SENSAGRI High Resolution Surface Soil Moisture product

The **SENSAGRI High Resolution Surface Soil Moisture** (**SSM) product** is an evolution of the ESA SEOM S-1 SSM product at 1 km (http://seom.esa.int/). The evolution consists of improving the resolution to "field scale" (i.e., ~0.1 km) where parcel borders are available, e.g., from EU Land Parcel Identification System (LPIS), by implementing an integrative use of Sentinel-1 (S1) and Sentinel-2 (S2) data.

The implemented SSM retrieval algorithm exploits a change detection approach requiring SAR time series with a short revisit time [Balenzano et al., 2011] and, for this reason, can be referred to as **a short-term change detection (STCD) approach**. Its rationale is that temporal changes of surface parameters influencing the radar backscatter, apart from SSM, (e.g., soil roughness, canopy structure, vegetation water content, etc.) usually take place at longer temporal scales than SSM changes (excluding cultivation practices). Therefore, SAR time series with a sufficiently short repeat cycle are expected to track changes in SSM only, since other parameters affecting radar backscatter can be considered constant. This approximation (also referred to as "alpha approximation") makes robust and relatively simple the retrieval approach and also expedites the processing.

The algorithm can be applied to bare and vegetated surfaces dominated by soil attenuated scattering that enables good radar sensitivity to SSM throughout the growing season. This land cover restriction implies that before the retrieval, a masking process obscuring those areas showing a poor radar sensitivity to SSM (i.e., areas dominated by volume scattering) is required. Masking is implemented as a two-step process. The first one consists of using global land cover maps (e.g. GlobCover, CCI LandCover) to mask areas such as forests, urban areas, water bodies, etc. The second masking level exploits an adaptive thresholding method applied to S1 cross-polarized observations. The method is based on the iterative solution of the Kittler-Illingworth algorithm [Satalino et al., 2014]. **As a result of the masking process, the SSM retrieval algorithm is applied only over those land surfaces dominated by soil attenuated scattering that show an adequate radar sensitivity to SSM.**

The code implementing the aforementioned STCD algorithm is referred to as **"Soil MOisture retrieval from multi-temporal SAR data" (SMOSAR)** [Balenzano et al., 2013].

The strength of the STCD algorithm is its conceptual simplicity and its robustness due to the fact that the SSM estimates depend on a single free parameter. Conversely, STCD is prone to the occurrence of abrupt changes of the vegetation and/or soil roughness status that can be wrongly interpreted as SSM changes. Such changes may have a limited impact at a resolution equal or above ~1 km, but they usually produce significant errors at "field scale" resolutions. **To this regards, the NDVI information derived from S2 supports the masking of abrupt changes of surface parameters not due to SSM changes, thus improving the overall SSM accuracy** [Satalino et al., 2018]. If NDVI is not available (e.g. cloud cover), then the ratio of VH/VV is considered [Veloso et al., 2017].

In summary, the implemented code transforms dense time series of N co-registered S1 IW & S2 images at 40m pixel size into N-SSM maps. The final step of the SMOSAR code is to average the SSM maps in order to improve the radiometric accuracy of the final product. **An adaptive strategy is implemented so that the final product is characterized by a fairly high spatial resolution (~0.1km) over agricultural areas, where SSM averages at field scale are performed using the information of parcel borders, wherever available. Conversely, over the remaining areas SSM is averaged at a resolution of 1 km.** The final SENSAGRI SSM product is resampled at a pixel size of 0.00052° (~50m), ranging between 0.015 m^3/m^3 to 0.60 m^3/m^3. The maps have a geographic lat/lon projection, WGS84 datum, in GeoTIFF format.

A co-registered standard deviation layer (> 0 m^3/m^3) is also provided with each SSM product. It is obtained by calculating the standard deviation associated to the above described averaging. **The standard deviation (stddev) map associated with the SSM product provides an estimate of SSM error (under the hypothesis of unbiased SSM estimates).**

The algorithm has been consolidated, improved and demonstrated at European scale. Temporal series of SSM products ranging from April 2017 to December 2018 have been derived and assessed over the SENSAGRI sites in Italy, Spain, France and Poland.

The accuracy of the S1&S2 SSM product at field scale has been estimated through direct comparison against 2017 and 2018 SSM observations: i) recorded by 3 hydrologic networks, located one in Italy and two in Spain; ii) collected during ground campaigns carried out in France, Italy and Spain. The issue of the spatial representativeness error (SRE) of point-like SSM measurements has been addressed.

At 1km, the SSM product has been formerly validated against: i) in situ SSM data acquired by 167 ground stations in Australia, USA, Canada and Europe, over an average period of approximately two years (between 2015 and 2018); ii) low resolution satellite products over a large area (~ 590 10^3 km^2) of the Mediterranean basin.

Based on the SENSAGRI data set (N=4040), the estimated rmse is 0.06 m^3/m^3 (1σ) at field scale, after correcting for the SRE, and the Pearson correlation is 0.5. Results show that SRE increases the ubrmse between 0.01m^3/m^3 and 0.02m^3/m^3, depending on the mean SSM values. Local biases have been observed for the effect of the soil texture and meteorological condition.

As an example, Figure 1 illustrates the SSM mean and SSM stddev map observed over the Spanish site on 27/06/2018. The map, which covers the Castile and León region (red contour), shows masked area in the northern part of the image due to the presence of mountains and vegetated areas, and SSM values ranging from dry to medium-wet values. The stddev values increase with the mean SSM, as expected.

Figure 2 reports details at high resolution of the SSM mean and SSM stddev maps in an area located at south-west of Valladolid. On the map, a valuable contrast of SSM among fields can be observed, and some are wetter than others. The map includes also the presence of masked fields (white polygons) and of masked surfaces, i.e. those in correspondence of urban areas.

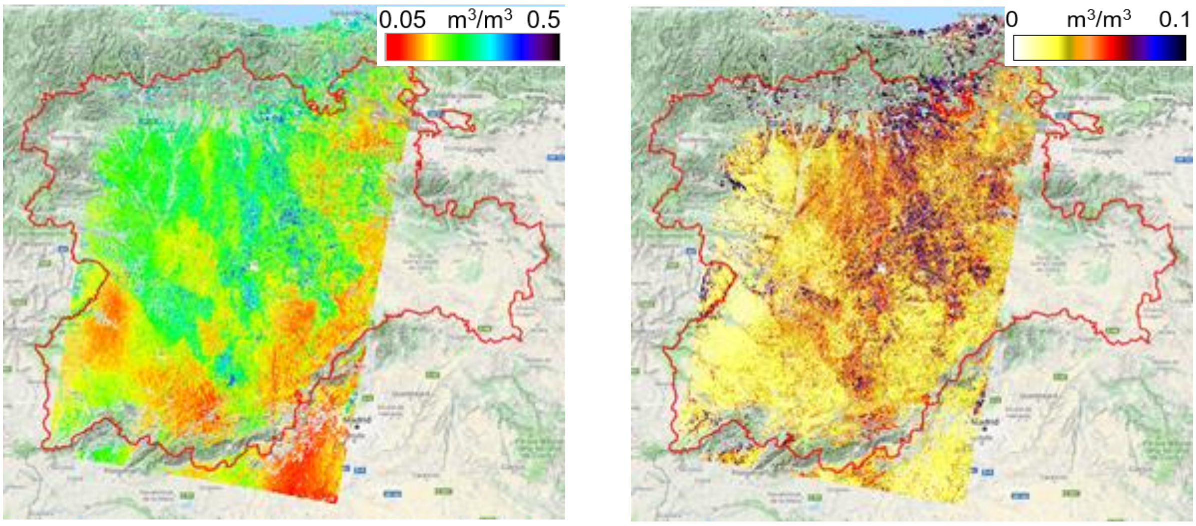

Figure 1. SSM product over the Spanish site on 27/06/2018. Left: SSM_mean. Right: SSM_stddev.

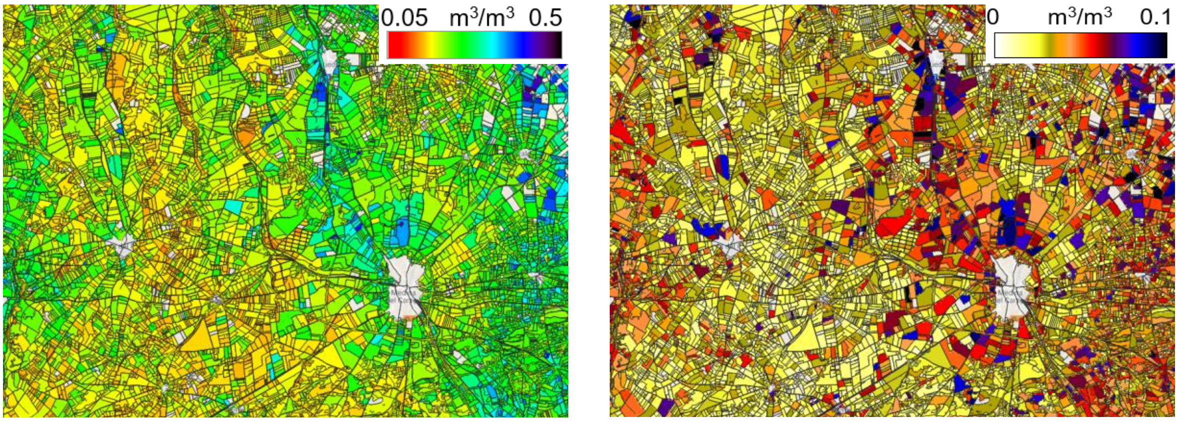

Figure 2. Zoom of SSM product over the Spanish site on 27/06/2018. Left: SSM_mean. Right: SSM_stddev.

SENSAGRI deliverables

SENSAGRI Deliverable D3.5: Final operational SSM prototype.
SENSAGRI Deliverable D3.6: Software of the final operational SSM prototype exploiting S1&S2.
SENSAGRI Deliverable D3.7. Final SSM products over test sites in Europe.
SENSAGRI Deliverable D3.8: Final SSM Algorithm Theoretical Basis Document.
SENSAGRI Deliverable D7.16: Second Validation of Surface Soil Moisture Maps.

References

Balenzano A., F. Mattia, G. Satalino, M. W. J. Davidson, “Dense temporal series of C- and L-band SAR data for soil moisture retrieval over agricultural crops”, IEEE Journal of Selected Topics in Applied Earth Obs. and Remote Sensing, Vol. 4, No. 2, pp. 439-450, June 2011.

Balenzano A., G. Satalino, F. Lovergine, M. Rinaldi, V. Iacobellis, N. Mastronardi, F. Mattia, “On the use of temporal series of L- and X- band SAR data for soil moisture retrieval. Capitanata plain case study”, European Journal of Remote Sensing, Vol. 46, pp. 721-737, 2013.

Satalino G., A. Balenzano, F. Mattia, and M. W. J. Davidson, “C-band SAR Data for Mapping Crops Dominated by Surface or Volume Scattering”, Geosci. and Remote Sensing Letters, Vol. 11, Issue 2, pp. 384-388, Feb. 2014.

Satalino G., F. Mattia, A. Balenzano, F. P. Lovergine, M. Rinaldi, A. P. De Santis, S. Ruggieri, D. A. Nafría García, V. Paredes Gómez, E. Ceschia, M. Planells, T. Le Toan, A. Ruiz and J.F. Moreno, “Sentinel-1 and Sentinel-2 for Soil Tillage Change Detection”, Proceedings of International Geoscience and Remote Sensing Symposium, Valencia (Spain), July 22-27, 2018.

Veloso, A., Mermoz, S., Bouvet, A., Le Toan, T., Planells, M., Dejoux, J. F., & Ceschia, E. “Understanding the temporal behavior of crops using Sentinel-1 and Sentinel-2-like data for agricultural applications”, Remote Sensing of Environment, 199, 415-426. 2017.