Reply to RC1 for the manuscript "An Extended Global Earth System Data Record on Daily Landscape Freeze-Thaw Status Determined from Satellite Passive Microwave Remote Sensing" by Youngwook Kim, J. S. Kimball, J. Glassy, and J. Du

Dear Anonymous Referee #1, thank you for your constructive comments on our manuscript. Please find below our responses to all of the review comments. The resulting responses and manuscript changes (in *italic*) are provided immediately after each reviewer comment (in **bold**).

Responses to Referee #1's comments:

The manuscript presents an improved global database of F/T surface state based on passive microwave observations at 37 GHz V-pol. The authors first depict the main features of the F/T maps, before assessing of the database against several in situ surface air temperatures, and other cryosphere data.
The study gives an interesting improvement of a long temporal series (1979-2014) of global F/T product based on TB at 37 GHz V-pol. The validation analysis also gives a good idea of the factor affecting the accuracy of the product. There are also some good analyses on temporal evolution of FT related parameters. However, the manuscript could be improved with a better explanation of the difference between this product and the Kim et al., (2011) product (see detail in the following report). Also, the FT definition should be precise in the manuscript. For example, at 37 GHz, the FT signal in fall probably come mostly for the soil freezing, while in spring the signal coms from the liquid water in snow and a signal from spring ice breakup (see Kang et al., 2010 and Roy et al., 2015). Some discussion on the physics behind the signal could thus be added.

In response to the above comments, we added landscape FT definition and provided FT signal characteristics at 37GHz. The detailed changes are summarized below:
For this investigation, we define landscape FT state as the predominant (frozen or thawed) condition of water within the satellite sensor field-of-view (FOV). The 37 GHz brightness temperature retrievals represent the mean emitted radiation from the integrated land surface within the FOV. The FT-ESDR landscape FT classification does not distinguish between vegetation, air, snow or soil FT elements (Kim et al., 2011, 2012), but is based on 37GHz brightness temperatures that are more closely related to surface temperature rather than soil temperature (Kim et al., 2011, 2012). We added additional clarification in the revised manuscript following reviewer recommendations (Ln 123-126): "*For this investigation, the FT-ESDR defines the predominant frozen or non-frozen condition of the landscape and does not distinguish among individual vegetation, snow and soil FT elements within a grid cell (Kim et al., 2011, 2012). The satellite microwave T_b retrievals represent the mean emitted radiation from the integrated land surface within the grid cell.*"

Hence, I recommend publication in Earth System and Science Data following some revisions as outlined in the following report.

1. Line 80: What zone are not included in the new version (only open water bodies: see Fig 1). What is the difference between open water inundated and open water bodies?
Changes from earlier product versions include a larger FT-ESDR domain encompassing all land areas affected by seasonal frozen temperatures, including urban, snow-ice dominant, open water body dominant, and barren land which are excluded from the prior FT-ESDR domain. The new FT-ESDR domain excludes grid cells where open water fraction was 100% (open water body) or less, and the mean cold temperature constraint index (CCI) was less than 5 days year^{-1} based on the 36-year CCI record. Our open water screening technique is based on a static land cover classification and does not account for seasonal variability in open water bodies (inundation). We added the following description in the revised manuscript (Ln 246-248) for further clarification of the static open water cover map used for the FT-ESDR relative to dynamic surface inundation variations:
"*A 300-m water body map for the 2010 epoch (from 2008 to 2012) produced from European Space Agency (Defourny et al., 2016) was used to derive fractional open water coverage (F_w, %) within each 25-km FT-ESDR grid cell; the F_w map only defines static open water body cover and does not account for temporally dynamic variations in surface inundation*."

We also switched terminology from open water inundation to open water dominant areas (Ln 81) in the revised text (See Reviewer 1, specific comment 2 below for our detailed response).

***2.* It is not clear what zone are not included in Kim et al., (2011) version and why they were excluded. It should also be clarify what was done in this study to monitor FT in these new areas that was not done in Kim et al., (2011)?**
The previous FT-ESDR (Kim et al., 2011) encompassed vegetated land areas where seasonally frozen temperatures are a major constraint to ecological processes, and excluded non-vegetated grid cells where the open water fraction is greater than 20%, or dominant land cover categories for permanent snow and ice, urban, and sparsely vegetated areas; this was done to emphasize frozen temperature constraints to vegetation growth, while reducing potential noise effects on the FT estimates over non-vegetated surfaces (e.g. due to lake ice and wave effects for large water bodies, and snow cover variability). The new FT-ESDR domain encompasses all frozen temperature affected land areas, including vegetated, urban, large open water, snow-ice dominant, and barren landscapes; the areas showed generally lower FT accuracy than vegetated land areas, but were still found to produce favorable product performance. For better clarity, we revised the text in the abstract (Ln26-28): "*The global domain encompasses all land areas affected by seasonal frozen temperatures, including urban, snow-ice dominant and barren land, which were not represented prior FT-ESDR versions.*" And we revised the text (Ln 152-159): "*The prior FT-ESDR global domain encompassed only vegetated land areas where seasonally frozen temperatures are a major constraint to annual vegetation growth; the domain excluded grid cells*

where the areal open water cover fraction exceeded 20% or was dominated by other non-vegetated land cover categories. The new FT-ESDR domain described in the current investigation is 41.5 percent (~27 million km2) larger than the prior record and encompasses all frozen temperature affected land areas (CCI>5 day yr^{-1}), including vegetated, urban, open water, snow-ice dominant, and barren landscapes defined from a static global IGBP land cover classification (Friedl et al., 2010)."

3. **Line 81: Do you mean SMMR and SSM/I operation as SSM/I only started in 1987? What time period is the Kim et al., (2011) product?**
We added SMMR into the text. For better clarity, we revised the text (Ln 81-83): "*We exploit SMMR and continuing SSM/I operations to develop a longer data record (1979-2014) than prior FT-ESDR releases (Kim et al., 2011) extending over a shorter 20-year record (1988-2010).*"

4. **Line 127-128: Continue your idea by developing on how these phenomenon will impact FT monitoring?**
There is ambiguity in the frequency dependent response of the microwave signal to surface soil, snow cover and vegetation elements, and moisture contents. Microwave signals at lower frequencies (e.g., L-band) have stronger sensitivity to soil permittivity with greater penetration through vegetation and into the near surface soil than at higher frequencies (Watanabe et al., 2011).
In accordance with the reviewer recommendations, we added the following additional explanation in the main text (Ln 135-137): "*Higher moisture levels in soil and vegetation layers reduce the effective depth of microwave FT sensitivity, while lower microwave frequencies have generally greater depth of FT sensitivity (Watanabe et al., 2011).*"

5. **Line 156: So there is a threshold for each pixel and each year? At what point the product will be different than the ERA-Interim information that is used to implement the threshold. It seems to me that the passive microwave product is probably very dependent of the ERA-Interim STA?**

The grid cell-wise MSTA FT threshold was defined annually using an empirical linear regression relationship between the satellite T_b retrievals and weighted ERA-Interim SAT. The annual calibration of the grid cell-wise MSTA FT thresholds was used for producing a consistent and continuous daily FT global data record. The FT-ESDR is more sensitive to landscape FT variations from soil, snow cover and vegetation elements within the sensor footprint than SAT that can be used to infer landscape FT state (e.g., 0°C SAT threshold). SAT and the T_b defined FT state reflect different physical attributes with different spatial and temporal distributions. For example, the SAT record shows much larger temporal variability relative to the T_b defined FT conditions which reflect changes in surface dielectric properties in surface soil, snow and vegetation cover. The use of SAT for calibration of T_b based FT thresholds contributes error and constrains potential FT-ESDR accuracy. The FT classification accuracy was directly proportional to the mean correspondence (r-value) between the satellite T_b retrievals and weighted ERA-Interim SAT used to define the grid cell-wise MSTA FT threshold (Figure 5c). The SAT influence is included in the FT quality assurance assessment and associated QA metric (Section 3.5). For better clarity, we revised the text in the revised manuscript as follows (Ln 194-211):

"*The MSTA approach assumes that the large changes in microwave dielectric constant of the land surface that occur around the 0°C temperature threshold are associated with landscape FT transitions that dominate the corresponding satellite 37 GHz Tb seasonal dynamics, rather than other potential sources of Tb variability (Kim et al., 2011). An advantage of the MSTA over the previous STA approach (Kim et al. 2011) is that the Tb threshold selection does not depend on frozen and non-frozen reference states derived by averaging Tb measurements over respective winter and summer periods, and is less sensitive to Tb data gaps during these reference periods. The grid cell-wise Tb thresholds and annual calibration used for the MSTA reduce the potential influence of spatial and temporal variations in climate and land surface conditions on FT classification accuracy, and promote greater consistency in global product performance over the long-term record. The daily SAT record used for the MSTA calibration approximates FT related shifts in near surface air temperatures using a fixed 0.0°C temperature threshold. In contrast, The 37 GHz Tb retrievals used to construct the FT-ESDR are sensitive to land surface dielectric variations stemming from FT related shifts in surface soil, snow cover and vegetation elements within the sensor footprint. The SAT and Tb records represent different physical phenomena with different spatial and temporal characteristics; these factors may contribute uncertainty to the MSTA thresholds and classification accuracy, which are represented in the FT-ESDR accuracy quality assurance metrics (Section 2.4).*"

***6.* Line 263: add units (days) to FS, it will clarify the "mean annual frozen season" term.**
We added the units (Ln 303).

***7.* Line 287-289: it seems that there is a significant decrease of agreement in 1987 and 1988. Could it be related to the sensors transition?**

This was attributed to significant gaps in the 1987 and 1988 sensor T_b records during the SMMR and SSM/I sensors transition, leading to greater associated uncertainty in the FT classifications. In accordance with the reviewer recommendations, we revised the text (Ln 326-329): "*The mean annual FT spatial classification agreement for 1987 and 1988 was lower than other years of record due to large temporal Tb gaps in December 1987 and January 1988 coinciding with the SMMR to SSM/I sensor transition period.*"

***8.* Line 428: is FS from lake dominated pixel or all pixels?**
FS is derived for lake dominated grid cells. Accordingly we revised the text (Ln 482-484): "*The FT-ESDR based mean annual FS metric over lake dominated grid cells was directly proportional to collocated annual ice duration observations ($r=0.938$; $p<0.001$) from the Global Lake and River Ice Phenology Database (1979-2013) as summarized in Figure 8.*"

***9.* It should be noted that there is generally a delay between snow melt (passive microwave signal) and lake breakup. It should be mentioned and discussed.**
In accordance with the reviewer recommendations, we added the following additional statement in the discussion (Ln 493-496): "*Generally earlier FT-ESDR derived primary spring thaw onset and a shorter frozen season relative to the in situ lake and river ice observations indicate earlier seasonal thawing of surrounding land areas, consistent with snowmelt and runoff driven lake and river ice breakup (Park et al. 2016b).*"

References

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