VERIFICATION OF HOURLY GSMAP RAINFALL ESTIMATES DURING THE FLOOD EVENTS IN KUMAMOTO PREFECTURE, JAPAN

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ABSTRACT

Japan and other countries have been greatly damaged by floods in the past due to heavy rainfall. Flood forecasting using rainfall data observed by satellite is a welcome development. GSMaP (Global Satellite Mapping Precipitation) data can present the amounts of rainfall with high temporal resolution. For that reason, it is important to measure the accuracy of hourly GSMaP data. Kumamoto Prefecture was chosen as the research location in this study. The aim of this research was to verify hourly GSMaP data in two type file (i.e., GSMaP_MVK and GSMaP_NRT) with rain gauge data and to define the rainfall pattern which causes flood. Verification of hourly rainfall data showed that GSMaP_MVK was reasonably good at detecting precipitation events and GSMaP_NRT was inadequate to represent the rainfall data. Two rainfall patterns were observed over Kumamoto Prefecture before the occurrence of the flood.

Keyword: GSMaP, verification, flood, Kumamoto

INTRODUCTION

Rainfall amount and its spatial distribution are important for flood prediction and water resources assessment (Shrestha et al., 2011). Japan and other countries have been greatly damaged by floods in the past due to heavy rainfall. A flood forecasting system using rainfall data observed by satellite is a welcome development. Recently, several kinds of global precipitation satellite data have become available. Some of them have resolutions of one hour and one degree, which may be defined as high temporal and spatial resolution. The GSMaP (Global Satellite Mapping Precipitation) data, as the highest temporal and spatial resolution satellite data, can detect a precipitation event with the same trend as rain gauge data, but the precipitation amount generally has been underestimated (Fukami, 2010; Kubota et al., 2009; Makino, 2012; Seto et al., 2009; Shrestha et al., 2011). Other writers have shown that GSMaP data products have been verified well in monthly and daily data. Shrestha et al. (2011) found that GSMAP_MVK+ performed better in flatter terrain than in the high mountain area over the Central Himalayas. Kubota et al. (2009) showed that rainfall estimates of GSMaP were the best over the ocean and were the worst over mountainous regions. GSMaP_MVK was least accurate in Africa (Thiemig et al., 2012). Aryastana (2012) found based on the GSMaP data analysis that Indonesia has three rainfall patterns before a flood occurs. Seto et al. (2009) noted that monthly GSMaP data had been verified well in Japan, so GSMaP data seemed to be good enough for flood detection.

GSMaP_MVK was verified from January through December 2004 in Japan to determine whether monthly data, daily data and 3 hourly data matched rain gauge data. The result showed that GSMaP_MVK of monthly, daily and 3 hourly data from May to October had high correlation and had the same trend as rain gauge data (Kubota et al., 2009). Although monthly, daily and 3 hourly data have been verified, hourly GSMaP data have not yet been verified especially in Kyushu, Japan. Hourly rainfall data is important to understand the rainfall pattern, especially when extreme rainfall occurs. The aims of this research were to verify hourly GSMaP data with rain gauge data and to define the rainfall pattern which causes flood.

METHOD

Study area

Kumamoto Prefecture is located in the west central Kyushu Island, Japan. The study area has an area of 389.53 km^2 from latitude 32°5’45”N to 33°6’17”N and longitude 129°59’8.75” E to

131°19’7.7”E. Kumamoto has a humid subtropical climate and has an elevation ranging from 2 m to 1193 m above the sea level. Precipitation occurs throughout the year with the heaviest in the summer season, especially in the months of June and July. In the summer season from 1981 to 2010, the variability of temperature range was from 12.23°C to 37.5°C and the average of precipitation was 326.4 mm/month.

Data sets

High spatial and temporal resolution satellite precipitation product was used, namely GSMaP data. Rain gauge data were used as reference points.

GSMaP data

GSMaP was initiated by the Japan Science and Technology Agency (JST) in 2002 and has been promoted by the Japan Aerospace Exploration Agency (JAXA) Precipitation Measuring Mission (PMM) science team since 2007 to produce a global precipitation product with high temporal and spatial resolution (Ushio et al., 2009). The GSMaP product is the combination from low orbit multi satellite microwave radiometer data, such as TRMM TMI, AQUA AMSRE, ADEOS II AMSRE and DMSP SSM/I and GEO infra red radiometer data (Okamoto et al., 2007). Brightness temperature at microwave frequencies as the input of GSMaP system was converted into precipitation data. The algorithm to regain surface precipitation rate based on the Aonashi et al, 1996 was conducted. The combination technique to produce 0.1 degree/1 hour resolution with the domain covering 60°N to 60°S was obtained using a morphing technique using an infra red cloud moving vector and Kalman Filter technique (Ushio et al, 2009). This product was called GSMaP_MVK.

GSMaP_NRT (near real time) is one of GSMaP products which uses the same algorithm as GSMaP_MVK, and after four hours of observation, data can be obtained (EORC & JAXA, 2013). GSMaP_MVK data are available from March 2000 until December 2010 while GSMaP_NRT are available from October 2008 until now. Hourly data of GSMaP_MVK and GSMaP_NRT for two weeks before the flood occurrence in the past 10 years in Kumamoto Prefecture were downloaded. Both GSMaP_MVK and GSMaP_NRT were processed by using OpenGRADS software. One pixel average of precipitation data was calculated based on the rain gauge data position.

Rain gauge data

Hourly observed rainfall data in Kumamoto Prefecture was obtained from AMEDAS (Automated Meteorological Data Acquisition System) data which was developed by the Japan Meteorological Agency (JMA). There are 36 rain gauge stations available in Kumamoto Prefecture, but only 29 rain gauge stations provided rainfall data until 2012. These data are available online on the JMA website (http://www.data.jma.go.jp) and the distribution of the rainfall stations is shown in Figure 1. Rain gauge data which represent the rainfall at the point were used as reference in our comparison.

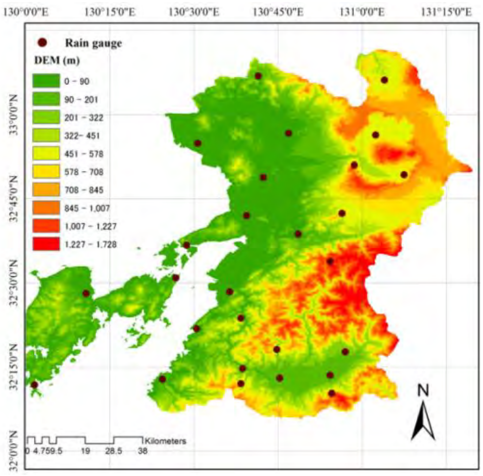

Figure 1. Distribution of 29 rain gauges in Kumamoto Prefecture

Table 1 summarizes the major specifications of rainfall data for GSMaP product and rain gauge data. We analyzed both data products which have the same temporal resolution that is 1 hour. The

GSMaP product domain is 60°N-60°S, but in this research only Kumamoto Prefecture was analyzed. AMEDAS data is available from November 1974 until now and the separation distance of each rain gauge is approximately 21 km.

Table 1. Detail product

Product	Temporal resolution	Spatial resolution	Start date	delay
GSMaP	1 hour	0.1 degree	March 2000	4 hour
Rain gauge	1 hour	Single point	November 1974	

Verification Method

Visual verification

There are several verification methods which can be used; one of them is visual verification. In this method, formatting the single point of rain gauge data sets into the spatial distributions with the same projection and the same color scale with GSMaP datasets was conducted. ArcGIS 10.1 was used as a tool to convert the single point data set into a raster data set, by using the kriging spatial interpolation method. The spherical model of kriging interpolation was chosen because of the very high correlation coefficient with the observed rain gauge data. This method was used to convert the daily point gauge observed rainfall data to a 0.1 degree latitude/longitude grid. Gridded precipitation data from the ground station was used for visual comparison with GSMaP precipitation data.

Continuous statistics

The aim of this method was to measure the correspondence between value of the estimates and the observation. To quantify the correspondence value, the following five statistical indices were used (Jiang et al., 2010). The correlation coefficient (r) was used to measure the fitness between GSMaP precipitation data and rain gauge observations. The Root Mean Square Error (RMSE) measured the average error magnitude. The mean error (E) measured average difference between GSMaP precipitation data and observed values. The relative bias (B) described the systematic bias of the satellite precipitation. The Nash-Sutcliffe (C_{NS}) measured the consistency of the satellite precipitation and gauge observation both amount and temporal distribution. These indices are given by following equations.

$$r = \frac{\sum_{i=1}^{n}(G_i-\bar{G})(S_i-\bar{S})}{\sqrt{\sum_{i=1}^{n}(G_i-\bar{G})^2}\sqrt{\sum_{i=1}^{n}(S_i-\bar{S})^2}} \quad (1)$$

$$B = \frac{\sum_{i=1}^{n}(S_i-G_i)}{\sum_{i=1}^{n}G_i} \text{x} 100\% \quad (4)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i-G_i)^2} \quad (2)$$

$$C_{NS} = 1 - \frac{\sum_{i=1}^{n}(S_i-G_i)^2}{\sum_{i=1}^{n}(G_i-\bar{G})^2} \quad (5)$$

$$E = \frac{1}{n}\sum_{i=1}^{n}(S_i-G_i) \quad (3)$$

Where n is the total number of the rain gauge data or GSMaP data; S_i is the satellite estimates and G_i is the rain gauge observation values.

Categorical statistics

Categorical statistics are used to measure the correspondence between the estimated and observed occurrence of events. Two categorical statistics were used, namely, the probability of detection (POD) and the false alarm ratio (FAR). POD measured how often the rain occurrence was correctly detected by satellite. FAR represented the fraction of diagnosed events that turned out to be wrong.

Table 2 summarizes the contingency to assess GSMaP rainfall detection capability with rain or no rain events. The threshold of rain/no rain used in the contingency table is 0 mm/hour.

Table 2. Contingency table of yes or no events/ with rain or no rain.

		Estimated rainfall	
		Yes	No
Observed rainfall	Yes	hits	misses
	No	false alarm	correct negative

In table 1, "hits" represents correctly estimated rain events, "misses" describes when rain is not estimated but actual rain occurs, "false alarm" represents when rain is estimated but actual rain doesn't occur, and "correct negative" represents correctly estimated no-rain events. Using the results shown in table 2, the parameters POD and FAR are calculated by following equations.

$$\mathrm{POD} = \frac{\mathrm{hits}}{\mathrm{hits+misses}} \quad (1) \qquad \mathrm{FAR} = \frac{\mathrm{false\ alarm}}{\mathrm{hits+false\ alarm}} \quad (2)$$

Time series graph

A time series graph was conducted to estimate the rainfall pattern before the flood occurrence and to estimate the time lag between GSMaP precipitation data and observed rainfall data. The classification of rainfall pattern was modified based on Aryastana, 2012.

RESULT AND DICUSSION

Visual verification

Figure 2 shows visual verification of GSMaP_MVK data after 9 hours time lag matching. It shows that the spatial distribution was almost same where the middle of that area had the highest rainfall. However, the GSMaP_MVK data still underestimated the actual rainfall. The highest concentration of GSMaP_MVK data in the Figure 2 was 20 mm/h and almost all at a high altitude.

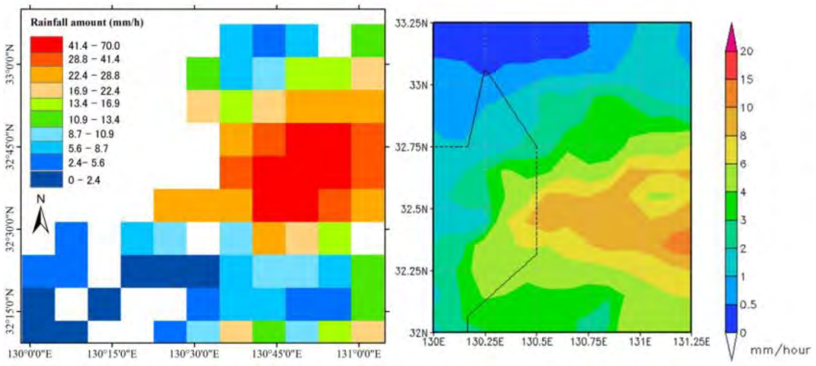

Figure 2. Spatial distribution of observed rainfall 6 July 2007 at 10.00 (left) and rainfall estimates by GSMaP_MVK 6 July 2007 at 01.00 (right).

Figure 3 shows visual verification of GSMaP_NRT data after 9 hours time lag matching. It shows that the spatial distribution was different and that the GSMaP_NRT data also underestimated actual rainfall. The highest concentration of GSMaP_NRT data in figure 3 was between 10 to 15 mm/h and almost all located at a high altitude.

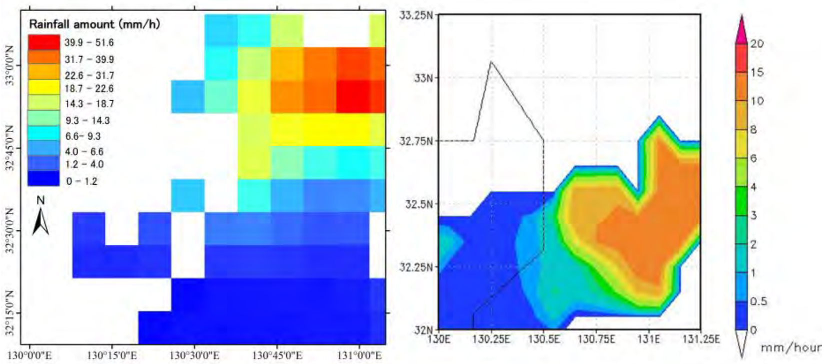

Figure 3. Spatial distribution of observed rainfall 12 July 2012 at 03.00 (left) and rainfall estimates by GSMaP_NRT 11 July 2012 at 19.00 (right).

Statistical verification

GSMaP_MVK

Figure 4 shows the validation result of GSMaP _MVK in Kumamoto Prefecture. The value of the five continuous statistics showed that GSMaP_MVK was reasonably good at detecting precipitation events before the flood occurrence.

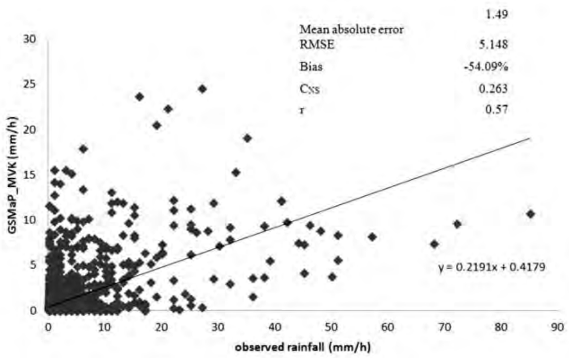

Figure 4.Scatter plot of rain gauge observation and GSMaP_MVK hourly scales in Kumamoto Prefecture.

For the area averaged hourly rainfall, the correlation coefficient was 0.57, RMSE was 5.148 mm with the bias percentage of -54.09% indicating an underestimation of rainfall. The underestimation of rainfall is consistent with the previous finding (Fukami et al., Kubota et al., 2009; Seto et al., 2008; 2010; Shrestha et al., 2011). Underestimation of GSMaP data resulted from no microwave radiometer information during the peak period for heavy rainfall (Kubota et al., 2009). In Kumamoto Prefecture, hourly GSMaP_MVK data has a lower correlation coefficient compared with the previous study which validated daily GSMaP_MVK data (Makino, 2012).

Table 3 shows the result of categorical statistics for which 2312 total points were observed. Hits frequency was 446 times, misses frequency was 135 times, false alarm frequency was 277 times and correct negative frequency was 1454 times.

Table 3. Contingency table of yes or no events/ with rain or no rain of GSMaP_MVK

		GSMaP_MVK	
		Rain	No Rain
AMEDAS	Rain	446	135
	No Rain	277	1454

POD: 0.768 ; FAR : 0.383

Based on table 3, POD and FAR value were 0.77 and 0.38. It means that 77% of rain occurrences were correctly detected and 38% of rain occurrences turned out to be wrong by GSMaP_MVK. These values of two categorical statistics showed that GSMaP_MVK product was reasonably good at detecting the precipitation events over Kumamoto Prefecture.

GSMaP_NRT

Figure 5 shows the validation result of GSMaP_NRT in Kumamoto Prefecture. The value of the five continuous statistics showed that GSMaP_NRT was not good at detecting precipitation events before the flood occurred. For the area averaged hourly rainfall, the correlation coefficient was 0.24 RMSE was 8.272 mm with the bias percentage of -87.042% indicating underestimation of rainfall.

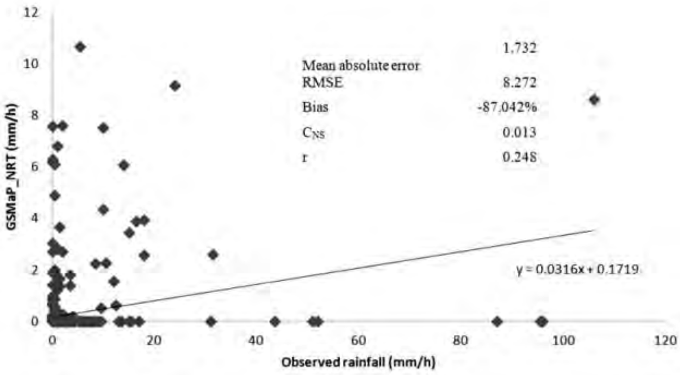

Figure 5. Scatter plot of rain gauge observation and GSMaP_NRT hourly scales in Kumamoto Prefecture

Table 4 shows the result of categorical statistics which 716 total points were observed. Hits frequency was 76 times, misses frequency was 137 times, false alarm frequency was 37 times and correct negative frequency was 466 times.

Table 4. Contingency table of yes or no events/ with rain or no rain of GSMaP_NRT

		GSMaP_NRT	
		Rain	No Rain
AMEDAS	Rain	76	137
	No Rain	37	466

POD 0.357; FAR 0.327

Based on table 4, POD and FAR values was 0.357 and 0.327. It means 35.7% of rain occurrences were correctly detected and 32.7% of rain occurrences turned out to be wrong by GSMaP_NRT. These values of two categorical statistics showed that GSMaP_NRT product was not so good at detecting the precipitation events in Kumamoto Prefecture. Nevertheless, GSMaP_NRT has the value of FAR similar with GSMaP_MVK and can be downloaded after 4 hour satellite observation. As a result, GSMaP_NRT can be used as emergency data analysis for precipitation data when rainfall observation data is not available.

History of floods in Kumamoto Prefecture

Between 2003 and 2013, there were nine flood events occurred in Kumamoto Prefecture. Flood occurs in June or July, which is the rainy season in Japan. During that period, Yamato city was attacked by flood two times (2006 and 2007) and the highest flood frequency was in 2007 (four times). The floods occurred when the heavy rain ranging from 221 mm/week to 608 mm/week fell. Extreme rainfall occurred in 2003 and 2012. Extreme rainfall causes rapid flooding and landslides. As a result, in 2012, 28 deaths were reported from this event with thousands forced to evacuate, and widespread property damage.

Time series graph

There were two kinds of rainfall pattern which caused flood, namely, a long term pattern and a short term pattern. The long term pattern refers to accumulative rainfall from one day to several days causing flood. The short term rainfall pattern refers to accumulative rainfall for several hours causing flood.

Long Term Pattern

Figure 6 (left) shows the rainfall pattern before the flood occurrence in Misato city. The blue line indicates hourly observed rainfall by AMEDAS while the red line indicates hourly rainfall estimates by GSMaP_MVK. The pattern of both rainfall data was similar, but there was time lag of 9 hours and GSMaP_MVK rainfall data was lower than observed rainfall. From this result, it seems that GSMaP_MVK was able to predict the rainfall occurrence around Kumamoto Prefecture when the flood occurred. The time series graph after time lag matching is shown in the Figure 6 (right).

Figure 6 (right) shows that the rainfall pattern for AMEDAS data and GSMaP_MVK data was almost the same and is classified as long term rainfall period. Nevertheless, GSMaP_MVK underestimated the value with the highest rainfall amount of 23.6 mm/h. The flood occurred after two weeks continuous rainfall with the highest amount of 80mm/hour. For two weeks rainfall, 6 days before the flood occurrence, the total amount of rainfall was 608 mm. This large amount of rainfall and low altitude area caused a flash flood in Misato city. A long term rainfall pattern occurred both in 2007 and 2006 in Yatsushiro city, Yamato city, Mifune city, Misato city, and Gyokuto city. In those events, the total amount of rainfall in a week was from 406 mm to 608 mm.

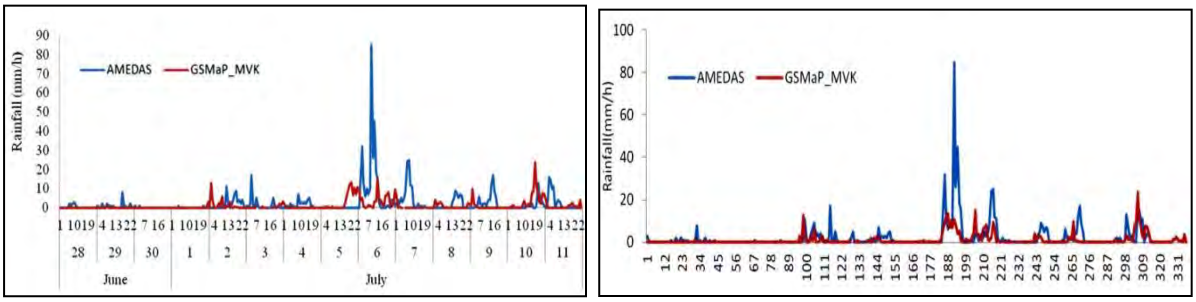

Figure 6. Rainfall pattern before the flood occurred in Misato city, 11 July 2007 (left), after time lag matching (right).

Short Term Pattern

The most recent flood occurred in Kumamoto Prefecture was on 12 July 2012. GSMaP_MVK is only available from 2000 to 2010, therefore GSMaP_NRT was chosen as a satellite precipitation data in this research. Both GSMaP_NRT and GSMaP_MVK have same algorithm, but GSMaP_MVK is the reanalysis version of GSMaP_NRT (EORC & JAXA, 2013). Figure 7 (left) shows the rainfall pattern before the flood occurrence in Kumamoto city. The blue line indicates hourly observed rainfall by AMEDAS while the red line indicates hourly rainfall estimates by GSMaP_NRT. The pattern between AMEDAS data and GSMaP data is hard to recognize, but the rainfall occurrence can be detected. The GSMaP_NRT value underestimated rainfall and the time lag with AMEDAS data was 9 hours earlier. GSMaP_NRT still has a possibility to detect the rainfall occurrences as explained before. The time series graph after time lag matching is shown in figure 7 (right).

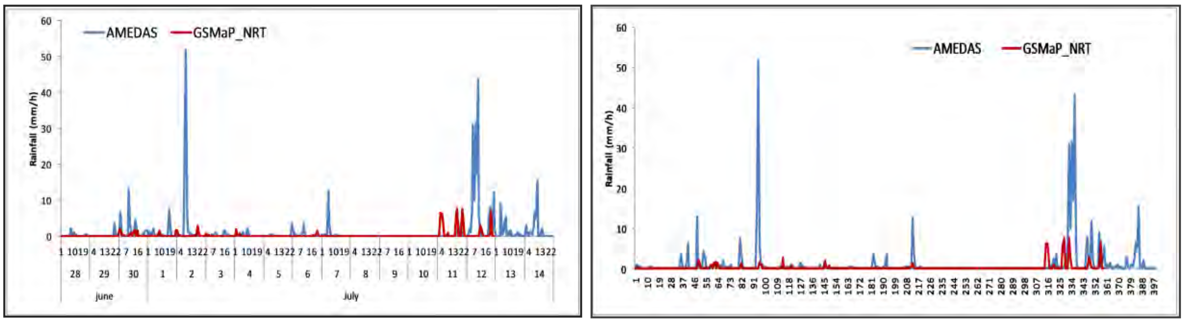

Figure 7. Rainfall pattern before the flood occurred in Kumamoto city, 12 July 2012 (left), after time lag matching (right).

Figure 7 (right) shows the rainfall pattern of two weeks difference, and looks similar on the 12 July 2012. A short term rainfall pattern occurred in this city. On 12 July 2012, heavy rainfall occurred for 5 hours with the peak rainfall amount of 133 mm. Kumamoto city is at low altitude area and Asootohime at high altitude had heavy rainfall of 435.5 mm for 5 hours. As a consequence, a flash flood attacked in Kumamoto city for the first time after 30 August 1980, when a flash flood damaged that city. The same rainfall pattern also occurred in Asootohime on 12 July 2012 and Minamata city on 21 July 2003. The short term rainfall pattern has a rainfall amount ranging from 199 mm to 435 mm for 5 hours. Because of this pattern, measurement of high temporal resolution of precipitation data became very important. However, rainfall is not the only indicator to predict the flood occurrence, but rainfall is the main cause of flood. Thus, the several approaches should be used to measure rainfall characteristics. One approach is to use precipitation satellite data which is easy to get, has high temporal resolution data and can easily reach isolated areas. For that reason, verification of hourly precipitation satellite data is important.

CONCLUSION

GSMaP_MVK was reasonably good at detecting precipitation events before the flood occurrence both spatially and temporally. GSMaP_NRT was not good at detecting precipitation events before the flood occurrence, especially for spatial distribution, but it can be used as emergency data analysis for precipitation data when rainfall observation data is not available. There were two rainfall patterns over Kumamoto Prefecture before the flood occurrence, namely “the long term period” and “the short term period”. In the long term period, the flood occurred when the rainfall amount ranged from 406mm to 608 mm for one week, while the short term period was from 199 to 435 mm for five hours.

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