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Evaluation and comparison of satellite precipitation estimates with reference to a local area in the Mediterranean Sea

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ABSTRACT

Precipitation is one of the major variables for many applications and disciplines related to water resources and the geophysical Earth system. Satellite retrieval systems, rain-gauge networks, and radar systems are complementary to each other in terms of their coverage and capability of monitoring precipitation. Satellite-rainfall estimate systems produce data with global coverage that can provide information in areas for which data from other sources are unavailable. Without referring to ground measurements, satellite-based estimates can be biased and, although some gauge-adjusted satellite-precipitation products have been already developed, an effective way of integrating multi-sources of precipitation information is still a challenge.

In this study, a specific area, the Sicilia Island (Italy), has been selected for the evaluation of satellite-precipitation products based on rain-gauge data. This island is located in the Mediterranean Sea, with a particular climatology and morphology, which can be considered an interesting test site for satellite-precipitation products in the European mid-latitude area. Four satellite products (CMORPH, PERSIANN, PERSIANN-CCS, and TMPA-RT) and two GPCP-adjusted products (TMPA and PERSIANN Adjusted) have been selected. Evaluation and comparison of selected products is performed with reference to data provided by the rain-gauge network of the Island Sicilia and by using statistical and graphical tools. Particular attention is paid to bias issues shown both by only-satellite and adjusted products. In order to investigate the current and potential possibilities of improving estimates by means of adjustment procedures using GPCC ground precipitation, the data have been retrieved separately and compared directly with the reference rain-gauge network data set of the study area.

Results show that bias is still considerable for all satellite products, then some considerations about larger area climatology, PMW-retrieval algorithms, and GPCC data are discussed to address this issue, along with the spatial and seasonal characterization of results.

1. Introduction

The development of remote sensing in recent decades has provided innovative resources to different hydrologic fields. Among the involved aspects, the availability of remote sensed data provided the knowledge of precipitation distribution at global scaleand with spatio-temporal resolutions useful for those climatological applications that do not require a long observation period. The main sensor sources used for precipitation estimates are constituted by passive microwave (PMW) data from polar-orbiting satellites (LEO, *Low Earth Orbiting* satellites) and the infrared (IR) data from geostationary satellites (GEO, *Geosynchronous Earth Orbiting*

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satellites). Moreover, satellite radar sensors and rain-gauge information are used in some cases for calibrating precipitation estimates considering a larger availability time. LEO-PMW data are directly correlated to clouds, and precipitation physical processes and different algorithms have been developed to retrieve precipitation information based on such relationships (Stephens and Kummerow, 2007). The most-commonly used PMW-retrieval algorithms are based on a Bayesian approach to extract precipitation information from a database of CRM (*Cloud Resolving Model*) simulation outputs, coupled with a radiative-transfer model. However, PMW sensors provide poor temporal and spatial sampling. On the other hand, IR-GEO data do not have a direct physical relationship with ground precipitation, because such information measure only the cloud-top IR-brightness temperature; however, IR-GEO data have time and space resolutions finer than PMW data. Because LEO-PMW and GEO-IR complement each other in retrieving precipitation information, the most consolidated satellite-precipitation products merge both PMW and IR data followingdifferent methods. In order to improve the quality of the results, different adjusted products, that merge satellite products with ground measurements, have been developed in recent years.

The development of rainfall estimates for fields different than climatology (i.e., hydrology and meteorology) is more difficult because it calls for more detailed information and high-performance elaboration, particularly in terms of resolutions and operability readiness. The main limit to the development of such estimates is the spatial and temporal limited availability of data provided by PMW sensors. Nevertheless, precipitation estimates with fine resolutions have been developed to combine LEO-PMW and IR-GEO data by means of complex algorithms that attempt to obtain estimates at the IR data resolution, while retaining the accuracy of the PMW data (Kidd and Huffman, 2011). These algorithms are implemented routinely, producing precipitation estimates whose features allow for their potential usage for hydrology and meteorology. The real suitability of such data sets results from their reliability in terms of estimates agreement with surface reference data and the associated level of uncertainty.

Therefore, difficulties in deriving precipitation estimates for hydrological applications based on satellite data and the necessity of measuring their associated uncertainty level, resulted in the development of a solid evaluation and validation scientific activity carried out by both developers and users. The IPWG (*International Precipitation Working Group*, http://www.isac.cnr.it/ipwg/IPWG.html, 2013) is committed to conducting several studies in order to carry out a systematic evaluation activity for operational satellite algorithms at continental scale (Turk et al., 2008). Among IPWG activities, PEHRPP (*Pilot Evaluation of High Resolution Precipitation Products*) was established to evaluate, intercompare, and validate many operational high-resolution precipitation algorithms. In particular, PEHRPP aims to characterize errors in many spatial and temporal scales and geographic regions.

Beyond IPWG and PEHRPP activities, others studies have been carried out with similar objectives. Some of these objectives compare different datasets to retrieve information about products and algorithms features. For example Gottschalck et al. (2005) considered different precipitation data sets as potential input to the Global Land Assimilation System, while Ebert et al. (2007) compared a selection of satellite products and NWP (*Numerical Weather Prediction*) models output data, finding corresponding strengths and weaknesses. Moreover, particular studies analyzed the performance of a single satellite product (Villarini and Krajewski, 2007; Hong et al., 2007; Su et al., 2008; Habib et al., 2009; Zeweldi and Gebremichael, 2009; Hirpa et al., 2010; Sohn et al., 2010; Scheel et al., 2011; Hongwei et al., 2012; Karaseva et al., 2012; Kidd et al., 2012; Vernimmen et al., 2012; Wang and Wolff, 2012; Yuan et al., 2012). Some of the more analyzed evaluation activities focus on the ability to reproduce climatology information, the representation of particular events or precipitation extremes (e.g. AghaKouchak et al., 2011), hydrological performances within models (e.g. Yilmaz et al., 2005), uncertainty and error characterization related to possible explanatory factors such as rain-rate magnitude (as observed by AghaKouchak et al., 2012), elevation or land/sea origin, retrieving algorithm analyses and comparisons between different products. It is worth pointing out that the evaluation activity needs to be considered with reference to a specific geographic region, because performances can be related to spatial and geographic features.

From the evaluation activity, some issues concerning PMW-retrieval algorithms have been pointed out. Michaelides et al. (2009) emphasized that the use of CRM data bases (necessarily constituted by a limited number of simulations because of their complexity and computational cost) in the satellite-retrieval algorithms may introduce large biases because CRM simulations are highly individual and do not satisfy the requirements for general algorithm applicability. In comparing satellite-precipitation retrieval and NWP estimates, Ebert et al. (2007) observed that they complement each other because satellite precipitation products are more accurate during the summer months and at lower latitudes, while NWP models show better performances during the winter months and at higher latitudes. Further issues related to satellite-precipitation estimates arise because remote sensing of mid and high-latitude precipitation is especially challenging as a result of some factors that affect the retrieval, i.e., light-intensity occurrences often near the sensors' minimum detectable signal, snow-precipitation occurrences that require to be specifically considered in the retrieval process, and related changes in surface emissivity (Bennartz, 2007). Issues about mid-latitude retrieval are confirmed by Sohn et al. (2010) who reported that some of the main satellite-precipitation products show considerable underestimation over the Korean Peninsula. Finally, Kidd et al. (2012) reported an overall underestimation by satellite products in European areas and addressed some difficulties arising in mid and high-latitude regions, such as those related to low intensities, frozen-precipitation occurrences, and issues with the surface backgrounds.

In our study, six of the most consolidated satellite-precipitation products are evaluated and compared against data from a dense rain-gauge network for the area of Sicilia, Italy, the largest Mediterranean island, which represents the transitional area between northern Africa and the European climatic regime very well. Because of its particular combination of geographic position, climatic features and morphology, this case study is very useful for retrieving different insights, both about strengths and weaknesses of estimates referred to as the considered geographic area and to general