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Comparison of different satellite rainfall products over the Italian territory

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In this study, a preliminary analysis of three satellite-derived rainfall products is carried out in order to evaluate their reliability and accuracy. Specifically, two state-of-art rainfall products are used: the PR-OBS-5 provided by EUMETSAT within the Satellite Application Facility on Support to Operational Hydrology and Water Management (H-SAF) project and the 3B42-RT product from the Tropical Rainfall Measuring Mission (TRMM) Multiple Precipitation Analysis (TMPA). The third product is obtained by applying a new inversion method, called SM2RAIN, to satellite soil moisture data. In this latter approach, the soil is considered to be a “natural raingauge” that is employed for "measuring" of rainfall. As benchmark, quality checked daily rainfall observations throughout the Italian territory for the period 2010-2011 are used. The comparison with ground observations is carried out in terms of correlation coefficients, R, and root mean square error, RMSE. The results show satisfactory R-values (and low RMSEs) between satellite and observed 5-day rainfall data with median R-values greater than 0.50. Moreover, by analyzing the error spatial patterns, and by considering the different temporal resolution of the products, the potential of integrating them in space and time is underlined as this can be expected to further improve the estimation of rainfall for hydrological applications over the Italian territory.

Keywords: Rainfall, Remote sensing, Soil moisture, Hydrological Applications

1. Introduction

Rainfall plays a key role in many natural and socioeconomic applications as, for instance, floods and landslides forecasting, weather prediction, agriculture and drought management (Dinku et al. 2007). However, rainfall estimates through in-situ measurements and satellite retrievals are impacted by many factors, such as the limited spatial representativeness of raingauges and the indirect nature of the satellite measurements (Brocca et al. 2013). Nevertheless, satellite rainfall products can be of great help in estimating rainfall where ground rainfall observation network (rain gauges and radar) are scarce or missing. These products usually provide global data with a spatial resolution of 0.25° and a time resolution of 3 hour (Huffman et al. 2007). Each product generally uses different algorithms and satellite sensors for estimating rainfall. Thus, before employing these products for operational applications, their limitations and potential must be assessed.

For this purpose, three satellite rainfall products are here analyzed over the Italian territory. The analysis considers two state-of-art products: the TMPA 3B42-RT (Huffman et al. 2007) and the PR-OBS-5 provided by EUMETSAT within H-SAF project (Mugnai et al. 2013). The third product is obtained from the application of the novel SM2RAIN method (Brocca et al. 2013) to satellite soil moisture data retrieved from the Advanced SCATterometer (ASCAT) sensor (Wagner et al. 2013). The analyzed products are compared with ground observations available for the period from January 2010 to December 2011.

2. Rainfall and soil moisture datasets

The observed rainfall dataset, for the period 2010-2011, is obtained starting from observations of about 3000 rain gauges data distributed over the whole Italian territory. The data are interpolated on a regular grid with spacing of 12.5 km by using the GRISO (Random Generator of Space Interpolations from Uncertain Observations) approach (Pignone et al. 2010) which maintains the observed punctual rain value on the rain gauge spatial position. Anomalous rainfall data are masked out and not used in this analysis.

Three satellite derived rainfall products were analyzed: the TMPA 3B42-RT, the PR-OBS-5 and the results of the application of the SM2RAIN method to satellite surface soil moisture data retrieved from ASCAT.

The 3B42-RT product is based on the use of microwave (MW) data to calibrate the infrared (IR) derived rainfall estimates and creates estimates that merge MW data (when available) and IR data (Huffman et al. 2007). The product is characterized by a temporal resolution of 3 hours and a spatial resolution of 0.25°.

The PR-OBS-5 (hereinafter defined as H05) is based on frequent precipitation measurements as retrieved by blending LEO (Low Earth Orbit) MW derived precipitation rate measurements and GEO (Geostationary Earth Orbit) IR imagery (Mugnai et al. 2013). This product provides daily rainfall data with a spatial resolution of ~5 km.

The ASCAT Surface Soil Moisture (SSM) product is obtained by backscattering measurements from the ASCAT sensor onboard the Metop-A satellite (Wagner et al. 2013). The temporal resolution is almost daily for the study area and the spatial resolution is ~25 km (resampled to 12.5 km).

In order to perform a fair comparison, all the analyzed datasets are interpolated on a regular grid with spacing of 12.5 km, for a total of 2043 pixels.

3. SM2RAIN method

To obtain a rainfall dataset from soil moisture observations, the SM2RAIN method, as proposed by Brocca et al. (2013), is applied to ASCAT Soil Water Index (SWI) data. The SWI is obtained after the application of an exponential filter, proposed by Wagner et al. (1999), to the ASCAT SSM product. The SWI has been chosen, instead of SSM, because it is less affected by noise (Brocca et al. 2012). The SM2RAIN method is based on the inversion of the soil water balance equation and allows of estimating rainfall from soil moisture data and its variation in time. The method needs four parameters to be calibrated that are obtained by minimizing the root mean square error against observed rainfall observations. For a complete description of this method the reader is referred to Brocca et al. (2013).

4. Results

As a first analysis, the four parameters of the SM2RAIN method are calibrated by considering a spatial subsample of the data (54 points) in central Italy for the period 2007-2012. This constant set of parameters is then applied to the 2043 grid points over the whole Italian territory thus obtaining the ASCAT-derived rainfall product (hereinafter defined as SM2R-ASC).

The correlation coefficient, R, and the Root Mean Square Error, RMSE, between each satellite dataset and the observed rainfall data are used to evaluate the performance. In Fig. 4.1, the R and RMSE maps for 5 days of accumulated rainfall are shown. As it can be seen, the satellite rainfall datasets show good correlations with the observations with median R-values of 0.68, 0.61 and 0.65 for SM2R-ASC, 3B42-RT and H05, respectively. In Tab. 4.1, a statistical summary of the performance scores of the comparison between satellite and observed rainfall data is shown by considering 1-day and 5-day accumulations. From the R maps, the issues related to the topographic complexity (over the Alps and the Apennines) for the SM2R-ASC product are evident while the 3B42-RT and H05 products show lower correlations for the South Italy (e.g. Lazio and Campania regions).

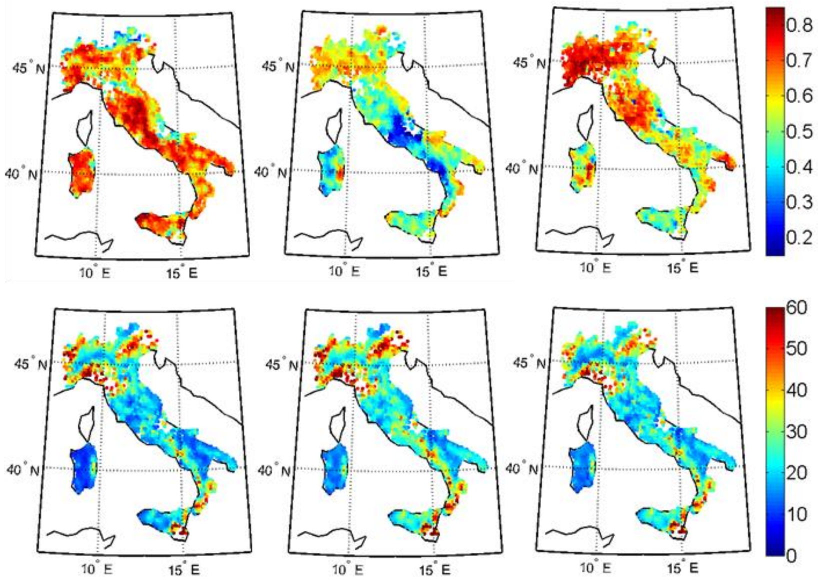

Fig 4.1 – Correlation, R, (upper panels) and root mean square error, RMSE, (lower panels) maps for 5-day accumulated rainfall for SM2R-ASC (left), H05 (middle) and 3B42-RT (right) products.

Rainfall product	**R 1 day**	**R 5 days**	**RMSE (mm) 1 day**	**RMSE (mm) 5 day**
SM2R-ASC	0.51(0.08)	0.66(0.11)	9.21(3.79)	19.61(13.36)
H05	0.46(0.09)	0.50(0.12)	9.49(3.76)	20.88(15.75)
3B42-RT	0.57(0.10)	0.61(0.12)	8.79(3.34)	25.06(10.5)

Tab. 4.1 - Mean (and standard deviation in brackets) values of the performance scores for 1 and 5 days of accumulated rainfall for the three analyzed products.

Besides the spatial variability, also the temporal one is investigated. For each product, the performance scores are estimated at monthly scale, in order to show seasonal fluctuations and temporal variability of their performance (see Fig. 4.2). The monthly scores describe similar patterns, mainly for the RMSE, and highlight the slightly better performance of the SM2R-ASC product (see also Tab. 4.1).
Finally, as an example, the timeseries of two randomly selected pixels are reported in Fig. 4.3, both in terms of rainfall intensity and cumulated rainfall. This analysis clearly shows, on one hand, that all the products tend to underestimate the rainfall amounts (negative bias) and this is a significant issue to be addressed in future studies. On the other hand, most peaks and troughs are well represented as it can be seen from the high R-values (R>0.7 for SM2R-ASC).

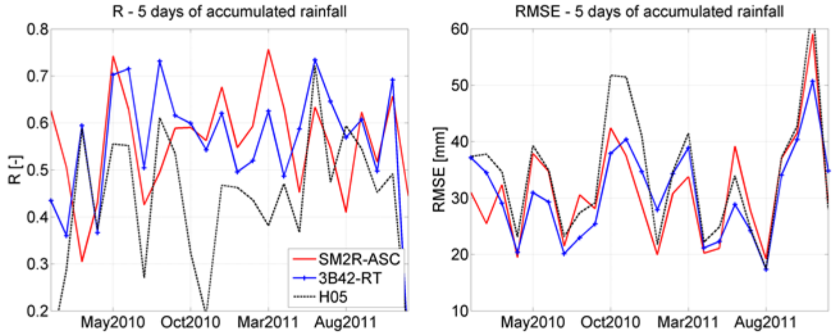

Fig 4.2 – Monthly correlation, R, and root mean square error, RMSE, for the three analyzed products and for 5-day accumulated rainfall.

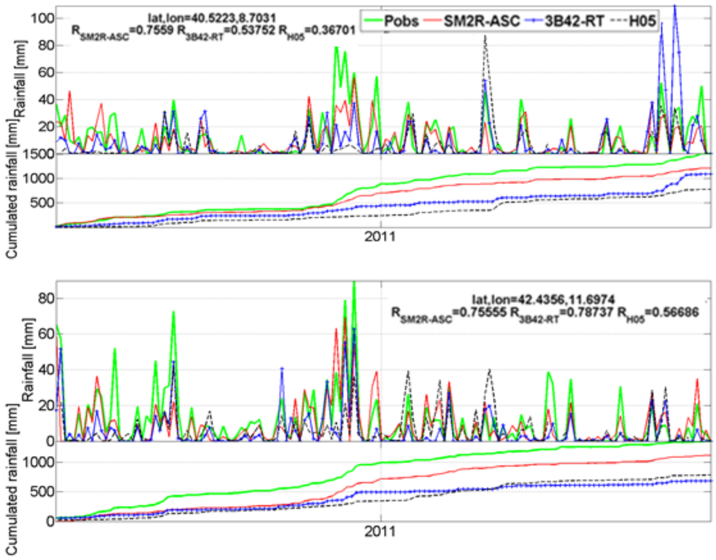

Fig.4.3 – Timeseries of two randomly selected pixels in Sardegna (upper panel) and Toscana (lower panel) for 5-day accumulated rainfall (R: correlation coefficient).

5. Conclusions

The three analyzed rainfall products show good correlations and quite low RMSE with the observed rainfall dataset throughout the Italian territory. In particular, the SM2RAIN method is found able to satisfactorily estimate rainfall by using satellite soil moisture observations as input. This method provides the worst results in mountainous regions, where satellite soil moisture retrievals are negatively impacted by topographic effects (Wagner et al. 2013). However, excluding these regions, the soil moisture derived rainfall product provides satisfactory results, even better than the state-of-the-art rainfall products. In future study we will investigate of how to optimally integrate the different rainfall products in space and time for optimizing their use within floods and landslides forecasting systems.

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