# Response to Reviewer 1 for "Investigating soil moisture-climate interactions with prescribed soil moisture experiments: an assessment with the Community Earth System Model (version 1.2)"

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We are thankful to the reviewers for their positive comments and their feedback, which helped us to improve the manuscript. We added the following main changes to the revised manuscript:

- Simulations with a new methodology to prescribe soil moisture, and its discussion. The new methodology prescribes soil water and ice but lets the model determine the relative proportions of the two components (PRES_FRAC).
- A more thorough discussion of the skewed soil moisture distribution, and the temperature response to the soil moisture prescription
- All figures were enlarged. Some figures were updated to include the new prescription method (Figure 1, Figure S4, and Figure S5). Figure 2 was enhanced to include time series of soil moisture for a whole year for an example grid point. Figure S9 was moved to the main text and is now Figure 6. Figure S6 and Figure S7 were removed to reduce the number of figures in the supplementary material. We added a new Figure S6 to show the ground heat flux anomalies for all seven simulations.
- Some minor adaptations to the manuscript text.

## Reviewer 1 (Bart van den Hurk)

General remarks
This manuscript carries out a timely analysis of the consequences of perturbing the land surface soil moisture budget as carried out in earlier experiments and proposed in LS3MIP. It compares various methodologies (with/without ice, with/without prescribing shallow top layer, using mean/median), concluding that the use of the median liquid is a more conservative method than when using means and including ice. It is well written and addresses an outstanding issue, and is thus worth publishing subject to some minor comments.

**A1:** We thank the reviewer for the encouraging comments.

P4, L4-L8: the algorithm uses a soil temperature threshold of zero degrees to trace the occurrence of soil ice. However, algorithms exist that allow a gradual fraction of soil water to be frozen in between a temperature range that may well include temperatures exceeding 0 degrees. How to deal with these parameterizations?

**A2:** The important part of the new algorithm is to not artificially add (or remove) soil ice. We recommend stopping the prescription as soon as ice appears in the soil, even if the temperature is larger than 0° C. We added this point to the manuscript on P4 L8:
The important characteristic of this new algorithm is that it never artificially adds ICE (see Section 3.2.2). Although (supercooled) LIQ and ICE can coexist in CLM4, we leave the soil hydrology entirely interactive below the freezing temperature.

And in Table 2 (Prescribing soil ice):
To prevent such anomalies the soil moisture prescription should be stopped as soon as the soil reaches freezing temperature.

P4, L23: when is there "too much variability"?

**A3:** We have not considered sub-daily soil moisture variations (or the effect thereof) and we have rephrased this paragraph to reflect this on P4 L26:
In this study we use daily mean values as linearly-interpolated monthly values can be too coarse (see below).

P5, L18: it may be worth spending a few words explaining (or speculating) why the soil moisture distribution shows a negative skewness and a median lower than a mean. Is it because soil moisture is more persistent in drier conditions due to lower values of hydraulic exchange coefficients? Or is there another reason behind this asymmetry?

**A4:** We added a new paragraph discussing the skewed distribution of SM on P5 L15:
In the dry season the median is generally smaller than the mean, with large rainfall events leading to outliers on the wet end of the distribution. For example on the 5th of April (Figure 2b), the difference is -2.3 mm, or -14.0%. During the wet period the median is usually larger than the mean, here it is dry years that lead to the asymmetry. However, the difference between median and mean are generally smaller, on the 21st of December, for example, (Figure 2c) it is 1.0 mm, or 3.8%. There are many processes that contribute to non-symmetric SM distributions: the positive skewed distribution of precipitation, the upper and lower bound in the water holding capacity of the soil (between the wilting point and saturation), as well as the strong nonlinear function of water flow (hydraulic conductivity) within the soil with respect to the SM state (Laio et al., 2001).

P5, L28: it's not the strength of the seasonality that is at play hear, but the occurrence of a short sharp peak in that climatology, that causes these rounding errors

**A5:** We rewrote the sentence on P6, L9:
True daily and interpolated monthly SM values can differ in regions with a short sharp peak in the seasonal cycle, as exemplified for a grid point in Central Africa (Figure 3a).

P6, L16: suggest to add "when comparing the median to the mean" at the end of this sentence.

**A6:** We added this to the sentence on P6, L25:
PRES_LIQ_MEDIAN has smaller temperature anomalies than RES_LIQ_MEAN, corresponding to the regions with smaller climatological SM when comparing the median to the mean (Figure 2).

P6, L17: the fact that the results in 2070-2099 are similar is surprising. You are not comparing the REF temperature in 1970-1999 to the simulated temperature by the end of the century I presume (otherwise we should have seen a major climate change signal). But also the GLACE-CMIP5 exp by Seneviratne et al (2013) did show an effect on net warming when prescribing climatological soil moisture. Why is this effect gone in this set-up?

**A7:** It is correct that we compare EXP - REF for 2070 to 2099 (where EXP is one of the experiments with prescribed SM).

The largest part of the global mean temperature signal is lost by not prescribing ICE. A second reason comes from taking the median in time instead of the mean (as in Seneviratne et al., 2013). For example for “PRES_LIQ_MEAN - REF”, the median for “2070 to 2099” minus “1971 to 2000” is -0.04° C (which is lost in the Figure title due to truncation), while for the mean it is -0.16 °C. In GLACE-CMIP5 the difference in warming for “EXPA – CTL” for the global land is -0.38 °C for the multi model mean, and -0.81 °C, -0.35 °C, -0.16 °C, -0.34 °C, -0.25 °C for CESM, EC-EARTH, ECHAM, GFDL, and IPSL. Thus, PRES_LIQ_MEAN is in the range of GLACE-CMIP5 models.

We addressed both points on P6, L27:
We find similar results when comparing the experiments to REF for the time period 2070 to 2099 (Figure S3 a to c). Thus, the global land warming between 1971 to 2000 and 2070 to 2099 is only slightly larger in REF than the experiments. This is in line with earlier findings (Seneviratne et al., 2013), although experiments in this study are at the lower end of the range of GLACE-CMIP5 models.

P7, L11: Koster et al (2004, 2006) did evaluate all perturbations under present climate conditions, which makes the effect of changing frozen soil water also smaller than in climate change set-ups.

**A8**: This is correct; we included this information on P7, L24:
In the GLACE experiments Koster et al. (2004) simulate a summer in the current climate, which reduces the influence of prescribing ICE.

P7, L18: I misread this sentence a few times. I would make the statement of 650 mm/yr for the addition of SM first, and then state that a similar amount is associated with removals of soil water. Now it looks like 650 mm/yr is the net effect.

**A9**: We rewrote the sentence as suggested on P8, L8:
During 1971 to 2000, the average amount of added SM (over the whole soil column) is about 650 mm year-1 (not shown). This is about three quarters of the global land mean precipitation in REF. However, a similar amount of SM is removed and the net water balance perturbation is much smaller because positive and negative perturbations largely compensate when integrated over the entire soil column.

Figures: they are generally pretty small, and stippling is difficult to see.

**A10**: We updated the figures.