COMPARISON BETWEEN GPM AND GRIDDED PRECIPITATION PRODUCT FROM INTERPOLATED RAIN GAUGE MEASUREMENTS

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ABSTRACT: Due to sparsely distributed synoptic stations in the Philippines, representation of precipitation is inadequate. Satellite-derived products, such as the Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Measurement (GPM), are available to complement synoptic data for more precise and robust measurements. However, these products tend to over- or underestimate rainfall depending on the season. Precipitation measurements from a dense network of rain gauges in the Philippines are available courtesy of the Department of Science and Technology – Advance Science and Technology Institute (DOST-ASTI). This study aims to create a gridded precipitation data over the Philippines from interpolated rain gauge measurements and validate its performance through comparison with GPM. Comparison of rain gauge data with overlapping synoptic measurements in a 0.25° grid showed distance-dependent likelihood. Thus, inverse distance weighting (IDW) was performed to combine multiple rain gauge measurements representative of precipitation over 0.1° grid. Strong positive correlations ($r = 0.58$ to 0.97) were obtained from comparing IDW values and monthly synoptic measurements suggesting that rain gauge measurements may be used as complimentary ground data. IDW values were then subjected to kriging and iterative method to create a monthly gridded precipitation. Results showed that the interpolated precipitation follows the wet and dry season as well as monsoon seasonality in the Philippines. The calculated differences between the interpolated precipitation and GPM monthly product revealed that the interpolated precipitation have lower estimates with respect to GPM regardless of season. This is in contrast with the strong positive relationship between monthly synoptic measurements and GPM ($r = 0.856$). Low estimates from the interpolated precipitation is due to isolated zero measurements from various rain gauges. This may be attributed to maintenance issues of the sensors where the data do not report broken and erroneous instruments. Further filtering of the dataset and regular maintenance of the sensors must be done to better incorporate the use of dense rain gauge network for the creation of a Philippine gridded precipitation.

1. INTRODUCTION

Synoptic stations measure various meteorological parameters necessary for weather and climatological studies. One of these parameters is precipitation, a vital element for water distribution and agriculture. There are 56 active Philippine synoptic stations distributed all over the country. These synoptic stations use rain gauges to establish ground-based precipitation measurements. However, with sparsely distributed synoptic stations, many areas in the Philippines still have no ground stations (Jamandre and Narisma, 2013). This inhibits good representation of precipitation distribution in the country (Veloria et. al, 2018). Forecasts utilizing these sparse precipitation measurements are also prone to error.

As complementary to the sparse synoptic measurements, satellite-derived and gridded re-analysis precipitation datasets are recently and openly available worldwide. The National Aeronautics and Space Administration (NASA) and Japan Aerospace Exploration Agency (JAXA) launched the Global Precipitation Measurement (GPM) mission's Core Observatory on February. With a fine spatial (0.1°) and temporal (30 minutes) resolution, the products of GPM aim to provide a more accurate and near real-time precipitation estimates. These products are available from March 2014 to present.

However, previous studies show that satellite-derived products are prone to over- or underestimation depending on the season (Jamandre and Narisma, 2013; Aghakouchak et. al, 2011). Moreover, gridded re-analysis datasets worldwide do not always account for localized conditions. Thus, we can't depend primarily on available worldwide gridded datasets especially in creating localized weather and environmental forecasts.

Department of Science and Technology – Advance Science and Technology Institute (DOST-ASTI) have installed numerous automated rain gauges (ARGs) all over the country. This initiative is a project that reports real-time precipitation measurements every 15 minutes. However, few studies have been conducted in order to fully utilize these ARGs, more so use these data to create a gridded precipitation. Thus, this study aims to create a gridded precipitation data over the Philippines from interpolated ARG measurements and validate its performance through comparison with GPM.

2. METHODOLOGY

2.1 Data Used

2.1.1 Synoptic Data

Synoptic station rainfall measurements from Philippine weather stations were obtained from the dataset of Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA). Monthly rainfall measurements, reported in amounts (mm), are obtained from available synoptic stations. The period considered covers the start of the station's operation (earliest is 1951) up to 2017.

Parsing and processing of rainfall measurements were done. Using the location data provided by PAGASA, station measurements were assigned to a cell in a gridded dataset over the country. The resolution of the grids used are in 0.25° and 0.1°.

2.1.2 Automated Rain Gauge Data

Precipitation measurements from Automated Rain Gauges (ARGs) were obtained from the Department of Science and Technology - Advance Science and Technology Institute (DOST-ASTI). The location of rain gauges from DOST-ASTI can be seen in their website http://philsensors.asti.dost.gov.ph.

The dataset comes with location information and gives precipitation data every 15 minutes. These measurements were then transformed to monthly aggregates per rain gauge station. After which, these measurements were assigned to a grid cell in 0.1° resolution.

2.1.3 Satellite Data

The Integrated Multi-satellitE Retrievals for GPM (IMERG) is the rainfall product of GPM. It combines measurements from various rainfall-relevant satellite passive microwave (PMW) sensors in the GPM constellation. The monthly product was obtained for the period 2014 to 2017. All satellite data were download from PMM website (https://pmm.nasa.gov/data-access/downloads).

2.2 Procedure

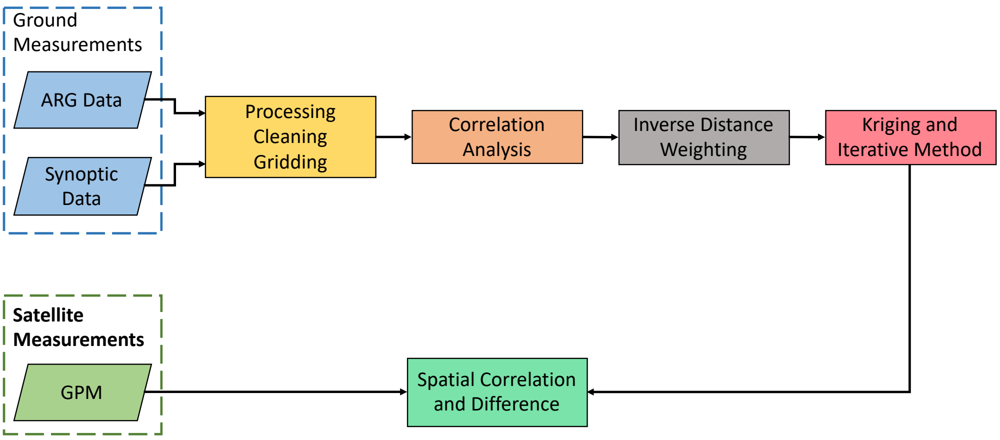

Figure 1. Process flow of the methods and analyses done.

The general process flow of the computations and analysis is summarized in Figure 1. Precipitation measurements from synoptic stations and automated rain gauges were parsed and processed to monthly totals. The duration of measurements considered starts from April 2014 up to December 2017, the overlapping period with available GPM product. Cleaning of the measurements were done in order to remove erroneous ARGs that report the following: (1) more than 1000 mm rainfall in a 15-minute period; (2) no measurements for the whole duration of 2014 to 2017; and (3) total of 0 mm rainfall for the whole year.

Filtered data were then assigned to grid cells of 0.25° and 0.1° resolutions. Four synoptic stations were selected to analyze the distribution and behavior of ground precipitation measurements in a satellite grid. These stations are the following: (1) Science Garden in Quezon City, (2) Ninoy Aquino International Airport in Pasay City, (3) Cebu city synoptic station, and (4) Davao City synoptic station. The four stations together with the ARGs present inside a satellite grid were used to analyze the likelihood of their measurements using the correlation analysis discussed in Section 2.2.1. This was done to assess the use of ARG measurements as complementary ground precipitation data.

Inverse distance weighting (Section 2.2.2) was done to incorporate measurements of rain gauges (and synoptic stations) in a 0.1° grid, the same resolution as GPM. Afterwards, kriging and iterative method was done in order to interpolate the grid all over the Philippines. Spatial correlation and difference between the interpolated precipitation and GPM were calculated to verify validity of the gridded product from ground measurements alone.

2.2.1 Correlation Analysis

Relationship of two time series was determined through correlation. The correlation coefficient, **r**, measures the extent of how two variables follow each other (Rarugal et. al, 2013) and is expressed as:

$$\boldsymbol{r} = \frac{1}{N}\sum_{n=1}^{N}\frac{(x_n - \langle x\rangle)(y_n - \langle y\rangle)}{\sigma_x \sigma_y} \tag{1}$$

where $\langle \boldsymbol{x} \rangle$ and $\langle \boldsymbol{y} \rangle$ are the means of time series station (x) and rain gauge (y) measurements, and $\boldsymbol{\sigma_x}$ and $\boldsymbol{\sigma_x}$ are their respective standard deviations. A correlation of 1 and -1 suggests that the two time series are directly and inversely correlated, respectively.

2.2.2 Inverse Distance Weighting

IDW is based on the concept of Tobler's first law (the first law of geography) from 1970. It was defined as everything is related to everything else, but near things are more related than distant things. The general idea of IDW is based on the assumption that the attribute value of an unsampled point is the weighted average of known values within the neighborhood. This involves the process of assigning values to unknown points by using values from a scattered set of known points. The value at the unknown point is a weighted sum of the values of N known points (Chen and Liu, 2012).

In this study, IDW is applied to the rain gauge data in order to interpolate the value at the centroid of the grid cell (0.1°) using the values of surrounding rain gauges within the cell. IDW is only done for grid cells with more than one rain gauges. Otherwise, the rain gauge inside the grid cell contributes solely to the cell's value. Lastly, grid cells with no rain gauges are left with unknown values. IDW is done using the equations

$$\mathbf{R_p} = \sum_{n=1}^{N} \boldsymbol{w_n R_n} \tag{2}$$

$$\mathbf{w_n} = \frac{\boldsymbol{d_n^{-\alpha}}}{\sum_{n=1}^{N} \boldsymbol{d_n^{-\alpha}}} \tag{3}$$

where R_p is the unknown rainfall data (mm), R_n is the rainfall data of rain gauges (mm), N is the number of rain gauges, w_n is the weighting of each rain gauge, d_n is the distance from each rain gauge to the grid's center, and α is the power that is generally assumed as two (Chen and Liu, 2012).

2.2.3 Kriging and Iterative Method

Unknown cells from the rain gauge data were then interpolated through kriging, a method of estimation using local weighted averaging (Oliver and Webster, 1990). Value of unknown cells were krigged using the equation

$$\boldsymbol{Z_{x,y}} = \frac{\text{sum of known-value neighbor cells}}{\text{number of known-value neighbor cells}} \tag{4}$$

where $Z_{x,y}$ is the interpolated cell affected by its neighbors. Iterative method was done until the difference between the previous and current cell values is less than 10^{-4}.

3. RESULTS AND DISCUSSION

The relationship between measurements of ARGs and Science Garden station in Quezon City was investigated first. Figure 1 shows the location of rain gauges surrounding the Science Garden Station in a 0.25° and 0.1° grid cell. A total of 13 rain gauges, represented by red pins, neighbor the synoptic station in consideration to the TRMM grid. Additional four rain gauges, represented by green pins, neighbor the synoptic station when we consider the GPM grid (middle left-most cell).

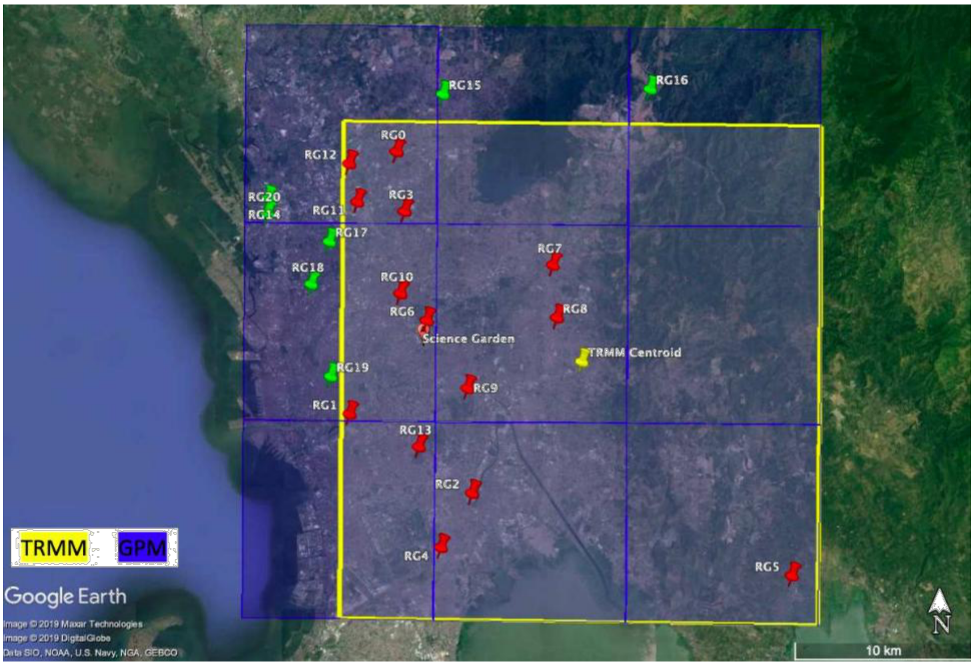

Figure 1. Distribution of DOST-ASTI rain gauges around Science Garden Station inside a TRMM (yellow) and GPM (blue) grid.

The relationship between the measurements of science garden and rain gauges inside a TRMM grid was investigated first. It was found out that distance relative to the true value, the synoptic station, affects the likelihood of their similarity as shown in Figure 2.

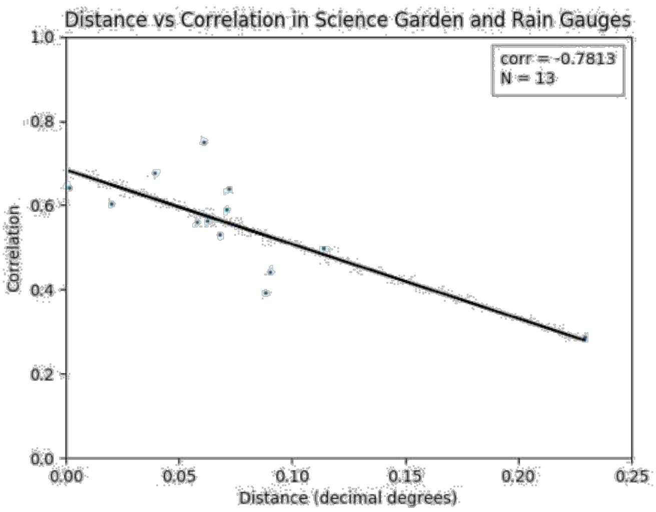

Figure 2. Relationship between correlation of measurements in rain gauges and their distance with respect to Science Garden. Spatial coverage is 0.25°.

Based from Figure 1, RG5 rain gauge is the farthest from Science Garden while RG6 is the closest. Observing their daily precipitation measurements for all the overlapping days since operation, it was found out that these rain gauges also have the lowest and highest correlation with Science Garden, respectively. This is shown in Figure 3.

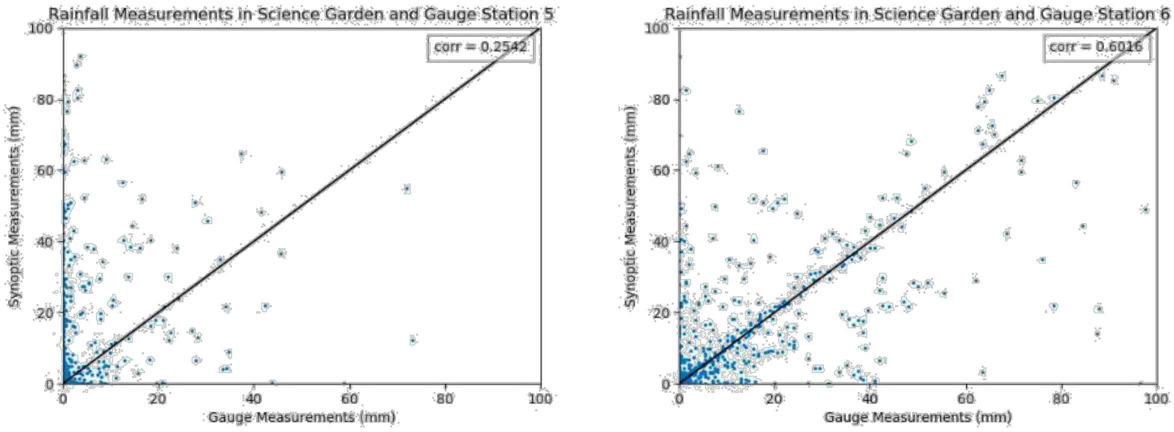

Figure 3. Relationship between precipitation measurements of the farthest and closest rain gauge from Science Garden.

Three other synoptic stations were considered in this analysis; the Cebu, Davao, and NAIA stations. The locations of the rain gauges in these stations are shown in Figure 4. Same analysis was done for these stations and the relationship of the correlation with respect to distance for all four synoptic stations is generalized in Figure 5. With a correlation of -0.493, it can be seen that distance affects the likelihood of similarity in a scattered system. This is in accordance to the Tobler's first law of geography (Chen and Liu, 2012).

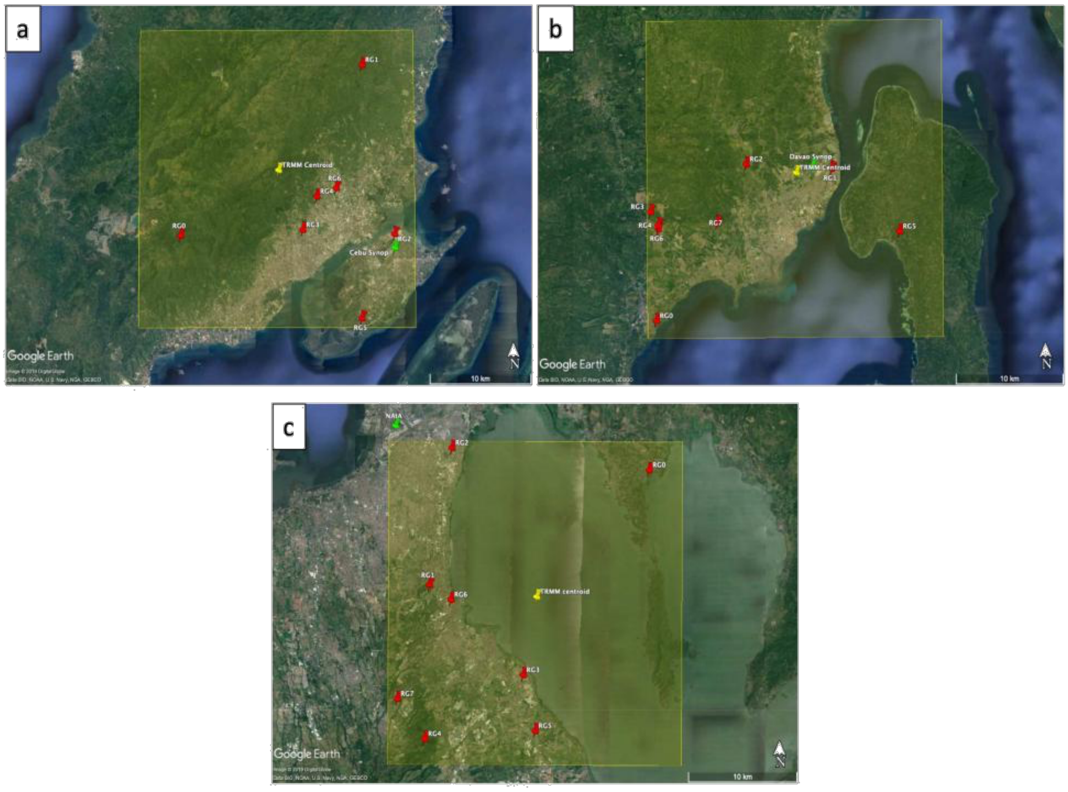

Figure 4. Distribution of DOST-ASTI rain gauges around (a) Cebu, (b) Davao, and (c) NAIA.

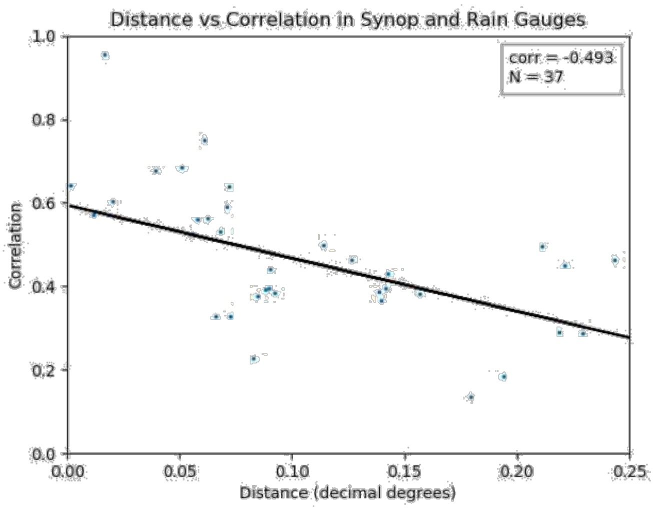

Figure 5. Relationship between correlation of measurements in rain gauges and their distance with respect to synoptic station. Spatial coverage is 0.25°.

With the established distance-dependent likelihood of the measurements from rain gauges and synoptic stations, inverse distance weighting was done in order to combine several measurements overlapping a grid. Table 1 summarizes the correlations obtained from IDW values and overlapping synoptic stations using monthly precipitation data. In general, IDW values are at par with station measurements. Low correlations were obtained for Casiguran and Butuan stations due to underestimated values computed from IDW. In contrast, IDW values in Borongan station overestimated station measurements.

Table 1. Correlation values of overlapping IDW values and synoptic stations.

Station	Value	Station	Value
Basco	0.8359	Catarman	0.7267
Tuguegarao	0.8409	Catbalogan	0.9672
Baguio	0.7929	Borongan	0.3134
Casiguran	0.2295	Tacloban	0.8997
Dagupan	0.7433	Mactan	0.7848
Iba	0.8347	Dumaguete	0.7886
Cabanatuan	0.5844	Surigao	0.8363
Clark	0.7065	Butuan	0.3141
Science Garden	0.9273	El Salvador	0.6605
NAIA	0.7846	Malaybalay	0.9596
Ambulong	0.6438	Cotabato	0.9574
Tayabas	0.7253	Francisco Bangoy	0.9302
Daet	0.8831	General Santos	0.8489
Virac	0.9091	Legazpi	0.8100

Kriging and iterative method were then employed to interpolate these IDW values of ground rainfall measurements. For visual consideration, the interpolated monthly rainfall for year 2015 is shown on Figure 6 at 0.1° resolution.

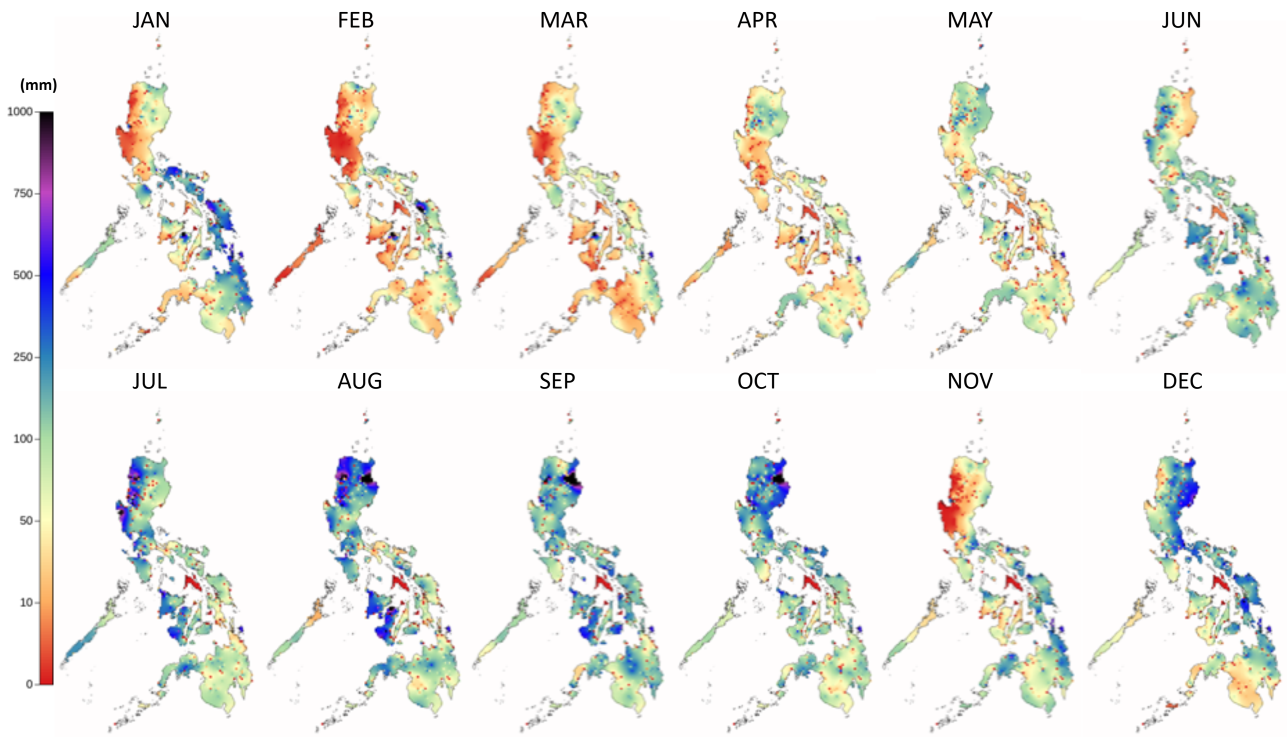

Figure 6. Interpolated monthly rainfall for the year 2015. Resolution is at 0.1°.

Based from Figure 6, the interpolated rainfall from ground measurements follow the monsoon seasonality in the country. Rainfall variability can also be seen wherein dry conditions were observed from November 2015 followed by huge amount of precipitation at the eastern part of the country for the month of December. This can be attributed to the Category 4 Typhoon Melor that landfall in Samar on December 13, 2015. This typhoon caused a state of calamity over the country due to severe damages in Southern Luzon, Oriental Mindoro, and Visayas (Mangosing, 2015).

The spatial correlation between the monthly interpolated and GPM products were calculated and is shown in Figure 7. Majority of the country have moderate to strong positive correlation. Low correlation was obtained in Palawan, with the least number of ARGs deployed, and other places scattered all over the country. It can also be seen that the places with low correlation are the places that have isolated zero measurements of monthly rainfall shown in Figure 6. These can be attributed to maintenance and quality issues of the ARGs deployed.

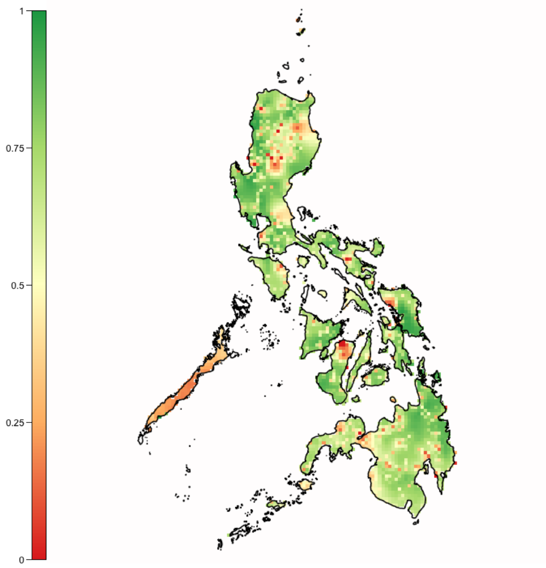

Figure 7. Spatial correlation between interpolated and GPM monthly rainfall products.

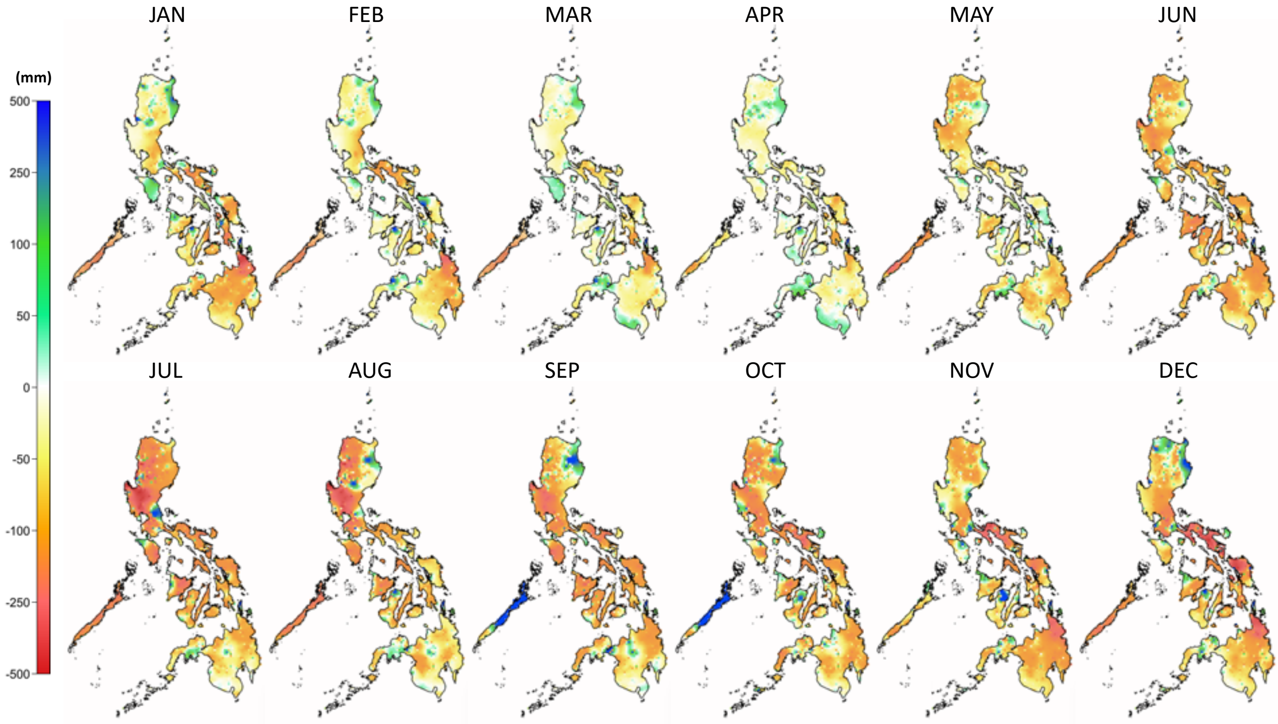

Figure 8. Monthly spatial difference between interpolated rainfall and GPM.

The average monthly rainfall from both interpolated and GPM products were obtained for the years 2014 to 2017. Afterwards, spatial differences were obtained between the two. As shown in Figure 8, lowest differences are depicted in months February to April. Moreover, monthly differences can be seen to range between -100 to 100 mm with negative values indicating higher GPM estimates than the interpolated product. Again, Palawan has the most extreme difference obtained having least ARGs situated in the area.

4. CONCLUSION

In this study, the use of ARGs deployed by DOST-ASTI as complementary ground precipitation data is investigated. Likelihood of measurements among ARGs and nearby synoptic stations show a distance-dependent relationship. Thus, inverse distance weighting was done in order to combine several measurements from various rain gauges.

Kriging and iterative method was employed to interpolate precipitation in a 0.1° grid. Interpolated monthly precipitation show good correlation with GPM for almost all places in the country except Palawan, having the least number of ARGs deployed. Differences obtained from the interpolated product and GPM range for approximated 100 mm wherein lowest differences are obtained during the months of February to April. In general, the study exhibited a method of creating an interpolated rainfall product from the complementary rain gauge data. Further quality measures on the dataset must be explored in order to remove isolated low measurements of rainfall in several areas.

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