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Performances of GPM satellite precipitation over the two major Mediterranean islands

Domenico Caracciolo[a,*], Antonio Francipane[c], Francesco Viola[b], Leonardo Valerio Noto[c], Roberto Deidda[b]

[a] Regional Environmental Protection Agency of Sardinia (ARPAS), viale Ciusa 6, Cagliari, Italy
[b] Dipartimento di Ingegneria Civile, Ambientale e Architettura (DICAAR), Università di Cagliari, via Marengo 2, Cagliari, Italy
[c] Dipartimento di Ingegneria Civile, Ambientale, Aereospaziale, e dei Materiali (DICAM), Università di Palermo, viale delle Scienze, Palermo, Italy

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ABSTRACT

This study aims to assess the reliability of satellite-precipitation products from the Global Precipitation Measurements (*GPM*) mission in regions with complex landscape morphology. Our analysis is carried out in the European mid-latitude area, namely on the two major islands of Mediterranean Sea, i.e. Sardinia and Sicily (Italy). Both islands experience precipitation originating from the interaction of steep orography on the coasts with winds carrying humid air masses from the Mediterranean Sea. The *GPM* post real-time *IMERG* (Integrated Multi-satellitE Retrievals from Global Precipitation Measurement) “Final” run product at 0.1° spatial resolution and half-hour temporal resolution have been selected for the two-year 2015–2016 period. Evaluation and comparison of the selected product, with reference to raingauge network data, are performed at hourly and daily time scales using statistical and graphical tools. The influences of morphology and land-sea coastal area transition on the reliability of the *GPM* product have been analysed.

Confirming previous studies, results showed that *GPM* satellite data slightly overestimate rainfall over the study areas, but they are well correlated with the interpolated raingauge data. Metrics based on occurrences above a given threshold and on total volume above the same threshold were applied and revealed better performances for the latter ones. Applying the same metrics we show how *GPM* performances improve as the temporal aggregation increases. Several drawbacks were detected in the coastal areas, which were characterized by worse performances than internal areas. Statistics are generally very similar for the two considered case studies (i.e., Sardinia and Sicily) except for correlation between topography and accuracy of *GPM* products, which was slightly higher for Sardinia.

1. Introduction

Reliable and accurate precipitation measurement or estimation is crucial for water resource management, and disaster monitoring (Hou et al., 2014). However, obtaining accurate high-resolution precipitation fields is still a challenging task for scientists and practitioners, especially in the poorer regions of the world. Satellite sensing provides valuable global and regional precipitation estimates (Gourley et al., 2010; Seyyedi et al., 2015), although the biases and errors of satellite-precipitation estimates need further analysis and research.

In recent years, a large number of quasi-global satellite precipitation products with various temporal and spatial resolutions have been developed and released to the public (Prakash et al., 2018; Sun et al., 2018), such as the Tropical Rainfall Measurement Mission (*TRMM*) Multi-satellite Precipitation Analysis (*TMPA*) (Huffman et al., 2007; Maggioni et al., 2016), the Climate Prediction Center MORPHing technique (*CMORPH*) analysis (Joyce et al., 2004), the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (*PERSIANN*) (Hsu et al., 1997; Sorooshian et al., 2000), and the Global Satellite Mapping of Precipitation (*GSMap*) (Kubota et al., 2007). These free and open access products have been validated through several regional (Ciabatta et al., 2017; Lo Conti et al., 2014; Sohn et al., 2010; Xue et al., 2013; Yong et al., 2012) and global (Long et al., 2015) studies.

The most recent international mission is the Global Precipitation Measurement (*GPM*) mission (Huffman et al., 2014; Huffman et al., 2017a; NASA, 2017; Skofronick-Jackson et al., 2017) which collects data from an international constellation of satellites, including the Core Observatory satellite and approximately ten partner satellites. The main purpose of the *GPM* mission is to establish the structure and magnitude

* Corresponding author.
E-mail address: dcaracciolo@arpa.sardegna.it (D. Caracciolo).

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of variations in precipitation in order to understand better the water and energy cycle (Hou et al., 2014). The measurements of the *GPM* Core Observatory satellite serve as a reference standard to combine precipitation measurements from all satellites that fly within a particular constellation. Additionally, the *GPM* precipitation measurements can be combined with other data to improve accuracy and reliability. As the successor of *TRMM* satellite, the *GPM* Core Observatory was deployed on February 28, 2014 by a joint effort of *NASA* and the Japan Aerospace Exploration Agency (*JAXA*). The *GPM* Core Observatory carries a dual-frequency precipitation radar, *DPR* (with the Ku-band at 13.6 GHz and Ka-band at 35.5 GHz), and a conical-scanning multichannel *GPM* Microwave Imager (frequency channels ranging between 10 and 183 GHz). *GPM* extends the sensor package compared to *TRMM* instruments, and, therefore, the *GPM* sensors can detect light and solid precipitation more accurately than *TRMM* sensors. The Integrated Multi-satellitE Retrievals from Global Precipitation Measurement (*IMERG*) provides three kinds of products, including the near real-time "Early" and "Late" run products, and the post real-time "Final" run product, the latter being the research level product (Huffman et al., 2015). The "Final" run product is calibrated by the Global Precipitation Climatology Centre (*GPCC*) monitoring data, whose source is the Global Telecommunications System (*GTS*) that collects data from about 7000 stations around the world (Schneider et al., 2014). The time delay between satellite observation and data release (i.e., latency) is equal to 6 h, 18 h, and 2.5 months for the "Early", "Late", and "Final" *IMERG* products, respectively. While "Early" and "Late" data are available starting from 1 of April 2015 and 7 of March 2015, respectively, the "Final" run data are available from the 12 of March 2014. Furthermore, the *IMERG* product is intended to intercalibrate, merge, and interpolate all microwave estimates of the *GPM* constellation, infrared estimates, gauge observations, and other data from potential sensors at 0.1° spatial resolution and half-hour temporal resolutions (Huffman et al., 2014). Therefore, the *GPM* products have a higher spatial and temporal resolution than *TRMM* products (whose resolutions were 0.25° in space and 3 h in time).

Several studies examined whether the rainfall products from the *GPM* mission are able to accurately estimate global precipitation (Asong et al., 2017; Behrangi and Wen, 2017; Chen and Li, 2016; Guo et al., 2016; Houze Jr et al., 2017; Li et al., 2017; Liu, 2016; Ning et al., 2017; Ning et al., 2016; Prakash et al., 2016a; Prakash et al., 2016b; Sahlu et al., 2016; Sanò et al., 2016; Sharifi et al., 2016; Speirs et al., 2017; Tang et al., 2016b). Hereafter, a brief review of the most recent and comprehensive studies from global to local scale is proposed with the aim of providing the order of magnitude of discrepancies between observations and satellite products and highlighting the reasons for such problems.

At global scale, Libertino et al. (2016) analysed the ability of *GPM* products to evaluate intense rainfall events. They compared the date of occurrence of the most severe daily rainfall events recorded each year by a global raingauge network with the ones estimated by *GPM*. The match rate between the two was found to approach 60%, indicating significant consistency between the two data sources. Behrangi and Wen (2017) analysed and quantified the errors at global scale resulting from temporal and spatial sampling of precipitation events using the V04 version of the *IMERG* product. Relative mean square error was calculated between the degraded (temporally and spatially) and original *IMERG* products. The temporal and spatial degradation was performed by producing temporal degradation at three-hour (T3), six-hour (T6), while keeping the original spatial resolution and spatial degradation at 0.5° (S5), and 1° (S10) with original temporal resolution. The results show generally larger errors over land than ocean, especially over mountainous regions. The relative error of T6 is almost 20% larger than T3 over tropical land, but is smaller in higher latitudes. Over land, relative error of T6 is larger than S5 across all latitudes, while T6 has larger relative error than S10 poleward of 20°S-20°N. Similarly, the relative error of T3 exceeds S5 poleward of 20°S-20°N, but does not exceed S10, except in very high latitudes. Similar results are also obtained over ocean, but the error ratios are generally less sensitive to seasonal changes; moreover the results show that the spatial and temporal relative errors are weakly correlated.

At local scale, Tang et al. (2016a) evaluated the post-real time Final *IMERG* product over Mainland China from April to December 2014, at the hourly timescale, against ground-based observations interpolated with inverse distance weighting and spline methods. The product was evaluated at gridded, regional, and national scales. *IMERG* performed well at the mid- and high-latitudes, as well as in relatively dry climate regions, and it reproduced the probability density function of 3-h and daily rainfall with good accuracy in the low ranges. Khodadoust Siuki et al. (2017) compared the half-hourly *IMERG* data with the 3-hourly raingauge data in northwest Iran for the period March–December 2014, using different evaluation indices for validation purposes. Results showed that correlation between *IMERG* and raingauge rainfall data is higher than that of *TRMM* and raingauge data, while bias confirmed that *IMERG* underestimated rainfall over the study area.

Two important aspects that were deemed crucial in determining the performances of the *GPM* product in reproducing observed rainfall, although not fully explored, regard the effects of morphology and the land-sea coastal area transition. One of the few works dealing with these topics was carried out by Kazamias et al. (2017), which evaluated *GPM* daily precipitation products over Greece and found reasonable agreement against raingauge observations, with the exception of coastal areas in which low correlations were observed. The *GPM* daily precipitation product overestimated rainfall, especially in complex terrain areas with high annual precipitation. In particular, rainfall estimates in western Greece had a strong positive bias. Another important contribution is from Kim et al. (2017), which assessed precipitation products from *GPM* using gauge-based precipitation data from Far-East Asia during the pre-monsoon and monsoon seasons. In both mountainous and coastal regions, the *GPM* showed uncertainties attributable to the presence of orographic convection and land-ocean transition.

Given these premises, the interest in testing *GPM* products in complex domains and in investigating the role of morphology in driving performances is clear. Following this research question, we selected the two major islands of the Mediterranean Sea, i.e. Sardinia and Sicily, to test satellite-precipitation *GPM-IMERG* products against data provided by dense raingauges over the two islands. Indeed, the particular combination of geographic position, climate, shape and morphology of both islands offers an interesting opportunity for the validation of satellite-precipitation data in the European mid-latitude area and in complex domains. The two islands are characterized by a complex morphology and by small spatial scale and long sea-land transition borders. Moreover, they experience precipitation originating from the interaction of steep orography on the coasts with winds carrying humid air masses from the Mediterranean Sea. The *GPM-IMERG* post real-time "Final" run product (version V04 released in spring 2017) at 0.1° spatial resolution and half-hour temporal resolution has been selected for the two-year period 2015–2016. Evaluation and comparison of the selected product are performed with reference to data provided by the raingauge network of the two islands. Both *GPM* and raingauge data have been aggregated at hourly and greater time scales, then the raingauge data have been spatially interpolated and resampled at the *GPM* grid resolution. In order to obtain general information about the performances of estimates related to the entire two islands, features of rainfall spatial distribution and the influence of the aggregation time scale have been investigated using statistical and graphical tools. The influences of landscape morphology and land-sea costal area transition on the correct estimation of rainfall through the *GPM* product have been analysed.

This work is organized as follows: description of the case study and details on raingauges and *GPM* datasets are provided in the Sections 2.1, 2.2 and 2.3, respectively, while the evaluation indices used to compare the *GPM* and the interpolated raingauge grids are described in Section 3. Results are summarized in Section 4: the agreements of