The review comments are shown in black, and the author responses are in red.

We would like to thank the reviewer for reviewing our manuscript. Please find below our responses to the comments.

This study investigates the relationship between precipitation and soil moisture in Finland using satellite-based data from NASA's SMAP mission, supported by ground-based radar and in situ measurements. It applies the SM2RAIN algorithm to estimate precipitation from soil moisture and characterizes soil moisture dry down patterns by fitting exponential models. The analysis covers two years (2018–2019) and highlights spatial and temporal variability in soil moisture, as well as challenges posed by snowmelt and water bodies in SM retrievals. The findings are valuable for understanding Arctic hydrological processes and suggest potential for broader application across the high-latitude regions.

The study is scientifically sound, methodologically thorough, and clearly communicated. It effectively combines multiple data sets and provides insight into soil moisture dynamics in a challenging environment. The use of dry down modeling and SM2RAIN adds value, and the discussion acknowledges key limitations transparently. Here are comments for further improvement before publications.

The SM2RAIN algorithm is applied assuming that evapotranspiration and runoff are negligible during precipitation events. While this assumption is common, it may not always hold true in regions such as Finland, particularly in wetland areas or under light rainfall with significant canopy interception and latent heat fluxes. It would strengthen the study to assess the potential bias this simplification introduces, possibly by incorporating flux tower ET data or ERA5-Land evapotranspiration estimates.

First, we would like to clarify that the neglected runoff term only includes surface runoff, whereas subsurface runoff is included in the SM2RAIN algorithm. Specifically, the drainage term (Eq. 2 in the manuscript), contains the subsurface runoff. We will clarify this in the manuscript.

Brocca et al. (2015) studied the impact of various terms on the precipitation (P) estimates derived from the SM2RAIN algorithm. Their research demonstrated that soil moisture variations and the drainage term are the most significant contributors, accounting for over 90% of the simulated P estimates. The study concluded that neglecting evapotranspiration and surface runoff terms does not weaken the algorithm's performance. Additionally, the use of satellite data with relatively coarse resolution further reduces the impact of surface runoff. The portion that does not infiltrate—due to factors such as impervious land cover or soil—may re-infiltrate downstream within the scale of a SMAP grid cell (Brocca et al., 2019).

Nevertheless, we acknowledge that limitations exist in the SM2RAIN algorithm. In future studies, analyzing more complex versions of the SM2RAIN algorithm would be worthwhile, although that is beyond the scope of this study. As this is the first study to analyze SM2RAIN's performance in the Arctic and in regions with seasonally frozen ground, we consider that the current simple form of the SM2RAIN algorithm is adequate. Now that the performance has been established in this study, the next step would be to study more complex versions of SM2RAIN and its performance in future studies. We will add discussion about the limitations and future perspectives in the manuscript.

The use of fixed empirical parameters (Z, a, b) from Brocca et al. (2014) across all grid cells is practical but may not adequately capture the spatial variability in soil hydraulic behavior. Given the known heterogeneity in Finnish soils, vegetation, and hydrological settings, a spatially stratified parameterization based on land cover or soil texture (e.g., from SoilGrids or FAO datasets) would be more representative. Alternatively, local calibration using available in situ or radar-based precipitation data could be tested in a subset of locations to explore the potential for improved accuracy.

We will calibrate the parameters and will take into account land cover or soil texture as suggested.

The exponential decay model used for drydowns is based on a first-order assumption that may oversimplify soil water loss processes in certain conditions, especially where rooting depth, vegetation type, or soil layering affects moisture dynamics. Exploring alternative drydown functions—such as bi-exponential or piecewise linear decay—on a subset of events could help determine whether the exponential model remains robust across regimes.

We acknowledge that limitations exist in the exponential decay model used for drydowns. In future studies, analyzing alternative drydown functions would be worthwhile, although that is beyond the scope of this study. As this is the first satellite-based study to analyze drydowns in the Arctic, we consider that using only the exponential decay model in this study is adequate. Now that the performance has been established in this study, the next step would be to study alternative drydown functions in future studies. We will add discussion about the limitations and future perspectives in the manuscript.

The study uses the SMAP L3 enhanced product oversampled to a 9 km grid, though the native resolution remains approximately 33 km. This discrepancy could lead to spatial artifacts or smoothing, especially near land-water boundaries or heterogeneous terrain. Clarification is needed on whether any additional spatial processing or filtering was applied to the SMAP data prior to analysis. It would also be useful to discuss the potential influence of footprint overlap on statistical independence in the drydown fitting.

We have not applied any additional spatial processing to the SMAP data. However, the radar data has been resampled to match the 33 km SMAP footprint. We will edit the text to clarify this and add discussion as suggested.

Only the descending (6 a.m.) SMAP overpasses are used, which is justified in terms of stability and retrieval quality. However, excluding ascending passes may overlook sub-daily variability—particularly relevant in summer months when diurnal SM cycles can be significant. The authors are encouraged to briefly quantify potential information loss from this exclusion or justify it further using SMAP data quality metrics for ascending overpasses.

It is true that some information may be lost due to using only the descending overpasses. However, the minor but systematic biases between the ascending and descending retrievals (e.g., Colliander et al., 2022) justify using only the descending retrievals for increased stability, consistency, and retrieval quality to characterize the drydowns. Combining the ascending and descending overpasses would introduce additional noise in the combined timeseries, degrading the stability of the timeseries, resulting in less accurate analysis. We will clarify this in the manuscript.

The approach of averaging in situ soil moisture within SMAP footprints is appropriate, but spatial heterogeneity within grid cells—especially in complex environments such as fens versus forests—could introduce representativeness errors in the validation. A quantitative assessment of subgrid variability (e.g., standard deviation or interquartile range across in situ probes) and its impact on satellite comparison would strengthen the validation component of the study.

We have only used averaged in situ measurements in Sodankylä, where multiple in situ measurements are available. In Hyytiälä, two in situ measurements are available, and we did not apply any averaging but showed both measurement sites individually (Fig. 6b in the manuscript). For other locations, only one measurement is available, so no averaging was made. However, we acknowledge that spatial variability in SM within a grid cell can be considerable. This is evident for example in Fig. 6b, where the two in situ measurements show large discrepancies. Therefore, we will analyze the standard deviation for Sodankylä in situ measurements and add discussion in the text accordingly.

Surface classification based on SMAP retrieval flags is a useful step; however, the interpretation of SMmin and τ values could be improved with more granular land surface information. Adding categorical breakdowns by vegetation type or soil class could help explain observed spatial patterns and potential retrieval biases, particularly in regions affected by water bodies. Additionally, it would be helpful to explicitly state the proportion of SMAP observations excluded by quality flags and assess whether this introduces systematic seasonal or regional sampling bias—e.g., due to frozen conditions or persistent cloud/snow cover.

We will add more detailed analysis of SM_{min} and τ values based on soil classes as suggested, and will also quantify the proportion of SMAP observations excluded by quality flags.

The springtime SM–P relationship is notably weaker due to snowmelt contributions to SM increases. While this is acknowledged, a more detailed discussion or methodology for separating snowmelt-induced SM changes from rainfall-driven changes would be beneficial. This could involve the use of modeled snowmelt fluxes from ERA5-Land, or analysis of coincident snow cover and air temperature data.

We will add discussion on this topic as suggested.

The study is limited to two years of data (2018–2019), which are suitable for identifying seasonal patterns but may not capture interannual variability. It would be useful to briefly contextualize whether either year exhibited anomalous precipitation or temperature relative to the climatological baseline or mention how a longer time series could help address questions of variability or trend detection.

We will edit the text according to the comment.

Given the stated potential for Arctic-wide application, the manuscript could benefit from a short discussion on the method's suitability for permafrost-affected regions. Permafrost soils introduce unique SM dynamics, including seasonal freeze-thaw cycles, active layer constraints, and limited drainage. Whether this methodology could be adapted or tested in northern permafrost zones (e.g., in northernmost Finland or elsewhere) is worth exploring.

We will add a brief discussion on this topic to the manuscript.

The use of the term "saturation" to describe SMAP retrievals near water bodies may be misleading for readers unfamiliar with remote sensing. Clarifying whether this refers to sensor saturation, retrieval floor/ceiling effects, or actual physical saturation of the soil column would improve clarity.

We will clarify this in the text.

References:

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