Validation of Satellite Precipitation Products over Cambodia

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Key Words: TRMM/3B42, GSMaP, Rainfall, Cambodia

1. Introduction

Reports regarding the Indochina Peninsula claim that the record-level drought in the Mekong River Basin in 2009 was the worst for the several years. However, a previous study1) notes that western Cambodia receives more rainfall than other regions of this country, even during the beginning of the dry season. This phenomenon was first suggested by numerical simulations using a regional climate model2), 3) and then validated by using ground truth rain gauge data1). Satellite rainfall products are powerful tools for understanding the spatio-temporal distribution of rainfall, especially in poorly gauged regions such as Cambodia. Thus, the validation and calibration of satellite rainfall products are important. For this purpose, in the Space Application For Environment (SAFE) prototyping in Cambodia (“Water Cycle and Agricultural Activities during the Post-Monsoon Season in the Stung Sangker River Basin and wider area in Western Cambodia”, May 2009–Jun 2009), in September 2009, we installed 16 new rain gauges and restarted the maintenance of 19 abandoned rain gauges to compare satellite products (TRMM/3B42 and GSMaP) and rain gauge data. The difference between the satellite products and rain gauge data was largest during the post-monsoon season. Rain gauge values were smaller than satellite product values in northern parts, but much larger than the satellite product values in the south. Reasons for the misdetection of rainfall by the satellite over southern parts were examined. We focused on cloud-top temperature during rainfall events by investigating the brightness temperature observed by the MTSAT infrared channel 1. This revealed that the cloud-top temperature was more than 273 K, even during rainfall events, which suggests that it is linked to a unique rainfall mechanism.

In Cambodia, a hydro-meteorological observation network was not fully re-instated following the civil war in the 1970s. Thus, there is a lack of ground truth data for calibrating satellite precipitation products. To improve this, in September 2009, 16 new rain gauges were installed around Tonle Sap Lake basin, adding to the 19 rain gauges already there. The year was classified into four seasons: “pre-monsoon”, “full-monsoon”, “post-monsoon”, and “dry” by referencing the zonal wind at 700 and 850 hPa. Then, the seasonally accumulated rainfall and its seasonally averaged diurnal distribution were compared with satellite products (TRMM/3B42 and GSMaP) and rain gauge data. The difference between the satellite products and rain gauge data was largest during the post-monsoon season. Rain gauge values were smaller than satellite product values in northern parts, but much larger than the satellite product values in the south. Reasons for the misdetection of rainfall by the satellite over southern parts were examined. We focused on cloud-top temperature during rainfall events by investigating the brightness temperature observed by the MTSAT infrared channel 1. This revealed that the cloud-top temperature was more than 273 K, even during rainfall events, which suggests that it is linked to a unique rainfall mechanism.

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Stakeholders involved in the work are those who use rainfall as a water resource, such as water-related central and regional government, irrigation associations, and farmers. Providing information on the available water resources quantitatively with high spatio-temporal resolution and higher accuracy than satellite products alone would contribute to the national water resources management system. This work is performed within the SAFE prototyping in Cambodia (“Water and Food Security under the Climate Change in Western Cambodia”, May 2012–May 2013). In this new project, we are trying to calibrate the GSMaP product with rain gauge data on a near real-time basis (five hours delay after observation). This calibrated rainfall product is used as an input to the Hydro-Crop model4) to simulate soil moisture, river discharge, available water resources for irrigation, and rice yield. The work presented here is in preparation for this application.

In the following section, the objectives of this work are outlined. Sections 3 and Chapter 4 explain the data and methodology used in this work, respectively. In Section 5, the results are presented and discussed, and then dissemination is discussed in Section 6. Finally, the direction of future work is described in Section 7.

2. Objectives

The overall goal of this prototyping is to reveal rainfall characteristics from satellite rainfall products calibrated by rain gauges. The specific objective of this study is to validate the satellite rainfall products over Cambodia for the preparation of calibration, as mentioned in Section 1.

3. Data

In this study, we used TRMM/3B42 and GSMaP for satellite rainfall products and data from 35 rain gauges for ground-based validation. In addition, we used the National Centers for Environmental Prediction-Final (NCEP-FNL)
reanalysis data to obtain the overall atmospheric conditions.

3.1. Satellite rainfall products

TRMM/3B42 and GSMaP data were used as satellite rainfall products.

1) TRMM: Tropical Rainfall Measuring Mission

The Tropical Rainfall Measuring Mission (TRMM) is a joint mission between the National Aeronautics and Space Administration (NASA) of the United States and the Japan Aerospace Exploration Agency (JAXA), and is designed to monitor and study tropical rainfall. Launched on November 28, 1997, it was the first mission to measure precipitation from space. It carries a precipitation radar (PR), together with a passive microwave imager (TMI), a visible-infrared radiometer (VIRS), a lightning sensor, and a cloud sensor. The PR, TMI, and VIRS are designed to obtain rainfall and other relevant information, such as rain type, height of the bright band, cloud type, and cloud-top height.

Various precipitation products have been created from the TRMM and other satellites, which are freely available for use and can be downloaded from the internet (http://disc.sci.gsfc.nasa.gov/precipitation/documentation/TRMM_README). Among these, product “3B42” provides precipitation estimates every 3 hours (0, 3, 6, 9, 12, 15, 18, and 21 UTC - Universal Time Coordinated) with a 0.25° × 0.25° spatial resolution, by combining various satellite systems as well as rain gauge data wherever possible. The 3-hourly precipitation value of the 3B42 product is actually the rainfall intensity during +/- 90 minutes from the nominal time (Fig. 1).

In this study, we used this product for the region of 94–110°E and 6–24°N. The acquired data are from 1 January 1999 to 31 December 2009.

2) GSMaP: Global Satellite Mapping of Precipitation

GSMaP products are also satellite precipitation data created by the JAXA satellite, which can be downloaded from the JAXA website (http://sharaku.eorc.jaxa.jp/GSMaP/index.htm). Among various products of GSMaP, we used a near real-time dataset (GSMaP-NRT). This product has higher spatio-temporal resolution than TRMM/3B42 (0.1° × 0.1°, hourly-based). In this study, we used this product for the region of 94–110°E and 6–24°N. The acquired data are from 1 January 1999 to 31 December 2009.

3.2. Rain gauge data

In June 2009, an investigation of the automatic rain gauges in the entire Tonle Sap Lake basin was conducted by the Department of Hydrology and River Works of the Ministry Of Water Resource and Meteorology (MOWRAM), under support from The University of Tokyo (UT). Previously, the Japan International Cooperation Agency (JICA), the Public Work Research Institute (PWRI, Japan), the National Institute of Rural Engineering (NIRE, Japan), and UT had installed a number of rain gauges under their projects and 24 of them were confirmed to be working at that time (Fig. 2 and Table 1).

Subsequently, during September to October 2009, 11 additional rain gauges were installed under a cooperative project between MOWRAM and UT. As the existing rain gauges mentioned above are located only in the southwest of the country, seven of the new gauges were installed in northern and eastern parts. We also installed rain gauges at two existing stations (Rattanak Mondol and Samlot) to check the consistency between the different types of rain gauges.

Two further rain gauges were installed in Pursat and Siem Reap as component parts of Automatic Weather Stations.

In this study, data from 1 January 2009 to 31 December 2009 were used.
this study, data for the region of 90–120E and 0–30N during 1 January 2009 to 31 December 2009 were used.

4. Methodology

First, we defined each season (pre-monsoon season, full monsoon season, post-monsoon season, and dry season) by reference to the NCEP-FNL reanalysis data. Next, we created 3-hourly rainfall data (same format as TRMM/3B42) both from rain gauges and from GSMaP. Then, we compared these 3-hourly datasets. The overall structure is shown in Fig. 3 as a flowchart.

4.1. Definition of seasons

To define each season we used the zonal wind at 700 and 850hPa over Cambodia (102.5–106.0E, 11.0–14.5N, Fig. 4). Those periods during which the zonal winds at 700 and 850hPa are positive are defined as the “full monsoon season” (Fig. 5). Periods before and after the “full monsoon season” are defined as “pre-monsoon” and “post-monsoon” seasons, respectively.

4.2. Data format conversion

For the comparison, we converted the rain gauge data and GSMaP data into the same format as the TRMM/3B42 data (3-hourly, 0.25° mesh). The definition of the time interval is shown in Fig. 1.

5. Results and Discussion

5.1. Overview of the rainfall in 2009

Fig. 6 is an example showing the detected rainfall from TRMM/3B42, drawing the annual rainfall amount as averaged from 1999 to 2009 (Fig. 6 left) and the anomaly of the annual rainfall in 2009 from that average (Fig. 6 right). Fig. 6 clearly shows one negative anomaly on the western side of the lake and another over the southern part of the country. This is the different phenomenon from the previous study that suggests more rainfall in western Cambodia\(^1\). The detailed discussion on it is given in the next section.

Similarly, the rainfall characteristics during the post-monsoon season (September to November) are shown in Fig. 7 as the anomaly from the 11-year average. As seen from these figures, the TRMM/3B42 dataset suggests that although Cambodia receives more rainfall in September, the rainfall amounts in October and November in 2009 were smaller than in other years.

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**Fig. 3.** Flowchart of this study and subsequent analysis.

**Fig. 4.** Target region to define each season.

**Fig. 5.** Zonal winds at 700 and 850 hPa for 2009.

**Fig. 6.** Annual rainfall amount [mm/yr] as averaged from 1999 to 2009 (left) and its anomaly in 2009 (right). Data from TRMM/3B42.
5.2. Earlier studies on the post-monsoon rainfall

From earlier studies\(^1\), \(^2\), \(^3\), it has been shown that post-monsoon rainfall is dominant in western Cambodia and that it rains mainly from midnight until early-morning. Fig. 8 shows the mean field from TRMM/3B42 for November 2007. Rainfall is detected in several grids at the west of the lake at 22:00LT and this spreads and strengthens by 01:00LT. At 04:00LT, the rainfall cells have moved to the western mountainous side, they weaken by 07:00LT, and finally disappear at 10:00LT. From these figures, we can presume the existence of a precipitation system that is triggered along the western lakeshore around 22:00LT and which moves towards the west until the early morning.

However, when we compare the TRMM/3B42 data with the rain gauge data, we often find large differences. For example, Fig. 9 shows data from three nights. In each of the panels (a)–(c), the accumulated twelve-hour rainfall totals (20:30–32:30LT) from TRMM are shown in the left-hand panels and those from the seven rain gauges are shown in the right-hand tables. These seven rain gauges are located within the six hatched cells shown in (d).

The tables in Fig. 9(a), (b) and (c) for rain gauge data show that in all three cases, some rainfall was recorded at each of the seven rain gauges. On the other hand, looking at the TRMM/3B42 data for night (a), almost no rainfall was detected across the entire region over and around the lake. For nights (b) and (c), some rainfall was detected, but only over eastern areas, and no rainfall was detected over the locations of the rain gauges.

This pattern is not just limited to these examples; there are actually many occasions of misdetection by TRMM/3B42 for the nocturnal rainfall over western Cambodia. In 2007, rain gauge data coverage was limited to western Cambodia, and thus it is not possible to make a validation for the entire region around the Tonle Sap Lake. However, we now have data for the northern and eastern side as well, and the post-monsoon season in 2009 is the first season in which we are able to make a full validation.

Therefore, hereafter we focus on two aspects of the rainfall in the 2009 post-monsoon season:

1) Is the rainfall amount in the post-monsoon season really larger in western Cambodia than other regions of the country, as suggested by the previous study\(^3\), and is this rainfall really more dominant at night through the early morning?

2) Is there a noticeable difference in the performance of TRMM/3B42 between the regions around the Tonle Sap Lake?

5.3. Results

5.3.1. Comparison of rainfall amount

We analyzed the rainfall data for the period following the rain gauge installation in September 2009, and the results are shown in Figs. 10–12.

The results during the post-monsoon season (Fig. 10) clearly show that the rain gauge rainfall is larger at the southwestern part of the lake than it is at the northeast. This tendency was not revealed by either TRMM/3B42 or GSMaP, which underestimate rainfall values in the southwest and overestimate them in the northeast. At some stations, the difference of rainfall from rain gauges and from satellite reaches to double. Thus, answering question 1) of Section 5.2., we see that the hypotheses raised there are correct. Regarding question 2), we see that the tendency of question 1) is not well captured by either TRMM/3B42 or GSMaP, owing to the spatial gap tendency over the country. It underestimated rainfall where rain gauge rainfall was large and it overestimated rainfall where rain gauge rainfall was small. Thus, there is less spatial distribution in the satellite rainfall
Comparisons of pre-monsoon and full-monsoon seasons are shown in Figs. 11 and 12. Fig. 11 shows that the rainfall during the pre-monsoon season is well captured for this year by TRMM/3B42 but is highly overestimated by GSMaP on the western side of the lake. During the full-monsoon season (Fig. 12), both the TRMM/3B42 and GSMaP seem be able to detect the rainfall well. At many of the stations, the differences are within ±20%.

As rainfall detectability during the post-monsoon season is well organized and there is a notable spatial distribution of rainfall, in the next section, we examine the reasons for the misdetection of rainfall on the southwestern side of the lake.

5.3.2. Reasons for the misdetection during post-monsoon season

Cloud-top temperature during rainfall events was examined using MTSAT IR-1 data, and the results are shown in Table 2. Clearly many of the rainfall events occurred under clouds where the cloud-top temperature was relatively high, at more than 273.5 K. As TRMM/3B42 refers to the cloud-top temperature in the process of the creation of the rainfall product, it might lead to the misdetection of rainfall events that occur under the clouds at low height. Previous study2, 3) suggests that a very localized circulation triggered over the warm lake initiates the local rainfall. Thus, such a local rainfall event would be one that would not be detected correctly by TRMM.

6. Dissemination

In applying these results, we are aiming to calibrate the GSMaP product and to make the rain-gauge-based modified GSMaP accessible to local users in Cambodia. Because of the historically poor rain gauge system, the rainfall pattern in Cambodia has not been clarified yet; however, these results will help to modify the satellite rainfall products and to elucidate the spatio-temporal distribution of rainfall over Cambodia. As the GSMaP-NRT is available after only four hours delay, we can provide rainfall data that are more reliable in near real-time. These data would be used for early warnings of floods and agricultural water management.
Table 2. Detected rainfall amount (from TRMM/3B42 (TRMM) and rain gauges (RG)) and brightness temperature (TB) during rainfall event. Brightness temperature lower than 273.5 K is shown in bold italic font.

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7. Future Direction

We are now developing the correction method for the GSMaP-NRT using rain gauge data. In February and March 2013, the authors installed a rain gauge data transmission system with which to send rainfall data directly from the rain gauges to the Department of Meteorology, Cambodia and then on to The University of Tokyo, Japan. Moreover, we have integrated a rice growth model and a hydrological model (Monichoth et al.) and plan to use this near real-time corrected GSMaP data as an input to this integrated model. Then, we could provide local people with information on rainfall, soil moisture, river discharge, available irrigation amounts, and rice yields on a near real-time basis.

Acknowledgments

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