquad : \text{differential advection of } \overline{\theta} \\
 & & \\
 & & -(1-2\sigma_w)\;\delta\omega\;\partial_p \delta\theta \qquad : \text{differential advection of } \delta\theta
\end{array}\right.$$

Water vapour equations are similar except for the gravity wave term :

$$(\partial_t \delta q_v)_{\mathrm{gw}} = -\frac{k_{\mathrm{gw}}}{\tau_{\mathrm{gw}}}\;\delta\theta\;\;\frac{\partial_z[\overline{q_v}\;+\;(1-2\sigma_w)\delta q_v]}{\partial_z[\overline{\theta}\;+\;(1-2\sigma_w)\delta\theta]}$$

Wake variable tendencies

Differential heat source due to deep convection: precipitating downdraughts cool the wakes .

$$
\left\{
\begin{array}{lll}
\partial_t \delta\theta & = & -\overline{\omega}\,\partial_p \delta\theta + \dfrac{\delta Q_1^{\mathrm{cv}} + \delta Q_1^{\mathrm{wk}}}{C_p} - \dfrac{k_{\mathrm{gw}}}{\tau_{\mathrm{gw}}}\,\delta\theta \\
 & & \text{where } \tau_{\mathrm{gw}} = \dfrac{\sqrt{\sqrt{\sigma_w}(1-\sqrt{\sigma_w})}}{4Nz\sqrt{D_{\mathrm{wk}}}} \\
 & & \text{is the damping time by gravity waves} \\
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\dfrac{\delta Q_1^{\mathrm{wk}}}{C_p} & = & -\dfrac{e_w}{\sigma_w}\,\delta\theta \qquad\qquad : \text{Entraînement} \\
 & & \\
 & & -\delta\omega\,\partial_p \overline{\theta} \qquad\qquad : \text{differential advection of } \overline{\theta} \\
 & & \\
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\end{array}
\right.
$$

Water vapour equations are similar except for the gravity wave term :

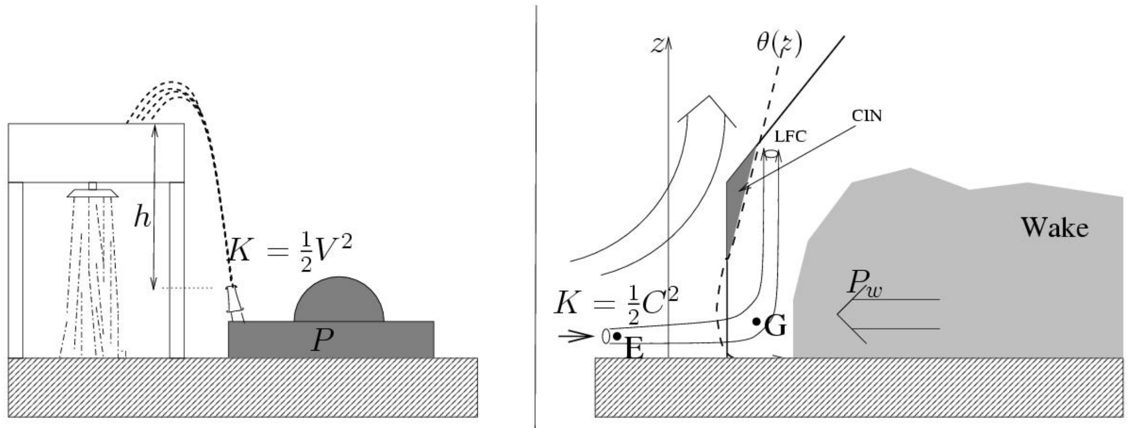
$$
(\partial_t \delta q_v)_{\mathrm{gw}} = -\frac{k_{\mathrm{gw}}}{\tau_{\mathrm{gw}}}\,\delta\theta\;\frac{\partial_z[\overline{q_v} \;+\; (1-2\sigma_w)\delta q_v]}{\partial_z[\overline{\theta} \;+\; (1-2\sigma_w)\delta\theta]}
$$

Large scale variable tendencies

$$\left\{ \begin{array}{lll} \partial_t \overline{\theta} & = (\partial_t \overline{\theta})_{LS} + \dfrac{Q_R + Q_1^{\mathrm{bl}} + Q_1^{\mathrm{cv}} + Q_1^{\mathrm{wk}}}{C_p} & \\ \\ \dfrac{Q_1^{\mathrm{wk}}}{C_p} & = \quad +(\partial_t \sigma_w - e_w)\ \delta\theta & : \text{Spreading \& entrainment (cooling)} \\ \\ & \quad\;\; -\sigma_w (1 - \sigma_w)\ \delta\omega\ \partial_p \delta\theta & : \text{Differential advection (heating)} \end{array} \right.$$

with similar equations for water vapour.

Coupling convection with sub-cloud processes: ALE & ALP; 1



(a) (b)

At least two variables:

- the **Available Lifting Energy (ALE)**
- the **Available Lifting Power (ALP)**.

Trigger

The **shower is triggered** when K > gh (K = ALE = Available Lifting Energy).

Convection is triggered when the maximum kinetic energy K (K = ALE) of air impinging on the gust front exceeds the convective inhibition: **ALE > |CIN|**

Closure

The pump (power P) yields a mass flow rate M. A fraction k (the engine efficiency) of P is used by the stream.

Closure: stream power M K = k P (= ALP)

The wakes provide a power P_W. A fraction k (the wake lifting efficiency) of P_W is used to lift draughts with mass flow rate M:

- overcoming inhibition => power M |CIN|
- velocity at LFC = w_B => power ½ M w_B^2
- dissipation => power 3/2 M w_B^2

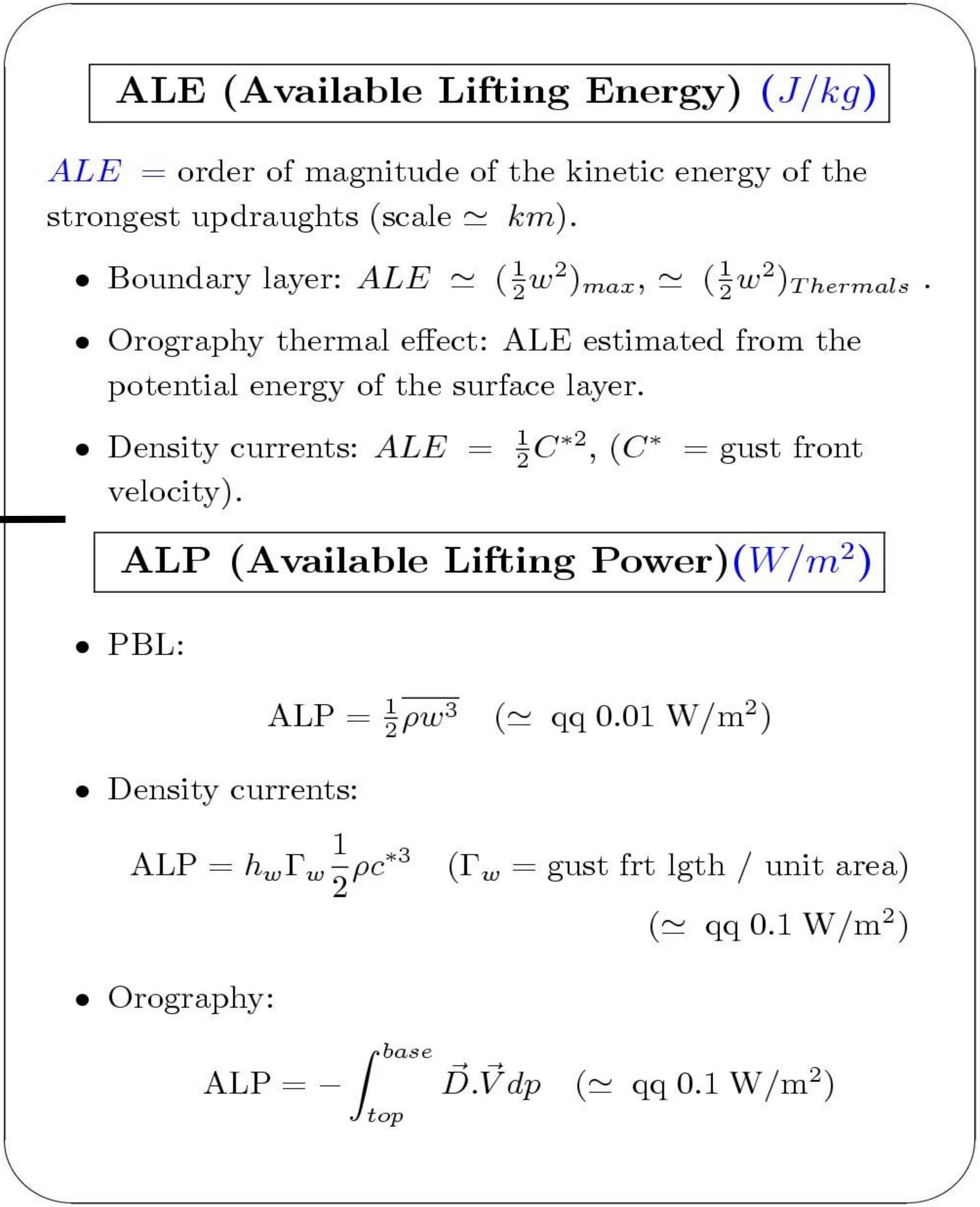
Closure: **M (|CIN| + 2 w_B^2) = k P_W (= ALP)**

Coupling convection with sub-cloud processes: ALE & ALP; 2

More generally, the convection parametrization is coupled to sub-cloud processes through the two variables: ALE (for the trigger) and ALP (for the closure).

$ALE = \sup(ALE_{PBL}, ALE_{ORO}, ALE_{WK})$

$ALP = ALP_{PBL} + ALP_{ORO} + ALP_{WK}$



ALE (Available Lifting Energy) (J/kg)

ALE = order of magnitude of the kinetic energy of the strongest updraughts (scale $\simeq$ km).

- Boundary layer: $ALE \simeq (\frac{1}{2}w^2)_{max}, \simeq (\frac{1}{2}w^2)_{Thermals}$.
- Orography thermal effect: ALE estimated from the potential energy of the surface layer.
- Density currents: $ALE = \frac{1}{2}C^{*2}$, (C^* = gust front velocity).

ALP (Available Lifting Power)(W/m^2)

- PBL:

$$\mathrm{ALP} = \frac{1}{2}\overline{\rho w^3} \quad (\simeq \text{ qq } 0.01\ \mathrm{W/m^2})$$

- Density currents:

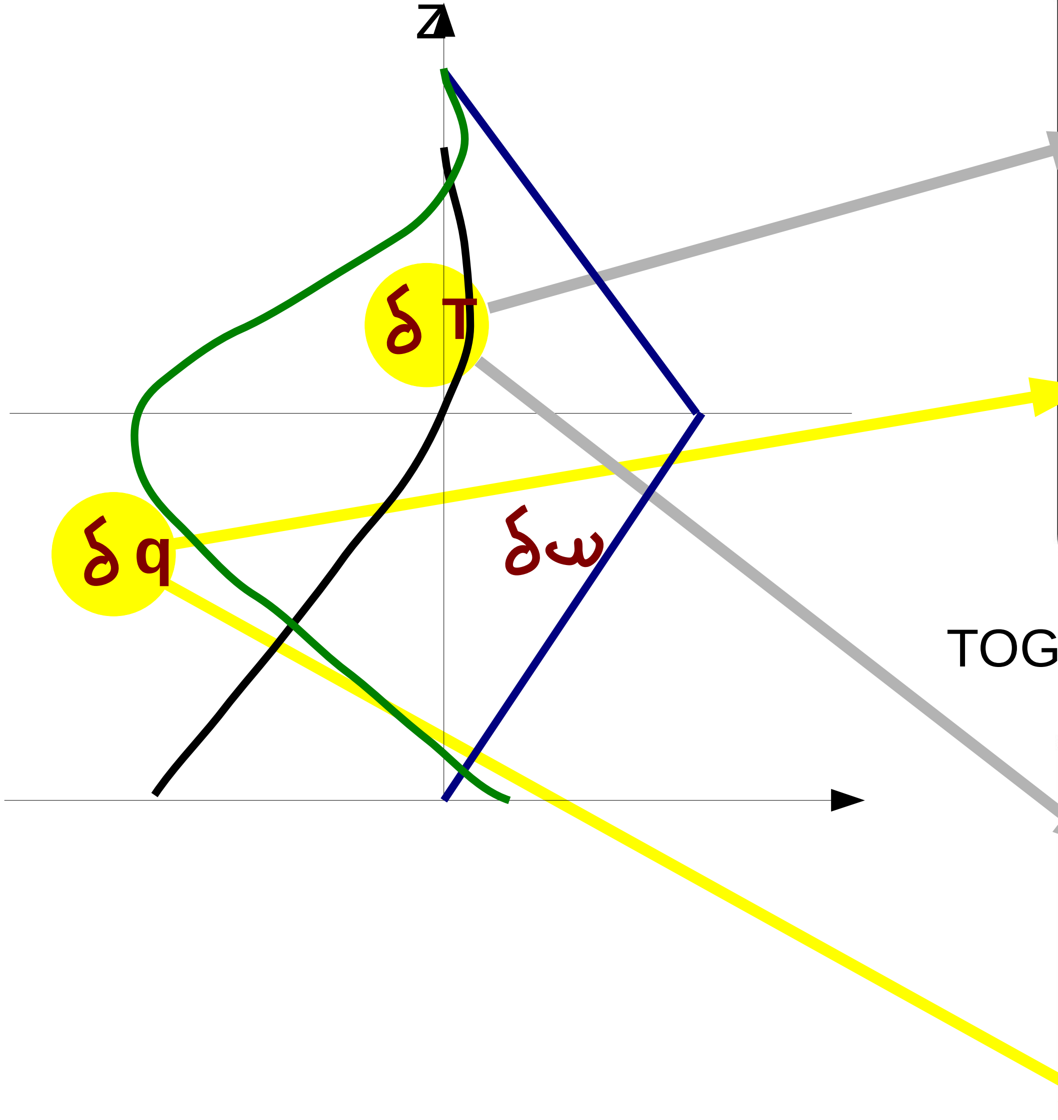
$$\mathrm{ALP} = h_w \Gamma_w \frac{1}{2} \rho c^{*3} \quad (\Gamma_w = \text{gust frt lgth / unit area})$$

$$(\simeq \text{ qq } 0.1\ \mathrm{W/m^2})$$

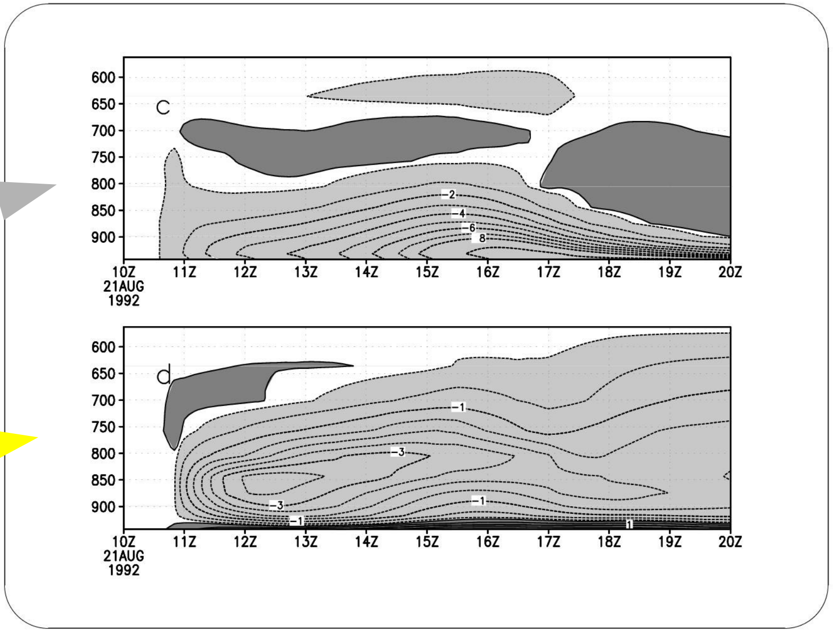
- Orography:

$$\mathrm{ALP} = -\int_{top}^{base} \vec{D}.\vec{V}\,dp \quad (\simeq \text{ qq } 0.1\ \mathrm{W/m^2})$$

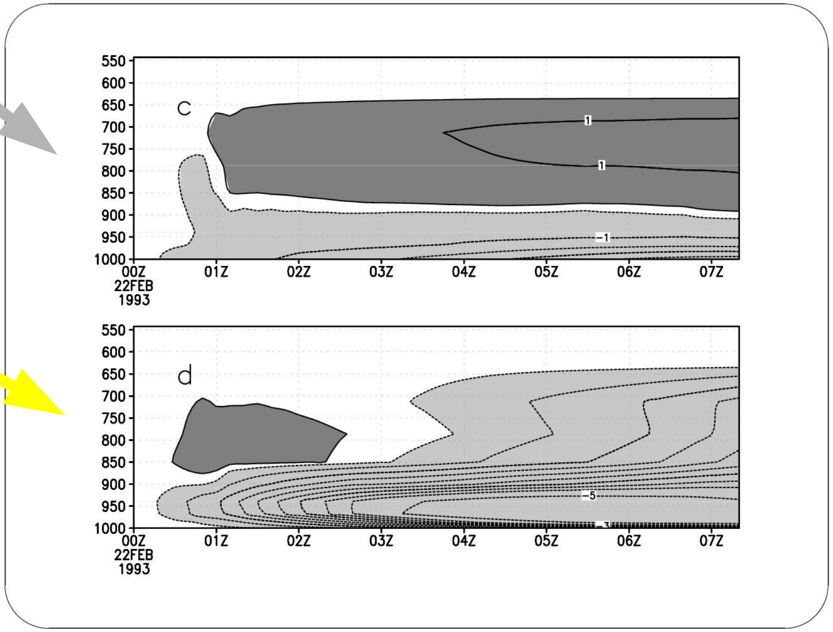
Simulated wake properties



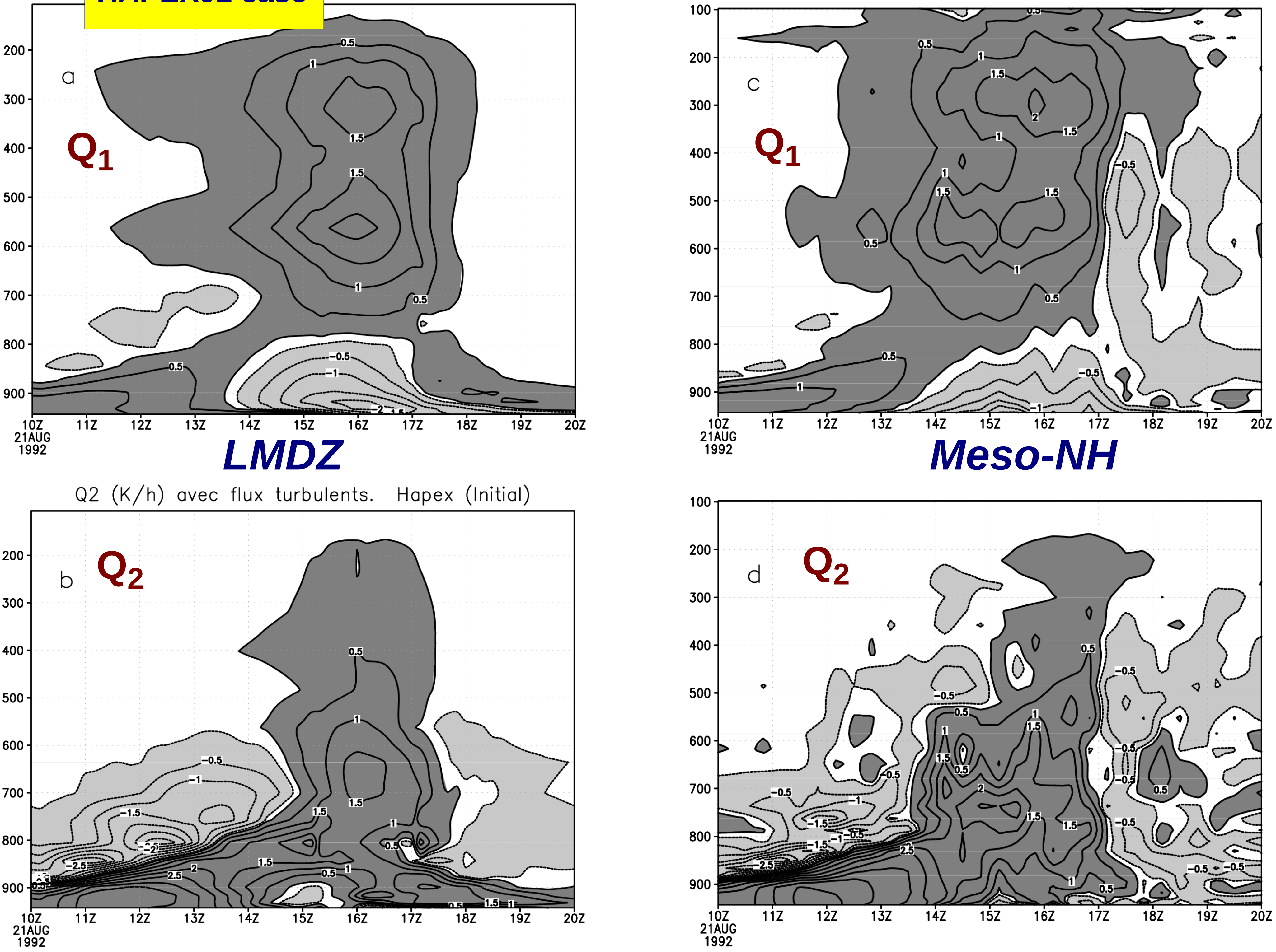
HAPEX92: 21 Aug 1992 squall line case



TOGA-COARE: 22 Feb 1993 squall line case



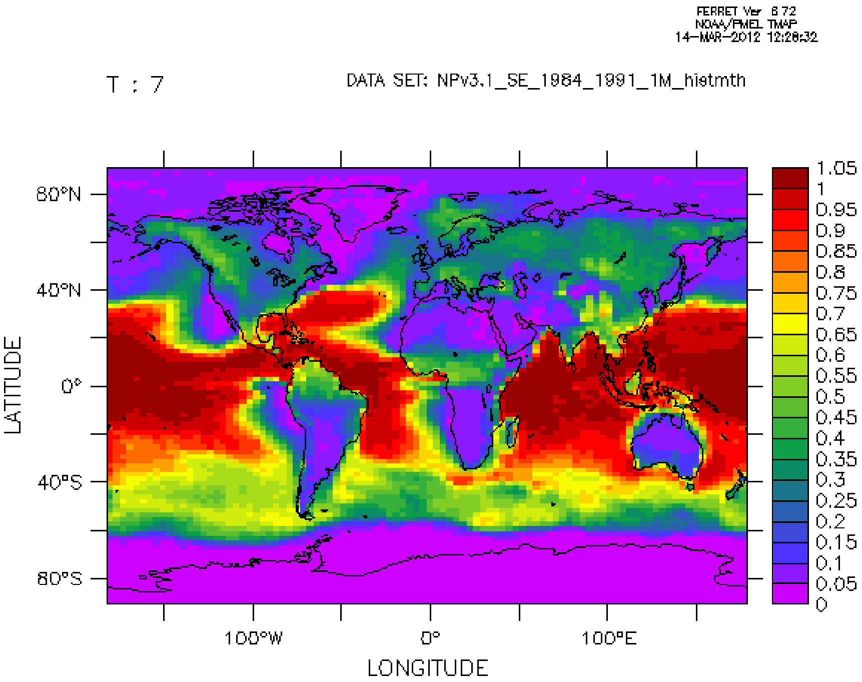
HAPEX92 case



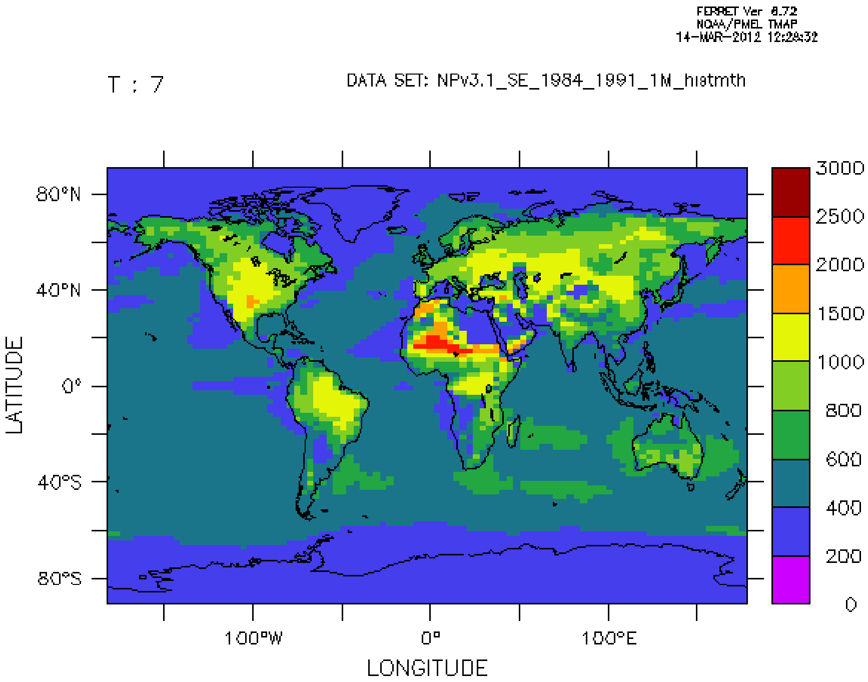
The wake parametrization present status

The wake parametrization is now routinely used in LMDZ5-NP (new physics) simulations.

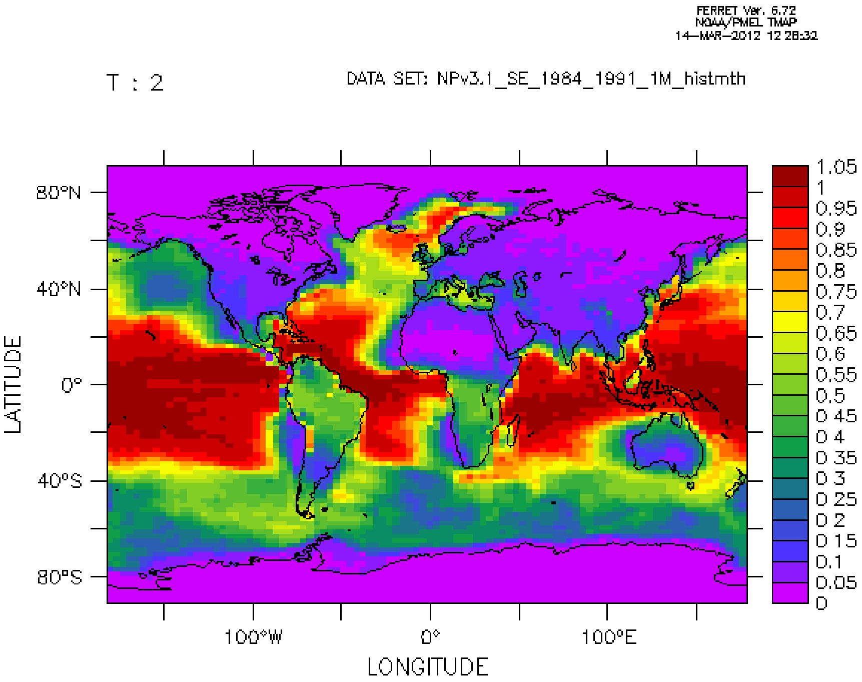
In IPSLCM5B **CMIP5 simulations**, the Emanuel convective scheme is coupled with the wake parametrization and with the PBL scheme (cloudy thermals; Rio and Hourdin, 2008) via ALE and ALP.



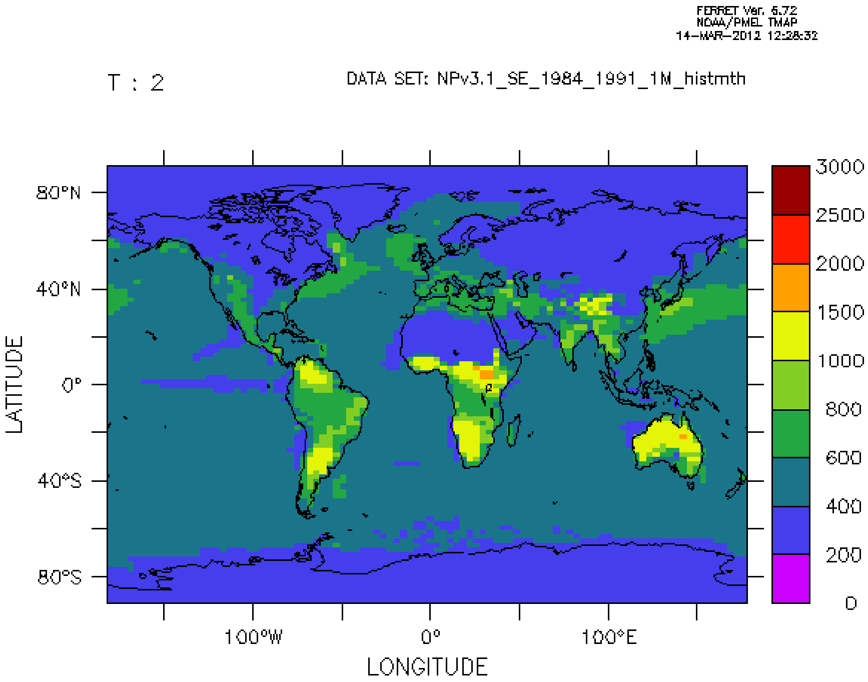
Wake presence time, Jul



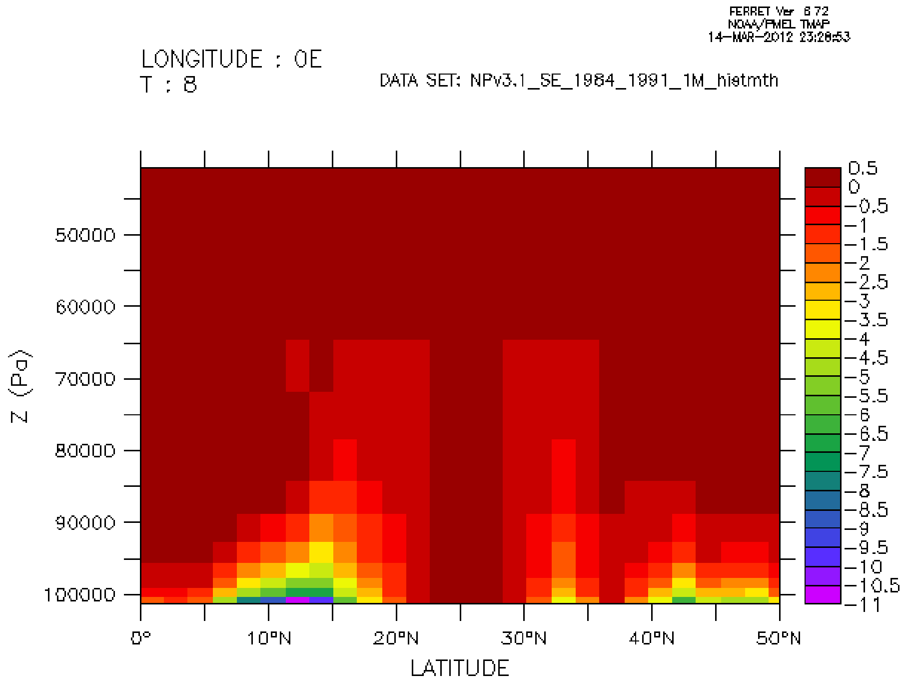
Wake height,Jul



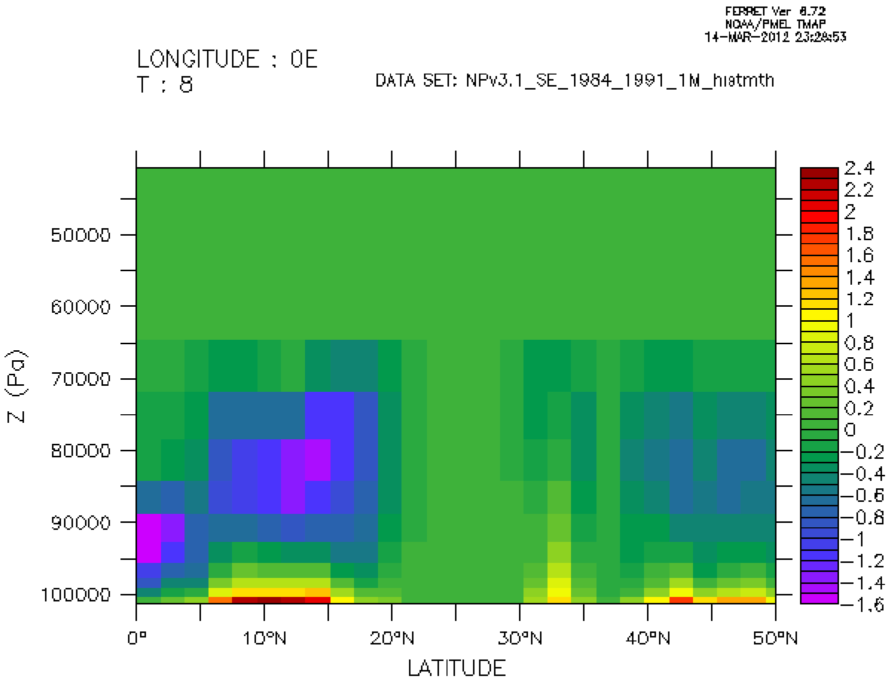
Wake presence time, Feb



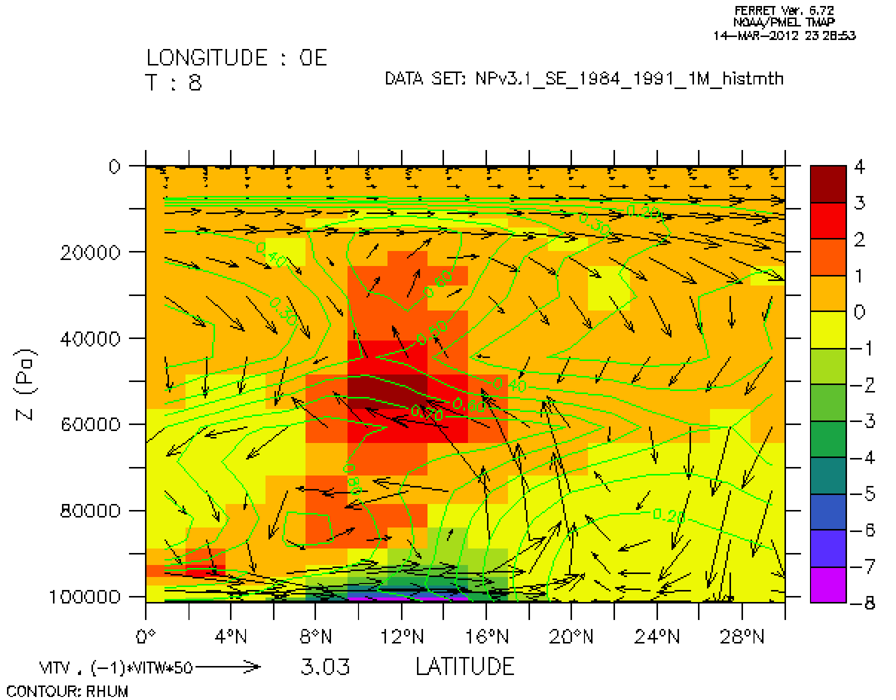
Wake height,Feb



WAKE_DELTAT*FW (K)



WAKE_DELTAQ*FW (g/kg)



(DTCON+DTWAK)*86400

And Now!

Ongoing developments:

- Improvement of some specific points of LMDZ parametrizations (splitting the PBL between the wake and the off-wake regions; introducing the ice thermodynamics).
- New parametrization of deep convection triggering (Nicolas Rochetin thesis).
- Introducing a representation of the wake population dynamic.

Need for satellite observations for the validation of deep convection triggering and for global analysis of cold pools.

Near future developments:

- Convection propagation.
- Anvil representation.

In the last two instances there are both technical issues (how do we do it?) and scientific issues (what are the processes to parametrize? **How to use satellite informations?**).