In blue: Reviewer's comments. [ ] = Numbering

In black: Answers to referees.
P=Page; L=Line; Track change version
In black and italic: Modification added to text.

Reviewer #2:

Synopsis:

The high latitudes are experiencing significant environmental changes that necessitate precise, large-scale, and long-term measurements of the interconnected hydrological and ecological systems. Microwave remote sensing is a critical tool for tracking gradual and sudden changes in the region and revealing the underlying relationships and mechanisms. This paper offers a timely and perceptive overview of microwave remote sensing in high-latitude environments, which is likely to benefit the scientific community and aid in the advancement of remote sensing research in carbon studies. Overall, the paper was clearly structured and nicely written. However, there are a few corrections and improvements to be made before I recommend it for publication:

Specific comments:

[1] Fig. 3(a): please change "Forest" to "Vegetation";

The correction was made in figure 2(a).

[2] Fig. 3(b): The figure illustrates three soil-vegetation interaction components, which are not shown in the associated equation and labels. A more complete equation consistent with the figure and accounting for the first-order scattering process is preferred.

Since the manuscript is mainly aimed at the carbon cycle science community, we think that going deeper in the vegetation scattering processes of microwaves would dilute the focus of our manuscript. We clarified in the Fig. 2 caption that the equation's vegetation term is an approximation of all first-order vegetation scattering processes.

P6, Fig. 2: *The σ_{veg} term is an approximation for the first-order vegetation scattering processes.*

[3] Fig. 4(a): Radar observations similar to passive microwave remote sensing are also affected by vegetation water content. Please consider to have "Vegetation water storage" under "Passive and Active" category.

Vegetation water storage was moved from the Passive column to the Passive and Active column in Fig. 4.

[4] Table 1: For the AMSR-E/2 column, the temporal coverage should start from 2002 instead of 2012.

The starting date was corrected in Table 1.

[5] Line 310: The statement "The rapid decrease of εsoil in freezing soils translates into a much higher microwave emission and backscattering from the surface" is not accurate. The decrease of soil dielectric constant typically corresponds to weaker radar backscattering from soil. However, for a complex high-latitude scenario with mixed soil, snow and vegetation, landscape freeze/thaw transitions can cause both enhanced or weakened microwave scattering depending on its frequencies. A nice reference explaining the rationale can be found at:

Zwieback, S., Bartsch, A., Melzer, T. and Wagner, W., 2011. Probabilistic Fusion of Ku- and C-band Scatterometer Data for Determining the Freeze/Thaw State. IEEE transactions on geoscience and remote sensing, 50(7), pp.2583-2594.

The statement was corrected, and references were added for the microwave emission and backscattering impact.

P11, L315-316: The rapid decrease of ε_{soil} in freezing soils translates into a much higher microwave emission *(Rautiainen et al., 2012)* and *weaker radar* backscattering *(Zwieback et al., 2011)* from the surface.

P54, L1814-1816: *Zwieback, S., Bartsch, A., Melzer, T. and Wagner, W.: Probabilistic Fusion of Ku- and C-band Scatterometer Data for Determining the Freeze/Thaw State. IEEE T. Geosci. Remote, 50(7), 2583-2594, doi: 10.1109/JSTARS.2015.2476358, 2011.*

[6] A recent work focusing on the possibility of detangling AGB and the vegetation water content from VOD (e.g. Line 392) can be found at:

Dou, Y., Tian, F., Wigneron, J.P., Tagesson, T., Du, J., Brandt, M., Liu, Y., Zou, L., Kimball, J.S. and Fensholt, R., 2023. Reliability of using vegetation optical depth for estimating decadal and interannual carbon dynamics. Remote Sensing of Environment, 285, p.113390.

The reference to the more recent work on AGB was added.

P14, L404-406: The microwave VOD sensitivity to both AGB and vegetation water status complicates its interpretation, although the study of the temporal and spatial trends of VOD can allow to distangle AGB vs the vegetation water content *(Dou et al., 2023)*.

P29, L796-798: *Dou, Y., Tian, F., Wigneron, J.P., Tagesson, T., Du, J., Brandt, M., Liu, Y., Zou, L., Kimball, J.S. and Fensholt, R.: Reliability of using vegetation optical depth for estimating decadal and interannual carbon dynamics. Remote Sens. Environ., 285, 113390, doi: 10.1016/j.rse.2022.113390, 2023.*

[7] For section 5.2, I recommend additional review of recent machine-learning based downscaling studies, which help to resolve the spatial heterogeneity of land parameters. For example, below is a recent paper on soil moisture downscaling:

Du, J., Kimball, J.S., Bindlish, R., Walker, J.P. and Watts, J.D., 2022. Local Scale (3-m) Soil Moisture Mapping Using SMAP and Planet SuperDove. Remote Sensing, 14(15), p.3812.

A quick overview of the results from Du et al. (2020) recent work was added to section 5.2.

P18, L518-520: *A recent study from Du et al. (2020) showed promising results in downscaling soil moisture to 3 m spatial resolution using machine-learning with microwave spaceborne data.*

P29, L812-813: *Du, J., Kimball, J.S., Bindlish, R., Walker, J.P. and Watts, J.D.: Local Scale (3-m) Soil Moisture Mapping Using SMAP and Planet SuperDove. Remote Sens., 14(15), 3812, doi: 10.3390/rs14153812, 2022.*

[8] I also recommend the authors add a short summary of the satellite GNSS-R technique for high-latitude studies. The novel approach shows promise in soil moisture, vegetation, water body and freeze/thaw detections. Here is a nice reference:

Rautiainen, K., Comite, D., Cohen, J., Cardellach, E., Unwin, M. and Pierdicca, N., 2021. Freeze–Thaw Detection Over High-Latitude Regions by Means of GNSS-R Data. IEEE Transactions on Geoscience and Remote Sensing, 60, pp.1-13.

The potential of the novel GNSS-R approach was added in Sect. 5.3 (Potential and upcoming spaceborne microwave remote sensing missions).

P19, L535-539: *Furthermore, the novel approach of opportunistic use of spaceborne reflectometry of the Global Navigation Satellite System (GNSS) (Li et al., 2022; Yu et al., 2022) already showed promising results in evaluating soil moisture (Edokossi et al., 2020), soil freeze/thaw state (Rautiainen et al., 2021) and snow water equivalent (Royer et al. 2021).*

P29, L822-824: *Edokossi, K., Calabia, A., Jin, S., and Molina, I.: GNSS-Reflectometry and Remote Sensing of Soil Moisture: A Review of Measurement Techniques, Methods, and Applications. Remote Sens., 12, 614, doi: 10.3390/rs12040614, 2020.*

P45, L1456-1458: *Rautiainen, K., Comite, D., Cohen, J., Cardellach, E., Unwin, M., and Pierdicca, N.: Freeze–Thaw Detection Over High-Latitude Regions by Means of GNSS-R Data. IEEE Trans. Geosci. Remote Sens., 60, 1-13, 4302713, doi: 10.1109/TGRS.2021.3125315, 2022.*

P46, L1521-1523: *Royer, A., Roy, A., Jutras, S., and Langlois, A.: Review article: Performance assessment of radiation-based field sensors for monitoring the water equivalent of snow cover (SWE). Cryosphere, 15, 5079–5098, doi: 10.5194/tc-15-5079-2021, 2021.*

P37, L1121-1123: *Li, W., Cardellach, E., Ribó, S., Oliveras, S., and Rius, A.: Exploration of Multi-Mission Spaceborne GNSS-R Raw IF Data Sets: Processing, Data Products and Potential Applications. Remote Sens., 14, 1344. doi: 10.3390/rs14061344, 2022.*

P53 L1793-1794, LX: *Yu, K., Han, S., Bu, J., An, Y., Zhou, Z., Wang, C., Tabibi, S., and Cheong, J. W.: Spaceborne GNSS Reflectometry. Remote Sens., 14, 1605, doi: 10.3390/rs14071605, 2022.*