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A review and synthesis of GPM products efficiency: Preliminary results

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Abstract

Accurate and reliable estimation of precipitation is essential for the understanding of the global hydrological cycle and Earth energy balance. Considering the sparse gauge distribution and other limitations, it is not always feasible to access precipitation data at every point of Earth. Although monitoring precipitation from space is an alternative to this, its performance across the globe is not comprehensive enough for hydrological applications. However, the recently launched GPM (Global Precipitation Measurement) is a multi-satellite network, providing globally more accurate and instantaneous observations of rain and snow at a very fine spatio-temporal resolution. Here, to gain a quantitative insight into the state of the art of GPM products, we explored approximately 100 peer-reviewed scientific articles that evaluated the GPM products over different geographic and climatic conditions throughout the world. Our review aims to identify the advantages and disadvantages of the GPM products at global scale and assist the developers to make improvements in the future versions.

1 Introduction

Precipitation is one of the important components of the water cycle. It plays a major role in the Earth energy balance and the global climate system [1]. However, getting accurate and continuous precipitation data at global scale is yet a major challenge, considering the sparse gauge distribution and limited radar coverage [2]. In contrast, the use of remote sensing precipitation products has the advantages of homogenous global coverage and regular interval. This allows not only to study non-gauged regions, but also to detect global changes in precipitation [3], as it fluctuates in various spatiotemporal scales [4, 5]. Even though satellite precipitation datasets are considered as one of the important sources of precipitation, they are often associated with a significant bias which limits their application in hydrological and other operational research studies.

Following the success of TRMM (Tropical Rainfall Measuring Mission), on 27 February 2014 NASA (National Aeronautics and Space Administration) and JAXA (Japan Aerospace Exploration Agency) jointly launched the GPM core observatory satellite [6]. The Integrated Multi-Satellite Retrievals for GPM (IMERG) algorithms integrate all the microwave and microwave-calibrated infrared (IR) precipitation from multiple satellites and provide precipitation at $0.1^\circ \times 0.1^\circ$ and 30 min spatio-temporal resolution [7]. There is a substantial number of studies carried out at both global [8, 9] and regional scale [10, 16], which evaluated the performance of IMERG precipitation compared to ground observations. Nonetheless, most of the studies were limited to a specific location and geographic condition rather than evaluating the performance at global scale. Therefore, more validation studies are still needed for a better understanding of the applicability and limitations of the GPM products at a global scale.

In this context, a quantitative analysis of the current status of the GPM precipitation products is carried out in this paper. The study was conducted using the recent literature (published between 2015 and 2018) which investigated the performance of GPM products under different evaluation protocols and spatiotemporal scales, as well as geographic and climatic conditions. The main aim of this study is to point out the strengths and the weaknesses of GPM products at a global level. Our work helps in identifying potential research gaps and opportunities, assisting the product developers in improving the GPM algorithms in the future versions. Additionally, it offers a ready-to-use roadmap to the user community, pinpointing the merits and caveats of GPM application that can be beneficial for both research and decision-making processes.

2 Methodology

The methodology involves a quantitative approach of approximately 100 recent publication (published mainly in Q1 and Q2 journals) which evaluated and compared the GPM precipitation products throughout the world. We created a database with all the necessary information regarding the performance of GPM precipitation products. The comprehensive analysis is carried out considering different criteria such as study area, climate type, surface type (land/ocean), precipitation type (rain/snow), record length, reference data (gauge/radar/satellite/model), temporal (hourly/daily) and spatial scale (grid-scale/regional average).

The database generated form all the reviewed articles designed in such a way that, each row represents an observation, whereas each column describes the specific attributes of the analysis. For instance, in terms of geographical distribution the database represents all the necessary information regarding the study area, its latitude, longitude, climate type, country name and its continents. Further, to determine whether the study evaluated rain or snow, the articles were classified into precipitation types. Generally, a study could be performed over land surface or ocean, and thus the reviewed articles were classified based on the evaluation surface types as well. Additionally, considering the fact that each specific study has different spatial-temporal evaluation criteria, the database has assigned two different classes; i) temporal scale: represents the temporal scale at which the evaluation takes place (hourly, daily, monthly or annually) and ii) spatial scale: represents the spatial scale over the GPM products evaluated against the observational datasets. Another important information regarding the evaluation of GPM products is, the length of validation duration. For this, the database has the record of the starting period, ending period and the total validation duration of each article. Furthermore, considering the difference source of reference datatypes used, the database has the records of each reference data type whether the study used either the gauge-based measurement, radar datasets or reanalysis model datasets to validate against the GPM products. In addition, considering the various number of statistical indices used for the performance analysis of GPM products, the database has classified into two additional classes namely; volumetric indices (probability of detection, false alarm ratio, and critical success index) and categorical indices (coefficient of correlation, root mean square error and bias). Moreover, the database has all the necessary information regarding the best performances, worst performances and the limitation of each study in three separate classes of the database. Finally, the database was analysed in *R* programming language to classify and quantify the main findings of global research on GPM performance.

3 Results

Results from the preliminary analysis reveals that most of the studies were conducted over China; knowledge is needed on the performance of the GPM products over other regions, especially over data-sparse regions. In terms of precipitation types, rain is the most commonly evaluated GPM products. There were relatively very few studies that evaluated the snowfall. The evaluation of GPM products has been conducted mostly by using in-situ gauge datasets followed by radar and model datasets. Furthermore, even though the length of validation duration varies with studies, most of the studies reported have less than two years of evaluation duration. In addition, among the studies that evaluated GPM IMERG products, IMERG final run product (research-level product) evolution is the most commonly reported products compared to the other two products (Early and Late run). In terms of the spatial-temporal resolution, the majority of the studies reported were evaluated either at $0.25^\circ \times 0.25^\circ$ or $0.1^\circ \times 0.1^\circ$ and at daily and sub-daily scales. Among the robust statistical evaluation matrixes, coefficient of correlation (COR), root mean square error (RMSE) and bias are more predominantly used matrixes in the time series evaluation, whereas the probability of detection (POD), false alarm ratio (FAR) and critical success index (CSI) are more frequent in the categorical indexes. In terms of surface types, GPM products performs better over land than over ocean. Finally, it shows better performance on monthly and annual time scales then daily and sub-daily scale.

The latest GPM IMERG products show significant improvement compared to the TRMM in the detection of light rainfall. However, the majority of studies revealed that there are issues with light precipitation when compared to ground measurements. Another common issue with the GPM IMERG products is substantial overestimation or underestimation of precipitation over the mountainous regions, and its poor performance over complex topographies. In addition, it shows significant bias in dry climates and over water surfaces, particularly over the ocean. Further, when it comes to the seasonal scale, there are significant discrepancies in the winter precipitation. There is a general agreement that the IMERG algorithm needs further improvements in the aforementioned areas.

On the bright side, GPM IMERG products perform quite robustly in various cases. For instance, considering the estimation and detection of regional precipitation patterns and their spatial mean, GPM IMERG products show equally good performance with the ground observations. In addition, IMERG has a higher detection ability of snowfall and light precipitation, compared to other satellite products. Furthermore, IMERG has the potential to detect and trace the hurricane trajectories, which indicates its applicability on detection of extreme events and natural hazards. All these factors reveal a wide range of promising potential applications in the near future.

We have to note that all these studies suffer from a common limitation: the very short validation period due to the lack of long term GPM records. In addition, even though the evaluation method used by the majority of the studies are valid and reliable, there are often issues with the underlying assumption of the particular methods. For instance, in the case of gauge measurements, it should be taken into consideration the number of gauges used, and their distribution and density over the validation sites. On top of this, in point-based measurements there is significant uncertainty associated with the point-to-area representation. Here, the type of interpolation techniques applied to the point measurements might severely affect the evaluation outcome.

4 Conclusions

This work reviewed the performance of the recently launched GPM products and discussed their advantages and disadvantages. Overall, despite the presented drawbacks, our analysis revealed more positive than negative results in the GPM evaluation studies across the world. We should note though that it has some crucial limitations in the estimation of orographic precipitation, convective cells and precipitation over complex topographies which hopefully will be improved in future algorithm versions. The outcomes of the study will help to identify the major research opportunities, and serves as a reference for the user community in terms of the estimation of potential applicability of GPM products.

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