The review comments are shown in black, the author responses are in red, and text from the revised manuscript in *red italics*.

Reviewer #1

Many thanks for addressing most of my suggestions. There is one point though I am quite adamant to see corrected in the published version about the spatial resolution (my "line 112" comment). I did not give the right reference then and should have put SMAP Handbook, but in this document the spatial resolution is well detailed on p 35 and is given as 39x47 km which is not 36 (again this is not the spatial resolution but the spatial sampling).

We would like to thank the reviewer for reviewing our manuscript. We have edited the text according to the comment as follows (lines 121-123):

SMAP has an effective field of view of 39 km × 47 km (Entekhabi et al., 2014). The Level 3 soil moisture products are gridded to a 36-km fixed Earth grid and oversampled into a 9 km grid (Entekhabi et al., 2014; O'Neill et al., 2021a).

Reviewer #2

We have edited our previous responses based on the editor's comment to provide specific explanations of the revisions we have made.

Major comments:

Lines 179-172 "Using…. 2014)": Not clear. Hence the SM2RAIN algorithm was not calibrated? This approach is not correct: SM2RAIN parameters need to be calibrated to each pixels, as they are dependent from the soil characteristic of the pixels. All the works of Brocca et al. after 2013 relied on this, to overcome the limits of 2013 paper. SM2RAIN should be calibrated against observations (without considering SM data obtained in frozen conditions). If the Authors prefer to not calibrate the data, they should still use some regionalization procedure to obtain SM2RAIN weight for each pixel (e.g. Filippucci et al 2021; 2022, here applied to ASCAT or S1 data). The parameters can change greatly according to the area. Moreover, this approach do not consider SM2RAIN temporal filter T. This would be important to assess the real performance of SM2RAIN in the area.

We have revised the approach and included both calibration and filtering as suggested. The SMAP data were temporally filtered using the exponential filter approach. The parameters Z, a, and b were calibrated by minimizing the root-mean-square error between the simulated and radar-based 5-day accumulated rainfall. We used data from year 2018 for calibration and data from year 2019 for validation. The revised text is below the next comment.

Moreover, SM2RAIN use interpolated daily data, normalized between 0 and 1. Did the Authors applied interpolation and normalization? It should be written and, if not applies, please explain why.

Yes, we have applied both interpolation and normalization. In case of missing SMAP data, the data were linearly interpolated, and a maximum data gap of three days was considered for the interpolation.

We have revised the text to clarify the preprocessing and calibration steps (lines 231-238):

Before using SMAP SM observations as input for the algorithm, the data needed to undergo a few preprocessing steps. First, in case of missing SMAP data, linear interpolation was used to generate daily values, with a maximum allowable data gap of three days for interpolation. Second, the SMAP data were *rescaled between 0 and 1, as relative SM is used as input in the SM2RAIN algorithm. Third, to address high-frequency fluctuations in satellite-based SM observations caused by measurement and retrieval errors, the SMAP data were temporally filtered using the exponential filter approach (Wagner et al., 1999). After these preprocessing steps, the SMAP data were ready to be applied to the SM2RAIN algorithm. The parameters Z, a, and b were calibrated by minimizing the root-mean-square error between the simulated and radar-based 5-day accumulated rainfall. We used data from year 2018 for calibration and data from year 2019 for validation.*

Regarding SM2RAIn quality, the error introduced by the snowmelt was already analyzed in Brocca et al., 2019, which applied mask to sm data during melting (0<T<3) in order to avoid this kind of noises. This should be implemented also here, to assess the very capabilities of NASA SMAP data.

We have revised the approach and excluded the melt season by only including Jun-Sep in the SM2RAIN analysis. We have edited the text (lines 238-240):

Since snowmelt affects SM and may lead to erroneous P estimates, we excluded the snowmelt season by only including the months from June to September in the SM2RAIN analysis.

Line 419 "while dense….challenge": I don't think that this conclusion is supported by this analysis. Dense vegetation show a realistic pattern, but it is not verified that the SM beneath the vegetation is actually sensed. One way to obtain a confirmation would be to use SM2RAIN to evaluate precipitation time series for all the pixels and then assess its performance per pixel (with indices as RMSE or Pearson correlation or BIAS). If the results in the densely vegetated area are similar to those around, then this indicates that the capacity of SMAP to estimate SM under vegetation are good. But I expect to find worse correlation. In general, I understand that the lack of SM data allow to validate SM just in few areas, but precipitation data are available for all the study areas, hence I encourage to use SM2RAIn to gain more information regarding the SM data quality

It is true that the lack of reference SM data complicates the validation of satellite-based SM retrievals. However, research has shown that SMAP is able to detect soil moisture beneath the vegetation (Colliander et al., 2020; Ayres et al., 2021). Using P data together with the SM2RAIN algorithm to evaluate SMAP SM retrievals would be a worthwhile study, but we consider it being out of scope of this study. We have edited the text as follows (lines 502-509):

Grid cells containing water bodies (classified as "water" and "water and dense vegetation") show a mode in SM^*_{min} *at 0.02* m^3 m^{-3}*, alongside a lower and less distinct peak at higher values. Since 0.02* m^3 m^{-3} *is the lower limit for SMAP SM retrievals, this may introduce an artifact in the results. Conversely, grid cells without water bodies ("low vegetation" and "dense vegetation") display more consistent distributions, each with a single peak around 0.13* m^3 m^{-3}*. These differences in distribution suggest that surface conditions significantly influence the SMAP SM retrievals. Specifically, this result indicates that water bodies complicate SM retrieval, while dense vegetation alone does not pose as much of a challenge. This conclusion is further supported by previous findings demonstrating SMAP's capability to detect SM beneath vegetation cover (Ayres et al., 2021; Colliander et al., 2020).*

Minor comments:

Lines 55-57 "While these….2019)": This is not completely true, as, for example, brocca et al. do not exclude artic region, just periods in which the soil is frozen. Check and correct

We have edited the text as follows (lines 62-67):

While these studies highlight the potential of this approach, they often exclude the Arctic region due to the challenges associated with SM retrieval (Ciabatta et al., 2018; Brocca et al., 2019; Koster et al., 2016; Zhang et al., 2019). Brocca et al. (2019) included the Arctic in their SM2RAIN analysis using data from the Advanced

Scatterometer (ASCAT). However, research has shown that the Soil Moisture Active Passive (SMAP) mission outperforms ASCAT in high-latitude environments (Chen et al., 2018; Zhang et al., 2020), highlighting the importance of evaluating whether SMAP can yield more accurate P estimates in these regions.

Lines 267-269 "This….site": Indeed, the discrepancies in SM between the two sites could be related to different precipitation pattern in the large SMAP pixel. However, it could be also related to error in SM measurement. Since Radar data have 250 meters spatial resolution, you could compare the radar Precipitation obtained in the pixels nearest to the Hyytiälä stations, to ensure that they are correlated with it and therefore there is no error in the observed SM measurements.

Thank you for the suggestion. Rather than using radar data from the pixel nearest to the Hyytiälä stations, we decided to use the in situ P measurements from all the locations shown in Fig. 2a. We have added the in situ P data in Figs. 6 and S3 and revised the text accordingly (lines 312-338).

Line 363 "Figure…. on SM": Not clear, please expand the reasoning behind the sentence

There is a typo in the sentence, and it should read Figure 11 instead of Figure 10. We have corrected the typo and also edited the sentence to make it clear for the reader (lines 432-433):

Figure 11 indicates that SM^*_{min} *is particularly influenced by surface classification, as its spatial variability closely resembles those shown in the surface flag map (Fig. 2c).*

Lines 386-387 "Our analysis….Fig. 7),": To be checked after proper SM2RAIN calibration (see major comment #1)

We have reviewed the conclusions after applying the calibration and preprocessing steps and revised the text accordingly. Although some minor differences were observed, the main conclusions remained unchanged.

References:

Ayres, E., Colliander, A., Cosh, M. H., Roberti, J. A., Simkin, S., & Genazzio, M. A. (2021). Validation of SMAP Soil Moisture at Terrestrial National Ecological Observatory Network (NEON) Sites Show Potential for Soil Moisture Retrieval in Forested Areas. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (Vol. 14, pp. 10903–10918). https://doi.org/10.1109/jstars.2021.3121206

Colliander, A., Cosh, M. H., Kelly, V. R., Kraatz, S., Bourgeau-Chavez, L., Siqueira, P., A. Roy, A.G. Konings, N. Holtzman, S. Misra, D. Entekhabi, P. O'Neill, S.H. Yueh.: SMAP Detects Soil Moisture under Temperate Forest Canopies. Geophysical Research Letters. Vol. 47. https://doi.org/10.1029/2020GL089697, 2020b.