# EVALUATION OF SATELLITE BASED PRECIPITATION AND ITS USAGE FOR FLOOD FORECAST AT BASIN SCALE

**Kazuki Tanuma[1], Oliver Cristian Saavedra Valeriano,[2] and Masahiro Ryo[3]**

[1]Civil Engineering, Tokyo Institute of technology, e-mail: tanuma.k.aa@m.titech.ac.jp
[2]Civil Engineering, Tokyo Institute of technology, e-mail: saavedra.o.aa@m.titech.ac.jp
[3]Civil Engineering, Tokyo Institute of technology, e-mail: ryo.m.aa@m.titech.ac.jp

Received Date: June 1, 2012

## Abstract

This study aims to investigate the applicability of Satellite Based Precipitation (SBP) combined with rain gauges as input to a distributed hydrological model (DHM) for flood forecast. SBP was evaluated at different scales in upper Chao Phraya basin against available local gauge network in Thailand. The procedure includes the usage of Root Mean Square Error (*RMSE*) to assess the accuracy of SBP and Relative Error (*RE*) to evaluate the degree of estimation. Furthermore, *RE* values were utilized to obtain correction factors at each rain gauge per season. DHM was run during 2007-2010 to validate spatial and temporal accuracy of improved SBP. The river discharge simulations using corrected SBP could reduce the overestimation gaps when compared to observed discharge in target period. It was noticed that SBP can enhance precipitation's pattern by using local gauge network. The obtained results show possibility to apply this procedure to other humid vegetated basins and also using other SBP dataset. We believe that this method can be useful not only for flooding risk assessment but also to support enhanced dam operation.

**Keywords**: Chao Phraya River, Distributed hydrological model, Flood, Satellite based precipitation, TRMM

## Introduction

Water demand in Thailand has been increasing due to population growth and associated sectors' including agriculture, drinking water, industry, hydropower generation, and navigation [1]. The spatial and temporal analysis of rainfall can provide a better understanding of the "socio-economic activities" as well as events such as disaster management including droughts, flooding and landslides. Thus, water assessment based on hydro-meteorological observations plays a key role not only in water resources management, but also in protection of Thai society. However, rain gauge networks might be sparse in developing countries due to maintenance costs and accessibility. On the other hand, as remote sensors installed at satellites can cover large areas over the globe continuously, the exploitation of these products in those countries has shown high potential. For example, in poorly gauged regions like in Thailand and the Amazon, the availability of a global data set was assessed by using error evaluations [2, 3]. Nowadays, there is an attempt to improve SBP, namely Tropical Rainfall Measuring Mission (TRMM) measurements with statistical evaluation in South America [4]. However, this product is monthly calibrated using global hydrology network (e.g. long term variability of rainfall); therefore, it doesn't have enough capability to accurately specify local flood events with short duration [5]. The possibility to quantify the biases or tendency at regional and local scales is still under investigation. The biases might be associated to the type of rainfall events within the basin and surroundings. The correction factor considering the biases could be applied to SBP and increase local precipitation measurements' accuracy. For example, in Bangladesh, the correction factors were extrapolated over regions with no in-situ data [6].

This paper aims to investigate the applicability of Satellite Based Precipitation (SBP) in combination with local rain gauge network to improve the spatial and temporal resolution of measurements in Chao Phraya. The process can be carried out in three steps: 1) evaluation of SBP products in regions with few gauges by scale difference; 2) validation of SBP correction method; 3) application of corrected products as input for hydrological model. The improved measurement product may allow us to detect the precipitation pattern and to quantify the risk of flooding.

## Study area

Chao Phraya basin is located in Thailand (Figure1). The basin is the center of rice production because monsoon weather normally brings enough rainfall from May to October. [2] The annual precipitation is about 1,200 mm/year. In the northern mountainous region, two major dams, Sirikit and Bhumipol, are in operation. The flood control point is set at Chao Phraya dam. The operations of these dams might reduce the effect on flooding at lower areas which are economically relevant like Bangkok and Ayutthaya.

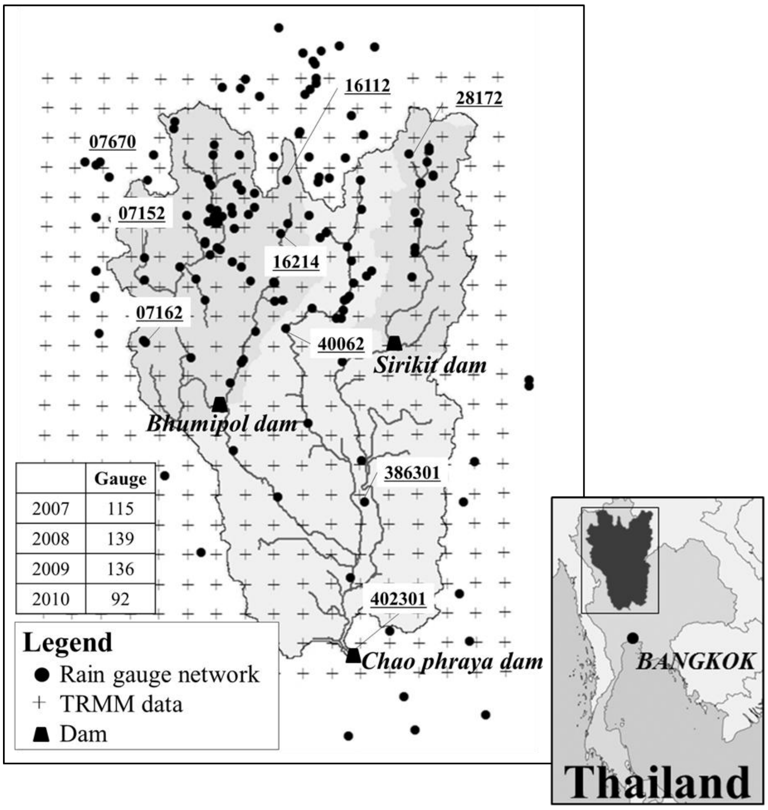


Figure 1. Chao Phraya River basin, Thailand

## Methodology

### Precipitation data

In order to measure rainfall intensities at land surface, two kinds of rain gauge network systems were employed. The first one was provided by the Royal Irrigation Department

(RID), Hydrology and water management center for upper northern region. The other one is managed by the Thai Meteorological Department (TMD). The temporal resolution for both is one day. Their spatial resolution is shown in dots in Figure 1. The chart on the Figure 1 shows the available gauges number at each year. In this study, TRMM Multi-satellite Precipitation Analysis (TMPA) research product 3B42 Version 6 is used as data set. TRMM launched by the National Aeronautics and Space Administration (NASA) and Japan Aerospace Exploration Agency (JAXA) in 1997 provides 3 hourly rainfall data in tropical area as global dataset. The spatial resolution is 0.25 degrees and the distribution over the basin is shown in Figure 1. The cross points represent average values within TRMM's mesh.

## Evaluation of Precipitation

The evaluation of SBP, namely TRMM was performed at gauges; sub-basin and basin scale. Firstly, it was selected 9 representative rain gauges compared with close satellite estimation points. Two indicators were applied to the comparison. To evaluate the accuracy of TRMM, the Root Mean Square Error (*RMSE*) was used as below;

$$RMSE = \sqrt{\frac{\sum\left(RG_{daily} - TRMM_{daily}\right)^2}{N}}\left(mm/day\right) \tag{1}$$

To calculate the satellite based precipitation bias, the Relative Error (*RE*) was used as below;

$$RE = \frac{TRMM_{daily} - RG_{daily}}{RG_{daily}}\left(-\right) \tag{2}$$

Where, $N$ is the number of the day in rainy season; $RG_{daily}$ is the daily value rain gauge measured; $TRMM_{daily}$ is the daily rainfall measured by the satellite. The same statistical parameters were applied to the area draining to three dams; Sirikit, Bhumipol and Chao Phraya as target areas. In the process, rain gauge and TRMM are interpolated by Thiessen polygons from point to 1 km computational grid in order to estimate the spatial distribution. Then, the average values of rain gauges and TRMM at whole target area were compared.

## Correction factors

We proposed a procedure to make correct the bias for monsoon effect. First of all, daily *RE*s were calculated at all rain gauge stations by comparing with the nearest satellite measurement points. Then, they were converted to correction factors (*CF*) by using equation (3) if $RG_{daily}$ is higher or equal to 1.0 mm/day. In addition, we set lower and upper bounds to the correction factor *CF* as 0.5 and 1.5 respectively to neglect the large estimation errors of TRMM.

$$CF = 1 - RE = 1 - \left(\frac{TRMM_{daily}}{RG_{daily}} - 1\right)\left(-\right) \tag{3}$$

Then, they are averaged over monsoon seasons using daily values, i.e pre-monsoon (May to June), main-monsoon (July to August) and post-monsoon (September to

October) to obtain seasonal correction factors. Secondly, Inverse Distance Weighted (IDW) is applied as interpolation method for correction factors to obtain spatial distribution at every 1 km grid. Thirdly, SBP at each point is multiplied using the spatial distribution of the correction factor. To obtain the corrected precipitation data set. Moreover, the relationship between the density of rain gauge network and the accuracy of correction was examined in 2008. It is useful for considering how to set and manage ground rainfall measurement products in developing countries and beneficial for the meteorological departments or authorities. Thus, this validation investigates how the number of rain gauge affects the accuracy of correction for satellite based estimation. The number of rain gauges was generated randomly decreasing to 80%, 60%, 50%, 40%, 20%, and 10%. The total samples were 139 gauges corresponding to 100% (Table 1). In this trial, it was attempted to keep distributed over whole basin to reduce spatial bias.

**Table 1. The Number, Percentage of Rain Gauges and Coverage Area per One Rain Gauge**

| Number of Rain Gauge | Coverage Area per One Rain Gauge ($km^2$) | (%) |
|---|---|---|
| 139 | 844 | 100 |
| 111 | 1056 | 80 |
| 83 | 1407 | 60 |
| 70 | 1689 | 50 |
| 56 | 2111 | 40 |
| 28 | 4222 | 20 |
| 14 | 8444 | 10 |

### Model application

Flood simulation was possible using the DHM and forced by two products; original TRMM and corrected TRMM. The DHM employed in this study is a grid-based geomorphology based hydrological model (GBHM). It solves the continuity, momentum and energy equations using two modules; hillslope model and water routing of the river network. The hydrological model has shown effectiveness to assess of flood peaks within the basin because of the capability to consider data's spatial heterogeneity. Main results targeted stream gauge stations P73 and W3A shown in triangles in Figure 1. The station P73 is located at Ping River and W3A at Wang River. These two stations are located upstream Bhumipol Dam; thus monitoring River discharge at these locations are critical important for dam operation. In this step, river discharges from 2008 to 2010 were simulated in P73 and W3A. The parameters in this model were calibrated beforehand by comparing the simulated discharge with rain gauge and the observed discharge in 2007.

## Result & Discussion

### Evaluation

*RMSE* and *RE* (2007-2010) at 9 stations during rainy season in target years are summarized in Table 2. The distance between rain gauges and satellite measurement points are shown in the table. Firstly, most of *RE*s values are positive. This means that TRMM tends to overestimate rain gauge measurements. However, *RE*s values are negative (underestimation) at Mae, Omkoi, Chae Hom stations. Therefore, it indicates this dataset can detect regional trends and spatial errors. Secondly, a clear result is not obtained in terms of distances. This might be due to the fact that TRMM estimates precipitation patterns rather than single points. The scatterplots in Figure 2 are results from daily average precipitation estimates from gauges and satellite product for the monsoon period (May to October) in 2007-2010. As magnitude of precipitation increases, the bias also increases at every location. In case of heavy precipitation (i.e. higher 50mm/day), TRMM tends to underestimate precipitation at gauges: 07670, 28172, 07152, 40062, and 386301. It can be inferred that TRMM may not be reliable for specific local rain gauges, but still can detect distribution. Therefore, as a next step, this product requires spatial and temporal improvement by using *RE*s at each rain gauge station.

**Table 2. Statistical Summary of Comparison between TRMM and Gauged Precipitation Estimates at Nine Points in Chao Phraya Basin in Monsoon Season**

| | | | | | | 2007 | | 2008 | | 2009 | | 2010 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rain Gauge ID | Station | Distance (m) | Elevation (m) | Coordinates East | Coordinates North | RE | RMSE (mm/day) | RE | RMSE (mm/day) | RE | RMSE (mm/day) | RE | RMSE (mm/day) |
| 7670 | The leverage | 10.36 | 710 | 98.03.09 | 19.10.10 | 1.04 | 14.22 | 1.64 | 12.90 | 0.62 | 14.43 | 1.27 | 14.31 |
| 7152 | Mae | 12.19 | 478 | 98.21.54 | 18.29.54 | -0.16 | 13.15 | -0.40 | 10.12 | -1.69 | 13.30 | N.A | |
| 7162 | Omkoi | 12.75 | 802 | 98.21.36 | 17.47.45 | -0.04 | 10.17 | -0.26 | 8.80 | -0.02 | 11.81 | N.A | |
| 16112 | Wangehna | 17.54 | 417 | 99.37.31 | 19.08.42 | 1.62 | 9.12 | 1.59 | 11.96 | 0.98 | 13.26 | 5.70 | 13.07 |
| 16214 | Chae Hom | 3.52 | 463 | 99.32.00 | 18.30.00 | -0.37 | 11.67 | N.A | | -0.73 | 9.71 | N.A | |
| 28172 | The King | 12.69 | 288 | 100.42.22 | 19.21.26 | 0.50 | 17.21 | 0.82 | 18.99 | 0.21 | 14.44 | 0.32 | 17.15 |
| 40062 | Wang piece | 15.95 | 110 | 99.36.24 | 17.53.56 | 1.17 | 19.65 | 1.76 | 13.82 | 1.71 | 14.95 | 1.55 | 18.96 |
| 386301 | Mounatin Dew | 8.15 | 39 | 100.17.33 | 16.26.17 | N.D | | 1.88 | 13.84 | 3.53 | 15.68 | 2.48 | 13.06 |
| 402301 | Dew Nat | 24.81 | 17 | 100.11.00 | 15.09.00 | N.D | | 3.35 | 15.49 | 2.46 | 13.20 | 2.08 | 19.28 |

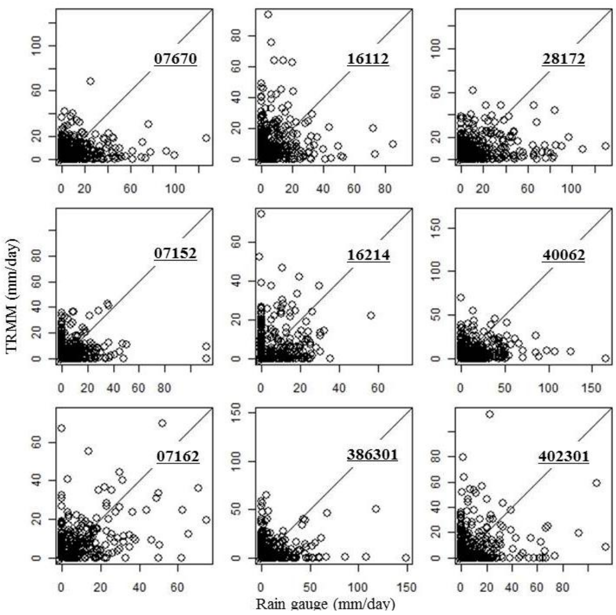


Figure 2. Scatter grams of daily precipitation measured by TRMM and gauges at nine stations (one per panel) in Chao Phraya basin, 2007-2010

Similarly to Table 2, Table 3 shows the statistical parameters, but in this case, for basin and sub-basin scale. The parameters are calculated by each monsoon periods (pre-monsoon, main-monsoon, post-monsoon). The analyzed drainage area of Chao Phraya reached 117,375km$^2$ in 2008-2010. However, only upper region of Chao Phraya basin, 70,495 km$^2$, was analyzed in 2007 due to data availability.

*RE* does not change dramatically showing underestimation tendency. However, the values of *RMSE* at sub-basin scale are smaller than those at point scale. Hence, the satellite's accuracy improvement can be noticed. Moreover, size of drainage areas to both dams is different. The Sirikit drainage area is about 3/5 of Bhumipol. In fact, the *RMSE* values within Sirikit are slightly higher than Bhumipol ones. Moreover, *RMSE* value of Chao Phraya basin is decreasing about 1 mm/day compared with sub basin. Thus, the performance of TRMM significantly depends on the evaluation scales. The biases increase as intensities of precipitation are getting higher in Figure 3. SBP's tendency seems difficult to define (underestimate or overestimate) in Figure 3, but there are regional characteristics at Sirikit and Bhumipol drainage areas. Within Bhumipol drainage area, TRMM can measure even weak rainfall (< 10mm). On the other hand, more missing data satellite estimates were found within Sirikit drainage area than Bhumipol. It can be noticed wider variation through the years of plotted points on Sirikit's panel in Figure 3. . Moreover, in Srikit catchment, the underestimation of TRMM in 2007 and the overestimation of that in 2008-2010 can be seen. Then, SBP's performance like TRMM are critical important to address spatial error at sub-basins.

**Table 3. Statistical Summary of Comparison between TRMM and Gauged Precipitation Estimates over Drainage Areas to Dams in Monsoon Season.**

| | | 2007 | | 2008 | | 2009 | | 2010 | |
|---|---|---|---|---|---|---|---|---|---|
| Basin name | Drainage area (km2) | RE pre/main/post | RMSE (mm/day) pre/main/post | RE pre/main/post | RMSE (mm/day) pre/main/post | RE pre/main/post | RMSE (mm/day) pre/main/post | RE pre/main/post | RMSE (mm/day) pre/main/post |
| Sirikit | 15,522 | 2.49/0.69/0.06 | 5.73/7.29/7.06 | 6.58/0.30/0.08 | 5.09/6.75/6.61 | 1.20/0.80/1.02 | 5.84/5.49/4.73 | 3.76/6.07/4.29 | 4.73/7.52/7.90 |
| Bhumipole | 26,239 | 2.20/-0.04/0.26 | 5.38/3.73/5.20 | 0.56/0.13/0.05 | 4.07/3.56/6.68 | 0.30/0.18/0.08 | 4.87/5.25/3.45 | 1.17/0.06/0.02 | 2.69/7.02/6.10 |
| | Average | 0.975 | 5.775 | 1.28 | 5.58 | 0.60 | 4.98 | 2.57 | 6.24 |
| Chao Phraya | 117,375* | 1.05/-0.20/9.13 | 4.84/4.68/5.00 | 1.52/1.03/0.83 | 4.38/4.58/6.13 | 0.66/0.39/0.70 | 3.54/4.23/3.39 | 0.69/0.55/0.81 | 2.51/5.44/5.58 |
| | Average | 3.18 | 4.84 | 1.13 | 5.09 | 0.58 | 3.74 | 0.69 | 4.73 |

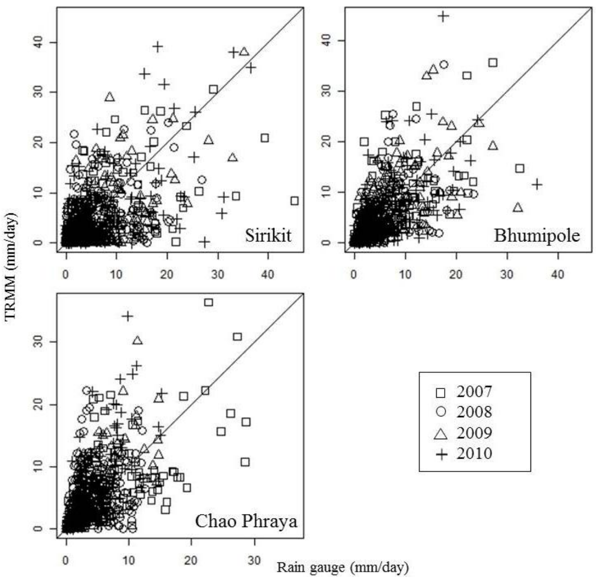


Figure 3. Scatter grams of daily-averaged precipitation from TRMM and gauged estimates over drainage areas to dams, 2007-2010

## Correction

Based on the evaluation step, we could obtain *CF*'s distribution from *RE* values through 2007 to 2010. The relationship between *RMSE* and coverage area per one rain gauge can be shown at Figure 4. The dashed line represents *RMSE* of uncorrected TRMM. First of all, *RMSE* increases as the density of rain gauge for correction decreases. Thus, the accuracy of correction gets worse as distribution of rain gauge network get sparser. In addition, the relationship is not linear as it can be expected.

These *RMSE* shown in Figure 4 fluctuate with changes in how to select rain gauges to reduce the number of them. However, in this case, *RMSE* can convert to the equation; $y = 0.9579 \ln( x( - 3.4275$. The original *RMSE* was 4.73. Thus, minimum coverage area per one rain gauge required for correction is calculated to 5,004 $km^2$.

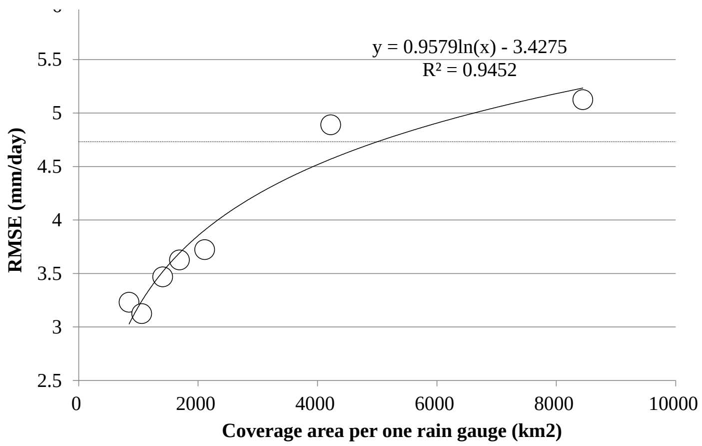


Figure 4. Correlation between *RMSE* and coverage area per one rain gauge over Chao Phraya basin in 2010

## Model application

Firstly, the comparison of the simulated discharge by original TRMM versus corrected TRMM can be seen in Figure 5. The period from 2007 to 2009 was chosen to carry out and validate the reliability of corrected TRMM. Dashed line represents simulated discharge with original TRMM and continuous line with corrected TRMM while white circles correspond to observed discharge.

The result indicates the simulation of original TRMM can detect the peak discharge up to some extent. However, the results tend to overestimate high rainfall events. The simulation of corrected TRMM can reduce the overestimation gaps showing more accurate discharge in target period. Therefore, it can be inferred that accuracy of precipitation is crucial for correct flood forecasting by simulating the discharge. Secondly, we simulated the discharge in 2010 by original TRMM and corrected TRMM (with 2008 and 2009 correction factors), and then compared them with the observation data in Figure 6. This means correction factors calculated in previous years were attempted to be applied as in real time basis. In upper part of Figure 6, it can be noticed that precipitation and discharge in 2010 is larger than the last three years. In fact, flooding started in the Northeast and Central Thailand early October due to abnormal late monsoon moisture over the Bay of Bengal.

The correction factors calculated in past years can't be very effective in 2010 because the intensities were higher. However, corrected TRMM can detect the peak of flooding and reduce the gaps obtained with original TRMM overestimates. It is expected the applicability of correction factors can be enhanced with more cases in near future.

## Conclusions

In this study, we demonstrated to obtain reliable flood simulation using SBP products like TRMM. It includes evaluation, correction factors for SBP and its application in hydrological modeling. At first, the performance of SBP was evaluated, and then, we defined the correction factors considering monsoon effect. Next, DHM was run to validate spatial and temporal accuracy of corrected TRMM. The results suggest that the correction factors obtained for target years can be effective even for following years that have no information of correction factor.

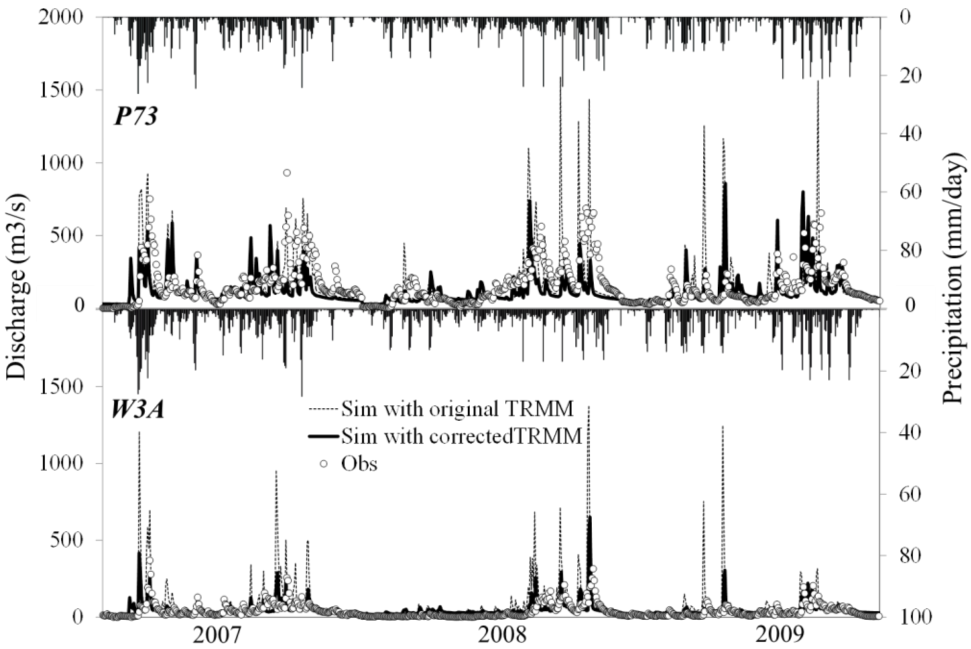


Figure.5 Flood simulation at P73 and W3A station from 2007 to 2009

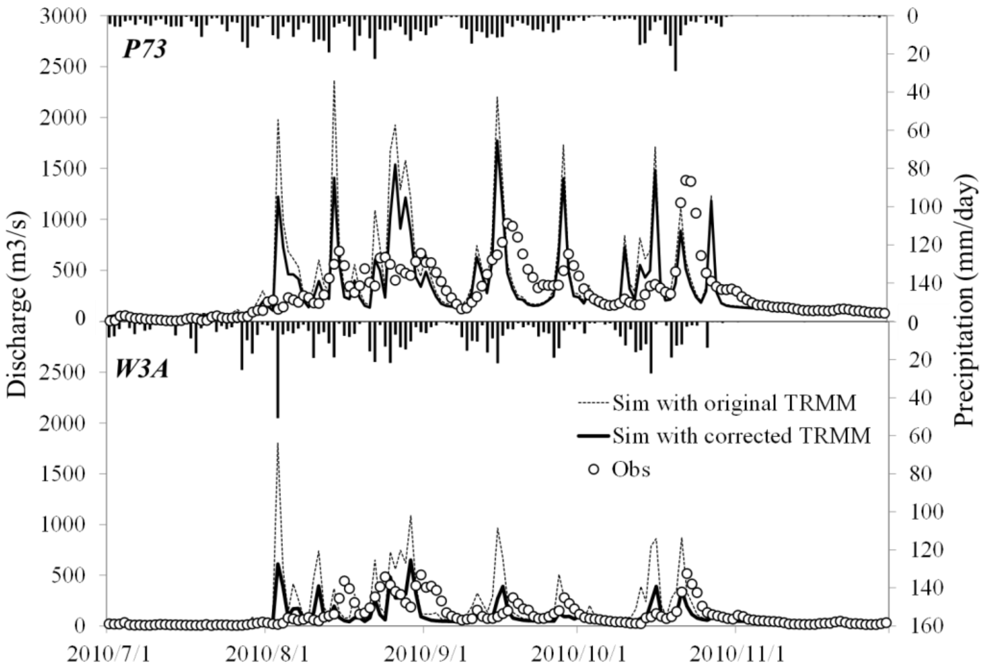


Figure 6. Flood simulation at P73 and W3A station in 2010

The model's parameters were calibrated in 2007 where less rainfall was observed. Therefore, in 2010 with higher intensities of rainfall, the results were not so satisfactory. However, the model calibrated by longer periods would have broad utility for other years. Our results might support assessment of flooding water volume in lower region. The simulations of inflow to dams are required for optimized and integrated dam operation rule during heavy rainfall.

Moreover, the correction method shown in this study has possibility to apply for the following uses. Firstly, this method can be used with other high resolution satellite rainfall products such as Global Satellite Mapping of Precipitation (GSMaP). Their error characteristics are just examined over the contiguous United States [7]. Currently, TRMM is scheduled to stop operation in 2014 when successor satellite will be launched. Thus, these methodologies introduced in this study are expected to be useful for other available SBP data sets as well. Secondly, correction factors could be extended where no rain gauges are available or regions with limited rain gauges. Local rain gauge network of neighboring countries could be applied for SBP correction, e.g. trans-boundary river basins. The approach of this study seems reliable in regions with few gauge networks as long as there is at least one gauge per 5,000 km$^2$.

It was found out that TRMM can provide comprehensive hydrological information like seasonal floods and overflow volumes. However, it should be considered the spatial and temporal ground validation of SBP carefully for water balance. Then, coupling enhanced SBP with DHM, may lead in to more accurate river discharge simulations. This is crucial not only for reducing disasters such as floods but also droughts and water management in other vegetated large basins.

## References

[1] K. Annan, K. Matsuura, and G. Young, *Water – A Shared Responsibility The United Nations World Water Development Report 2*, UN-WATER/WWAP/2006/3, UNESCO Publishing, Berghahn Books, Paris, France, 2006.

[2] R. Chokngamwong, and L.S. Chiu, "Thailand daily rainfall and comparison with

TRMM products," *Journal of Hydrometeorology*, Vol. 9, No. 2, pp. 256-266, 2008.
[3] F. Su, Y. Hong, and D.P. Lettenmeier, "Evaluation of TRMM mutisatellite precipitation analysis (TMPA) and its utility in hydrologic precipitation in the la plata basin," *Journal of Hydrometeorology,* Vol. 8, No. 3-4, pp. 622-640, 2007.
[4] D.A. Vila, L.G. G. De Gongcalves, D.L. Toll, and J.R. Rozante, "Statistical evaluation of combined daily gauge observations and rainfall satellite estimates over continental south america," *Journal of Hydrometeorology*, Vol. 10, No. 2, pp. 533-543, 2009.
[5] G.J. Huffman, D.T. Bolvin, E.J. Nelkin, D.B. Wolff, R.F. Adler, G. Gu, Y. Hong, K.P. Bowman, and E.F. Stocker, "The TRMM multisatellite precipitation analysis: quasi-global, multi-year, combined-sensor precipitation estimates at fine scale," *Journal of Hydrometeorology*, Vol. 8, No. 1, pp. 38-55, 2007.
[6] Saavedra Valeriano O.C., T. Koike, and M. Rahman, "Towards global river discharge assessment using a distributed hydrological model and global data sets," *Investigación & Métodos, Journal of the Bolivian Private University,* Vol. 9, pp. 95-102, 2010.
[7] Y. Tian, C.D. Peters-Lidard, J.B. Eylander, R.J. Joyce, G.J. Huffman, R.F. Adler, Kuo-lin Hsu, F.J. Turk, M. Garcia, and J. Zeng, "Component analysis of errors in satellite-based precipitation estimates," *Journal of Geophysical Research*, Vol. 114, No. D24101, 2009. doi: 10.1029/2009JD011949