ESA Contract Report

SMOS ESL contract 4000130567/20/I-BG

Contract Report to the European Space Agency

Quarter 4 2025: Operations Service Report

Authors: Jana Kolassa, Pete Weston, Kirsti Salonen and Patricia de Rosnay
Contract officer: Raffaele Crapolicchio

January 2026

Series: ECMWF - ESA Contract Report

A full list of ECMWF Publications can be found on our web site under:

http://www.ecmwf.int/publications/

European Centre for Medium Range Weather Forecasts
Shinfield Park, Reading, RG2 9AX, England

Abbreviations

BUFR ..... Binary Universal Form for the Representation of meteorological data
CCU ..... Central Computer Unit
CESBIO ..... Centre d'Etudes Spatiales de la Biosphère
DPGS ..... Data Processing Ground Segment
ECFS ..... ECMWF's File Storage system
ECMWF ..... European Centre for Medium-range Weather Forecasts
ESA ..... European Space Agency
ESAC ..... European Space Astronomy Centre
ESL ..... Expert Support Laboratory
FTP ..... File Transfer Protocol
MIRAS ..... Microwave Imaging Radiometer using Aperture Synthesis
NetCDF ..... Network Common Data Form
NRT ..... Near Real Time
NWP ..... Numerical Weather Prediction
SAPP ..... Scalable Acquisition and Pre-Processing system
SEKF ..... Simplified Extended Kalman Filter
SMOS ..... Soil Moisture and Ocean Salinity

1. Introduction

This document summarises the production and dissemination status of the European Space Agency (ESA) Soil Moisture and Ocean Salinity (SMOS) neural network (NN) nominal soil moisture product for the fourth quarter of 2025. The NN nominal product is produced at the European Centre for Medium-range Weather Forecasts (ECMWF) and it processes raw SMOS BUFR files within 30 minutes of their arrival via the Scalable Acquisition and Pre-Processing system (SAPP). The SMOS BUFR files should be available to ECMWF less than 165 minutes from the initial observation time and the NN product NetCDF files should be delivered to ESA less than 240 minutes from the initial observation time in the corresponding source BUFR file. Statistics of the production and timeliness of the delivered product are presented, reasons for the lack of completeness and/or failure to meet the timeliness deadline are given and corrective actions (if possible) are described in this report.

2. Quarterly statistics of completeness and timeliness of the SMOS NN product

Figure 1 shows the time series of daily file completeness and timeliness as defined by files that are delivered to ESA within 240 minutes of the initial observation time in the corresponding input BUFR file. The percentages are calculated by dividing the total time covered in the output files by the 24 hours in any single day. For example, for a single day if there are 30 BUFR files covering 48 minutes of data each and 1 file is not produced and 1 file is delivered late then the completeness percentage is 96.67% and the timeliness percentage is 93.33%. The time series covers the fourth quarter of 2025, 1 October to 31 December 2025. The data shows that for quarter 4 the monthly average completeness is above 98% and the monthly average timeliness is above 90% for all months. A more detailed explanation of the periods where the daily completeness drops below 95% and the daily timeliness drops below 80% can be found in section 3.

Table 1 shows the monthly and entire quarter mean statistics of completeness and timeliness. The completeness is 99.7%, 98.8% and 98.7% for October, November and December, respectively, resulting in an entire quarter average of 99.1%. The timeliness is 97.4%, 93.0% and 93.9% for October, November and December, respectively, resulting in an entire quarter average of 94.8%.

Month	Completeness	Timeliness
October	99.7%	97.4%
November	98.8%	93.0%
December	98.7%	93.9%
Quarter	**99.1%**	**94.8%**

Table 1: Monthly mean statistics of completeness and timeliness of SMOS NN nominal soil moisture product delivery

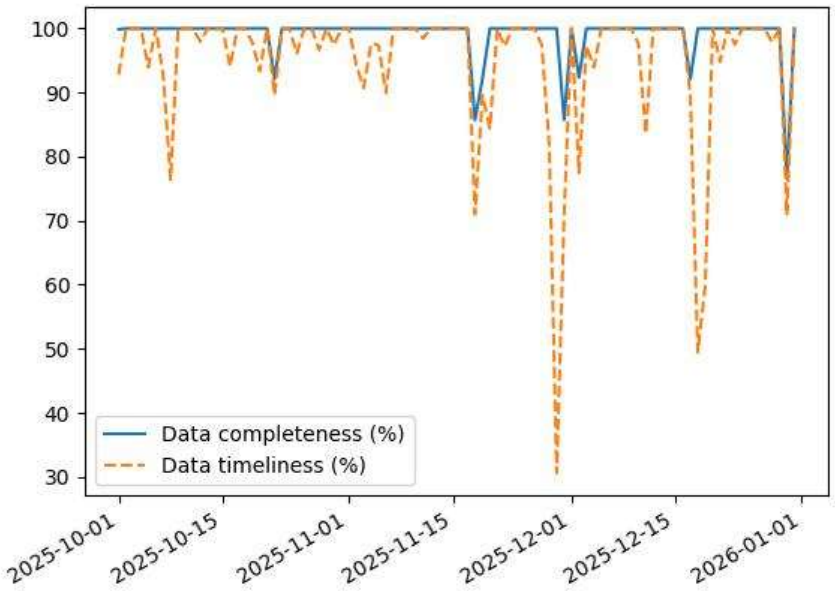


Figure 1: Daily SMOS NN nominal soil moisture production completeness and delivery timeliness percentages (see text for how these are calculated) for the fourth quarter of 2025: 1 October to 31 December 2025

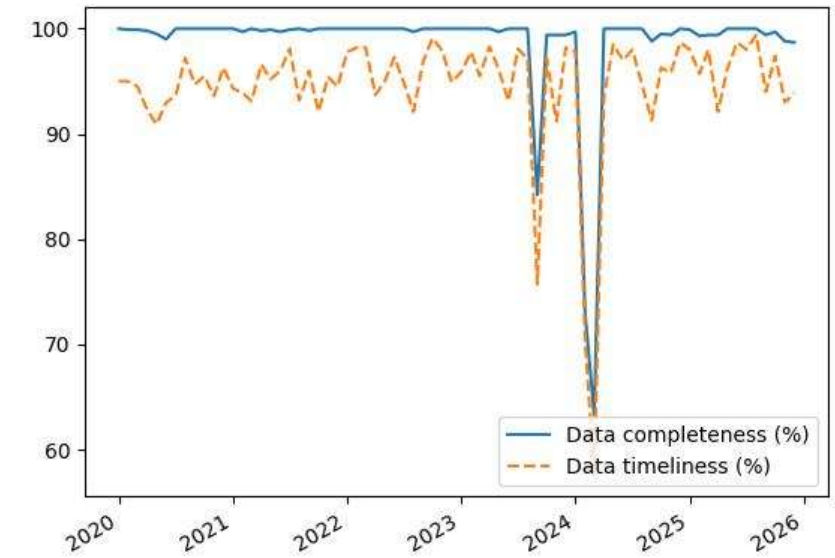


Figure 2: Monthly SMOS NN nominal soil moisture production completeness and delivery timeliness percentages (see text for how these are calculated) for the period January 2020 to December 2025

Figure 2 shows the monthly statistics of completeness and timeliness since January 2020. After September 2023 the level of completeness slightly dropped compared to previous years but for the past year it is close to 100%. The drop after September 2023 results from a change to the completeness calculation, which now takes into account missing BUFR files. Previously, the completeness was set to 100% if the time covered in the NetCDF files matched the time covered in the BUFR files, regardless of how much of the day was covered by the BUFR files. With the new behaviour the statistics are sensitive to any missing BUFR files and thus are a more accurate representation of completeness. In February and March 2024 both the completeness and timeliness dropped significantly due to SMOS being in the safe hold mode. The data became available for users again on 12 March and the statistics have returned to the normal levels in April 2024. The notable drop in the completeness and timeliness in September 2023 was caused by an on-board GPS anomaly. Table 2 summarises the ECMWF related events affecting the production completeness and delivery timeliness for the period of January 2020 to September 2025. During quarter 4 of 2025 there were no ECMWF related events.

Documented in Quarterly report	**Drop in production completeness**	**Drop in delivery timeliness**
Q4 2020, 27.10.2020		4-hour delay in the processing at ECMWF due to ECMWF network outage.
Q1 2021, 5.2.2021	Completeness 93.3% due to single BUFR file for full SMOS orbit not being processed due to anomaly on the server where the processor runs.	
Q2 2021, 28.4.2021 and 22.6.2021	Completeness 94.3% and 92.7%, both instances caused by an anomaly on the server where the processor runs.	
Q3 2021, 13.9.2021	Completeness 93.5% due to an anomaly on the server where the processor runs.	
Q3 2022, 15.8.2022	Completeness 92.1% due to over 36-hour delay to the delivery of the BUFR files. The SMOS NN processor has a feature that allows it to catch	

	up on older files but only goes back one previous day.	
Q2 2023, 30.5.2023 and 27.6.2023	Completeness 91.3%. This was caused by the number of observations exceeding a hard-coded limit of 200000 within the processor. On the 27.6.2023 ECMWF implemented cycle 48r1. This resulted in an inconsistent version of the processor being run from 09:00 on 27June until 13:00 on 28 June. On 28.6.2023 the processor was corrected and most of the missing files were produced and disseminated. One of the dissemination triggers was not reset after the 48r1 related failures so 7 files covering ~12 hours were not disseminated. These files have been transferred manually by FTP to retain a full archive.	
Q4 2023, 21.11.2023		The SMOS NN processor working directory was temporarily moved to a new location but some auxiliary files which the processor depends upon were not accessible. The issue was fixed on 22.11.2023 and the missing files were reprocessed and disseminated.
Q1 2025, 07.02.2025		6-hour delay in the processing at ECMWF due to a server outage.

Q1 2025, 12.02.2025		9-hour delay in the processing at ECMWF due to a major network outage.

Table 2: Summary of ECMWF related events affecting the production completeness and delivery timeliness for the period of January 2020 to December 2025

3. Operational anomalies in this quarter

Completeness:

During the fourth quarter of 2025, several issues reduced the completeness of data produced at ECMWF below 95% (Figure 1). The most significant was a recurring anomaly experienced by SMOS, where the onboard GPS time jumped suddenly, requiring a switch of the time source from GPS to PROTEUS. Following this anomaly, no MIRAS event packages were received, and the remaining science data were temporarily degraded. This issue affected the BUFR file delivery on 18 November (1 file missing), 19 November (1 file missing), 30 November (2.5 files missing), and 2 December (1 file missing), reducing the completeness below 95% on each day.

Additionally, on 22 October and 17 December, a single BUFR file was missing on each day, again reducing completeness below 95%. In both cases, the missing file coincided with a warm NIR calibration of the instrument. However, the link between these calibrations and missing files remains unclear, as other warm NIR calibration manoeuvres during the quarter did not cause data loss.

Finally, one BUFR file was missing on 30 December. At the time of writing, no SMOS Weekly Report is available to confirm whether this was related to a spacecraft anomaly.

Timeliness:

In quarter 4, the timeliness of the data production dropped below 80% on 8 days. On 18 November, 30 November and 2 December, the drop in timeliness is related to a delayed delivery of the BUFR files caused by the SMOS onboard time anomaly discussed above.

On 29 November,18 December and 19 December, the drop in timeliness was caused by an onboard CCU reset that affected the NRT service at ESA.

On 8 October, several BUFR files were delivered late, leading to a delay in the processing. The reason for the delayed BUFR file delivery is unknown.

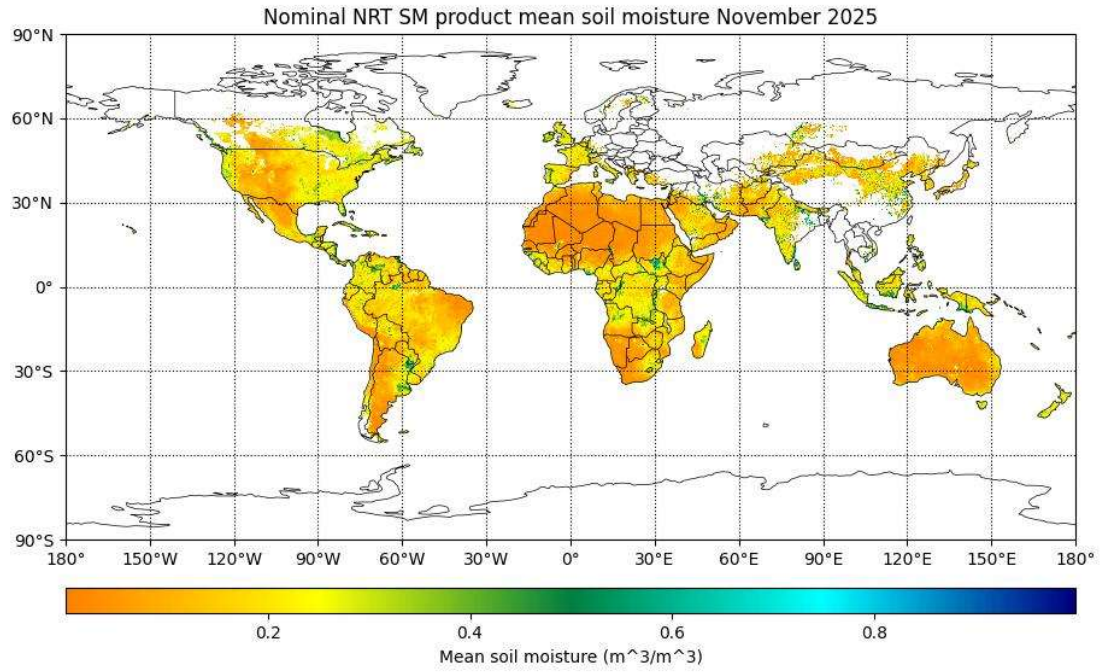
Finally, there was a delay in the BUFR file delivery on 30 December resulting in reduced production timeliness. As before, no information of possible spacecraft or server anomalies is available at the time of writing, so the cause for the observed delay is unclear.

4. Comparisons between the ESA nominal and ECMWF assimilation neural network products

In this section the retrieved soil moisture from both the nominal neural network product delivered to ESA and the assimilation XGBoost product used at ECMWF will be compared. The month chosen for the comparison is November 2025 as this is the middle month of the quarter.

Figure 3 shows that data is missing over large areas of China, parts of Southeast Asia, Northern India, the Middle East, and Europe for the ECMWF assimilation product due to extensive radio frequency interference (RFI) in the SMOS brightness temperatures over those regions. The extent of the RFI-affected areas is reduced in the ESA nominal product due to a different use of RFI flags in the training of the nominal and assimilation products, but large data gaps remain over Europe, China and parts of Southeast Asia. Additionally, large data gaps exist over North America and Northern Eurasia, which are likely caused by frozen soils during this time of the year.

Figure 3 also shows that the two products continue to have significant differences, with the ECMWF assimilation soil moisture product generally moister than the ESA nominal product in November 2025. The maps show that the differences are largest in the tropics over South America, central Africa and the maritime continent in particular. The products are in better agreement over the extra-tropical Southern hemisphere as well as in arid regions. The differences are due to the different datasets which the products are trained on and to a lesser extent the different ML algorithms.



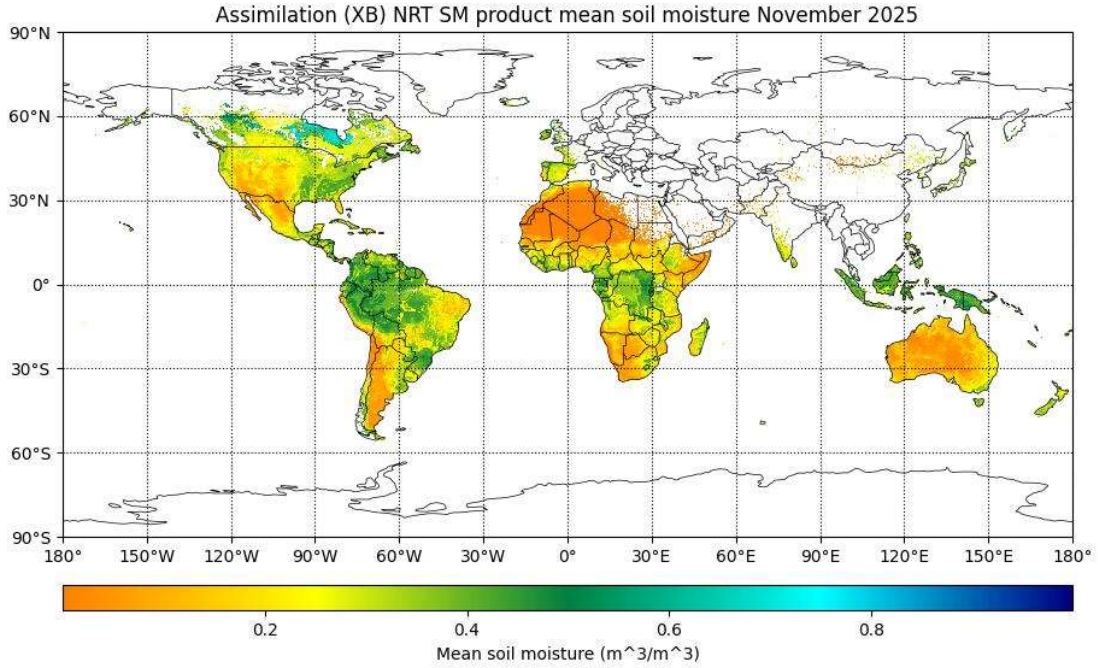


Figure 3: Mean retrieved soil moisture (m^3/m^3) for November 2025 for the nominal NRT product (upper) and assimilation NRT product (lower)

The nominal ESA product is trained on historical values of SMOS level 2 soil moisture whereas the ECMWF assimilation product is trained on the ECMWF model soil moisture. These datasets have different characteristics and represent different soil depths which lead to the differences in Fig. 3. The SMOS level 2 soil moisture represents the uppermost 2-3cm of soil whereas the ECMWF model soil moisture represents the uppermost 7cm of soil.

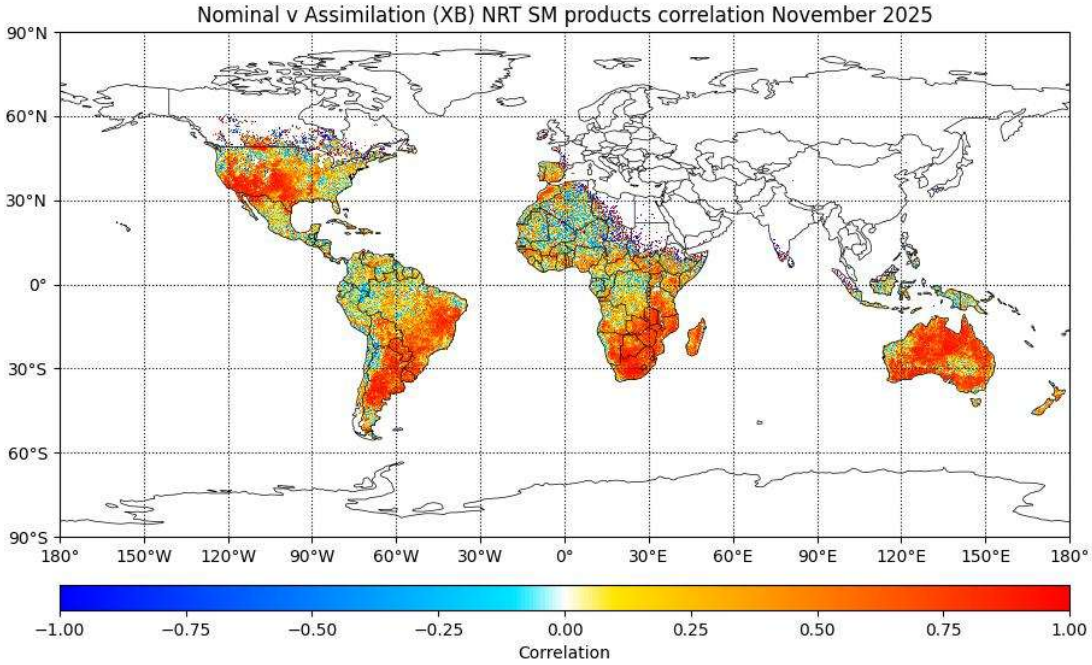


Figure 4: Correlation between the ESA nominal neural network product and the ECMWF assimilation XGBoost product in November 2025

Figure 4 shows that the two products have the strongest correlations in parts of North America, South America, Southern Africa away from heavily forested areas, as well as over Australia. There are moderate correlations in the tropics with the weakest (and sometimes negative) correlations over arid regions such as Central Australia and the heavily forested areas of South America and central Africa.