Applicability of Satellite-Based Rainfall Product to Flood Runoff Analysis with Integrated Flood Analysis System (IFAS) in Asia

Kazuhiko Fukami*[1], *G. Ozawa, M. Miyamoto, H. Inomata

Corresponding author[1]
International Centre for Water Hazard and Risk Management (ICHARM) under the auspices of the United Nations Educational, Scientific and Cultural Organisation (UNESCO), Public Works Research Institute (PWRI), Ibaraki, Japan.
Email: k-fukami@pwri.go.jp

Abstract
Monsoon Asia suffers from flood disasters every year. Flood forecasting and warnings are key measures implemented to reduce casualties and damage caused by floods. However, the implementation of flood forecasting and warning systems has not really progressed in developing countries despite the availability of recommendations in documents such as the Hyogo Framework for Action (2005-2015). Therefore, the International Centre for Water Hazard and Risk Management (ICHARM) under the auspices of the United Nations Educational, Scientific and Cultural Organisation (UNESCO) has been promoting the application of the Integrated Flood Analysis System (IFAS) as the basis for a flood forecasting system for poorly-gauged rivers in developing countries through the Global Earth Observation System of Systems-Asian Water Cycle Initiative (GEOSS-AWCI) and other international frameworks. One of the key technologies of IFAS is to utilise satellite-based rainfall data for flood runoff analyses in poorly gauged rivers. IFAS implemented a self-correction system for satellite-based data, without any ground-based in-situ rain gauge data, to modify under-estimated satellite-based rainfall data in poorly gauged river basins. The verification studies revealed the high potential of IFAS, coupled with satellite-based rainfall data with a self-correction algorithm, to identify extreme flood events. Further areas to improve IFAS-based flood runoff analyses and forecasting are also discussed.

***Keywords**: satellite-based rainfall data, GSMaP_NRT, self-correction algorithm, Integrated Flood Analysis System (IFAS), Global Precipitation Measurement Mission (GPM), flood forecasting*

Introduction

Monsoon Asia experiences flood disasters every year during the monsoon season. Typical examples observed in the past two years have included flood disasters caused by Typhoon Morakot and Typhoon Ketsana (2009), floods in Southern China and the Indus River floods in Pakistan (2010). The implementation of flood forecasting and warning systems is a key strategy to reduce casualties and damage caused by large-scale flood events such as these. However, implementation in developing countries has not made sufficient progress and, for that reason, UNESCO/ICHARM developed the Integrated Flood Analysis System (IFAS) as a base flood forecasting system for poorly gauged rivers in developing countries. The present paper describes the concept to promote the implementation of a flood forecasting/warning system using IFAS coupled with satellite-based rainfall data in poorly gauged rivers. The significance of satellite-based rainfall data and IFAS were also investigated and discussed in the context of flood disaster mitigation through flood early warning in developing countries.

Concept of Integrated Flood Analysis System (IFAS)

The design concept of IFAS as a common fundamental tool for flood forecasting/warning systems in poorly gauged rivers was developed in a joint research endeavour (2005-2007) with the Infrastructure Development Institute (IDI) and nine private consultancy companies (Figure 1) with the following objectives:

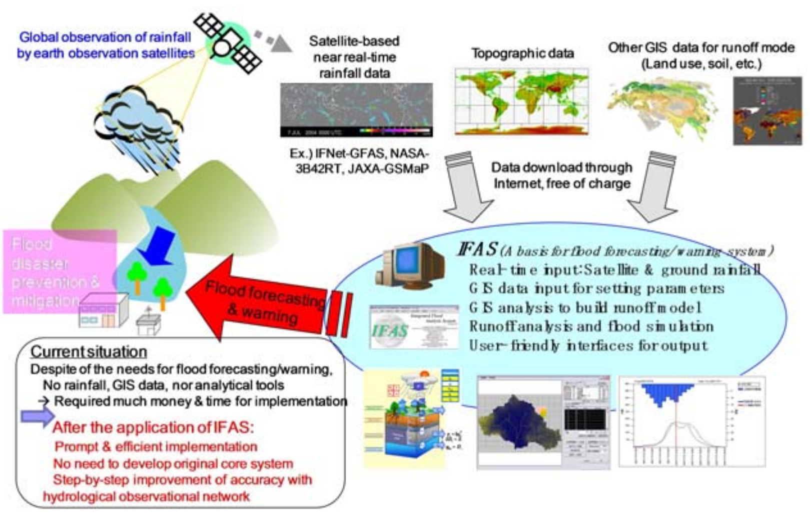


Figure 1. Concept of Integrated Flood Analysis System (IFAS)

i. Develop interfaces to obtain satellite-based rainfall data and ground-based rainfall data to secure worldwide availability of data for flood forecasting/analysis;
ii. Adopt two types of distributed-parameter hydrological models, PWRI Distributed Hydrologic Model (PDHM) Ver.2 and Block-wise TOP (BTOP) model, the parameters of which can be estimated as the first approximation based on globally-available GIS databases to secure worldwide availability of hydrological models for flood forecasting/analysis;
iii. Implement GIS analysis modules in the system to set up the parameters for the flood forecasting/analysis model, therefore no need to depend on external GIS software;
iv. Prepare a series of easy-to-understand graphical user interfaces for data input, modelling, runoff-analysis and output display; and
v. Distribute the executable program, free of charge, from the ICHARM/PWRI website.

ICHARM also offers technical training seminars so that developing countries can utilise provided information and technologies as easily as possible. Such packaged activities have been regarded as one of the core activities of the Flood Working Group of GEOSS-AWCI to build capacities for flood runoff analysis and management in developing countries. The overall structures, features and interfaces of IFAS have already been introduced (Sugiura *et al.*, 2009). In the present paper the authors focus on the applicability of satellite-based rainfall data to flood runoff analysis in terms of accuracies of areal rainfall & flood runoff estimation.

Accuracy of Satellite-based Rainfall Data and the Effect of its Self-correction Method

According to the concept of IFAS, IFAS has a function to incorporate not only ground-based rainfall data (csv data) but also satellite-based near-real-time rainfall products such as NASA-3B42RT, NOAA-CMORPH, JAXA-GSMaP_NRT, etc. (Table 1) for flood runoff simulations.

From the table, GSMaP_NRT seems more promising for the purpose of flood forecasting due to its high temporal and spatial resolution and its quick delivery. According to the validation study for a few river basins of Japan and USA (black plots, Figure 2), however, it was clarified that GSMaP_NRT (3hr-cumulative catchment-area-averaged rainfall amount) tended to underestimate rainfall intensity, in particular, in cases of heavy rainfall. Then Shiraishi *et al.*, 2009 disovered an empirical relationship between spatial correlation factor (presumably corresponding to the movement speed of precipitation cells, Figure 3) and the degree of underestimation. Based on this empirical relationship, they developed a self-correction method for GSMaP_NRT without ground-based rainfall data (red plots, Figure 2). This method is expected to be very

ARCP2009-01CMY-Fukami

Flood Risk Management Demonstration Project under the Asian Water Cycle Initiative for the Global Earth Observation System of Systems (FRM/AWCI/GEOSS)

Project Leader:

Mr. Kazuhiko Fukami
International Centre for Water Hazard and Risk Management (ICHARM) under the auspices of United Nations Educational, Scientific and Cultural Organisation (UNESCO)
Public Works Research Institute (PWRI)
JAPAN
Tel: +81 29 879 6779
Fax: +81 29 879 6809
Email: k-fukami@pwri.go.jp

APN Funding:

US$84,000 (For 2 Years)

Research Highlights

- The authors (UNESCO-ICHARM) developed a free toolkit: the Integrated Flood Analysis System (IFAS), as the basis for a flood forecasting system for poorly-gauged rivers in developing countries. IFAS can incorporate not only ground-based rain gauge data but also satellite-based rainfall products and can build two types of distributed-parameter flood-runoff models based on global GIS data without the need for GIS analytical software.

- A typical satellite-based rainfall product, JAXA-GSMaP_NRT, underestimated heavy rainfall intensity. Therefore, ICHARM developed an original algorithm to make self-corrections for GSMaP_NRT data without using ground-based rainfall data. This empirical algorithm has worked well as a whole to modify such a systematic underestimation.

- The combination of the self-corrected satellite-based rainfall data, global GIS data and IFAS has very high potential to promptly and efficiently implement a flood analysis and forecasting system even in poorly-gauged rivers, in the sense that major extreme flood phenomena can be identified even if the coincidence of hydrographs are not sufficient from low to high flow.

- To improve the reliability and accuracy of IFAS-based flood runoff analyses with satellite-based rainfall data, we need more frequent direct observation from space (i.e. GPM mission) and the coupling of satellite-based rainfall data with ground-based in-situ rain gauge data.

Table 1. Major satellite-based rainfall products freely available on the Internet

Productname	3B42RT	CMORPH	GSMaP_NRT
Developer and provider	NASA/GSFC	NOAA/CPC	JAXA/EORC
Coverage	N60° - S60°		
Resolution	0.25°	0.25°	0.1°
Resolution time	3 hours	3 hours	1 hour
Time lag	10 hours	15 hours	4 hours
Coordinate system	WGS		
Historical data	Dec 1997-	Dec 2002-	Dec. 2007～
Sensors	TRMM/TMI Aqua/AMSR-E AMSU-B DMSP/SSM/I IR	Aqua/AMSR-E AMSU-B DMSP/SSM/I TRMM/TMI IR	TRMM/TMI Aqua/AMSR-E ADEOS-Ⅱ/ AMSR SSMI IR AMSU-B

practical and useful for poorly gauged river basins to use satellite-based rainfall data for flood forecasting purposes since it is difficult to prepare a fully designed network of telemeter rain gauges when starting the implementation of a flood forecasting system.

According to another study for the case of Typhoon Morakot in Taiwan in 2009, this method seemed effective to get the first-order approximated areal rainfall distribution in poorly-gauged river basins. Figure 4 clearly shows the effect of the self-correction method on 3hr-cumulative rainfall amount (mm) of JAXA-GSMaP_NRT.

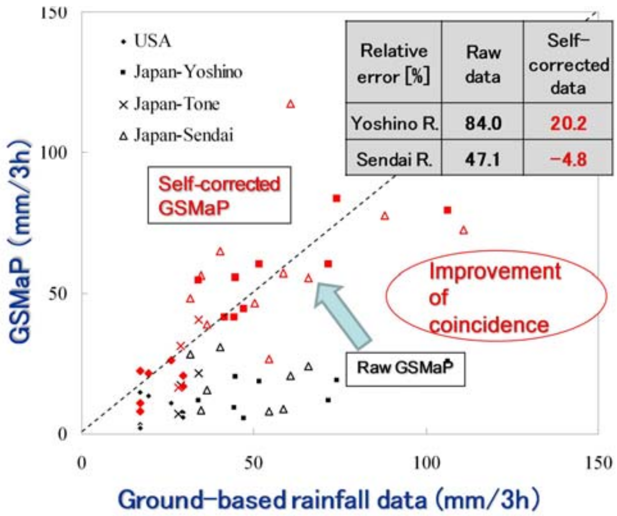


Figure 2. Comparison between satellite-based (JAXA-GSMaP_NRT) and ground-based areally averaged rainfall data for a few river basins in Japan and USA. (Black plots: raw GSMaP_NRT; red plots: self-corrected GSMaP_NRT)

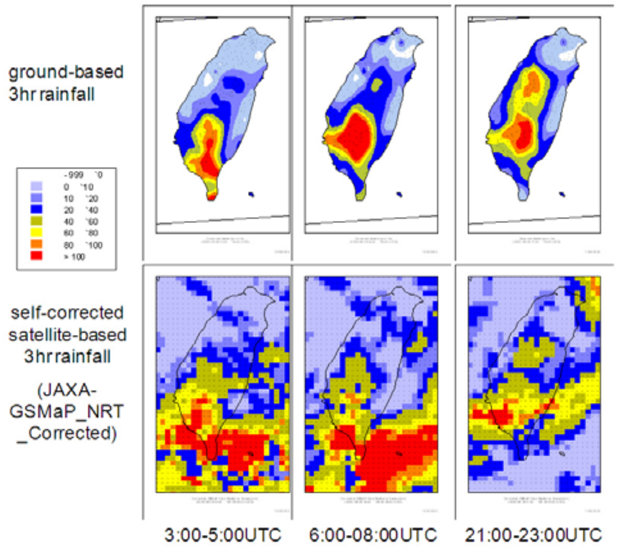
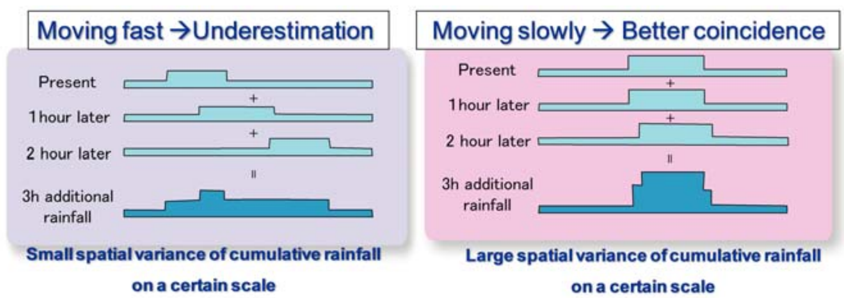


Figure 4. Comparison of temporal & spatial distribution of ground-based (upper) and satellite-based (self-corrected GSMaP_NRT, below) 3-hr cumulative rainfall, August 8, 2009 (Typhoon Morakot, Taiwan)

However, we also discovered some cases in which self-corrected satellite-based rainfall data cannot reproduce flood hydrographs properly (Figure 5). It was clarified that such poor results could be obtained if the frequency of real observation of rainfall from space was insufficient during the rainfall increasing period. Therefore, it is almost apparent that we need the real implementation of Global Precipitation Measurement (GPM) mission, which has been planned by JAXA, NASA and other space agencies making it possible to observe any area in the world once every three hours (in 5-6 hours at present). Figure 6 shows another application of IFAS with self-corrected GSMaP_NRT rainfall data for hydrograph simulation at the Hkamti streamflow gauging station of the Chindwin River in Myanmar (27,420 km^2). There is only one rain gauge at Hkamti and no rain gauge in the upstream area. Therefore, it is not surprising that runoff simulation with self-corrected satellite-based rainfall data was better than that with one rain gauge data, in the sense that the former hydrograph was not so coincident under low flow conditions but very successful in identifying three of the biggest flood peaks of 2008. This suggests that self-corrected satellite-based rainfall data without any ground-based rain gauge data are insufficient not enough to precisely reproduce

Figure 3. Empirical relationship between spatial correlation (rainfall-field movement speed) and the degree of underestimation of JAXA-GSMaP_NRT



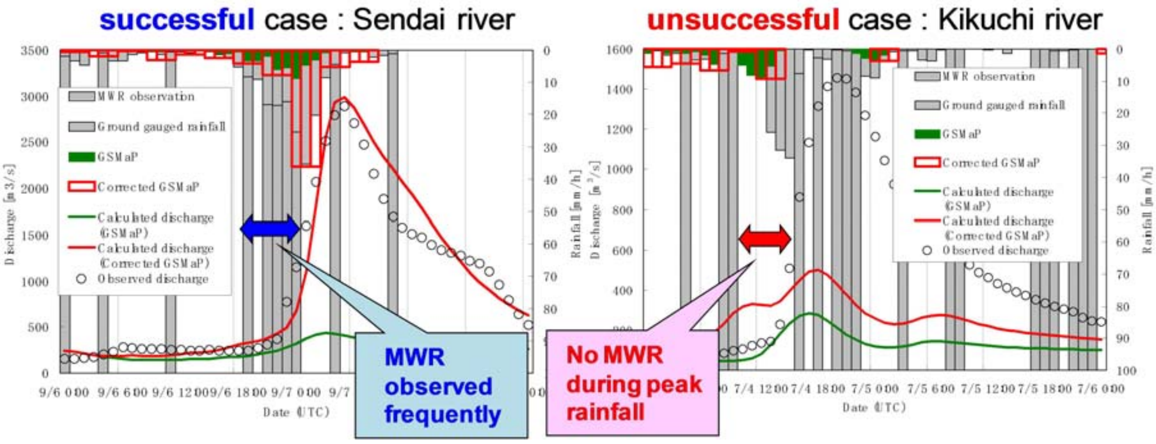


Figure 5. Difference of frequency of microwave radiometric observation from satellites between successful and unsuccessful cases to reproduce flood hydrograph

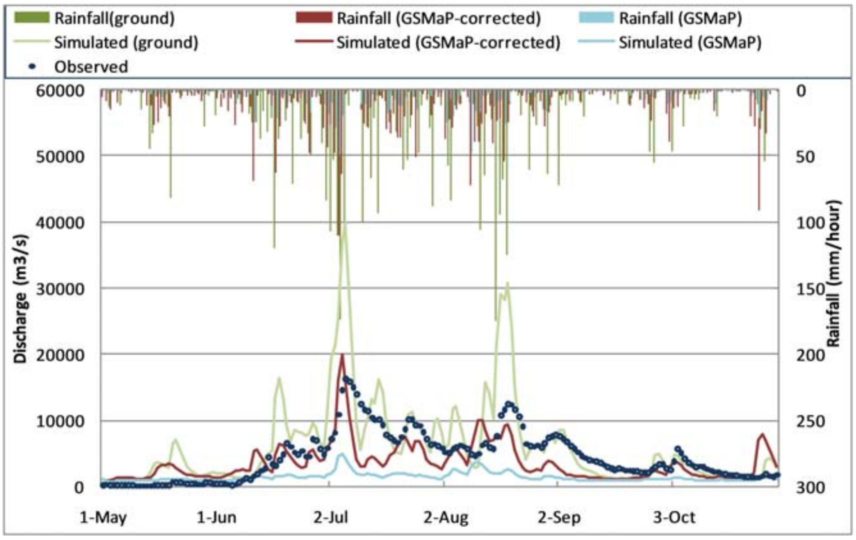


Figure 6. IFAS-based hydrograph simulation with ground-based & satellite-based (raw & self-corrected GSMaP) rainfall data and observed hydrograph for flood season of 2008 at Hkamti station of Chindwin River of Myanmar.

hydrographs from low to high flow, but still of some use to identify major extreme flood events.

Conclusions

Our tentative conclusions regarding the potential of IFAS and satellite-based rainfall data for flood forecasting and early warning are as follows:

i. The combination of satellite-based rainfall information (with ICHARM's original self-correction algorithm), global GIS data and IFAS has very high potential to promptly and efficiently implement a flood analysis & forecasting system even in poorly gauged rivers;

ii. Namely, major extreme flood phenomena can be identified through satellite-based flood runoff analysis and forecasting even if hydrographs observing low to high flow are inaccurate and;

iii. To further improve the reliability and accuracy of IFAS-based flood runoff analysis with satellite-based rainfall data, we need more frequent direct observations from space (i.e. GPM mission) and the coupling of satellite-based rainfall data with ground-based in-situ rain gauge data.

References

- Sugiura, T. *et al.* 2009. *Development of Integrated Flood Analysis System (IFAS) and its Applications*. Proceedings of the 8th International Conference on Hydroinformatics, 12-16 January 2009. Concepción, Chile.
- Shiraishi, Y. *et al.* 2009. 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. Hydraulic Eng., JSCE, 53, 385-390 (in Japanese).

Acknowledgements

The authors express sincere thanks to all members of the Flood Working Group activities of GEOSS-AWCI and for the financial support from APN, the University of Tokyo and Japan Aerospace Exploration Agency (JAXA), which made this international study possible.