We thank reviewer #1 for their comments on our manuscript. Our answers to the comments are below in blue, after the reviewer's comments.

The manuscript presents a machine-learning-based approach to downscale SMAP soil moisture data from 9 km to finer resolutions of 1 km and 250 m for boreal forests. The model integrates SMAP data with soil, vegetation, and weather inputs to provide higher spatial resolution soil moisture estimates, addressing the limitations of SMAP's coarse coverage in northern latitudes. Validation against in situ measurements shows improved accuracy, with reduced RMSE and increased correlation compared to raw SMAP data. However, the methodology is limited to forested areas, excluding peatlands and other land types. While the approach demonstrates the potential for high-resolution soil moisture mapping, several areas require substantial improvement before publication.

Major Comments:

1. SMAP Mission provides SMAP-Sentinel 3 km and 1 km soil moisture (https://doi.org/10.1016/j.rse.2019.111380), and it is very strange to see that these are not discussed in the literature section.
    - We apologize; this was an oversight on our part. We will add a discussion about SMAP/Sentinel data to our manuscript.

2. One of the key advantages of this study is its complement to the SMAP Sentinel Soil Moisture product, particularly by addressing NASA's limitation in providing soil moisture data over northern latitudes. However, while this contribution is acknowledged, the paper could have been strengthened significantly by demonstrating a more direct comparison with SMAP Sentinel dense time series in areas where such data are available. I would suggest the author replicate the same method over the mainland where SMAP Sentinel retrieval is available and compare for multiple locations. This can help a wider audience understand how the discussed method is reliable when compared to the operational product. This would provide a robust validation framework and establish the superiority or limitations of the proposed methodology.
    - We acknowledge this point; however, the model constructed in our manuscript is meant only for boreal forested areas. We consider that this kind of additional model construction and data compilation is out of the scope of this study and would need another paper.

3. The reliance on static inputs such as bulk density and silt content raises concerns about the adaptability of the model to regions beyond the boreal forests of Northern Finland. The training set's limited geographic and environmental variability suggests that the model may not perform well in regions with differing soil or vegetation characteristics. This could potentially undermine the generalizability of the approach, and expanding the training dataset to include diverse boreal forest sites would address this shortcoming.

- Unfortunately, the number of freely available boreal forest soil moisture in situ sites and their data is very limited, which prevents us from adding more in situ sites with different soil properties. Therefore, to demonstrate the applicability of the constructed model beyond Northern Finland, we validated it against soil moisture data from forested sites in Alaska. These sites differ notably in soil properties compared to the Finnish dataset: in Northern Finland's sites the bulk density ranges from 0.55 cg/cm^3 to 0.65 cg/cm^3 and silt content from 27.7 g/kg to 34.5 g/kg while in Alaskan sites bulk density varies from 0.41 cg/cm^3 to 0.79 cg/cm^3 and silt content from 48.9 g/kg to 70.2 g/kg. We acknowledge that this point should have been stated more clearly in the manuscript. We will revise the text to better explain the choices and clarify the limitations related to data availability.

4. The exclusion of peatlands from the study is a significant limitation, especially given their critical role in carbon storage in boreal ecosystems. Although the authors briefly discuss this gap, they fail to propose a concrete pathway for integrating peatlands into future models. More effort should have been made to outline how the methodology could be adapted to incorporate such essential land cover types.
    - Peatlands are excluded as there is data from only a few peatlands in situ sites available. As peatland can vary from dry to almost saturated, there would need to be many more in situ sites to be able to add peatland values to the model. In addition, there is great variation in moisture conditions at such a small spatial scale that even our 250 m pixel size is insufficient to capture it realistically. We have already outlined in the manuscript how peatlands could be included (L. 343-345).

5. The discussion around uncertainty analysis highlights the model's heavy dependence on soil properties, which dominate the prediction outcomes. While these are undoubtedly critical inputs, the relative insensitivity of the model to weather-related inputs like precipitation suggests a potential flaw in the approach. The coarse resolution of ERA5-Land data used for precipitation might be a

contributing factor, and exploring higher-resolution meteorological datasets could refine the model's sensitivity to short-term climatic variations.

- Yes, this is a good point. We will examine whether replacing ERA5-L data with higher spatial resolution precipitation and temperature data (e.g. 1 km spatial resolution data from https://en.ilmatieteenlaitos.fi/gridded-observations-on-aws-s3) improves the results. If that is the case, we will then explore the possibility of using a similar approach (i.e. kriging interpolation to weather station data) to provide precipitation and other quantities on around 1 km spatial resolution over Alaska (as this kind of data set does not, to our knowledge, exist). We will also explore the possibility of using satellite-based data to replace ERA5-L data.

6. The use of a machine-learning-based gradient boosting model (LightGBM) is appropriate for capturing complex relationships, but the small training dataset limits the robustness of the approach. Therefore, it's important to discuss the limitations of the method used and how to overcome them.
   - We will add more text to the manuscript about this.

7. The SMAP L3_SM_P_E spatial resolution is 33 km, which is gridded to 9 km, but this is not mentioned anywhere in the manuscript. Typically, downscaling should consider the original 33 km resolution rather than the 9 km gridded resolution. If the model directly uses the 9 km gridded data as the spatial resolution, I recommend reprocessing the model by considering the original 33 km resolution. Additionally, the revised version should clearly explain how this resolution is incorporated into the methodology.
   - The original resolution of SMAP L3_SM_P_E and the gridded one are mentioned in the manuscript in L. 35—36, and L. 69. It is true, that downscaling is typically done by using the original resolution, but not always. For example, the SMAP downscaled to 1 km product (Fang et al. 2022) uses the enhanced 9 km data product. Also, as we do have only a few in situ stations available, using the original spatial resolution would lead to even fewer static parameter values. Therefore, we cannot change the SMAP data to coarser resolution data.

Fang, B., Lakshmi, V., Cosh, M., Liu, P.-W., Bindlish, R., and Jackson, T. J.: A global 1-km downscaled SMAP soil moisture product based on thermal inertia theory, Vadose Zone Journal, 21, e20 182, https://doi.org/https://doi.org/10.1002/vzj2.20182, 2022

8. While the authors discuss future L-band missions like NISAR and ROSE-L, more focus should be given how this method will be useful for this mission.
    - We will add text about this to the manuscript.

9. Validation against in situ measurements shows promising accuracy improvements, but the exclusion of outliers like DIS0004 suggests sensitivity to anomalies that the model should handle better.
    - We will look into this as well. It is possible that the site DIS0004 actually has very different silt content (and also maybe bulk density) values than what we acquire from SoilGrids, which could explain the outlier nature of the DIS0004.

10. The conclusion section needs attention as it does not read well. Please consider rewriting the section more scientifically.
    - We will consider this.

Minor Comments:

1. L2: “Phenomena” is not appropriate here.
    - We will correct that.
2. L4: “High spatio-temporal scale” would be more appropriate.
    - We will change “high temporal and spatial scales” to “High spatio-temporal scale”
3. L37: “Short distance” is not appropriate. Rephrase as “spatially heterogeneous.”
    - We will correct this.
4. L41: Citation of the operational 1 km SMAP soil moisture product is missing (https://doi.org/10.1016/j.rse.2019.111380).
    - We will add this citation.
5. There are multiple sites in Alaska where in-situ soil moisture is available, and those should be included, such as the site from Delta Junction (NEON site).
    - We will add Delta Junction site to the validation.
6. A description of the study site is required in the main text.
    - We will add the description of study site to the manuscript.
7. It is unclear why CORINE land cover is used. The new ESA 10 m land cover provides more sufficient information for this study and spatially has more detail than CORINE.

- CORINE has a spatial resolution of 100 m, which is closer to the smallest acquired spatial resolution of 250 m. ESA 10m WorldCover data has unnecessarily high spatial resolution for our study.

8. L336: The NISAR mission will provide a 200 m soil moisture product as an operational soil moisture product. It is suggested to include proper citations in the manuscript (https://doi.org/10.1016/j.rse.2023.113667 and https://doi.org/10.1016/j.rse.2024.114288).
   - We will add these citations to the manuscript.
9. L338: NISAR will be launched in April 2025.
   - We will correct this.