Community Comments

1. The authors need to reappraise their motive of this study, because NOAA and NCEP soil moisture (SM) products (a spatial resolution of 2 degrees) are usually not qualified for hydro-meteorological studies (flood or drought as reviewed by Peng et al. 2020, in Remote Sensing of Environment) in mainland China. As pointed out by the other reviewer, such coarse spatial resolutions would cause representativeness errors. Although spatial averaging to some extent can alleviate such an effect, I still think errors of representativeness (together with differences in effective soil depth) might contribute substantially to the bias values. That is probably the reason why CCI (0.25 degrees) and ERA-5 (31 kilometers) have a slightly better performance.

Response: During this revision, the bias error caused by the mismatch of spatial representativeness between in situ data and all SM products has been removed by introducing the unbiased root mean square error (ubRMSE) (see Figure 3, Figure 11 and Table 3). Furthermore, the comparison was conducted at regional scales by calculating the reginal average of monthly value for all SM products, which can reduce the uncertainty caused by grid mismatch to some extent.

2. The presentation of results should be improved. In numerous cases, the authors repeat the overestimation of modelling SM data and the underestimation of remotely sensed SM data.

Response: Thanks for your suggestion, and we have refined the presentation of the results.

Line 237-245: *Generally, most SM products are able to capture the overall spatial distribution of the SM value, although the NOAA SM is highly overestimated all through the region. According to the in situ observations, SM is the lowest in the northwest and increases to the northeast and southeast. Except for NCEP, all the other datasets are able to represent the wet center in the northeast of China. SM is underestimated by ESA CCI, but overestimated for all the analysis datasets, except in Northwest China. In the ERA5 dataset, the region in the north of Northwest China is much drier than the other products, with average value less than 0.05* m^3/m^3*. ERAI and ERA5 SM products are able to represent the decreasing trend from southeast to northwest, which is failed for the NCEP SM. The* *largest biases reaching 0.15 m^3/m^3 are found in southern Northeast China, and the largest inconsistency is found in the northwest.*

Line 257-262: *Generally, all the reanalysis products have positive bias of 0.08~0.15 m3/m3, 0.05~0.10 m^3/m^3, 0.07~0.13 m^3/m^3, and 0.01~0.05 m^3/m^3 in the NE, NC, YH, and NW regions, respectively. ESA CCI tend to have negative bias with observations around -0.06~0 m^3/m^3. All products perform well in the NW region, and the worst performance is found in the NC region. ERAI largely overestimates SM in all the research regions, while NOAA and NCEP SM has the lowest bias among the reanalysis datasets. Reanalysis can better reproduce the variation characteristics than remote sensing during extreme events period, probably due to large percent of missing data, and instrument constrict.*

3. Some descriptions contradict each other throughout the manuscript. For example, in Lines 188-190, the authors first report the underestimation in northwest China and then report the opposite side.

Response: There was a typo, which we have corrected as follows:

Line 239-240: *Except for NCEP, all the other datasets are able to represent the wet center in the northeast of China.*

4. In Line 79, the authors promise to discuss on sources of SM errors. However, most of the explanations are speculations and even key words. In Line 223 for example, why different land surface types and varying soil parameters cause differences between CCI and model outputs? In Line 227, how vegetation presence leads to a clear SM seasonal cycle? In Line 237, how precipitation and frozen soils increase autocorrelation? Then in the following sentence, what particular soil type and texture decreases autocorrelation?

Response: Earlier studies have showed that low soil moisture content at top layer are associated with low precipitation and high evaporation (Jasper et al., 2006; Harmsen et al., 2009). Furthermore, the land surface vegetation and soil texture also play an important role. We add some details on the different land surface types and varying soil parameters as follows:

Line 279-285: *The difference in ESA CCI is smaller than all reanalysis products, especially in the period where in situ SM value is low, which is in line with Ma et al. (2019) that ESA*

CCI have relative poor skills with lower time series correlations in sparse or dense VOD conditions but good performance in moderate densely vegetated areas (Zeng et al., 2015). Furthermore, soil types (silt, clay, sand) also plays an important role in terms of different regions. Chakravorty et al. (2016) studied the influence of soil texture on regional scale performance and found that large fractional RMSE is associated with large percentage of sand, might be one of the reasons that poor performance is found in the NW region.

Line 287-288: *Seasonal cycle of SM in the NE region is obvious, partly due to the sufficient water content there.*

Line 300-301: *The lowest autocorrelation coefficient is found in the NW region, possibly because of the particular sand soil with relative high porosity and low water holding capacity.*

What is worth to say, our result is that the SM autocorrelation is low in summer and winter, indicating that the SM during these seasons are more easily influenced by precipitation and snow.

Related references:

Jasper K, Calanca P, Fuhrer J. Changes in summertime soil water patterns in complex terrain due to climatic change. Journal of Hydrology, 2006, 327: 550-563.

Harmsen E W, Norman L M, Nicole J S, J E Gonzalez. Seasonal climate change impacts on evapotranspiration, precipitation deficit and crop yield in Puerto Rico. Agricultural Water Management, 2009, 96: 1085-1095.

5. Section 3.2.2, how autocorrelation is related to the performance of soil moisture products.

Response: The aim of this figure is to study the soil moisture memory in different seasons. **Line 306-308:** *The information of soil moisture autocorrelation gives hint for the assimilation of surface soil moisture into land surface models (Crow and Van den Berg, 2010), in which during summer and winter, some other related meteorological elements should be considered.*

Related references:

Crow, W., and Van den Berg, M.: An improved approach for estimating observation and model error parameters in soil moisture data assimilation, Water Resources Research, 46(12), doi:10.1029/2010WR00940, 2010.

6. Lines 288-289. Is this a manifestation of scaling effect? Spatial averaging (coarse resolution) masks out extremely low and high SM values.

Response: We have added the following supplementary information in the revised manuscript.

Line 343-345: *Figure 10 shows the rBias under different humid/arid conditions by utilizing SC-PDSI (Wells et al., 2004). The rBias of JJA SM between in situ observation and remote sensing/reanalysis was calculated at each in situ grid point as the bias divided by the mean of in situ observations, and then averaged over regions.*

7. Line 45, temporarily should be temporally.

Response: Corrected, thanks. **(Line 47)**

8. Line 65-66, this sentence makes no sense.

Response: This sentence was deleted.

9. Line 86, plus is incorrect here.

Response: "with a spatial resolution of 0.25° plus 0.25°" has been corrected into "with a spatial resolution of 0.25°". **(Line 85)**

10. Line 87, delete underlying.

Response: The word of "underlying" has been deleted as suggested. **(Line 88)**

11. The method section should provide more details, such as data interpolation in the vertical direction. The CCI has a penetration depth of < 2 cm, and the effective soil depth for model outputs is 0-10 cm, and the in-situ measurement depth is 10 cm. Such differences might also cause representativeness errors.

Response: The detailed information about the operation of measurements has been added in the revised manuscript, and also listed in Table 1.1.

Line 132-135: *The ISMN provides a global in-situ soil moisture database, which has been widely used for validation of satellite products and model simulation (e.g. Albergel et al., 2012). The SM data at the depth of 0~5 cm and 5~10 cm was obtained and averaged as the value at the depth of 0~10 cm.*

Line 140-141: *The SM data was observed at the depth of 10 cm, 20 cm, 50 cm, 70 cm, and 100 cm using drying methods, with the data at 10-cm depth utilized.*

Line 153-155: *The SM mass percent was measured at 11 levels with the depth of 0~5 cm, 5~10 cm, 10~20 cm, 20~30 cm, 30~40 cm, 40~50 cm, 50~60 cm, 60~70 cm, 70~80 cm, 80~90 cm, and 90~100 cm, in which the value at 10 cm depth are calculated as the average of the values at the depth of 5~10 cm and 10~20 cm.*

Line 156-159: *Considering that the field capacity and the dry bulk density are not measured at all stations, data from 119 stations are selected from 1981 to 2013. Not all in situ data were suitable for evaluation given instrumental error and observational conditions, for example, the available measurement period, installation depth and sensor placement. Therefore the evaluation was conducted in unfrozen and snow-free seasons, such as June-July-August (JJA).*

Furthermore, the representativeness errors have been talked about in the Discussion section.

Line 368-373: *ESA CCI SM product showed the top layer soil content at 5-cm depth or so. The in-situ measurement depth and model output are at the depth of 0-10cm, which were also treated as the top layer soil content. Such difference would also cause representativeness errors. Previous studies have found that there is a close relationship between surface SM and SM in the upper ten centimetres (i.e., Albergel et al., 2008; Dorigo et al., 2015), so the SM measurements at the depth of 10 cm were chosen as the reference to evaluate satellite-based and reanalysis products. Furthermore, introducing ubRMSE and conducting comparison at regional scale can remove the bias error caused by mismatch of grid cell to some extent.*

Related references:

Albergel, C., Rüdiger, C., Pellarin, T., Calvet, J. C., Fritz, N., Froissard, F., et al. (2008). From near-surface to root-zone soil moisture using an exponential filter: An assessment of the method based on in-situ observations and model simulations. Hydrology and Earth System Sciences, 12, 1323–1337.

Dorigo, W. A., Gruber, A., De Jeu, R. A. M., Wagner, W., Stacke, T., Loew, A., Albergel, C., Brocca, L., Chung, D., Parinussa, R. M., and Kidd, R.: Evaluation of the ESA CCI soil moisture product using ground-based observations, Remote Sens. Environ., 162, 380–395, https://doi.org/10.1016/j.rse.2014.07.023, 2015.

12. Line 166, climate should be climatological.

Response: Corrected. **(Line 92)**

13. Line 178, Discussions should be Discussion.

Response: Corrected, thanks. **(Line 232)**

14. Lines 184-185, this sentence has been already in the previous section, and obviously does not belong to Result section.

Response: We didn't find this sentence in the previous section, and reserved this sentence. (**Line 234-236**)

15. Line 199, improper use of According to.

Response: This sentence has been changed as follows.

Line 253-254: *As referred in Table 2, all temporal variabilities of SM are averaged over the Northeast China, North China, Yangtze-Huai, and Northwest China regions, which are abbreviated as NE, NC, YH, and NW, respectively, below.*

16. Line 214, what kind of mechanism?

Response: The interpretation has been deleted.

17. Line 217, what is variability performance?

Response: This sentence has been changed into "implying a good performance of variability". **(Line 273)**

18. Lines 217-18, this sentence "demonstrating…" makes no sense.

Response: This sentence has been changed into "demonstrating that both products represent poor performance of changing characteristics." (**Line 273-274**)

19. Line 232, the snow-covered and frozen grids were not removed in this study?

Response: In the former manuscript, we only discarded in situ soil moisture data during snow or frozen days. During this revision, the months with large percent of frozen and snow days were discarded for comparison. Furthermore, if the in situ observation were missing, all reanalysis data at the same period were also treated as missing value.

Line 157-159: *Not all in situ data were suitable for evaluation given instrumental error and observational conditions, for example, the available measurement period, installation depth and sensor placement. Therefore the evaluation was conducted in unfrozen and snow-free seasons, such as June-July-August (JJA).*

Line 227-231: *The comparisons were performed as follows: (i) make a correspondence between all soil moisture data sets and in situ SM by using the values at the nearest neighbor grids; (ii) compare all the SM products at regional scales by calculating the reginal average of monthly value of all SM products, which has been proved can reduce the uncertainty caused by grid mismatch to some extent (Nie et al., 2008); (iii) if the in situ observation were missing, all reanalysis data at the same period were also treated as missing value, which were not taking into account.*

Related references:

Nie, S., Luo, Y., Zhu, J.: Trends and scales of observed soil moisture variation in China, Advance in Atmosphere Science, 25, 43–58, 2008.

20. Line 300, the explanations are unclear and confusing.

Response: The explanation was improved by integrating the relationship between net radiation and evaporation.

Line 358-366: *Previous studies have showed that soil moisture is influenced by the combination of precipitation and evaporation, in which land surface evaporation is linked with temperature and surface net radiation (Jasper et al., 2006; Harmsen et al., 2009). Figure 12 shows scatter plots of (a, d, g) precipitation, (b, e, h) temperature, and (c, f, i)* *net radiation anomalies versus observed SM anomalies over different regions in (left column) MAM, (middle column) JJA, and (right column) SON seasons. Obvious positive correlations are found between precipitation and SM in the YH regions during MAM and SON seasons, and in the NE and NC regions during JJA season. Temperature and net radiation show negative correlation with in the NE, NC, and YH regions. The correlation coefficient is low for all meteorological variables in the NW region, which may be attributed to the special soil type there. Soil moisture in the NE and NC regions tends to be influenced by temperature during cold seasons. SM in the YH region tend to be influenced by radiation during warm seasons, due to the large evaporation there.*

Related references:

Jasper K, Calanca P, Fuhrer J. Changes in summertime soil water patterns in complex terrain due to climatic change. Journal of Hydrology, 2006, 327: 550-563.

Harmsen E W, Norman L M, Nicole J S, J E Gonzalez. Seasonal climate change impacts on evapotranspiration, precipitation deficit and crop yield in Puerto Rico. Agricultural Water Management, 2009, 96: 1085-1095.

21. Line 321, it is not quite right to say “CCI is not useful”.

Response: This sentence has been changed as follows:

Line 409-410: *However, ESA CCI shows poor performance in terms of its low correlation and missing values, especially in Northeast China.*

22. Why not use GLDAS (the same grid resolution as CCI) or CLDAS (more spatial details) data as validation reference? Although with a shorter temporal coverage, other optimized SM data in mainland China can also serve as references. These data reduce representativeness errors.

Response: Thanks for your advice. Firstly, this study is focus on the long-term evaluation, so those products with shorter temporal coverage were not considered in this study. Secondly, the estimation using GLDAS and CLDAS data as reference will be considered in the further study.