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Identification of rainfall area in Indonesia using infrared channels of Himawari-8 Advance Himawari Imager (AHI)

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Abstract. The study aims to investigate the use of Infrared (IR) channels of Himawari-8/AHI for identification of rainfall area in Indonesia. The parameters used include the IR brightness temperature (BT) at 10.4 microns (T10.4) and seven IR BT differences (BTD), which were inferred as proxies for cloud properties. Identification of rainfall in this study is based on lookup table (LUT) approach, which is used to create probability of rainfall map. The LUTs were developed by combining the IR at 10.4 microns and IR BTD with the transportable X-band radar data, gathered during the campaign period on 15 March – 5 May 2017. Statistical skill scores were used in the study to determine the overall performance of the methods. The study indicated that the best IR and BTD combination to identify rainfall area is from the bands correlated to cloud-top height proxy (T10.4 and BTD 13.3- 10.4). In visual comparison with Global Satellite Mapping of Precipitation (GSMaP) hourly rainfall image, this IR-BTD method produced rain maps with high similarity. In general, almost all IR-BTD combinations could be used to identify rainfall area with comparable results. However combination of T10.4 and BTD at 6.2 & 7.3 micron generate high false alarm rates and underestimate the area of rainfall.

Keywords : Himawari-8, Brightness temperature, Cloud, Lookup Table, X-band radar.

1. Introduction

Indonesia hosts one of the most variable climate system in the world. Rainfall variability in this region is highly variable and convoluted due to its geographical features and complex topography conditions. Rainfall pattern in Indonesia is also incoherent spatially and temporally [1]. Scientific investigations on rainfall variability is important since it influences many aspects of life of million people living in the region. Moreover, the most frequently natural disasters occurred in Indonesia, such as floods and landslides are primarily triggered by extreme rainfall events. Study on rainfall in this region is necessary in order to improve knowledge and quality of weather/climate forecasting, and the Decision Support System (DSS) development to minimize the risk of disaster impact. Thus, accurate rainfall measurements are crucial and highly needed, which includes better methods of rainfall estimation from remotely-sensed instrument.

Over the past three decades, there have been numerous attempts to use satellite measurements for rainfall estimation, which is proven to be cost-effective, continuous and reliable sources over the remote regions where rainfall data is very limited [2,3]. A range of rainfall estimation techniques has been developed. The methods that utilized visible (VIS) and infrared (IR) measurements rely upon the



information provided by cloud-top characteristics. In spite of their indirect relationship between the cloud-top and rain-rate [4], they have the advantage of frequent observations compared to the techniques that use passive microwave (PM). In addition, the use of geostationary-orbit satellite data for this purpose offers very good temporal resolution that the dynamic of cloud and rainfall can be observed.

The newest generation of Japanese geostationary meteorological satellites, Himawari-8/9, equipped with an Advanced Himawari Imager (AHI) instrument, with significantly higher radiometric, spectral, and spatial resolution than those previously available in the geostationary orbit. The satellites have 16 observation bands, specifically: 3 VIS bands, 3 NIR bands, and 10 IR bands with high spatial resolution: 0.5 or 1 km for VIS and NIR bands and 2 km for IR bands [5]. Moreover, a temporal resolution of ten minutes provides real time monitoring of rainfall and cloud activities. The IR bands of AHI are currently not yet fully utilized for rainfall estimation researches. Therefore, this study seeks to investigate the use of IR channels of AHI brightness temperature (BT) and brightness temperature difference (BTD) to identify rainfall area specifically within Indonesia region.

Previous several studies pointed out that IR BTD can be a proxy of cloud properties, which can be associated with rainfall rate [6,7]. These cloud properties include cloud-top height, cloud optical thickness, cloud phase, and cloud water path. This study will examine the capability of the wide range Himawari-8 IR channels for rainfall area detection. Identification on the rainfall area is based on look-up table (LUT) approach, which is developed by utilizing the X-band radar data observed during a weather observation campaign in Bandung for about two months. The LUTs are used to produce probability of rain (POR) maps which are determined from the combination of IR and IR BTD channels of AHI observation.

2. Data dan area of study

The data used in this study includes the IR and IR BTD from Himawari-8 AHI (Table 1), the constant altitude plan-position indicator (CAPPI) product at 3km altitude of horizontal reflectivity from the transportable X-band radar, and the GSMaP MVK hourly rainfall rate product. The radar data were obtained during the observation campaign in Bandung on 15 March – 5 May 2017. The instrument was installed at Rancakasumba Substation (107.77 E, 7.04 S) located in Majalaya, south of Bandung city and covered the area within 100 km radius (Figure 1). For evaluation, the study area was expanded to the almost all region of Indonesia (10 S – 10 N; 95 W – 150 W) and the study period was extended to March until 31 December 2017.

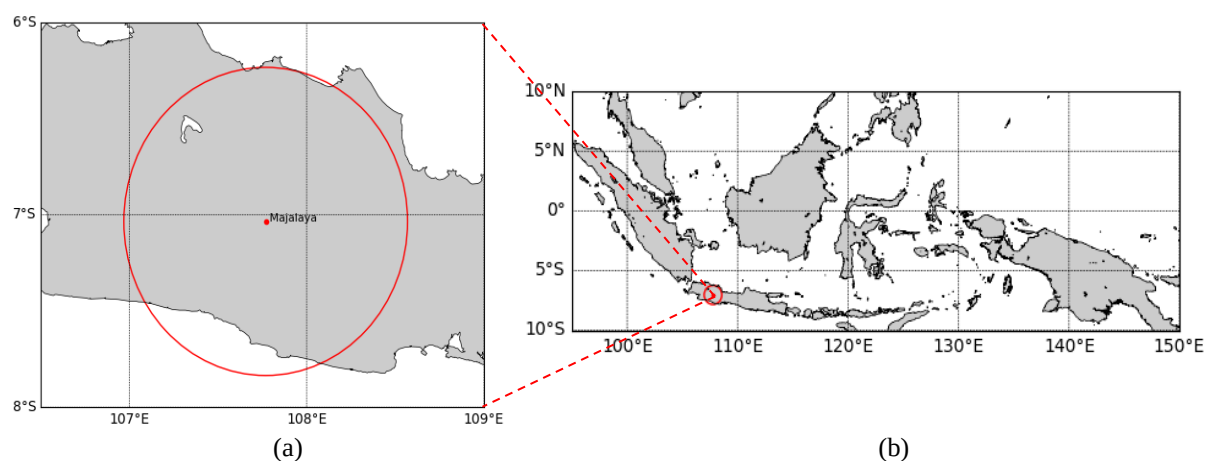


Figure 1. Location of the transportable radar at Rancakasumba substation, Majalaya (a) and the area of study for verification stage (b). Red circle shows the area coverage of radar.

Table 1. Selected BTM combinations used in creation of POR LUT

Related cloud property	Label	IR-BTD Combination
Cloud Top Height	CTH1	$T_{10.4} \text{ \& } T_{6.2-10.4}$
	CTH2	$T_{10.4} \text{ \& } T_{6.2-7.3}$
	CTH3	$T_{10.4} \text{ \& } T_{13.3-10.4}$
	CTH4	$T_{10.4} \text{ \& } T_{9.6-13.3}$
Cloud Optical Thickness	COT1	$T_{10.4} \text{ \& } T_{10.4-12.3}$
	COT2	$T_{10.4} \text{ \& } T_{8.6-12.3}$
Cloud Phase	CP	$T_{10.4} \text{ \& } T_{8.6-10.4}$

3. Methods

Initial step to derive rainfall area from Himawari-8 is creating the POR LUT. These LUTs were developed based on relationship between IR and BTM with the collocated X-band radar data. Different BTM combinations in this process were utilized, thus, creating different LUTs. These POR LUTs were used to produce POR maps. Rainfall maps were determined and assessed to classify rain from no-rain based on POR threshold. Furthermore, a comparison of the resulting rainfall maps with another satellite rainfall data known as GSMaP hourly rainfall data was performed to validate the output maps within the region of Indonesia.

3.1. LUT Construction

POR is defined as the percentage value of rain event frequency over the total number of events. The equation is presented as [7]:

$$POR(x_1, \dots, x_n) = \frac{N_{rain}(x_1, \dots, x_n)}{N_{rain}(x_1, x_2, \dots, x_n) + N_{no-rain}(x_1, \dots, x_n)} \quad (1)$$

Where $(x_1, \dots, x_n)$ are the combination of IR-BTD as listed in Table 1, and $N_{rain}(x_1, \dots, x_n)$ and $N_{no-rain}(x_1, \dots, x_n)$ are the number of pixels with rain and with no-rain denoted by $(x_1, \dots, x_n)$ respectively. There are seven combinations of IR and BTM used in this study (Table 1).

POR LUTs are created through temporal and spatial matching of IR and BTM maps with the radar reflectivity maps. Rain and no-rain pixels were identified and assigned from radar reflectivity data to the equivalent IR and BTM pixels. The POR distribution as a function of IR and BTM combinations were generated by using Equation 1. Each IR and BTM combinations produced an LUT which in turn can be utilized to create maps with rain and no-rain areas. Finally, a map classifying rain from no-rain areas were derived by setting the threshold in POR distribution applying the LUT on satellite data images. This study used a threshold value of 0.32 [7].

3.2. Verification metrics

The categorical statistics [8], was used in this study to further evaluate and compare the performances of each IR and BTM combinations in Himawari-8 rainfall area detection. The categorical statistics applied in this study included: i) Probability of Detection (POD); ii) False Alarm Ratio (FAR); iii) Probability of False Detection (POFD); and iv) Critical Success Index (CSI), all calculated as follows [9]:

$$PD = H/(H + M) \quad (2)$$

$$FAR = F/(H + M) \quad (3)$$

$$POFD = F/(F + C) \quad (4)$$

$$CSI = H/(H + F + M) \quad (5)$$

Table 2. Contingency table used for computation of categorical statistics.

Forecasted or estimated	Observed	
	Rain	No-rain
Rain	Hits (H)	False Alarm (F)
No-rain	Misses (M)	Correct Negative (C)

The POD is the fraction, which the Himawari-8 algorithm correctly estimated rainfall events as measured in observed rain maps. It ranges from 0 to 1 with a perfect value of 1. FAR is the fraction, which the satellite algorithm has detected rainfall events, but there is no rain events in observed rain maps. It ranges from 0 to 1 with a perfect value of 0. POFD is almost similar to FAR, but the condition is on observations rather than the forecasts. It ranges from 0 to 1 with a perfect value of 1. CSI is a fraction, which satellite algorithm has correctly estimated rainfall but taking into account the false alarms in contrast to POD. It ranges from 0 to 1 with a perfect value of 1. In this study, observation data of rainfall events were obtained from GSMaP MVK hourly data product. The calculation of these statistical scores were applied for each pixel of rainfall area map derived from each LUT, which matched spatiotemporally with the GSMaP data.

4. Results and Discussion

4.1. Probability of Rain (POR) LUT

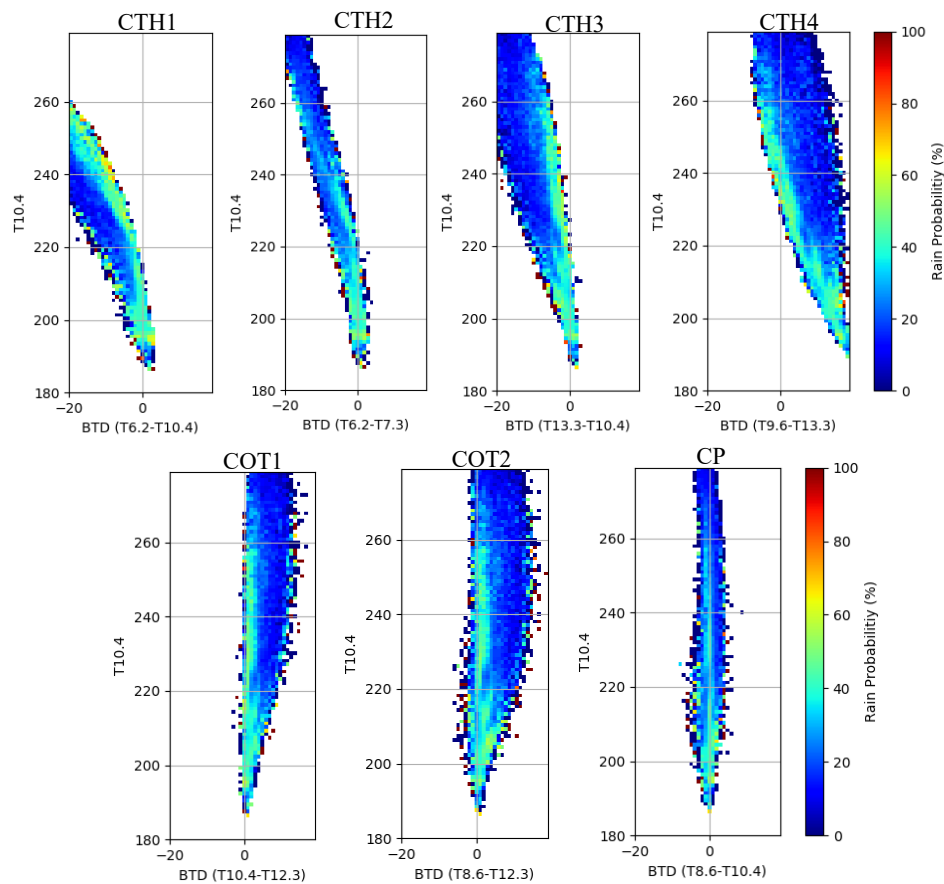
**Figure 2.** Probability of rain (POR) LUTs developed from IR-BTD combinations

Figure 2 shows the POR LUTs produced by comparing IR and BT/D combinations to the X-band radar reflectivity which has been identified as rainfall. The POR was calculated by using Equation (1). To determine rainfall area from these LUTs, a threshold value of 0.32 have been used. IR and BT/D values that have POR higher than or equal to the threshold will be assigned as rainfall area, and vice versa. This threshold was successfully used to define rain and no-rain area using the similar method in Phillipines [7]. Determining a proper threshold value in this method is really important since it significantly affects the rainfall area generated by the LUTs.

The POR LUTs indicate that rain areas ($POR \geq \text{threshold}$) have brightness temperature at 10.4 microns ($T_{10.4}$) generally lower than 260K. This is acceptable, since lower temperature is strongly associate with clouds, and colder clouds highly correlated with rain. The LUTs also show that there were no/very least POR values could reach 100%. This means that there are no exact values of IR-BTD combination could determine rainfall with high certainty. POR distribution mostly lies in the data range of 20-30%. This implies that the uncertainty of IR method to detect rainfall should be noticed.

4.2. Comparison with GSMaP Data

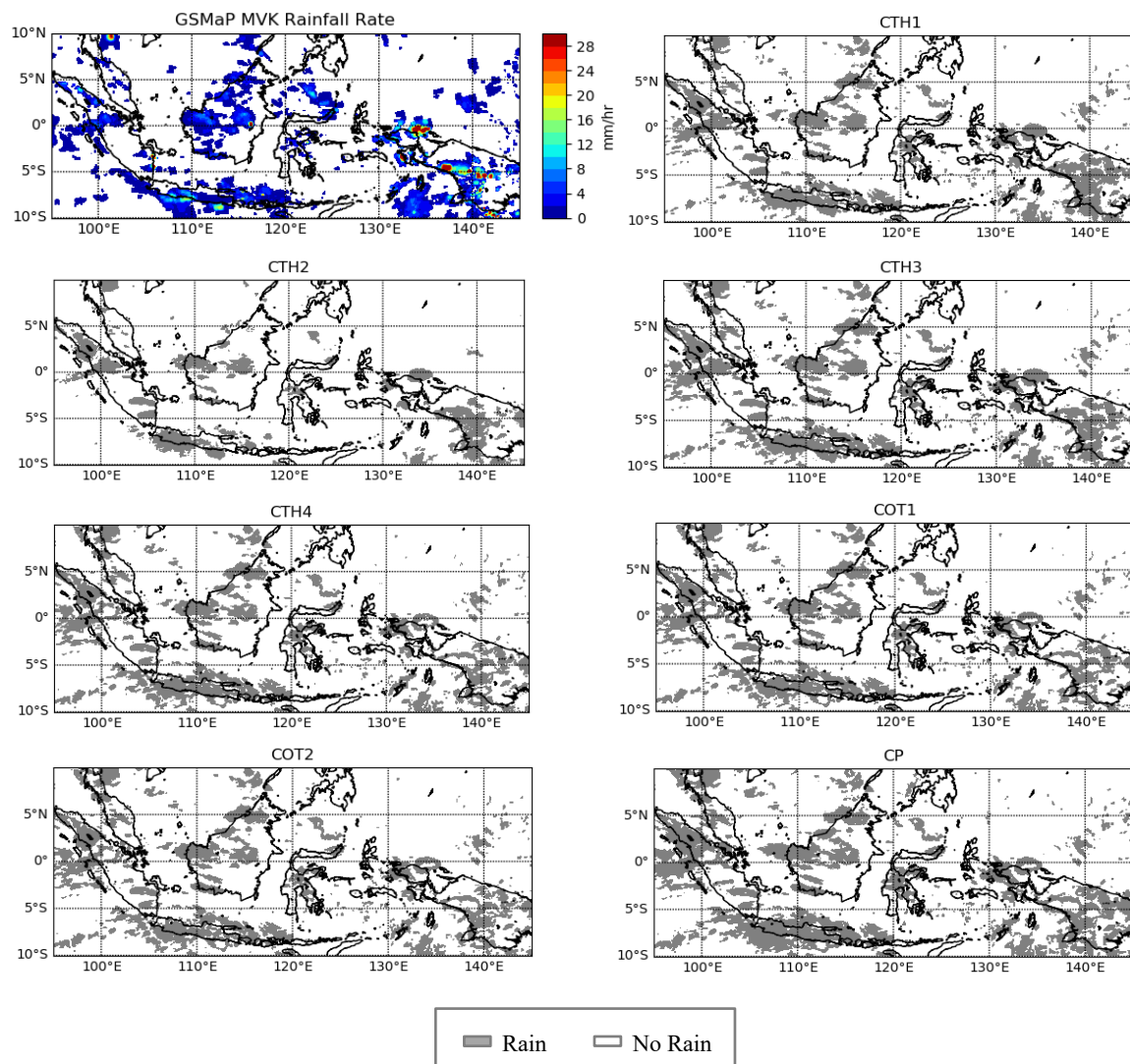


Figure 3. Comparison of GSMaP rain rate product and rain area maps produced by IR-BTD combinations taken at April 06, 2017 12:00 UTC

POR LUTs that have been created were used to generate rainfall area. The performance of the method of each IR-BTD combination will be evaluated by comparing them with rain rate products from GSMaP data. The intensity of GSMaP rainfall will not be further analysed since comparison was only done to investigate whether rain or no-rain occurred at the region of interest. Figure 3 shows one of example of the comparison results. In visual comparison, generally all IR-BTD combinations could be used to identify rainfall area with relatively high similarities to GSMaP product. There was only one exception, that is CTH2, which seems to generate smaller area of rain compared to the others. Almost all of IR-BTD combinations generated an overestimation compared to GSMaP, except CTH2 which is mostly underestimates. However, in several locations there were also the cases where rainfall occurrence in GSMaP were not appeared in the rain maps produced by LUTs. Almost all of combinations of BTd used in the method yielded the similar pattern of rainfall area. The differences amongst them were not significant.

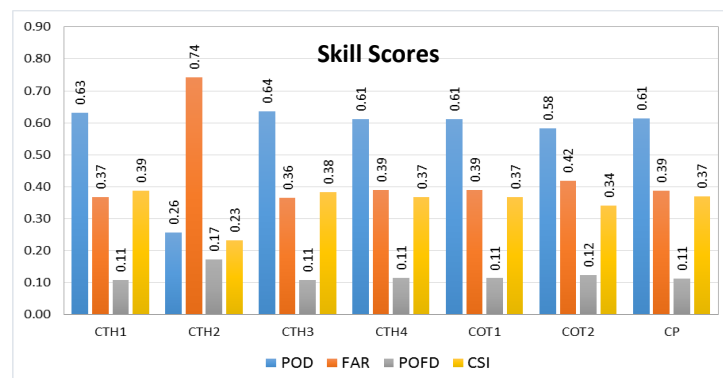


Figure 4. Some statistical scores used in the study to evaluate performance of the method.

Figure 4 shows the comparison of rainfall area produced by LUTs method and rain rate product of GSMaP qualitatively. This study used four categorical statistics (i.e. POD, FAR, POFD and CSI) to examine the performance of the methods. Based on their statistical scores, almost all IR-BTD combination have similar results, except CTH2. Very high FAR (0.74) obtained by CTH2, showing that this combination has the poorest accuracy compared to the others. The best combination of IR-BTD to detect rainfall area is from CTH3 (POD=0.64, FAR=0.36, POFD=0.11, CSI=0.38), which also has very close result to CTH1 (POD=0.63, FAR=0.37, POFD=0.11, CSI=0.39). It is interesting to see that the CTH3 and CTH2, that have the strongest and the poorest correlation with GSMaP, come from the same group that represent cloud top height properties.

Three channels (BT at 10.4 micron and BTd at 6.2 & 7.3 micron) were involved in CTH2 combination. The use of BT at 6.2 microns in CTH1 produced good results, which is acceptable since T6.2 can represents amount of water vapour in upper layer of atmosphere thus it can relate to clouds and rainfall. This channel usually used to extracting deep convective clouds with heavy rainfall [10]. However, the combination of T6.2 and T7.3 as used in CTH2 generated the lowest score. Brightness temperature at 7.3 micron is also sensitive to water vapour, but its capability to retrieve rainfall area when combined with other water vapour channel (T6.2) is poor.

Underestimation of rainfall area produced by CTH2 may also caused by inappropriate threshold value used to define rain and no-rain from POR LUT. Modification of this value, for example by lowering the threshold for CTH2, might generate larger areas of rainfall and expected to be more consistent to the GSMaP observation. However, even after changing this value for CTH2, the results were not too different. Figure 5 shows one example of the change of rainfall area produced by CTH2 by setting the threshold to become 10% and 20%. Based on the Figure 5, modification of threshold value for CTH2 have no impact to the rainfall area map generated.

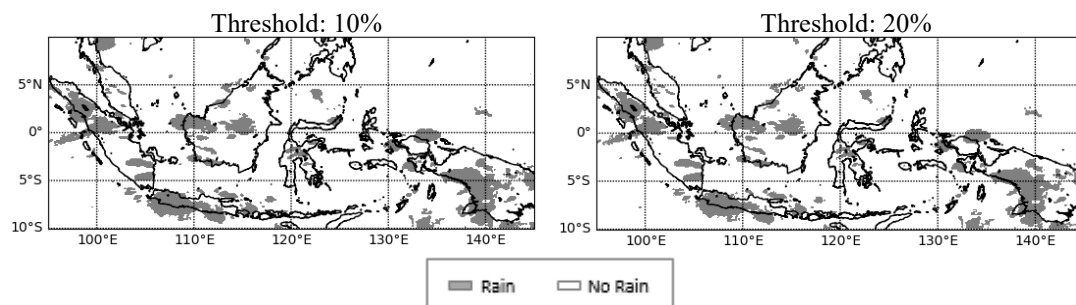


Figure 5. Rainfall area generated from CTH2 after changing the threshold value of rain/no-rain to 10% (left) and 20% (right)

5. Conclusion

This study investigated the application of Himawari-8 infrared channels for rainfall area identification through LUT method, which is developed based on relationship between IR-BTD of AHI and X-band radar reflectance. Almost all combinations of IR BT and BTD have generated rainfall area with comparable result to GSMaP data observation. However, combination of BT at 10.4 micron and BTD at 6.2 & 7.3 micron based on this study is not recommended to be used for rainfall area retrieval. The method used in the study can be utilized as initial step for satellite-based rainfall rate estimation or specifically for heavy rainfall potential area detection which is highly related to the natural disaster. In addition, further investigation on specific type of clouds and other different cases of rain like thunderstorms, is still needed.

Acknowledgments

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