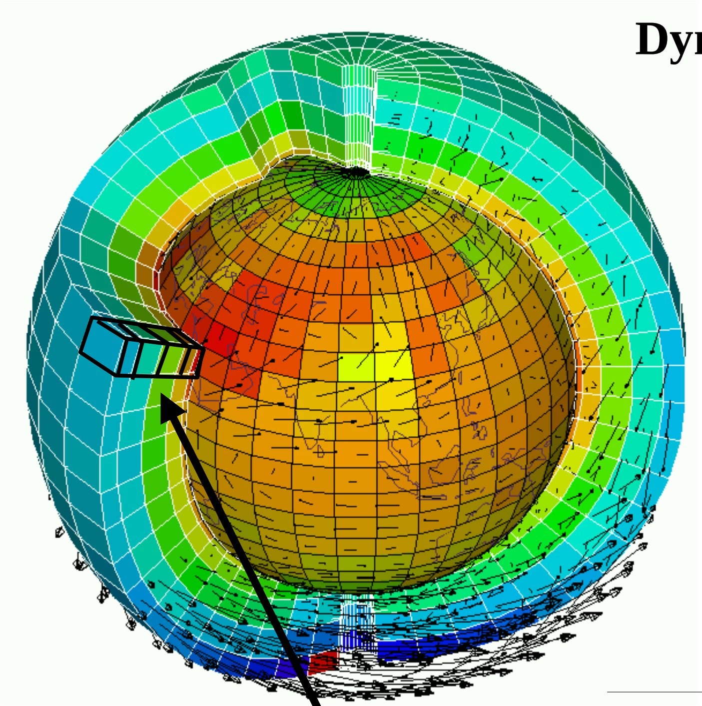
The physical parameterizations of LMDZ

LMDZ team
Laboratoire de Météorology Dynamique / IPSL / CNRS /SU
LMDZ training, January 2024

Part I : today (Frédéric presenting)
- **Principles**
- **Radiation (clear sky)**
- **Reynolds decomposition**
- **Turbulent diffusion**
- **Mass flux representation of the convective boundary layer**
- **Subgrid scale orography**
- **Practice**

Part II : tomorrow (Jean-Baptiste presenting)
- **Convection**
- **Clouds**



Dynamical core : primitive equations discretized on the sphere

- Mass conservation

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

- Potential temperature conservation

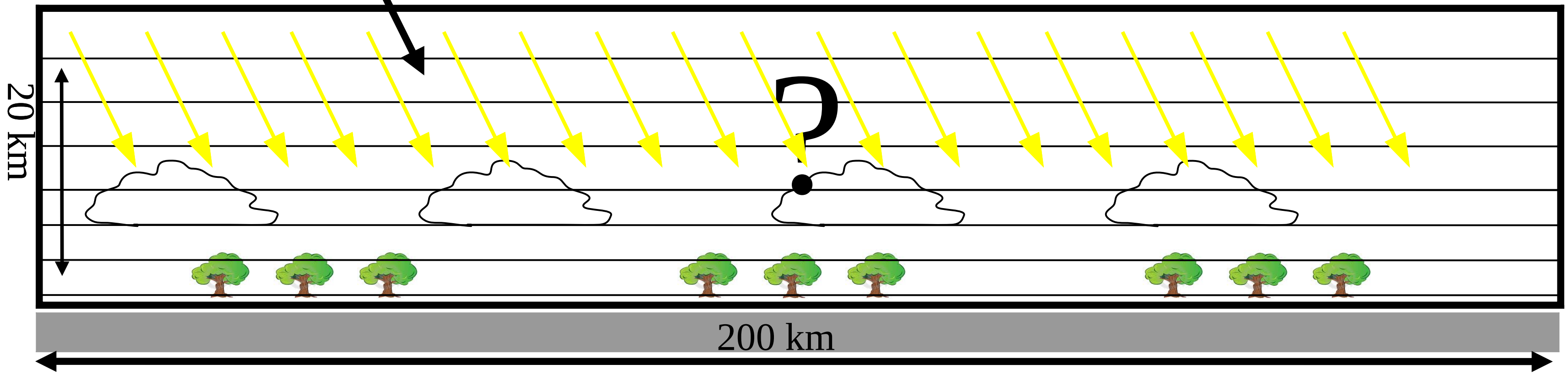
  $D\theta\ /\ Dt = Q\ /\ Cp\ \ (p0/p)^{\kappa}$

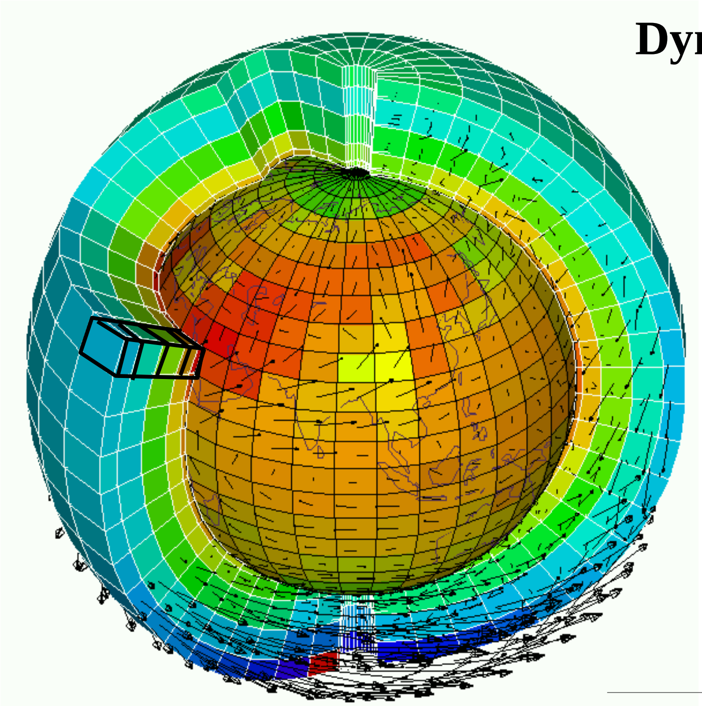
- Momentum conservation

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

- 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)**

Model tendencies

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

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

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

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

```
reg/l=3
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vector/o/l=3/col=14 vitv[i=@ave],-100*vitw[i=@ave]
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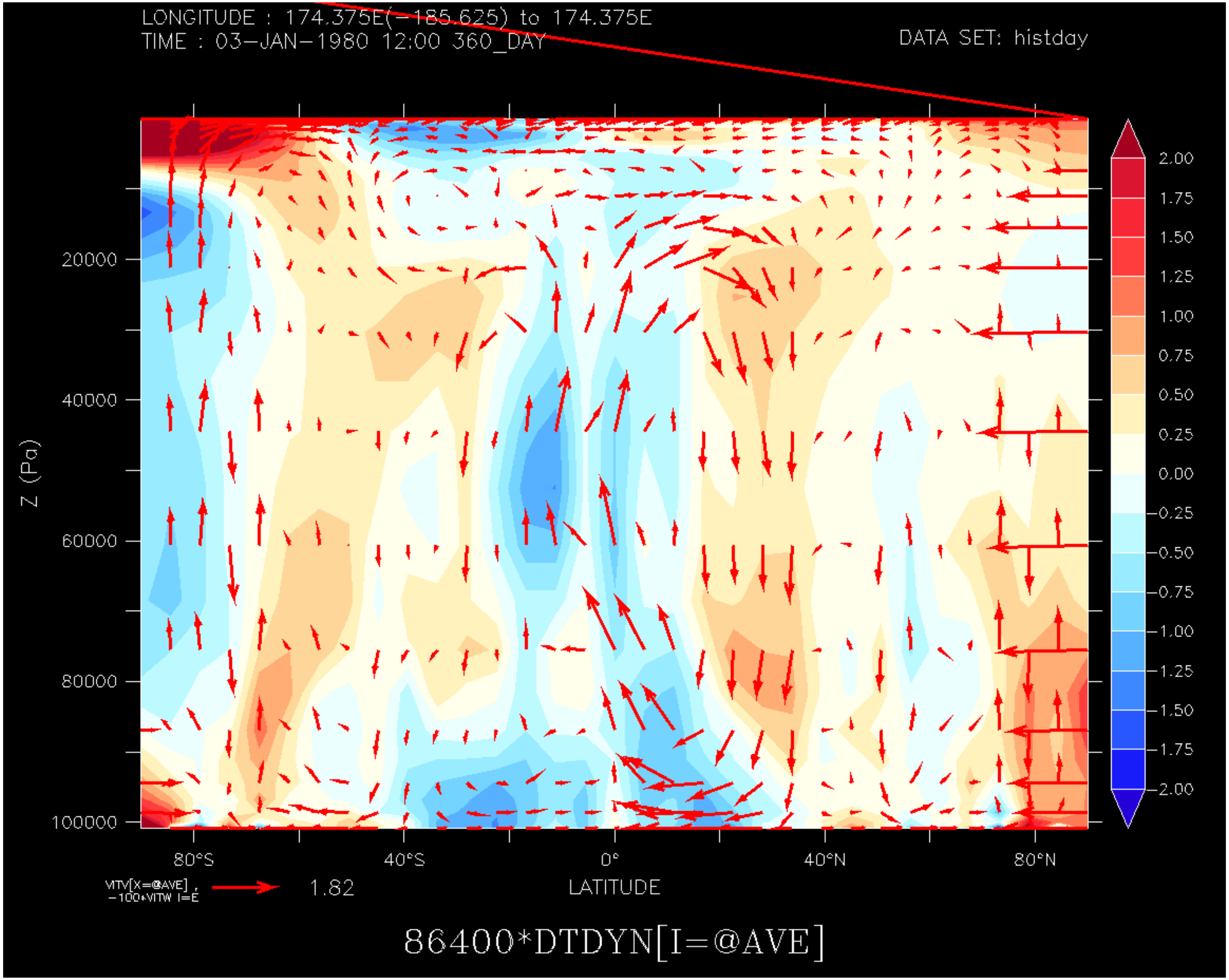

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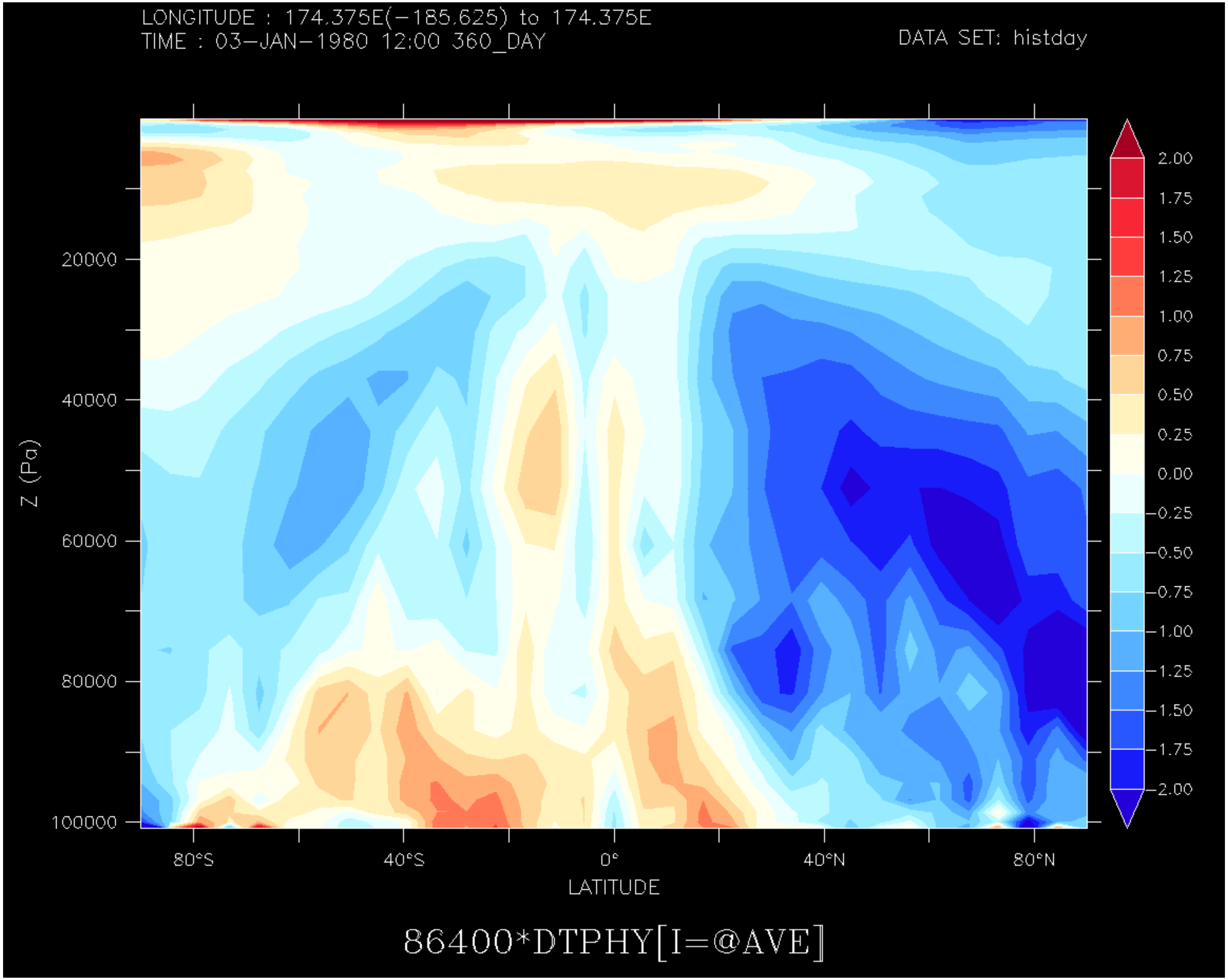
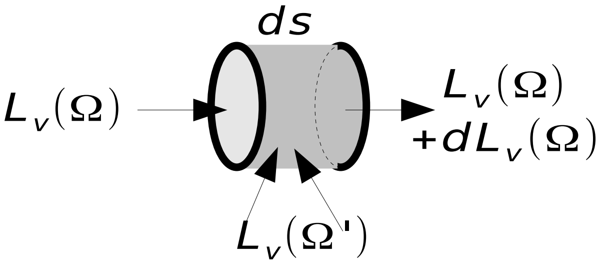


Parameterization of radiative transfer



Radiative transfer : well known equations ...
Giving the evolution of luminance along a line of sight:

$$\frac{dL_\nu(\Omega)}{ds} = \underbrace{-\kappa_\nu L_\nu(\Omega)}_{\textbf{absorption}} + \underbrace{\kappa_\nu B_\nu(T)}_{\textbf{emission}} - \underbrace{\sigma_\nu L_\nu(\Omega)}_{\textbf{Scattered in other directions}} + \underbrace{\sigma_\nu \frac{1}{4\pi}\int_{4\pi} P(\Omega',\Omega) L_\nu(\Omega')\, d\Omega'}_{\textbf{Scattered from other directions}}$$

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

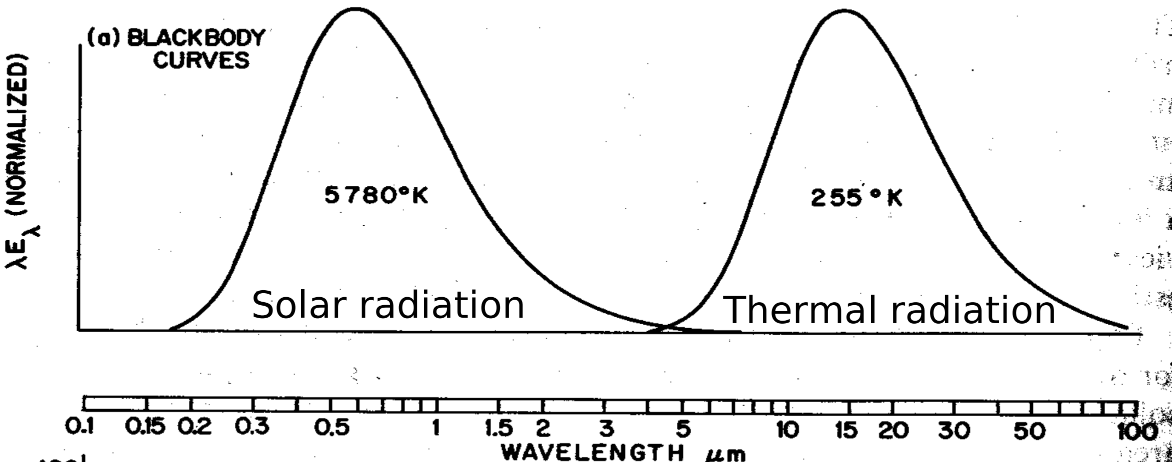
Computing radiation for one full scene with reference methods for the spectral integration (line-by-line) and angular (discrete ordinates, Monte-Carlo) integrations, even for a plan parallel atmosphere without clouds, may take hours of CPU hours on super computers.

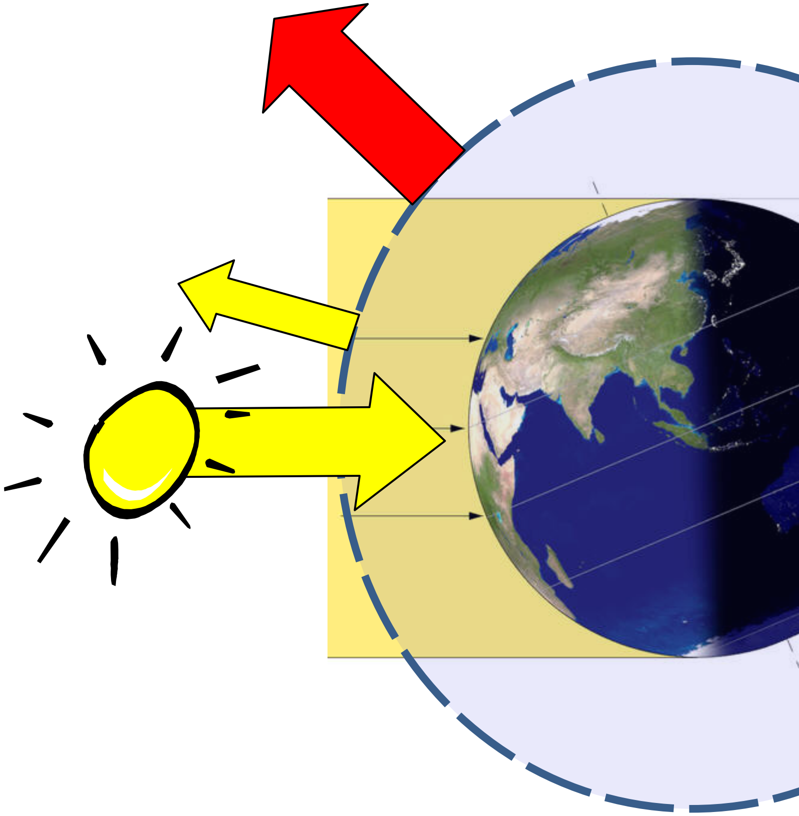
In LMDZ : using codes developed and used at ECMWF
3 codes avec des mots clé : **oldrad / rrtm / ecrad**

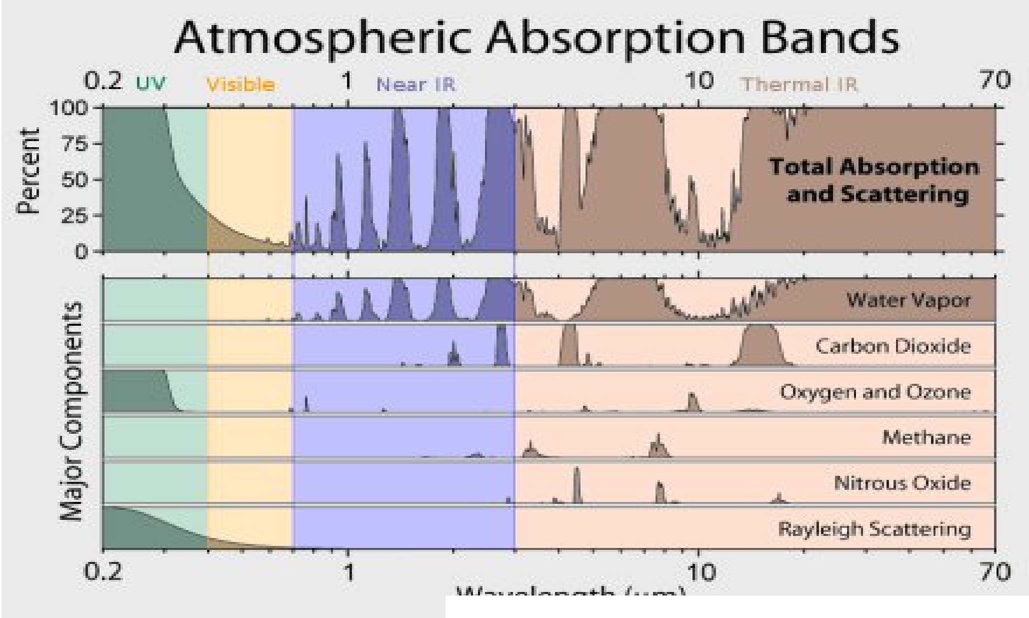
ECrad can be seen as a tool box with various options for :
Spectral integration : **S/RRTM or ECCKD**
Solver : **McICA, Tripleclouds or Spartacus**

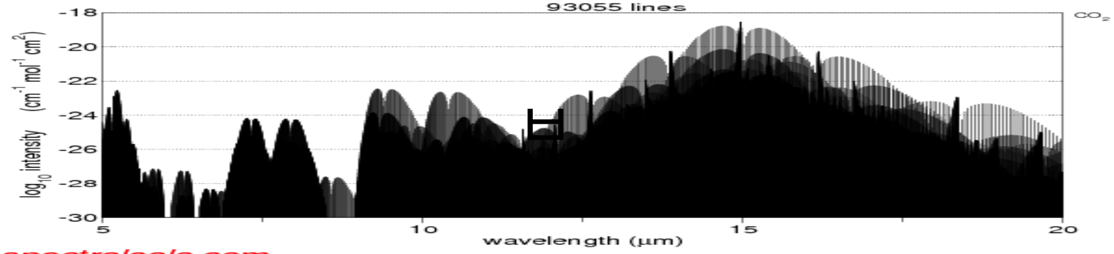
Spectral : separating radiation between solar and thermal infrared

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 N2 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.

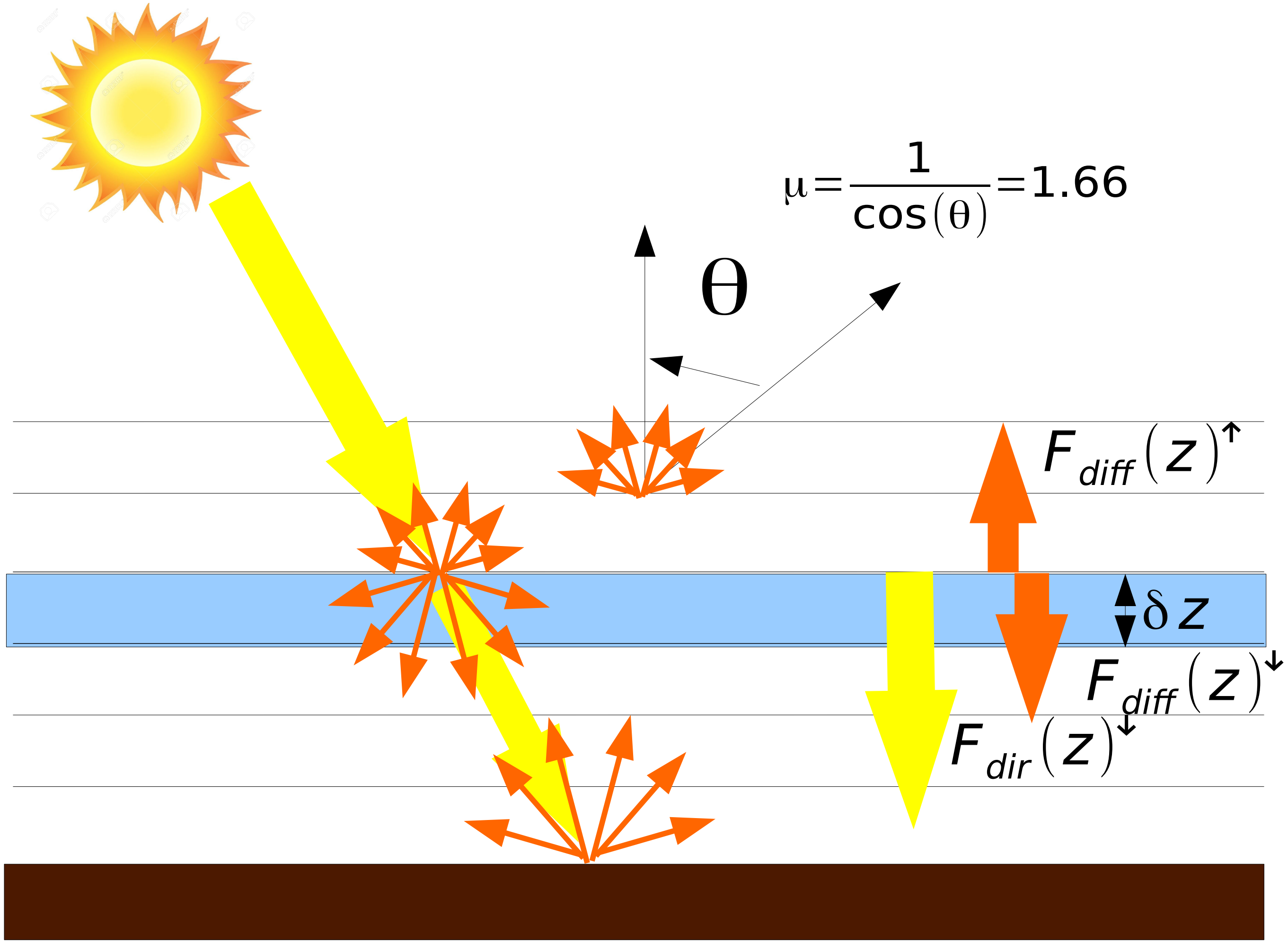
Name in .def files	SW	LW
oldrad	2 bands	6 bands
rrtm	6 bands	K-distributions (RRTM)
ecrad	K-distributions (SRTM) ECCKD	K-distributions (RRTM) ECCKD

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-Eddigton approximation for scattering by strongly asymmetric phase functions



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

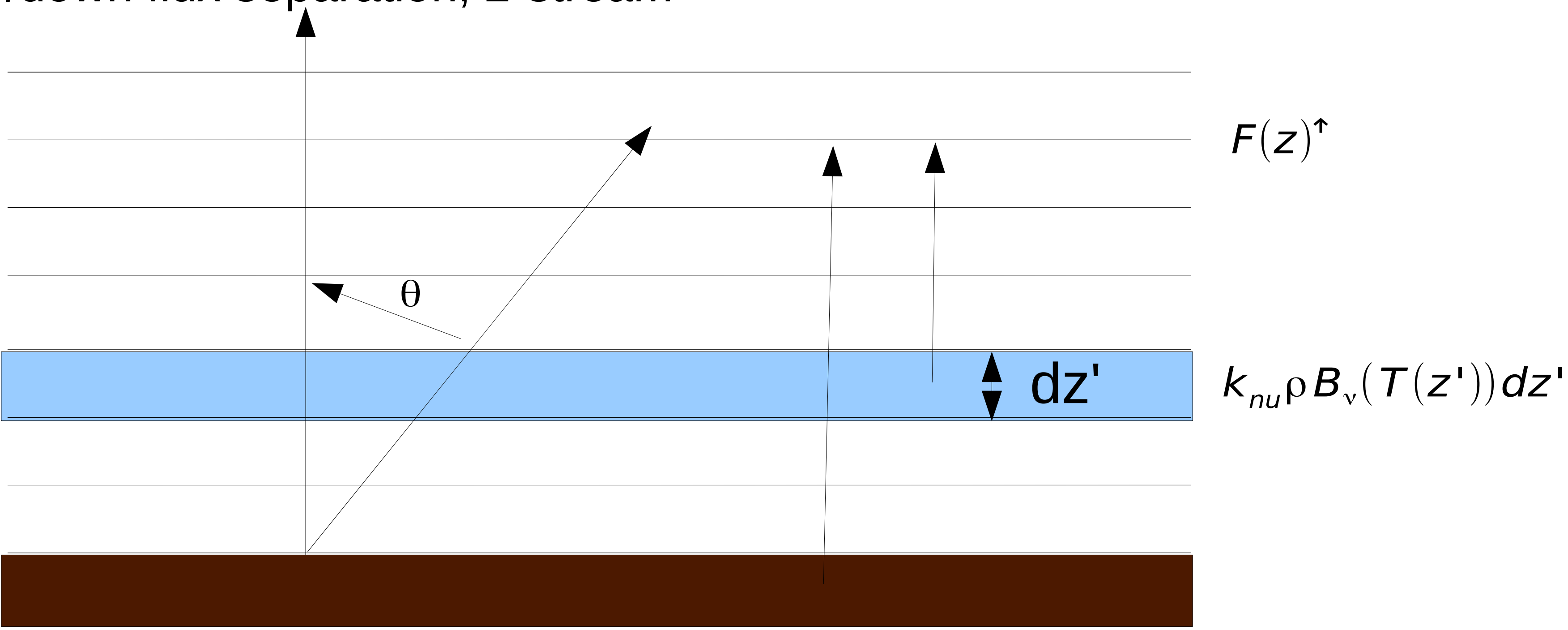
$$F(z)^{\uparrow}$$

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

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

Infrared, non-scattering case

Plane parallel approximation: homogeneous semi-infinite space
Diffuse" approximation
Up/down flux separation, 2-stream



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

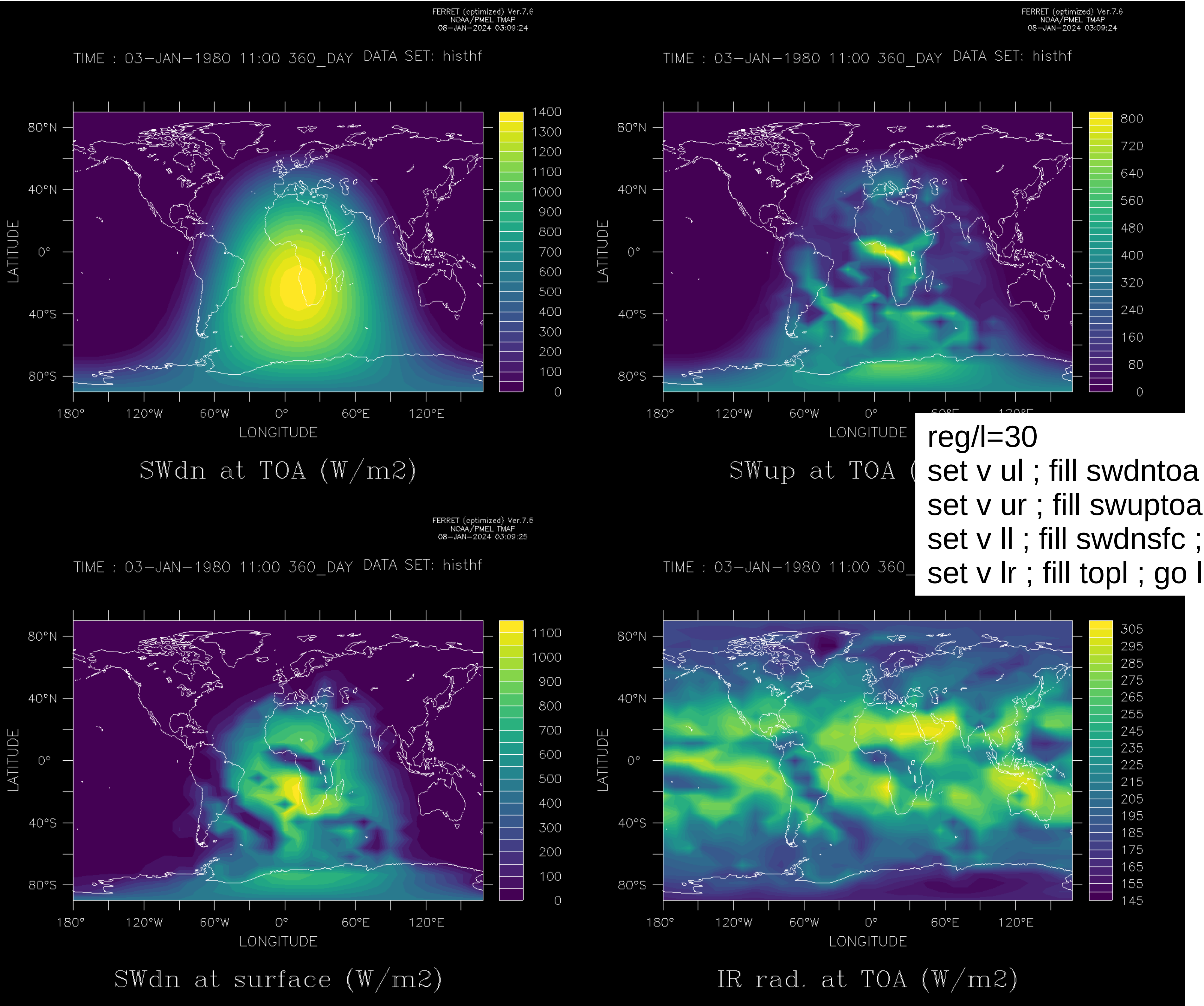
$$\mu=\frac{1}{\cos(\theta)}=1.66$$

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

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

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

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



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reg/l=30
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set v ur ; fill swuptoa ; go land
set v ll ; fill swdnsfc ; go land
set v lr ; fill topl ; go land
```

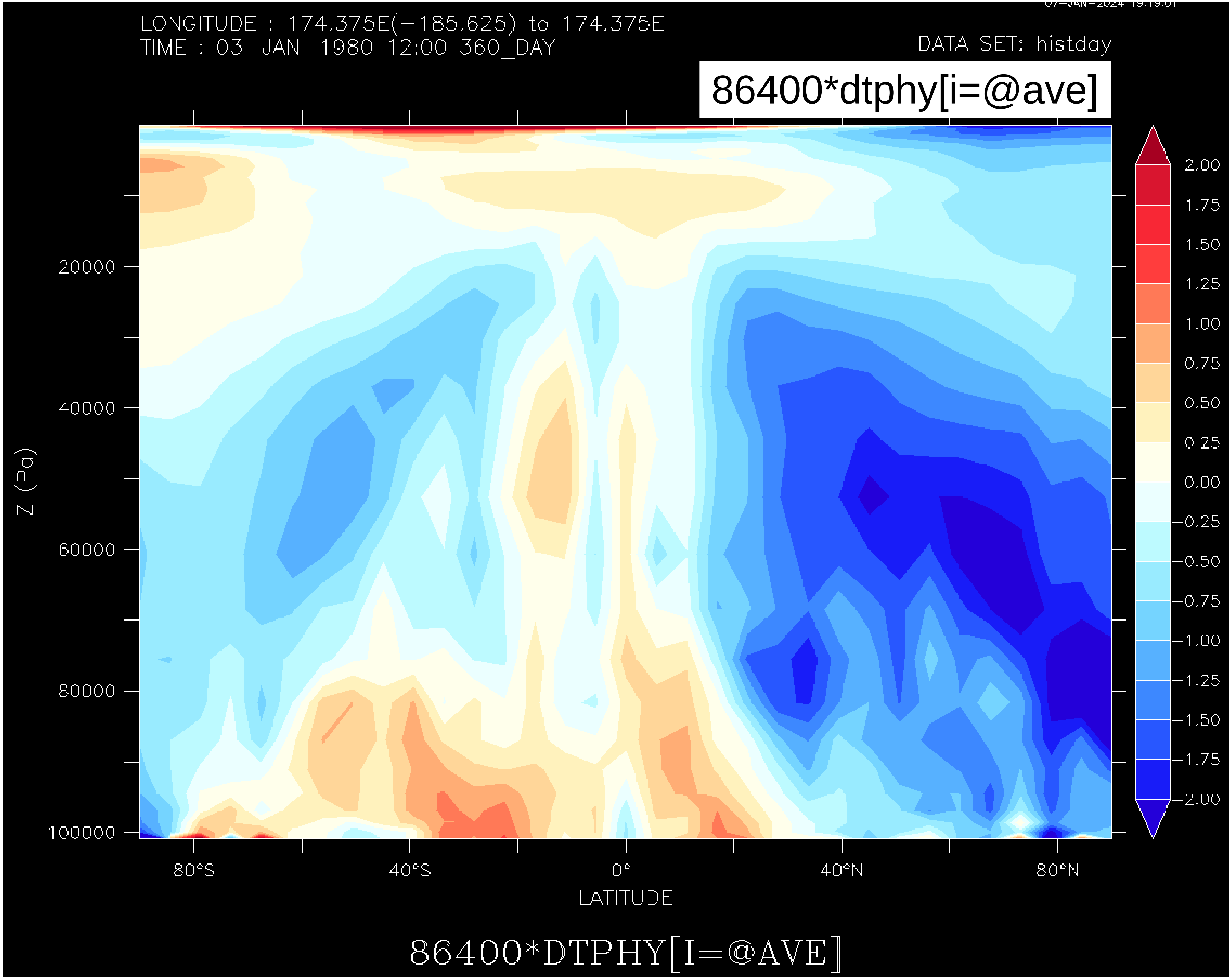
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TIME : 03-JAN-1980 12:00 360_DAY
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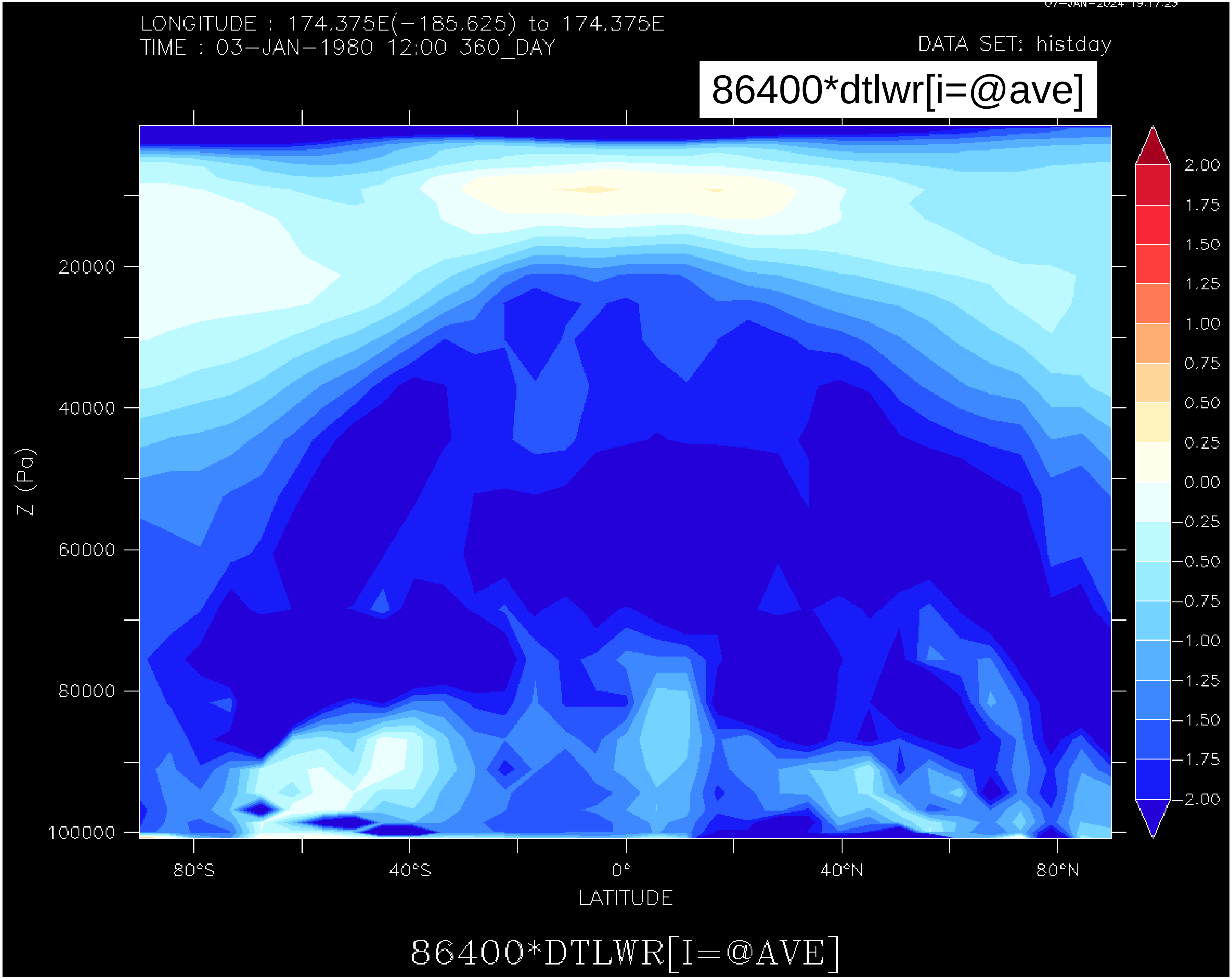
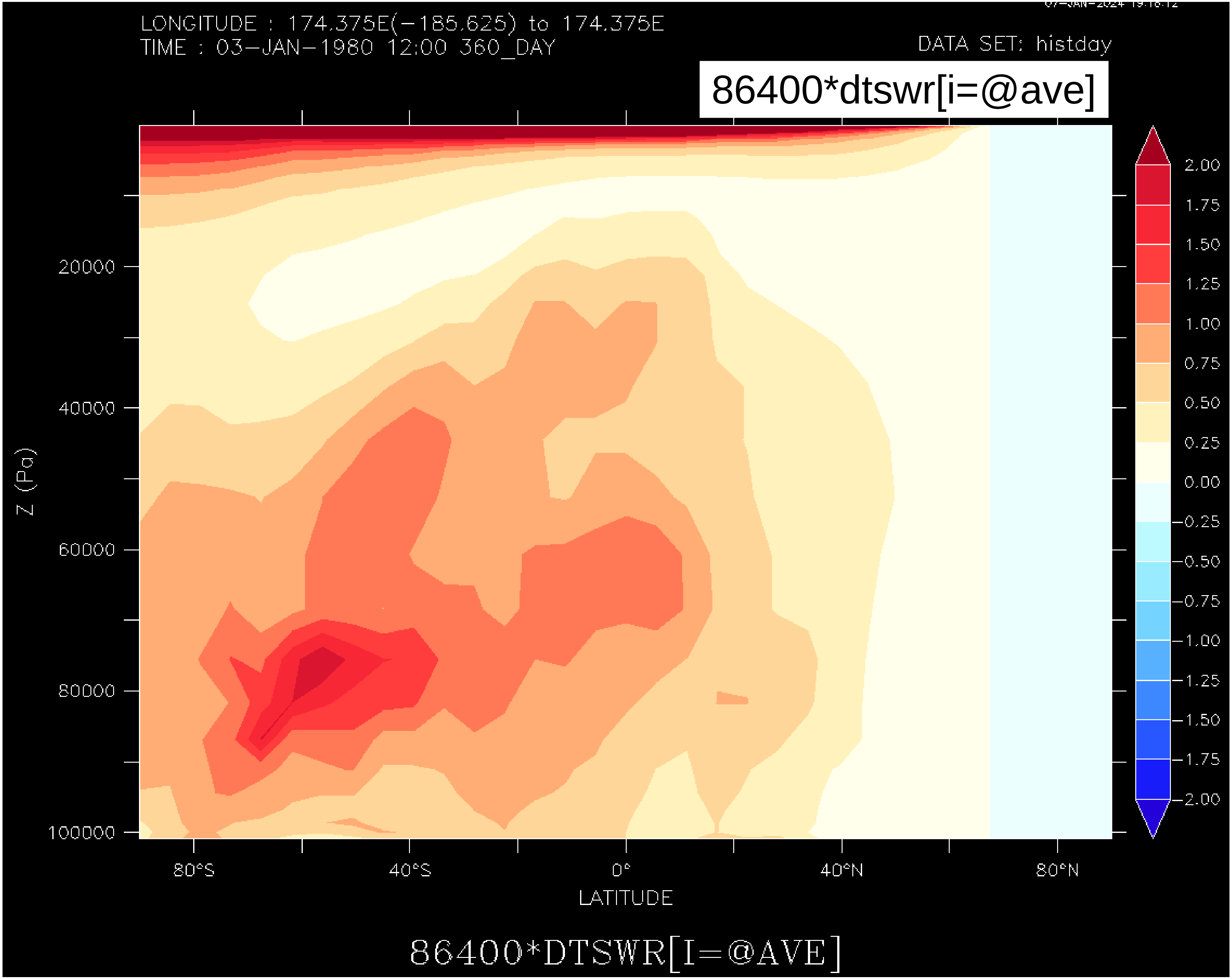
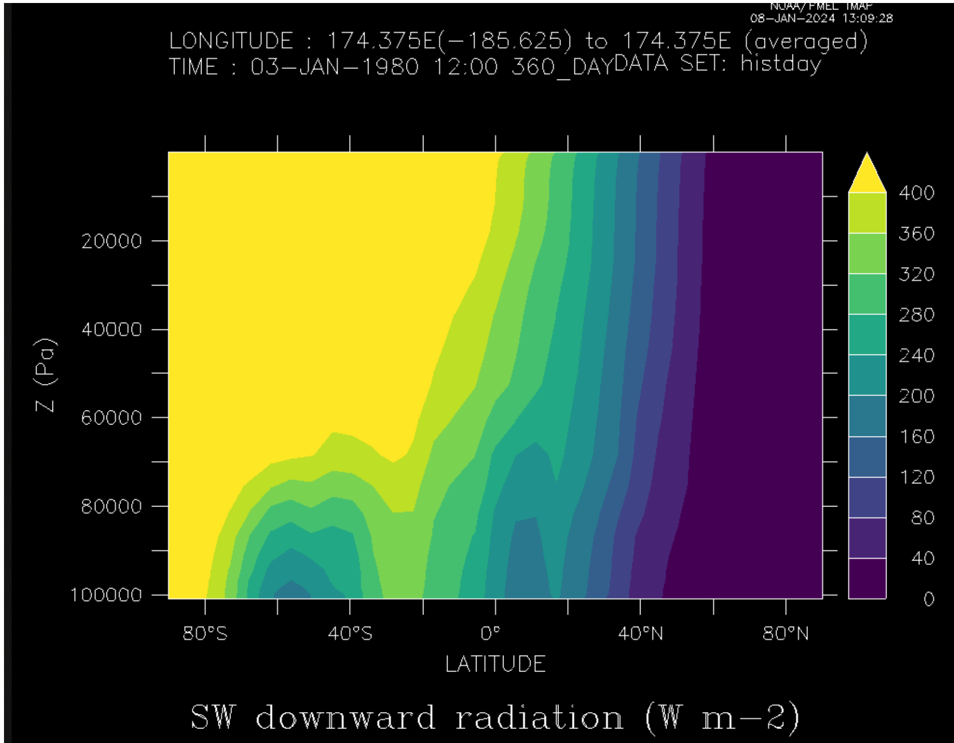
86400*dtphy[i=@ave]
Z (Pa)
20000
40000
60000
80000
100000
80°S
40°S
0°
40°N
80°N
LATITUDE
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
-1.25
-1.50
-1.75
-2.00
86400*DTPHY[I=@AVE]

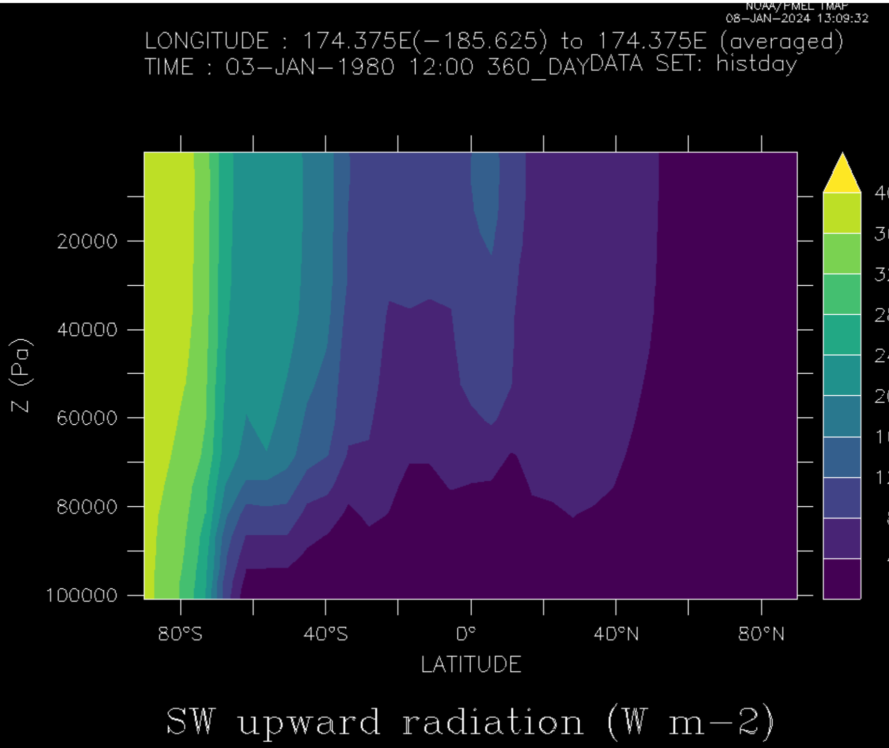
86400*dtlwr[i=@ave]





86400*dtswr[i=@ave]





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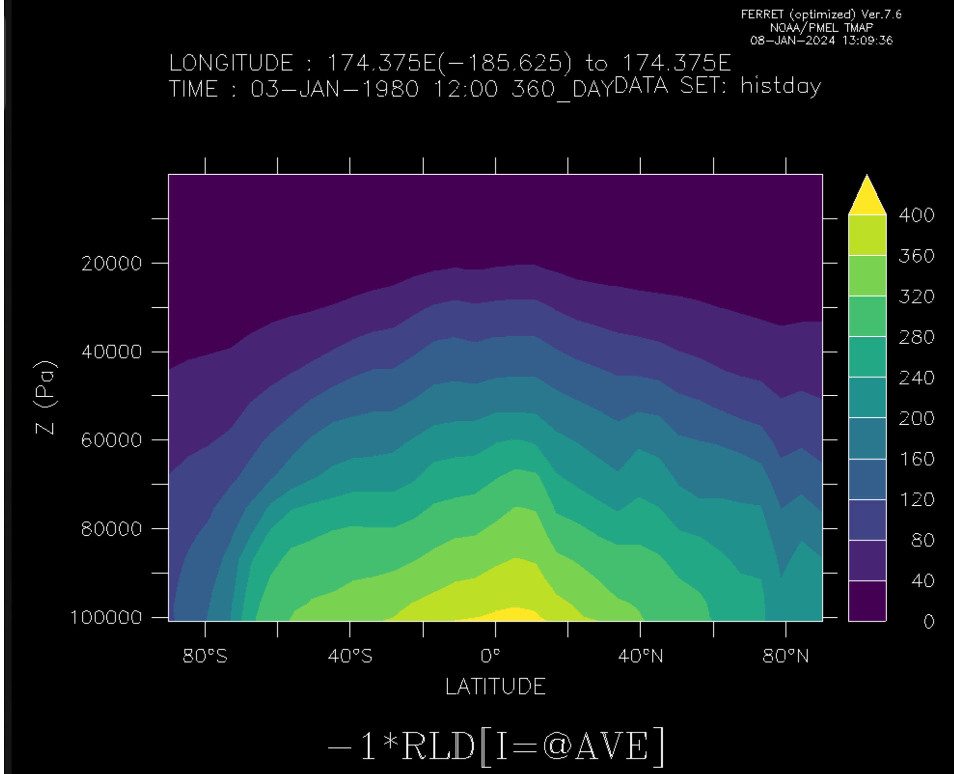
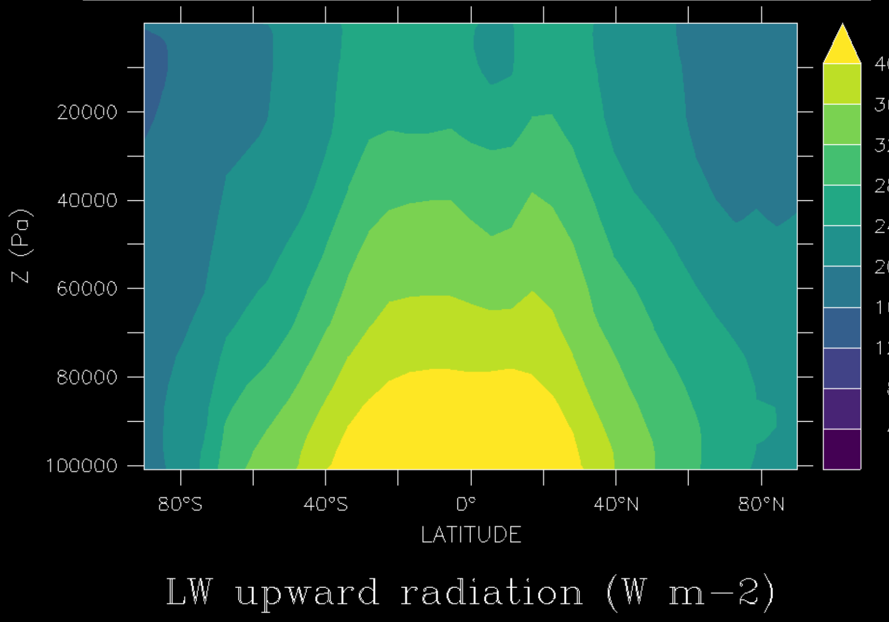
set v ur ; fill/lev=(0,400,40)(Inf) rsu[i=@ave]
set v ll ; fill/lev=(0,400,40)(Inf) -1*rld[i=@ave]
set v lr ; fill/lev=(0,400,40)(Inf) rlu[i=@ave]
```





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

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

$$= \quad \widetilde{\rho}\,\overline{\mathbf{v}}\,\overline{c} + \widetilde{\rho}\,\overline{\mathbf{v}'c'}$$

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

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

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

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

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

$Dq/Dt = Sq$

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

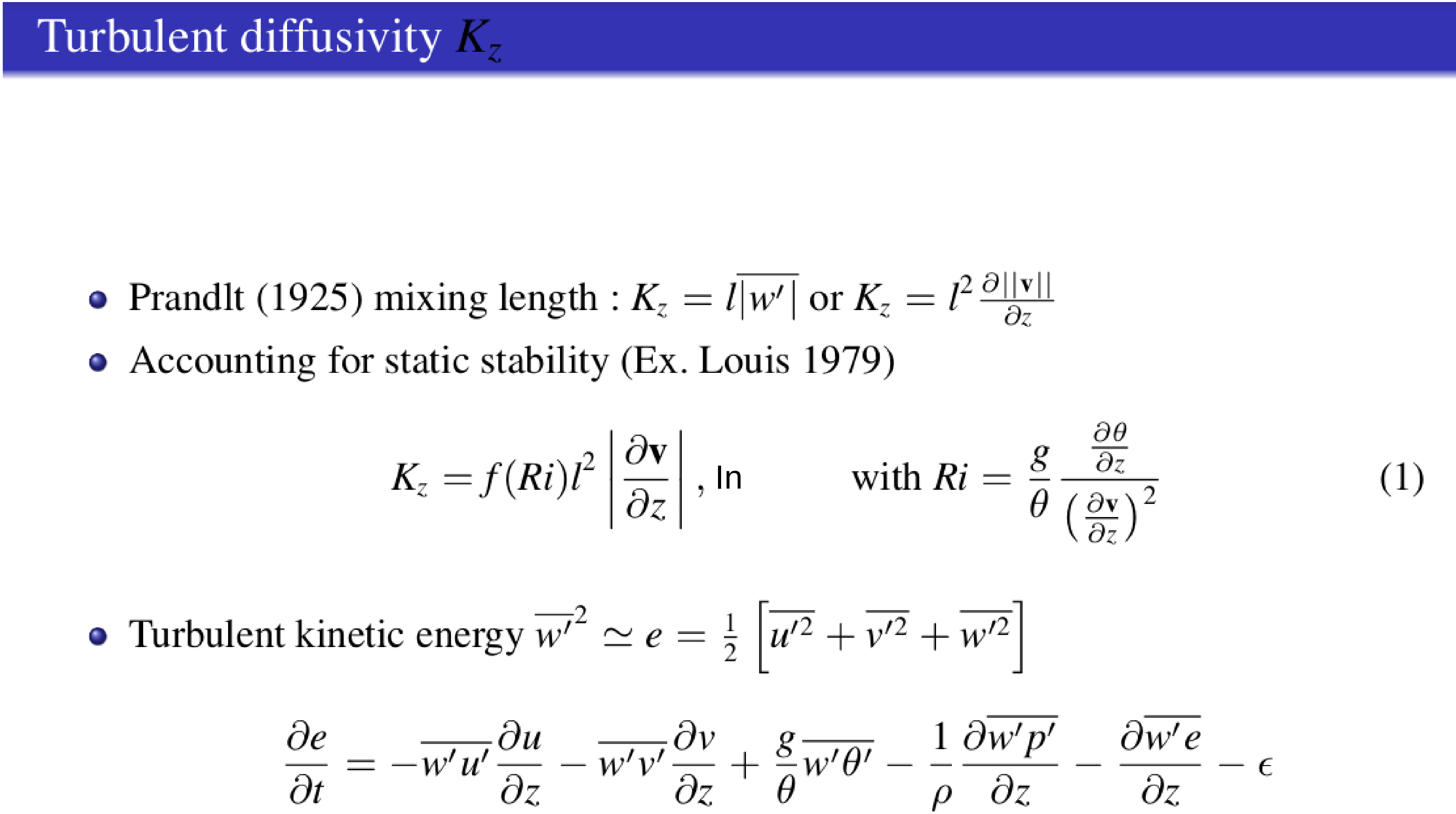
Turbulent diffusion : bases

Boundary layer approximation (horizontal homogeneity)
+ eddy diffusion

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

- 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

```
set v ll ; fill/lev=(-Inf)(-300,50,10)(Inf) sens ; go land thick
set v lr ; fill/lev=(-Inf)(-300,50,10)(Inf) flat ; go land thick
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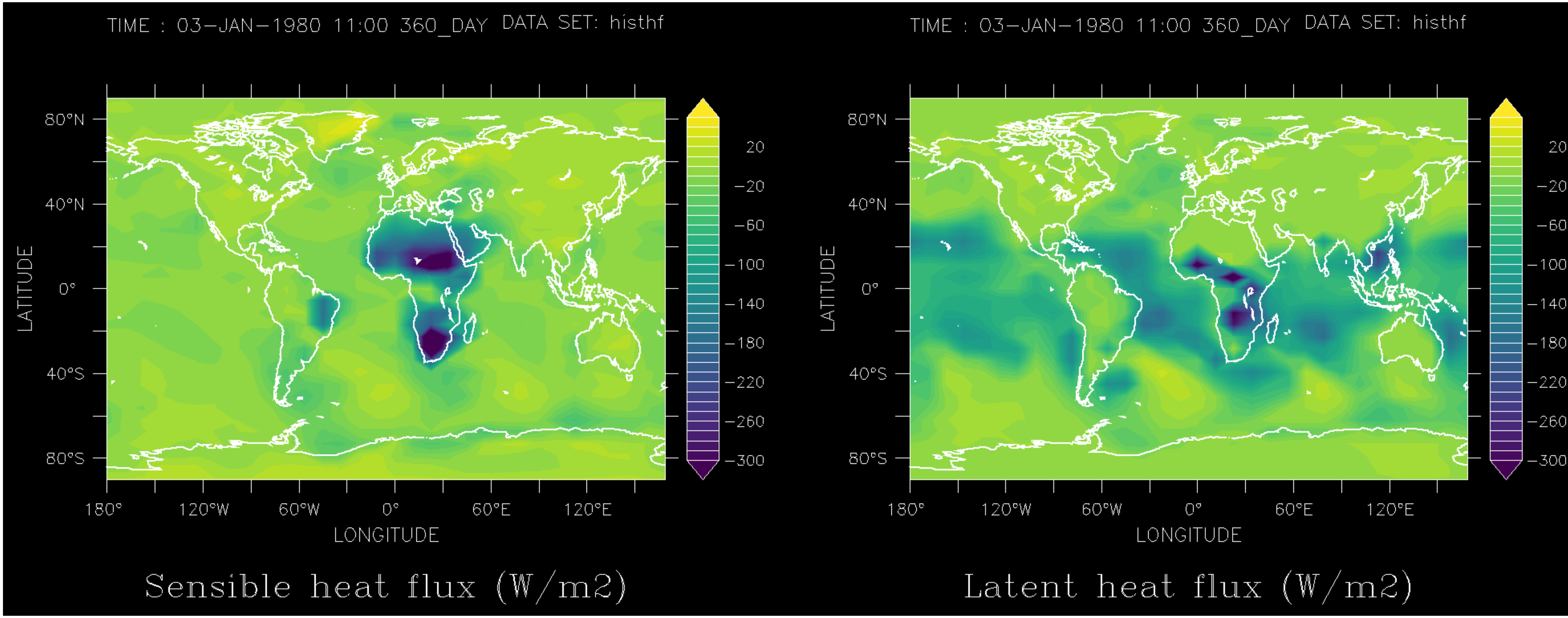

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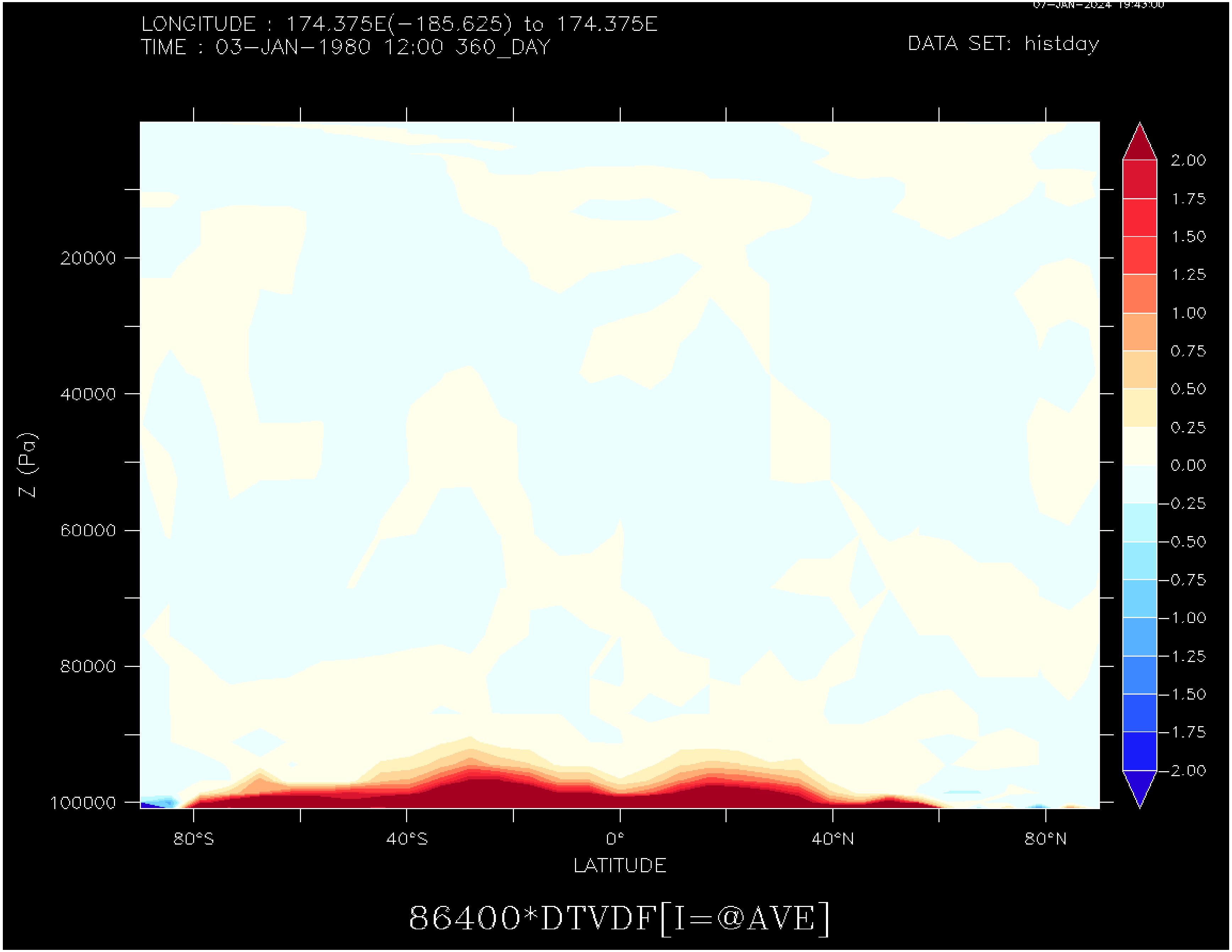

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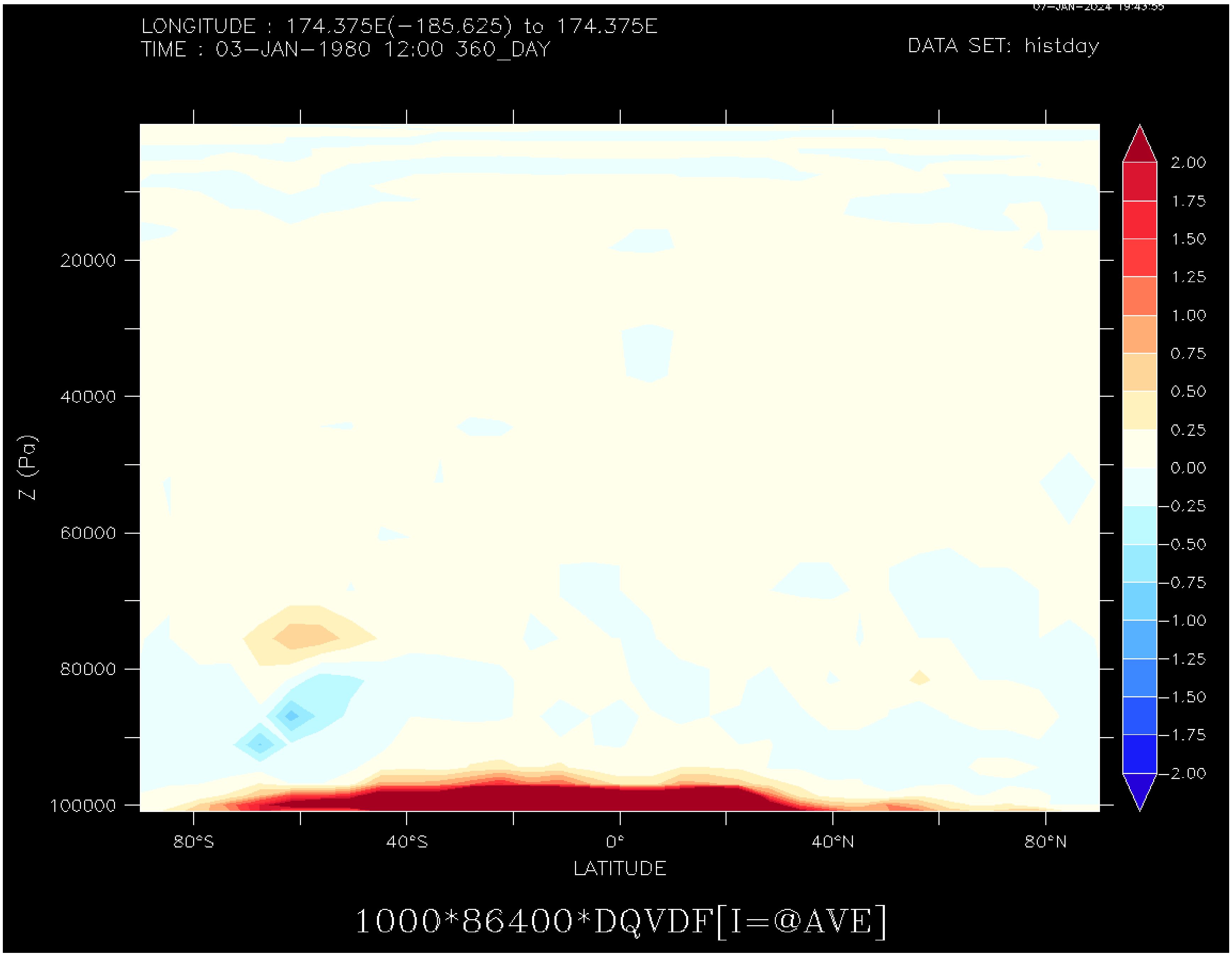

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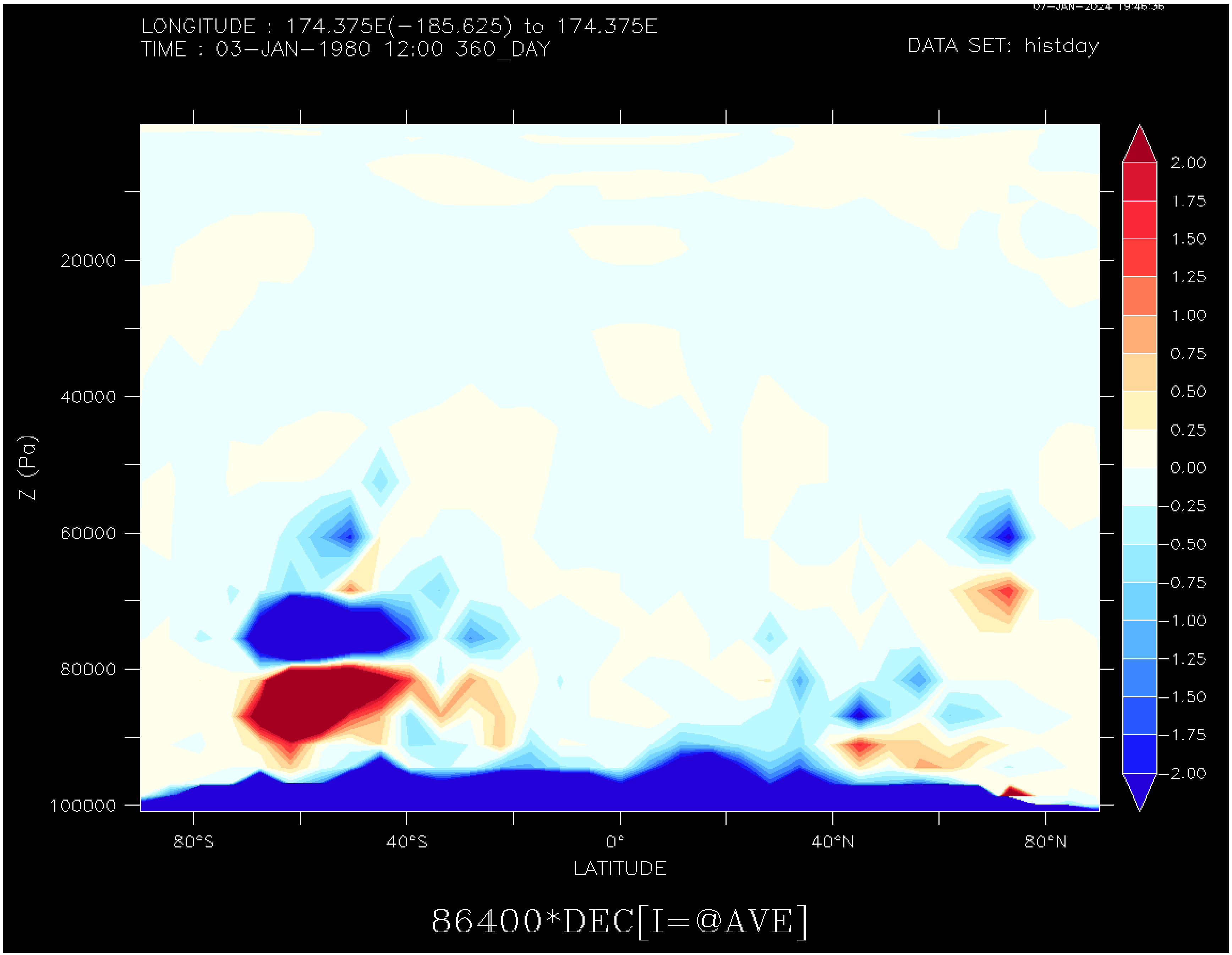
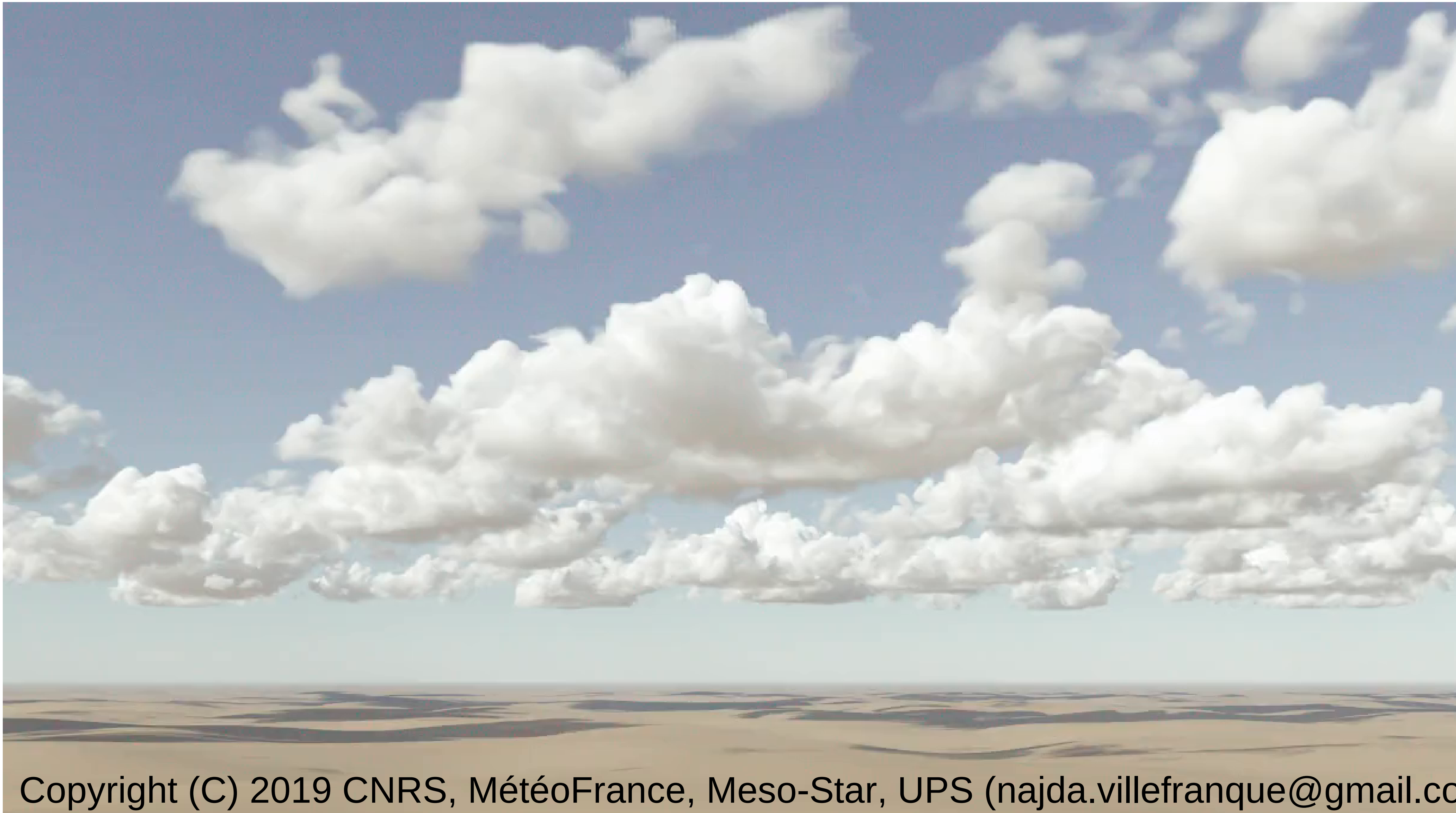
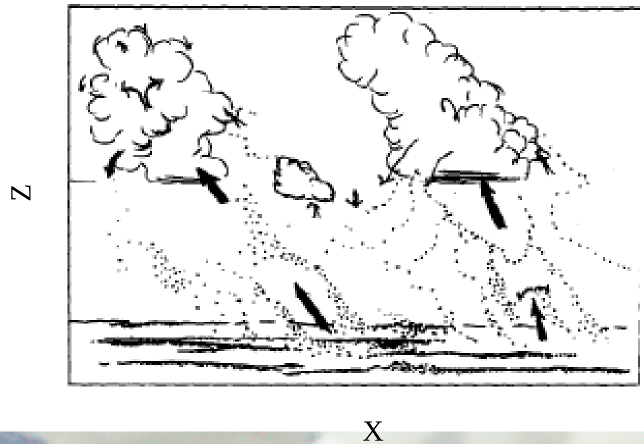


Parameterization of the convective boundary layer

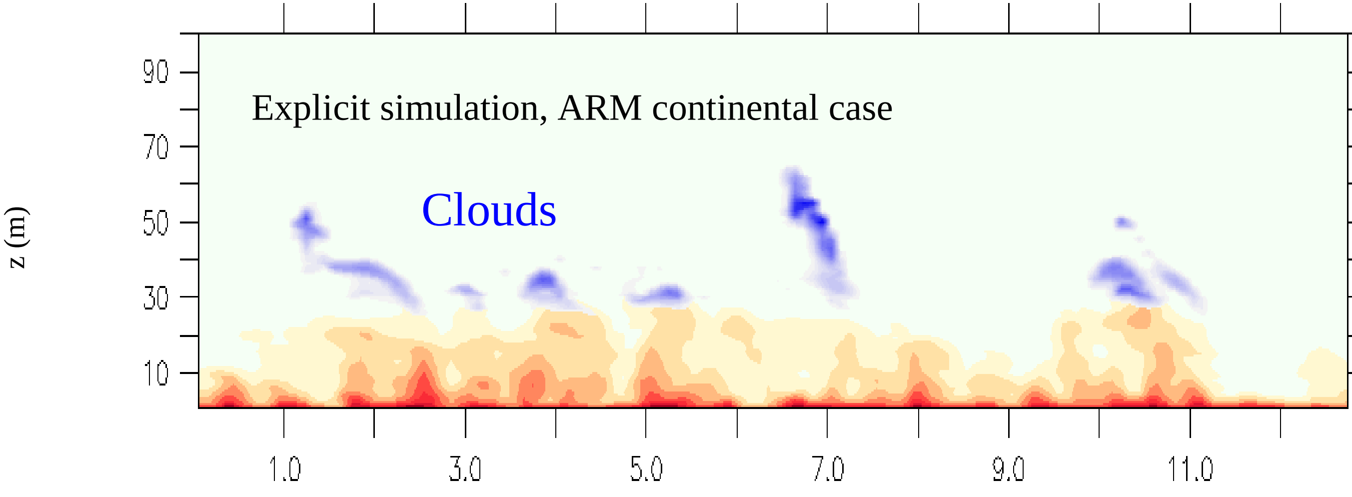
Based on high resolution explicit (LES) simulations
Movie entirely based on physics : MesoNH LES and physical rendering with htrdr (Villefranque)

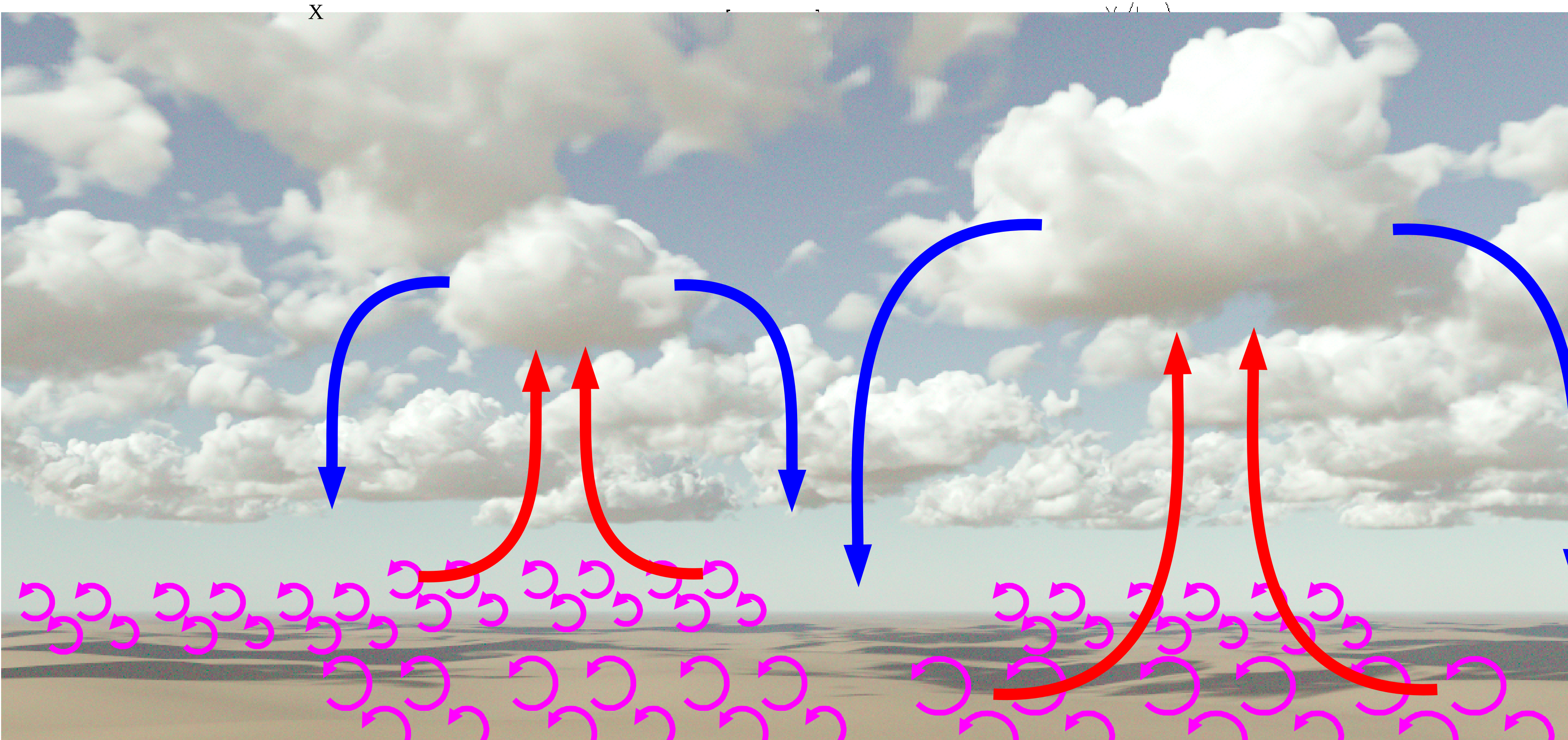


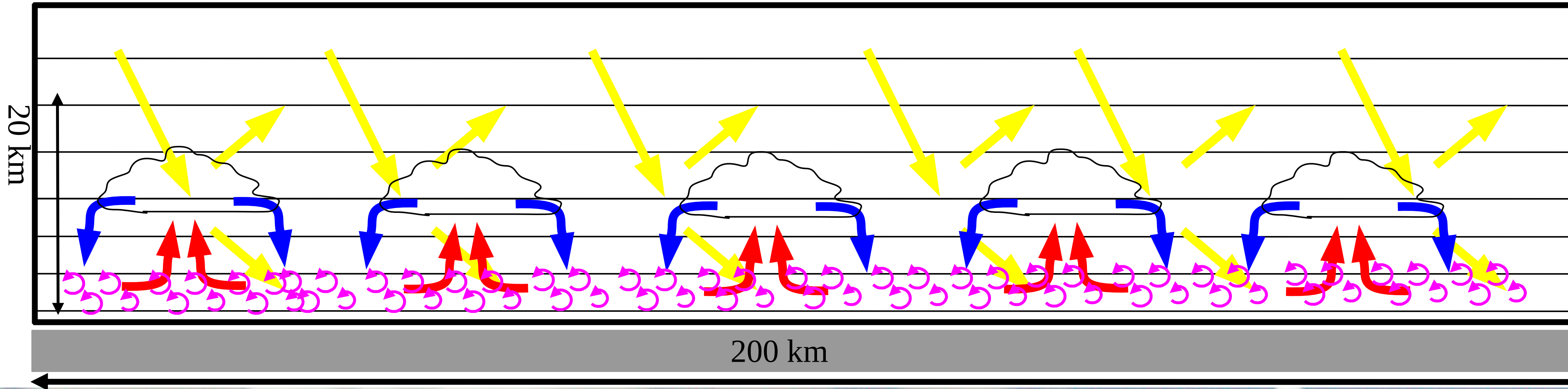
LeMone and Pennell, MWR, 1976

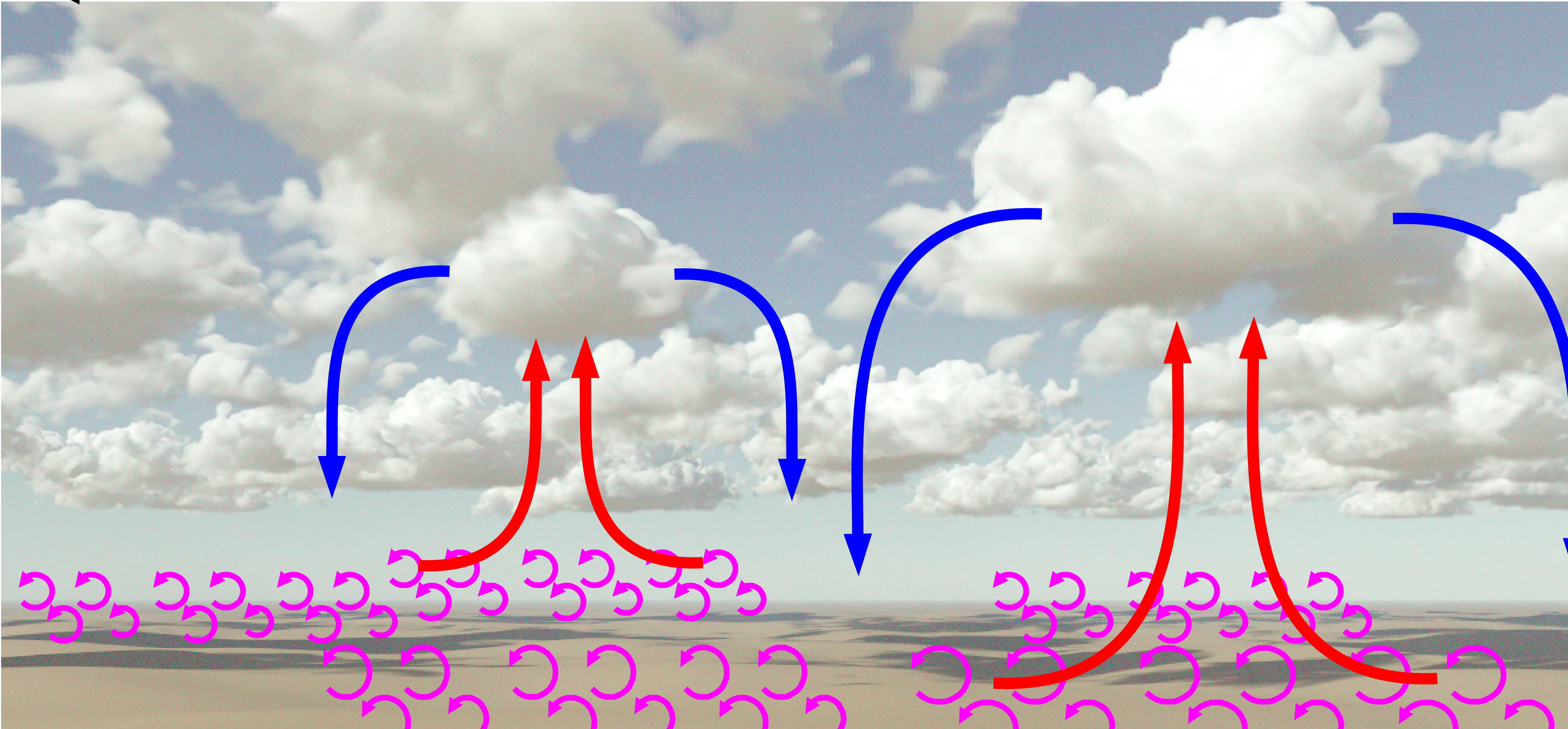


Meso-NH simulation



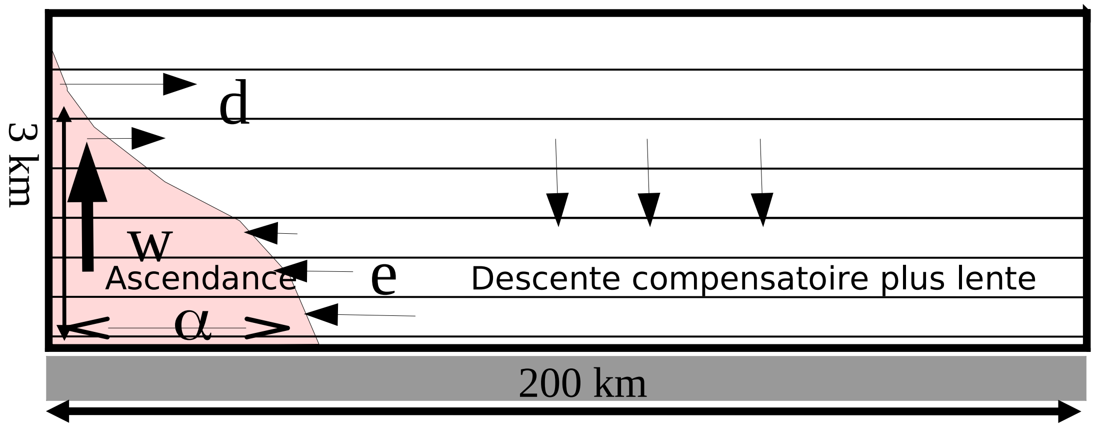



20 km
200 km



2. Couche limite convective

Le modèle du thermique



Conservation de la masse :

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

Conservation de la masse du composant q

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

Equation du mouvement

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

ıt la poussée d'Archimède

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

$$e = f \max(0, \frac{\beta_1}{1+\beta_1}(a_1 \frac{B}{w^2} - b))$$

$$d = f \max(0, -\frac{a_1 \beta_1}{1+\beta_1} \frac{B}{w^2} + c(\frac{(q_a - q)/q_a}{w^2})^d)$$

Variables internes de la paramétrisation :

w : vitesse moyenne des panaches ascendants

α : fraction de la surface couverte par les ascendances

e : taux d'entrée latérale d'air dans le panache (entrainement)

d : sorties d'air depuis le panache (détrainement)

q_a : concentration du composant q dans l'ascendance

Terme source pour les équations explicites

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

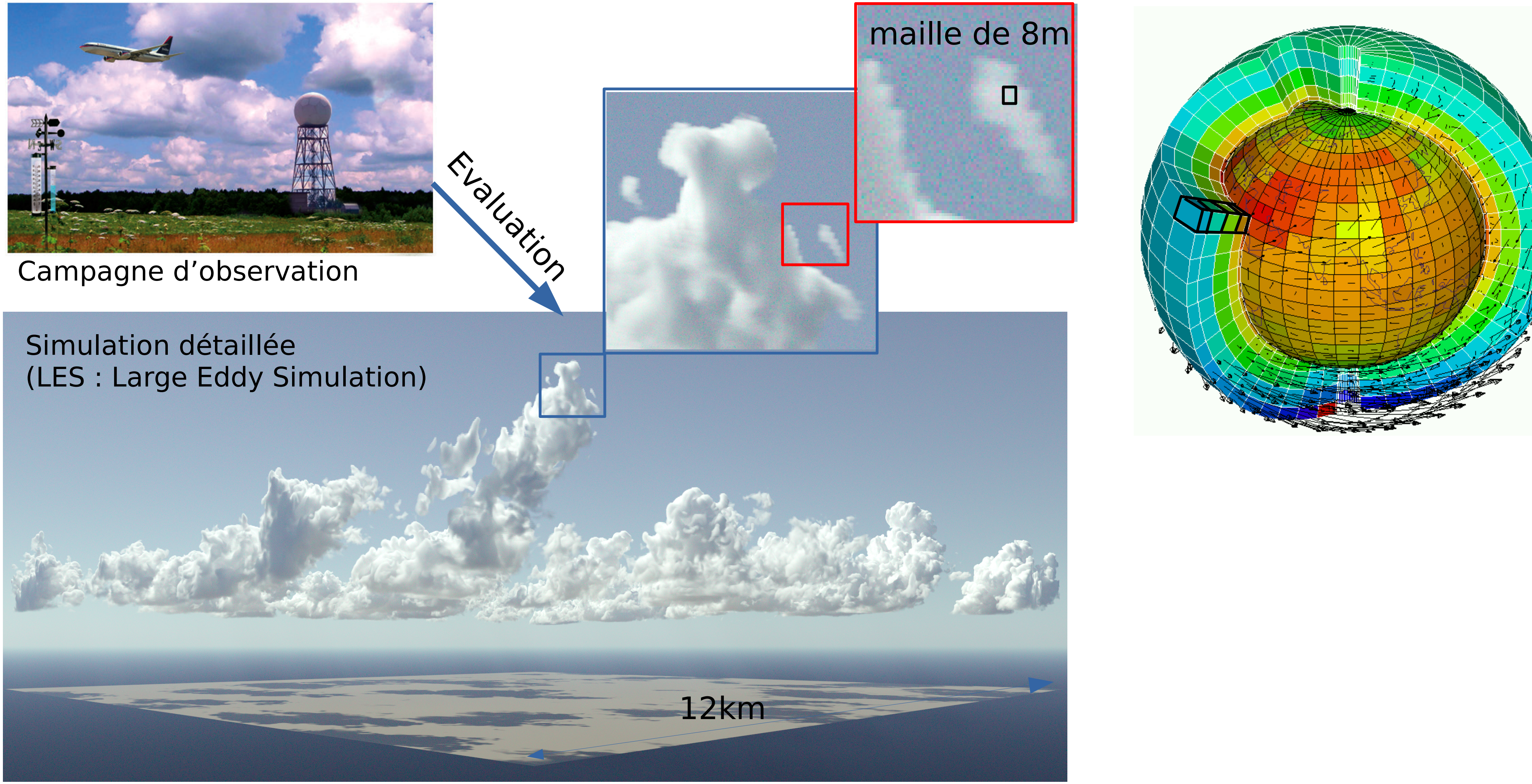
Diffusion turbulente

Transport par le modèle de panache

4 Paramètres libres :

$a_1 = \frac{2}{3},\ \beta_1 = 0.9,\ b = 0.002,\ c = 0.012 m^{-1},\ d = 0.5$

Etc ...



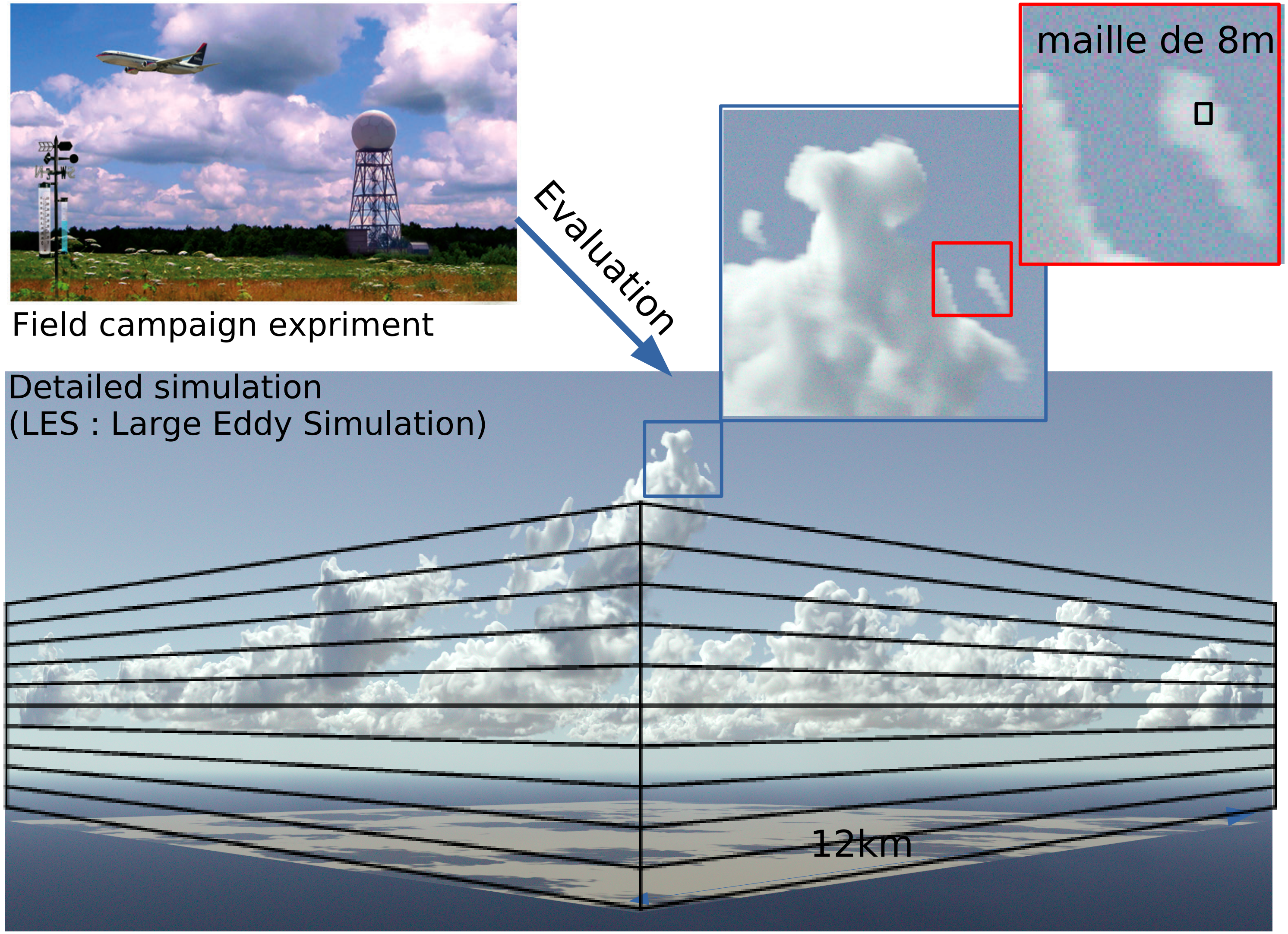
Campagne d'observation

Evaluation

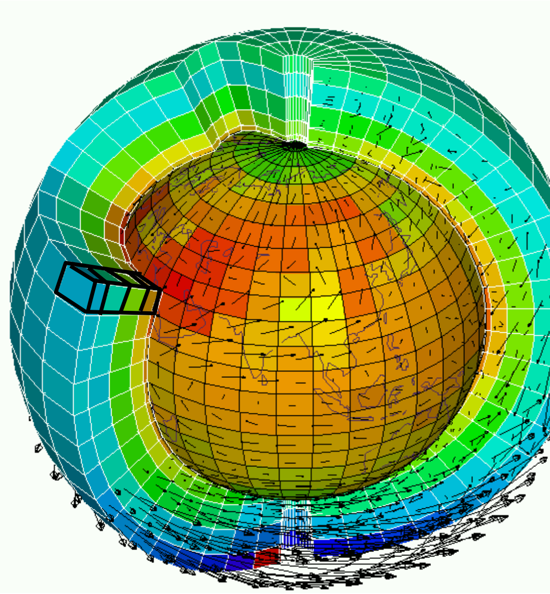
Simulation détaillée
(LES : Large Eddy Simulation)

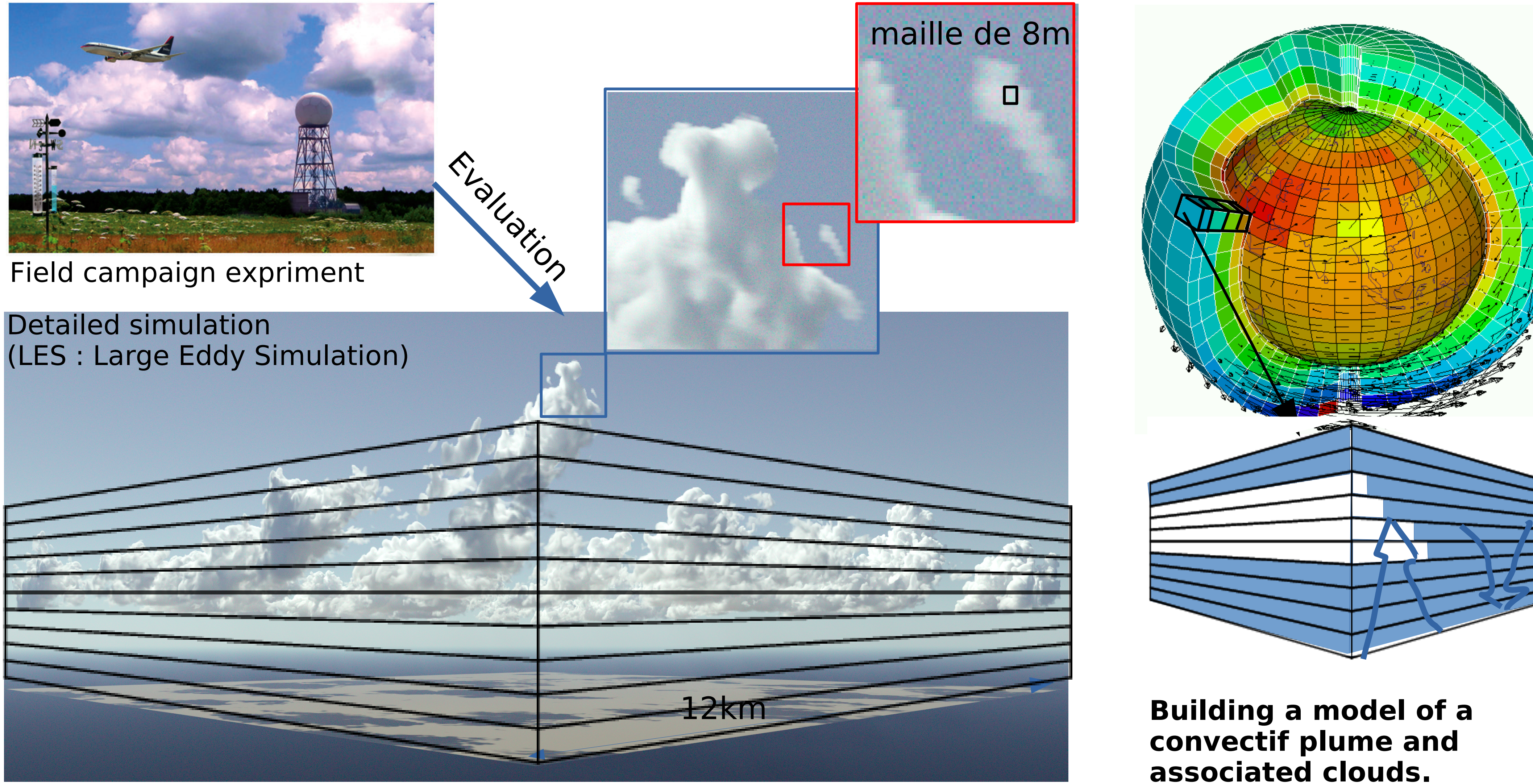
maille de 8m

12km


Field campaign expriment

Detailed simulation
(LES : Large Eddy Simulation)





Field campaign expriment

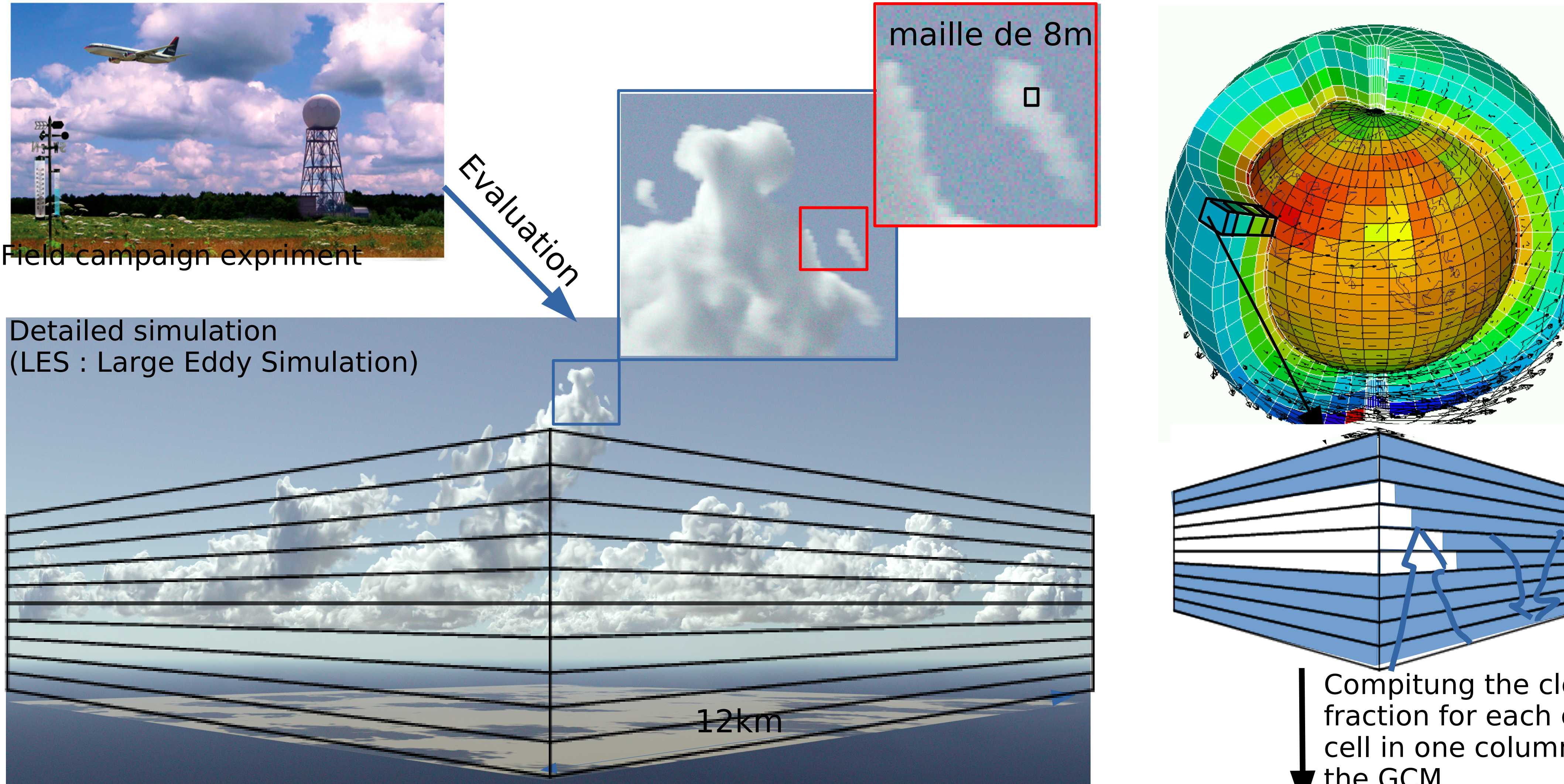
Evaluation

Detailed simulation
(LES : Large Eddy Simulation)

maille de 8m

12km

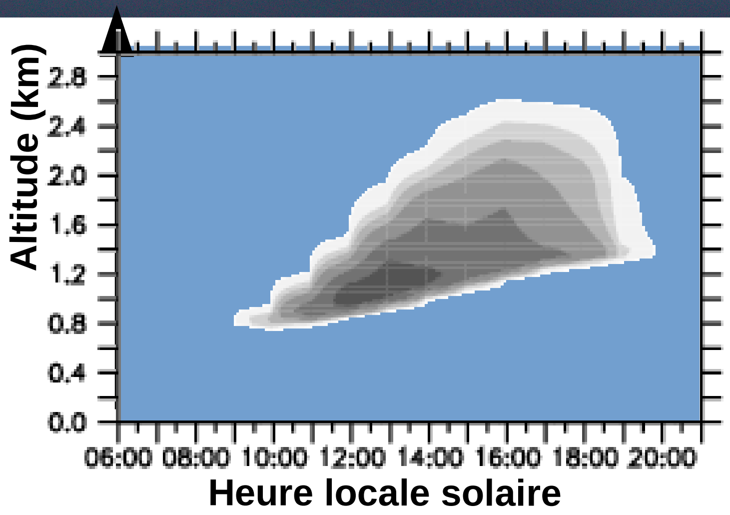
Building a model of a convectif plume and associated clouds. Trying to represent an idealized mean cloud



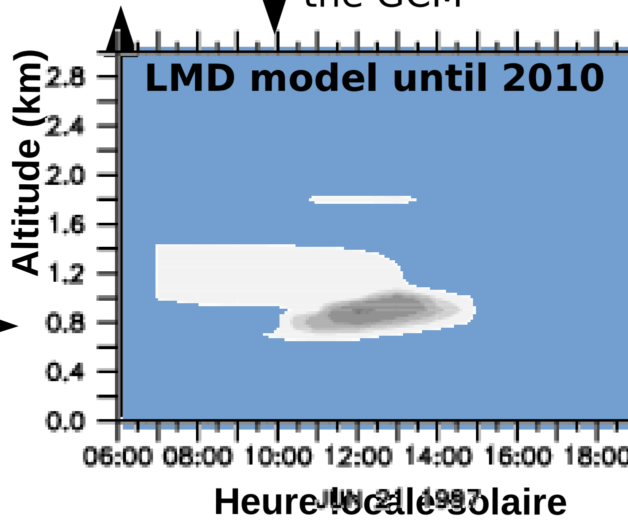
Detailed simulation
(LES : Large Eddy Simulation)

Compitung the cl
fraction for each
cell in one colum
the GCM

Computing at each altitude the fraction of the horizontal domain covered by clouds.
Also called :
the cloud fraction

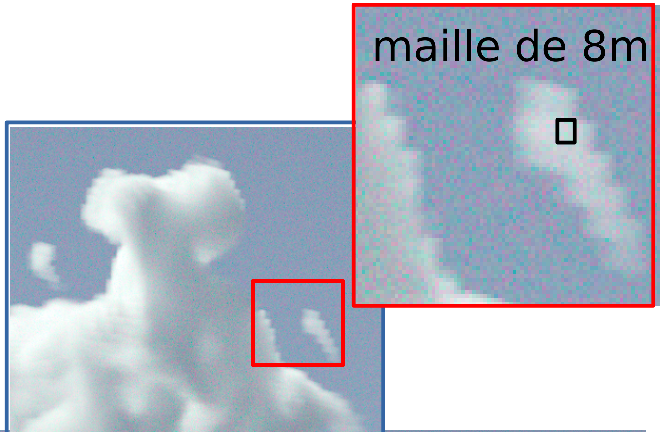


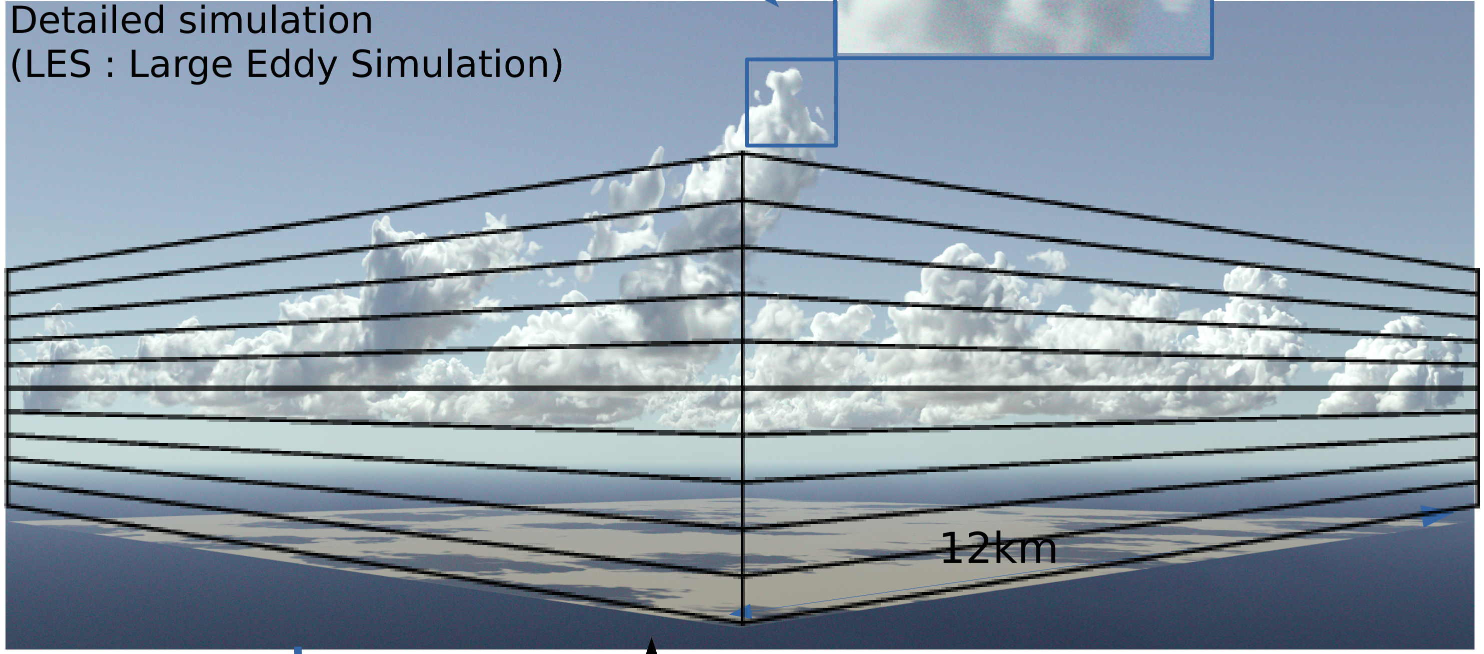
Evaluation


LMD model until 2010

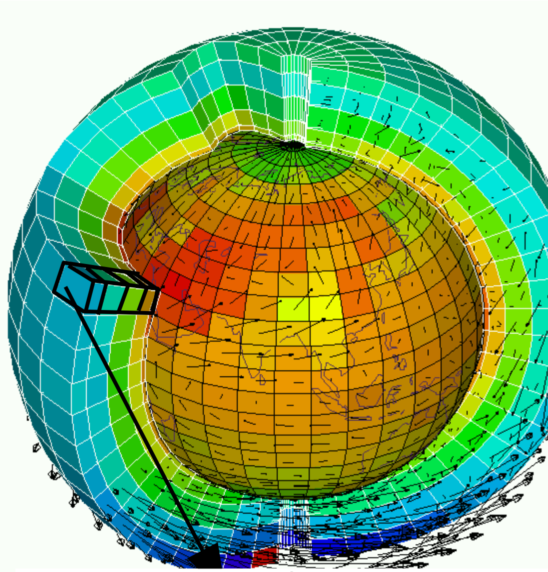
Field campaign expriment

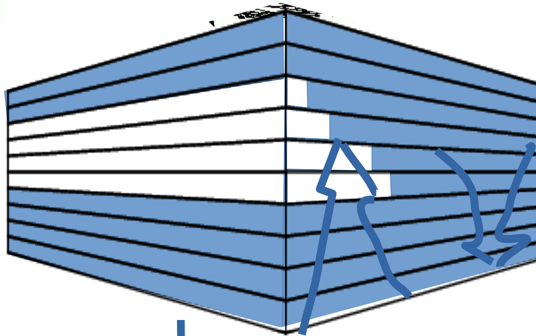
Evaluation





Detailed simulation
(LES : Large Eddy Simulation)





Compitung the cl
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cell in one column
the GCM

Computing at each altitude the fraction of the horizontal domain covered by clouds.
Also called :
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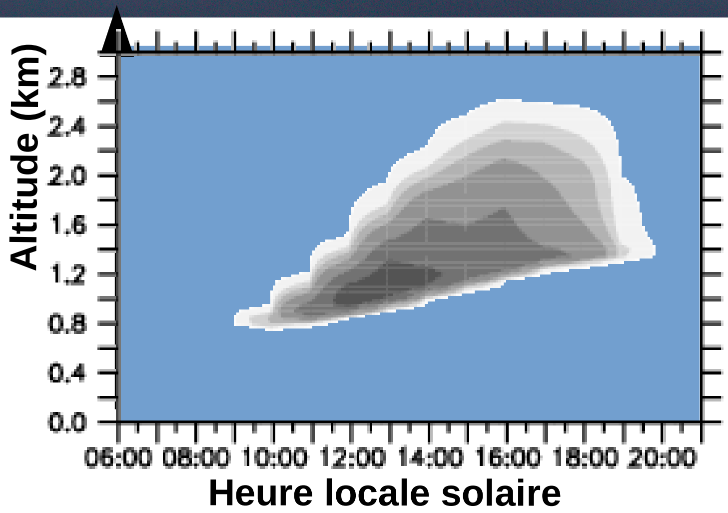
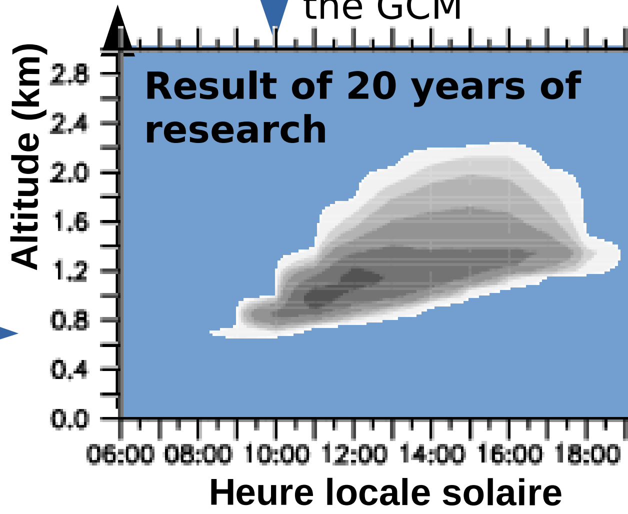


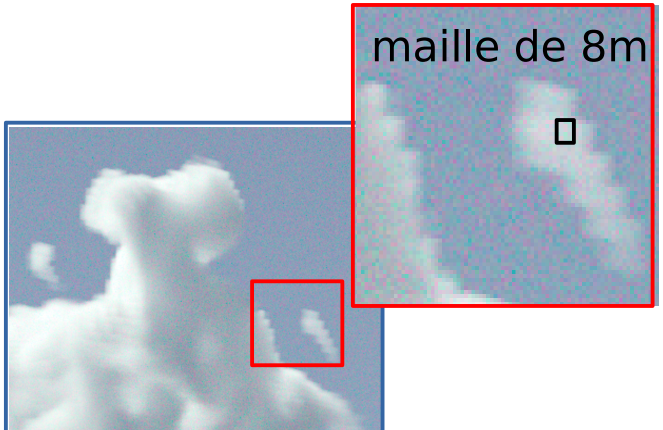
Evaluation

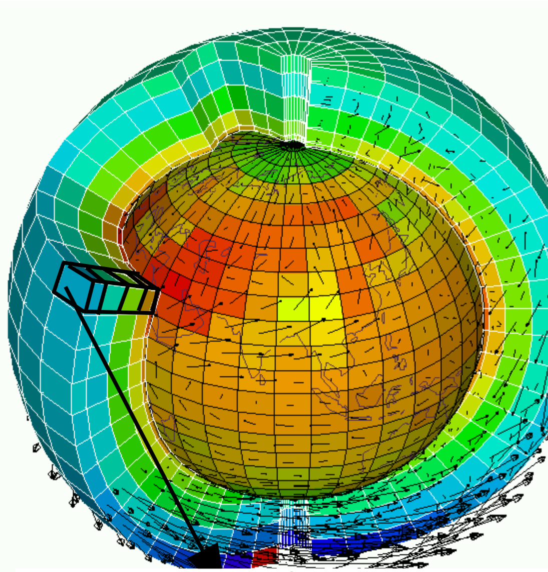


Result of 20 years of research

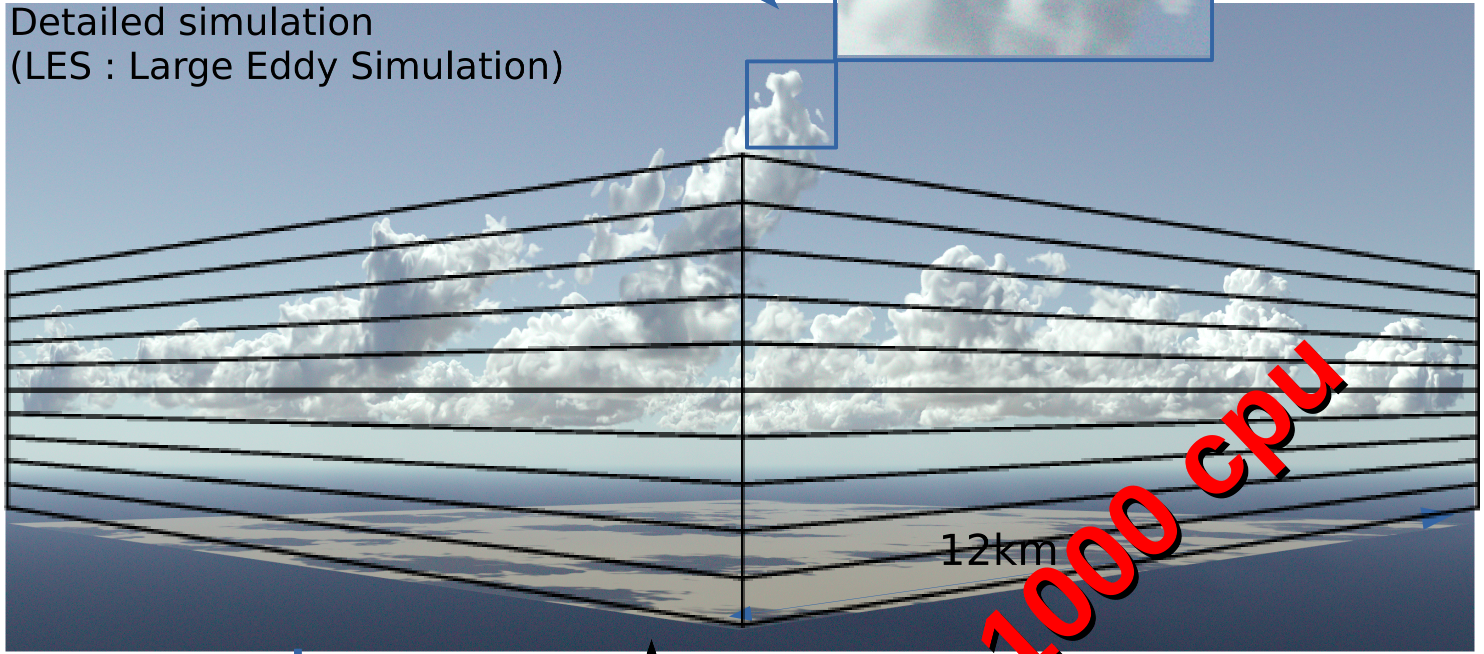
Field campaign expriment

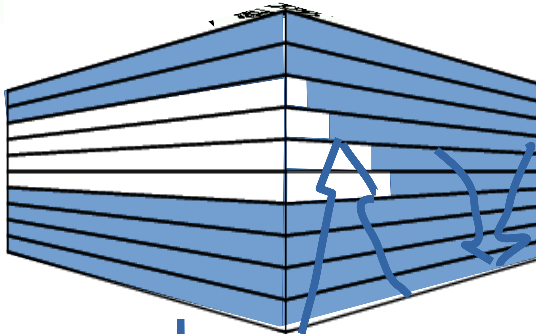
Evaluation





Detailed simulation
(LES : Large Eddy Simulation)





Compitung the cl
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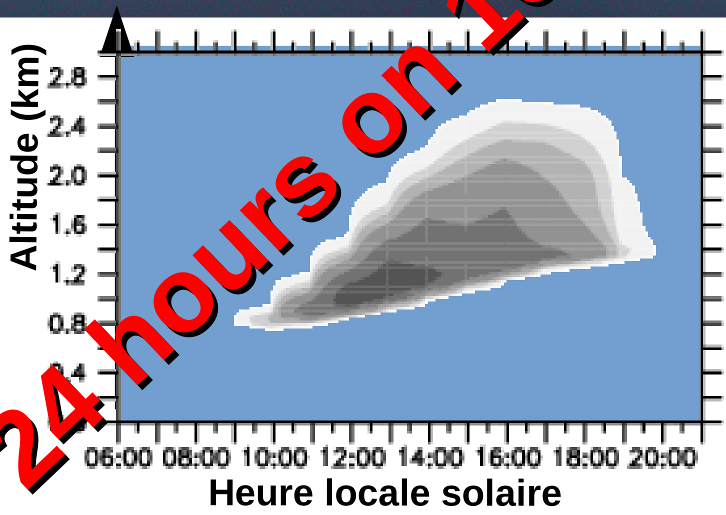
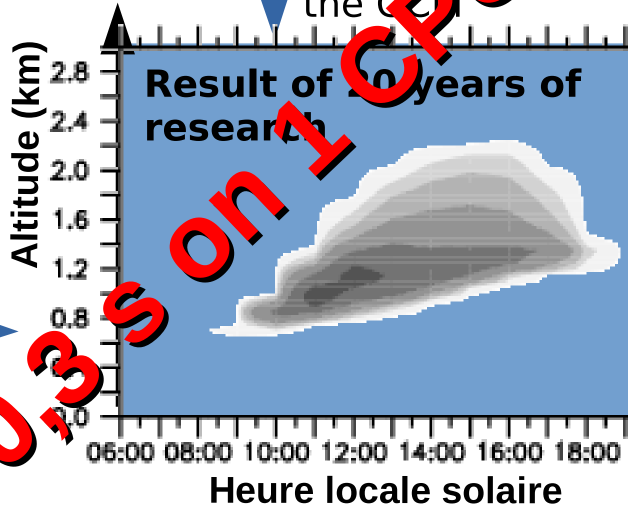


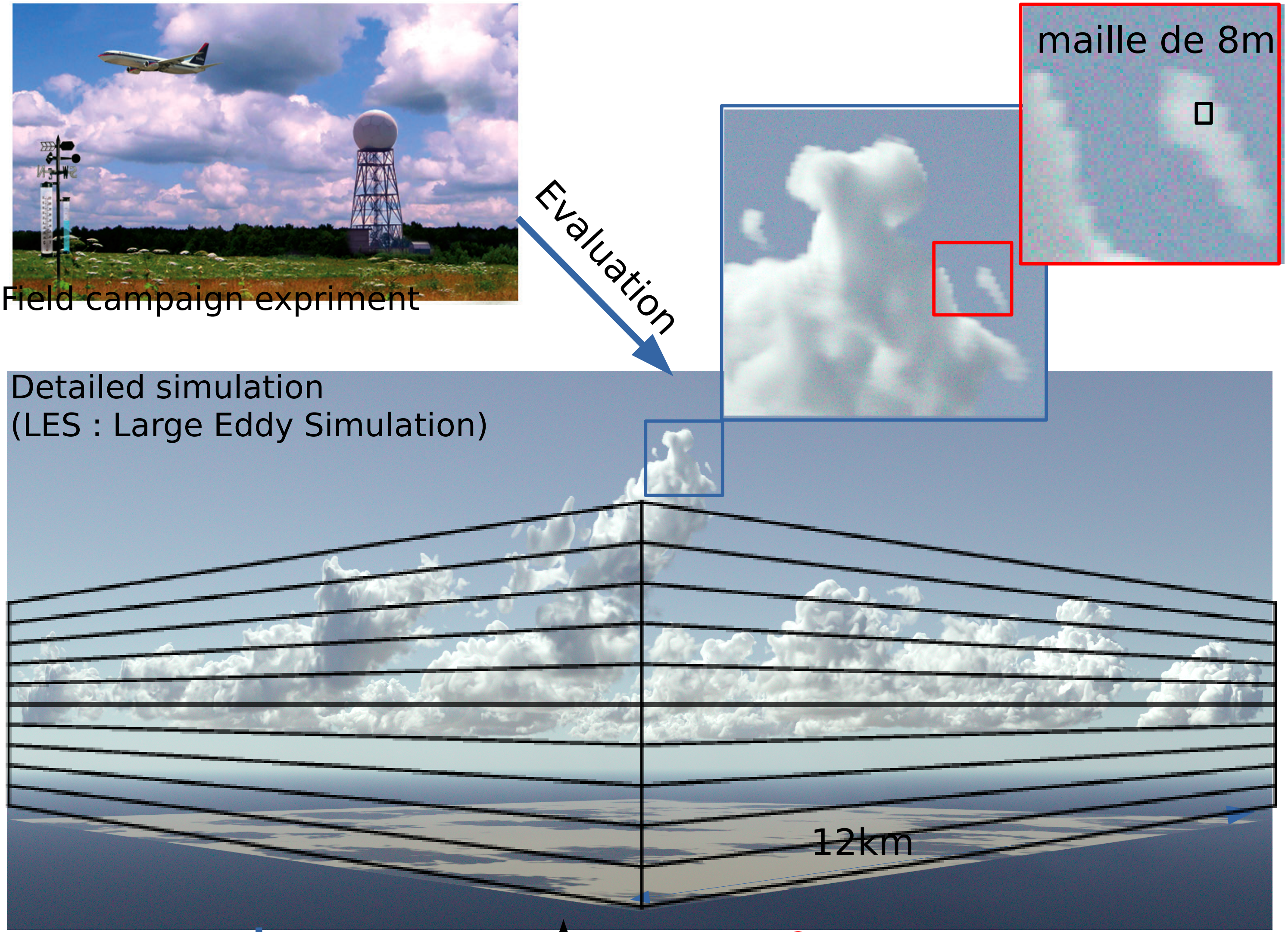
24 hours on 1000 cpu

Evaluation

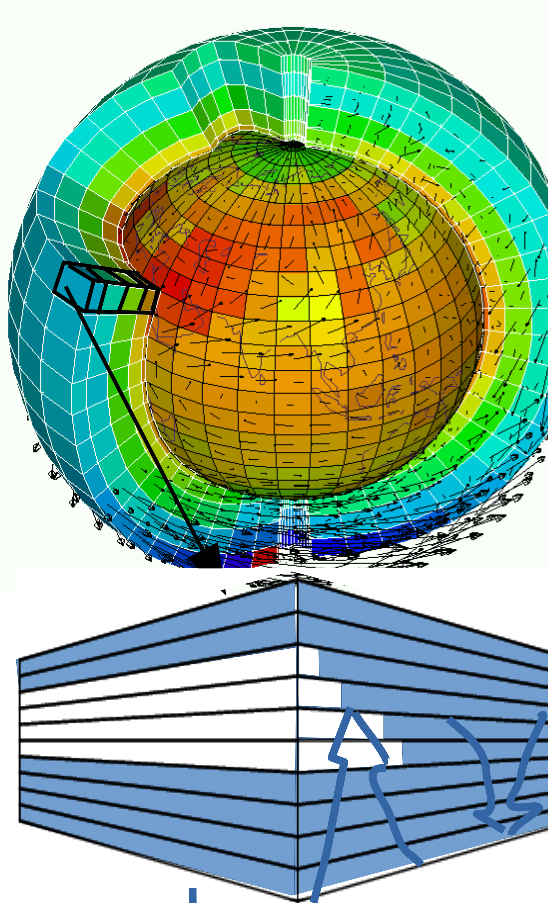


Result of 20 years of research

0,3 s on 1 CPU



Detailed simulation
(LES : Large Eddy Simulation)



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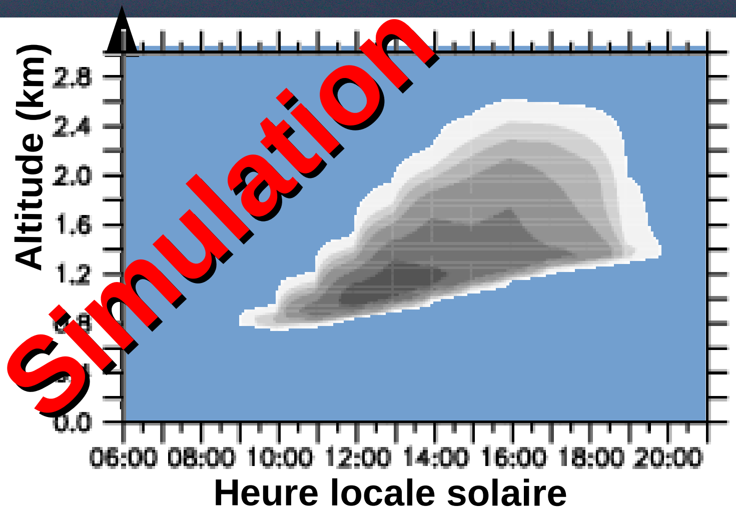
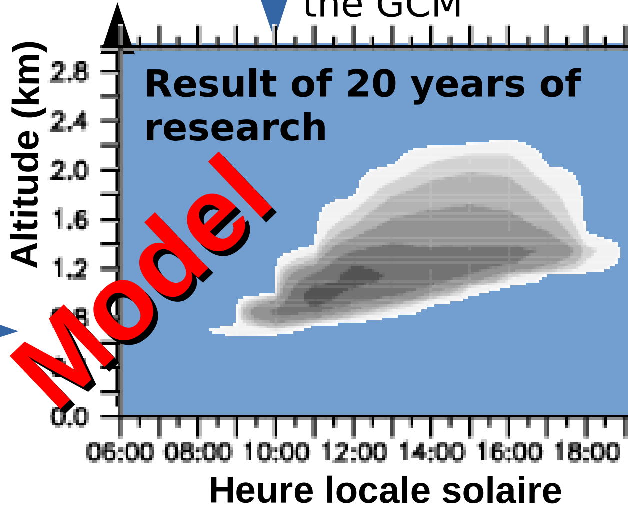
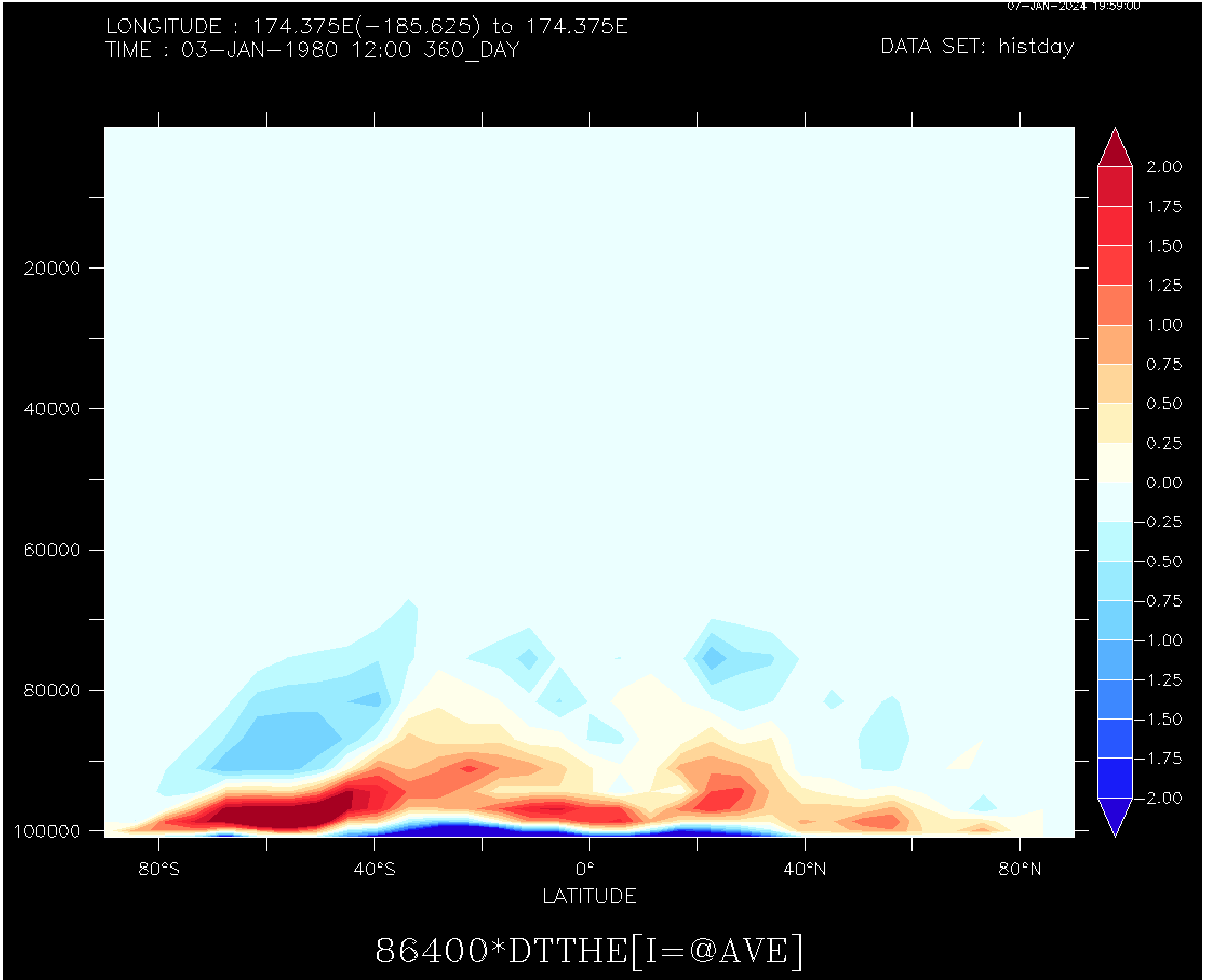


Evaluation

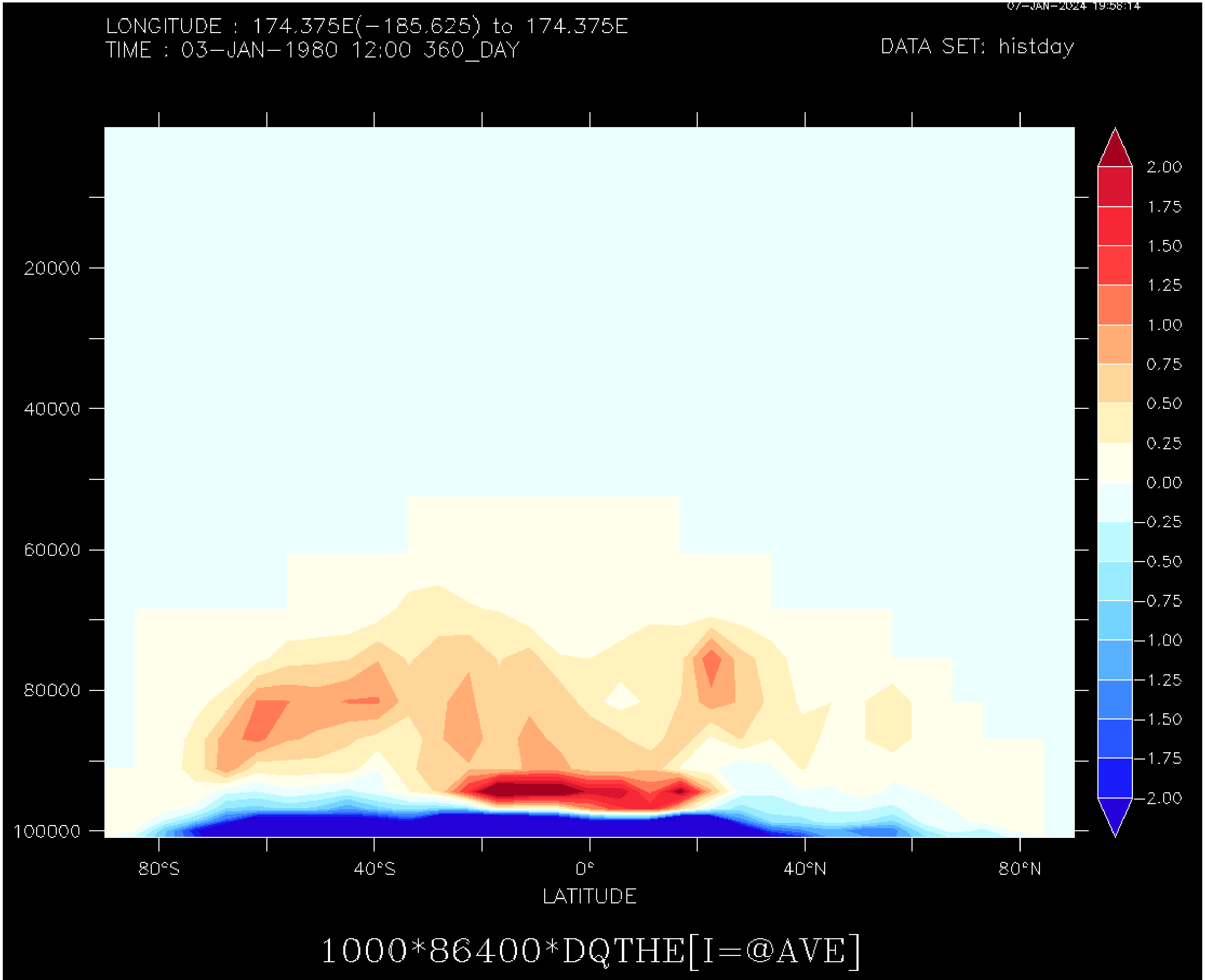


Result of 20 years of research

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



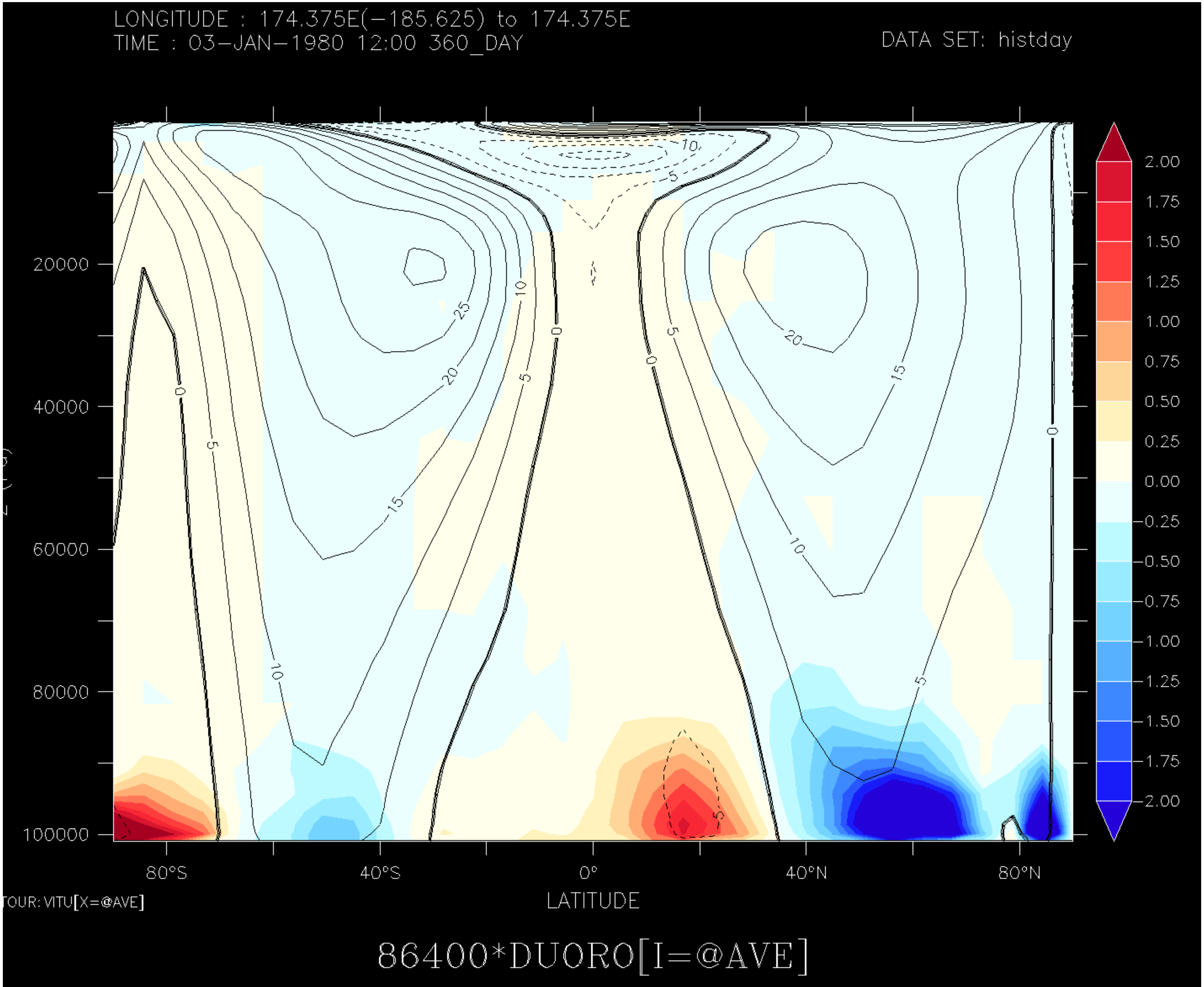
fill/lev=(-Inf)(-2,2,0.25)(inf)/pal=blue_darkred 1000*86400*dqthe[i=@ave]



Parameterization of subrid-scale orography

- Marine presentation

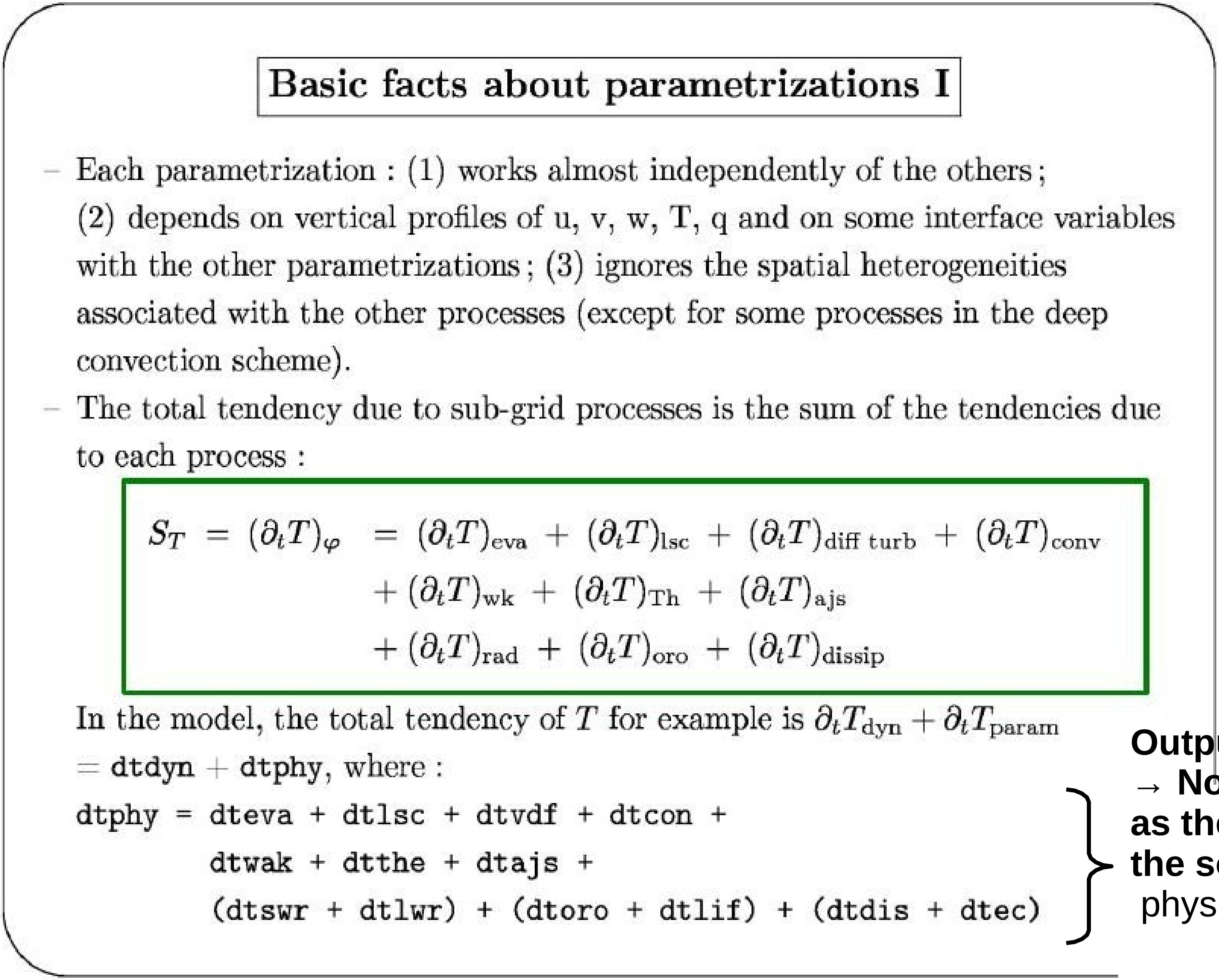
```
fill/lev=(-Inf)(-2,2,0.25)(inf)/pal=blue_darkred 86400*duoro[i=@ave]
contour/o/color=white/lev=(-Inf)(-30,30,5) vitu[i=@ave]
```



Practice

Try to analyse the diurnal cycle of temperature and humidity
Choose for instance a location in Sahel : 0W, 12N

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 :

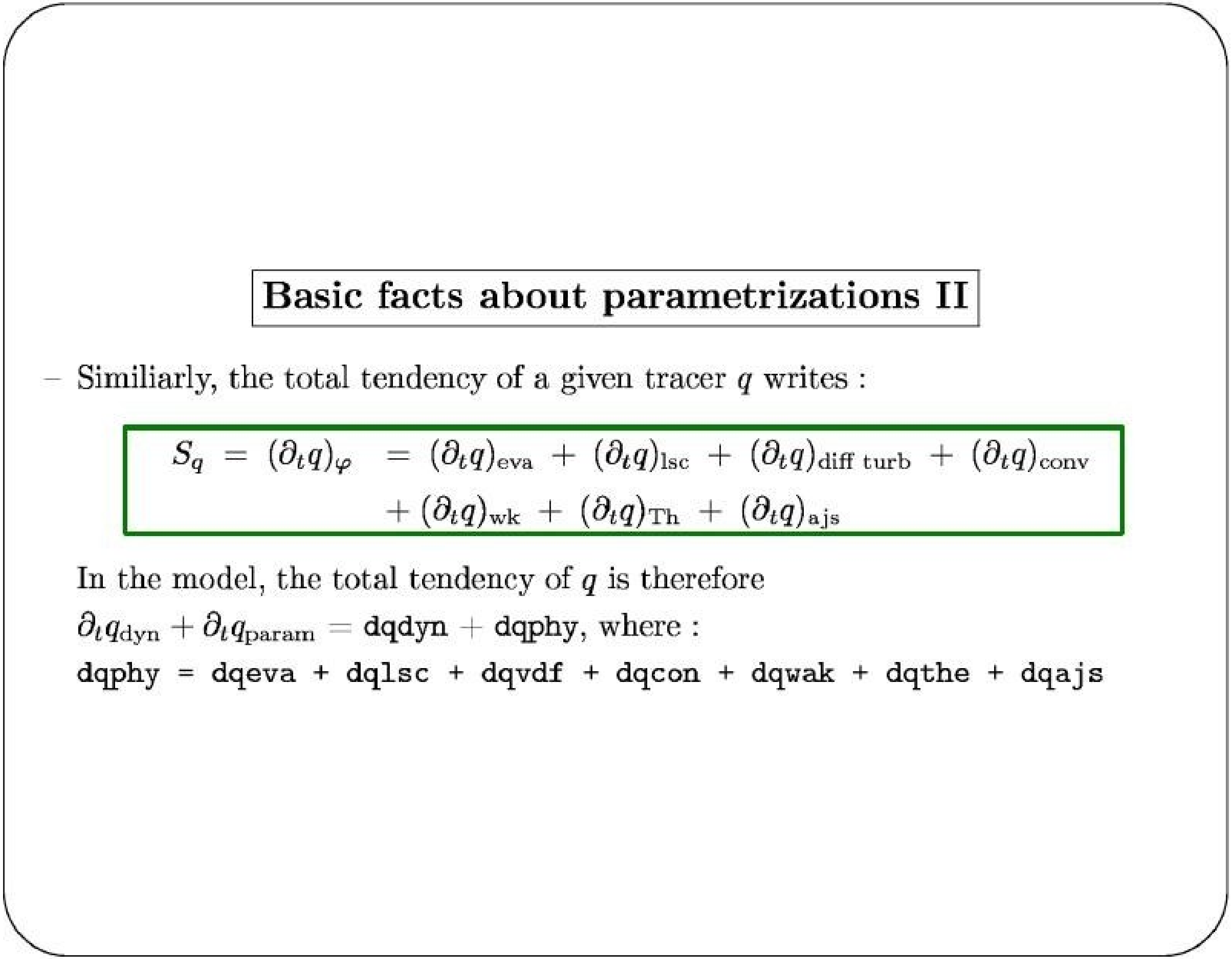
$$\begin{aligned} S_T = (\partial_t T)_\varphi &= (\partial_t T)_{\mathrm{eva}} + (\partial_t T)_{\mathrm{lsc}} + (\partial_t T)_{\mathrm{diff\ turb}} + (\partial_t T)_{\mathrm{conv}} \\ &+ (\partial_t T)_{\mathrm{wk}} + (\partial_t T)_{\mathrm{Th}} + (\partial_t T)_{\mathrm{ajs}} \\ &+ (\partial_t T)_{\mathrm{rad}}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

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 :

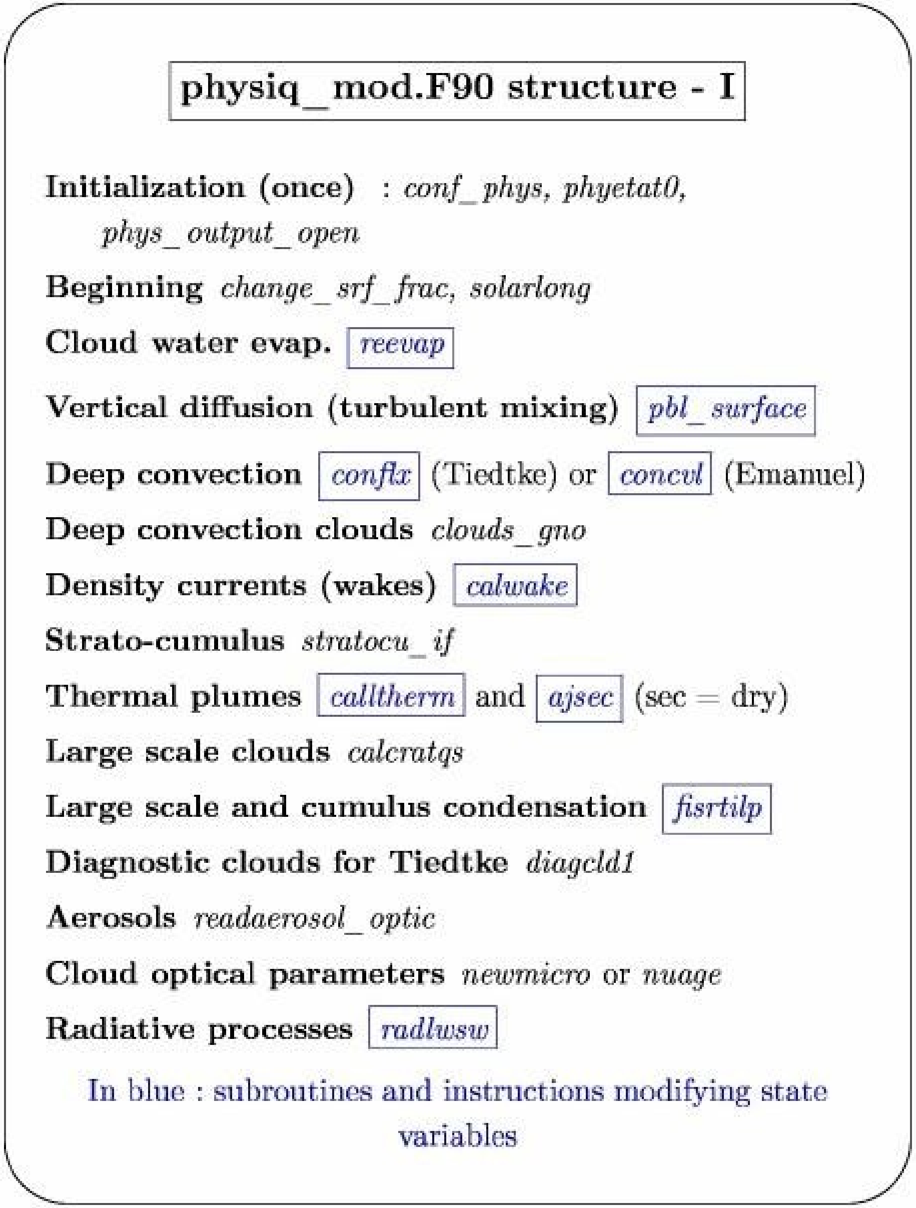
$$\boxed{\begin{aligned} S_q \;=\; (\partial_t q)_\varphi \;&=\; (\partial_t q)_{\mathrm{eva}} + (\partial_t q)_{\mathrm{lsc}} + (\partial_t q)_{\mathrm{diff\ turb}} + (\partial_t q)_{\mathrm{conv}} \\ &+ (\partial_t q)_{\mathrm{wk}} + (\partial_t q)_{\mathrm{Th}} + (\partial_t q)_{\mathrm{ajs}} \end{aligned}}$$

In the model, the total tendency of q is therefore

$\partial_t q_{\mathrm{dyn}} + \partial_t q_{\mathrm{param}} = \texttt{dqdyn} + \texttt{dqphy}$, 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*

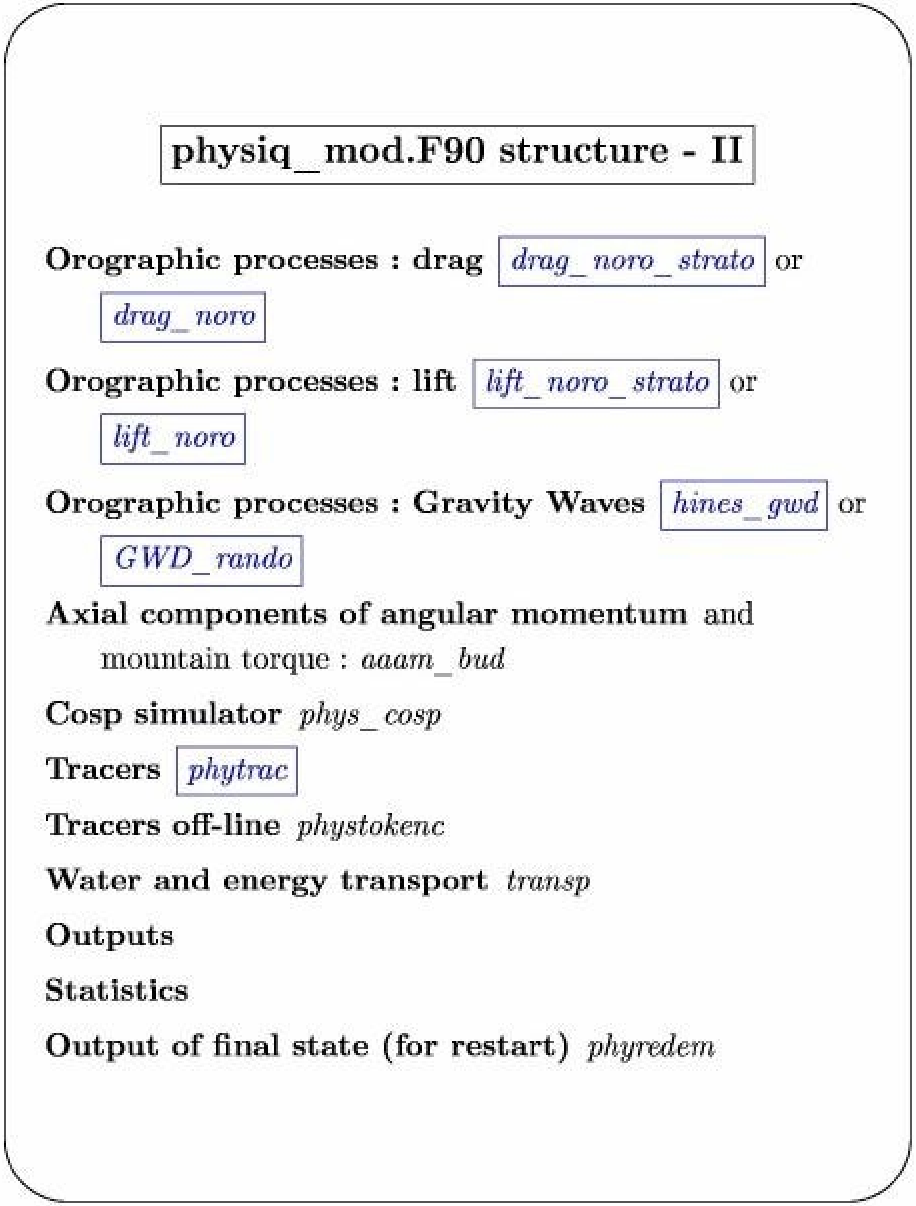
Diagnostic clouds for Tiedtke *diagcld1*

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*

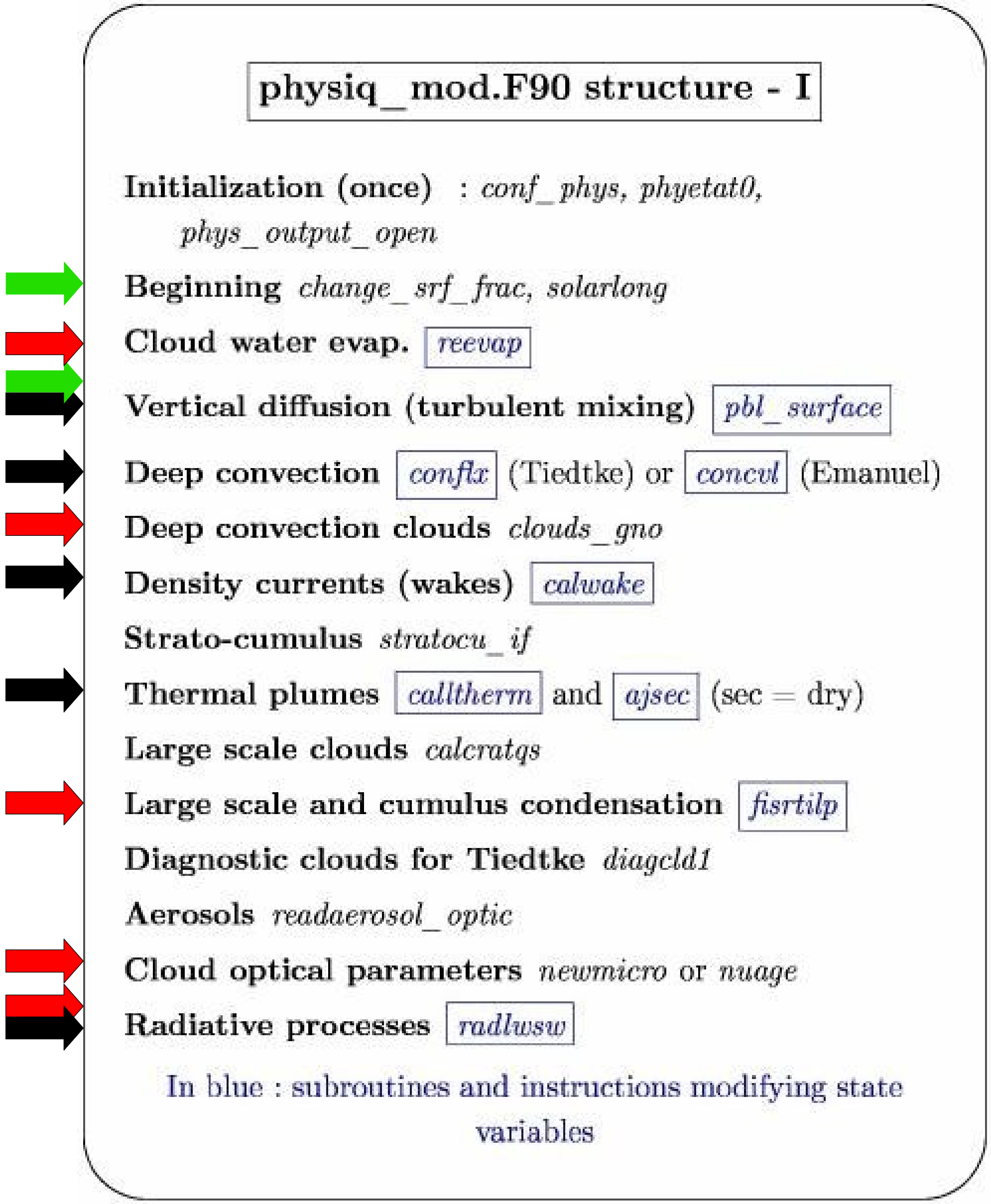
Water and energy transport *transp*

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*

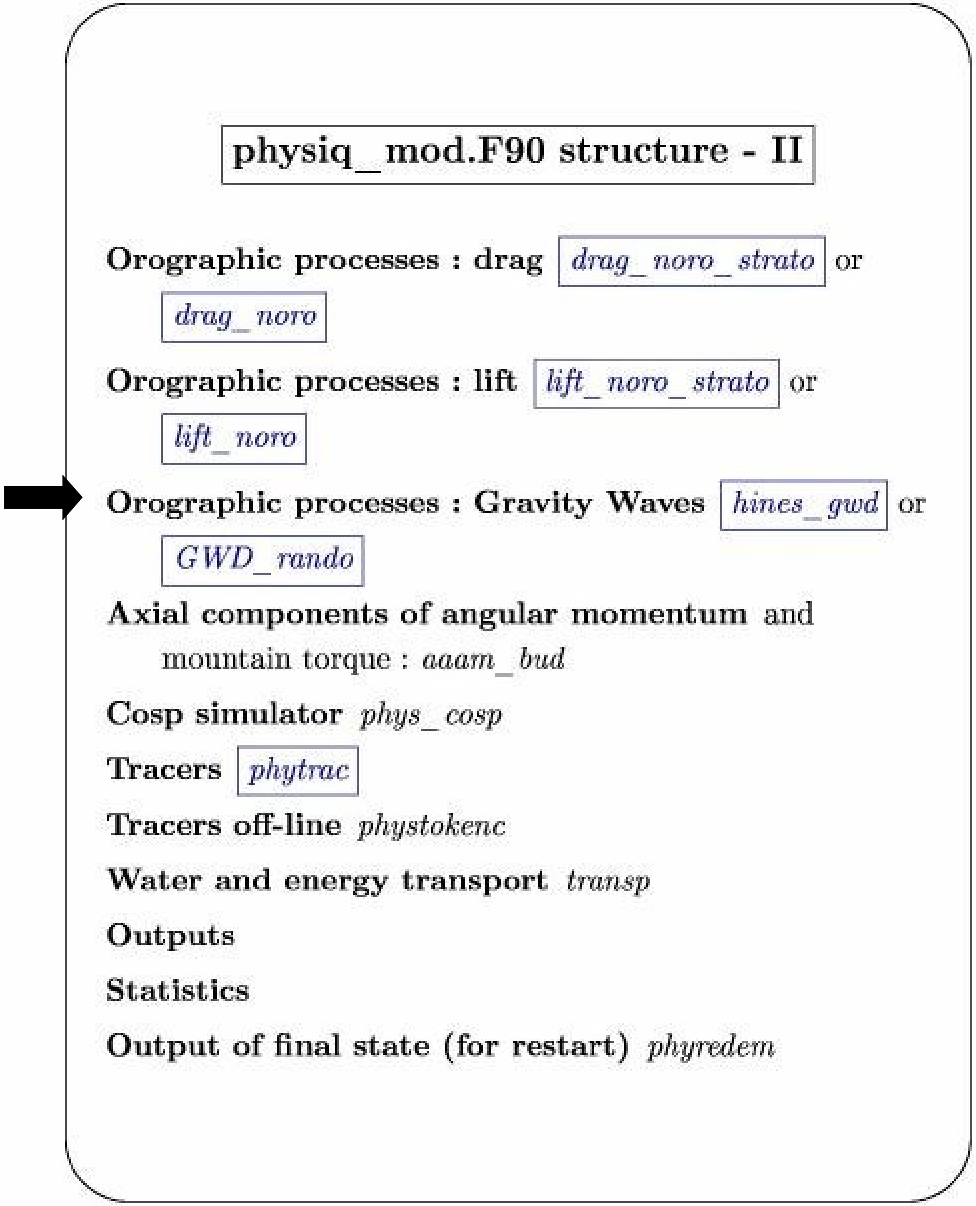
Diagnostic clouds for Tiedtke *diagcld1*

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*

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Cosp simulator *phys_cosp*

Tracers *phytrac*

Tracers off-line *phystokenc*

Water and energy transport *transp*

Outputs

Statistics

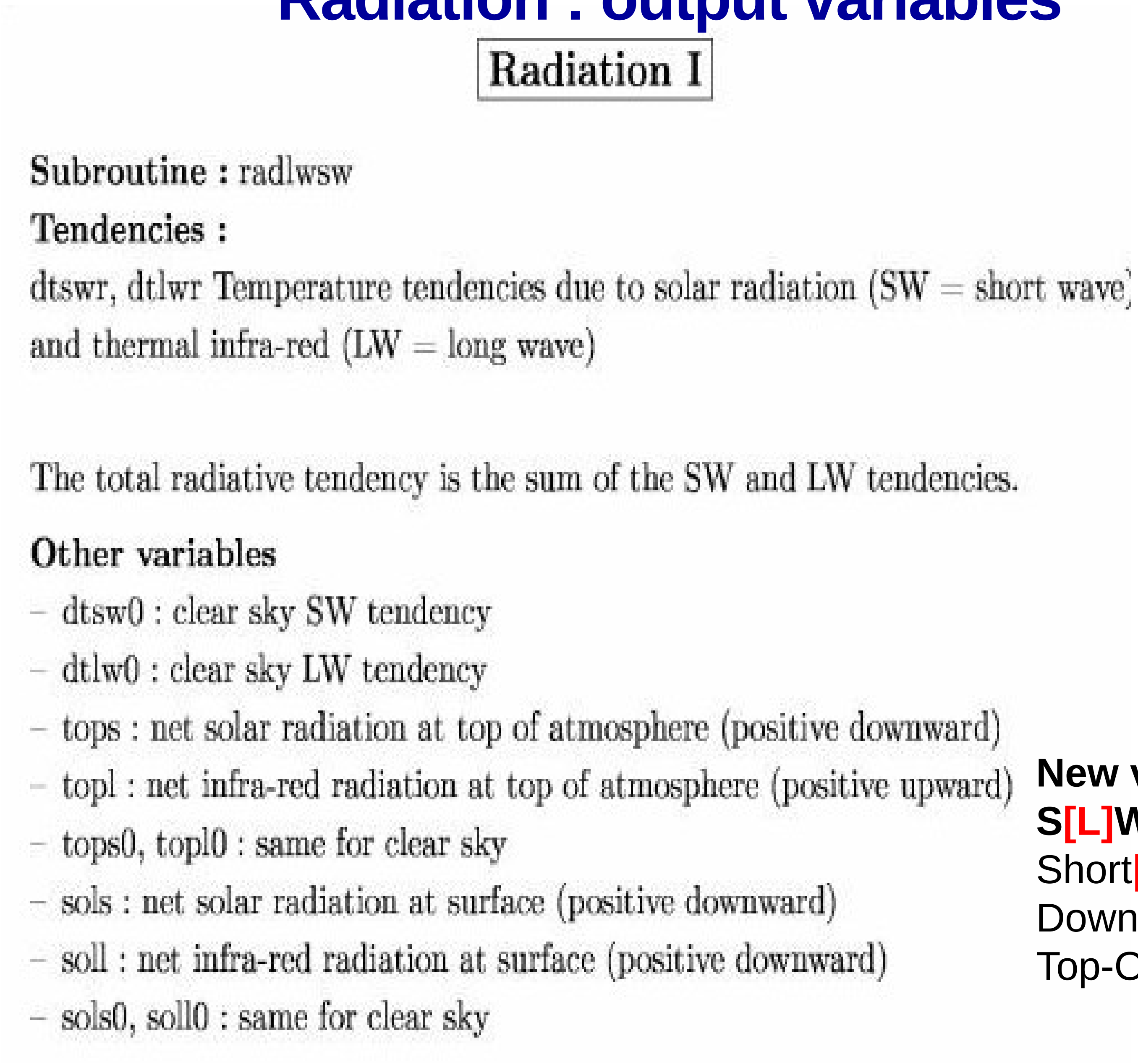
Output of final state (for restart) *phyredem*

Effect of subrid-scale transport ← Today

Coupling with surface ← Tomorrow

Clouds and radiation ← Tomorrow

Radiation : output variables



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

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

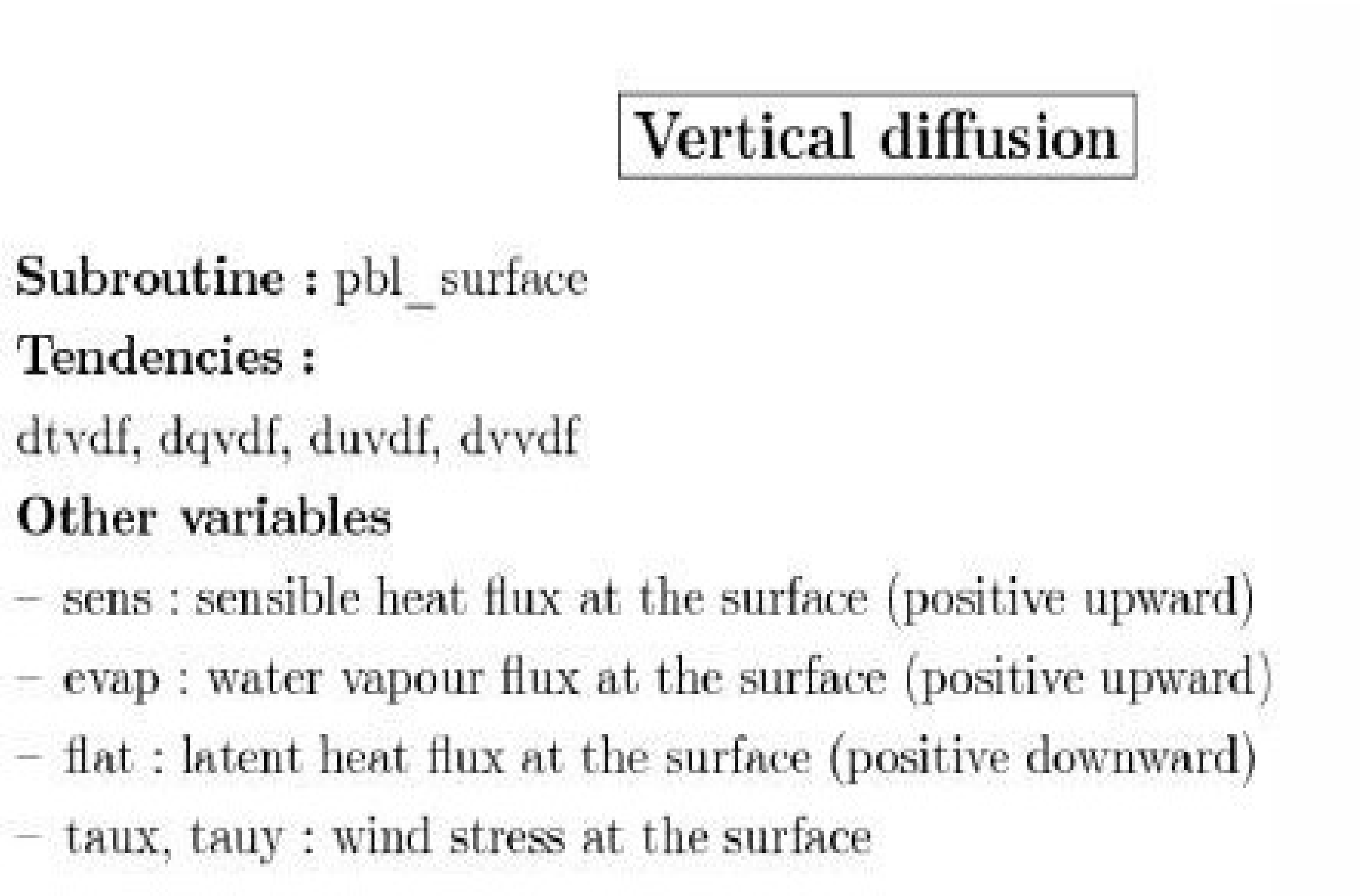
In physiq.def (deepL translation)

```
####################################################################
#
# 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 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)

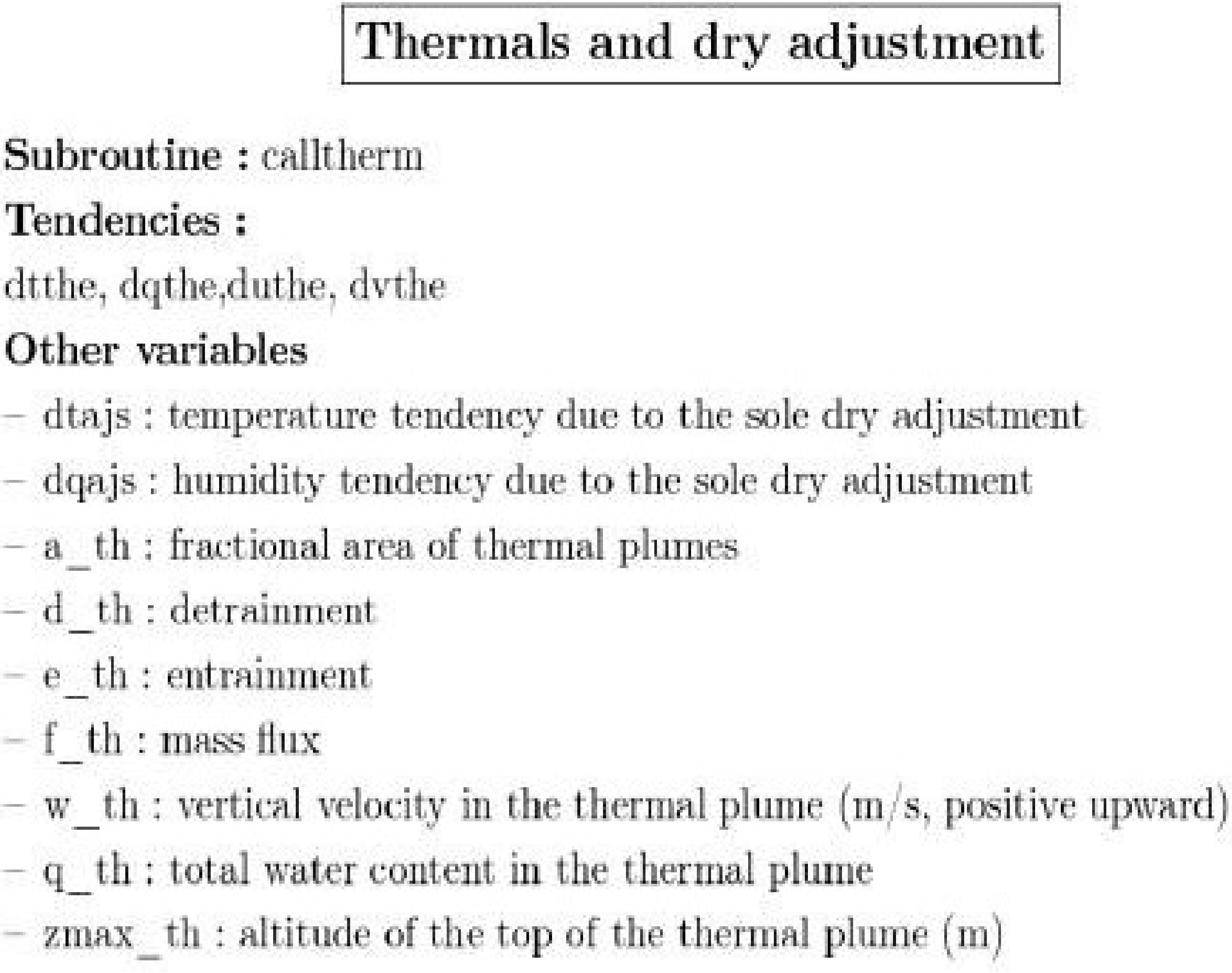
```
###############################################################################
# Turbulent boundary layer
###############################################################################

        # 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 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
```

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+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)