Improvements of Soil Thermodynamics in ORCHIDEE for CMIP6

- Thermal properties: conductivty and capacity (new parameterizations, recent correction of bugs and tests)

$$Cp\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left[\lambda\frac{\partial T}{\partial z}\right]$$

- Vertical discretization

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1. Soil Thermal Conductivity

OLD

$$\boldsymbol{\kappa}(\boldsymbol{\theta}) = \boldsymbol{\kappa_{dry}} + \frac{\boldsymbol{\theta} - \boldsymbol{\theta_w}}{\boldsymbol{\theta_f} - \boldsymbol{\theta_w}} \times (\boldsymbol{\kappa_{wet}} - \boldsymbol{\kappa_{dry}})$$

θ: Volumetric soil moisture.

θ_f, θ_w: θ at field capacity & wilting point.

κ_{dry}, κ_{wet} **(prescribed)**.

(**same property for different soil classes**).

CMIP6

$$\boldsymbol{\kappa}(\boldsymbol{\theta}, \boldsymbol{st}) = \boldsymbol{K_e}(\boldsymbol{\theta}, \boldsymbol{st}) \times [\boldsymbol{\kappa_{sat}}(\boldsymbol{st}) - \boldsymbol{\kappa_{dry}}(\boldsymbol{st})] + \boldsymbol{\kappa_{dry}}(\boldsymbol{st})$$

$$\kappa_{sat}(st) = \left[\left(\kappa_q^{q(st)} \kappa_o^{1-q(st)}\right)\right]^{1-n_p(st)} \kappa_w^{n_p(st)}$$

$$\kappa_{dry}(st) = \frac{0.135 \times [1 - \boldsymbol{n_p}(\boldsymbol{st})] \times 2700 + 64.7}{2700 - 0.947 \times [1 - \boldsymbol{n_p}(\boldsymbol{st})] \times 2700}$$

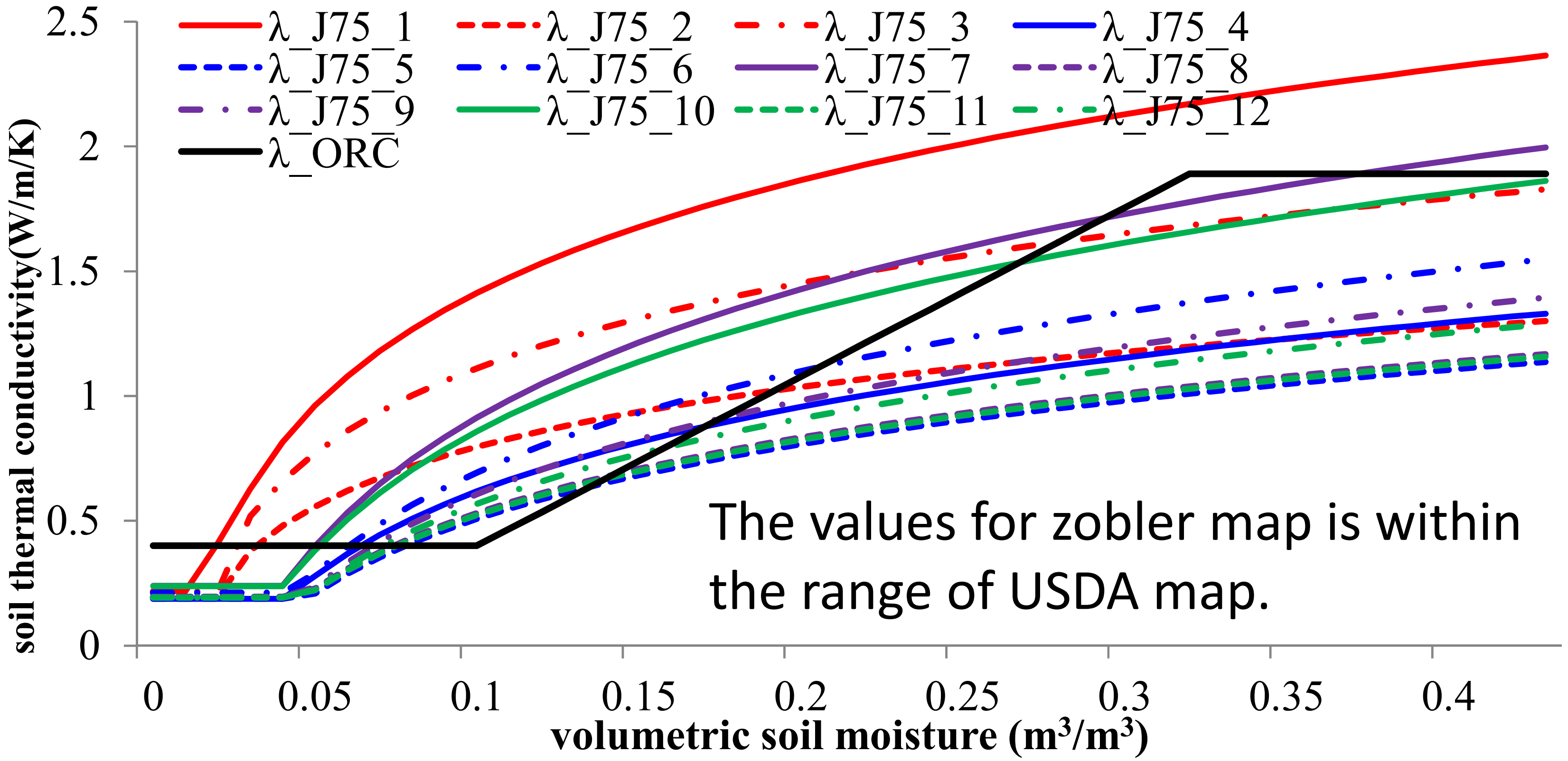
$$Ke(\theta, st) = \left(0.7 \times \log\left[\frac{\theta(st)}{n_p(st)}\right] + 1.0\right), \theta/np > 0.05,$$

Coarse [1-3 of USDA; 1 of FAO]

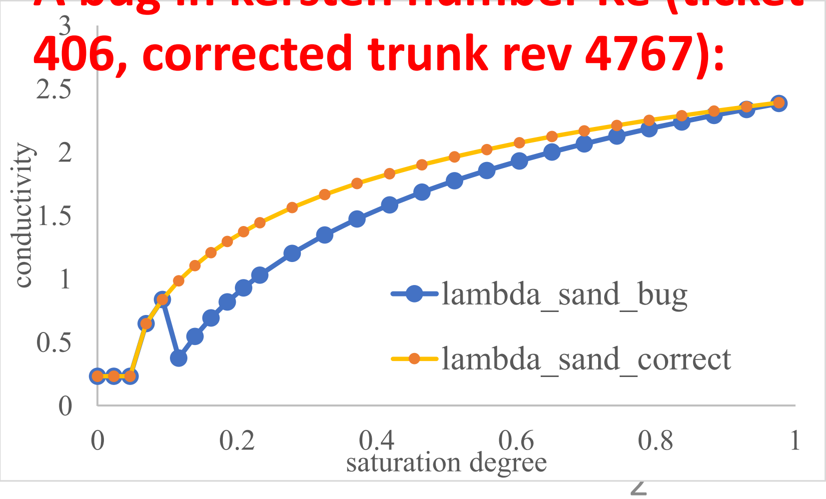
$$Ke(\theta, st) = \log\left[\frac{\theta(st)}{n_p(st)}\right] + 1.0, \theta/np > 0.1,$$

Fine [other classes]

Johansen, O. [1975, J75] , *Peters-Lidard et al.* [1998]



A bug in kersten number Ke (ticket 406, corrected trunk rev 4767):



2. Soil Heat Capacity

OLD

$$C_p(\theta) = C_{dry} + \frac{\theta - \theta_w}{\theta_f - \theta_w} \times (C_{wet} - C_{dry})$$

θ: Volumetric soil moisture.

θ_f, θ_w: θ at field capacity & wilting point.

C_{dry} . C_{wet}, **(prescribed)**.

(same property for different soil classes).

CMIP6

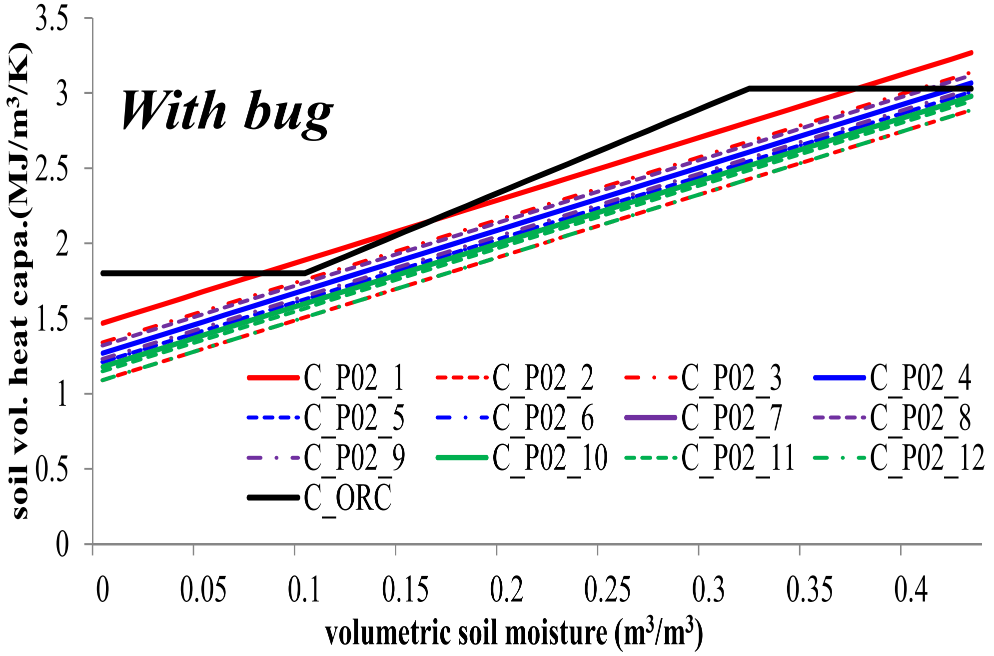
$$C_P(\theta, st) = C_{v,d}(st) * (\mathbf{1 - \theta_s}) + \frac{W(st)}{\Delta z} \times C_{v,w}$$

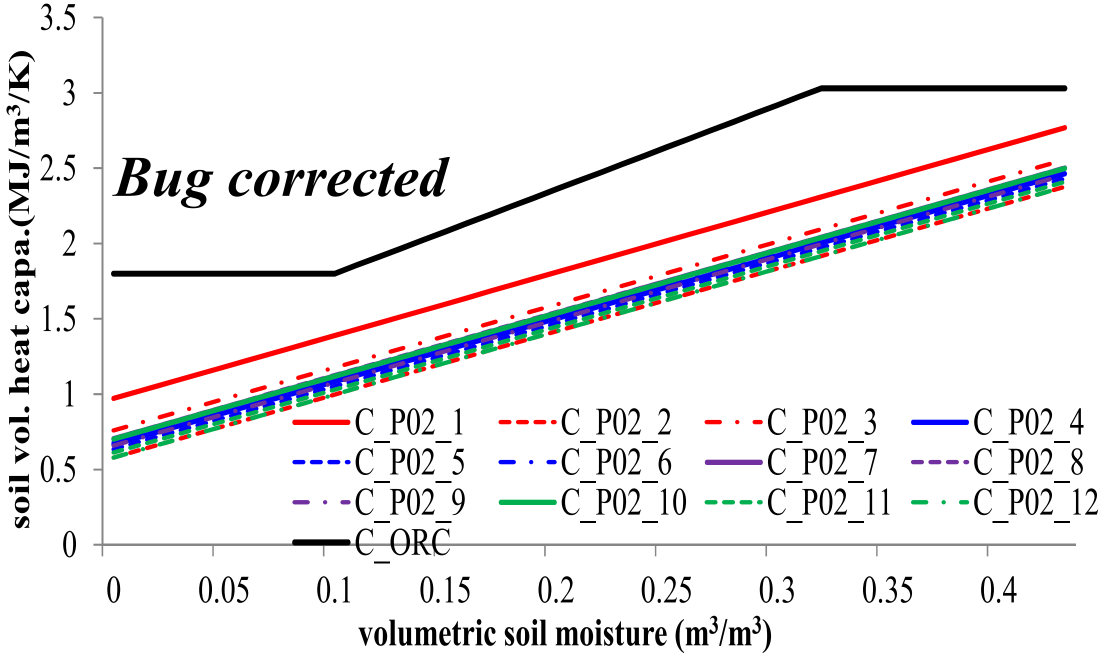
Cd: Dry capacity, *Pielke* [2002].

Bug: 1-θs was missing (ticket 410, corrected trunk rev 4768).

$$m_t C_t = m_d C_d + m_w C_w \Rightarrow \rho_t C_t = \frac{m_d}{V_T} C_d + \frac{m_w}{V_T} C_w =$$

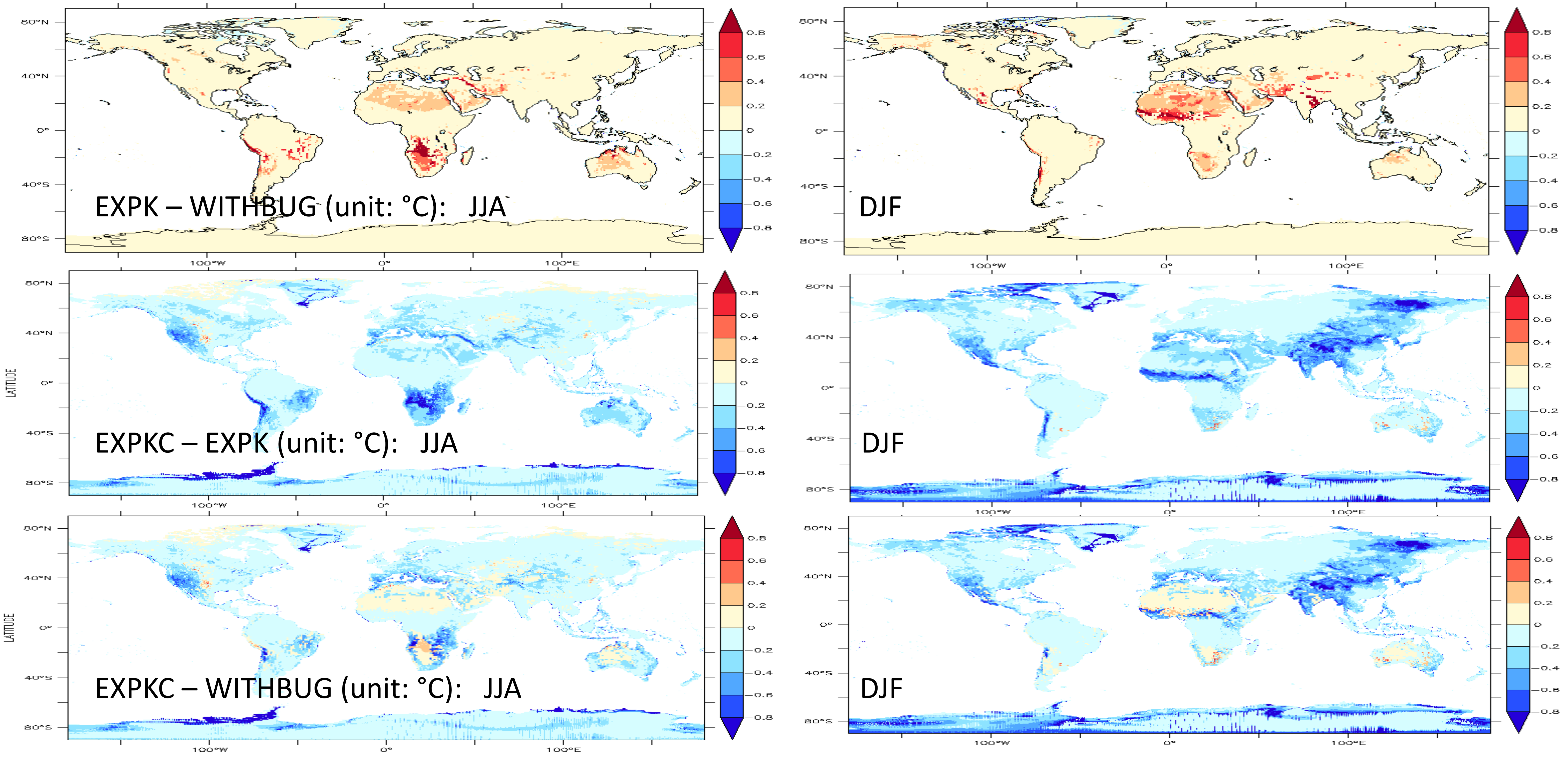
$$\frac{m_d}{V_d} \frac{V_d}{V_T} C_d + \frac{V_w}{V_T} \rho_w C_w = \rho_d \left(1 - \frac{V_w}{V_T}\right) C_d + \frac{V_w}{V_T} \rho_w C_w$$





The new thermal properties (capacity + conductivity) induce an decrease of Ts (1-2K) [Wang et al., 2016, GMD]

Small impacts of bugs (conductivity & capacity) on Surf. T (WFDEI_GPCC; offline; no freezing)

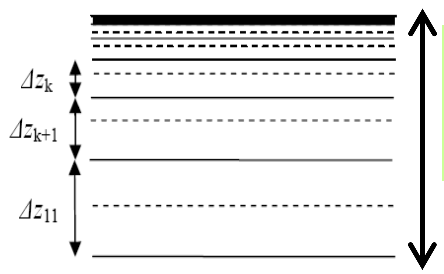


The impacts in coupled mode are also small:
https://vesg.ipsl.upmc.fr/thredds/fileServer/IPSLFS/fabric/lmdz/MultiSimu/THERMPROP/BIASGLOBJJA.html

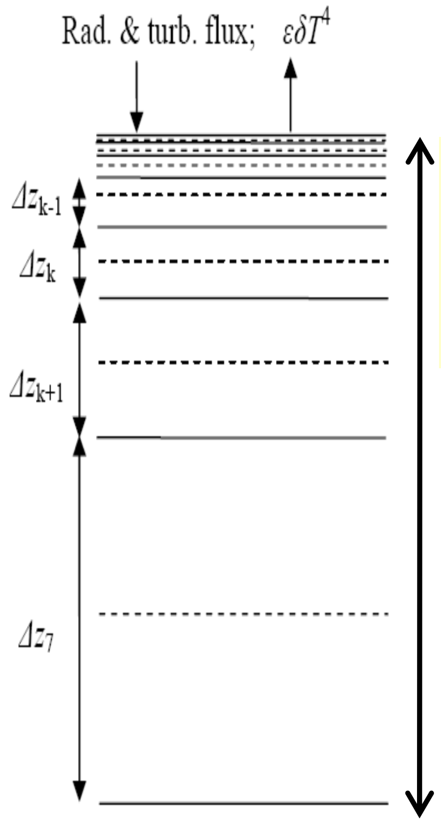
3. Same soil vertical discretization for temperature and moisture

OLD: Different layers for Water & Temp.

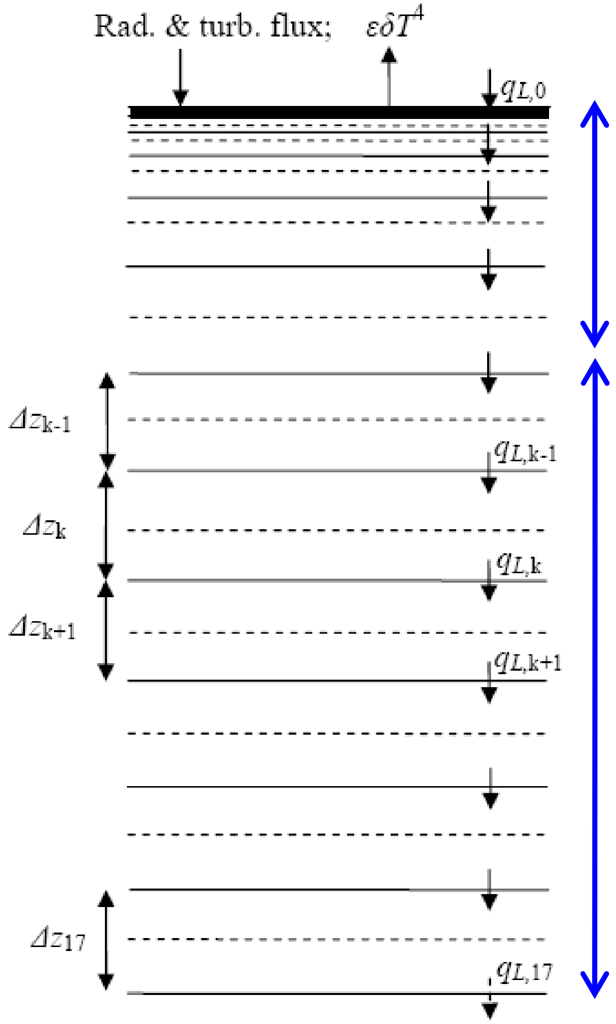
CMIP6: New discretization [*Wang et al.*, 2016, GMD]



2 Meters
11 Layers



~5 M
7 L



2 M

8 M (Flexible with physics)

Hydrology | **Thermodynamics** | **Thermodynamics**

Conclusions:

- Main developements for CMIP6 in soil thermal: vertical discretization and new thermal properties.

- The Ts changes < +/- 1K for new discretization , decreases 1-2K for new thermal properties.

- The impacts of bugs (recently found) on surface meteorology is small for both offline and coupled mode.