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.

The paper reads well and is interesting. It covers a topic not always fully assessed but I never the less have questions about a few facts. For this reason I think maybe the manuscript should be resubmitted (hence my reject suggestion) to account for the issues raised in the first two points. But I agree it could be only major revisions should the authors be able to address the 2 issues.

Maybe the most striking is why is it important to assess rainfall in Arctic environment where – to my understanding – most of the water comes under the form of solid precipitation. In other words what is the real impact of assessing exactly liquid precip and how the errors in liquid precip relate to uncertainties in solid precip.

Precipitation in both solid and liquid form is essential for the Arctic region. Depending on the specific location, over half of the total annual precipitation can be in liquid form. Figure 1 illustrates the proportion of rainfall relative to total precipitation based on ERA5 data from 2000 to 2024, both for the entire year and specifically for the months of April to September, which are the focus of this study. The figure shows that in extensive areas of the Arctic, liquid precipitation constitutes over half of the annual total precipitation. For Apr-Sep, the fraction further increases.

Additionally, research indicates that total precipitation in the Arctic has increased by 9% during 1971-2019, which is driven by a 25% increase in rainfall (AMAP, 2021). AMAP (2021) also states that while precipitation (both solid and liquid) estimates are available from the reanalyses, their quality for the Arctic region remains poorly established. Therefore, there is a clear need to improve the estimates of liquid precipitation in the Arctic. We will elaborate on this more in the manuscript.

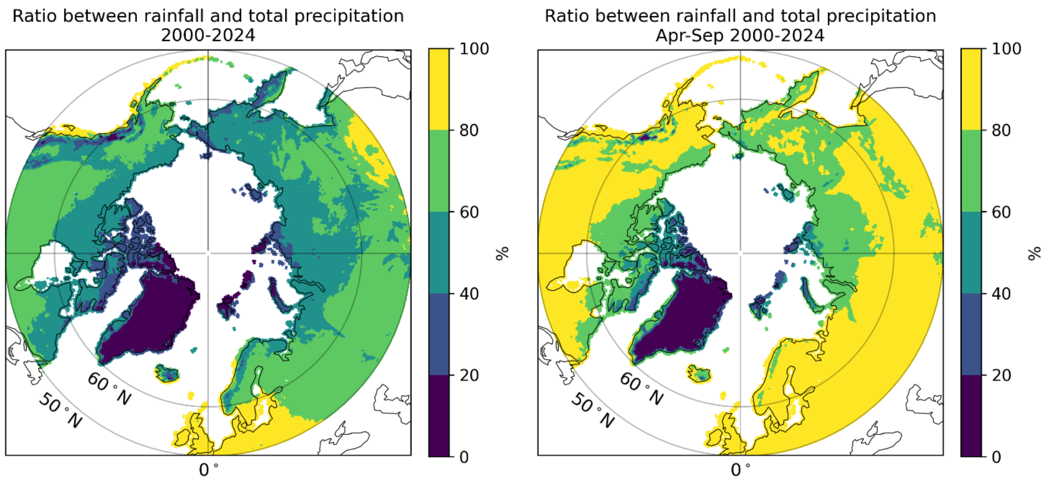

Figure 1. The proportion of rainfall relative to total precipitation based on ERA5 data from 2000 to 2024.

A second big question is about the neglecting of run off. (line 169). To me, but I might be wrong especially for Arctic areas, most of the run off occurs during rainfall or immediately after, so it cannot be negligible.

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.

I also have question on some aspects of the range of soil moisture. Maps show SM in excess of 0.7 m3/m3 but (figure 4) but I doubt the field capacity is higher than 0.5 m3/m3. So even the range seems excessive. It could corresponds to flooded areas but then the range being minimal, it would correspond to water bodies. But surely SMAP sees and flags water bodies (otherwise SM estimates are bound to be wrong) so what is it exactly? The authors might want to elaborate on this as it is most intriguing.

It is correct that SMAP sees and flags water bodies. As mentioned in the manuscript (lines 147-148), a grid cell is marked as water if the water fraction exceeds 5%. If the water fraction exceeds 50%, the SM retrieval is skipped. This means that if the water fraction within a grid cell is between 5% and 50%, a correction is applied and the grid cell is flagged for the high water fraction, but SM is still retrieved. The water bodies affect the quality of SM retrievals and therefore, the grid cells flagged for high water fraction do not have recommended quality (Fig. 2b).

Finland is characterized by an abundance of lakes, as shown in Fig. 2c, where large areas are flagged for high water fraction (light and dark blue areas). However, Finnish lakes are often small and vary in shape and size. Consequently, even though many grid cells are flagged for high water fraction, SM is still retrieved in most of them because the water fraction does not exceed 50%. The number of lakes is especially high in southeastern Finland, which also shows the highest SM values (Fig. 4). The presence of numerous lakes leads to saturated SMAP SM retrievals in these regions.

We acknowledge that water bodies complicate SM retrievals. As mentioned in the manuscript (lines 143-146), Finland is a challenging region for satellite-based SM retrieval, as large areas of the study region are covered with either water, dense vegetation, or both. However, despite the quality concerns, we chose to include all grid cells in our analysis, regardless of the surface flags, to evaluate how well the methods used in this study perform under suboptimal SM retrieval conditions. As the surface conditions affect the SM retrieval, we have identified these regions based on the SMAP surface and quality retrieval flags and divided the study area into four classes (Fig. 2c). We will provide further elaboration on this in the manuscript.

I am not sure also I understand the lower limit of 0.02 m3/m3 for SMAP Does it mean that SMAP SM estimates are never lower than this value? And if yes what is the rationale for this.

The lower limit for SMAP soil moisture retrieval is 0.02 m^3m^{-3}, meaning that the soil moisture values are never lower than that value. This limit is established by the SMAP team (O'Neill et al., 2021) and is beyond our control.

I have also a question for the authors on the choice of SM2RAIN. As here are some limitations linked to the assumptions of the approach (such as the one made above). So why use such algorithm? Why not use more robust approaches assimilating SMAP data in a simplistic model to infer rainfall? Of course such approaches require a initialisation through a first guess precip usually from systems such as IMERG. Did the authors consider such approaches which should be more reliable and why did they or did not? I am thinking of Pellarin et al for instance.

While it is true that the algorithm has limitations, one of the main advantages of the SM2RAIN algorithm is that it requires only soil moisture information to estimate precipitation. This is particularly beneficial for our purposes. Our aim is to apply this method across the entire Arctic, and the ability to rely solely on SM information provides a significant opportunity to estimate precipitation in remote Arctic regions. Despite its limitations, the algorithm has shown promising results in other regions. This study aims to investigate whether this approach can be effectively used in the Arctic. We will revise the manuscript to clarify why this approach is being utilized.

Line 112 a point of detail, the native spatial resolution of SMAP is not 36 km (it is an ellipse) but rather 39x47 km according to the SMAP handbook. So this statement is somewhat misleading. As very rightly indicated the 9 km grid corresponds to oversampling but this is not clear in table 1 where the resolution is indicated as being 9 km. The latter should be corrected.

The user guide for the SMAP product states that "the native spatial resolution of the radiometer footprint is approximately 36 km" (Section 1.3.2 in O'Neill et al., 2021). After consideration, we have decided to keep the text on line 112 unchanged to maintain consistency with the product user guide.

The resolution mentioned in Table 1 (9 km) corresponds to the grid resolution of the product used in this study. This table is designed to clearly present the data products used in this study, making it easier for readers to refer to the exact products used in the research. Since the SMAP product used in this study has a grid resolution of 9 km (with radiometer footprint defined native resolution), we believe it is clearer for readers to specify that resolution in the table.

References:

AMAP, 2021. AMAP Arctic Climate Change Update 2021: Key Trends and Impacts. Arctic Monitoring and Assessment Programme (AMAP), Tromsø, Norway. viii+148pp

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