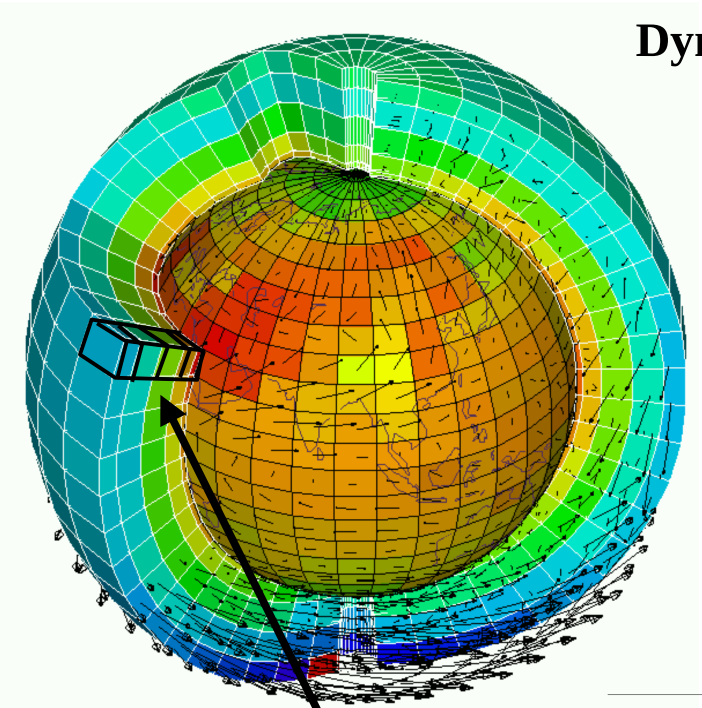
The physical parametrizations in LMDZ

LMDZ Team

Laboratoire de Météorologie Dynamique

December 2021



Dynamical core : primitive equations discretized on the sphere

- Mass conservation

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

- Potential temperature conservation

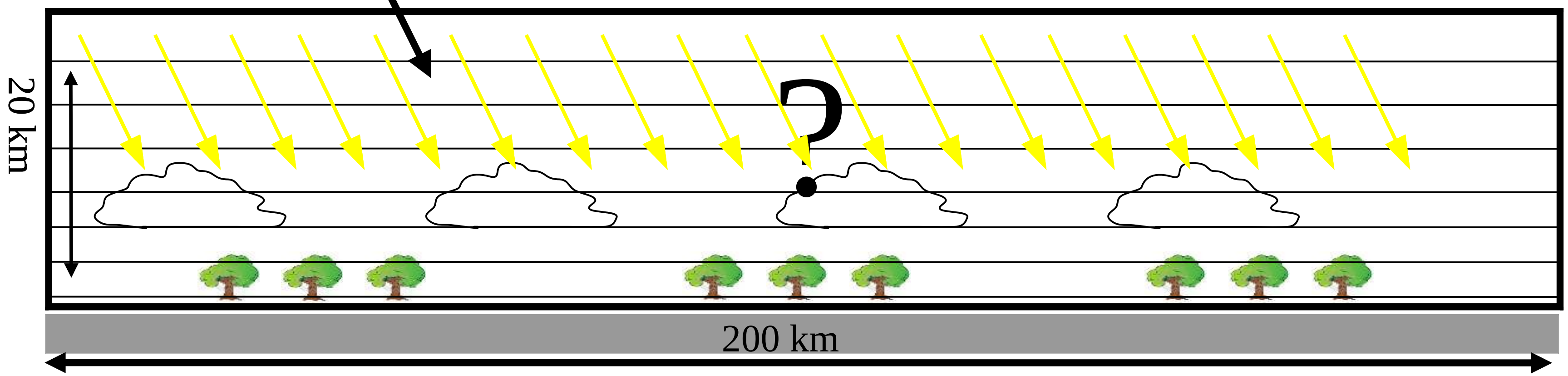
  $D\theta \, / Dt = Q \, / \, Cp \; (p_0/p)^{\kappa}$

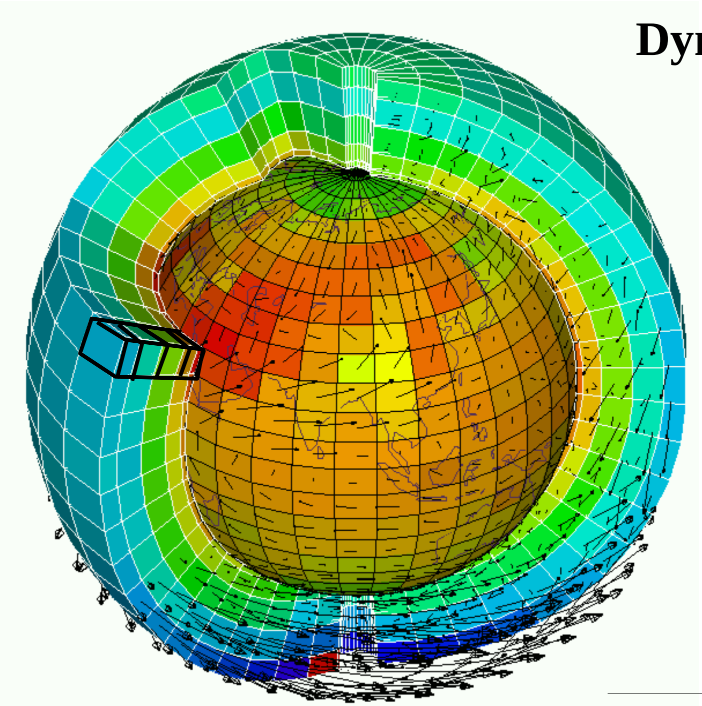
- Momentum conservation

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

- Secondary components conservation

  $Dq/Dt = Sq$





Dynamical core : primitive equations discretized on the sphere

- Mass conservation

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

- Potential temperature conservation

  $D\theta\ / Dt = Q\ / Cp\ \ (p_0/p)^{\kappa}$

- 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

  $Dq/Dt = Sq$

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)**
- $\underline{F}$: 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 :

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

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

From model outputs

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*

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*

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

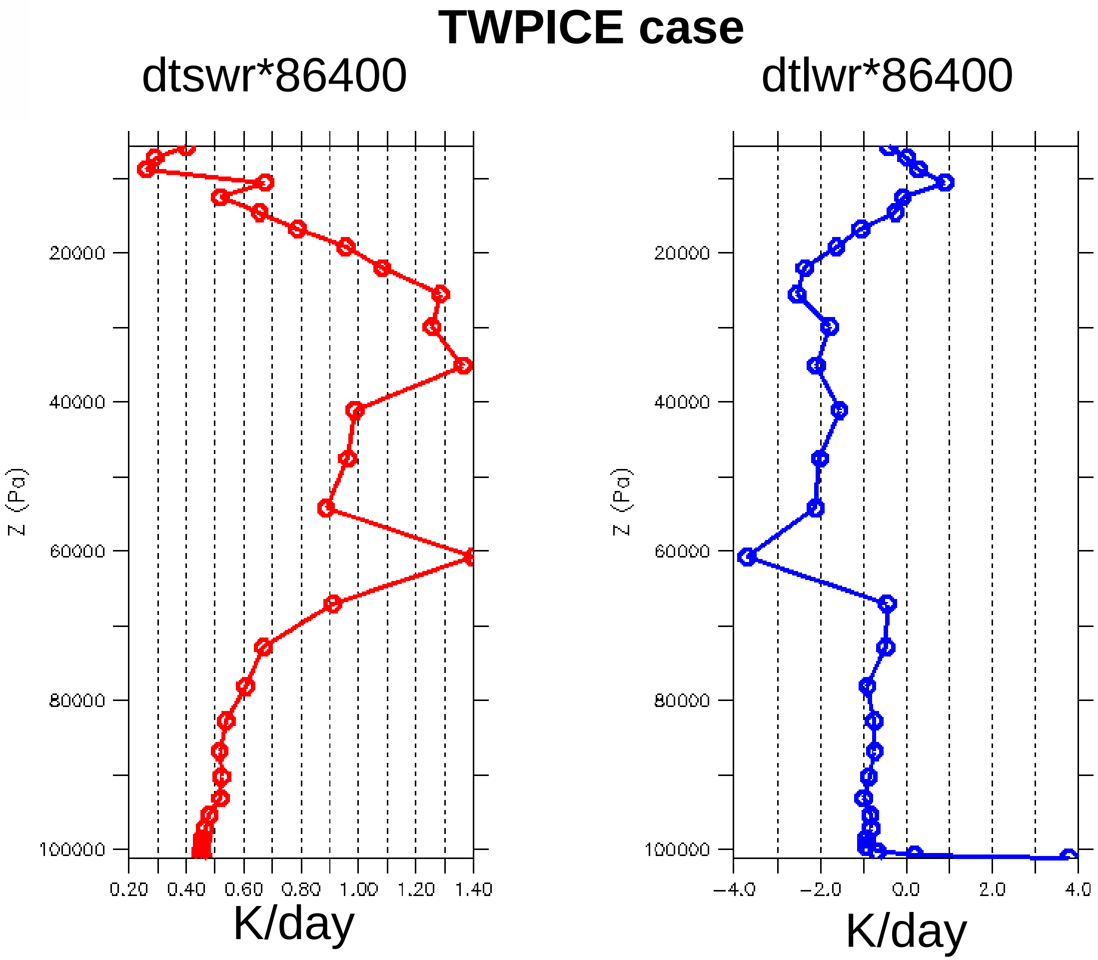
New variables :

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

Today : Parameterization of subrid-scale motions

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

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

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

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

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

Today : Parameterization of subrid-scale motions

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

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"

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

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

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

$$Dq/Dt = Sq \qquad \frac{\partial c}{\partial t} + \mathbf{v.grad}\, c = -\frac{1}{\rho} \mathrm{div}\,(\rho \overline{\mathbf{v}' c'}) = -\frac{1}{\rho} \frac{\partial \overline{\rho w' c'}}{\partial z}$$

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 $\leftrightarrow$ 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)

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

- 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

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

In physiq.def (deepL translation)

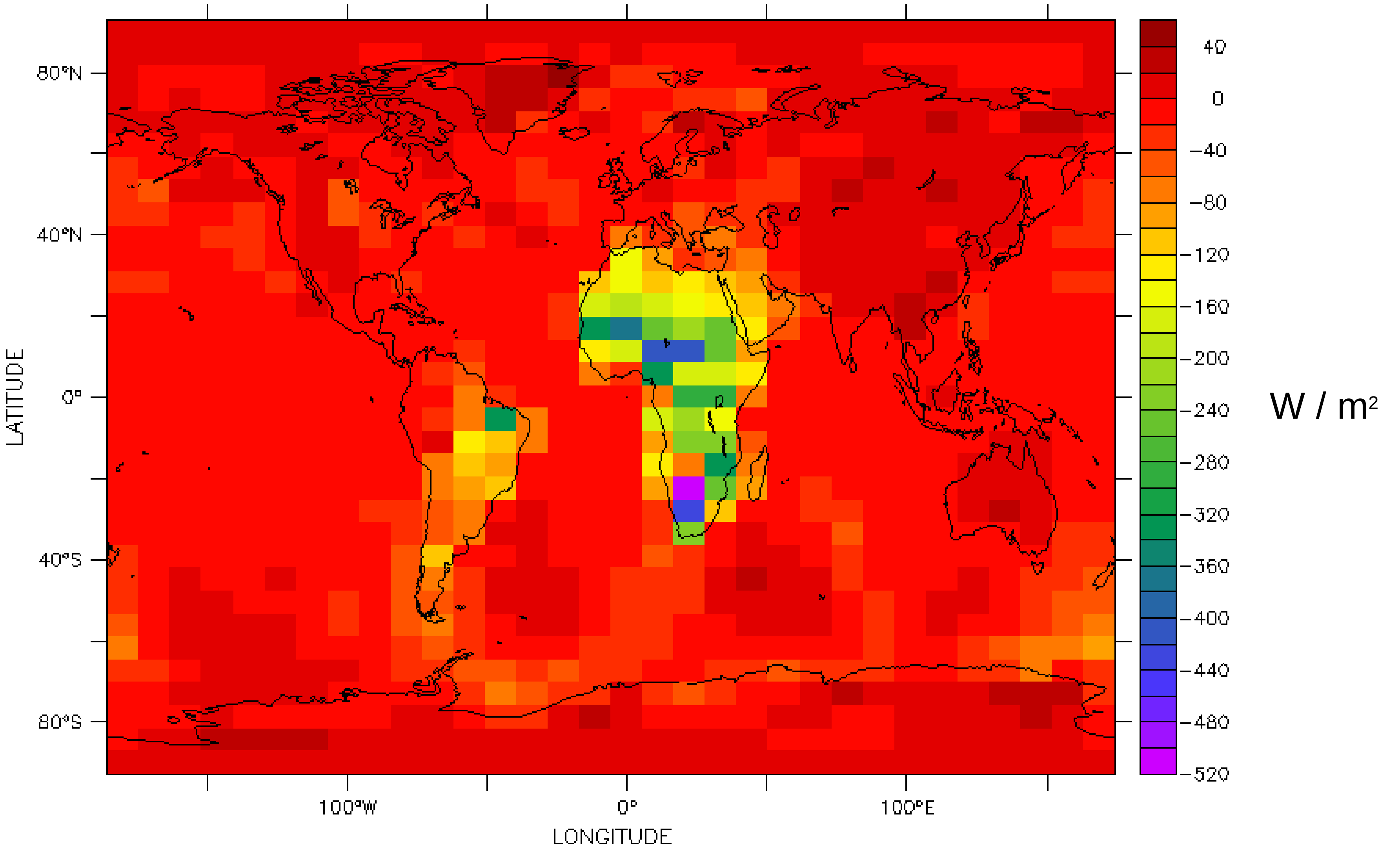
```
        # New version of Mellor and Yamada
new_yamada4=y

        # 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**

<u>Sensible heat flux at 12h GMT on January 2nd</u>



Turbulent diffusion : practice

Vertical diffusion

Subroutine : pbl_surface

Tendencies :

dtvdf, dqvdf, duvdf, dvvdf

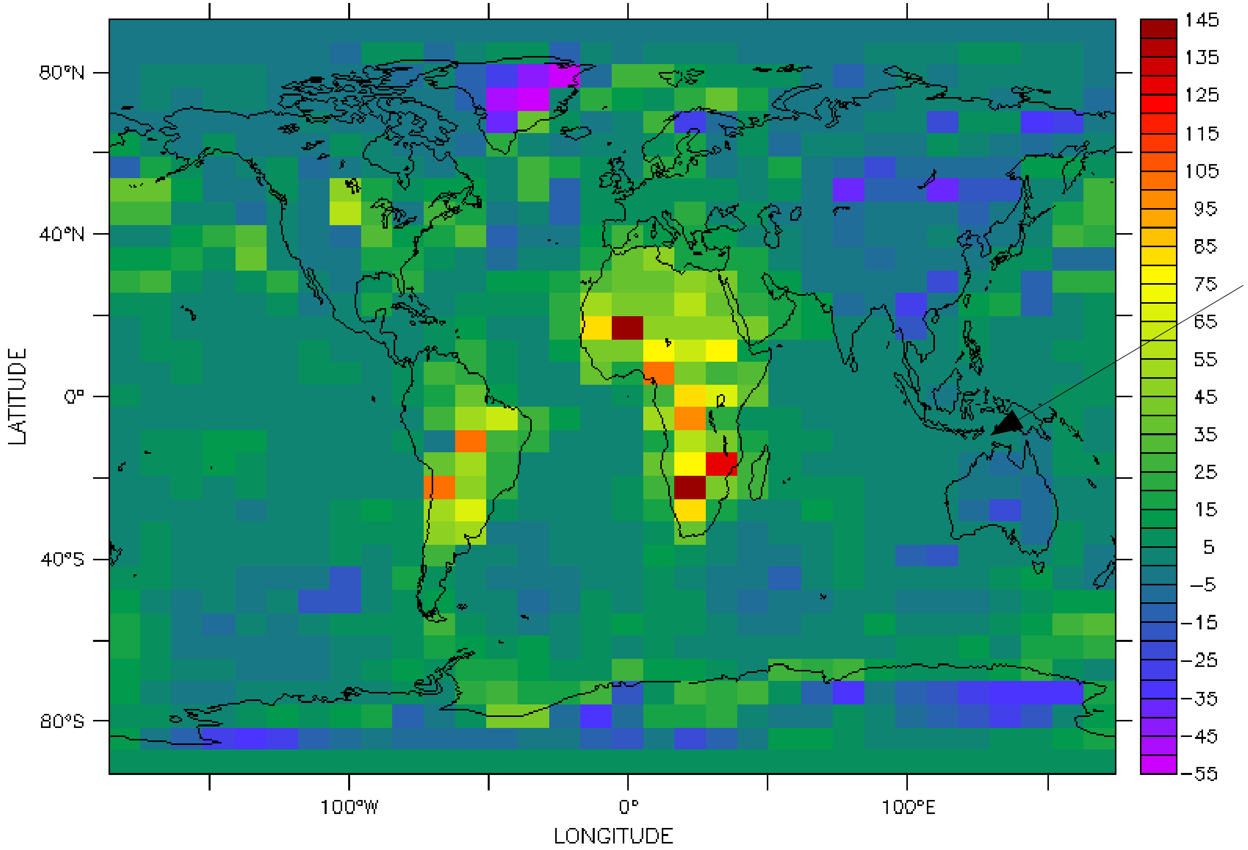
Other variables

- 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

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

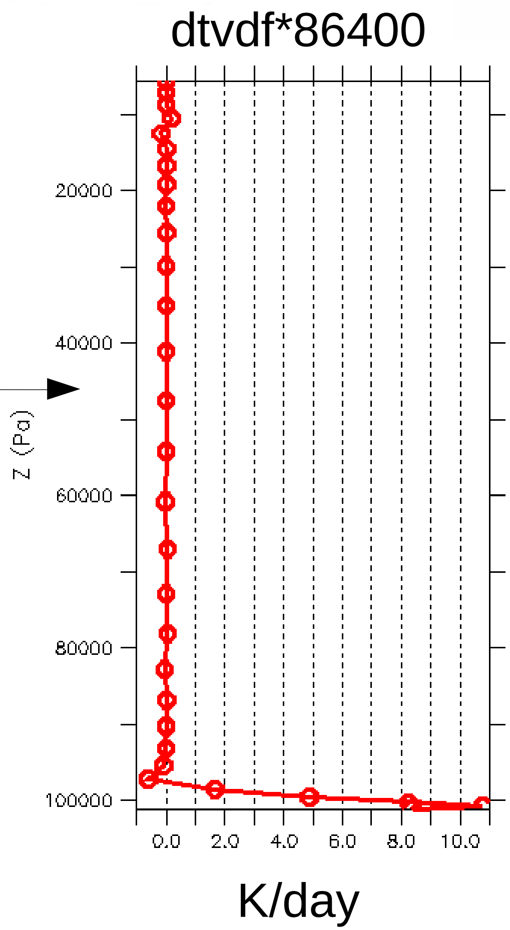
ferret

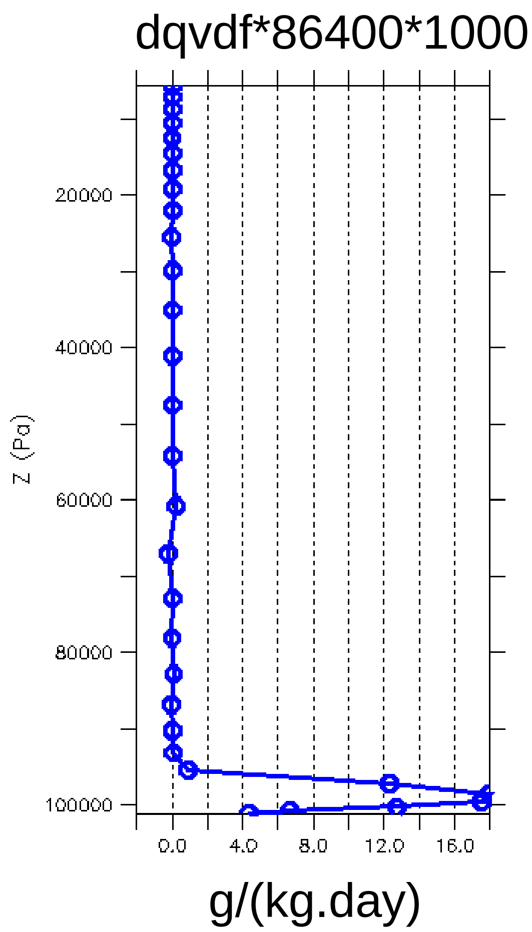
use histhf.nc

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

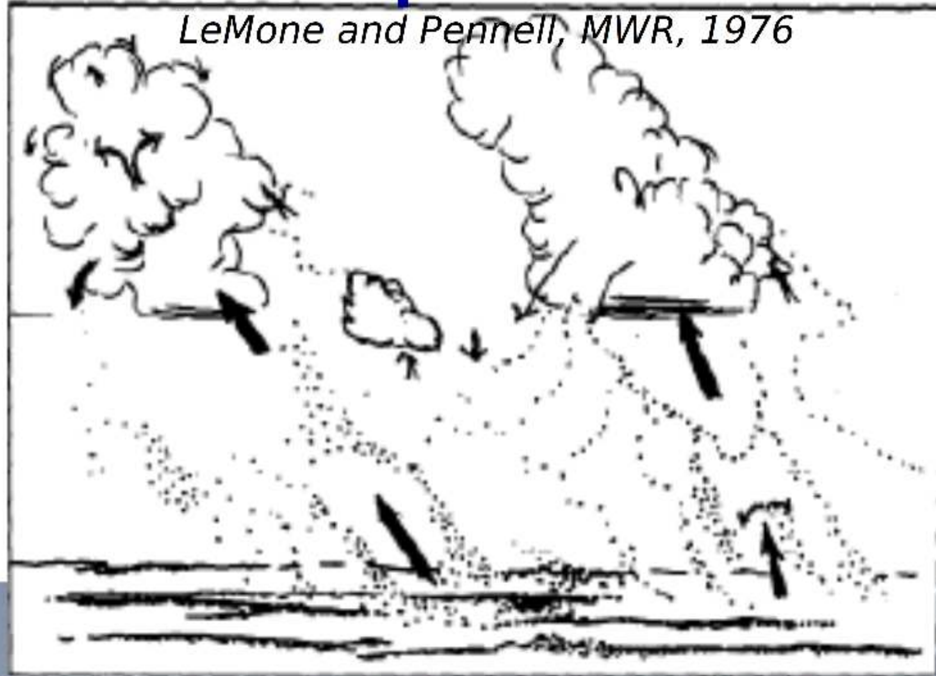
plot/l=48/thick=3/x=…/y=.../k=10:39 dqvdf*86400*1000

TWPICE case





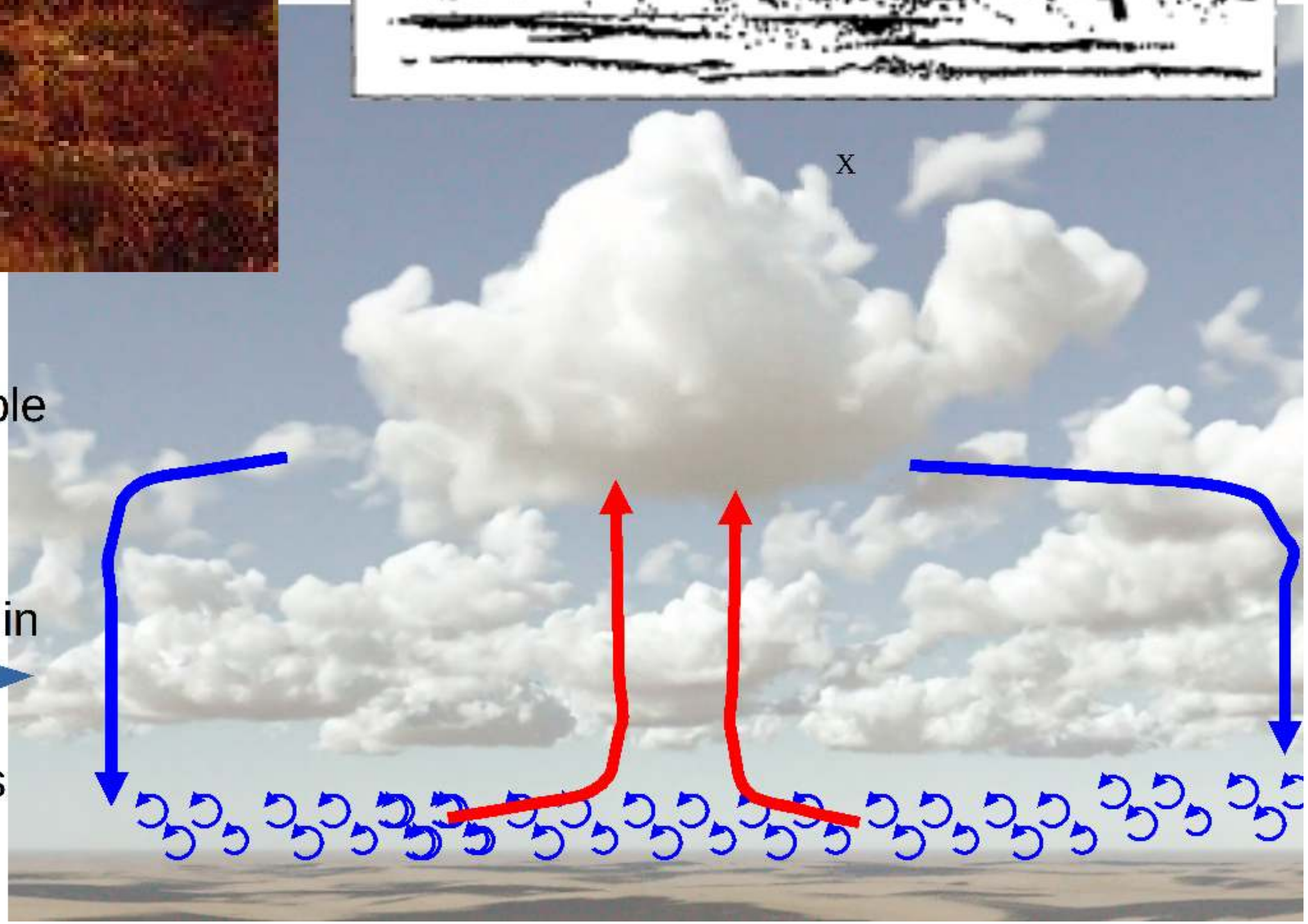
he « thermal plume model »



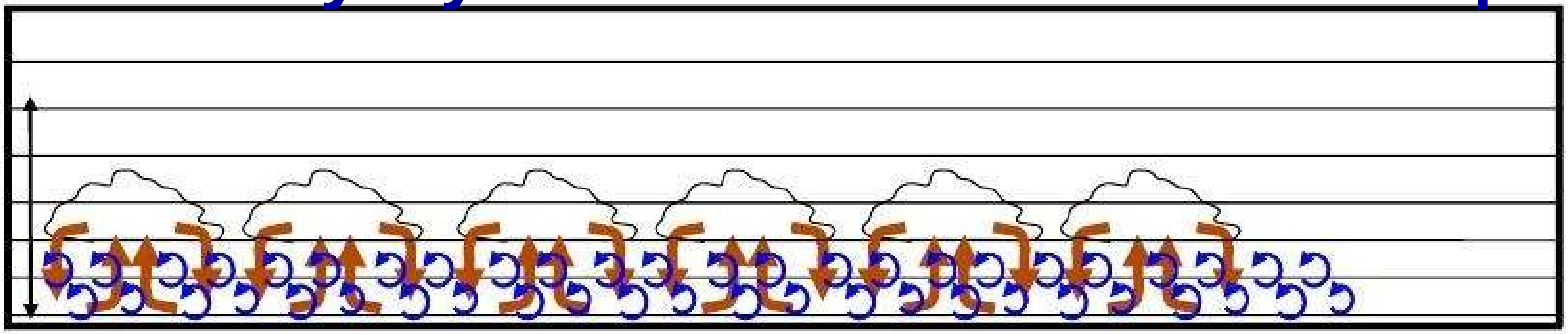
LeMone and Pennell, MWR, 1976

Organised turbulence/convection

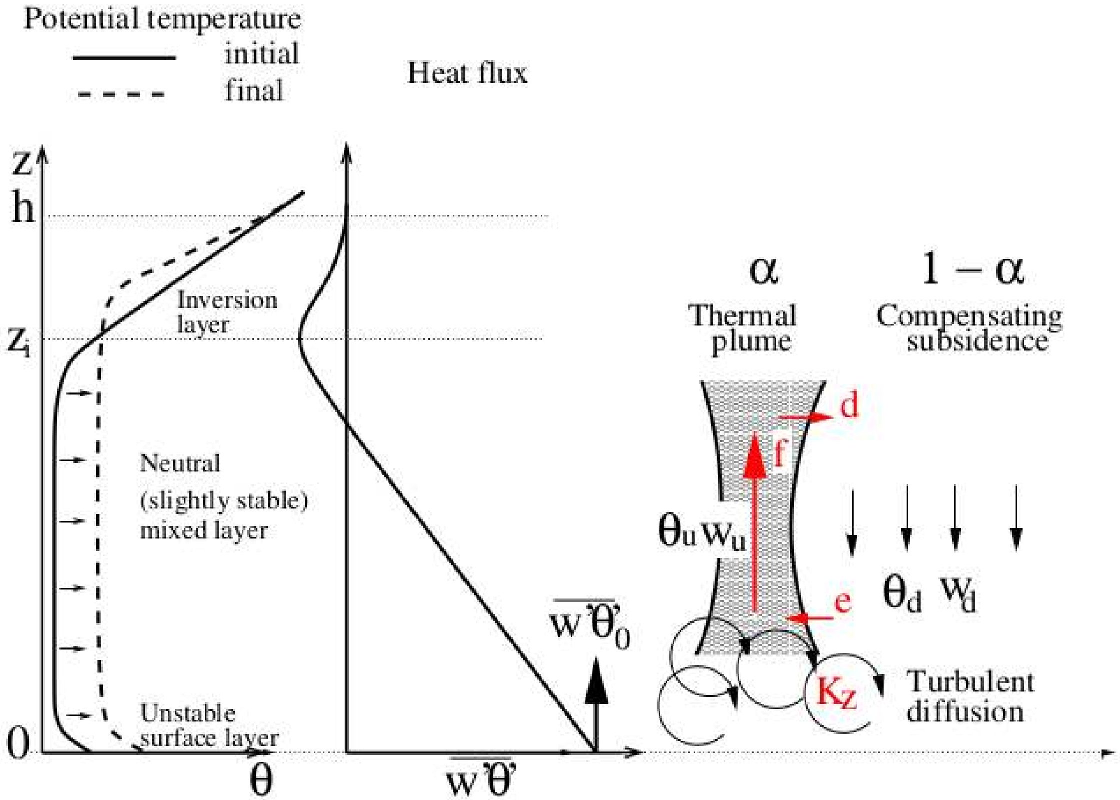
- When the boundary layer is unstable (upward > 0 sensible heat flux)
- Still in the « boundary layer »
- Above the « surface layer »
- Often dominates vertical transport in the « mixed layer »
- Often asscociated with cumulus
- Represented in explicit simulations (LES). Here at 8m resolution



Boundary layer convection : the « thermal plume model »



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

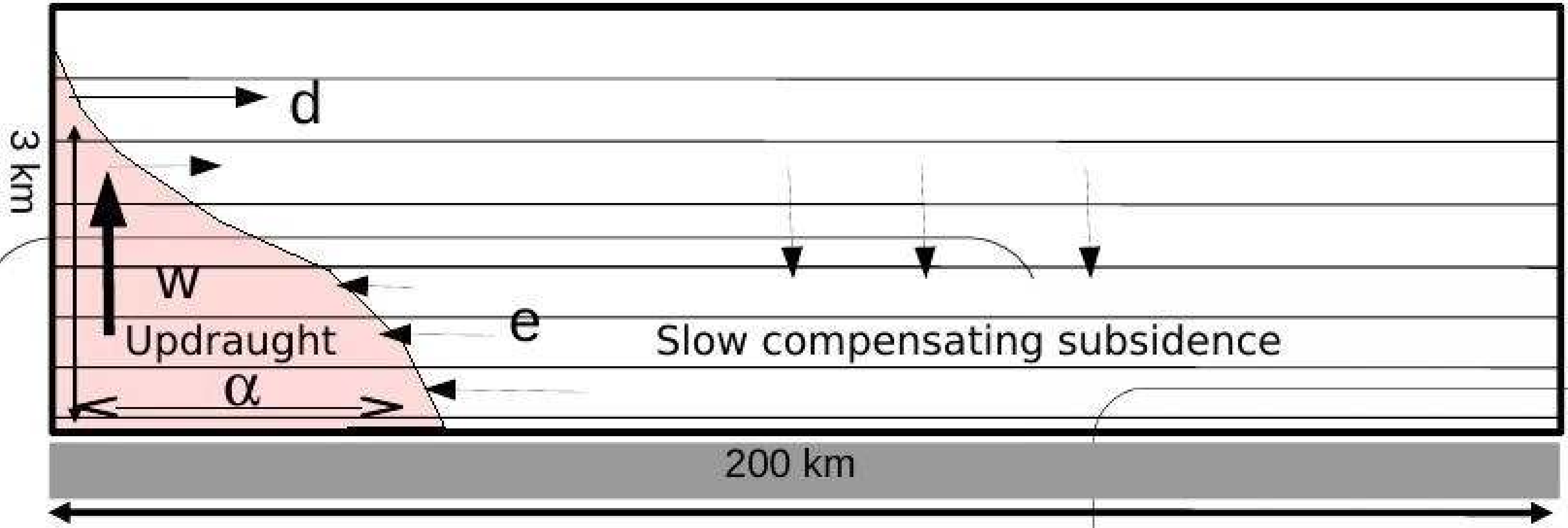
$$f = \alpha \rho w_u$$

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

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

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

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 :

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

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 **:**

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

$$d = ...$$

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

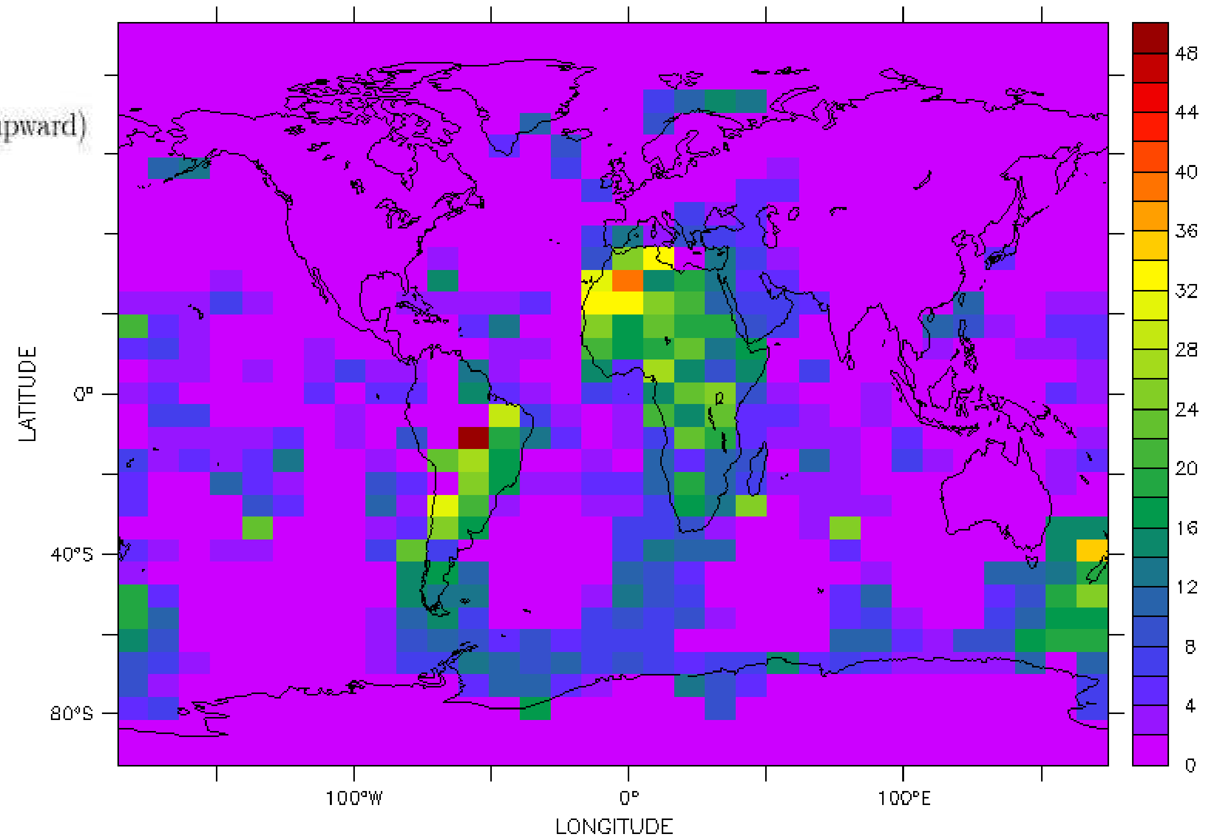
Other variables

- 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

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)

TWPICE case

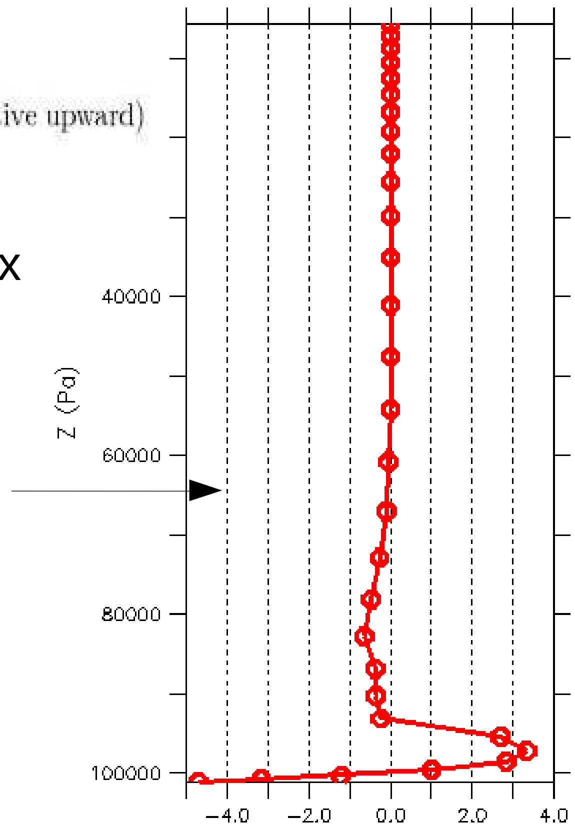
ferret

use histhf.nc

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

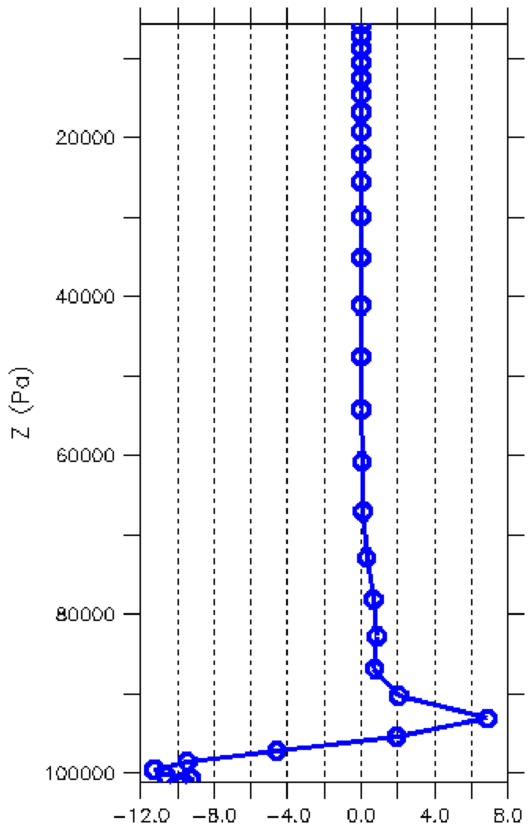
plot/l=48/thick=3/x=…/y=.../k=10:39 dqthe*86400*1000

dtthe*86400



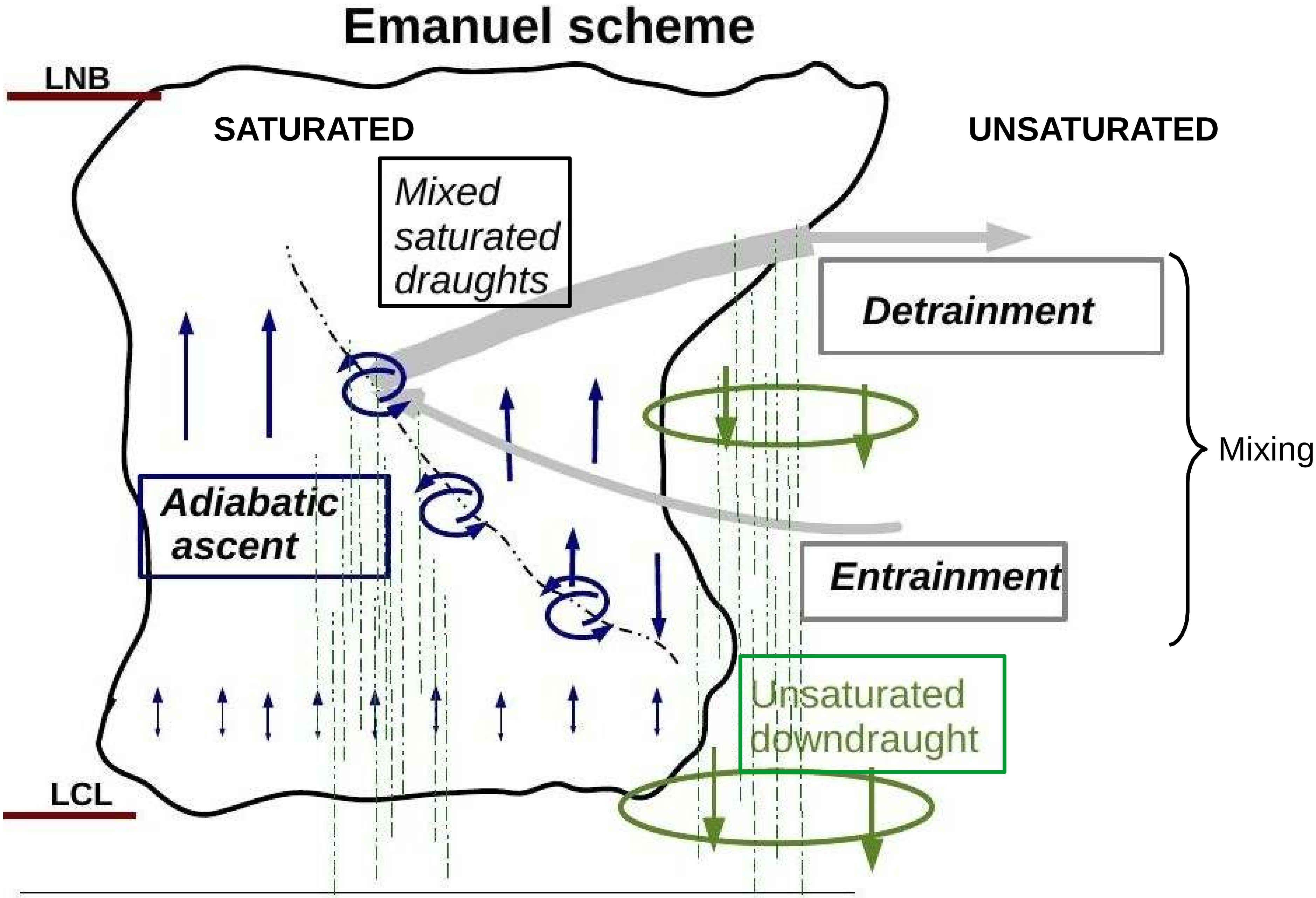
K/day

dqthe*86400*1000



g/(kg.day)

Deep convection : Emanuel scheme



Deep convection : practice

Deep convection

Subroutine : concvl

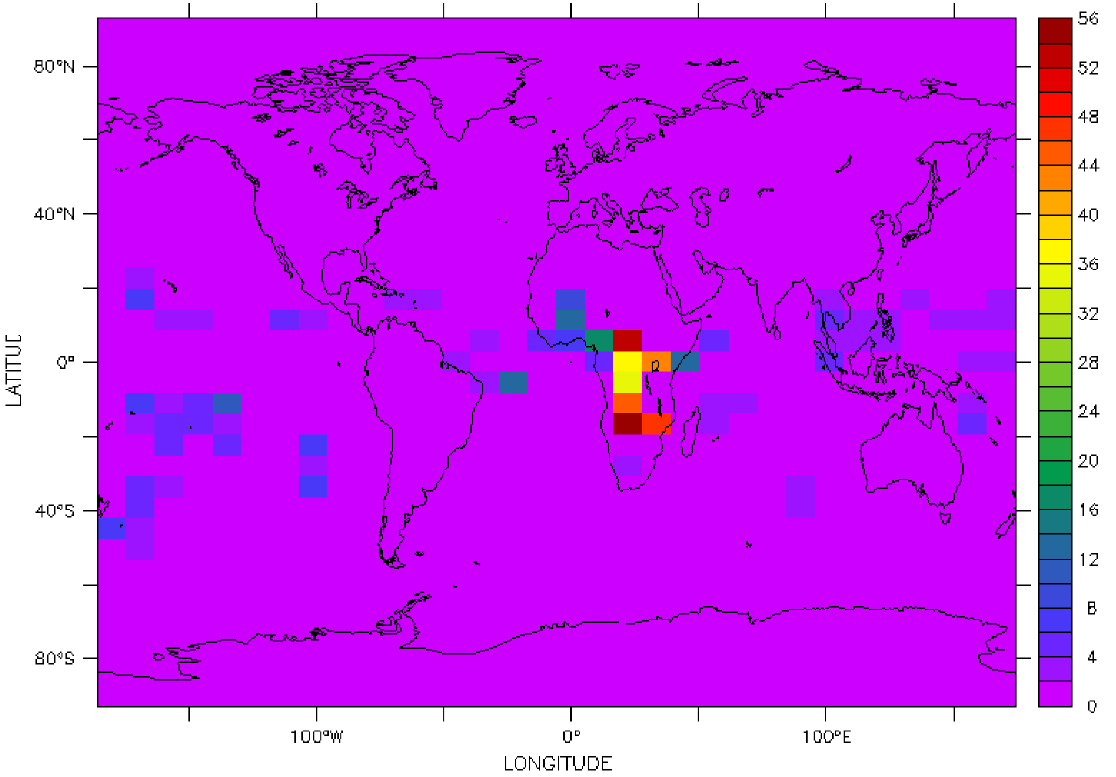
Tendencies :

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.

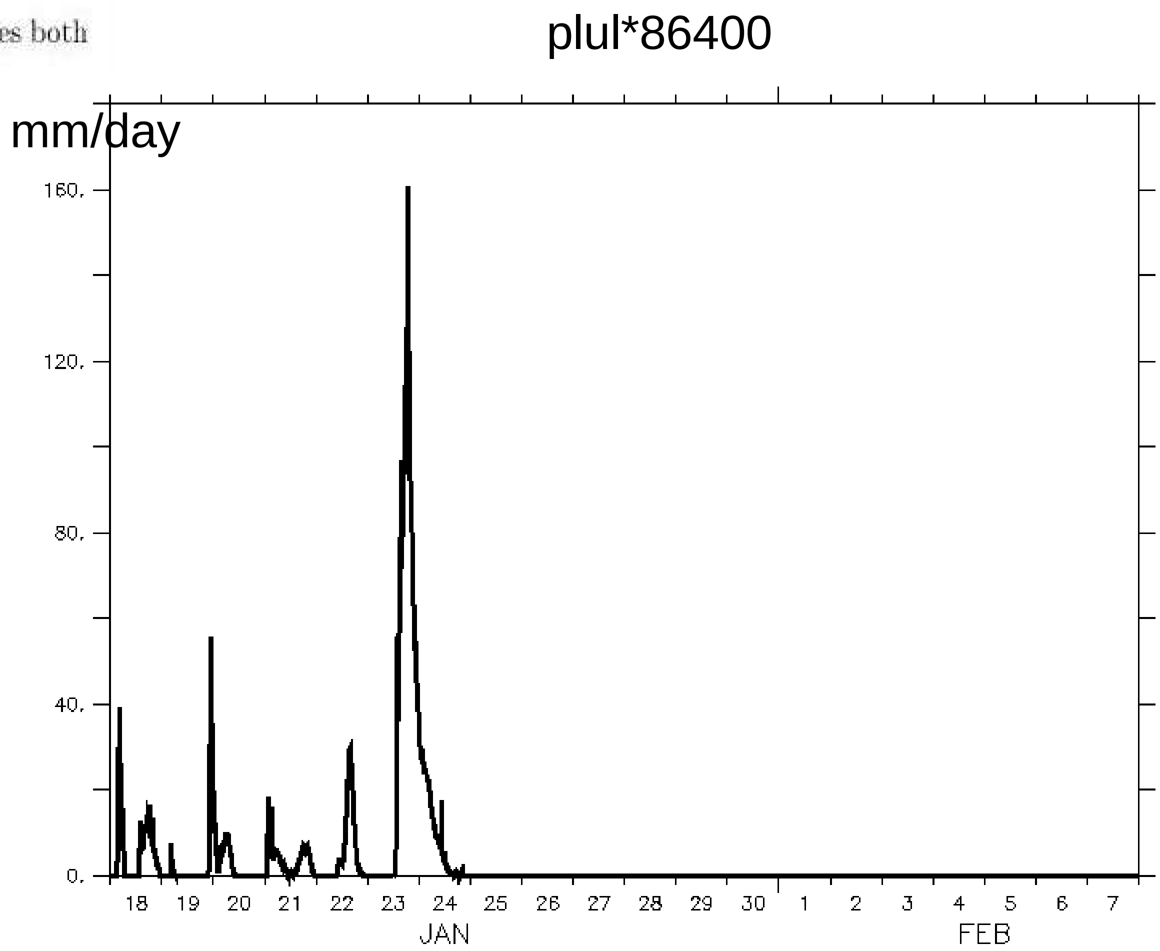
Other variables

- 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**

TWPICE case →



```
############################################################################
# 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
```

In physiq.def

Deep convection : practice

Deep convection

Subroutine : concvl

Tendencies :

dtcon, dqcon, ducon, dvcon

Other variables

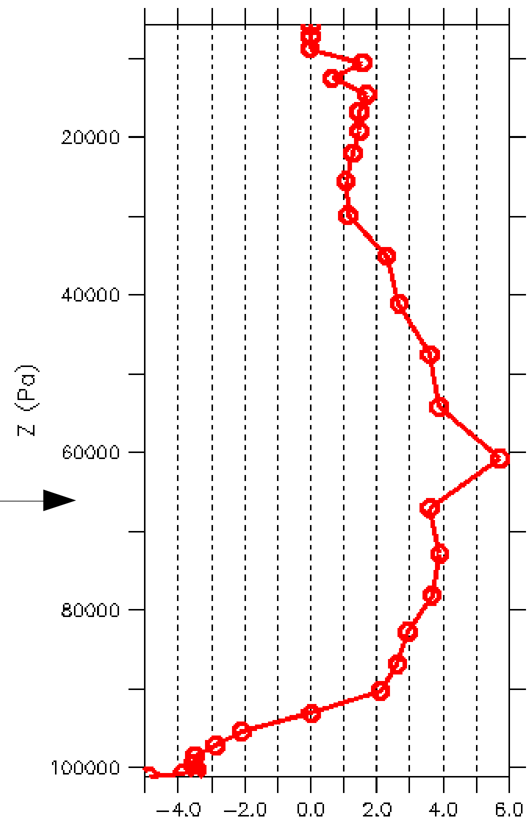
- pluc : convective precipitation at the surface
- ftd : temperature tendency due to the sole unsaturated downdraughts
- fqd : moisture tendency due to the sole unsaturated downdraughts
- clwcon : condensed water of convective clouds ("in cloud" condensed water content)
- Ma : mass flux of the adiabatic 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**

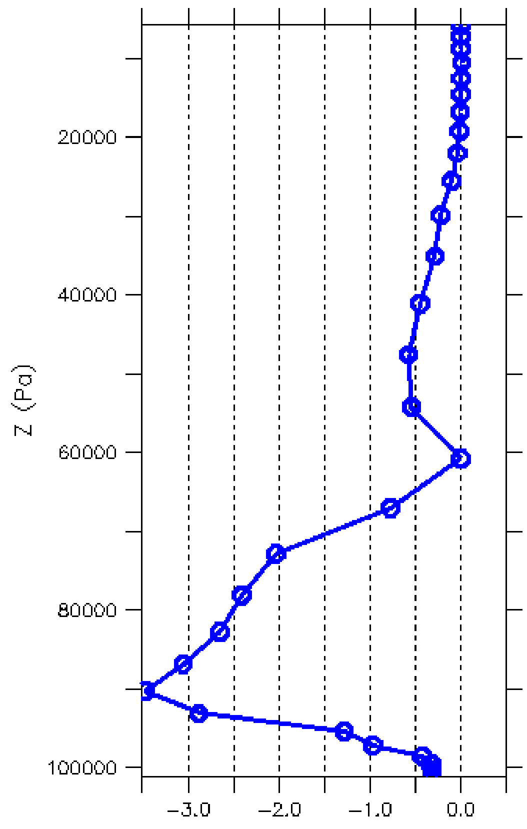
TWPICE case →

dtcon*86400



K/day

dqcon*86400*1000



g/(kg.day)

Deep convection : practice

Deep convection

Subroutine : concvl

Tendencies :

dtcon, dqcon, ducon, dvcon

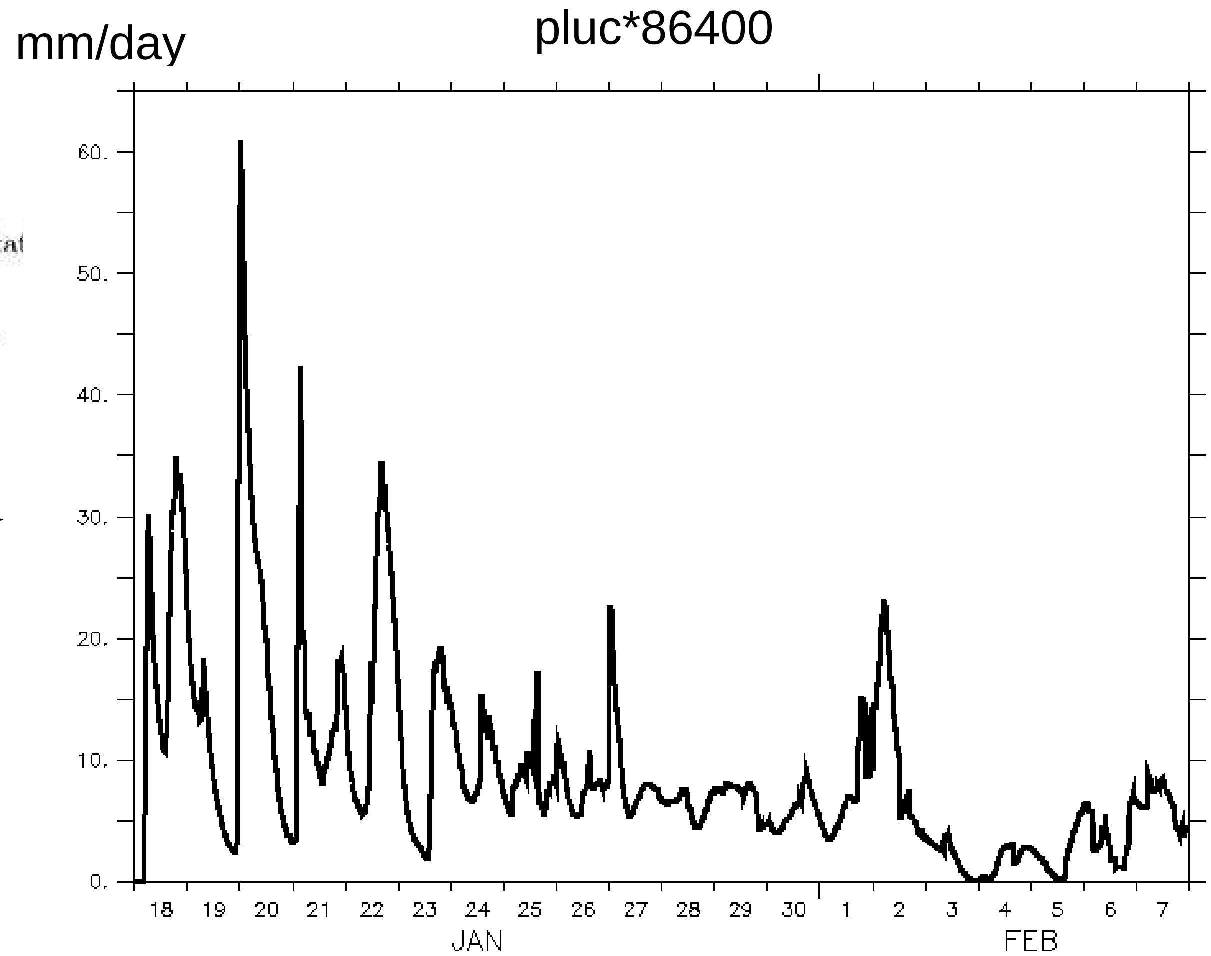
Other variables

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

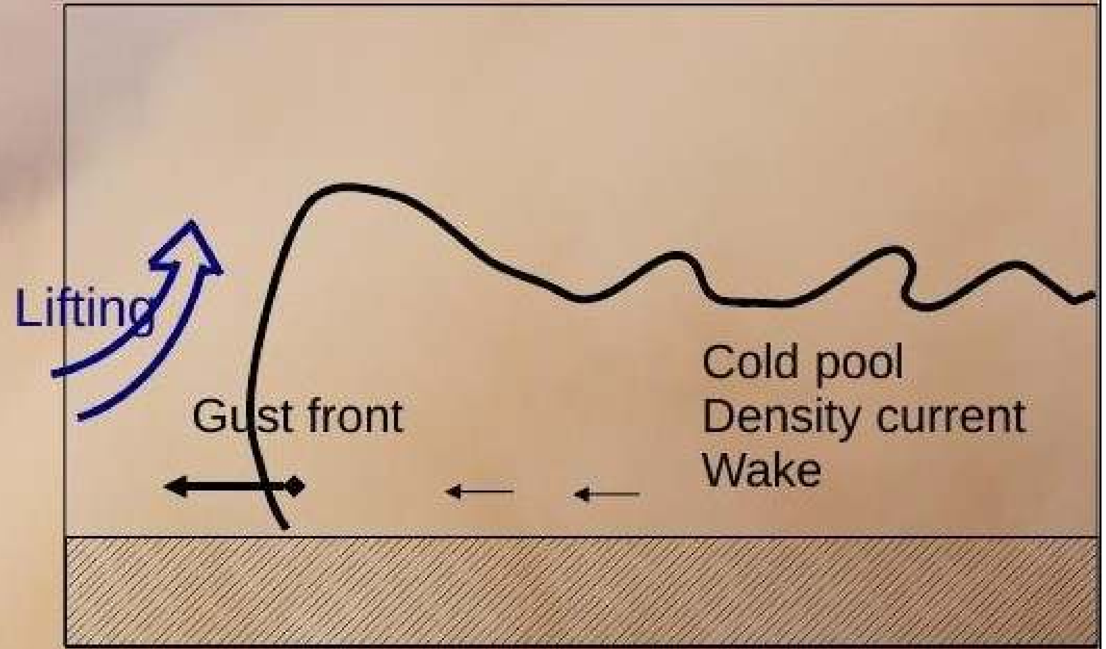
ferret

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

TWPICE case →

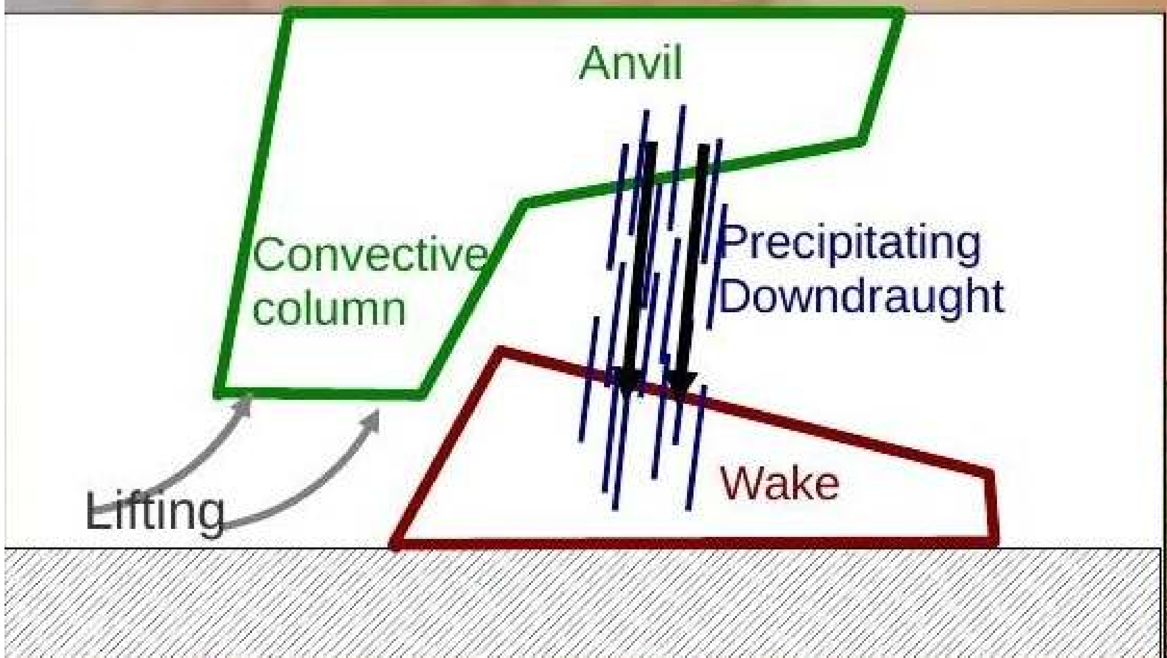


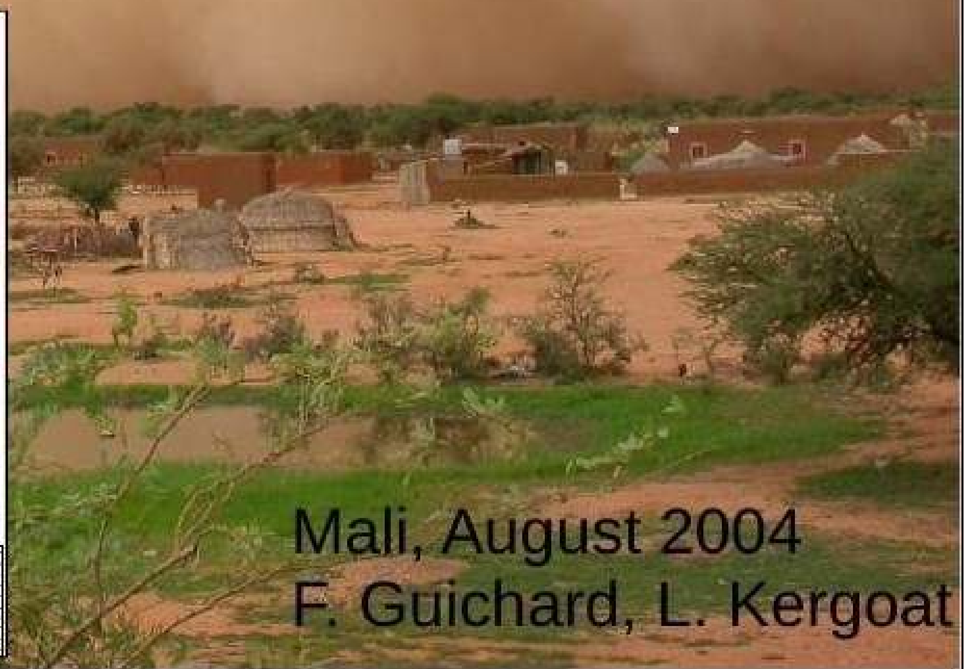
Density currents / cold pools / wakes



Created by reevaporation of convective rainfall

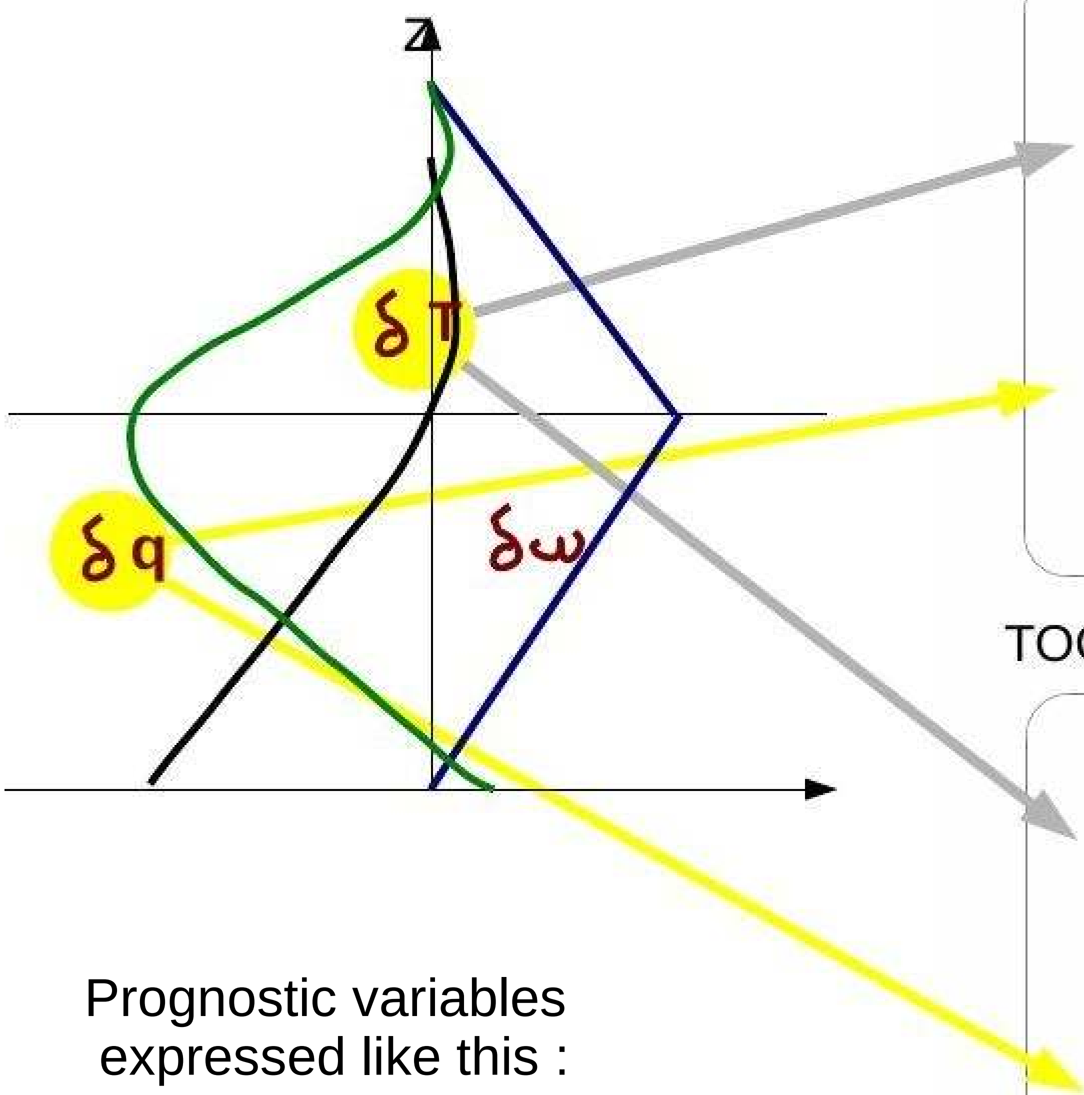
Trigger new convecttive cells by lfiting air



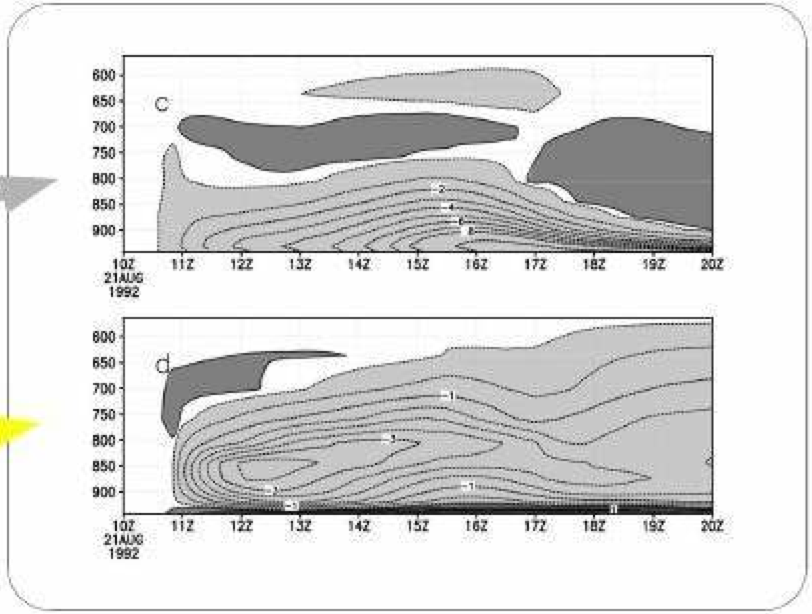


Density currents / cold pools / wakes

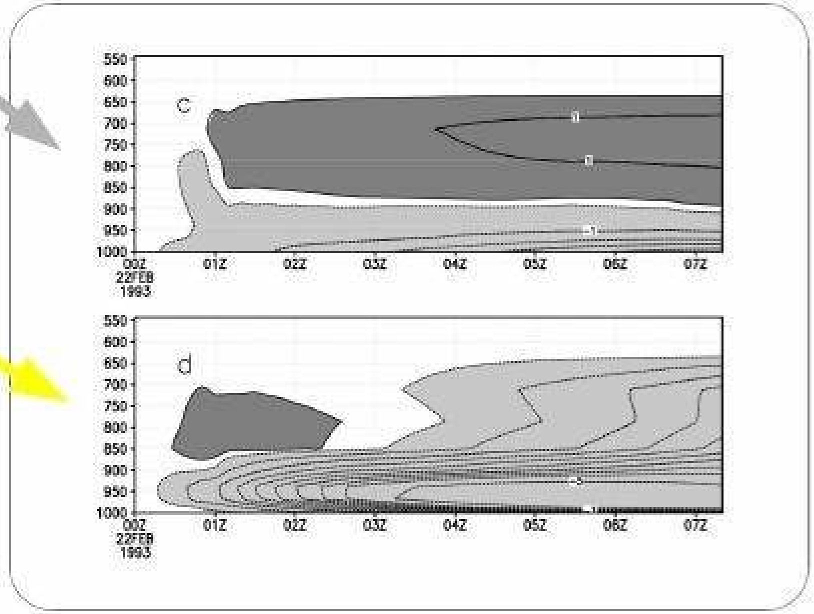
Simulated wake properties



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

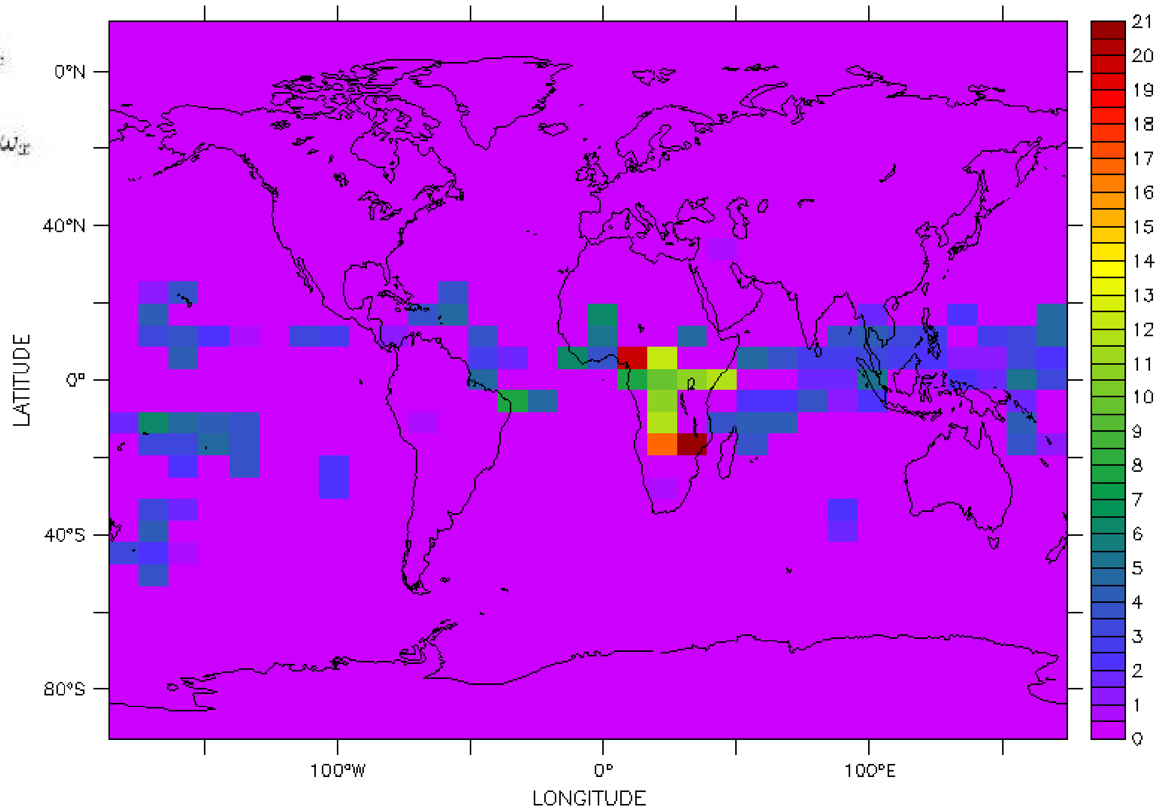
Other variables

- 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 »



DTWAK[K=@MAX]*86400

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 $\omega_w - \omega_x$

wk for « wakes »

TWPICE case →

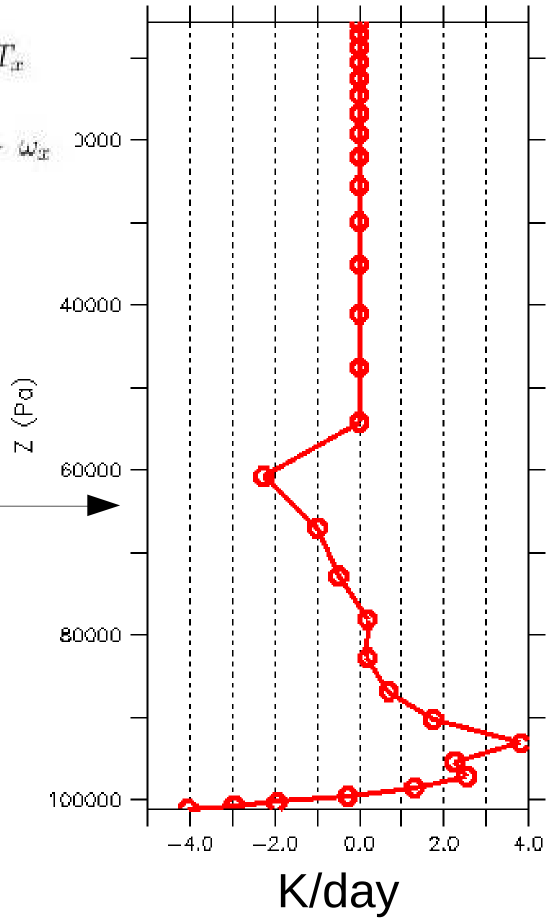
ferret

use histhf.nc

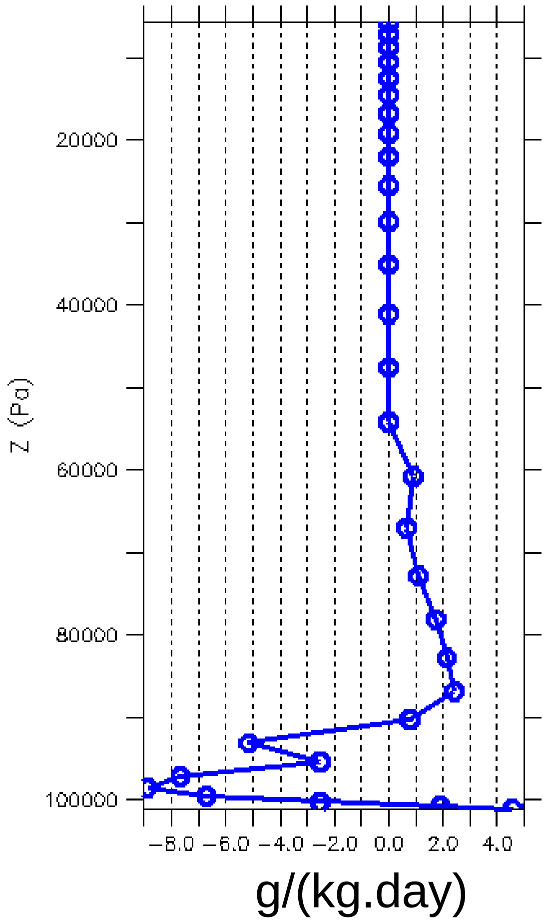
plot/l=48/thick=3/x=…/y=…/k=10:39 dtwak*86400

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

dtwak*86400



dqwak*86400*1000



Density currents : practice

Cold pools (wakes)

Subroutine : calwake

Tendencies :

dtwak, dqwak

Other variables

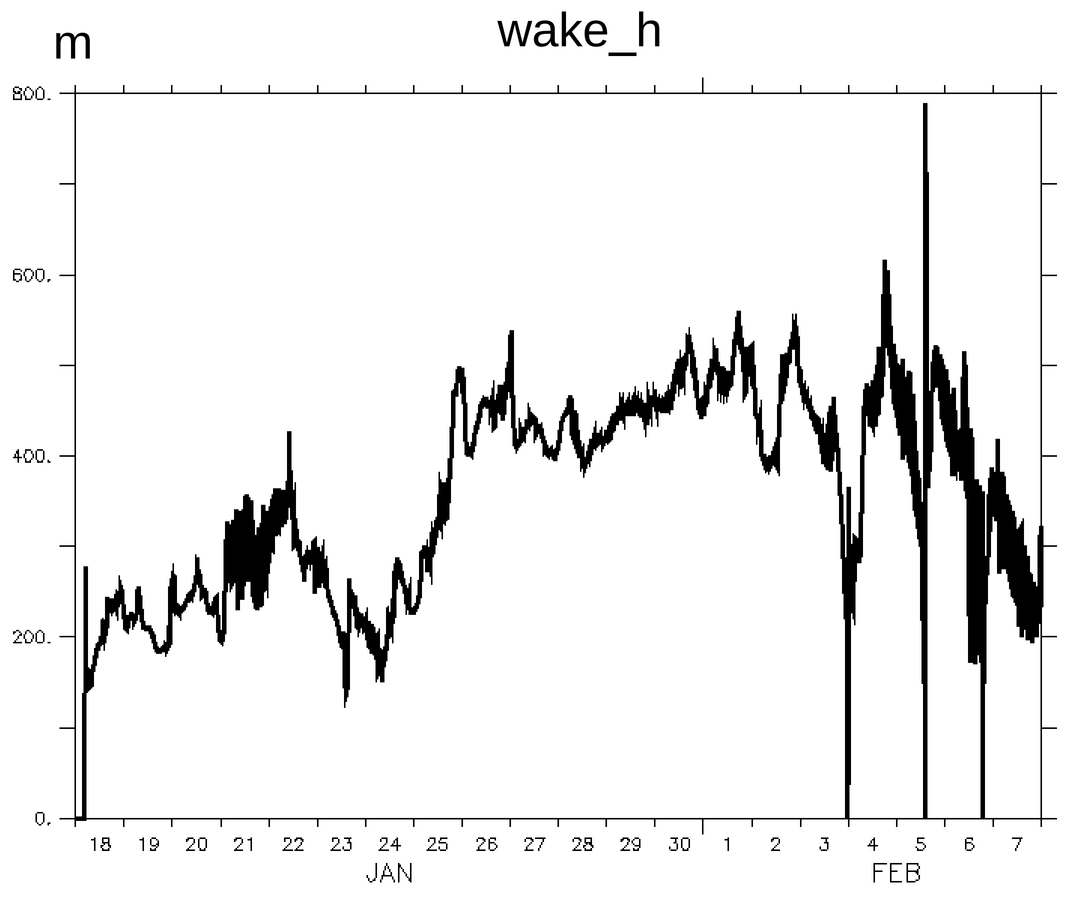
- Alp_wk : lifting power due to cold pools
- Ale_wk : lifting energy due to cold pools
- wake_s : fractional area of cold pools
- wake_h : cold pool height
- wape : WAke Potential Energy
- wake_deltat : vertical profile of temperature difference $T_w - T_x$
- wake_deltaq : vertical profile of humidity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

ferret

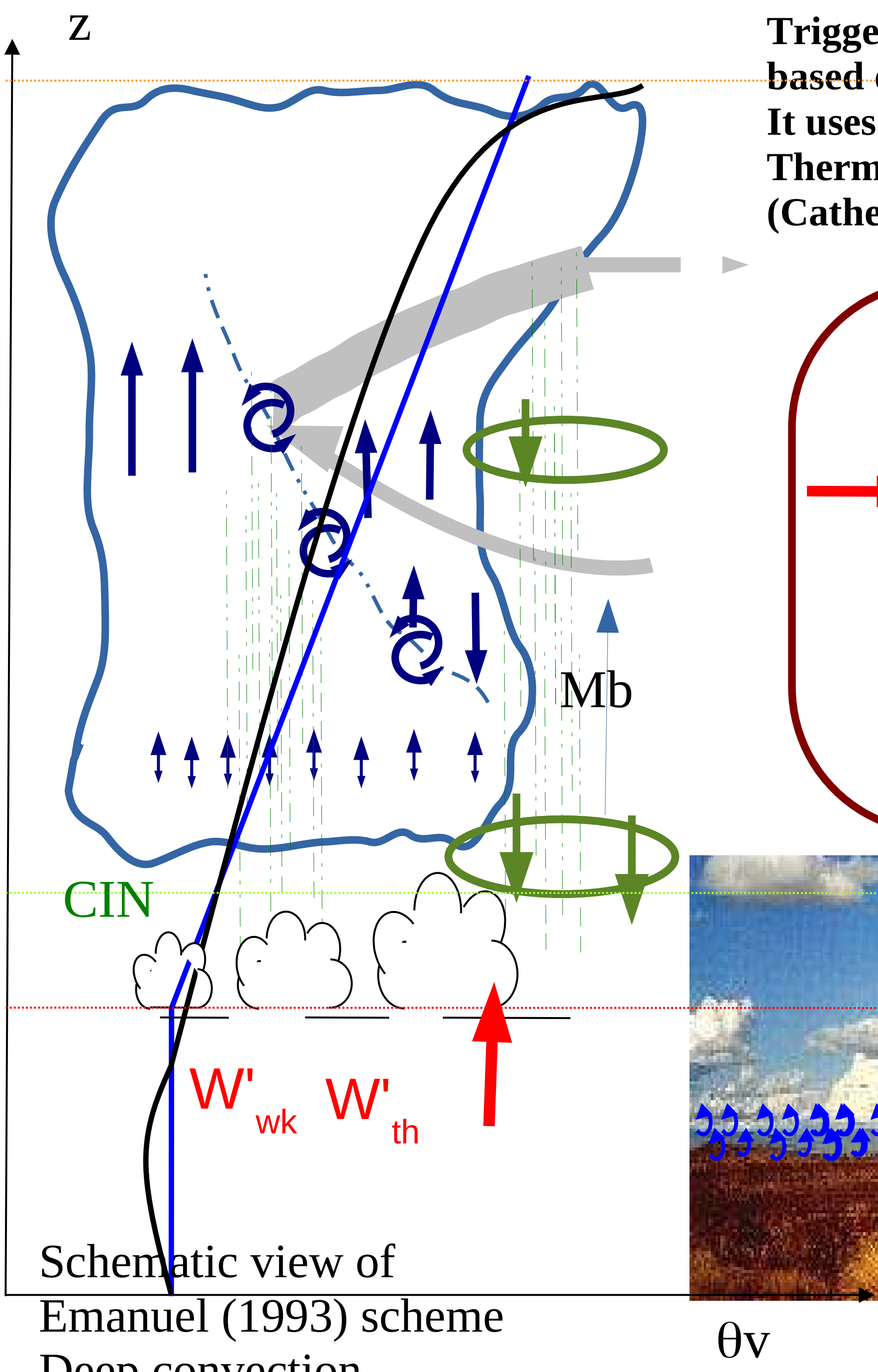
- **use histhf.nc**
- **plot/thick=3/x=…/y=… wake_h**

wk for « wakes »

TWPICE case →



What drives deep convection : triggering and closure



Schematic view of
Emanuel (1993) scheme
Deep convection

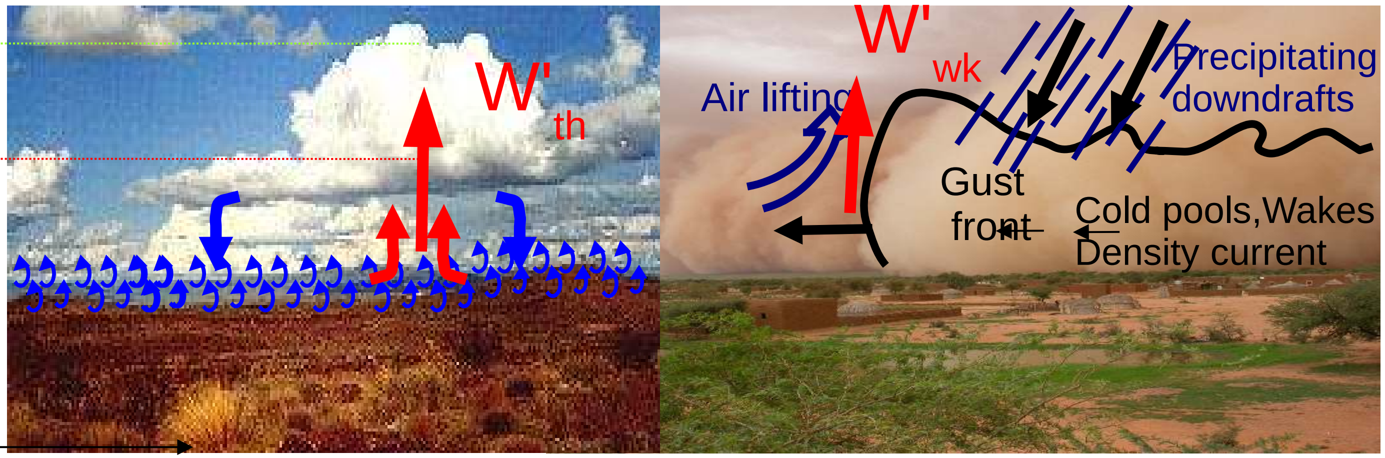
Triggering (is convection active?) and closure (with which intensity?) are based on sub cloud processes in LMDZ
It uses estimations of subgrid scale vertical velocity provided by the Thermal plume model and the cold pool scheme
(Catherine Rio''s PhD)

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

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

Available lifting power
ALP (W/m²) scaling with w'^3.

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



What drives deep convection : triggering and closure

Deep convection

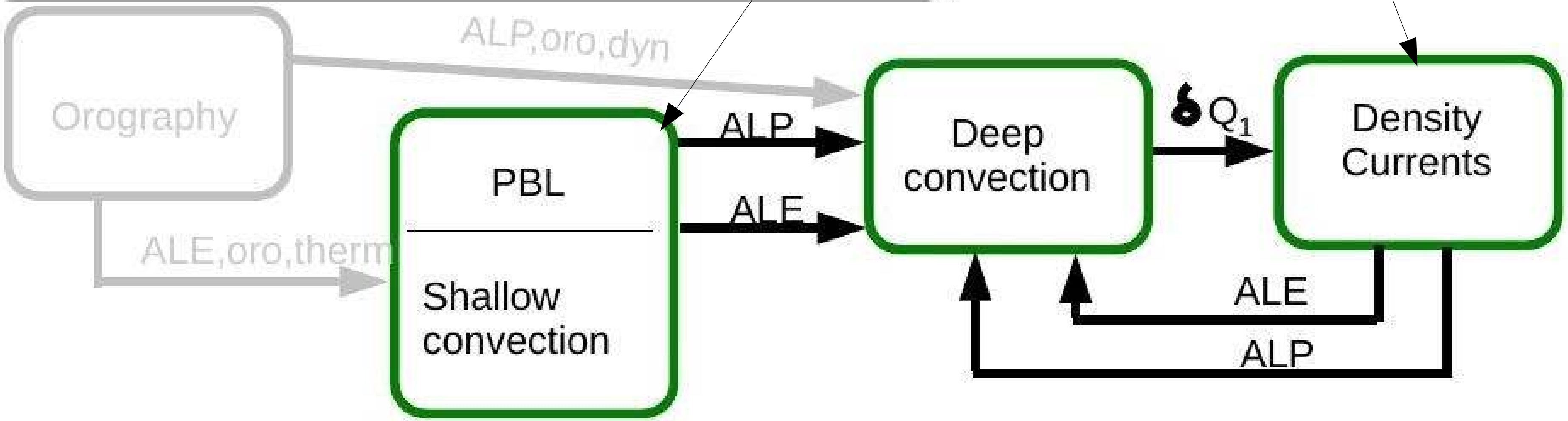
Subroutine : concvl
Tendencies :
dtcon, dqcon, ducon, dvcon
Other variables

- 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

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 !

The parameterization of subgrid scale orography in LMDZ

Mountains influence the dynamics of the atmosphere at different length scales:

- They force **gravity waves** that take angular momentum from the earth and transport it through the atmosphere over long distances

- **At large-scales** mountains contribute to the steady planetary wave, to the storm tracks, to the low-frequency variability

- F is the force exerted by an obstacle on a fluid

- **The drag** is the component of the force F that decelerates the fluid because it is opposite to the wind

- **The lift** is the component of the force that modifies the direction of the flow but does not decelerate it.

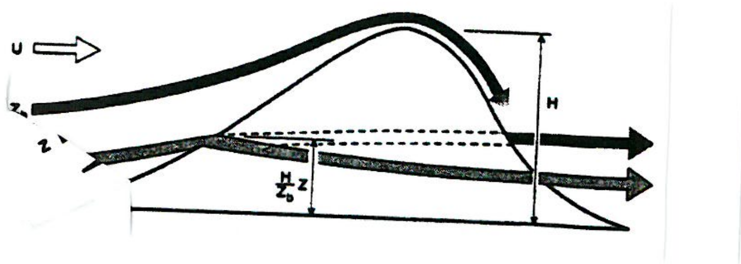
Outline

- Drag controlled by gravity waves
- Lift and forcing of the steady planetary waves

- Why are gravity waves important for stratospheric circulation?
- Why are planetary waves important for stratospheric circulation?

1. drag_noro : drag controlled by gravity waves

The Lott and Miller (1997) scheme treats the Subgrid Scale Dynamics controlled by the Gravity Waves



Non-dimensional height of the mountain: H_n = NH/U
H is the maximum height of the obstacle

- At small H_n all the flow goes aver the mountain, gravity waves are forced by the vertical motion of the fluid

Tau the surface stress due to the gravity wave :

$$\tau = \rho b G B(\gamma) N U H^2$$

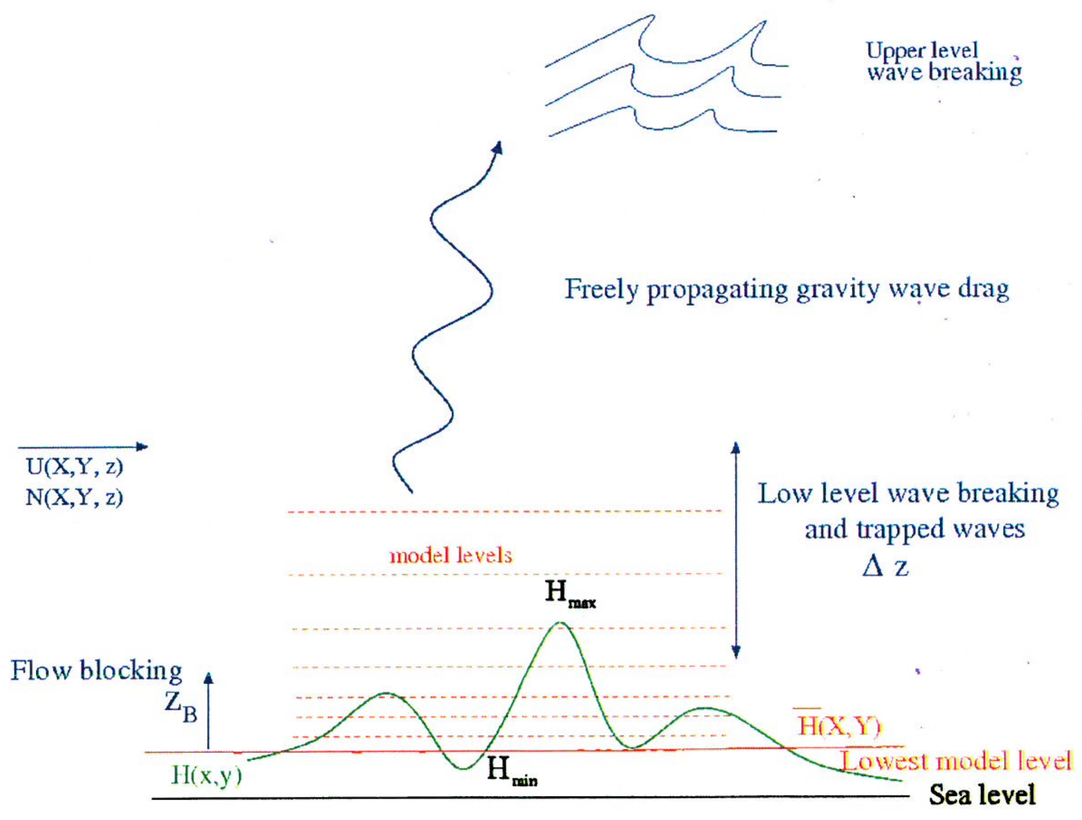
- At large H_n the vertical motion of the fluid is limited and part of the low-level flow goes around the mountain for $z<z_b$.

The surface stress is then : $\tau = \rho C_d z_b b U^2$

drag_noro

The scheme depends on 4 parameters C_d, G, R_{ic} and z_b.

- C_d and G control the amplitude of the blocked-flow drag and of the gravity-wave drag.
- R_{ic} and z_b control the vertical distribution of these drags.

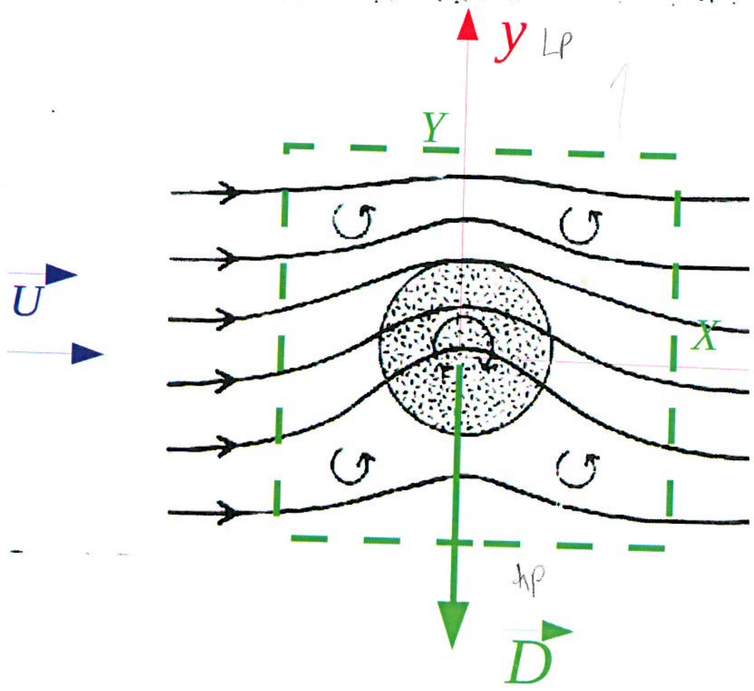


2. lift_noro: The component of the force that modifies the direction of the flow

Pressure force acting on the mountain to the left due to the background pressure gradient associated with the mean flow:

$F = MV \rho U f$; MV is the mountain volume

The lifting of the air over the mountain is balanced by the force acting on the mountain and then results in a push to the right (*Smith 1979*).



Between the narrow ridges of a mountain air can be blocked and separated from the large-scale flow.

A region of complex terrain acts as if it has a height larger than the actual height.

A solution could be to increase the sizes of the mountains

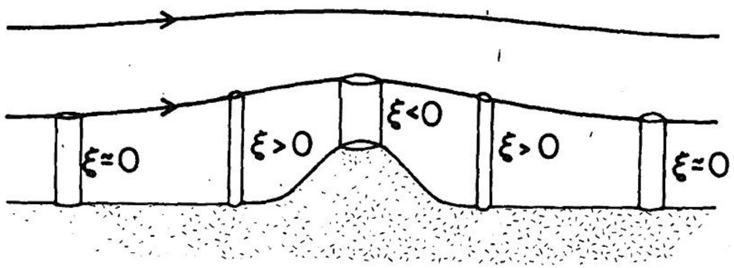
In lift-noro the mean orography is kept and the missing forces are applied.

Conservation of potential vorticity for an adiabatic motion:

$$PV = \frac{1}{\rho}(f + \xi_r)\frac{d\theta}{dz}$$

If the motion to the South or North is large enough, one can't consider that *f* is constant.

The mountain triggers a steady Rossby wave.



3. Why are gravity waves important for the middle atmosphere circulation?

The sources of gravity waves are orography, but also convective and frontal systems.

Gravity waves can propagate vertically and break.

The moment flux deposition due to gravity wave breaking is parameterized (for example in hines_gwd).

This breaking affects the mean circulation in the stratosphere (Quasi-Biennal Oscillation) and the mesosphere (changes in the zonal wind).

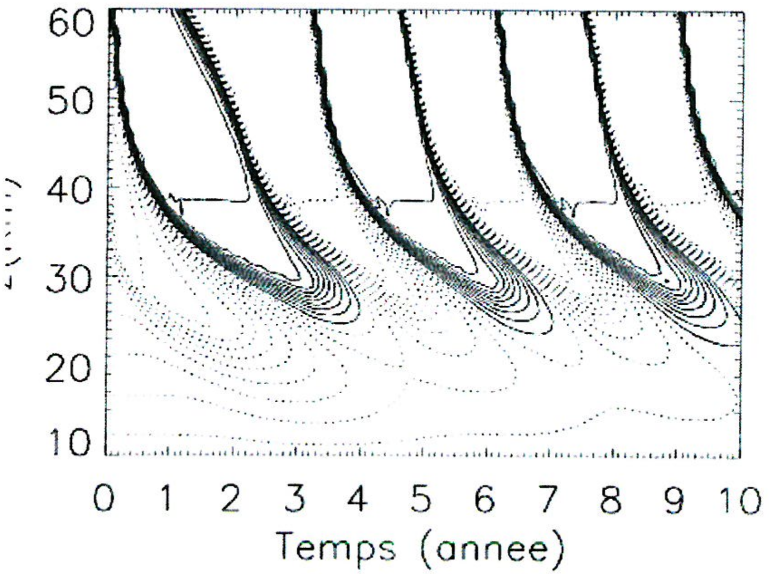
=> Quasi-Biennal Oscillation

Altitude de déferlement des ondes de gravité :

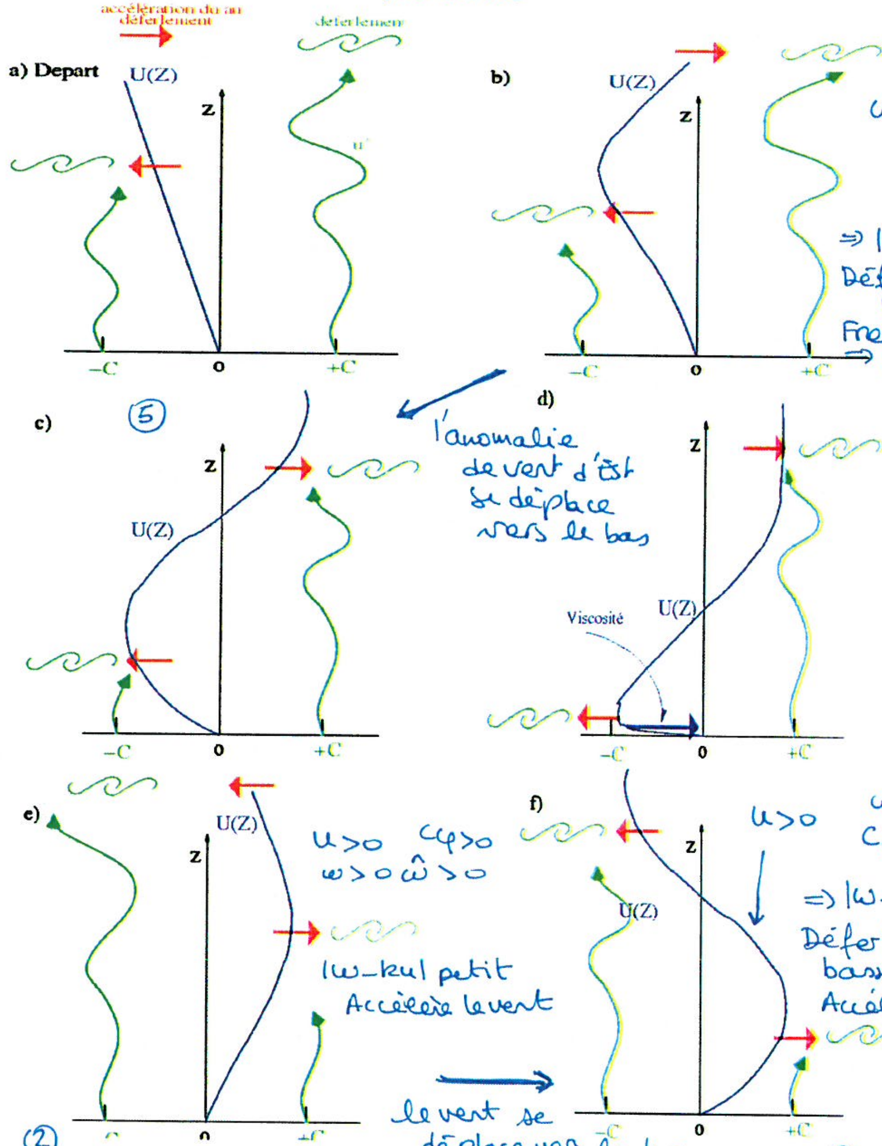
$$z = 2H \ln\left(\frac{|\omega - ku|}{|m|\, w_0}\right)$$

- $\hat{\omega} > 0$ Accélère le vent moyen
- $\hat{\omega} < 0$ Freine le vent moyen

$\bar{u}$ (m/s)



① $\omega > 0$ $\hat{\omega} > 0$ $c_\varphi > 0$
$u < 0 \Rightarrow |\omega - ku|$ grand
Pénétration de l'onde à haute Altitude



④ $\omega < 0$ $\hat{\omega} < 0$
$c_\varphi < 0$
$u < 0$
$\Rightarrow |\omega - ku|$ faible
Déferlement à basse altitude
Freine
=> Anomalie vent d'Est

⑤ l'anomalie de vent d'Est se déplace vers le bas

② $u > 0$ $c_\varphi > 0$
$\omega > 0$ $\hat{\omega} > 0$
$|\omega - ku|$ petit
Accélère le vent

le vent se déplace vers le bas

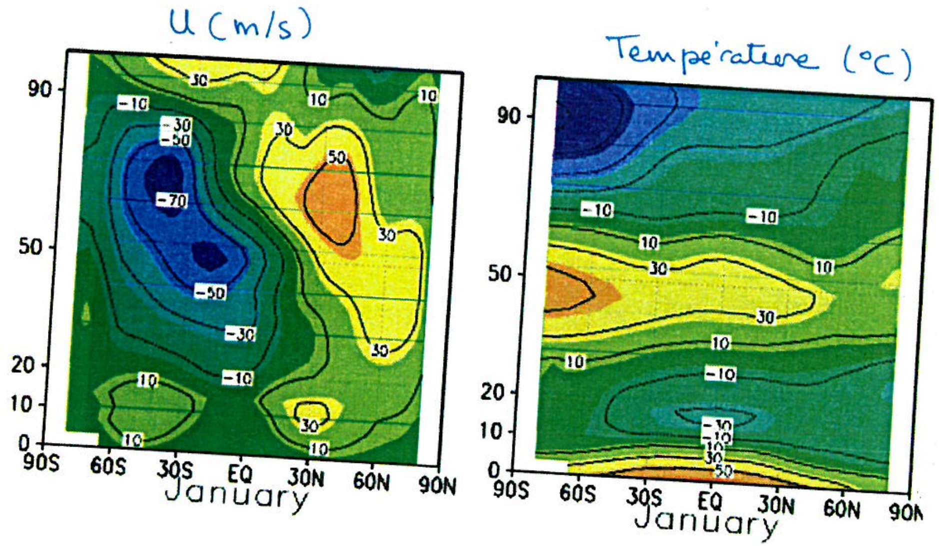
③ $u > 0$
$\omega > 0$ $\hat{\omega} > 0$
$c_\varphi > 0$
$\Rightarrow |\omega - ku|$ petit
Déferlement à basse altitude
Accélère le vent

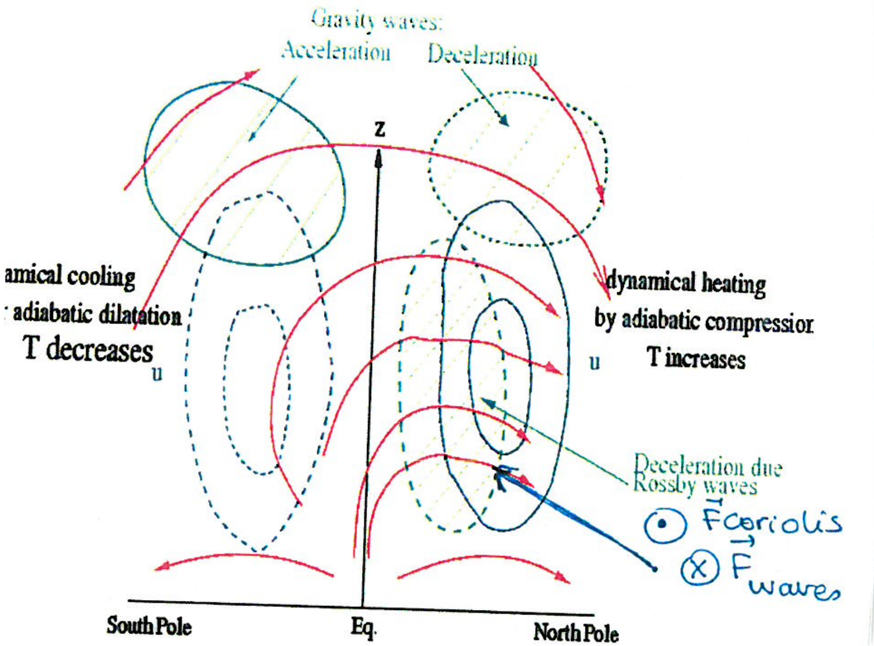
In the mesosphere

-At 50 km in the stratosphere, there is a maximum of Temperature at the summer pole

- Thermal wind: In January, u>0 in the Northern Hemisphere u<0 in the Southern Hemisphere

- But not in the mesosphere, because of gravity wave breaking!





4. Why are planetary waves important for stratospheric circulation?

-At 50 km in the stratosphere, there is a maximum of Temperature at the summer pole

- Thermal wind: In January, u>0 in the Northern Hemisphere u<0 in the Southern Hemisphere

-But the meridional gradient of temperature is less strong than what is expected by radiative considerations.

- This is because of the Brewer-Dobson circulation, linked to Rossby-wave breaking.