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Earth System Dynamics Discussions

Interactive comment on "A theoretical approach to assess soil moisture–climate coupling across CMIP5 and GLACE-CMIP5 experiments" *by* Clemens Schwingshackl et al.

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We thank the reviewer for the valuable comments. In the following we explain how we implemented them. You find our answers in italic.

General Comment:

This paper is essentially technical. It aims at evaluating the soil moisture/temperature coupling accross CMIP5 and GLACE-CMIP5 simulations. It compares two ways of estimating the sensitivity of evaporative fraction and daily

maximum temperature to soil moisture. The success of the comparison in numerous regions is an indication that the methodology recently described by the same authors in the Journal of Climate (2017) can be used to evaluate the sensitivity of evaporative fraction and temperature to soil moisture variations in a changing climate directly from the CMIP6 outputs. However, since the data from only 4 (out of 6) of the models which contributed to the GLACE-CMIP5 experiment are analysed, it will be interesting to verify that the results are confirmed with the forthcoming LS3MIP data which are part of the CMIP6/Deck and should include a larger number of models. From the process analysis point of view the analysis misses a thorough investigation of the discrepancies in the sensitivities; for instance, for Central Europe, the analyis could have brought additional evidence for the non-local processes possibly involved in the SM-temperature coupling, the Sahel would have deserved a more in-depth analysis as well.

The regions with the highest differences between the experiment- and sensitivity-based estimates are central Asia and central North America. In both regions, the experiment-based effect on TX (i.e., δTX_θ) is stronger than the sensitivity-based effect. The reason for this difference is that the sensitivity-based estimates underestimate the effect on EF. To highlight this mechanism, we are going to include another row in Figures 3 and 4 where we show the effect on EF (δEF_θ) caused by the mean soil moisture shift between Clim20C and CTL (see Figure 1 below).

The underestimation of EF in central Asia and central North America depends on the considered soil depth: while the sensitivity-based estimates show an increase of δEF_θ when using total soil moisture, they reveal a decrease when using surface soil moisture (see Fig. 2 below). This points to a decoupling of surface and total soil moisture, as was described by Berg et al. (2017). Because the affected regions in central Asia and central North America are mostly covered with grassland and shrub land, evaporation is more influenced by the evolution of surface soil moisture than by the evolution of total soil moisture. Consequently, surface soil moisture is the controlling factor for EF *in these regions.*

For the Sahel region, both the experiment- and sensitivity-based estimates show a strong sensitivity of EF to soil moisture, but almost no absolute effect on EF and TX. The reason for this is that soil moisture changes only slightly between CTL and Clim20C in the Sahel region and, thus, there is only a small effect on EF and TX.

In central Europe, the discrepancies are mostly evident for extreme temperatures, especially for TX_x. The reason for this could either be secondary feedbacks (as we mention in the manuscript) or in the construction of the EF(θ) framework. If a region lies mainly in the wet regime and enters the transitional regime only rarely, the regime classification might not be sensitive enough to distinguish the transitional regime from the wet one and the transitional regime could thus be missed. Consequently, the strong soil moisture effect on TX_x in the transitional regime would not be captured adequately.

In our manuscript, we are going to include another row in Figures 3 and 4 where we show the effect on EF (δEF_θ). Moreover, we are going to add Fig. 2 (see below) that shows the sensitivity-based estimates when using surface soil moisture instead of total column soil moisture for GLACE-CMIP5 to the supplementary information.

Specific comments:

- Which data were missing in the 2 GLACE-CMIP5 models discarted?

The missing data are:

- *for IPSL daily soil moisture and daily net radiation for all 3 experiments*
- *for CESM daily soil moisture for all 3 experiments; daily latent and sensible heat fluxes for CTL*

We are going to include this information in a footnote in Supplementary Table S1.

- It would help the reader if the various experiments and various "key measures" tested were summarized in a table.

To make the overview of the three experiments clearer, we are going to show them as bullet points in a list in the text. Moreover, we are going to provide a table with an overview about the key measures that we use.

- The sensitivity is evaluated according to the total soil moisture (which is the soil moisture variable used in GLACE-CMIP5) however did the authors try to evaluate the sensitivity to the superficial soil moisture (mrsos in the CMIP5 datasets)? If so, how the sensitivities compare with the sensitivities based on the total soil moisture?

We performed the same analysis for the GLACE-CMIP5 models using surface soil moisture instead of total soil moisture (note that for the analysis of surface soil moisture only 3 models are left because there is no daily surface soil moisture available for MPI-ESM). Generally, we find similar patterns as for total soil moisture (see Fig. 2 below), although the sensitivities of EF and TX to soil moisture changes are stronger when using surface soil moisture. The absolute effects on EF and TX are very similar for both total and surface soil moisture. As described above, in certain regions the usage of surface soil moisture gives results closer to the experiment-based estimates. This is very likely caused by the decoupling of surface and total soil moisture trends in these regions (see Berg et al., 2017).

The effects on $\delta TX_{\theta_{Q1}}$ are stronger when considering surface soil moisture instead of total soil moisture. This is caused by the stronger drying of the uppermost soil (compared to the total soil) in CTL (see Berg et al. 2017). Hence, the difference between the lowermost soil moisture distribution percentiles between CTL and Clim20C is much larger for surface soil moisture than for total soil moisture. Yet, the effects on $\delta TX_{\theta_{Q1}}$ from total soil moisture should be more reliable than the ones from surface *soil moisture: on the one hand, soil moisture in the GLACE-CMIP5 experiments is prescribed in the total soil column (and not only in the surface layer) and on the other hand, in many regions evapotranspiration does not only depend on the surface soil moisture, but on soil moisture in the deeper soil layers as well.*

- Could the authors add grid boxes delineating the regions discussed in Figure 6 at least on one maps (may be in figure 2)?

Thank you for this suggestion. We are going to show the regions in Figure 5 because it is the one with the closest link to Figures 6 and 7.

- p.9 l. 8 What "latitudinal corrected" means?

We are going to replace it by "area-weighted global average", which is the correct term for the area-correction that we applied.

- Section 4.3. It is not clear to me how figure 1b supports the sentence "This can be explained by 2) the lower tails of the soil moisture distribution show a particular strong shift ".

If you consider Figure 1b, you can see that the variability of CTL is much larger than the variability of Clim20C. Because of this the differences between the mean of CTL and the mean of Clim20C is lower than the difference between the 1st percentile of CTL and the 1st percentile of Clim20C. This is essentially due to the construction of Clim20C, which does not allow any soil moisture values outside of the 1971-2000 climatology.

We are going to state this in the manuscript as: "This can be explained by two reasons: [. . .] 2) the lower tails of the soil moisture distribution show a stronger shift between CTL and Clim20C than the means of the distribution (this is essentially caused by the construction of Clim20C that does not allow for any soil moisture values outside of the 1971-2000 climatology, see Figure 1b)"

- p 12 line 26 In Discussion misture instead of moisture.

We corrected it.

- When discussing the impact of the soil moisture on the daily temperature it could be worthwhile to mention that in addition to its impact through the latent heat, it has an impact through the thermal heat transfer via its impact on the soil thermal properties (e.g. Cheruy et al." JAMES 2017).

Yes, indeed soil moisture also affects the thermal properties of the soil and can influence near-surface air temperatures through this process. We are going to mention the possible effects of this process in our discussion section.

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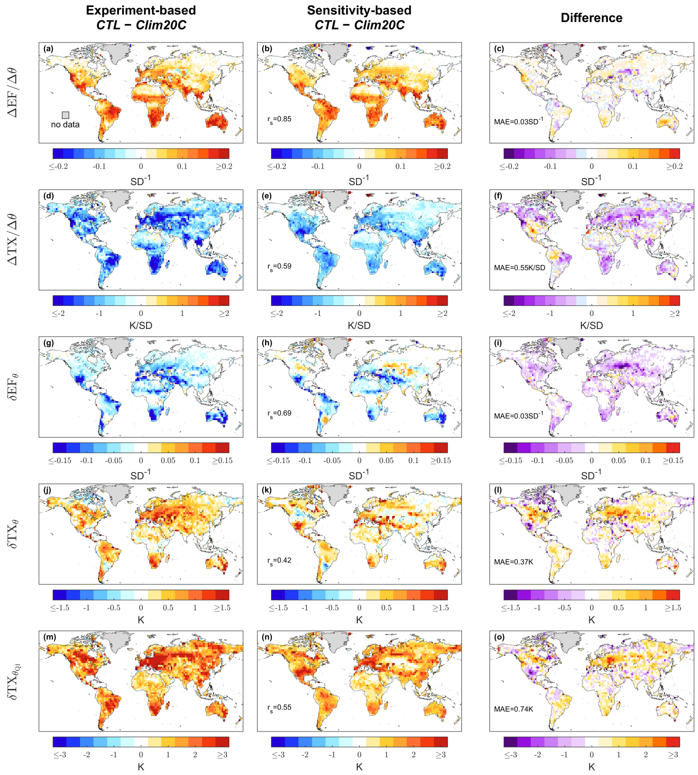

Fig. 1. As Figure 3 in the manuscript but with an additional row showing the absolute effect of the soil moisture shift between Clim20C and CTL on EF (delta EF_theta).

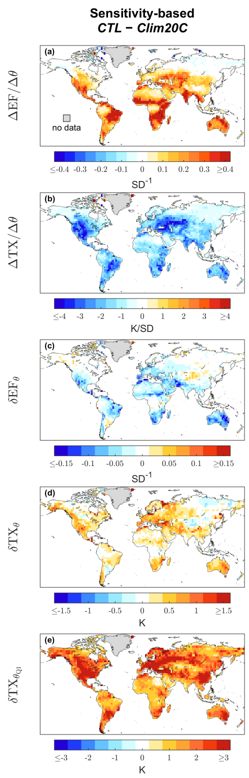

Fig. 2. As Fig. 1 (central column) but using surface soil moisture instead of total column soil moisture. Note that only 3 models are included here, since there is no daily surface soil moisture available