Response to Comments from Anonymous Referee #2

We thank referee #2 for the comments. The added/modified parts are highlighted in blue. The reviewer's comments are in italic.

General Comments

The authors present a clear, concise description of the soil moisture and temperature treatment in the IPSL ORCHIDEE model. The study modifies the existing model and demonstrates some sensitivity model results. Overall, the manuscript is written well and focused. I find two deficiencies with the manuscript: 1) there is no comparison to observations, and thus no evidence that the new model is actually better than the original; and 2) the results are merely presented and there is very little explanation of why the results are different. Since the study is presented as a sensitivity study, there is no need to address 1), though it would be nice to see some verification.

Answer:

For point 1): This paper deals with the physical parameterization of the soil thermodynamics. When focusing on an individual process and because of error compensation, the comparison with observations can be misleading for the evaluation of the improvements. For this reason and as the reviewer noticed, we choose to present the results as a sensitivity study; in this case the improvements are reflected by increasing the realism of the model with respect to the soil thermal properties (taking into account both soil texture and soil moisture effects), the soil vertical discretization (consistent between water and temperature), and the soil heat transfer process (coupled heat conduction and convection).

For point 2): This is addressed in the Specific Comment 1 of the reviewer as well. Our response is detailed hereafter

Specific Comments

Comment 1. *Most of the analysis does not have a sufficient amount of explanation of results. For example, p10 L17 states the model modification effect on Brazil. Why do these changes occur there and nowhere else? What contributes to the changes there? I had these questions throughout sections 3 and 4.*

Answer: The explanations of results are going to add in **Sections 3.2, 3.3, 3.4 and 4**. They correspond to the following **part (1), (2), (3) and (4)**, respectively.

(1) Section 3.2 The soil vertical discretization and soil depth with constant soil thermal properties

Page 8421 (Lines 21-25) in 'gmdd-8-8411-2015.pdf': The impact of soil vertical discretization on the surface temperature and on the turbulent fluxes is almost negligible everywhere except over very humid regions such as Brazil where the differences can reach 0.5–1 K for the temperature (Fig. 5c and d) and 10–15 Wm^{-2} for the turbulent fluxes (Fig. 5e–h). One possible cause for this difference could be the insufficient soil depth in EXP_{5m} (5 m for temperature) for simulating the soil temperature annual cycles. Another possible contribution comes from the increase of total runoff ($R_{OFF,\ TOT}$, the sum of surface runoff and deep drainage) over tropical humid regions (see Fig. R2 (k and l) below) for EXP_{5m} (2M11L for moisture) due to the slightly change of hydraulic conductivity vertical profile (Fig. R1 (a) below). The hydraulic conductivity at surface for EXP_{5m} is smaller than EXP_{8m}, and it prevents more water to penetrate into the soil. At bottom layer, the hydraulic conductivity for EXP_{5m} (at 2m) is higher than EXP_{8m} (at 8m), and it generates more drainage in EXP_{5m}. This variation also induces a decrease of soil moisture (e.g., at 1st layer, Fig. R2 (m and n)) in EXP_{5m} comparing with EXP_{8m}. The near-surface air humidity is also decreased over these regions (Fig. R2 (o and p)) following the change of surface moisture, and it corresponds to smaller precipitation and evaporation in EXP_{5m} than in EXP_{8m} (Fig. R2 (q and r)). Previous studies also find that the deeper soil depth leads to a higher soil moisture (Decharme et al., 2013). In Brazil and central Africa, there are more intense rain events, and the impact is larger over these regions.

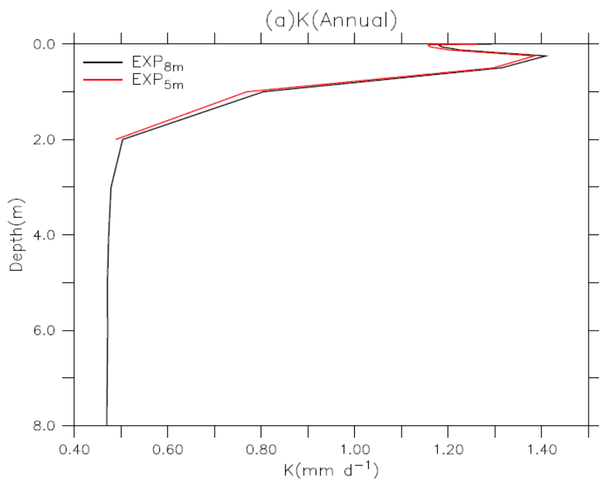

Figure R1. The annual mean vertical profile of hydraulic conductivity (K) averaged over (50W-70W, 5S-20S) for EXP_{8m} (black) and EXP_{5m} (red).

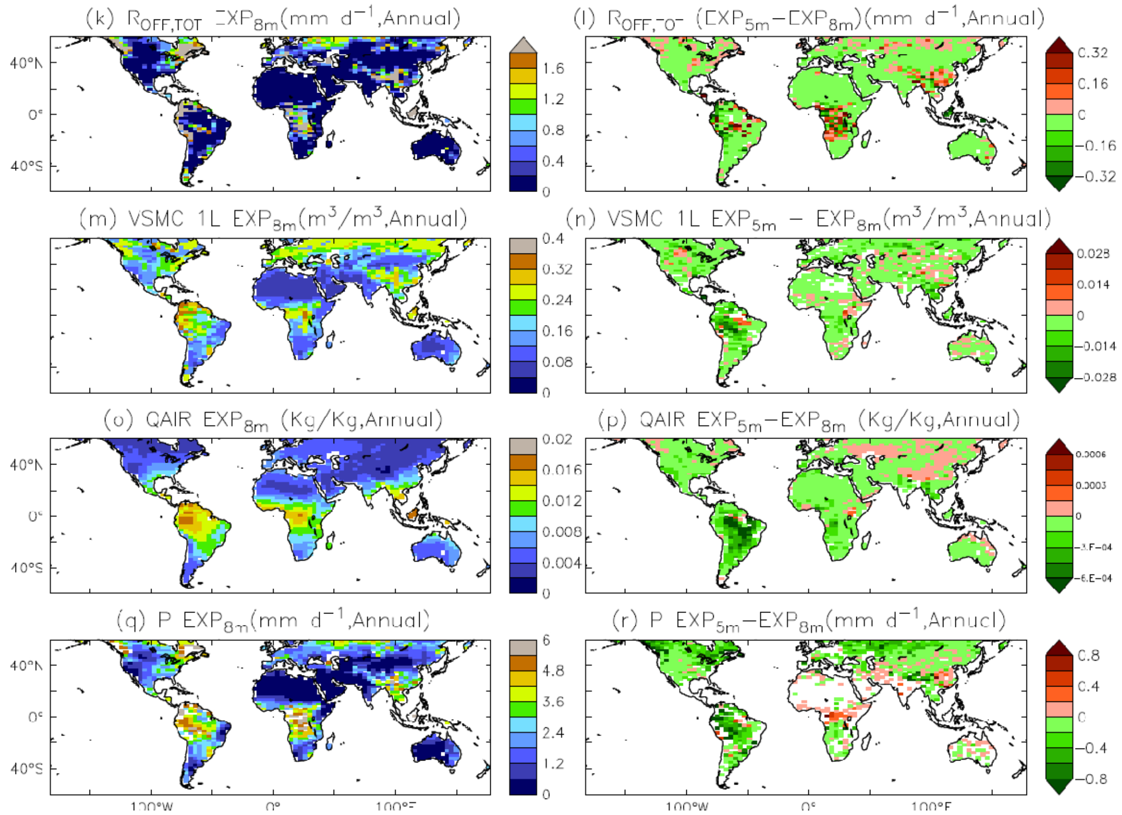

Figure R2. Same as Fig. 5 in old manuscript, but for total runoff (k, l), volumetric soil moisture at top layer (m, n), air humidity (o, p), and precipitation (q, r). The Figs. k, l, q, and r are going to add to the revised manuscript.

(2) Section 3.3 The effects of the rainfall heat flux at the surface

Page 8422 (Lines 15-20): Figure 7a shows the 20 year annual mean rain water flux ($q_{L,0}$ in Eq. 3) at the surface. This flux is maximum in tropical regions (approximately 3-5 mm d^{-1}) because of the higher rainfall in these regions, corresponding to -0.5 to -0.75 Wm^{-2} rainwater heat flux (H_1 in Eqs. 2 and 3; H_1 depends on $q_{L,0}$ and the temperature gradient of rainfall and surface). The overall effect on the temperature is very weak and results in a slight cooling (less than 0.3 K, Fig. 7d) because the rainfall is colder than the soil surface (Fig. 7b). The negative H_1 reduces the net energy at surface, and the surface temperature decreases based on surface energy budget (Eq. 2).

(3) Section 3.4 Evaluation of the full soil thermodynamics scheme

Page 8423 (Lines 1-18): The soil thermal conductivity, soil heat capacity, and soil thermal inertia decrease (increase, respectively) over arid (humid, respectively) regions as a result of the texture and the moisture dependence of the soil thermal property (Fig. 8a–c). The soil thermal property in EXP_{8m} (1.329 $Wm^{-1}K^{-1}$ and 2.135 $Jm^{-3}K^{-1}$) is obtained from an averaged moisture (0.21 m^3m^{-3}). The wetter (drier) the regions are, the larger the increase (decrease) of soil thermal property for $EXP_{8m,LT,TP}$. A lower thermal inertia corresponds to lower heat storage ability in the soil. The soil heat diffusivity decreases over the whole globe with large decreases over arid areas such as Sahara, west Australia, South Africa and South America (Fig. 8d). The downwards energy transport from the heated surface during the day is slower with a smaller heat diffusivity, but less heat is transferred towards the surface to compensate the radiative cooling during the night. However, the effect is larger during the night than during the day: the daily maximum air temperature increases by ~0-1 K (Fig. 8g and h) while the daily minimum air temperature decreases by ~1-5 K over more than 50% of the regions (Fig. 8i and j), resulting in a net cooling. This is mainly because the turbulent transfer is stronger during the day than during the night, and the impacts on daily maximum temperature are compensated by the turbulent flux. These results were analyzed by ~~Kumar et al. (2014) and~~ Ait Mesbah et al. (2015). From the energy point of view, the surface cooling induces a net radiation increase due to a decreased radiative cooling (Fig. 8k and l). This net radiation increase is compensated by an increased sensible heat flux (Fig. 8m and n). The effect of the soil thermal properties is stronger during the dry season over the Sahara (20–35°E, 10–35°N, not shown). Both the soil heat capacity and thermal conductivity decrease over the Sahara region due to the low soil moisture (see Figure 1). [‘Kumar et al. (2014)’ is going to be deleted.]

(4) Section 4 The impact of the soil thermodynamics on the temperature variability

Page 8423 (Lines 21-27) and Page 8424 (Lines 1-4): The new soil thermodynamics induces an overall increase of the mean Diurnal Temperature Range (DTR, the difference between the daily maximum temperature and the daily minimum temperature) and the intra-annual Extreme Temperature Range (ETR, the difference between the highest temperature of one year and the lowest temperature of the same year) due to an increase of daily maximum temperature and a decrease of daily minimum temperature (Fig. 8h and j). DTR increases by 1 to 3K over ~60% of the regions and 4 K over 5% of the regions (Fig. 9a and b) and ETR increases by 1–4 K over ~60% of the regions and 5–6 K over 8% of the regions (Fig. 9c and d), respectively. The impact of the new soil thermodynamics is strong over arid and semi-arid areas (due to the change of soil thermal property by soil moisture and soil texture effects) but also over mid-latitude regions such as the Central North America and in particular over the South Great Plains, where the soil-moisture/atmosphere coupling plays a significant role (Koster et al., 2004).

Comment 2. *The bulk water budget terms should be more of a focus. For example, Fig 5 shows several regions that have >5W/m^2 differences. If I'm reading this figure correctly, that equates to 50 – 100 mm of water that is being shifted from one part of the water budget to another. That is a significant amount. Where is that water coming from or going to? Similarly, I think latent heat flux is more important to include in Fig. 7 and 8 than say T_s or $R_{lw,up}$ (which is basically the same at T_s in Fig 8).*

Answer:

(1) The change of total runoff, the insufficient depth for modeling soil temperature annual cycles, as well as the stronger rainfall intensity over tropical regions could be the causes for the difference (>5W/m^2) in **Figure 5** (please see 'Answer (1)' for 'Specific Comment 1' above).

(2) Figure 7: The 'Latent heat flux' was checked (see Fig. R3 below). Its variation is not significant, so this variable is not included in Figure 7 in the manuscript.

Latent heat flux $EXP_{8m,LT}$ - EXP_{8m} (W m^{-2} Annual mean)

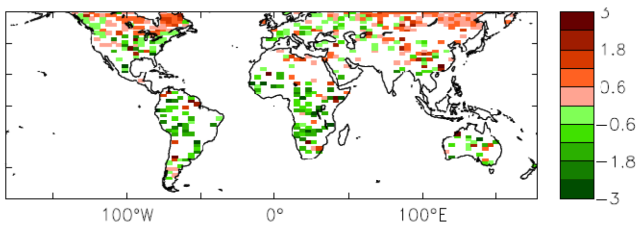

Figure R3. The same as Figure 7 in old manuscript, but for the difference of latent heat flux between $EXP_{8m,LT}$ and EXP_{8m}.

(3) Figure 8: The '*Rlw,up*' (Fig. 8k and l in old manuscript) is going to remove. The figure for 'Latent heat flux' is going to add (see Fig. R4 below). The following explanations are going to add to **Section 3.4** in the revised manuscript: The change in latent heat flux (around +/- 2 W m^{-2}) is much less than sensible heat flux (around +/- 6 W m^{-2}) for most regions. This is reasonable because the moisture between the two experiments does not change significantly (both experiments use 8M17L discretization), thus the variation of latent heat flux (water cycle) is small.

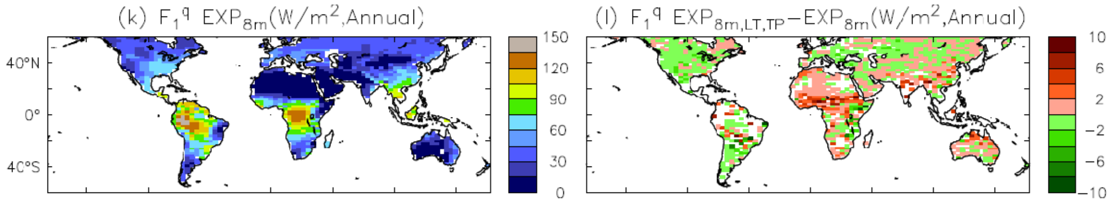

Figure R4. The same as Fig. 8 in old manuscript, but for latent heat flux (F_1^q). These two figures are going to add to Fig. 8 (Fig. 8k and l) in revised manuscript. (Meanwhile, remove '*Rlw,up*' in Fig. 8k and l in old manuscript).

Comment 3. *p13L7: Explain what ITV and ITnV are and what the magnitude of the changes in these values mean before you state the values to give the reader some context in these somewhat abstract terms.*

Answer: The explanations for *ITV and ITnV* are going to add (see below).

[Section 4] Page 8424 (Lines 11-14): In order to understand if and how it varies with the soil thermodynamics, the inter-diurnal temperature variability (Kim et al., 2013) of the daily mean (ITV) and of the minimum temperature (IT_NV) are evaluated for the control experiment and for the experiment with the full soil scheme. The ITV is calculated by averaging absolute inter-diurnal daily mean temperature T_{2m} differences over n_d days (n_d is the number of days over 20 years), and IT_NV is calculated by averaging daily minimum temperature $T_{2m,min}$ in the same way.

$$\mathrm{ITV} = \frac{1}{n_d-1}\sum_{i=1}^{n_d-1}\left|T_{2m,i+1} - T_{2m,i}\right| \quad (17)$$

$$\mathrm{IT}_N\mathrm{V} = \frac{1}{n_d-1}\sum_{i=1}^{n_d-1}\left|T_{2m,min,i+1} - T_{2m,min,i}\right| \quad (18)$$

Unlike the measures of mean climate variability, these variables capture the chronological sequence of the variable change throughout the whole period [Kim et al., 2013]. The larger the ITV (IT_NV) is, the larger the difference of daily variable between two consecutive days.

Comment 4. *The figures/captions need some clarity. The lines are labeled in the figures but the labels are not explained in the caption. This happens many times. For example, what are all the lines in Figure 4? I can guess what 90D, 270D, etc. are but they should be explicitly described in the caption.*

Answer: Figure captions to be revised for **Figures 1, 3, 4, 6, and 10** as below.

Figure 1. The variation of **(a)** soil thermal conductivity λ and **(b)** soil heat capacity C_P with volumetric soil moisture for different soil textures (coarse, medium, fine) by

using ORCHIDEE standard parameterization (black line) and the revised parameterization (λ is revised by using J75 method, and C_P is revised by using P02 data). The coarse, medium and fine soil are shown in blue, red and green lines, respectively.

Figure 3. The variation of required soil depth for simulating annual cycles of soil temperature/heat flux with volumetric soil moisture **(a)**, and the variation of soil temperature/heat flux amplitude decaying ratio with soil layers **(b)** for different soil textures: coarse (COA), medium (MED) and fine (FIN). The soil heat convection by liquid water transport (8.64mmd^{-1}) is considered in "*L*" (dashed line), and it is excluded in "*NL*" (solid line). The black, red and blue lines represent coarse, medium and fine soils, respectively.

Figure 4. The comparison of daily soil temperature (*T* , **a** and **b**) and soil heat flux (*G*, **c** and **d**) between analytical method (AM) and finite difference method (FDM) for soil heat conduction-convection model by using 8M17L discretization with liquid water flux q_L = 1E-7m s^{-1} (8.6mm d^{-1}): time serials **(a**, **c)** and vertical profiles **(b**, **d)**. The black lines and red lines in (a) plot the values at the first layer (1L) and at the 17th layer (17L), respectively. The black lines and red lines in (c) plot the values at the surface (0L) and at the 16th layer (16L), respectively. The symbol '△', '○', '＋', '□' in (b) and (d) correspond to AM values at 90th day (90D), 270th day (270D), 180th day (180D), and 360th day (360D), respectively. The different lines '———', '– – – – –', '---------' and '— — —' in (b) and (d) correspond to FDM values at 90D, 270D, 180D and 360D, respectively.

Figure 6. The vertical profiles of soil temperature in MAM **(a)**, JJA **(b)**, SON **(c)** and DJF **(d)** over South Africa (50–70° W, 5–20°S) for 8M17L (EXP_{8m}, black line) and 5M7L (EXP_{5m}, red line) vertical discretizations.

Figure 10. The probability density function (PDF) for DTR (1 column) and IT_NV (2 column), and the box plot of DTR (3 column) and IT_NV (4 column) over the Sahara (1 line), the Sahel (2 line), the central US (3 line) and north China (4 line) between $EXP_{8m,LT,TP}$ (in yellow) and EXP_{8m} (in blue) with daily values. The grid point value is weighted by its areas. In the box plot, the red central mark and the blue dot are the median and mean, and the edges of the box and the 25 and 75 percentiles. The whiskers extend to the most extreme data points not considered outliers. Points are drawn as outliers if they are larger than $X_{25th}+3\cdot(X_{75th}-X_{25th})$ or smaller than $X_{25th}-3\cdot(X_{75th} -X_{25th})$, where X_{25th} and X_{75th} are the 25 and 75 percentiles respectively. The red diamond and the values are the 99 and 1 percentiles. The percentage (%,

dSTD, dSkewness in PDF; values in brackets in box plot) measures the difference between the two simulations: $(EXP_{8m,LT,TP}-EXP_{8m})/EXP_{8m}\cdot 100\%$.

Technical Corrections

Comment 1. *Most of the manuscript reads very well. I suggest a re-read of the introduction section. I suggest changing LSM to mean 'Land Surface Model' and refer to the plural as LSMs. This will read better and not conflict with the later use of LSM, i.e., ORCHIDEE LSM.*

Answer: We re-read the 'Introduction'. Following modifications are to be done in the revised manuscript.

(1) Change 'LSM' to 'LSMs' in **Page 8412 (Lines 23-24), Page 8413 (Lines 5, 8, 14, and 23)**.

(2) Page 8413 (Lines 8-10): 'However, the location of the lower boundary in LSM used in climate models with identical heat transfer processes ranges from 2 to 10m (Anderson et al., 2004; Table 1)'. [change 'and describing' to 'with'].

(3) Page 8413 (Lines 14-16): 'Several studies investigated the influence of this process on the land-surface variables based on 1-D experiments based on site observations (e.g. Kollet et al., 2009).' [change 'parameters' to 'variables'].

Comment 2. *In Table 1, the Noah LSM should not have Niu et al. (2011) as a reference. A more appropriate reference is Ek et al. (2003).*

Answer: Niu et al. (2011) **to be replaced by** Ek et al. (2003) in Table 1 in the revised manuscript.

Ek, M. B., Mitchell, K. E., Lin, Y., Rogers, E., Grunmann, P., Koren, V., Gayno, G., and Tarpley, J. D.: Implementation of Noah land surface model advances in the National Centers for Environmental Prediction operational mesoscale Eta model, J. Geophys. Res., 108(D22), 8851, doi:10.1029/2002JD003296, 2003.