Implicit coupling between the atmospheric boudary layer and the continental surface for solving the surface temperature

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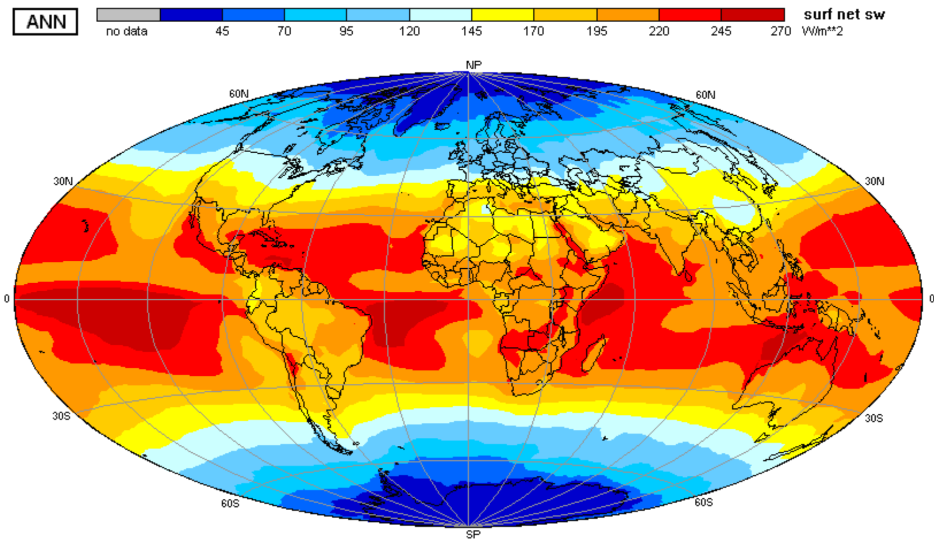
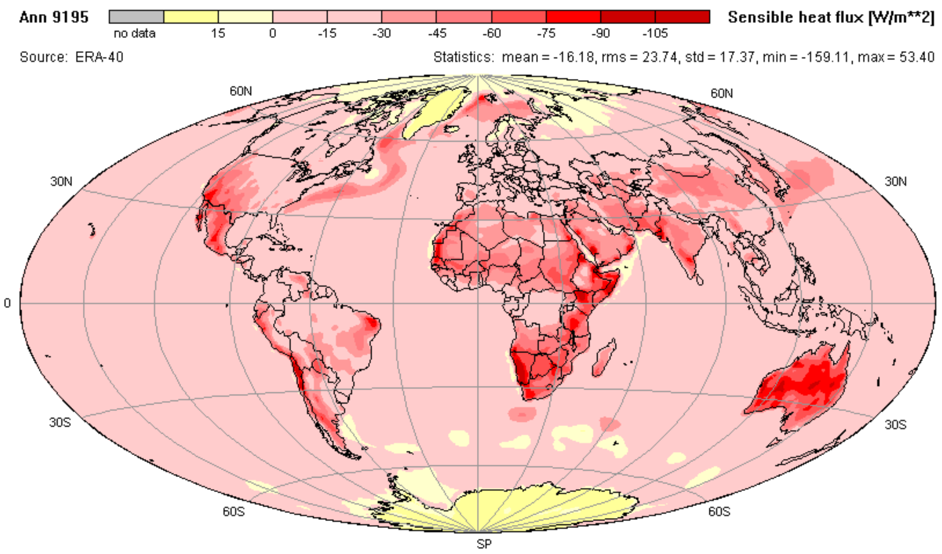
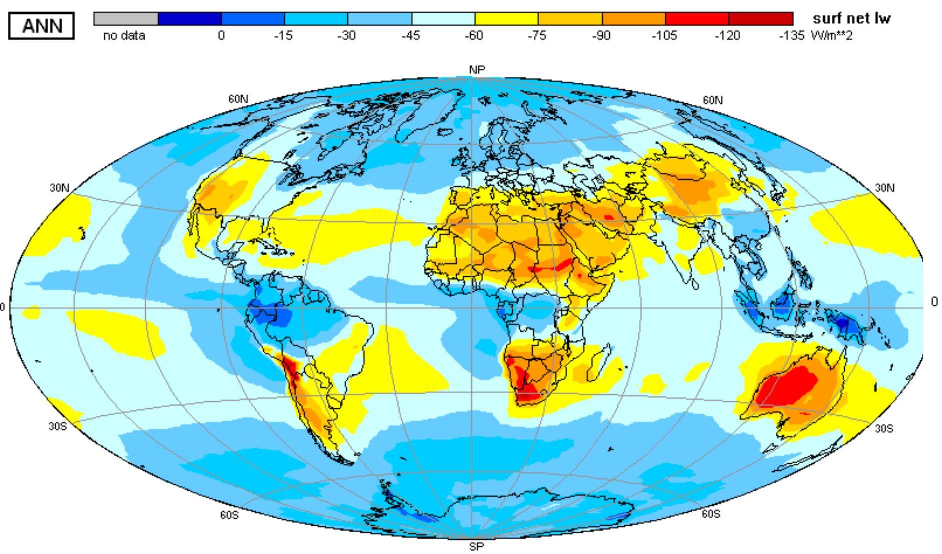
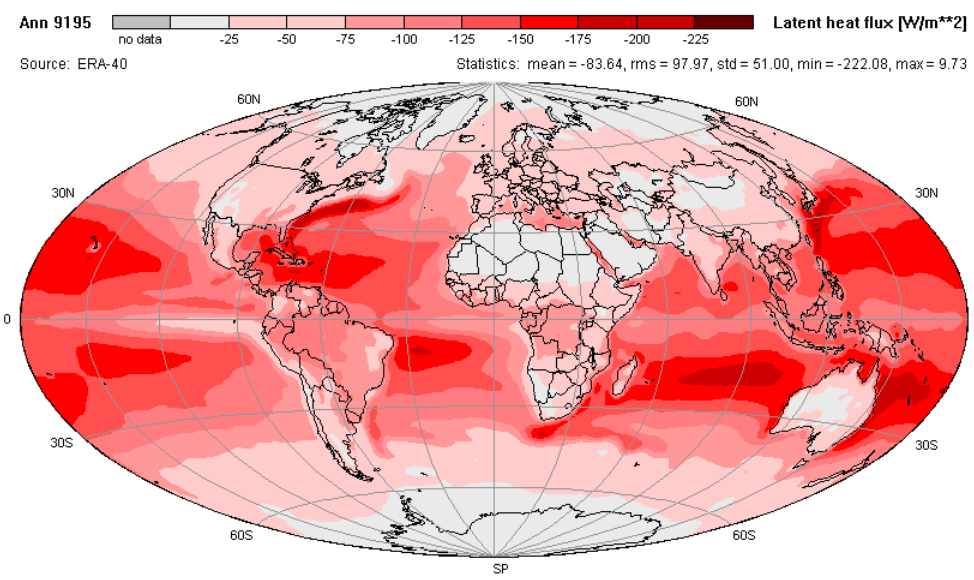
- Introduction
- Surface energy budget equation
- Turbulent fluxes
- Radiation
- Solving for the Surface temperature
- Routines used

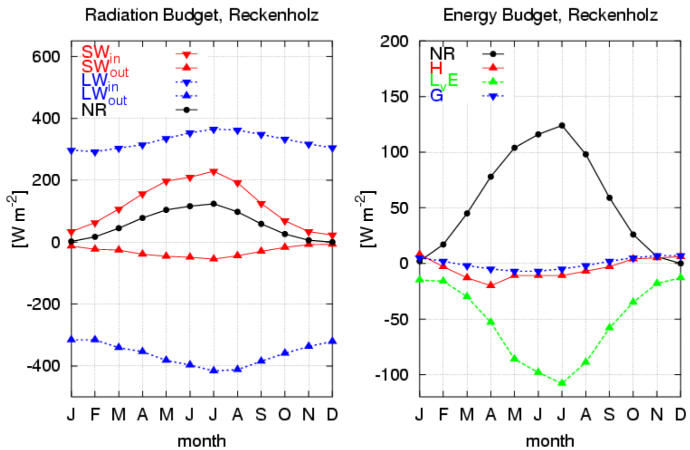
SW_net + LW_net + H + L.E   + G = 0



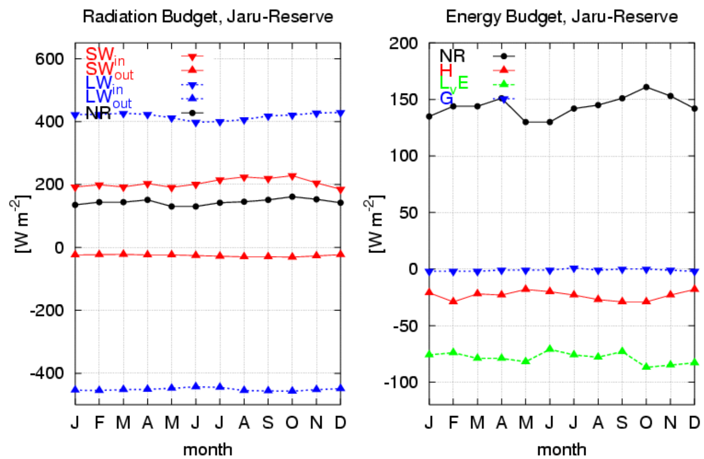






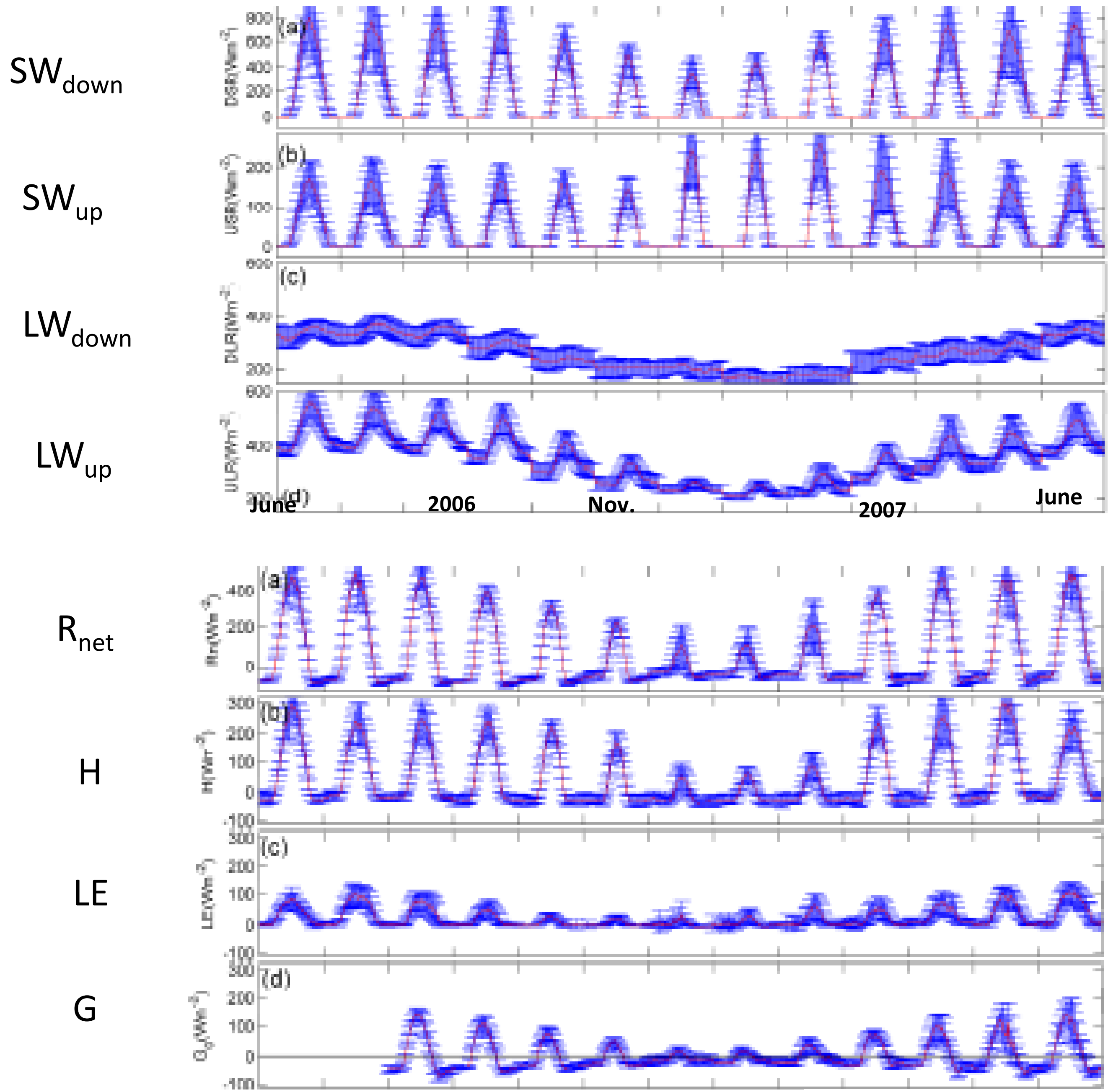


Grassland in Switzerland



Tropical Rain Forest

Diurnal variations of weekly mean of surface energy budget terms (44N, 116E, Steppe, China)



Hydrol. Earth Syst. Sci., 13, 987–998, 2009

Z. Gao et al.: Seasonal and diurnal variations in moisture, heat and CO_2 fluxes

Surface energy budget

$$C_s \frac{\partial}{\partial t} T_s = SW_{net} + LW_{net} + F^t_{H,s} + L.E + G \quad (1)$$

$$LW_{net} = LW_{down} - \varepsilon\sigma {T_s}^4 - (1-\varepsilon) LW_{down} \quad (2)$$

$$F^t_{H,s} = \rho \left| \overrightarrow{v} \right| C_d (H^t_1 - H^t_s) \quad (3)$$

$$L.E^t_s = L\rho \left| \overrightarrow{v} \right| C_d \beta (q^t_1 - q_{sat}(T^t_s)) \quad (4)$$

Implicit coupling: The atmospheric temperature, humidity and surface conditions are estimated synchroneously (at the same time step)

$$C_s \frac{(T_s^t - T_s^{t-\delta t})}{\delta t} = SW_{net}^t + LW_{net}^t + H^t + L.E^t + G^t \tag{5}$$

$$C_s \frac{(T_s^t - T_s^{t-\delta t})}{\delta t} = SW_{net} + LW_{down} + G^t - \varepsilon\sigma * {T_s^t}^4 + H^t + L.E^t \tag{6}$$

G^t, computed by thermosoil

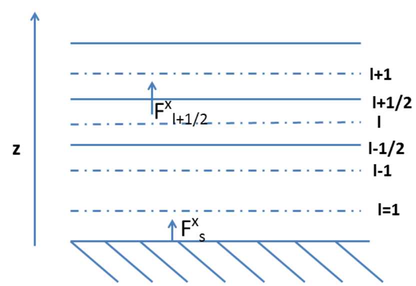
C_s is the apparent surface heat capacity and is computed by thermosoil

Turbulent fluxes and their dependence on the surface temperature

The diffusion equation of the potential enthalpie or the specific humidity (X) in the boundary layer $F^X = -\rho k \frac{\partial}{\partial z} X$ and $\frac{\partial}{\partial t} X = -\frac{1}{\rho} \frac{\partial}{\partial z} F^X$ and the continuity equation are discretized in space and time.

$$\frac{X_l^t - X_l^{t-\delta t}}{\delta t} = \frac{-g}{\delta P_l} (F_{l+1/2}^X - F_{l-1/2}^X) \tag{7}$$

$$F_{l-1/2} = -\rho_{l-1/2} k_{l-1/2} \frac{(X_l^t - X_{l-1}^t)}{z_l - z_{l-1}} \tag{8}$$



$$F_{X,s}^t = \rho \, |\overrightarrow{v}| \, C_d (X_1^t - X_s^t) \tag{9}$$

For the interface variable this can be re-written as

$$X_1^t = A_X^1 + B_X^1.F_{s,X}^t \delta t \tag{10}$$

$$X_2^t = C_2^X + D_2^X H_1^t \tag{11}$$

$$F_{X,s}^t = \rho \, |\overrightarrow{v}| \, C_d(X_1^t - X_s^t) \tag{12}$$

$$A_X^1 = \frac{X_1^{t-\delta t}\delta P_1 + S_2^X C_2^X}{\delta P_1 + S_2^X(1 - D_2^X)} \tag{13}$$

$$B_X^1 = \frac{-g}{\delta P_1 + S_2^X(1 - D_2^X)} \tag{14}$$

with $S_2 = \frac{g^2 \rho_{3/2}^2 k_{3/2} \delta t}{P_1 - P_2}$ and A_X^1 and B_X^1 do not contain any information on the surface contition at the time t and can be computed from the PBL prior to the land surface processes.

Sensible heat flux

$$H_1^t = A_H^1 + B_H^1 . F_{s,H}^t \delta t \tag{15}$$

$$F_{s,H}^t = \frac{1}{zikt}(H_1^t - H_s^t) \tag{16}$$

with $H = C_p T(\frac{P_r}{P})^\kappa$, $H_s = C_p T_s$ and $\frac{1}{zikt} = \rho |\overrightarrow{v}| C_d$

$$F_{s,H}^t = \frac{1}{zikt}(A_H^1 + B_H^1 . F_{s,H}^t \delta t - H_s^t) \tag{17}$$

$$F_{s,H}^t = \frac{1}{zikt}[\frac{(A_H^1 - H_s^{t-\delta t})}{1 - \frac{1}{zikt} B_H^1 \delta t} - \frac{(H_s^t - H_s^{t-\delta t})}{1 - \frac{1}{zikt} B_H^1 \delta t}] \tag{18}$$

$$F_{s,H}^t = sensfl_{old} - sensfl_{sns}(T_s^t - T_s^{t-\delta t}) \tag{19}$$

➢ $sensfl_{old}$ is based on the surface condition at the previous time step $(t - \delta t)$ and the atmospheric condition at the time step t

➢ $sensfl_{sns}$ is a sensivity term to the variation of surface temperature. ➢ In the ORCHIDEE code, A_H^1 is called petBcoef, $B_H^1 \delta t$ is called petAcoef

Latent heat flux (evaporation)

$$F_{s,q}^t = L\rho\,|\overrightarrow{v}|\,C_d\beta(q_1^t - q_{sat}(T_s^t)) \tag{20}$$

$$q_{sat}(T_s^t) = q_{sat}(T_s^{t-\delta t}) + \left.\frac{\partial q_{sat}}{\partial t}\right|_{(T=T_s^{t-\delta t})}(T_s^t - T_s^{t-\delta t}) \tag{21}$$

$$q_1^t = A_q^1 + B_q^1.F_{s,q}^t\delta t \tag{22}$$

$$F_{s,q}^t = \frac{1}{zikt}\beta(A_q^1 + B_q^1.F_{s,q}^t\delta t - q_{sat}(T_s^{t-\delta t}) + \left.\frac{\partial q_{sat}}{\partial t}\right|_{(T=T_s^{t-\delta t})}(T_s^t - T_s^{t-\delta t})) \tag{23}$$

$$F_{s,q}^t = \frac{\frac{1}{zikt}\beta(A_q^1 - q_{sat}(T_s^{t-\delta t})}{(1-\frac{1}{zikt}\beta B_q^1\delta t)} - \frac{\frac{1}{zikt}\beta\left.\frac{\partial q_{sat}}{\partial t}\right|_{(T=T_s^{t-\delta t})}}{(1-\frac{1}{zikt}\beta B_q^1\delta t)}(T_s^t - T_s^{t-\delta t}) \tag{24}$$

In the ORCHIDEE code, A_q^1 is called peqBcoef, $B_q^1\delta t$ is called peqAcoef

$$L.F_{s,q}^t = L.lareva_{old} - \frac{L}{C_p}lareva_{sns}(H_s^t - H_s^{t-\delta t}) \tag{25}$$

Radiation

$$netrad = SW_{net} + LW_{down} - \varepsilon\sigma * {T_s^t}^4 - (1-\varepsilon)LW_{down} \tag{26}$$

In the present version the LW emissivity is set one

$$netrad = SW_{net} + LW_{down} - (1-\varepsilon)LW_{down} - \varepsilon\sigma * {T_s^{t-\delta t}}^4 - 4\varepsilon\sigma {T_s^{t-\delta t}}^3 (T_s^t - T_s^{t-\delta t}) \tag{27}$$

$$netrad = netrad_{old} + netrad_{sns}(T_s^t - T_s^{t-\delta t}) \tag{28}$$

surface temperature at the new time step

$$sum_{old} = netrad_{old} + sensfl_{old} + lareva_{old} \tag{29}$$

$$sum_{sns} = netrad_{sns} + sensfl_{sns} + lareva_{sns} \tag{30}$$

$$C_s \frac{(T_s^t - T_s^{t-\delta t})}{\delta t} = sum_{old} + G + sum_{sns}(T_s^t - T_s^{t-\delta t}) \tag{31}$$

$$(T_s^t - T_s^{t-\delta t}) = \frac{\delta t(sum_{old} + G)}{C_s - sum_{sns}\delta t} \tag{32}$$

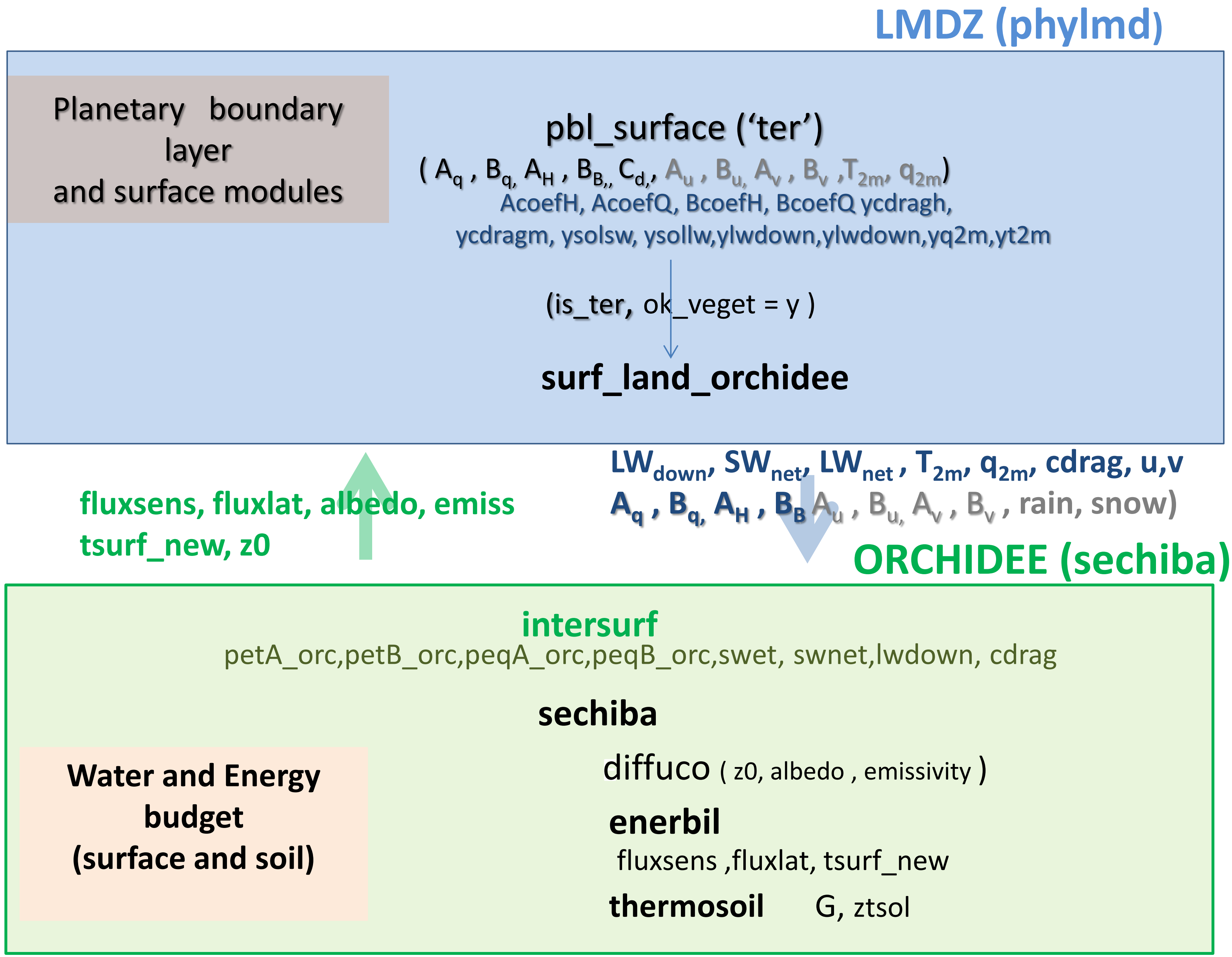
About the radiation the time step of the radiation is usually longer than the one of ABL and LSM

➢ Favoring the energy conservation: Between two calls of the radiation code, the change of T_s is supposed not impact LW_{net} LW_{net} is computed by the radiation code in LMDZ, the radiation in enerbil and in LMDZ is consistent and the radiation is computed in LMDZ.

➢ LW_{up} is updated as T_s is updated. The radiation used by enerbil and by LMDZ are not consistent

➢ LW_{up} can be averaged over the time-steps between two calls of the radiation (account for the variation of T_s induced by varying surface conditions) (not yet implemented).

Atmosphere/surface coupling in LMDZOR



More information on

http://forge.ipsl.jussieu.fr/orchidee/wiki/Documentation/CouplingLMDZ