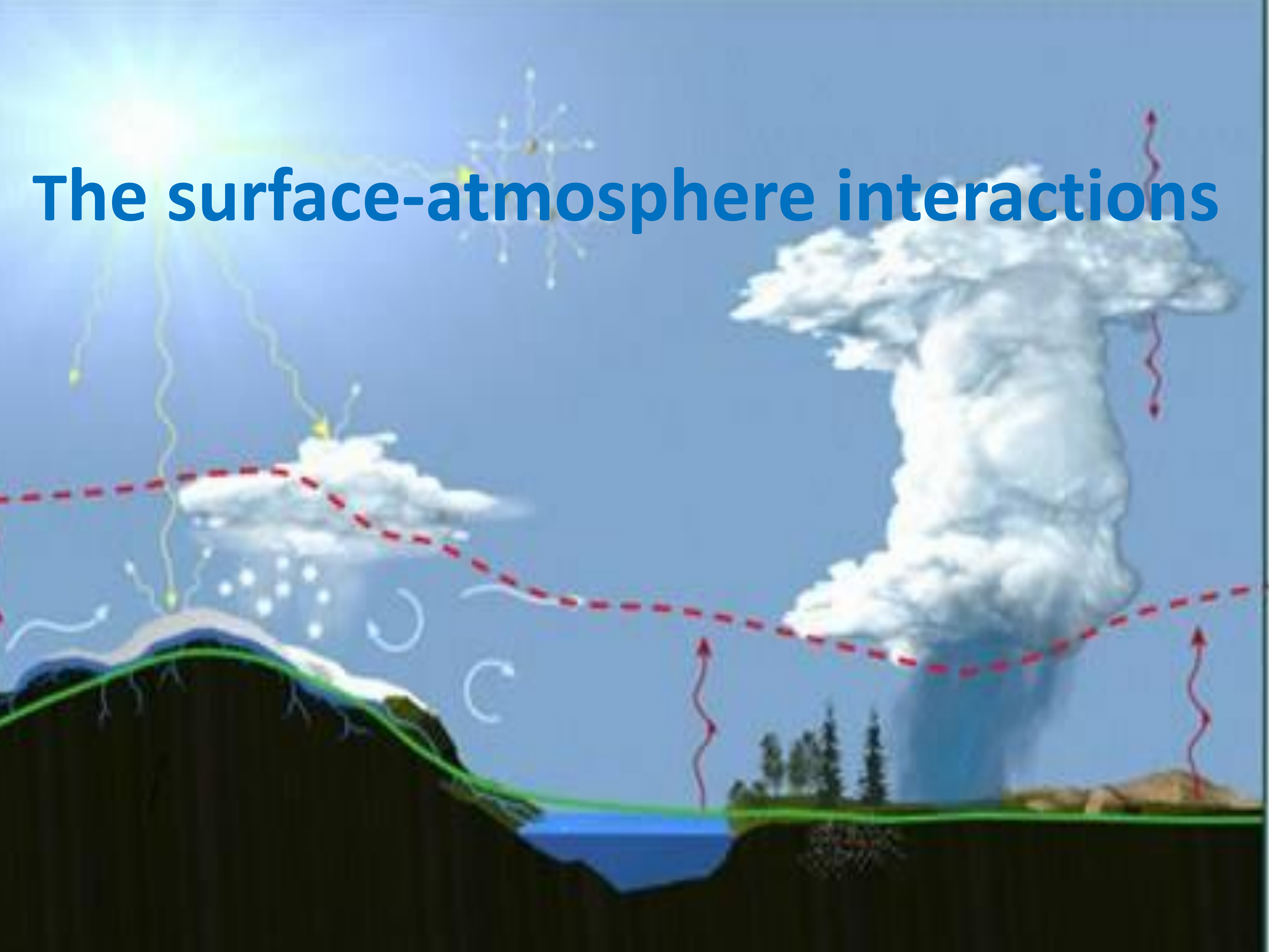
The surface-atmosphere interactions



Atmosphere-surface interactions in IPSL-CM

In LMDZ:
Each surface grid can be decomposed in a maximum of 4 sub-grid of different type:
land (_ter), continental ice (_lic), open ocean (_oce) and sea_ice (_sic)

Radiation at the surface depends on mean surface properties (albedo, emissivity)

Turbulent diffusion depends on local sub-grid properties but each sub-surface sees the same atmosphere




COUPLING BETWEEN ATMOSPHERE AND SURFACE

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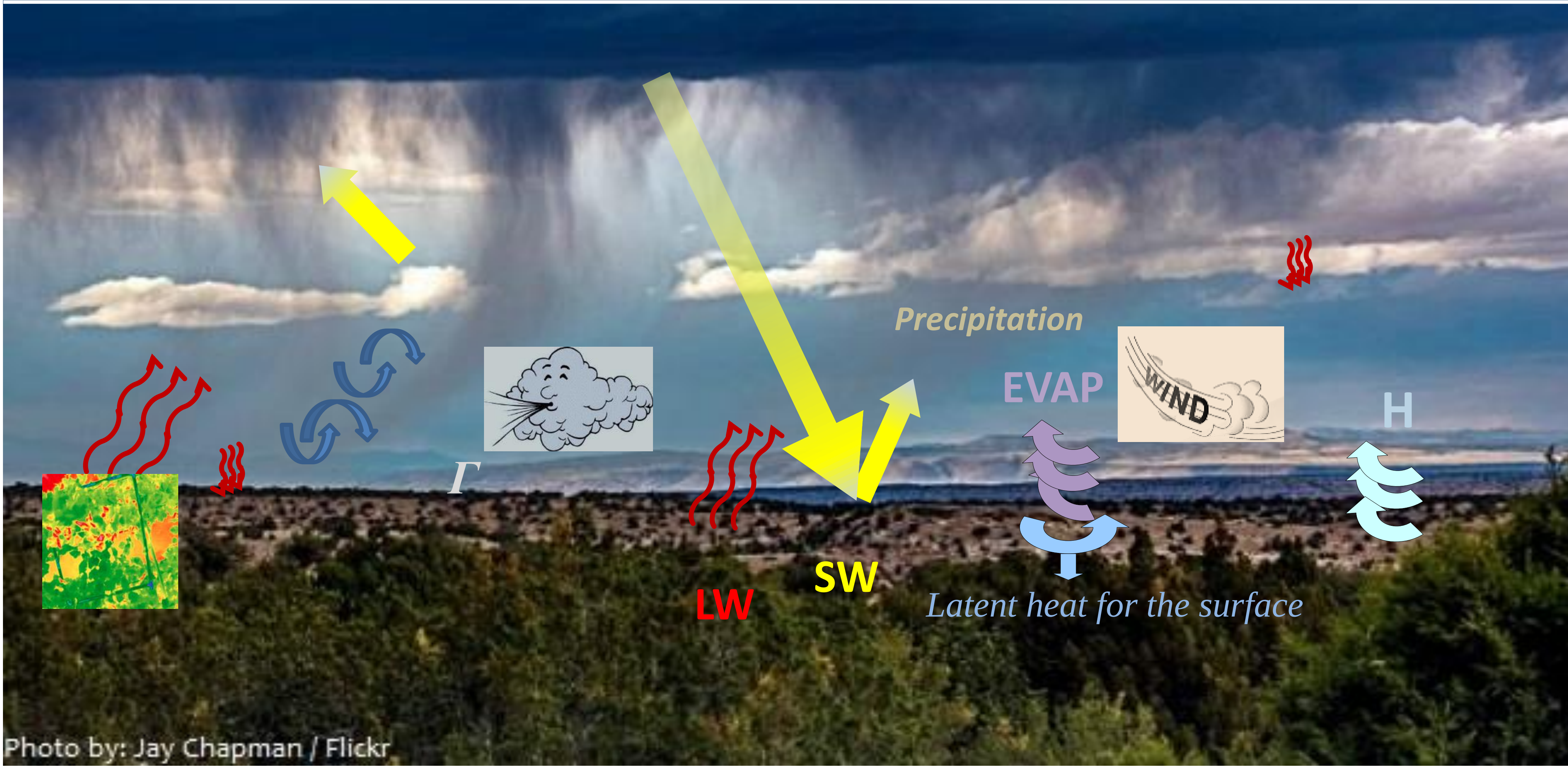
Processes involved



The **atmosphere and the surface are coupled** through *turbulence* (in boundary layer) and *radiatio* (SW and LW).

Surface impacts atmosphere via orography, roughness, albedo, emissivity

Change of a variable X with the time due to the turbulent transport

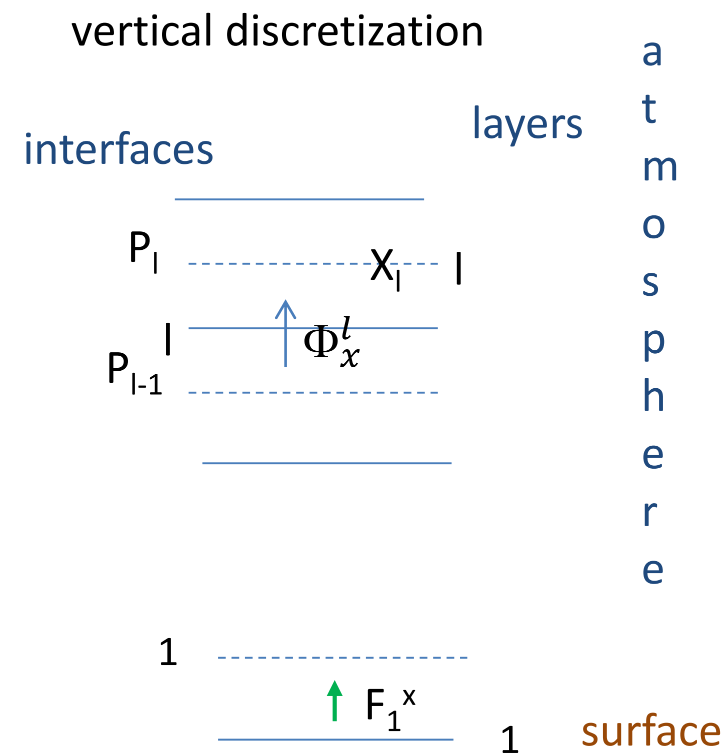
(continuity) : $$\frac{\partial X}{\partial t} = -\frac{1}{\rho}\frac{\partial \Phi}{\partial z}$$

$$\Phi = -\rho k_z \frac{\partial X}{\partial z}$$

Turbulent diffusion (pbl_surface, LMDZ)

$$\Phi = -\rho k_z \frac{\partial X}{\partial z}$$

$$\Phi_x^l = -K_l\,(X_l - X_{l-1})$$



X= specific humidity, enthalpie, momentum

$\delta P = (P_{l-1} - P_l) = \rho g \delta z = m_l\, g$

Turbulent diffusion (pbl_surface, LMDZ)

$$\Phi = -\rho k_z \frac{\partial X}{\partial z}$$

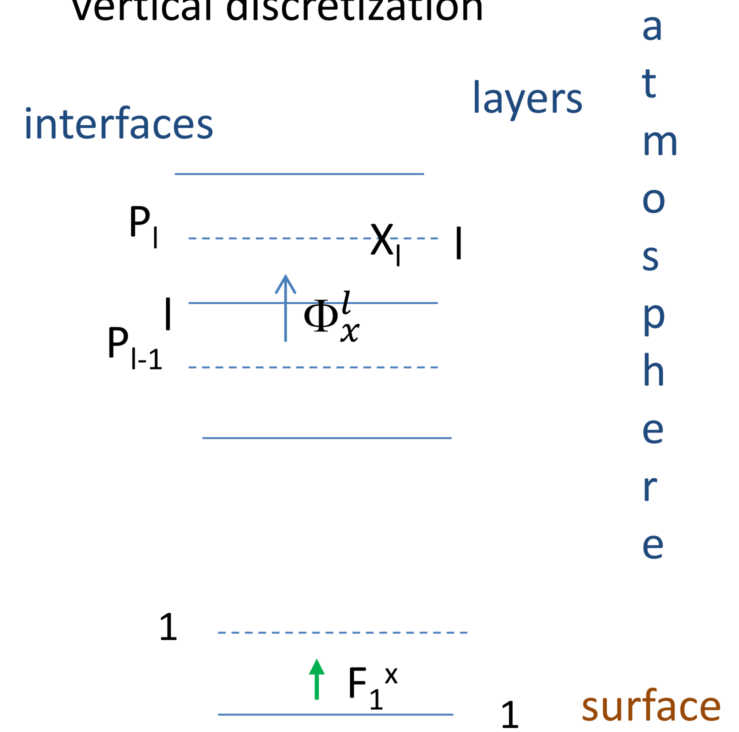
vertical discretization

$$F_1^q = \beta\rho V C_{d,q}\,(q_1 - q_s(T_s))$$

$$F_1^h = \rho V C_{d,h}\,(T_1 - T_s)$$

$$F_1^u = \rho V C_{d,m}\,(u_1 - u_o)$$

$$\Phi_x^l = -K_l\,(X_l - X_{l-1})$$



$$C_{dm} = \kappa^2/(\ \ln(\frac{z}{z0m}) * \ln(\frac{z}{z0m}))\ * F_{stab}$$

$$C_{dh} = \kappa^2/(\ \ln(\frac{z}{z0m}) * \ln(\frac{z}{z0h}))\ * F_{stab}$$

X= specific humidity, enthalpie, momentum

$\delta P = (P_{l-1} - P_l) = \rho g \delta z = m_l\, g$

$$\Phi^{l}_{x} = -K_l\,(X_l - X_{l-1}) \qquad \frac{\partial X}{\partial t} = -\frac{\partial \Phi}{m_l}$$

Time discretization

$$m_l \frac{X_l(t+\delta t) - X_l(t)}{\delta t} = \phi_l(t+\delta t) - \phi_{l+1}(t+\delta t)$$

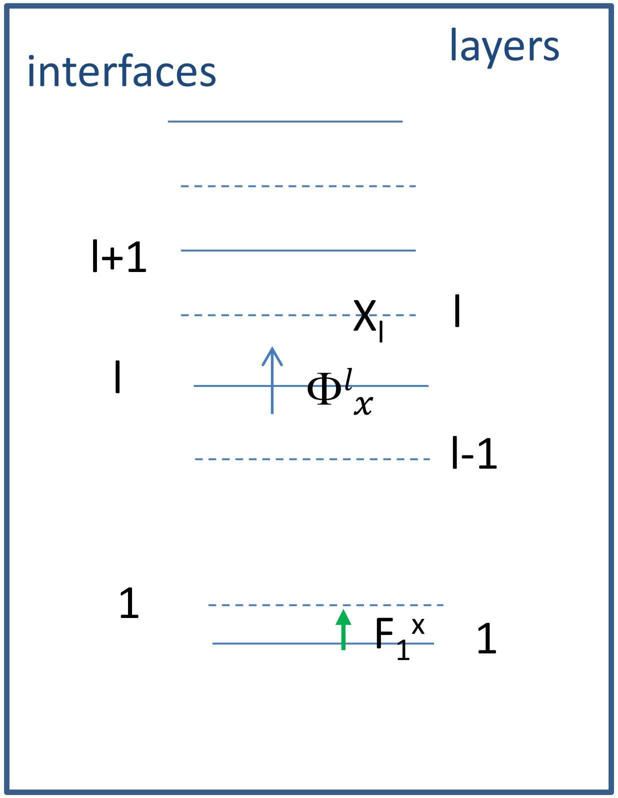
$$m_l \frac{X_l - X_l^0}{\delta t} = \phi_l - \phi_{l+1}$$

with $X_l = X_l(t+\delta t)$, $X_l^0 = X_l(t)$

$$m_l \frac{X_l - X_l^0}{\delta t} = K_{l+1}(X_{l+1} - X_l) - K_l(X_l - X_{l-1})$$

$$-K_l X_{l-1} + \left(\frac{m_l}{\delta t} + K_{l+1} + K_l\right) X_l + K_{l+1} X_{l+1} = \frac{m_l}{\delta t} X_l^0$$

X



Tri-diagonal system that can be solved for the vector X= Enthalpy, specific humidity.wind…

Solving the tridiagonal system

$$\left(\frac{m_l}{\delta t} + K_{l+1} + K_l\right) X_l = \frac{m_l}{\delta t} X_l^0 + K_{l+1} X_{l+1} + K_l X_{l-1}$$

which may be written as:

$$\left(\delta P_l + R_{l+1}^X + R_l^X\right) X_l = \delta P_l \; X_l^0 + R_{l+1}^X \; X_{l+1} + R_l^X \; X_{l-1} \quad (2 \le l < n)$$

$$\text{with } R_l^X = g \delta t K_l$$

At the top (l=n, $\Phi_n = 0$)

$$\left(\delta P_n + R_n^X\right) X_n = \delta P_n \; X_n^0 + R_n^X \; X_{n-1}$$

At the bottom: (l=1) : $m_1 \frac{X_1 - X_1^0}{\delta t} = \Phi^1{}_x - \Phi^2{}_x$

$$m_1 \frac{X_1 - X_1^0}{\delta t} = K_2 (X_2 - X_1) - F_1^X$$

$$\left(\delta P_1 + R_1^X\right) X_1 = \delta P_1 \; X_1^0 + R_2^X \; X_2 - g \delta t F_1^X$$

With F_1^X : flux of X at the bottom of the first layer (i.e. between the surface and the atmosphere), positive downward.

$$K_l = \frac{k_z \rho^2 g}{P_{l-1} - P_l}$$

Solving the tridiagonal system

Starting from top:

$$\left(\delta P_n + R_n^X\right) X_n = \delta P_n \ X_n^0 + R_n^X \ X_{n-1}$$

can be written as:

$$\boxed{X_n = C_n^X + D_n^X X_{n-1}}$$

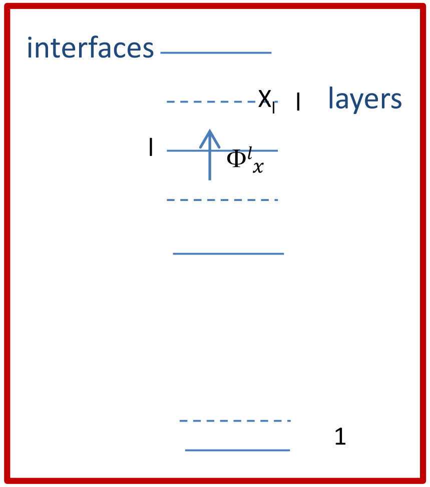
with

$$C_n^X = \frac{X_n^0 \delta P_n}{\delta P_n + R_n^X}$$

$$D_n^X = \frac{R_n^X}{\delta P_n + R_n^X}$$

with $R_l^X = g \delta t K_l$

Solving the tridiagonal system



$$X_{l+1} = C^X_{l+1} + D^X_{l+1} X_l$$

$$\left(\delta P_l + R^X_{l+1} + R^X_l\right) X_l = \delta P_l\, X^0_l + R^X_{l+1}\, X_{l+1} + R^X_l\, X_{l-1} \quad (2 \le l < n)$$

$$\left(\delta P_l + R^X_{l+1}\left(1 - D^X_{l+1}\right) + R^X_l\right) X_l = \delta P_l\, X^0_l + R^X_{l+1}\, C^X_{l+1} + R^X_l\, X_{l-1}$$

with $R^X_l = g\delta t K_l$

So we obtain by reccurence:

$$X_l = C^X_l + D^X_l X_{l-1} \qquad (2 \le l \le n)$$

with, for $(2 \le l < n)$

$$\begin{cases} C^X_l = \dfrac{X^0_l \delta P_l + R^X_{l+1} C^X_{l+1}}{\delta P_l + R^X_l + R^X_{l+1}(1 - D^X_{l+1})} \\ D^X_l = \dfrac{R^X_l}{\delta P_l + R^X_l + R^X_{l+1}(1 - D^X_{l+1})} \end{cases}$$

depend only on properties in the layers above and the variables at the previous time step.

In LMDZ routine calc_coef

Solving the tridiagonal system

At the bottom of the boundary layer $X_2 = C_2^X + D_2^X X_1$

$$(\delta P_1 + R_2^X)\, X_1 = \delta P_1\; X_1^0 + R_2^X\; X_2 - g\delta t F_1^X$$

replacing X_2 in the equation above:

$$\boxed{X_1 = A_1^X + B_1^X . F_1^X . \delta t}$$

with

$$A_1^X = \frac{X_1^0 \delta P_1 + R_2^X C_2^X}{\delta P_1 + R_2^X (1 - D_2^X)}$$

$$B_1^X = \frac{-g}{\delta P_1 + R_2^X (1 - D_2^X)}$$

$F_1^u = \rho V C_{d,m} (u_1 - u_o)$

$u_1 = A_1 + B_1 F_1^u \delta t$

Solving the tridiagonal system

interfaces layers

downhill

$$C_n^X = \frac{X_n^0 \delta P_n}{\delta P_n + R_n^X}$$

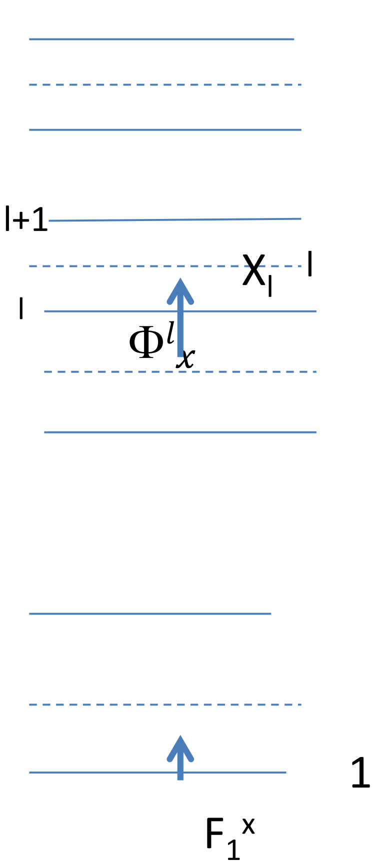
$$D_n^X = \frac{R_n^X}{\delta P_n + R_n^X}$$

depend only on properties in the layers above and the variables at the previous time step.

$$C_l^X = \frac{X_l^0 \delta P_l + R_{l+1}^X C_{l+1}^X}{\delta P_l + R_l^X + R_{l+1}^X (1 - D_{l+1}^X)}$$

$$D_l^X = \frac{R_l^X}{\delta P_l + R_l^X + R_{l+1}^X (1 - D_{l+1}^X)}$$

$$X_l = C_l^X + D_l^X X_{l-1}$$



In LMDZ
climb_hq_down
climb_wind_down

$$A_1^X = \frac{X_1^0 \delta P_1 + R_2^X C_2^X}{\delta P_1 + R_2^X (1 - D_2^X)}$$

$$B_1^X = \frac{-g}{\delta P_1 + R_2^X (1 - D_2^X)}$$

?

$$X_1 = A_1^X + B_1^X F_1^X \delta t$$

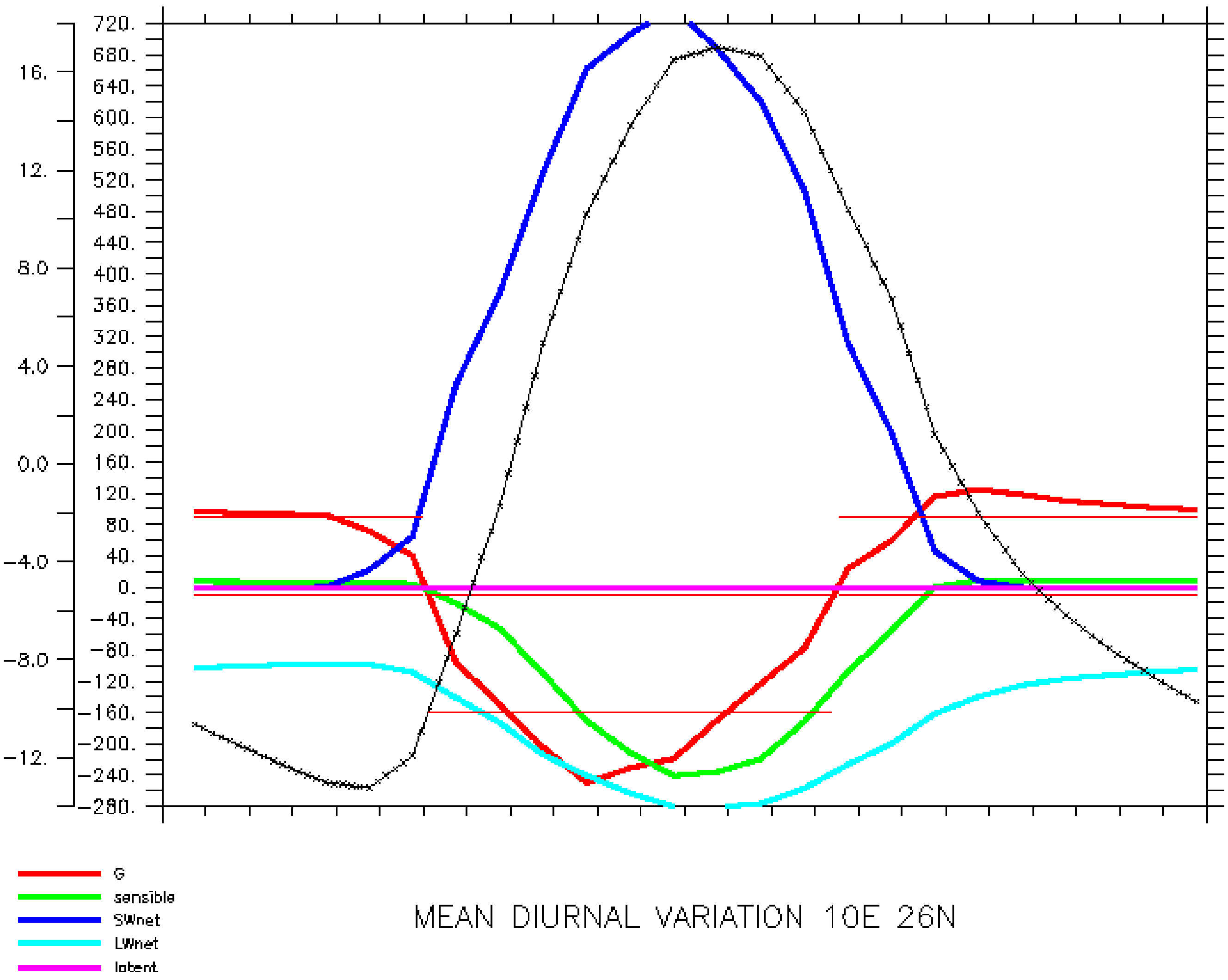
X= wind, enthalpie, specific humidity, tracers

Once F_1^x (flux of water mass, heat between the surface and the atmosphere) is known, the X_i can be computed from the first layer to the top of the PBL

Surface energy budget:

Case of the continental surface

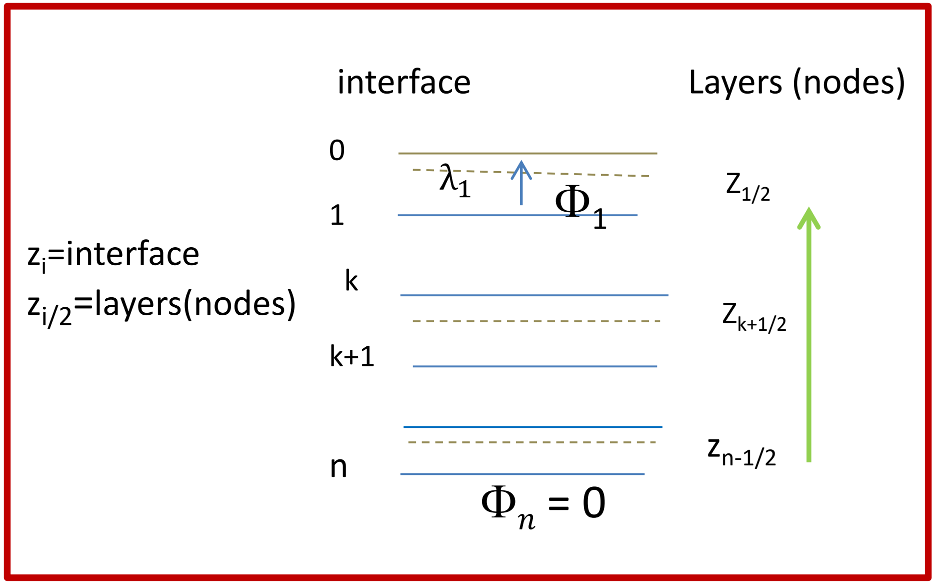
$$SW_{net} + LW_{net} + F + L + \Phi_1 = 0$$



Fast Variations requires an implicit approach to solve the energy budget equations

- Heat conduction : Diffusion equation $C\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\lambda\frac{\partial T}{\partial z}\right)$

$$\Phi_T = -\lambda\frac{\partial T}{\partial z} \quad ;$$



- **Bottom** : $\Phi = 0$

$$C^t_{p_{n-1/2}}\frac{T^t_{n-1/2}-T_{n-1/2}}{\delta t} = \frac{1}{z_N - z_{N-1}}\left[-\lambda_{n-1}\frac{T^t_{n-1/2}-T^t_{n-3/2}}{z_{n-1/2}-z_{n-3/2}}\right]$$

- Intermediate layers

$$C^t_{p_{k+1/2}}\frac{T^t_{k+1/2}-T^t_{k+1/2}}{\delta t} = \frac{1}{z_{k+1}-z_k}\left[\lambda_{k+1}\frac{T^t_{k+3/2}-T^t_{k+1/2}}{z_{k+3/2}-z_{k+1/2}} - \lambda_k\frac{T^t_{k+1/2}-T^t_{k-1/2}}{z_{k+1/2}-z_{k-1/2}}\right]$$

- First layer

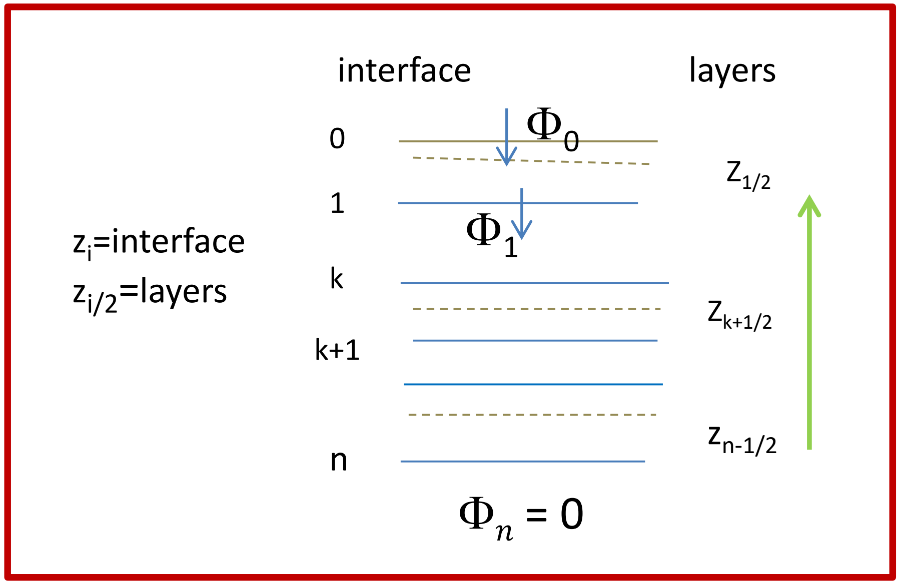
$$T^t_{3/2} = \alpha^t_1\, T^t_{\frac{1}{2}} + \beta^t_1$$

- Heat conduction : Diffusion equation

$$\Phi_T = -\lambda \frac{\partial T}{\partial z} \quad ;$$

$$\frac{\partial T}{\partial t} = -\frac{1}{C}\frac{\partial \Phi_T}{\partial z}$$

We obtain by recurrence (same as for atmosphere)



- First layer

$$T^t_{3/2} = \alpha^t_1 \, T^t_{\frac{1}{2}} + \beta^t_1$$

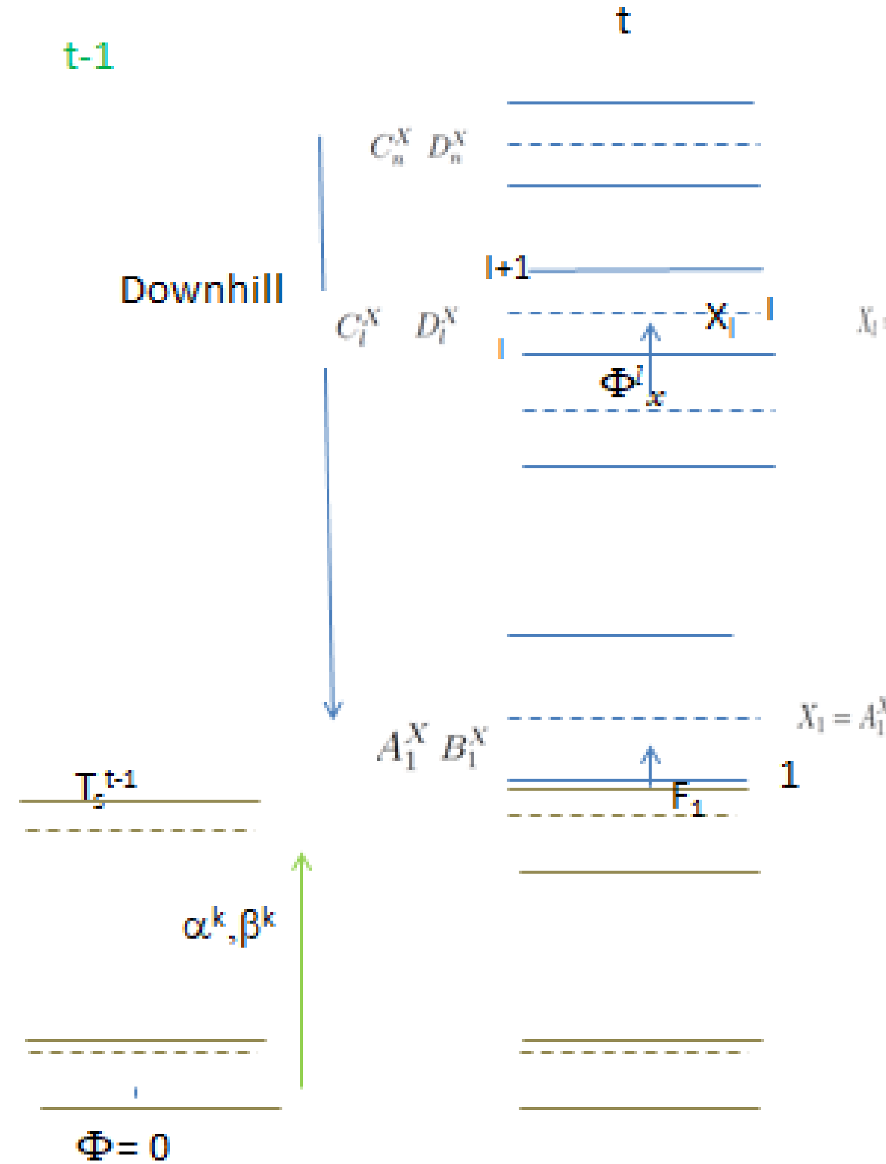
- Intermediate layers

$$T^t_{k+1/2} = \alpha^t_k \, T^t_{k-1/2} + \beta^t_k$$

At t, α_k and β_κ depend on $T_{k1/2}$ at the previous time step they can be computed with a recurrence relationship from one layer to the other.

- **Bottom** : $\Phi_n = 0$ $\quad T^t_{n-1/2} = \alpha^t_{n-1} \, T^t_{n-\frac{3}{2}} + \beta^t_{n-1}$

In LMDZ
climb_hq_down
and
climb_wind_down



At t α_k and β_k depend on T_k at the previous time step and on the underlying layers:
They can be pre-computed

- Top: Continuity between sub-surface and atmosphere + vertical discretization

$$\Phi_1 = \text{Rad} + \sum F^{\downarrow}\left(T_S^t\right) - \varepsilon\sigma(T_S^t)^4$$

$$C_{p_{1/2}}^t \frac{T_{1/2}^t - T_{1/2}}{\delta t} = \frac{1}{z_1 - z_0}\left[\lambda_1 \frac{T_{3/2}^t - T_{1/2}^t}{z_{3/2} - z_{1/2}}\right] + Rad + \sum F^{\downarrow}\left(T_S^t\right) - \varepsilon\sigma(T_S^t)^4$$

- Top: Continuity between sub-surface and atmosphere

(1) $$C_{p_{1/2}}^{t}\frac{T_{1/2}^{t}-T_{1/2}}{\delta t}=\frac{1}{z_1-z_0}\left[\lambda_1\frac{T_{3/2}^{t}-T_{1/2}^{t}}{z_{3/2}-z_{1/2}}\right]+\sum F^{\downarrow}(T_S^t)-\varepsilon\sigma(T_S^t)^4$$

(2) $$T_{3/2}^{t}=\alpha_1^t\ T_{\frac{1}{2}}^{t}+\beta_1^t$$

T_s is extrapolated as a function of $T_{\frac{1}{2}}^{t}$ taking advantage of (2)

(very thin layers, and continuity of the temperature - Hourdin 1993))

$$C'*\frac{T_S^t-T_S^0}{\delta t}=G'*+SW_{net}+LWd+\sum F^{\downarrow}(T_S^t)-\varepsilon\sigma(T_S^t)^4$$

Case of the continental surface

$$\begin{cases} F^t_{\mathrm{s,H}} = A^1{}_H + B^1{}_H F^t_{s,H} \partial t & \text{Turbulent diffusion Atmosphere} \\ F^t_{s,H} = \frac{1}{zikt}(H^t_1 - H^t_s) \quad \frac{1}{zikt} = \rho |\overrightarrow{v}| C_d & \text{Bulk formulation} \end{cases}$$

$$F^t_{s,H} = \frac{1}{zikt}(A^1_H + B^1_H . F^t_{s,H} \delta t - H^t_s)$$

$$F^t_{s,H} = \frac{1}{zikt}\left[\frac{(A^1_H - H^{t-\delta t}_s)}{1 - \frac{1}{zikt} B^1_H \delta t} - \frac{(H^t_s - H^{t-\delta t}_s)}{1 - \frac{1}{zikt} B^1_H \delta t}\right]$$

$C_d{}^x$ drag coefficient (Monin Obukhov, constant f
in the surface layer)
depends on

- roughness lenghts (gustiness, vegetation), orography
- Richardson number (boundary layer stability)
- Formulation depends on the sub-surface typ

$$F^t_{s,H} = sensfl_{old} - sensfl_{sns}(T^t_s - T^{t-\delta t}_s)$$

- Top boundary condition:

Continuity of the fluxes and the temperature between sub-surface and atmosphere

$$C' * \frac{T_S^t - T_S^0}{\delta t} = G' * + SW_{net} + LW_d + \sum F^{\downarrow}(T_S^t) - \varepsilon\sigma(T_S^t)^4$$

Solved using the sensitivity of the flux to the surface temperature to calculate the flux at the new time-step

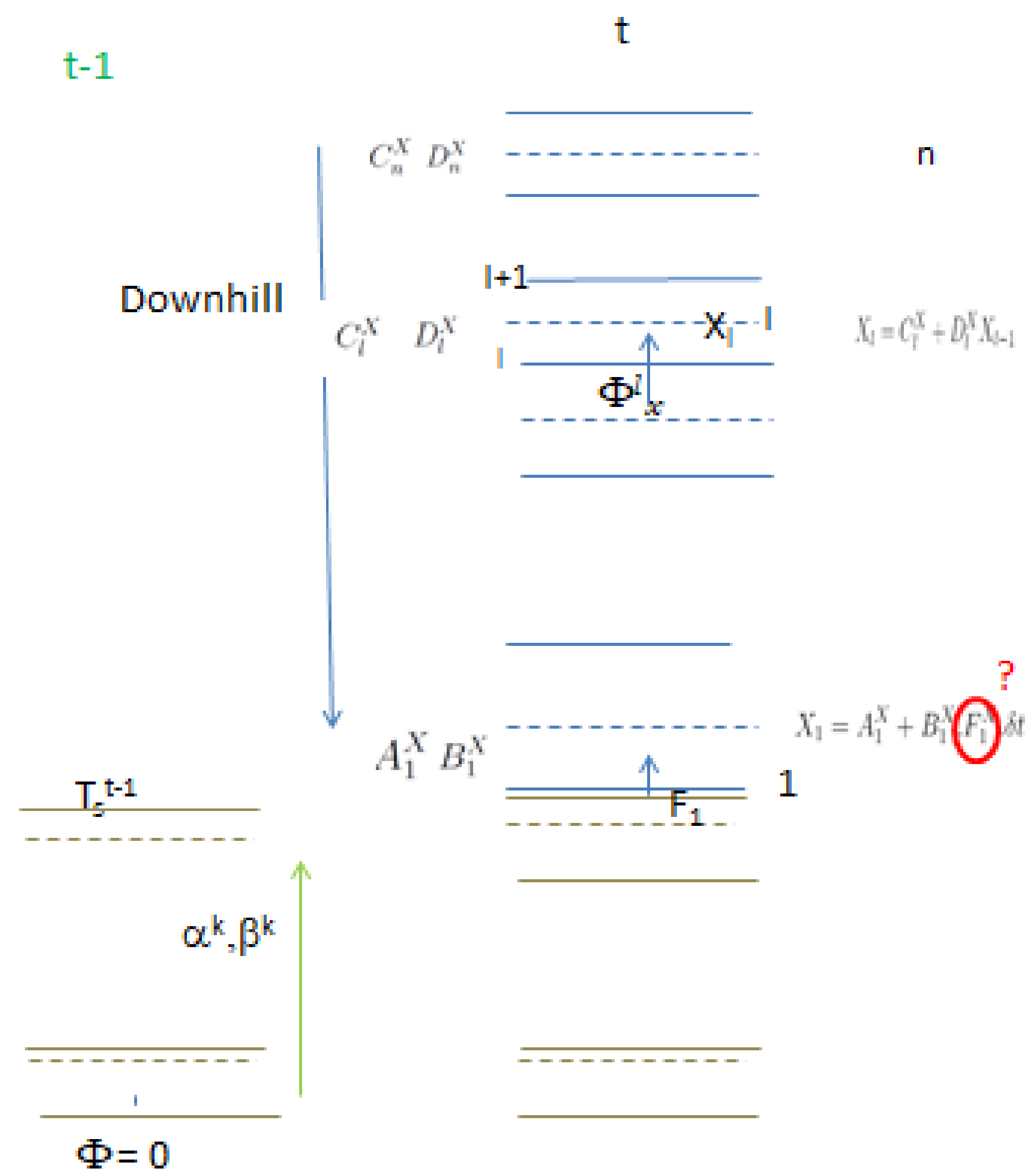
$$F_{s,H}^t = sensfl_{old} - sensfl_{sns}(T_s^t - T_s^{t-\delta t})$$

$$\sigma * T_s^{t-\delta t^4} - 4\varepsilon\sigma T_s^{t-\delta t^3}(T_s^t - T_s^{t-\delta t})$$

$$T_S^t = f(SW_{net} + LWd, T_S^0, F_S^0)$$

In LMDZOR

In LMDZ
climb_hq_down
and
climb_wind_down



At t α_k and β_k depend on T_k at the previous time step and on the underlying layers:
They can be pre-computed

ORCHIDEE (thermosoil)

Hourdin 1993

Atmosphere-surface interactions in IPSL-CM

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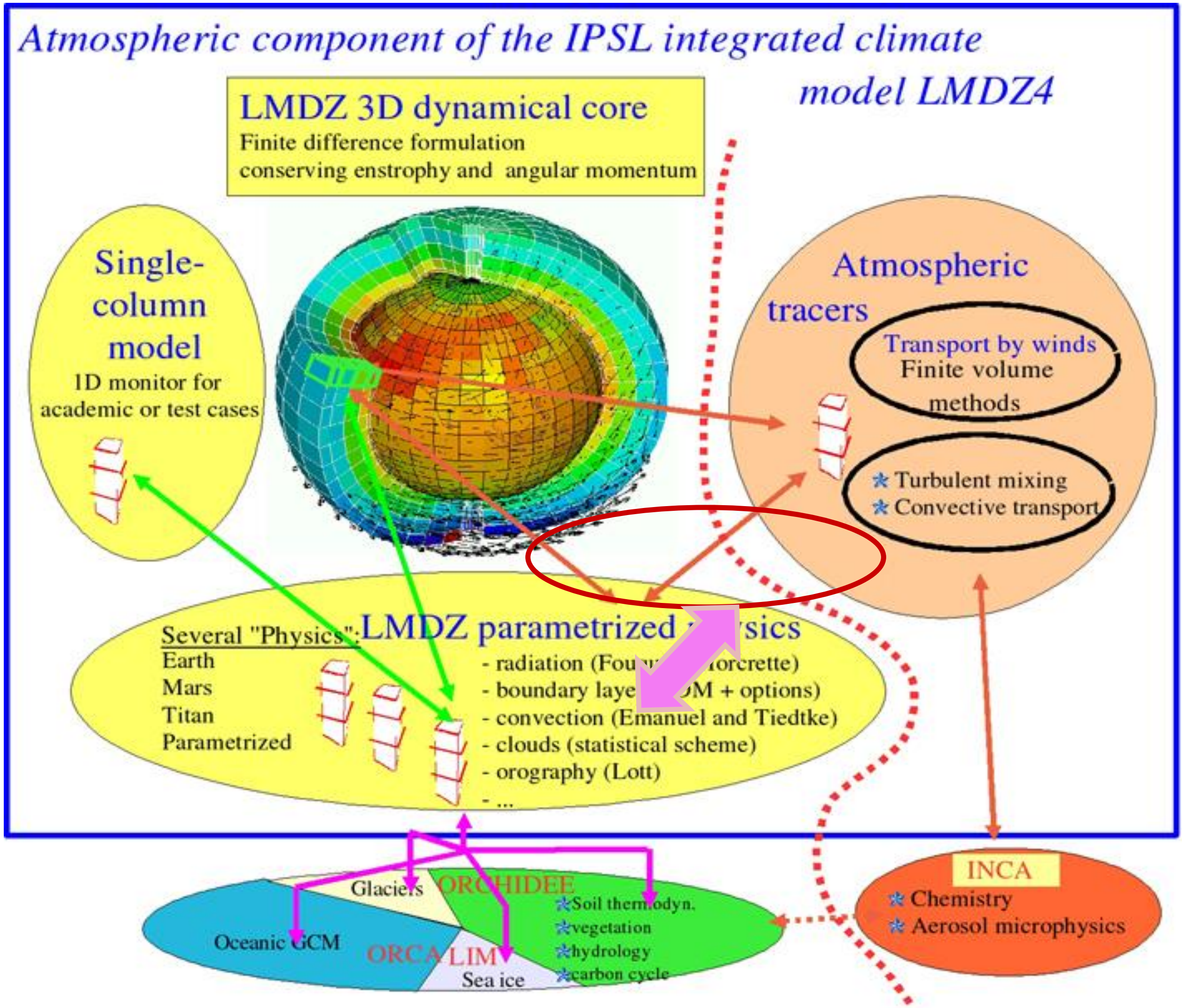
Radiation at the surface depends on mean surface properties (albedo, emissivity)

Turbulent diffusion depends on local sub-grid properties but each sub-surface sees the same atmosphere

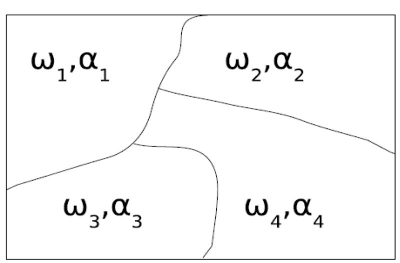


Coupling between atmospheric column(s) and sub-surfaces

Each grid cell is divided into several sub-areas or ``sub-surfaces'' of fractions ω_i

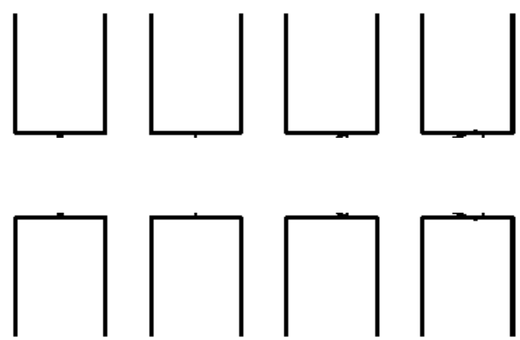
Sub-surfaces

$$\sum_i \omega_i = 1$$



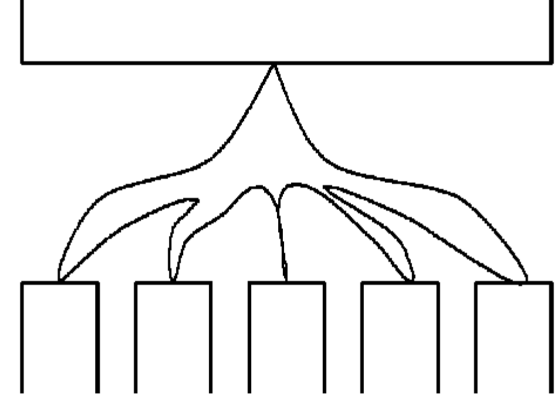
Turbulent flux

One PBL over **each** sub-surface



Radiative flux

One column **covers all** the sub-surface



Each sub surface has to compute *F_1* using variables *X_1*, *A_1* and *B_1*

The boundary layer tendencies in the atmosphere are mixed between sub-columns (equivalent of averaging the surface flux)

Derivation of local sub-surface **net solar radiation** from grid average net solar radiation

The grid average net flux Ψ_s at surface has been computed for each grid point by the radiative code

We want (1) to conserve energy and (2) to take into account the value of the local albedo αi of the sub-surface.

We compute the downward SW radiation as

$$F_{\downarrow}^{s} = \frac{\Psi_s}{(1-\alpha)}$$

with the mean albedo

$$\alpha = \sum_i \omega_i \alpha_i$$

For each sub-surface i, the absorbed solar radiation reads:

$$\psi_i^s = (1-\alpha_i) F_{\downarrow}^{s}$$

$$\psi_i^s = \frac{(1-\alpha_i)}{(1-\alpha)} \bar{\Psi}^s$$

One may verify that this procedure ensure energy conservation, i.e.

$$\sum_i \omega_i \psi_i^s = \Psi_s$$

Derivation of local sub-surface **net longwave radiation** from grid average net longwave radiation

The net longwave (LW) radiation $\bar{\Psi}^L$ has been computed by the radiative code for each grid cell. How to split it depending on the sub-surfaces local properties and ensuring energy conservation?

If the downward longwave flux $F_\downarrow$ is uniform within each grid, the net LW flux for a sub-surface i may be written as:

$$\psi_i^L(T_i) = \epsilon_i \left(F_\downarrow - \sigma T_i^4 \right) \quad (1)$$

where T_i is the surface temperature of sub-surface i and ϵ_i its emissivity. A linearization around the mean temperature $\bar{T}$ gives:

$$\psi_i^L(T_i) \approx \epsilon_i \left(F_\downarrow - \sigma \bar{T}^4 \right) - 4\epsilon_i \sigma \bar{T}^3 (T_i - \bar{T}) \quad (2)$$

To conserve the energy, the following relationship must be true:

$$\sum_i \omega_i \psi_i^L = \bar{\Psi}^L \quad (3)$$

Using Eq. 2 gives

$$\sum_i \omega_i \psi_i^L = \bar{\epsilon} \left(F_\downarrow - \sigma \bar{T}^4 \right) - 4\sigma \bar{T}^3 \sum_i \omega_i \epsilon_i \left(T_i - \bar{T} \right) \quad (4)$$

where $\bar{\epsilon} = \sum_i \omega_i \epsilon_i$ is the mean emissivity.

Derivation of local sub-surface **net longwave radiation** from grid average net longwave radiation

$$\sum_i \omega_i \psi_i^L = \bar{\epsilon}\left(F_\downarrow - \sigma \bar{T}^4\right) - 4\sigma\bar{T}^3 \sum_i \omega_i \epsilon_i \left(T_i - \bar{T}\right) \quad (4)$$

where $\bar{\epsilon} = \sum_i \omega_i \epsilon_i$ is the mean emissivity. The second term on the right hand side is zero if

$$\bar{T} = \frac{\sum_i \omega_i \epsilon_i T_i}{\bar{\epsilon}} \quad (5)$$

To ensure energy conservation, we need in addition to verify:

$$\bar{\Psi}^L = \bar{\epsilon}\left(F_\downarrow - \sigma \bar{T}^4\right) \quad (6)$$

Which is consistent with the definition of the net LW flux at the surface. We rewrite now Eq. 2 as:

$$\psi_i^L(T_i) \approx \frac{\epsilon_i}{\bar{\epsilon}} \bar{\Psi}^L - 4\epsilon_i \sigma \bar{T}^3 (T_i - \bar{T}) \quad (7)$$

Due to radiative code limitation, in LMDZ, we always must have $\varepsilon_i = 1$
Energy conservation: the radiation is computed by the atmospheric model,

Atmosphere/surface coupling in LMDZOR

LMDZ (phylmd)

Planetary boundary layer
and surface modules

pbl_surface

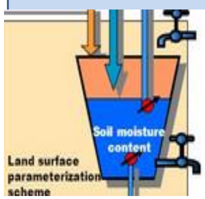
(A_q , B_q, A_H , B_B, C_{dh}, A_u , B_u, A_v , B_v , C_{dh}, T_1, q_1, u_1, v_1, LW_{net}, LW_{down}, Sw_{net})

AcoefH, AcoefQ, BcoefH, BcoefQ cdragh,lwdown,swnet

,

(is_ter, ok_veget = n)

surf_land_bucket



(soil.F90: soil T, heat capacity, conduction,
calcul_flux : sens,flat,tsurf_new
Hydro= water budget (snow, precip, Evap)

(is_ter, ok_veget = y)

surf_land_orchidee

Atmosphere/surface coupling in LMDZOR

LMDZ (phylmd)

Planetary boundary layer and surface modules

pbl_surface

(A_q , $B_{q,}$ A_H , $B_{B,}$ $C_{dh,}$, A_u , $B_{u,}$ A_v , B_v , C_{dh}, T_1, $q_{1,}$ u_1,$v_{1,}$ $LW_{net,}$ $LW_{down,}$ Sw_{net})

AcoefH, AcoefQ, BcoefH, BcoefQ cdragh,lwdown,swnet

,

(is_ter, ok_veget = y)

surf_land_orchidee

LW_{dwn}, SW_{net}, LW_{net} , T_1, q_1, $cdrag_h$, u_1,v_1

A_q , $B_{q,}$ A_H , B_{B}, rain, snow)

fluxsens, fluxlat, albedo, ε, tsurf_new, z0

ORCHIDEE (sechiba)

intersurf

petA_orc,petB_orc,peqA_orc,peqB_orc,swet, swnet,lwdown, cdrag

Water and Energy budget (surface and soil)

diffuco (z0, albedo , emissivity)

enerbil fluxsens ,fluxlat, tsurf_new

thermosoil G, ztsol

Hydrol: hydrology – diffusion scheme

Atmosphere/surface coupling in LMDZOR

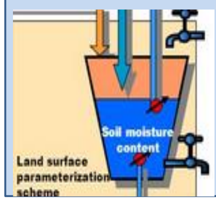
LMDZ (phylmd)

Planetary boundary layer
and surface modules

pbl_surface

(A_q , B_q, A_H , B_B, C_{dh}, A_u , B_u, A_v , B_v , C_{dh}, T_1, q_1, u_1,v_1, LW_{net}, LW_{down}, Sw_{net})
AcoefH, AcoefQ, BcoefH, BcoefQ cdragh,lwdown,swnet
,

(is_ter, ok_veget = n)
surf_land_bucket



(soil.F90: soil T, heat capacity, conduction,
calcul_flux : sens,flat,tsurf_new
Hydro= water budget (snow, precip, Evap)

(is_ter, ok_veget = y)
surf_land_orchidee

LW_{dwn}, SW_{net}, LW_{net} , T_1, q_1, $cdrag_h$, u_1,v_1
A_q , B_q, A_H , B_B, rain, snow)

fluxsens, fluxlat, albedo, ε, tsurf_new, z0

intersurf

ORCHIDEE (sechiba)

petA_orc,petB_orc,peqA_orc,peqB_orc,swet, swnet,lwdown, cdrag

Water and Energy budget (surface and soil)

diffuco (z0, albedo , emissivity)
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Hydrol: hydrology – diffusion scheme

In subroutine PHYSIQ

loop over time steps

Call tree

CALL change_srf_frac : Update fraction of the sub-surfaces (pctsrf)

....

CALL pbl_surface Main subroutine for the interface with surface

Calculate net radiation at sub-surface

Loop over the sub-surfaces nsrf

Compress variables (Consider only one surface type and only the points for which the fraction for this sub-surface in not zero)

CALL cdrag: coefficients for turbulent diffusion at surface (cdragh and cdragm)

CALL coef_diff_turb: coef. turbulent dif. in the atmosphere (ycoefm et ycoefm.)

CALL climb_hq_down downhill for enthalpy H and humidity Q

CALL climb_wind_down downhill for wind (U and V)

CALL surface models for the various surface types: **surf_land**, **surf_landice**, **surf_ocean** **or** **surf_seaice**.

Each surface model computes:

- evaporation, latent heat flux, sensible heat flux, momentum
- surface temperature, albedo (emissivity), roughness lengths

CALL climb_hq_up : compute new values of enthalpy H and humidity Q

CALL climb_wind_up : compute new values of wind (U and V)

Uncompress variables : (some variables are per unit of sub-surface fraction, some are per unit of grid surface fraction)

Cumulate in global variables after weighting by sub-surface fractions

Surface diagnostics : (T, q, wind are evaluated at a reference level (2m) owing to an interpolation scheme based on the MO laws).

End Loop over the sub-surfaces

Calculate the mean values over all sub-surfaces for some variables

End pbl-surface

THANK YOU FOR YOUR ATTENTION

- Technical note **:** Description of the interface with the surface and the computation of the turbulent diffusion in LMDZ (J.L.Dufresne)
- Thèse F. Hourdin 1993 (section 3.3.3 and annexes)
- Wang F., F. Cheruy, J.L. Dufresne, 2016: The improvement of soil thermodynamics and its effects on land surface meteorology in the IPSL climate model. Geosci. Model Dev., 9, 363–381, 2016   www.geosci-model-dev.net/9/363/2016/

Case of the continental surface

- Surface energy budget

$$SW_{net} + LW_{net} + F + L + \Phi_0 = 0$$

$$SW_{net} + LW_d \underline{- \varepsilon\sigma T_s^4 + F + L + \Phi_0} = 0$$

depends on Ts

$$L = \beta\rho V C_d (q_1 - q_s(T_s))$$

$$F = \rho V C_d (T_1 - T_s)$$

- Heat conduction in the soil: diffusion equation :

$$\Phi_T = -\lambda \frac{\partial T}{\partial z}$$

$$\frac{\partial T}{\partial t} = -\frac{1}{C} \frac{\partial \Phi_T}{\partial z}$$

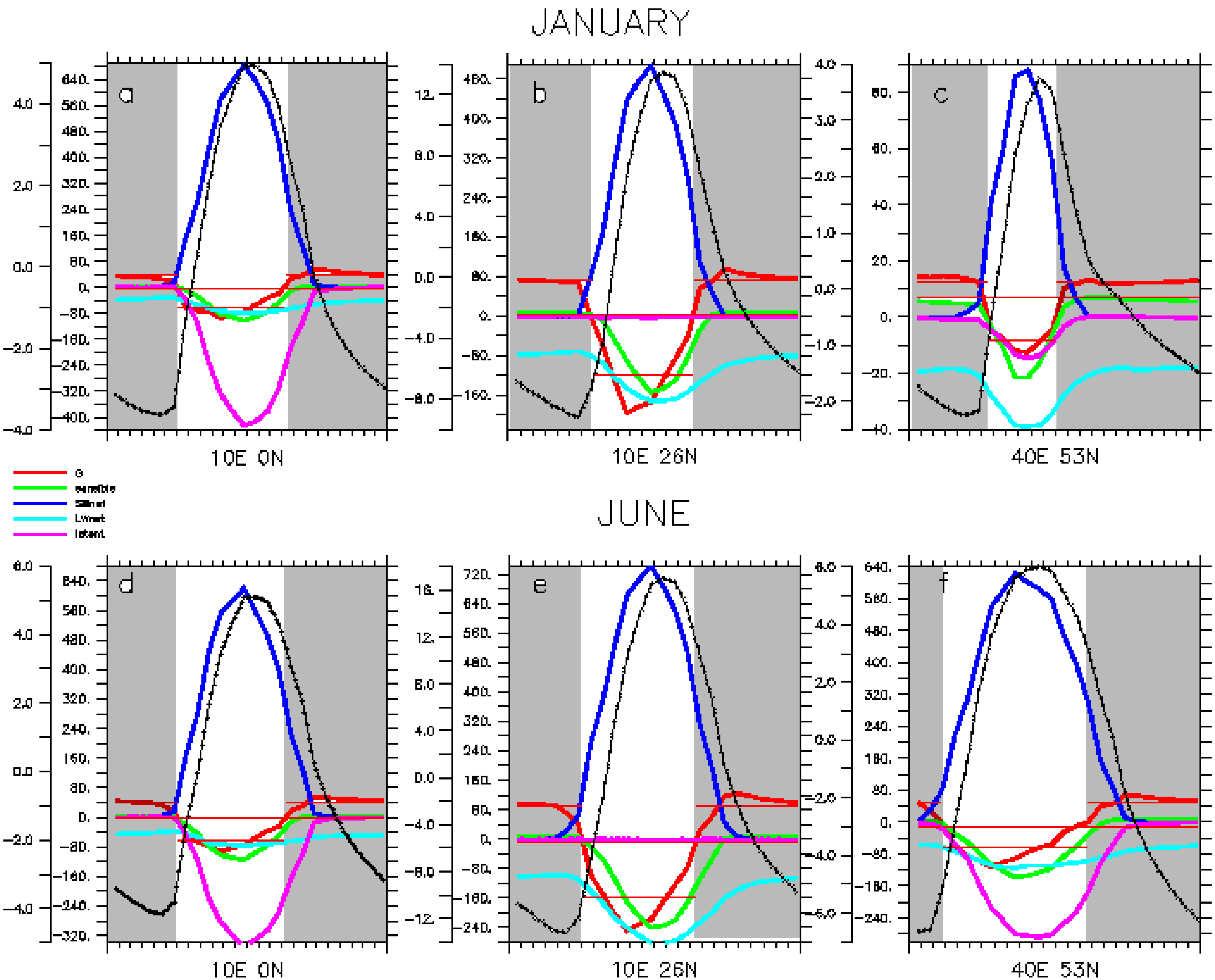
Boundary conditions:

- ✓ bottom : $\Phi = 0$
- ✓ top: Continuity of the fluxes and the temperature between sub-surface and atmosphere

Surface energy budget:

$$SW_{net} + LW_{net} + F + L + \Phi_0 = 0$$

Case of the continental surface



Fast Variations requires an implicit approach to solve the energy budget equations

Cheruy et al. 2019