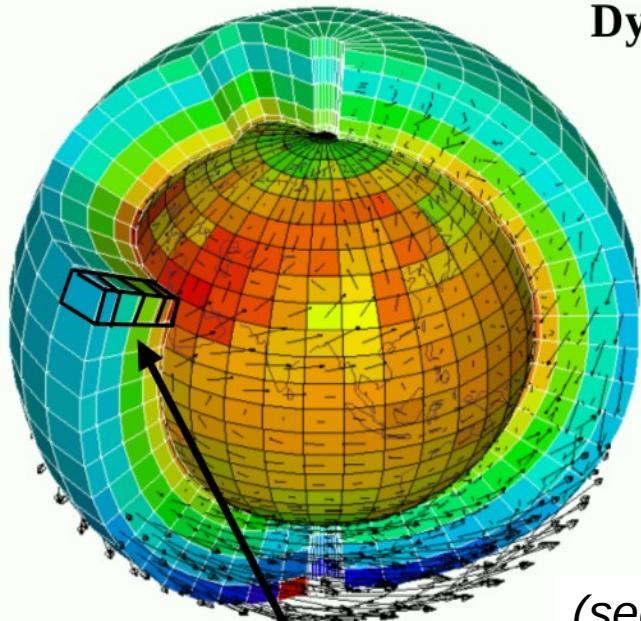


# The physical parametrizations in LMDZ

LMDZ Team

Laboratoire de Météorologie Dynamique  
December 2017

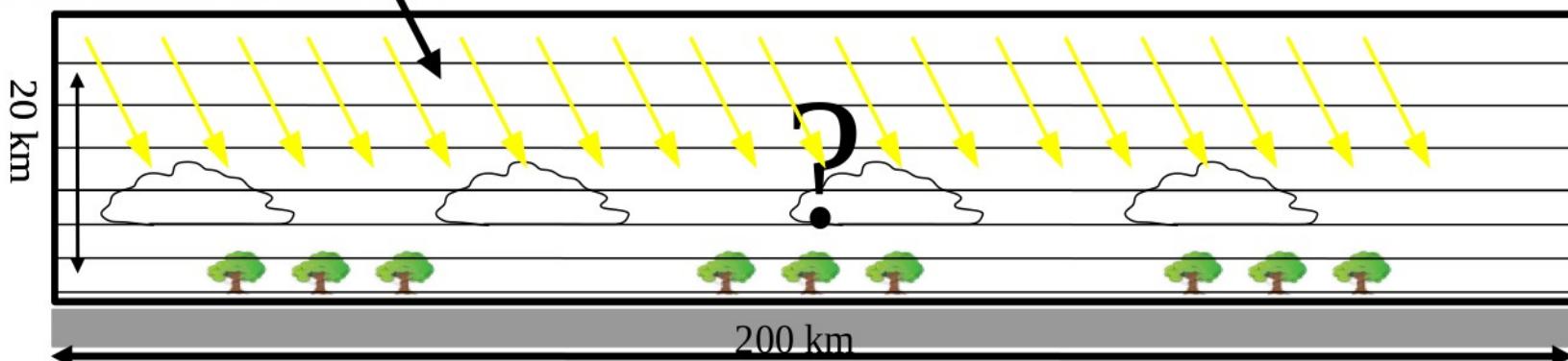
# Quick reminder : general equations



Dynamical core : primitive equations discretized on the sphere

- Mass conservation  
$$D\rho/Dt + \rho \operatorname{div} \underline{U} = 0$$
- Potential temperature conservation  
$$D\theta/Dt = Q / Cp \ (p_0/p)^\kappa$$
- Momentum conservation  
$$D\underline{U}/Dt + (1/\rho) \operatorname{grad} p - g + 2 \ \underline{\Omega} \wedge \underline{U} = \underline{F}$$
- Secondary components conservation  
$$Dq/Dt = Sq$$

(see yesterday's presentation by F. Hourdin)



## Atmospheric GCM equations

### Primitive equations in pressure coordinates

Momentum equation :

$$\partial_t \vec{v} + (\vec{v} \cdot \vec{\nabla}_p) \vec{v} + \omega \partial_p \vec{v} + f \vec{k} \times \vec{v} + \vec{\nabla}_p \Phi = \vec{S}_v$$

transport      Coriolis      gravity

Continuity equation :

$$\vec{\nabla}_p \cdot \vec{v} + \partial_p \omega = 0$$

Component conservation :

$$\partial_t q + \vec{v} \cdot \vec{\nabla}_p q + \omega \partial_p q = S_q$$

Thermodynamic equation :

$$\partial_t \theta + \vec{v} \cdot \vec{\nabla}_p \theta + \omega \partial_p \theta = \frac{\theta}{c_p T} \dot{Q}_{net}$$

Sources

$\Phi = gz$  geopotential  
 $\omega = \partial_t p$  vert. velocity  
 $q$  specific humidity  
 $\dot{Q}_{net}$  heating rate  
 from all diabatic sources

$\vec{S}_v$ ,  $S_q$  and  $\dot{Q}_{net}$  : source terms determined by the **physical parametrizations** and the **radiative transfer scheme** :

- planetary boundary layer, shallow and deep convection
- scattering and absorption by cloud droplets and crystals
- drag due to topography...

## Model tendencies

The integration of a given prognostic variable  $X$  ( $T, \vec{v}(u, v, w), p, \rho, q_{vap}$ ) can be written as :

$$X_{t+\Delta t} = X_t + \left( \frac{\partial X}{\partial t} \right)_{\text{dyn}} \Delta t \text{ (dynamical core)} \quad (1)$$

$$+ \left( \frac{\partial X}{\partial t} \right)_{\text{param}} \Delta t \text{ (parameterizations)} \quad (2)$$

## Basic facts about parametrizations I

- 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 for some processes in the deep convection scheme).
- The total tendency due to sub-grid processes is the sum of the tendencies due to each process :

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

In the model, the total tendency of  $T$  for example is  $\partial_t T_{\text{dyn}} + \partial_t T_{\text{param}}$   
 $= \text{dtdyn} + \text{dtphy}$ , where :

$\text{dtphy} = \text{dteva} + \text{dtlsc} + \text{dtvdf} + \text{dtcon} +$   
 $\text{dtwak} + \text{dtthe} + \text{dtajs} +$   
 $(\text{dtswr} + \text{dtlwr}) + (\text{dotoro} + \text{dtlif}) + (\text{dtdis} + \text{dtec})$

## Basic facts about parametrizations II

- Similarly, the total tendency of a given tracer  $q$  writes :

$$\begin{aligned} S_q = (\partial_t q)_\varphi &= (\partial_t q)_{\text{eva}} + (\partial_t q)_{\text{lsc}} + (\partial_t q)_{\text{diff turb}} + (\partial_t q)_{\text{conv}} \\ &\quad + (\partial_t q)_{\text{wk}} + (\partial_t q)_{\text{Th}} + (\partial_t q)_{\text{ajs}} \end{aligned}$$

In the model, the total tendency of  $q$  is therefore

$$\partial_t q_{\text{dyn}} + \partial_t q_{\text{param}} = \mathbf{dqdyn} + \mathbf{dqphy}, \text{ where :}$$

$$\mathbf{dqphy} = \mathbf{dqeva} + \mathbf{dqlsc} + \mathbf{dqvdf} + \mathbf{dqcon} + \mathbf{dqwak} + \mathbf{dqthe} + \mathbf{dqajs}$$

## physiq\_mod.F90 structure - I

Initialization (once) : *conf\_phys*, *phyetat0*,  
*phys\_output\_open*

Beginning *change\_srf\_frac*, *solarlong*

Cloud water evap. *reevap*

Vertical diffusion (turbulent mixing) *pbl\_surface*

Deep convection *conflx* (Tiedtke) or *conclv* (Emanuel)

Deep convection clouds *clouds\_gno*

Density currents (wakes) *calwake*

Strato-cumulus *stratocu\_if*

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

Large scale clouds *calcratqs*

Large scale and cumulus condensation *fisrtlp*

Diagnostic clouds for Tiedtke *diagcld1*

Aerosols *readaerosol\_optic*

Cloud optical parameters *newmicro* or *nuage*

Radiative processes *radlwsu*

In blue : subroutines and instructions modifying state  
variables

## physiq\_mod.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*

## Turbulent diffusion

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

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

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

$$De/Dt = f(dU/dz, d\theta/dz, e, \dots)$$

$$Dl/Dt = \dots$$

## Turbulent diffusion : numerics

**Process :** Turbulent mixing of moisture ( $q$  in kg/kg) and potential enthalpy ( $H = C_p\theta$ ).

$$\left\{ \begin{array}{l} \frac{dq}{dt} = \partial_z \phi_q \\ \phi_q = K_z \partial_z q \\ \phi_q|_{\text{srf}} = -\text{Evap} \end{array} \right. \quad \left\{ \begin{array}{l} \frac{dH}{dt} = \partial_z \phi_\theta \\ \phi_\theta = K_z \partial_z H \\ \phi_\theta|_{\text{srf}} = \phi_{\text{sens}} \left( \frac{p_0}{p_{\text{srf}}} \right)^\kappa \end{array} \right. \quad \begin{matrix} (\text{Fluxes positive downward}) \\ (3) \end{matrix}$$

**Spatial discretization :** (moisture)

$$\left\{ \begin{array}{l} m_i \partial_t q_i = \phi_{q,i+1} - \phi_{q,i} \\ \phi_{q,i} = K_i (q_i - q_{i-1}) \\ \phi_{q,1} = -\text{Evap} \end{array} \right. \quad (4)$$

**Implicit scheme,** yields for the first atmospheric layer :

$$\begin{aligned} q_{1,t+\delta t} &= A + B \phi_{q,1} \delta t \\ \phi_{q,1} &= K_1 (q_{1,t+\delta t} - q_{\text{srf}}) \end{aligned} \quad (5)$$

$A$  and  $B$  are coefficient resulting from solving Eq. (4) over the whole atmosphere.

**Eqs. (5) are the mixed boundary conditions for the sub-surface model.**

## Turbulent diffusion : numerics

**Process :** Turbulent mixing of moisture ( $q$  in kg/kg) and potential enthalpy ( $H = C_p\theta$ ).

$$\left\{ \begin{array}{l} \frac{dq}{dt} = \partial_z \phi_q \\ \phi_q = K_z \partial_z q \\ \phi_q|_{\text{srf}} = -\text{Evap} \end{array} \right. \quad \left\{ \begin{array}{l} \frac{dH}{dt} = \partial_z \phi_\theta \\ \phi_\theta = K_z \partial_z H \\ \phi_\theta|_{\text{srf}} = \phi_{\text{sens}} \left( \frac{p_0}{p_{\text{srf}}} \right)^\kappa \end{array} \right. \quad \begin{matrix} (\text{Fluxes positive downward}) \\ (3) \end{matrix}$$

**Spatial discretization :** (moisture)

$$\left\{ \begin{array}{l} m_i \partial_t q_i = \phi_{q,i+1} - \phi_{q,i} \\ \phi_{q,i} = K_i (q_i - q_{i-1}) \\ \phi_{q,1} = -\text{Evap} \end{array} \right. \quad (4)$$

**Implicit scheme,** yields for the first atmospheric layer :

$$\begin{aligned} q_{1,t+\delta t} &= A + B\phi_{q,1}\delta t \\ \phi_{q,1} &= K_1(q_{1,t+\delta t} - q_{\text{srf}}) \end{aligned} \quad (5)$$

$A$  and  $B$  are coefficient resulting from solving Eq. (4) over the whole atmosphere.

**Eqs. (5) are the mixed boundary conditions for the sub-surface model.**

$q_1, q_2, q_3, \dots, q_n$  (time  $t$ )

$\downarrow$   
A, B, K

**BL scheme**

$\downarrow$

**Soil scheme**

$\downarrow$   
Evaporation

**BL scheme**

$q_1, q_2, q_3, \dots, q_n$  (time  $t + dt$ )

## Vertical diffusion

Subroutine : pbl\_surface

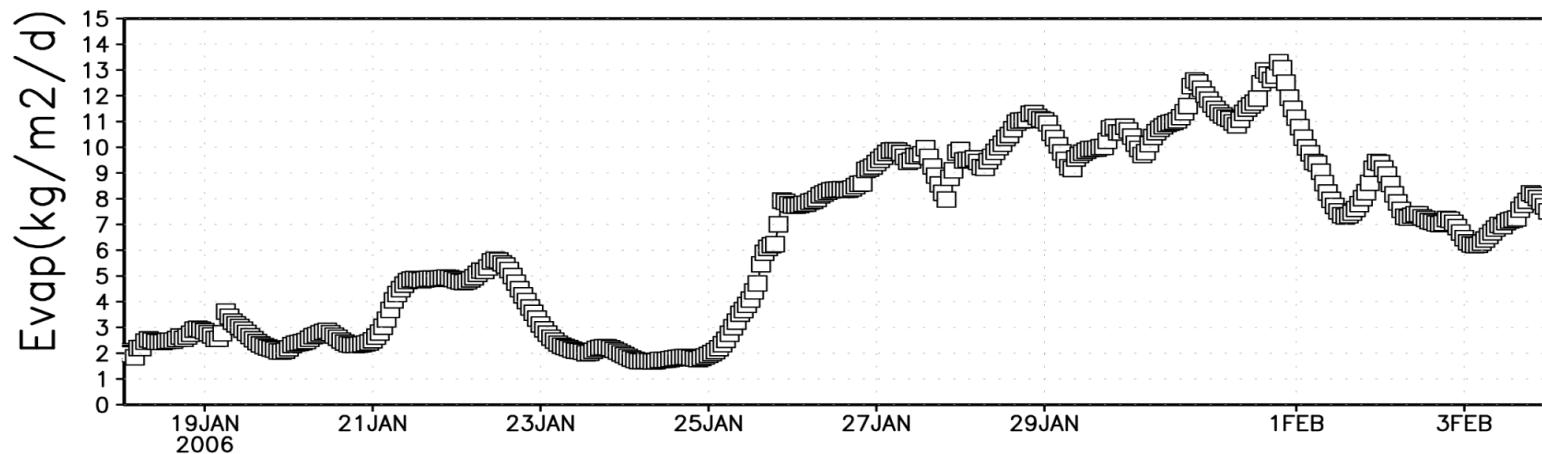
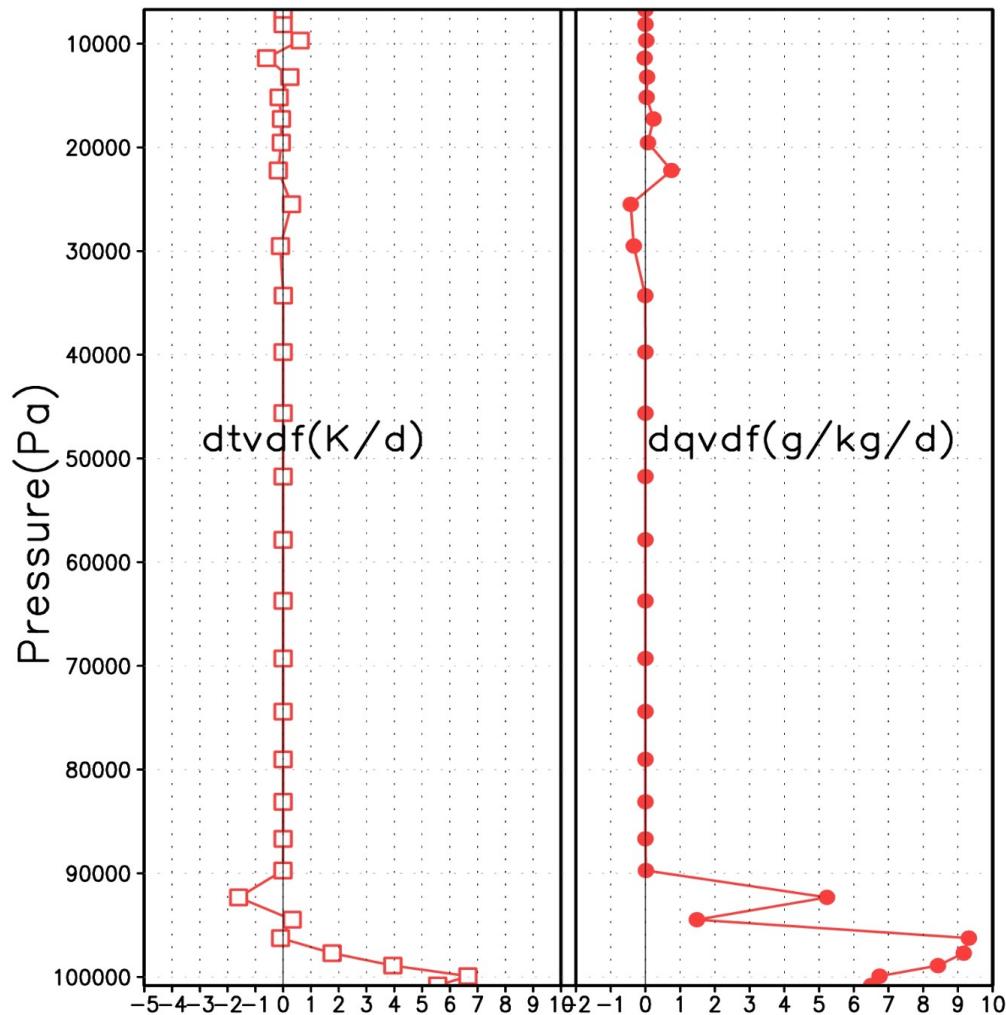
Tendencies :

dtvdf, dqvdf, duvdf, dvvdf

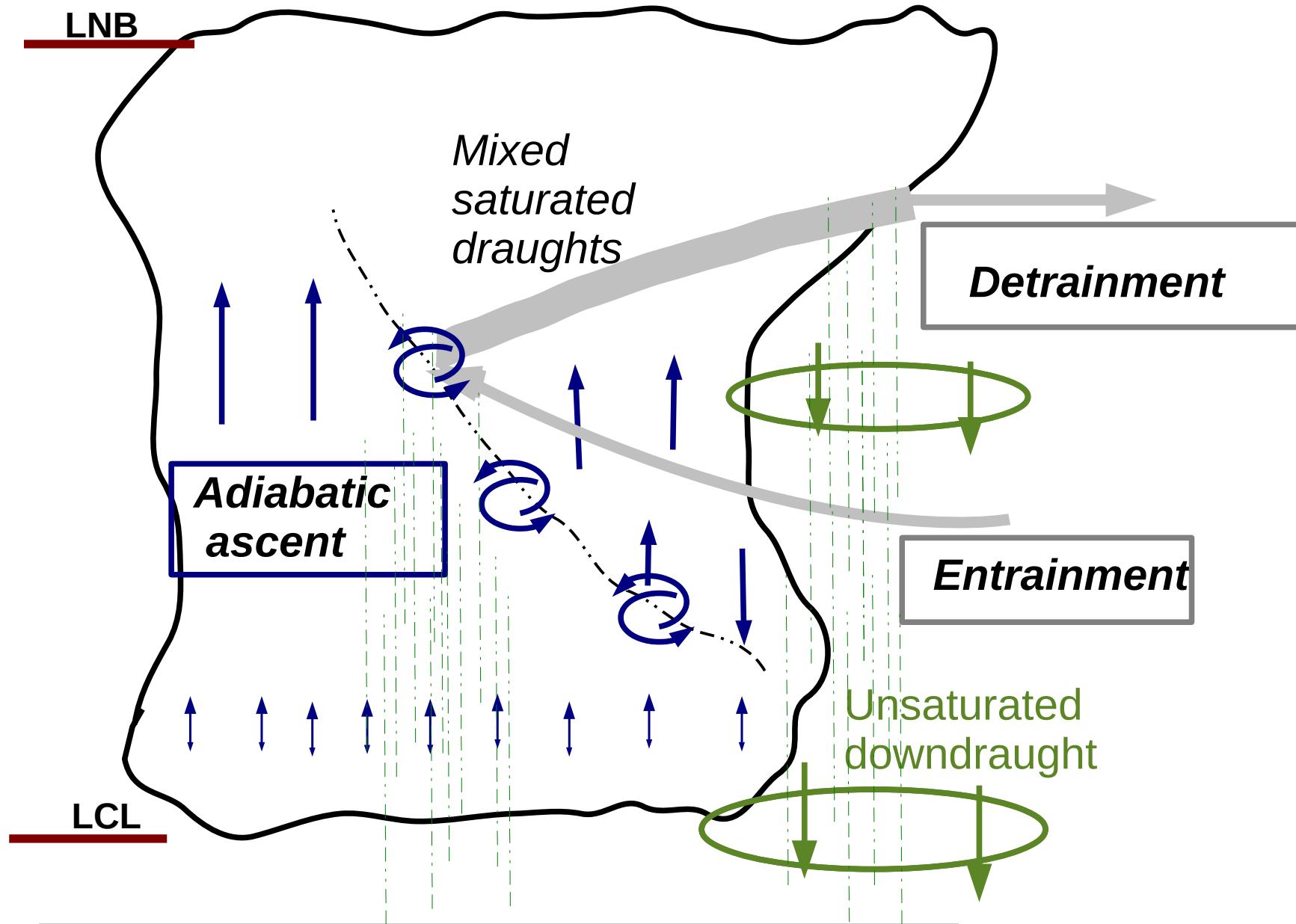
### Other variables

- 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

TWPice average



# Emanuel scheme



## Deep convection

**Subroutine :** concvl

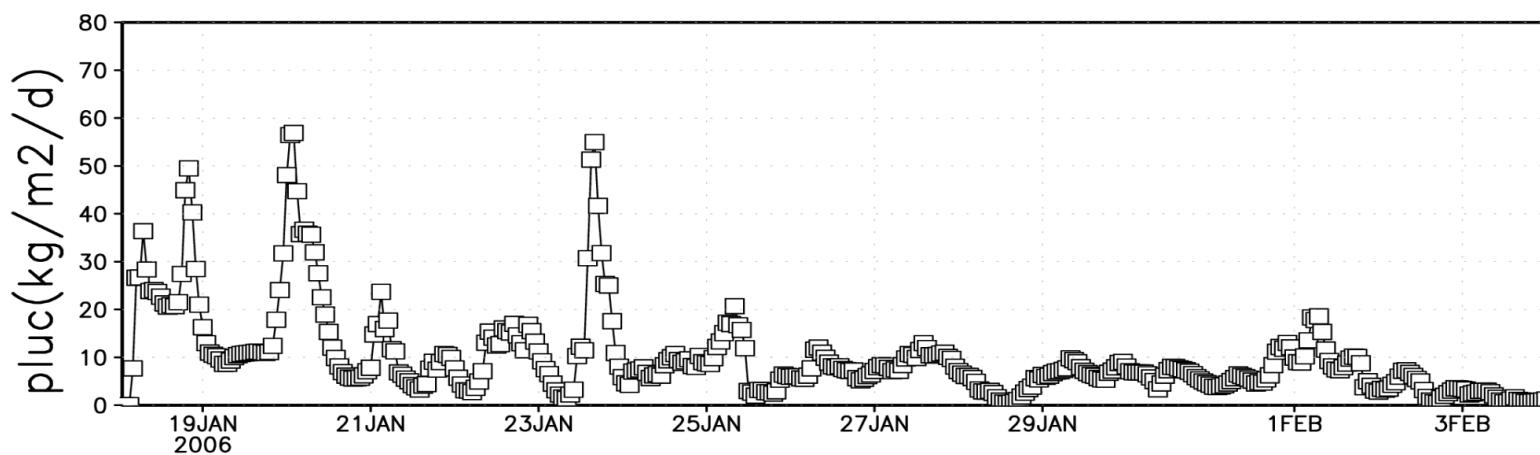
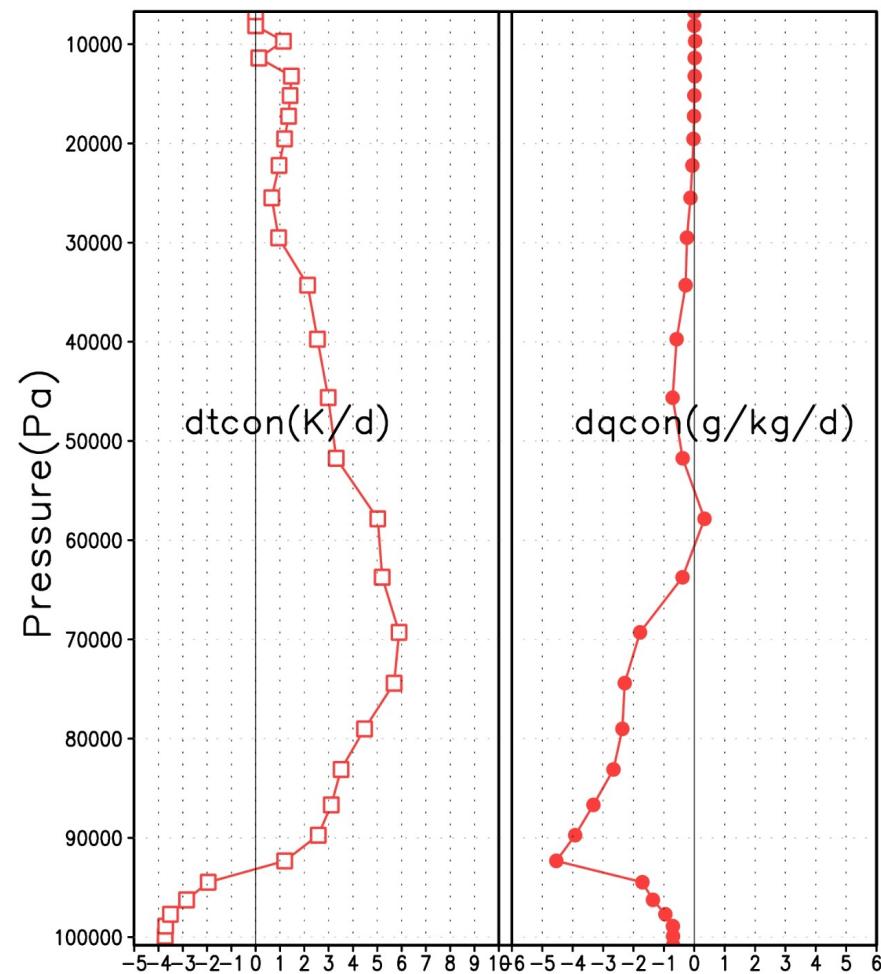
**Tendencies :**

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)
- pr\_con\_l : vertical profile of convective liquid precipitation
- pr\_con\_i : vertical profile of convective ice precipitation

TWPice average



## Deep convection

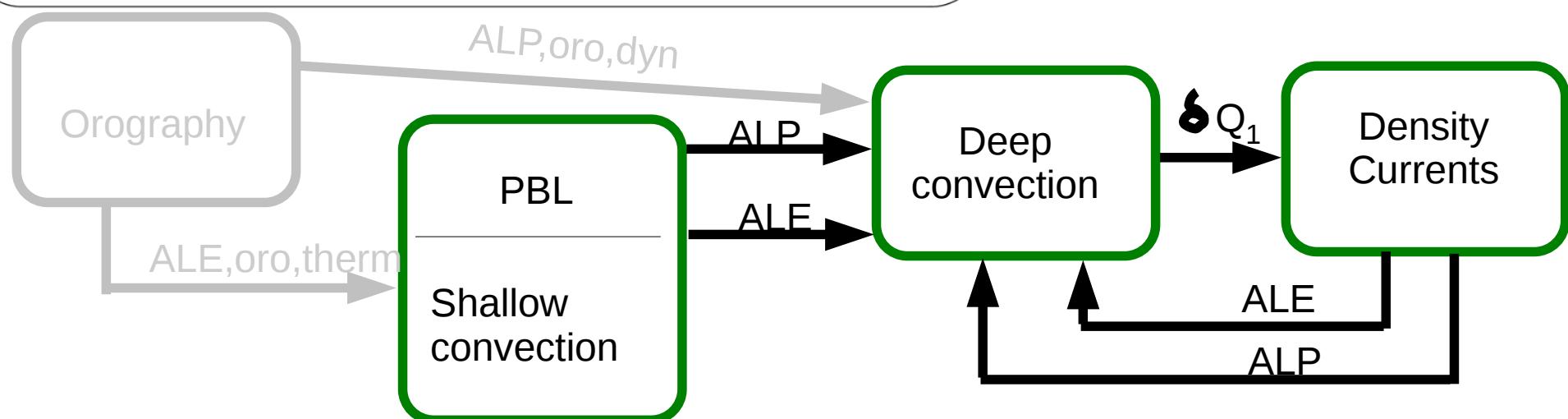
**Subroutine :** concvl

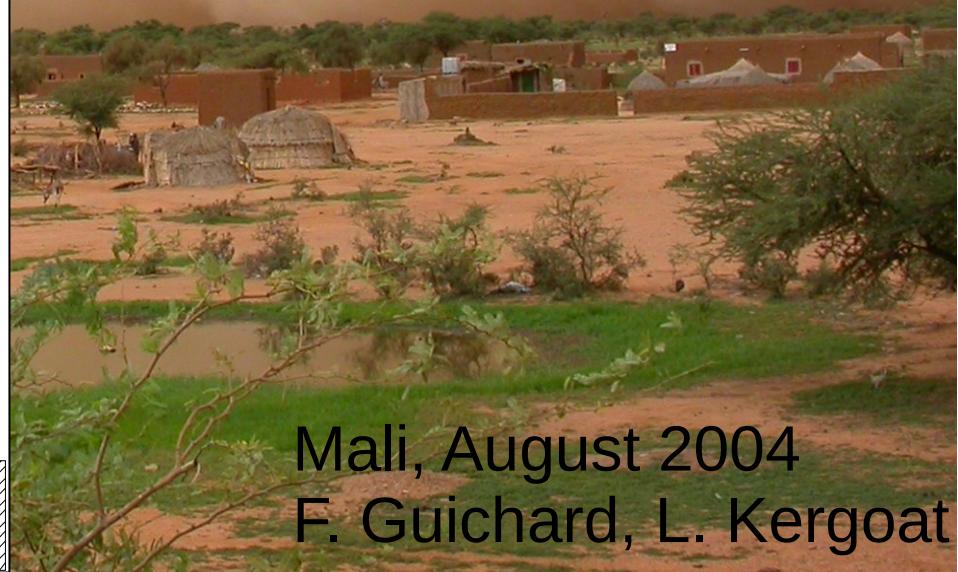
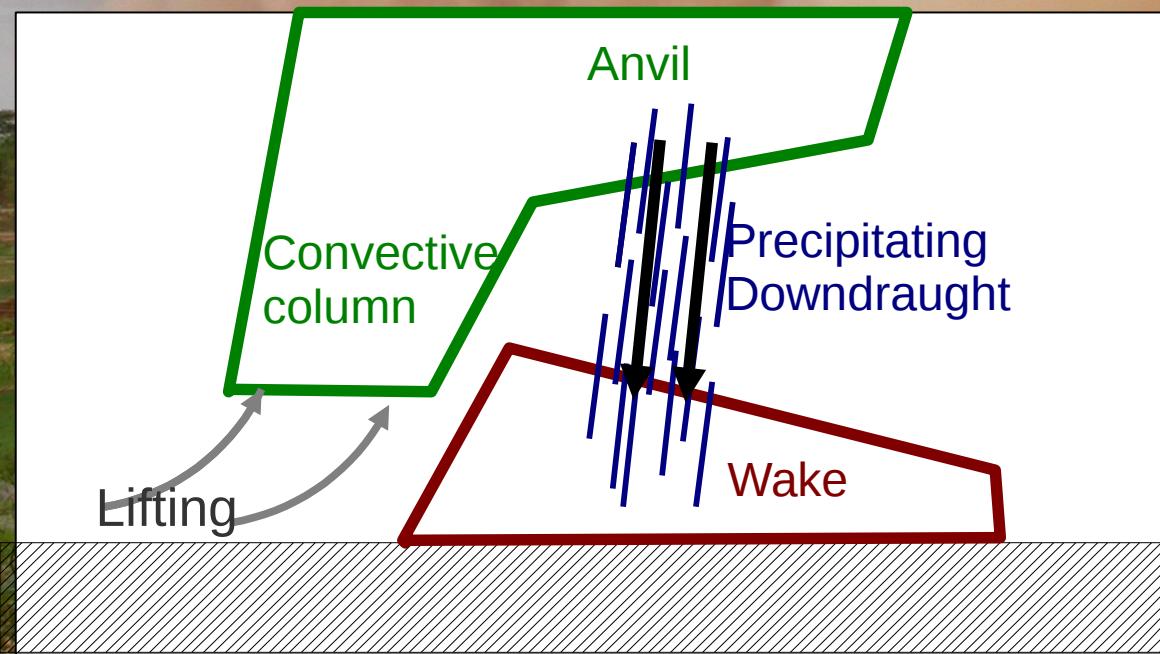
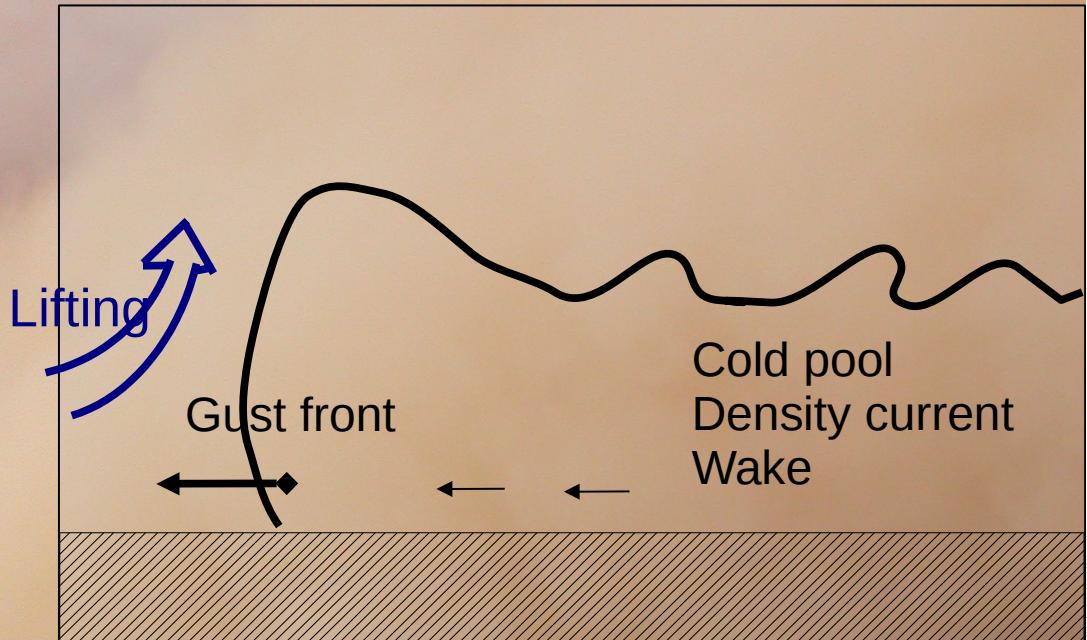
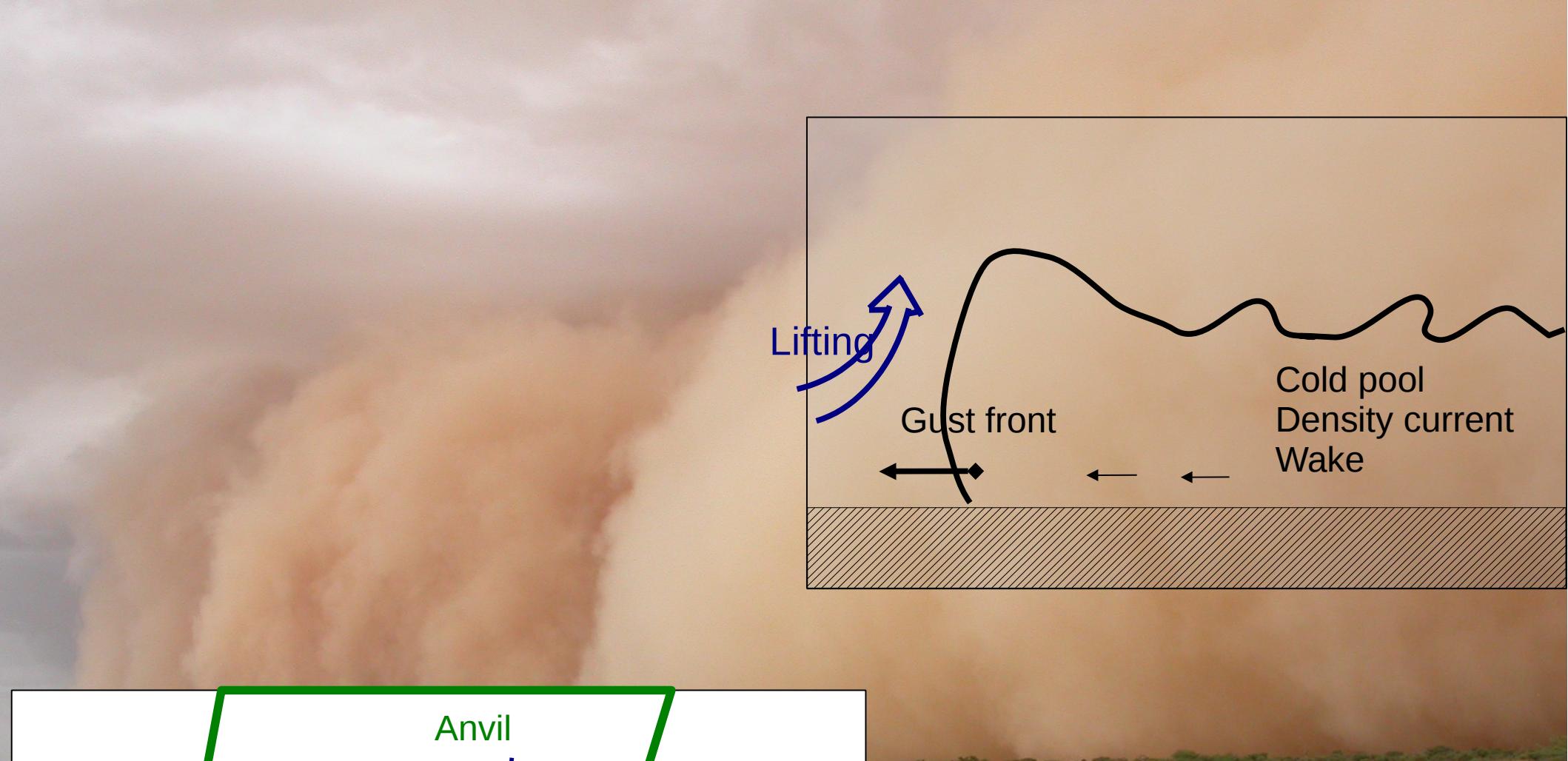
**Tendencies :**

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)
- pr\_con\_l : vertical profile of convective liquid precipitation
- pr\_con\_i : vertical profile of convective ice precipitation

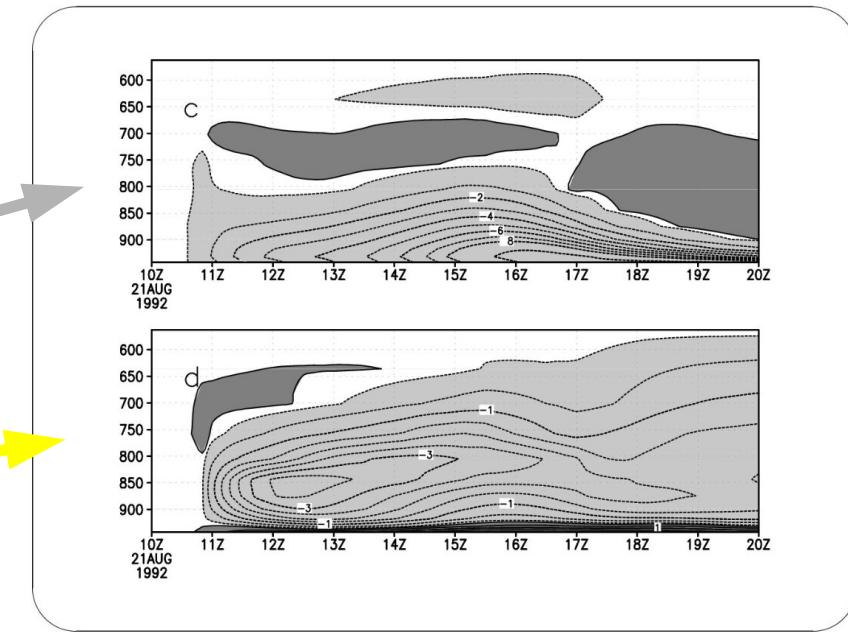
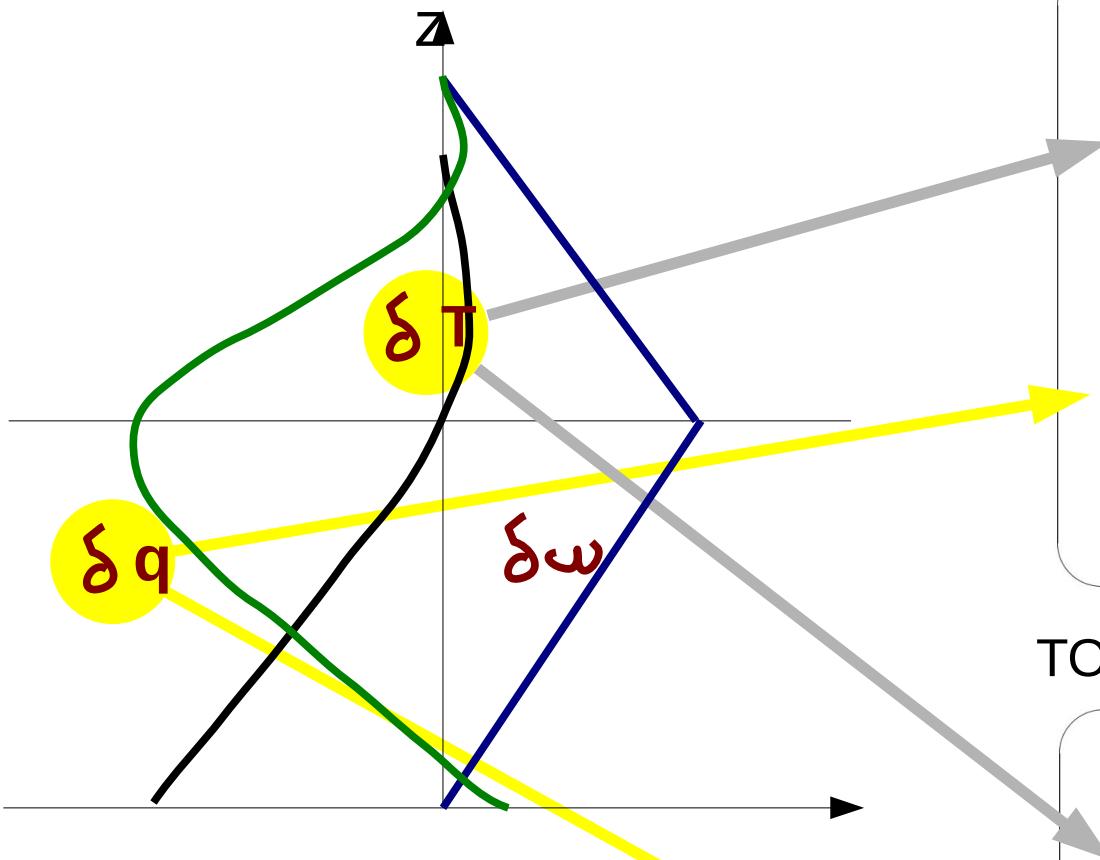




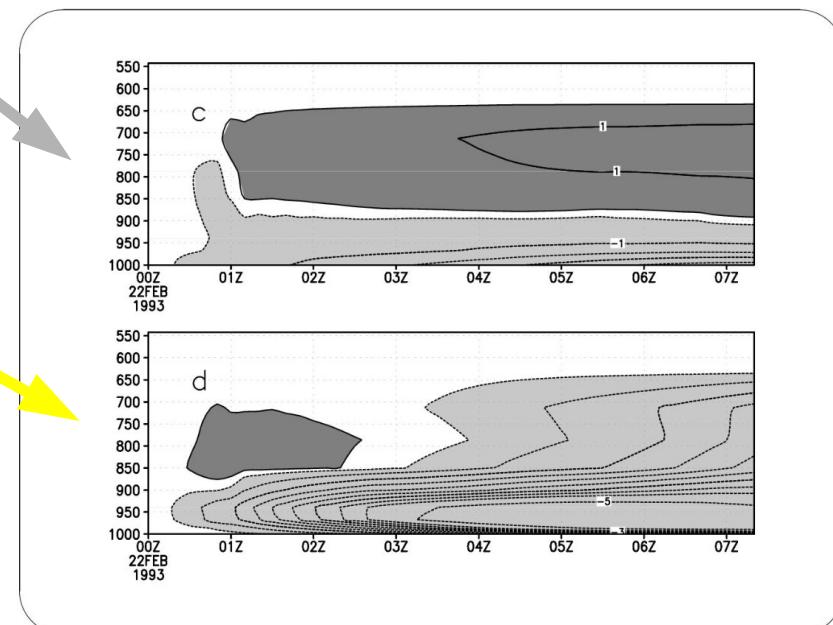
Mali, August 2004  
F. Guichard, L. Kergoat

# Simulated wake properties

HAPEX92: 21 Aug 1992 squall line case



TOGA-COARE: 22 Feb 1993 squall line case



## Cold pools (wakes)

**Subroutine :** calwake

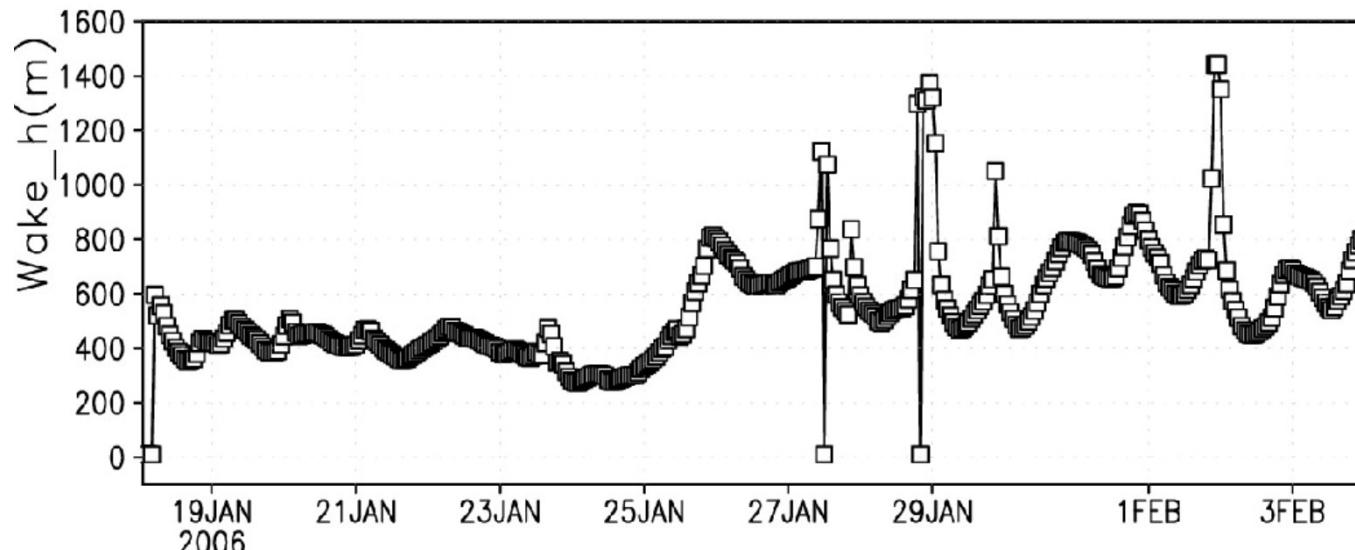
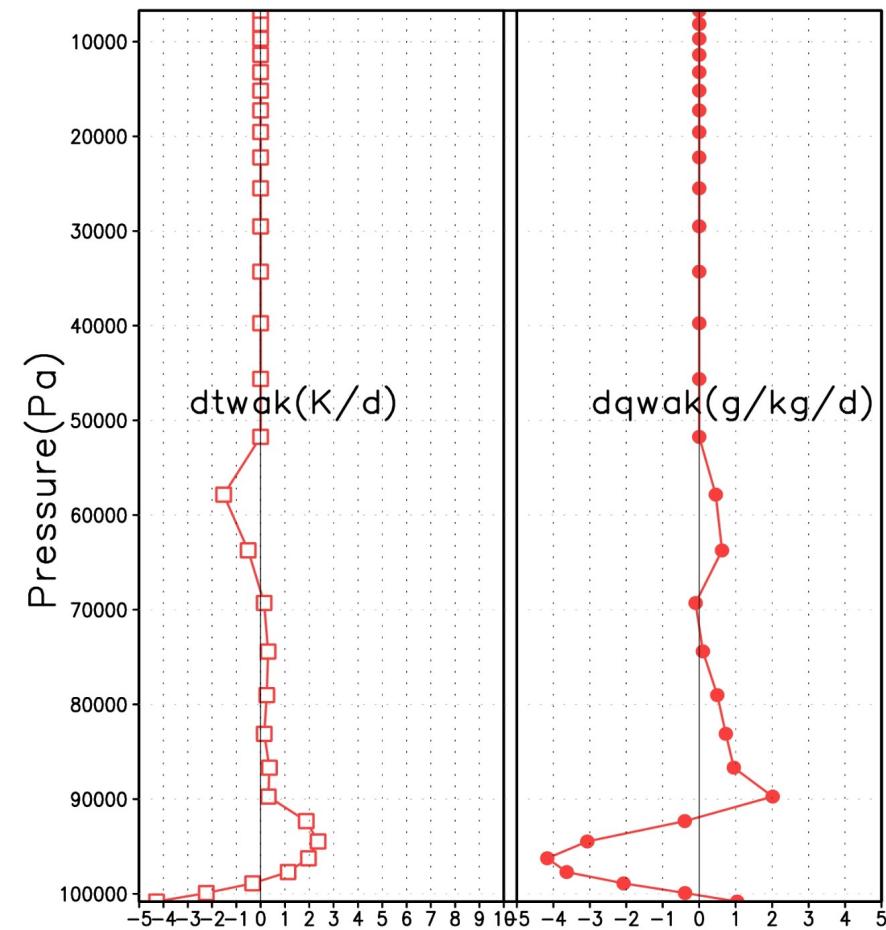
**Tendencies :**

dtwak, dqwak

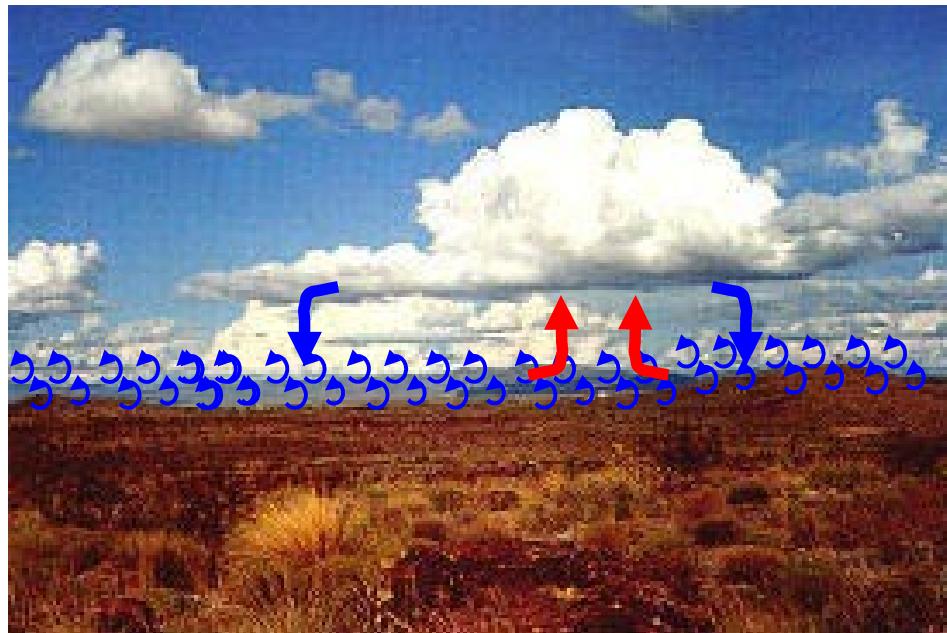
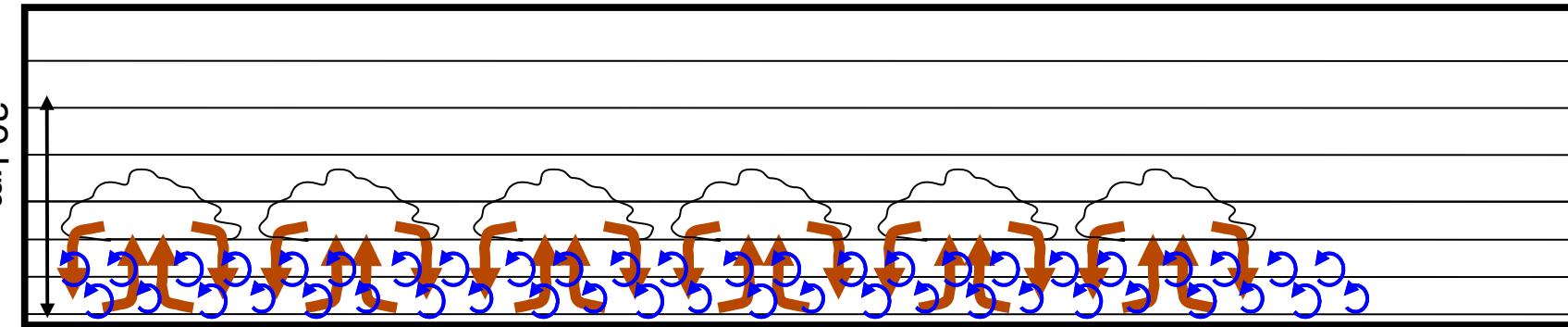
**Other variables**

- 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  $\omega_w - \omega_x$

TWPice average

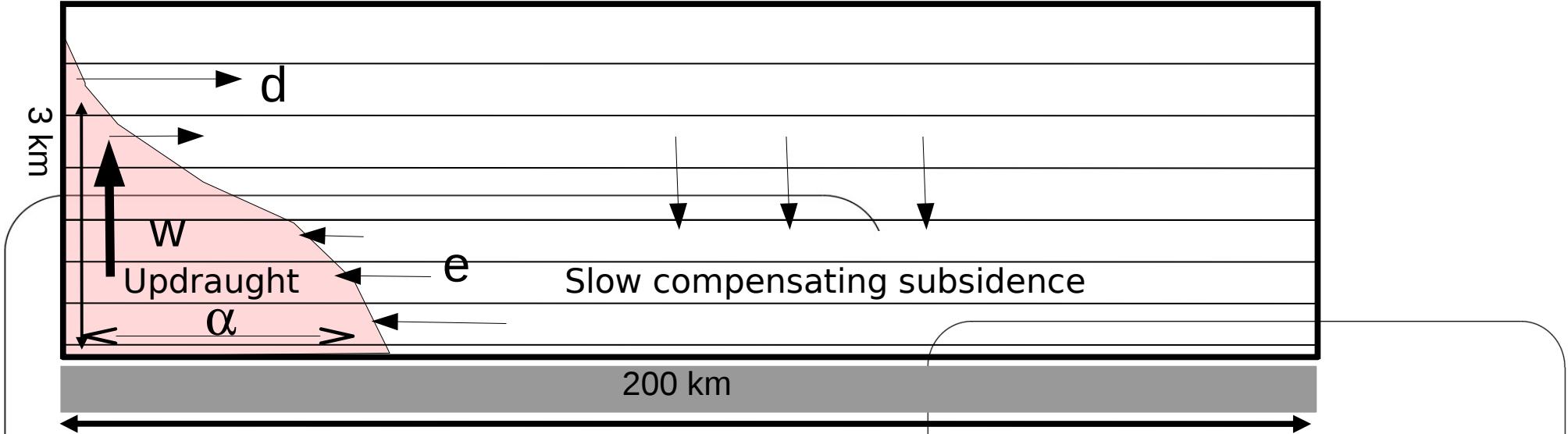


In a model column there are structures of boundary layer scale



**“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
- $\alpha$  = 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 constituent  $q$  in the updraughts

### Source term for the explicit equations :

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

**Turbulent Diffusion**

**Transport by the thermal plume model**

- Mass conservation

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

- 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 :

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

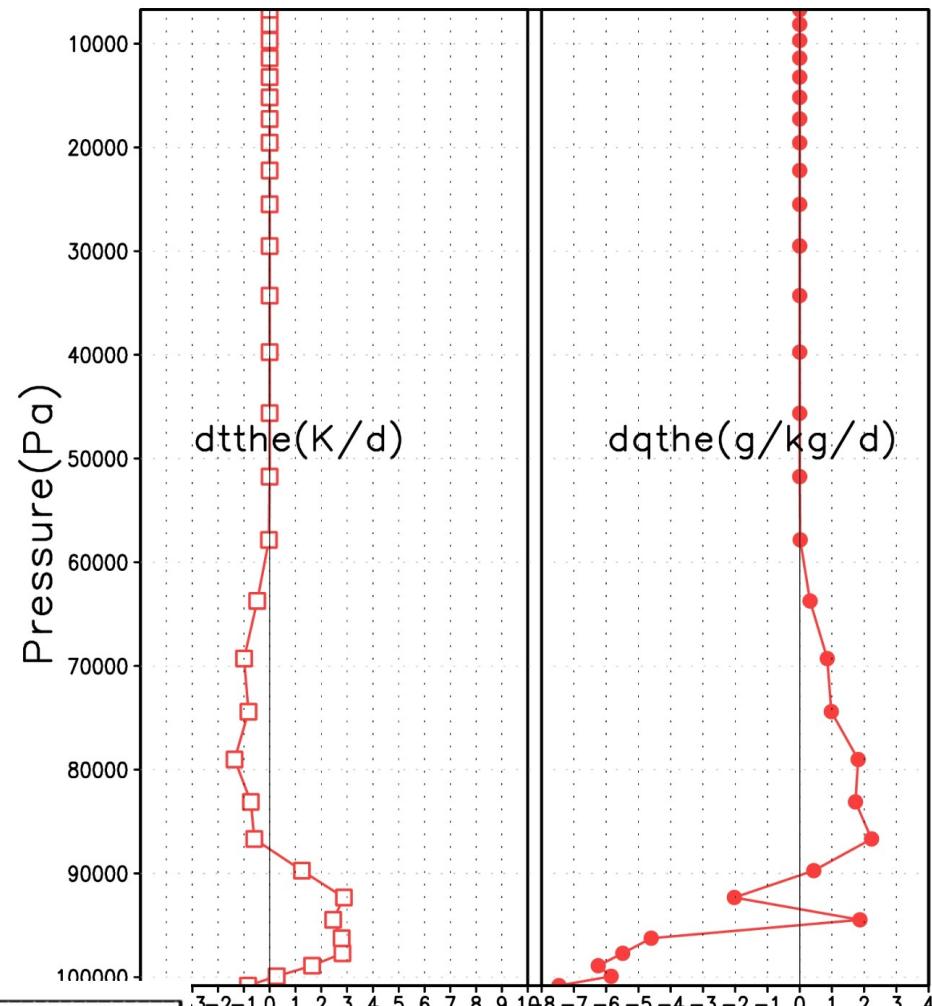
- and the complex part lies in the expression of  $e$  and  $d$  :

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

$$d = \dots$$

Etc ...

TWPice average



## Thermals and dry adjustment

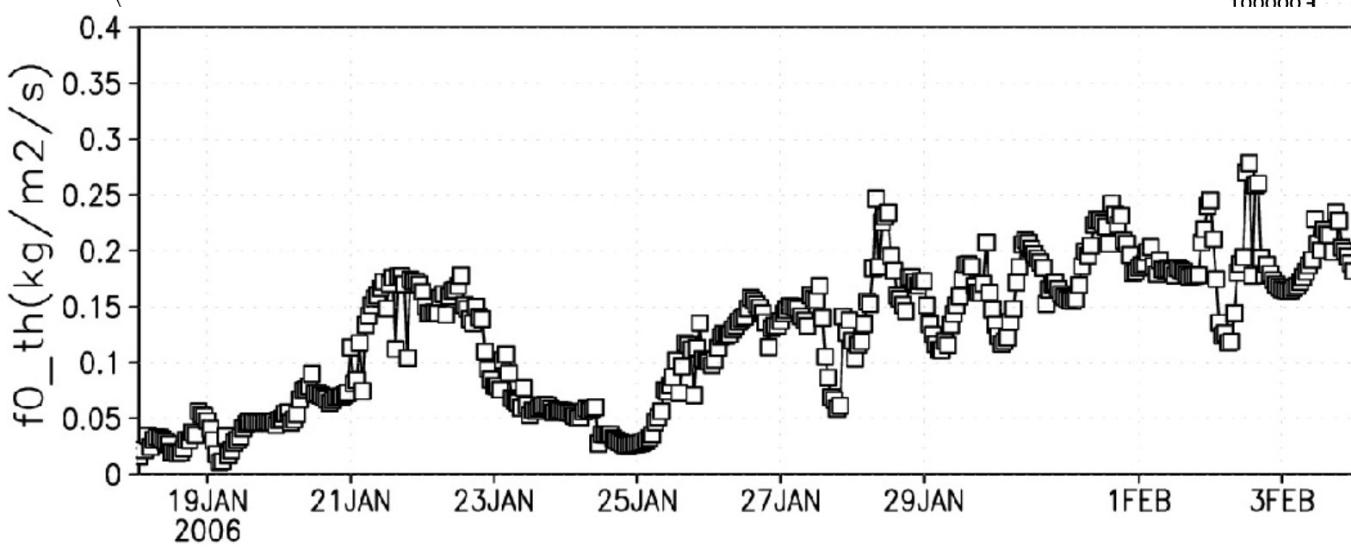
Subroutine : calltherm

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)



## Large scale condensation (evap & lsc)

Subroutines : reevap & fisrtlp

Tendencies :

dteva, dqeva : tendencies due to cloud water evaporation

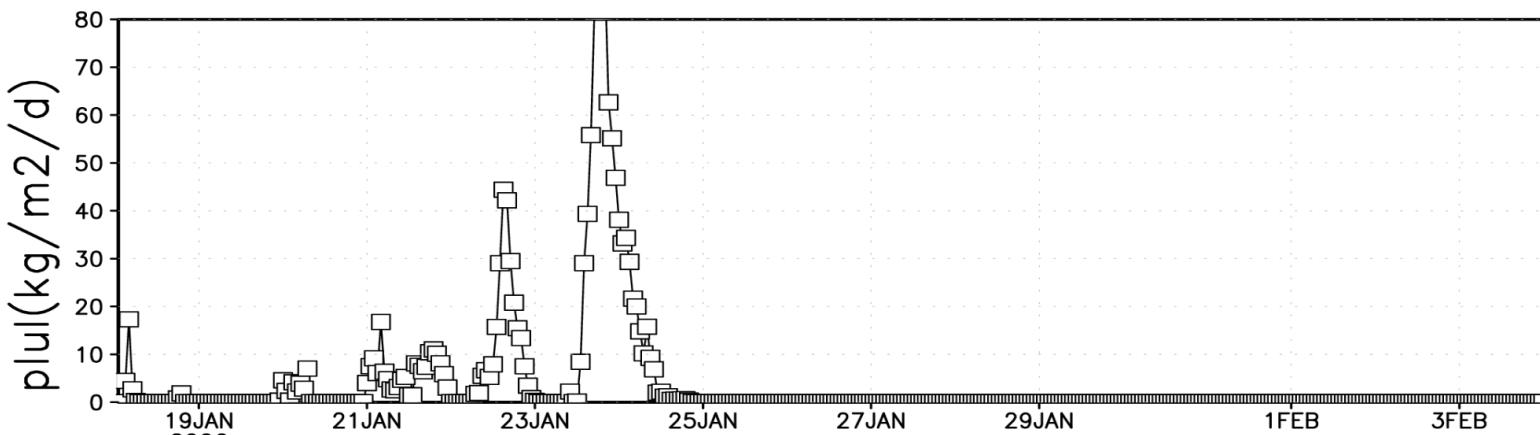
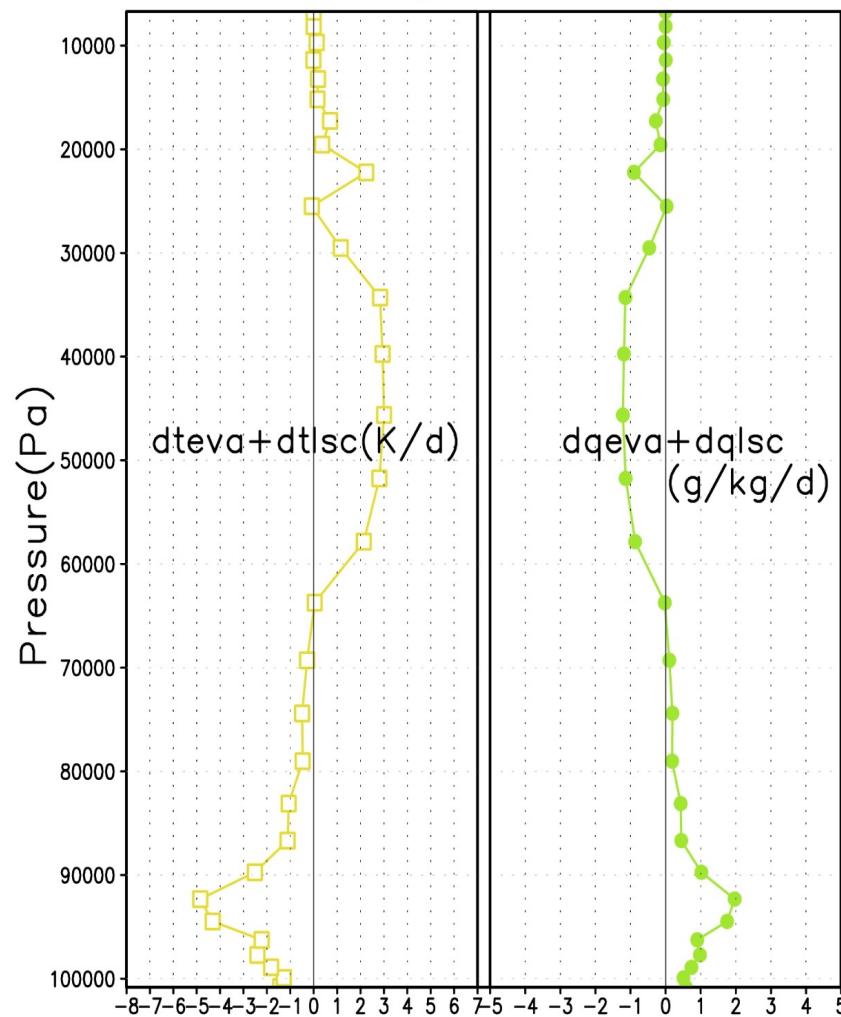
dtlsc, dqlsc : tendencies due to cloud water condensation

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
- pr\_lsc\_l : vertical profile of large scale liquid precipitation
- pr\_lsc\_i : vertical profile of large scale ice precipitation

TWPice average



## Radiation I

Subroutine : radlwsw

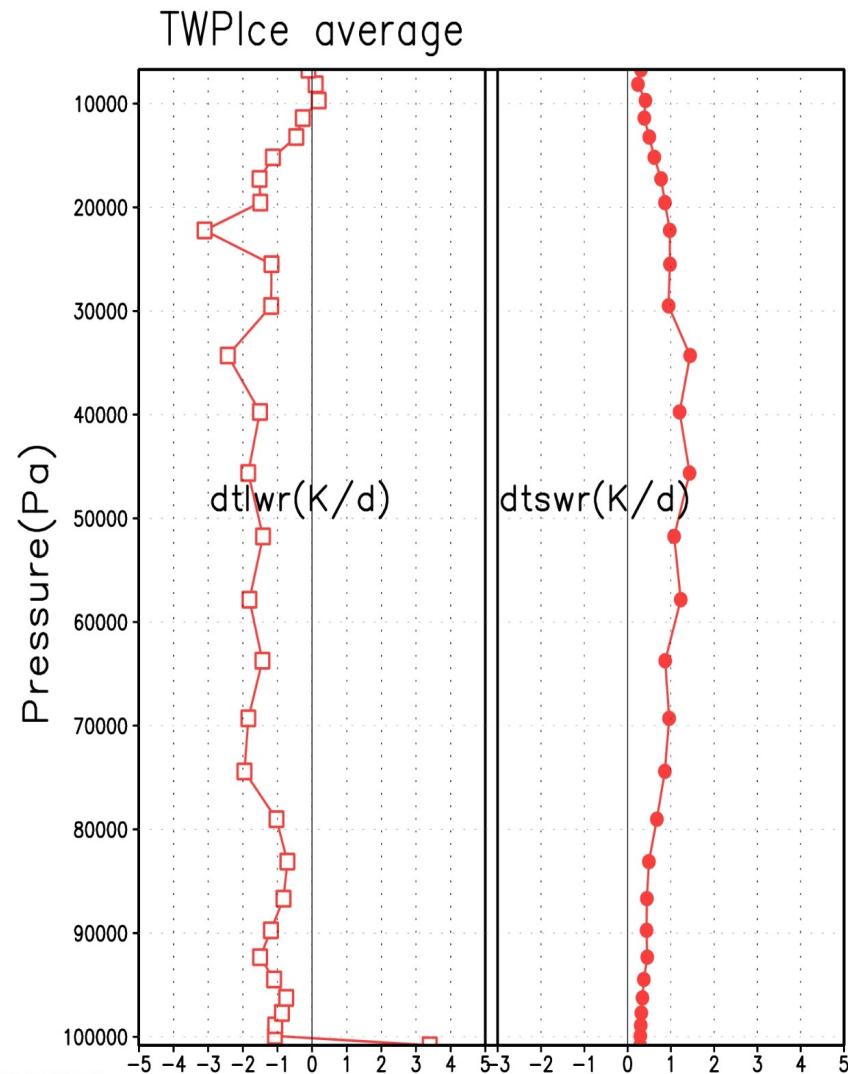
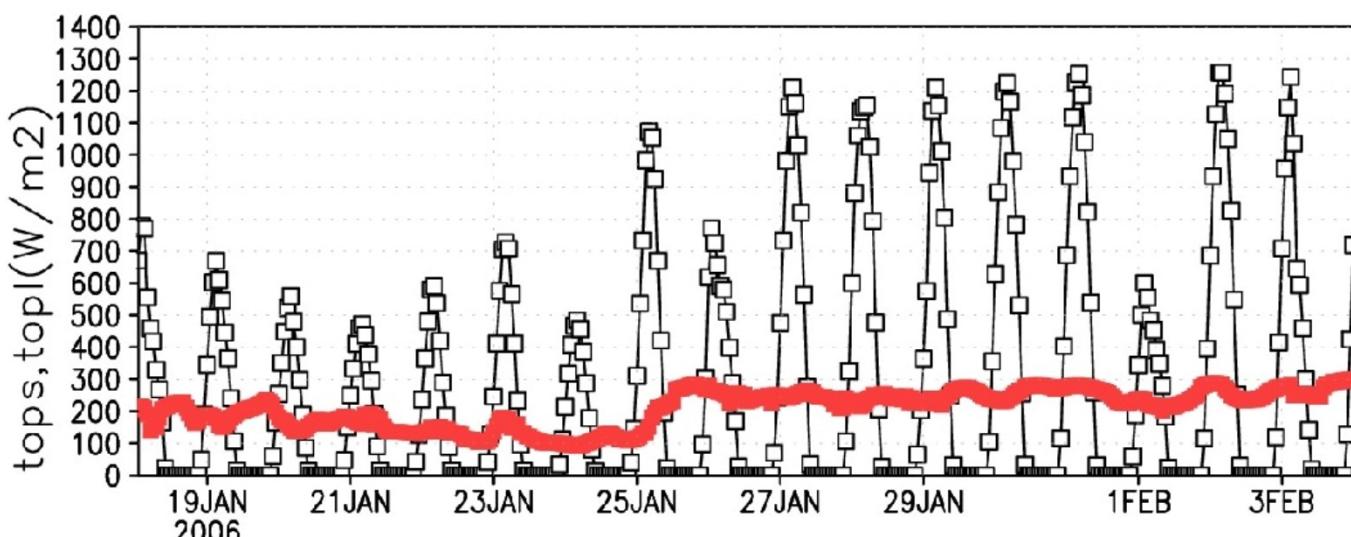
Tendencies :

$dtswr$ ,  $dtlw$  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



## Radiation II : Energy budget

**Energy budget at the top of the atmosphere :**

$$\text{nettop} = \text{tops-topl} = (\text{SWdn} - \text{SWup}) - (\text{LWup} - \text{LWdn})$$

Energy input (received solar energy minus reflected solar and emitted LW energy)

Positive in the tropics, negative at the poles

**Surface energy budget** (from the atmosphere to the surface) :

$$\text{bil}_s = \text{soll} + \text{sols} + \text{sens} + \text{flat}$$

$$\text{soll} = \text{lwdnsfc} - \text{lwupsfc} \text{ (same for sols)}$$

**flat** : latent heat flux (from the atmosphere to the surface)

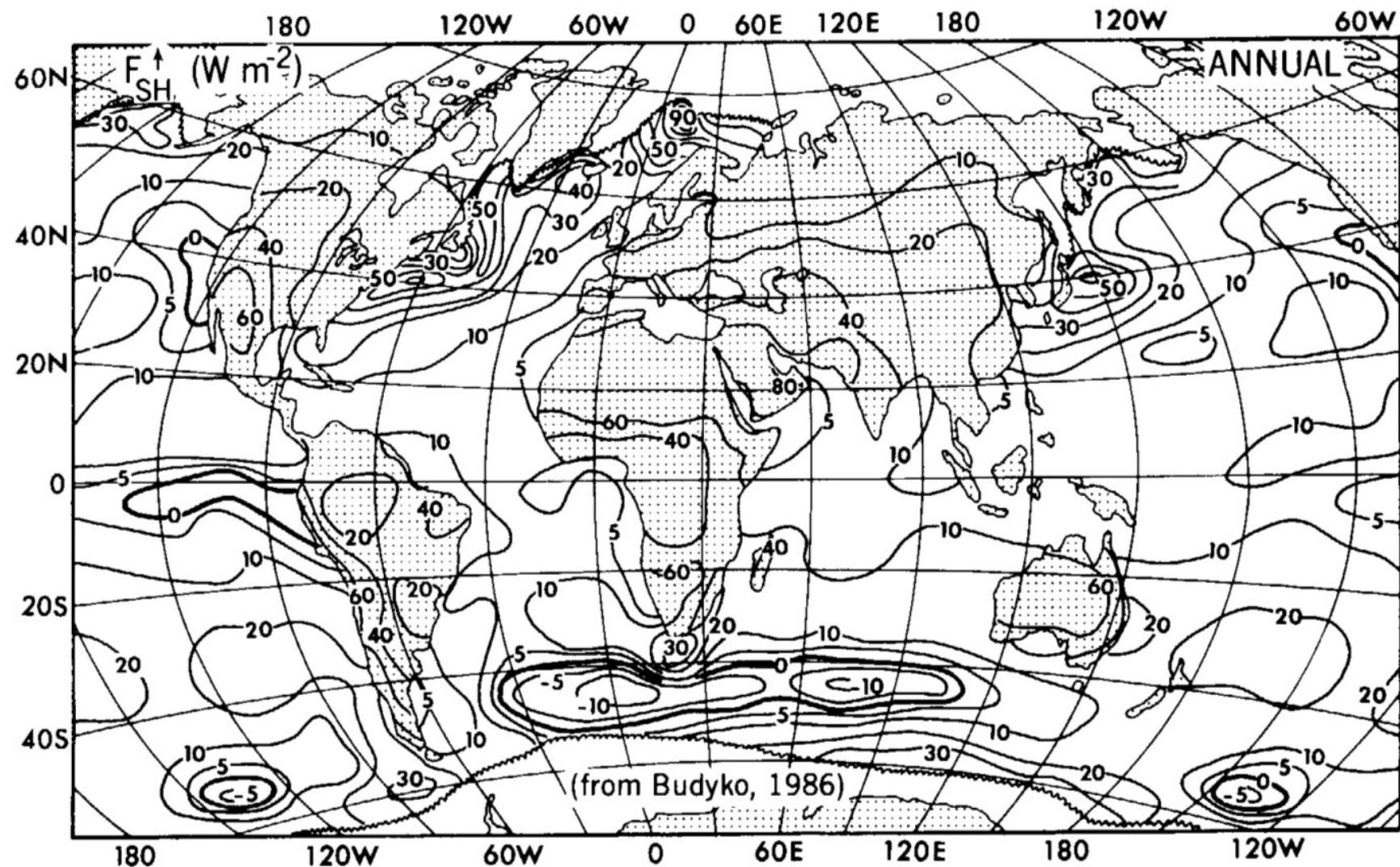
Negative when there is surface evaporation

**sens** : sensible heat flux (from the atmosphere to the surface)

Positive when the atmosphere heats the surface (polar regions)

Negative when the atmosphere is heated by the surface (continents & oceans)

In the model, this would be (- sens)



**FIGURE 10.8.** Global distribution of the sensible heat flux from the earth's surface into the atmosphere in  $\text{W m}^{-2}$  for annual-mean conditions after Budyko (1986).