



ESA Contract Report

SMOS ESL contract 4000130567/20/I-BG

Contract Report to the European Space Agency

Quality control plan for Brightness Temperature monitoring - 2024

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May 2024

Series: ECMWF - ESA Contract Report

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Report history

Version	Date	Authors	Description
Original document	October 2020	Pete Weston and Patricia de Rosnay	Quality control plan for Brightness Temperature monitoring
1 st update	October 2021	Pete Weston and Patricia de Rosnay	Updates: SMAP appendix added
2 nd update	April 2022	Pete Weston and Patricia de Rosnay	Updates: Description of the new quality control procedures implemented in May 2021 Updated future developments
3 rd update	May 2024	Kirsti Salonen, Pete Weston and Patricia de Rosnay	Updates: New operational monitoring website Implementation of monitoring ascending and descending orbits separately

Abbreviations

BUFR	Binary Universal Form for the Representation of meteorological data
CMEM	Community Microwave Emissivity Modelling platform
ECMWF	European Centre for Medium-range Weather Forecasts
ESA	European Space Agency
IFS	Integrated Forecast System
MIRAS	Microwave Imaging Radiometer using Aperture Synthesis
NRT	Near Real Time
NWP	Numerical Weather Prediction
QC	Quality Control
RFI	Radio Frequency Interference
SMAP	Soil Moisture Active-Passive
SMOS	Soil Moisture and Ocean Salinity
Tb	Brightness Temperature

1. Introduction

This document outlines the current quality control procedures applied within the European Space Agency (ESA) Soil Moisture and Ocean Salinity (SMOS) brightness temperature (T_b) monitoring run routinely at the European Centre for Medium-range Weather Forecasts (ECMWF). It also proposes possible future enhancements to this strategy. Effective quality control is important to avoid poor quality data skewing the monitoring statistics and in a possible future assimilation configuration will be important to avoid poor quality data contributing to degraded analyses and forecasts.

2. Current quality control for SMOS monitoring at ECMWF

2.1. Operational monitoring of the NRT SMOS brightness temperatures

The operational ECMWF SMOS monitoring system (Muñoz-Sabater et al, 2013) is part of the ECMWF integrated forecasting system (IFS). The monitoring system runs twice per day at 00UTC and 12UTC and compares SMOS observations with a high-quality stable reference state provided by the short-range operational forecast fields from the IFS. The resolution of the model fields used is T_L399 which is roughly equivalent to each model grid box being 50km x 50km in size. This resolution has been chosen to closely match the SMOS field of view size which is approximately 50km in diameter. The observation locations are interpolated to model grid point locations and the Community Microwave Emissivity Modelling platform (CMEM) is used as the observation operator to convert model fields of temperature, humidity etc. into equivalent brightness temperatures at top of atmosphere in sensor antenna frame. The brightness temperatures output from CMEM are in the Earth reference frame. To transform these into the SMOS antenna reference frame the following formulae are used:

$$T_{B\ SMOS\ XX} = \cos^2(\theta) * T_{B\ CMEM\ H} + \sin^2(\theta) * T_{B\ CMEM\ V}$$

$$T_{B\ SMOS\ YY} = \sin^2(\theta) * T_{B\ CMEM\ H} + \cos^2(\theta) * T_{B\ CMEM\ V}$$

where θ is the sum of the geometric and Faraday rotation angles which are both provided with the observations in the LIC BUFR files, $T_{B\ CMEM}$ are the brightness temperatures output from CMEM in the Earth reference frame, and $T_{B\ SMOS}$ are the final simulated brightness temperatures in the SMOS antenna reference frame. For more details see section 2.3.4 of de Rosnay et al. (2020). This then allows the modelled brightness temperatures to be subtracted from the collocated observed values to calculate what are known as “first guess departures”. More details of the monitoring system configuration can be found in de Rosnay et al. (2020).

Analysing the statistical distributions of these first guess departures is a key part of assessing the quality of the SMOS observational data. The samples for the statistical analysis can then be split up temporally and geographically, by ascending and descending orbits as well as by instrument characteristics such as polarisation, incidence angle etc. Several different types of monitoring plot are produced, as follows:

- Time series: Statistics are plotted as lines against time on the x-axis for the past two months with statistics accumulated in 12 hour chunks. The statistics plotted are mean and standard deviation of first guess departures, the mean observed and first guess brightness temperatures and number of observations. These plots allow global trends and jumps in the statistics to be identified. Time series for the past 12 months and since November 2021 are also provided.

- Hovmöller: Statistics are plotted as a heat map with time on the x-axis and latitude on the y-axis for the past two months with statistics accumulated in 2.5° latitude bins and 12 hour chunks. The statistics plotted are mean and standard deviation of first guess departure, mean and standard deviation of observed value and number of observations. These plots allow local trends and jumps in the statistics to be identified.
- Maps: Statistics are accumulated over the past month and plotted as a heat map with longitude on the x-axis and latitude on the y-axis. The same statistics as for the Hovmöller plots are plotted. These plots allow an even more localised analysis of the statistics to be performed.
- Scatter: Statistics are accumulated over the past month and plotted as a 2-dimensional histogram with incidence angle on the x-axis and first guess departure on the y-axis. These plots allow the distributions of first guess departures at different incidence angles to be analysed.

The samples used to produce the time series can be filtered by area, including global, Northern and Southern Hemisphere extra tropics, Tropics and North and South poles. Filtering by continents is unavailable at the time of updating the report but will be re-implemented in the near future. The loose definitions of the continents are: Europe (120°W-120°E, 35°N-77.5°N), Asia (0°W-120°W, 40°N-82.5°N), North America (120°E-0°E, 20°N-77.5°N), South America (120°E-0°E, 40°S-17.5°N) and Australia (0°E-120°W, 47.5°S-7.5°S). Also, the time series, Hovmöller and map plots are produced separately for data:

- Over sea or over land
- With different incidence angles: 30°, 40° or 50°
- With different polarisations: H (XX) or V (YY) at the SMOS antenna reference frame
- Ascending and descending orbits separately as well as both combined

The monitoring plots described above are published online and can be seen at <https://www.ecmwf.int/en/forecasts/quality-our-forecasts/monitoring/smos-monitoring>. Example plots and corresponding analysis can be seen in Salonen et al. (2023).

The operational monitoring web page was completely renewed in January 2024. The new features for SMOS include:

- Daily update of most products. Previous state of statistics is also accessible by choosing the previous base time on the selection menu.
- Availability of three types on timeseries: last 60 days, last 12 months and since November 2021. The last two are updated weekly.
- Monitoring of ascending and descending orbits separately as illustrated in the maps of Fig. 1. Ascending and descending statistics are available in the time series, maps and Hovmöller plots.

Because the short-range operational forecast, which the SMOS data are compared against, is so stable, any changes in the first guess departure statistics will indicate changes to the quality of the SMOS data which could represent instrument anomalies, changes in calibration, changes to the screening or improvements in the processing algorithms.

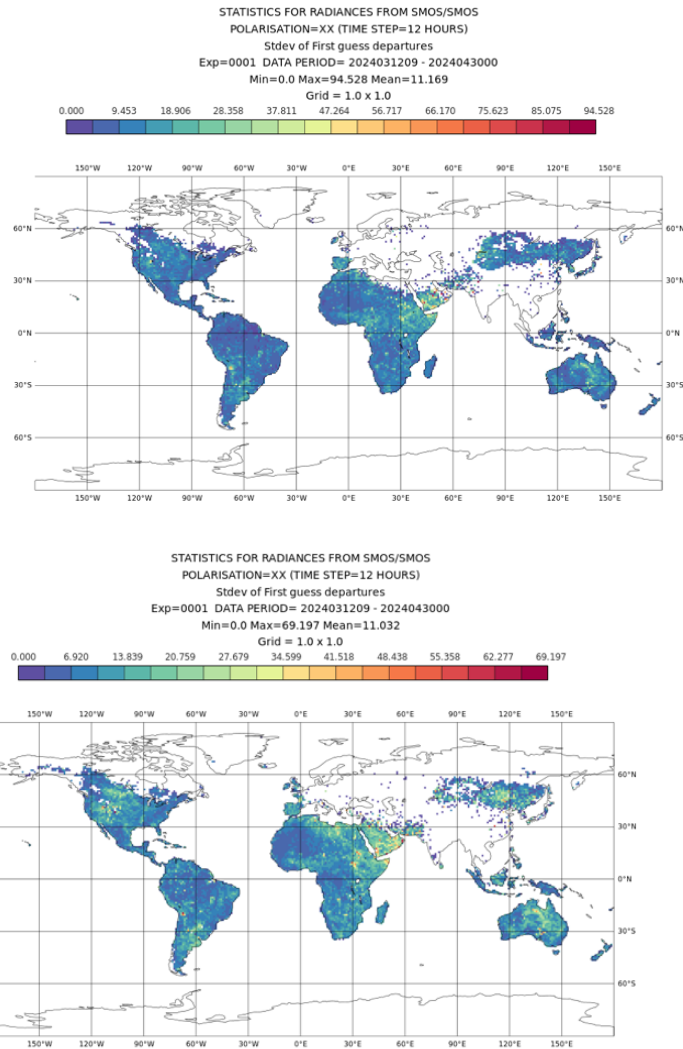


Figure 1: Maps showing an example of SMOS monitoring for descending (upper panel) and ascending (lower panel) orbits separately. The covered period is 12th March – 30th April 2024.

2.2. Current quality control

The current quality control described here is used for operational monitoring of the SMOS observations. It was implemented in May 2021 with IFS cycle 47r2 and it is currently used in IFS cycle 48r1. Data quality information is supplied with each observation in the NRT BUFR files. A series of bits in the SMOS BUFR flag table (de Rosnay et al, 2015) are set to indicate any problems with the associated data. Table 1 shows a summary of these bits and the meaning of each one.

At ECMWF, before the monitoring runs, a pre-screening program is run to remove observations which are known to contain anomalous data or cannot be handled successfully by the monitoring system. Currently, if bit number 3 of the SMOS information flags in the SMOS input BUFR files is set then this indicates that the observation is in the border between the exclusive alias-free zone and the extended alias-free zone and any observations with this bit set are not processed any further. In addition, bit

number 7 indicates that data has been affected by solar reflection and any observations with this bit set are not processed any further. Any observations which have any of bit numbers 1, 4 or 9 set are affected by RFI and, although these are processed by the monitoring system, there are a set of monitoring plots which only plot data without any of these bits being set i.e. those observations not affected by RFI.

Table 1 shows that there are a number of additional bits to the five that are already used. A systematic analysis of the effect of these bits being set had on the first-guess departure statistics has previously been performed. This concluded that the effect of the other bits on the first-guess departure statistics was negligible so data with any of the other bits set are processed within the monitoring system.

Bit number	Meaning
1	Pixel is affected by RFI effects as identified in the AUX_RFILST or it has exceeded the BT thresholds
2	Pixel is located in the hexagonal alias directions centred on a Sun alias (if Sun is not removed, measurement may be degraded in these directions)
3	Pixel is close to the border delimiting the Extended Alias free zone or to the unit circle replicas borders.
4	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 expected BT, from each snapshot measurements, corresponding to 0.16 of the radius of the RFI circle flagged)
5	Pixel is inside the exclusive zone of Alias free.
6	Pixel is located in a zone where a Moon alias was reconstructed
7	Pixel is located in a zone where Sun reflection has been detected
8	Pixel is located in a zone where a Sun alias was reconstructed
9	Measurement is affected by RFI effects as identified in the AUX_RFI list whose contribution generates a contamination in Brightness Temperature above 30K in the corresponding polarization
10	Scene has not been combined with an adjacent scene in opposite polarisation during image reconstruction

11	Direct Moon correction has been performed during image reconstruction of this pixel
12	Reflected Sun correction has been performed during image reconstruction of this pixel
13	Direct Sun correction has been performed during image reconstruction of this pixel
All 14	Missing value

Table 1: SMOS information flags from the flag table (code 025144) as part of the SMOS NRT product specification. Options in bold are currently used for SMOS brightness temperature data quality control for operational monitoring at ECMWF.

After the pre-screening the remaining SMOS observations are read into the IFS and further screening procedures are undertaken to avoid areas where the observations cannot be accurately modelled by CMEM, for example over snow-covered surfaces. These are summarised in table 2. In addition to the checks in table 2 each observation location is classified as land if the model land-sea mask value in the collocated grid point is greater than 0.95 and sea if the land-sea mask value is less than 0.01. The procedures in table 2 are performed for observations over both land and sea but it would be possible to implement different quality control procedures depending on whether the observation is over land or sea if deemed necessary.

Screening reason	Threshold for rejection
Extreme values	Measured Tb less than 50K or greater than 340K
Snow	Model snow depth greater than 1cm
Frozen surfaces	Model 2 metre temperature less than 273K
Sea-ice	Model sea-ice concentration greater than 1%
Coasts	Model land-sea mask values between 0.01 and 0.95

Table 2: Quality control applied to SMOS observations within the IFS

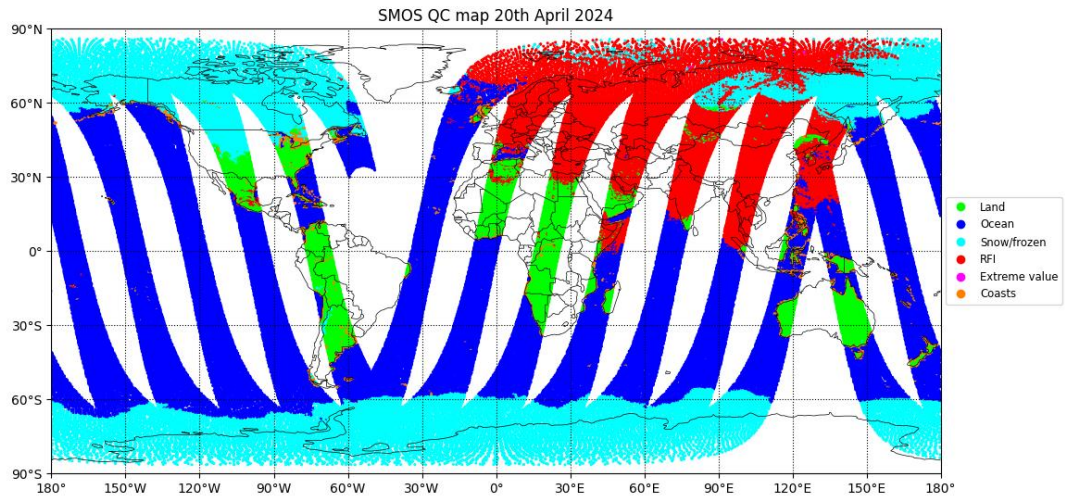


Figure 2: Map showing SMOS observations classified by surface type (land: green; sea: blue) and quality control rejection reason (extreme value: magenta; snow, frozen ground or sea ice: cyan; RFI: red; coasts: orange) for data between 09:00 and 21:00 UTC on 20th April 2024.

Figure 2 shows the geographical distribution of the surface type and quality control applied. As expected, most observations at high latitudes are screened out by the snow, frozen surface and sea ice checks. There are large areas of RFI detections over the middle East, Eastern and Northern Europe, Arctic Ocean, Russia and Asia. Areas affected by RFI have significantly increased due to the ongoing Russo-Ukrainian war. Very few observations are screened out by the simple extreme value check. Around all of the coasts, inland lakes and small islands observations are screened out by the coast check.

Figure 3 provides a breakdown of typical numbers of observations during a 12-hour period which are classified as land or sea and also the numbers of observations screened out by the checks detailed in table 2. The check which screens out the most observations is the snow/frozen surfaces check although this number decreases during the Northern hemisphere summer when the snow melts and ground thaws over much of Canada and Russia. The comprehensive RFI screening in the v724 SMOS L1 Tbs screens out the next most, followed by the coastal screening and finally the extreme value check accounts for the least.

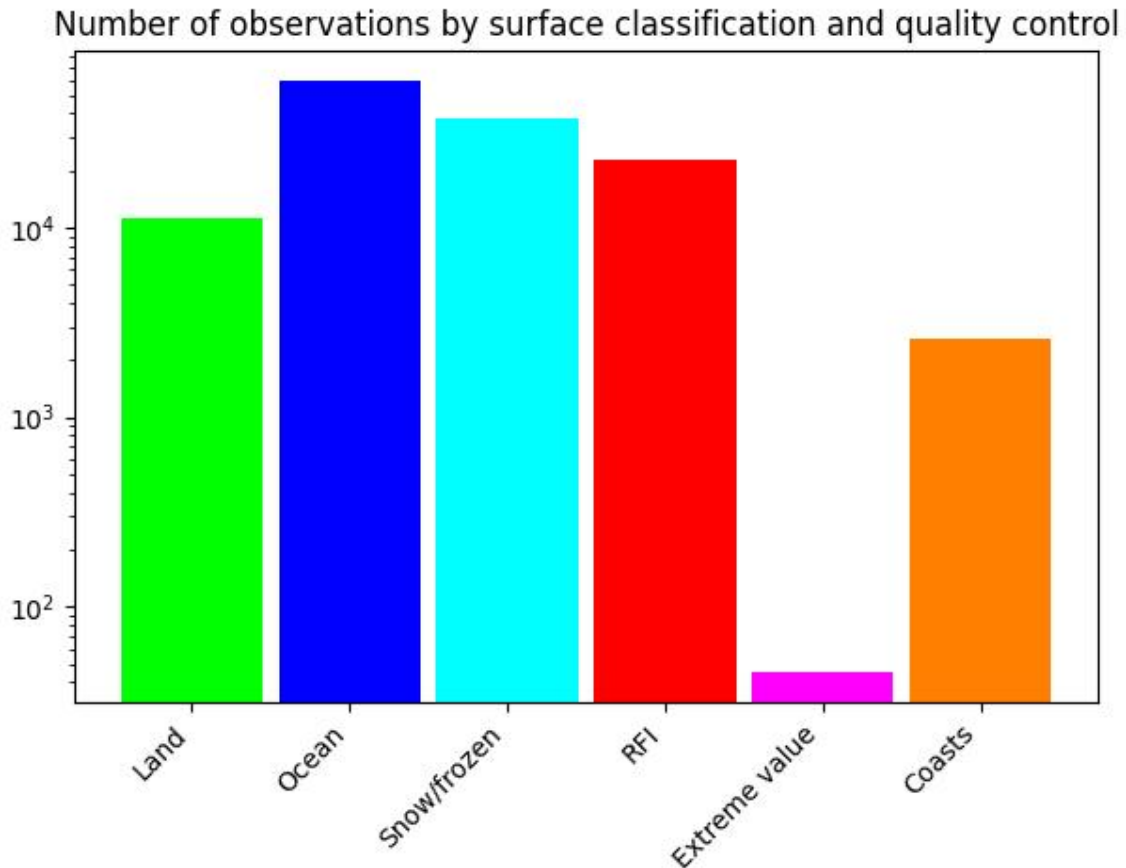


Figure 3: Bar chart showing the breakdown of number of SMOS observations classified by surface and quality control check triggered for data between 09:00 and 21:00 UTC on 20th April 2024. Note the logarithmic scale.

A thorough description and analysis of the implemented quality control enhancements can be found in Weston and de Rosnay (2021).

3. Possible future developments of the quality control

This section describes possible future enhancements to the quality control procedures.

3.1. Enhanced RFI screening

As shown in Weston & de Rosnay (2021) the RFI screening has been significantly improved in recent years but remains sub-optimal and misses screening out many SMOS observations which are clearly affected by RFI. ECMWF was part of the ESA RFI4EO project led by Zenithal Blue Technologies aimed at using various statistical and pattern recognition algorithms (ground RFI detection system - GRDS) to improve the RFI screening (Oliva et al., 2021). Results using a month of SMOS data indicated that the GRDS system demonstrates significant improvements over the v620 screening, for example see figure 4, where hot spots over Northern India and the middle East are almost completely removed when the GRDS screening is applied.

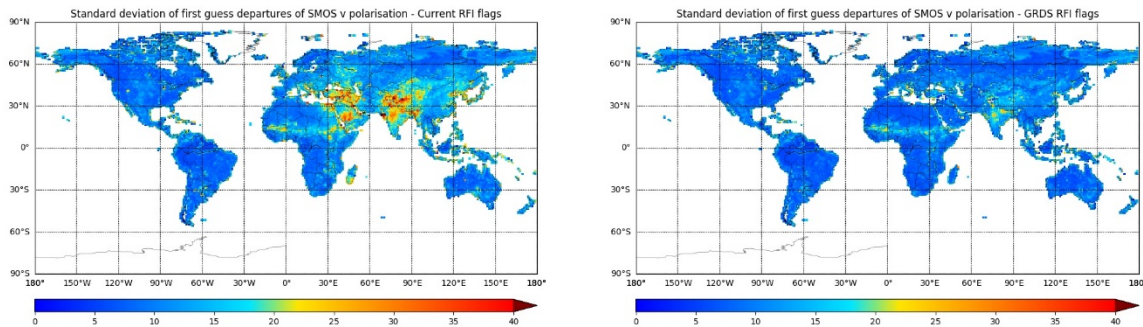


Figure 4: Gridded maps of standard deviation of SMOS first-guess departures at V polarisation with the operational v620 RFI screening (left) and new GRDS-based screening (right). The sample of data for both plots is the same and comes from between 1st July 2019 and 31st July 2019

3.2. Improved monitoring over ocean

There is ongoing work at ECMWF to improve the sea-ice and coastal screening in other MW radiance observations which could be applied to SMOS data in the future. In particular, the use of FASTEM (Liu et al., 2011) as part of the RTTOV (Saunders et al., 2018) radiative transfer model to calculate surface emissivities over ocean could be used to produce more realistic and accurate simulated Tbs for SMOS over ocean. In coastal areas a weighted average of the FASTEM/RTTOV simulated Tb and the CMEM simulated Tb using the fraction land-ocean mask information could be used. This has the potential to significantly improve the quality of the first-guess departures in coastal regions and could lead to the relaxation of the coastal screening documented in section 2.2.

4. SMAP monitoring

Monitoring of the NASA Soil Moisture Active Passive (SMAP) data using the same framework as for the SMOS monitoring was implemented with IFS cycle 47r2 on 11th May 2021. As with the SMOS monitoring, the SMAP monitoring plots are published online and are available at <https://charts.ecmwf.int/catalogue/packages/obstat/?facets=%7B%22Instrument%22%3A%5B%22SMAP%22%5D%7D>. On the renewed monitoring web site similar features are available for SMAP than for SMOS. However, the separate monitoring for ascending and descending orbits implemented for SMOS is not available for SMAP and currently there is no plan to implement it for SMAP as it would require substantial resources. The SMAP satellite was launched in 2015 and the instrument measures at L-band (1.41GHz) the same frequency as SMOS. Comparisons between the monitoring statistics for SMOS and SMAP are very relevant for unpicking observation and model issues in the first-guess departures, in particular shared quality control issues.

The quality control and screening procedures used for SMOS and SMAP are similar where possible. For example, the same frozen surface and coastal screening is applied to both instruments. However, RFI screening is applied to SMOS data using the information from the BUFR flag table (table 1) whereas SMAP has onboard RFI screening which is applied to the data before it arrives at ECMWF. CMEM is used with the same settings as the observation operator for both the SMOS and SMAP observations.

It is possible in the future that different quality control procedures may be needed for SMOS and SMAP observations given the different instrument designs and slightly different data quality characteristics. However, at present, keeping the quality control procedures as similar as possible is convenient as it facilitates direct comparisons of the data quality between the two instruments and reduces maintenance overheads of the L-band monitoring system as a whole.

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