Reviewer #2

Review on A novel global freeze-thaw state detection algorithm based on passive L-band microwave remote sensing, by Lv et al., (tc-2021-369).

This paper used Diurnal Amplitude Variation (DAV) to detect the landscape FT status over Northern hemisphere using SMAP L-band H-pol brightness temperatures. The performance of the FT classification was assessed using ERA5 2m air temperature and other global SMAP FT data records. The paper covers a topic that is suitable to readers of The Cryosphere and should be of particular interest to those interested in FT classification algorithm development and FT dynamics under climate change. However, the manuscript has concluded with lack of detail in describing method and FT classification algorithm, and insufficient FT agreement assessment. Additional analysis on relationship between L-band signal and soil temperature should be added to improve the conclusion (See "line 329-331" below). The suggested major revisions are as follows:

- Major concern is FT agreement assessment. Authors used air and skin temperatures, and soil temperatures at several depths from a single site (Xilinhot). Agreement assessment from only one site is not enough for global scale FT validation. FT sensitivity to L-band Tb signal varies on land cover type and climate regions.

Reply: Sorry for the misunderstanding. Agreement assessment (Section2.4) is achieved in the domain latitude > 20°N by ERA5-land and SMAP FT products (both TB and F/T information contained). We did not calculate the agreement at the Xilinhot site. The role of the Xilinhot site is to illustrate the assumption/algorithm of the new method described in Section 2.3 at the Xilinhot site. We revise the subtitle of Section 2.3.

- In the accuracy agreement at global domain, ERA5 is a model reanalysis data with uncertainty as well. Authors should include additional global FT agreement assessment instead of using only ERA5 data.

Reply: We agree that more assessments should be taken, and ERA5-land is just one reanalysis product. As we mentioned in the Discussion, the lack of ground truth is vital to developing the L-band remote sensing FT products. To acquire precise soil temperature/air temperature data is beyond the scope of this study. The SMAP FT team uses WMO's air temperature, and WMO's air temperature is still sparse for the agreement assessment. For instance, how to deal with the scale mismatch between the weather station and SMAP's footprint? How to account for sub-grid open water fraction, terrain heterogeneity, tree cover, precipitation, and snowmelt and on with the weather station data? These problems can be avoided for ERA5-land air temperature in the evaluation, and we are aware that the ERA5-land air temperature is not appropriate for validation which needs FT ground truth for sure. Similar words are added in Line 331-334.

- Additional analysis on relationship between L-band signal (FT dynamics as well) and soil temperature should be added to improve the conclusion. That would be the possible reason why L-band microwave remote sensing can be used for better penetration depth monitoring.

Reply: The penetration depth issue and sensing depth issue for soil moisture retrieving from L-band is still not clear (Lv et al. 2019 on IEEE TGRS). The problem is more complex for frozen soil because the dielectric profile is not continuous if freeze-thaw transitions happen in the middle layers of a profile, and a complete frozen soil profile shall have much deeper penetration theoretically. Thus, we can not even get a precise penetration depth for the case

of a freeze-thaw transition. By using the air temperature, we avoid this complicated situation. Otherwise, to select which layer and according to what standard in comparison with the SMAP FT products would be vulnerable. In this study, we use the same method as the SMAP handbook, which is considered as the state-of-art in this topic, to get the agreement.

- Although this study provided better overall FT classification accuracy, it is not clear that what factors (or which land cover type?) contribute to improve FT classification accuracy or degrade. Other landscape factors affect FT classification accuracy. The factors include sub-grid open water fraction, terrain heterogeneity, tree cover, precipitation and snowmelt and on. To improve the quality of the paper, additional analysis and discussion on this should be required.

Reply: Thank you for your suggestion. We admit the method is not perfect, but seeing from the result, the agreement (Figure 9) with air temperature and SMAP FT products doesn't rely on the sub-grid open water fraction, tree cover, precipitation, and snowmelt much. The terrain is a major factor for sure because we can see Tibet and Rocky mountains in Figure 9. However, even without considering so many factors, the new algorithm shows comparable agreement with SMAP's FT products. We can not say the new algorithm is better, but that's already inspiring。

In SMAP-FT products, sub-grid open water fraction, terrain heterogeneity, tree cover, precipitation, and snowmelt are not fully discussed yet. The assessment for SMAP FT products is restricted with core site soil temperature and WMO weather station. We are trying to contact the SMAP FT team to get their ground data for considering the landscape, and we believe this will improve the new algorism in the future.

Additional edits are noted below:

Line 66: Are the limitations not clearly described? Authors should include what the limitations are in more details.

Reply: the sentence is revised.

Line 72-74: This is not clear to me. Author should clarify it.

Reply: the sentence is clarified by Eq. 8. But it should not be mentioned in here. So I deleted it from the text.

Line 87: Authors should justify why you used 36km instead of 9km brightness temperature (Tb) data records. Indeed, SMAP data are provided at both 36-km and 9-km spatial resolution. The 9-km spatial resolution is closer to 0.1 degree ERA5.

Reply: As noted on https://nsidc.org/data/SPL3FTP_E/versions/3 "is derived from SMAP enhanced Level-1C brightness temperatures (SPL1CTB_E)." For SPL1CTB_E, Backus-Gilbert optimal interpolation techniques are used to extract enhanced information from SMAP antenna temperatures before they are converted to brightness temperatures. The authors are not familiar with Backus-Gilbert optimal interpolation techniques, and the interpolation will certainly reshape the original DAV signal. Thus, we prefer the raw 36km F/T products.

Line 89: This study used older version of SMAP data.

Reply: We use data downloaded from https://nsidc.org/data/SPL3FTP/versions/3. This is the most recent version of these data. The TB data is stored in the same file as the FT products.

Line 92, 98: ERA5 data provide hourly. What time did authors use for agreement assessment? Is it 6PM or 6AM? Authors should include data source (e.g., web link).

Reply: "According to longitude, the hourly data are interpolated to 6 am and 6 pm local time." is added in Line 97. This is the same method we used in Lv et al. 2016 RSE. The data source is

added in Line 90.

Line 118-123: The relevant citation should be included (Xu?, Derksen? Kim?).

Reply: Xu et al., 2018 is added in Line 128.

Line 134: Surface air temperature from global weather stations were used for landscape FT classification accuracy assessment, not for validation. Authors should check and revise it.

Reply: Thank you very much. "accuracy assessment" replaces "validation" through the text. "reanalysis data" is deleted from Line 133.

Line 165: Why did you use H-pol? Is there any justification?

Reply: "The DAV signals between H and V polarizations have few differences(Sharifnezhad et al., 2021)" is added in Line 175.

Line 178-179: Is this your assumption?

Reply: Thank you. We use "assume" instead of "define" in Line 188.

Line 212: Authors should include in-situ data description in Data sections (e.g., relevant references, data source (web site)).

Reply: There is in-situ data used in this study. At the Xilinhot site, the ERA5 reanalysis data and SMAP data covering the same location are used.

Line 222: Figure 4 does not show soil moisture variations. How did you provide the influence of soil moisture on Tb? If it is soil moisture influence, how much variation in soil moisture?

Reply: The influence of soil moisture on Tb is implicitly included in the TB signal. Figure 3 shows the freezing line as well as the SMAP's FT state, which indicates that the soil is frozen.

Line 263: The geographic location of Xilinhot site should be provided to check if this site is within a domain applied to SCV algorithm in SMAP FT Products.

Reply: Thank you for your suggestion. "(43°30′–45°N, 115°–117°E)" is added in Line 117. The location of Xilinhot is marked in Figure 9, where the comparison is made between the new algorithm and SMAP's FT products. SMAP FT Products downloaded from https://nsidc.org/data/SPL3FTP/versions/3 and applied to the entire north hemisphere.

Line 286: SMAP FT sate products were compared new FT data. Authors should provide more details on SMAP FT state products used in this validation. Which overpass time did you use? (e.g., 6am or 6pm?).

Reply: Section 2.4 explains in detail that both 6 am and 6 pm SMAP products are used and how we construct the daily SMAP FT dataset matching the time resolution of the new algorithm. As suggested by your previous comments, there is no validation in this study but an accuracy assessment.

Line 293: Authors compared two FT state data with different spatial resolution. You should include how to reproject one data from another in method sections. Is it from 0.1 degree to 36km?

Reply: The two FT state data are derived from both SMAP's 36 km data. The SMAP's FT product files contain the TB raw data already. So there is no spatial resolution difference between these two FT state data. "All elements from ERA5-land are interpolated to SMAP 36 km resolution in this study." In Line 107

Line 296: Why was it worse in latitudes above 60N and low latitudes below 30N? Is it false frozen or thawing? What if you use skin or/and soil temperature? Could it be a better agreement?

Reply: The agreement is worse or better does not mean the false frozen or thawing. In SMAP

FT official handbook (Page 24) and Kim et al. 2021 (conclusion part) on Remote Sensing, the agreement between SMAP FT product mission requirement is 80%. According to Kraatz et al. 2018, agreement with 0–5 cm soil temperature at SMAP grids containing CVS stations is about 70%.

Although using the skin/soil temperature may make the results looks better, we would not recommend this in the accuracy assessment because 1) the skin temperature does not correspond with the sensing depth of L-band and 2) the soil temperature from ERA-5-land is criticized in previous studies as "ERA5 is a model reanalysis data with uncertainty as well", so the soil temperature is not reliable for validation. What we did with the ERA5-land is the accuracy assessment by comparing with SMAP FT products and ERA-5 land air temperature.

Air temperature is used in SMAP FT official handbook (Section 4.2.3 CALIBRATION AND VALIDATION in Algorithm Theoretical Basis Document (ATBD) SMAP Level 3 Radiometer Freeze/Thaw Data Products (L3_FT_P and L3_FT_P_E)). Since we lack in-situ soil temperature data as in that handbook, air temperature is the last option we can take in this study.

Line 324: Some studies reported the results on FT accuracy assessment with soil temperature derived FT state. Authors should discuss the results from previous studies.

Reply: "Some studies use soil temperature to evaluate SMAP FT products, and with 0–5 cm, soil temperature at SMAP grids containing CVS stations is about 70%. " is added in Line 341-342. As the core idea in the discussion, we agree that a lack of in situ soil temperature observations presents a key data gap in assessing frozen soil extents.

Line 329-331: Because you did not use soil temperature (indeed, soil temperature from one site only), this statement is not clear conclusion.

Reply: soil temperature is not adopted as explained above. This part does not discuss soil temperature either. The assessment for SMAP FT products is restricted with core site soil temperature and WMO weather station. We are trying to contact the SMAP FT team to get their ground data for considering the landscape

Line338: Is spatial resolution of ERA5 1degree? In data section, the resolution is 0.1 degree.

Reply: Thank you. It is corrected as "0.1°x0.1° lat-lon grid (0 to 100 km^2)".

Figure 1: It would be great to include the latitude/longitude of Xilinhot site.

Reply: Thank you. "(43°30′–45°N, 115°–117°E)" is added

Figure 3: It is too complicated. Author could remove unnecessary time-series lines.

Reply: Figure 3 removes soil temperature lines.

Figure 4: Where (or what) is Maqu?

Reply: Thank you. The title part is removed.

Figure 5: Authors should describe study domain in details. E.g., how to define your domain?

Reply: "and we focus on the domain from 20°N to 85.044°N" is added in Line 87 as well as Figure 5.