https://doi.org/10.20965/jdr.2021.p0786

Paper:

A Comparison Between Global Satellite Mapping of Precipitation Data and High-Resolution Radar Data – A Case Study of Localized Torrential Rainfall over Japan

Yoshiaki Hayashi[*,†], **Taichi Tebakari**[**], **and Akihiro Hashimoto**[*]

[*]Department of Civil Engineering, Fukuoka University
8-19-1 Nanakuma, Jonan-ku, Fukuoka 814-0180, Japan
[†]Corresponding author, E-mail: yhayashi@fukuoka-u.ac.jp
[**]Department of Environment and Civil Engineering, Graduate School of Engineering, Toyama Prefectural University, Toyama, Japan
[Received October 23, 2020; accepted March 24, 2021]

This paper presents a case study comparing the latest algorithm version of Global Satellite Mapping of Precipitation (GSMaP) data with C-band and X-band Multi-Parameter (MP) radar as high-resolution rainfall data in terms of localized heavy rainfall events. The study also obliged us to clarify the spatial and temporal resolution of GSMaP data using high-accuracy ground-based radar, and evaluate the performance and reporting frequency of GSMaP satellites. The GSMaP_Gauge_RNL data with less than 70 mm/day of daily rainfall was similar to the data of both radars, but the GSMaP_Gauge_RNL data with over 70 mm/day of daily rainfall was not, and the calibration by rain-gauge data was poor. Furthermore, both direct/indirect observations by the Global Precipitation Measurement/Microwave Imager (GPM/GMI) and the frequency thereof (once or twice) significantly affected the difference between GPM/GMI data and C-band radar data when the daily rainfall was less than 70 mm/day and the hourly rainfall was less than 20 mm/h. Therefore, it is difficult for GSMaP_Gauge to accurately estimate localized heavy rainfall with high-density particle precipitation.

Keywords: observation characteristics, C-band radar, X-band MP radar, GPM/GMI, GSMaP

1. Introduction

Rainfall data are important for flood/runoff analyses, the planning of river courses and conservation of water resources. Rainfall is measured in various ways, including direct observations at rain-gauge stations and via remote sensing and ground-based radar, such as the eXtended RAdar Information Network (XRAIN). Recently, Global Satellite Mapping of Precipitation (GSMaP) has been used to estimate global rainfall using multiple observation satellites. Thus, it is possible to provide hourly rainfall data globally, over both land and sea. Moreover, GSMaP data are very useful rainfall data for developing countries with a lack of hydrological facilities.

Many researchers have been working on improving GSMaP precipitation estimation accuracy. For example, in studies of the development and improvement of the GSMaP precipitation estimation algorithm, Kubota et al. [1] introduced the production and validation of retrieved rainfall data obtained from satellite-borne microwave radiometers by the GSMaP Project, Ushio et al. [2] evaluated and compared with other high-resolution precipitation products and the ground-based data collected by the Automated Meteorological Data Acquisition System (AMeDAS) near Japan, and Kubota et al. [3] studied the verification of the relationship between data observed by observation satellites with various sensors and precipitation. Aonashi et al. [4] suggested that Tropical Rainfall Measuring Mission/Microwave Imager (TRMM/TMI) scattering signals obtained under various conditions should be corrected using the TRMM/TMI precipitation extraction algorithm; accuracy was verified at a 10 mm/h rainfall threshold. Sakolnakhon [5] studied the verification statistics used in evaluating the rainfall estimated by satellites over Thailand during the 2000–2010 period, and Seto et al. [6] showed that algorithm version 7 of the GSMaP product has improved accuracy over version 6 in the case of extreme rainfall estimation. Yamamoto et al. [7] incorporated an orographic/nonorographic rainfall classification scheme into the GSMaP algorithm for passive microwave radiometers and improved rainfall estimation over the entire Asian region. Mega et al. [8] introduced the GSMaP_Gauge algorithm and showed the validation of the algorithm. Moreover, Takido et al. [9] evaluated both the GSMaP products and Radar-AMeDAS rainfall data by spatial and temporal resolution in first-class river basins in Japan. Yamaji et al. [10] reported an Observing System Simulation Experiment (OSSE) on the accuracy of GSMaP caused by increases in spaceborne precipitation radar observation evaluated over the Japan area. Chen et al. [11] suggested the results of the GSMaP products performance using six purely satellite-derived global precipitation estimates over mainland China for the period from February 2017 to January 2019. Satge et al. [12] reported 23 gridded precipitation datasets' reliability across West Africa through direct comparisons with rain-gauge measurement at the daily and monthly time scales over a four-year period (2000–2003).

Studies of the use of GSMaP products in numerous countries and regions have validated its accuracy [13–27]. Bui et al. [28] used GSMaP in the analysis of quantitative rainfall estimates and runoff prediction capability at a basin scale. Seto et al. [29] performed a 50-year value of 48-hour rainfall amount calculated all over Japan and the surrounding ocean using GSMaP data from 2001 to 2009. Tebakari et al. [30] used GSMaP data to clarify the rainfall characteristics of flood disasters in regions featuring low-density hydrological observations. Admojo et al. [31] used GSMaP and other satellite-based rainfall data to evaluate one of the distributed hydrological model, IFAS, in a flood event. Acierto et al. [32] used GSMaP products and GPM data for the development of an early flood warning system. Chen et al. [33] clarified the input source errors of GSMaP precipitation estimates in terms of the crucial geographic and climatic factors. Otsuka et al. [34] introduced the GSMaP RIKEN Nowcast as a new GSMaP product using previous GSMaP products. Tashima et al. [35] showed GSMaP_Gauge_NRT to be effective in demonstrating feasibilities for the monitoring in Asia-Pacific regions of heavy rainfall and drought events.

However, most studies compared and evaluated GSMaP and related satellite data with ground-based observation data in various regions and rainfall events. In addition, most research cases that have been analyzed used version 6 or earlier of the GSMaP algorithm; few have studied the latest version. Moreover, few studies have focused on the difference in spatial or temporal resolution data using localized heavy rainfall event that have caused recent disaster. Finally, no studies have evaluated how GSMaP accuracy is affected by direct satellite observations or the frequency of satellite inputs. Therefore, considering the improvement in the accuracy of GSMaP data and the possibility of using it in extreme weather analyses, research performed based on these analysis conditions is necessary.

Through as a case study, our principal objective was to clarify the observation characteristics of GSMaP products using C-band and X-band Multi-Parameter (MP) radar data, which provide high-resolution ground observational data. In particular, we verified the precipitation estimation characteristics of GSMaP based on the difference in spatial and temporal resolution of rainfall data using recent, localized heavy rainfall events. We directly compared GSMaP products by the latest algorithm version and high-resolution radar data by the passage frequency of the microwave radiometric satellite; these data are key to GSMaP estimates.

2. Materials and Methods

2.1. Rainfall Events

This case study has used three localized torrential rainfall and typhoon events cited in "Meteorological rainfall events that caused disasters from 1989–2020," published by the Japan Meteorological Agency [36]. The first example of localized torrential rainfall was the northern Kyushu heavy rainfall of July 2012, for which we analyzed data from July 14 of that year. The second example was the Kanto–Tohoku heavy rainfall of September 2015, for which we analyzed data from September 9 of that year. The third example was Typhoon No.15 (Corney) of 2015, which crossed the Kyushu region in late August; we analyzed the rainfall data of August 25, 2015.

2.2. Satellite and Radar Data

Our study used GSMaP products as satellite data. GSMaP is global rainfall data observed by multiple observation satellites with various sensors, such as the Global Precipitation Measurement/Microwave Imager (GPM/GMI) and the Global Change Observation Mission Water/Advanced Microwave Scanning Radiometer-2 (GCOM-W/AMSR2).

This study used four types of GSMaP product. The first is GSMaP_MVK, which is the rain-gauge non-adjusted rainfall data estimated by combining the data derived from Passive Microwave and Infrared radiometers. The second product is GSMaP_Gauge. This product is based on the GSMaP_MVK and adjusted with global rain-gauge analysis data supplied by the National Oceanic and Atmospheric Administration (NOAA). The third product is GSMaP_RNL, which is re-analyzed GSMaP_MVK data. The fourth product is GSMaP_Gauge_RNL, which is rain-gauge data (derived from GSMaP_RNL data). The data making in detail of these products already has been shown by a previous study [4].

We used GSMaP_RNL and GSMaP_Gauge_RNL in analyzing the rainfall event of July 14, 2012, and GSMaP_MVK and GSMaP_Gauge in analyzing the rainfall events of August 25 and September 9, 2015. In addition, we wished to analyze by version 7 of the latest GSMAP algorithm, but the data were only available after March 2014. Therefore, the rainfall event of July 14, 2012, used version 6 of the GSMaP algorithm, while the other events used version 7. The minimum latitudinal and longitudinal spatial resolutions of GSMaP were both 0.1°, and the temporal resolution was one hour. In addition, the detailed specification of each version of GSMaP algorithm has already been shown by a previous study [37].

The C-band radar at 26 sites throughout Japan is operated by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT). The precipitation estimation method of this radar is based on the Z–R relationship, and radar-estimated data was calibrated with reference to data from rain-gauge stations. The spatial resolution of the data was 1 km, and the temporal resolution was 5 min.

The X-band MP radar (also operated by the MLIT,

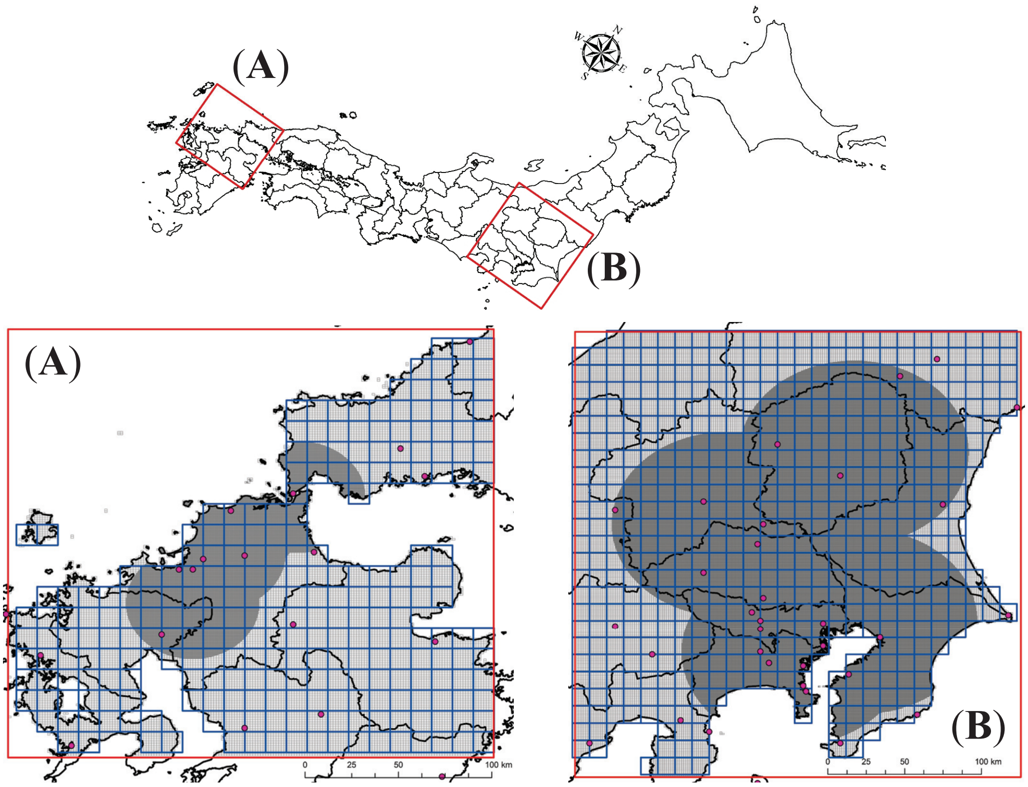


Fig. 1. Location map of the study area with mesh data of both radars and GSMaP, point of rain-gauge stations by NOAA, (A) is northern Kyushu region and (B) is Kanto region. The dark area of these maps is showing a high-accuracy observation area of X-MP respectively.

hereinafter referred to as X-MP) is currently installed at 39 sites throughout Japan; we used the composite data of X-MP. The precipitation estimation was quantitated using the Z–R and KDP–R relationships based on the threshold values of specific differential phases (called the KDP values). The spatial resolution was 250 m, and the temporal resolution was 1 min. The technical characteristics of these radars already have been shown in a previous study [38]. Missing data from areas of radio wave extinction were not corrected using alternative observation data. This study used rainfall data within a 30-km radius of each radar site because previous studies [39, 40] reported that these data were very accurate.

Figure 1 shows the analysis areas of the northern Kyushu and Kanto regions in this study. Localized torrential rainfall was analyzed in both regions; typhoon rainfall was analyzed only in northern Kyushu. All analyses employed only GSMaP data and those of both ground-based radars. In addition, the location of rain-gauge stations by NOAA is added to **Fig. 1**. GSMaP_Gauge_RNL and GSMaP_Gauge were calibrated to GSMaP_RNL and GSMaP_MVK using rainfall data by NOAA.

2.3. Analysis Methods of GSMaP and Radar Data

We compared GSMaP to C-band radar and X-MP data as various spatial and temporal resolutions using two methods. First, we compared GSMaP data to observational radar data; this was done to clarify the observational features of the three datasets, which differed in terms of spatial and temporal resolution. We then re-analyzed the radar data using the method of the previous study [41], which smooths radar rainfall data to the resolution afforded by GSMaP. **Fig. 2** shows the method to simply recalculate the radar data to the same temporal and spatial resolutions as GSMaP. The mesh data of GSMaP and the radars shown in **Fig. 1** and at least 50% of all available radar data were used to create the GSMaP grid.

First, we compared the GSMaP data to both radar datasets to explore the effects of differences in the temporal and spatial resolutions of precipitation on the GSMaP data. GSMaP rainfall data are based on brightness temperature by GPM/GMI and some observation satellites. We focused on the GPM/GMI, which is one of the composed satellites of GSMaP. The GPM/GMI is a multi-frequency, multi-polarized, conical, scanning microwave radiometer that estimates precipitation by evaluating rainfall and thermal radiation from the ground. In addition, GPM/GMI observation provides important data because of this data has affected precipitation estimation of the other GPM Constellation Satellites.

Second, we compared the GSMaP data to radar data directly observed by the GPM/GMI when it was over the study area. This analysis used the rainfall event of September 9, 2015, and additionally analyzed the outcomes when the GPM/GMI passed over the region of analysis both once and twice. The purpose of this analysis

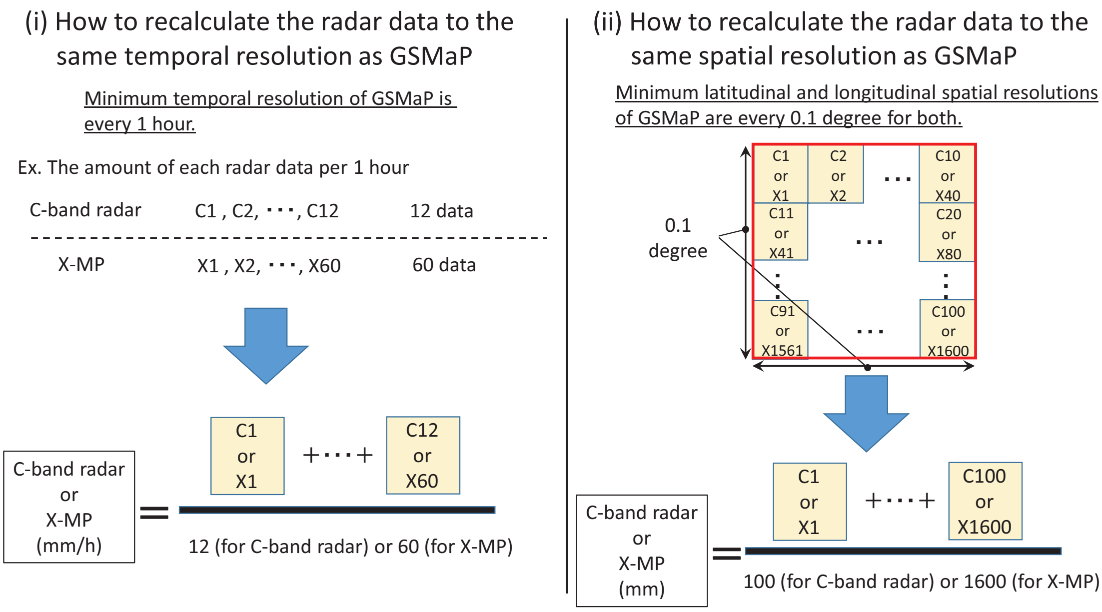


Fig. 2. Schematic diagram how to recalculate the radar data to the same temporal and spatial resolutions as GSMaP, (i) is temporal resolution and (ii) is spatial resolution.

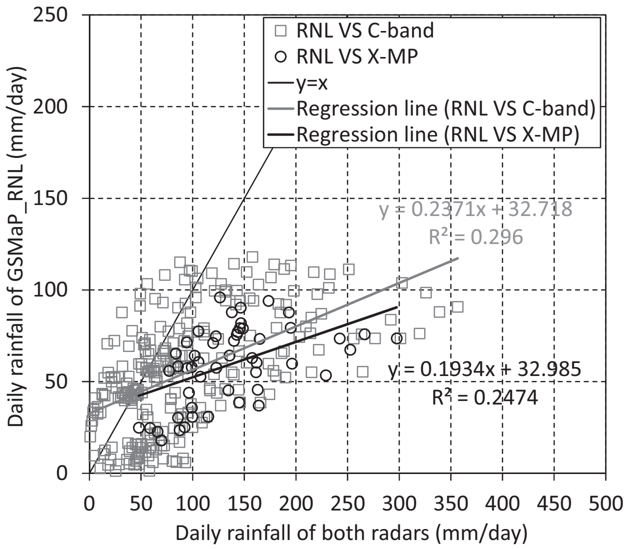


Fig. 3. Scatter plots of daily rainfall of GSMaP_RNL and both radars on July 14, 2012.

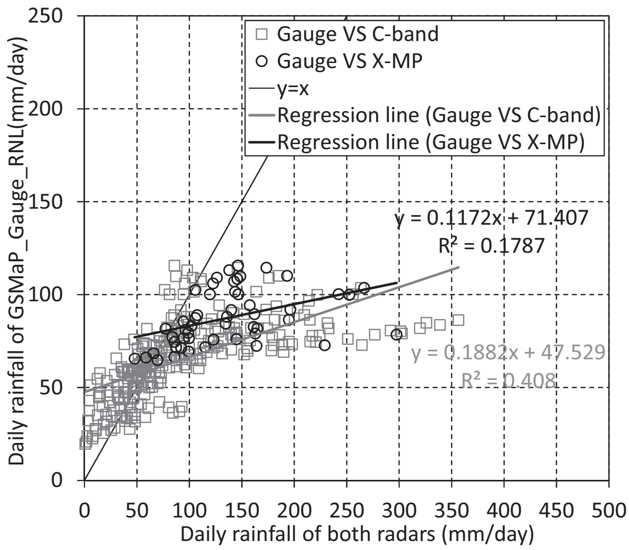


Fig. 4. Scatter plots of daily rainfall of GSMaP_Gauge_RNL and both radars on July 14, 2012.

was to clarify how the estimation accuracy of the GSMaP data was affected by the observation area and frequency of the GPM/GMI passes over the analysis area.

Finally, we compared GSMaP data to the maximum, minimum, and average values of X-MP data included at the GSMaP grid where the daily rainfall of the C-band radar was the largest value on September 9, 2015, in the analysis area.

3. Results and Discussion

Figures 3 and **4** show scatter plots of daily rainfall by the GSMaP_RNL, GSMaP_Gauge_RNL, C-band radar and X-MP on July 14, 2012. As shown in **Fig. 3**, GSMaP_RNL tended to underestimate rainfall compared to both the C-band radar and X-MP. In particular, when the GSMaP_RNL rainfall was over 50 mm/day, the variance with respect to rainfall recorded by the radars was significantly larger than when the rainfall amount was lower.

Figure 4 shows that GSMaP_Gauge_RNL also underestimated rainfall compared to the radars. However, when the GSMaP_Gauge_RNL rainfall was less than 70 mm/day, the variation with respect to the radars was low; the data were distributed adjacent to the y = x line,

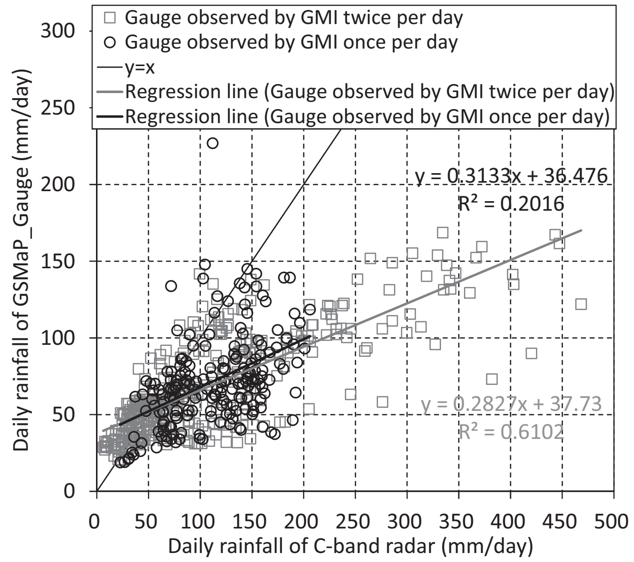


Fig. 5. Scatter plots of daily rainfall of GSMaP_Gauge separated observed by GPM/GMI once or twice per on September 9, 2015.

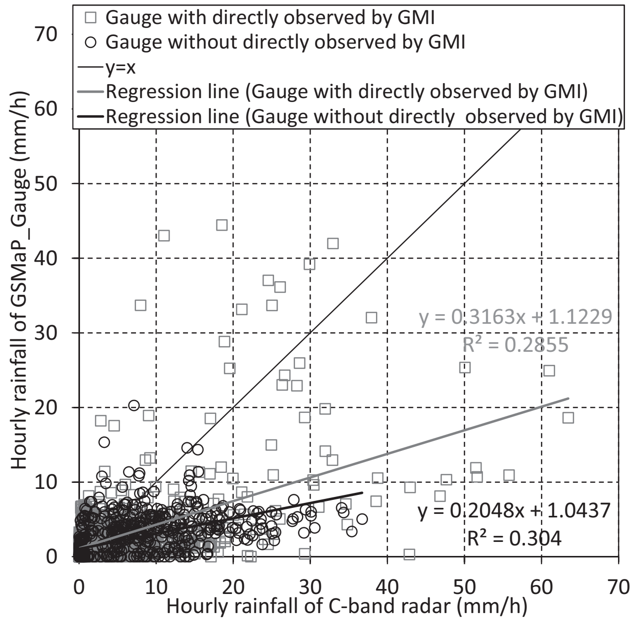


Fig. 6. Scatter plots of hourly rainfall of GSMaP_Gauge separated observed by GPM/GMI or not on September 9, 2015.

reflecting corrections imparted by the rain-gauge data. When rainfall exceeded 70 mm/day, the analyses were similar to the result of **Fig. 3**; this was also the case when other GSMaP_MVK and GSMaP_Gauge rainfalls were studied. One possible reason is that it was affected by the observation distribution of the rain-gauge station by NOAA used for the GSMaP_Gauge data correction, as shown in **Fig. 1**. Therefore, even if there was not a heavier daily rainfall event, such as 50 or 70 mm/day, the GSMaP data might need to use carefully for using runoff and flood analysis.

Figure 5 shows scatter plots of daily rainfall of GSMaP_Gauge and C-band radar by GPM/GMI status (the satellite was over part of the study area at once or twice on September 9, 2015). When the daily rainfall of GSMaP_Gauge was under 70 mm/day, the GPM/GMI data recorded on both satellite passes were very similar to the C-band radar data. However, this was not the case when rainfall was heavier. GSMaP_Gauge underestimates C-band radar data, and a previous study [42] showed a similar result. Therefore, it is difficult to observe accurately against localized heavy rainfall using microwave radiometer, expected that the GMI and GSMaP estimation algorithm will be more improved. Moreover, the GSMaP_Gauge data derived during a single GPM/GMI pass and double were similar result comparing with C-band radar data, because the precipitation distribution was spatially and temporally interpolated using GSMaP data of one-hour ago and the cloud-moving vector by infrared radiometer of the geostationary meteorological satellite, such as "Himawari" when the GPM/GMI could not perform direct observations. GPM/GMI observation frequency is therefore highly significant when rainfall is under 70 mm/day but is less affected when rainfall is heavier with cumulonimbus clouds.

Figure 6 shows scatter plots of hourly rainfall by both the GSMaP_Gauge and C-band radar (as in **Fig. 5**), divided into data obtained directly by GPM/GMI and data estimated by other satellites (such as other microwave radiometers and infrared radiometer data by the above-mentioned geostationary satellites) when the GPM/GMI was not above the area of observation. The GSMaP_Gauge underestimated C-band radar rainfall of over 20 mm/h (medium-intensity rainfall) whether the observations were direct or not. Therefore, observational characteristics of the GSMaP_Gauge in this event did not vary markedly by direct/indirect observational status. It can be seen that the GPM/GMI precipitation estimation algorithm might require improvement because the GPM/GMI observational parameters were not very accurate. Moreover, hourly rainfall of GSMaP_Gauge data (regardless of direct or indirect observation by GPM/GMI) in this event does not enough to quality as ground-based observation data, the application of the data for precipitation and runoff analysis must be careful.

Figure 7 shows the time series of GSMaP_MVK and GSMaP_Gauge data, the maximum, minimum, and average values of X-MP data, on September 9, 2015, and the periods of direct (overhead) GPM/GMI observation. The maximum, minimum, and averages of GSMaP_MVK and GSMaP_Gauge data derived by direct observation were similar to those of the X-MP. However, during heavy rainfall, both GSMaP_MVK and GSMaP_Gauge underestimated the radar data; this was the case when GPM/GMI observations were either direct or indirect, as reported above for other rainfall events. Therefore, GSMaP observational features are similar to those of the X-MP when precipitation is low, but GSMaP underestimated the radar data when precipitation was heavy. GSMaP data must

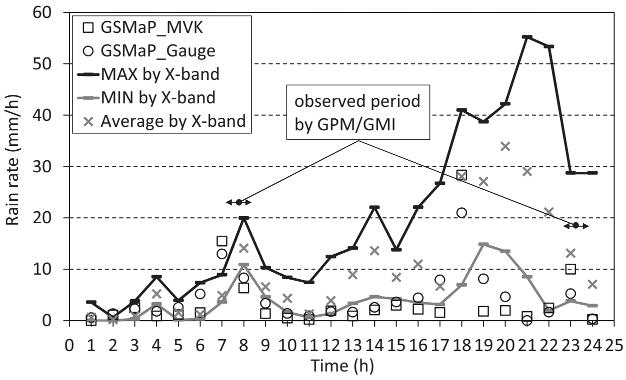


Fig. 7. Time series of two types of GSMaP products and the maximum, minimum, and average values afforded by the X-MP on September 9, 2015, indicated the period observed by GPM/GMI was overhead the study area.

therefore be used with caution during the high-intensity rainfall period.

4. Conclusions

This case study clarified the observation characteristics of GSMaP products using C-band radar and X-MP data, such as high-resolution radar data with heavy rainfall events. The results of the analyses are summarized as follows.

(1) The observation characteristic of GSMaP_Gauge_RNL, which calibrated GSMaP_RNL with the rain-gauge data was similar to that of the C-band radar under 70 mm/day of daily rainfall, as events with a relatively small amount of rainfall. However, GSMaP_Gauge_RNL has not been similar to the radar so much when daily rainfall of over 70 mm/day, the calibration effect of the rain-gauge data was not drastically. This was the same result as in the analysis of the typhoon event using GSMaP_MVK and GSMaP_Gauge.

(2) When rainfall events at either under 70 mm/day of daily rainfall or 20 mm/h of hourly rainfall, the precipitation estimation of the GSMaP_MVK and GSMaP_Gauge might not affect whether the GPM/GMI directly observing and its frequency above the analysis area.

Therefore, in the analysis conditions of this paper, we proposed that the current GSMaP observation system and precipitation estimation method cannot accurately observe rainfall events with localized high-intensity rainfall, however can generally observe events with low rainfall with good accuracy.

Finally, we consider the analyses performed in this study to be insufficient, and more analyses of different types are needed, and were able to suggested in this paper where more detailed analysis is needed as future work.

Acknowledgements

We used C-band and X-MP data provided by the Technical Development Consortium on the X-MP of the Ministry of Land, Infrastructure, Transport and Tourism of Japan. GSMaP data were provided by the Earth Observation Research Center via the Japan Aerospace Exploration Agency (JAXA/EORC). The authors thank their colleagues who work in these institutions.

References:

[1] T. Kubota, S. Shige, H. Hashizume, K. Aonashi, N. Takahashi, S. Seto, M. Hirose, Y. N. Takayabu, T. Ushio, K. Nakagawa, K. Iwanami, M. Kachi, and K. Okamoto, "Global precipitation map using satellite-borne microwave radiometers by the GSMaP project: production and validation," IEEE Trans. on Geoscience and Remote Sensing, Vol.45, No.7, pp. 2259-2275, 2007.

[2] T. Ushio, K. Sasashige, T. Kubota, S. Shige, K. Okamoto, K. Aonashi, T. Inoue, N. Takahashi, T. Iguchi, M. Kachi, R. Oki, T. Morimoto, and Z. Kawasaki, "A Kalman filter approach to the Global Satellite Mapping of Precipitation (GSMaP) from combined passive microwave and infrared radiometric data," J. of the Meteorological Society of Japan. Ser. II, Vol.87A, pp. 137-151, 2009.

[3] T. Kubota, T. Ushio, S. Shige, S. Kida, M. Kachi, and K. Okamoto, "Verification of high-resolution satellite-based rainfall estimates around Japan using a gauge-calibrated ground-radar dataset," J. of the Meteorological Society of Japan. Ser. II, Vol.87A, pp. 203-222, 2009.

[4] K. Aonashi, J. Awaka, M. Hirose, T. Kozu, T. Kubota, G. Liu, S. Shige, S. Kida, S. Seto, N. Takahashi, and Y. N. Takayabu, "GSMaP passive microwave precipitation retrieval algorithm: algorithm description and validation," J. of the Meteorological Society of Japan. Ser. II, Vol.87A, pp. 119-136, 2009.

[5] K. P. N. Sakolnakhon, "Comparison the estimation rainfall from Global Satellite Mapping of Precipitation (GSMaP) to ground-based precipitation data over Thailand," 1st Joint Project Team Meeting for Sentinel Asia STEP3 (JPTM2013), 2013.

[6] S. Seto, T. Iguchi, N. Utsumi, M. Kiguchi, and T. Oki, "Evaluation of extreme rain estimates in the TRMM/PR standard product version 7 using high-temporal-resolution rain gauge datasets over Japan," Scientific Online Letters on the Atmosphere, Vol.9, pp. 98-101, 2013.

[7] M. K. Yamamoto and S. Shige, "Implementation of an orographic/nonorographic rainfall classification scheme in the GSMaP algorithm for microwave radiometers," Atmospheric Research, Vol.163, pp. 36-47, 2013.

[8] T. Mega, T. Ushio, T. Kubota, M. Kachi, K. Aonashi, and S. Shige, "Gauge adjusted global satellite mapping of precipitation (GSMaP_Gauge)," 2014 31th URSI General Assembly and Scientific Symp. (USRI GASS), pp.1-4, 2014.

[9] K. Takido, O. C. Saavedra, M. Ryo, K. Tanuma, T. Ushio, and T. Kubota, "Spatiotemporal evaluation of the gauge-adjusted Global Satellite Mapping of Precipitation at the basin scale," J. of the Meteorological Society of Japan. Ser. II, Vol.94, No.2, pp. 185-195, 2016.

[10] M. Yamaji, T. Kubota, and R. Oki, "Observing system simulation experiment on the accuracy of Global Mapping of Precipitation (GSMaP) by future small precipitation radar constellation," 2019 IEEE Int. Geoscience and Remote Sensing Symp. (IGARSS2019), pp. 7594-7597, 2019.

[11] H. Chen, B. Yong, Y. Shen, J. Liu, Y. Hong, and J. Zhang, "Comparison analysis of six purely satellite-derived global precipitation estimates," J. of Hydrology, Vol.581, 124356, 2020.

[12] F. Satgé, D. Defrance, B. Sultan, M.-P. Bonnet, F. Seyler, N. Rouché, F. Pierron, and J.-E. Paturel, "Evaluation of 23 gridded precipitation datasets across West Africa," J. of Hydrology, Vol.581, 124412, 2020.

[13] Y. Tian, C. D. Peters-Lidard, R. F. Adler, T. Kubota, and T. Ushio, "Evaluation of GSMaP precipitation estimates over the Contiguous United States," J. of Hydrometeorology, Vol.11, No.2, pp. 556-574, 2010.

[14] M. Shrestha, K. Takara, T. Kubota, and S. Bajracharya, "Verification of GSMaP rainfall estimates over the Central Himalayas," Annual J. of Hydraulic Engineering, Vol.67, No.4, pp. I_37-I_42, 2011 (in Japanese with English abstract).

[15] G. Ozawa, H. Inomata, Y. Shiraishi, and K. Fukami, "Applicability of GSMaP correction method to typhoon "Morakot" in Taiwan," Annual J. of Hydraulic Engineering, Vol.67, No.4, pp. I_445-I_450, 2011 (in Japanese with English abstract).

[16] S. Seto, T. Tsunekawa, and T. Oki, "A new rain detection method to complement high-resolution globe precipitation products," Hydrological Research Letters, Vol.6, pp. 82-86, 2012.

[17] T. Ngo-Duc, J. Matsumoto, H. Kamimera, and H.-H. Bui, "Monthly adjustment of Global Satellite Mapping of Precipitation (GSMaP) data over the VuGia-ThuBon River basin in Central Vietnam using an artificial neural network," Hydrological Research Letters, Vol.7, No.4, pp. 85-90, 2013.

[18] W. Veerakachen, M. Raksapatcharawong, and S. Seto, "Performance evaluation of Global Satellite of Precipitation products over the Chaophraya River basin, Thailand," Hydrological Research Letters, Vol.8, No.1, pp. 39-44, 2014.

[19] K. Tsujimoto, T. Koike, S. I. Monichoto, K. Aida, K. Tamagawa, T. Nukui, and S. Sobue, "Validation of satellite precipitation products over Cambodia," Trans. of the Japan Society for Aeronautical and Space Sciences, Aerospace Technology Japan, Vol.12, No.ists29, pp. Tn.41-Tn.46, 2014.

[20] Marzuki, R. Oktaviani, L. Meylani, H. Hashiguchi, M. Vonnisa, and Harmadi, "One-Minute rain gauge distribution in Indonesia derived from TRMM, GPM and GSMaP data," 2018 Progress in Electromagnetics Research Symposium (PIERS-Toyama), Vol.2018, pp. 2134-2138, 2018.

[21] P. Deng, M. Zhang, H. Guo, C. Xu, J. Bing, and J. Jia, "Error analysis and correction of the daily GSMaP products over Hanjiang and River basin of China," Atmospheric Research, Vol.214, pp. 121-134, 2018.

[22] S. Prakash, A. K. Mitra, A. AghaKouchak, Z. Liu, H. Norouzi, and D. S. Pai, "A preliminary assessment of GPM-based multi-satellite precipitation estimates over a monsoon dominated region," J. of Hydrology, Vol.556, pp. 865-876, 2018.

[23] M. Saber and K. K. Yilmaz, "Evaluation and bias correction of satellite-based rainfall estimates for modelling flash floods over the Mediterranean region: Application to Karpuz River basin, Turkey," Water, Vol.10, No.5, p. 657, 2018.

[24] D. Lu, B. Yong, "Evaluation and hydrological utility of the latest GPM IMERG V5 and GSMaP V7 precipitation products over the Tibetan Plateau," Remote Sensing, Vol.10, No.12, p. 2022, 2018.

[25] I. Rashid, A. A. Parray, and S. A. Romshoo, "Evaluating the performance of remotely sensed precipitation estimates against In-Situ observations during the September 2014 mega-flood in the Kashmir Valley," Asia-Pacific J. of Atmospheric Science, Vol.55, pp. 209-219, 2019.

[26] M. Nashwan, S. Shahid, X. Wang, "Assessment of satellite-based precipitation measurement products over the hot desert climate of Egypt," Remote Sensing, Vol.11, No.5, p. 555, 2019.

[27] P. Deng, M. Zhang, J. Bing, J. Jia, and D. Zhang, "Evaluation of the GSMaP_Gauge products using rain gauge observations and SWAT model in the upper Hanjiang River basin," Atmospheric Research, Vol.219, pp. 153-165, 2019.

[28] T. H. Bui and H. Ishidaira, "Evaluation of satellite-gauge merging precipitation methods for rainfall runoff simulation," Annual J. of Hydraulic Engineering, Vol.71, No.4, pp. I_79-I_84, 2017 (in Japanese with English abstract).

[29] S. Seto and R. Taguchi, "Judgement of heavy rainfall corresponding to emergency warning by Global Satellite Mapping of Precipitation," Annual J. of Hydraulic Engineering, Vol.72, No.4, pp. I_223-I_228, 2016 (in Japanese with English abstract).

[30] T. Tebakari, S. Wongsa, and Y. Hayashi, "Flood in southern Thailand in December 2016 and January 2017," J. Disaster Res., Vol.13, pp. 793-803, 2018.

[31] D. D. Admojo, T. Tebakari, and M. Miyamoto, "Evaluation of a satellite-based rainfall product for a flood event: a case study," Annual J. of Hydraulic Engineering, Vol.74, No.4, pp. I_73-I_78, 2018 (in Japanese with English abstract).

[32] R. A. Acierto, A. Kawasaki, W. W. Zin, A. T. Oo, K. Ra, and D. Komori, "Development of a hydrological telemetry system in Bago River," J. Disaster Res., Vol.13, No.1, pp. 116-124, 2018.

[33] H. Chen, B. Yong, J. J. Gourley, J. Liu, L. Ren, W. Wang, Y. Hong, and J. Zhang, "Impact of the crucial geographic and climatic factors on the input source errors of GPM-based global satellite precipitation estimates," J. of Hydrology, Vol.575, pp. 1-16, 2019.

[34] S. Otsuka, S. Kotsuki, M. Ohhigashi, and T. Miyoshi, "GSMaP RIKEN Nowcast: Global precipitation nowcasting with data assimilation," J. of the Meteorological Society of Japan, Vol.97, pp. 1099-1117, 2019.

[35] T. Tashima, T. Kubota, and R. Oki, "Precipitation extremes monitoring using Global Satellite Mapping of Precipitation (GSMaP) products," IEEE Conference Proceedings, Vol.2019, pp. 4463-4466, https://doi.org/10.1109/IGARSS.2019.8898435, 2019.

[36] Japan Meteorological Agency, "Meteorological rainfall events that caused disasters from 1989–2020," http://www.data.jma.go.jp/obd/stats/data/bosai/report/index_1989.html (in Japanese) [accessed August 21, 2020]

[37] T. Kubota, K. Aonashi, T. Ushio, S. Shige, Y. N. Takayabu, M. Kachi, Y. Arai, T. Tashima, T. Masaki, N. Kawamoto, T. Mega, M. K. Yamamoto, A. Hamada, M. Yamaji, G. Liu, and R. Oki, "Global Satellite Mapping of Precipitation (GSMaP) products in the GPM era," Satellite precipitation measurement, Vol.67, pp. 355-373, 2020.

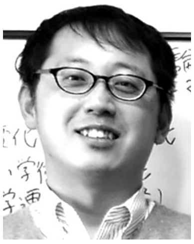
[38] D.S. Kim and M. Maki, "Validation of composite polarimetric parameters and rainfall rates from an X-band dual-polarization radar network in the Tokyo metropolitan area," Hydrological Research Letters, Vol.6, pp. 76-81, 2012.

[39] Y. Hayashi, T. Tebakari, and K. Yamasaki, "Accuracy of quantitative precipitation estimation by X-band Multi-Parameter Radar using rain-gauge data over Hokuriku region," J. of Hydrology and Water Resources, Vol.27, No.2, pp. 67-76, 2014 (in Japanese with English abstract).

[40] S. Tsuchiya, M. Kawasaki, and H. Godo, "Improvement of the radar rainfall accuracy of XRAIN by modifying of rainfall attenuation correction and compositing radar rainfall," Annual J. of Hydraulic Engineering, Vol.71, No.4, pp. I_457-I_462, 2015 (in Japanese with English abstract).

[41] E. Nakakita, K. Morimoto, and Y. Touge, "Estimation of future changes in the occurrence frequency of the guerrilla-heavy rainfall events using a 5-km-mesh reginal climate model," Annual J. of Hydraulic Engineering, Vol.73, No.4, pp. I_133-I_138, 2017 (in Japanese with English abstract).

[42] Y. Shiraishi, K. Fukami, and H. Inomata, "A proposal of correction method using the movement of rainfall area on satellite-based rainfall information by analysis in the Yoshino River basin," Annual J. of Hydraulic Engineering, Vol.53, pp. 385-390, 2009 (in Japanese with English abstract).



Name:
Yoshiaki Hayashi

Affiliation:
Research Associate, Department of Civil Engineering, Fukuoka University

Address:
8-19-1 Nanakuma, Jonan-ku, Fukuoka 814-0180, Japan

Brief Career:
2005-2016 Technician, Department of Civil Engineering, Fukuoka University
2017- Research Associate, Department of Civil Engineering, Fukuoka University

Selected Publications:
- "Study on Characteristics of Areal Rainfall Using Rain-Gauge Data and Radar Data in the Tedori River Basin by Several Analyses," Annual J. of Hydraulic Engineering, Vol.73, No.4, pp. I_235-I_240, 2017.
- "Observation System and Temporal–Spatial Characteristics of the Japan Rain-Gauge Network," J. of Japan Society of Hydrology and Water Resources, Vol.30, No.1, pp. 43-53, 2017.
- "Study on Areal Rainfall Using Rain-Gauge Data and High-Resolution Radar Data in Medium and Small River Basins," Annual J. of Hydraulic Engineering, Vol.72, No.4, pp. I_1231-I_1236, 2016.
- "Study on Characteristics of Observed Polarization Parameter by X-band Multi-Parameter Radar over Hokuriku Region," Annual J. of Hydraulic Engineering, Vol.71, No.4, pp. I_475-I_480, 2015.

Academic Societies & Scientific Organizations:
- Japan Society of Civil Engineers (JSCE)
- Japan Society of Hydrology and Water Resources (JSHWR)
- Japan Society for Natural Disaster Science (JSNDS)

Name:
Taichi Tebakari

Affiliation:
Professor, Department of Civil and Environmental Engineering, Chuo University

Address:
1-13-27 Kasuga, Bunkyo-ku,Tokyo 112-8551, Japan

Brief Career:
2002- Researcher, Public Works Research Institute
2006- Assistant Professor, Department of Civil Engineering, Fukuoka University
2009- Associate Professor, Department of Environment and Civil Engineering, Graduate School of Engineering, Toyama Prefectural University
2021- Professor, Department of Civil and Environmental Engineering, Chuo University

Selected Publications:
- S. P. Gopalan, N. Hanasaki, A. Champathong, and T. Tebakari, "Impact assessment of reservoir operation in the context of climate change adaptation in the Chao Phraya River basin," Hydrological Processes, Vol.35, No.1, e14005, 2020.
- T. Tebakari, "Use of high-resolution elevation data to assess the vulnerability of the Bangkok metropolitan area to sea level rise," Hydrological Research Letters, Vol.14, No.4, pp. 136-142, 2020.
- S. Zenkoji, S. Oda, T. Tebakari, and B. Archevarahuprok, "Spatial characteristics of flooded areas in the Mun and Chi River baisins in Northeastern Thailand," J. Disaster Res., Vol.14, No.9, pp. 1337-1345, 2019.
- T. Tebakari, S. Wongsa, and Y. Hayashi, "Floods in Southern Thailand in December 2016 and January 2017," J. Disaster Res., Vol.13, No.4, pp. 793-803, 2018.

Academic Societies & Scientific Organizations:
- American Society of Civil Engineers (ASCE)
- Japan Geoscience Union (JpGU)
- Japan Society of Civil Engineers (JSCE)
- Japan Society of Hydrology and Water Resources (JSHWR)

Name:
Akihiro Hashimoto

Affiliation:
Associate Professor, Department of Civil Engineering, Fukuoka University

Address:
8-19-1 Nanakuma, Jonan-ku, Fukuoka 814-0180, Japan

Brief Career:
2003- Assistant Professor, Tokyo Denki University
2006- Research Assistant Professor, Kyushu University
2016- Associate Professor, Department of Civil Engineering, Fukuoka University

Selected Publications:
- "Clarification and Application of Inundation Processes in Basins with Insufficient Observation Devices Installed," J. Disaster Res., Vol.10, No.3, pp. 495-502, 2015.

Academic Societies & Scientific Organizations:
- Japan Society of Civil Engineers (JSCE)
- Oceanographic Society of Japan (JOS)
- International Association for Hydro-Environment Engineering and Research (IAHR)