Assessment of the SURFEX LDAS-MONDE soil moisture and LAI data products

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Abstract

In this document, the SURFEX LDAS-MONDE soil moisture and LAI data products are evaluated using independent observations. LAI products, as well as other SURFEX model vegetation variables, are evaluated using solar-induced fluorescence observations from Sentinel-5P. The soil moisture products are evaluated using in-situ soil moisture observations in southwestern France.

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1. Solar-induced observations

The Sentinel-5p+ Innovation (S5P) project includes a component to develop novel products using data from the Tropospheric Monitoring Instrument (TROPOMI). TROPOMI's ability to measure in multiple spectral bands, including ultraviolet, visible, near-infrared and shortwave infrared, allows improved imaging of various pollutants and high-resolution monitoring of solar-induced fluorescence (SIF). This work uses a level 2 SIF product disseminated by the ESA TROPOSIF project (https://s5p-troposif.noveltis.fr/). It is derived using a retrieval approach using the 743-758 nm spectral window. The TROPOMI SIF product has an advantage over other SIF products, such as those from the Global Ozone Monitoring Experiment-2 (GOME-2), due to the finer spatial resolution of TROPOMI (7.5×3.5 km pixels with daily revisit).

The SIF product used is available on a daily basis from 1 May 2018 to 31 December 2020. Over the study area (28.05°-71.95° N and 25.95° W-45.95° E), typical satellite pass times are between 07:00 and 15:00 UTC. As the SIF product differs in spatial resolution with respect to open-loop (OL) and analysis simulations (7.5 km for the former and ~10 km for the latter), we produced an average interpolated SIF gridded dataset at a spatial resolution of 0.1°x0.1°. The mean SIF values are shown in Figure 1.

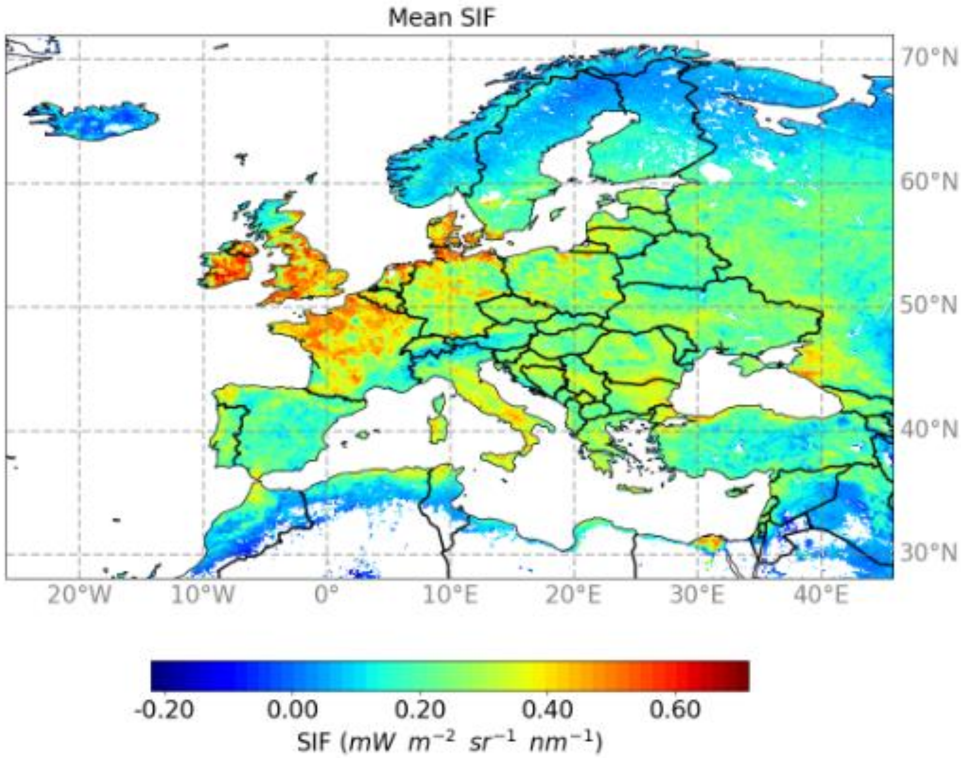

Figure 1 - Averaged Sun Induced Fluorescence (SIF) TROPOMI observations for the period from 1 May 2018 to 31 December 2020.

The largest mean SIF values are observed in parts of Ireland, England, and France. The Nile valley is also visible. Note that few negative values are present.

2. Root-zone soil moisture observations

In situ soil moisture observations are used at a depth of 0.3 m in southwestern France. They are derived from the SMOSMANIA network (Calvet et al. 2016, https://doi.org/10.5194/soil-2-615-2016) of Meteo-France, which provides soil moisture and soil temperature observations every 12 minutes at soil depths of 0.05, 0.1, 0.2, 0.3 m since 2007. For the study period from 1 May 2018 to 31 December 2020, continuous observations at 0.3 m without missing data are available for the Saint-Felix de Lauragais (SFL) station, and the data from SFL are used for the evaluation. These data are available from the International Soil Moisture network (https://ismn.earth).

3. Validation of LAI and other vegetation variables

In this study, the SURFEX LDAS-MONDE simulations of leaf area index (LAI) and gross primary production (GPP), obtained with and without assimilation (OL and analysis, respectively) of LAI observations, are compared with the TROPOMI SIF product. Since hourly GPP simulations are available, the time is chosen to fit the S5-P transit time. The mean GPP values for the hours used to estimate the correlation coefficient between this variable and SIF are shown in Figure 2 for OL and for the difference between the analysis and OL, at a spatial resolution of 0.1°x0.1°.

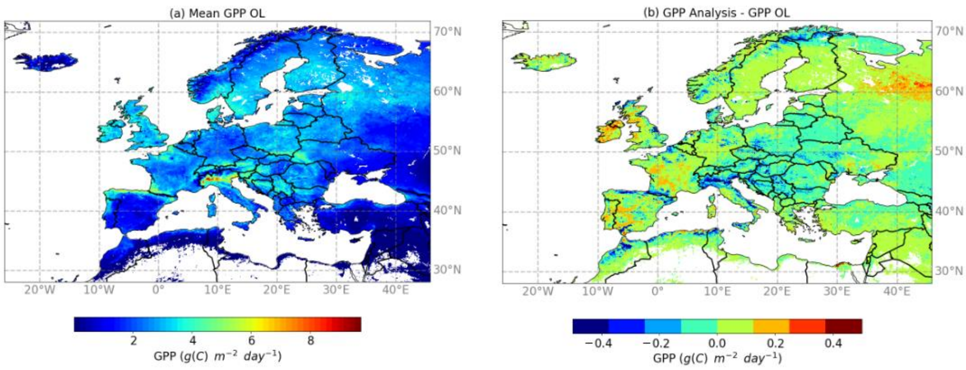

Figure 2 – Simulated GPP: mean value for OL simulation (a) and analysis minus OL (b), for the period from 1 May 2018 to 31 December 2020.

For the period considered, high GPP values around 9 g(C) m^{-2} d^{-1} are found in northern Spain, southern France and northern Italy, as well as in Slovenia. As expected, areas with sparse vegetation (e.g. northern Scandinavia, northern Africa) show low GPP values. The difference between the two experiments shows that, in general, the analysis shows higher GPP values than the OL. The increase in GPP due to assimilation is more pronounced in regions such as Ireland, parts of France and Spain, and the Russian boreal forest. However, in the cereal producing areas of France, Spain, Italy and North Africa, the OL produces higher GPP values than the analysis. This is also observed to some extent in Eastern European countries.

Figure 3 provides a visual representation of the mean simulated LAI values within the domain for both the OL and the analysis.

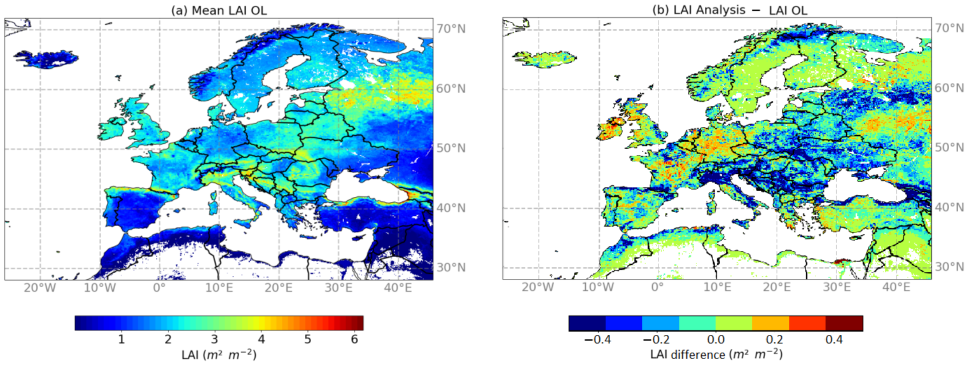

Figure 3 – Simulated LAI: mean value for OL simulation (a) and analysis minus OL (b), for the period from 1 May 2018 to 31 December 2020.

Regions with elevated mean LAI values (> 2.5 m² m^{-2}) are mainly located in Slovenia, northern Spain and certain areas of northern Russia characterised by deciduous forests. It is interesting to note that the assimilation tends to reduce LAI in these regions. Otherwise, there is a consistent trend towards higher LAI values in the analysis over most of the domain. Both OL and analysis GPP and LAI simulations can be compared with the gridded SIF observations at 0.1°x0.1°, which is the native resolution of the model. To assess the correlation between GPP analysis, LAI analysis and SIF observations, temporal correlation coefficients with SIF are calculated for GPP and LAI over the entire domain from 1 May 2018 to 31 December 2020. The results, shown in Figure 4, show robust correlations over much of the domain with correlation coefficients (*R*) greater than 0.7 for both GPP and LAI.

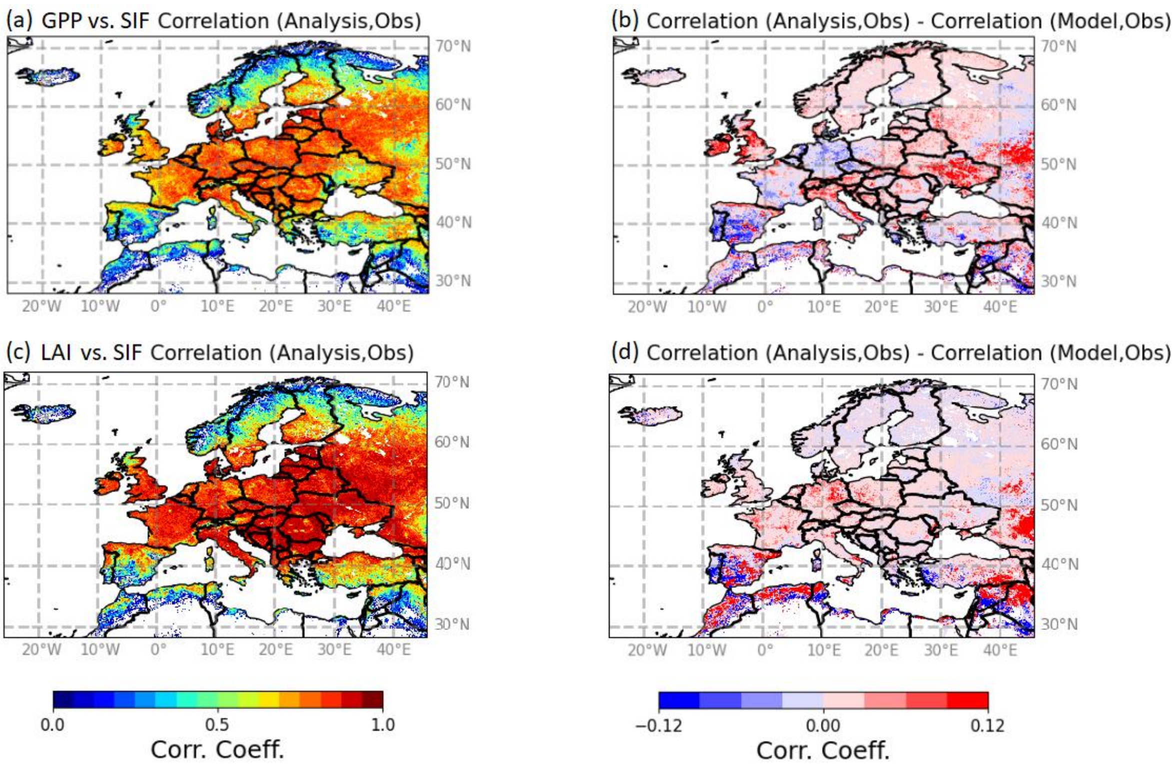

Figure 4 – GPP (a,b) and LAI (c,d) vs. SIF correlation (a,c) and correlation difference (b,d) between analysis and OL, for the period from 1 May 2018 to 31 December 2020.

Semi-arid regions such as parts of Spain, together with Nordic regions at high latitudes, show weaker correlation values. Figure 4 also shows the difference in correlation coefficients between the analysis and the OL. For GPP, improvements (shown in red) are mainly observed over cereal agricultural areas in Eastern Europe, especially near the Black Sea in central and eastern Ukraine, in Italy, France, Spain, over Ireland and the UK. However, LAI assimilation tends to weaken this relationship in some areas of France, throughout Germany and the Czech Republic, and in parts of Spain and Portugal. When comparing the analysed LAI derived from the analysis with the SIF product, the relationship with SIF is generally better than with GPP across Europe, as shown in Figure 4c. When comparing the analysis with the OL (Figure 4d), improvements can be seen over almost the whole study area, but in different places than for GPP. For example, the assimilation improves the correlation between LAI and SIF over Germany and the Czech Republic, while the correlation between GPP and SIF is reduced.

Figure 5 shows the correlation between GPP and SIF in the context of a 4-day forecast scenario.

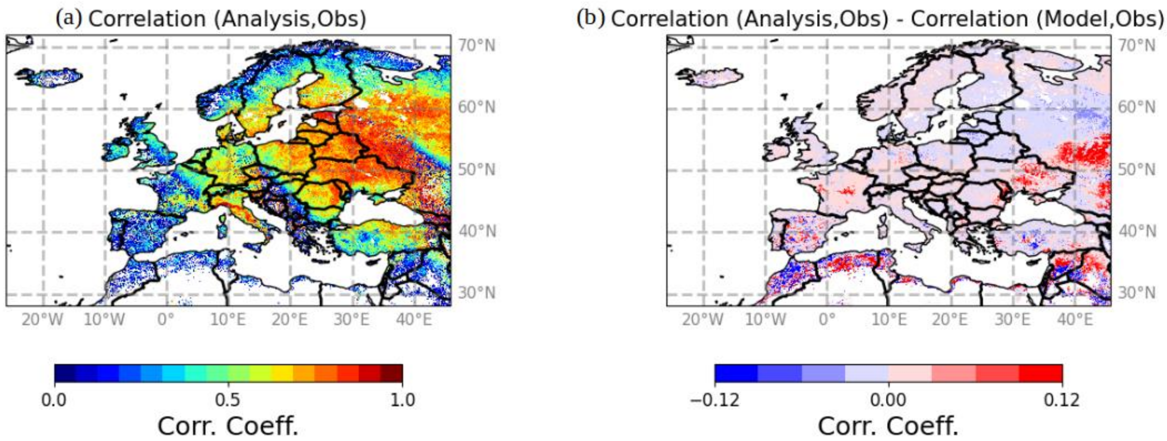

Figure 5 – 4-day forecast GPP vs. SIF correlation and correlation difference (b,d) between analysis and OL, for the period from 1 May 2018 to 31 December 2020.

For 4-day forecasts, low *R* values are observed for Western and Southern Europe and the UK. However, good relationships remain for Eastern Europe and Western Russia ($R > 0.6$). Assimilation tends to improve the relationship between GPP and SIF over most of the study area. The differences between the OL and assimilation experiments are less pronounced compared to the hindcast simulations. However, there are notable improvements, especially over Ukraine and Russia, where the assimilation process leads to a significant improvement in the GPP-SIF relationship.

The correlation between LAI and SIF in the context of a 4-day forecast scenario is similar to hindcast results shown if Figure 4cd. However, more significant differences could be found with large lead times, e.g. 8 days (Albergel et al. 2019, https://doi.org/10.3390/rs11050520).

4. Validation of root-zone soil moisture

The model soil layer corresponding to the SMOSMANIA in situ measurements at 0.3 m depth is layer 5 (0.2-0.4 m soil layer). The OL and analysis root zone soil moisture (RZSM) simulations for layer 5 are compared with observations from the Saint-Felix de Lauragais (SFL) station of the SMOSMANIA network for the study period (1 May 2018 to 31 December 2020). The OL, analysis and in situ time series are shown in Figure 6.

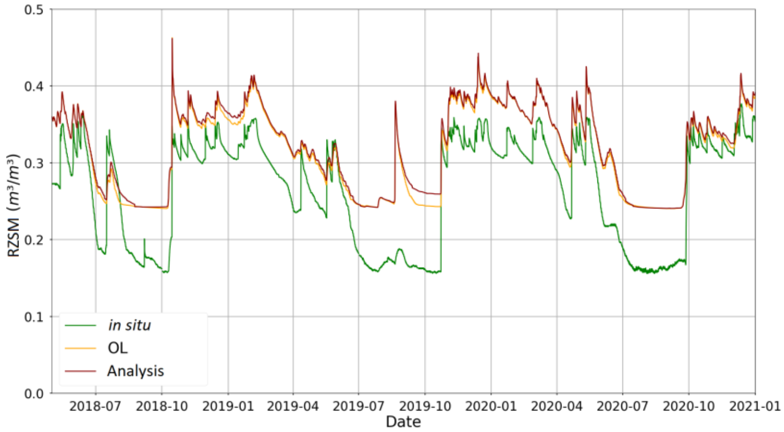

Figure 6 – Hourly time series of root-zone soil moisture at the SFL station from in situ measurements, OL and analysis simulations from 1 May 2018 to 31 December 2020.

The temporal patterns of the OL and analysis results clearly correlate with the observed seasonal variability of the RZSM, with similar times of rewetting events. The observed RZSM values range between 0.16 and 0.37 $m^3\ m^{-3}$, while the corresponding variations in the OL and analysis simulations show values between 0.25 and 0.46 $m^3\ m^{-3}$. The largest simulated RZSM values can be explained by differences between the soil properties used in the model, such as porosity, and the local soil properties around the soil moisture probe. Differences between the OL and analysis simulations occur during certain periods of the year, such as the autumn of 2019. Figure 7 shows the 4-day RZSM forecast from the OL and analysis initial conditions over SFL, together with the in situ observations.

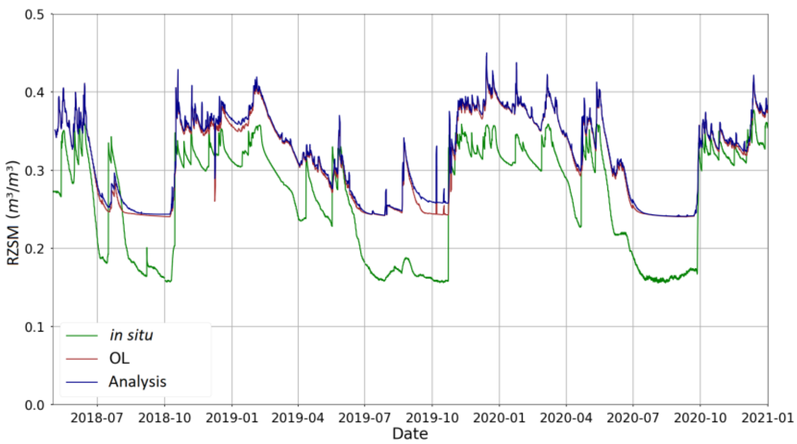

Figure 7 – As in Figure 6, except for 4-day forecasts.

Compared to the RZSM hindcast simulations in Figure 6, the forecast simulations are similar, but with some perturbations. For example, a dip in the RZSM is simulated on 8 December 2018. This is due to the fact that on this day the predicted temperature at 30 cm soil depth reaches freezing values, which reduces the amount of liquid water in the soil. Table 1 shows the correlation coefficient values between the RZSM simulations and the in situ observations.

Table 1. Correlation coefficients (*R*) between RZSM measured at the SFL SMOSMANIA station and simulated by the ISBA model in OL and analysis configurations, for hindcast and forecast setups, for winter, spring, summer, and fall seasons, and for the whole period of study from 1 May 2018 to 31 December 2020.

Seasons	**Hindcast**		**4-day forecast**	
	OL	Analysis	OL	Analysis
Winter	0.66	0.69	0.55	0.58
Spring	0.82	0.83	0.79	0.79
Summer	0.74	0.77	0.76	0.79
Autumn	0.96	0.95	0.95	0.94
All	0.92	0.93	0.91	0.92

It can be seen that the autumn season (September-October-November) shows the most robust agreement, with an *R* value reaching 0.96. Similarly, the spring season (March-April-May) shows a substantial agreement with an *R* value reaching 0.83. Conversely, the winter (December-January-February) and summer (June-July-August) seasons show comparatively lower levels of agreement, with *R* values not exceeding 0.69 and 0.79, respectively. Overall, the *R* values do not vary much from one experiment to another when all seasons are considered together. However, there are noticeable differences in the *R* values when looking at specific seasons. In particular, the forecast simulations tend to show slightly smaller *R* values than the hindcast simulations, except in summer. This effect is most pronounced in the winter season, where the forecast simulations do not perform as well as in the other seasons.

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