ESA CONTRACT REPORT

Contract Report to the European Space Agency

SMOS Operational Emergency

SMOS long term assessment based on re-analyses: strategy and work plan

Authors: Patricia de Rosnay and Pete Weston

Report for ESA contract 4000125399/18/I-BG

Technical Officer: Matthias Drusch

CCN1: Additional scope for work

European Centre for Medium-Range Weather Forecasts
Europäisches Zentrum für mittelfristige Wettervorhersage
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Abbreviations

CCN...................... Contract Change Notice
ECMWF .... European Centre for Medium-range Weather Forecasts
ESA .... European Space Agency
ESL....................... Expert Support Laboratories
HTESSEL .... Hydrology Tiled ECMWF Scheme for Surface Exchanges over Land
IFS .... Integrated Forecast System
LDAS .... Land Data Assimilation Scheme
NRT...................... Near Real Time
QC .... Quality Control
RMSE................... Root Mean Square Error
SMOS .... Soil Moisture and Ocean Salinity
StDev.................... Standard Deviation

1. Introduction

This document proposes a long-term strategy and work plan to assess the European Space Agency (ESA) Soil Moisture and Ocean Salinity (SMOS) soil moisture and brightness temperature products. It proposes different strategies and work plans for the Near Real Time (NRT) brightness temperature product and for the two SMOS neural network Soil Moisture (SM) products developed for ESA and for the European Centre for Medium-Range Weather Forecasts (ECMWF) assimilation purposes. The proposed approaches are based on SMOS-dedicated monitoring suites to compute first guess departure statistics against the ERA5 reanalysis. Brightness temperature monitoring is proposed to rely on the Integrated Forecasting System (IFS) monitoring suite adapted to SMOS. Soil moisture monitoring suites for both the ECMWF and the ESA neural network products, are proposed using the surface stand-alone analysis with ERA5 atmospheric analysis forcing. The monitoring suites will be based on IFS cycle 46r1 developments that allow to ingest SMOS neural network soil moisture products (ECMWF 2019). The required input data sets are described, and a detailed work plan is proposed with corresponding required resources.

2. SMOS monitoring and assessment at ECMWF: current status

2.1. Operational monitoring of the NRT brightness temperature product

The SMOS NRT brightness temperature product is currently monitored at ECMWF using the operational IFS suite (Muñoz-Sabater et al, 2013). This monitoring has been operational at ECMWF for nearly 10 years using evolving IFS cycles with regular updates about once per year. In 2010, in the early days of the mission, SMOS monitoring was relying on IFS cycle 36r1 which includes the Community Microwave Emission Modelling Platform (CMEM) to compute forward brightness temperature in the IFS. In 2019, IFS cycle 46r1 is used. The SMOS operational monitoring is conducted at the operational spatial resolution which was 16 km in 2010 and 9 km from 2016. Using the operational IFS system ensures that the best performing up-to-date system is used for monitoring. This configuration is optimal for real time monitoring. It is conducted for incidence angles of 30, 40 and 50 degrees and at horizontal and vertical polarisations. At each angle and polarisation, observations are compared to the IFS forward model computation (standard deviation and mean are computed). Observation values and number of observations are also monitored and maps and regional time series plots are produced and published on the ECMWF website (https://www.ecmwf.int/en/forecasts/quality-our-forecasts/monitoring/smos-monitoring). Figure 1 shows the map of the standard deviation of SMOS brightness temperatures at 40 degrees incidence angle from 13 November 2019 to 12 December 2019.

While this multi-angular operational monitoring is suitable for real time monitoring, it is not suitable for long-term monitoring and long-term assessment of the SMOS product which require the use of a consistent system configuration across the multi-year monitored period.

2.2. Long term monitoring of the NRT brightness temperature product based on ERA-Interim

Long term monitoring and assessment of SMOS brightness temperature data was conducted for a period covering 7 years, from 2010 to 2016, using a consistent monitoring system (de Rosnay et al., 2018, 2019a, 2020). The monitoring set-up used the Community Microwave Emission Modelling Platform (CMEM) version 5.1 (de Rosnay et al., 2018), an offline version of the ECMWF land surface model H-TESSEL (Hydrology-Tiled ECMWF Scheme for Surface Exchanges over Land, Balsamo et al., 2009) and the ERA-Interim reanalysis atmospheric forcing (Dee et al., 2011). For this monitoring a combination of consistent reprocessed and operational level 1 TB products from the SMOS processor v5.05 was used from January 2010 to March 2012 and from April 2012 to April 2015, respectively. Since v5.05 was the latest reprocessed version available of the full NRT TB product, monitoring from May 2015 to December 2016 used the operational SMOS NRT TB from the processor version 6.20. This monitoring required to run an offline H-TESSEL re-analysis forced by ERA-Interim atmospheric conditions from 2010 to 2016. Then the output of H-TESSEL (including soil moisture, temperature, snow mass) was used as input of offline forward simulations of SMOS brightness temperature using CMEM at both horizontal and vertical polarisations and at 40 degrees incidence angle. Comparison between the forward reanalysis-based brightness temperature allowed to assess the SMOS brightness temperature after a seasonal bias correction was applied. Metrics used included standard deviation of first guess departure, mean bias before and after bias correction, correlation. Results showed that the consistency between SMOS and ECMWF reanalysis-based TBs gradually improved between 2010 and 2016, pointing out improvements of level 1 SMOS TB products quality through the SMOS lifetime (Figure 2).

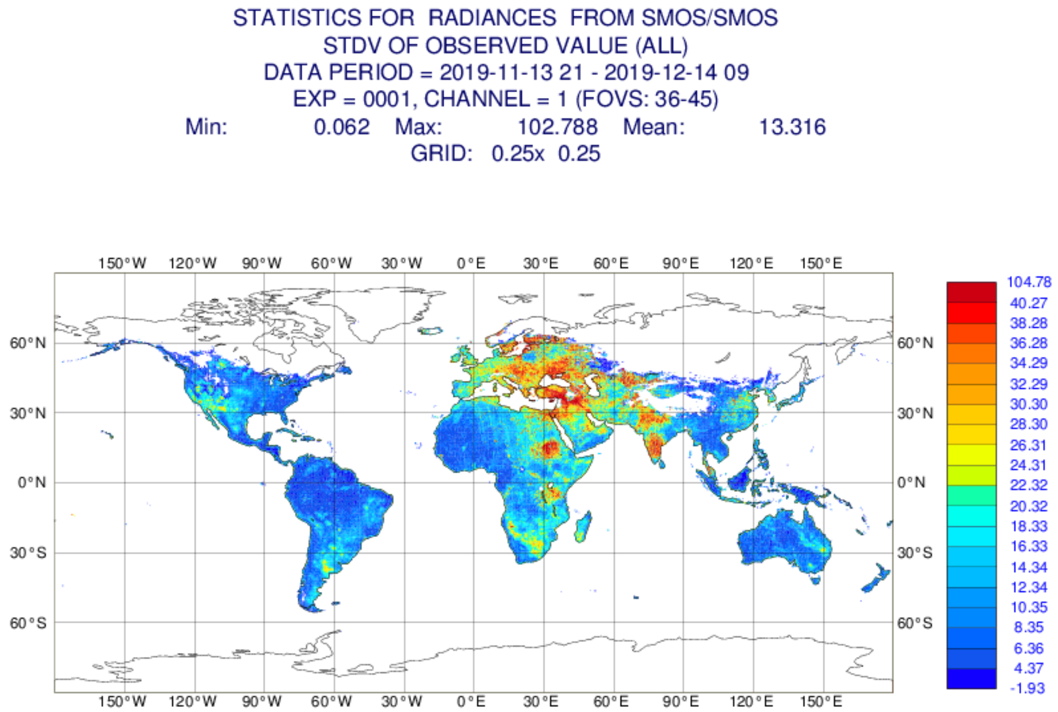
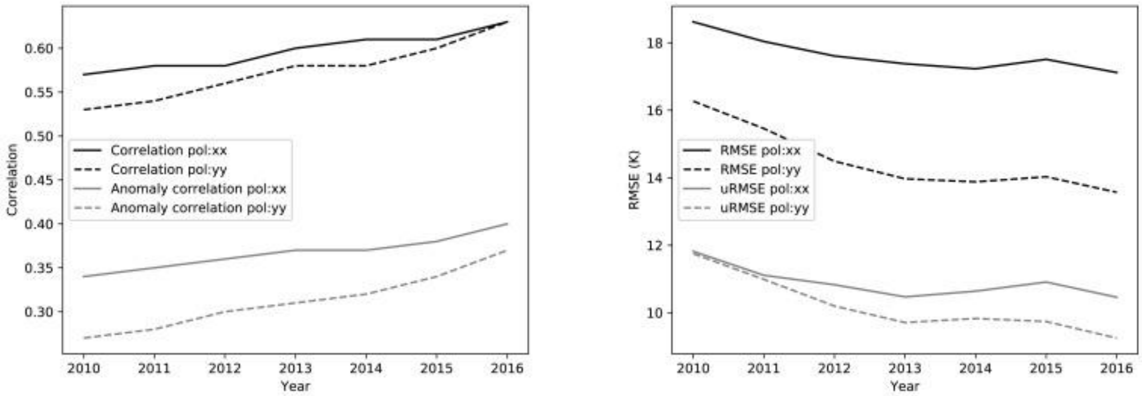


Figure 1: Operational SMOS brightness temperature monitoring: standard deviation of SMOS brightness temperature (K) from 13 November 2019 to 12 December 2019.



(a) Correlation (b) Root mean square error

Figure 2: Global mean statistics of SMOS TBs monitoring from 2010 to 2016, comparing SMOS observations to ECMWF CMEM reanalysis of L-Band TB, at 40° incidence angle, at X (solid line) and Y (dashed line) polarisations. Left panel depicts correlation (black) and anomaly correlation (grey). Right panel depicts Root Mean Square Error (RMSE, black) and unbiased RMSE (grey). From de Rosnay et al. (2020).

The SMOS brightness temperature long-term monitoring described in de Rosnay et al. (2020) was a one-off exercise conducted for a single incidence angle to evaluate SMOS brightness temperature data on a multi-year period. It showed that developing and setting up an operational long-term monitoring suite would be very relevant to monitor the SMOS data consistently through its life time with an operational real time component consistent with the past periods.

2.3. SMOS soil moisture neural network product assessment

The ESA Level 2 SM retrieval algorithm is based on a detailed geophysical modelling and cannot provide SM in NRT. Rodriguez-Fernandez et al (2016) and Muñoz-Sabater et al (2016) developed the ESA SMOS NRT SM product using a neural network (NN) approach. The NN inputs are SMOS brightness temperatures for horizontal and vertical polarizations and incidence angles from 30 to 45°. In addition, the NN uses surface soil temperature from the IFS. The NN was trained on SMOS Level 2 (L2) SM. The SMOS ESA NRT SM product (or the SMOS nominal NRT SM product) is processed at ECMWF operationally and it is distributed by ESA.

In addition, for the purpose of data assimilation, ECMWF developed a soil moisture product trained on the ECMWF soil moisture data. The first version of this product is described in Rodriguez-Fernandez et al. (2019) were the NN was trained on ERA-Interim soil moisture. The version that was implemented for operational assimilation was trained on the ECMWF operational soil moisture and it was implemented for operational assimilation in the IFS cycle 46r1 in June 2019 (de Rosnay et al. 2019b).

In the context of the ESA SMOS ESL (Expert Support Laboratories) project proposal, which is currently in review, these two products will be regularly assessed and monitored in real time along with the brightness temperature data.

3. Proposed long-term assessment and monitoring strategy and work plan

Previous monitoring activities described above emphasized the need for developing reanalysis-based long-term SMOS monitoring to assess SMOS data using consistent data and a consistent monitoring system for past periods up to near real time.

A long-term monitoring strategy is proposed here to complement the current operational monitoring of brightness temperature and to support the continuous SMOS neural network product assessment conducted in the context of the ESL project. It is detailed in Table 1 for the three following products: NRT brightness temperature, ESA NRT SM and ECMWF SM. Work plan is indicated by providing required resources for each product.

An up-to-date reprocessed brightness temperature dataset would be necessary to ensure a suitable long-term monitoring of any of the three products. The longest consistent SMOS NRT brightness temperature product data record currently available is based on the SMOS processor v5.05, available from January 2010 to April 2015. From April 2015 SMOS products based on processor v6.0 have been used for brightness temperature and SMOS NN training and production. Hence, reprocessed NRT brightness temperature product using the most recent version of the SMOS processor and covering the entire SMOS life time would be required. It would have to be consistent with the operational SMOS NRT brightness temperature product which would also need to be updated to use the most recent version of the processor. The reprocessed NRT brightness temperature dataset would need to be acquired at ECMWF, which involves some resources as indicated in Table 1. Although the personnel resources required is limited to 1 Person-month (PM), the actual time needed for the acquisition would be significantly longer due to the large volume of data to process as shown by the tentative schedule indicated in green in the Table. Based on previous experience from the ESA SMOS data assimilation study (de Rosnay et al., 2019a), 6 months of actual time would be necessary, during which the monitoring suites would be prepared.

For the long-term brightness temperature assessment, the proposed strategy relies on the IFS monitoring suite which has been used for satellite monitoring activities at a low computing cost. This suite computes the standard monitoring statistics as in operations, but instead of running the full 4D-Var it reads a reference analysis as input, so that the cost is reduced significantly. It is suitable to run long term monitoring using reanalysis as reference dataset. It is proposed to use the ERA5 reanalysis input (Hersbach et al., 2020). To run a 10 years SMOS monitoring experiment 3 months of actual time would be necessary, with 5 two-year streams running in parallel. It must be adapted for SMOS monitoring which has a specific set-up because of the SMOS data volume.

SMOS data	Reprocessed data		Monitoring: suite format	Forcing (reference)	CMEM forward computation	Bias correction: needs and variable	Monitoring: maintenance products metrics
	Input Data	Processing					
NRT Brightness temperature	Reprocessed NRT TB 2010-2020 (ESA)	Acquisition at ECMWF	IFS monitoring only suite 46R1 adapted for SMOS ODB	ERA5 atmospheric and land reanalysis	Yes	Yes Brightness temperature	Maps, time series, hovmoeller Mean, standard deviation
Resources		1 PM	4 PM			6 PM	4PM
Schedule	T00A	T00A+6	T00A+8			T00A+18	T00A+12
Nominal ESA NRT SM	Reprocessed ESA L2SM & NRT TB 2010-2020 (ESA)	Training reprocessed NRT TB (CESBIO, T00B+6); Quality check; Reprocess ESA NRT SM ; Acquisition on ECMWF archive	Stand-alone LDAS 46R1 Adapted for SMOS monitoring GRIB	ERA5 atmospheric reanalysis	No	TBD Soil moisture (optional)	Maps, time series, hovmoeller, histograms Mean, standard deviation, correlation, rmse
Resources		6 PM	4 PM			3 PM	4PM
Schedule	T00B	T00B+12	T00B+16			T00B+23	T00B+20
ECMWF NRT SM	Reprocessed NRT TB 2010-2020 (ESA)	Training reprocessed NRT TB & ERA5 SM (CESBIO, T00A+6); Quality check ; Reprocess NRT SM ; Acquisition on ECMWF archive	Stand-alone LDAS 46R1 GRIB	ERA5 atmospheric analysis	No	No	Maps, time series, hovmoeller, histograms Mean, standard deviation, correlation, rmse
Resources		7 PM	4 PM				4PM
Schedule	T00A	T00A+13	T00A+17				T00A+21

Table 1: Long term monitoring and assessment strategy, and work plan for the SMOS NRT brightness temperature, the nominal ESA NRT SM, and the ECMWF NRT SM products monitoring. We propose the three suites to run at the ERA5 spatial resolution (30km). For each monitoring suite, estimated resources required by ECMWF are indicated in blue and a tentative schedule is given in green, accounting for 6 months estimated to be necessary for CESBIO for neural network retraining (to be discussed and approved by CESBIO).

For the SMOS neural network SM products, it would be necessary to re-train the neural networks using an up-to-date SMOS brightness temperature product. The ECMWF NRT SM product training would also need to account for the ERA5 reanalysis. The monitoring suites would use the stand-alone Land Data Assimilation System (LDAS), described in Fairbairn et al. (2019) which allows to run land data assimilation and monitoring at low computing cost without running atmospheric data assimilation. The Stand-alone LDAS would read the ERA5 atmospheric reanalysis. It would be adapted to enable SMOS soil moisture monitoring based on the GRIB input and output files of the suite. It is expected that running 10 years of monitoring using this system would take 4 to 5 months, running 10 1-year streams in parallel, at the ERA5 resolution.

For these three monitoring suites, 10-year reanalysis-based monitoring would be produced until near real time is reached. Once the suites have caught up with present dates, the real time stream of ERA5, ERA5T, would be used and the long-term monitoring would be continued and maintained in real time.

It is proposed that monitoring results would be published on the ECMWF web site were a dedicated space would be allocated for the long-term reanalysis-based SMOS monitoring and assessment.

Table 1 proposes a tentative schedule (in green) and indicates required resources for each monitoring suite. It is an approximate schedule which arbitrarily accounts for 6 months for CESBIO to retrain the neural network processors (pending CESBIO approval) and estimates ECMWF schedule for acquisition, reprocessing soil moisture for 2010-2020, setting up new monitoring suites based on the IFS and the stand-alone LDAS, and developing adequate monitoring products and web interfaces. The tentative schedule is valid for each monitoring suite individually. Developing several suites in parallel with limited resources will certainly affect the schedule of each suite.

This proposed strategy indicates possibilities and work plan for long term SMOS monitoring. There is no commitment from ECMWF to develop and to do this monitoring as it is not part of any ongoing project. However, this document can provide relevant input for potential future Contract Change Notice (CCN) dedicated to SMOS long-term assessment.

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