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Research Paper

On the synergy of SMAP, AMSR2 AND SENTINEL-1 for retrieving soil moisture

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ABSTRACT

An algorithm for retrieving soil moisture content (SMC) from synergic use of both active and passive microwave acquisitions is presented. The algorithm takes advantage of the integration of microwave data from SMAP, Sentinel-1 and AMSR2 for overcoming the SMAP radar failure and obtaining a SMC product at enhanced resolution (0.1° × 0.1°) and improved accuracy with respect to the original SMAP radiometric SMC product. A disaggregation technique based on the Smoothing filter based intensity modulation (SFIM) allows combining the radiometric and SAR data. Disaggregated microwave data are used as inputs of an Artificial Neural Networks (ANN) based algorithm, which is able to exploit the synergy between active and passive acquisitions. The algorithm is defined, trained and tested using the SMEX02 experimental dataset and data simulated by forward electromagnetic models based on the Radiative Transfer Theory. Then the algorithm is adapted to satellite data and tested using one year of SMAP, AMSR2 and Sentinel-1 co-located data on a flat agricultural area located in the Po Valley, in northern Italy. Spatially distributed SMC values at 0.1° × 0.1° resolution generated by the Soil Water Balance Model (SWBM) are considered as reference for this purpose. The synergy of SMAP, Sentinel-1 and AMSR2 allowed increasing the correlation between estimated and reference SMC from R ≅ 0.68 of the SMAP based retrieval up to R ≅ 0.86 of the combination SMAP + Sentinel–1 + AMSR2. The corresponding Root Mean Square Error (RMSE) decreased from RMSE ≅ 0.04 m^3/m^3 to RMSE ≅ 0.024 m^3/m^3.

1. Introduction

Satellite remote sensing has become an essential tool for observing the main land surface parameters at several temporal and spatial scales. The ever-increasing number of satellite missions and the consequent augmented availability of long-term global data sets of land surface parameters have improved noticeably our knowledge on the carbon, energy and hydrological cycles. In this respect, the moisture content of soil (SMC), which is one of the main driving factors of the hydrological cycle, is receiving an increasing attention, and dedicated satellite sensors have been recently launched. Microwaves are the most suitable frequencies for such a purpose, due to their independence of cloud cover and solar illumination, and, especially in the low part of the microwave spectrum, for the direct sensitivity to the water content of the observed surfaces. Besides the Soil Moisture and Ocean Salinity (SMOS) (Silvestrin et al., 2001; Mecklenburg et al., 2012), operating at L band, one of most popular satellite sensors dedicated to the global SMC monitoring is SMAP (Entekhabi et al., 2010; Entekhabi et al., 2004), which is characterized by the unique feature of carrying on board both a radiometer and a radar operating in the same band (L band), although with different spatial resolutions.

The aim of SMAP was in improving the accuracy and the spatial resolution of SMC available products by fusing information from radar backscattering (σ^0) at higher resolution (1–3 Km) and radiometric brightness temperature (Tb) at lower resolution (≅ 40 Km). SMAP mission was planned for estimating SMC at three different resolutions: 36 Km (radiometer only), 9 Km (radar + radiometer), and 3 Km (radar only). Das et al. (2011) presented an algorithm that estimates soil moisture by combining SMAP Radiometer and Radar data. The algorithm is based on the integration of the spatial heterogeneity at fine resolution detected by SAR observations with the coarse resolution radiometer measurements for generating a disaggregated Tb at intermediate-resolution. The algorithm was validated using airborne data from the passive and active L band system and simulated data. Results indicated that the algorithm allows retrieving soil moisture at 9-km resolution, within the SMAP accuracy requirements over slightly vegetated areas (Das et al., 2014).

Unfortunately, the radar onboard SMAP failed a few months after

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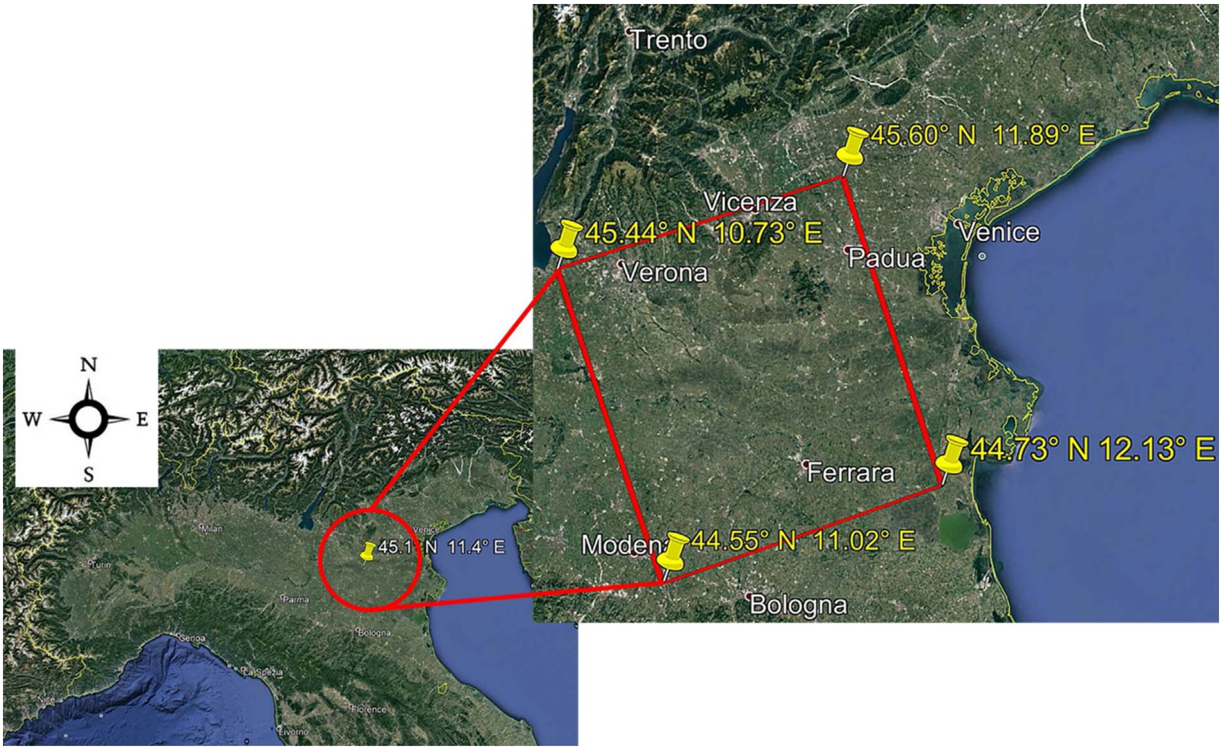

Fig. 1. The test area location in Italy from Google Earth.

the launch, preventing the generation of the two SMC products at higher resolution. The research prosecuted therefore on the SMAP radiometric product only. This study uses as a reference the SMAP radiometric-only soil moisture product based on the application of the Backus Gilbert optimal interpolation to the SMAP radiometric data. The gridded radiometer and soil moisture products are posted at 9 km spacing but maintain the SMAP radiometer field-of-view resolution (half-power and −3 dB) of about 30 km to 40 km. These data are hosted at the National Snow and Ice Data Center (NSIDC) as enhanced Level-1C (L1C) 9 Km Brightness Temperature product. L2 and L3 enhanced SMC products at 9 Km posting derived from L1C SMAP Tb data are also distributed by NSIDC (O'Neill et al., 2016).

The possibility of exploiting the SMAP synergy with other microwave sensors, for replacing the SMAP radar data and restoring the combined radar and radiometer SMC product has been also investigated. Das et al. (2016) identified the Sentinel-1A SAR data as the most suitable for replacing the SMAP radar acquisitions, despite the different frequency, due to the similar orbit configuration, that allows overlapping with small time difference and to the availability of co-pol and cross-pol from Sentinel 1A observations.

The synergy of SMAP with Sentinel-1 and AMSR2 is evaluated in this study, which is focused on the development of an algorithm able to merge microwave data from SMAP and AMSR2 radiometers and Sentinel-1 (S-1) SAR for obtaining an improved SMC product at 0.1° x 0.1° resolution, which is similar to the discontinued SMAP radar/radiometer product.

This study is implemented in two steps: at first, the SMEX02 experimental dataset is considered for defining a retrieval algorithm based on Artificial Neural Networks (ANN). ANN are indeed able to take advantage of synergistic L band acquisitions from the JPL Passive Active L and S band Sensor (PALS) and to account for ancillary information on vegetation biomass (Plant water content – PWC) and surface temperature (LST). The algorithm was later on adapted to satellite data and validated using one year of combined SMAP, S-1 and AMSR2 acquisitions on a test area located in the Po valley, in northern Italy. For this scope, all the SMAP, AMSR2 and S-1 acquisitions collected at the same date and closest time over the selected test area were considered. SMAP and AMSR2 data were disaggregated at the target resolution of $0.1^\circ \times 0.1^\circ$ using the well-established Smoothing filter based intensity modulation disaggregation (SFIM – Santi 2010). Reference SMC data for comparison are derived from the Soil Water Balance Model (SWBM – Brocca et al., 2014, 2008) that has been largely validated over Italy and Europe. The model SMC takes advantage of high fidelity precipitation information and it is spatially mapped for comparison with airborne and satellite retrievals. It represents a complimentary approach to the use of sparse in situ measurements, which suffer from spatial representativeness errors, for evaluating the retrieval algorithms. Such errors are difficult to distinguish from retrieval errors and they are limited in spatial coverage.

After a description of the two test areas and the experimental data used in this work, provided in section 2, the sensitivity of microwave data to the target SMC is presented in section 3. The ANN algorithm implementation and test on both test areas is described in section 4, that also contains some comparison with the official SMAP SMC product and discussion on the results.

2. Test areas AND DATA

Two different test areas have been considered in this study. The popular Walnut Creek watershed in central Iowa, USA, on which the SMEX02 experiment was carried out, was considered for defining the retrieval concept and for implementing the algorithm, due to the availability of detailed measurements of a large set of surface parameters.

The possibility of adapting the algorithm to satellite data was then evaluated on a flat agricultural area in the Po Valley, northern Italy, for which time series SMAP, AMSR2 and Sentinel-1 acquisitions were available. The area has an extension of ~ 120 Km × 120 Km, and its center coordinates are 11.4 °E and 45.1 °N (Fig. 1).

The area is mainly covered by large fields of wheat and corn, with a small percentage of sugarcane; the Po River crosses it from west to east. The town of Verona and its surroundings, in the upper left corner, is the