Read-me-first note for the release of the SMOS Level 1 data products	
Processor version	Level 1 version 724, NRT version 724
Release date by ESA	25 May 2021 Revised on 20 December 2021
Authors	SMOS Calibration team and Expert Support Laboratory Level 1
Further information	Information on how to access the SMOS data can be found here: SMOS Science Products - Earth Online (esa.int) (https://earth.esa.int/eogateway/catalog/smos-science-products) Details about the processing algorithms can be found in the Level 1 Data Processing Model (DPM) documents: ▪ SO-DS-DME-L1OP-0007 v2.24 (L1A) ▪ SO-DS-DME-L1OP-0008 v2.25 (L1B) ▪ SO-DS-DME-L1OP-0009 v2.17 (L1C) Information about the Level 1 products structure can be found in the SMOS Level 1 and Auxiliary Data Products Specifications document: ▪ SO-TN-IDR-GS-0005, v6.5 The documents are available here: SMOS Science Products - Earth Online (esa.int) (https://earth.esa.int/eogateway/catalog/smos-science-products) Information about the SMOS Level 1 data quality can be found in the Monthly Quality reports and in the Mission Reprocessing report available here: MIRAS QUALITY CONTROL REPORTS - Earth Online (esa.int) (https://earth.esa.int/eogateway/instruments/miras/quality-control-reports)
Contact for helpline	ESA's HelpDesk at eohelp@esa.int

1. Introduction

This note summarises the quality of the SMOS Level 1 data products generated by the version 724 of the Level 1 Operational Processor (L1OP) which has been in operation from 25 May 2021 and by the version 724 of the Near Real Time (NRT) Processor which has been in operation from 2 August 2021.

The version 724 of the L1OP processor has also been used for the reprocessing campaign for which the complete data set from 12 January 2010 to 24 May 2021 is now available.

This note is organised as follows:

- Main **improvements** in the data set processed with Level 1 version 724.
- **Calibration** baseline changes for the generation of the Level 1 version 724 with respect to the previous version 620.
- **Important information for L1B users**
- Known **caveats** in the quality of the SMOS Level 1C data products generated by version 724 of the Level 1 Operational Processor (L1OP) and version 724 Near Real Time (NRT) Processor.
- Further Level 1 version 724 data **quality information**
- MIRAS instrument configuration
- **Changes in RFI flags**

2. Main improvements in the Level 1 version 724 data set

The Level 1 version 724 data set has mainly improved in three areas:

- The stability of the measurements, particularly for the long-term and the orbital drift, but also the seasonal variations, which have been greatly mitigated,
- The spatial biases have been reduced after several improvements in calibration and image reconstruction techniques, and
- The RFI flagging: more flags have been added at either snapshot or pixel level indicate presence of RFI for a better filtering of corrupted data.

The improvements can be seen in the below Figures.

Figure 1 shows the long term and seasonal stability of Brightness Temperature difference between Level 1 dataset and an ocean forward model. (similar improvements have been achieved for other regions with differing temperature conditions such as Antarctica). The stability has clearly improved in the new version of the processor thanks to enhancements in the calibration approach. Generally, the new calibration approach has also led to colder measurements with a smaller ocean bias for the version 724 data set as shown in Table 1.

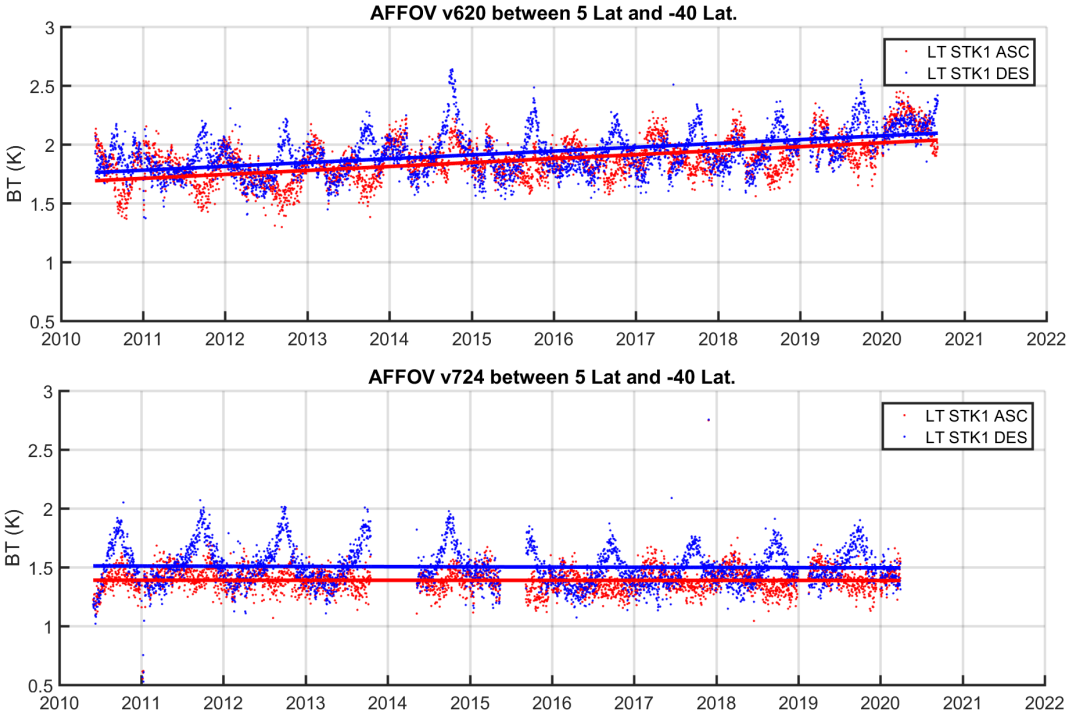


Figure 1 The figure shows the long term stability during SMOS mission life time over ocean. The lines show the evolution of the bias defined as the differences between the SMOS measured first Stokes parameter and the one derived from an ocean forward model. Red for the ascending passes and blue for descending passes. The top panel shows the result for the previous operational version of the Level 1 processor version 620. The bottom panel shows the result for the now operational Level 1 processor version 724.

The stability metrics of the Alias-Free field of view are summarised in Table 1 for ascending and descending orbit direction. The following key indicators of the time series have been computed: the overall slope, the standard deviation of the curves to account for the seasonal variation and the overall bias with respect to the ocean forward model. All metrics have been improved with the version 724.

Orbit Direction	Metric AFFOV	Pol	Units	v620	v724
ASC	Long Term trend	X	[mK/yr]	38	17
		Y	[mK/yr]	20	-18
		Stk-1	[mK/yr]	30	0
	Seasonal var. [std. deviation]	X	[K]	0.39	0.15
		Y	[K]	0.35	0.16
		Stk-1	[K]	0.37	0.11
	Bias	X	[K]	1.94	1.62
		Y	[K]	1.78	1.15
		Stk-1	[K]	1.86	1.39

DES	Long Term trend	X	[mK/yr]	16	-2
		Y	[mK/yr]	44	-2
		Stk-1	[mK/yr]	30	-2
	Seasonal var. [std. deviation]	X	[K]	0.56	0.44
		Y	[K]	0.52	0.40
		Stk-1	[K]	0.49	0.38
	Bias	X	[K]	2.16	1.81
		Y	[K]	1.70	1.19
		Stk-1	[K]	1.93	1.50

Table 1: Brightness Temperature stability metrics comparison between Level 1 v620 and v724 dataset.

Figure 2 shows the difference between ascending and descending passes for the Stokes-1 biases (difference of L1 data set Brightness Temperature measurements minus Ocean forward model) . The new data set version 724 shows a more consistent result between ascending and descending passes due to an improved calibration approach.

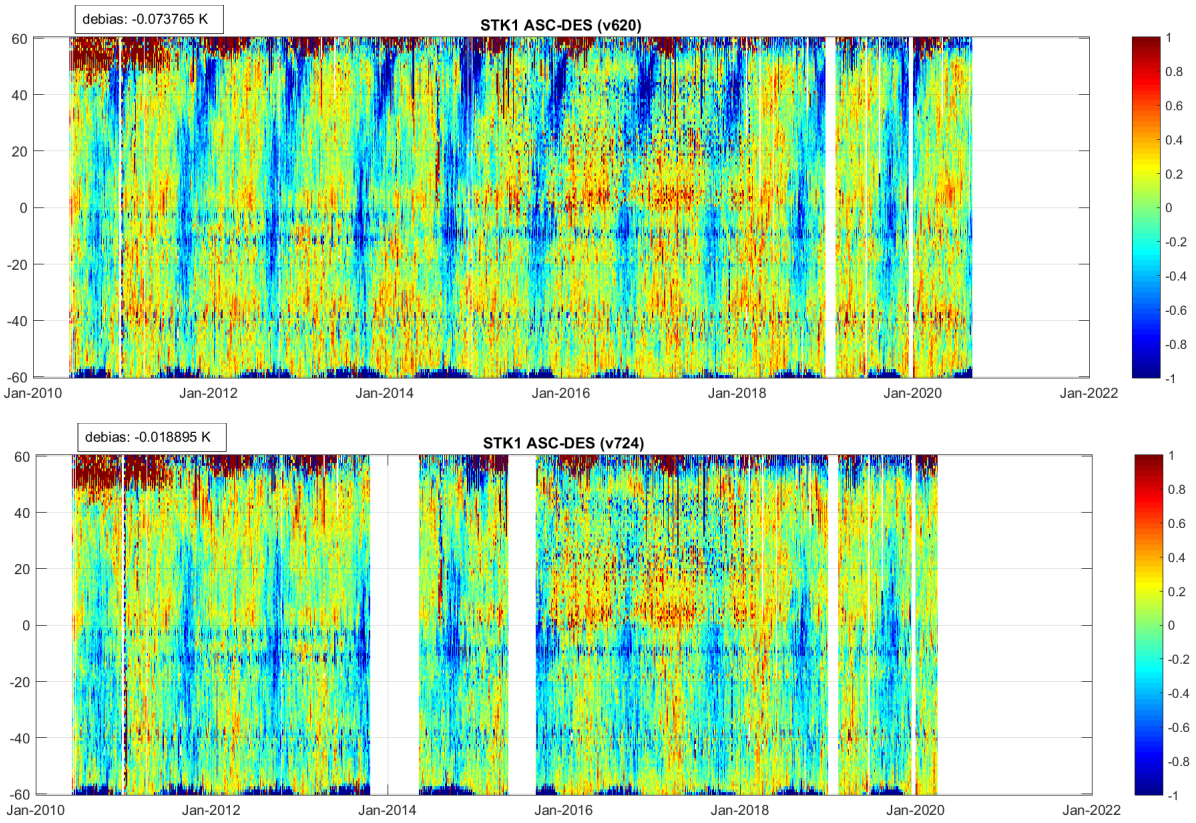


Figure 2. Hovmoller diagram showing the difference in temperatures [K] between ascending and descending measurements for the first Stokes parameter measurements over the ocean in the Alias-Free field of view. The diagram shows latitude versus time. Top panels corresponds to the previous processor version 620 and bottom panel to the now operational version 724.

Figure 3 shows the improvements for the spatial ripples of the Brightness Temperature difference between Level 1 dataset and ocean forward model. The large negative bias present in the previous processor version 620 data (large dark blue area in the bottom of the EAF-FOV) is less evident in the now operational version 724 data. The spatial biases of the Level 1 processor version 724, although reduced, will still require the application of an Ocean Target Transformation (OTT) correction to retrieve the sea surface salinity.

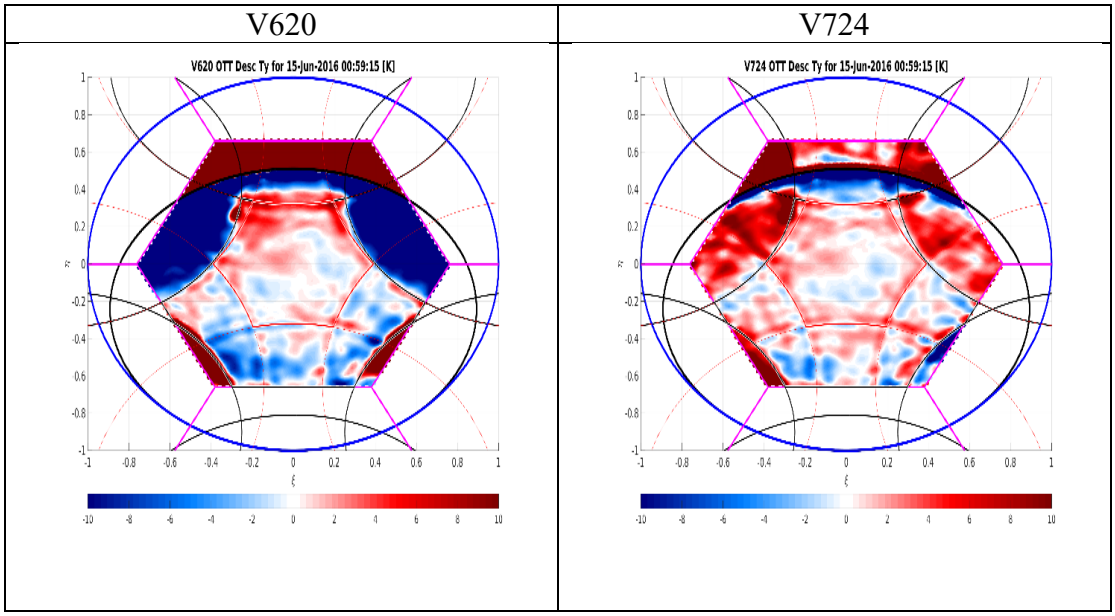


Figure 3 Difference in the extended alias free field of view (EAF-FOV) of the antenna reference frame between the Y-polarisation brightness temperature as measured by SMOS and the one derived from the ocean forward model. The left panel shows the bias for the previous Level 1 processor version 620, the right panel shows the same quantity but for the now operational version 724.

Further information about the SMOS products performances are provided in the SMOS mission reprocessing verification report and in the SMOS monthly data Quality Control report both available here:
(https://earth.esa.int/eogateway/instruments/miras/quality-control-reports)

Users are invited to consult the SMOS QC monthly report to stay up-to-date on the SMOS data quality.

3. Calibration baseline adopted in the Level 1 version 724 data set

The following changes to the calibration have been applied in the v724 with respect to the previous operational dataset:

a. The SMOS calibration team found that the parameters related to the Noise Injection Radiometer (NIR) calibrations are far more stable than it is possible to measure during the external calibration acquisitions. As a consequence of

that, even though NIR calibration continue to be acquired every two weeks for monitoring purposes, the NIR parameters have been fixed to a constant value.

b. A new method to estimate the Power Measurement System (PMS) Gain based on direct measurements from the Uncorrelated Noise source is used in the v724 calibration baseline.

c. NIR antenna losses have been adjusted for both X and Y polarisation.

d. The thermistor reading at the patch of the NIR antenna has been adjusted to compensate for unintended inner thermal coupling.

4. Important information for L1B users

A new Gibbs-correction algorithm is used in the v724 image reconstruction process. This algorithm subtracts a simplified Brightness Temperature model (artificial scene) from the expected image for each snapshot. This effect reduces the Gibbs ring phenomena and Land-Sea contamination in the retrieved image. As a result the reconstructed image at L1B is simply the difference between the sensed scene by the sensor and the artificial scene. The information about the artificial scene is added back at the L1C processing level. However, any user that wants to start from L1B products needs to add this information by themselves.

ESA provides the Artificial Scene Library (ASL) to perform this operation for L1B users. The ASL can be found in the following link:

Data - Earth Online (esa.int)
(https://earth.esa.int/eogateway/missions/smos/data)

5. Caveats

The main known limitations that affect the presently available Level 1 (v724) data product are:

a) Fixed spatial ripple
The snapshot images at L1 are affected by a fixed spatial bias that scales with brightness temperature (see Figure 3). This spatial bias has been mitigated particularly for Y polarisation. This problem is corrected for the ocean scenes in a pre-processing stage of the L2 ocean salinity with the Ocean Target Transformation (OTT).

b) Early mission drift
A transitory period in the instrument, corresponding to the commissioning phase and changing conditions in the instrument settings, affects data from January 2010 until May 2010. The consequence of this problem affects the stability of the image accounting for variations of brightness temperature of up to 1-2 K throughout this period in X and Y polarisation, the fluctuations in each polarisation being slightly different. After this transition period, the measurements have been largely stable in

the long-term, with estimated drifts of brightness temperature below 0.02 Kelvin/year as seen in Table 1.

c) *Land-sea contamination*
Land-sea contamination refers to an increase or decrease of brightness temperature observed in the ocean coastal area around continental masses. A residual effect is still observed in certain areas with an amplitude of about 1-1.5 K in horizontal and vertical polarisation, and in third and fourth Stoke parameter, similar to the previous version of the processor. The Land-Sea contamination is mitigated in the Level 2 sea surface salinity processor by applying an empirical correction of the Level 1 Brightness Temperature.

d) *Residual seasonal variations*
Seasonal variations have been greatly mitigated with respect to previous processor versions in particular for ascending orbit direction. A remaining residual seasonal variation has been observed to be less than 0.45 K over ocean, as shown in Table 1.

e) *Residual orbital drift*
Some of the orbital drift observed in previous versions of the processor have been corrected or mitigated. The most noticeable orbital drifts occurs during the instrument Sun eclipse. They happen yearly in descending orbits in high northern latitudes during late November till mid-January, as a consequence of a large instrument thermal gradient. A new characterisation of the receivers has been introduced in v724. This new characterisation has managed to reduce the orbital drift in the Alias-Free field of view (see figure 2), but some overcorrection is observed in the extended part of the field-of-view.

f) *Radio frequency interference (RFI)*
RFI affect both land and ocean data. Some very strong sources have been observed to affect data up to 3,000 km away from the position of the interfering antenna through the secondary lobes. The flagging of RFI has been greatly improved with respect to the previous version. The algorithm to flag the measurements affected by the RFI is detailed in the Data Processing Model documents available here: https://earth.esa.int/eogateway/catalog/smos-science-products

Further information of the RFI flags is presented in section 8.

Note though that in some cases, when a particular strong RFI is present in an orbit, an excessive flagging of all RFI flags (pixel and snapshots) occurs, lasting up to several minutes.

6. Further Level 1 version 724 data quality information

The most common sources of data degradation are:

- the saturation of the NIR measurements due to the presence of RFI,
- occasional jumps of the fringe washing function phase due to the effects of space radiation.
- other instrument anomalies.

Those degradations are tracked in the quality flag that can be used to filter the corrupted measurements (for a detailed description of the quality flags in the Level 1A, 1B and 1C data see the SMOS Level 1 and Auxiliary Data Products Specifications document available here:
https://earth.esa.int/eogateway/catalog/smos-science-products

7. MIRAS instrument Configuration

To date, MIRAS instrument has been in two different configurations due to an on-board anomalies.

- arm A on the nominal side and arm B and C on the redundant side from January 11, 2010 until January 12, 2011;
- arm A and arm B on the nominal side and arm C on the redundant side from January 12, 2011, onwards.

The version 724 reprocessed data set takes into account the different MIRAS instrument configuration by the usage of a set of auxiliary and calibration files.

8. RFI Flags

RFI flag information has changed with respect to previous versions. New RFI flags have been added and some of the v620 RFI flags have been moved to a different position.

A schema of the list of flags in the new L1c v720 products is presented in **Figure 4**.

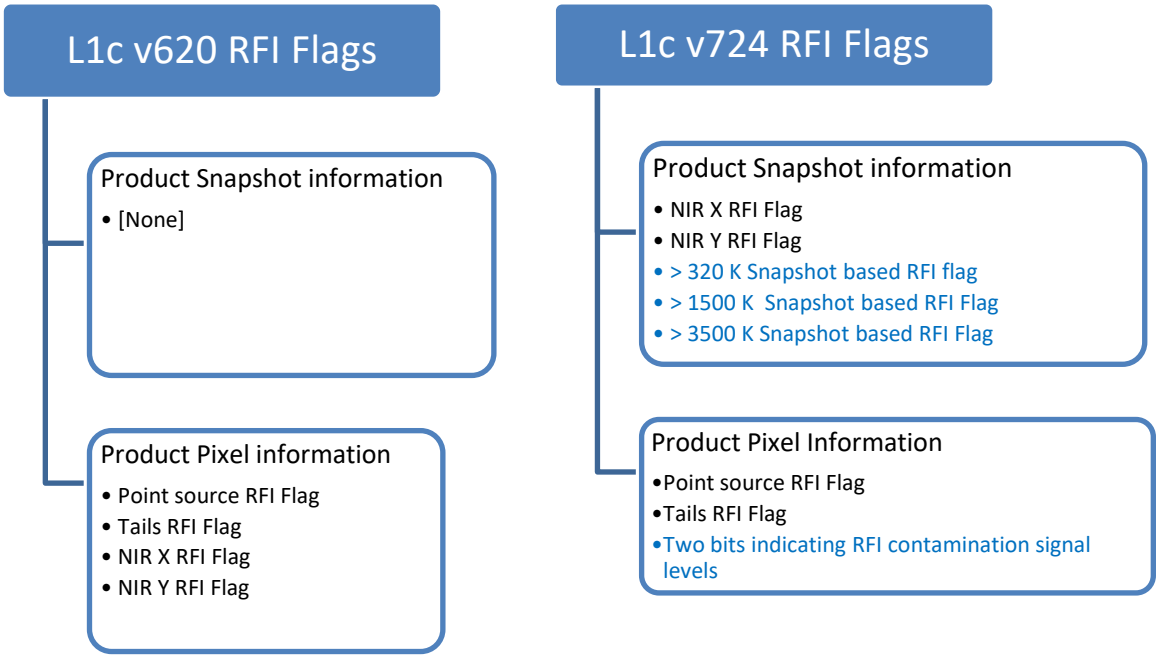


Figure 4: List of RFI related flags in the current L1c v620 products (left) and in the new v724 L1c products (right). In blue refers to the new flags added in the v724 L1c products.

Some of them were added in the snapshot RFI information portion of the L1c products. A detailed description of the modification is provided in the next paragraphs.

Point source and tail RFI flags.
Point source and Tail RFI flag present in the v620 are still present in the version 724. However, the bit location of the Point source RFI flag has changed with respect to the previous version. Please see RFI pixel bit information below.

The NIR RFI flags:
The X and Y NIR RFI flag, derived from the respective NIR measurements and applied to the entire snapshot, have moved from the pixel based-flags to a new snapshot-based flags. The sensitivity parameter have also been adjusted and they are now less sensitive to changes than it was in the version 620.

Two new RFI categories have been added:

Snapshot-based RFI flag
The new snapshot-based RFI flag flags the entire snapshot for data that present anywhere in the field of view any Brightness Temperature above the following thresholds:

- above 320 K
- above 1,500 K
- above 3,500 K

The three thresholds are represented in three different flags. See section 8.1.

Note that the first threshold is very sensitive and flags a large quantity of data. The threshold is intended for use in certain validation activities or in Polar applications. Natural emission in certain land areas (equatorial/desert) could be above the 320 K threshold. Ocean areas near land masses and outside the polar regions can also have this flag raised despite no presence of RFI.

Pixel-based RFI quantification

This new two-bit flag reports the expected RFI contamination signal present in each pixel of the image, by assigning it into 4 different bins:

- no RFI or RFI contamination signal below 10K.
- RFI contamination signal between 10K and 20K.
- RFI contamination signal between 20K and 30K.
- RFI contamination signal above 30K.

The bins are expressed in absolute terms, and computed form the theoretical impulse response of the RFI signal in SMOS. An example of the process followed is shown in **Figure 5**.

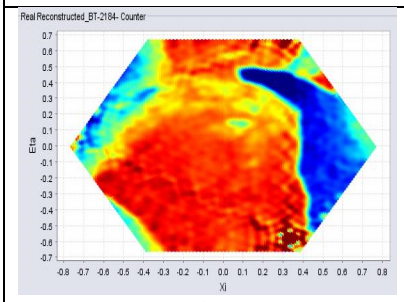
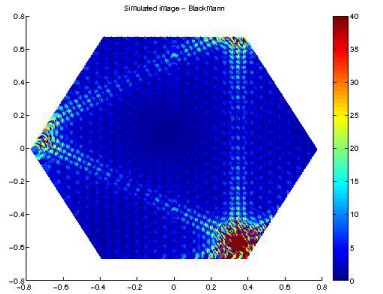
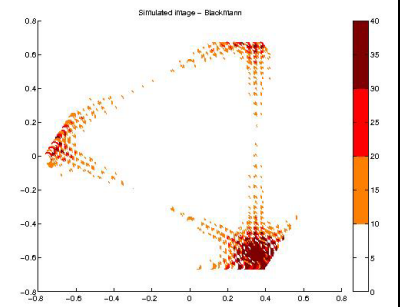
Measurements & RFI intensity	Theoretical Impulse Response of the RFI (in absolute terms)	Binned contamination flags
 RFI: 4273 K		

Figure 5: RFI contamination signal characterization process. Left figure shows one SMOS snapshot with presence of one strong RFI. Middle figure shows the estimated impulse response of the RFI signal for the same snapshot. Right figure shows the quantization level in 4 bits of the middle figure.

8.1. Bit position for RFI flags:

- Snapshot flags: A new 8-bit snapshot-based flag has been introduced in the v724 products. This field contains the following RFI flags:
  - [x x x x:x x **1**] means that the analysis of the NIR BT or System Temperatures standard deviation in X polarisation has reported this snapshot as an outlier of the expected trend, which is a clear indicator of the presence of one or more RFI sources in the data; that the Temperatures were saturated or in the vicinity of such saturation and there is a high probability that the measurement is affected.
  - [x x x x:x x **1** x] same as above for Y polarization.

- [x x x x:x **1** x x] means that the snapshot from that integration time is affected by an RFI source point whose intensity exceeds 320 K threshold.
- [x x x x:**1** x x x] means that the snapshot from that integration time is affected by an RFI source point whose intensity exceeds the 1,500 K threshold.
- [x x x **1**:x x x x] means that the snapshot from that integration time is affected by an RFI source point whose intensity exceeds the 3,500 K.

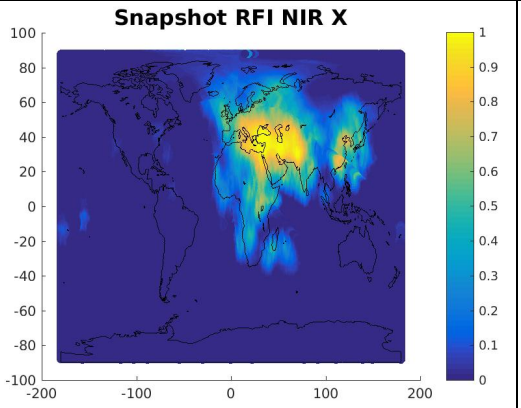
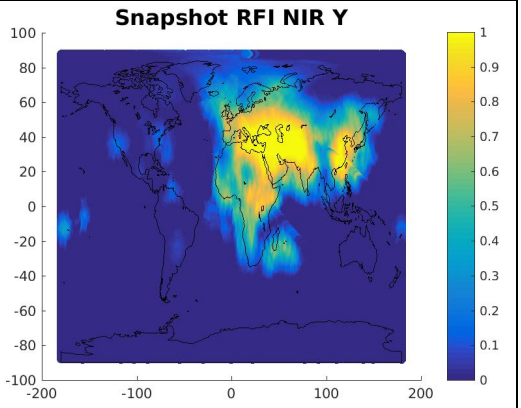
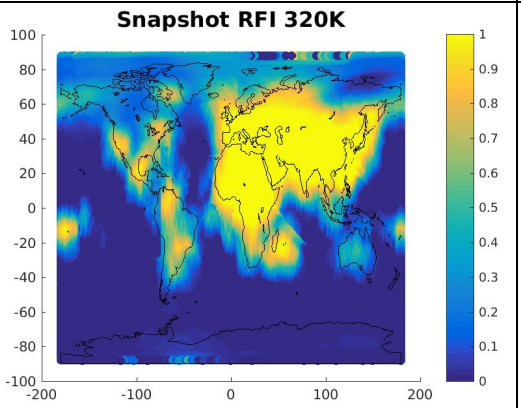
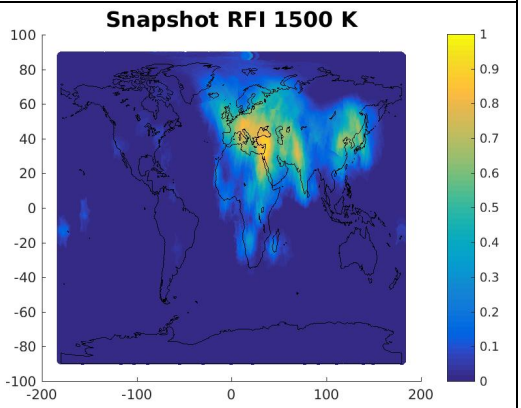
- Pixel flags:
  - [x x x x:x x x x:x **1** x x:x x x x] means that the measurement is affected by point source RFI as identified in the AUX RFI list (flag is set in a circle around the RFI position, with a radius dependant on the RFI expected BT defined in the AUX RFI list), or it is outside the range of [0 to 350 K] for X or Y polarisation; [-200 to 200K] for XY polarization or is in a region affected by a very strong RFI source that saturated the NIR.
  - [x x x x:**1** x x x:x x x x:x x x x] means that the measurement is affected by the tails of a point source RFI as identified in the AUX RFI list (tail width is dependent on the RFI estimated BT from each snapshot measurements) or is in a region affected by a very strong RFI source that saturated the NIR.
  - [**0 0** x x:x x x x:x x x x:x x x x] means that the measurement is not affected by a nearby point source RFI identified in the AUX RFI list or whose contribution generates a contamination in BT below 10K in that pixel.
  - [**0 1** x x:x x x x:x x x x:x x x x] means that the measurement is affected by a nearby point source RFI identified in the AUX RFI list whose contribution generates a contamination in BT above 10K in that pixel or is in a region affected by a very strong RFI source that saturated the NIR.
  - [**1 0** x x:x x x x:x x x x:x x x x] means that the measurement is affected by a nearby point source RFI identified in the AUX RFI list whose contribution generates a contamination in BT above 20K or is in a region affected by a very strong RFI source that saturated the NIR.
  - [**1 1** x x:x x x x:x x x x:x x x x] means that the measurement is affected by a nearby point source RFI identified in the AUX RFI list whose contribution generates a contamination in BT above 30K or is in a region affected by a very strong RFI source that saturated the NIR.

8.2 RFI flag occurrence:

An indication of the amount of times that the above RFI flags are raised is provided below. A 6-day sample of data from March 2020 has been selected for this detection analysis.

Global maps are presented below, showing in each case the probability of the different flags being raised.

- **Snapshot-based RFI flags:**

<table>
<tr><td colspan="2">#pixels flagged / #observations</td></tr>
<tr><td>NIR-X</td><td>NIR-Y</td></tr>
<tr><td> 
</td><td> 
</td></tr>
<tr><td>BT > 320K</td><td>BT > 1500K</td></tr>
<tr><td> 
</td><td> 
</td></tr>
<tr><td colspan="2">BT > 3500 K</td></tr>
</table>

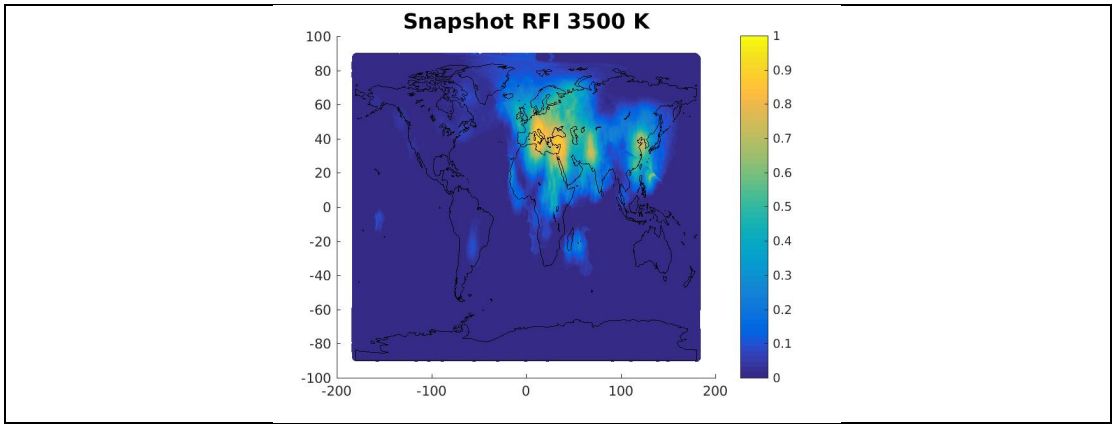


Figure 6: Global map of the occurrence of the snapshot-based RFI flags for a 6 day period in March 2020.

These flags are raised for the entire snapshot, which flags a big amount of data. Note that the use of a threshold of 320K to flag the presence of RFI leads to a large amount of data (sometimes 100%) being flagged in or around land masses, particularly Europe, Asia and Africa.

- **Pixel-Based RFI Flags:**

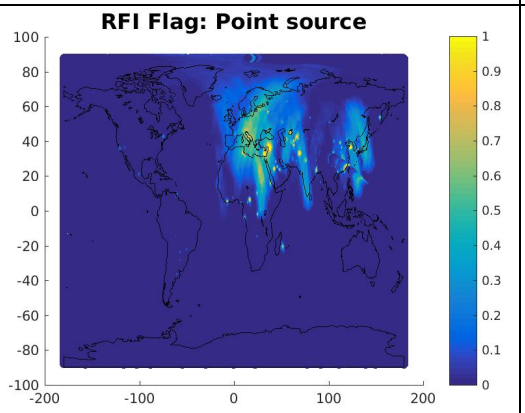
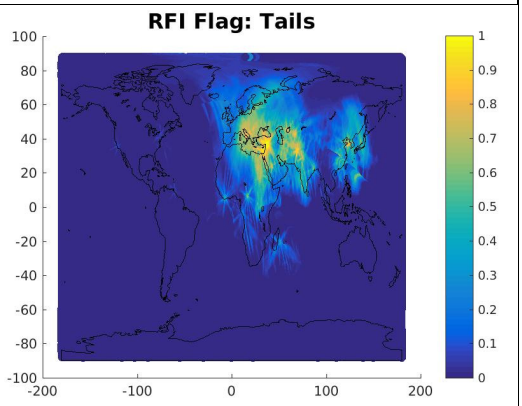
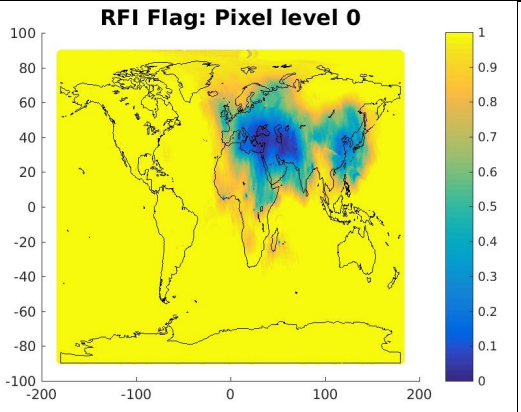
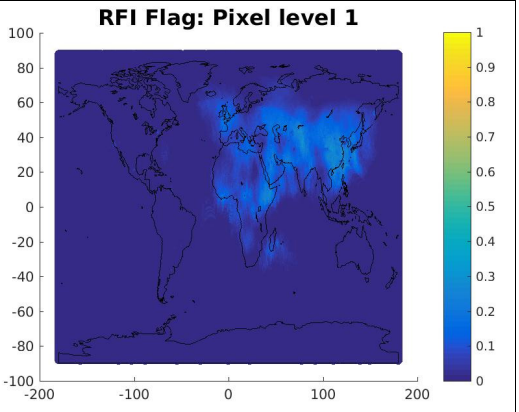
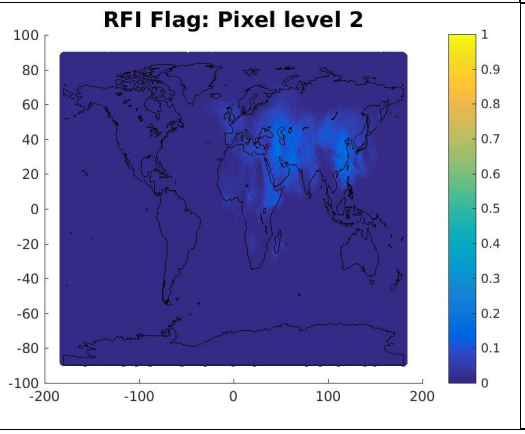
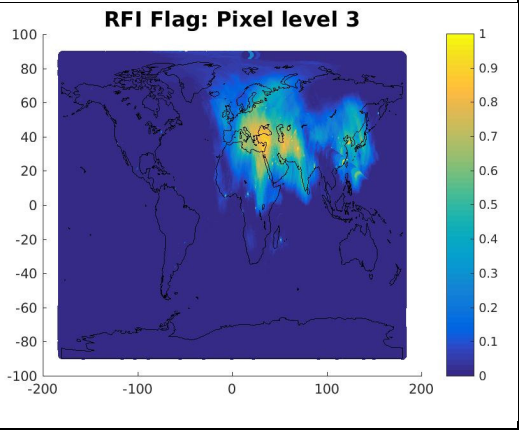
#pixels flagged / #observations	
RFI Point Sources	RFI tails
	
None or RFI contamination <10 K	10K < RFI contamination < 20K
	
20K < RFI contamination < 30K	RFI contamination > 30K
	

Figure 7: Global map of the occurrence of the pixel-based RFI flags for a 6 day period in March 2020

The point RFI flags clearly identify the RFI sources with a circular area around them. Many sources are observed in East Asia, the Middle-East, equatorial Africa, and some spread in America. Note that some tracks are also observed with this algorithm. This is due to the fact that this flag is also raised when a pixel is clearly above a natural emission level.

The tails flag is raised for the side-lobes of the most intense RFI observed in the RFI sources flag.

Then a quantization level is applied for all RFIs present in the RFI list ADF, and reported as a separate flag. Note that despite the RFI contamination quantization not being very granular, most of the RFI contamination in certain regions is marked only on the highest threshold (i.e.: above 30K). This indicates the strong contamination received by RFI.