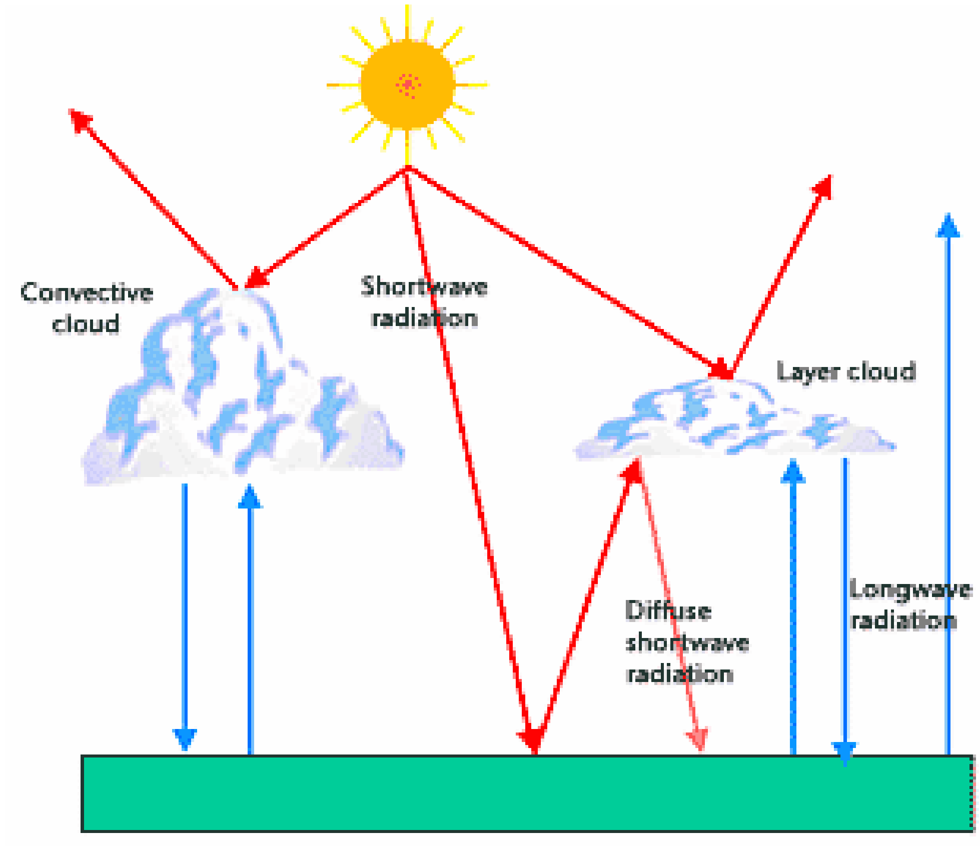
Parametrizzazioni

- Le equazioni differenziali della circolazione dell'atmosfera descrivono moti aventi un intervallo di scale spaziali che vanno dalla scala molecolare alla scala planetaria
- La discretizzazione delle equazioni del moto risolve solo le scale spaziali superiori al passo di griglia
- L'influenza dei moti non risolti su quelli risolti può essere importante anche su scale temporali brevi e deve quindi essere presa in considerazione
- L'effetto dei moti su scale non risolte viene calcolato in funzione dei campi esplicitamente previsti dal modello. Questa operazione viene indicata col termine "**parametrizzazione**"

Parametrizzazione dei flussi radiativi



- Radiation fluxes are computed with a combined application of the Geleyn scheme (Ritter and Geleyn, 1992) and the ECMWF scheme (cycle 26, Morcrette, 1991; Mlawer *et al*., 1997), with Tegen (Tegen *et al,* 1997) aerosol climatology.

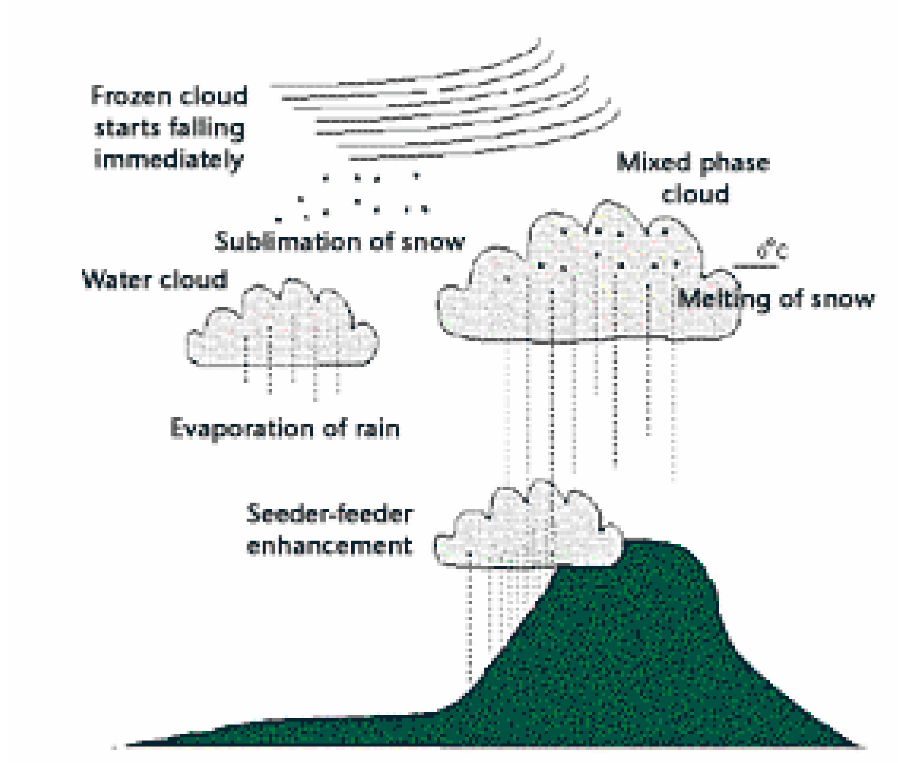
- The Geleyn scheme, with the option of maximum cloud coverage, is called approximately every NTSRC timestep (~20 minutes), and has been modified to take into account explicit cloud concentration.

- The ECMWF scheme is used to correct the surface and internal radiative fluxes of the Geleyn scheme. It is computed every 3*NTSRC timesteps at alternate horizontal grid points to spare computational time.

- Surface fluxes of visible and infrared radiation are converted into one-time step increments to obtain a smooth time evolution of surface temperature and turbulent fluxes of heat and moisture.

- Local cloud fraction is parameterized by a linear function of explicit cloud water/ice content, corrected with a linear function of relative humidity to account for subgrid fluctuations leading to cloud formation close to saturation.

Parametrizzazione della precipitazione a grande scala

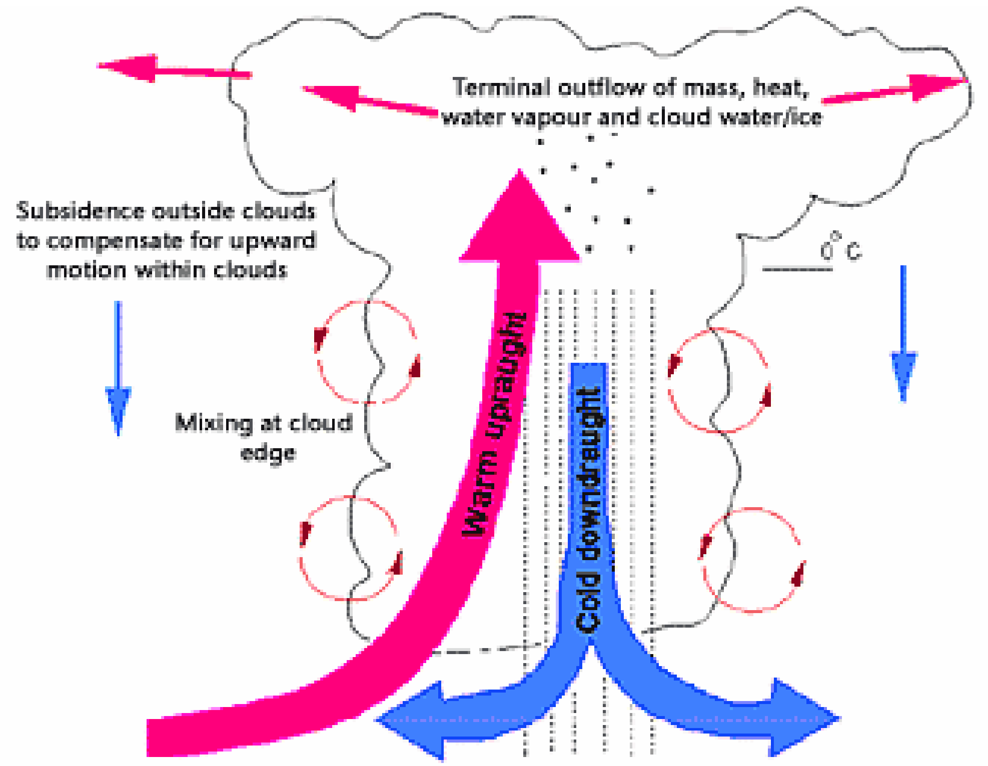


I processi di trasformazione tra le idrometeore sono elencati di seguito. Tali processi sono calcolati in funzione della temperatura e della concentrazione delle specie idriche e comprendono:

1. Condensazione e evaporazione di acqua di nube
2. Sublimazione e formazione di nube ghiacciata
3. Evaporazione della pioggia
4. Scioglimento del ghiaccio di nube, neve e grandine
5. Formazione e crescita dei nuclei di ghiaccio pristini
6. Formazione della pioggia per conversione da acqua di nube
7. Incremento della pioggia per raccolta di acqua di nube
8. Formazione di neve dal ghiaccio di nube
9. Formazione di grandine per accrescimento in presenza di acqua di nube
10. Formazione di grandine per accrescimento in presenza di nube ghiacciata
11. Trasformazione di pioggia in grandine
12. Caduta di pioggia, neve e grandine con differenti velocità

- I calcoli relativi ai processi microfisici sono effettuati nella *subroutine* LSMICR.
- I processi di condensazione e sublimazione 1 e 2 forniscono il contributo più importante al riscaldamento locale dovuto al rilascio di calore latente.
- Quando un generico strato del modello, caratterizzato da umidità specifica q e temperatura T, risulta soprasaturo, e cioè $q > q_{SAT}(T, P)$, l'umidità specifica viene riportata verso il valore di saturazione e l'eccesso di vapore convertito in acqua o ghiaccio di nube.
- Durante la condensazione del vapor d'acqua viene rilasciata una determinata quantità di calore latente che riscalda lo strato in esame.
- L'umidità specifica alla saturazione viene calcolata utilizzando formule analitiche (esatte?)

Parametrizzazione della convezione su scale non risolte



The subgrid-scale precipitation is treated in Bolam following the Kain-Fritsch (KF) convective parameterization scheme (Kain and Fritsch, 1993; Kain, 2004).
The KF scheme has shown considerable success in simulating the development and evolution of convection under a variety of convective and synoptic environments (Kuo *et al*., 1996; Wang and Seaman, 1997; Ferretti *et al*., 2000). The KF scheme is based on the Fritsch-Chappel triggering algorithm. It has been developed for mesoscale models with a grid size of a few tens of kilometers.

In this scheme, convection is triggered by lifting a lower-level slab layer with an impetus heating as a function of grid-scale vertical motion at the lifting condensation level.
The convective adjustment is based on convective available potential energy (CAPE) and, once convection is triggered, CAPE is assumed to be removed in a grid column within a convective time scale. This time scale is in the range of 30-40 min, depending on the averaged wind speed between the lifting condensation level and 500 hPa.
The triggering vertical velocity is automatically adjusted to the grid spacing.

- The KF parameterization used in Bolam has been completely recoded, using liquid water static energy (instead of Bolton approximation of equivalent potential temperature) as thermodynamic conserved quantity.

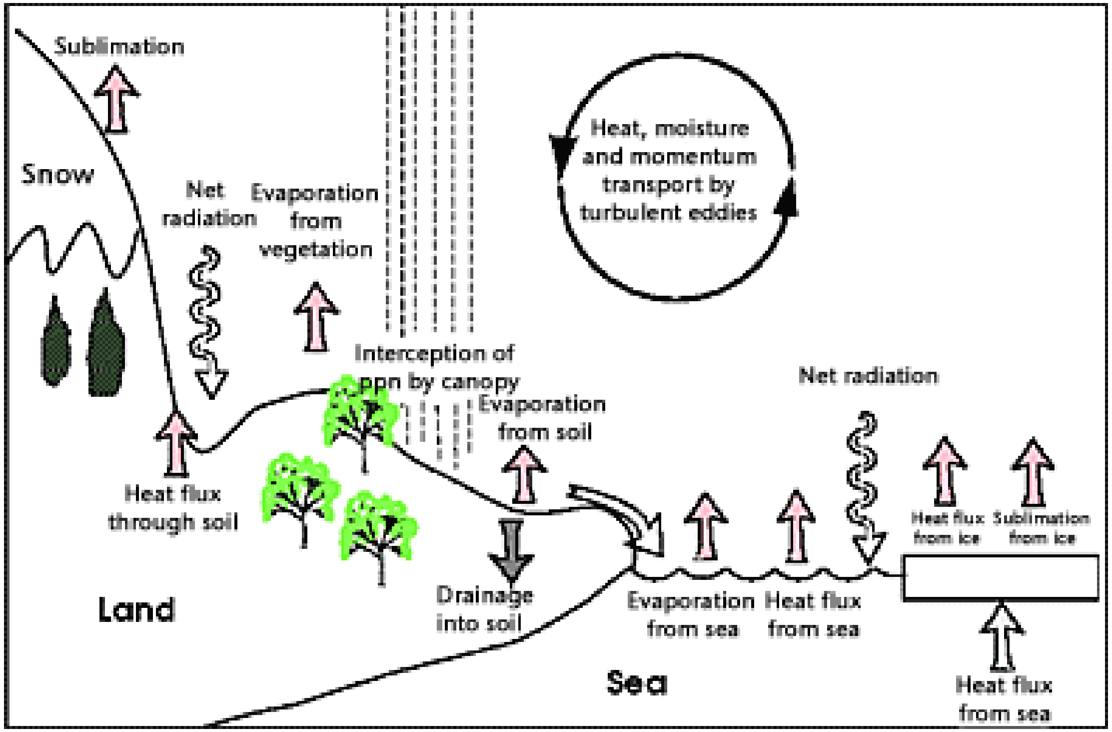
- Additional modifications have been introduced with respect to the Kain (Kain, 2004) version, regarding the dependency of downdraft on ambient relative humidity (the downdraft mass flux has been increased at low humidity)

- The precipitation rate (the fraction of total condensate converted into precipitation) has been made to increase with height above the cloud base.

- The cloud depth threshold establishing the onset of shallow convection has been increased.

The above changes tend to slightly reduce, on average, the temperature at low tropospheric levels around and below cloud base, hence stabilizing a little more efficiently the lower troposphere. This has also the effect of reducing to some extent the intensity of small scale cyclogenesis in the presence of convection.

Bilancio idrico e termico del suolo e Turbolenza nello strato limite



- The SL is modeled accordingly to the classical Monin-Obukhov similarity theory (Monin and Obukhov, 1955).

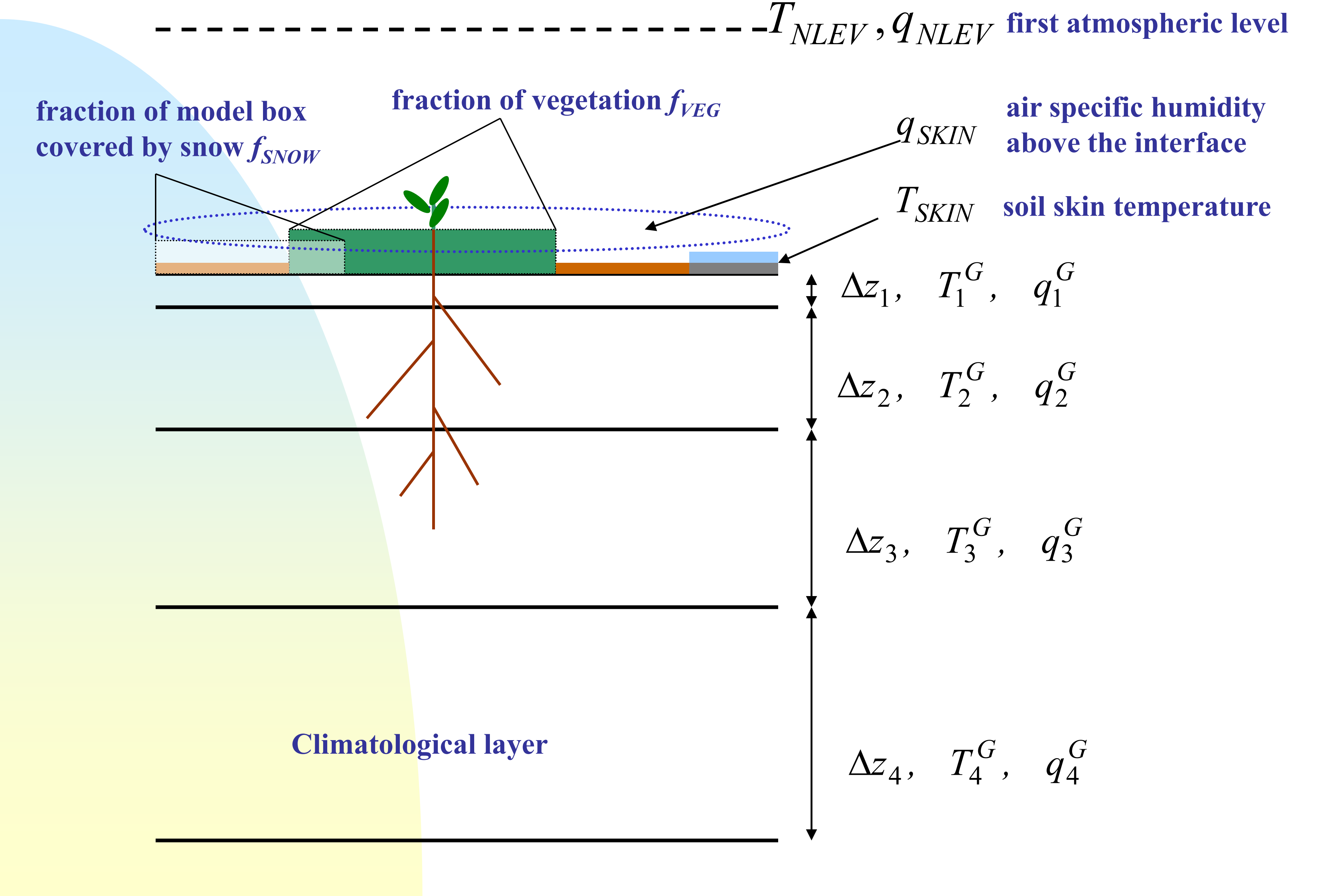
- The Businger (see Fleagle and Businger, 1980) stability functions are used in the unstable SL, while Holtslag (Beljaars and Holtslag, 1991) functions apply to the stable case.

- The roughness length over land, initially defined depending on vegetation and sub-grid orographic variance, is modified as a function also of snow coverage conditions.

- Over the sea, a Charnock roughness representation is introduced for computing momentum fluxes. It takes into account the dependence of wave height on the surface wind speed, while roughness lengths for temperature and humidity in stable and unstable conditions are defined according to Large and Pond, 1981.

- The mixing length (ML) based turbulence closure, widely used to compute the PBL fluxes for atmospheric modeling (see, for instance, Cuxart *et al*, 2006) is applied to model the turbulent vertical diffusion of momentum, potential temperature and specific humidity in the free atmosphere.
- The turbulence closure is of order 1.5, in which the turbulent kinetic energy (TKE) equation is integrated in time (Zampieri *et al*, 2005). Given the relatively low resolution employed, advection of TKE is not computed because it is usually negligible with respect to local sources and sinks.
- To take into account buoyancy effects in case of saturated atmosphere, the ML definition depends on the Richardson number based on equivalent potential temperature.
- In the unstable case, a modified version of the non-local ML (Bougeault and Lacarrere, 1989) is applied.
- In the stable case, a modified Blackadar (Blackadar, 1962) formulation is used.
- The TKE dissipated is fed back into resolved temperature in the form of "frictional heating".

Soil scheme of BOLAM



Soil and vegetation properties

- f_{VEG} Fraction of vegetation (seasonal function)
- *L.A.I.* Leaf Area Index (seasonal function)
- q_{WILT}, q_{REF} Evapotranspiration range (m^3/m^3)
- q_{MIN}, q_{MAX} Minimum and maximum water in soil (m^3/m^3)
- $\rho_W K_W$ Coefficient of water diffusivity in soil ($kg/m^2/s$)
- Ψ_G Hydric potential (m) at saturation
- b Exponent of hydric potential
- $\rho_G C_G$ Dry soil thermal capacity per unit volume ($J/m^3/{}^oK$)
- ε Emissivity (function of water content and vegetation)
- α Albedo (function of water content and vegetation)

Heat conduction is evaluated from the diffusion equation:

$$\boxed{\rho_G C_G \frac{\partial T^G}{\partial t} = \frac{\partial}{\partial z}\left(K_G \frac{\partial T^G}{\partial z} \right)}$$

K_G thermal conductivity:

$$\boxed{K_G = 0.5 + 1400\, e^{-6-\log_{10}|\Psi|}, \qquad \Psi = \Psi_G \left(\frac{q_{MAX}}{q^G} \right)^b}$$

Soil water (volumetric) content equation:

$$\boxed{\rho_W \frac{\partial q^G}{\partial t} = -\frac{\partial \Pi}{\partial z}}$$

Analytic (empirical) expression for water fluxes (Kg/m^2/sec, positive upward):

$$\boxed{\Pi = -\frac{\rho_W K_W b}{q_{MAX}} \left|\Psi_G\right| \left(\frac{q^G}{q_{MAX}}\right)^{b+2} \frac{\partial q^G}{\partial z} - \rho_W K_W \left(\frac{q^G}{q_{MAX}}\right)^{2b+3}}$$

Diffusional conductivity **Hydraulic conductivity**

Clapp and Hornberger, 1978, *Water Resour. Res*

- 1 - calcolo QSKIN (subroutine soil_qskin)
- 2 - calcolo flussi turbolenti (subroutine vdiff)
- 3 - calcolo TSKIN (subroutine soil_veg)

  calcolo HSNOW (soil_veg)

  calcolo WVEG

  calcolo nuovi QG e TG (soil_veg)

  melting and freezing (soil_veg)

$$\boxed{q_{SAT} = q_{SAT}(T_{SKIN})}$$

Saturation of surface air at time *t*

$$\boxed{f_{VEG}^{*} = \begin{cases} f_{VEG} \quad , & f_{SNOW} \le 1 - f_{VEG} \\ 1 - f_{SNOW} \quad . & f_{SNOW} > 1 - f_{VEG} \end{cases}}$$

fraction of model box covered by vegetation and free of snow

$$\boxed{f_{WETL} = \frac{W_{VEG}}{W_{VEG}^{MAX}}, \qquad W_{VEG}^{MAX} = 0.02 * L.A.I.}$$

fraction of wet leaf

Definition of q_{SKIN} at current time t

$$
\begin{aligned}
&q_{SKIN} = \\
&f_{SNOW} q_{SAT} \\
&+ f^*_{VEG}\left(f_{WETL} q_{SAT} + (1 - f_{WETL}) q_{VEG}\right) \\
&+ \left(1 - f_{SNOW} - f^*_{VEG}\right) q_{SOIL}
\end{aligned}
$$

Efficiency of evapotranspiration (depending on insolation and *L.A.I.)*

$$Z_{TRASP} = \frac{0.004\Phi^{\updownarrow}_{VIS} + .05}{0.81(0.004\Phi^{\updownarrow}_{VIS} + 1.)} \quad \frac{L.A.I.}{STOMINR} \sum_{k=1}^{3} C_k^W \cdot f_{deficit}$$

$$C_k^W = \frac{1}{3} \begin{cases} 1, & q_k^G \geq q_{REF}^G \\ \dfrac{q_k^G - q_{WILT}^G}{q_{REF}^G - q_{WILT}^G} & q_{WILT}^G < q_k^G < q_{REF}^G \\ 0, & q_k^G \leq q_{WILT}^G \end{cases}$$

efficiency of root pumping

$$E_{EVTR} = \frac{Z_{EVTR}}{Z_{EVTR} + \rho_S C_D}$$

$$q_{VEG} = q_{NLEV} + \left(q_{SAT} - q_{NLEV}\right) E_{EVTR}$$

Minumun stomatal resistance over a single leaf (reduced over grass – increased over needleleaf forest)

***STOMINR*=200. (sec/m)**
***STOMINR*=100. (grass)**
***STOMINR*=500. (needleleaf forests)**

Reduction of evaporation over forests Stress funtion due to humidity deficit

$$f_{deficit} = (1 - f_{forest}) + f_{forest} e^{-.0003 \cdot \max(q_{SAT} - q_{NLEV}, 0) P_S / \varepsilon}$$

Air specific humidity over bare soil and pools (Z_G is the 'surface wetness')

$$q_{SOIL} = q_{SAT}\, Z_G + q_{NLEV}\,(1 - Z_G)$$

$$Z_G = 1, \qquad (glaciers \quad or \quad pools)$$

$$Z_G = \frac{Z_{bares}}{Z_{bares} + \rho_S C_D}$$

$$Z_{bares} = \frac{\rho_S \mu_A}{\sqrt{|\Psi_G|}\left(1 - q_{1REL}^G\right)^{F_2}},$$

$$q_{1REL}^G = \frac{q_1^G - q_{WILT}^G}{q_{MAX}^G - q_{WILT}^G}$$

'Relative' water content

$$F_2 = \frac{18.}{b} + .5, \qquad \rho_S \mu_A \approx 2.3 \cdot 10^{-5} \left(T_{SKIN} / T_0 \right)^{1.75}$$

coefficient of molecular diffusivity of vapor into air

$$Z_G = 0, \quad q_1^G < q_{WILT}^G$$

Atmospheric vertical diffusion

$$\theta^{V}, q_{NLEV}$$

Updated temperature and specific humidity at first atmospheric level

$$\rho_S C_D$$

Updated drag coefficient of humidity and temperature (over land only)

$$\Phi_q = \rho_S C_D \left(q_{SKIN} - q_{NLEV} \right)$$

Turbulent flux of specific humidity (kg/m^2/s) positive upward

$$\Phi_H = \frac{\rho_S C_D \left(\theta^{V}_{SKIN} - \theta^{V}_{NLEV} \right)}{\left(\frac{P_0}{P_S} \right)^{R_d / C_P} \left(1 + \left(R_V / R_d - 1 \right) q_{SKIN} \right)} C_P$$

Turbulent flux of heat (Watt/m^2) positive upward

Humidity flux disaggregation using the updated value of q_{NLEV}

Flux over snow in kg/m²/s

$$\Phi_{SNOW} = \min\left(\rho_S C_D f_{SNOW}\left(q_{SAT} - q_{NLEV}\right), \quad \rho_W H_{SNOW} / \Delta t\right)$$

Flux over the fraction of wet leaf

$$\Phi_{WETL}\begin{pmatrix} q_{SAT} > q_{NLEV} \\ q_{SAT} < q_{NLEV} \end{pmatrix} = \begin{pmatrix} \min\left(\rho_S C_D f_{VEG}^{*} f_{WETL}\left(q_{SAT} - q_{NLEV}\right), \quad W_{VEG} / \Delta t\right) \\ \rho_S C_D f_{VEG}^{*}\left(q_{SAT} - q_{NLEV}\right) \end{pmatrix}$$

Evapotranspiration from the fraction of dry leaf and from the *k*-th soil layer (kg/m²/s)

$$\Phi_{EVTR_K}\begin{pmatrix} q_{SAT} > q_{NLEV} \\ q_{SAT} < q_{NLEV} \end{pmatrix} = \begin{pmatrix} \rho_S C_D f_{VEG}^{*}\left(1 - f_{WETL}\right)\left(q_{VEG} - q_{NLEV}\right)\dfrac{C_k^W}{\sum_j C_j^W} \\ 0 \end{pmatrix}$$

Humidity flux over the fraction of bare soil and pools (it conserves water exactly).

$$\Phi_{SOIL} = \Phi_q \quad - \Phi_{SNOW} \quad - \Phi_{WETL} \quad - \sum_k \Phi_{EVTR\,k}$$

Residual precipitation and W_{VEG} update

Precipitation intercepted by leaves (it can be negative)

$$P_{INTC} = min((W_{VEG}^{MAX} - W_{VEG})/\Delta t + \Phi_{WETL}, \quad P_{RAIN}\ f_{VEG}^{*})$$

$\boldsymbol{W_{VEG}}$ update

$$W_{VEG} = W_{VEG} + \Delta t\ P_{INTC} - \Delta t\ \Phi_{WETL}$$

Computation of residual precipitation at the ground - When the intercepted precipitation is negative, the (negative) specific humidity flux increases the residual precipitation (in parole povere, rugiada che cade a terra)

$$P_{RES} = P_{RAIN} - P_{INTC}$$

Snow height update

$$H_{SNOW} = H_{SNOW} + \frac{\Delta t}{\rho_W}(P_{SNOW} - \Phi_{SNOW})$$

1-Fall-Sublimation

$$T_{SNOW} = \iota T_{SKIN} + (1-\iota)T_1^G \,, \qquad \iota \leq 1/2$$ (melting parameter)

$$\Delta H_{SNOW} = H_{SNOW}\, min\left(1, \quad \frac{C_I\, max(T_{SNOW} - 273.15, 0)}{L_I^W}\right)$$

$$P_{MELT} = \rho_W \Delta H_{SNOW} / \Delta t$$ (Kg/m²/s)

$$H_{SNOW} = H_{SNOW} - \Delta H_{SNOW}$$

2-Melting

$$f_{SNOW} = min(1, \quad H_{SNOW} / H_{REF})$$

3-Snow fraction update

T_{SKIN} : soil temperature at the upper interface from flux balance

$$\Phi_H(T_{SKIN}) + L\Phi_q(T_{SKIN}) - \Phi_{VIS}^{\updownarrow} - \Phi_{IR}^{\updownarrow}(T_{SKIN}) = \Pi_H(T_{SKIN})$$

$$L = L_W^V + f_{SNOW} L_I^W ,$$

$$\Pi_H = -\Lambda_1 (T_{SKIN} - T_1^G)$$

Surface heat exchange coefficient Λ_1

Numerical limitation

$$\Lambda_1 = \min\left[\frac{2}{\Delta z_1}\left(K_G + f_{SNOW}\left(K_{SNOW} - K_G\right)\right),\ \frac{\Delta z_1}{\underline{2}\,\Delta t}\left(\rho_G C_G + \rho_W C_W q_1^G + \rho_W C_I \frac{H_{SNOW}}{\Delta z_1}\right)\right]$$

$$K_G = 0.5 + 1400\, e^{-6-\log_{10}|\Psi|}, \qquad \Psi = \Psi_G\left(\frac{q_{MAX}}{q_1^G}\right)^b$$

T_{SKIN} : soil temperature at the upper interface from flux balance

Newton step:

$$\Phi_H(T_{SKIN}^n) + L\Phi_q(T_{SKIN}^n) - \Phi_{VIS}^{\updownarrow} - \Phi_{IR}^{\updownarrow}(T_{SKIN}^n) - \Pi_H(T_{SKIN}^n) = R$$

$$T_{SKIN}^{n+1} = T_{SKIN}^n + \Delta T_{SKIN} \quad \Rightarrow$$

$$\Phi_H(T_{SKIN}^{n+1}) + L\Phi_q(T_{SKIN}^{n+1}) - \Phi_{VIS}^{\updownarrow} - \Phi_{IR}^{\updownarrow}(T_{SKIN}^{n+1}) - \Pi_H(T_{SKIN}^{n+1}) = 0$$

$$d_T\Phi_q \approx \rho_S C_D \frac{dq_{SKIN}}{dT_{SKIN}}, \qquad d_T\Phi_H \approx C_P \rho_S C_D, \qquad d_T\Phi_{IR}^{\updownarrow} \approx 4\varepsilon\sigma_0 T_{SKIN}{}^3$$

$$d_T\Pi_H = -\Lambda_1$$

$$\Rightarrow \quad \boxed{R + (d_T\Phi_H + Ld_T\Phi_q + d_T\Phi_{IR}^{\uparrow} + \Lambda_1)\Delta T_{SKIN} \approx 0}$$

Water flux and content update of the first soil layer (m^3/m^3)

$$\Pi_1 = -P_{RES} - P_{MELT} + \Phi_{SOIL} + \sum_{k=1} \Phi_{EVTR_k}$$

Δz_1

$$q_1^G(t+\Delta t) = q_1^G(t) + \frac{\Delta t}{\rho_W \Delta z_1}\left(-\Pi_1 + \Pi_2\right)$$

Kg/m²/s

$$\Pi_2 = -\frac{\rho_W K_W b}{q_{MAX}} \left|\Psi_G\right| \left(\frac{q^G_{1+1/2}}{q_{MAX}}\right)^{b+2} \frac{min(q_{MAX}, q_1^G) - q_2^G}{.5(\Delta z_1 + \Delta z_2)} - \rho_W K_W \left(\frac{q^G_{1+1/2}}{q_{MAX}}\right)^{2b+3}$$

$$+ \sum_{k=2} \Phi_{EVTR_k}, \qquad q^G_{1+1/2} = \frac{\Delta z_1 q_2^G + \Delta z_2 \, min(q_{MAX}, q_1^G)}{\Delta z_1 + \Delta z_2}$$

$$q_1^G(t+\Delta t) < q_{MIN} \quad \Rightarrow \quad \begin{cases} \Pi_2 = \Pi_1 - \dfrac{\Delta z_1 \rho_W}{\Delta t}\left(q_1^G(t) - q_{MIN}\right) \\ q_1^G(t+\Delta t) = q_{MIN} \end{cases}$$

Flux correction

Water flux and content update of the second soil layer (m^3/m^3)

$$\Pi_2$$

$$q_2^G(t+\Delta t) = q_2^G(t) + \frac{\Delta t}{\rho_W \Delta z_2}\left(-\Pi_2 + \Pi_3\right)$$

$$\Pi_3 = -\frac{\rho_W K_W b}{q_{MAX}}\left|\Psi_G\right|\left(\frac{q_{2+1/2}^G}{q_{MAX}}\right)^{b+2}\frac{q_2^G - q_3^G}{.5(\Delta z_2 + \Delta z_3)} - \rho_W K_W\left(\frac{q_{2+1/2}^G}{q_{MAX}}\right)^{2b+3}$$

$$+\sum\nolimits_{k=3}\Phi_{EVTR_k}\,, \qquad q_{2+1/2}^G = \frac{\Delta z_2 q_3^G + \Delta z_3 q_2^G}{\Delta z_2 + \Delta z_3}$$

$$q_2^G(t+\Delta t)\begin{matrix} < q_{MIN} \\ > q_{MAX}\end{matrix} \Rightarrow \begin{cases} \Pi_3 = \Pi_2 + \dfrac{\Delta z_2 \rho_W}{\Delta t}\left(\begin{matrix} q_{MIN} \\ q_{MAX}\end{matrix} - q_2^G(t)\right) \\ q_2^G(t+\Delta t) = \begin{matrix} q_{MIN} \\ q_{MAX}\end{matrix} \end{cases}$$

Flux correction

T_1^G tendency: irreversible mixing and heat diffusion

heating due to heat exchange with snow at air temp. $\boldsymbol{T}_{\mathbf{NLEV}}$

heating due to mixing with rain at air temp. $\boldsymbol{T}_{\mathbf{NLEV}}$

Cooling due to melting snow

heat capacity at new time level

$$
\begin{aligned}
\left(\rho_G C_G \Delta z_1 + \rho_W C_W q_1^G \Delta z_1 + \rho_W C_I H_{SNOW}\right)\Delta T_1^G = &-P_{MELT} L_I^W \Delta t \\
&+ P_{RES}\Delta t C_W (T_1 - T_1^G) + P_{SNOW}\Delta t C_I (T_1 - T_1^G) \\
&+ \Lambda_1 (T_{SKIN} - T_1^G)\Delta t + \Lambda_2 (T_2^G - T_1^G)\Delta t \\
&+ \Pi_2 \Delta t C_W (T_{1+1/2}^G - T_1^G) + P_{MELT} C_W (273.15 - T_1^G)\Delta t \\
&- \left((\Phi_{SOIL} + \sum_k \Phi_{EVTR_k}) C_W + \Phi_{SNOW}\, C_I \right) (T_{SKIN} - T_1^G)\Delta t
\end{aligned}
$$

heating due to mixing with water diffused from below (including root pumping)

diffusion of heat

heating due to mixing with melted snow at freezing temp.

cooling (heating) due to the increase (decrease) of evaporating water/ice to temperature $\boldsymbol{T_{SKIN}}$

T_2^G tendency

$$\left(\rho_G C_G \Delta z_2 + \rho_W C_W q_2^G \Delta z_2 \right) \Delta T_2^G =$$
$$+ \Lambda_2 (T_1^G - T_2^G) \Delta t + \Lambda_3 (T_3^G - T_2^G) \Delta t$$
$$- \Pi_2 \Delta t C_W (T_{1+1/2}^G - T_2^G) + \Pi_3 \Delta t C_W (T_{2+1/2}^G - T_2^G)$$

Final temperature update

$$T_k^G = T_k^G + \Delta T_k^G, \qquad k = 1, 2, 3$$

Calcoli finali

‘Runoff’

‘Icing’