

The physical parameterizations of LMDZ

LMDZ team

Laboratoire de Météorology Dynamique / IPSL / CNRS /SU

LMDZ training, Janvier 2026

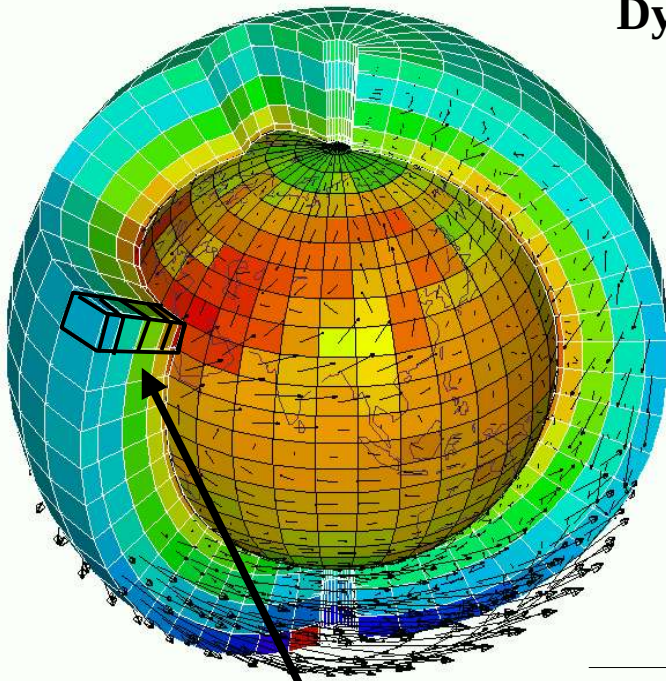
Part I : Frédéric presenting

- Principles
- Radiation (clear sky)
- Reynolds decomposition
- Turbulent diffusion
- Mass flux representation of the convective boundary layer
- Subgrid scale orography

Part II : Jean-Baptiste presenting

- Moist convection, shallow and deep
- Cold pools
- Clouds
- Cloud radiation interaction

Dynamical core : primitive equations discretized on the sphere



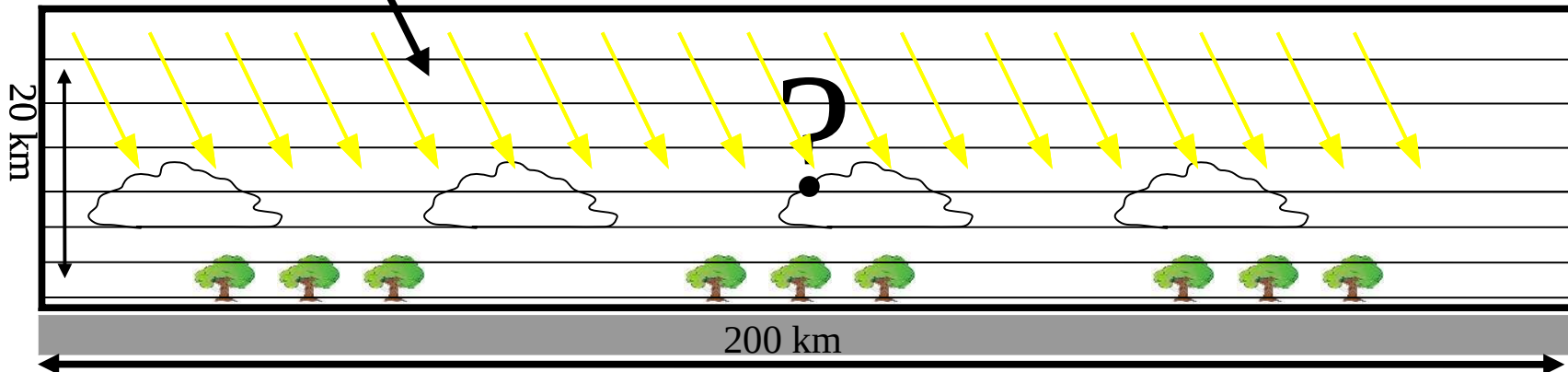
- Mass conservation

$$D\rho/Dt + \rho \operatorname{div}\underline{U} = 0$$
- Potential temperature conservation

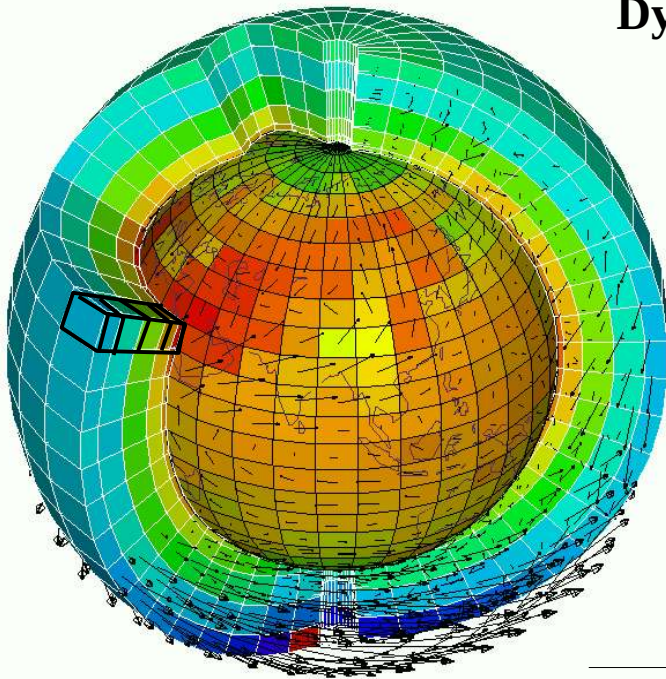
$$D\theta / Dt = Q / C_p (p_0/p)^\kappa$$
- Momentum conservation

$$D\underline{U}/Dt + (1/\rho) \operatorname{grad} p - g + 2 \underline{\Omega} \wedge \underline{U} = \underline{F}$$
- Secondary components conservation

$$Dq/Dt = Sq$$



Dynamical core : primitive equations discretized on the sphere



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

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)**

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

$\text{temp}(t+\text{dtphys})-\text{temp}(t)=\text{dtdyn}+\text{dtphy}$

$\text{ovap}(t+\text{dtphys})-\text{ovap}(t)=\text{dqdyn}+\text{dqphy}$

$\text{vit}[u/v](t+\text{dtphys})-\text{vit}[u/v](t)=\text{dudyn}+\text{duphy}$

Physics time-step :

$\text{dtphys}=\text{daysec}*\text{iphysic}/(\text{day_step})$, $\text{day_sec}=86400$

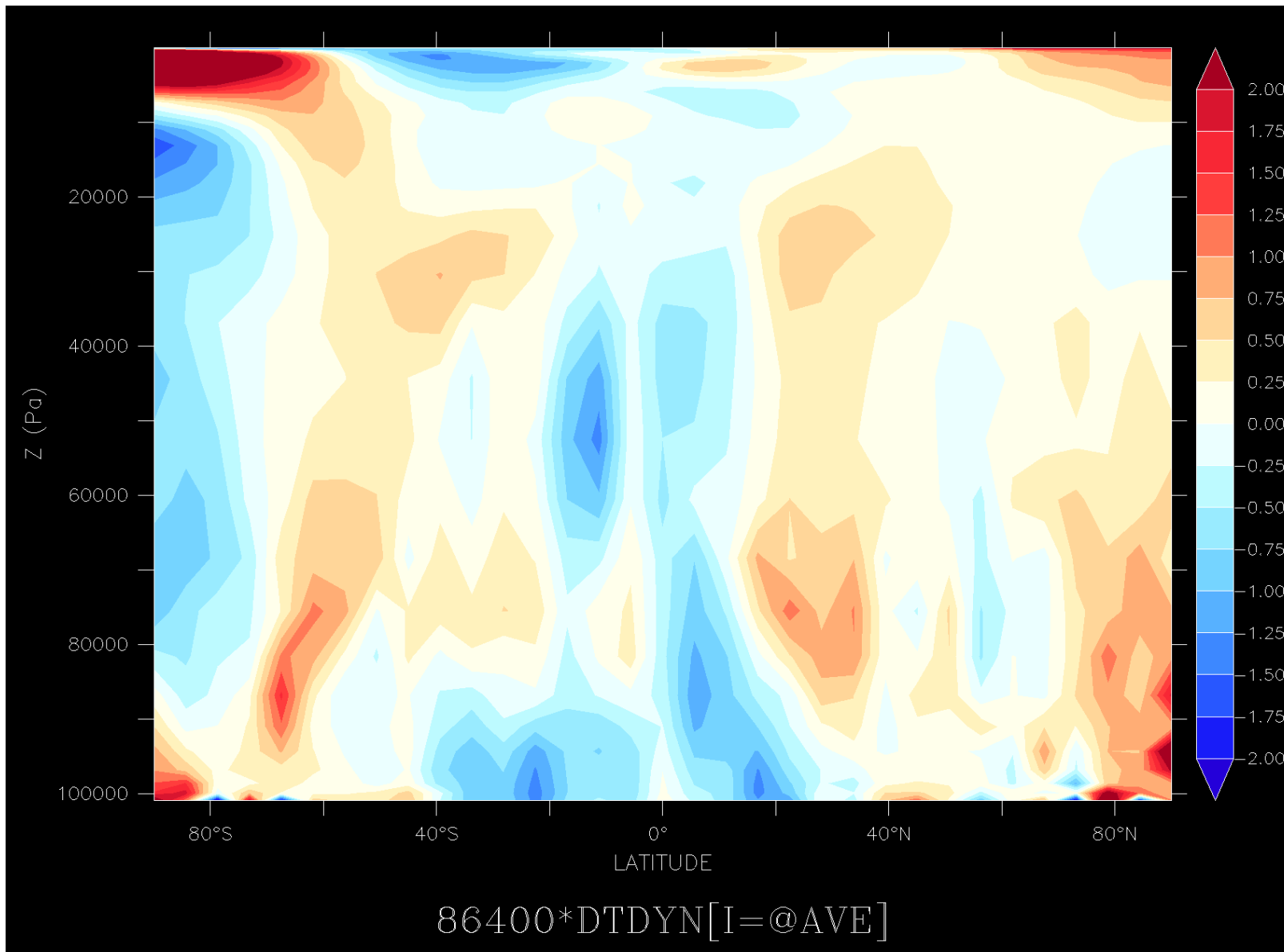
Zonal mean heating by large scale dynamics (K/day)

use histday.nc

reg/l=3

fill/lev=(-Inf)(-2,2,0.25)(inf)/pal=blue_darkred 86400*dtdyn[i=@ave]

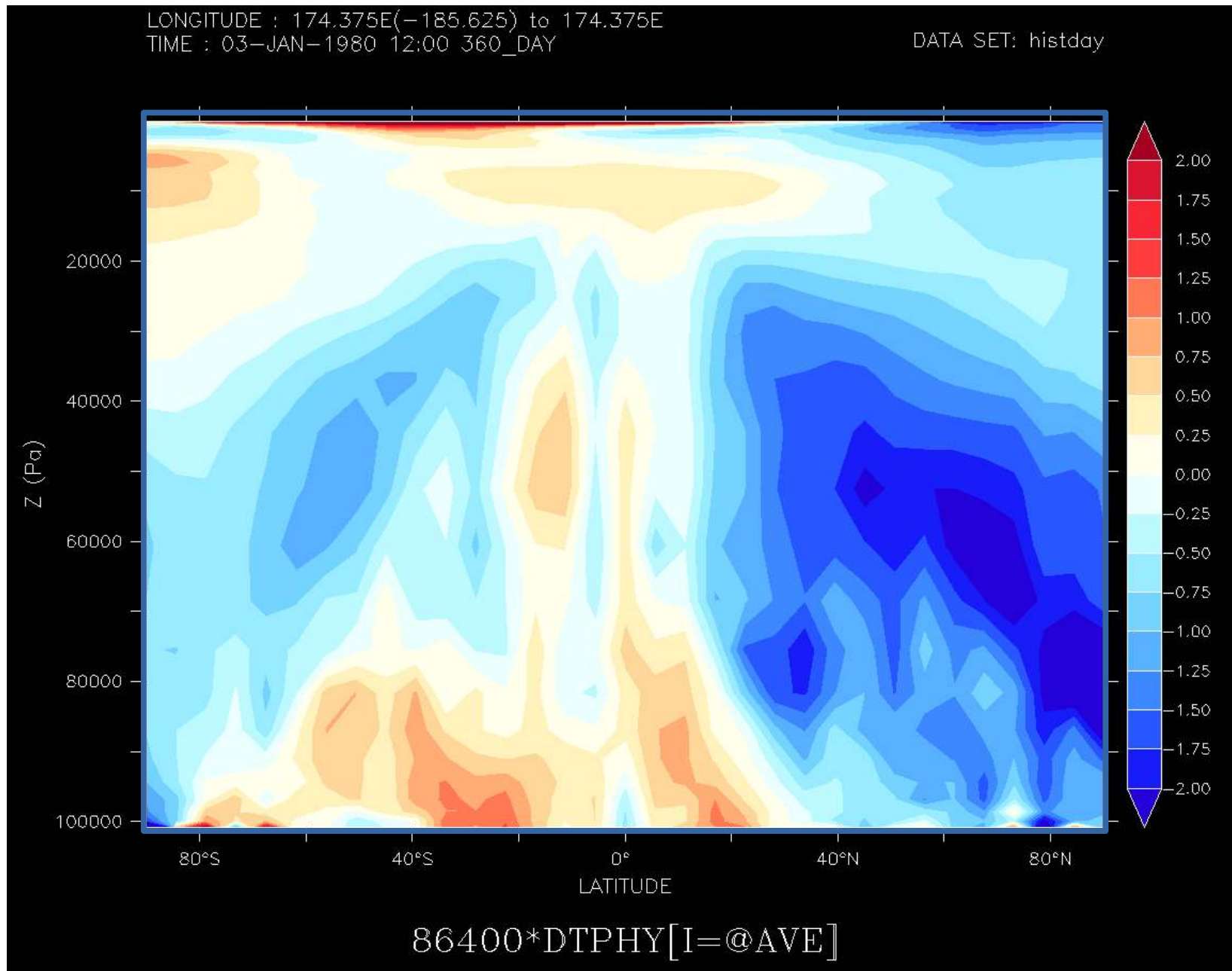
(prendre le temps d'expliquer la commande)



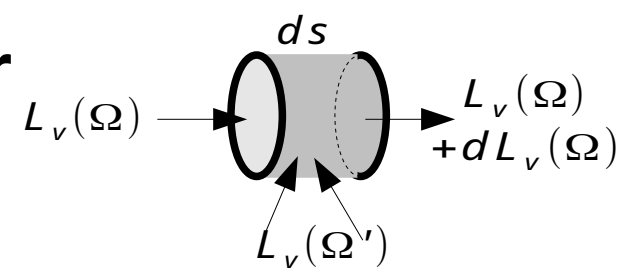
Zonal mean heating by large scale dynamics (K/day)

reg/l=3

fill/lev=(-Inf)(-2,2,0.25)(inf)/pal=blue_darkred 86400*dtphy[i=@ave]



Parameterization of radiative transfer



Radiative transfer : well known equations ...

Giving the evolution of luminance along a line of sight:

$$\frac{dL_v(\Omega)}{ds} = \underbrace{-\kappa_v L_v(\Omega)}_{\text{absorption}} + \underbrace{\kappa_v B_v(T)}_{\text{emission}} - \underbrace{\sigma_v L_v(\Omega)}_{\text{Scattered in other directions}} + \underbrace{\sigma_v \frac{1}{4\pi} \int_{4\pi} P(\Omega', \Omega) L_v(\Omega') d\Omega'}_{\text{Scattered from other directions}}$$

Computation of energy fluxes very costly

- should be integrated over all frequencies ν
- should be integrated on angles
- knowing radiative properties of scatterers and absorbers is a question by itself

Computing radiation for one full scene with reference methods for the spectral integration (line-by-line) and angular (discrete ordinates, Monte-Carlo) integrations, even for a plan parallel atmosphere without clouds, may take hours of CPU hours on super computers.

In LMDZ : using codes developed and used at ECMWF

3 codes avec des mots clé : **oldrad** / **rtrm** / **ecrad**

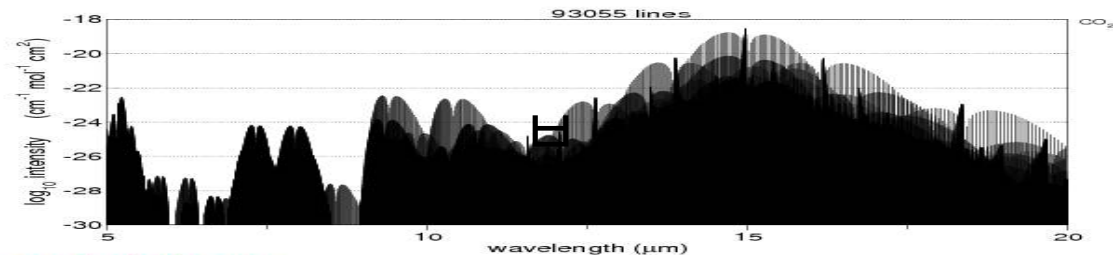
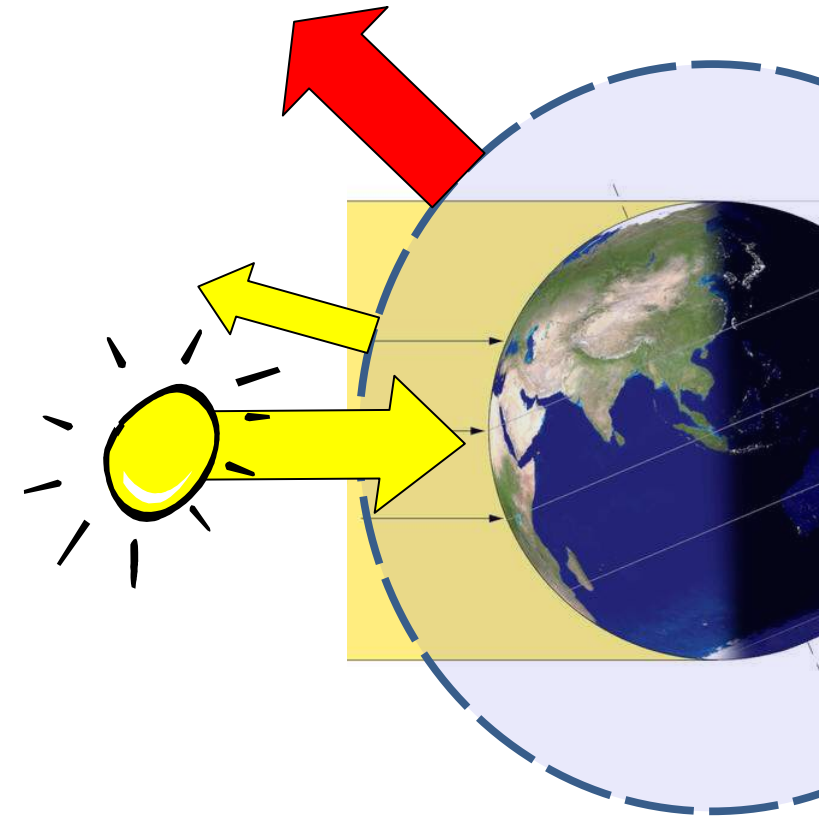
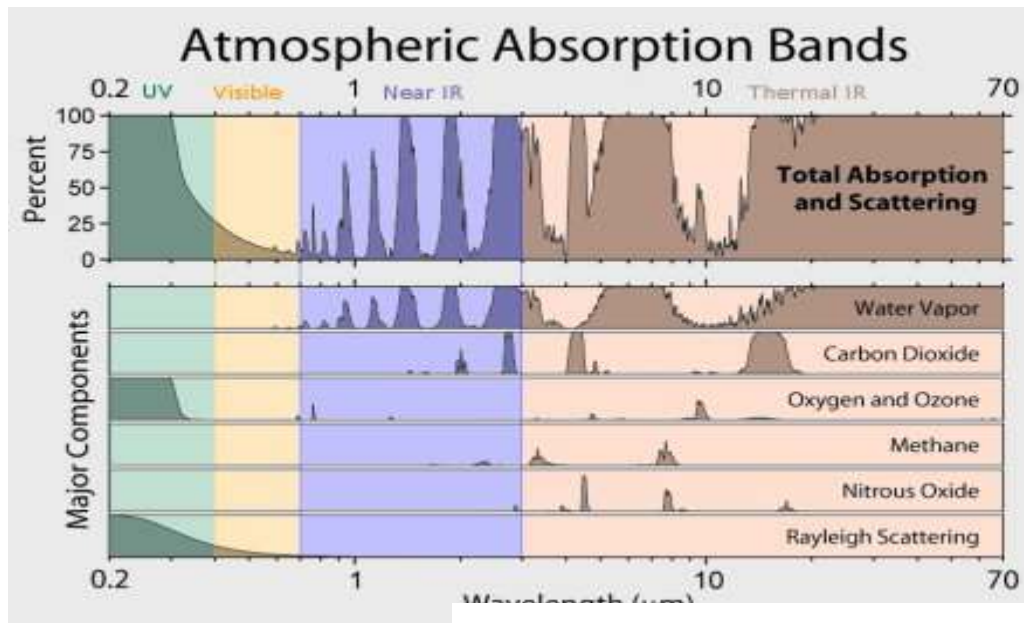
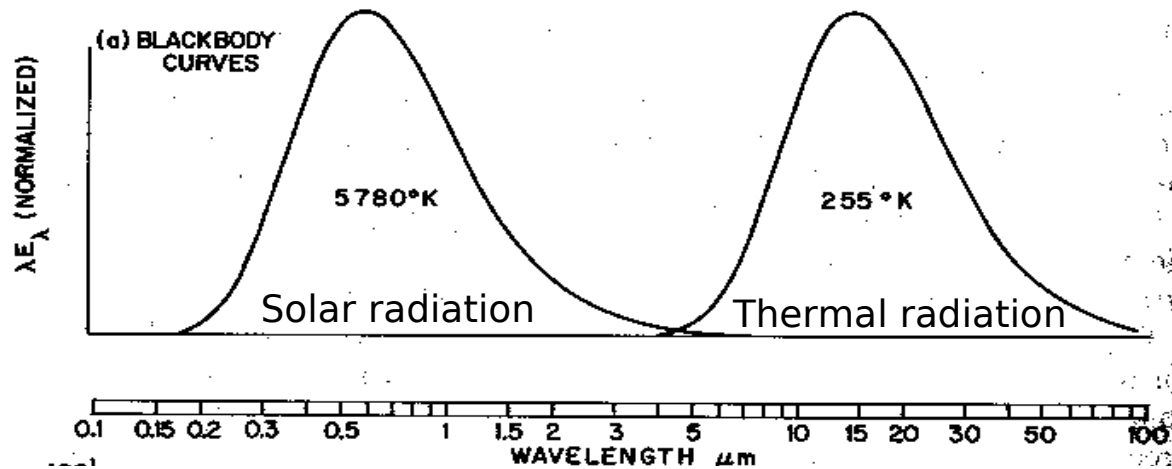
ECrad can be seen as a tool box with various options for :

Spectral integration : **S/RRTM** or **ECCKD**

Solver : **McICA**, **Tripleclouds** or **Spartacus**

Spectral : separating radiation between solar and thermal infrared

Valid thanks to the linearity of the radiative transfer equation with respect to sources



Approaches for spectral integration

Emissivity / band models (code « Fouquart Morcrette, 1980)

$$\epsilon_{\Delta\nu}(z_1, z_2) = \frac{1}{\Delta\nu} \int_{\Delta\nu} \epsilon_\nu(z_1, z_2) d\nu$$

Loosing a fundamental property : $\epsilon_{\Delta\nu}(z_1, z_2) = \epsilon_{\Delta\nu}(z_1, z) \epsilon_{\Delta\nu}(z, z_2)$

Cost in N^2 instead of N , where N is the number of layers

K-distribution methods

Replacing the integration on ν by an integration on k .

$k(P, T)$ differ depending on the transition considered.

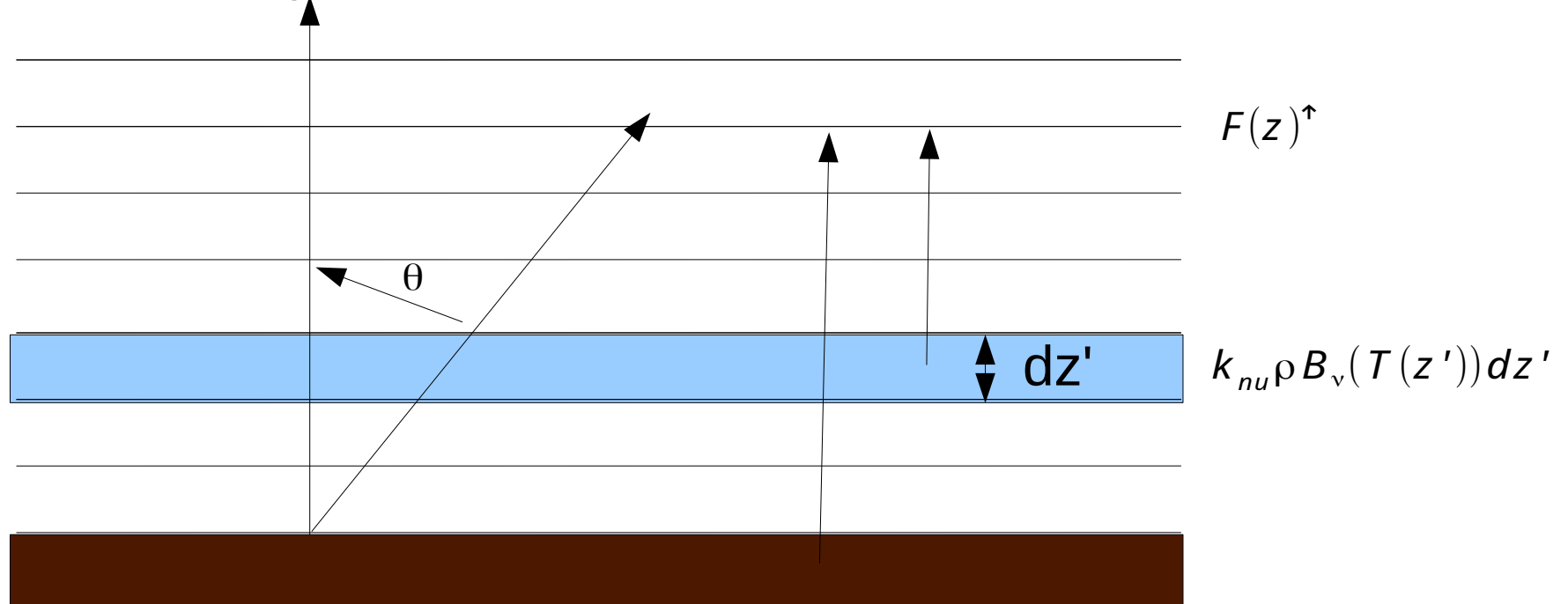
Name in .def files	SW	LW
oldrad	2 bands	6 bands
rrtm	6 bands	K-distributions (RRTM)
ecrad	K-distributions (SRTM) ECCKD	K-distributions (RRTM) ECCKD

Infrared, non-scattering case

Plane parallel approximation: homogeneous semi-infinite space

Diffuse" approximation

Up/down flux separation, 2-stream



$$\frac{\partial F(z)^\uparrow}{\partial z} = -k_{\nu} \rho \mu F(z)^\uparrow + k_{\nu} \rho \mu B_{\nu}(T) \quad \mu = \frac{1}{\cos(\theta)} = 1.66$$

$$\epsilon_{\nu}(z_1, z_2) = \exp \left[-\mu \int_{z_1}^{z_2} k_{\nu}(P, T) \rho dz \right]$$

$$F(z)^\uparrow = B_{\nu}(T_s) \epsilon(0, z) + \int_0^z k_{\nu} \rho B_{\nu}(T(z')) \epsilon(z', z) dz'$$

$$F(z)^\uparrow = B_{\nu}(T_s) \epsilon(0, z) + \int_0^z B_{\nu}(T(z')) \frac{\partial \epsilon(z', z)}{\partial z'} dz'$$

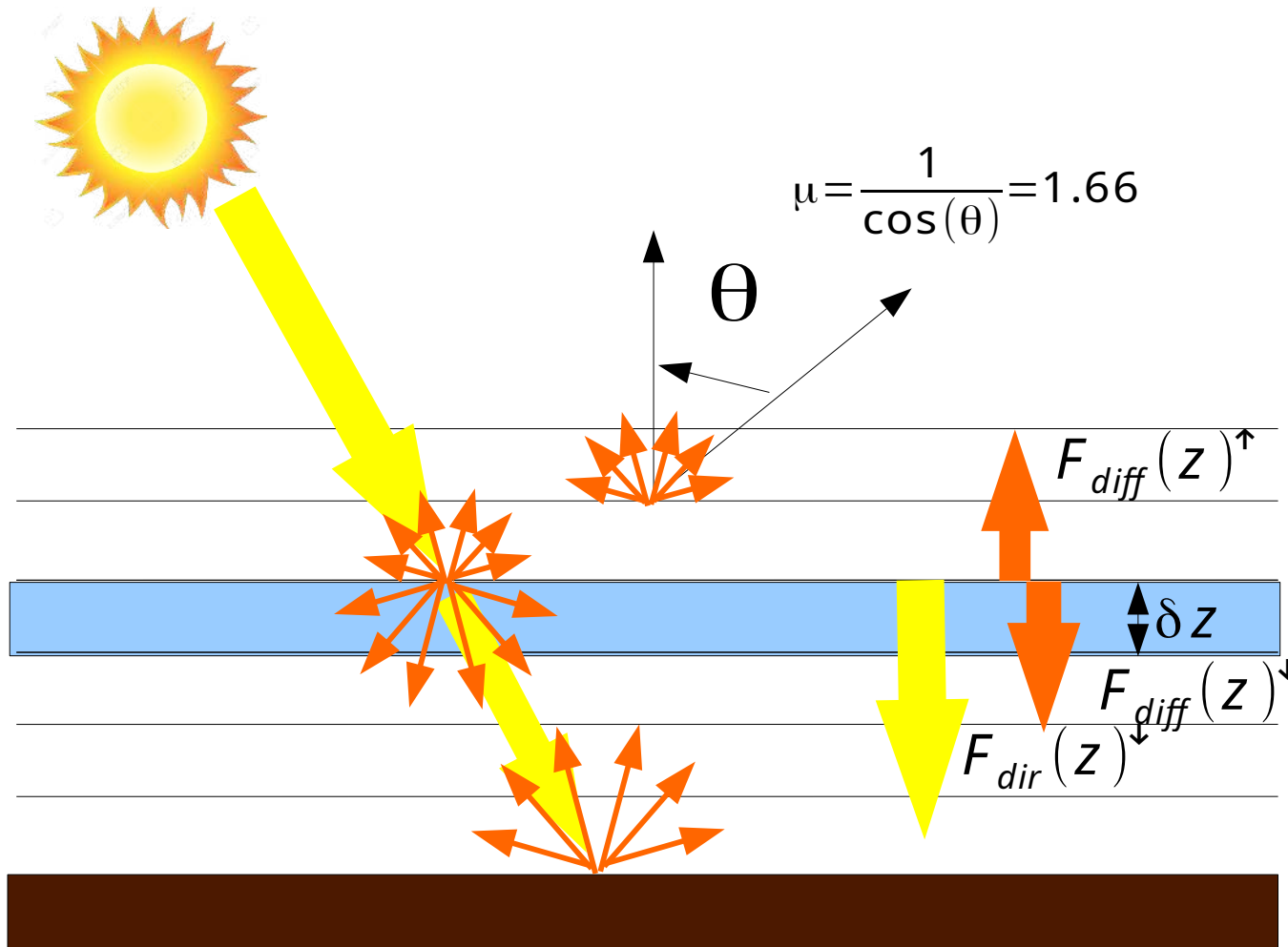
$$Q = \frac{\partial T}{\partial z} = \frac{1}{\rho C_p} \frac{\partial F(z)^\uparrow}{\partial z}$$

Solar radiation : Direct radiation + 2-stream for diffuse radiation

Plane parallel approximation: homogeneous semi-infinite space

Upward and downward photons are grouped into two streams

Delta-Eddington approximation for scattering by strongly asymmetric phase functions



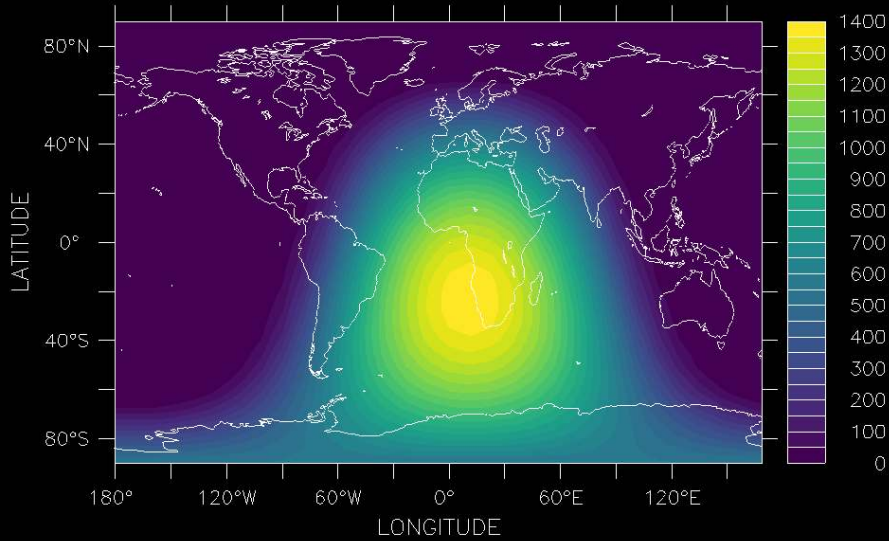
$$F^{\uparrow} = F_{diff}^{\uparrow} - F_{diff}^{\downarrow} - F_{dir}^{\downarrow}$$

$$F(z)^{\uparrow}$$

$$F(z - \delta z)^{\uparrow}$$

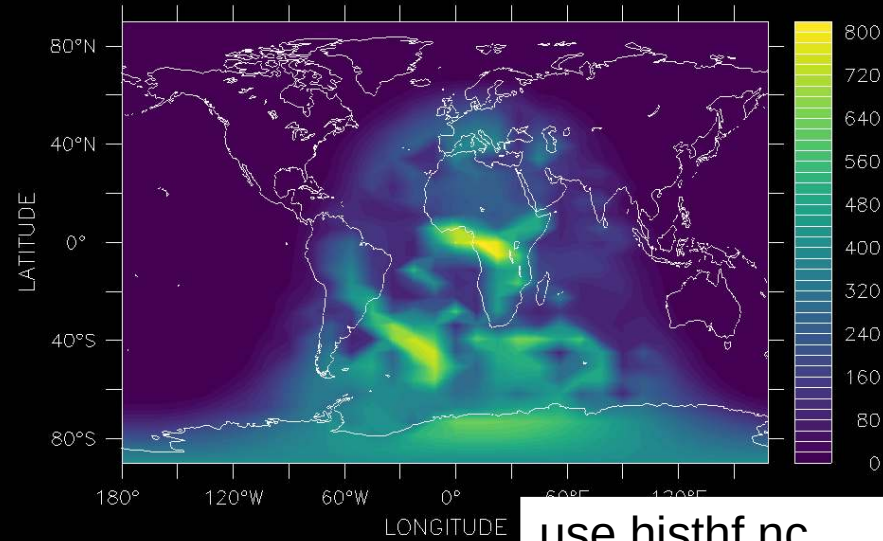
$$Q = \frac{F(z) - F(z - \delta z)}{C_p \rho \delta z}$$

TIME : 03-JAN-1980 11:00 360_DAY DATA SET: histhf



SWdn at TOA (W/m2)

TIME : 03-JAN-1980 11:00 360_DAY DATA SET: histhf



SWup at TOA (W/m2)

use histhf.nc

reg/l=30

set v ul ; fill swdntoa ; go land

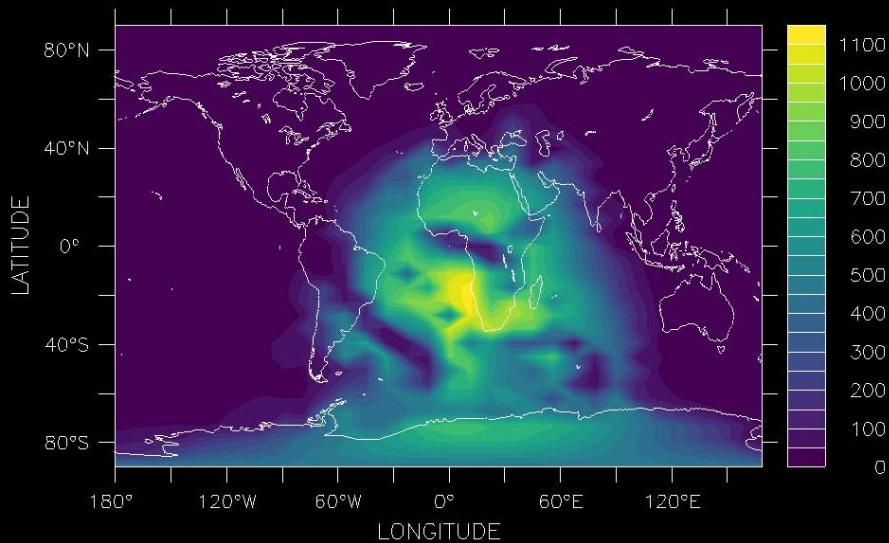
set v ur ; fill swuptoa ; go

land

set v ll ; fill swdnsfc ; go land

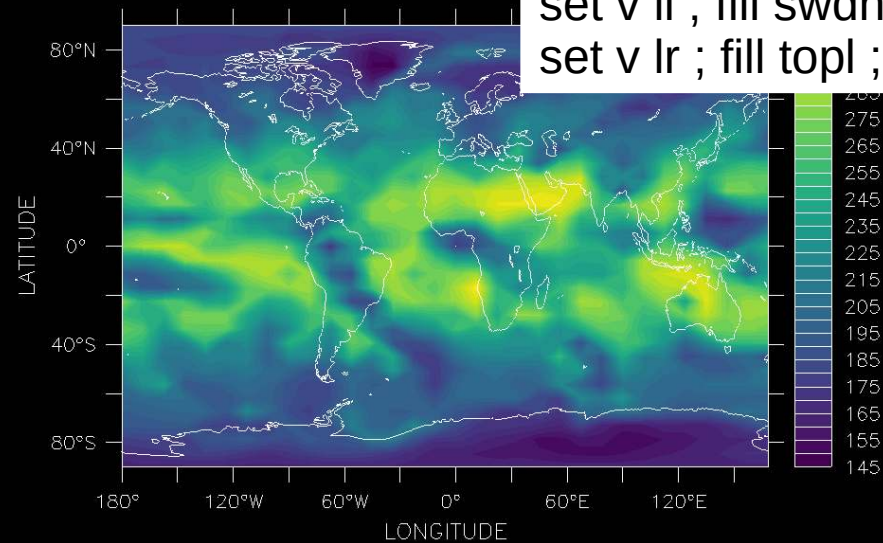
set v lr ; fill topl ; go land

TIME : 03-JAN-1980 11:00 360_DAY DATA SET: histhf

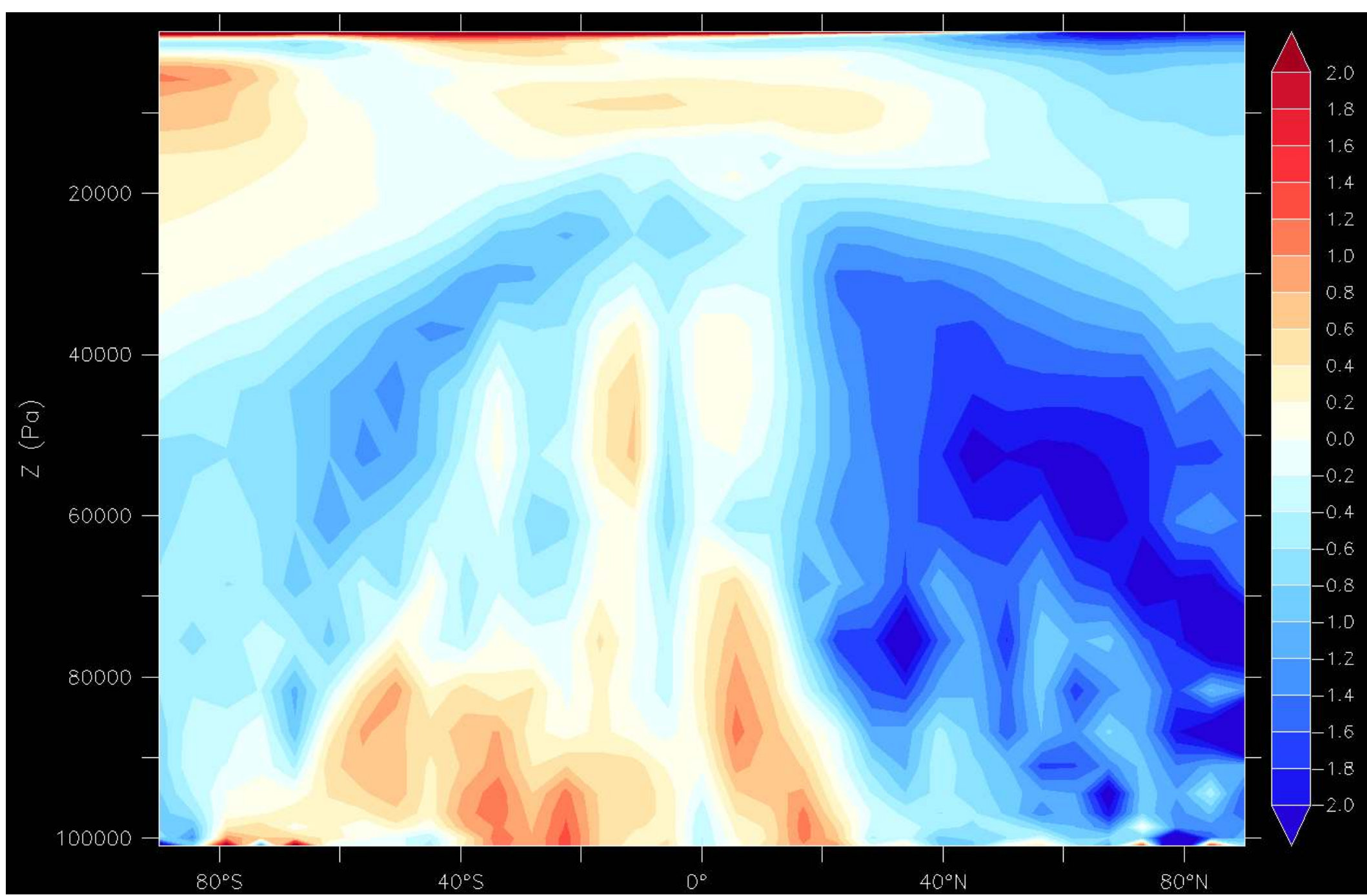


SWdn at surface (W/m2)

TIME : 03-JAN-1980 11:00 360_DAY DATA SET: histhf

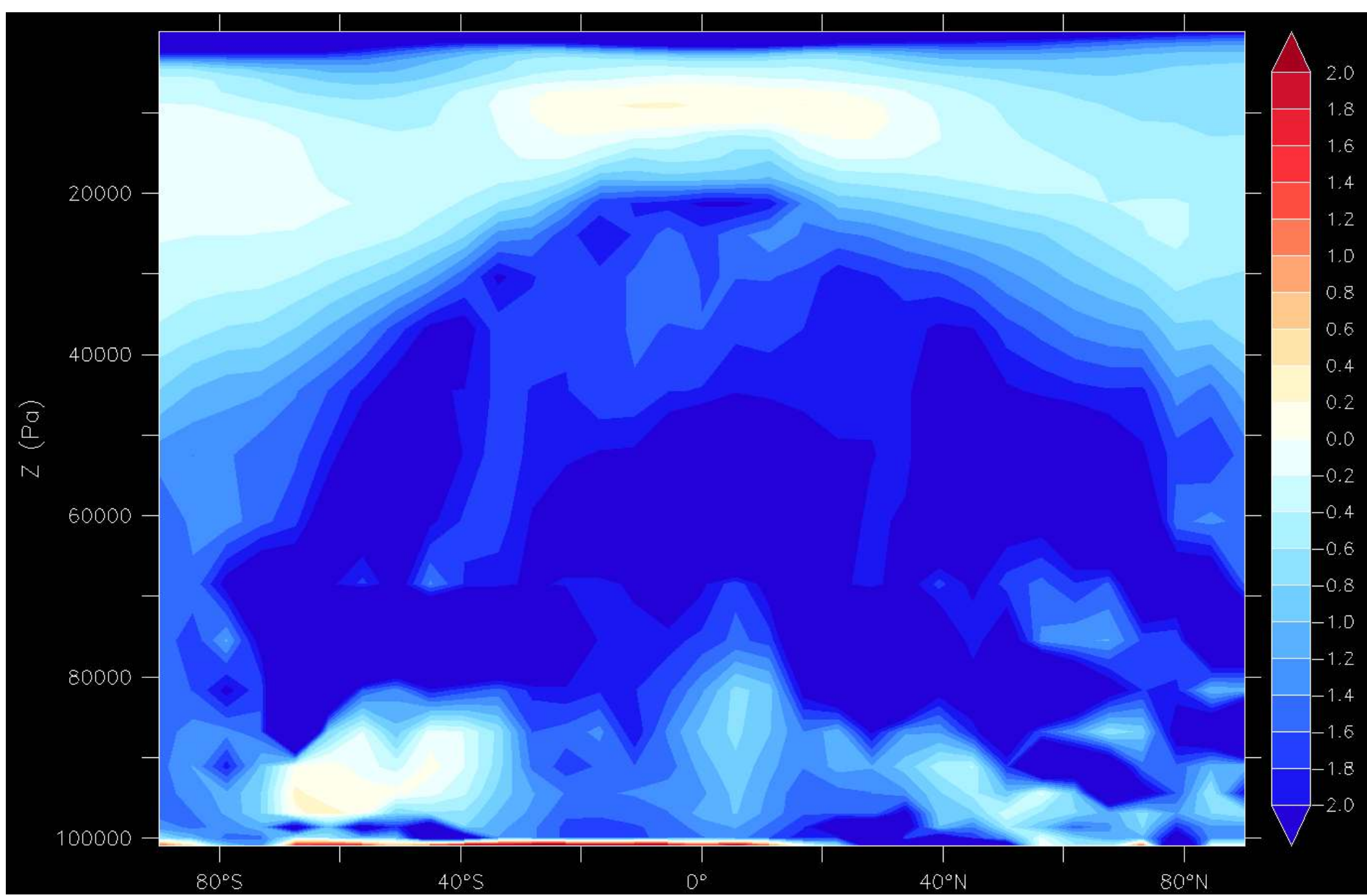


IR rad. at TOA (W/m2)



fill/lev=(-Inf)(-2,2,0.2)(Inf)/pal=blue_darkred 86400*Dtphy[l=25:36@ave,i=@ave]

86400*DTPHY[L=25:36@AVE,I=@AVE]



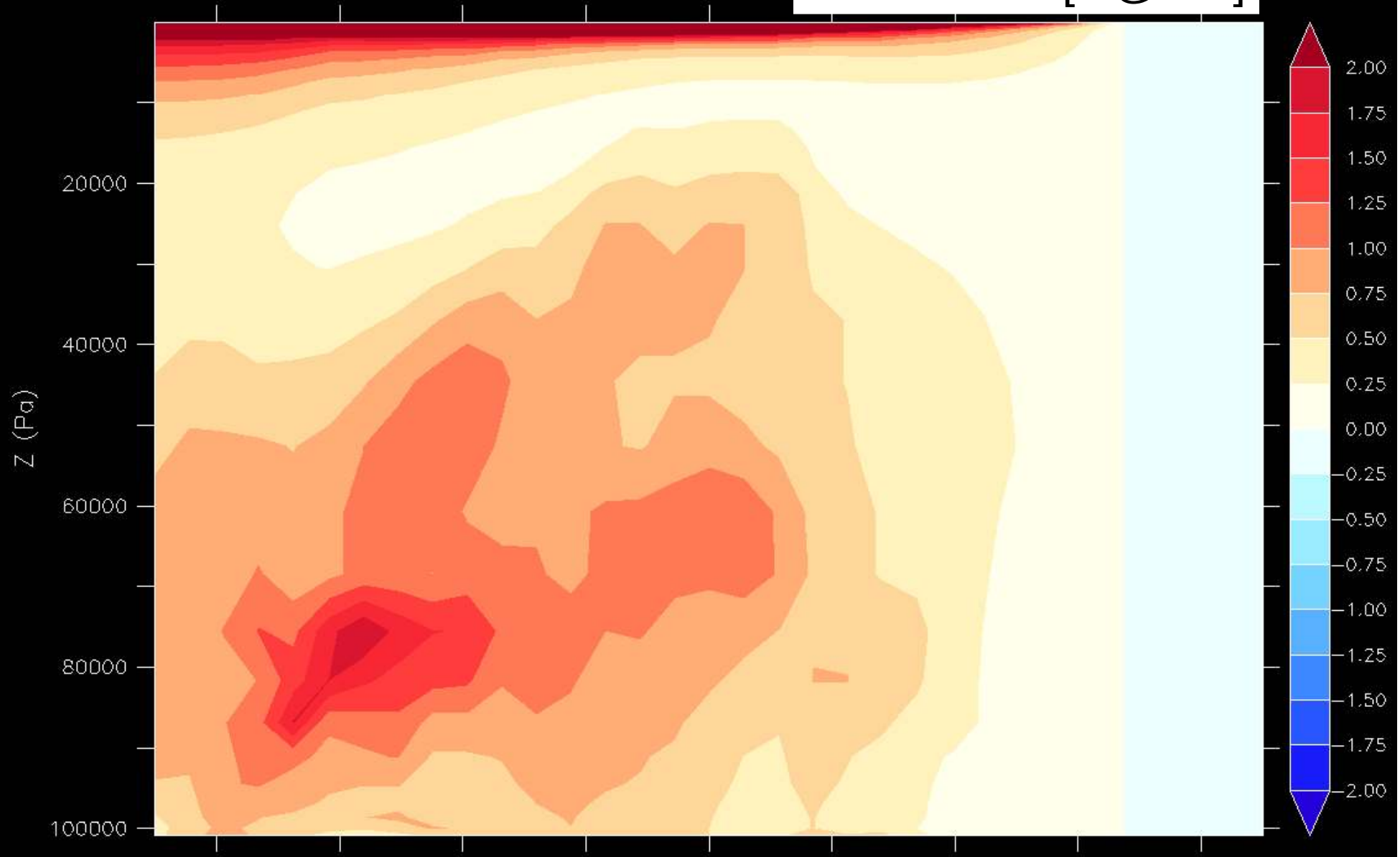
`fill/lev=(-Inf)(-2,2,0.2)(Inf)/pal=blue_darkred 86400*dtlwr[l=25:36@ave,i=@ave]`

`86400*DTLWR[L=25:36@AVE,I=@AVE]`

LONGITUDE : 174.375E(-185.625) to 174.375E
TIME : 03-JAN-1980 12:00 360_DAY

DATA SET: histday

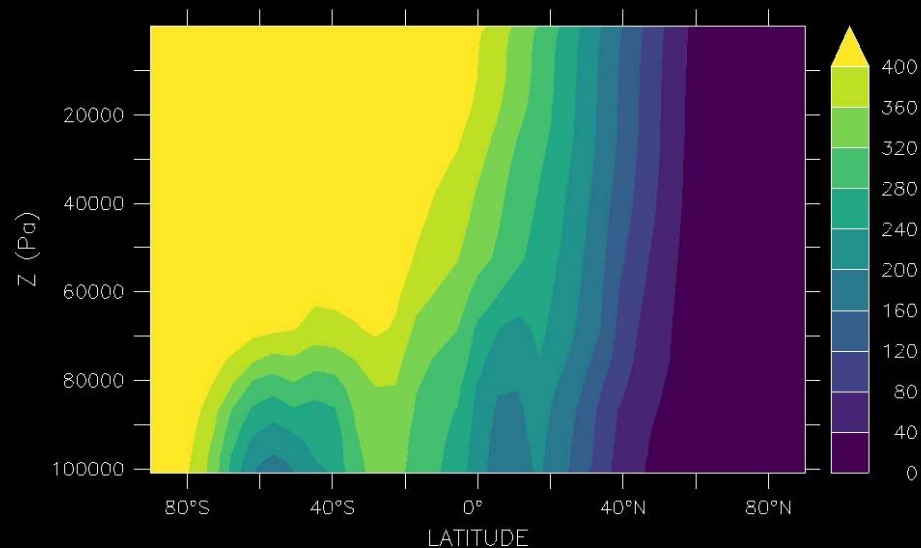
86400*dtswr[i=@ave]



fill/lev=(-Inf)(-2,2,0.2)(Inf)/pal=blue_darkred 86400*dtswr[l=25:36@ave,i=@ave]

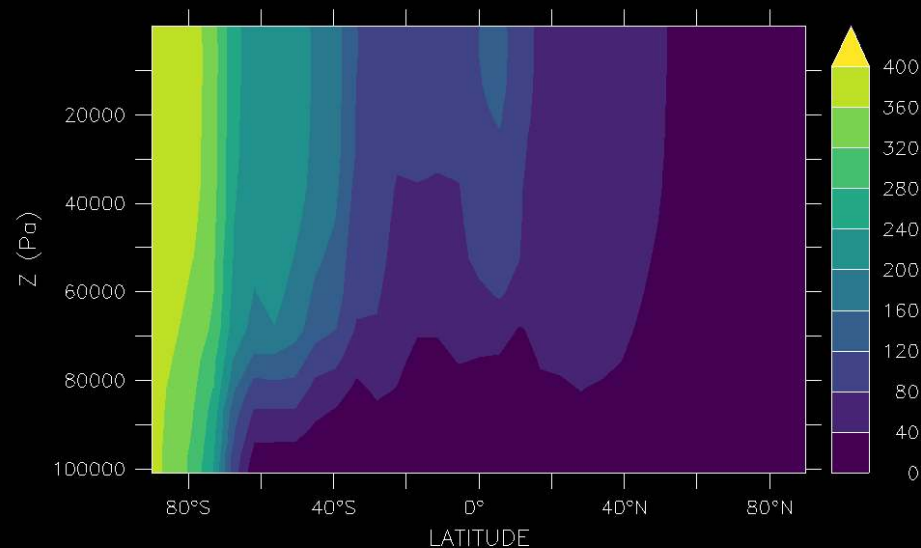
86400*DTSWR[I=@AVE]

LONGITUDE : 174.375E(-185.625) to 174.375E (averaged)
TIME : 03-JAN-1980 12:00 360_DAYDATA SET: histday



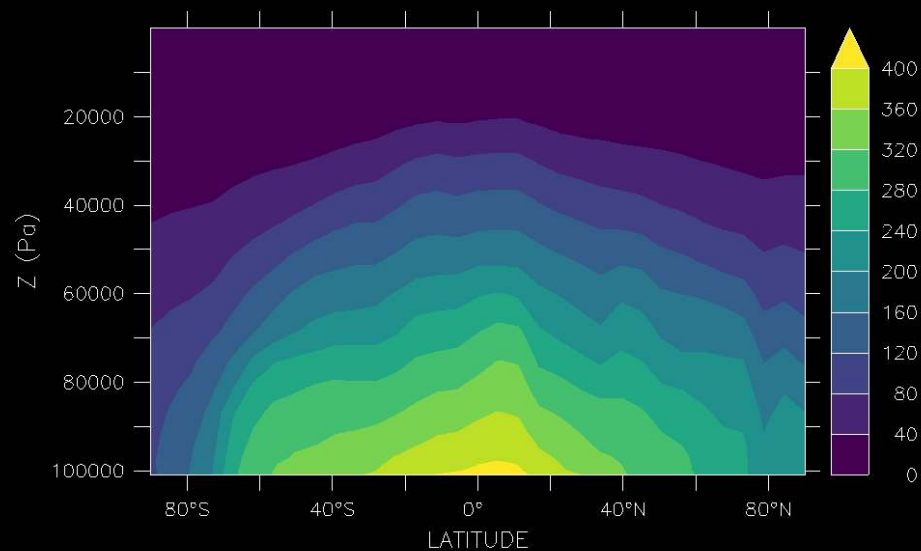
SW downward radiation (W m^{-2})

LONGITUDE : 174.375E(-185.625) to 174.375E (averaged)
TIME : 03-JAN-1980 12:00 360_DAYDATA SET: histday



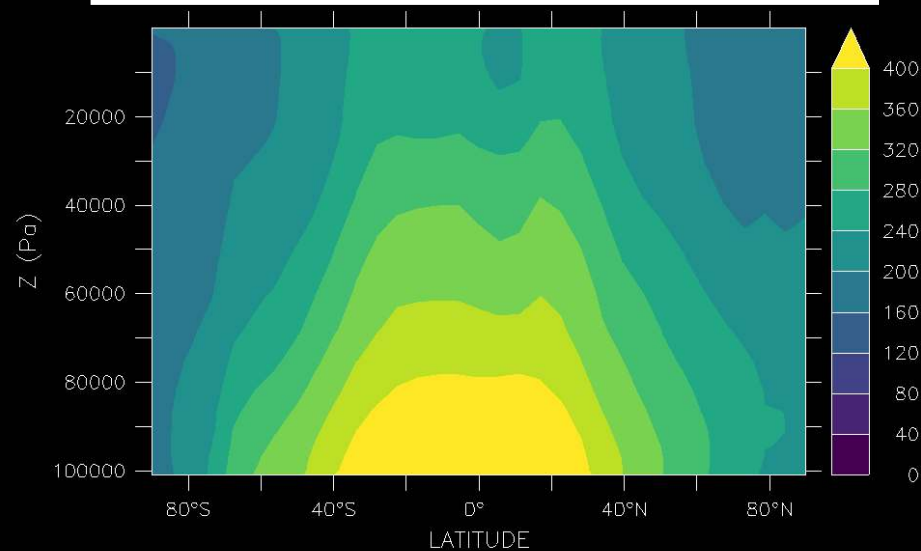
SW upward radiation (W m^{-2})

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$-1 \times \text{RLD}[I=@\text{AVE}]$

```
set v ul ; fill/lev=(0,400,40)(Inf) rsd[i=@ave]
set v ur ; fill/lev=(0,400,40)(Inf) rsu[i=@ave]
set v ll ; fill/lev=(0,400,40)(Inf) -1*rls[i=@ave]
set v lr ; fill/lev=(0,400,40)(Inf) rlu[i=@ave]
```



LW upward radiation (W m^{-2})

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

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

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

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

$$\begin{aligned} \Rightarrow \rho \tilde{\mathbf{v}} c &= \rho (\bar{\mathbf{v}} + \widetilde{\mathbf{v}'}) (\bar{c} + c') \\ &= \tilde{\rho} \bar{\mathbf{v}} \bar{c} + \tilde{\rho} \overline{\mathbf{v}' c'} \end{aligned}$$

$$\begin{aligned} \frac{\partial \rho c}{\partial t} + \widetilde{\text{div}(\rho \mathbf{v} c)} &= 0 \quad \Rightarrow \quad \frac{\partial \tilde{\rho} \bar{c}}{\partial t} + \text{div}(\tilde{\rho} \bar{\mathbf{v}} \bar{c}) + \text{div}(\tilde{\rho} \overline{\mathbf{v}' c'}) = 0 \\ \frac{\partial \bar{c}}{\partial t} + \mathbf{\bar{v}} \cdot \mathbf{\bar{grad}} \bar{c} &= -\frac{1}{\tilde{\rho}} \text{div}(\tilde{\rho} \overline{\mathbf{v}' c'}) = -\frac{1}{\tilde{\rho}} \frac{\partial \overline{\rho w' c'}}{\partial z} \end{aligned}$$

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$$Dq/Dt = Sq$$

$$\frac{\partial c}{\partial t} + \mathbf{v} \cdot \mathbf{grad} c = -\frac{1}{\rho} \text{div}(\rho \overline{\mathbf{v}' c'}) = -\frac{1}{\rho} \frac{\partial \overline{\rho w' c'}}{\partial z}$$

Turbulent diffusion : bases

**Boundary layer approximation (horizontal homogeneity)
+ eddy diffusion**

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

- 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

- Prandtl (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)

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

- 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

Surface Momentum flux : $\tau_x = -\rho C_d ||V_h|| U_1$

Surface sensible heat flux : $H = \rho C_d ||V_h|| (T_s - T_1)$

Surface latent heat flux : $LE = \rho C_d ||V_h|| \beta (Q_s(T_s) - Q_1)$

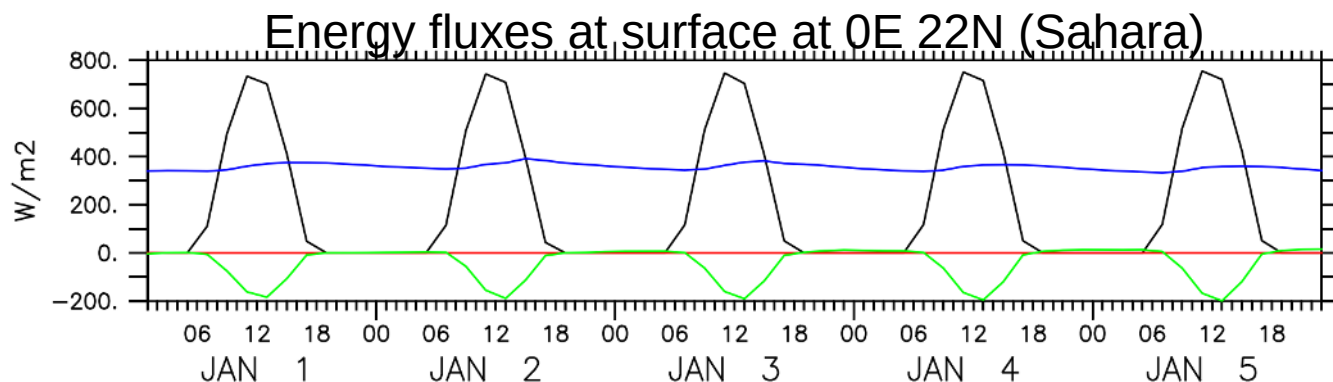
reg/x=0/y=22/l=1:60/k=28:39

set v upper

plot swdnsfc,flat,sens,lwdnsfc

set v lower

fill/k=25:39/lev=(-Inf)(-10,10,1)(Inf)/pal=blue_darkred 86400*dtvdf



SW down radiation at surface

Sensible $H = \rho C_d ||V_h|| (T_s - T_1)$

— SWDNSFC
— SENS

— FLAT
— LWDNSFC

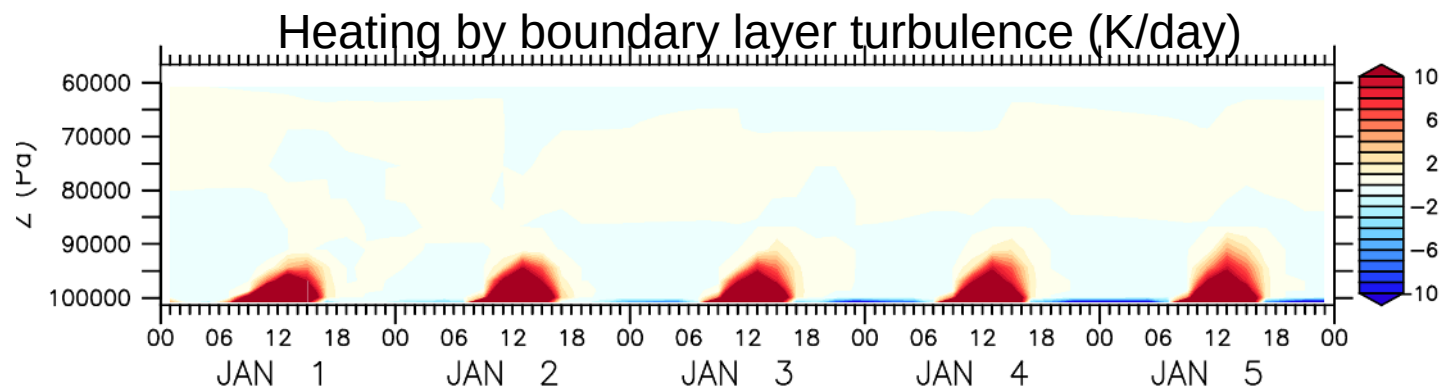
SW down radiation at surface

Latent $LE = L \rho C_d ||V_h|| \beta(Q_s(T_s) - Q_1)$

LONGITUDE : 0E
LATITUDE : 22.5N
YEAR : 1980
CALENDAR: 360_DAY

PyFerret (optimized) Ver.7.63
NOAA/PMEL TMAP
13-JAN-2026 14:24:24

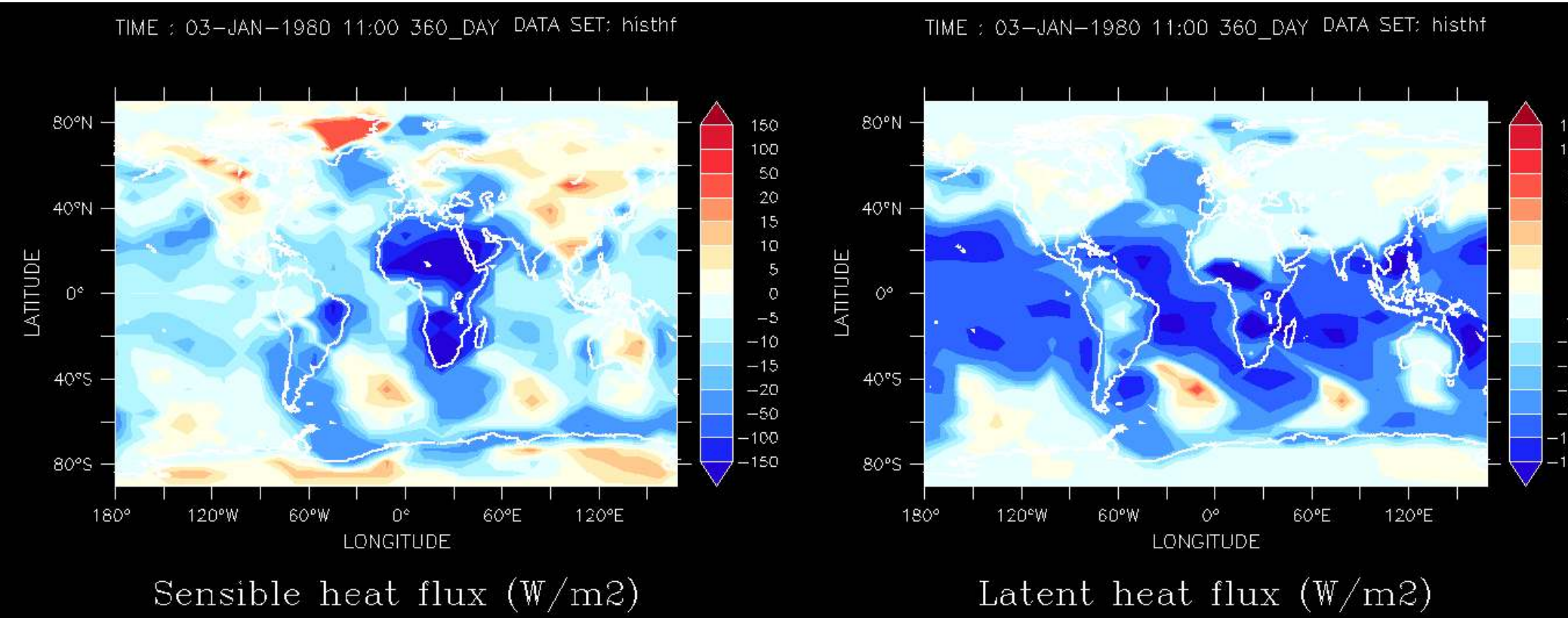
DATA SET: histhf



86400*DTVDF

Surface sensible heat flux : $H = \rho C_d ||V_h|| (T_s - T_1)$
Surface latent heat flux : $LE = \rho C_d ||V_h|| \beta (Q_s(T_s) - Q_1)$

```
reg/l=30  
set v ll ; fill/lev=(-Inf)(-150,-50,50)(-20,20,5)(50,150,50)(Inf)/pal=blue_darkred sens ; go land thick  
set v lr ; fill/lev=(-Inf)(-150,-50,50)(-20,20,5)(50,150,50)(Inf)/pal=blue_darkred flat ; go land thick
```



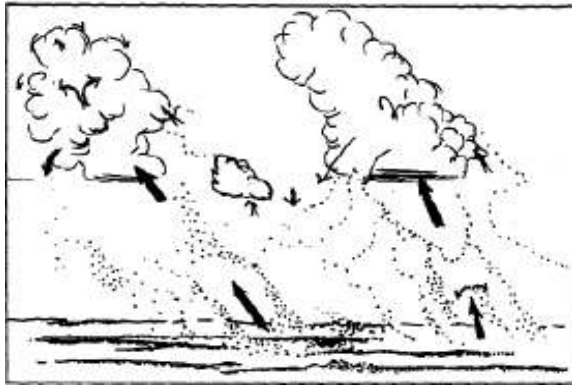
Parameterization of the convective boundary layer

Based on high resolution explicit (LES) simulations

Movie entirely based on physics : MesoNH LES and physical rendering with htrdr (Villefranque)



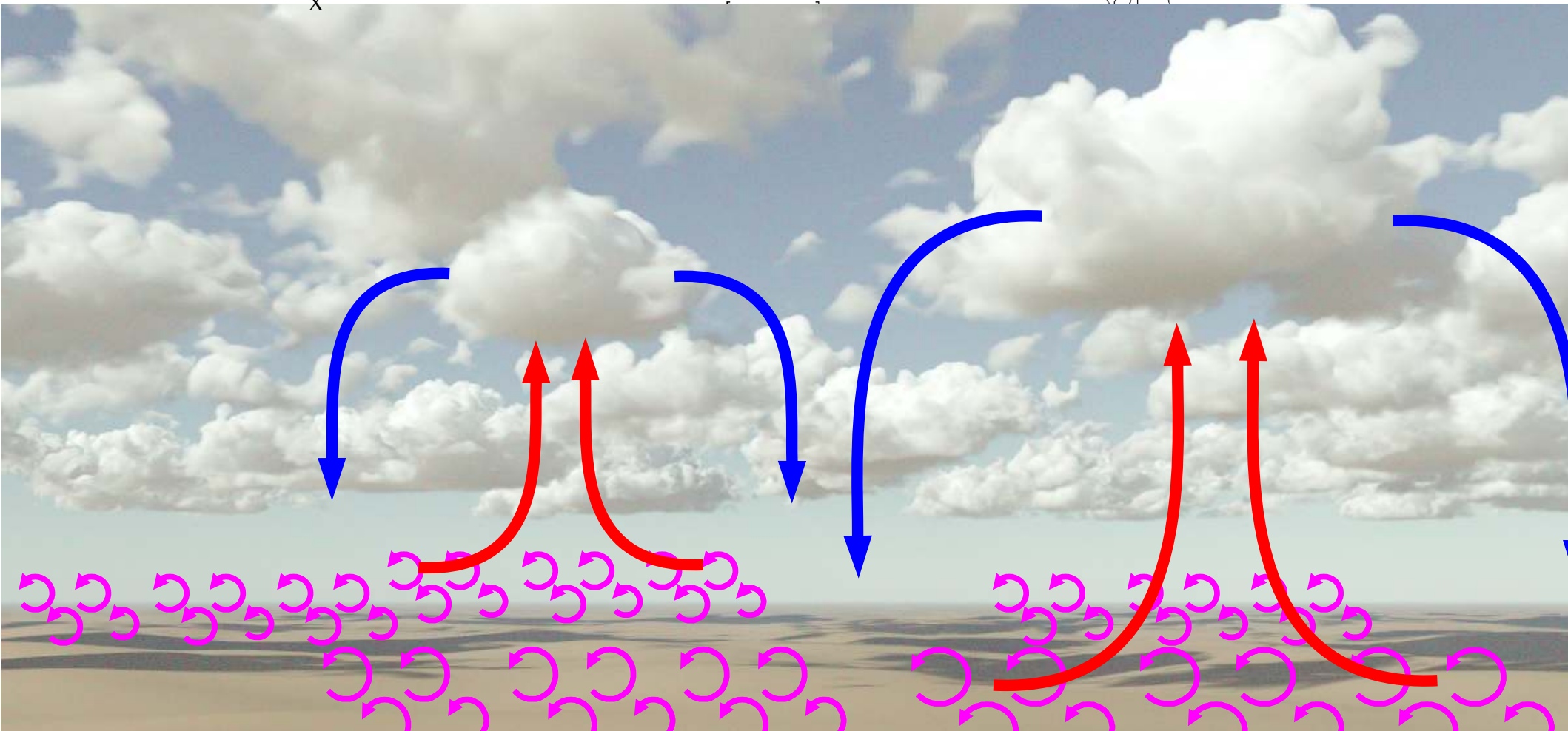
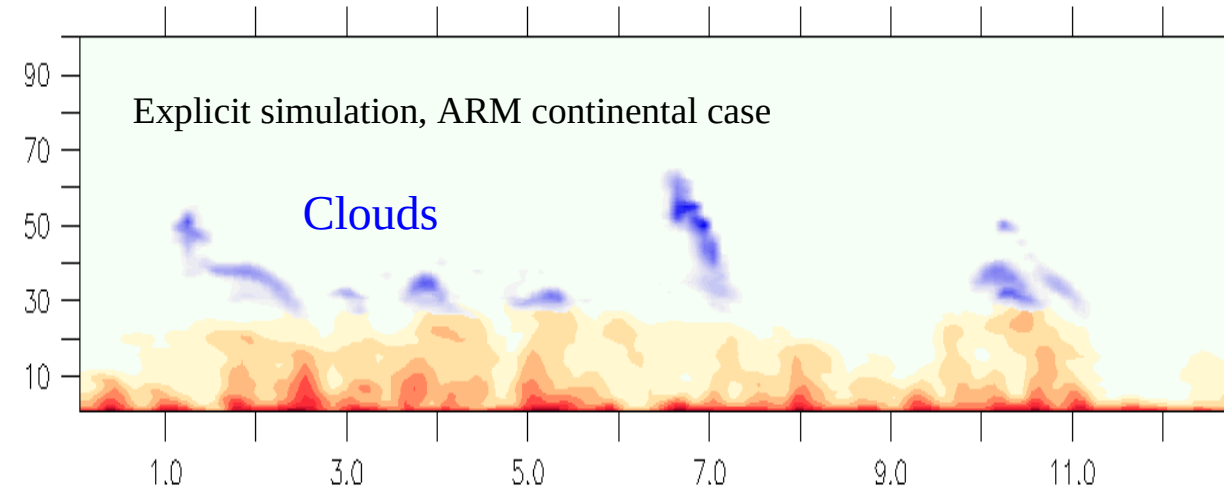
LeMone and Pennell, MWR, 1976

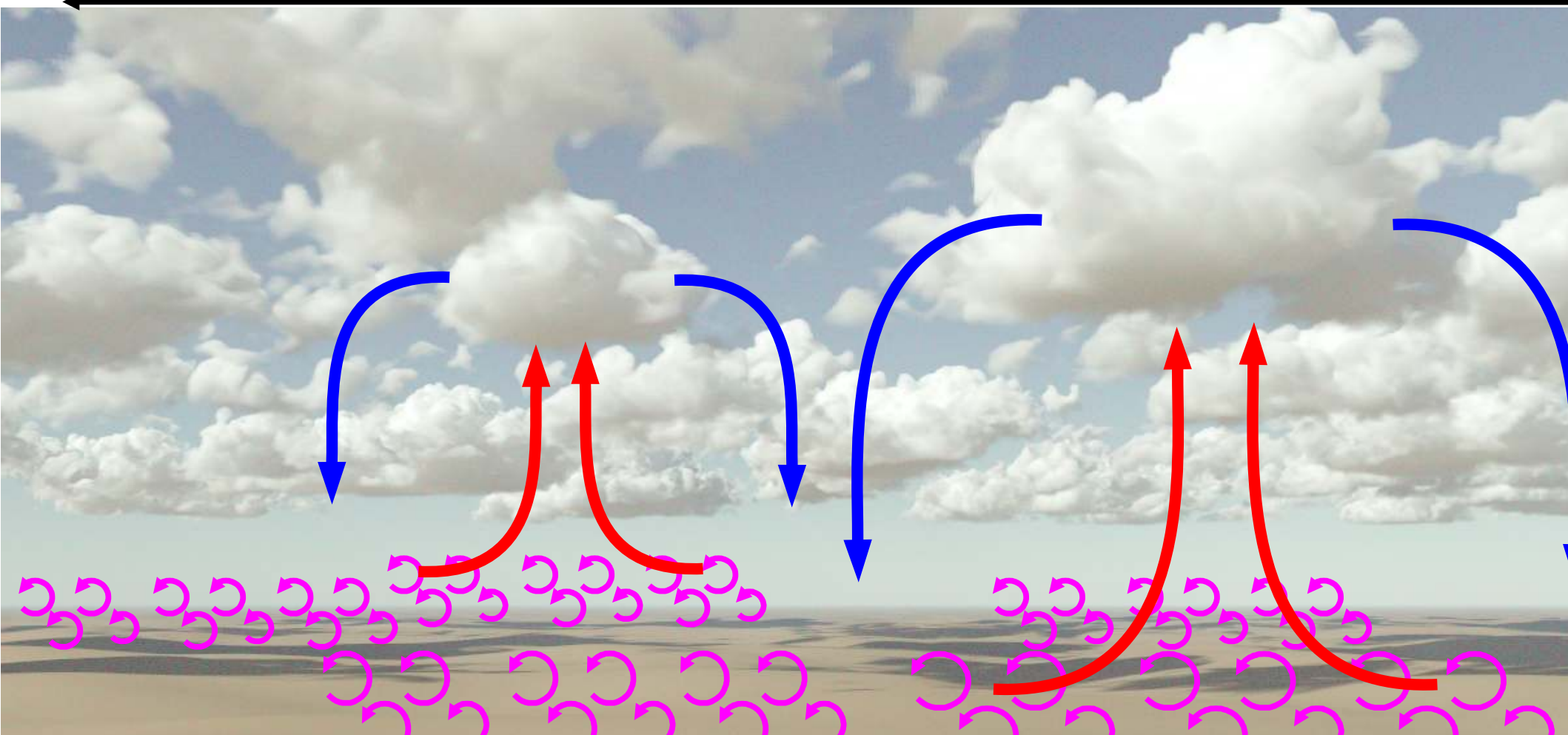
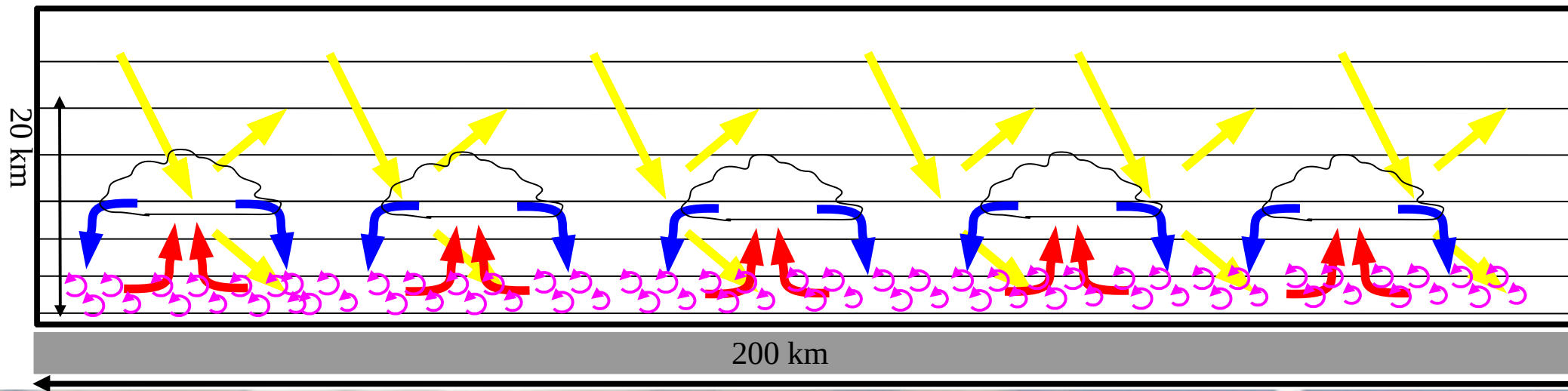


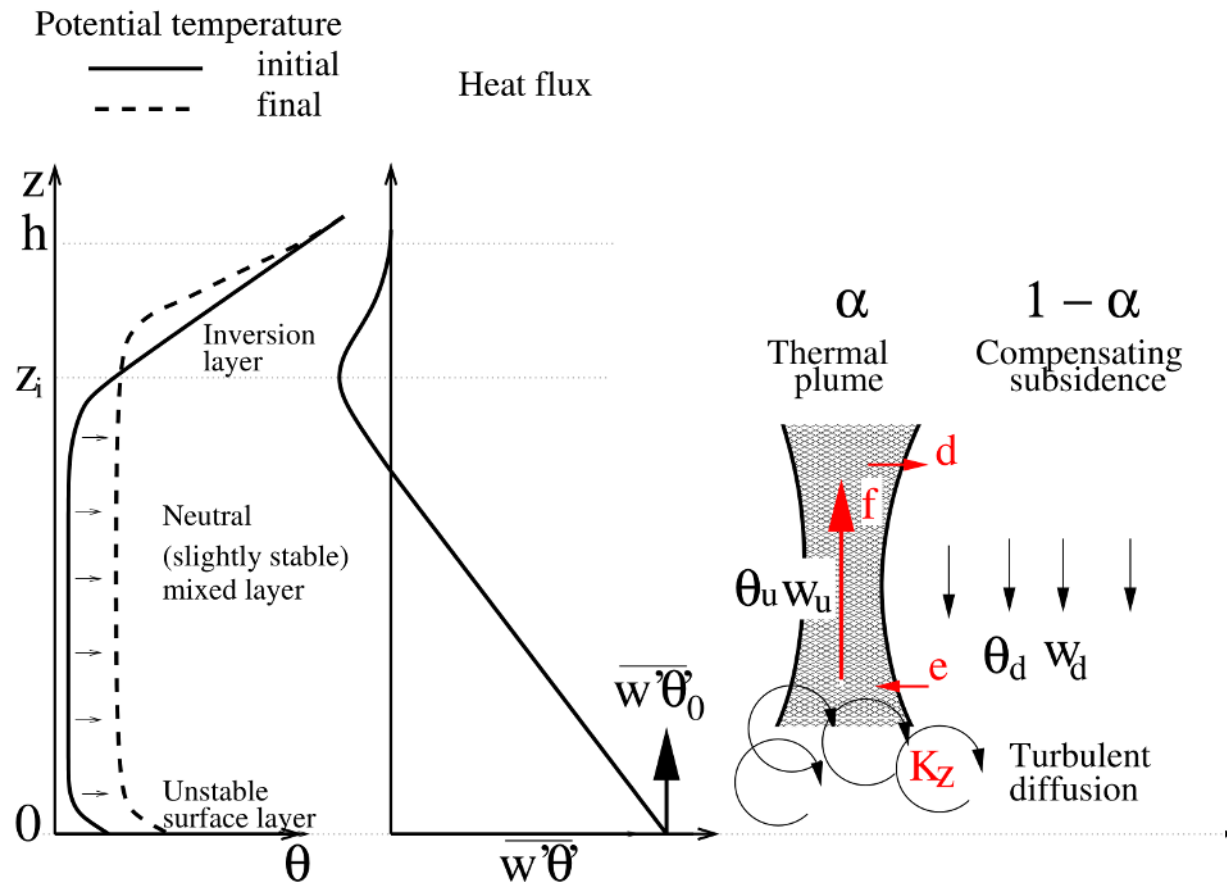
z

x

z (m)







Separation into 2 sub-columns :

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

ascending plume of mass u_x

$$f = \alpha \rho w_u$$

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

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

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

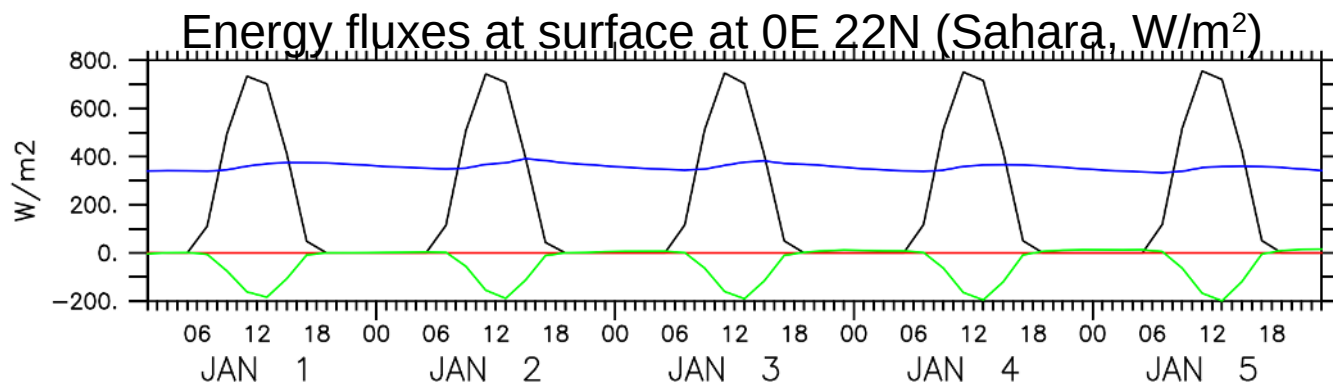
reg/x=0/y=22/l=1:60/k=28:39

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— SWDNSFC

— SENS

— FLAT

— LWDNSFC

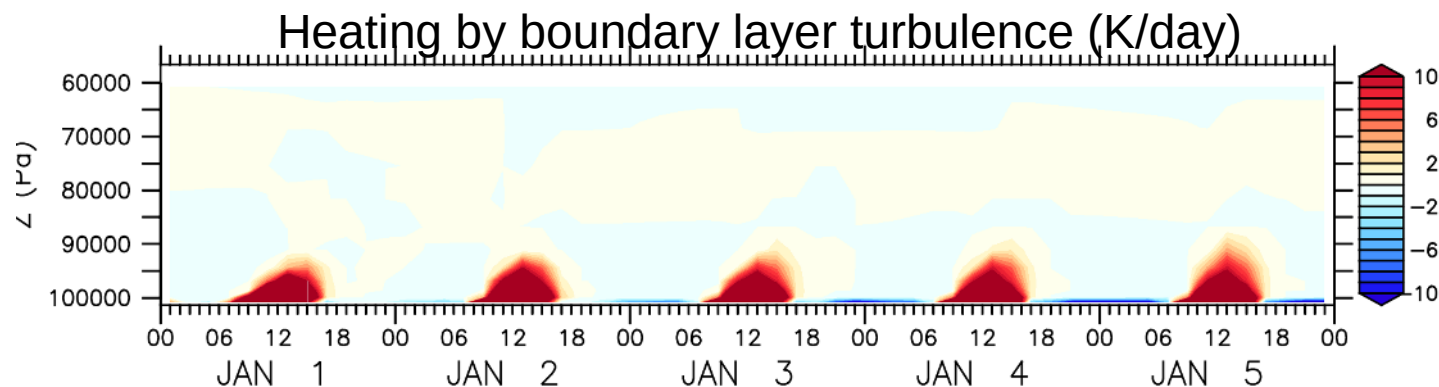
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13-JAN-2026 14:24:24

DATA SET: histhf



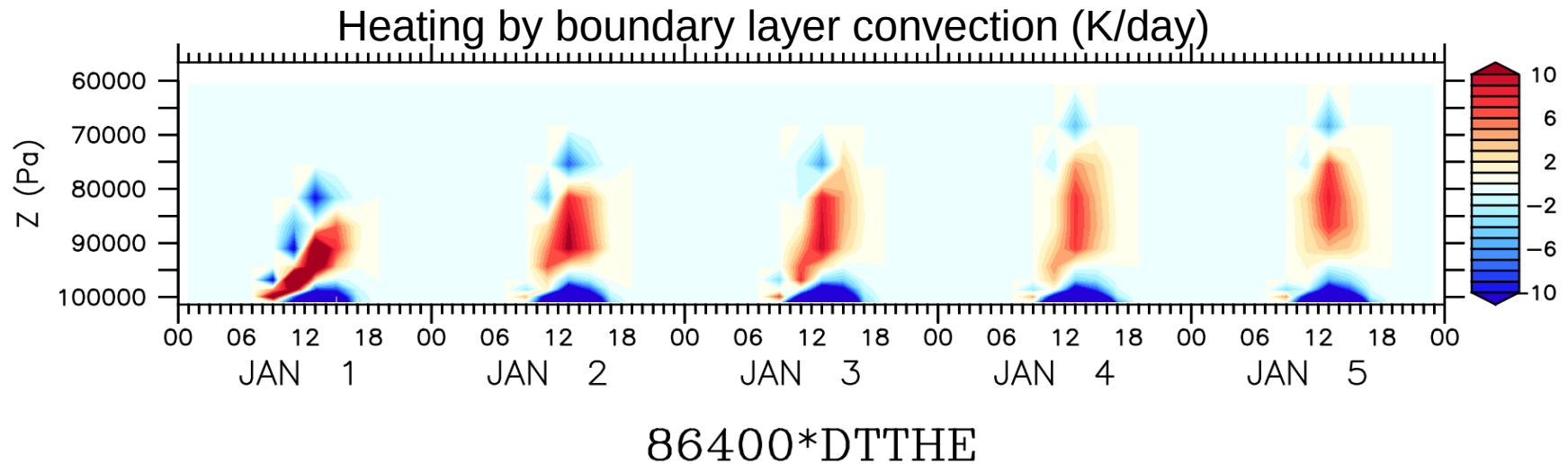
86400*DTVDF

set v upper

fill/k=25:39/lev=(-Inf)(-10,10,1)(Inf)/pal=blue_darkred 86400*dtthe

set v lower

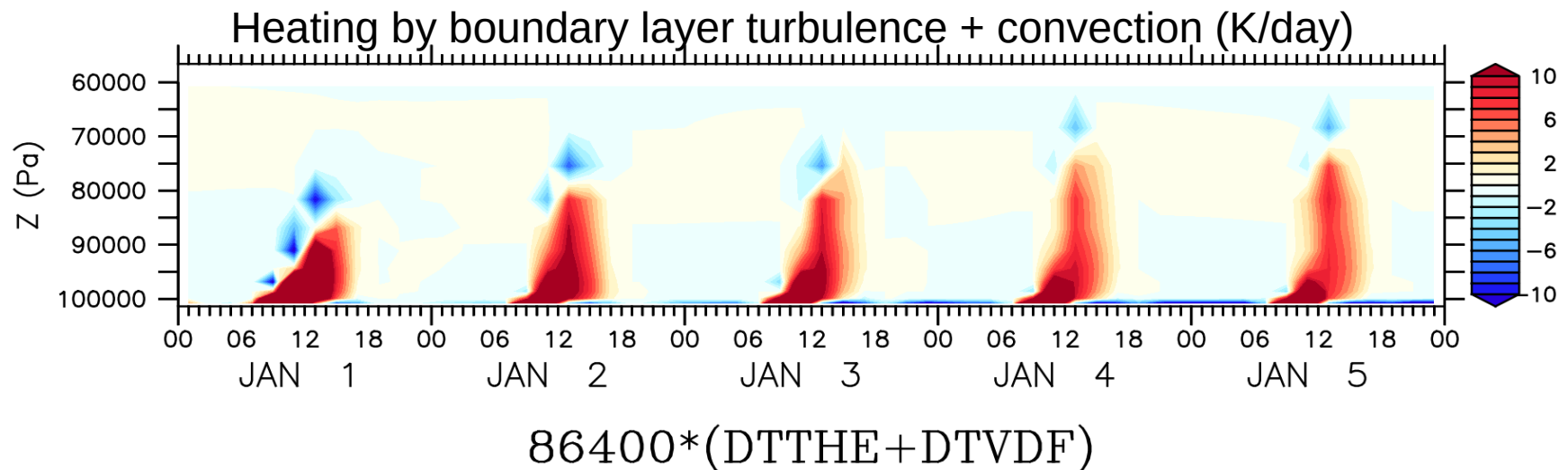
fill/k=25:39/lev=(-Inf)(-10,10,1)(Inf)/pal=blue_darkred 86400*(dtthe+dtvdf)

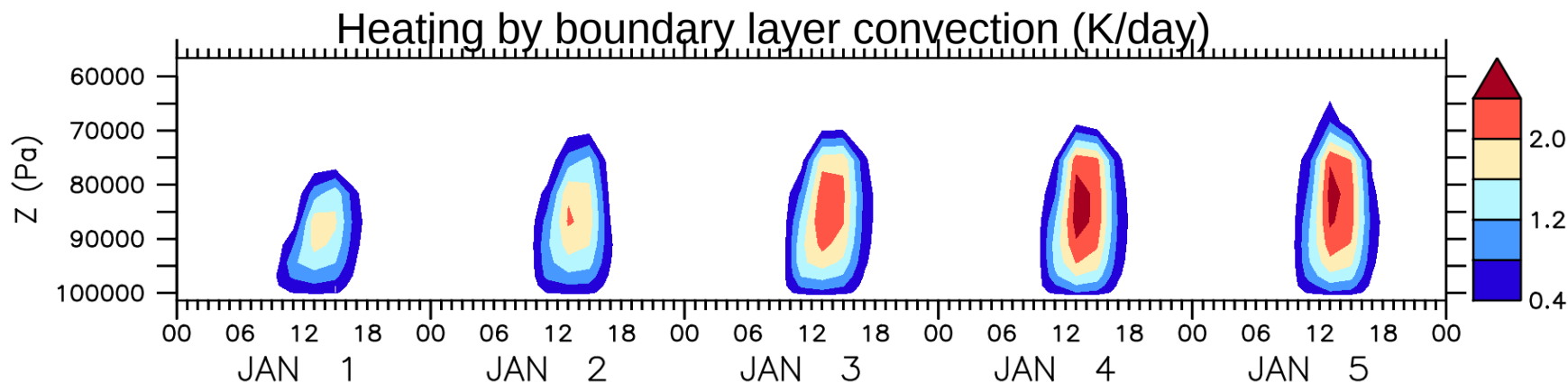


LONGITUDE : 0E
LATITUDE : 22.5N
YEAR : 1980
CALENDAR: 360_DAY

PyFerret (optimized) Ver.7.63
NOAA/PMEL TMAP
13-JAN-2026 14:25:41

DATA SET: histhf



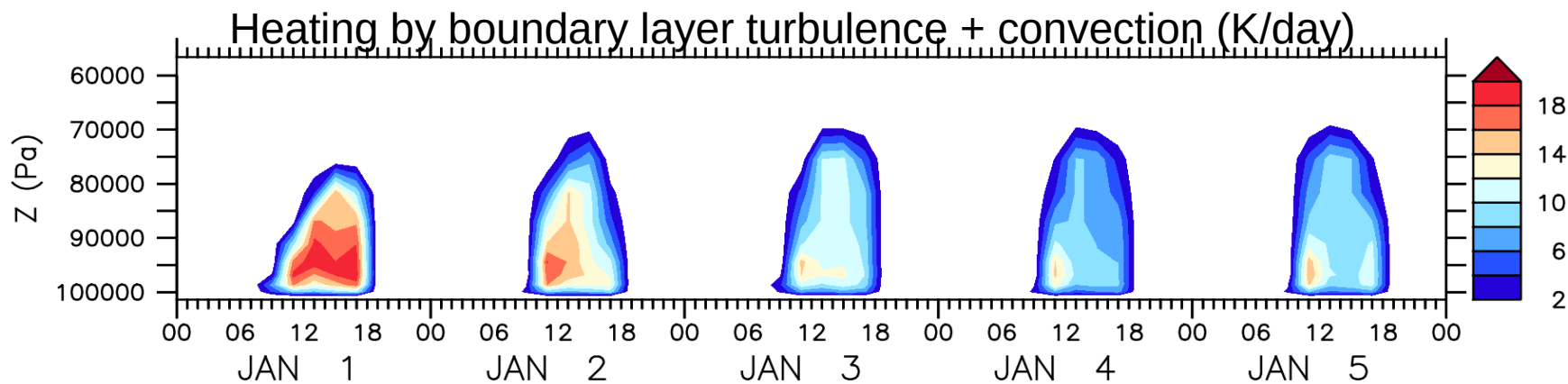


Thermal plume vertical velocity (m/s)

LONGITUDE : 0E
LATITUDE : 22.5N
YEAR : 1980
CALENDAR: 360_DAY

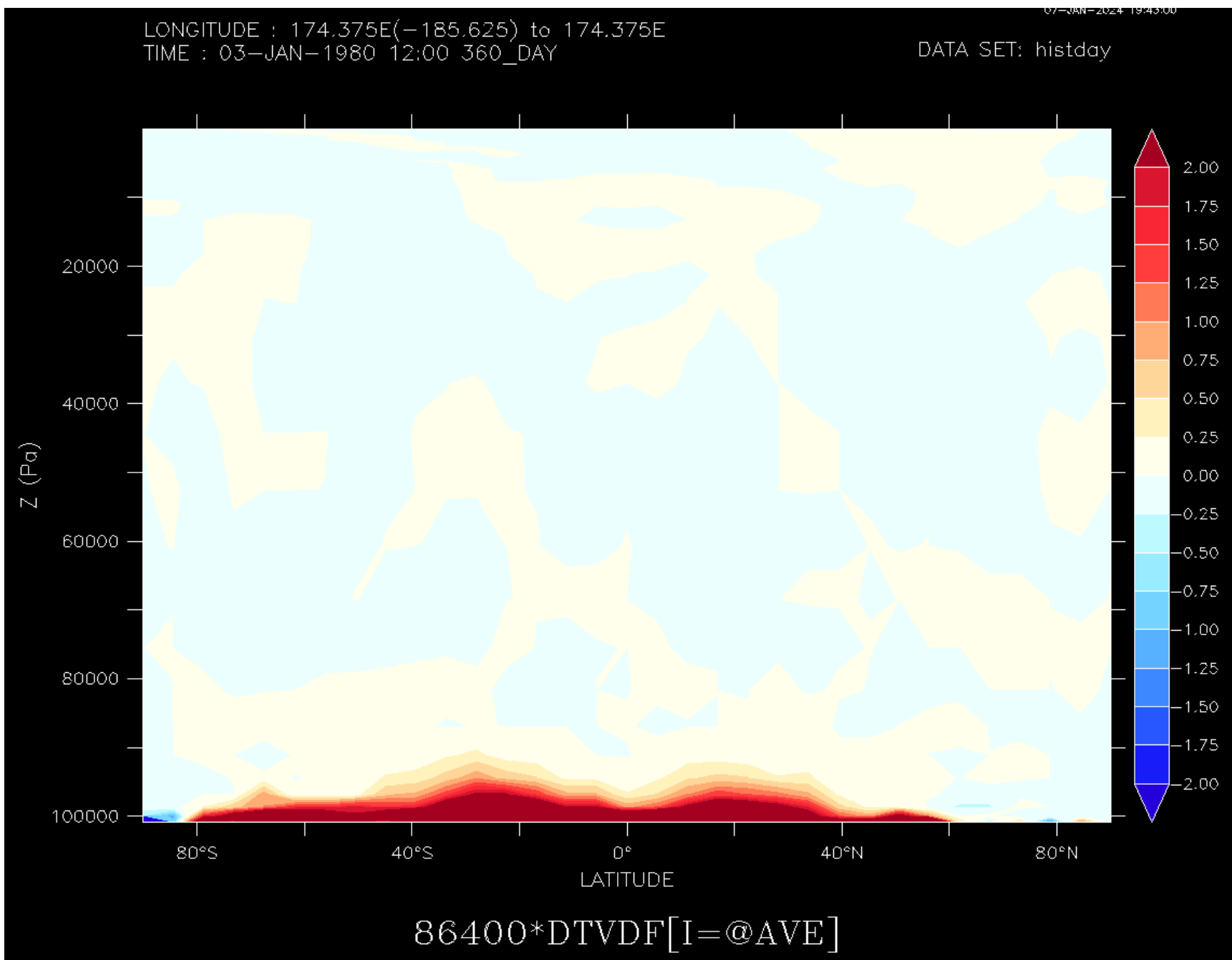
PyFerret (optimized) Ver.7.63
NOAA/PMEL TMAP
13-JAN-2026 14:27:07

DATA SET: histhf

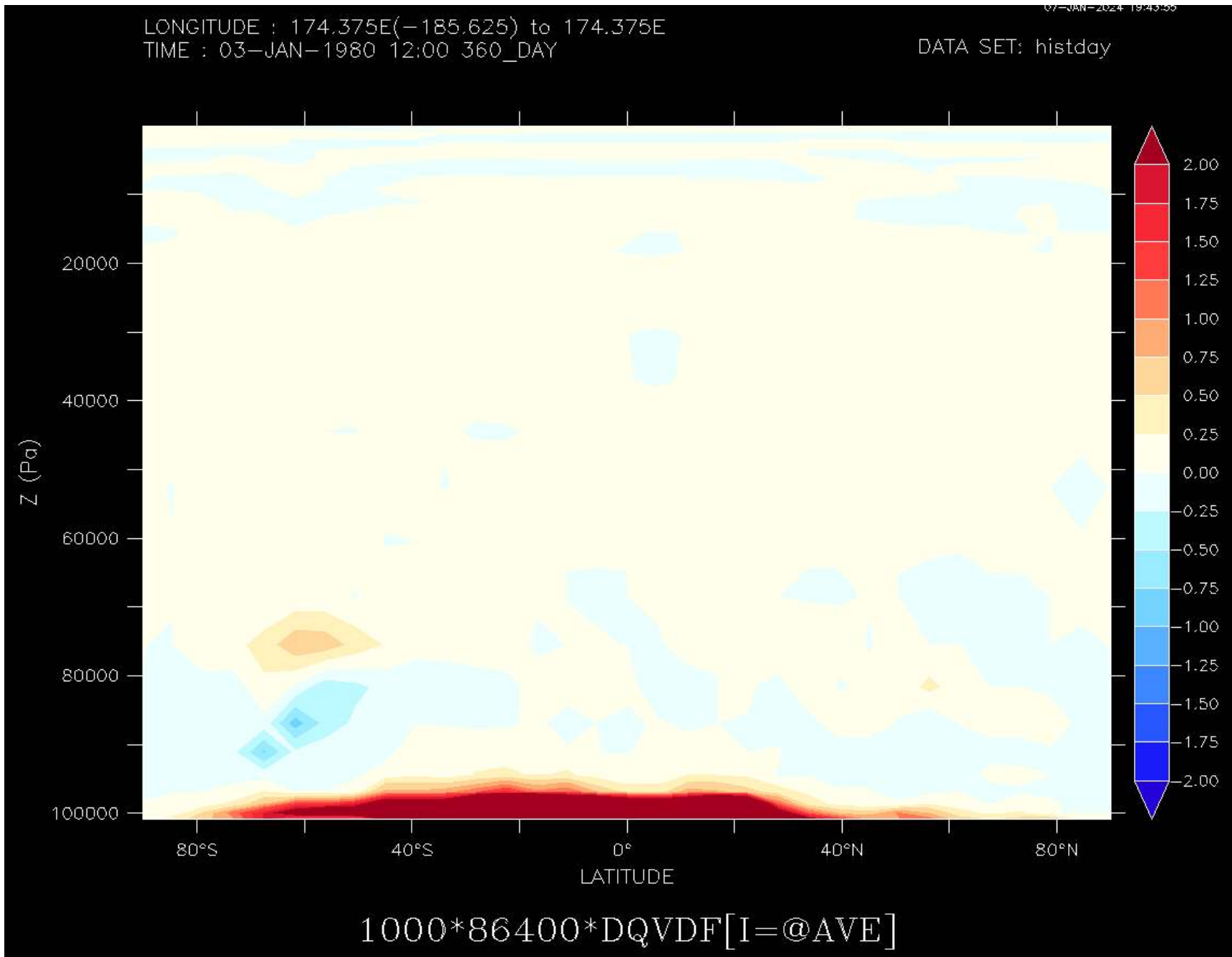


A_TH*100

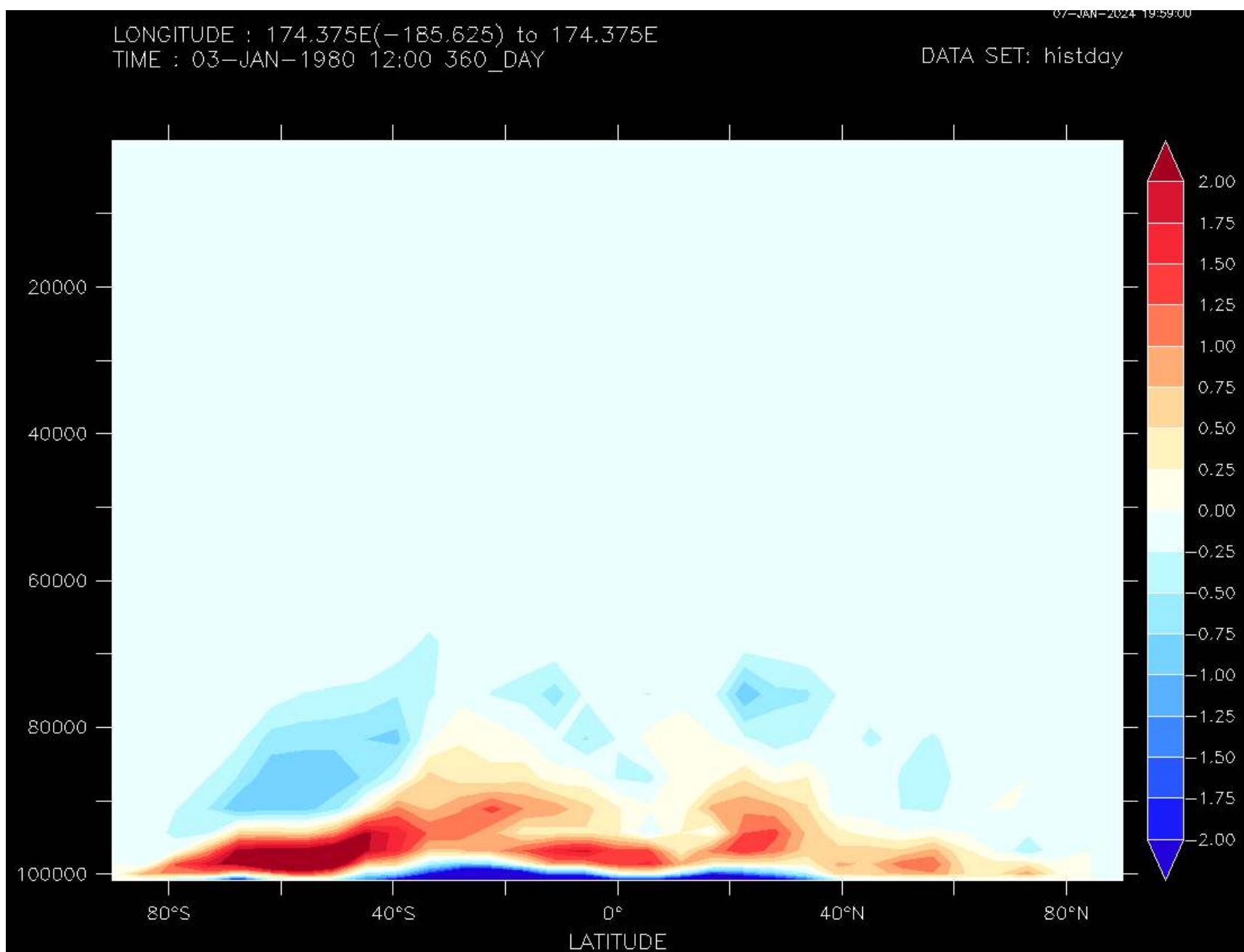
fill/lev=(-Inf)(-2,2,0.25)(inf)/pal=blue_darkred
86400*dtvdf[i=@ave]



fill/lev=(-Inf)(-2,2,0.25)(inf)/pal=blue_darkred 1000*86400*dqvdf[i=@ave]

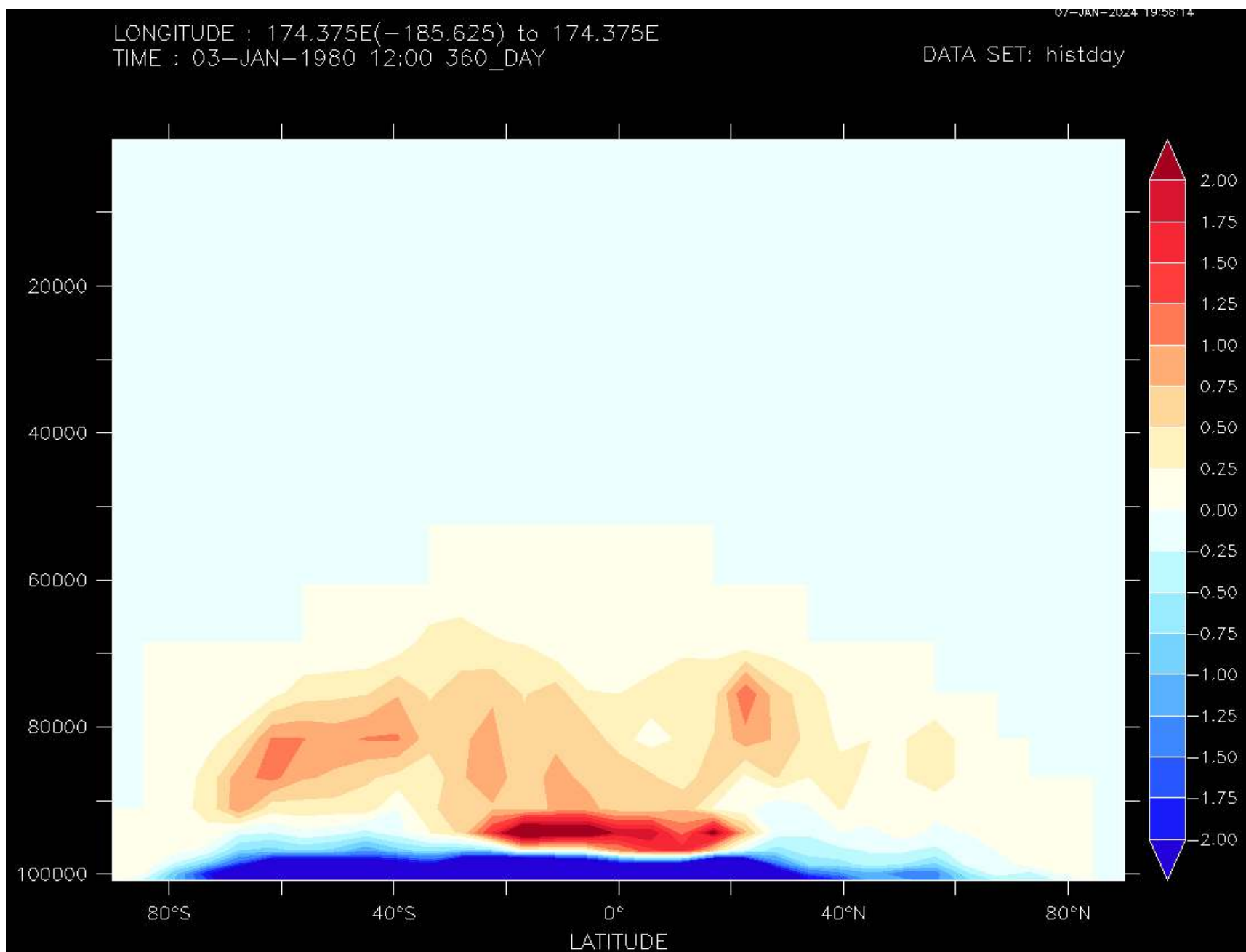


fill/lev=(-Inf)(-2,2,0.25)(inf)/pal=blue_darkred 86400*dtthe[i=@ave]



86400*DTTHE[I=@AVE]

fill/lev=(-Inf)(-2,2,0.25)(inf)/pal=blue_darkred 1000*86400*dqthe[i=@ave]



1000*86400*DQTHE[I=@AVE]

Parameterization of subgrid-scale orography

- Marine presentation

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

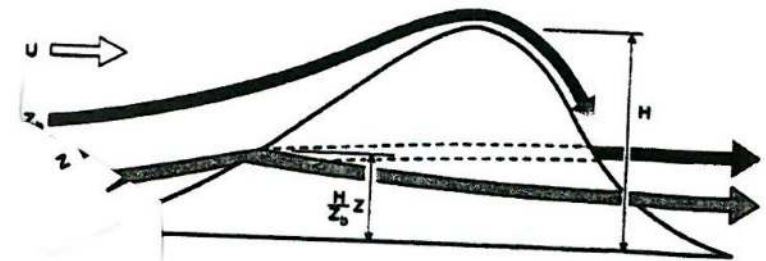
- At small H_n all the flow goes over the mountain, gravity waves are forced by the vertical motion of the fluid

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 $z < z_b$.

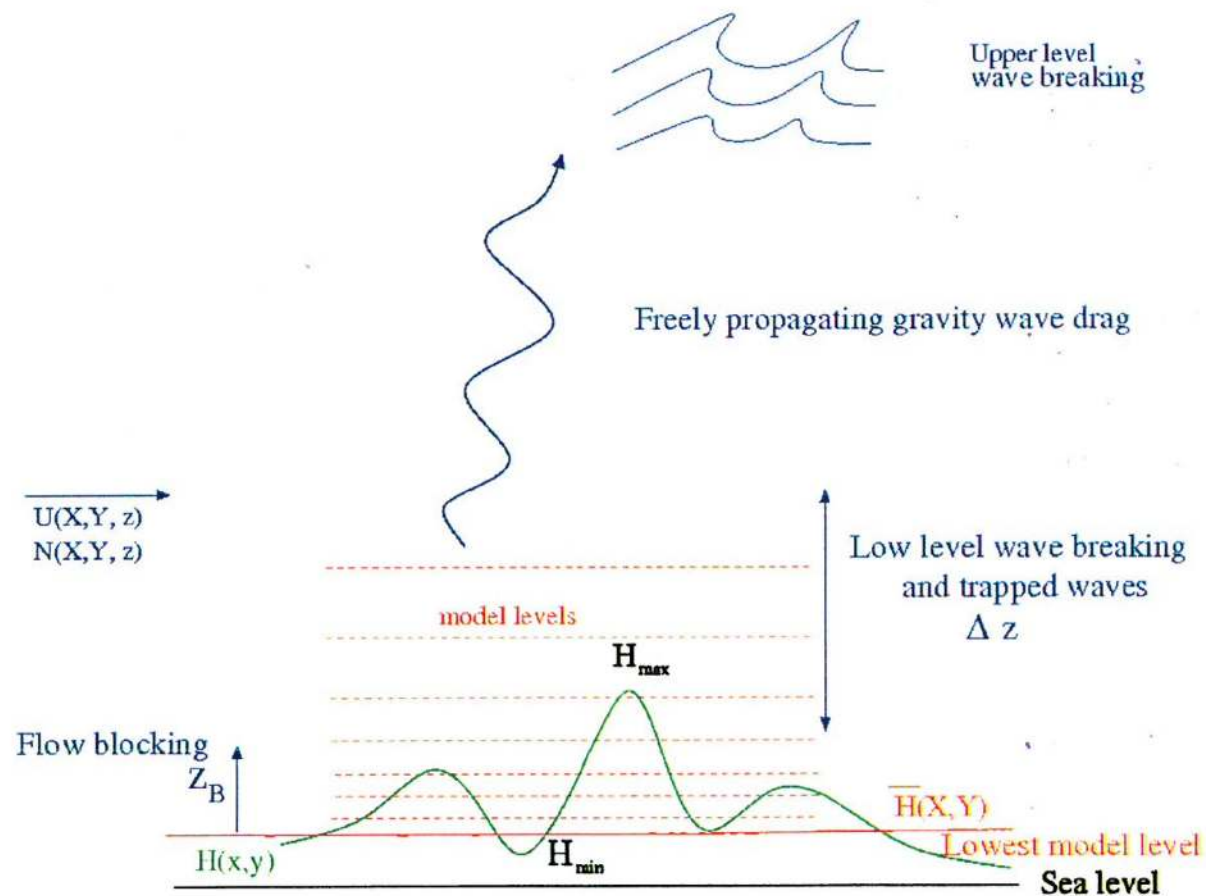
The surface stress is then : $\tau = \rho C_d z_b b U^2$



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

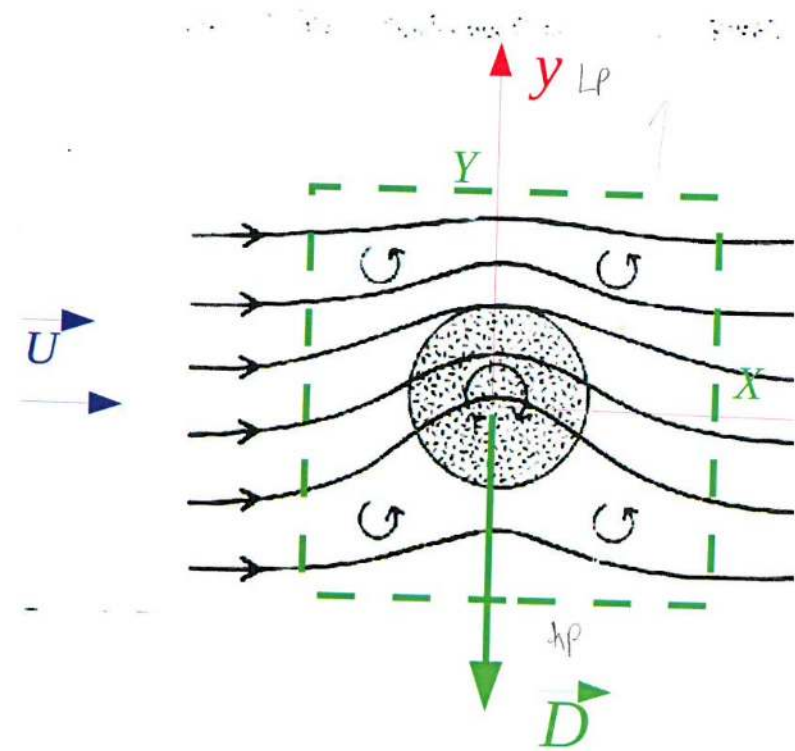
The lifting of the air over the mountain is balanced by the force acting on the mountain and then results in a push to the right (*Smith 1979*).

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.

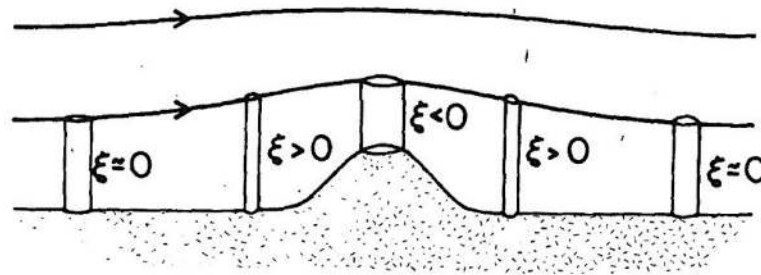


Conservation of potential vorticity for an adiabatic motion:

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

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.

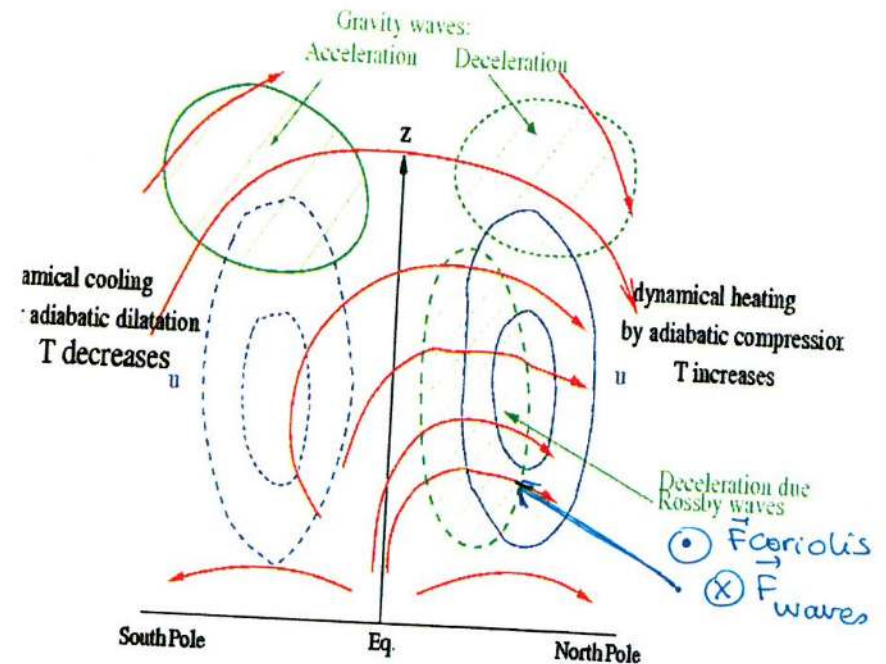
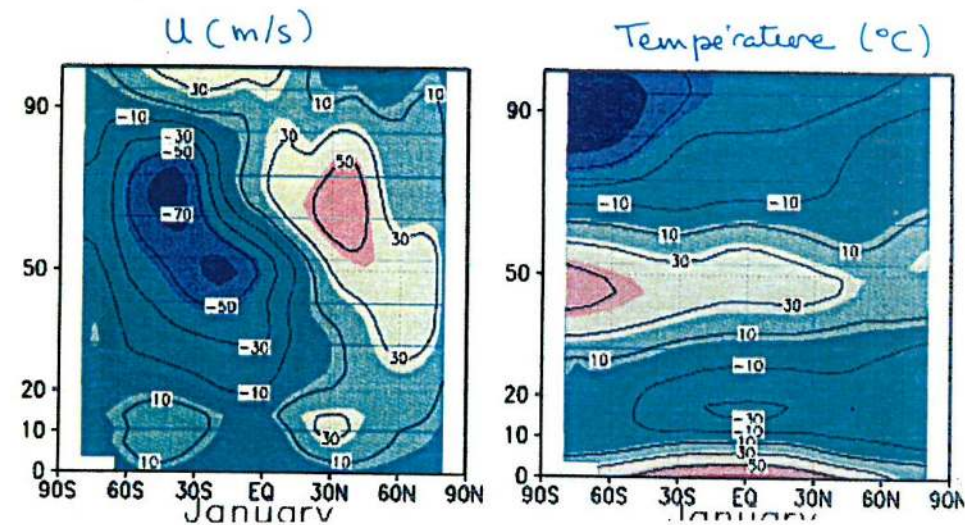
Gravity waves can propagate vertically and break.

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-Biennial Oscillation) and the mesosphere (changes in the zonal wind).

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.



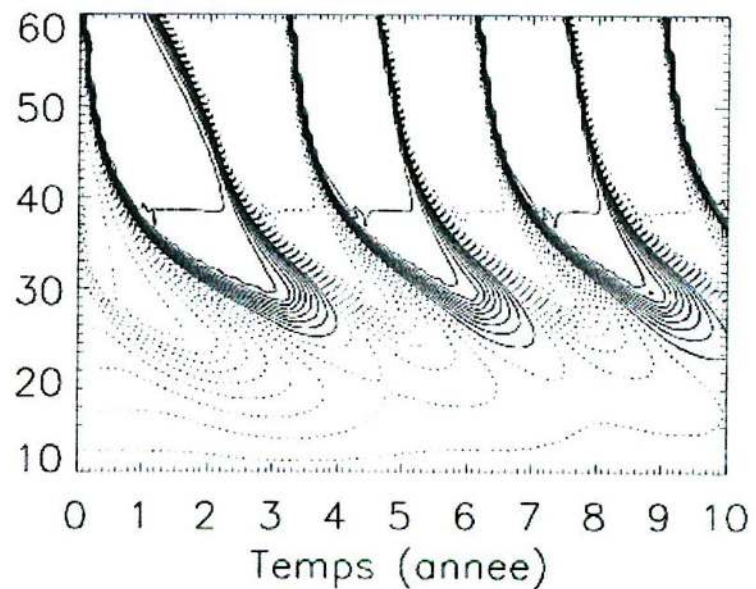
=> Quasi-Biennial Oscillation

Altitude de déferlement des ondes de gravité:-

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

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

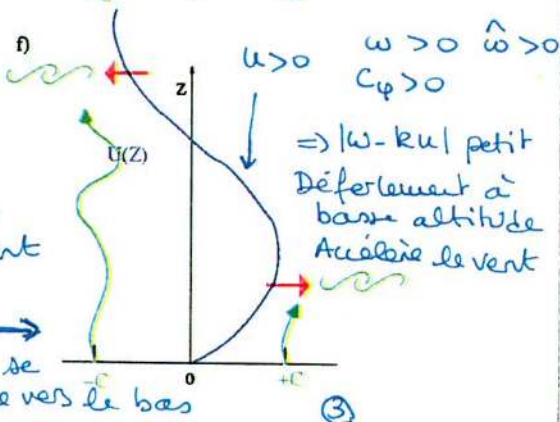
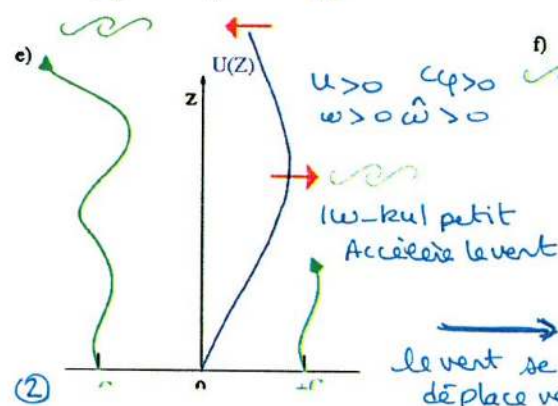
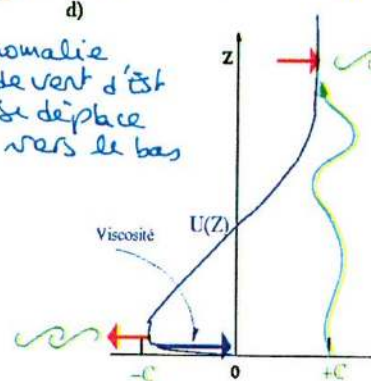
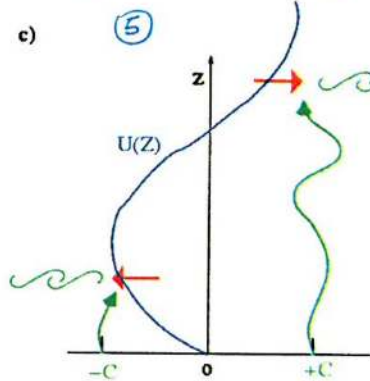
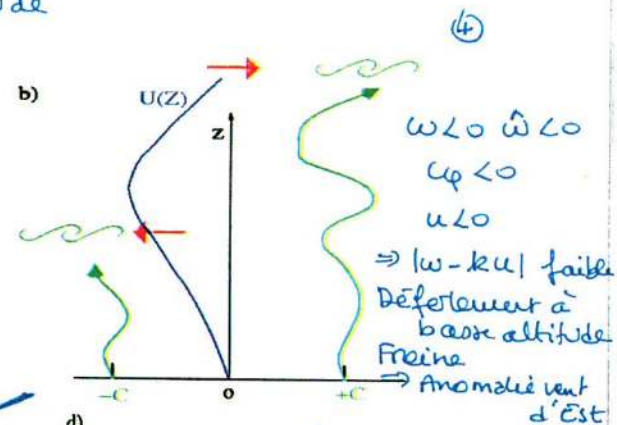
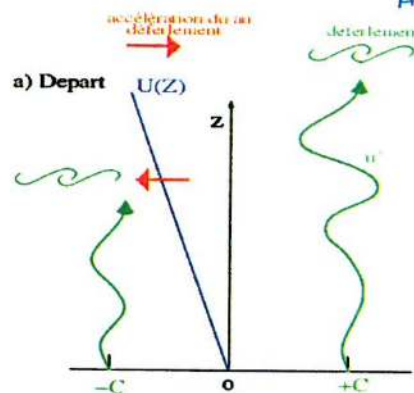
$\bar{u}$ (m/s)



① $\omega > 0 \quad \hat{\omega} > 0 \quad c_p > 0$

$u < 0 \Rightarrow |w - ku| \text{ grand}$

Pénétration de l'onde à haute altitude

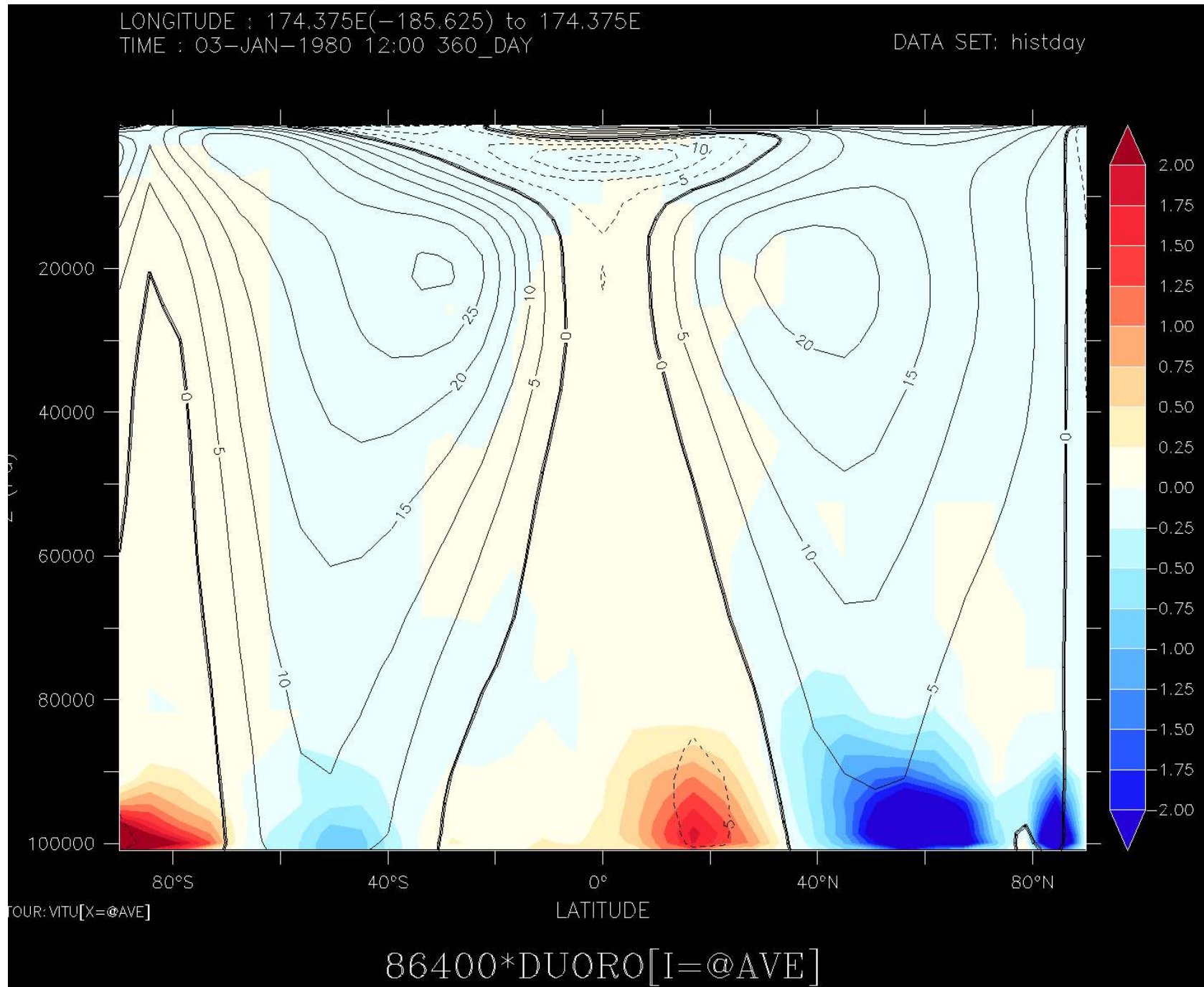


②

le vent se déplace vers le bas

③

fill/lev=(-Inf)(-2,2,0.25)(inf)/pal=blue_darkred 86400*duoro[i=@ave]
contour/o/color=white/lev=(-Inf)(-30,30,5) vitu[i=@ave]



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 :

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

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

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Output names
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as their name in
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 physiq_mod.f90

Specific humidity tendencies

Basic facts about parametrizations II

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

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

In the model, the total tendency of q is therefore

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

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

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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 *concul* (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 *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*

Subroutine structure

physiq_mod.F90 structure - I

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

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Orographic processes : drag *drag_noro_strato* or *drag_noro*

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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

Coupling with surface

Clouds and radiation

Today

Tomorrow

Radiation : output variables

Radiation I

Subroutine : radlsw

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

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

Radiation : control parameters

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 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
```

Turbulent diffusion : output variables

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

Turbulent diffusion : control parameters

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 stratoculus.  
# 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
```

Radiation : input parameters

In physiq.def (deepL translation)

```
#####
```

```
# 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  $z * (1 + \text{fact\_thermals\_ed\_dz})$  to  
compute
```

```
# training (A. Jam)
```

```
fact_thermals_ed_dz=0.07
```

Thermal plume model : output variables

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)