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Evaluation of GPM IMERG Performance Over the Titicaca Lake Basin at Different Time Scales †

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Abstract: Accurate precipitation measurements are very important as an input for water resources management and various hydrometeorological applications. Integrated Multi-Satellite Retrievals for Global Precipitation Measurement (GPM) (IMERG) satellite precipitation products (SPP) have been widely used to complement rain gauge measurements. However, they must be evaluated before use and are still lacking in the Titicaca lake basin (TLB). In this research, the evaluation of the performance of GPM IMERG on the TLB at different time scales (daily, monthly and annual) was carried out. The evaluation was performed using rain gauge observations for the period 2003–2016 and three IMERG, namely early (IMERG-E), late (IMERG-L), and final (IMERG-F). Accordingly, three performance metrics were used that evaluated the accuracy (correlation coefficient, CC), error (root mean square error, RMSE), and bias (percent bias, PBIAS) of the satellite estimates. In general, monthly IMERG SPP correlated best with rain gauge measurements. In all evaluations performed (daily, monthly, and annual), IMERG-F was in better agreement with rain gauge measurements at the TLB, with small differences with IMERG-E and IMERG-L. The IMERG SPPs show potential for use in various hydrometeorological applications in the TLB.

Keywords: South American Altiplano; Titicaca lake basin; GPM IMERG; satellite precipitation products

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1. Introduction

Precipitation is an important variable for hydrological, agricultural, industrial and energy systems [1]. It has a great impact on people's lives and the control of the hydrological cycle, as well as fluctuations that affect water resources management, environmental planning and disaster mitigation [2,3]. Its utility is fundamental as input to hydrological models, meteorological models and climate models [4,5]. The most accurate precipitation measurements are those taken directly with a rain gauge [6]. However, the availability of such data is limited to the few areas where weather stations have been installed [7].

Climatological and hydrometeorological applications of SPPs have been significantly improved with the appearance of the GPM IMERG [8]. IMERG combines data from GPM constellations of satellites to estimate precipitation over most of the earth's surface which lacks terrestrial rain gauges, and offers three runs to meet different users' latency and accuracy requirements, including IMERG Early (IMERG-E), IMERG Late (IMERG-L) e IMERG Final (IMERG-F) [9], which has led to the use of IMERG being considered by many researchers to evaluate its performance.

In recent years, the use of SPPs from IMERG has shown promising performance in detecting precipitation on different time scales, for example, in mainland China, an evaluation of monthly precipitation products of IMERG and TRMM 3B43 [10] was carried out, in Brazil [11], IMERG grid-level evaluation was conducted over Brazil at various spatial and temporal scales, in Thailand [12], a hydrological evaluation and application of TRMM and GPM precipitation products in a tropical monsoon basin was focused on, while a comprehensive evaluation of GPM-IMERG and MRMS with hourly ground observations was conducted across Canada [13]. Additionally, [14] evaluated GPM-IMERG, TMPA-3B42, and ERA-Interim in different topographic and climatic conditions in Iran, in Singapore [15], GPM and TRMM precipitation products were evaluated, [16] compared satellite precipitation products GPM IMERG, TMPA 3B42, and PERSIANN-CDR over Malaysia, [17] focused on a complete comparison of GPM IMERG with nine satellite and reanalysis datasets, while a first validation of IMERG over Spain is presented in [18]. Ref. [19] developed a precipitation dataset through simultaneous use of IMERG, synoptic measurements, and automatic rain gauge measurements in the Philippines, while [20] evaluated and compared daily precipitation of GPM and TRMM products over the Mekong River basin, in China [21], an evaluation of the IMERG version 05B precipitation product was conducted and compared with IMERG version 04A at hourly and daily scales, while in Myanmar, TRMM and GPM precipitation products were used for sub-daily scale flood simulations in a sparsely gauged river basin [22], and a comprehensive evaluation of the latest IMERG and GSMaP precipitation products of the GPM era was conducted in mainland China [23]. Although GPM IMERG SPP has been used in hydrological modeling in the TLB [24], its performance has not yet been evaluated at different time scales.

From this perspective, the objective of this research was to evaluate the performance of GPM IMERG at different time scales in the Titicaca Lake basin, and its importance lies in improving the understanding of climate variability and its impact on flood risk management, hydrological modeling, and hydroclimatic studies. The hypothesis is that the quality and accuracy of GPM IMERG precipitation estimates vary at different time scales in the TLB.

2. Materials and Methods

2.1. Study Area

The TLB is located in southern Peru (Puno department) and west Bolivia (La Paz department) (Figure 1). It is part of the Titicaca hydrographic region and the Titicaca-Desaguadero-Poopó-Salar de Coipasa (TDPS) endorheic system, bordered by the eastern and western mountain ranges. It covers an approximate area of 53,919.1 km^2, its maximum altitude according to the digital elevation model (DEM) is 6397 m.s.a.l., minimum altitude 3758 m.s.a.l., with an average of 4190.2 m.s.a.l. Most of the TLB has a flat topography with a mean slope of 13.7%. The mean annual precipitation is 683.3 mm, 59.5% of the annual precipitation occurs in austral summer, 2.3% in winter and 22.1% and 16.1% in the transition periods from wet to dry (autumn) and from dry to wet (spring), respectively.

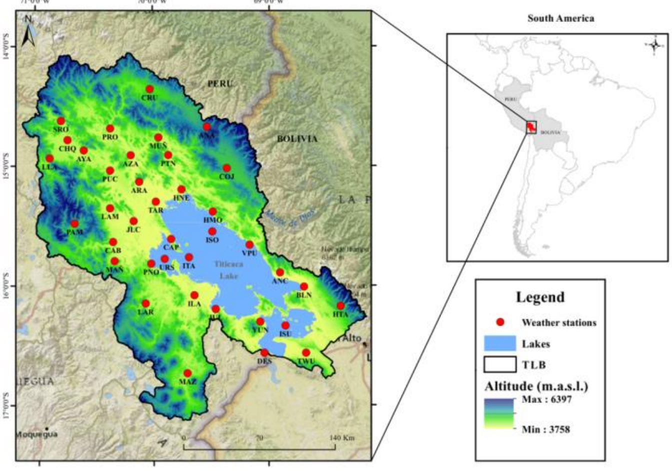

Figure 1. Location of TLB with weather stations in relation to South America.

2.2. Cartographic Information

The DEM was generated by NASA's Shuttle Radar Topography Mission (SRTM) at a spatial resolution of ~90 m, and was obtained from the Google Earth Engine (GEE) platform (https://earthengine.google.com/), Image ID CGIAR/SRTM90_V4 [25].

2.3. Rain Gauge Measurements

Rain gauge measurements were obtained from the Servicio Nacional de Meteorología e Hidrología (SENAMHI) Perú, considering a total of 33 meteorological stations. Also, from the Servicio Nacional de Meteorología e Hidrología (SENAMHI) Bolivia, five weather stations within the TLB were considered (Figure 1). The total number of weather stations considered was 38, with a daily recording period from 1 January 2003 to 31 December 2016.

2.5. GPM IMERG Satelital Precipitation Products

En esta investigación se evaluaron los SPPs GPM IMERG (IMERG-E, L y F) versión 6 (V06). GPM produces precipitation data with a temporal resolution of up to 30 min, spatial resolution of 0.1° × 0.1° (latitude 60° N-S) and in three executions (IMERG-E, L and F). En secuencia, IMERG-E y L son datos casi en tiempo real con un retraso de 4 horas y 14 horas después del tiempo de observación respectivamente, sin embargo, IMERG-F tiene un retraso de 3,5 meses [9]. IMERG-E can be used when rapid responses are required such as possible flood or landslide warnings, while IMERG-L for agricultural forecasting or drought monitoring [26].

GPM-IMERG V06 data were obtained from the National Aeronautics and Space Administration (NASA) GIOVANNI online (Web) server (https://giovanni.gsfc.nasa.gov/giovanni/). The data were collected for the same period as the rain gauge measurements.

2.6. Method

Performance Evaluation of SPPs GPM IMERG

The homogeneity of the rain gauge measurements was verified through the non-parametric CUSUM test using the TREND program (https://toolkit.ewater.org.au/Tools/TREND). TREND is designed to facilitate statistical analysis of trends, changes and randomness in hydrological and time series data [27]. Missing data were filled in using the random forest method incorporated in the MICE (Generates Multivariate Imputations by Chained Equations) package for the R project [28]. Homogeneity was checked with monthly data after filling in missing data [29,30].

Comparisons between IMERG and rain gauges were performed using a pixel to point approach as performed in previous studies [14]. This is based solely on observed precipitation measurements.

In effect, three continuous statistical metrics were used to evaluate performance (Table 1). These metrics aim to quantitatively compare the performance of IMERG measurements with rain gauge measurements. The evaluations were performed with different temporal variations, that is, daily, monthly and annual. The lack of rain gauge measurements in some areas of the TLB could limit the ability to fully evaluate IMERG measurements.

Table 1. Statistical performance metrics.

Metrics	Equation	Range	Optimal Value
Root mean square error (RMSE)	$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - S_i)^2}$	0.0 to ∞	0.0

Correlation coefficient (CC)	$CC = \frac{\sum_{i=1}^{n}(O_i - \bar{O})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(S_i - \bar{S})^2}}$	−1.0 to 1.0	1.0
Percentage bias (PBIAS)	$PBIAS = \frac{\sum_{i=1}^{n} O_i - S_i}{\sum_{i=1}^{n} O_i} x\, 100$	−∞ to ∞	0.0

S is the satellite measurement; O the rain gauge measurement; $\bar{S}$ and $\bar{O}$ denote the mean values of S and O respectively; n indicates the number of data pairs.

3. Results

3.1. Daily Evaluation

Figure 2 shows the distribution of continuous statistical quantities compared between rain gauge measurements and the three IMERGs. In summary, the mean CC values in relation to the rain gauge for IMERG-E, IMERG-L and IMERG-F were 0.33, 0.32 and 0.35, respectively. Although low values of CC could be seen, IMERG-F appears to be more consistent with rain gauge observations at the TLB (Figure 2a–c). The average RMSE value (Figure 2d–f) is between a range of 3.96 mm/day to 7.96 mm/day (mean 5.19 mm/day) for the three IMERGs evaluated. The spatial distribution of PBIAS (Figure 2g–i) showed an underestimation (overestimation) of precipitation at 77% (23%) (mean) of the stations, with overestimates of precipitation in the eastern and northeastern part of the TLB for all three IMERGs. The mean PBIAS values were -13.52% (IMERG-E), −20.54% (IMERG-L) and 2.68% (IMERG-F).

3.2. Monthly Evaluation

The results indicate that IMERG-F was relatively better. The highest (lowest) co-relation (Figure 3a–c) of the monthly evaluation was observed in IMERG-F (IMERG-E) data in relation to the rain gauges with an average CC value of 0.90 (0.85). IMERG-F showed a correlation greater than 0.79 with a maximum value of 0.94, followed by IMERG-E with a correlation greater than 0.70 and a maximum value of 0.92, while the CC of IMERG-L was between a range of 0.68 to 0.92. The monthly RMSE results (Figure 3d–f) were between an average range of 32.01 mm/month (IMERG-F) to 42.22 mm/month (IMERG-L) compared to the rain gauge data. IMERG-F compared to IMERG-L and E obtained lower errors at most stations (Figure 3f).

3.3. Annual Evaluation

Regarding the annual IMERG products, the error increases and the correlation decreases with respect to the monthly evaluation, resulting worse in some stations. Figure 4 shows the spatial distribution of the continuous statistical quantities compared between annual rain gauge measurements and the three IMERGs. The highest (lowest) correlation (Figure 4a–c) of the annual assessment was observed in the IMERG-F (IMERG-L) data relative to the rain gauge data with a mean CC value of 0.50 (0.43). IMERG-F mostró un CC entre −0,55 y 0,85, seguido por IMERG-E con un CC entre −0,58 a 0,91, mientras que el CC de IMERG-L varió de −0,65 a 0,92. For IMERG-E, L and F negative correlations were found in 5%, 5% and 3%, while a 3% resulted with CC < 0.15 (0.11, 0.09 and 0.06) of the total of stations respectively. Consequently, the CC was greater than 0.15 in 92% of the stations evaluated, with a mean of 0.51 for the three IMERGs. On the other hand, the annual RMSE results (Figure 4d–f) were between an average range of 175.28 mm/year (IMERG-F) to 262.84 mm/year (IMERG-L) compared to the rain gauge data.

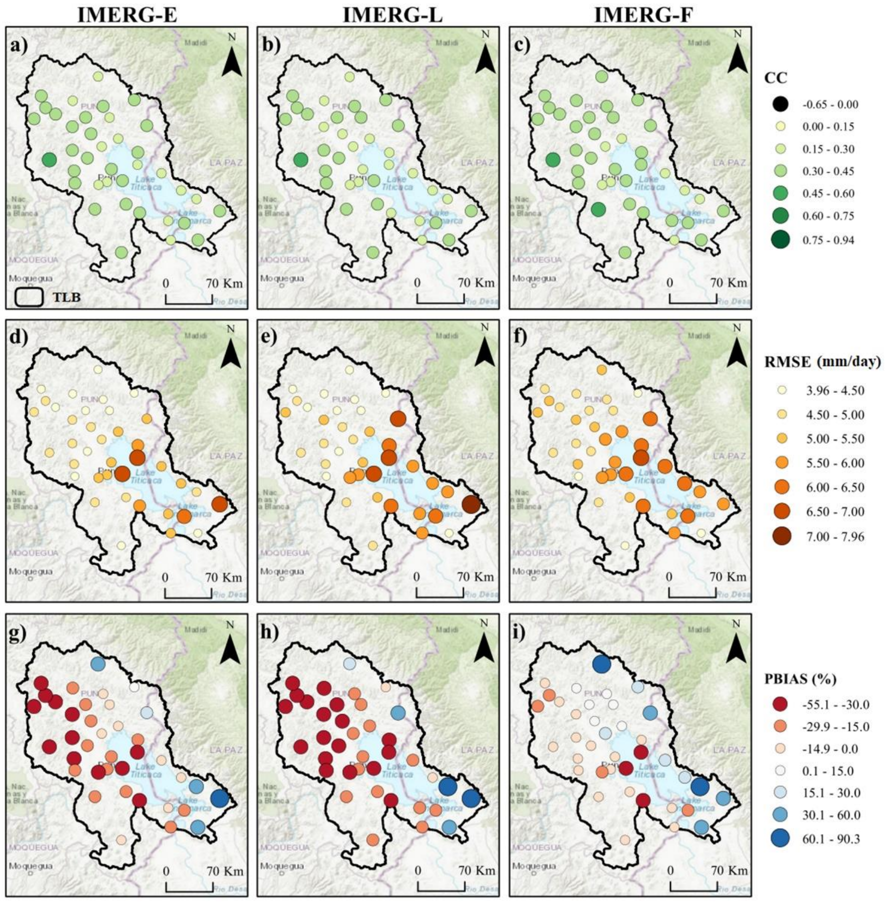

Figure 2. Spatial distribution of CC (**a**–**c**), RMSE (**d**–**f**) and PBIAS (**g**–**i**) of daily rain gauge data in relation to IMERG.

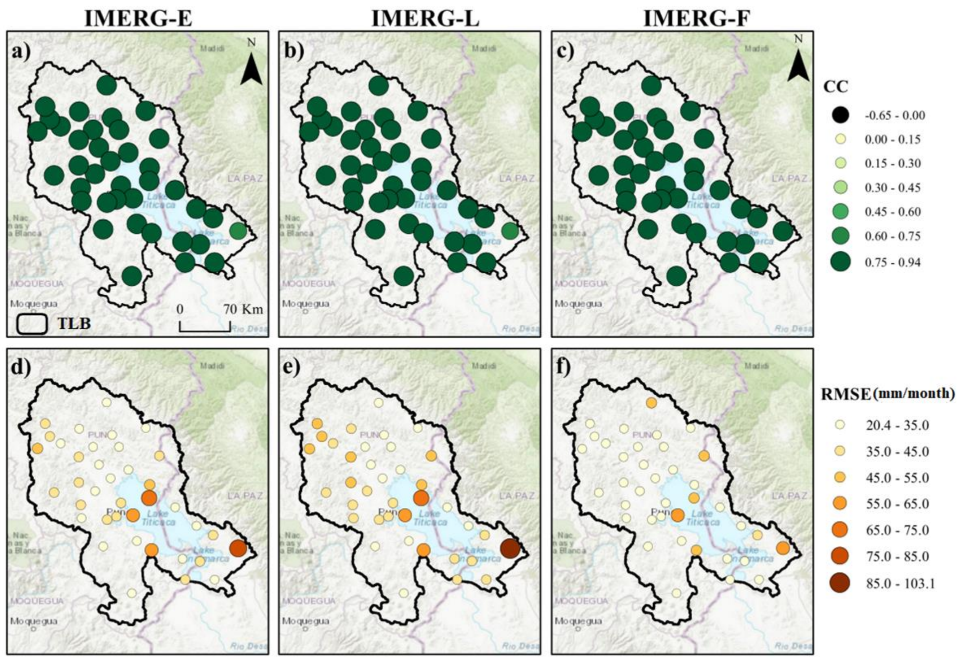

Figure 3. Spatial distribution of CC (**a**–**c**) and RMSE (**d**–**f**) of monthly rain gauge data in relation to IMERG.

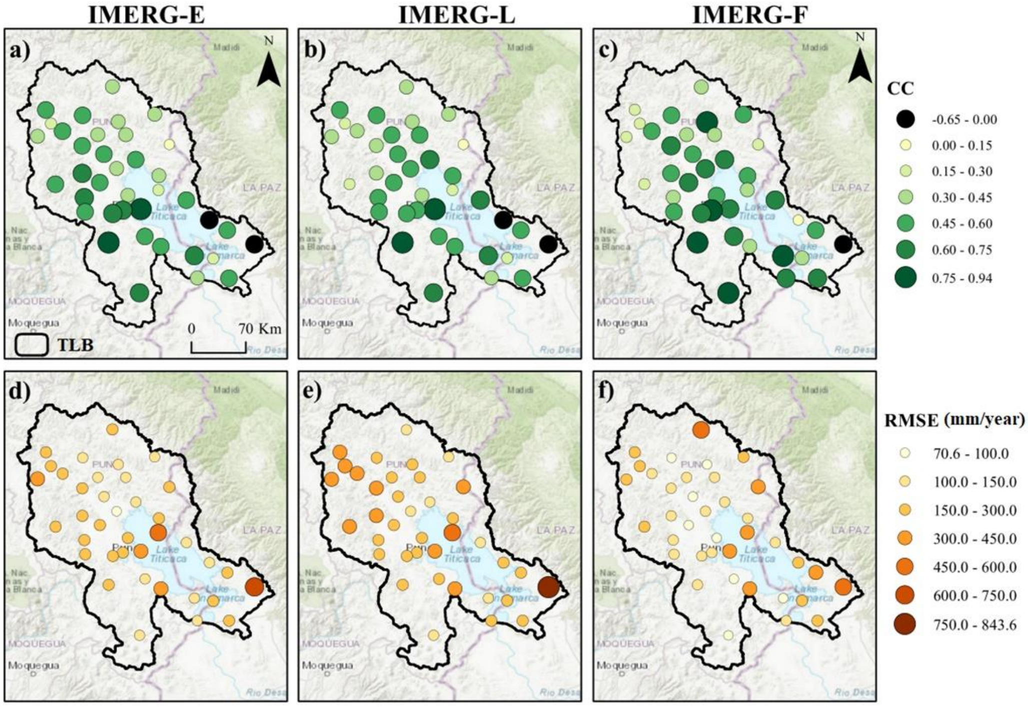

Figure 4. Spatial distribution of CC (**a**–**c**) and RMSE (**d**–**f**) of annual rain gauge data in relation to IMERG.

4. Discussion

Validation of precipitation products is very important for climate and hydrological studies [31]. In general, it was possible to find an accuracy of the SPP IMERG on increasing time scales (daily, monthly and annual). Performance was better for monthly data in representing local precipitation in the TLB. The accuracy of the monthly IMERG data relative to the rain gauge data shows variance at some stations, and on average the CC at a monthly scale shows a high acceptance value unlike the other scales (i.e., monthly > annual > daily). This is similar to what was reported at other places [16,17,19]. However, when evaluating the annual IMERG data, negative values of CC and close to zero were found, indicating a deficiency in the measurement of annual precipitation by IMERG. The accuracy of IMERG is good with higher latency and lower with medium latency (i.e., IMERG-F > IMERG-E > IMERG-L), which is why IMERG-F is recommended for use in the TLB. The main reason for the difference in performance is that SPPs are calibrated with terrestrial data [23]. However, the choice of IMERG product will depend to a greater extent on the type of application in the TLB. The accuracy of IMERG data may also be affected by the magnitude of precipitation, and there are indeed considerable biases for all latencies.

5. Conclusions

In this study, the evaluation of GPM IMERG performance over the Titicaca Lake Basin at different time scales was performed by validating an IMERG grid point with rain gauge measurements. It is concluded that:

In general, IMERG products provide a valuable opportunity to understand the precipitation characteristics detected by remote sensors. However, the performance could differ on different time scales, with the most encouraging result according to the performance metrics being the monthly time scale, especially IMERG-F, followed by an annual and daily scale. The difference between IMERG-E and IMERG-L were minimal due to the fact that they maintain a faster latency. Despite this, considerable biases can be observed in the IMERG data and in future research, bias correction is necessary before using the data for consideration in various hydrometeorological applications.

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References

1. Carrasco, M.; Yarlequé, C.; Posadas, A. Datos faltantes de precipitación pluvial diaria mediante la Transformada Wavelet. *Rev. Peru. Geo-Atmosférica* **2010**, *88*, 76–88.
2. Hamill, T.; Kiladis, G. Comparison of Global Precipitation Estimates across a Range of Temporal and Spatial Scales. *J. Clim.* **2016**, *29*, 7773–7795. https://doi.org/10.1175/JCLI-D-15-0618.1.
3. Lee, J.; Lee, E.; Seol, K. Validation of Integrated MultisatellitE Retrievals for GPM (IMERG) by using gauge-based analysis products of daily precipitation over East Asia. *Theor. Appl. Climatol.* **2019**, *137*, 2497–2512. https://doi.org/10.1007/s00704-018-2749-1.
4. Katiraie-boroujerdy, P.; Nasrollahi, N.; Hsu, K.; Sorooshian, S. Evaluation of satellite-based precipitation estimation over Iran. *J. Arid. Environ.* **2013**, *97*, 205–219. https://doi.org/10.1016/j.jaridenv.2013.05.013.
5. Mahmoud, M.T.; Mohammed, S.A.; Hamouda, M.A.; Mohamed, M.M. Impact of topography and rainfall intensity on the accuracy of imerg precipitation estimates in an arid region. *Remote Sens.* **2021**, *13*, 13. https://doi.org/10.3390/rs13010013.
6. Sun, Q.; Miao, C.; Duan, Q.; Ashouri, H.; Sorooshian, S.; Hsu, K.L. A Review of Global Precipitation Data Sets: Data Sources, Estimation, and Intercomparisons. *Rev. Geophys.* **2018**, *56*, 79–107. https://doi.org/10.1002/2017RG000574.
7. Ahuja, S.; Dhanya, C. Regionalization of Rainfall Using RCDA Cluster Ensemble Algorithm in India. *J. Softw. Eng. Appl.* **2012**, *5*, 568–573. https://doi.org/10.4236/jsea.2012.58065.
8. Mahmoud, M.T.; Al-Zahrani, M.A.; Sharif, H.O. Assessment of global precipitation measurement satellite products over Saudi Arabia. *J. Hydrol.* **2018**, *559*, 1–12. https://doi.org/10.1016/j.jhydrol.2018.02.015.
9. Huffman, G.J.; Bolvin, D.T.; Braithwaite, D.; Hsu, K.L.; Joyce, R.J.; Kidd, C.; Nelkin, E.J.; Sorooshian, S.; Stocker, E.F.; Tan, J.; et al. Integrated multi-satellite retrievals for the global precipitation measurement (GPM) mission (IMERG). *Satell. Precip. Meas.* **2020**, *1*, 343–353.
10. Chen, F.; Li, X. Evaluation of IMERG and TRMM 3B43 monthly precipitation products over mainland China. *Remote Sens.* **2016**, *8*, 472. https://doi.org/10.3390/rs8060472.
11. Gadelha, A.; Coelho, V.; Xavier, A.; Barbosa, L.; Melo, D.C.; Xuan, Y.; Huffman, G.; Petersen, W.; Almeida, C. Grid box-level evaluation of IMERG over Brazil at various space and time scales. *Atmos. Res.* **2019**, *218*, 231–244. https://doi.org/10.1016/j.atmosres.2018.12.001.
12. Li, R.; Shi, J.; Ji, D.; Zhao, T.; Plermkamon, V.; Moukomla, S.; Kuntiyawichai, K.; Kruasilp, J. Evaluation and hydrological application of TRMM and GPM precipitation products in a tropical monsoon basin of Thailand. *Water* **2019**, *11*, 818. https://doi.org/10.3390/w11040818.
13. Moazami, S.; Najafi, M. A Comprehensive Evaluation of GPM-IMERG V06 and MRMS with Hourly Ground- Based Precipitation Observations across Canada. *J. Hydrol.* **2021**, *594*, 125929. https://doi.org/10.1016/j.jhydrol.2020.125929.
14. Sharifi, E.; Steinacker, R.; Saghafian, B. Assessment of GPM-IMERG and other precipitation products against gauge data under different topographic and climatic conditions in Iran: Preliminary results. *Remote Sens.* **2016**, *8*, 135. https://doi.org/10.3390/rs8020135.
15. Tan, M.; Duan, Z. Assessment of GPM and TRMM precipitation products over Singapore. *Remote Sens.* **2017**, *9*, 720. https://doi.org/10.3390/rs9070720.
16. Tan, M.; Santo, H. Comparison of GPM IMERG, TMPA 3B42 and PERSIANN-CDR satellite precipitation products over Malaysia. *Atmos. Res.* **2018**, *202*, 63–76. https://doi.org/10.1016/j.atmosres.2017.11.006.

17. Tang, G.; Clark, M.; Papalexiou, S.; Ma, Z.; Hong, Y. Have satellite precipitation products improved over last two decades? A comprehensive comparison of GPM IMERG with nine satellite and reanalysis datasets. *Remote Sens. Environ.* **2020**, *240*, 111697. https://doi.org/10.1016/j.rse.2020.111697.
18. Tapiador, F.; Navarro, A.; García-Ortega, E.; Merino, A.; Sánchez, J.L.; Marcos, C.; Kummerow, C. The contribution of rain gauges in the calibration of the IMERG product: Results from the first validation over Spain. *J. Hydrometeorol.* **2020**, *21*, 161–182. https://doi.org/10.1175/JHM-D-19-0116.1.
19. Veloria, A.; Perez, G.; Tapang, G.; Comiso, J. Improved rainfall data in the Philippines through concurrent use of GPM IMERG and ground-based measurements. *Remote Sens.* **2021**, *13*, 2859. https://doi.org/10.3390/rs13152859.
20. Wang, W.; Lu, H.; Zhao, T.; Jiang, L.; Shi, J. Evaluation and comparison of daily rainfall from latest GPM and TRMM products over the Mekong River Basin. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.* **2017**, *10*, 2540–2549. https://doi.org/10.1109/JSTARS.2017.2672786.
21. Xu, S.; Shen, Y.; Niu, Z. Evaluation of the IMERG version 05B precipitation product and comparison with IMERG version 04A over mainland China at hourly and daily scales. *Adv. Space Res.* **2019**, *63*, 2387–2398. https://doi.org/10.1016/j.asr.2019.01.014.
22. Yuan, F.; Zhang, L.; Soe, K.M.; Ren, L.; Zhao, C.; Zhu, Y.; Jiang, S.; Liu, Y. Applications of TRMM- and GPM-era multiple-satellite precipitation products for flood simulations at sub-daily scales in a sparsely gauged watershed in Myanmar. *Remote Sens.* **2019**, *11*, 140. https://doi.org/10.3390/rs11020140.
23. Zhou, Z.; Guo, B.; Xing, W.; Zhou, J.; Xu, F.; Xu, Y. Comprehensive evaluation of latest GPM era IMERG and GSMaP precipitation products over mainland China. *Atmos. Res.* **2020**, *246*, 105132. https://doi.org/10.1016/j.atmosres.2020.105132.
24. Asurza, F.; Ramos, C.; Lavado, W. Assessment of Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Measurement (GPM) products in hydrological modeling of the Huancane river basin, Peru. *Sci. Agropecu.* **2018**, *9*, 53–62. https://doi.org/10.17268/sci.agropecu.2018.01.06.
25. Jarvis, A.; Reuter, H.; Nelson, A.; Guevara, E. Hole-Filled Seamless SRTM Data V4, International Centre for Tropical Agriculture (CIAT). 2008. Available online: http://srtm.csi.cgiar.org (accessed on).
26. Sungmin, O.; Foelsche, U.; Kirchengast, G.; Fuchsberger, J.; Tan, J.; Petersen, W.A. Evaluation of GPM IMERG Early, Late, and Final rainfall estimates using WegenerNet gauge data in southeastern Austria. *Hydrol. Earth Syst. Sci.* **2017**, *21*, 6559–6572. https://doi.org/10.5194/hess-21-6559-2017.
27. Chiew, F.; Siriwardena, L. TREND trend/change detection software—User Guide. *Catchment Model. Toolkit* 2005, 29.
28. van Buuren, S.; Groothuis-Oudshoorn, K. Mice: Multivariate imputation by chained equations in R. *J. Stat. Softw.* **2011**, *45*, 1–67. https://doi.org/10.18637/jss.v045.i03.
29. Tomas-Burguera, M.; Vicente-Serrano, S.M.; Beguería, S.; Reig, F.; Latorre, B. Reference 634 crop evapotranspiration database in Spain (1961–2014). *Earth Syst. Sci. Data* **2019**, *11*, 1917–1930. https://doi.org/10.5194/essd-11-1917-2019.
30. Woldesenbet, T.A.; Elagib, N.A.; Ribbe, L.; Heinrich, J. Gap filling and homogenization of climatological datasets in the headwater region of the Upper Blue Nile Basin, Ethiopia. *Int. J. Climatol.* **2017**, *37*, 2122–2140. https://doi.org/10.1002/joc.4839.
31. Wong, J.S.; Razavi, S.; Bonsal, B.R.; Wheater, H.S.; Asong, Z.E. Inter-comparison of daily precipitation products for large-scale hydro-climatic applications over Canada. *Hydrol. Earth Syst. Sci.* **2017**, *21*, 2163–2185. https://doi.org/10.5194/hess-21-2163-2017.