RC: Reviewer Comment, AR: Author Response, ☐ New Manuscript text

Dear Referee,

We would like to thank you very much for your positive review of our manuscript. Please find our responses to your comments below. These should be considered as preliminary (part of the interactive discussion) as implementation of the final changes also depends on another referee report that is still pending.

Thanks again for your efforts!

Kind regards,

Chansheng He

(on behalf of all the authors)

The comments of editor and reviewers are in black color with bold text, the author's answers are indicated in blue color, as well as old text passages. New text passages are indicated in green color.

General Comments

The authors provided datasets of soil properties and long-term soil moisture over the Qilian Mountain based on in-situ observations. The dataset is very useful and important to help the scientific community to understand the soil hydrological processes, to improve the land surface modelling and to develop the soil moisture products over QTP. As the field sampling of profile soil samples and long-term maintenance of soil moisture stations over large scale mountainous areas is difficult, led to the scarce of the large scale in-situ SHP and SM dataset over QTP. Overall, this is a clearly written paper and the structure of the manuscript is well organized. The manuscript can be accepted after addressing my following questions.

AR: We thank the reviewer for the positive evaluation and the comments.

Major Comments

RC: **For the dataset, the spatial distribution of the soil properties datasets has been made public. Besides, it's suggested to upload the representative original measurements of the soil properties (e.g. the key SHP datasets for the main land covers), which can be applied for large-scale modelling and ecohydrological study easily. I also noticed that the number of different soil properties varied at different layers. Please add the detailed instruction of the specific number of each soil properties, which is important for its application.**

AR: As stated in the manuscript, some samples were lost while being transported from the field to the laboratory and the soil depth varied across the large-scale mountainous areas, we finally selected eight sites which has relatively complete profile SHP data and can represent the main land covers (two sites for each main land covers of forestland, high coverage grassland, medium coverage grassland and barren land) in the study area. The selected original measurements of the key SHP datasets for the main land covers have be uploaded into the public datasets (https://doi.org/10.5281/zenodo.6130983). What's more, the specific number of each soil properties (Table S1) has been added in the revised manuscript.

☐ **Table S1. The specific number of the measured soil properties in the datasets.**

depth/cm	clay	silt	sand	bulk	SOC	K_S	SWRC
5	198	198	198	158	30	174	140
15	25	25	25	25	25	25	25
25	162	162	162	64	30	65	56
40	23	23	23	30	28	30	22
60	21	21	21	30	24	24	19
all	429	429	429	307	137	318	262

Note: bulk, SOC, and K_S represent the soil bulk density, soil organic carbon and soil saturated hydraulic conductivity, respectively. SWRC represents the parameters (α, n, saturated soil moisture and residual soil moisture) related to soil water retention curve.

RC: Table1: Why the observed profile SHP is calculated as the average of the surface SHP and subsurface SHP? In my opinion, it should be calculated using the depth-weighting method. The different calculation of profile SHP will influence the validation of profile soil datasets.

AR: Thank you for your reminder. Yes, the profile SHP should be calculated using the depth-weighting method. As the surface depth and subsurface depth of the measured SHP is 5 cm and 25 cm, the surface and subsurface depth represent the depth of 0-15 cm and 15-30 cm, respectively. The profile SHP is calculated as follows:

$$SHP_{profile} = \frac{(15 \times SHP_{surface} + 15 \times SHP_{subsurface})}{30} = \frac{(SHP_{surface} + SHP_{subsurface})}{2}$$

Thus, the depth-weighted profile SHP is equal to the average of surface and subsurface SHP.

RC: From Figure 6 I can find that the spatial distribution of different soil properties is generated through different method, such as the ordinary Kriging method, the Cokriging method, and the Inverse Distance Weighted method. In my opinion, the different spatial pattern of soil properties can also be caused by the different methods. What's more, what's the spatial resolution of the soil properties dataset?

AR: After evaluating the suitable method of spatial interpolation for each SHPs, the Kriging and Cokriging methods were found to be not suitable for some variables. Thus, the Inverse Distance Weighted method was adopted to generate the measured SHP products. The new figure is showed as Figure 6. And the text about the spatial distribution of SHP, which is different with the previous description, has been changed in the revised manuscript. What's more, the spatial resolution of the generated SHP products is 900 m.

- ☐ The residual SM is high in the middle and south parts of the study area, while the saturated SM is high in the southeastern and middle parts of the study area. α is high in the southeast and low in the midle part of the study area;

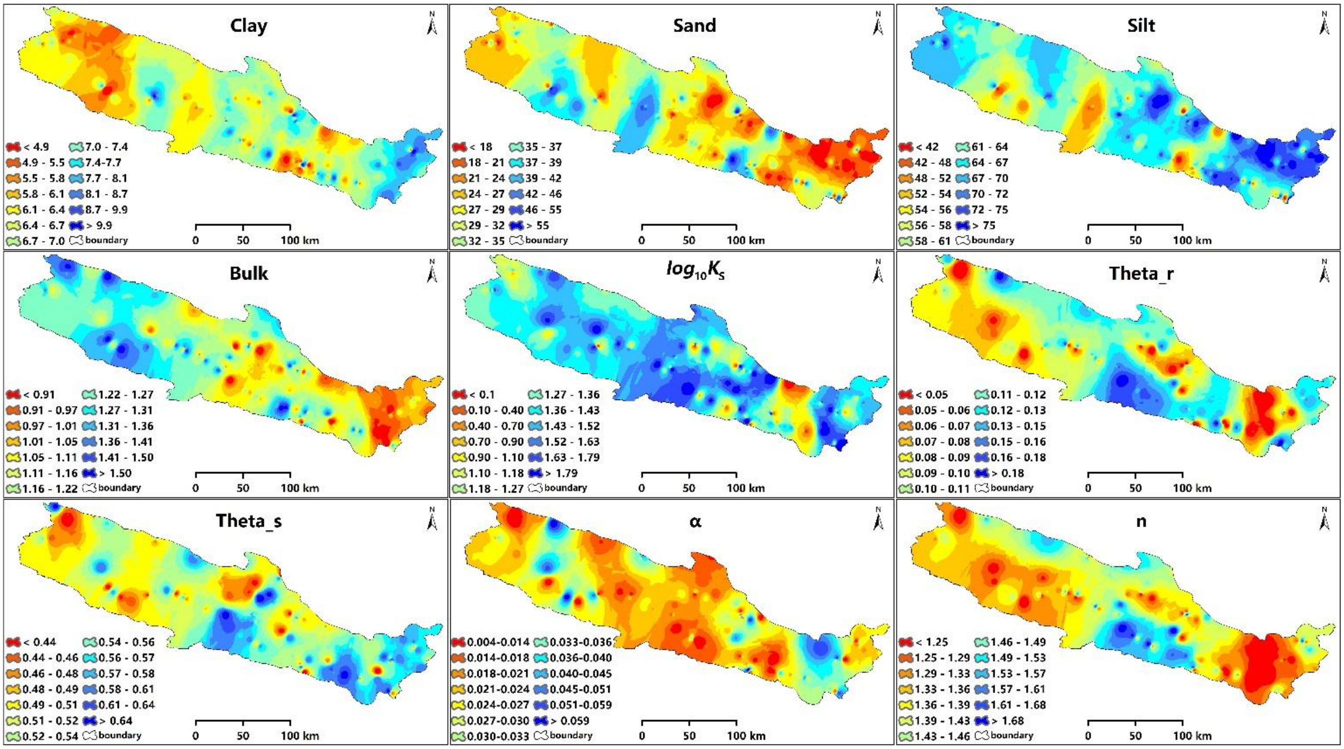

Figure 6. The spatial distribution of soil texture (sand, silt, clay, %), Bulk (g/cm^3), $log_{10}K_S$ (log_{10} transformed saturated hydraulic conductivity, cm/day), the residual SM (Theta_r, cm^3/cm^3), saturated SM (Theta_s, cm^3/cm^3), α and n in the study area.

RC: **Please notice that the spatial resolution of different SHP datasets or SM datasets are different, which will influence your validation. Please discuss it in the manuscript. Besides, the authors are suggested to validate the three SM products at daily scale instead of monthly scale.**

AR: Thank you for the comments. Yes, the spatial resolutions of the SHP datasets and SM datasets are different. For the SHP datasets, the spatial resolution of HWSD, ZhangYG, and DaiYJ (with spatial resolution of almost 1 km, FAO/IIASA/ISRIC/ISS-CAS/JRC, 2012; Zhang et al., 2018; Dai et al., 2019a) is larger than that of the SoilGrids2.0 (250 m, Poggio et al., 2021). For the SM datasets, the spatial resolution of the GLDAS_Noah product (nearly 25 km, Roddell and Beaudoing, 2017) has a larger spatial resolution than the ERA5_Land and SMAP_L4 product (9 km, Muñoz-Sabater et al., 2021; Reichle et al., 2017). In our opinion, the different spatial resolutions will influence the spatial heterogeneity of the estimated SHP or SM when comparing with the observations. Thus, the discussion about the influence of spatial resolution on the evaluation of SHP and SM products has been added in the discussion part as follows:

- Since the estimated soil properties used the average value to represent soil variable for each grid and neglected the soil spatial heterogeneity within each grid (Dai et al., 2019b; Zheng et al., 2015), the spatial heterogeneity of SHP has been shown to decrease with the increase of spatial resolution (Jin et al., 2015; Lin et al., 2006; Li et al., 2021). It should be noted that the spatial heterogeneity of the estimated SHPs from different soil datasets is also influenced by the spatial resolution of the soil datasets, which leads to the relatively lower R value in the evaluation of the SHP datasets.

  We should also note that the performances of GLDAS and ERA5_Land products can also be influenced by its spatial resolution. Since the ERA5_Land product (9 km, Muñoz-Sabater et al., 2021) has the finer spatial resolution than the GLDAS_Noah product (nearly 25 km, Roddell and Beaudoing, 2017), the ERA5_Land product can better capture the spatial distribution pattern of the observed soil moisture than the GLDAS_Noah.

AR: Besides, the validations of the SM products at daily scale was performed as suggested. Results are shown in Figure S6 (scatterplots comparing the different SM products with observations) and Figure S7 (the results of the evaluation metrics for the different products). Results of evaluations indicate that the performance of different SM products at daily scale are similar to that at monthly scale. This part has been added in the revised supplement. The new figures (Figure S6 and Figure S7) are showed as follows:

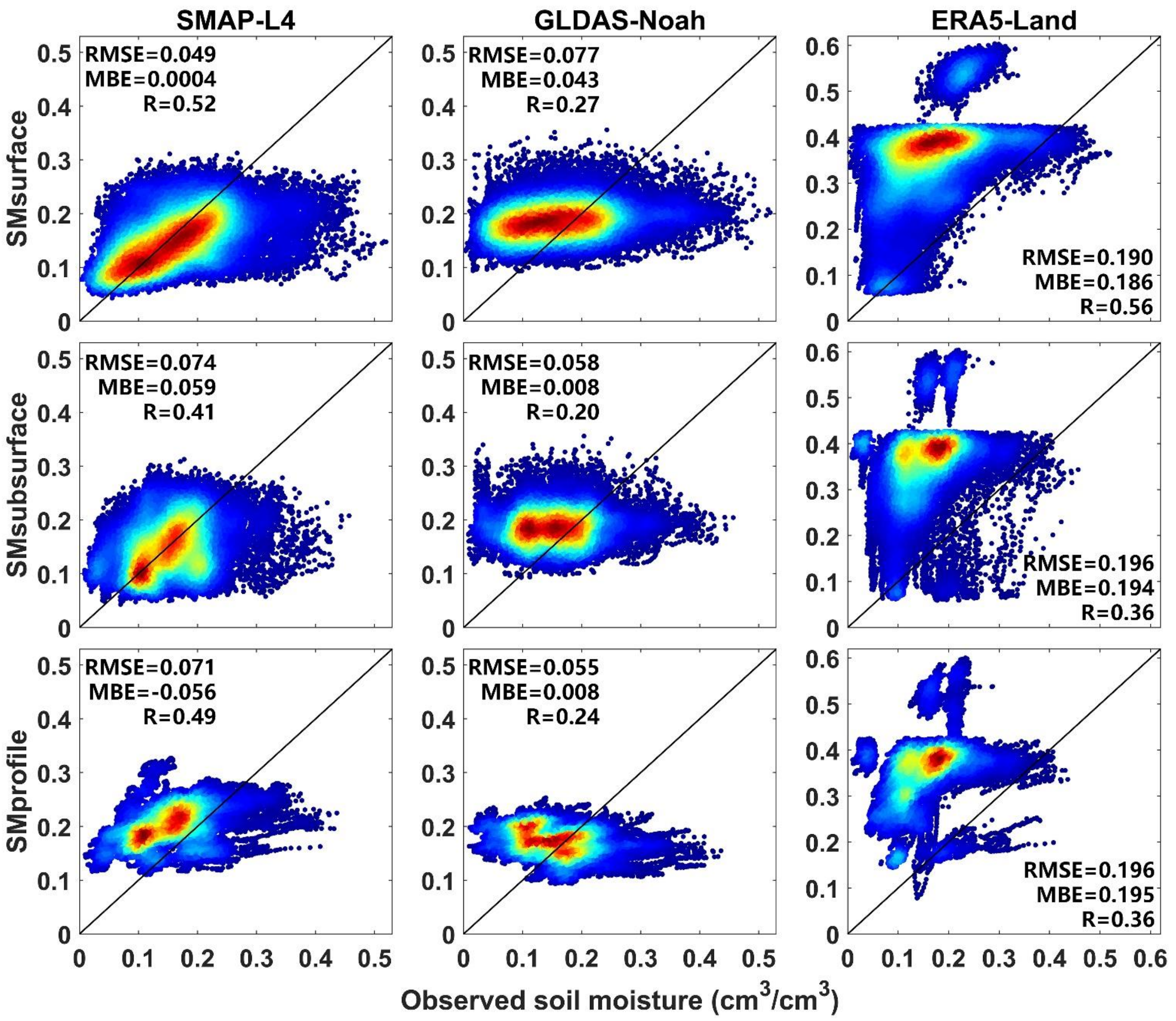

Figure S6. Scatterplots comparing the different derived SM products with the observed SM for different soil layers at daily scale. The metrics within each plot show the median value of the metrics for all stations. The smoothed color density in the scatter plots shows the density of points.

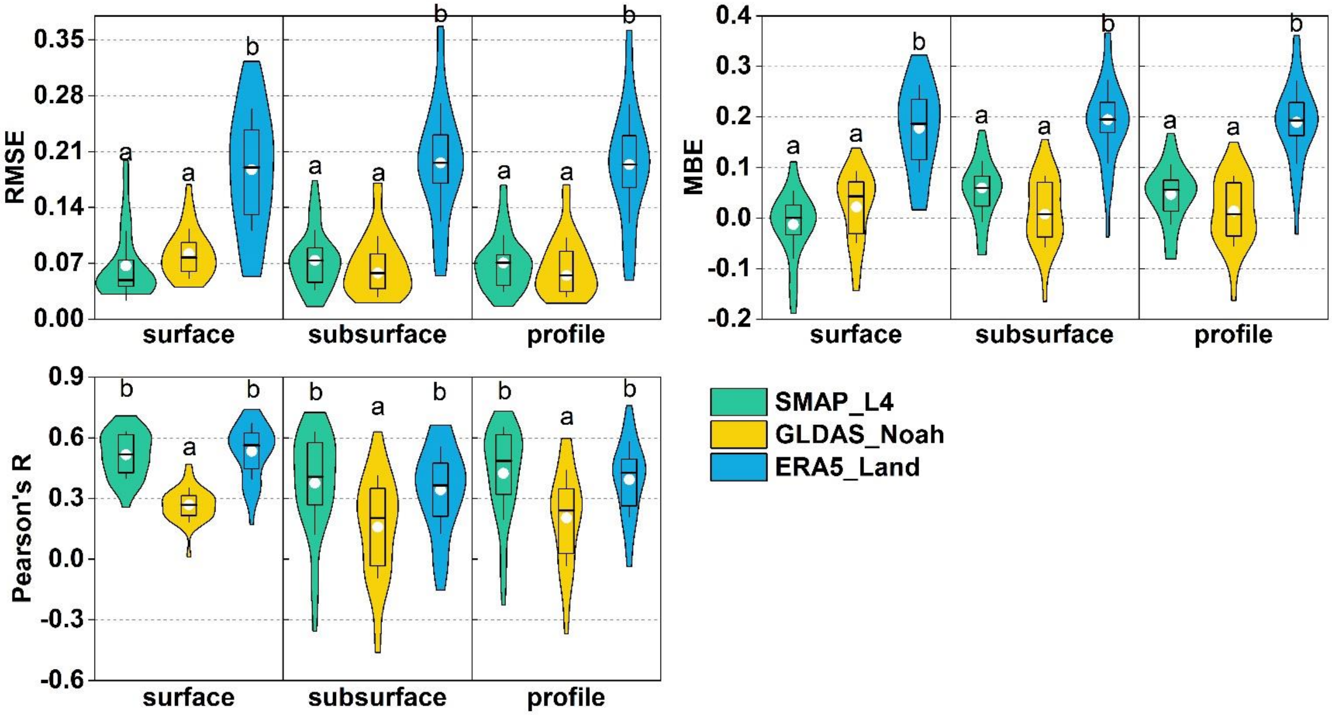

Figure S7. Metrics for comparing the different SM products (GLDAS2.1_Noah, ERA5_Land, SMAP_L4) with the in-situ SM observations for different soil layers at daily scale. The different letters above the volin plot indicate the significant differences ($p < 0.05$) between different products for each soil layer.

Specific Comments

RC: L11: Please change the "describing and predicting" to "describe and predict"

AR: Yes, it was done as suggested.

RC: L18: Please delete the "of" before "SM".

AR: Yes, it was done as suggested.

RC: L35: Please change the "Earth" to "earth".

AR: Yes, it was done as suggested.

RC: L41: Please change the "soil-sampling" to "soil sampling"

AR: Yes, it was done as suggested.

RC: L42-43: Please rewrite the sentence.

AR: Yes, the sentence was changed as follows.

- This makes the estimated SHP data from many widely-used soil databases highly uncertain for mountainous areas.

RC: L50: I think "and" should be replaced by "especially".

AR: Yes, it was done as suggested.

RC: L51: Please use the abbreviation "SHPs" replace the "soil hydraulic properties"

AR: Yes, it was done as suggested.

RC: L52: I think that "individual" should be replaced by "different".

AR: Yes, it was done as suggested.

RC: L60-61: The statement is unclear, please rewrite the sentence.

AR: Yes, the sentence was changed as follows.

- Ground-based SM measurements are the most accurate and important means for developing and validating the spatially-contiguous data derived from satellites or from land-surface models

RC: L68-69: The statement is unclear, please rewrite the sentence.

AR: Yes, the sentence was changed as follows.

- This study presents a long-term SM dataset collected through a SM monitoring network that was established in 2013, and the SHP dataset through field-sampling from both the random soil profiles and the long-term SM monitoring stations, on the northeastern edge of the QTP.

RC: L72: Please change the "soil-property" to "soil property".

AR: Yes, it was done as suggested.

RC: L83: Please change the "land-cover" to "land cover".

AR: Yes, it was done as suggested.

RC: L95: Please check the name of the dataset, we can't find the dataset in the website.

AR: The name is "Landuse/landcover data of the Heihe River Basin (2011)". It was changed as suggested.

RC: L99: please delete the "mountainous"

AR: Yes, it was done as suggested.

RC: L106: It should be "study area"

AR: Yes, it was done as suggested.

RC: L109: Please change the "long-term" to "long term"

AR: Yes, it was done as suggested.

RC: L115: "Since the soil freezes in winter, SM data are only available for the growing seasons (May to October, Tian et al., 2019)". Why only the SM data are only available for the growing seasons? I think the ECH2O 5TE probe can measure the liquid soil water content during winters.

AR: Yes, the 5 TE probe can only measure the liquid water content and can't measure the soil water content in solid state (Cobos and Chambers, 2010; Zhao et al., 2013). Most of the soil water converts from the liquid state into solid state during the freezing period in the QTP(Zhao et al., 2013; Zheng et al., 2018; 2019), which leads to the underestimate of the soil water content by the 5TE probe during the winters (Tian et al., 2019; 2020). Thus, we only keep the measured SM data during the growing season to represent the actual soil moisture content in the study area.

RC: L122: Please delete the "a" before metal cylinder.

AR: Yes, it was done as suggested.

RC: L131: You have mentioned the size of the cylinder above, no need to mention it again.

AR: Yes, it was done as suggested.

RC: L145: Please delete "," after "(also written as cm H2O)"

AR: Yes, it was done as suggested.

RC: L171: What is the specific depth of the surface layer and subsurface layer?

AR: The depth of the surface layer and subsurface layer is 5 cm and 25 cm, respectively.

RC: L178: Please delete "types" after product.

AR: Yes, it was done as suggested.

RC: L201: Please unify the format of "CV" in the manuscript.

AR: Thank you. It was unified into "C_V" throughout the manuscript as suggested.

RC: L228: The parameter "l" should be n.

AR: Yes, it was done as suggested.

RC: Table3: What is $\log_{10}K_S$, please explain.

AR: $log_{10}K_S$ is the K_S value with the log_{10} transformation. It was illustrated in the revised manuscript.

RC: L248: It should be Figure5, not Figure4.

AR: Yes, it was done as suggested.

RC: Figure7: The unit of bulk is wrong, please correct it.

AR: Thank you. The unit of bulk has been changed to g/cm^3.

RC: L314: Please change the "full profile SM" to "profile SM"

AR: Yes, it was done as suggested.

RC: L315: Please change the "or" to "and"

AR: Yes, it was done as suggested.

RC: L311: It's Figure 10 not Figure 11.

AR: Yes, it was done as suggested.

RC: L333-334: Please check the value of spatial CV and temporal CV.

AR: Thank you. It was changed as follows.

- The spatial variability of SM varies from 0.32 to 0.65 over the study area, with a mean C_V of 0.45, and this is higher than the temporal variability of SM over the study period (2014–2020), which varied from 0.03 to 0.52, with a mean C_V of 0.18

RC: Figure 9: Please check the legend of the soil moisture value.

AR: Thank you. The range of the first-class soil moisture is <0.075, not <0.75. It was changed.

RC: L353: What is the equation of NRMSE?

AR: NRMSE is the Normalized root mean square error, it is calculated as follows:

$$NRMSE = 100 \times \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y}_i)^2} \Big/ \bar{y}$$

Where y and $\hat{y}$ is the observations and simulations of products, respectively. $\bar{y}$ is the mean of observations. N is the number of comparisons.

RC: L359-362: It's better to move this sentence to the end of next paragraph.

AR: Thank you. The sentence was moved into the next paragraph and revised as follows.

- These results suggest that the clay content, sand content and BD are overestimated in both the SoilGrid and HWSD datasets, and that the silt content is underestimated for 0–30 cm soil depths in the study area. The soil texture and BD values in the SoilGrid dataset have higher precision than those from HWSD, and the K_S values in the ZhangYG dataset have higher precision than those in the DaiYJ for the study area. Besides, the low Pearson's R value and the scatterplot indicate that the soil datasets do not capture the spatial distribution of the SHPs (soil texture, BD and KS) in mountainous areas with complex terrain.

RC: L361: What's the performance of ZhangYG dataset?

AR: Thank you. The estimated $log_{10}K_S$ in the ZhangYG dataset has an NRMSE (PBIAS) and R of 33.1% (8.3%) and 0.17 for the depth of 5 cm in the study area. It was added in the revised manuscript as follows.

- While the estimated $log_{10}K_S$ in the ZhangYG dataset has an NRMSE (PBIAS) and R of 33.1% (8.3%) and 0.17 for the depth of 5 cm in the study area.

RC: Figure 12: Please add the unit of the soil moisture

AR: The unit is (cm^3/cm^3). It was added as suggested.

RC: L401: Please check the format here.

AR: Thank you. We have checked the format, the blank was deleted in the revised manuscript.

RC: L421: Please delete the "of" after "understanding".

AR: Yes, it was done as suggested.

RC: L428-L429: This paragraph is the discussion about soil moisture, please delete the "SHP"

AR: Yes, it was done as suggested.

RC: L442: Please change the "some" to "different".

AR: Yes, it was done as suggested.

References:

Cobos, D. R., and Chambers, C.: Calibrating ECH2O soil moisture sensors, Application Note, Decagon Devices, Pullman, Washington, 2010.

Dai, Y., Shangguan, W., Wei, N., Xin, Q., Yuan, H., Zhang, S., Liu, S., Lu, X., Wang, D., and Yan, F.: A review of the global soil property maps for Earth system models, SOIL, 5, 137-158, https://doi.org/10.5194/soil-5-137-2019, 2019b.

Dai, Y., Xin, Q., Wei, N., Zhang, Y., Shangguan, W., Yuan, H., Zhang, S., Liu, S., and Lu, X.: A Global High-Resolution Data Set of Soil Hydraulic and Thermal Properties for Land Surface Modeling, J. Adv. Model. Earth Sy., 11, 2996-3023, https://doi.org/10.1029/2019MS001784, 2019a.

FAO, IIASA, ISRIC, ISSCAS, and JRC: Harmonized World Soil Database (HWSD), version 1.1, 2012.

Jin, X., Zhang, L. h., Gu, J., Zhao, C., Tian, J., and He, C. S.: Modeling the impacts of spatial heterogeneity in soil hydraulic properties on hydrological process in the upper reach of the Heihe River in the Qilian Mountains, Northwest China, Hydrol. Processes, 29, 3318-3327, https://doi.org/10.1002/hyp.10437, 2015.

Li, X., Xu, X., Wang, X., Xu, S., Tian, W., Tian, J., and He, C.: Assessing the Effects of Spatial Scales on Regional Evapotranspiration Estimation by the SEBAL Model and Multiple Satellite Datasets: A Case Study in the Agro-Pastoral Ecotone, Northwestern China, Remote Sens., 13, 1524, 2021.

Lin, H., Bouma, J., Pachepsky, Y., Western, A., Thompson, J., van Genuchten, R., Vogel, H.-J., and Lilly, A.: Hydropedology: Synergistic integration of pedology and hydrology, Water Resour. Res., 42, https://doi.org./doi:10.1029/2005WR004085, 2006.

Muñoz-Sabater, J., Dutra, E., Agustí-Panareda, A., Albergel, C., Arduini, G., Balsamo, G., Boussetta, S., Choulga, M., Harrigan, S., Hersbach, H., Martens, B., Miralles, D. G., Piles, M., Rodríguez-Fernández, N. J., Zsoter, E., Buontempo, C., and Thépaut, J. N.: ERA5-Land: a state-of-the-art global reanalysis dataset for land applications, Earth Syst. Sci. Data, 13, 4349-4383, https://doi.org./10.5194/essd-13-4349-2021, 2021.

Poggio, L., de Sousa, L. M., Batjes, N. H., Heuvelink, G. B. M., Kempen, B., Ribeiro, E., and Rossiter, D.: SoilGrids 2.0: producing soil information for the globe with quantified spatial uncertainty, SOIL, 7, 217-240, https://doi.org/10.5194/soil-7-217-2021, 2021.

Reichle, R. H., Lannoy, G. J. M. D., Liu, Q., Ardizzone, J. V., Colliander, A., Conaty, A., Crow, W., Jackson, T. J., Jones, L. A., Kimball, J. S., Koster, R. D., Mahanama, S. P., Smith, E. B., Berg, A., Bircher, S., Bosch, D., Caldwell, T. G., Cosh, M., González-Zamora, Á., Collins, C. D. H., Jensen, K. H., Livingston, S., Lopez-Baeza, E., Martínez-Fernández, J., McNairn, H., Moghaddam, M., Pacheco, A., Pellarin, T., Prueger, J., Rowlandson, T., Seyfried, M., Starks, P., Su, Z., Thibeault, M., Velde, R. v.

d., Walker, J., Wu, X., and Zeng, Y.: Assessment of the SMAP Level-4 Surface and Root-Zone Soil Moisture Product Using In Situ Measurements, J. Hydrometeorol., 18, 2621-2645, https://doi.org./10.1175/jhm-d-17-0063.1, 2017.

Roddell, M. and Beaudoing, H.: GLDAS Noah Land Surface Model L4 3 hourly 0:25 × 0:25 degree V2.1, NASA GESDISC DATA ARCHIVE, Greenbelt, Maryland, USA, https://doi.org/10.5067/E7TYRXPJKWOQ, 2017.

Zhang, Y., Schaap, M. G., and Zha, Y.: A High-Resolution Global Map of Soil Hydraulic Properties Produced by a Hierarchical Parameterization of a Physically Based Water Retention Model, Water Resour. Res., 54, https://doi.org/10.1029/2018WR023539, 2018.

Zhao, C.L., Jia, X.X., Shao, M. A., and Zhang, X.: Using pedo-transfer functions to estimate dry soil layers along an 860-km long transect on China's Loess Plateau, Geoderma, 369, 114320, https://doi.org/10.1016/j.geoderma.2020.114320, 2020.

Zheng, D., van der Velde, R., Su, Z., Wang, X., Wen, J., Booij, M. J., Hoekstra, A. Y., and Chen, Y.: Augmentations to the Noah Model Physics for Application to the Yellow River Source Area. Part I: Soil Water Flow, J. Hydrometeorol., 16, 2659-2676, https://doi.org./10.1175/jhm-d-14-0198.1, 2015.

Zheng, D., van der Velde, R., Su, Z., Wen, J., Wang, X., and Yang, K.: Impact of soil freeze-thaw mechanism on the runoff dynamics of two Tibetan rivers, J. Hydrol., 563, 382-394, https://doi.org./10.1016/j.jhydrol.2018.06.024, 2018.

Zheng, D., Li, X., Wang, X., Wang, Z., Wen, J., van der Velde, R., Schwank, M., and Su, Z.: Sampling depth of L-band radiometer measurements of soil moisture and freeze-thaw dynamics on the Tibetan Plateau, Remote Sens. Environ., 226, 16-25, https://doi.org./10.1016/j.rse.2019.03.029, 2019.