Remote Sensing of Environment 212 (2018) 21–30

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Integration of microwave data from SMAP and AMSR2 for soil moisture monitoring in Italy

E. Santi[a,*], S. Paloscia[a], S. Pettinato[a], L. Brocca[b], L. Ciabatta[b], D. Entekhabi[c]

[a] Institute of Applied Physics, National Research Council, Florence, Italy
[b] Research Institute for Geo-Hydrological Protection, National Research Council, Perugia, Italy
[c] Massachusetts Institute of Technology, Parsons Laboratory, Cambridge, USA

ARTICLE INFO

Keywords:
Soil Moisture Content (SMC)
SMAP
AMSR2
Retrieval algorithm
Artificial Neural Networks (ANN)

ABSTRACT

In this study, an integration of microwave data obtained from the SMAP and AMSR2 satellite radiometers has been attempted, to achieve an accurate estimation of the Soil Moisture Content (SMC). This research aimed to overcome the failure of radar sensor in SMAP satellite as well as the failure to generate the radar/radiometer combined SMC product at a spatial resolution of 9 km × 9 km.

A disaggregation technique, based on the Smoothing Filter based Intensity Modulation (SFIM), enabled us to obtain co-located SMAP and AMSR2 brightness measurements at L, C, X, Ku and Ka bands at approximately 10 km × 10 km on the selected test area, which corresponds to the entire Italian territory. These disaggregated microwave data were used as inputs of the "HydroAlgo" retrieval algorithm based on Artificial Neural Networks (ANN), which were able to exploit the synergy between radiometric acquisitions from these two sensors. The algorithm was defined, implemented and tested using all the overlapping orbits of SMAP and AMSR2 over Italy throughout the 9_month period between April and December 2015. Distributed SMC reference values for implementing and validating the algorithm were obtained from the Soil Water Balance hydrological model, SWBM. Through HydroAlgo, an SMC product at a resolution of approximately 10 km × 10 km was obtained. This result is close to the original Radar/Radiometer SMC product from SMAP, with an average correlation coefficient $R > 0.75$ and RMSE ≅ 0.03 m^3/m^3, in both ascending and descending orbits.

1. Introduction

Among the satellites dedicated to the Soil Moisture Content (SMC) retrieval that have been launched in recent years, The Soil Moisture Active Passive (SMAP) mission combined data from an L-band radiometer and radar to create a finer resolution product than previous SMC missions (Entekhabi et al., 2010). The SMAP instrumental design, with the conically scanning L-band radar and radiometer that use the same rotating antenna, is an improved release of the former HYDROS mission concept, which was proposed to NASA in 2001 and subsequently canceled in 2005 due to budget constraints (Entekhabi et al., 2004).

SMAP aims at improving the accuracy and spatial resolution of soil moisture estimates, compared to those currently achievable from the ESA Soil Moisture and Ocean Salinity (SMOS) mission (Silvestrin et al., 2001; Mecklenburg et al., 2012), through the fusion of information coming from the radar, at higher resolution (1–3 km), and radiometer, at lower resolution (≅40 km), although it is less affected by surface features such as soil roughness. This instrument design serves to estimate SMC at three different spatial resolutions: 36 km × 36 km using the radiometer only, 9 km × 9 km using the radar/radiometer combination, and 3 km × 3 km using the radar only.

In particular, algorithms suitable for taking advantage of the synergy between active/passive microwave observations have been developed (e.g. Das et al., 2011; Leroux et al., 2016). A robust and simple algorithm, used for merging L band radiometer and L band radar observations to obtain high-resolution (9 km) soil moisture estimates from SMAP mission, was presented in Das et al. (2011). The algorithm take advantage of the accuracy of radiometric soil moisture retrievals by merging it with the fine-scale spatial resolution of radar observations. The algorithm was validated using the airborne Passive and Active L-band System (PALS) instrument dataset from Soil Moisture Experiments, 2002 (SMEX02) and a four-month synthetic data set in an Observation System Simulation Experiment (OSSE) framework. The results indicated an improvement in RMSE of 0.015 to 0.02 cm^3/cm^3 SMC with respect to retrievals based on radiometer measurements re-sampled to a finer scale. A significant effort of the SMAP team was also carried out in field experiments aimed at developing and testing these algorithms, such as SMAPVEX, carried out in 2012 and 2015 in Canada (Piles et al.,

* Corresponding author.
E-mail address: e.santi@ifac.cnr.it (E. Santi).

https://doi.org/10.1016/j.rse.2018.04.039
Received 19 June 2017; Received in revised form 17 April 2018; Accepted 21 April 2018
0034-4257/

Fig. 1. The test area considered in this work (Italy).

2009; McNairn et al., 2015), as well as SMAPEX, carried out in Australia (Panciera et al., 2014).

Unfortunately, a radar sensor failure a few months after the launch set a serious constraint on the SMAP capabilities in monitoring SMC and prevented further generation of the combined radar and radiometer SMC product at 9 km resolution. Recently, an attempt to overcome this problem involved making an enhanced Level-1C (L1C) 9 km Brightness Temperature (Tb) product available at NSIDC which was derived from SMAP Level-1B (L1B) antenna temperatures interpolated by using the Backus-Gilbert optimal interpolation. L2 and L3 enhanced SMC at 9 km resolution taken from the L1C Tb data are also available (O'Neill et al., 2016). It should be mentioned however that these data are posted at 9 km spacing while maintaining the SMAP radiometer field-of-view resolution (half-power and −3 dB) of about 36 km.

Other approaches to this problem were also developed by merging data from different sensors. The joint use of airborne L band Multi-beam Radiometer and the L band F-SAR of DLR was considered in Montzka et al. (2016). In this case, the analysis was carried out using three fusion techniques, starting from the SMC estimated by passive sensors and disaggregation by active sensor, passing to a subsequent disaggregation of brightness temperature using backscatter and retrieving soil moisture, and finally by fusing two single-source soil moisture products from radar and radiometer. The best result was obtained by the fusion of brightness temperatures and backscatter, reaching the same accuracy of the soil moisture retrieval based on radiometer only, but with higher spatial resolution.

In this paper, we attempted to improve the resolution and the accuracy of the SMAP radiometric product by considering SMAP in synergy with the Advanced Microwave Scanning Radiometer 2 (AMSR2), which is the heir to the previous AMSR-E. This multifrequency radiometer, which was launched by JAXA in 2012 onboard the Global Change Observation satellite (GCOM-W), operates at 6.9, 7.3, 10.6, 18.7, 23.8, and 36.5 GHz with a sampling of approximately 10 km, and at 89 GHz, with a sampling of approximately 5 km in both V and H polarizations. AMSR2 data were considered in this study with the twofold purpose of disaggregating SMAP L band data up to approximately 10 km × 10 km and deriving the ancillary information on vegetation water content, surface temperature and snow cover for improving the SMC retrieval accuracy. The analysis was performed on 9 months of acquisitions over Italy, from April to December 2015, considering all the overlapped SMAP and AMSR2 overpasses on the same date and at the closest times.

SMAP data were first resampled on the AMSR2 lat/lon grid at 10 km × 10 km resolution, then disaggregated based on AMSR2 data by applying the Smoothing Filter based Intensity Modulation (SFIM) technique, previously described and validated using AMSR-E data in Santi (2010). This filtering enabled obtaining disaggregated SMAP brightness temperatures, which were then used for generating an improved SMC product at 10 km × 10 km resolution, which is close to the 9 km × 9 km of the SMAP enhanced SMC product.

The proposed SMC retrieval algorithm was a new implementation of the previous Artificial Neural Networks (ANN) based HydroAlgo (Santi et al., 2012; Mladenova et al., 2014), implemented for AMSR-E data and already tested on heterogeneous landscapes and complex environments with successful results (Santi et al., 2016b). A new ANN was trained with the innovative method of combining experimental and model data. The ANN based algorithm was capable to merge data obtained from different sources, in order to improve the retrieval accuracy, and adding or removing inputs with a few modifications.

Reference SMC data, used for comparison, were obtained taken from the well-established Soil Water Balance Model (SWBM) developed in (Brocca et al., 2014).

A brief description of the test area and experimental data used in this study is provided in Section 2, followed by the presentation of the SWBM in Section 3, and the description of the disaggregation technique and the ANN algorithm in Sections 4 and 5. Section 6 provides the results of the HydroAlgo validation performed in the test area.

2. Test area and satellite data

The selected test area (Fig. 1) corresponds to the entire Italian territory, from Sicily to the Alps, and covers a surface of > 301,340 km^2, with a 2.4% occupied by rivers and lakes. Longitude ranges from 6.7° E to 18.5° E and latitude from 36.7°N to 47°N. The landscape is