ORCHIDEE DEV: 18 novembre, 2014

The Soil Thermal Dynamics in ORCHIDEE

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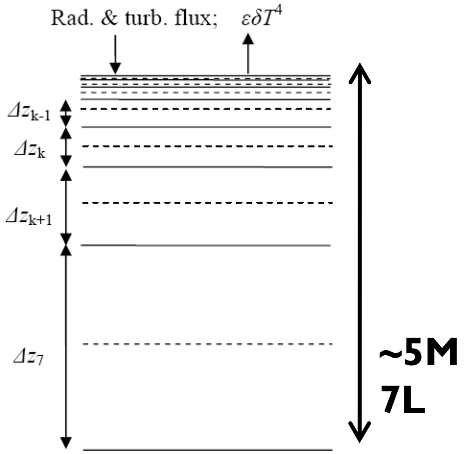
LMD

Soil Thermal Model in ORC11

- **Current ORC-11 soil model:** **(1)** soil moisture changes with soil textures, but soil thermal properties do not; **(2)** different soil vertical discretization for moisture and temperature; **(3)** soil heat convection is neglected. **Energy imbalance !**

Soil Thermal [F. Hourdin, 1992]

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



Cp: soil heat capa. (J/m3/K),

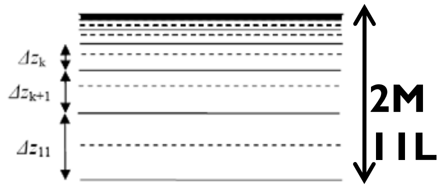
λ*:* thermal conduc. (W/m/K).

1 soil texture.

Soil Hydrology [P. de Rosnay, 1999]

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

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



θ: soil moisture (m^3/m^3);

q_L: liquid water flux (m/s);

3 Soil Textures for Moisture

Revised

Revision (1):

***Cp* and *λ* change with 3 soil textures & moisture!**

——— Layer

--------- Node

Soil Thermal Properties

Soil Heat Capacity:

Soil Thermal Conductivity:

Currently:

$$C_P(\theta) = C_{dry} + wet\,(C_{Wet} - C_{dry})$$

$$wet = \frac{\theta - \theta_w}{\theta_f - \theta_w}$$

$$\kappa(\theta) = \kappa_{dry} + wet\,(\kappa_{Wet} - \kappa_{dry})$$

Soil thermal properties change with soil moisture, but independent of soil texture.

Revised:

$$C_P(\theta, st) = C_d(\mathrm{st}) + \theta C_W$$

Dry capacity, Pielke [2002]; Volumetric SM

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

$$\kappa_{dry} = \frac{0.135\,\gamma_d + 64.7}{2700 - 0.947\,\gamma_d} \qquad \gamma_d = (1 - n_p) \times 2700$$

porosity

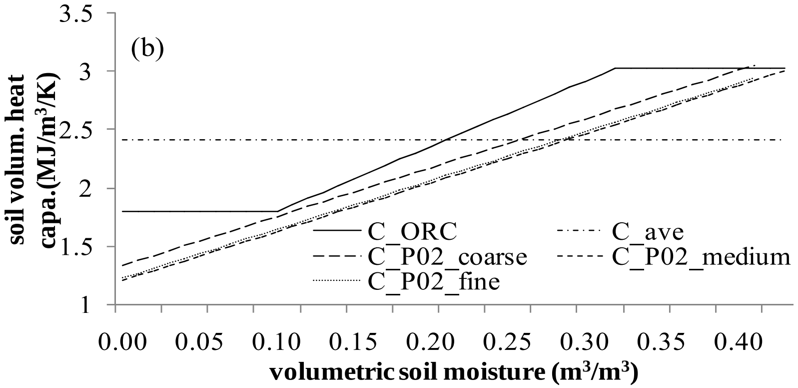
$$\kappa_{sat} = \kappa_s^{1-n}\,\kappa_i^{n-x_u}\,\kappa_w^{x_u} \qquad \kappa_s = \kappa_q^{q}\,\kappa_o^{1-q}$$

quartz

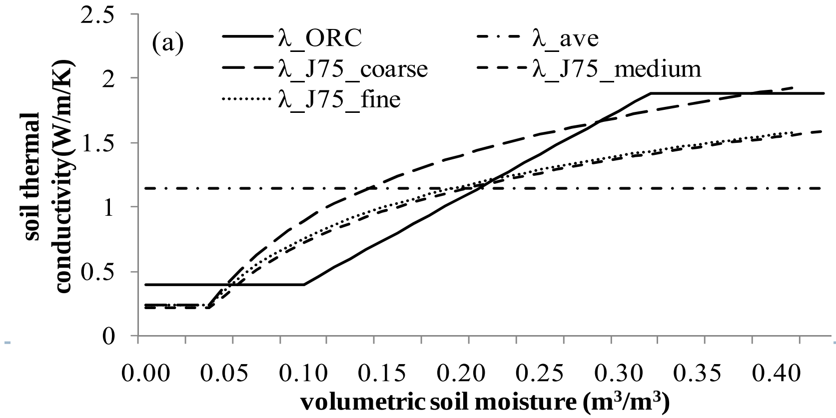
$$Ke = 0.7\log Sr + 1.0$$

Saturation degree

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



Soil thermal properties change with soil texture & soil moisture.

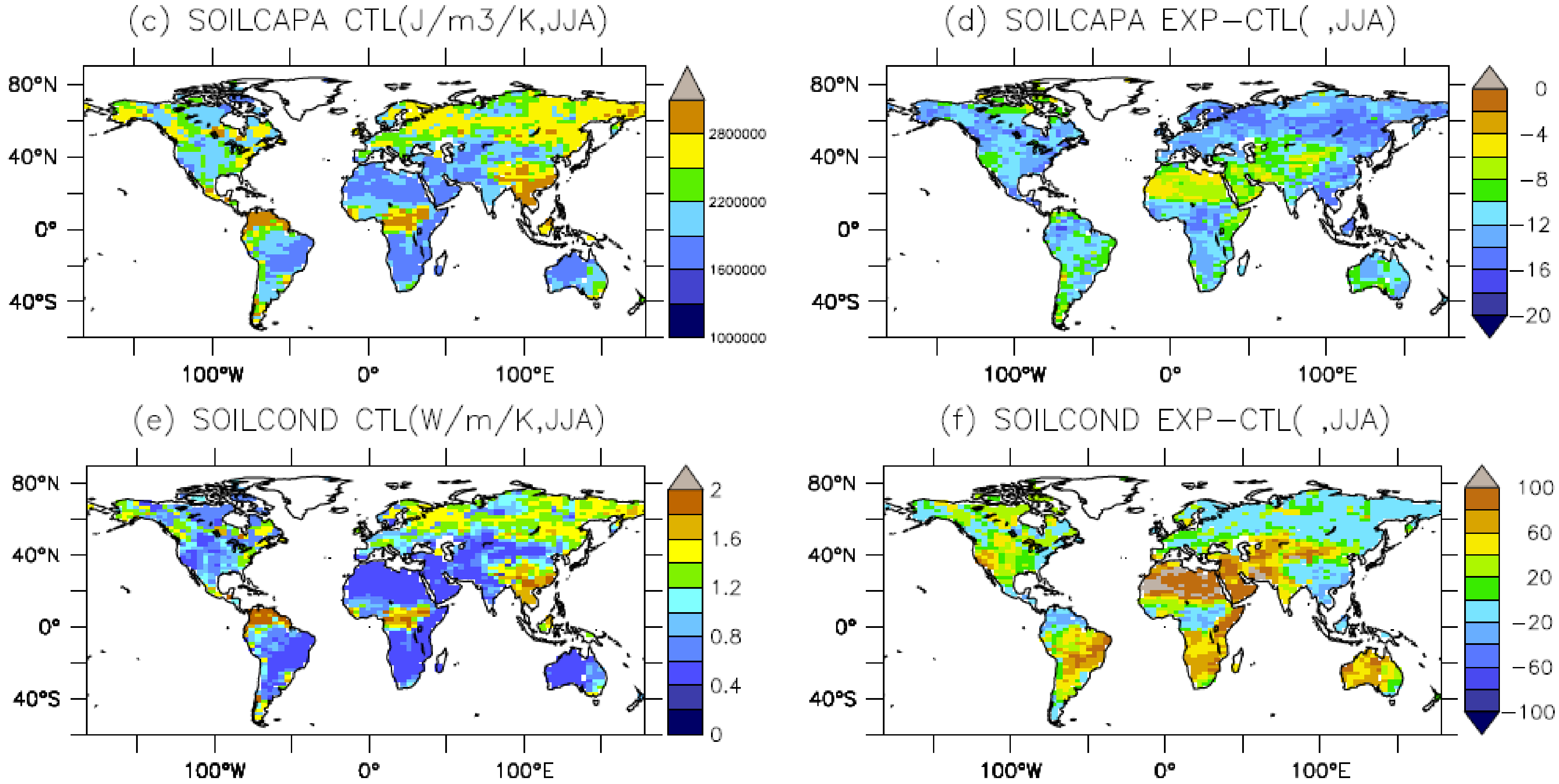


Soil Thermal Properties in ORC-LMDZ JJA (3-Year AVE)

Item	λ, C_p	Layer
CTL	original	original
EXP	revised	original

- Standard

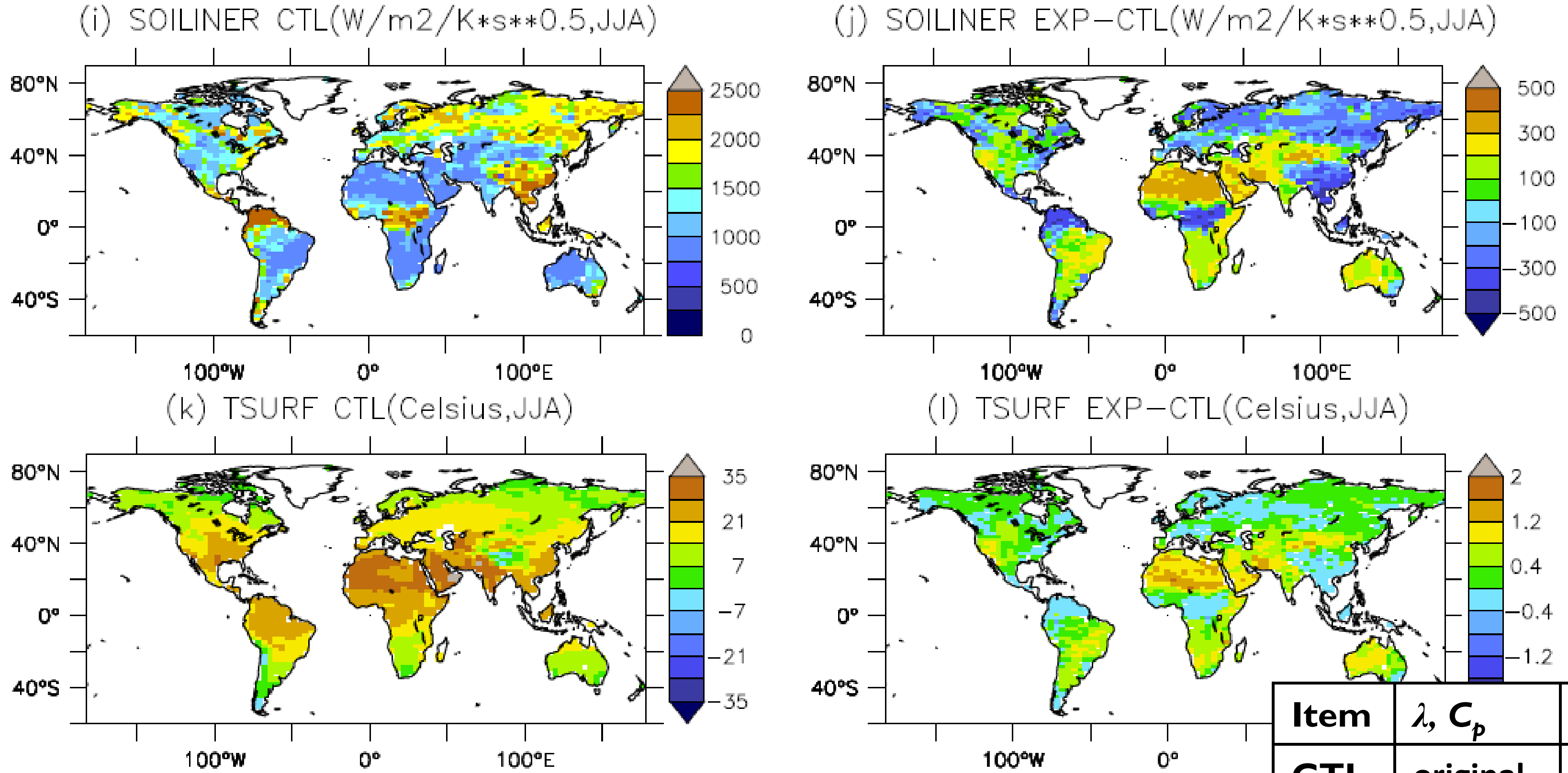
Revised – Standard, %



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

Definition: Soil thermal inertia, P = $(\lambda * C_p)^{0.5}$, ($W/m^2/K*s^{0.5}$), The resistance of soil to temp. change. The higher the P is, the slower the temperature varies during a full heating/cooling cycle (e.g., 24-hour day).

- **Standard** **Revised - Standard**

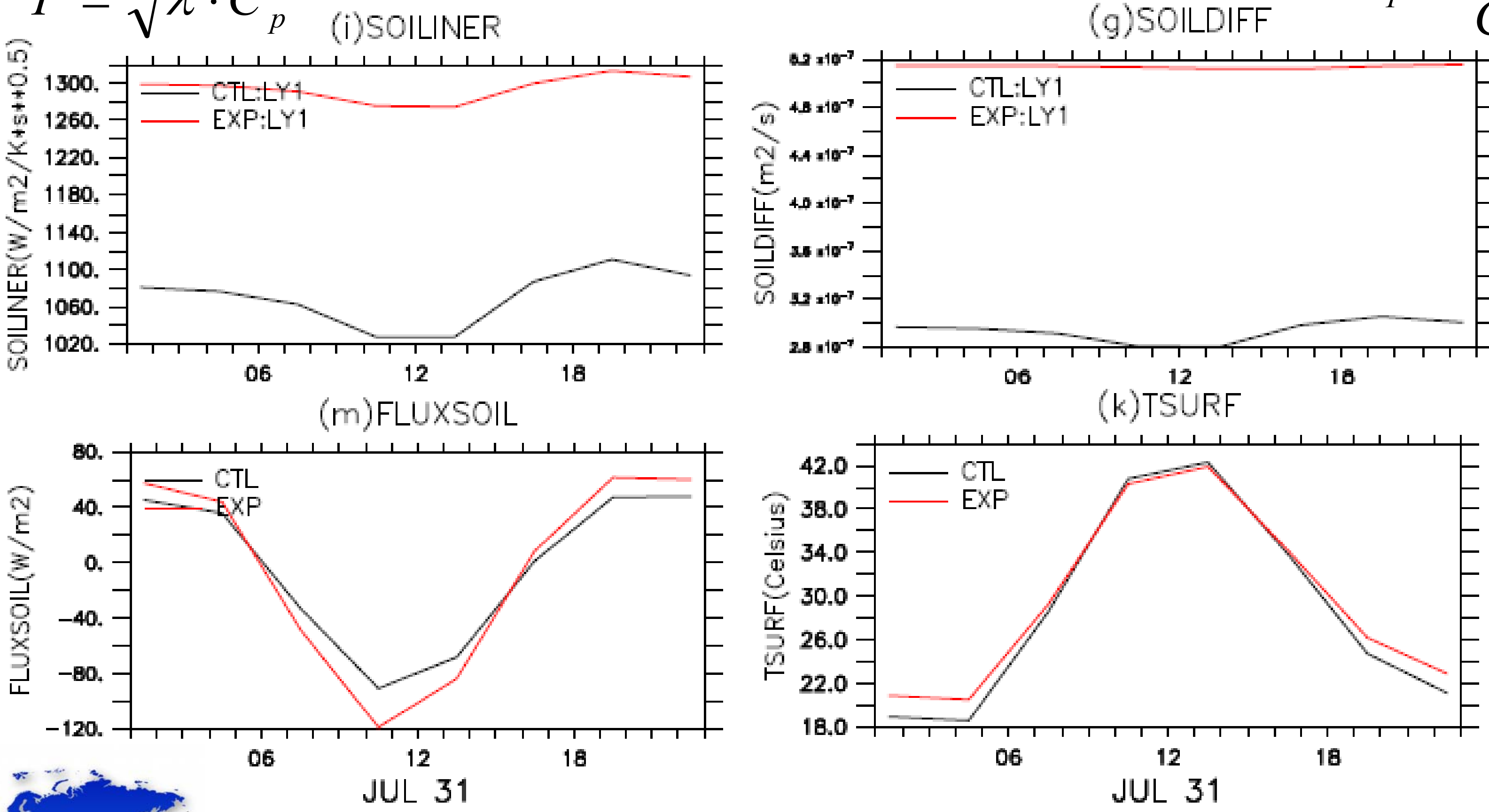


Item	λ, C_p	Layer
CTL	original	original
EXP	revised	original

Soil Thermal Prop. Effect: Diurnal Cycle

$$P = \sqrt{\lambda \cdot C_p}$$

$$K_T = \frac{\lambda}{C_p}$$

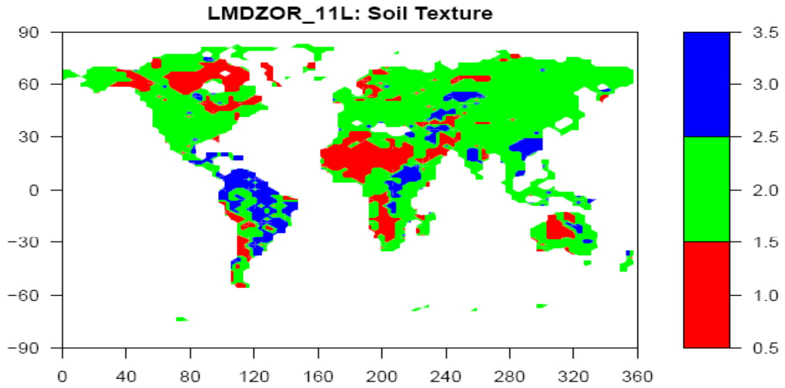


Sahara: 20W-5E, 10N-35N

Item	λ, C_p	Layer
CTL	original	original
EXP	revised	original

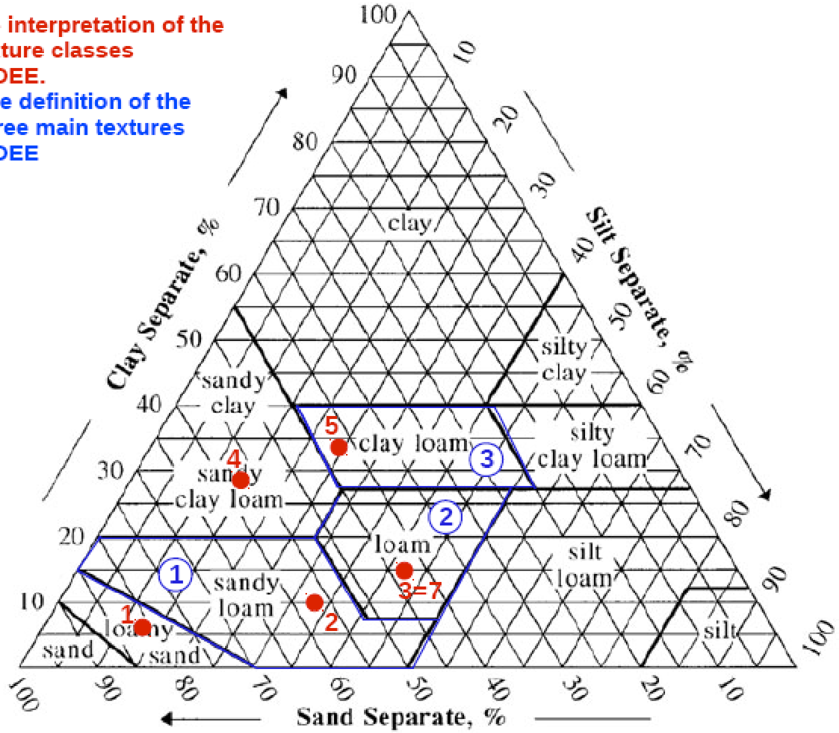
Soil Texture Classes

- **Currently**



Coarse (1), Medium (2), Fine (3)

In red, the interpretation of the Zobler texture classes in ORCHIDEE.
In blue, the definition of the default three main textures in ORCHIDEE



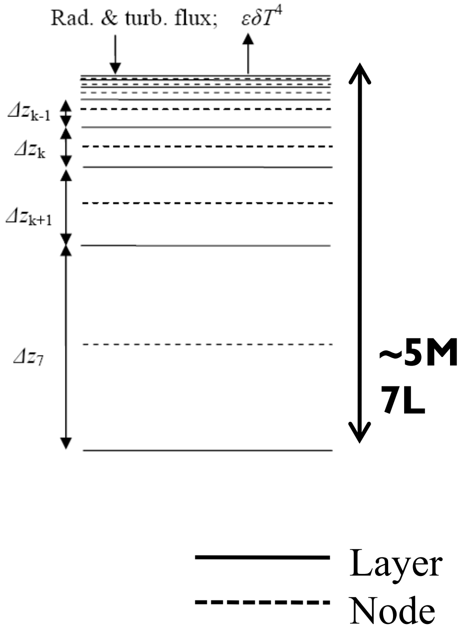
USDA triangle and its 12 soil texture classes [*Agnes Ducharne*, Feb. 2014]
USDA 12 Soil texture map in preparation;
Soil thermal property parameterization for 12 classes done !

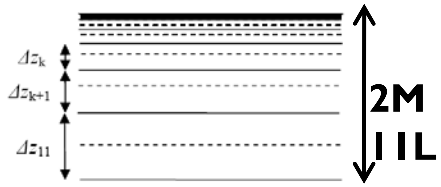
Soil Thermal Model in ORC11

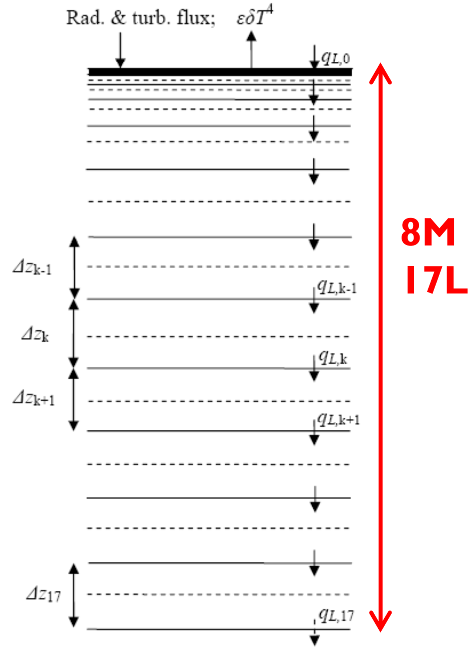
- **Current ORC-11 soil model:** (1) soil moisture changes with soil textures, but soil thermal properties do not; **(2) different soil vertical discretization for moisture and temperature;** (3) soil heat convection is neglected. **Energy imbalance !**

Soil Thermal [*F. Hourdin*, 1992] **Soil Hydrology** [*P. de Rosnay*, 1999] **Revised**

Revision (2)





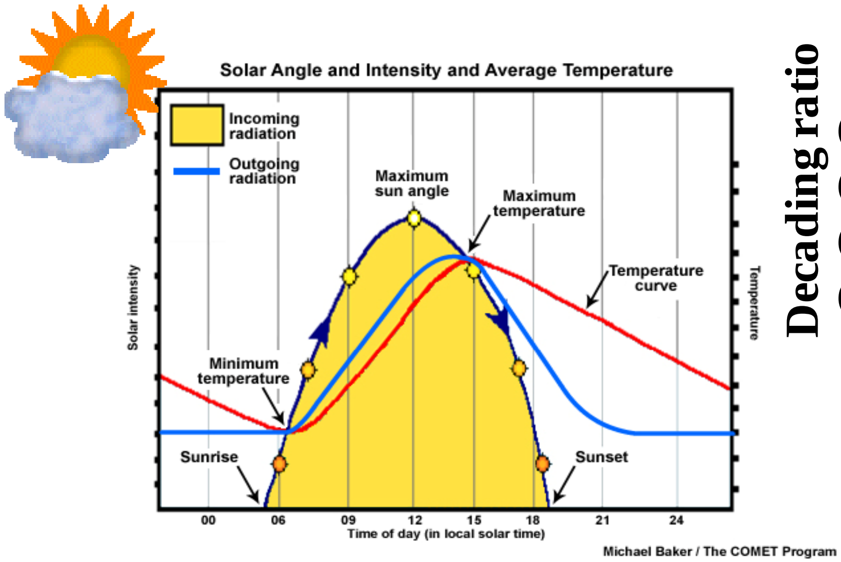


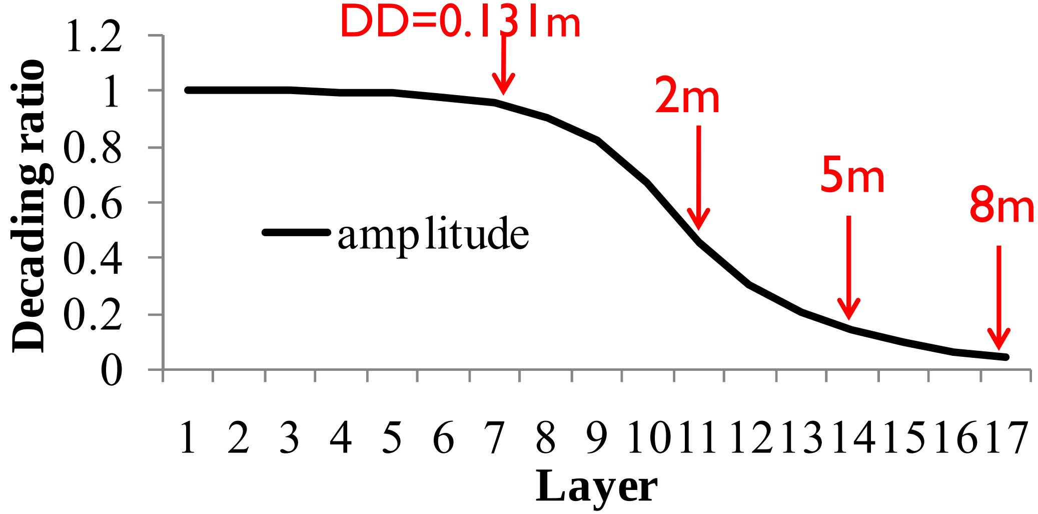
Soil Layer Thickness

	5M7L		8M17L	
layer	*zz* (m)	*zl* (m)	*zz* (m)	*zl* (m)
1	1.419E-2	3.426E-2	0	0.978E-3
2	6.264E-2	1.028E-1	1.955E-3	3.910E-3
3	1.595E-1	2.398E-1	5.865E-3	9.775E-3
4	3.533E-1	5.139E-1	1.369E-2	2.151E-2
5	7.409E-1	1.062	2.933E-2	4.497E-2
6	1.516	2.158	6.061E-2	9.189E-2
7	3.066	4.351	1.232E-1	1.857E-1
8			2.483E-1	3.734E-1
9			4.985E-1	7.488E-1
10			9.990E-1	1.500
11			2.000	2.00/<u>2.50</u>
12			<u>3.001</u>	<u>3.501</u>
13			<u>4.002</u>	<u>4.502</u>
14			<u>5.003</u>	<u>5.503</u>
15			<u>6.004</u>	<u>6.504</u>
16			<u>7.005</u>	<u>7.505</u>
17			<u>8.006</u>	<u>8.006</u>

Why Extend Soil Depth to 8M ?

- The amplitude of soil temperature decreases with depth.





λ= 1.329W/m^2/K , C = 2.135 J/m^3/K (medium wetness)

Damping Depth (*DD*): at which the amplitude decreases to the fraction 1/e of the surface amplitude. The required soil depth for

Diurnal Cycle: 3*DD* ≈ 0.393m

Annual Cycle: 3*DD**sqrt(365) ≈ 7.500 m

Analytical Solution: Soil Heat Conduction

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

- The **analytical solution** can be obtained by the **boundary/initial conditions:**

$$T(0,t) = \overline{T} + A_0 \sin(\omega t - \Phi)$$

$$\lim_{z\to\infty} T(z,t) = \overline{T}$$

$$T(z,0) = \overline{T} + A_0 e^{-\frac{z}{D}} \sin\left(-\frac{z}{D} - \Phi\right)$$

$$T(z,t) = \overline{T} + A_0 e^{-\frac{z}{D}} \sin\left(\omega t - \frac{z}{D} - \Phi\right)$$

$$w = \frac{2\pi}{\tau}$$

$$D = \sqrt{\frac{2K_T}{\omega}} = \sqrt{\frac{K_T \tau}{\pi}}$$

$$K_T = \frac{\lambda}{C_p}$$

Angular velocity of earth rotation

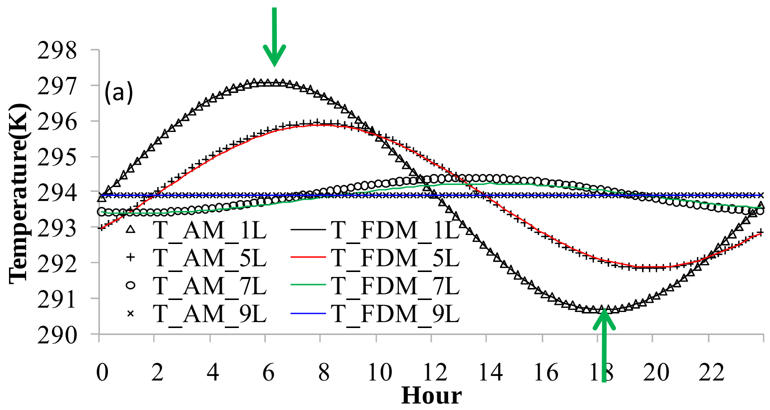
Harmonic period of surface temperature (86400s diurnal cycle)

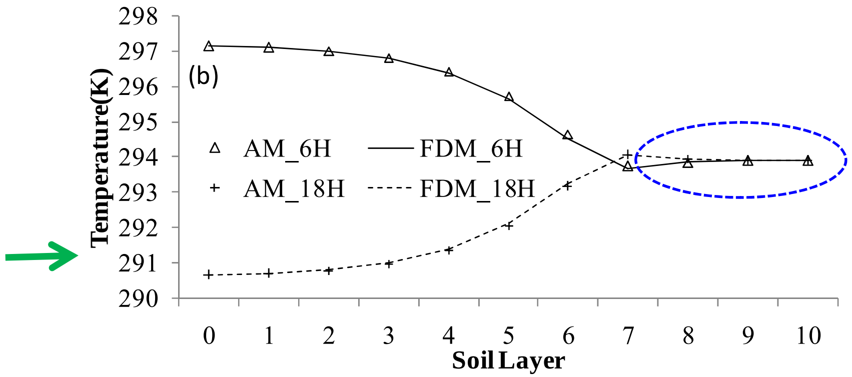
Numerical (FDM) vs. Analytical Solution (1D)

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

Diurnal Cycle: Time series at different layers

Vertical profile at different time steps





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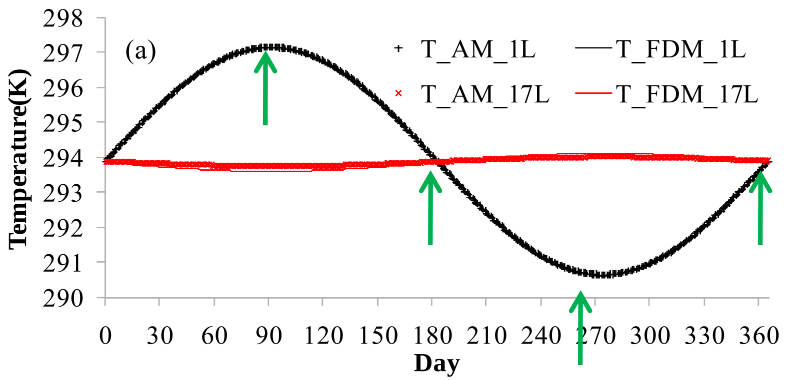
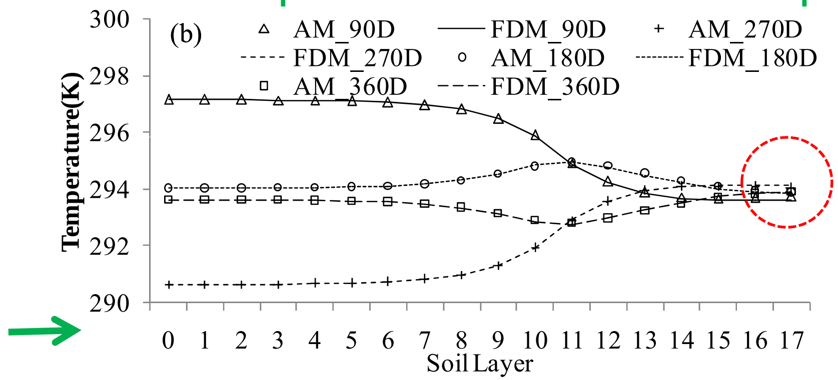
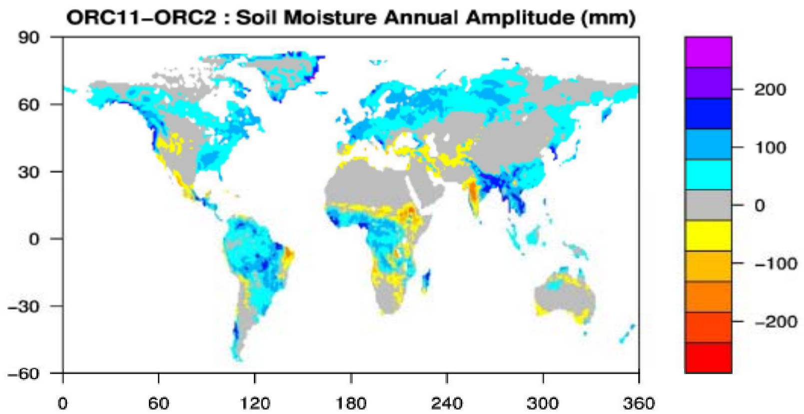
Vertical profile at different time steps

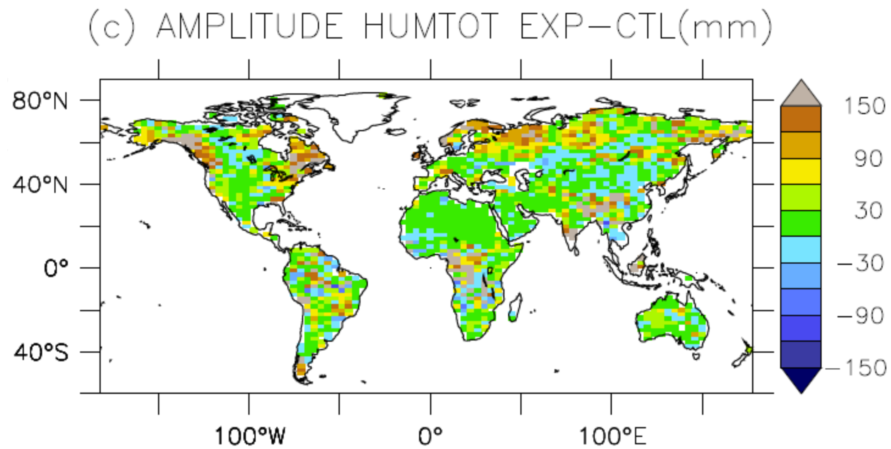




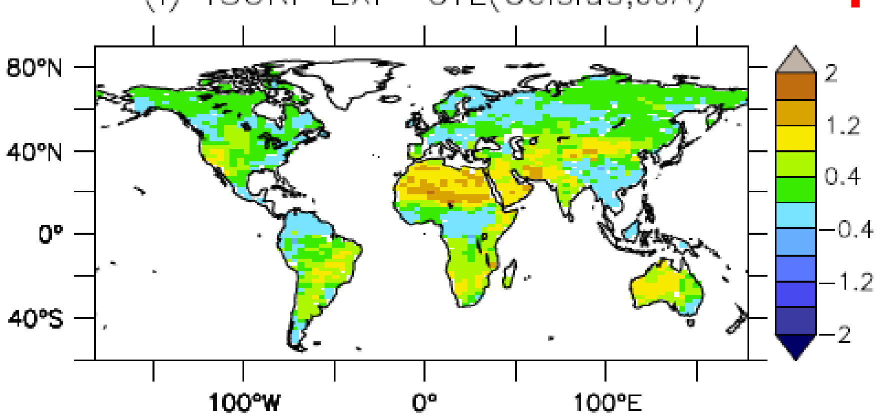
Discretization Effects (3-Year; SM,T)

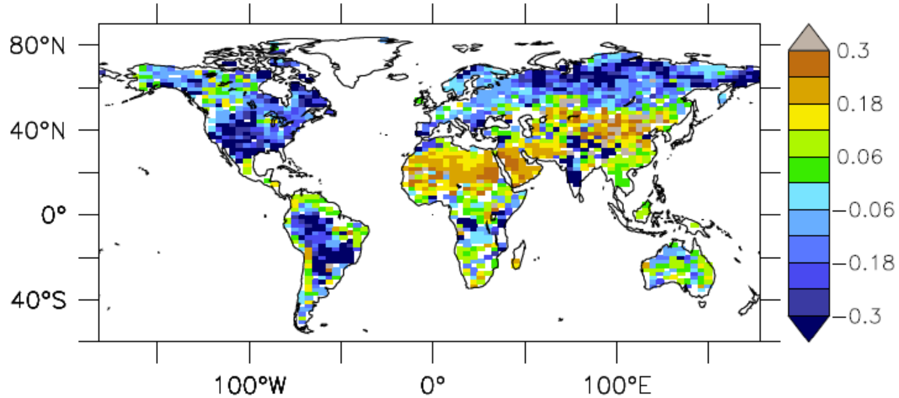
- **Moisture Annual Amplitude (mm)**





- **Land Surface Temperature (Celsius, JJA)**

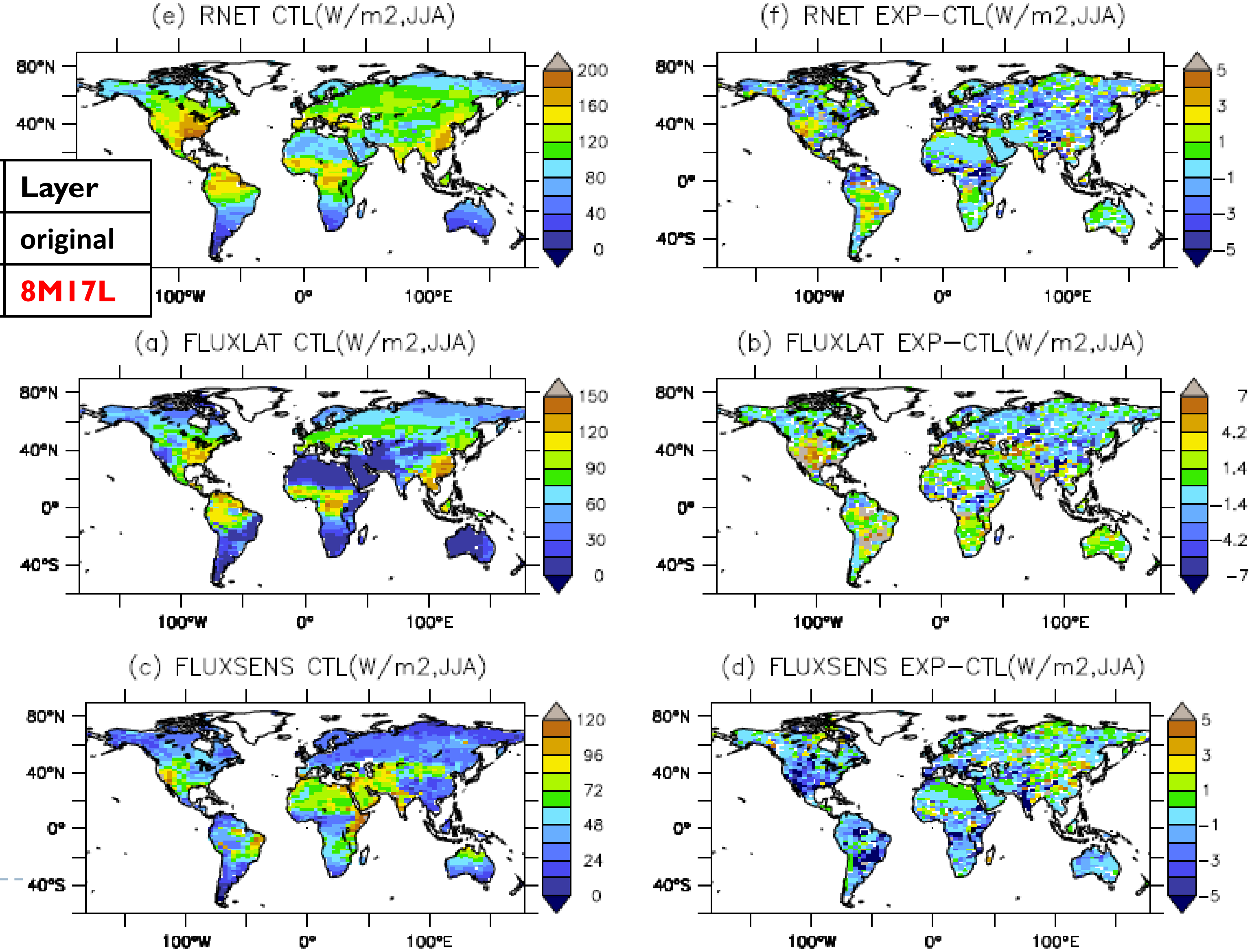




Thermal property effects **Discretization effects**

Discretization Effects (3-Year; Rn, LE, H)

Item	λ, C_p	Layer
CTL	constant	original
EXP	constant.	8M17L



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

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

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

Revised

Revision (3)

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

Cp: soil heat capa. (J/m3/K),

λ: thermal conduc. (W/m/K).

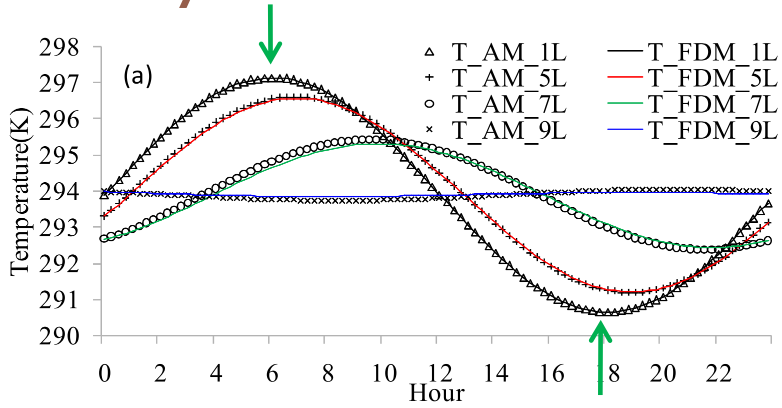
θ: soil moisture (m^3/m^3);

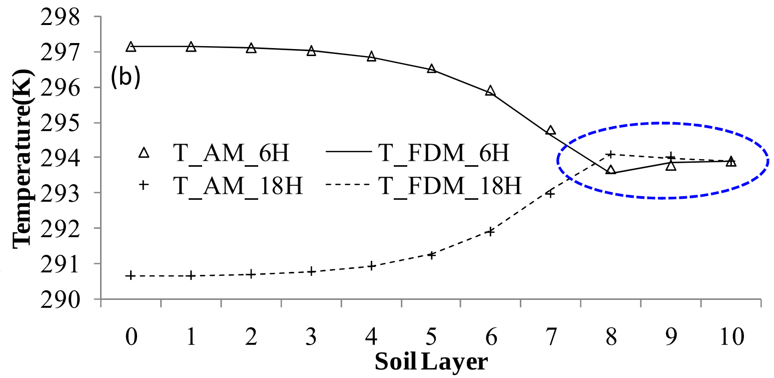
q_L: liquid water flux (m/s);

Numerical (FDM) vs. Analytical Solution Soil Heat Cond.-Convec. Steady Flow (1D)

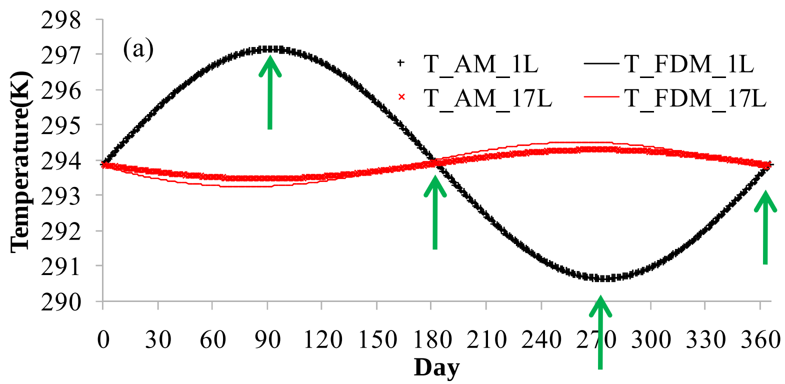
$$Cp\frac{\partial T}{\partial t}=\frac{\partial}{\partial z}\left[\lambda\frac{\partial T}{\partial z}\right]-C_W\frac{\partial q_L T}{\partial z}$$

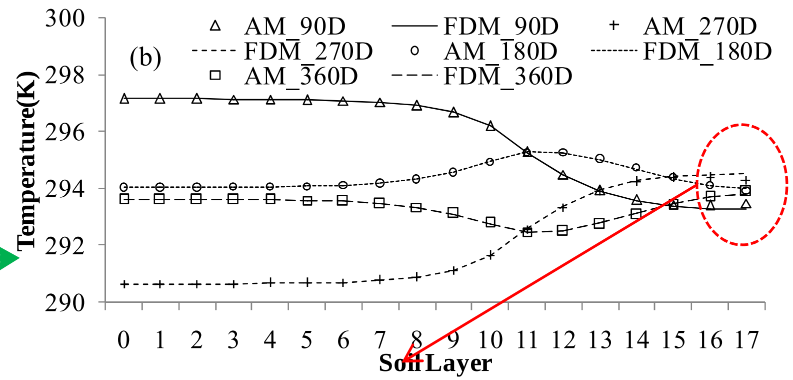
Diurnal Cycle: Time series at different layers — Vertical profile at different time steps





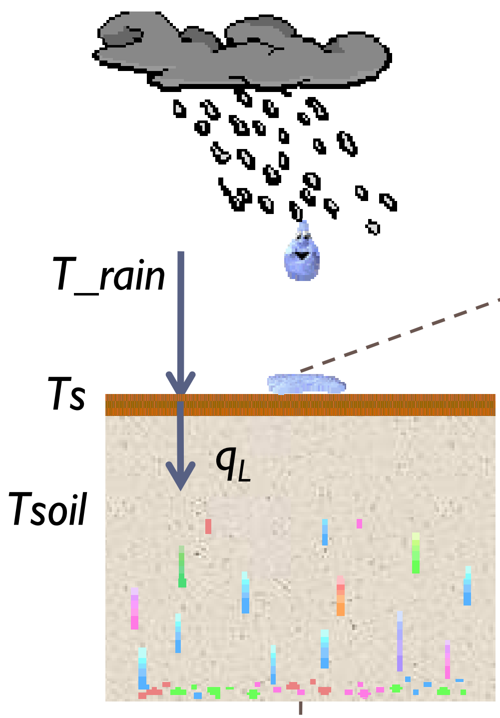
Annual Cycle: Time series at different layers — Vertical profile at different time steps





q_L=1E-7 m/s (8.6 mm/d)

Soil Heat Conduction-Convection Coupling



Land Surface BC:

- Surface Energy Balance:

  $Cp \times dTs/dt = Rnet + LH + SH + G + H\_rain$

  $H\_rain = Cw \times (T\_rain - Ts) \times q_{L,0}$

  $T\_rain \approx T\_wetbulb$

  $T\_wetbulb \sim f\,(Tair, Qair, Ps)$

Bottom BC: zero flux, dT/dz=0

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

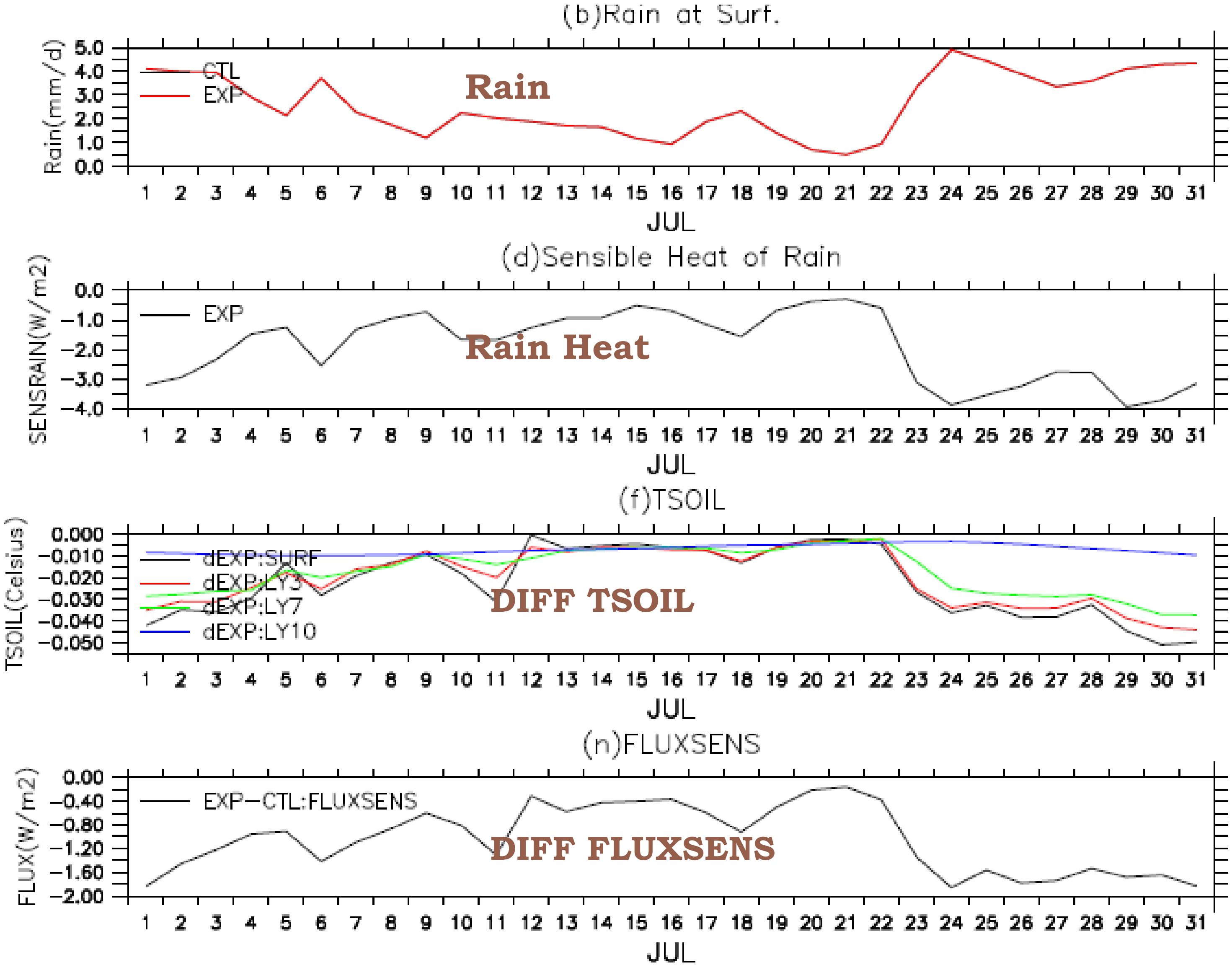
The Effects of Liquid Water Transfer: ORCHIDEE Forced Mode, Daily Scale

60W-110W,

25N-45N

EXP-CTL: SURF
Layer 3
Layer 7
Layer 10

EXP-CTL: FLUXSENS
Positive upward



T_{soil} Vertical Profiles

Item	λ, C_p	q_L	Dep.
CTL 8M	Ave.	N	8M 17L
EXP1 8M	Rev.	Y	
EXP2 8M	Ave.	Y	

60W-110W, 25N-45N

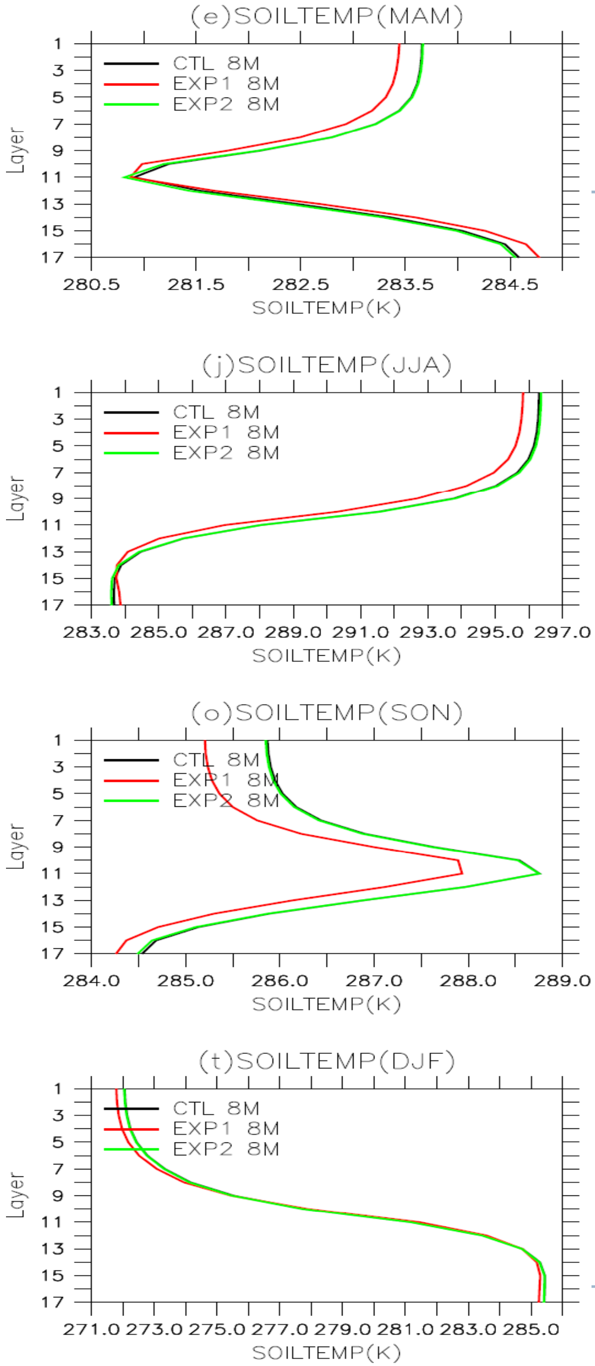
Conclusion: Soil thermal property (texture) effects are larger than q_L effects.

MAM

JJA

SON

DJF



Check Numerical Stability in ORC-LMDZ (3-Hour Time Step, July)

Item	λ, C_p	Liquid water (q_L)	Soil Depth
CTL	original	Not included	original
EXP	Revised.	Yes, included	8M17L

Conclusion: (1) No extreme high/low temperature; (2) No oscillations in PTN, FLUXLAT.