The physical parametrizations in LMDZ

LMDZ Team

Laboratoire de Météorologie Dynamique

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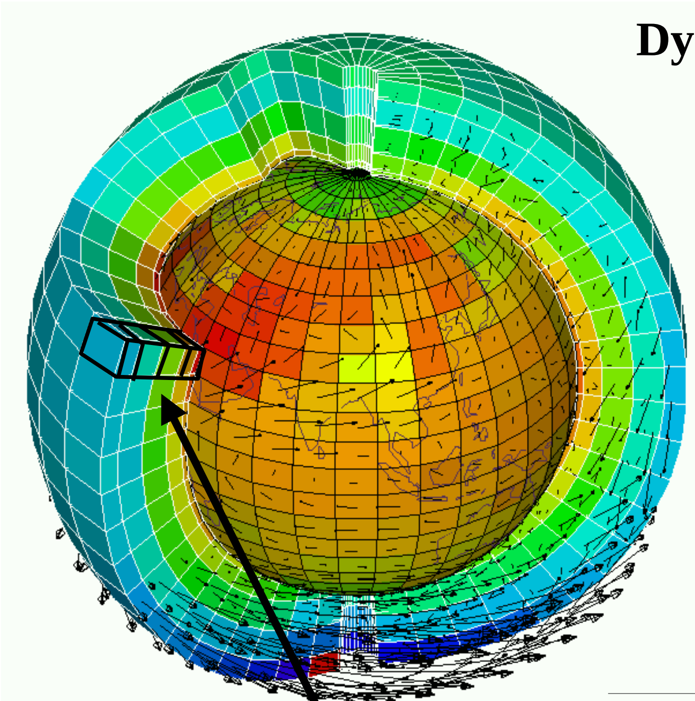


Dynamical core : primitive equations discretized on the sphere

- Mass conservation

  $D\rho/Dt + \rho\,\mathrm{div}\underline{U} = 0$

- Potential temperature conservation

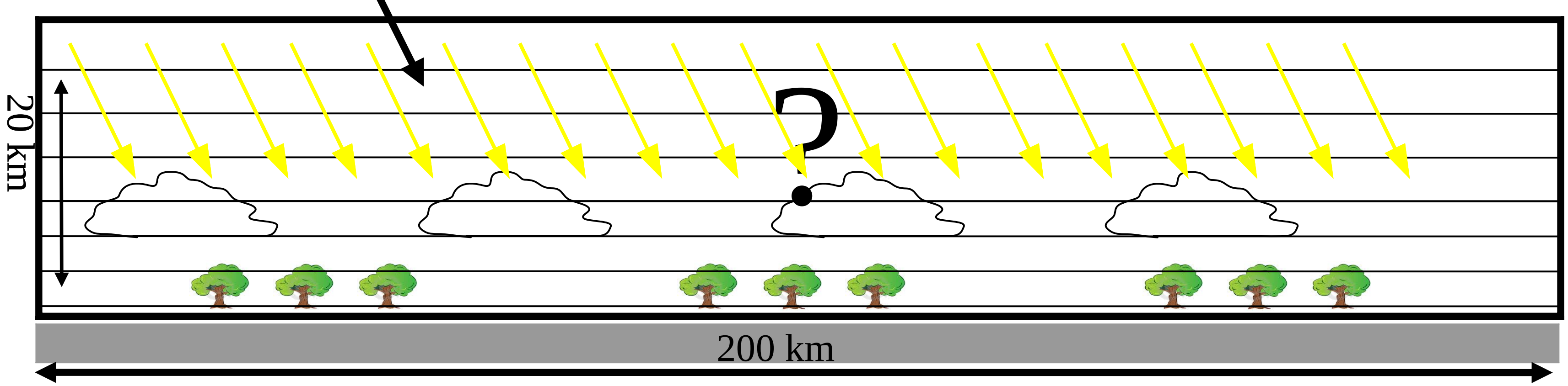
  $D\theta\,/\,Dt = Q\,/\,Cp\;(p0/p)^{\kappa}$

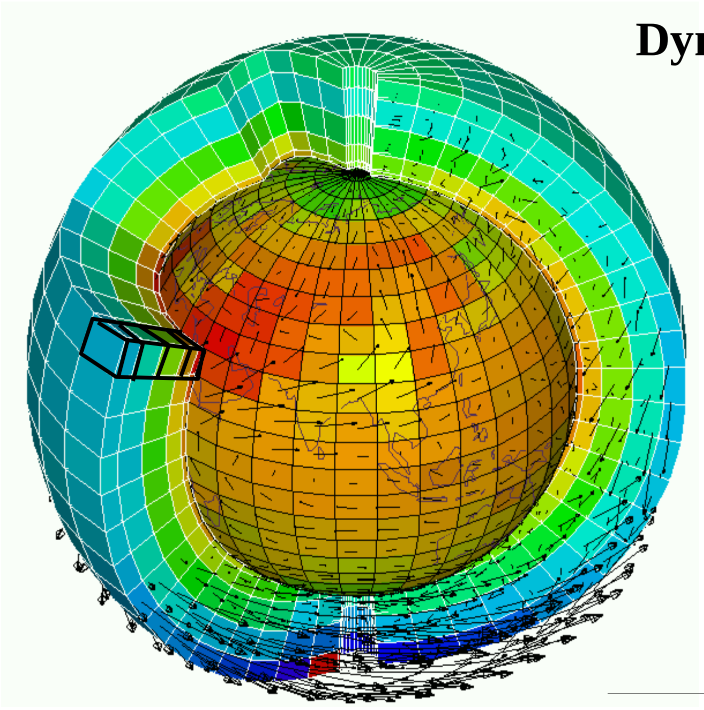
- Momentum conservation

  $D\underline{U}/Dt + (1/\rho)\,\underline{\mathrm{grad}}p - \underline{g} + 2\,\underline{\Omega} \wedge \underline{U} = \underline{F}$

- Secondary components conservation

  $Dq/Dt = Sq$





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- Secondary components conservation

  $Dq/Dt = Sq$

Parameterizations purpose : account for the effect of processes non resolved by the dynamical core

→ **Traditional « source » terms in the equations**

- *Q* : Heating by radiative exchanges, thermal conduction (neglected), condensation, sublimation, **subgrid-scale motions (turbulence, clouds, convection)**
- *F* : Molecular viscosity (neglected), **subgrid-scale motions (turbulence, clouds, convection)**
- *Sq* : condensation/sublimation (q= water vapor or condensed), chemical reactions, photo-dissociation (ozone, chemical species), micro physics and scavenging (pollution aerosols, dust, ...), **subgrid-scale motions (turbulence, clouds, convection)**

Tendencies

Model tendencies

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

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

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

<u>From model outputs</u>
temp(t+dtphys)-temp(t)=dtdyn+dtphy
ovap(t+dtphys)-ovap(t)=dqdyn+dqphy
vit[u/v](t+dtphys)-vit[u/v](t)=dudyn+duphy

Physics time-step :
dtphys=daysec*iphysic/(day_step) ,   day_sec=86400

Temperature tendencies

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 :

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

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

```
dtphy = dteva + dtlsc + dtvdf + dtcon +
        dtwak + dtthe + dtajs +
        (dtswr + dtlwr) + (dtoro + dtlif) + (dtdis + dtec)
```

Output names → Not the same as their name in the source code !
physiq_mod.f90

Specific humidity tendencies

Basic facts about parametrizations II

– Similiarly, the total tendency of a given tracer q writes :

$$S_q = (\partial_t q)_\varphi = (\partial_t q)_{\mathrm{eva}} + (\partial_t q)_{\mathrm{lsc}} + (\partial_t q)_{\mathrm{diff\ turb}} + (\partial_t q)_{\mathrm{conv}} + (\partial_t q)_{\mathrm{wk}} + (\partial_t q)_{\mathrm{Th}} + (\partial_t q)_{\mathrm{ajs}}$$

In the model, the total tendency of q is therefore

$\partial_t q_{\mathrm{dyn}} + \partial_t q_{\mathrm{param}} =$ `dqdyn` + `dqphy`, where :

`dqphy = dqeva + dqlsc + dqvdf + dqcon + dqwak + dqthe + dqajs`

Subroutine structure

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 *concvl* (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 *fisrtilp*

Diagnostic clouds for Tiedtke *diagcld1*

Aerosols *readaerosol_optic*

Cloud optical parameters *newmicro* or *nuage*

Radiative processes *radlwsw*

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*

Subroutine structure

physiq_mod.F90 structure - I

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

Beginning *change_srf_frac, solarlong*

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Effect of subrid-scale transport ← Today

Coupling with surface

Clouds and radiation ← Tomorrow

Radiation

Radiation I

Subroutine : radlwsw

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

```
ferret
use histhf.nc
plot/thick=3/k=10:39 (dtswr[x=@ave,y=-30:30@ave,l=@ave])*86400
plot/thick=3/k=10:39 (dtswr[x=@ave,y=-30:30@ave,l=@ave])*86400
```

New variables :

S[L]Wdn[up]TOA[SFC][clr] :

Short[Long]Wave

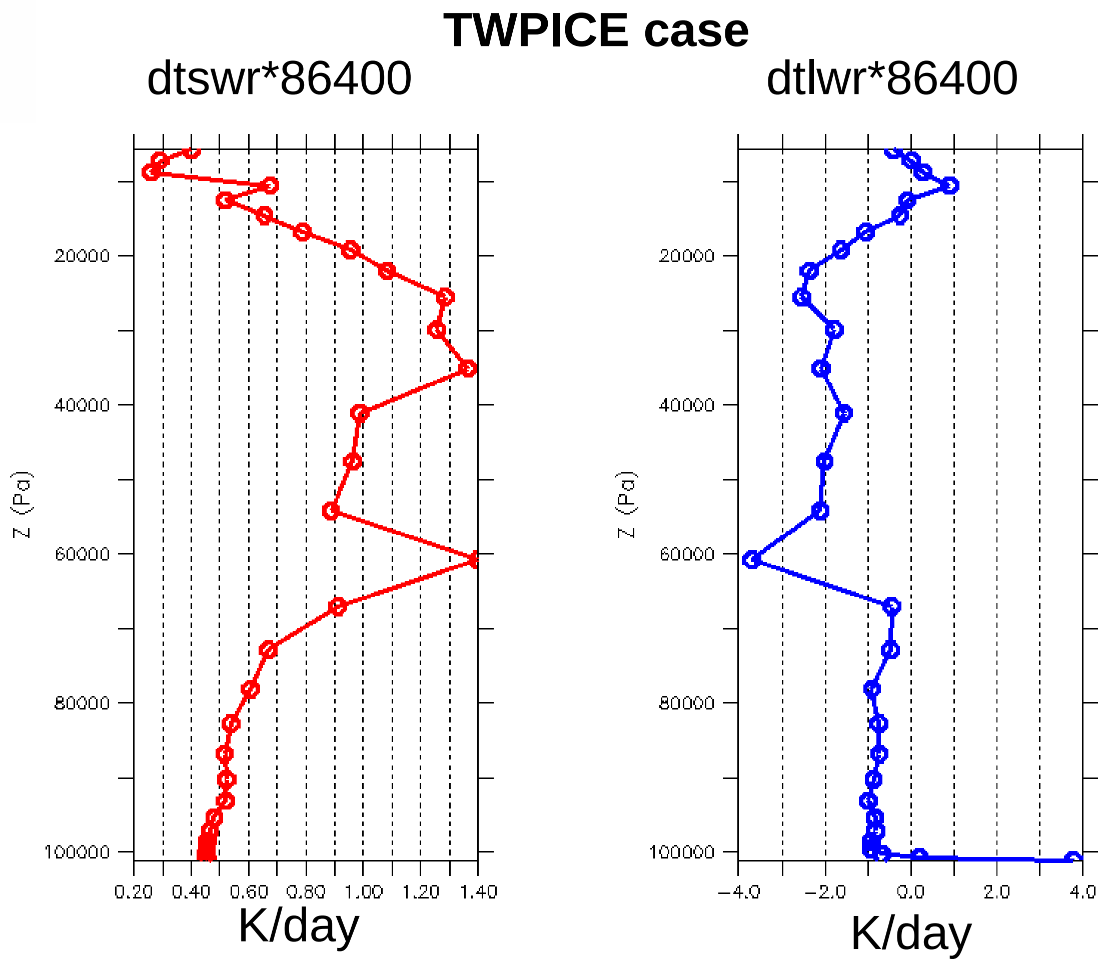
Downward[upward] radiative flux at

Top-Of-Atmosphere[Surface][clear-sky]

Cloud radiative effect (CRE) :

Old names : VAR - VAR0

New names : VAR - VARclr



In physiq.def (deepL translation)

```
#############################################################################
#
# Radiation
#############################################################################
#
        # activation of the new RRTM radiation code
        # 0: Old code and 1: RRTM (D=0)
iflag_rrtm=1

        # Number of strips for SW. Set 2 if if iflag_rrtm=0
NSW=6
```

In config.def

```
#Radiative transfer code
#**************************
# added this flag to activate/deactivate the radiation (MPL)
# 0: no radiation. 1: radiation is activated (D=1).
iflag_radia=1
## Number of calls of radiation routines ( per day)
nbapp_rad=24
```

Today : Parameterization of subrid-scale motions

- Reynolds decomposition
- Turbulence
- Boundary layer convection
- Deep convection
- Subgrid-scale orography

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Based on the Reynolds decomposition between
- large-scale/resolved/explicit variables (dynamical core)
- subgrid-scale/unresolved/turbulent fluctuations (parameterizations)

Reynolds decomposition

$\widetilde{X}$: "average" or "large scale" variable

$\overline{X} = \widetilde{\rho \mathbf{v}} / \widetilde{\rho}$: air mass weighted "average"

$X = \widetilde{X} + X'$: X', turbulent fluctuation

$$\Longrightarrow \widetilde{\rho \mathbf{v} c} = \widetilde{\rho\,(\overline{\mathbf{v}} + \mathbf{v}')\,(\overline{c} + c')} = \widetilde{\rho}\,\overline{\mathbf{v}}\,\overline{c} + \widetilde{\rho}\,\overline{\mathbf{v}' c'}$$

$$\widetilde{\frac{\partial \rho c}{\partial t} + \mathrm{div}\,(\rho \mathbf{v} c)} = 0 \quad \Longrightarrow \quad \frac{\partial \widetilde{\rho} \overline{c}}{\partial t} + div(\widetilde{\rho}\,\overline{\mathbf{v}}\,\overline{c}) + \mathrm{div}\left(\widetilde{\rho} \overline{\mathbf{v}' c'}\right) = 0$$

$$\frac{\partial c}{\partial t} + \mathbf{v}.\mathbf{grad}\, c = -\frac{1}{\rho} \mathrm{div}\left(\rho \overline{\mathbf{v}' c'}\right) = -\frac{1}{\rho} \frac{\partial \overline{\rho w' c'}}{\partial z}$$

Today : Parameterization of subrid-scale motions

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Reynolds decomposition

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$$\Longrightarrow \widetilde{\rho \mathbf{v} c} = \rho \, \widetilde{(\overline{\mathbf{v}} + \mathbf{v}') \, (\overline{c} + c')} = \widetilde{\rho} \, \overline{\mathbf{v}} \, \overline{c} + \widetilde{\rho} \, \overline{\mathbf{v}' c'}$$

$$\widetilde{\frac{\partial \rho c}{\partial t} + \operatorname{div}(\rho \mathbf{v} c)} = 0 \quad \Longrightarrow \quad \frac{\partial \widetilde{\rho} \overline{c}}{\partial t} + div(\widetilde{\rho} \, \overline{\mathbf{v}} \, \overline{c}) + \operatorname{div}\left(\widetilde{\rho} \overline{\mathbf{v}' c'}\right) = 0$$

$$Dq/Dt = Sq$$

$$\frac{\partial c}{\partial t} + \mathbf{v}.\mathbf{grad}\, c = -\frac{1}{\rho} \operatorname{div}\left(\rho \overline{\mathbf{v}' c'}\right) = -\frac{1}{\rho} \frac{\partial \rho \overline{w' c'}}{\partial z}$$

Turbulent diffusion : Mellor et Yamada

I. Turbulent diffusion or eddy diffusion

Boundary layer approximation (horizontal homogeneity)
+ eddy diffusion

$$\overline{w'c'} = -K_z \frac{\partial c}{\partial z} \qquad \longrightarrow \qquad \frac{\partial c}{\partial t} = \frac{1}{\rho} \frac{\partial}{\partial z} \left(\rho K_z \frac{\partial c}{\partial z} \right)$$

- Analogy with molecular viscosity (Brownian motion ↔ turbulence)
- Down-gradient fluxes.
- Turbulence acts as a "mixing"

Turbulent diffusion : Mellor et Yamada

Turbulent diffusivity K_z

- Prandlt (1925) mixing length : $K_z = l\overline{|w'|}$ or $K_z = l^2 \frac{\partial ||\mathbf{v}||}{\partial z}$
- Accounting for static stability (Ex. Louis 1979)

$$K_z = f(Ri) l^2 \left| \frac{\partial \mathbf{v}}{\partial z} \right| \text{, In} \qquad \text{with } Ri = \frac{g}{\theta} \frac{\frac{\partial \theta}{\partial z}}{\left(\frac{\partial \mathbf{v}}{\partial z}\right)^2} \tag{1}$$

- Turbulent kinetic energy $\overline{w'}^2 \simeq e = \frac{1}{2}\left[\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right]$

$$\frac{\partial e}{\partial t} = -\overline{w'u'}\frac{\partial u}{\partial z} - \overline{w'v'}\frac{\partial v}{\partial z} + \frac{g}{\theta}\overline{w'\theta'} - \frac{1}{\rho}\frac{\partial \overline{w'p'}}{\partial z} - \frac{\partial \overline{w'e}}{\partial z} - \epsilon$$

In LMDZ : Mellor and Yamada (Yamada 1983 version, see also Vignon et al. publications)

Turbulent diffusion : coupling with surface

$$\frac{\partial c}{\partial t} = -\frac{1}{\rho}\frac{\partial F_c(z)}{\partial z}$$

$$F_c(z > 0) = -K_z \rho \frac{\partial c}{\partial z}$$

At surface :

$F_c(z = 0)$ imposed or

$$F_c(z = 0) = \rho C_d ||V|| (c_s - c_1)$$

Where c_s and c_1 are values of c at the surface and in the first model layer respectively

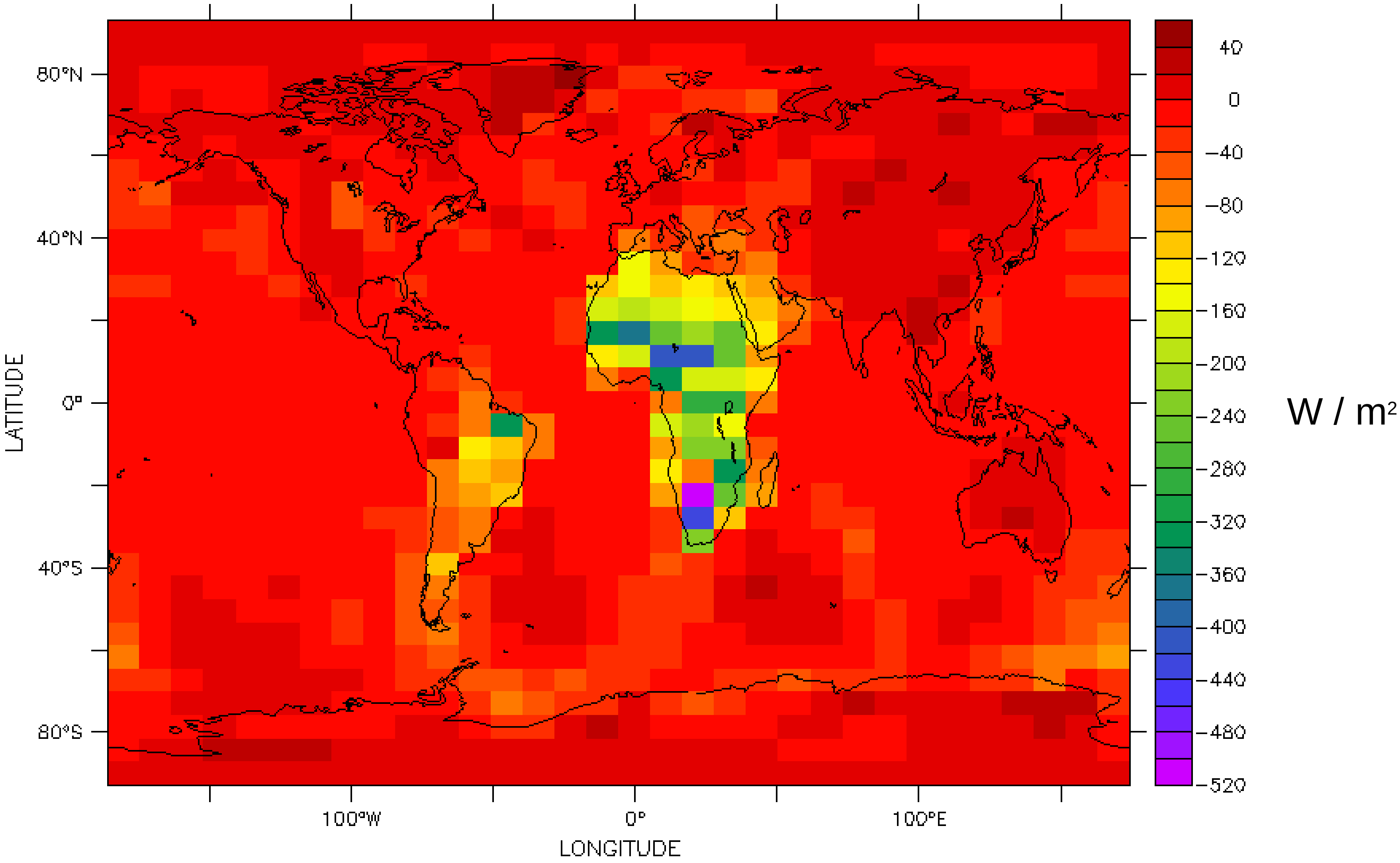
In physiq.def (deepL translation)

```
################################################################################
# Turbulent boundary layer
################################################################################

        # New version of Mellor and Yamada
new_yamada4=y

        # Choice of numerical scheme for new_yamada4=y
        # 1 MAR diagram. Good for stable CL but destroys the stratocus.
        # 5 MAR schema modified. Precaunise.
yamada4_num=5

        # Stable boundary layer control flag
iflag_corr_sta=4

        # min on the surface stability functions
f_ri_cd_min=0.01

        # max of Ric for Kz. Larger decoupling for larger Ric.
yamada4_ric=0.18

        # minimum mixing length for Kz
lmixmin=0

        #shema of the surface layer (D:1, 1:LMD, 8:Mellor-Yamada)
iflag_pbl=12

        # Thresholds for turbulent diffusion
ksta_ter=1e-07
ksta=1e-10

        #ok_kzmin : Kzmin calculation in the surface CL (D: y)
ok_kzmin=n
```

Turbulent diffusion : practice

cd /LMDZ20211102.trunk/modipsl/modeles/LMDZ/BENCH32x32x39 ferret
- **use histhf.nc**
- **shade/l=48 sens**
- **go land 1**

Sensible heat flux at 12h GMT on January 2nd



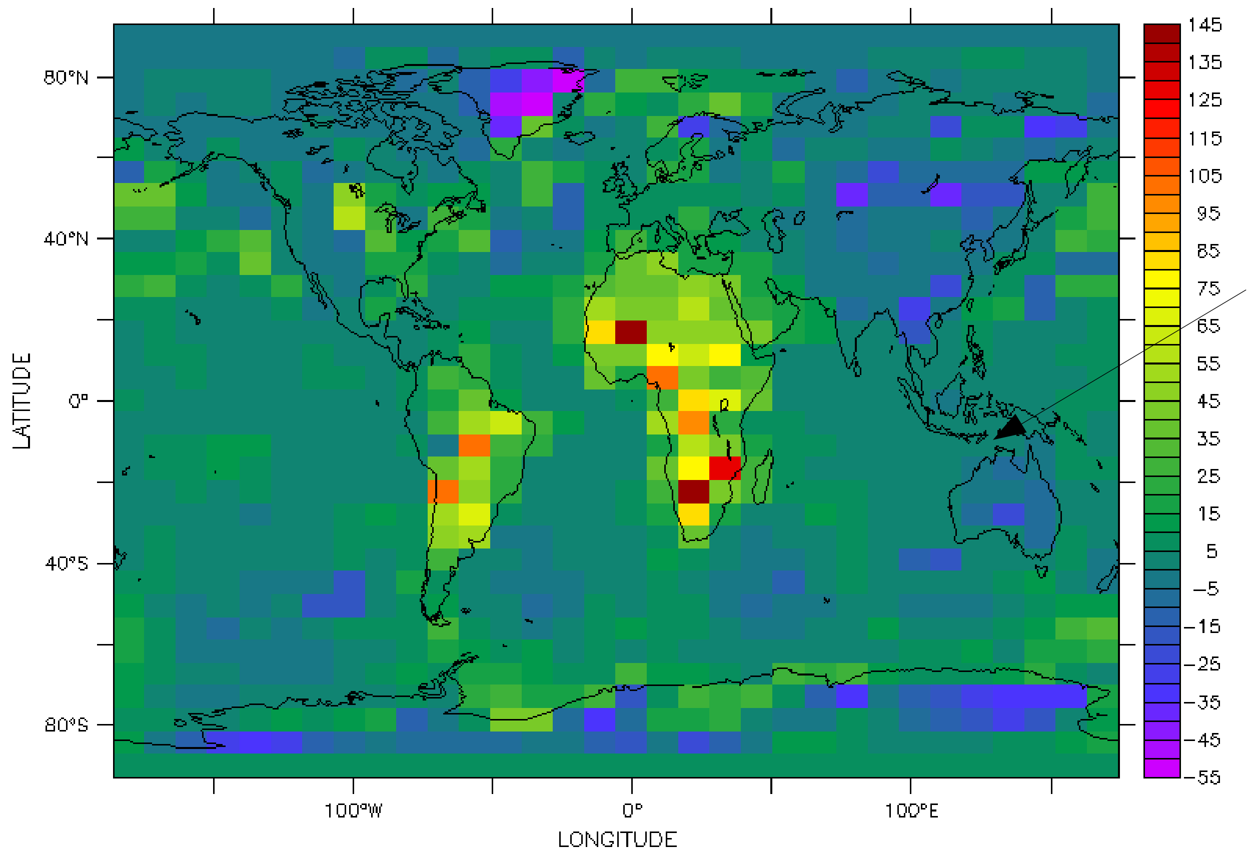
Turbulent diffusion : practice

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

ferret
- **use histhf.ns**
- **shade/l=48 dtvdf[k=@max]*86400**
- **go land 1**

Then choose a relevant location like for example :
x=20/y=-10



DTVDF*86400

1D case study
TWP-ICE

→ My plots in the following

Turbulent diffusion : practice

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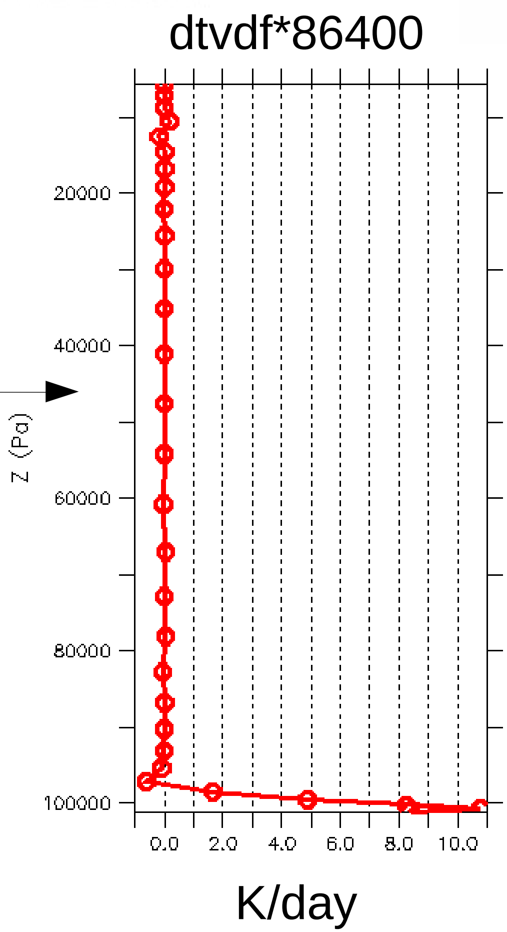
ferret

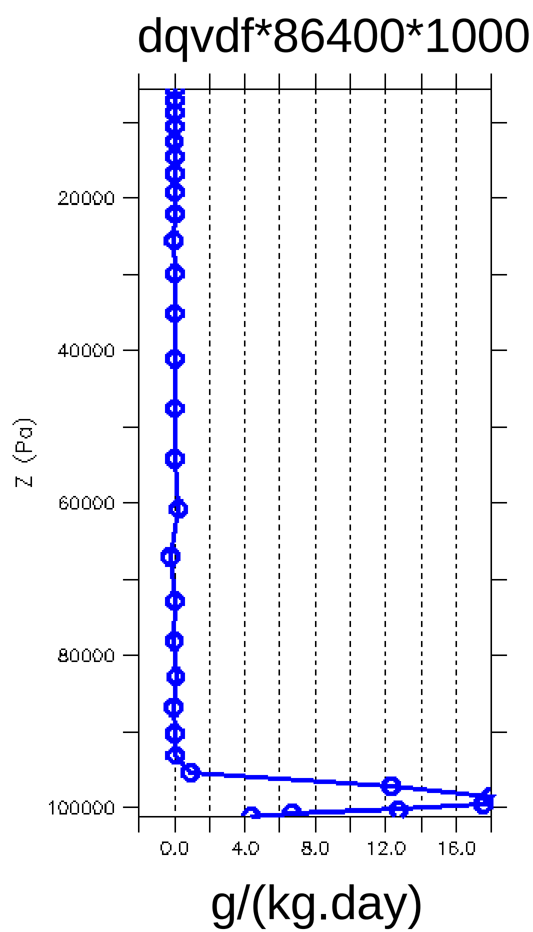
use histhf.nc

plot/l=48/thick=3/x=…/y=…/k=10:39 dtvdf*86400

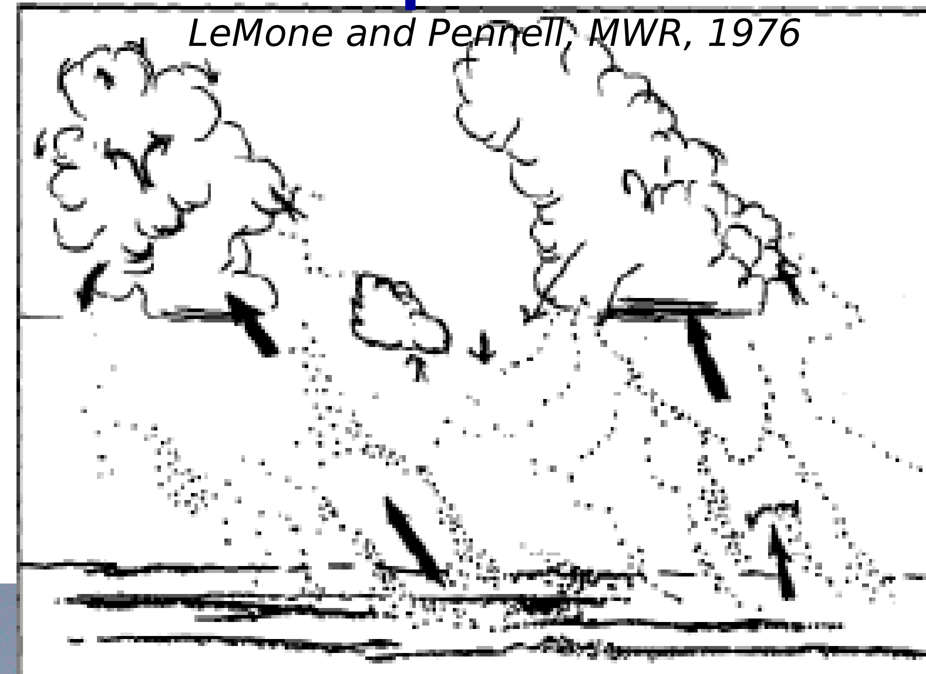
plot/l=48/thick=3/x=…/y=.../k=10:39 dqvdf*86400*1000

TWPICE case





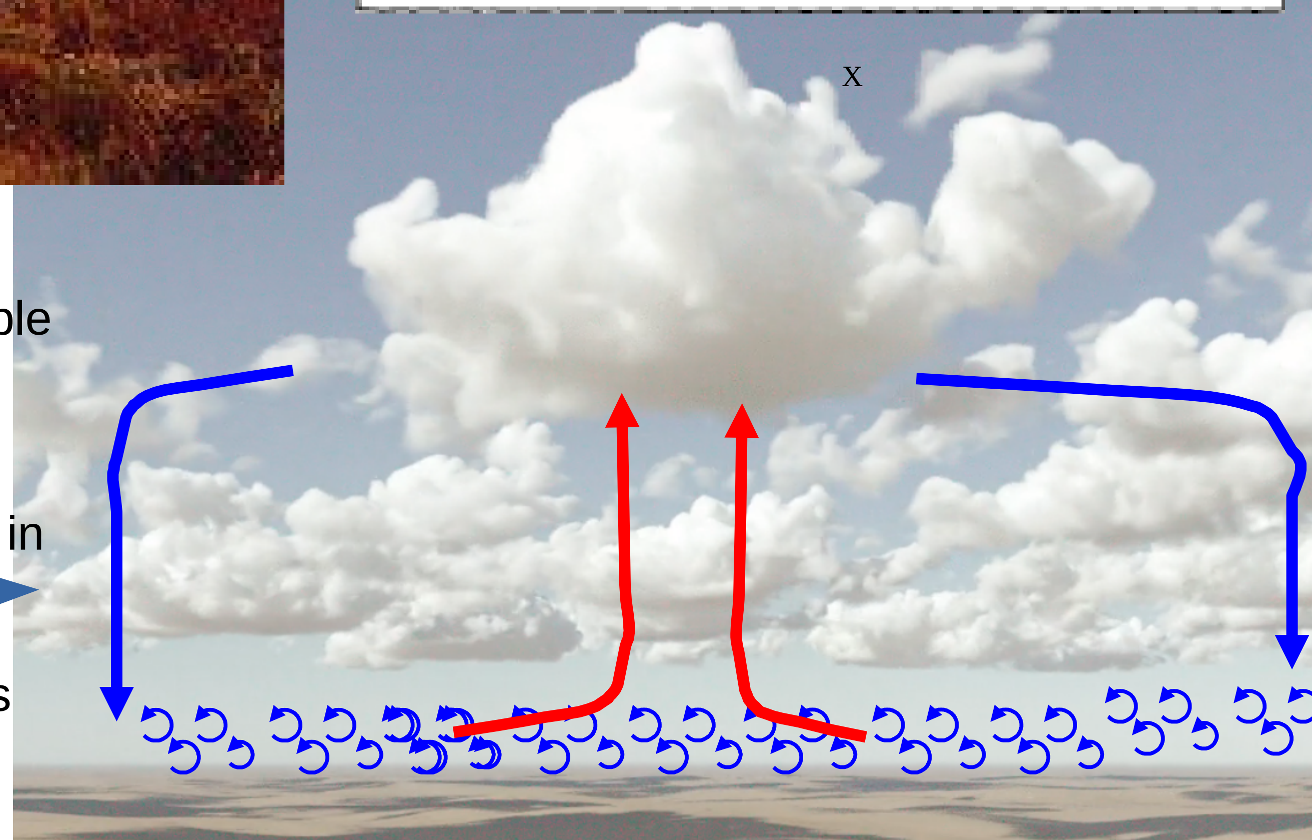
Boundary layer convection : the « thermal plume model »



LeMone and Pennell, MWR, 1976

Organised turbulence/convection

- When the boundary layer is unstable (upward > 0 sensible heat flux)
- Still in the « boundary layer »
- Above the « surface layer »
- Often dominates vertical transport in the « mixed layer »
- Often asscociated with cumulus
- Represented in explicit simulations (LES). Here at 8m resolution



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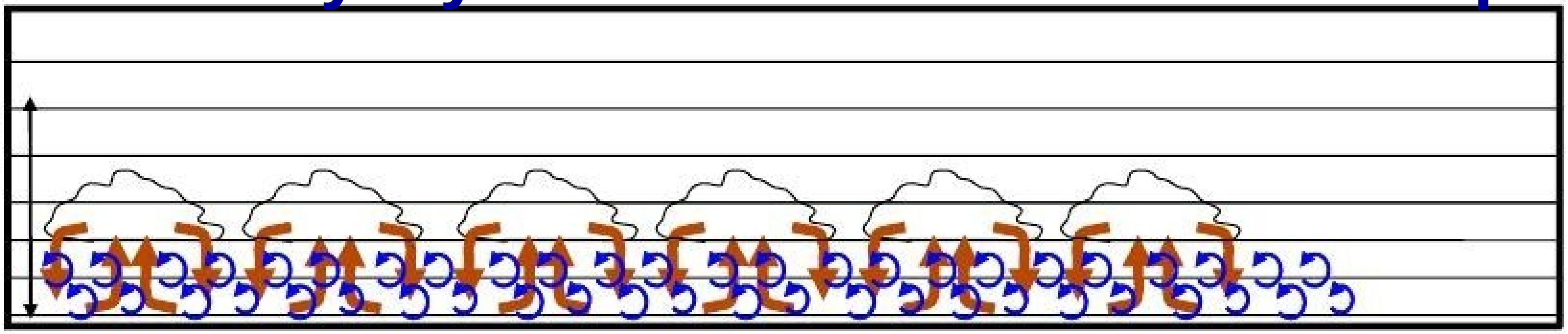
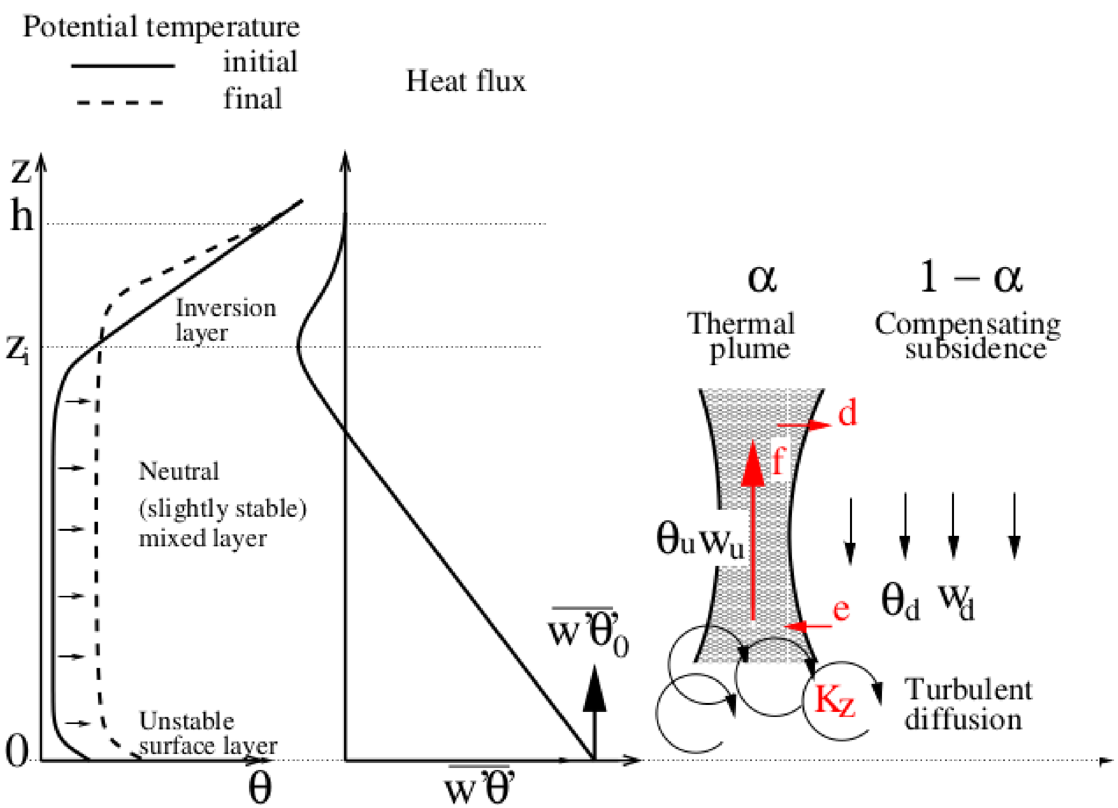


Combinaison of turbulent diffusion with a « mass flux scheme » representing a mean thermal plume or cell or roll



Separation into 2 sub-colums :

$$X = \alpha X_u + (1-\alpha) X_d$$

ascending plume of mass flux

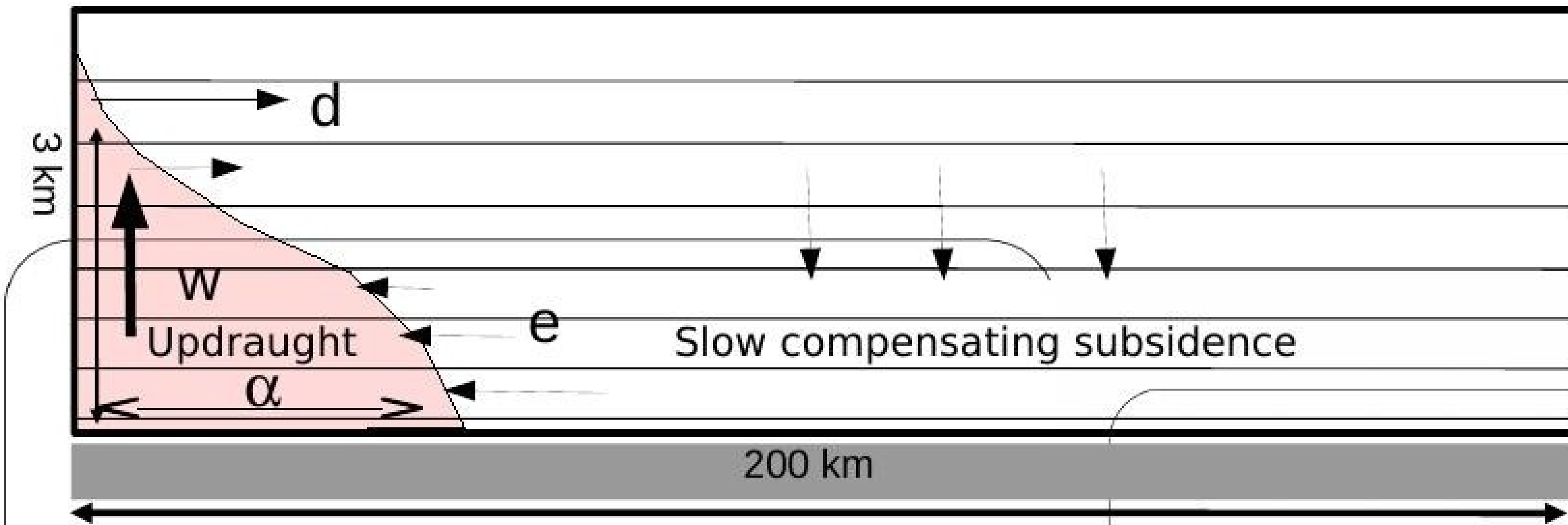
$$f = \alpha \rho w_u$$

$$\frac{\partial f}{\partial z} = e - d$$

$$\frac{\partial f c_u}{\partial z} = e c_d - d c_u$$

$$\rho \overline{w'c'} = -\rho K_z \frac{\partial c}{\partial z} + f\,(c_u - c_d) \qquad (9)$$

Boundary layer convection : the « thermal plume model »



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 :

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

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 :**

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

$$d = \ldots$$

Etc ...

```
##########################################################################
# Convective boundary layer / thermal model
##########################################################################

        # Dry convection (D:0, 0:dry adjustment,=>1:thermal model)
iflag_thermals=18

        # no splitting time for thermals
        # TURNS BUT POSES MORE PROBLEMS THAN IT SOLVES
nsplit_thermals=1

        # tau_thermals to have a time constant on the thermals.
        # invalid
tau_thermals=0

        # Flag controlling training and practice
iflag_thermals_ed=8

        # We will look for the air at z * ( 1+fact_thermals_ed_dz) to
compute
        # training (A. Jam)
fact_thermals_ed_dz=0.07
```

In physiq.def (deepL translation)

Boundary layer convection : practice

Thermals and dry adjustment

Subroutine : calltherm

Tendencies :

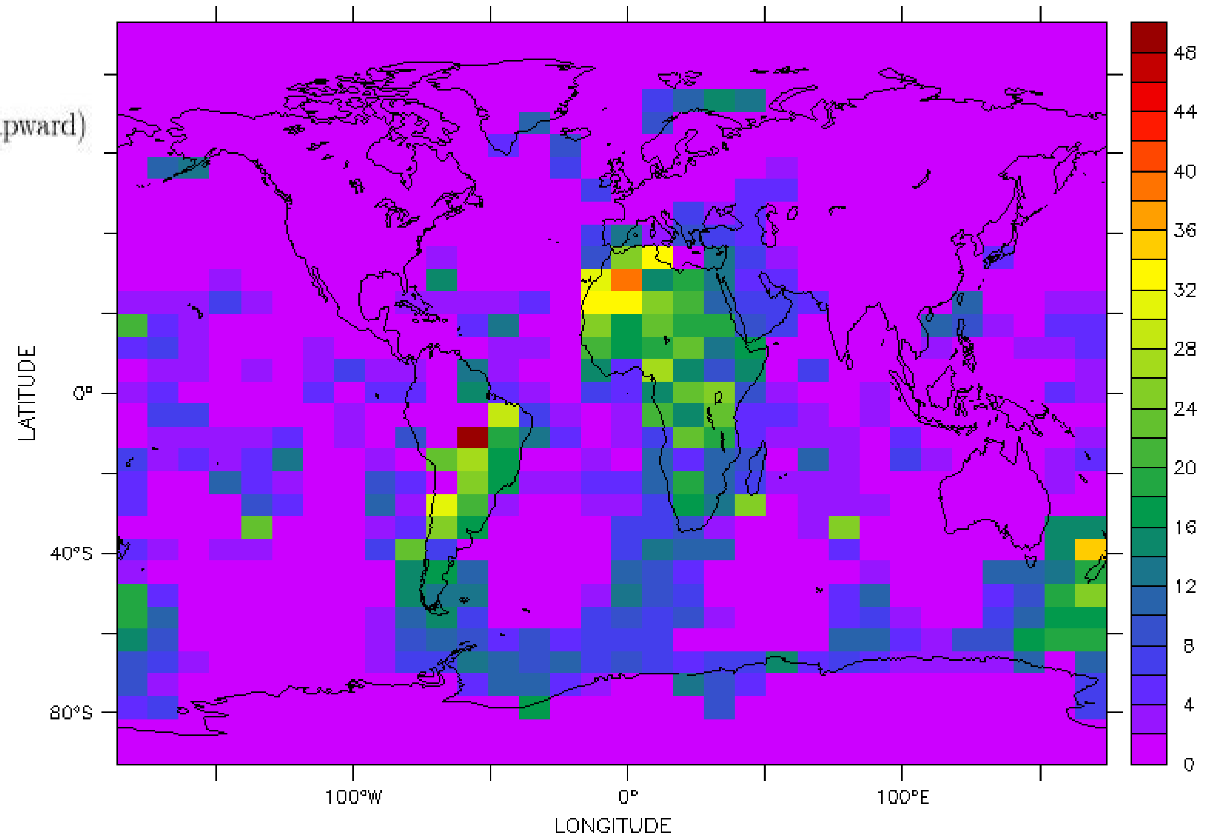
dtthe, dqthe,duthe, dvthe

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)
- f0_th : Thermal closure mass flux (kg/m².s)

ferret

- **use histhf.ns**
- **shade/l=48 dtthe[k=@max]*86400**
- **go land 1**



DTTHE[K=@MAX]*86400

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TWPICE case

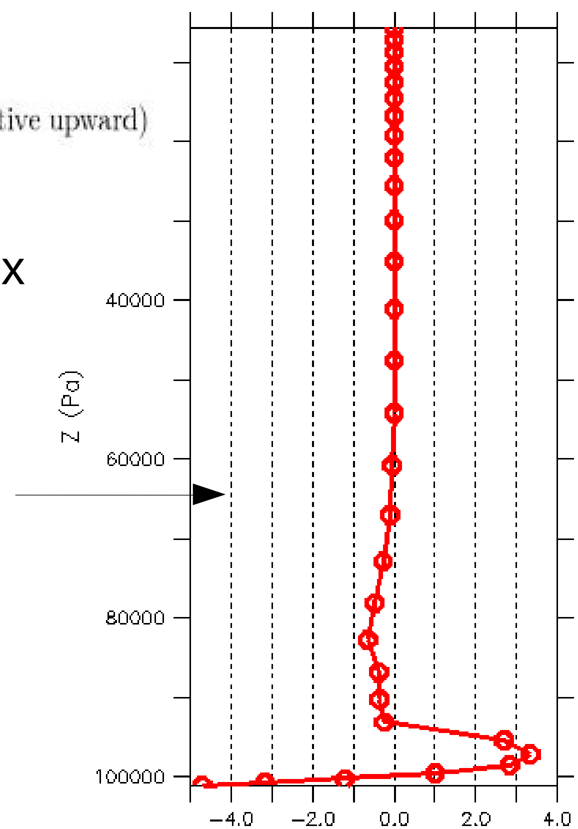
ferret

use histhf.nc

plot/l=48/thick=3/x=…/y=…/k=10:39 dtthe*86400

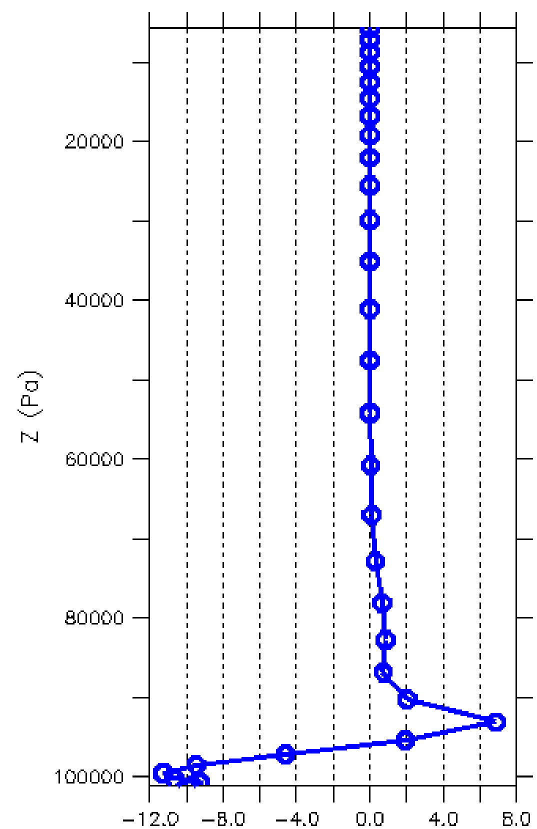
plot/l=48/thick=3/x=…/y=.../k=10:39 dqthe*86400*1000

dtthe*86400



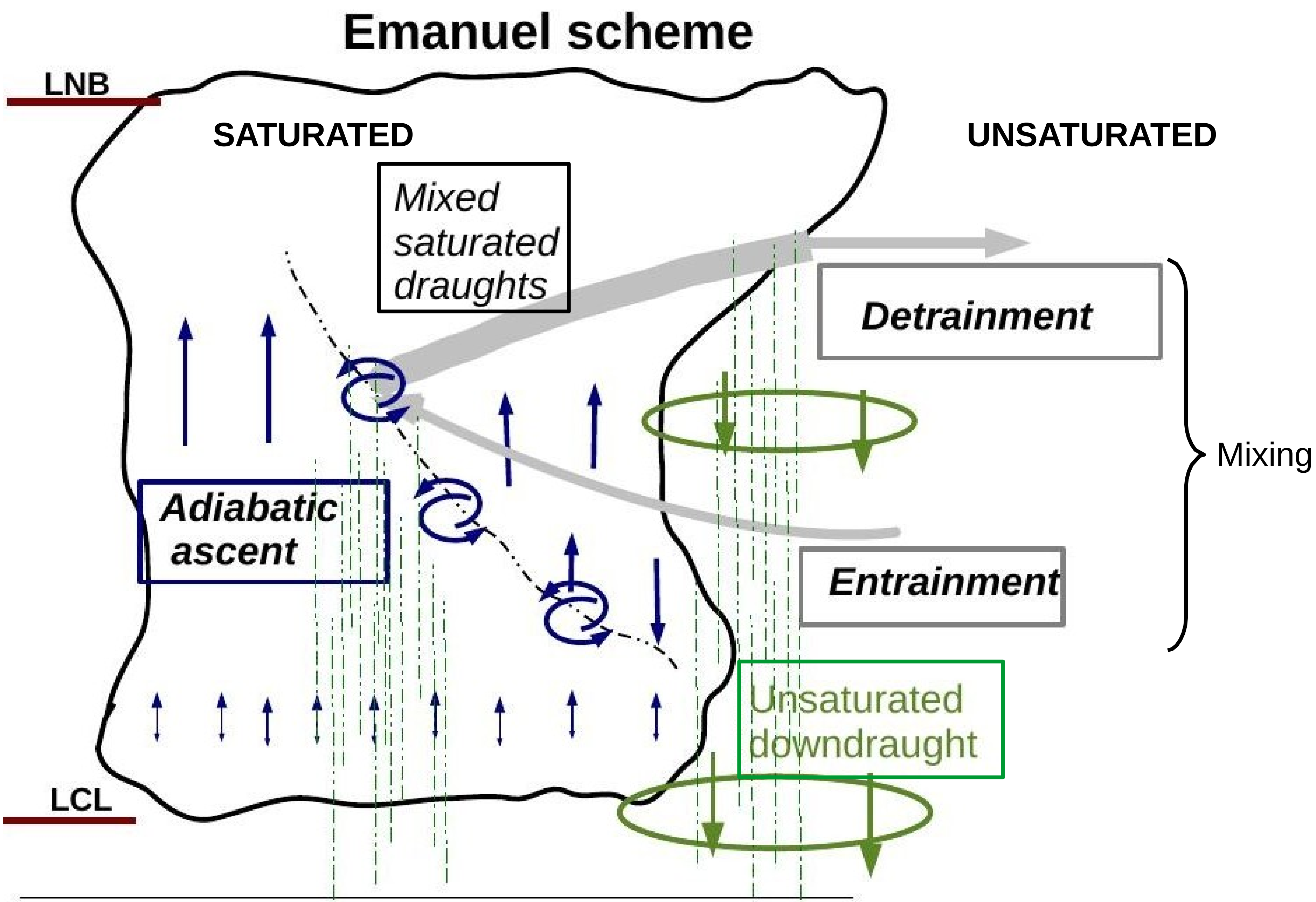
K/day

dqthe*86400*1000



g/(kg.day)

Deep convection : Emanuel scheme



Deep convection : practice

Deep convection

Subroutine : concvl

Tendencies :

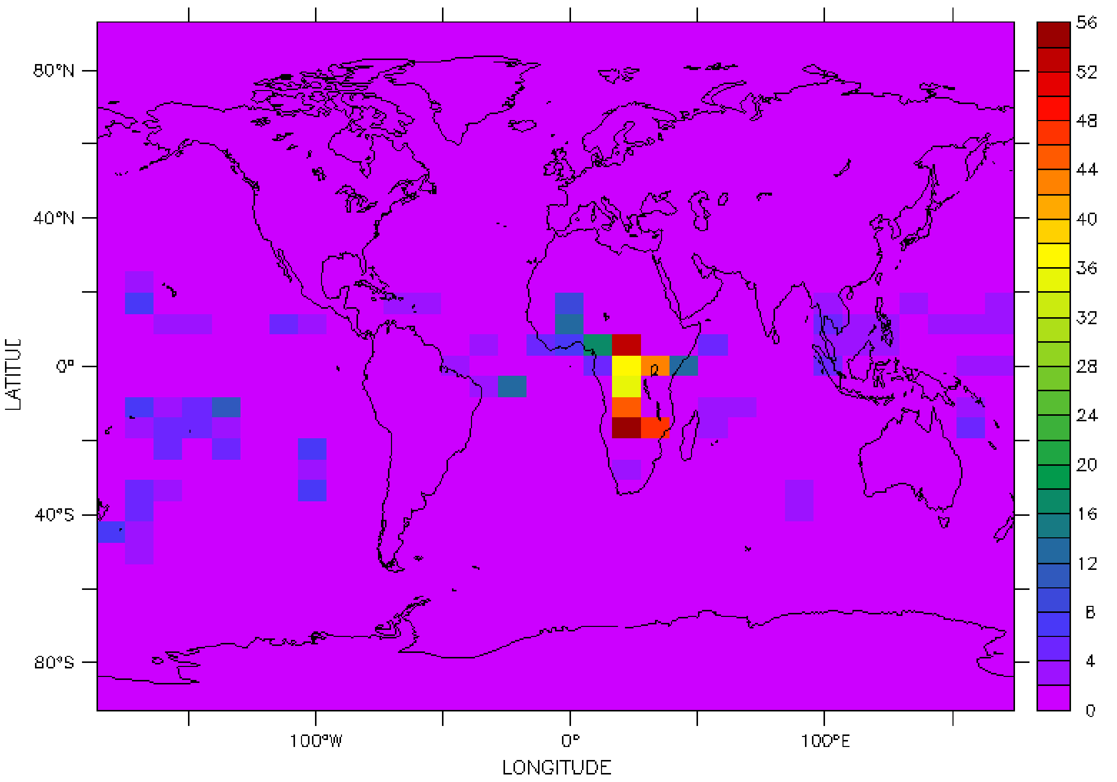
dtcon, dqcon, ducon, dvcon

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

ferret

- **use histhf.ns**
- **shade/l=48 dtcon[k=@max]*86400**
- **go land 1**



DTCON[K=@MAX]*86400

Large scale condensation & evaporation : practice

Large scale condensation (evap & lsc)

Subroutines : reevap & fisrtilp

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.

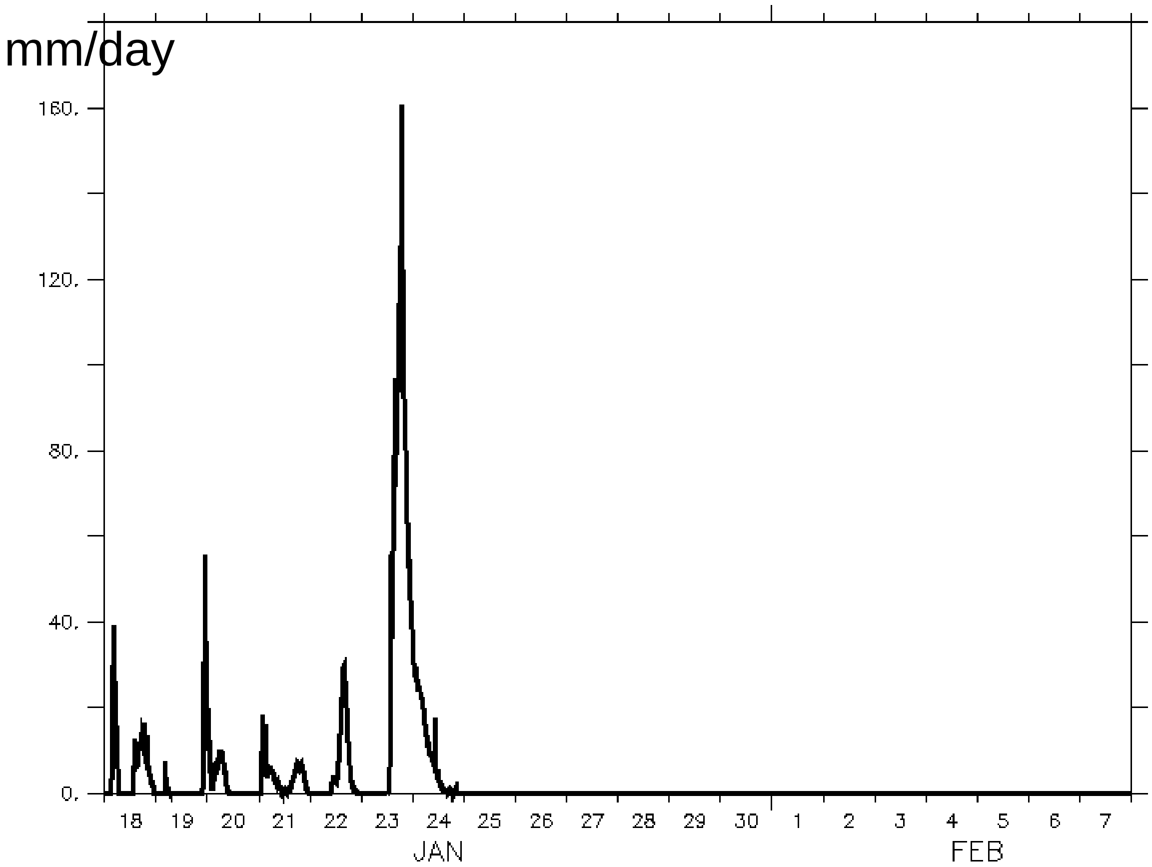
Other variables

- 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

ferret

- **use histhf.nc**
- **plot/l=48/thick=3/x=…/y=… plul*86400**

plul*86400



TWPICE case →

In physiq.def

```
################################################################################
# Convection
################################################################################
	#Convection scheme switch
	# (D:2, 1:LMD, 2:Tiedtke, 3:KE New Physics, 30:KE AR4)
iflag_con=3

	#output level of energy conservation diagnostics
if_ebil=0

	#maximum efficiency of cld water->precipitation conversion (D: 0.993)
epmax=0.999

	#Convective entrainment mixing law (D:1, 0:AR4=flat PDF, 1=PDF)
iflag_mix=1

	#weights of the bell shaped and flat PDF (used only if iflag_mix=1) (D: 1 0)
qqa1=1
qqa2=0

	#reference fractional area of precipitating downdraughts,
	# def = original: 0.01
sigdz=0.003

	#flag for wb (= vert velocity at LFC);
	# 0->wb=wbmax, 1->wb=f(plfc) bounded, 2->wb=f(plfc) linear, D=1
	# Si iflag_wb>=10 : wbeff_min=iflag_wb*0.1
	# wbmax : assymptotic value
flag_wb=50
wbmax=2.8
```

Deep convection : practice

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 (precipita downdraught)
- pr_con_l : vertical profile of convective liquid precipitation
- pr_con_i : vertical profile of convective ice precipitation

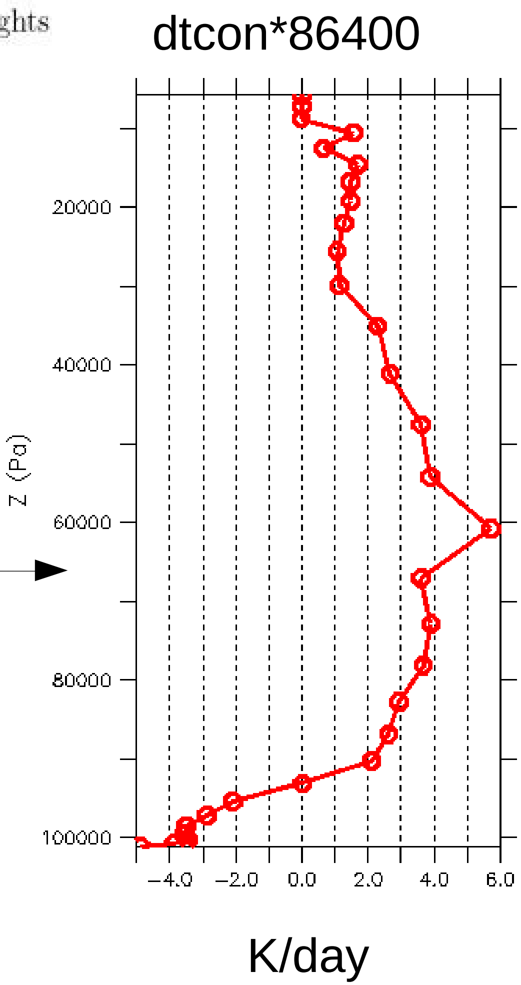
ferret

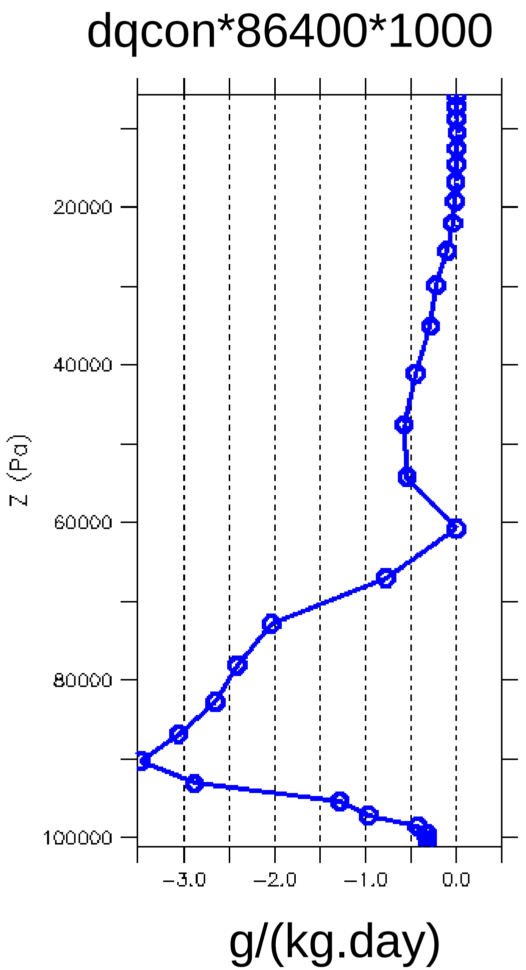
use histhf.nc

plot/l=48/thick=3/x=…/y=…/k=10:39 dtcon*86400

plot/l=48/thick=3/x=…/y=.../k=10:39 dqcon*86400*1000

TWPICE case





Deep convection : practice

Deep convection

Subroutine : concvl

Tendencies :

dtcon, dqcon, ducon, dvcon

Other variables

- pluc : convective precipitation at the surface
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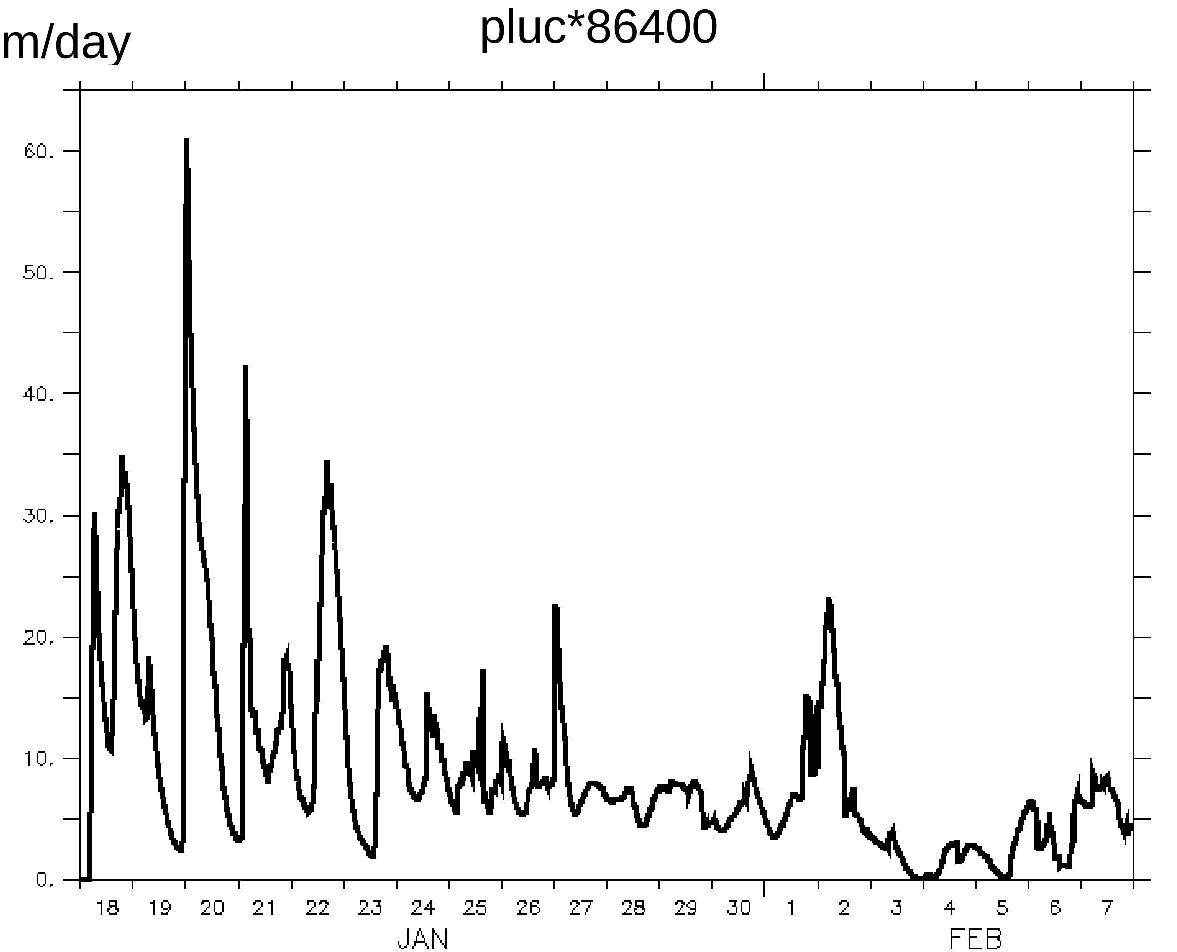
- pr_con_l : vertical profile of convective liquid precipitation
- pr_con_i : vertical profile of convective ice precipitation

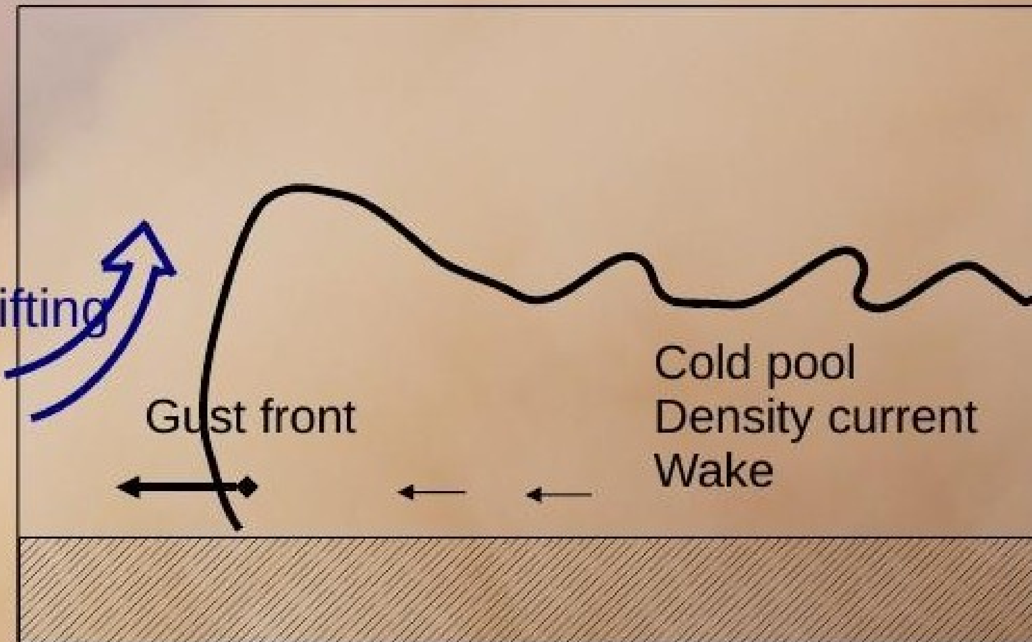
ferret

- **use histhf.nc**
- **plot/thick=3/x=…/y=… pluc*86400**

TWPICE case →

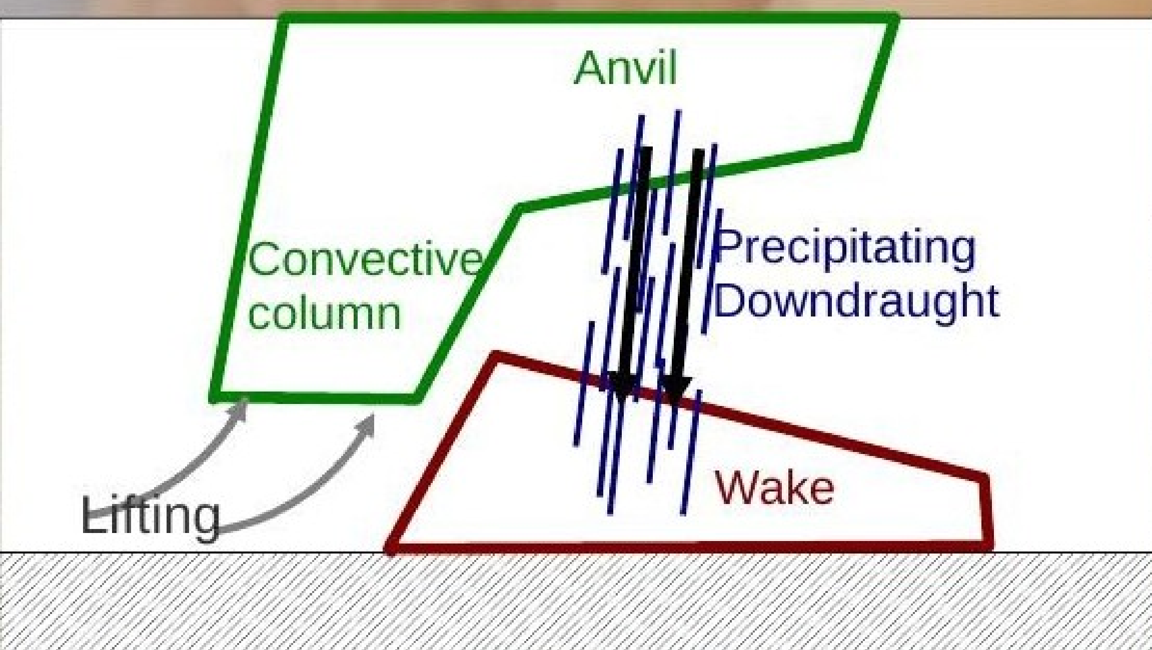


Density currents / cold pools / wakes



Created by reevaporation of convective rainfall

Trigger new convecttive cells by lfiting air

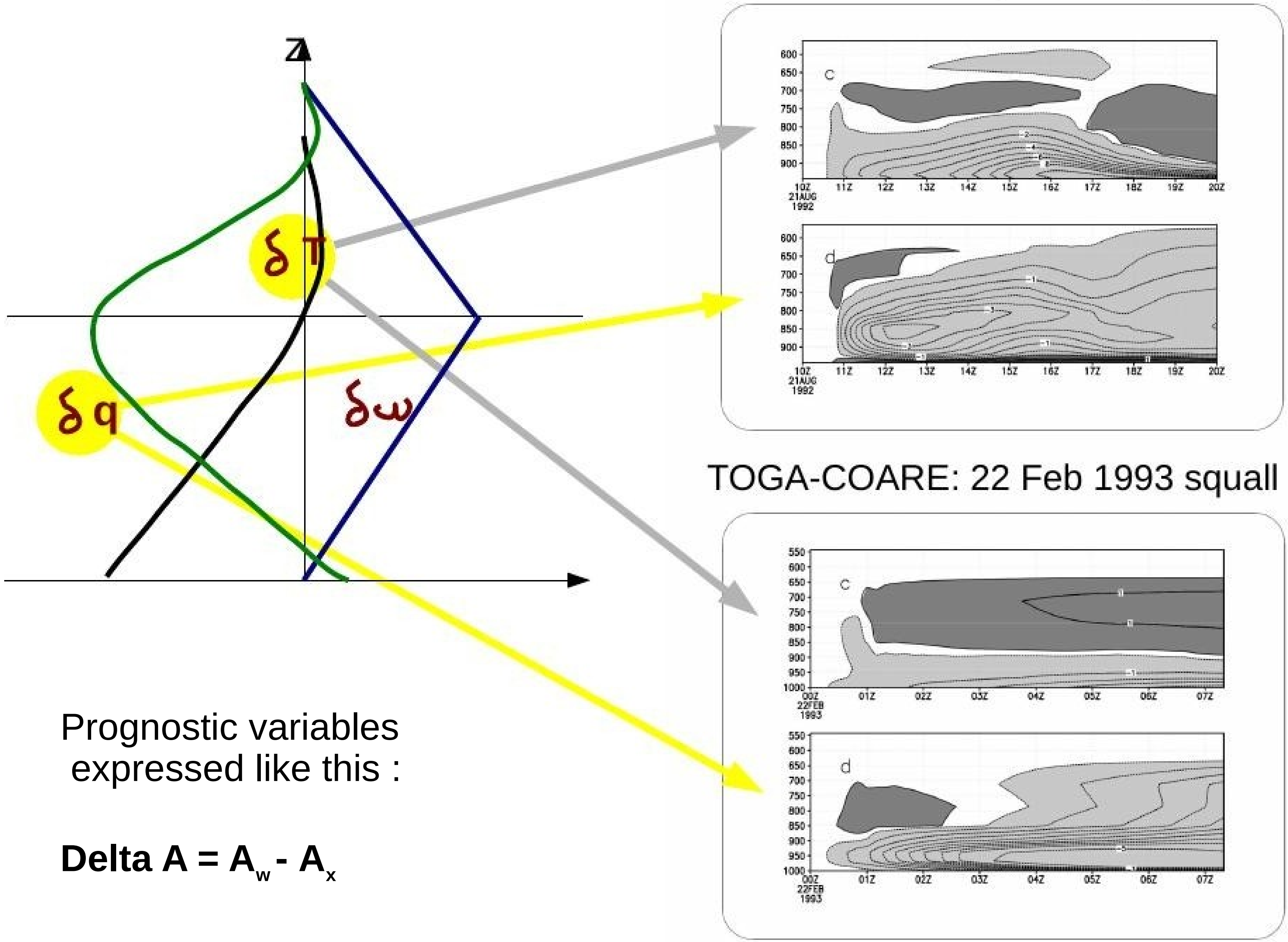


Density currents / cold pools / wakes

Simulated wake properties

HAPEX92: 21 Aug 1992 squall line case

TOGA-COARE: 22 Feb 1993 squall line ca



Prognostic variables
expressed like this :

Delta A = A_w - A_x

Density currents : practice

Cold pools (wakes)

Subroutine : calwake

Tendencies :

dtwak, dqwak

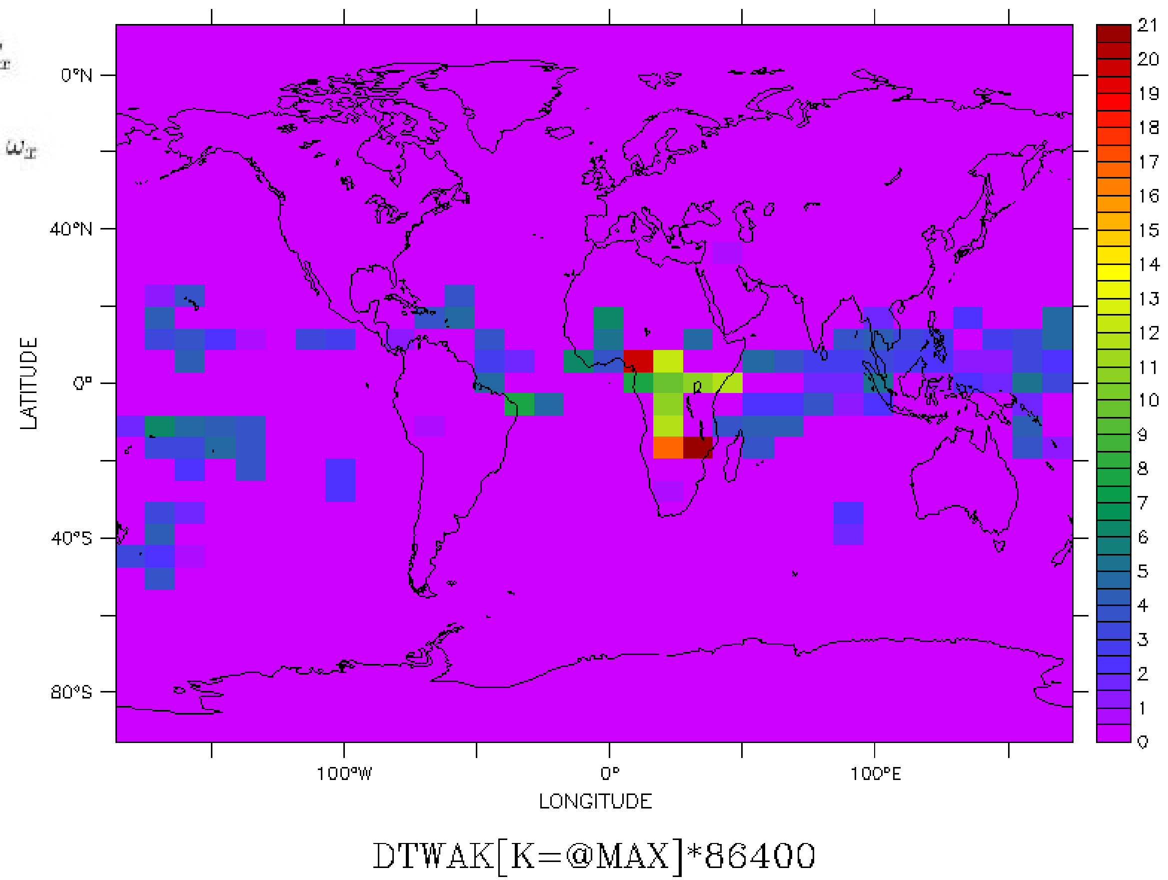
Other variables

- 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 $\omega_w - \omega_x$

ferret

- **use histhf.ns**
- **shade/l=48 dtwak[k=@max]*86400**
- **go land 1**

wk for « wakes »



Density currents : practice

Cold pools (wakes)

Subroutine : calwake

Tendencies :

dtwak, dqwak

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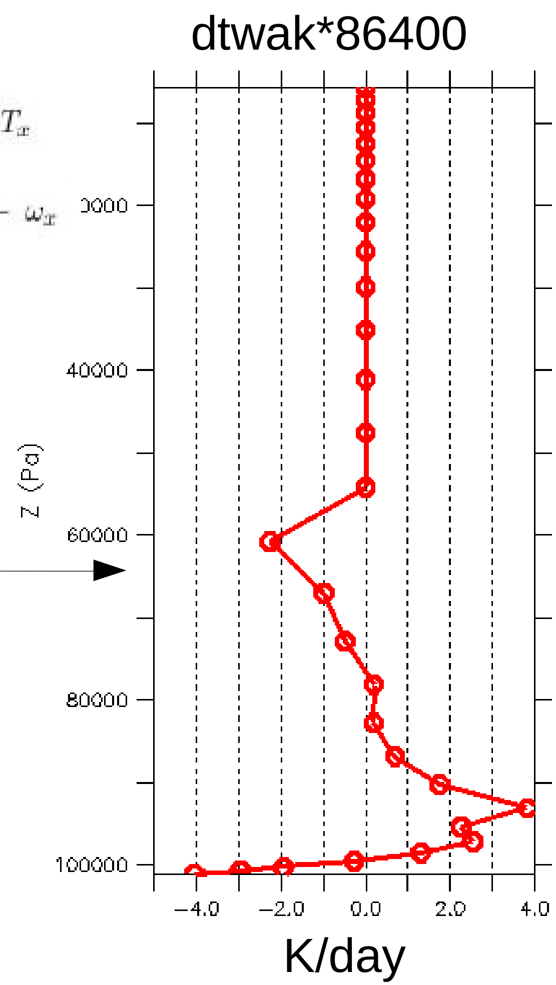
- wake_omg : vertical profile of vertical velocity difference $\omega_w - \omega_x$

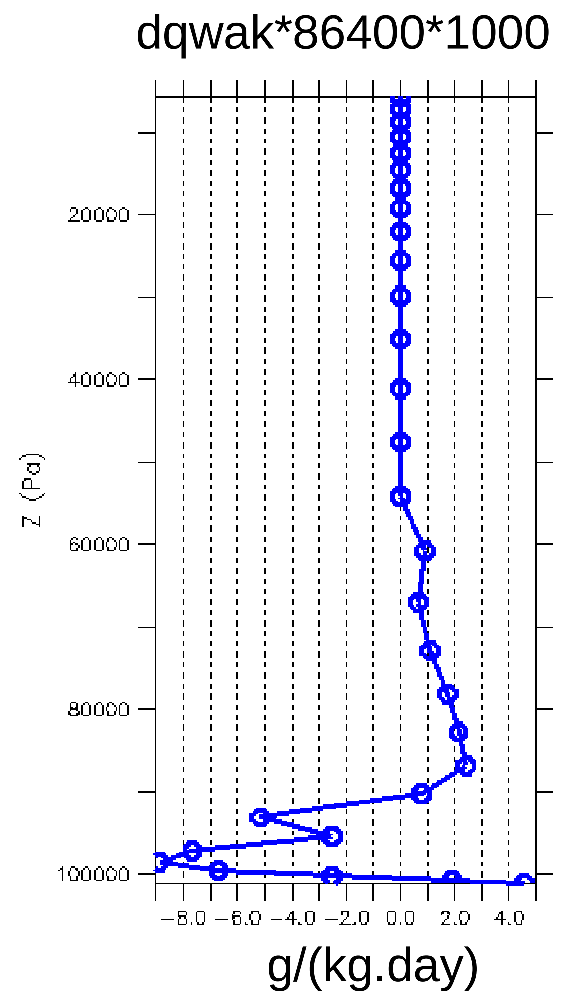
wk for « wakes »

TWPICE case →

ferret

- **use histhf.nc**
- **plot/l=48/thick=3/x=…/y=…/k=10:39 dtwak*86400**
- **plot/l=48/thick=3/x=…/y=.../k=10:39 dqwak*86400*1000**





Density currents : practice

Cold pools (wakes)

Subroutine : calwake
Tendencies :
dtwak, dqwak
Other variables

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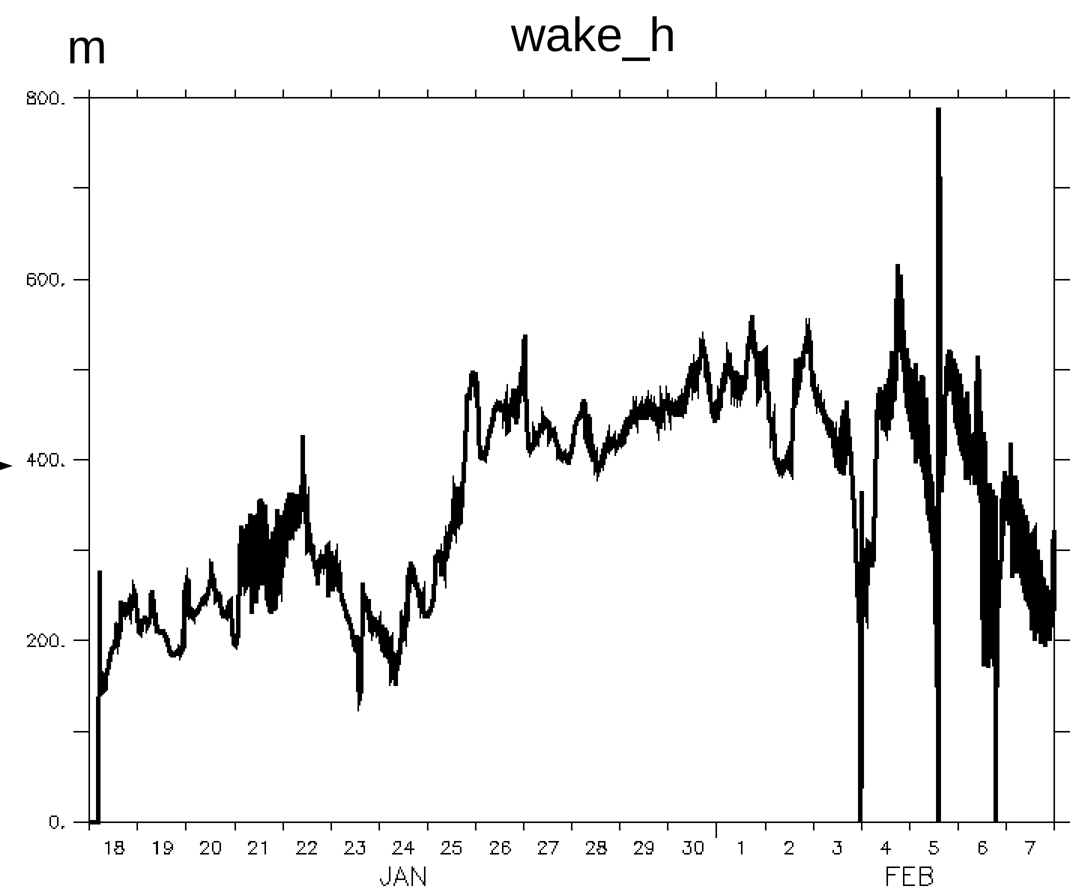
- wake_omg : vertical profile of vertical velocity difference $\omega_w - \omega_x$

ferret
- **use histhf.nc**
- **plot/thick=3/x=…/y=… wake_h**

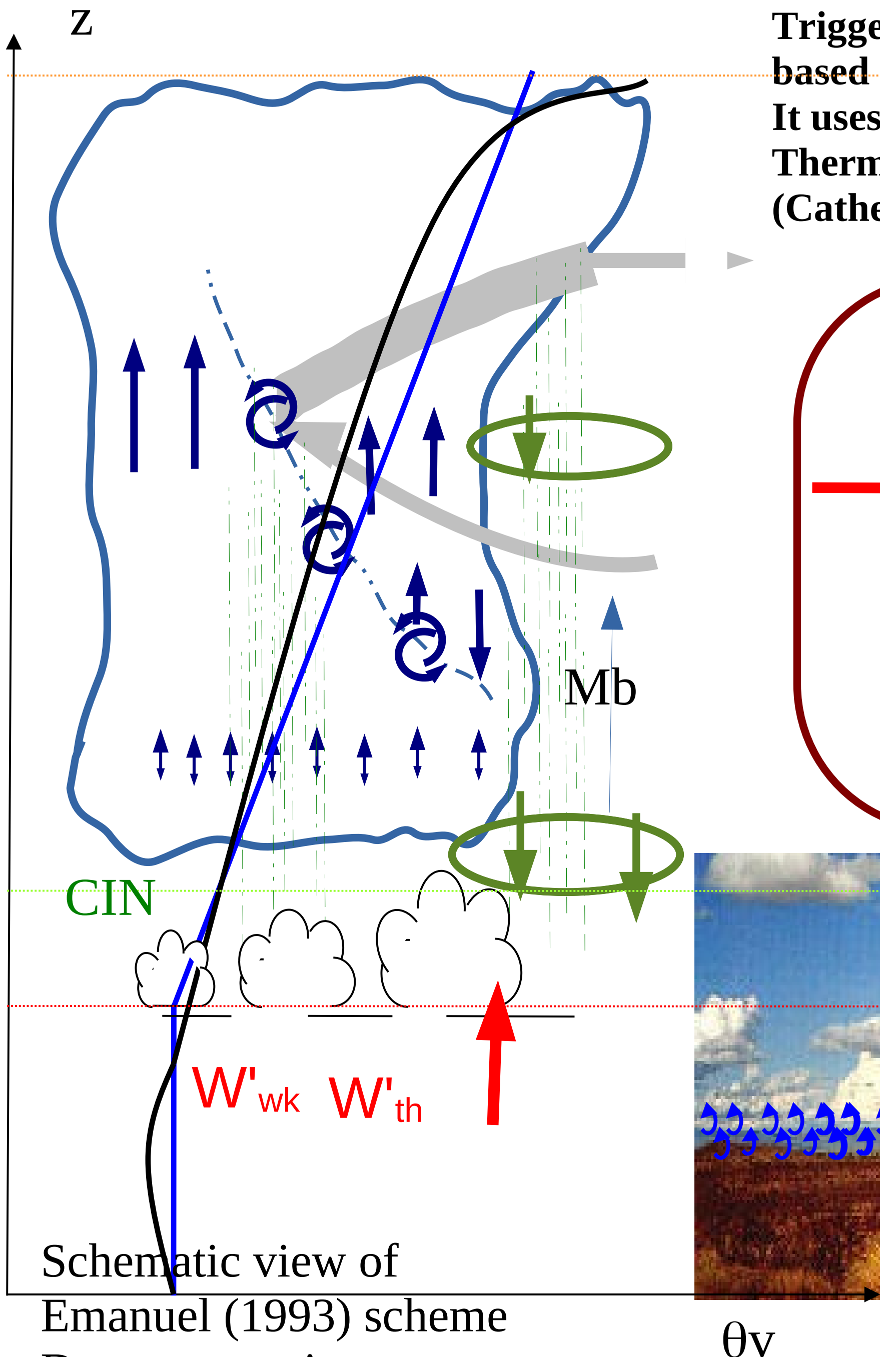
wk for « wakes »

TWPICE case →



What drives deep convection : triggering and closure

Triggering (is convection active?) and closure (with which intensity?) are based on sub cloud processes in LMDZ
It uses estimations of subgrid scale vertical velocity provided by the Thermal plume model and the cold pool scheme
(Catherine Rio''s PhD)



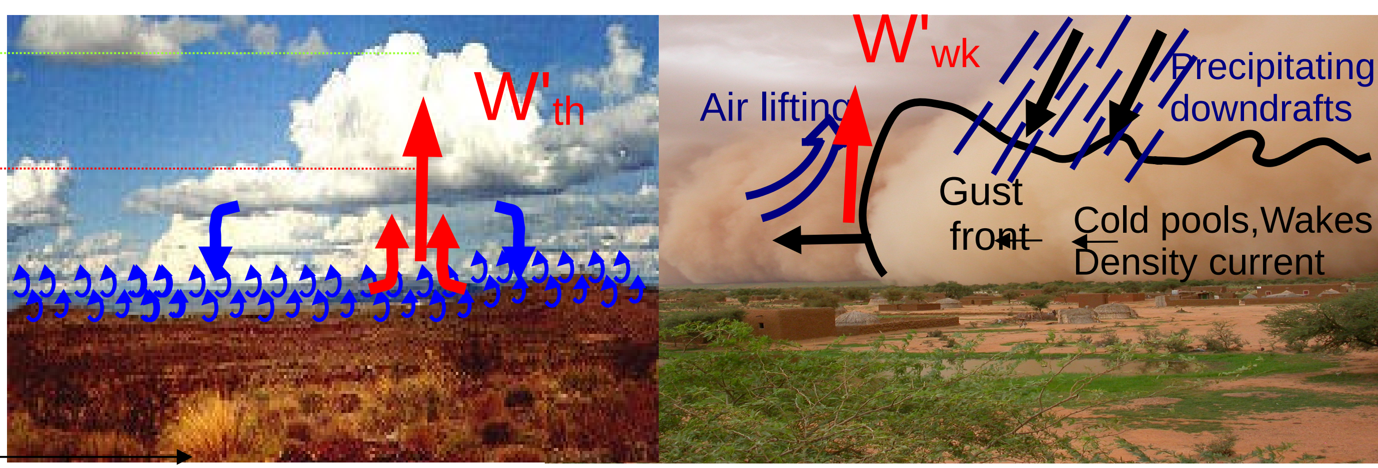
Schematic view of
Emanuel (1993) scheme
Deep convection

Available lifting energy
ALE (J/kg) scaling with w'^2.

→ Triggering: max (ALE_{th}, ALE_{wk}) > |CIN|

Available lifting power
ALP (W/m^2) scaling with w'^3.

→ **Closure** : $MB=f(ALP_{th}+ALP_{wk})$



What drives deep convection : triggering and closure

Deep convection

Subroutine : concvl

Tendencies :

dtcon, dqcon, ducon, dvcon

Other variables

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- ftd : temperature tendency due to the sole unsaturated downdraughts
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- 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
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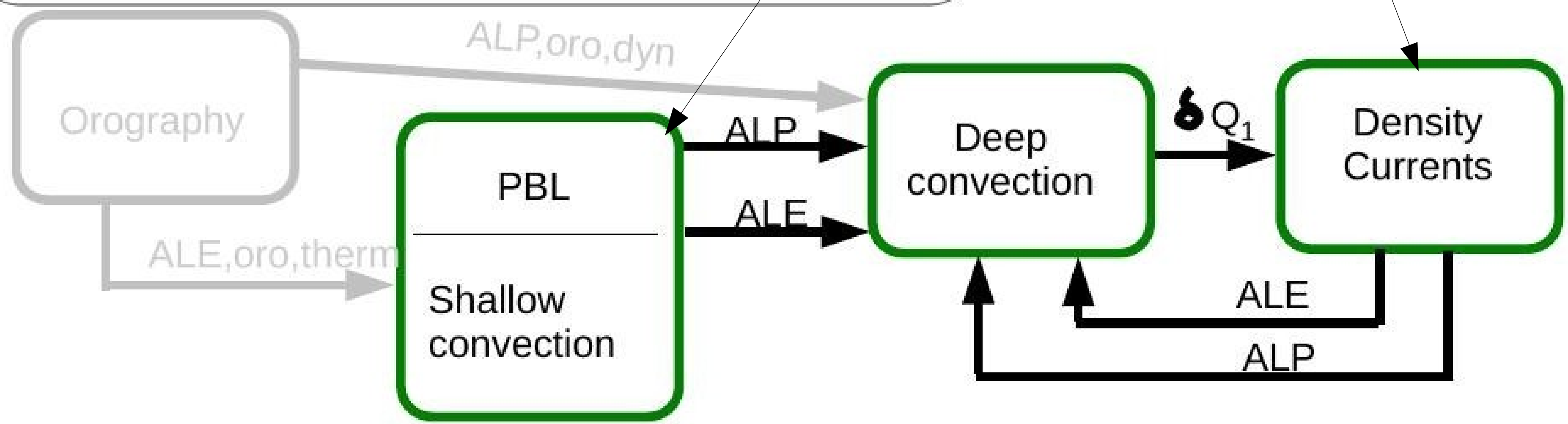
- dnwd0 : mass flux of the unsaturated downdraught (precipitating downdraught)
- pr_con_l : vertical profile of convective liquid precipitation
- pr_con_i : vertical profile of convective ice precipitation

The deep convection scheme is then coupled to 2 PBL processes :

1. Thermals

2.Density currents (or wakes or cold pools)



In physiq.def (deepL translation)

```
############################################################
# Flags wakes
############################################################

        #Wake scheme switch (D:0, 0:AR4, 1:New Physics)
iflag_wake=1

        #multiplicative factor of the damping by gravity waves, def: 4.
coefgw=4

        #wake density = number of wake centers per m2, def: 8.E-12
        #wdens_ref=8.E-12
wdens_ref_o=1e-09
wdens_ref_l=8e-12

        # Ajustement convectif prealable au calcul des poches
ok_adjwk=y

        # Prevent some crashes
        # Filter out bad wakes
flag_wk_check_trgl=n
iflag_wk_check_trgl=2
iflag_alp_wk_cond=1
```

Energy budgets

Radiation II : Energy budget

Energy budget at the top of the atmosphere :

`nettop = tops-topl = (SWdn-SWup) - (LWup-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) :

`bils = soll + sols + sens + flat`

`soll = lwdnsfc-lwupsfc` (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)

Try to do it !

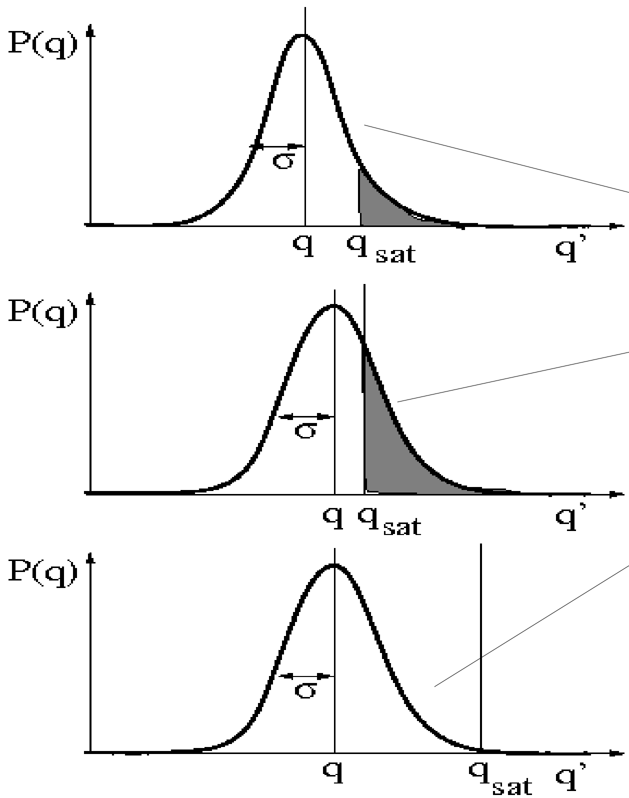
PARTIE RAYONNEMENT NUAGES → JB

Large scale condensation & evaporation

Représentation des nuages

q : concentration en vapeur d'eau
q_{sat} : concentration maximum à saturation
Si $q > q_{sat}$:
→ la vapeur d'eau condense = nuage

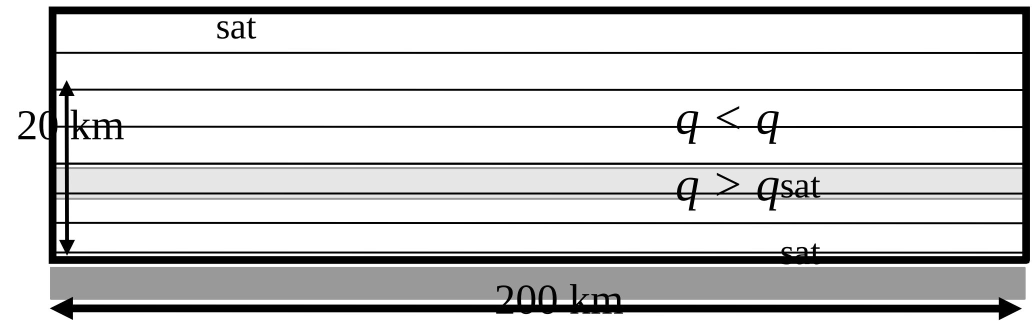
On connait q et q_{sat} à l'échelle de la maille
→ Fraction de la maille couverte de nuages ?



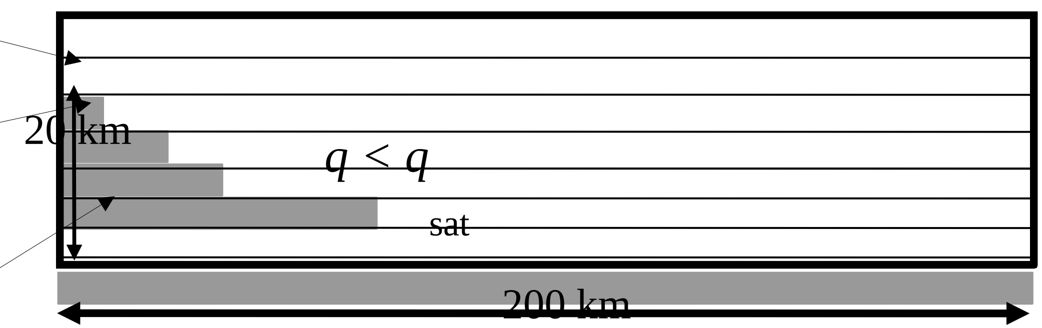
Paramétrisation simple : gaussienne $\sigma / q = 20\%$

Modèle « tout ou rien » :

Si $q > q_{sat}$ maille nuageuse, sinon ciel clair.



Modèle « statistique » :
On suppose une distribution statistique de q' dans la maille autour de q

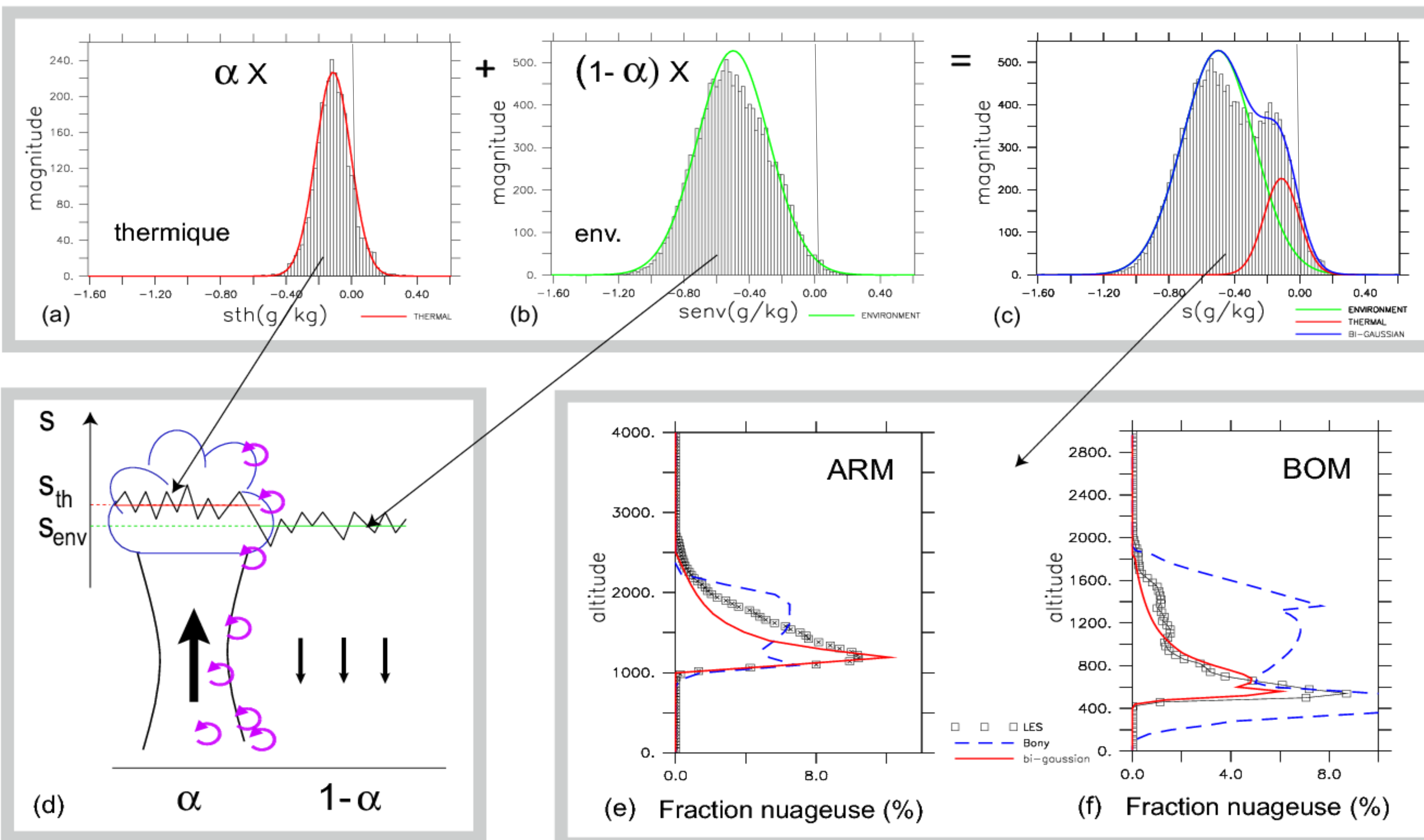


Intervient dans ***Q***
→ condensation
→ prise en compte des nuages dans le code radiatifs

Large scale condensation & evaporation

Nouvelle paramétrisation de nuages couplée aux thermiques :

Utilisation d'une PDF bi-gaussienne pour la distribution d'eau totale sous nuageuse
Une gaussienne pour les panaches thermiques et une pour l'environnement
Comparaison des distributions prédites par ce schéma avec les distributions des LES



Jam et al., 2012

```
#######################################################################
# Cloud parameters
#######################################################################
```

In physiq.def (deepL translation)

```
        #precipitation thresholds for stratum clouds (D: 2.6e-4 2.6e-4)
cld_lc_lsc=0.00065
cld_lc_con=0.00065

        #time constant to remove water lsc and convective water
        # (D: 3600. 3600.)
cld_tau_lsc=900
cld_tau_con=900

        #corrective factors on the speed of ice crystals falling (D: 1 1)
ffallv_lsc=0.8
ffallv_con=0.8

        # coefficient on the evaporation of rain (D: 2.e-5 n)
        # rule a 3.e-5 on cases of cumulus in 1D
coef_eva=0.0001

        # flag for rain evaporation
        # 0: nothing
        # 1: old-fashioned
        # 2: takes into account the maximum cloud surface above to calculate
        # the maximum reevaporation, as a deviation from saturation. TIP
iflag_evap_prec=2

        # Modification of the temperature range for the mixed phase
        # cloud liquid/ice
        # Controlled by t_glace_min/max, exponent_ice,
        # iflag_t_glace (D=0)
t_glace_min=243.15
t_glace_max=273.15
```

Large scale condensation & evaporation : practice

Large scale condensation (evap & lsc)

Subroutines : reevap & fisrtilp

Tendencies :

dteva, dqeva : tendencies due to cloud water evaporation

dtlsc, dqlsc : tendencies due to cloud water condensation

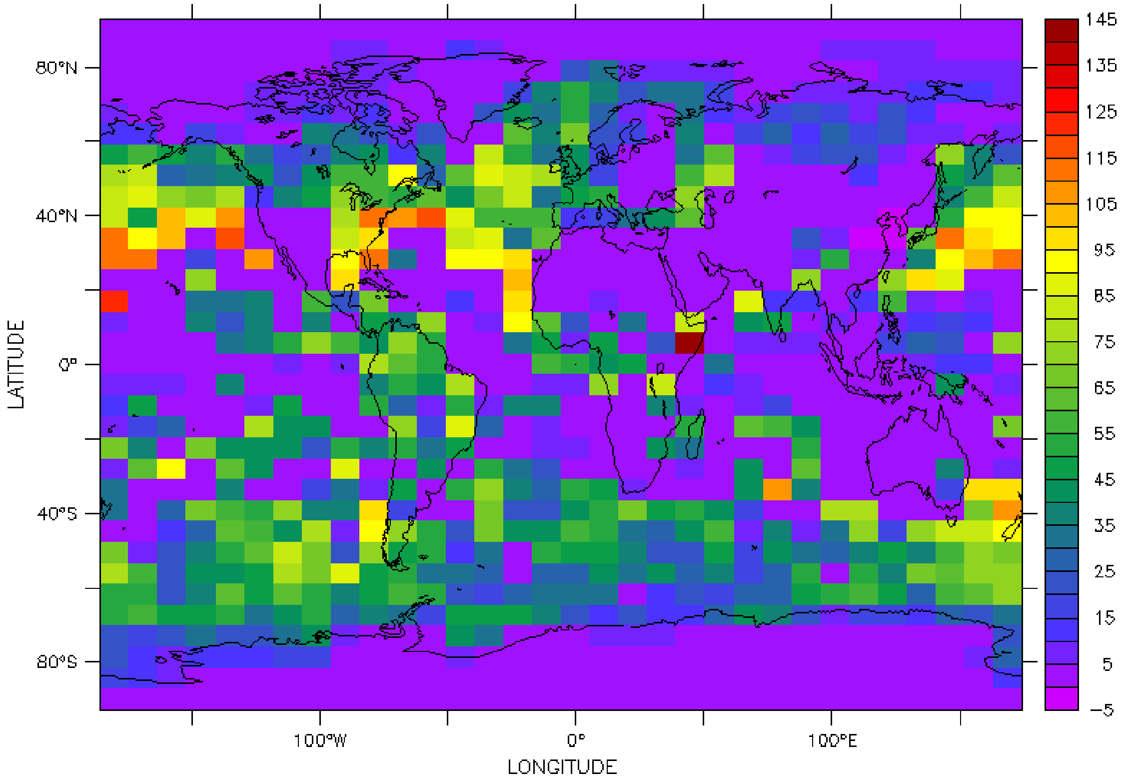
Total tendencies are the sums of the evaporation and condensation tendencies.

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

ferret

- **use histhf.ns**
- **shade/l=48 dtlsc[k=@max]*86400**
- **go land 1**



DTLSC[K=@MAX]*86400+DTEVA[K=@MAX]*86400

Large scale condensation & evaporation : practice

Large scale condensation (evap & lsc)

Subroutines : reevap & fisrtilp

Tendencies :

dteva, dqeva : tendencies due to cloud water evaporation

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- pr_lsc_i : vertical profile of large scale ice precipitation

ferret

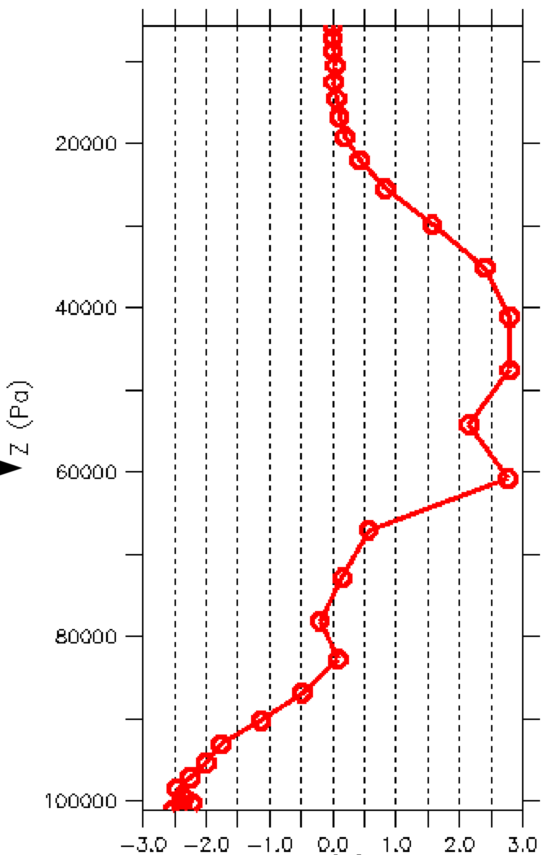
use histhf.nc

plot/l=48/thick=3/x=…/y=…/k=10:39 (dtlsc+dteva)*86400

plot/l=48/thick=3/x=…/y=.../k=10:39 (dqlsc+dqeva)*86400*1000

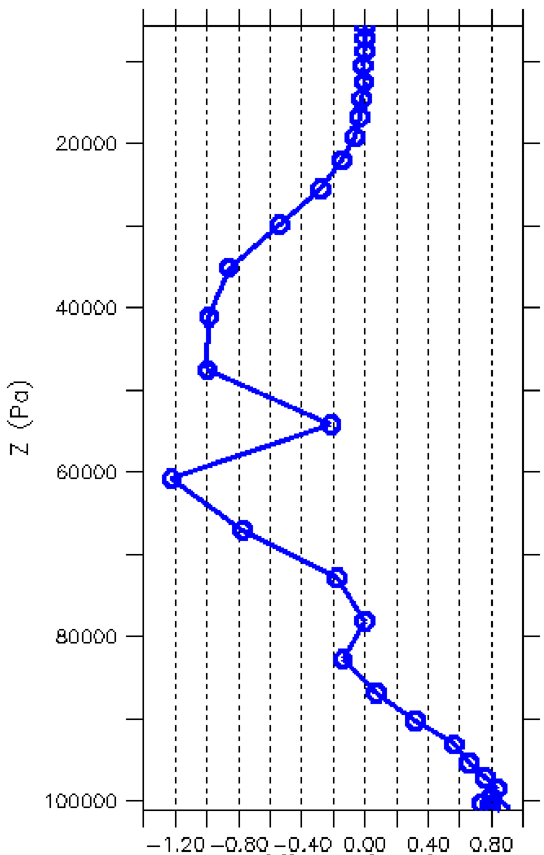
TWPICE case

(dtlsc+dteva)*86400



K/day

(dqlsc+dqeva)*86400*1000



g/(kg.day)

PARTIE PBL numérique → Frédérique

Turbulent diffusion

Turbulent diffusion

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

$$Dq/Dt = S_q \quad \text{où} \quad S_q = \frac{1}{\rho}\frac{\partial}{\partial z}(\rho K_z \frac{\partial q}{\partial z})$$

← Downgradient flux

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

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

Shear (↑ dU/dz) Bouyancy (↑ $d\theta/dz$)

In LMDZ : TKE computed with Mellor and Yamada scheme

Turbulent diffusion

Turbulent diffusion : numerics

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

$$\begin{cases} \dfrac{dq}{dt} = -\partial_z \phi_q \\ \phi_q = -K_z \partial_z q \\ \phi_q|_{\mathrm{srf}} = -\mathrm{Evap} \end{cases} \qquad \begin{cases} \dfrac{dH}{dt} = -\partial_z \phi_\theta \\ \phi_\theta = -K_z \partial_z H \\ \phi_\theta|_{\mathrm{srf}} = \phi_{\mathrm{sens}} (\dfrac{p_0}{p_{\mathrm{srf}}})^\kappa \end{cases} \quad (3)$$

(Fluxes positive downward)

Spatial discretization : (moisture)

$$\begin{cases} m_i \partial_t q_i = \phi_{q,i+1} - \phi_{q,i} \\ \phi_{q,i} = K_i (q_i - q_{i-1}) \\ \phi_{q,1} = -\mathrm{Evap} \end{cases} \quad (4)$$

Implicit scheme, yields for the first atmospheric layer :

$$q_{1,t+\delta t} = A + B\phi_{q,1}\delta t$$
$$\phi_{q,1} = K_1 (q_{1,t+\delta t} - q_{\mathrm{srf}}) \quad (5)$$

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

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

$H = C_p T + gz$ = Dry static energy , here conserved

Water (left) and energy (right) conservation Diffusion

(dowgradient flux)

Surface fluxes

Turbulent diffusion is the only one parameterization which « see » the surface

First atmospheric layer

Turbulent diffusion

Turbulent diffusion : numerics

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

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

Spatial discretization : (moisture)

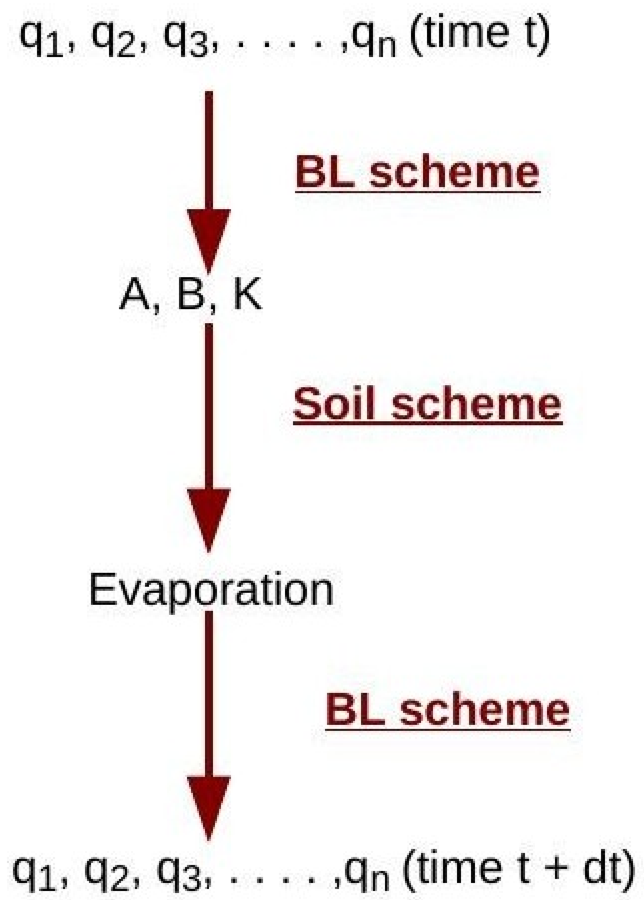
$$\left\{\begin{array}{ll} m_i \partial_t q_i & = \phi_{q,i+1} - \phi_{q,i} \\ \phi_{q,i} & = K_i(q_i - q_{i-1}) \\ \phi_{q,1} & = -{\rm Evap} \end{array}\right. \qquad (4)$$

Implicit scheme, yields for the first atmospheric layer :

$$\begin{array}{rl} q_{1,t+\delta t} & = A + B\phi_{q,1}\delta t \\ \phi_{q,1} & = K_1(q_{1,t+\delta t} - q_{\rm srf}) \end{array} \qquad (5)$$

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

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



ELIMINE

Boundary layer convection : practice

Thermals and dry adjustment

Subroutine : calltherm

Tendencies :

dtthe, dqthe,duthe, dvthe

Other variables

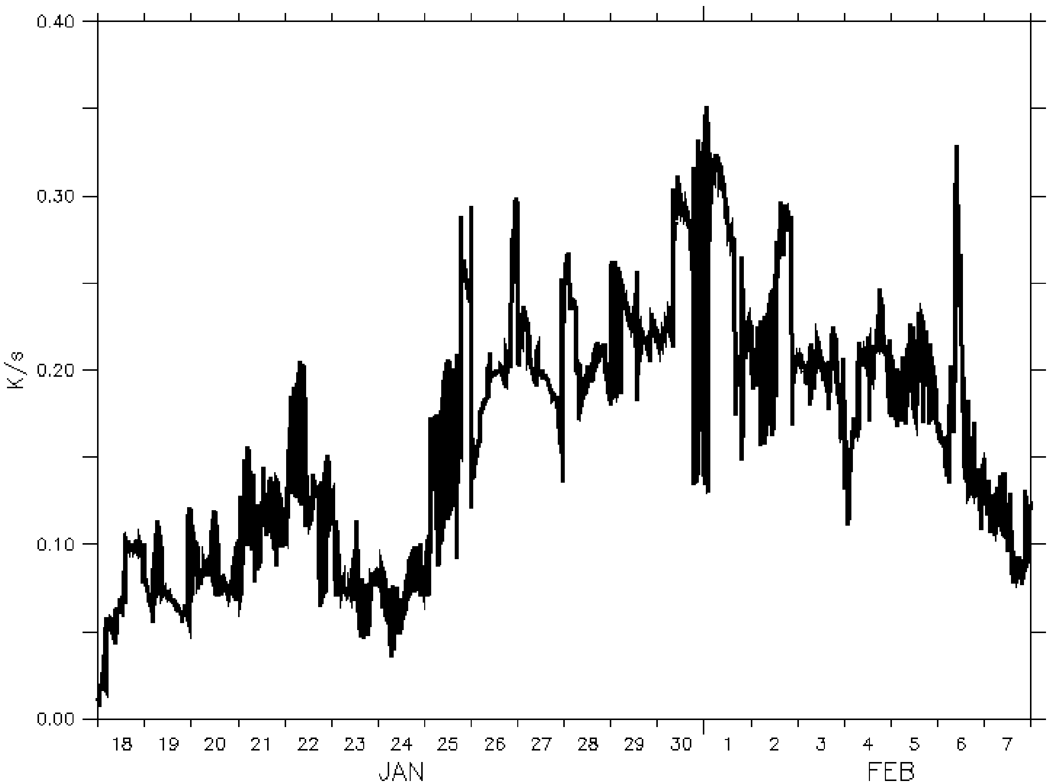
- dtajs : temperature tendency due to the sole dry adjustment
- dqajs : humidity tendency due to the sole dry adjustment
- a_th : fractional area of thermal plumes
- d_th : detrainment
- e_th : entrainment
- f_th : mass flux
- w_th : vertical velocity in the thermal plume (m/s, positive upward)
- q_th : total water content in the thermal plume
- zmax_th : altitude of the top of the thermal plume (m)
- f0_th : Thermal closure mass flux (kg/m².s)

ferret

- **use histhf.nc**
- **plot/thick=3/x=…/y=… f0_th**

TWPICE case →

f0_th



Thermal closure mass flux (K/s) kg/(m².s)

Parameterization = source terms

Atmospheric GCM equations

Primitive equations in pressure coordinates

Momentum equation :

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

transport Coriolis gravity

Continuity equation :

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

Component conservation :

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

Thermodynamic equation :

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

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**

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