ESA Contract Report

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Contract Report to the European Space Agency

Quarter 2 2021: Operations Service Report

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Abbreviations

BUFR .... Binary Universal Form for the Representation of meteorological data
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 second quarter of 2021. 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 second quarter of 2021, 1st April 2021 to 30th June 2021. The data shows that for the vast majority of days the completeness is 100% or very close to 100% and the timeliness is greater than 90%. An explanation of the periods where completeness drops below 95% and 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 above 99% for all months and the entire quarter average is 99.8%. The timeliness is 95% or above for all months and the entire quarter average is 95.9%.

Month	Completeness	Timeliness
April	99.8%	96.6%
May	99.9%	95.2%
June	99.7%	96.0%
Quarter	**99.8%**	**95.9%**

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

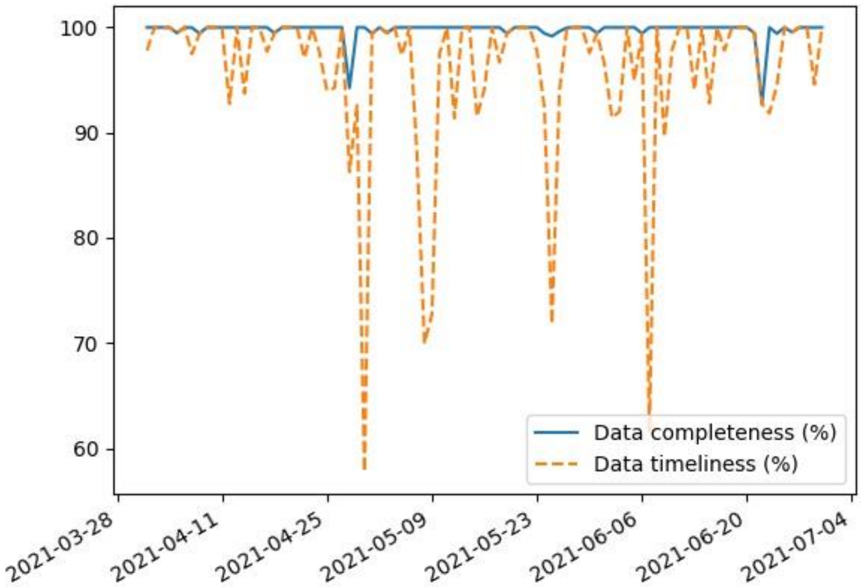


Figure 1: Daily SMOS NN nominal soil moisture production completeness and delivery timeliness percentages (see text for how these are calculated) for the second quarter of 2021: 1st April to 30th June 2021

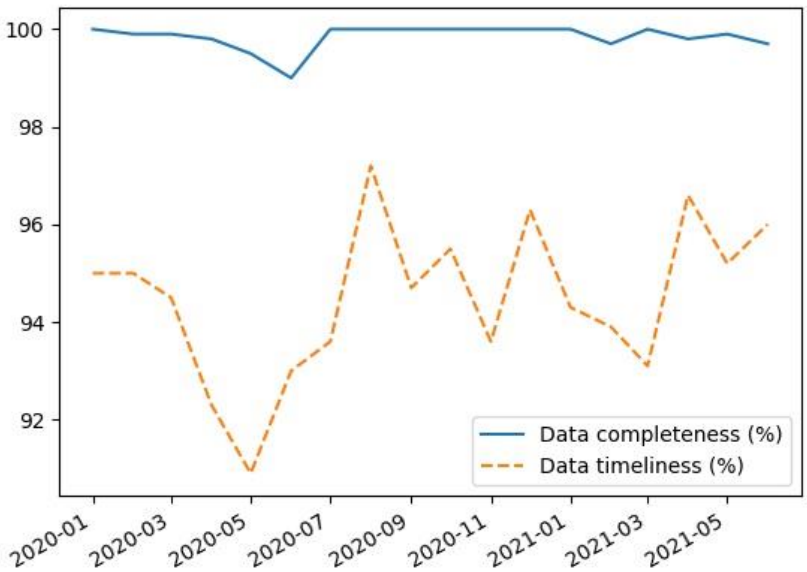


Figure 2: Monthly SMOS NN nominal soil moisture production completeness and delivery timeliness percentages (see text for how these are calculated) for the period January 2020 to June 2021

Figure 2 shows the monthly statistics of completeness and timeliness since January 2020 and shows that the completeness has remained fairly constant in quarter 2 of 2021 compared to quarter 1 of 2021, while the timeliness has improved slightly.

3. Operational anomalies in this quarter

Figure 1 shows that there were two days where completeness dropped below 95% this quarter. These were on 28th April and 22nd June where the completeness dropped to 94.3% and 92.7% with each representing a single BUFR file for a full SMOS orbit not being processed. Both instances were caused by an anomaly on the server where the processor runs which meant some external software modules were unavailable and thus the processor failed. This failure has occurred before but is very difficult to protect against. Fortunately, it happens very rarely but if it starts happening more regularly further investigations into protective measures will be made. There are some other days where the percentage drops very slightly below 100% and these are due to a small number of input SMOS BUFR files containing only ocean points. When the neural network processor encounters such a file it skips the file because the neural network product is only validly produced over land.

Figure 1 also shows that there are several days in the past three months where the timeliness drops significantly below 80%, namely 30th April, 8th May, 9th May, 25th May and 7th June, where it drops to 57.8%, 70.0%, 72.8%, 71.8% and 61.7% respectively. Most of these significant drops were caused by ESA delays to the delivery of the BUFR files due to a degraded near-real time (NRT) dissemination service. On 8th May and 9th May the delay was due to a failure in the NRTP processor due to MPI processing. On the 25th May the delay was due to the operational deployment of the new Level 1 and Level 2 SMOS processors. On the 7th June the delay was due to problems in the SMOS DPGS Core system. These events are out of ECMWF's control, so no corrective action can be taken to stop these events happening in the future.

On the 30th April the delay was due to an outage of the ECFS system which is used to store the SMOS BUFR files and output SMOS neural network netCDF files. This outage lasted from midnight until 12:30pm and meant that no processing could happen during that period. After the outage the processing caught up on the files that had arrived in the meantime meaning no drop in completeness.

Other than those events described above there were no other operational anomalies this quarter.

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 neural network product used at ECMWF will be compared. Figure 3 shows that data is missing over China and the Middle East due to extensive radio frequency interference (RFI) in the SMOS brightness temperatures over those regions.

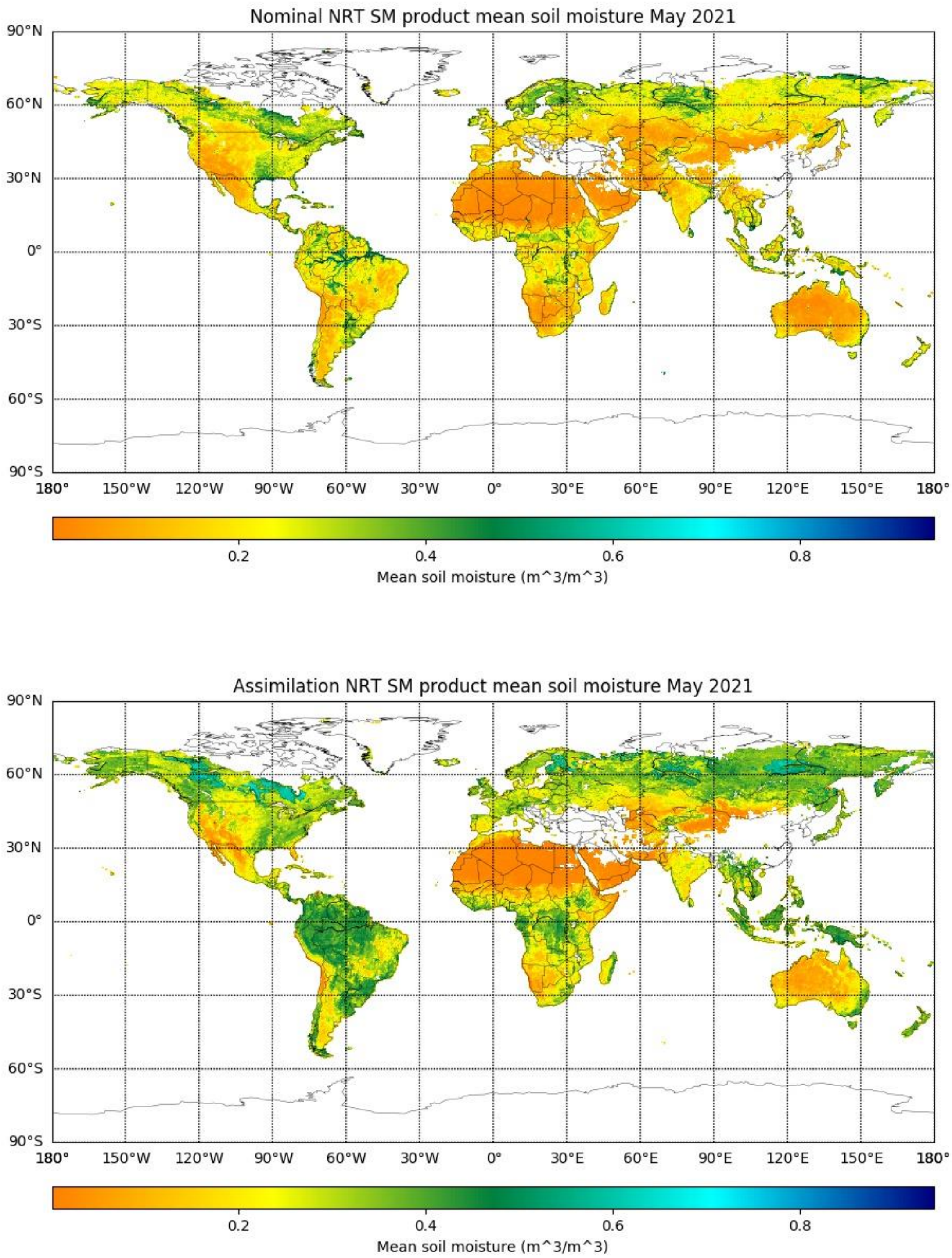


Figure 3: Mean retrieved soil moisture (m^3/m^3) for May 2021 for the nominal NRT product (upper) and assimilation NRT product (lower)

Figure 3 also shows that the two products have significant differences with the ECMWF assimilation soil moisture product generally moister than the ESA nominal product in May 2021. The maps show that the differences are largest in the tropics (over South America, central Africa and the maritime continent in particular) and the Northern high latitudes (Siberia and Northern Canada). The products are in better agreement over Europe, the US as well as in arid regions. The differences are due to the different datasets which the two neural networks are trained on and are consistent with what is seen in April and June 2021 as well as other months throughout the year. 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 figure 3.

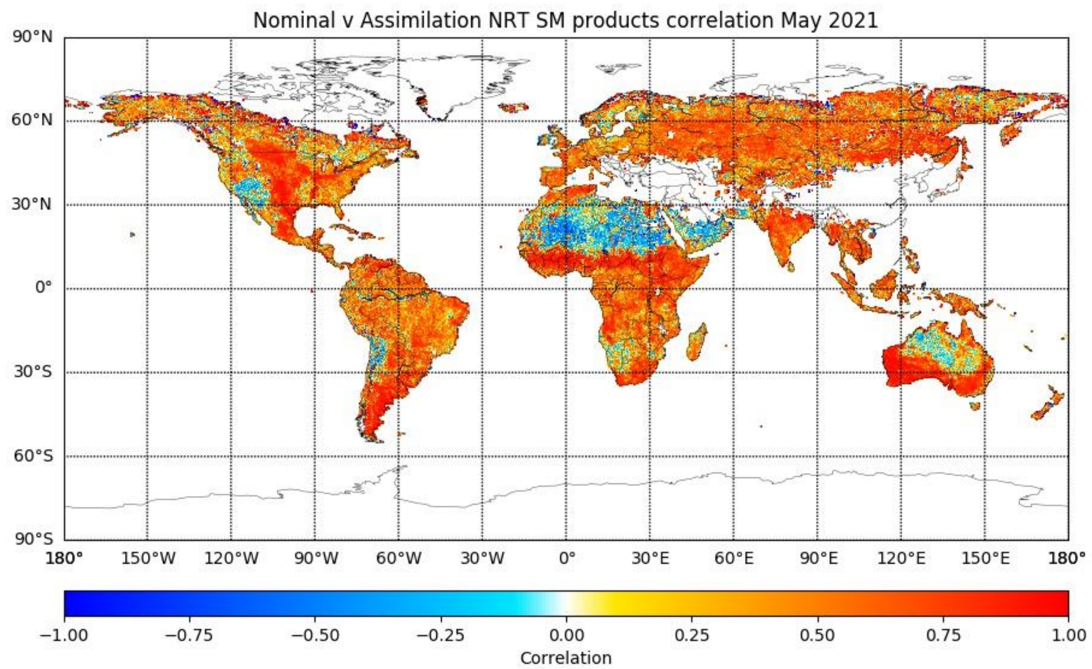


Figure 4: Correlation between the ESA nominal neural network product and the ECMWF assimilation neural network product in May 2021

Figure 4 shows that the two products have the strongest correlations in the far South of South America, Australia as well as the central US and Sahel. There are moderate correlations in the remainder of the Northern mid-latitudes and tropics with the weakest (and sometimes negative) correlations over arid regions such as the Sahara desert, Arabian peninsula, Western US, the Andes and central Australia.

5. Re-training of the neural network with v724 reprocessed SMOS data

During this quarter further progress has been made on the re-training of the neural network with the latest reprocessed SMOS level 1 v724 and SMOS level 2 soil moisture v700 data. The Centre d'Etudes Spatiales de la Biosphère (CESBIO) performed the re-training of both the ESA nominal and ECMWF assimilation neural network products. The new weights and parameters for the v300 neural networks were delivered to and implemented at ECMWF and the operational neural network processor was tested by running it offline with the new parameters. The results of the ECMWF operational processor and the CESBIO processor were compared and were found to be near identical (Rodriguez-Fernandez et al., 2021).

In addition, the v300 ECMWF assimilation neural network product was run for a longer period, a month between 20th June 2019 and 19th July 2019. Comparisons with the v100 product were made and an assimilation experiment was then run to compare the results on the numerical weather prediction (NWP) system of assimilating the v300 product compared to the currently operational v100 product.

5.1. Comparison of v300 and v100 ECMWF assimilation neural network products

Figure 5 shows that in most areas of the world the number of valid soil moisture retrievals is similar or slightly increased with the new version. However, there are areas of Eastern Europe, the middle East, North-Eastern Asia and the Sahara desert where the number of valid soil moisture retrievals is significantly lower. These and surrounding areas are heavily affected by radio frequency interference (RFI) so increased RFI screening is the most likely explanation for the drops in these areas.

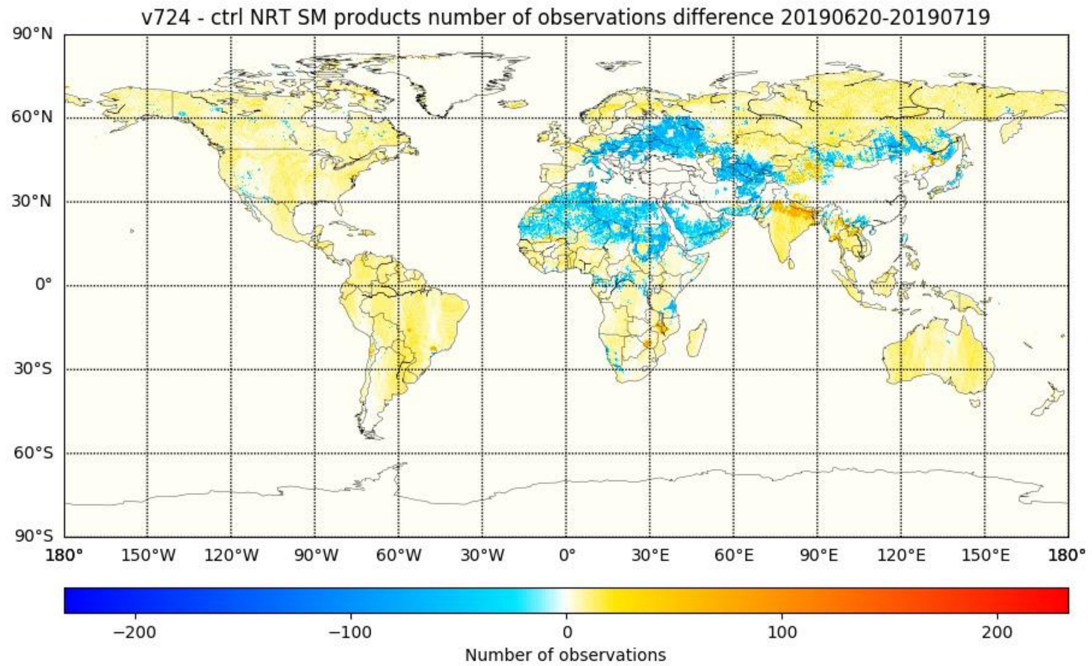
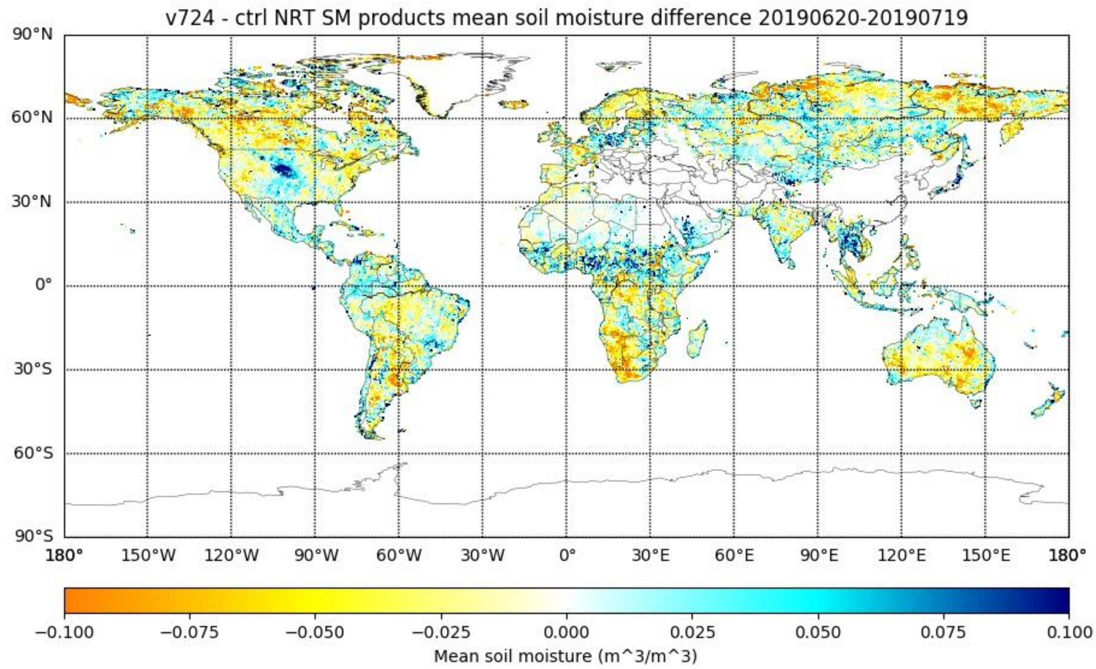


Figure 5: Difference in the number of valid soil moisture retrievals between v300 and v100 of the ECMWF assimilation neural network processors. Data are accumulated between 20th June 2019 and 19th July 2019.



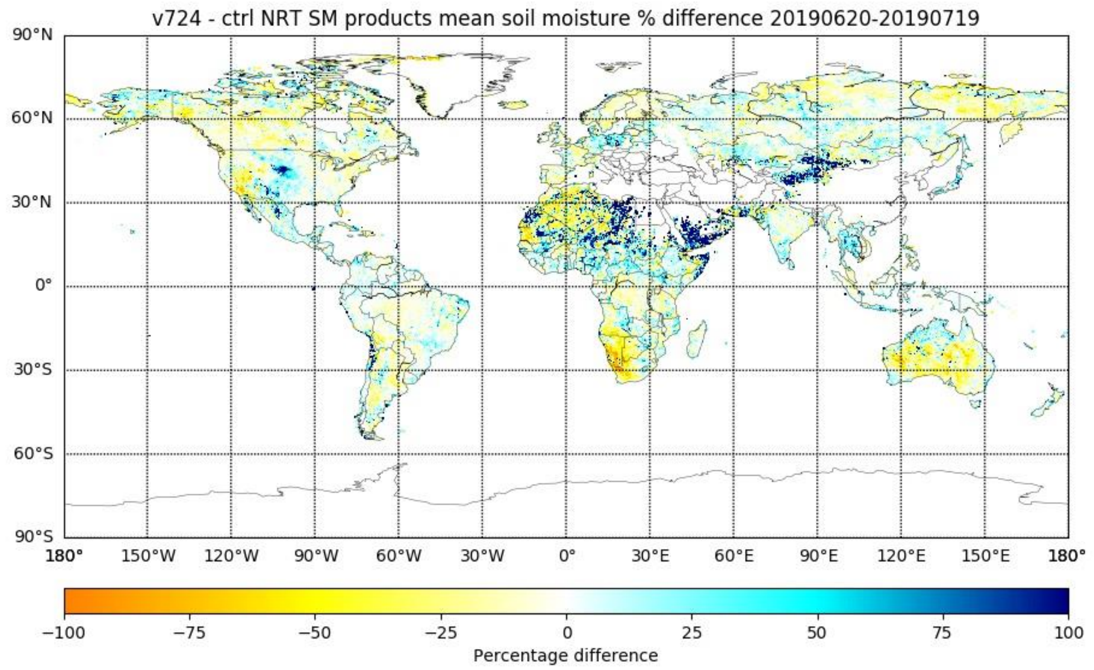


Figure 6: Mean differences in retrieved soil moisture between v300 and v100 of the ECMWF assimilation neural network processors. The upper panel shows the raw mean difference, the lower panel shows the percentage difference. Data are averaged between 20th June 2019 and 19th July 2019.

Figure 6 shows that there are some regional differences in the soil moisture between the new and current neural network products. By looking at the lower panel it can be seen which of the differences are significant. The most significant differences are moistening over the central US and drying over the

Namib desert and central Australia. These differences are most likely explained by changes to the underlying ECMWF model soil moisture since the previous version was trained, because this is the target used to train the neural network. Changes in the characteristics of the L1 brightness temperatures from the reprocessing could also contribute to these differences. The apparently large relative differences over the Sahara desert, middle East and Gobi desert are due to the very low soil moisture in these areas and so are probably mostly noise. In other areas the differences are relatively small.

5.2. Assimilation results

A pair of assimilation experiments were run to assess the impact on the NWP system of assimilating the new v300 neural network product compared to the current v100 product. Both experiments ran for a month between 20th June 2019 and 19th July 2019, ran at a resolution of $T_{CO}399$ (approx. 25km grid spacing) and used the "SSA only" experiment mode (Fairbairn et al, 2019) where the operational atmospheric analysis is used to initialise the atmosphere while the land data assimilation system, including the soil moisture simplified extended Kalman filter (SEKF), runs as usual to assimilate the SMOS neural network soil moisture. This mode was chosen as it runs significantly faster than the full assimilation system. The control experiment assimilates the currently operational v100 SMOS neural network soil moisture while the test experiment assimilated the new v300 SMOS neural network soil moisture.

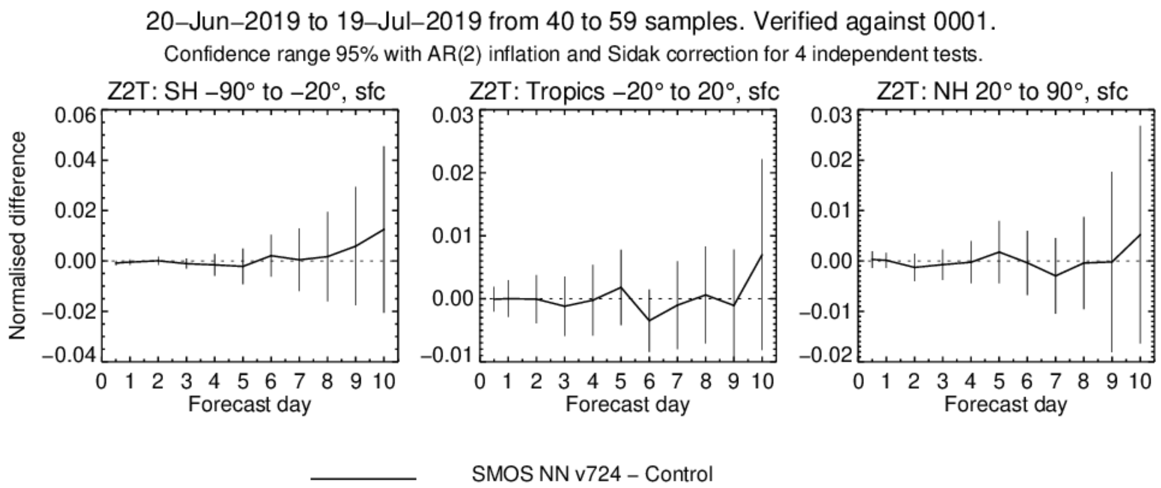


Figure 7: Normalised difference in 2 metre temperature forecast RMSE between the test and control experiments (see text for experiment descriptions) for the Southern hemisphere extra-tropics (left panel), tropics (centre panel) and Northern hemisphere extra-tropics (right panel).

Figure 7 shows that there are very small differences in the 2 metre temperature forecast errors between the two experiments. Any differences that are visible are not statistically significant as indicated by the error bars spanning zero on the y axis. The 2 metre temperature forecast impact has been shown as it is the most likely variable to show an impact from the assimilation of the SMOS neural network soil moisture (Rodriguez-Fernández et al, 2019) but all other variables show similar results. This indicates that changing to the new v300 SMOS neural network is having a neutral impact on the forecasts in the NWP system.

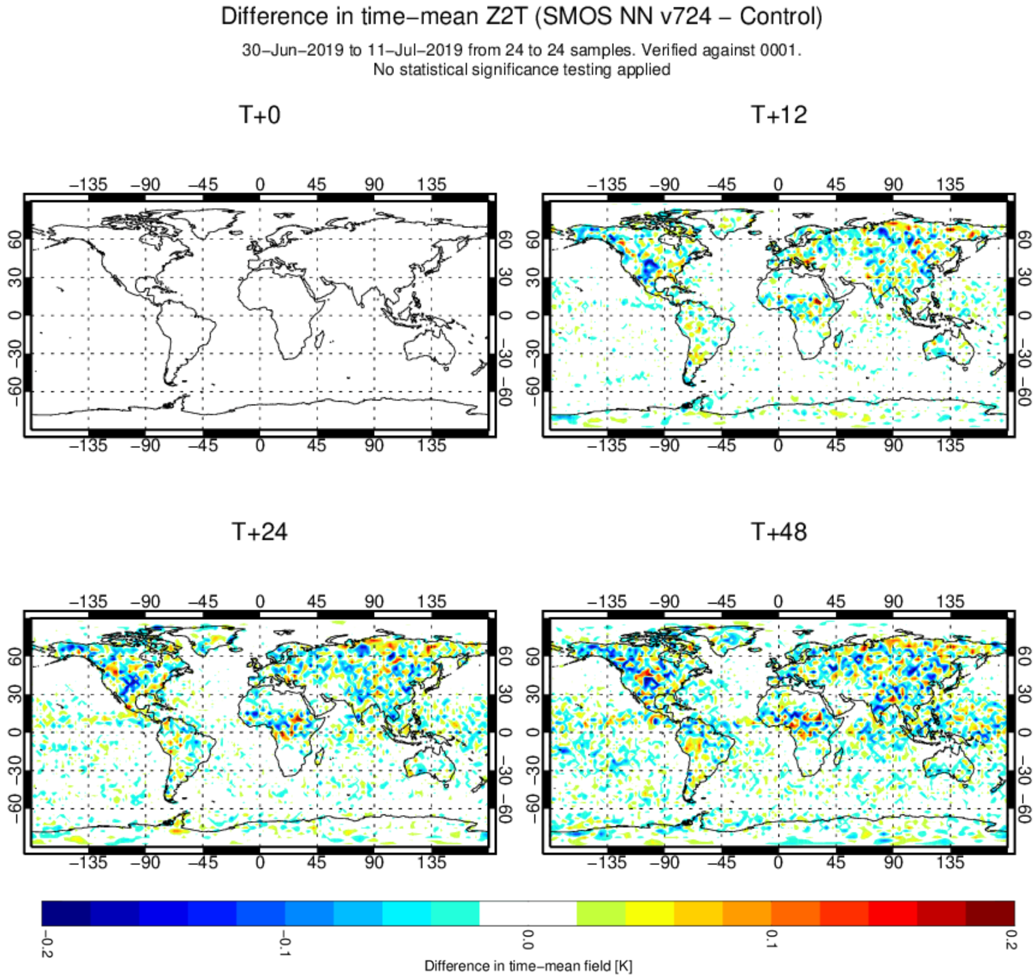


Figure 8: Mean difference in 2 metre temperature forecasts from T+0 to T+48 hours between the test and control experiments (see text for experiment descriptions).

Figure 8 shows that there are small mean differences in the 2 metre temperature forecasts resulting from the change to assimilating the v300 SMOS neural network soil moisture. Given the mixture of small positive and negative signals most of this is probably noise, however there is a significant mean reduction of up to 0.2K over the central US. This almost exactly corresponds to the area where the v300 soil moisture is moister than the v100 soil moisture as shown in figure 6. If the model soil is moister then a corresponding cooling of the near surface temperatures would be expected so this looks to be a real physical impact of the new v300 neural network soil moisture.

Figure 9 shows that there is a corresponding reduction in the mean 2 metre temperature forecast error in this area, which suggests this change is beneficial to the NWP forecasts.

Based on these results the new v300 SMOS neural network processor will be implemented operationally at ECMWF in the near future and the soil moisture product will be assimilated into the ECMWF land data assimilation system.

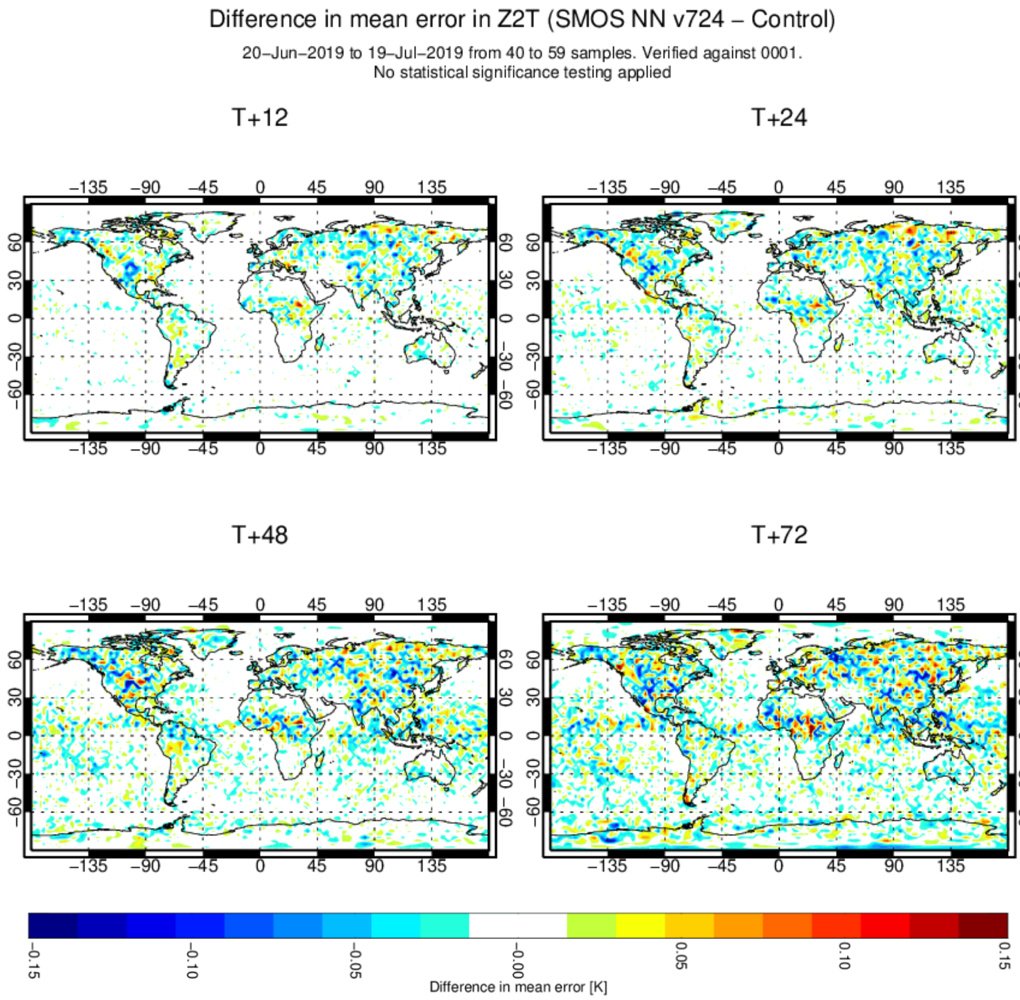


Figure 9: Difference in mean 2 metre temperature forecast error from T=12 to T+48 hours between test and control experiments (see text for experiment descriptions).

6. References

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