AMA2015: 19 January, 2015

Revision of Soil Thermodynamics and Its Impacts on Surface Meteorology in ORCHIDEE-LMDZ Coupled Model

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Outline

- **Background**: Soil thermal & hydrology in ORCHIDEE-11
- **Three revisions** in ORCHIDEE-11
  - I. Soil thermal property parameterization
  - II. Soil vertical discretization
  - III. Including soil heat convection by liquid water transfer
- **Conclusions**

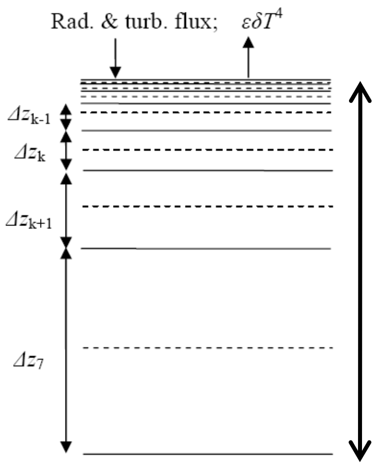
Background:
Soil Thermal & Hydrology in ORCHIDEE-11

Currently: Ⅰ. soil moisture changes with soil textures, but soil thermal properties do not; Ⅱ. different soil vertical discretizations for moisture & temperature; Ⅲ. soil heat convection process is neglected. **Energy imbalance !**

Soil Thermal [*F. Hourdin, 1992*]

Ⅰ. One soil texture.

Ⅱ.



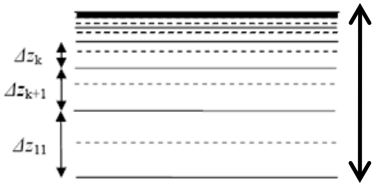
~5 Meters
7 Layers

Ⅲ. $$Cp(\theta)\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left[\lambda(\theta)\frac{\partial T}{\partial z}\right]$$

Cp: soil heat capa. (J/m³/K),
λ: thermal conduc. (W/m/K).

Soil Hydrology [*P. de Rosnay, 1999*]

Three soil textures:
Coarse, Medium, Fine



2 M
11 L

$$\frac{\partial \theta}{\partial t} = \frac{\partial q_L}{\partial z} - s$$

$$q_L = -D(\theta)\frac{\partial \theta}{\partial z} + K(\theta)$$

θ: soil moisture (m³/m³);
q_L: liquid water flux (m/s);

Revisions

Ⅰ. **Soil Thermal Properties change with soil textures & moisture.**

Ⅱ. **Same soil vertical layers for temperature & moisture.**

Ⅲ. **Coupling soil heat convection-conduction.**

Ⅰ. Soil Thermal Properties in ORCHIDEE

Currently | **Revised**

Soil Heat Capacity

Currently:

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

Revised:

$$C_p(\theta, st) = C_d(st) + \theta(st) \times C_w$$

θ: Vol. soil moist.; *Cd:* Dry capacity, *Pielke* [2002].

Soil Thermal Conductivity

Currently:

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

θ: Volumetric soil moisture.

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

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

(same thermal property for different soil textures).

Revised:

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

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

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

$$K_e(\theta, st) = 0.7 \log S_r[\theta(st)] + 1.0$$

κ_q, κ_o, κ_w: *κ* for quartz, other minerals, water **(prescribed)**.

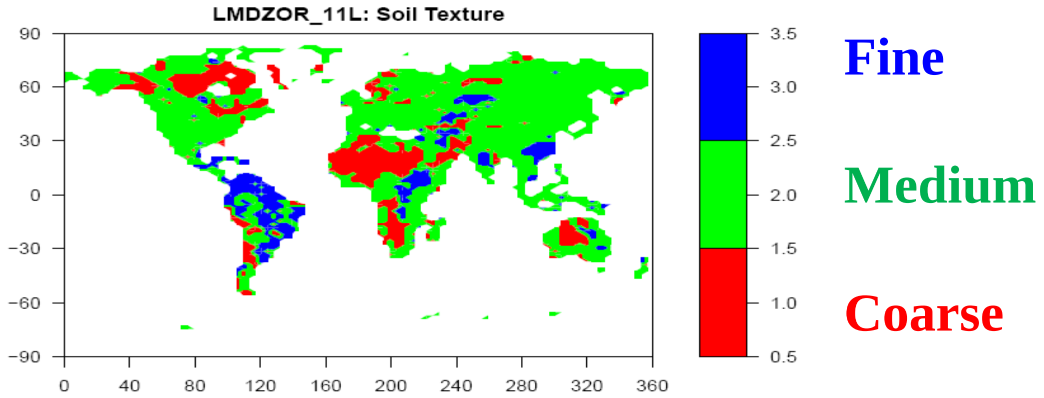
n_p: porosity; ***Sr***: Saturation degree; ***q***: quartz.

(thermal property **varies with different soil textures**)

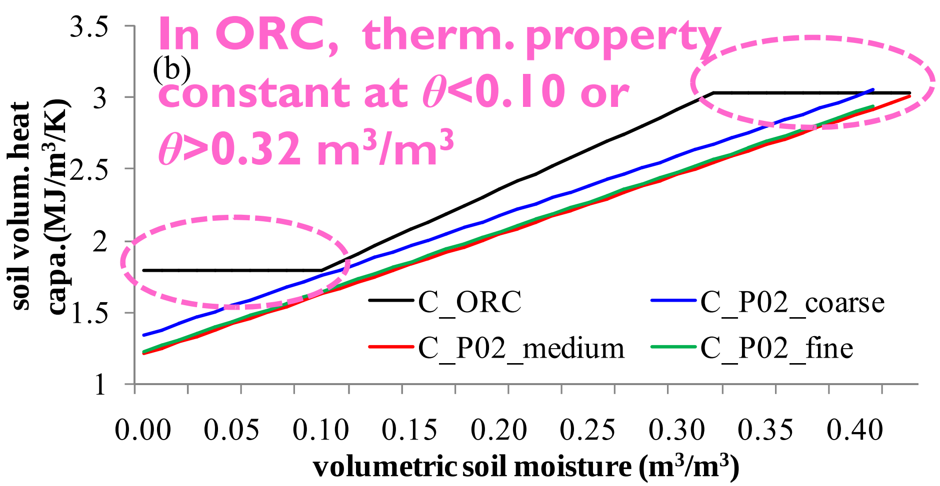
Johansen, O. [1975, J75] , *Peters-Lidard et al.* [1998]

Soil Thermal Properties with ---
3 Soil Texture Classes

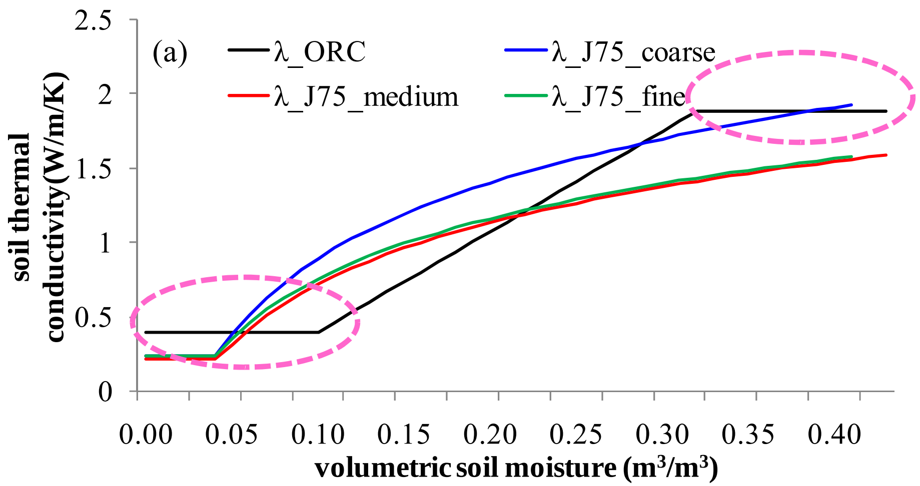
Three Soil Textures in ORCHIDEE-11



Soil Heat Capacity

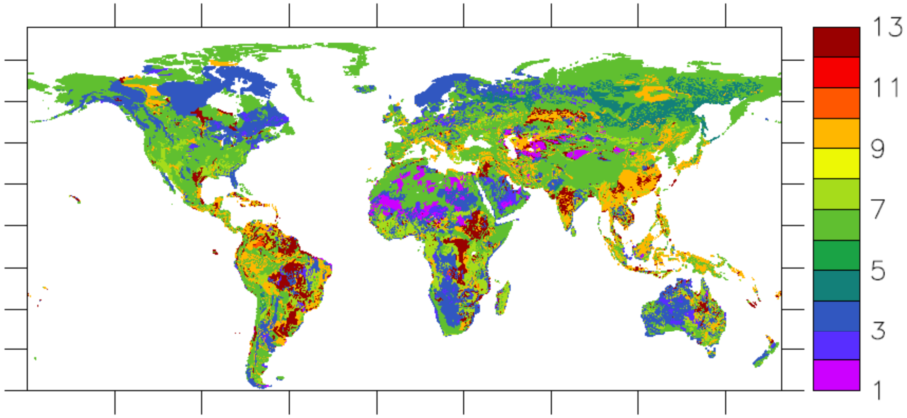


Soil Thermal Conductivity

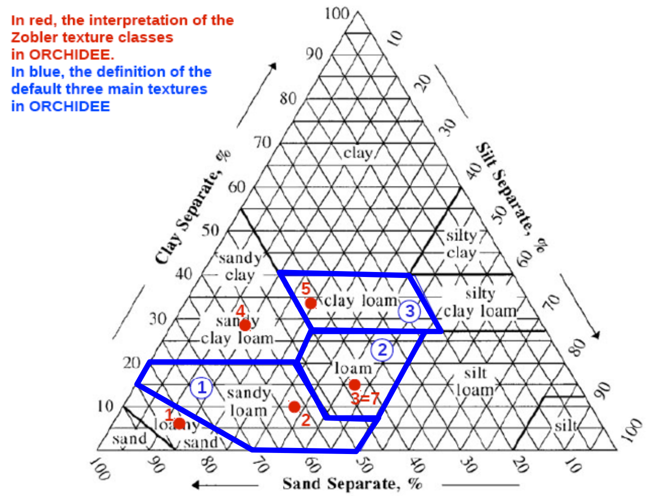


Soil Thermal Properties with ---
USDA 12 Soil Texture Classes

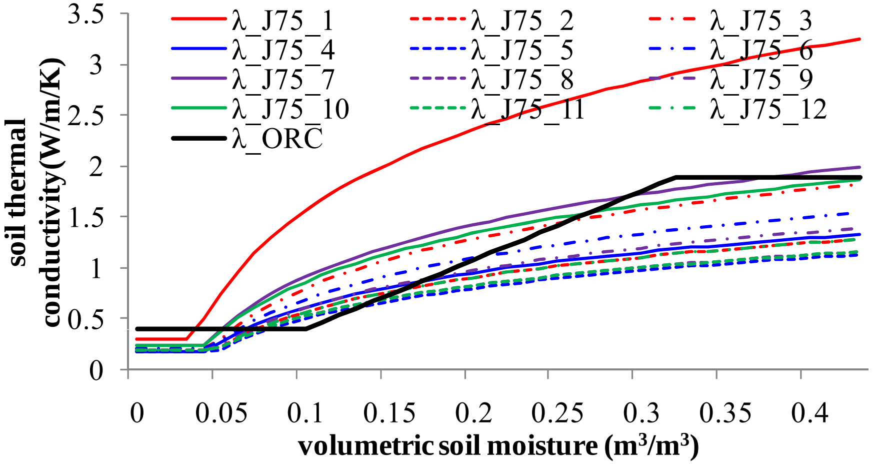
USDA 12 Soil Textures



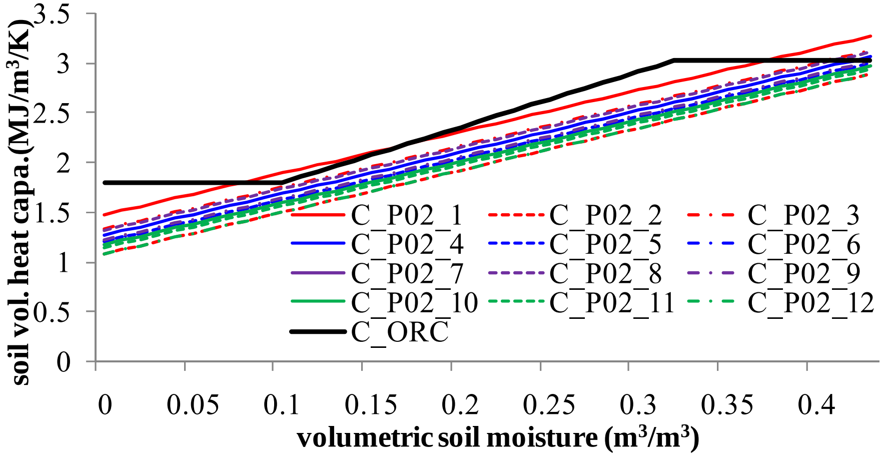
USDA Soil Texture Triangle



Soil Heat Capacity



Soil Thermal Conductivity

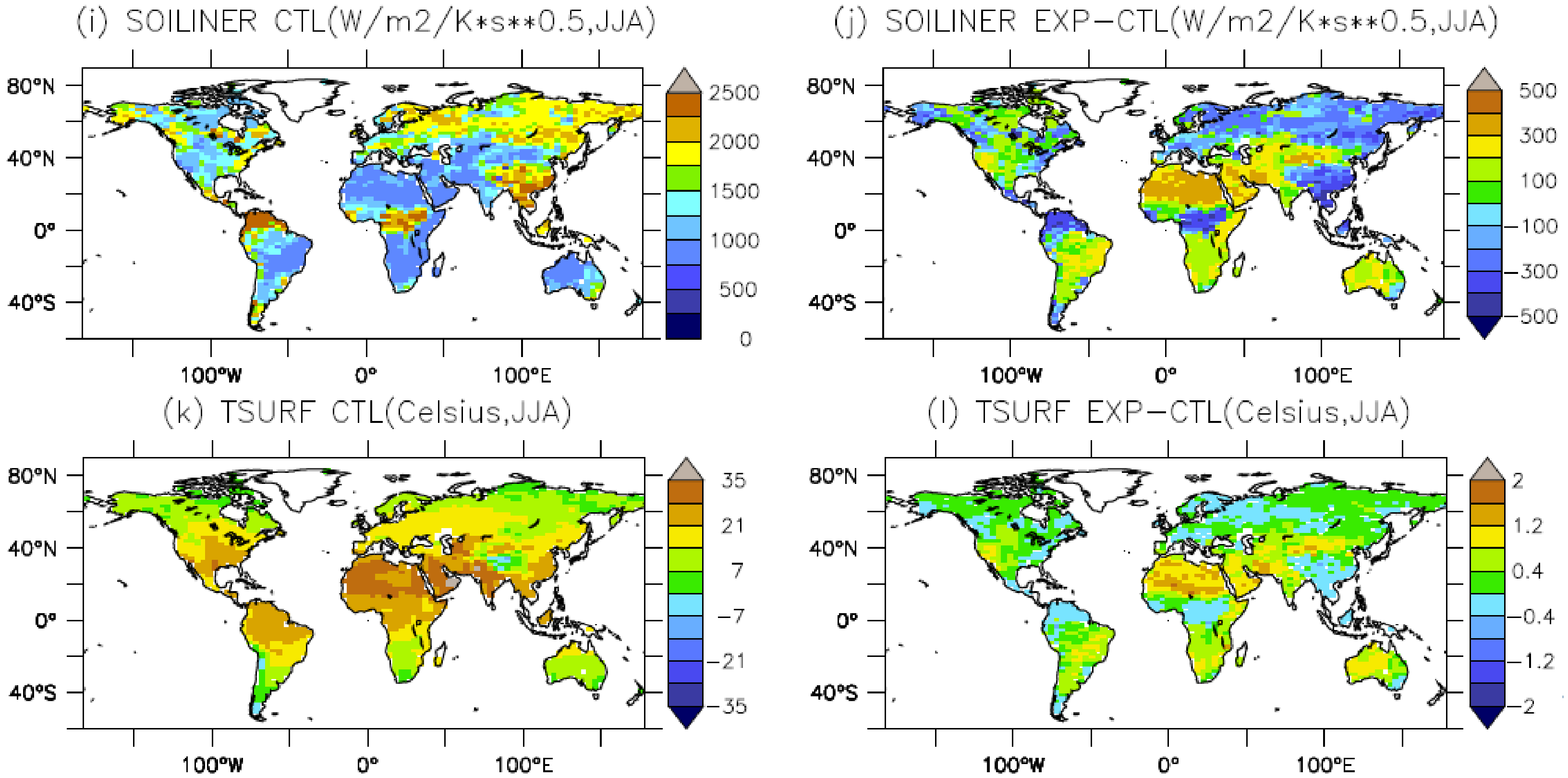


Effects of Soil Thermal Properties (3 textures) in ORC-LMDZ, JJA (3-Year AVE)

	Thermal property	Discretization	moisture	
CTL	Standard method	Standard	3 textures	Nudged
EXP	Revised (3 textures)			

Soil thermal inertia, P = $(\lambda C_p)^{0.5}$, $(W/m^2/K*s^{0.5})$, resistance of soil to temp. change.

Standard **Revised - Standard**



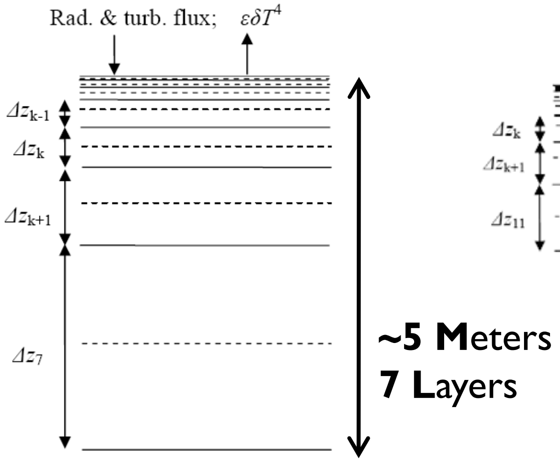
Ⅱ. Soil Vertical Discretizations in ORCHIDEE

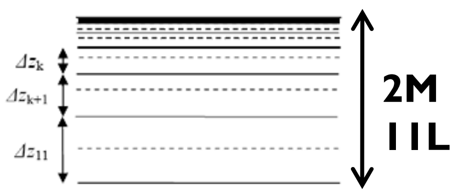
Currently: Different soil vertical discretizations for moisture & temperature; Energy imbalance !

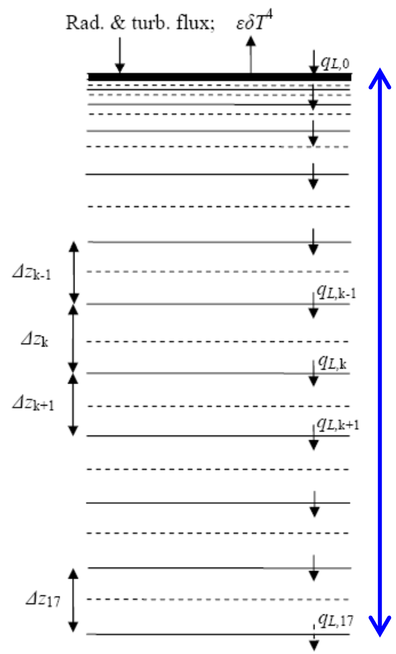
Revised: The same soil vertical discretization for moisture & temperature.

Soil Thermodynamics
[F. Hourdin, 1992]

Hydrology
[P. de Rosnay, 1999]







8M
17L

Above 2m: same with standard hydro. model;

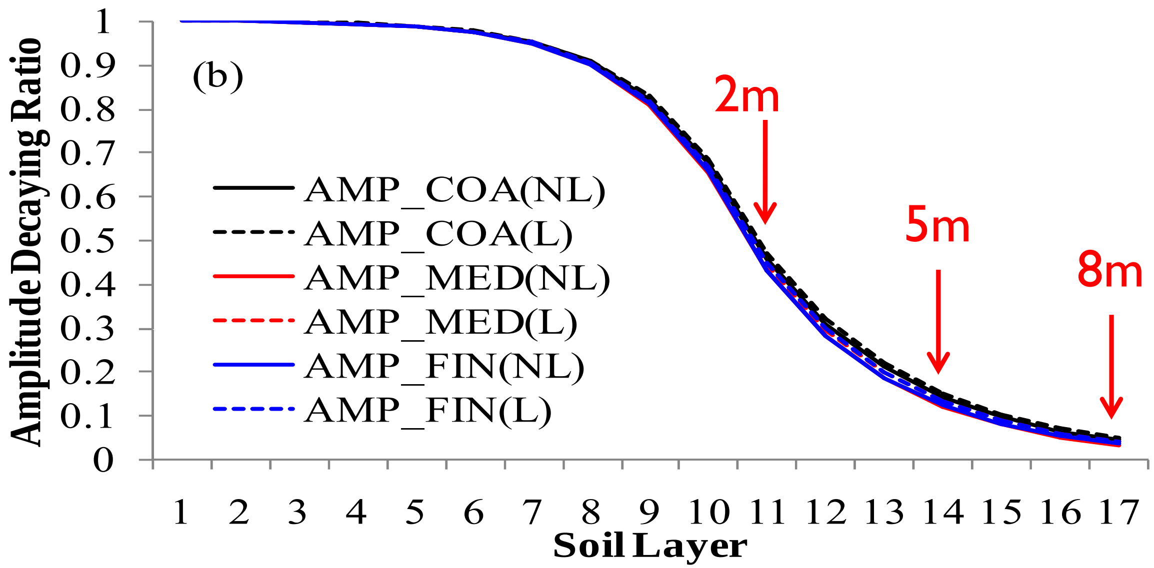
Below 2m: increased by 1m for each layer.

BC: Zero heat flux.

Why Extend Soil Depth to 8M ?

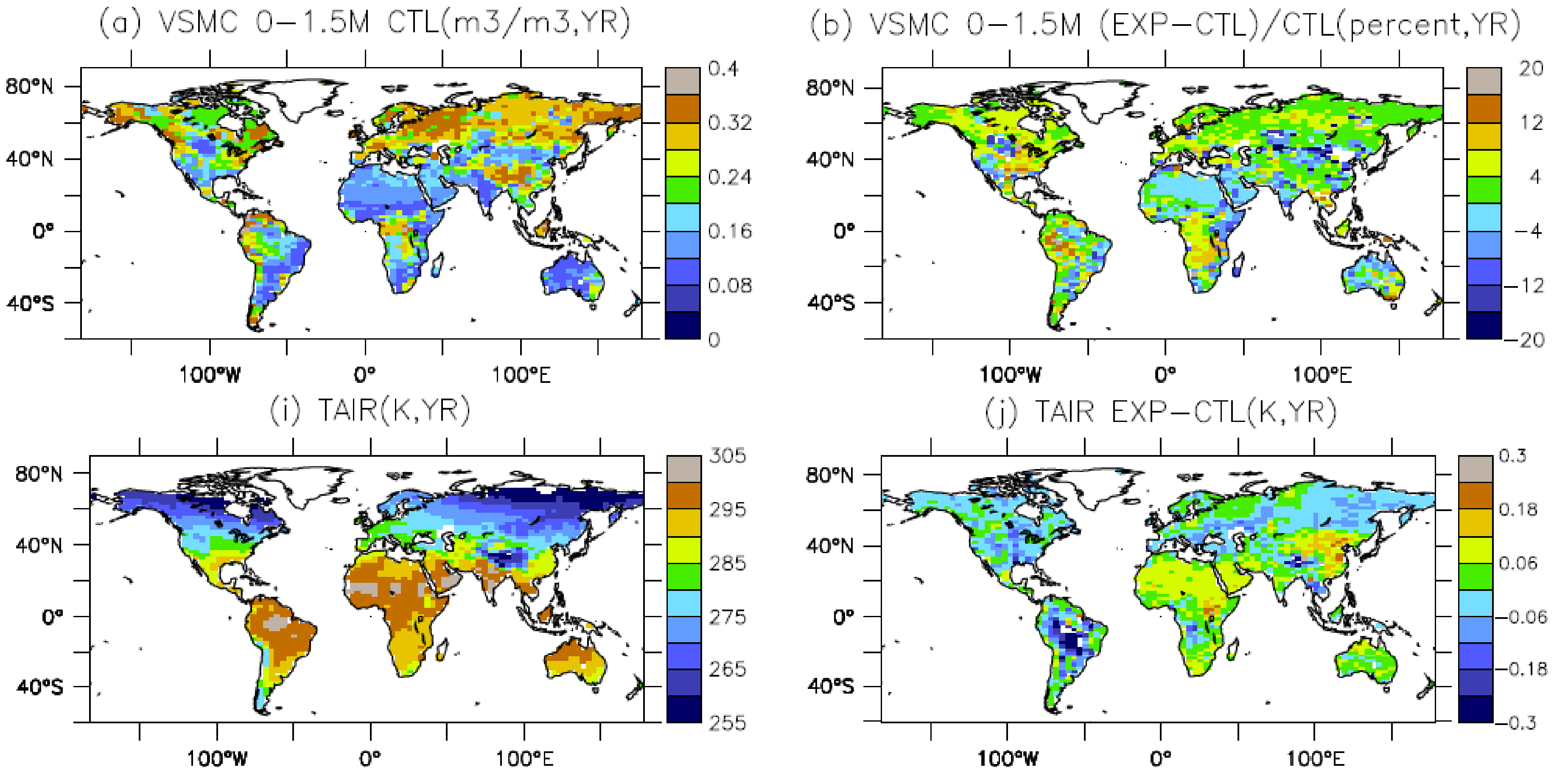
- **Diurnal/Annual cycle of temperature (solar/net radiation).**
- **The amplitude of soil temperature variation decreases with depth.**
- **To have enough soil depth to simulate the diurnal/annual cycles of soil temperature.**

The decaying of temperature amplitude with soil depth →



Soil Discretization Effects (3-Year)

	Soil Discretization	Thermal Property	
CTL	Standard	Constant globally	Nudged
EXP	Revised (8 meters)		



Ⅲ. Soil Heat Conduction-Convection Coupling (Numerical)

Currently: soil heat convection is neglected, only conduction is considered.

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

Cp: soil heat capa. (J/m^3/K),

λ: thermal conduc. (W/m/K).

[*F. Hourdin,* 1992]

Revised: Soil heat convection-conduction coupled.

$$Cp(\theta,st)\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left[\lambda(\theta,st)\frac{\partial T}{\partial z}\right] - C_W\frac{\partial q_L T}{\partial z} - S$$

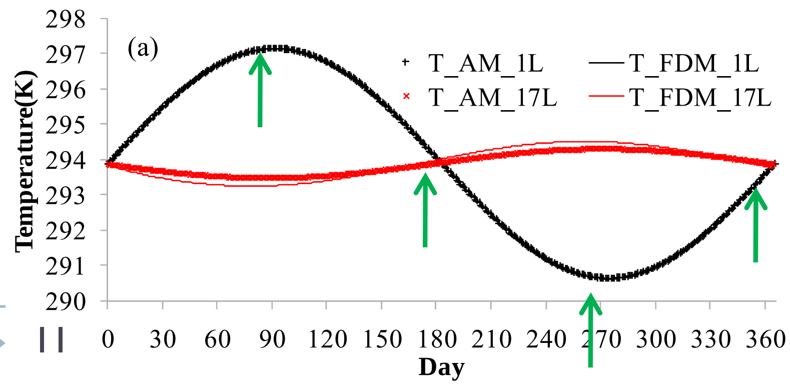
$$\frac{\partial \theta}{\partial t} = \frac{\partial q_L}{\partial z} - s$$

Cw: water heat capa. (J/m^3/K),

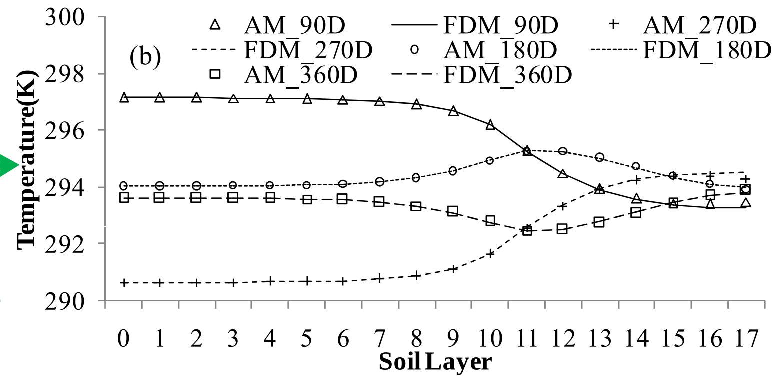
θ: soil moist. (m^3/m^3); q_L: liquid water flux (m/s)

Evaluation of the revised model in 1-D case (q_L=1E-7 m/s, 8.6 mm/d) by analytical solutions.

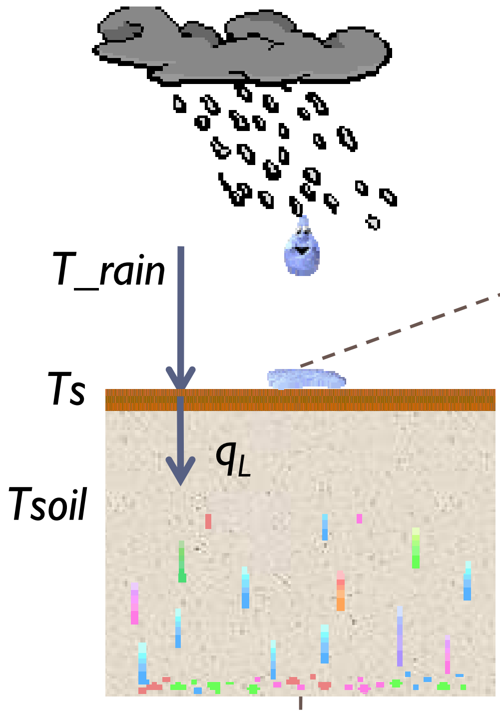
Annual Cycle: Time series at different layers



Vertical profile at different time steps



Soil Heat Conduction-Convection Coupling (Boundary Conditions in ORCHIDEE-11)



Bottom BC: zero flux, dT/dz=0

Land Surface BC:

- Surface Energy Balance:

  Cp × *dTs/dt* = *Rnet* + *LH* + *SH* + *G* + ***H_rain***

  H_rain = Cw × (***T_rain*** - *Ts*) × $q_{L,0}$

  T_rain ≈ *T_wetbulb* [*Gosnell et al.*, 1995]

  T_wetbulb ~ *f* (*Tair, Qair, Ps*)

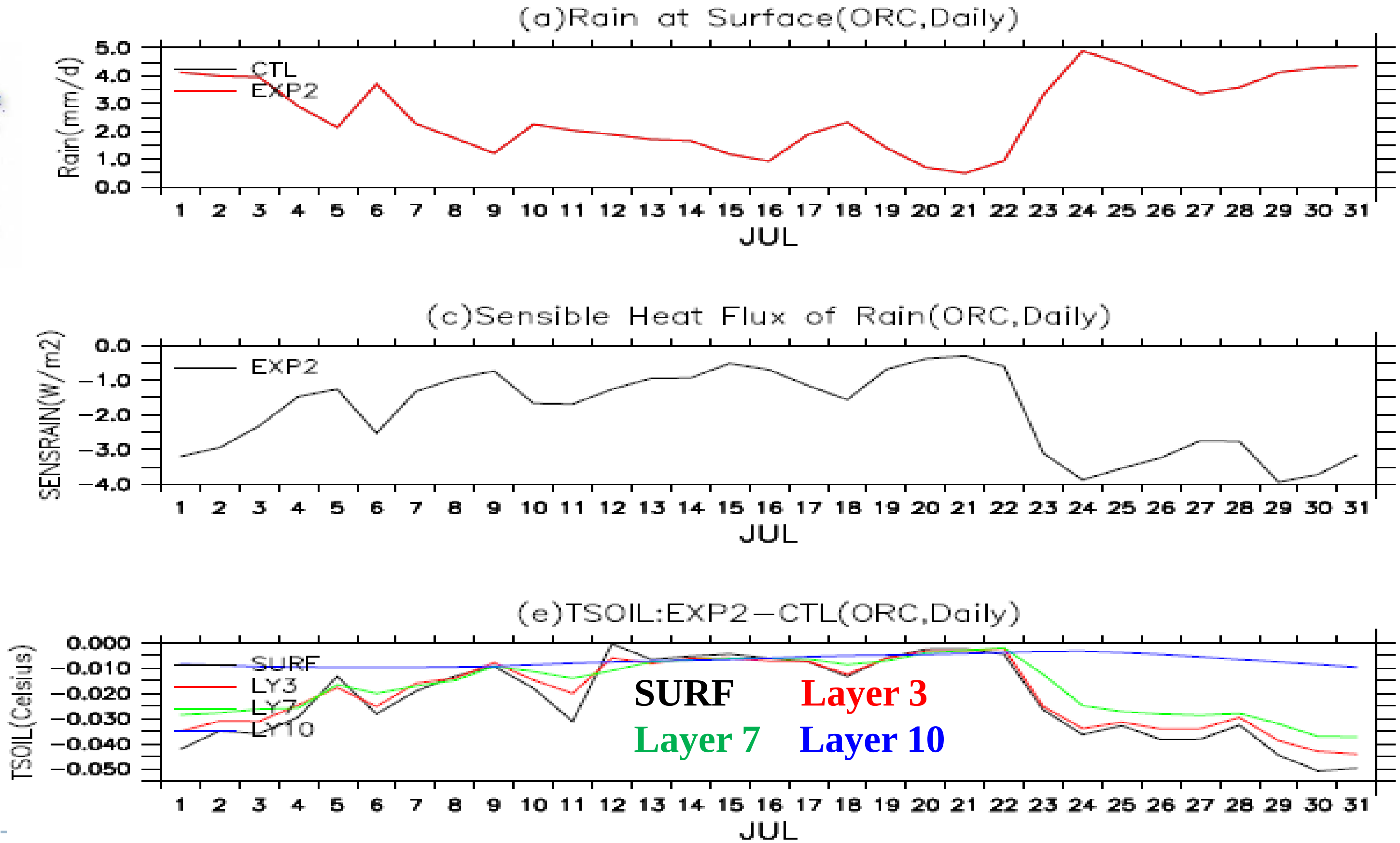
$$Cp(\theta, st)\frac{\partial T}{\partial t} = \underbrace{\frac{\partial}{\partial z}\left[\lambda(\theta, st)\frac{\partial T}{\partial z}\right]}_{\text{Conduction}} - \underbrace{C_W \frac{\partial q_L T}{\partial z}}_{\text{Convection}} - S$$

The Effects of Liquid Water Transfer in Soil: ORCHIDEE-11 Forced Mode

	Soil Heat Convection	Soil Discretization	Thermal Property
CTL	No	Revised (8 meters)	Constant
EXP	Yes		

60W-110W,

25N-45N



Conclusions

- The ORC-11 soil thermal model was modified to conserve energy: Ⅰ. thermal property; Ⅱ. same soil layer for moisture & temp.; Ⅲ. soil heat convection-conduction.

    I. The Sahara, western Australia are mostly affected by soil thermal properties (soil texture effects), with the surface temperature changes ~1.5K (maximum) in JJA.

    II. For most regions, the annual average surface temperature (soil moisture) changes < +/-0.1K (+/-10%) due to the different soil vertical discretization.

    III. In daily or 3h time scale, the soil temp. varies ~0.05 K with rainfall ~0-5mm/d (US, Summer). The variation decreases at larger time scale (monthly).

- Others:

    - The changing of discharge/runoff (~ +/-10% humid regions) due to revision of soil discretization (?)
    - The consideration of soil freezing parameterization (?)

Thank You! Questions & Comments ?

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