The physical parametrizations in LMDZ

LMDZ Team

Laboratoire de Météorologie Dynamique

Atmospheric GCM equations (samples)

Dynamic equations in Pressure coordinates

$$\left\{ \begin{array}{l} \partial_t \vec{V} = \boxed{-(\vec{V}.\vec{\nabla})\vec{V} - \omega \partial_p \vec{V}} - \boxed{\vec{\nabla}\Phi} \; - \boxed{f\vec{k} \text{ x } \vec{V}} \; + \vec{S_V} \\ \\ \vec{\nabla}.\vec{V} + \partial_p \omega = 0 \\ \\ \partial_t q = -\vec{V}.\vec{\nabla} q - \omega \partial_p q + S_q \end{array} \right. \quad \left\{ \begin{array}{l} \Phi = gz \quad \text{geopotential} \\ \\ \omega = \partial_t p \quad \text{vert. velocity} \\ \\ q = \text{specific humidity} \end{array} \right. \quad (1)$$

transport — gravity — Coriolis

Sources: $\vec{S_V}$, S_q

$\vec{S_v}$ and S_q : source terms determined by **physical parametrizations** :

- planetary boundary layer
- deep convection (big cumulus and cumulonimbus)
- clouds
- radiative processes
- orography
- soil . . . .

Basic facts about parametrizations

- Each parametrization : (1) works almost independently of the others ; (2) depends on vertical profiles of u, v, w, T, q and on some interface variables with the other parametrizations ; (3) ignores the spatial heterogeneities associated with the other processes (except with the wakes).
- The total tendency due to sub-grid processes is the sum of the tendencies due to each process :

$$
\begin{aligned}
S_T = (\partial_t T)_\varphi &= (\partial_t T)_{\text{eva}} + (\partial_t T)_{\text{lsc}} + (\partial_t T)_{\text{diff turb}} + (\partial_t T)_{\text{conv}} \\
&+ (\partial_t T)_{\text{wk}} + (\partial_t T)_{\text{Th}} + (\partial_t T)_{\text{ajs}} + (\partial_t T)_{\text{rad}} + (\partial_t T)_{\text{oro}}
\end{aligned}
$$

physiq.F90 structure - I

Initialization (once) : *conf_phys, phyetat0, phys_output_open,*

Beginning *change_srf_frac, solarlong, cloud water evap.*

Vertical diffusion (turbulent mixing) *pbl_surface*

Deep convection *conflx* (Tiedtke) or *concvl* (Emanuel) or *conema3* (Emanuel old)

Deep convection clouds *clouds_gno*

Density currents (wakes) *calwake*

Strato-cumulus *stratocu_if*

Thermal plumes *calltherm* and *ajsec* (sec = dry)

Thermal plume clouds *calcratqs*

Large scale condensation *fisrtilp*

Diagnostic clouds for Tiedtke *diagcld1*

Aerosols *readaerosol_optic*

Cloud optical parameters *newmicro* or *nuage*

Radiative processes *radlwsw* (bis)

In blue : subroutines and instructions modifying state variables

physiq.F90 structure - II

Orographic processes : drag *drag_noro_strato* or *drag_noro*

Orographic processes : lift *lift_noro_strato* or *lift_noro*

Orographic processes : Gravity Waves *hines_gwd* or *GWD_rando*

Axial components of angular momentum and mountain torque : *aaam_bud*

Cosp simulator *phys_cosp*

Tracers *phytrac*

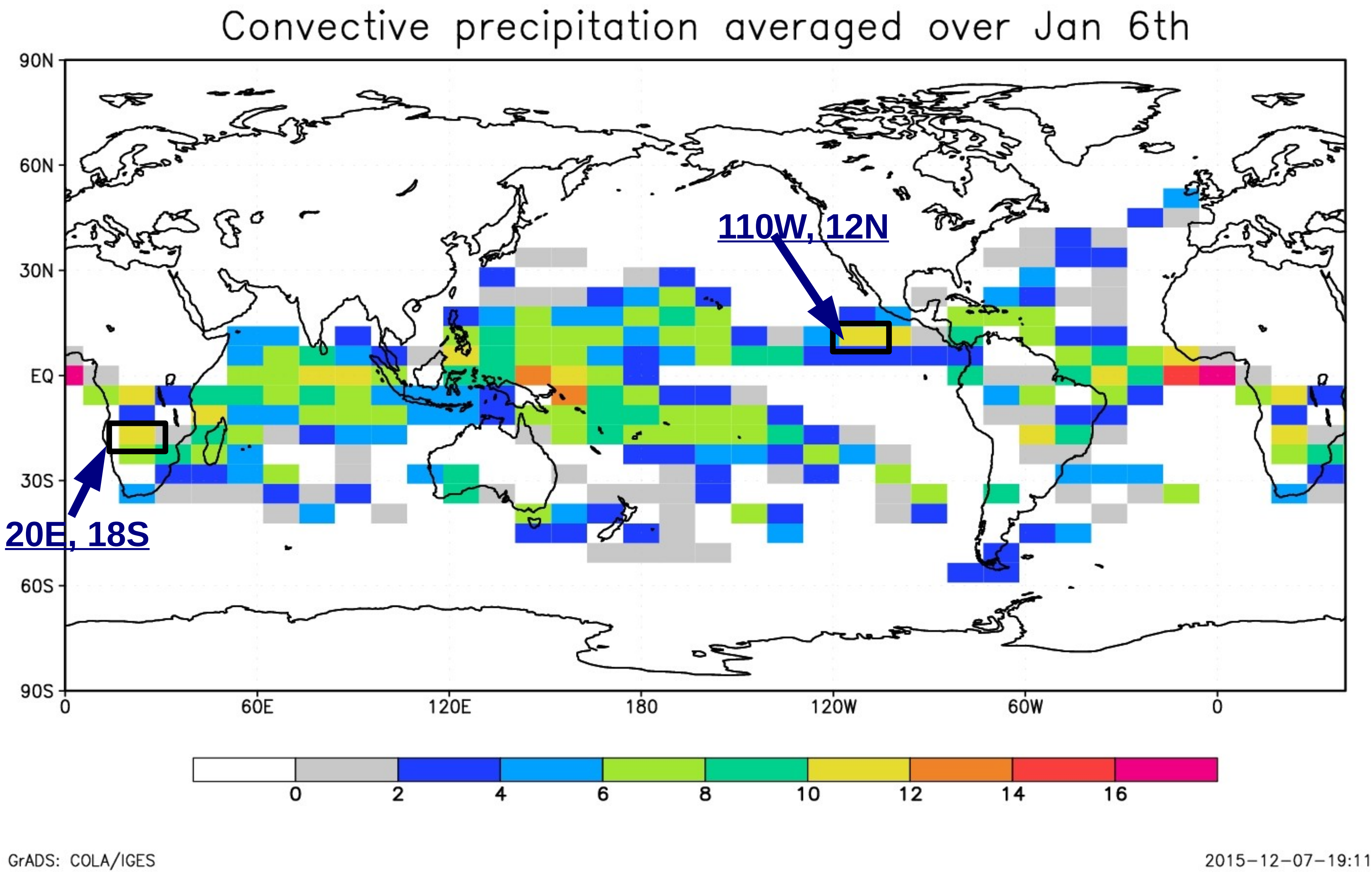
Tracers off-line *phystokenc*

Water and energy transport *transp*

Outputs

Statistics

Output of final state (for restart) *phyredem*


Convective precipitation averaged over Jan 6th
110W, 12N
20E, 18S
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
0
2
4
6
8
10
12
14
16
GrADS: COLA/IGES
2015-12-07-19:11

Turbulent diffusion

- Turbulent diffusion or "turbulent mixing" : transport by small random movements. Similar to molecular diffusion.

$$Dq/Dt = S_q \quad \text{où} \quad S_q = \frac{\partial}{\partial z}(K_z \frac{\partial q}{\partial z})$$

- **Prandtl mixing length** : $K_z = l\,|w|$
  l : characteristic length of the small movements
  w : characteristic velocity
- **Turbulent kinetic energy (TKE)** : $K_z = l\,\sqrt{e}$

$$\begin{aligned} De/Dt &= f(dU/dz, d\theta/dz, e, ...) \\ Dl/Dt &= ... \end{aligned}$$

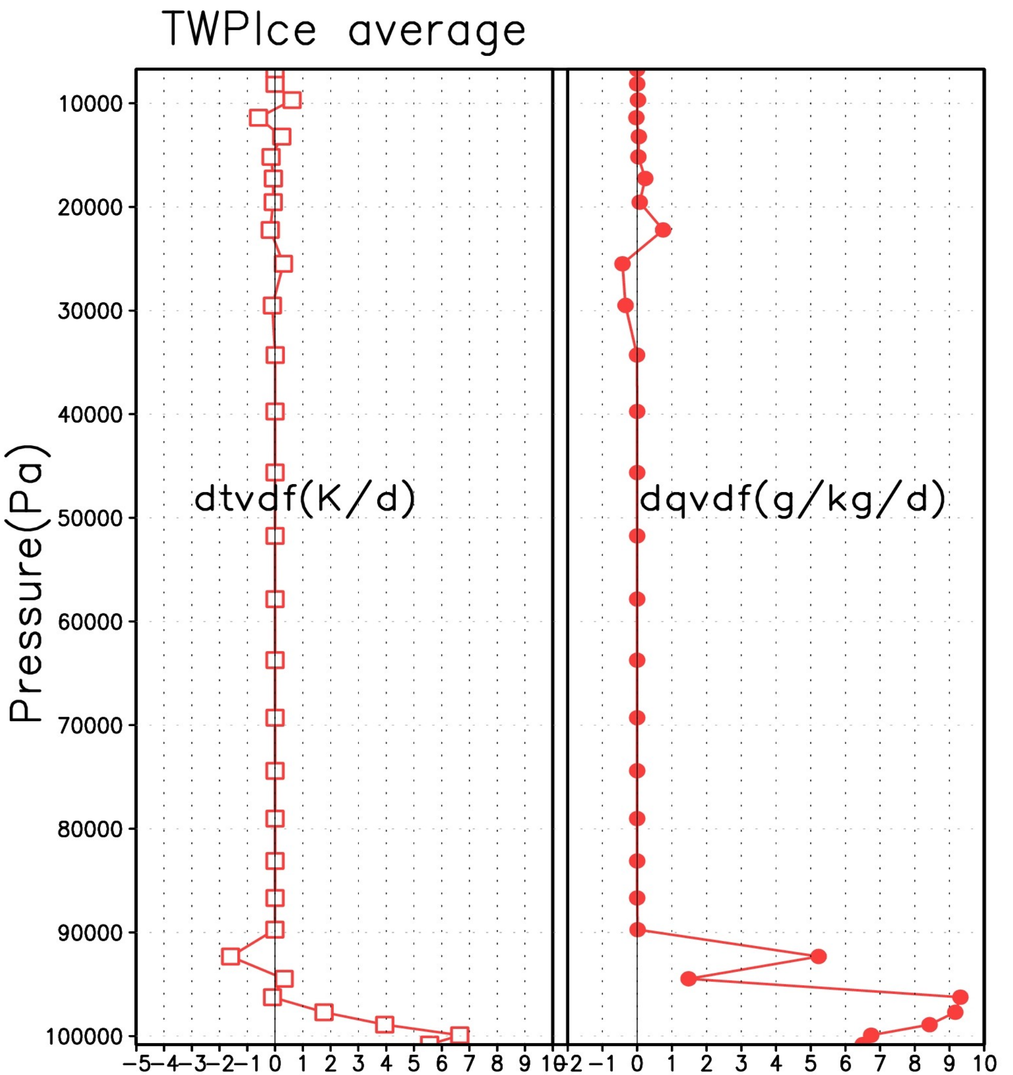
Vertical diffusion

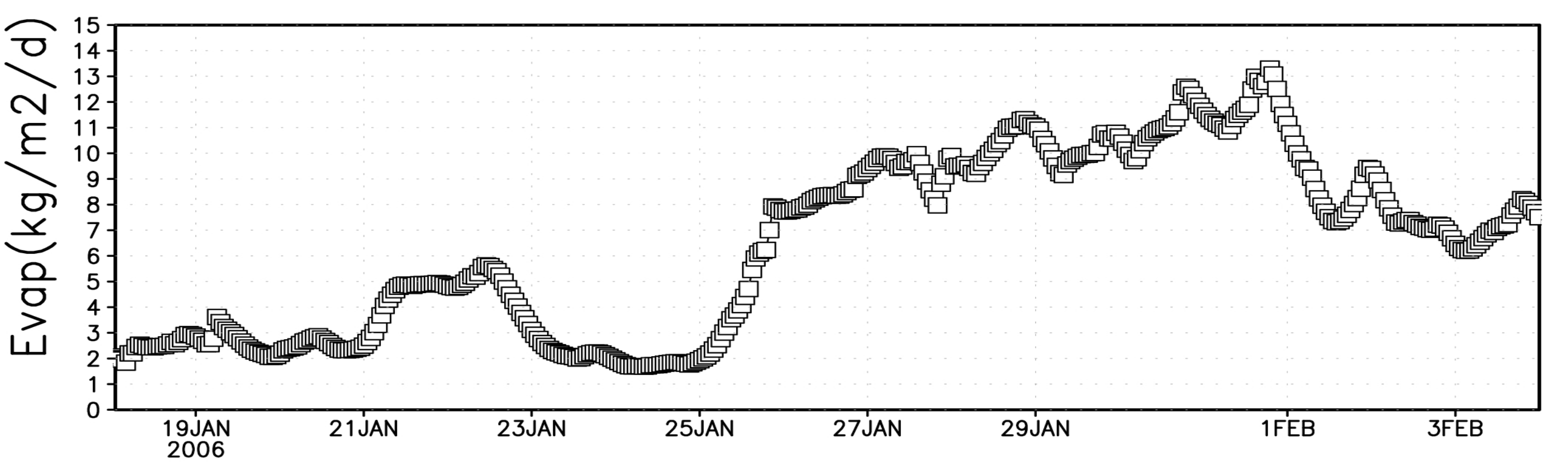
Tendencies :

dtvdf, dqvdf, duvdf, dvvdf

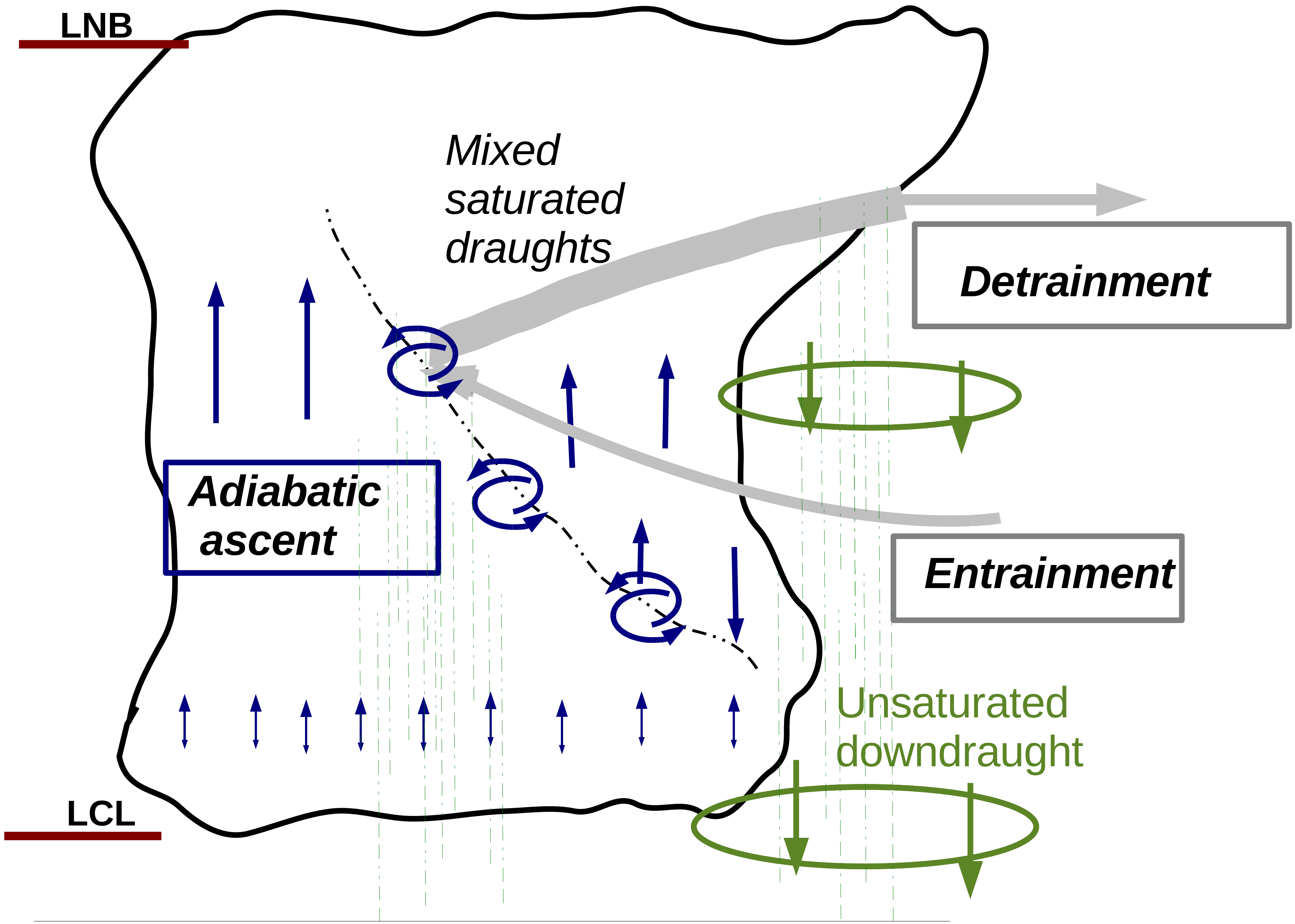
Other variables

- sens : sensible heat flux at the surface (positive upward)
- evap : water vapour flux at the surface (positive upward)
- flat : latent heat flux at the surface (positive downward)
- taux, tauy : wind stress at the surface





Emanuel scheme



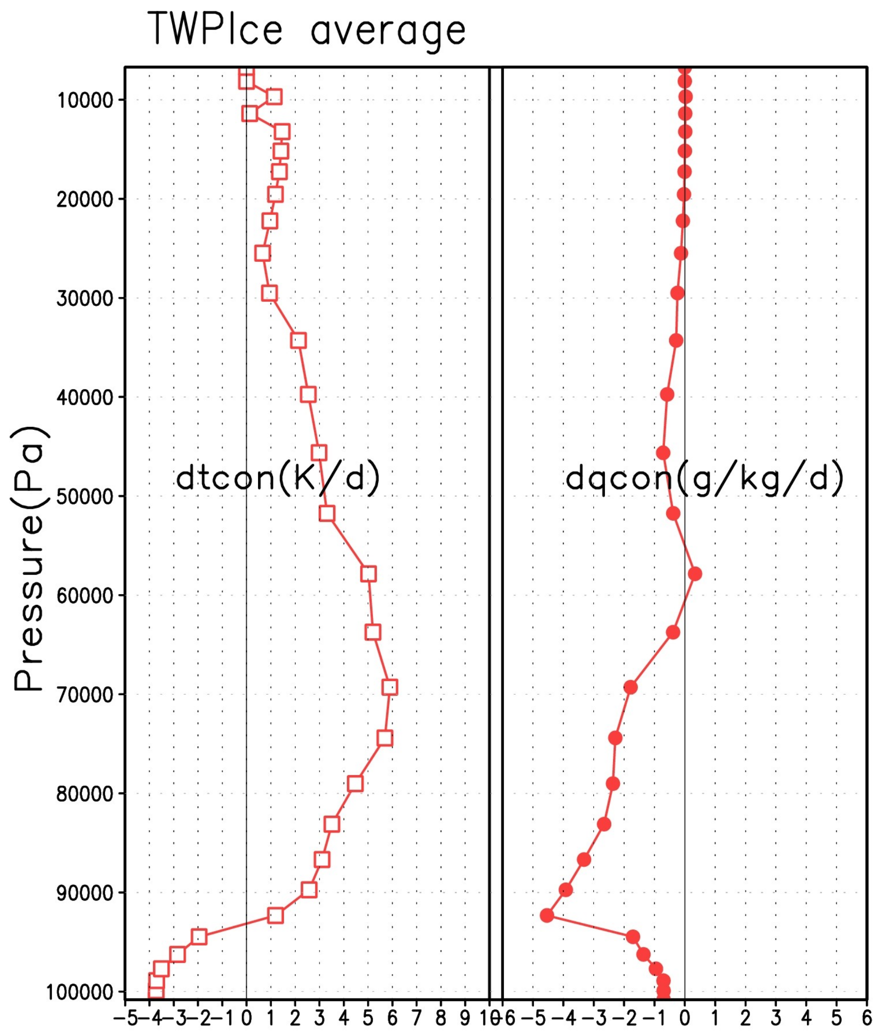
Deep convection

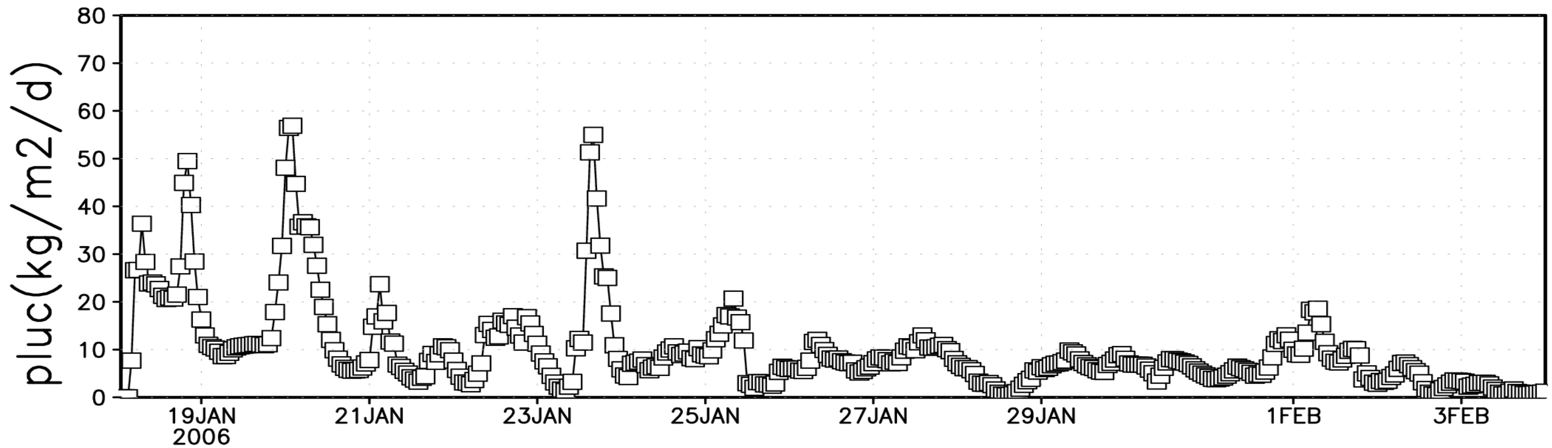
Tendencies :

dtcon, dqcon, ducon, dvcon

Other variables

- pluc : convective precipitation at the surface
- ftd : temperature tendency due to the sole unsaturated downdraughts
- fqd : moisture tendency due to the sole unsaturated downdraughts
- clwcon : condensed water of convective clouds ("in cloud" condensed water content)
- Ma : mass flux of the adiabatic ascent
- upwd : mass flux of the saturated updraughts
- dnwd : mass flux of the saturated downdraughts
- dnwd0 : mass flux of the unsaturated downdraught (precipitating downdraught)
- Vprecip : vertical profile of convective precipitation





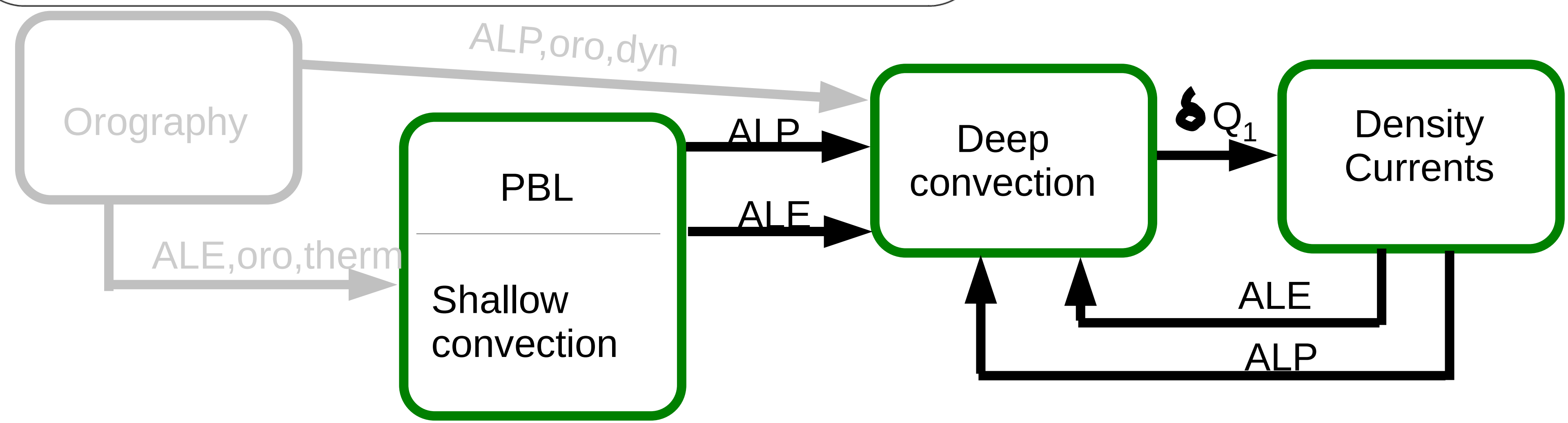
Deep convection

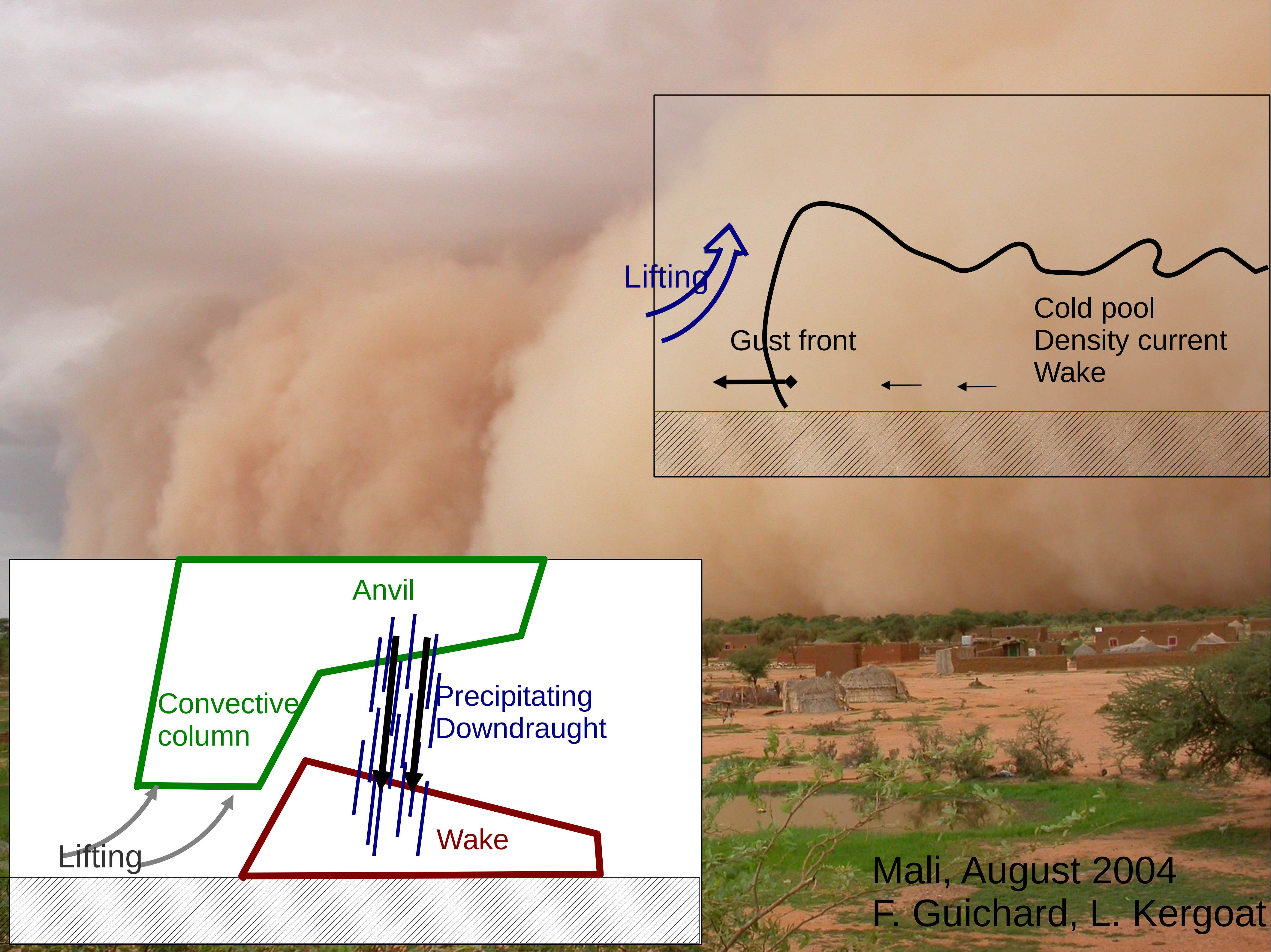
Tendencies :

dtcon, dqcon, ducon, dvcon

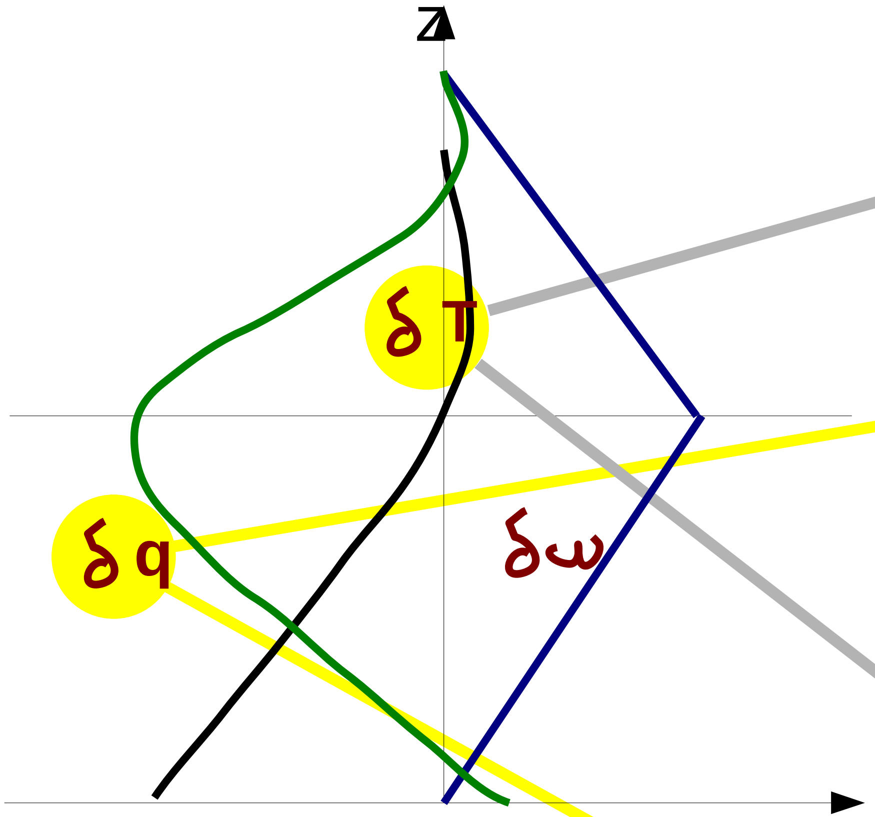
Other variables

- pluc : convective precipitation at the surface
- ftd : temperature tendency due to the sole unsaturated downdraughts
- fqd : moisture tendency due to the sole unsaturated downdraughts
- clwcon : condensed water of convective clouds ("in cloud" condensed water content)
- Ma : mass flux of the adiabatic ascent
- upwd : mass flux of the saturated updraughts
- dnwd : mass flux of the saturated downdraughts
- dnwd0 : mass flux of the unsaturated downdraught (precipitating downdraught)
- Vprecip : vertical profile of convective precipitation

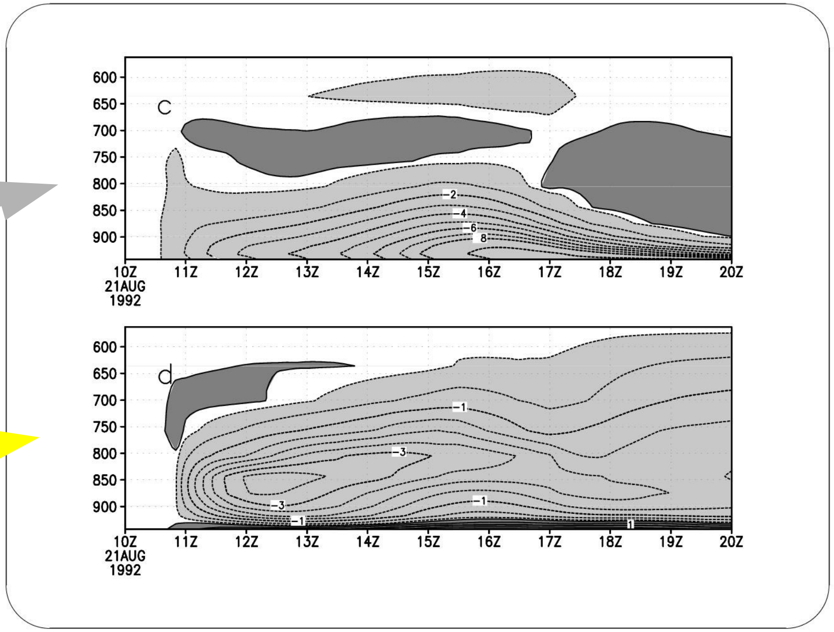



Lifting
Gust front
Cold pool
Density current
Wake
Anvil
Convective column
Precipitating Downdraught
Wake
Lifting
Mali, August 2004
F. Guichard, L. Kergoat

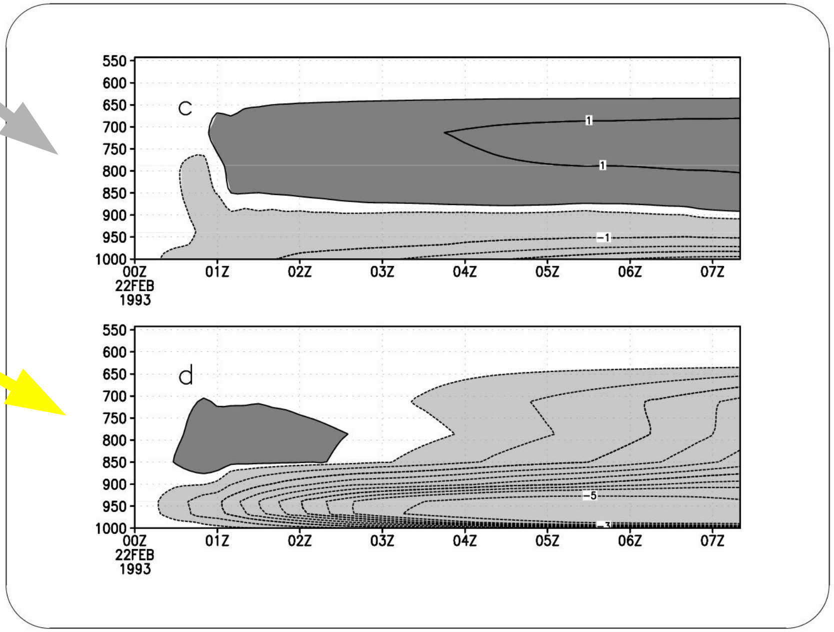
Simulated wake properties



HAPEX92: 21 Aug 1992 squall line case



TOGA-COARE: 22 Feb 1993 squall line ca



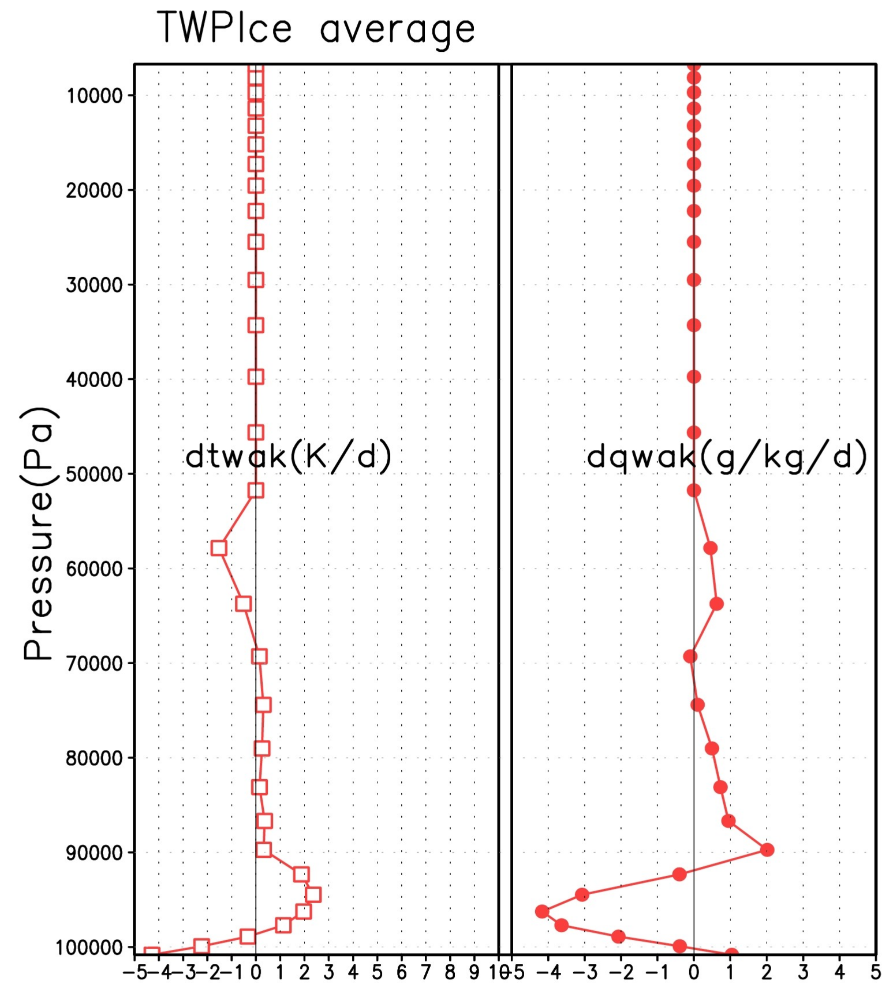
Cold pools (wakes)

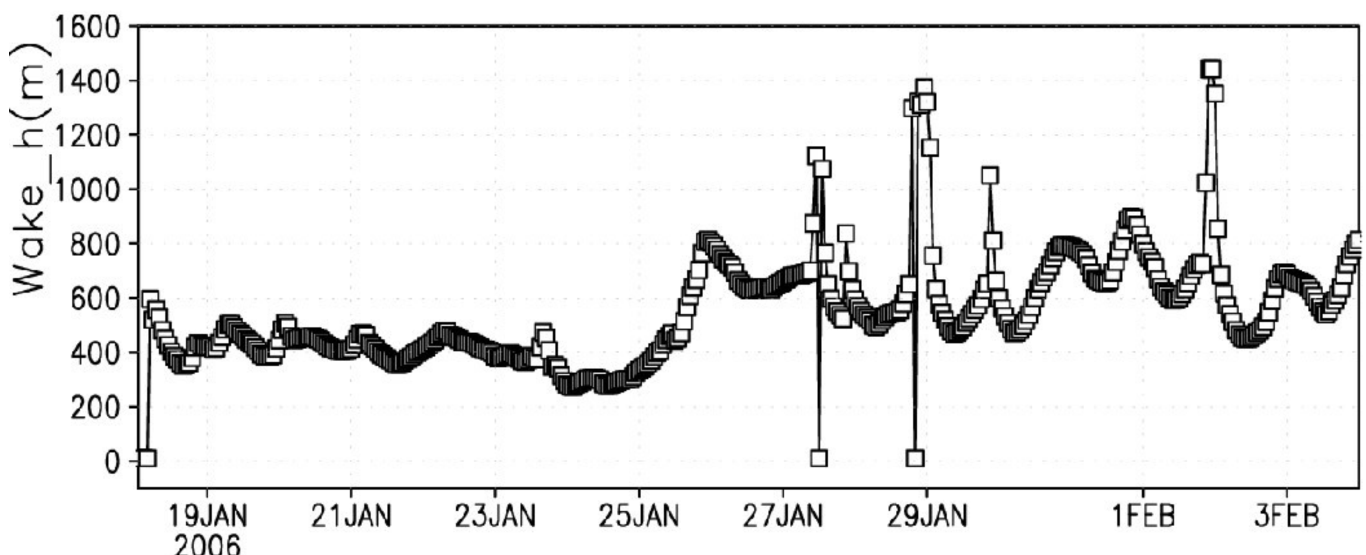
Tendencies :

dtwak, dqwak

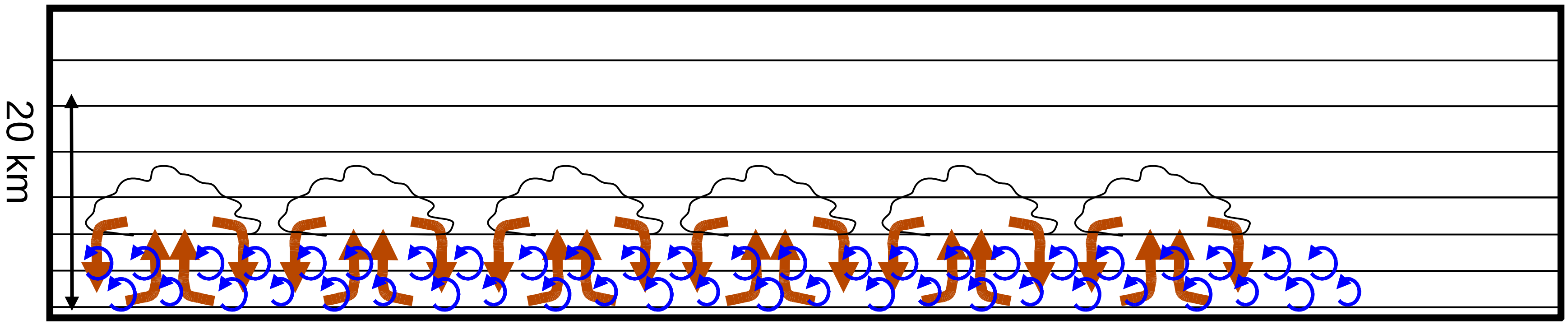
Other variables

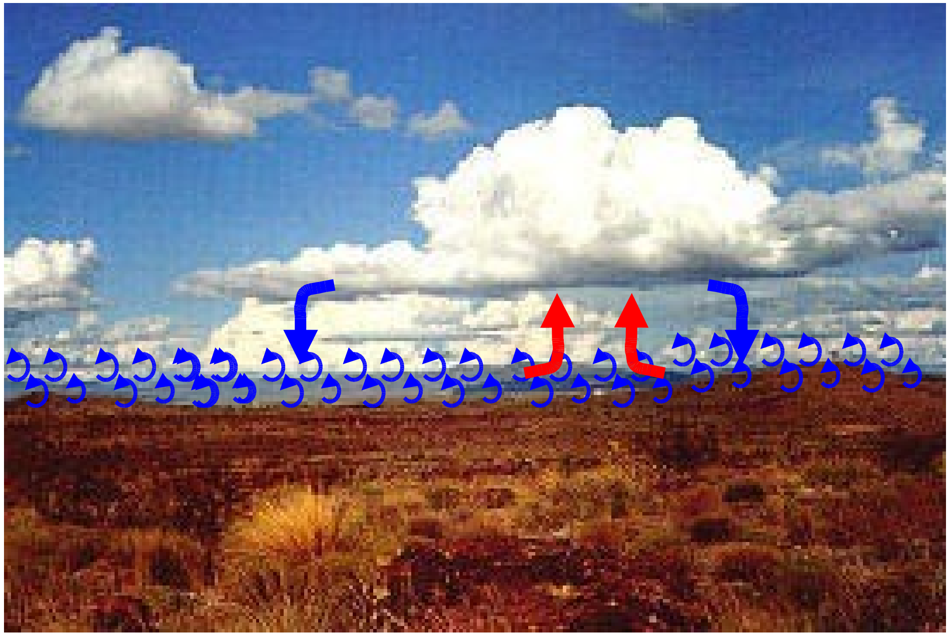
- Alp_wk : lifting power due to cold pools
- Ale_wk : lifting energy due to cold pools
- wake_s : fractional area of cold pools
- wake_h : cold pool height
- wape : WAke Potential Energy
- wake_deltat : vertical profile of temperature difference $T_w - T_x$
- wake_deltaq : vertical profile of humidity difference $q_w - q_x$
- wake_omg : vertical profile of vertical velocity difference $\omega_w - \omega_x$





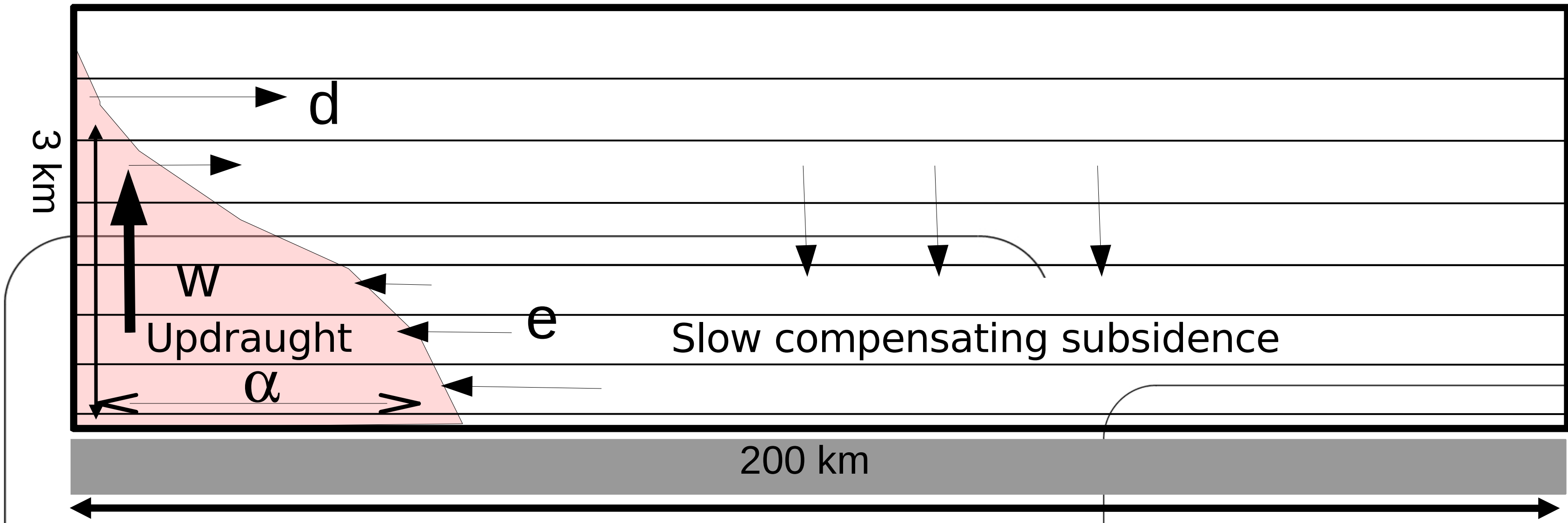
In a model column there are structures of boundary layer scale





“The Thermal Model”:
Each column is split in two parts: Ascending air from the surface and subsiding air around it.

The model represents a mean plume (the thermal) and a mean cloud.



Internal variables of the parametrization :

- w = mean vertical velocity of ascending plumes
- α = fractionnal area covered by the updraughts
- e = lateral input rate of air into the plume (entrainment)
- d = output rate of air from the plume (detrainment)
- q_a = concentration of constituant q in the updraughts

Source term for the explicit equations :

$$S_q = -\frac{1}{\rho}\frac{\partial}{\partial z}\overline{\rho w' q'} = \frac{1}{\rho}\frac{\partial}{\partial z}\left[\rho K_z \frac{\partial q}{\partial z}\right] - \frac{1}{\rho}\frac{\partial}{\partial z}\left[f(q_a - q)\right]$$

Turbulent Diffusion

Transport by the thermal plume model

- **Mass conservation**

$$\frac{\partial f}{\partial z} = e - d \quad \text{where} \quad f = \alpha \rho w$$

- **Mass conservation of constituent** q

$$\frac{\partial f q_a}{\partial z} = eq - dq_a$$

- **Equation of movement**

$$\frac{\partial f w}{\partial z} = -dw + \alpha \rho B$$

- **where B is the buoyancy :**

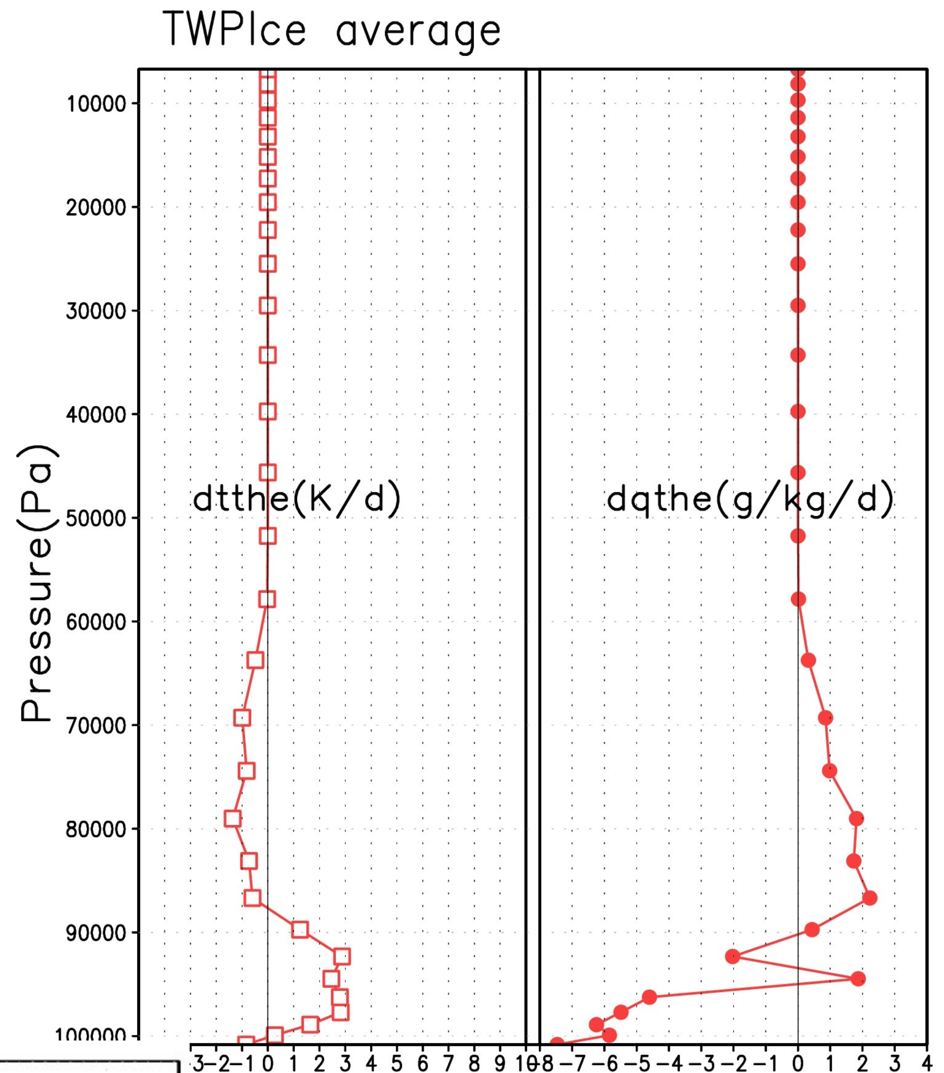
$$B = g\frac{\theta_{va} - \theta_v}{\theta_v}$$

- **and the complex part lies in the expression of** e **and** d **:**

$$e = f\, max\left(0, \frac{\beta}{1+\beta}(a_1 \frac{B}{w^2} - b)\right)$$

$$d = ...$$

Etc ...



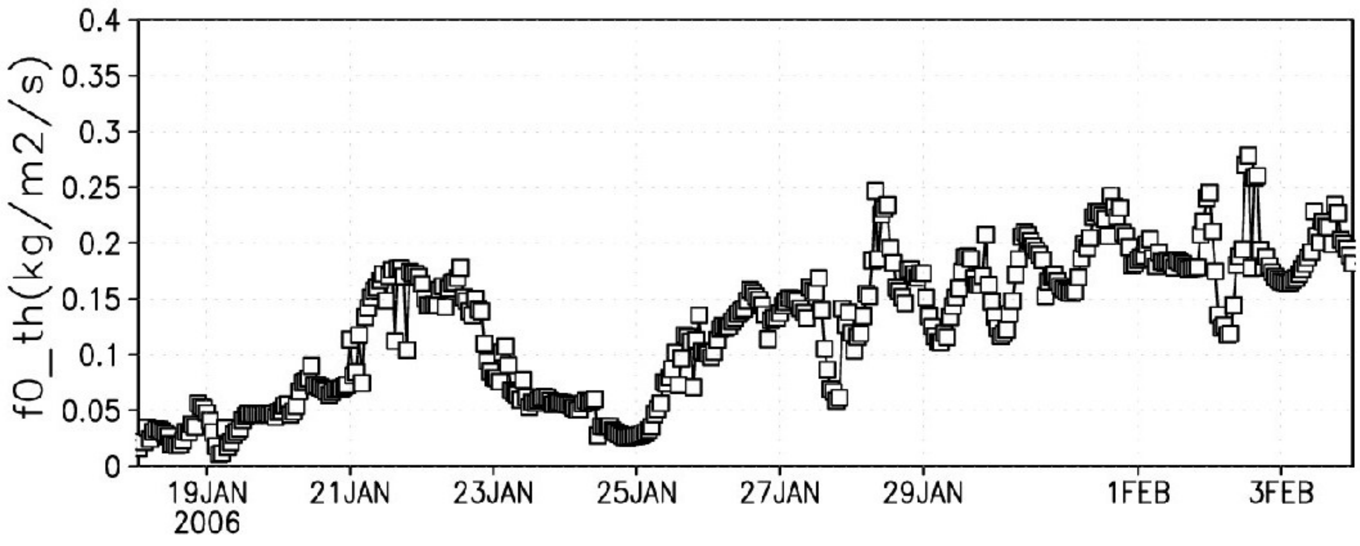
Thermals and dry adjustment

Tendencies :

dtthe, dqthe,duthe, dvthe

Other variables

- dtajs : temperature tendency due to the sole dry adjustment
- dqajs : humidity tendency due to the sole dry adjustment
- a_th : fractional area of thermal plumes
- d_th : detrainment
- e_th : entrainment
- f_th : mass flux
- w_th : vertical velocity in the thermal plume (m/s, positive upward)
- q_th : total water content in the thermal plume
- zmax_th : altitude of the top of the thermal plume (m)



Orography

Tendencies :

dtoro, duoro, dvoro : tendencies of temperature and velocity due to the drag
dtlif, dulif, dvlif : tendencies of temperature and velocity due to the lift

Total tendencies are the sums of the drag and lift tendencies.

Large scale condensation (evap & lsc)

Tendencies :

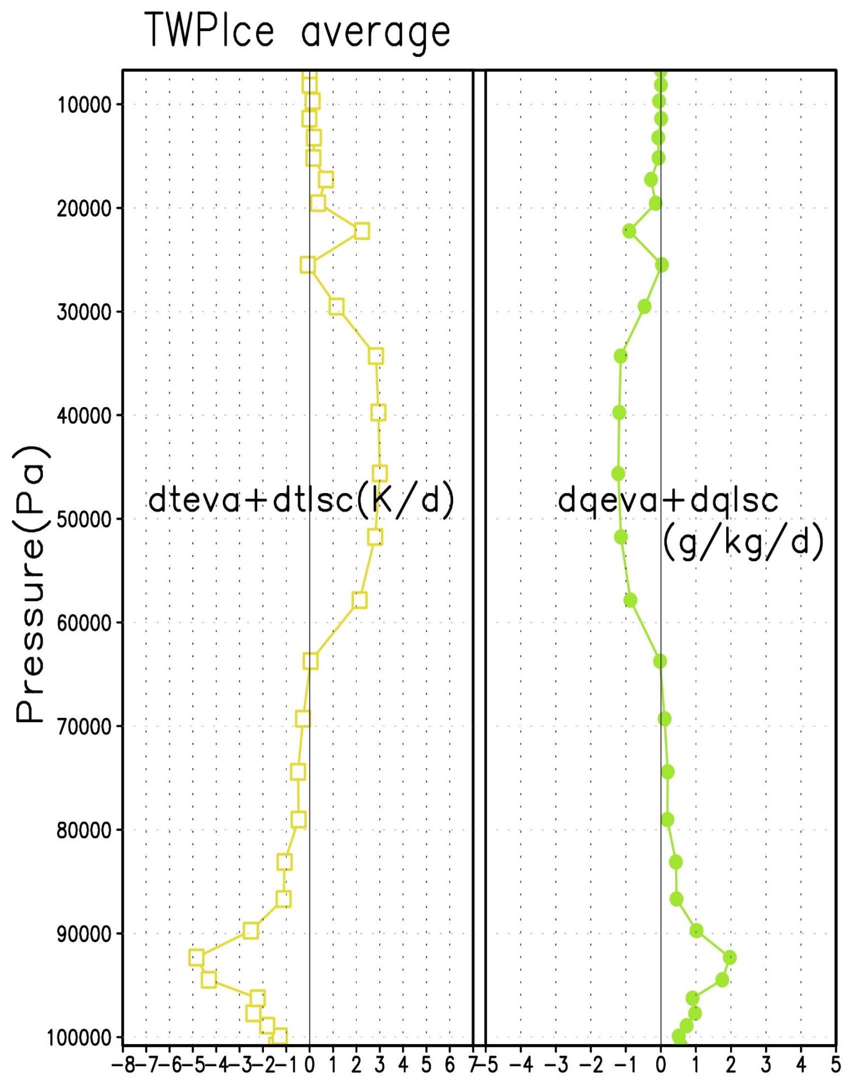
dteva, dqeva : tendencies due to cloud water evaporation

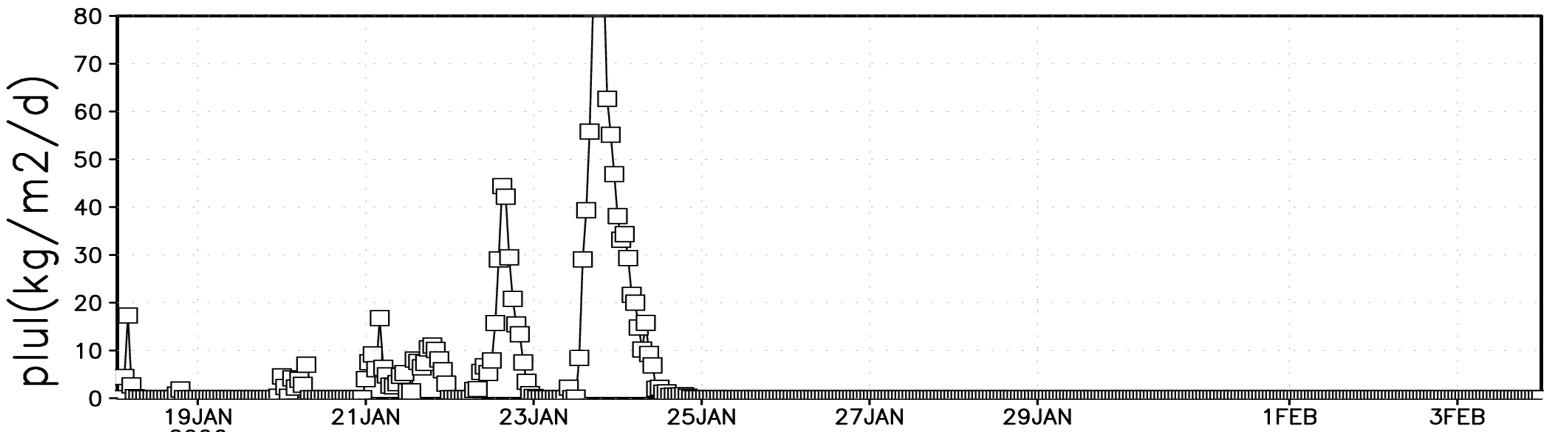
dtlsc, dqlsc : tendencies due to cloud water condensation

Total tendencies are the sums of the evaporation and condensation tendencies.

Other variables

- plul : so called "large scale" or "stratiform" precipitation ; encompasses both stratiform precipitation and boundary layer cumulus precipitation.
- rneb : cloud cover





Radiation

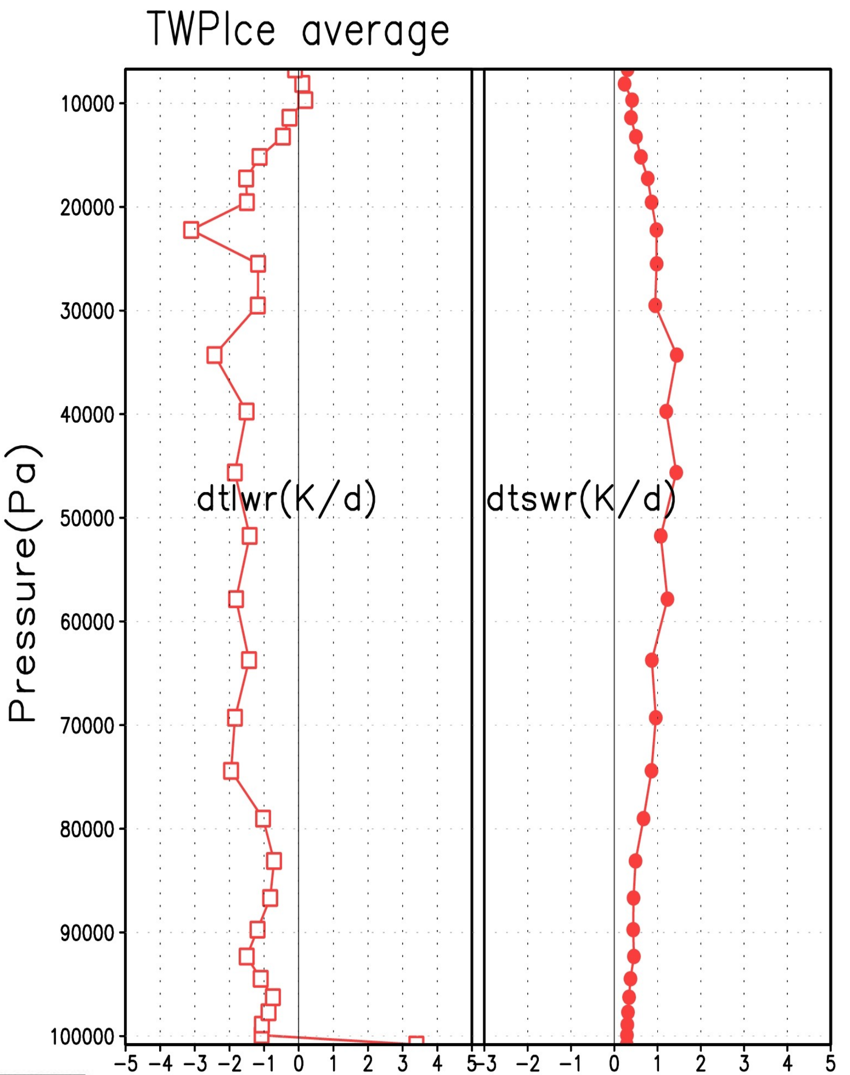
Tendencies :

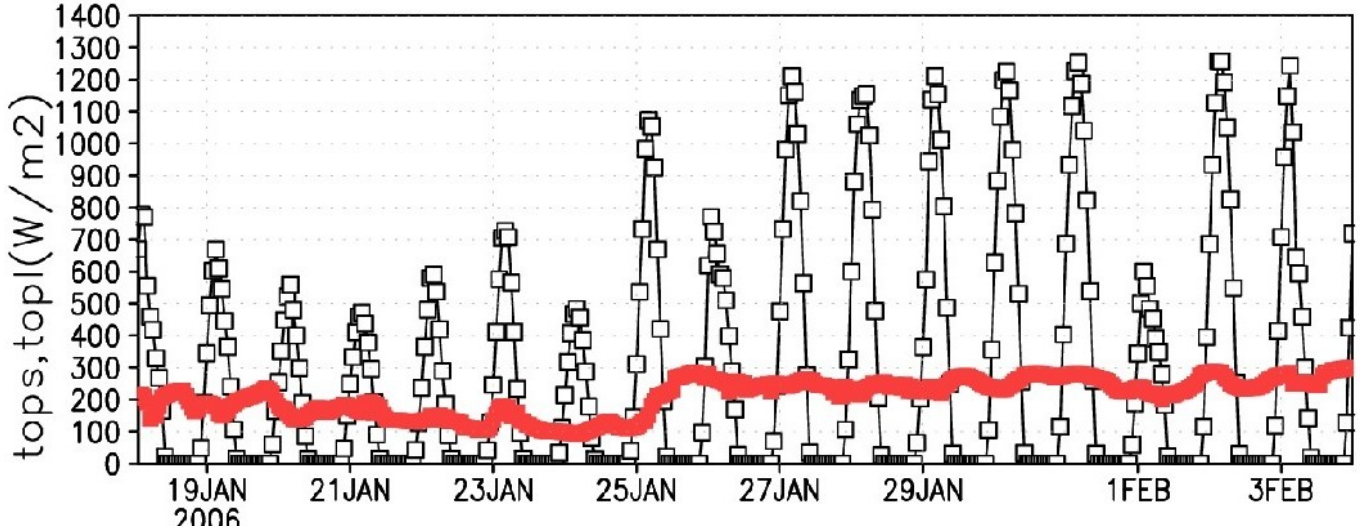
dtswr, dtlwr Temperature tendencies due to solar radiation (SW = short wave) and thermal infra-red (LW = long wave)

The total radiative tendency is the sum of the SW and LW tendencies.

Other variables

- dtsw0 : clear sky SW tendency
- dtlw0 : clear sky LW tendency
- tops : net solar radiation at top of atmosphere (positive downward)
- topl : net infra-red radiation at top of atmosphere (positive upward)
- tops0, topl0 : same for clear sky
- sols : net solar radiation at surface (positive downward)
- soll : net infra-red radiation at surface (positive downward)
- sols0, soll0 : same for clear sky





LMD	LMDZ5A	LMDZ5B
Boundary layer	Turbulent diffusion + Counter gradient (Louis/Laval)	Turbulent diffusion (Mellor and Yamada) + Convective boundary layer Mass flux scheme (thermal model, Rio/Hourdin)
Convection	Mass flux scheme by Emanuel. CAPE closure	Modified Emanuel scheme. ALE/ALP trigger/closure coupled with the thermal model + cold pools
Surface	2 layer Sechiba model	2 layer Sechiba model