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Daily precipitation estimation through different microwave sensors: Verification study over Italy

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ABSTRACT

The accurate estimation of rainfall from remote sensing is of paramount importance for many applications as, for instance, the mitigation of natural hazards like floods, droughts, and landslides. Traditionally, microwave observations in the frequency between 10 and 183 GHz are used for estimating rainfall based on the direct interaction of radiation with the hydrometeors within precipitating clouds in a so-called top-down approach. Recently, a bottom-up approach was proposed that uses satellite soil moisture products derived from microwave observations (<10 GHz) for the estimation of accumulated rainfall amounts. The integration of the bottom-up and top-down approaches has large potential for providing high accurate rainfall estimates exploiting their different and complementary nature.

In this study, we perform a long-term (3 years) assessment of different satellite rainfall products exploiting the full range of microwave frequencies over Italy. Specifically, the integration of two top-down algorithms (CDRD, Cloud Dynamics and Radiation Database, and PNPR, Passive microwave Neural network Precipitation Retrieval) for estimating rainfall from conically and cross-track scanning radiometers, and one bottom-up algorithm (SM2RAIN) applied to the Advanced SCATterometer soil moisture product is carried out. The performances of the products, individually and merged together, are assessed at daily time scale. The integration of top-down and bottom-up approaches provides the highest performance both in terms of continuous and categorical scores (i.e., median correlation coefficient and root mean square error values equal to 0.71 and 6.62 mm, respectively). In such a combination, the limitations of the two approaches are compensated allowing a better estimation of ground accumulated rainfall through SM2RAIN while, overcoming the limitations of rainfall estimation for intense events during wet conditions through CDRD-PNPR product. The accuracy and the reliability of the merged product open new possibilities for their testing in hydrological applications, such as the monitoring and prediction of floods and droughts over large areas, including regions where ground-based measurements are sparse or not available.

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1. Introduction

In the last decades, Earth Observation (EO) technology has been consolidated as a unique global information source for earth science. The increasing global multi-mission EO observational capacity provides today an unprecedented potential to observe, describe and predict hydrological parameters and key processes governing the water cycle from local to global scales. Satellite products essential to hydrological applications, as well as for climate studies and extreme events monitoring (i.e., floods and droughts), such as soil moisture (SM) and precipitation, are developed and made available by space agencies [i.e., the National Aeronautics and Space Administration (NASA), the Japan Aerospace Exploration Agency (JAXA), the National Oceanic and Atmospheric Administration (NOAA), the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), the European Space Agency (ESA)] and through international programs/projects, such as the European 7th Framework Programme for Research and Technological Development EartH2Observe project (http://www.earth2observe.eu/), the ESA Climate Change Initiative

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(ESA CCI, http://cci.esa.int/), the NOAA Soil Moisture Operational Product System (NOAA SMOPS, http://www.ospo.noaa.gov/Products/land/smops/), and the EUMETSAT Satellite Application Facility on support to Operational Hydrology and Water Management (H-SAF, see Mugnai et al., 2013a).

The main SM and precipitation products developed worldwide are based on microwave (MW) radiometry (Huffman et al., 2007; Bartalis et al., 2008; Owe et al., 2008; Entekhabi et al., 2010; Kerr et al., 2012; Hou et al., 2014). Microwave (MW) radiation is the most effective for precipitation retrieval because of the direct interaction of radiation with the frozen and liquid hydrometeors within precipitating clouds (e.g., Smith et al., 1992; Mugnai et al., 1993; Petty, 1995; Panegrossi et al., 1998; Stephens and Kummerow, 2007; Kidd and Levizzani, 2011), as opposed to visible or infrared observations sensitive to the upper portion of the clouds (i.e., Schmetz et al., 2002). In the last decades, MW precipitation retrieval from space has seen great advances thanks to improving sensing capabilities of active and passive MW sensors on board a constellation of Low Elevation Orbit (LEO) satellites orbiting around the Earth, and to the refinement of precipitation retrieval techniques, particularly relevant over land (i.e., Tapiador et al., 2012). To overcome the low spatial and temporal resolution of LEO MW measurements, Passive MW (PMW) precipitation retrievals are combined with geostationary (GEO) infrared (IR) observations to provide merged MW/IR precipitation products (e.g., Joyce et al., 2004; Huffman et al., 2007; Huffman et al., 2016; Ashouri et al., 2015). These products are widely used not only for applications where frequent observations (at high resolutions, i.e. 5–10 km^2) are the most useful (e.g., extreme event monitoring, hydrological applications), but also for climatological studies. Their accuracy, however, depends mostly on the quality of the PMW precipitation retrievals, and particularly on the availability of frequent PMW overpasses over the region of interest (Nijssen and Lettenmaier, 2004). It is worth noting that MW/IR products can be affected by larger uncertainty with respect to MW only products because of the use of GEO IR measurements not directly related to surface precipitation in most cases.

The number of available LEO research and operational satellites equipped with conical scanning and cross-track scanning MW radiometers used for precipitation retrieval has increased in the last years thanks to the effort of international organizations (i.e., NASA, NOAA, EUMETSAT, JAXA). With the launch of the NASA/JAXA Global Precipitation Measurement (GPM) mission on February 27, 2014 (Hou et al., 2014), the constellation of MW radiometers orbiting around the Earth ensures a 3-hourly global coverage (hourly or less at mid-high latitudes). The hearth of the constellation is the GPM Core Observatory (GPM-CO) equipped with the new GPM Microwave Imager (GMI), a high resolution conically scanning multichannel PMW radiometer, and the Dual-frequency Precipitation Radar (DPR), consisting of a Ku-band and a Ka-band radar. Besides the GPM-CO, the constellation includes: the conically scanning Special Sensor Microwave Imager and Sounder (SSMIS) (on board the U.S. DMSP satellites F16, F17, F18), and Advanced Microwave Scanning Radiometer 2 (AMSR-2, on board JAXA's GCOM W1 satellite) and the cross-track scanning Advanced Microwave Sounding Unit-A/Microwave Humidity Sounder (AMSU-A/MHS) [on board the U.S. NOAA 18 and 19 satellites and the European MetOp-A/B (and MetOp-C in 2018) satellites], Advanced Technology Microwave Sounder (ATMS) (on board the NOAA/NASA Suomi NPP satellite, and the JPSS series in the future), and Sondeur Atmosphérique du Profil d'Humidité Intertropicale par Radiométrie (SAPHIR) (on board the French-Indian Megha- Tropiques satellite). The full exploitation of the constellation of MW radiometers in the GPM constellation towards higher temporal sampling of the precipitation is currently at the base of operational precipitation products delivered by international agencies and organizations.

Traditionally, PMW retrieval algorithms are based on the principle that surface precipitation can be estimated from the multichannel brightness temperature (TB) measurements because these are affected (in different ways depending on channel frequency, viewing geometry, spatial resolution, and surface background conditions) by the microphysical properties and 3-D distribution of liquid and frozen hydrometeors within the precipitating cloud, and, therefore, can be related to surface precipitation. In PMW physically-based approaches, the relationships between TBs and surface precipitation are built through the use of cloud-radiation databases (modelled or empirical). These databases are used either as *a priori* information in Bayesian approaches (e.g., Marzano et al., 1999; Kummerow et al., 2001, 2011; Di Michele et al., 2005; Casella et al., 2013; Sanò et al., 2013; Kidd et al., 2016) or as *training* datasets in neural network approaches (e.g., Surussavadee and Staelin, 2008; Sanò et al., 2015a) to retrieve surface precipitation from PMW measurements. These methods can be categorized as top-down approaches (Brocca et al., 2014), and they provide instantaneous precipitation rate estimate at the surface at the time of the satellite observation. Cumulated precipitation (or the daily mean precipitation, provided as Level 3 product on a regular spatial grid) can be obtained by integrating over time (or averaging) the instantaneous precipitation rate estimated by successive LEO satellite overpasses at each location (e.g., Panegrossi et al., 2016).

By following a completely different approach, some researchers recently proposed to estimate (Brocca et al., 2013, 2014; Birman et al., 2015) or correct (Crow and Bolten, 2007; Crow et al., 2011; Pellarin et al., 2009, 2013; Wanders et al., 2015; Zhan et al., 2015) rainfall from SM, land surface temperature and soil emissivity observations. In particular, Brocca et al. (2013) developed an innovative methodology for precipitation estimation based on the principle that the soil can be treated as a "natural raingauge". In contrast with classical top-down approaches, this new bottom-up approach attempts to measure rainfall by SM measurements derived from a satellite sensor. The method is based on the inversion of the soil water balance equation and was found to be very effective for precipitation estimation from daily to five-daily scale, on a local and on a global scale (Brocca et al., 2013, 2014, 2015, 2016; Massari et al., 2014; Ciabatta et al., 2015b, 2016; Abera et al., 2016; Koster et al., 2016).

Quality assessment of satellite precipitation products around the globe is crucial to promote the use of such products in remote areas where ground-based precipitation measurement networks are not available. Extensive validation of precipitation products delivered by international programs is usually carried out over regions where high quality reference ground-based measurements are available (see Gottschalck et al., 2005; Ebert et al., 2007; Tian et al., 2009, 2010; Stampoulis and Anagnostou, 2012; Kirstetter et al., 2013; Maggioni et al., 2014; Puca et al., 2014; Tang et al., 2014; Ciabatta et al., 2015a). These studies highlighted some difficulties in retrieving accurate precipitation estimates in regions characterized by complex orography, sea-land interface, presence of frozen soil, and sub-cloud evaporation processes. Thanks to the recent increase of the number of satellites available, to the improved technology, and to the advancements in the precipitation retrieval, many of the above mentioned issues were significantly reduced. For instance, Panegrossi et al. (2016) showed that the constellation of PMW radiometers in the GPM era can be effectively used to monitor precipitation, also in particularly challenging regions, with complex orography and extremely variable surface conditions, such as the Mediterranean area. Moreover, the analysis of heavy precipitation events occurred in the Fall 2014 in Italy has shown that by combining the overpasses from cross-track AMSU-A/MHS and conically scanning SSMIS radiometers it is possible to obtain daily mean precipitation estimates in

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