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# Validation of GPM IMERG extreme precipitation in the Peninsular Malaysia and Philippines by station and radar data

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**Abstract**. Extreme precipitation is ubiquitous in the Maritime Continent (MC) but poorly predicted numerical weather prediction (NWP) models. NWP evaluation against accurate measures of heavy precipitation is essential to improve their forecasting skill. Here we examine the potential utility of the Global Precipitation Measurement (GPM) Integrated Multi-Satellite Retrieval for GPM (IMERG) for NWP evaluation of extreme precipitation in the MC. For that purpose, we use radar data in Subang (Malaysia) and station data from the Global Historical Climatology Network (GHCN) in Malaysia and the Philippines. We find that earlier studies may have underestimated IMERG performances in the MC due to large spatial sampling errors of ground precipitation measurements, especially during extreme precipitation conditions. We recommend using the 95$^{th}$ percentile for NWP evaluation of extreme daily and sub-daily precipitation against IMERG. At higher percentiles, the IMERG rainfall rates tend to diverge from ground observation and may therefore be treated with caution.

## 1. Introduction

The Maritime Continent (MC) is a region separating the Indian ocean from the Pacific, including the countries of Malaysia, the Philippines, and Indonesia, among others. It is considered as one of the wettest places on Earth. However, precipitation does not fall continuously but rather episodically and with the occurrence of extreme precipitation events [1-2]. Extreme precipitation in this region is associated with destructive floods that have both a human and a material cost. The consequences are even more critical that the local population is particularly vulnerable [3-6].

Unfortunately, such extreme precipitation events are still poorly predicted by Numerical Weather Prediction models (NWP). The first step of NWP improvement is their evaluation against accurate observations of precipitation extremes. These observations can be made locally through the use of ground-based radar or gauges. However, only gridded satellite measurements can cover the whole MC with an accurate spatio-temporal resolution. These latter gridded satellite observations of precipitation in the MC are therefore indicated for NWP evaluation, while not being exempt from errors.

Here we are proposing to validate one such satellite dataset, the Global Precipitation Measurement (GPM) Integrated Multi-Satellite Retrieval for GPM (IMERG) [7], to be used for NWP evaluation of extreme precipitation. The IMERG precipitation product gathers more than ten satellite measurements, including the GPM Core Observatory satellite, which is said to carry the most advanced satellite precipitation sensors currently in space [8].

In the same way that other satellite precipitation products, the IMERG performances in retrieving extreme precipitation were shown to be climatically and regionally dependent. For instance, it was shown to underestimate precipitation extremes over Austria [9] or Singapore [10] but also to overestimate precipitation extremes over central Amazon [11] or the Netherlands [12]. Previous studies evaluating IMERG over the MC did not correctly account for the spatial sampling errors of ground measurements, i.e., errors of representativeness of a pointwise measure of precipitation inside the IMERG mesh. These errors can significantly affect the retrieved skill of IMERG, as shown in earlier studies [13-15].

The present study investigates the skill of IMERG in reproducing extreme precipitation over the MC by considering the spatial sampling error and aims to provide guidance for its use in NWP evaluation. This is done by comparing the IMERG V06B final product with the Global Historical Climatology Network (GHCN) gauge dataset over Malaysia and the Philippines, and a ground-based weather radar dataset from western Peninsular Malaysia.

The precipitation datasets of this study are briefly described in section 2. The evaluation of IMERG daily precipitation in the MC is performed in section 3. Section 4 concludes the study by providing practical guidance for NWP evaluation of precipitation extremes against IMERG in the MC.

## 2. Data

The Integrated Multi-Satellite Retrievals for GPM (IMERG) V06B Final product is used and evaluated in this study [7]. IMERG precipitation is calculated through a complex algorithm that accounts for precipitation estimates from several satellites. These include measurements from both passive microwave (PM) and infra-red (IR) sensors. While PM precipitation estimates are prioritized by IMERG, IR estimates are used to fill in the gaps. Thus, the IMERG product provides precipitation estimates every 30 minutes at 0.1° of horizontal resolution. In this study, we use 19 years of IMERG precipitation from 1 January 2001 to 31 December 2019 over both Malaysia and the Philippines.

The Global Historical Climatology Network (GHCN) [16-17] is the gauge network used in this study. It includes several stations over Malaysia and the Philippines (Fig. 1). Stations were grouped into 6 clusters located in Western Peninsular Malaysia (5 stations), Eastern Peninsular Malaysia (3 stations), Northwest Borneo (6 stations), Northwestern Philippines (4 stations), and Eastern Philippines (9 stations). Finally, the single mountainous station in Northwestern Philippines defines the last cluster. Each of these stations is associated with their nearest neighbor IMERG grid point, and only available days in common with IMERG data were retained for analysis.

The radar is an S-band Doppler weather radar operated by MetMalaysia and is located in Subang (Western Peninsular Malaysia, Fig. 1). Data spans 89 days between 11 January 2019 and 15 April 2019. The radar provides 10-minutes measures of instantaneous precipitation close to this region at a spatial resolution of 0.0045°. Here we use this high radar spatial resolution to estimate the spatial sampling error of GHCN single gauges when compared to their IMERG nearest grid point.

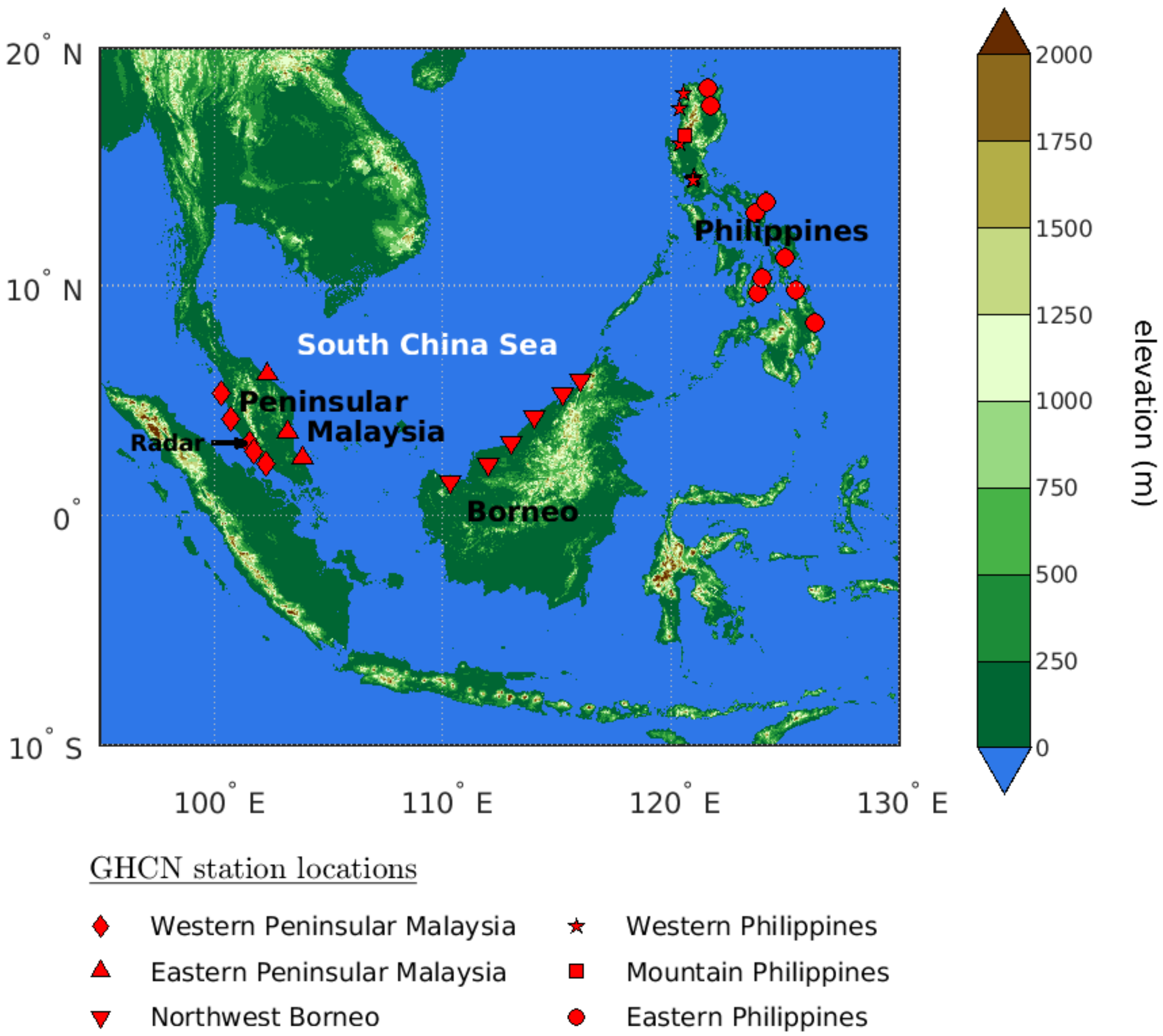


**Figure 1.** Topographic map of the Maritime Continent (shaded). The locations of the GHCN stations are highlighted by red markers: diamonds for western Peninsular Malaysia; upward triangles for eastern Peninsular Malaysia; downward triangles for northwest Borneo; stars for western Philippines; circles for eastern Philippines; a square for the mountain Philippines station.

## 3. Evaluation of IMERG extreme precipitation

The IMERG product is first evaluated in Subang (Western Peninsular Malaysia), where both radar and gauge data are available. A quantile-quantile diagram of IMERG versus GHCN precipitation for boreal winter (October - March) is shown in Fig. 2 (blue line). The green lines represent the quantile-quantile diagram of Subang radar precipitation averaged on the IMERG 0.1° grid versus itself at its original resolution (0.0045°). It can be interpreted as the theoretical expectation of the quantile-quantile relationship between IMERG and GHCN, given their difference in spatial resolution. Departures of the IMERG versus GHCN quantile-quantile diagram from these lines can therefore be associated with IMERG errors. The straight green line was obtained by linearly interpolating instantaneous radar precipitation at instants with missing values. In contrast, the dashed green line was obtained by replacing radar missing values by 0 mm/h. Finally, the grey shading represents the uncertainty of radar precipitation due to the Z—R relationship (three different relationships were tested).

Figure 2 shows that the IMERG versus GHCN quantile-quantile plot lies between the two radar control lines for percentiles between the $60^{th}$ and the $95^{th}$ percentiles, or between 2 mm/day and 35 mm/day. It shows that IMERG provides a reasonable estimation of daily precipitation for this range of precipitation. The IMERG $95^{th}$ percentile is particularly in agreement with the interpolated radar control line, with a low uncertainty of about 20%. Therefore, the $95^{th}$ percentile is expected to be a reasonable choice for evaluating NWP extreme precipitation against IMERG.

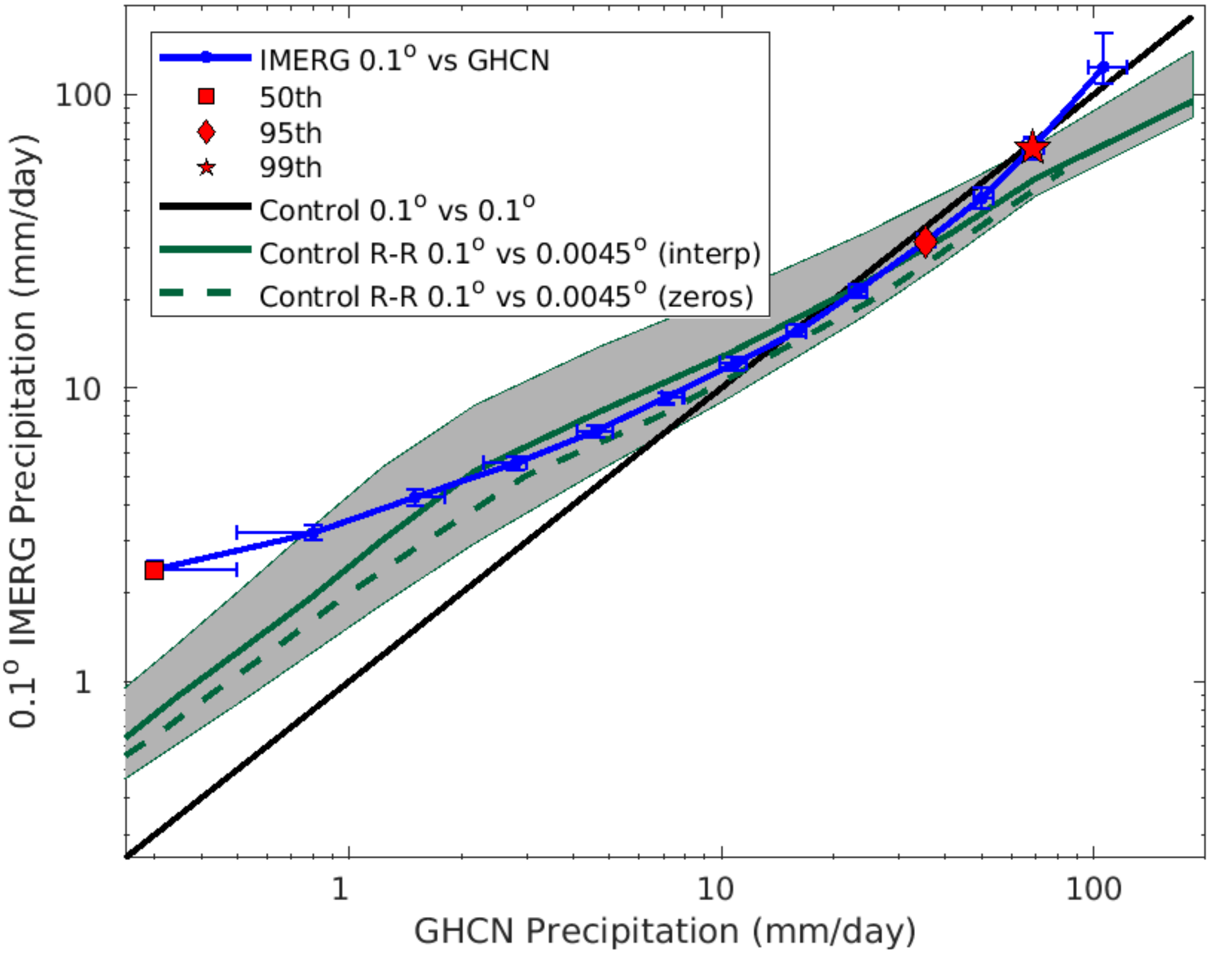


**Figure 2.** Quantile-quantile diagram of GHCN daily precipitation of the three weather stations at Subang in Fig. 1 versus their nearest neighbor IMERG daily precipitation for boreal winter (blue line). Quantiles are calculated at 5% intervals from the $50^{th}$ to the $95^{th}$ percentile, then at the $97.5^{th}$, $99^{th}$, and $99.9^{th}$ percentiles. The red markers highlight the $50^{th}$ (square), $95^{th}$ (diamond) and $99^{th}$ (asterisk) percentiles. Error bars show the 95% confidence interval. The black line shows the 1:1 control line. To account for spatial sampling error, the green lines represent the quantile-quantile diagram of Subang radar daily precipitation in low-land areas versus the corresponding (nearest neighbor) daily precipitation of the Subang radar averaged on the IMERG grid, with temporal interpolation over missing values (solid green line; control R-R), and by substituting each instantaneous missing value by zero (green dashed line). The grey shading corresponds to the merged 95% confidence intervals of the green lines.

Conversely, IMERG percentiles tend to exceed the expectation at percentiles beyond the $95^{th}$ percentile, while remaining close to GHCN estimates. It is therefore not recommended to use IMERG at percentiles higher than the $95^{th}$ percentile for NWP evaluation. Likely, the gauge correction made at the end of the IMERG algorithm (for the Final version of the product) is responsible for this overestimation of IMERG for the most extreme precipitation. Finally, IMERG tends to overestimate precipitation from 0 mm/day to 1 mm/day (or below the 55$^{th}$ percentile) compared to the expectation given its spatial resolution.

The analysis was then repeated for the six clusters of GHCN stations defined in Fig. 2. Figure 3 displays the quantile-quantile diagrams for the six corresponding regions and for both boreal winter (October - March) and boreal summer (April - September). The spatial sampling error cannot be adequately evaluated in these regions because of the lack of radar data. It is however very likely that the shape of the expectation line in all of these regions is similar to the one that was drawn for Subang, which is being above the 1:1 line at low percentiles and below the 1:1 line for the highest percentiles.

In Western Peninsular Malaysia, Eastern Peninsular Malaysia, Northwest Borneo, Western and Eastern Philippines during boreal summer, the GHCN-IMERG quantile-quantile diagram is similar to the one obtained in Subang. This similarity suggests that the same conclusion holds for these regions: the 95$^{th}$ percentile of precipitation is recommended for NWP evaluation against IMERG, but highest percentiles are not indicated and must be treated with caution. Although IMERG underestimates low precipitation in Eastern Philippines during boreal winter, the most extreme percentiles are close to the GHCN percentiles as well, suggesting an overestimation of IMERG precipitation estimates for the most extreme percentiles again.

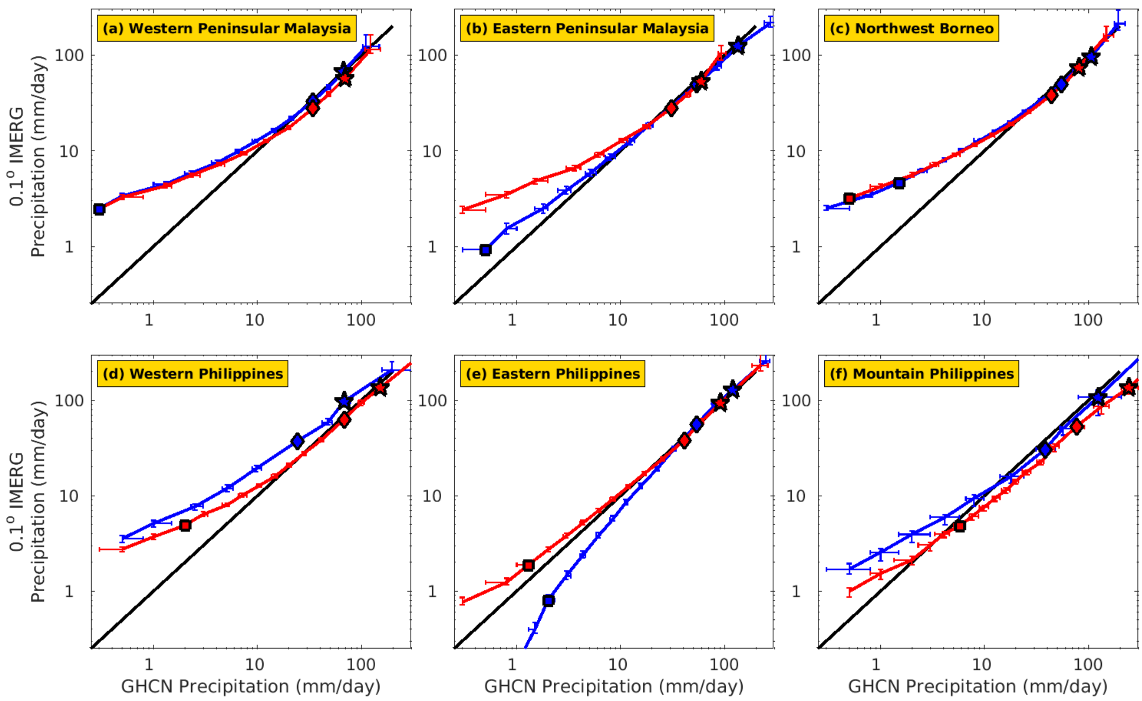


**Figure 3.** Quantile--quantile diagrams of GHCN daily precipitation versus nearest grid point IMERG daily precipitation during northern winter (October-March, blue) and northern summer (April-September, red) for: (a) Western Peninsular Malaysia, (b) Eastern Peninsular Malaysia, (c) North Western Borneo, (d) Western Philippines, (e) Eastern Philippines, (f) Mountain Philippines. The red markers highlight the 50$^{th}$ (square), 95$^{th}$ (diamond) and 99$^{th}$ (asterisk) percentiles. The black line shows the 1:1 control line.

A specific behavior is the case of Western Philippines during boreal winter. Indeed, the IMERG-GHCN quantile-quantile line lies above the 1:1 line for all percentiles, showing that IMERG may also overestimate the 95$^{th}$ percentile of daily precipitation in this region. IMERG is therefore not recommended for NWP evaluation of extreme precipitation in Western Philippines during boreal winter.

The case of the mountainous station is controversial since we may expect more systematic intra-grid precipitation differences, for instance between a single mountain and its surrounding valleys. While we observe that the IMERG extreme precipitation percentiles are lower than those of GHCN, we can no more presume on the quantile-quantile expectation that is certainly very sensitive to the station location and radically different that of Subang. It is therefore difficult to draw any conclusion for this region and even more for the general performance of IMERG in any mountainous areas.

## 4. Conclusions

In this study, we investigated the suitability of the IMERG precipitation product for NWP evaluations of extreme precipitation in the MC. We found that the large intra-grid variability of precipitation extreme leads to significant spatial sampling errors when IMERG is compared to a single station, and this must therefore be taken into account for the validation of IMERG in the MC. The use of a radar dataset in Subang made it possible to estimate the spatial sampling error and compare IMERG to GHCN gauges given their difference in spatial resolution.

We found that IMERG can be used for NWP evaluation of extreme daily precipitation in most parts of Malaysia and the Philippines. We recommend using the 95$^{th}$ percentile of precipitation as IMERG estimations are accurate for this percentile. The use of IMERG at higher percentiles such as the 99$^{th}$ percentile is not recommended since IMERG tends to overestimate daily precipitation at these percentiles.

An exception of these general conclusion is Western Philippines during boreal winter when IMERG tends to overestimate every precipitation percentile. It is therefore not recommended to use IMERG in this location at this period of the year. We also could not draw any conclusion on the utility of IMERG in mountainous areas because of the presence of large and unmeasurable spatial sampling errors.

A similar analysis was made for IMERG sub-daily precipitation against radar and the overall conclusion is that the IMERG 95$^{th}$ percentile is still suitable at these timescales.

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