Response to reviewers

We are delighted to read that the reviewers appreciate the content and presentation of our study. We are thankful for their comments and suggestions. We will address them and include the corresponding modifications in an updated version of the manuscript.

Second review

General Comments

In this study, the authors have investigated the relative contribution of observation based ecological, hydrological and meteorological variables in explaining weekly temperature forecast errors in the ECMWF Subseasonal to Seasonal (S2S) reforecasts during 2000-2017, using lead times of 1-6 weeks. Temperature forecast errors are found to be most strongly affected by climate related variables such as surface solar radiation and precipitation. However, vegetation greenness and soil moisture are found to be relevant for central Europe, eastern North America and southeastern Asia. Authors claim that the relationships between forecast errors and independent Earth observations reveal new variables on which future forecasting system development could focus by considering related process representations in detail and data assimilation, to improve subseasonal to seasonal forecasts.

The paper is well-written, lucid and enjoyable and could be a valuable contribution to subseasonal to seasonal scale research. I have a few comments which may be noted below.

We appreciate the positive comments and constructive feedback from the reviewer. We think that the quality of our manuscript has significantly improved after addressing the reviewer's comments.

Specific comments

- Why was annual mean temperature considered in the computation of the metric? It is possible that the forecasts and the observations have different annual cycles in a year as well as different interannual variability; so that would add additional biases while computing the weekly forecast errors.

  B1. We thank the reviewer for raising this point, which was also mentioned by reviewer #1. In response, we introduce a modification in the forecast error metric: we use weekly climatologies based on the 2001-2017 period instead of the annual averages to account for potentially different seasonal cycles in forecasts and observations.

- The areas in Figure 3 either have proximity to the ocean or are inland, and the results based on these small areas have been generalized for these six regions. I wonder, how much does the position of the selected areas affect the relative influence of climate, circulation and land surface variables on temperature forecast errors?

B2. The selected regions (black squares in Figure 3) are case studies to further understand the relationships between the forecast errors and the most relevant variable within those regions; we chose the regions based on the most relevant variables, not based on their geographical locations. We expect a strong influence of the positions of the regions in our results of the most relevant Earth system variables, therefore we do not want to imply with our results that the results can be generalised to the whole continent where each region is located. We apologise for the confusion; To avoid any confusion, we will change the name of the regions following the variable of interest instead of the continent they are located.

- If we compare Figure A4 and the global "hot-spots" of land-atmosphere coupling (Koster et al. 2004), it is surprising that in JJA, surface and deep layer soil moisture do not turn out to be the most relevant Earth system variables for temperature forecast errors over Africa, NA and India. Rather, climate and circulation related variables appear to have a greater impact. I wonder if this is due to some deficiencies in the land surface scheme, land-atmosphere coupling or some other factor?

  B3. This is a very good point. We can expect that during this season of strong land-atmosphere coupling in these regions, soil moisture variables would be particularly relevant for forecast errors. While not shown in Figure A4 as the most relevant variable, the land surface variables are still related to temperature forecast errors in JJA across Africa, North America and India even though not always as the most relevant variable (Figure 5). Furthermore, if soil moisture is not the most relevant driver for forecast errors in those regions during JJA, it might be because the land surface scheme is either very good (and it can not be further improved) or the climate and circulation variables are comparatively less well assimilated/represented. This way, we think that other climatic processes related with precipitation, for instance cloud formation and the migration of the intertropical convergence zone (ITCZ) may be more relevant for forecast errors in those regions during the rainy season (JJA). We will clarify these points in the manuscript in section 3.2.

- The memory of surface soil moisture anomalies is much less (except in arid, forested and snow-covered regions) compared to that of the root zone and is certainly lower than the lead time of 3 weeks considered for temperature forecasts. However surface soil moisture turns out to be the relevant variable for temperature forecast errors than deeper layer soil moisture. What is the reason?

  B4. Surface soil moisture affects evaporation from soils as well as the transpiration from short vegetation which lacks deep-reaching roots. Through these pathways it can have a significant impact on the surface energy balance and hence temperature. Furthermore, surface soil moisture typically exhibits a larger variability compared with deeper soil moisture which can also lead to stronger impacts on temperature.

  In dense forest regions we expect that the deep soil moisture has a stronger effect in temperature forecast errors than the surface soil moisture because their rooting systems are more suitable to extract water from the deepest layers. Nevertheless, as seen in Figures 2 and 3, there are no results in a large fraction of the grid cells located in rainforests probably due to the low density of temperature observations. This can explain why in Table 3 we see a small fraction of grid cells where deep soil moisture is the most relevant driver for forecast errors.

We will clarify these points in the manuscript in section 3.3 and section 4.

- In the South Asian summer monsoon region the atmosphere depicts significant ‘internal’ low-frequency variability that could be generated due to various factors such as non-linear scale interactions, the distribution of orography, land and ocean and their interaction with wind flow etc. How much does this factor affect the evolution of temperature forecasts errors over the SA region in JJA?

  B5. Did the reviewer mean the AS region instead of the SA region? In that case, we agree with the reviewer that this region is characterised by a complex topography and by the presence of nonlinear processes due to the summer monsoon that make it difficult to predict temperature, especially at the subseasonal level. Besides, and probably because of the complex topography (especially in the northernmost part of the region), there is not enough data assimilation in the forecasting system to accurately constrain the initial conditions of the forecasting model, which further increases the errors. Nevertheless, this region does not particularly show strong forecast errors like other regions (Figures 2 and 7), probably due to a good representation of the monsoon onset and magnitude within the forecasting system, which provides most of the predictability for temperature in this region.

References

Koster R. D. and Co-authors (2004), Regions of strong coupling between soil moisture and precipitation, *Science*, 305, 1138-1140.