Technical Note - SMOS Level 3 Brightness Temperature (TB) Users'manual and useful tips Quality assessment flags

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ACRONYMS

- CATDS	:	Centre Aval du Traitement des Données SMOS
- SMOS	:	Soil Moisture and Ocean Salinity
- SMAP	:	Soil Moisture Active and Passive

Contents

1 Goal of the document

The CATDS L3 TB data set provides a users' friendly packaging of the more cumbersome L1 product. To provide users with an optimal data set, most of the data is kept even when affected by perturbing factors, the latter being identified through flags. The goal of this document is to present the data set, with a description of the flags and their exact meaning, together with suggestions on how to use them. It must be understood though that the way to use such flags is very much usage dependent. Should one want as much data as possible in an area affected by RFI, he/she will accept maybe more degraded data while someone wanting to verify say a fundamental measurement issue might want to filter out all data non 100% pure. So user's discretion on the use of suggested threshold is a key point and choice has to be tuned to the user's actual requirements.

2 Introduction

This note introduces several methods used to quantify the quality of SMOS Level 3 Brightness Temperature (SMOS L3TB) products [1]. It is mainly related to spurious effects like radio frequency interference (RFI) rather than issues related to the instrument or reconstruction algorithms addressed in other L1 related document. The user is encouraged to consult the product specification ([2],[3]) and algorithm theoretical baseline ([4]) documents when using L3TB data.
Although some quality thresholds are introduced here the exact thresholds to be used depends on the application. For example, an application that may be attempting to estimate soil moisture or other parameters of interest over a specific location may have more stringent requirements than an application dealing with climate trends.

3 SMOS L3TB product content

The L3TB product is derived directly from SMOS L1 with some modifications. The polarization is at ground level, data is binned to fixed angle values, and data is provided in NetCdf on the EASE-2 grid projection with a 25 km sampling. TB values are provided in horizontal, vertical, and Stokes 3 and 4 polarisations. The TB values are provided for 15 angle bins (each bin 5-degree wide), centered on angles 2.5 to 62.5. Note that bin 9 is centered on 40 and has a width of 2 degrees rather than 5. Also note that bin 15 is empty and is reserved for future use. All TB values (H, V, S3, S4) are accompanied with the following parameters, among others:

- *Pixel_Radiometric_Accuracy*
- *Pixel_BT_Standard_Deviation (hereafter Standard_Dev)*

For each bin the following parameters, among others, are provided

- *Nviews*: number of views
- *Nb_RFI_Flags*: Number of views suspected to have RFI
- *Nb_SUN_Flags*

See the document [5] for a complete specification of the product content.

Note that filters are applied on the L1 TB to remove spurious data following the criteria displayed in Figure 1. Be careful, the bottom rows ("RFI" and "Sun Correction") of Table 1 in [2] (not reported here) are not used anymore for this new version of the L3TB (version 330).

Filtering criteria	Applied test
Thresholds	$50\,\mathrm{K} < \mathrm{TB}_X$ and $\mathrm{TB}_Y < 340\,\mathrm{K}$ $-50\,\mathrm{K} < \mathrm{TB}_{xy} < +50\,\mathrm{K}$
Amplitude	$50\,\mathrm{K} < \sqrt{\mathrm{TB}_x^2 + \mathrm{TB}_y^2} < 500\,\mathrm{K}$
Standard deviation	$\mathrm{TB} - 2 \cdot \mathrm{ATB} < \mathrm{TB} < \mathrm{TB} + 2 \cdot \mathrm{ATB}$
First Stokes	$\mathrm{ST1} - \overline{\mathrm{ST1}} < 5 + 4 \cdot \mathrm{ATB}$
Spatial resolution[a]	$\mathrm{SMEF} < (55 \times 55)\,\mathrm{km}^2$ $L_{\mathrm{ma}}/L_{\mathrm{mi}} < 1.5$ BORDER FOV (flag is off)

Figure 1: Filters and Criteria applied on the L1TB to produce the L3TB, from Table 1 in Al Bitar et al. 2017.

4 Quality assessment indicators

When using the L3TB, one should perform a few tests so as to estimate the quality of the TB values and their adequation to a given use, and in particular:

- check that TB values are within a given realistic range,
- $\frac{Nb\_RFI\_Flags}{Nviews}$: is used as an indicator of the level of RFI contamination for a given bin.
- $\frac{Standard\_Dev}{Pixel\_Radio\_Accuracy}$: can be used as an indicator of spurious effects, including RFI, for each bin.

5 Analysis

To be able to filter efficiently the brightness temperatures according to their "quality", two metrics are suggested. They are based on the two following quantities:

- $\frac{mean(Nb\_RFI\_Flags)}{mean(Nviews)} >$ threshold
- $\frac{mean(Standard\_Dev)}{mean(Pixel\_Radio\_Accuracy)} >$ threshold

for both H and V

In both cases above "mean" is taken over all bins.

In order to determine reasonable thresholds for those ratios, two approaches were used. In Sect. 5.1 several thresholds of those ratios are compared to thresholds on the RFI_Prob variable from the L2SM (**c'est realement le L2SM ou le L3SM ?****) datasets. In Sect. 5.2 different thresholds on those ratios are applied and the after-filtering L3 BTs are compared to those of SMAP. The goal is to benefit from the onboard filtering of RFI implemented on SMAP thanks to the experience acquired with SMOS.**

5.1 Comparison to the L2 RFI_Prob parameter

We have used L3TB products (Ascending mode only) for May 2017 and have compared results using the RFI probability values obtained from the operational level2 product (L2SM) from ESA DPGS. The L2SM product used is V650 remapped to EASE 2 grid. The L2SM product contains 9 parameters, including the RFI probability values. Note that RFI probability data has a memory of two weeks since L2SM uses

current RFI file in order to compute RFI prob. In addition L2SM RFI prob is a single figure per EASE 2 grid, whereas we are interested in bin per bin estimates.
Figure 1 shows the number of days in May 2017 for which:

- L2SM RFI > threshold, ranging from 0 to 50% (0.5) (top row),
- $\frac{mean(Nb\_RFI\_Flags)}{mean(Nviews)}$ > threshold, (middle row),
- $\frac{mean(Standard\_Dev)}{mean(Pixel\_Radio\_Accuracy)}$ > threshold (bottom row)

This figure indicates a threshold of 0.4 to 0.6 for $\frac{Nb\_RFI\_Flags}{Nviews}$ and a threshold of 1.4 to 1.6 for $\frac{mean(Standard\_Dev)}{mean(Pixel\_Radio\_Accuracy)}$ loosely correspond to a threshold of 0.1 to 0.2 for L2SM RFI probability, which are conservative thresholds used in many studies.

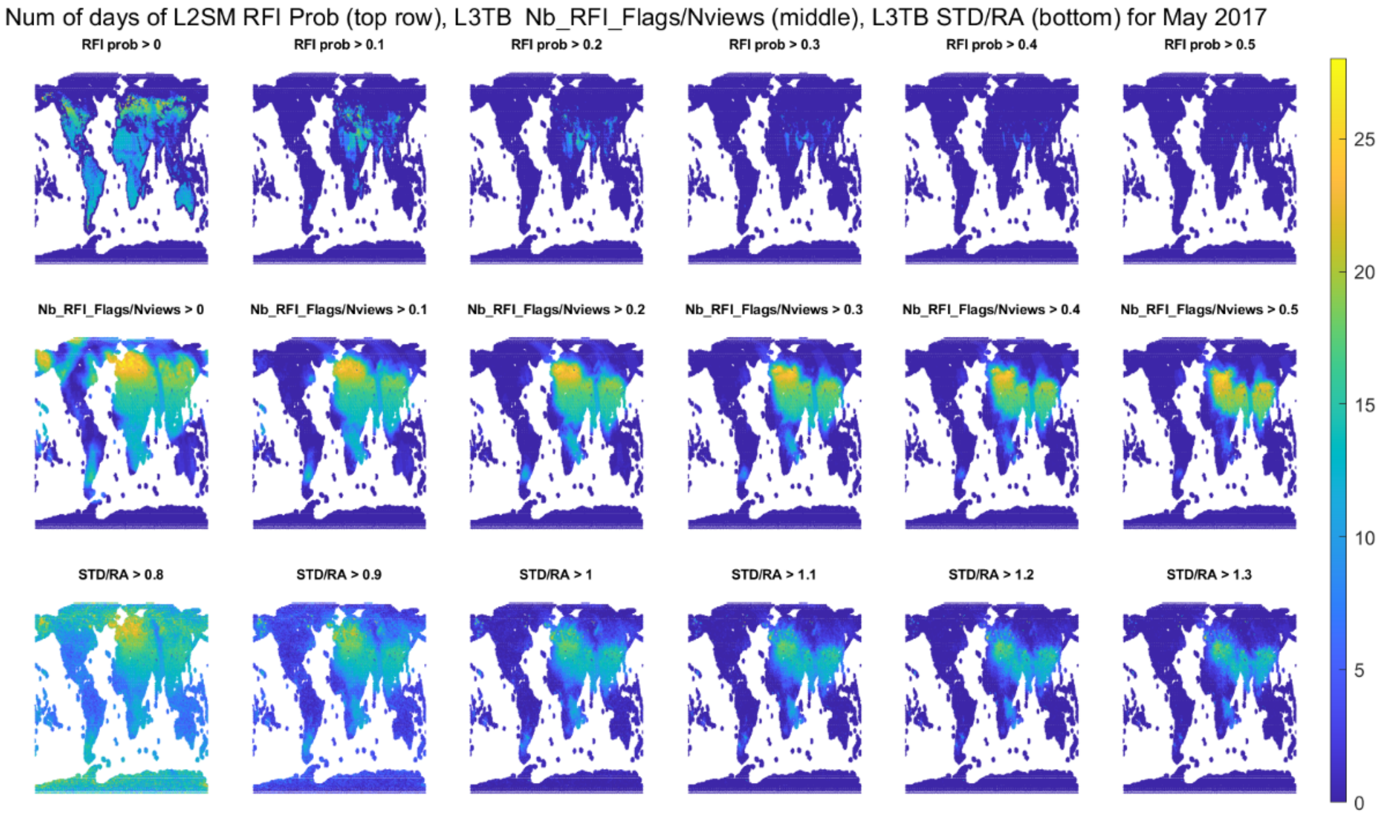

Figure 2: Number of days in May 2017 for which (top panels) L2SM RFI > threshold, (middle panels) $\frac{mean(Nb\_RFI\_Flags)}{mean(Nviews)}$ > threshold, and (bottom panels) $\frac{mean(Standard\_Dev)}{mean(Pixel\_Radio\_Accuracy)}$ > threshold.

5.2 Comparison of SMOS and SMAP TBs

Making use of the experience acquired with SMOS, SMAP carries a 16 channels filterbank allowing onboard RFI filtering. Here, the SMOS L3TB are filtered using the two ratios described above and different thresholds. Then, the filtered SMOS L3TB are compared to those measured by SMAP and a number of metrics are computed. The goal is to determine the thresholds that allow to keep as much data as possible in areas affected by RFI.

The SMOS L3TB were compared to the those from the SMAP L3 Version 6 product at 36 km resolution from January 2015 to December 2020. Only the ascending TB at bin 9 from SMOS and the descending TB from SMAP were used and only observations above -60 degrees north were considered. The SMOS L3TB were interpolated from the 25 km to the 36 km EASE-Grid using the closest neighbor approach. The

SMAP TB without water body correction were used and filtered by applying the following binary flags (see document [6] for a complete specification of the product content):

- Observation has acceptable quality
- Observation within physical range
- RFI was not detected in the observation
- RFI was not detected corrected in the observation
- Observation had acceptable NEDT
- Observation was a valid value
- Observation was free of RFI

The metrics used to compare the filtered SMOS TB to those measured by SMAP are the Pearson correlation (R), the standard deviation of the difference (STDD) and the bias.

Figure 3 shows global scatter plots of SMOS and SMAPS TB for the H and V polarizations while Figs. 4-5 shows maps of R, STDD, bias in between SMOS and SMAP TB as well as the number of SMOS observations available after filtering.

Figures 3a,b present the comparison between the SMOS and SMAP TB as global scatter plots using only the SMAP flags described above. The results show that the agreement between the TB is relatively good for both the H and V polarizations (correlations around 0.85/0.84). However, Figures 4a,b,c and 5a,b,c, show that the correlation drops significantly (and the STDD and bias increase) within the regions the most subjected to be affected by RFI: from 0 to 50 degrees north and from 0 to 125 degrees east.

The goal is to select filtering threshold values for $\frac{Standard\_Dev}{Pixel\_Radio\_Accuracy}$ and $\frac{Nb\_RFI\_Flags}{Nviews}$ that allow to maintain good values of the metrics used to compare to SMAP (high values for R and low values for bias and STDD) while keeping as many SMOS data as possible. Figure 6 presents the correlation between SMOS and SMAP TB obtained for different thresholds of the two ratios. For both of them, the correlation does not vary significantly according to the thresholds (Figures 6a,c) but the number of observations remaining after filtering actually does (Figures 6b,d). It means that using very low or low thresholds can filter out lots of data. A good trade-off could be to discard observations for which $\frac{Standard\_Dev}{Pixel\_Radio\_Accuracy}$ and $\frac{Nb\_RFI\_Flags}{Nviews}$ exceed 1.8 and 0.8, respectively. It should increase the agreement between SMOS and SMAP TB while conserving around 90% of the data.

Figures 3c,d present the global comparison between the SMOS and SMAP TB after filtering out the SMOS observations for which the ratios $\frac{Nb\_RFI\_Flags}{Nviews}$ and $\frac{Standard\_Dev}{Pixel\_Radio\_Accuracy}$ respectively exceed 0.8 and 1.8. This filtering allows the correlation to increase by roughly 0.05. The benefice is more noticeable in Figures 4e,f,g and 5e,f,g, where the correlation significantly increases while the STDD and the bias decrease in the regions the most sensitive to RFI (from 0 to 50 degrees north and from 0 to 125 degrees east). However, there is a clear loss of observations in these areas. The number of observations per pixel goes from 200 to 50 in average after being filtered (Figures 4d,h and 5d,h).

In order to discard less data in the areas more sensitive to RFI, an alternative approach is chosen to filter the SMOS TB. By default, all the TB over the Globe for which $\frac{Nb\_RFI\_Flags}{Nviews}$ and $\frac{Standard\_Dev}{Pixel\_Radio\_Accuracy}$ are respectively strictly above 1.8 and 0.8 are discarded. However, in regions where these flags discard more than 10% of the observations within the time series, a less strict filtering approach is applied and only TB for which $\frac{Standard\_Dev}{Pixel\_Radio\_Accuracy}$ is above 1.8 are filtered out. Figure 7 highlights the regions where the ratio $\frac{Nb\_RFI\_Flags}{Nviews}$ is used or not.

Figures 3e,f present the global comparison between the SMOS and SMAP TB after using this alternative filtering. The agreement between the two data sets is quite similar to that found in Figures 3c,d, where the first filtering is used. Figures 4i,j,k and 5i,j,k present the agreement between SMOS and SMAP TB at a pixel scale using the alternative filtering described above. Comparing these maps to those computed without filtering (Figures 4a,b,c and 5a,b,c), it can be observed that the correlation increases while the STDD and bias decrease in the regions the most sensitive to RFI. Even if the improvement is not as much significant as the one obtained using the first filtering approach (Figures 4e,f,g and 5e,f,g), the number of observations remaining after filtering is much more higher. Indeed, comparing Figures 4h to 4k and 5h to 5k, around 75 observations per pixel were preserved.

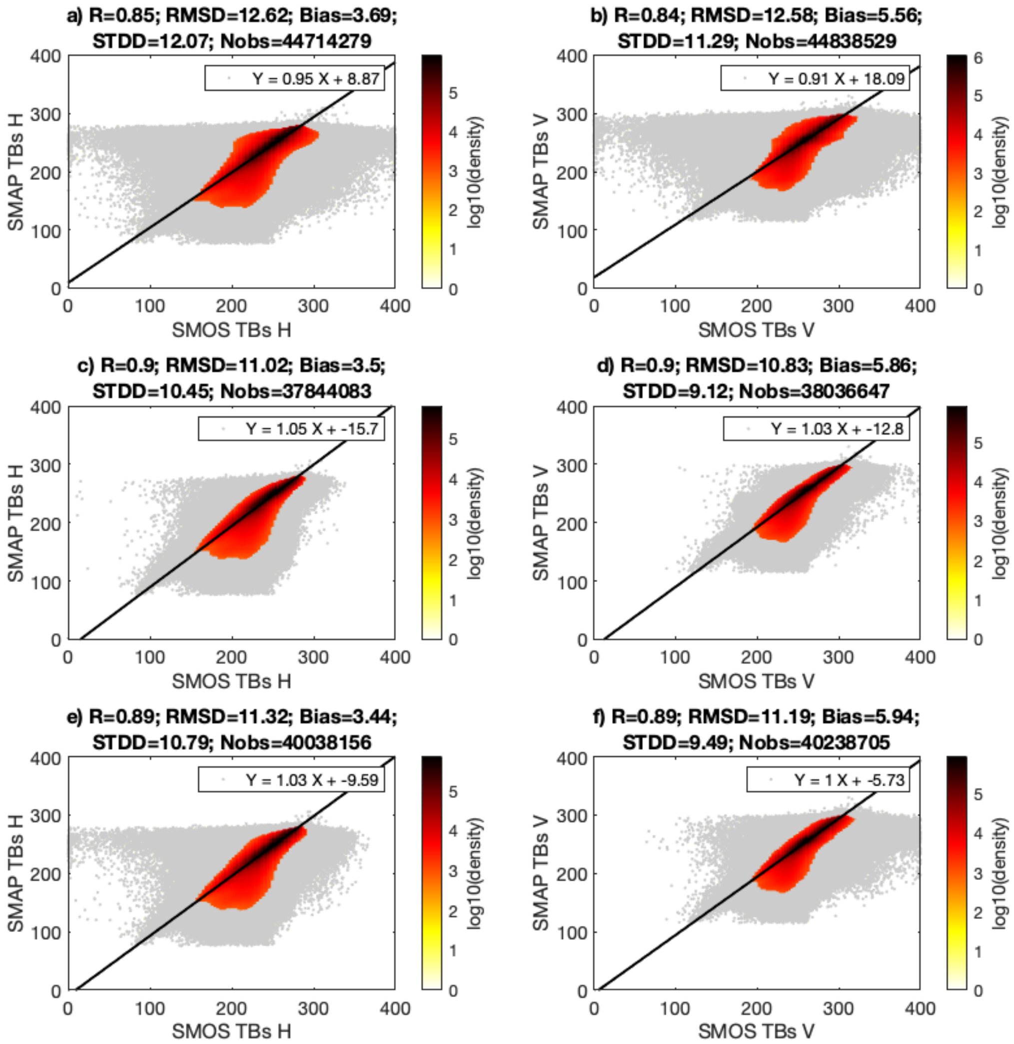

Figure 3: Scatter plots of the global comparison between SMOS and SMAP brightness temperatures from 2015 to 2020 in terms of correlation (R), root mean squared error (RMS), bias and standard deviation of the difference (STDD). No filtering is applied on the SMOS observations in the first row. The second row shows the results after filtering out SMOS data for which $\frac{Standard\_Dev}{Pixel\_Radio\_Accuracy}$ and $\frac{Nb\_RFI\_Flags}{Nviews}$ exceed 1.8 and 0.8, respectively. The third row plots the comparison using a alternative filtering: observations for which $\frac{Standard\_Dev}{Pixel\_Radio\_Accuracy}$ and $\frac{Nb\_RFI\_Flags}{Nviews}$ exceed 1.8 and 0.8 are discarded only if they represent less than 10% of the data within a time series. Otherwise, only the $\frac{Standard\_Dev}{Pixel\_Radio\_Accuracy}$ is used to filter out the data.

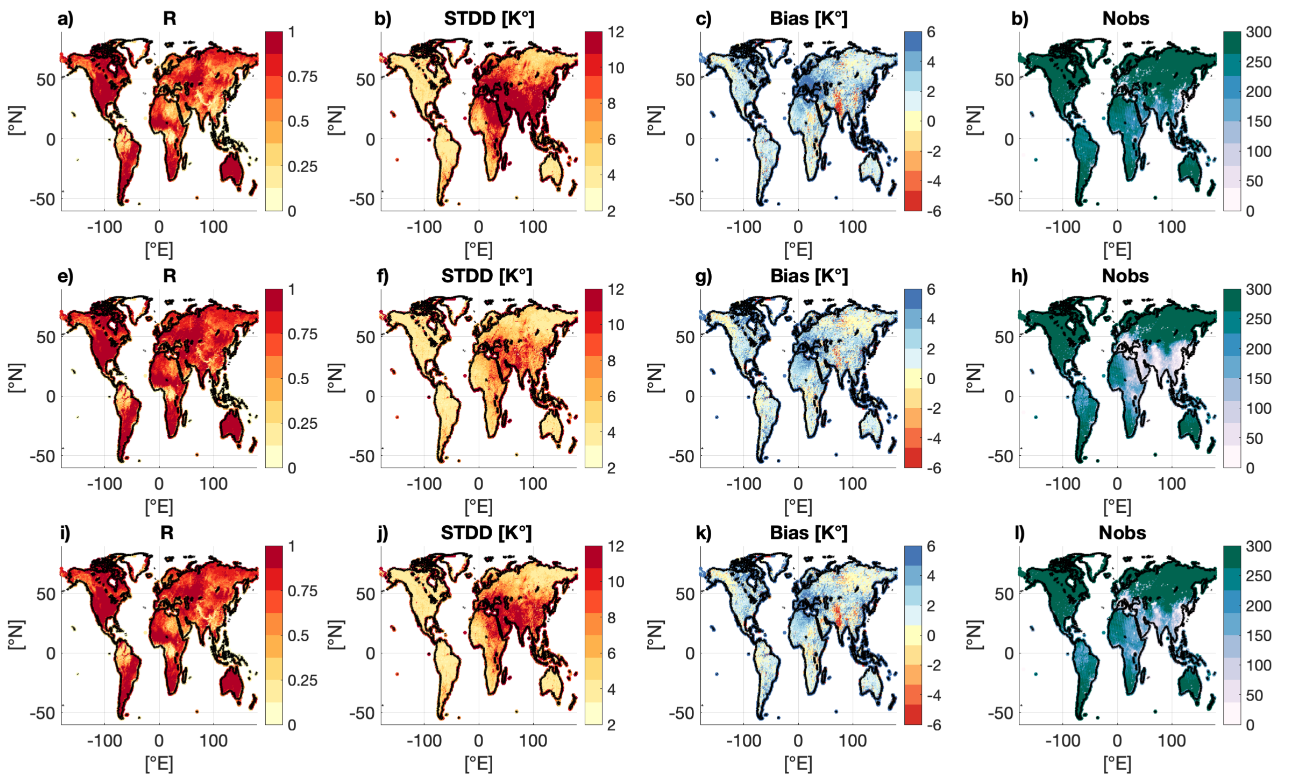

Figure 4: Comparison between SMAP and SMOS H-polarization brightness temperatures from 2015 to 2020 in terms of correlation (R), standard deviation of the difference (STDD) and bias. Nobs represents the number of observations available per pixel. No filtering is applied on the SMOS observations in the first row. The second row shows the results after filtering out SMOS data for which $\frac{Standard\_Dev}{Pixel\_Radio\_Accuracy}$ and $\frac{Nb\_RFI\_Flags}{Nviews}$ exceed 1.8 and 0.8, respectively. The third row plots the comparison using a alternative filtering: observations for which $\frac{Standard\_Dev}{Pixel\_Radio\_Accuracy}$ and $\frac{Nb\_RFI\_Flags}{Nviews}$ exceed 1.8 and 0.8 are discarded only if they represent less than 10% of the data within a time series. Otherwise, only the $\frac{Standard\_Dev}{Pixel\_Radio\_Accuracy}$ is used to filter out the data.

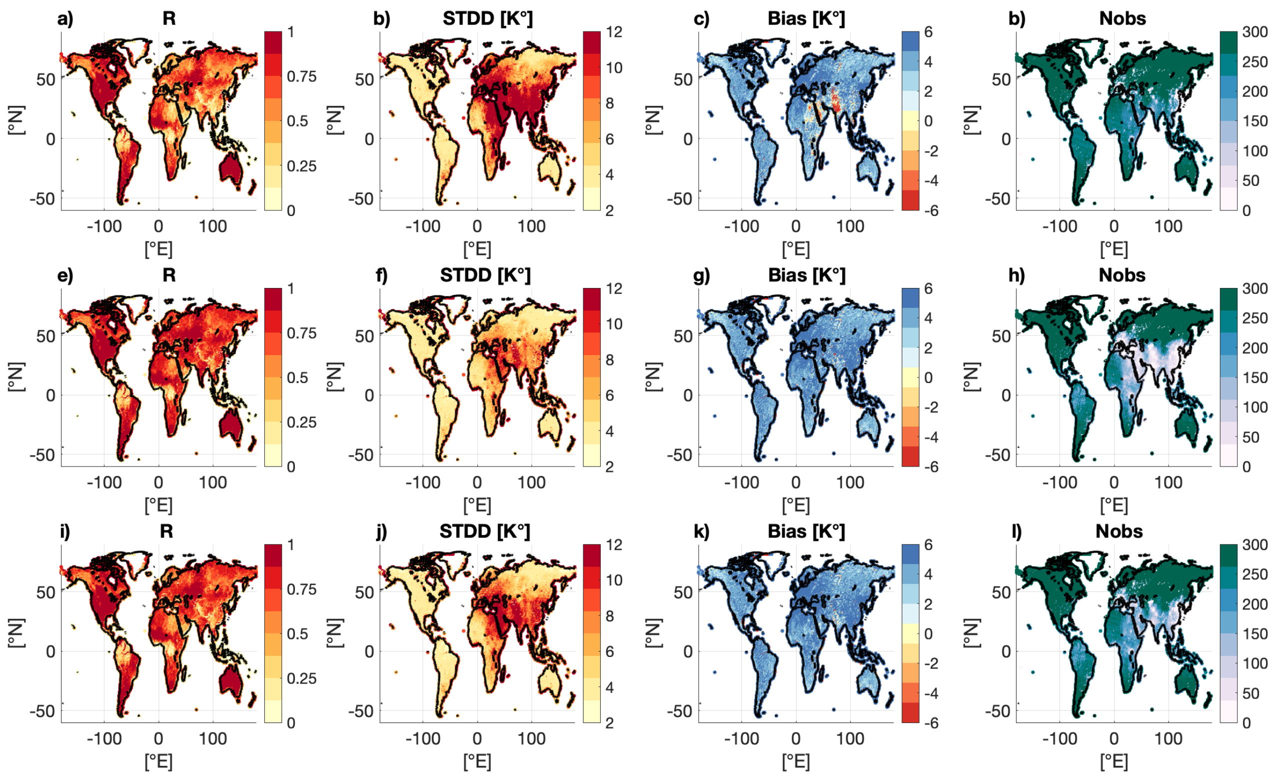

Figure 5: Same as Fig. 4 but for V-polarization Tbs.

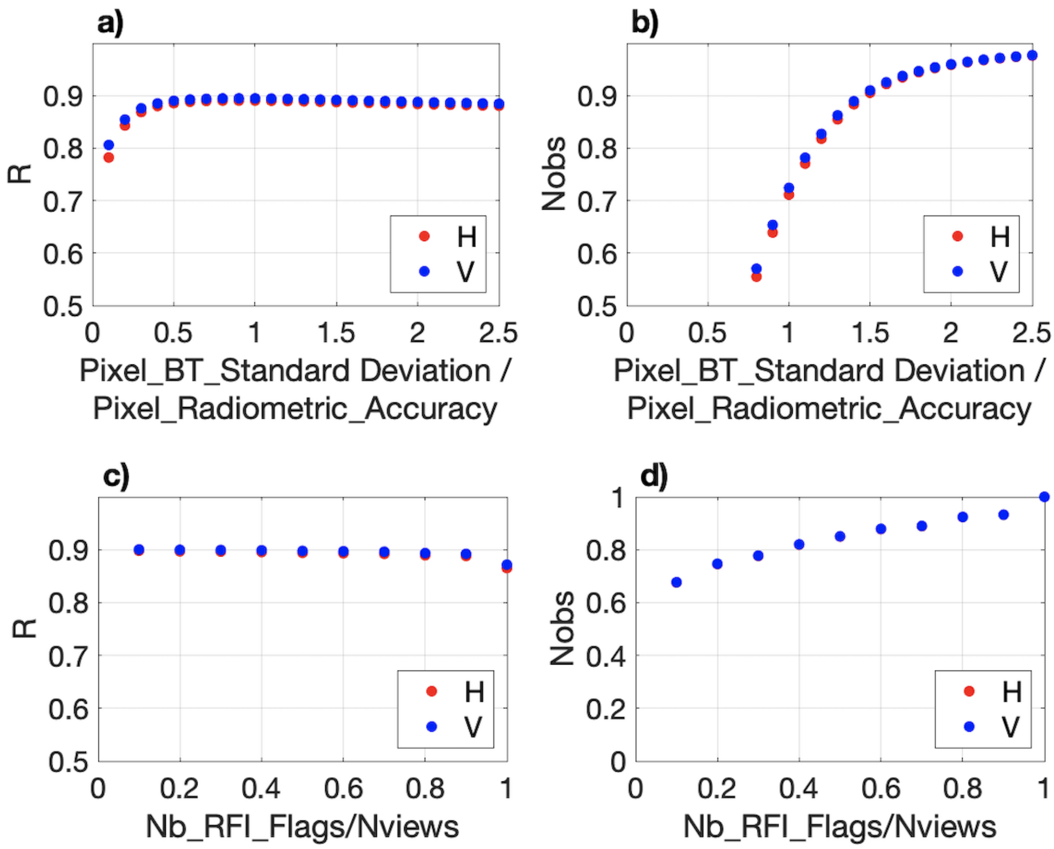

Figure 6: Global correlation (R) between SMOS and SMAP brightness temperatures as a function of the thresholds used for the ratios $\frac{Standard\_Dev}{Pixel\_Radio\_Accuracy}$ and $\frac{Nb\_RFI\_Flags}{Nviews}$. Within each plot, the SMOS observations for which the ratios $\frac{Standard\_Dev}{Pixel\_Radio\_Accuracy}$ and $\frac{Nb\_RFI\_Flags}{Nviews}$ exceed the thresholds shown in the x-axis are discarded for the correlation computation. The two flags are applied independently. The percentage of observations remaining after the filtering (Nobs, ranging from 0 to 1) is also shown side by side with the correlation.

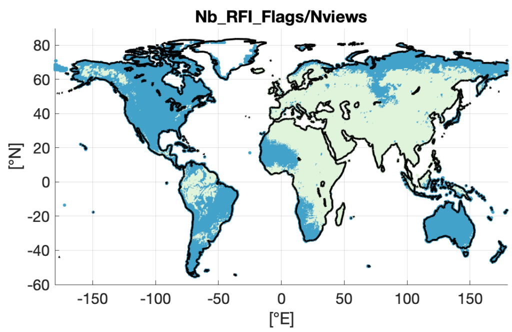

Figure 7: Blue areas correspond to pixels where $\frac{Standard\_Dev}{Pixel\_Radio\_Accuracy}$ and $\frac{Nb\_RFI\_Flags}{Nviews}$, with 1.8 and 0.8 as thresholds respectively, are used to filter the SMOS TB. Light green areas correspond to pixels where $\frac{Nb\_RFI\_Flags}{Nviews}$ is not used for the filtering but $\frac{Standard\_Dev}{Pixel\_Radio\_Accuracy}$ is still applied with 1.8 as threshold.

6 Conclusions and Recommendations

The $\frac{Nb\_RFI\_Flags}{Nviews}$ > threshold can be used to filter out "contaminated" TB values for bins 5 to 13. For other bins the number of measurements is too small and this method may not be appropriate. The

$\frac{Standard\_Dev}{Pixel\_Radio\_Accuracy}$ > threshold is a complementary filter, which is more sensitive and stronger to identify low-quality TB values.

For applications that require to filter out very strictly the data, it is advised to use a threshold value between 0.4 and 0.6 for the $\frac{Nb\_RFI\_Flags}{Nviews}$ ratio. A threshold from 1.4 to 1.6 is recommended for the $\frac{Standard\_Dev}{Pixel\_Radio\_Accuracy}$ ratio to only conserve data that have a RFI probability below 10%. This strict filtering can create blank regions where RFI are often present.

It has been shown that a less strict filtering using $\frac{Standard\_Dev}{Pixel\_Radio\_Accuracy}$ and $\frac{Nb\_RFI\_Flags}{Nviews}$ ratios with thresholds of 1.8 and 0.8 provide good agreement with SMAP TB while keeping much more SMOS data in regions affected by RFI. When the number of observations is critical and a less strict RFI filtering is acceptable, it is even recommended to not use the $\frac{Nb\_RFI\_Flags}{Nviews}$ filter: in particular in regions from 0 to 50 degrees north and from 0 to 125 degrees east, where more than 10% of the data are lost by using the two filters together.