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Rainfall estimation for real time flood monitoring using geostationary meteorological satellite data

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Abstract

Rainfall estimation by geostationary meteorological satellite data provides good spatial and temporal resolutions. This is advantageous for real time flood monitoring and warning systems. However, a rainfall estimation algorithm developed in one region needs to be adjusted for another climatic region. This work proposes computationally-efficient rainfall estimation algorithms based on an Infrared Threshold Rainfall (ITR) method calibrated with regional ground truth. Hourly rain gauge data collected from 70 stations around the Chao-Phraya river basin were used for calibration and validation of the algorithms. The algorithm inputs were derived from FY-2E satellite observations consisting of infrared and water vapor imagery. The results were compared with the Global Satellite Mapping of Precipitation (GSMaP) near real time product (GSMaP_NRT) using the probability of detection (POD), root mean square error (RMSE) and linear correlation coefficient (CC) as performance indices. Comparison with the GSMaP_NRT product for real time monitoring purpose shows that hourly rain estimates from the proposed algorithm with the error adjustment technique (ITR_EA) offers higher POD and approximately the same RMSE and CC with less data latency.
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Keywords: Hourly rain rate; Infrared threshold rainfall; Satellite remote sensing

1. Introduction

The estimation of rainfall is an important and contributing factor to several issues regarding the impact of climate change. Natural disasters such as floods, landslides and droughts are the result of excesses or deficits of rainfall in many parts of the world. Enhancing our capability to monitor rainfall with high spatial and temporal resolutions can be advantageous in preventing and mitigating the severity of flood calamities in the future (Li et al., 2013). There are several methods for rainfall measurement and estimation. Rain gauges can directly measure the amount of rainfall, while radars play an important role in real time rainfall monitoring although its accuracy decreases with distance. However, in some areas, both rain gauge and radar are not feasible due to cost, technological infrastructure or topography. Rainfall estimation by satellites is therefore an alternative to achieve real time rainfall estimation with high spatial resolution and wide coverage. Despite surface rainfall gauge measurements being point based over an integral of time, while satellite estimates are instantaneous measurements over an integral of space, relationships between the satellite and surface datasets have been found in previous works (Goodman et al., 1994). Since point gauge rainfall measurements are considered representative of the average rainfall hourly accumulated over co-located satellite pixel areas, these data are used to correlate with satellite data received at the beginning of each hour to compute hourly rain estimates over each pixel area. The computed rain estimates are considered as

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representatives of the averages hourly rainfall measured by point gauges.

A number of rainfall estimation products with near-global coverage have the potential to be used. For hourly monitoring purposes, most products use input data from the thermal infrared (TIR) sensors onboard geostationary (GEO) satellites that may be combined with passive microwave (PM) data to increase its accuracy. Some of these well-known techniques include the Precipitation Estimation from Remote Sensing Information using Artificial Neural Network (PERSIANN; Hsu et al., 1997), the Climate Prediction Center MORPHing technique (CMORPH; Joyce et al., 2004), and the Global Satellite Mapping of Precipitation (GSMaP; Ushio et al., 2009). The main differences among them are the manner in which data inputs are combined. The PERSIANN algorithm uses a three-layer feed-forward artificial neural network (ANN) technique to estimate rainfall rate from TIR data. The CMORPH technique, one of the best products at present, combines the greater accuracy of PM rainfall estimates with the better temporal resolution of TIR observations. The PM rainfall estimates are morphed by motion vectors derived from half-hourly TIR data. The GSMaP algorithm is similar to CMORPH in which the PM estimates are propagated using TIR-derived motion vectors. A difference is that GSMaP algorithm applies the Kalman filter to the propagated PM estimates to update TIR rainfall estimates when the PM estimates are absent. There are two available GSMaP products: the near real time version GSMaP_NRT and the non-real time version GSMaP_MVK which provides more accuracy by using backward propagation and additional data from the Advanced Microwave Sounding Unit (AMSU). A comparison of the performance of both GSMaP products is shown in our previous work (Veerakachen et al., 2014). In this work, only GSMaP_NRT product is considered since GSMaP_MVK product is not available for real time monitoring purpose.

The accuracy of these estimates may vary over different regions of the world. Evaluation of satellite precipitation products by using a station network of about 600 rain gauges over Colombia, Dinku et al. (2009) found CMORPH to be the best product, whereas the PERSIANN product overestimated and GSMaP_NRT underestimated the rainfall. For real time monitoring, the PERSIANN rain estimate is available with 2 days latency (http://hydis8.eng.uci.edu/persiann), the CMORPH product is available with 18 h delay (http://www.cpc.ncep.noaa.gov/products/janowiak/cmorph_description.html), while the GSMaP_NRT algorithm offers estimates with 4 h data latency (http://sharaku.eorc.jaxa.jp/GSMaP/index.htm). Since the least data latency is preferred for flood monitoring and warning systems, GSMaP_NRT is the most appropriate rain estimate product available at present.

To reduce the time delay for real time flood monitoring, an alternative for satellite rainfall estimation is to develop GEO-IR rain estimate technique using only TIR input data obtained from GEO meteorological satellites. This data can be received (sub-) hourly through a satellite-based Digital Video Broadcast via Satellite (DVB-S) service under the Integrated Global Data Dissemination Service (IGDDS) project of the World Meteorological Organization (WMO). Data latency could therefore be reduced enabling real time rainfall estimation. There are a number of GEO-IR based rainfall estimation technique. For flash flood monitoring a technique with less complexity and less data input is preferred. The well-known Convective Stratiform Technique (CST) is complicated and related to the climatic conditions (Adler and Negri, 1988) while the NESDIS Auto Estimator considers several factors in addition to IR cloud top temperature, such as cloud growth rate, relative humidity, and cloud structure (Vicente et al., 1998). The simple GOES Precipitation Index (GPI) estimates rain within the area of 50×50 km by the fraction of area that has cloud top temperature less than 235 K (Arkin and Meisner, 1987). In the Tropics, the optimal threshold for cold cloud filtering has been found to be 253 K (Goodman et al., 1994). The Negri-Adler-Wetzel (NAW) technique also uses 253 K threshold to identify cloud area (Negri et al., 1984). However, the NAW technique gives only two rain estimates, 8 mm h^{-1} for heavy rain and 2 mm h^{-1} for light rain. The Infrared Power law Rain rate (IPR) relationship between rainfall amount and IR brightness temperature, representing cloud top temperature, was found to be useful in estimating rain rate as a continuous function of cloud brightness temperature (Goodman et al., 1994). The Infrared Threshold Rainfall (ITR) technique has been proposed using 253 K threshold to identify rain cloud and IPR relationship for rainfall estimation (Pegram et al., 2004). The accuracy of rain estimates may be improved through the use of regional rainfall statistics.

The purpose of this work is to develop rainfall estimation algorithms based on an ITR method adjusted by local rain gauge data that is (1) computationally efficient using only TIR inputs from GEO satellite to reduce estimation latency providing more lead time for flood monitoring and warning system and (2) sufficiently competent to offer equivalent performance to the GSMaP_NRT by compensating for performance degradation through regional data calibration. Results are validated and compared with those of GSMaP_NRT to examine which algorithm would be appropriate for a flood warning and monitoring system.

2. Materials and methods

2.1. Study area and data sources

The Chao-Phraya river basin, located between 13.5°–16.1°N and 99.5°–101°E, is chosen as the study area. With a total area of 20,125 km^2, the basin is regarded as a principal water way with the most fertile rice and fruit-growing area of the country; it is also heavily affected

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