RC3

This is my first review of the paper "Multi-scale soil moisture data and process-based modeling reveal the importance of lateral groundwater flow in a subarctic catchment" by Jari-Pekka Nousu et al.

The paper is well-written and presents a valuable contribution to the literature. As models and data improve in resolution, many processes become scale-dependent, making what is overlooked at a coarse scale crucial at high resolution. This manuscript addresses this issue by comparing different model parameterizations and SAR-based soil moisture with a robust experimental dataset.

I do not have major comments on the study, but I suggest some moderate revisions:

We would like to thank the reviewer for the positive assessment and comments on our study. Our answer to each comment is written in blue. Responses to the annotated manuscript is provided as answers to each comment in a separate PDF file.

Update the Bibliography: The bibliography is outdated. Please revise it to include more recent works. I have provided some suggestions in the annotated PDF.

Thank you for providing these relevant suggestions. We will update the bibliography accordingly.

Enhance Section 3.4: Section 3.4 is overly qualitative and could be improved significantly. Consider incorporating metrics to quantitatively demonstrate the differences between SAR data, various model parameterizations, and in situ data. Temporal stability analysis, as discussed in Dari et al. 2019 (https://www.sciencedirect.com/science/article/abs/pii/S0022169419300575), could be particularly useful. Comparing different statistical spatial measures from various soil moisture spatiotemporal dynamics would be highly relevant.

Thank you for your valuable insights. We agree that quantitative material will improve section 3.4. Metrics of model versions and SAR against in-situ data are already provided in Fig. 6 of the manuscript. We have made an alternative version of Fig. 6 to better quantify the performance of the model and SAR within specific soil types (see below). This new figure will be included in the supplement of the revised manuscript. This figure highlights the uncertainties in soil parameterization based on the geospatial soil type data: many of the peat soil points of the 2D approach are overestimated (few also underestimated). We will highlight the uncertainties in soil parameters in the revised manuscript.

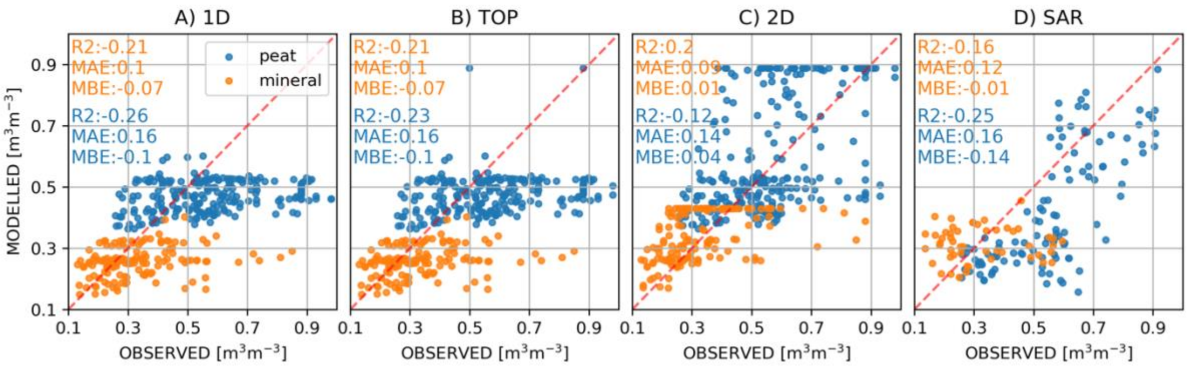

Figure 1. Comparison of simulated rootzone soil moisture content and SAR-based surface soil moisture estimates against spatiotemporal manual in-situ soil moisture observations. The blue color of the points correspond to peat soil and the orange color to mineral soil.

The temporal stability analysis proposed by Dari et al., 2019 is indeed an interesting approach, and we appreciate the suggestion. However, there are many approaches that can be useful for our specific case. To bring in more quantitative analysis, we have calculated relevant metrics of the model predictions and SAR estimates and summarized them in the table below.

Table 5. Statistics of SpaFHy-1D, SpaFHy-TOP, SpaFHy-2D and SAR morning estimates. Low and high soil moisture quantiles are represented as q = 0.1 and q = 0.9, respectively. All statistics were calculated for those days when SAR morning estimates were available.

Data	mean ($m^3\ m^{-3}$)	variance ($m^3\ m^{-3}$)	q = 0.1 ($m^3\ m^{-3}$)	q = 0.9 ($m^3\ m^{-3}$)
SpaFHy-1D	0.29	0.01	0.25	0.47
SpaFHy-TOP	0.30	0.01	0.25	0.47
SpaFHy-2D	0.39	0.04	0.25	0.82
SAR	0.34	0.02	0.22	0.65

In addition, we have made a density scatterplot comparison of SpaFHy-2D and SAR for peat and mineral (medium texture) soils, including metrics of mean absolute difference (MAD) and mean difference (MD) (see below). This figure will be included in the supplement of the revised manuscript and referred to at L394: "This is also supported by a quantitative comparison of SpaFHy-2D and SAR estimates in Fig. SX; both SAR and SpaFHy-2D are divided between two groups on peatlands; cluster of wet points impacted by the lateral groundwater dynamics and cluster of drier points not impacted by the lateral flow."

When comparing the soil moisture estimates based on SAR to those based on the model, one must consider that the SAR based soil moisture value of a model pixel is an average of all values of original SAR pixels within the model pixel, whereas the model considers the pixel homogeneously with one soil moisture value. Inevitably averaging the original SAR based soil moisture estimates reduces the variation range of the soil moisture values. For that reason, the lowest soil moisture estimates based on SAR tend to be larger than those of the model and the large soil moisture estimates based on SAR tend to be smaller than those of the model.

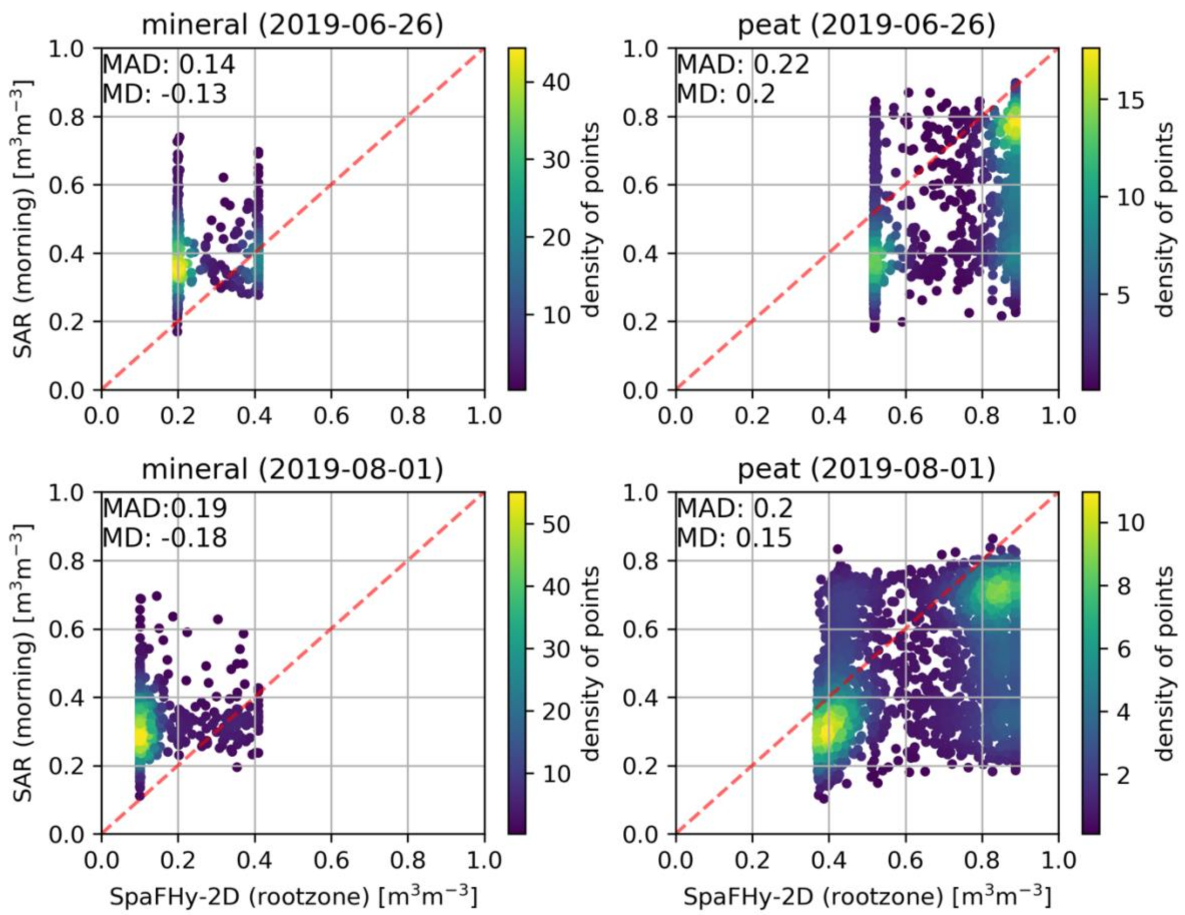

Figure 2. Density scatterplots of SpaFHy-2D vs. SAR on mineral (left column) and peat (right column) soil on 2019-06-26 (first row) and 2019-08-01 (second row). Mean absolute difference (MAD) and mean difference(MD) are presented in each panel.

Clarify SAR Estimates: While there is already a paper on SAR estimates, more detailed information about the retrievals should be included in this manuscript to provide better context.

The SAR retrieval method was based on the gradient boosting machine learning method and the following input variables were used: 1) day/time of soil moisture to be calculated, 2) time difference between the SAR image acquisition and the time for which the soil moisture is to be calculated, 3) altitude of terrain, 4) local slope of terrain, 5) local aspect angle of terrain, 6) land cover class, 7) local incidence angle of SAR, 8) azimuth difference of SAR looking direction and terrain slope, 9) leaf area index estimate based on SAR image, 10) cosine of SAR incidence angle, 11) VH backscattering coefficient of SAR pixel, 12) VV backscattering coefficient of SAR pixel, 13) average VH backscattering coefficient of land areas in SAR image, 14) average VV backscattering coefficient of land areas in SAR image. The leaf area index estimation algorithm for SAR is another gradient boosted algorithm that is trained with the reduced simple ratio (RSR) index based on an optical image. The land cover class is one of 30 classes derived from the multitemporal statistics of the SAR images in the area. The backscattering coefficient values of SAR used as input for the soil moisture and effective LAI retrieval methods are nonlocally averaged using the PIMSAR method (Manninen and Jääskeläinen 2021).

The description starting at L269 is slightly modified to give the previous overall information without going too much in details; "The soil moisture retrieval using SAR images is based on the gradient boosting machine learning method using as input variables nonlocally averaged VH and VV backscattering coefficients, multitemporal SAR statistics, terrain data, effective LAI estimates based on SAR, SAR overpass information and date/time for soil moisture estimate to be calculated. It is validated against discrete and continuous in-situ soil moisture measurements at Pallas (Manninen et al., 2021)."

Based on these points, my recommendation is moderate revisions. I have also attached the annotated PDF with additional comments for further guidance.

Thank you for the revision, and the additional comments. These comments will be considered in order to further improve the manuscript.

References

T. Manninen and E. Jääskeläinen, "Pixel Based Multitemporal Sentinel-1 SAR Despeckling PIMSAR," in IEEE Geoscience and Remote Sensing Letters, vol. 19, pp. 1-5, 2022, Art no. 4011705, doi: 10.1109/LGRS.2021.3065300. keywords: {Backscatter;Indexes;Synthetic aperture radar;Standards;Radar polarimetry;Spatial resolution;Wetlands;Land surface;synthetic aperture radar (SAR) data;vegetation},

Dari, J., Morbidelli, R., Saltalippi, C., Massari, C., & Brocca, L. (2019). Spatial-temporal variability of soil moisture: Addressing the monitoring at the catchment scale. Journal of Hydrology, 570, 436–444. https://doi.org/10.1016/J.JHYDROL.2019.01.014