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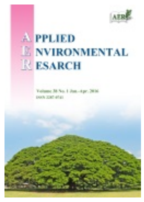

Radar Quality Index for a Mosaic of Radar Reflectivity over Chao Phraya River Basin, Thailand

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Abstract

The weather radar is one of the tools that can provide spatio-temporal information for nowcast which is useful for hydro-meteorological disasters warning and mitigation system. The ground-based weather radar can provide spatial and temporal information to monitor severe storm over the risky area. However, the usage of multiple radars can provide more effective information over large study area where single radar beam may be blocked by surrounding terrain Even though, the investigation of the sever storm physical characteristics needs the information from multiple radars, the mosaicked radar product has not been available for Thai researcher yet. In this study, algorithm of mosaicked radar reflectivity has been developed by using data from ground-based radar of Thai Meteorological Department over the Chao Phraya river basin in the middle of Thailand. The Python script associated with OpenCV and Wradlib libraries were used in our investigations of the mosaicking processes. The radar quality index (RQI) field has been developed by implementing an equation of a quality radar index to identify the reliability of each mosaicked radar reflectivity pixels. First, the percentage of beam blockage is computed to understand the radar beam propagation obstructed by surrounding topography in order to clarify the limitations of the observed beam on producing radar reflectivity maps. Second, the elevation of beam propagation associated with distance field has been computed. Then, these three parameters and the obtained percentage of beam blockage are utilized as the parameters in the equation of RQI. Finally, the detected radar flare, non-precipitating radar area, has been included to the RQI field. Then, the RQI field has been applied to the extracted radar reflectivity to evaluate the quality of mosaicked radar reflectivity to inform end user in any application fields over the Chao Phraya river basin.

Keywords: Radar mosaicking; Radar Quality Index; Thailand; Chao Phraya River Basin; Python

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Introduction

The developing countries including Thailand, people still have suffered from disaster since they are lacking adequate information to cope with disaster. Well preparedness for disaster management is one of the most important responsibilities of the governments all over the world. However, appropriate information is needed to cope with spatial and temporal variations of destructive disaster. The deployment of the weather radar network from Thai Meteorological Department (TMD) has provided meteorologists with critical information toward the issuance of warning for severe weathers, severe storms and flash flood. In addition, the information of moving precipitation derived only from the single radar has provided information to public over the radar coverage. The disadvantage of using single radar has been addressed such as spatial differences in the sampling properties for both horizontal and vertical, beam blockage, range-dependent biases [1]. However, the mosaicking of multiple radars will provide more information for meteorologists to observe an evolution of severe storm which can increase the accuracy on forecasting and warning system.

In developed countries such the United State, the algorithm of the national mosaicking of multiple radar has been developed by using the operational WSR-88D for producing real time radar-derived rainfall product to support the warning and forecasting mission of the National Weather Service more than 20 years [2]. Recently, the national mosaic integrating radar, rain gauge, satellite and numerical weather prediction data have been fused into a seamless national 3D radar mosaic product [3]. The depiction and rendering of storm structure from the 3D radar mosaic products can provide more insightful information which US meteorologists can apply to their warning systems. This can help reducing the losses from the hydro-meteorological disasters. However, in the developing countries including Thailand, official mosaicked radar products are unavailable to be used for research purpose and real-time monitoring of severe weather.

Several factors affect to radar reflectivity observed by the weather radar leading to uncertainty of the radar measurements. Zhang et al. [4] have introduced the Radar Quality Index (RQI) by a combined measure for beam blockage and the vertical profile of reflectivity (VPR) effects in a national radar mosaic network. The quality of the next-generation multi-sensor quantitative precipitation estimation (QPE) varies in both space and time due to a number of factors, which includes: (1) errors in measuring radar reflectivity; (2) segregation of precipitation and non-precipitation echoes; (3) uncertainties in Z–R relationships; and (4) variability in VPR. The RQI field is developed to describe the radar QPE uncertainty associated with VPRs. The RQI field accounts for radar beam sampling characteristics (blockage, beam height and width) and their relationships with respect to the freezing level. However, the VPRs information is hard to derive from TMD data due to limitation of elevation angles used in the operational observation. In fact, the radar network over the middle of Indochina Peninsula mainly in Thailand is quite densely distributed, but rainfall products derived from these radars are not yet publicity. In addition, these radars are not unified in terms of their set parameters, scheduling of observation times, and data for-mats [5]. Apart from radar observation products, Friedrich et al. [6] have proposed the first quality control concept for radar reflectivity, polarimetric parameters and Doppler velocity based on a pixel-pixel basis. The quality-index field is transferred together with the radar data to end user who chooses the amount of data and the level of quality used for further processing.

In this study, the RQI for TMD radar mosaicking product has been developed based on the study of Mahavik and Sarintip [7-8]. A simple method was developed in this present study to obtain mosaicked radar reflectivity over the Chao Phraya River basin which locates in the middle of Thailand. The developed RQI field has been integrated with detected radar flares which are the non-precipitating rain pixel

Data and study area

Radar reflectivity data of two stations, which are Phitsanulok and Chainat, has been used in mosaicking process to find radar flares. The Phitsanulok and Chainat weather radar stations are located in the Chao Phraya river basin, Thailand (Figure 1).

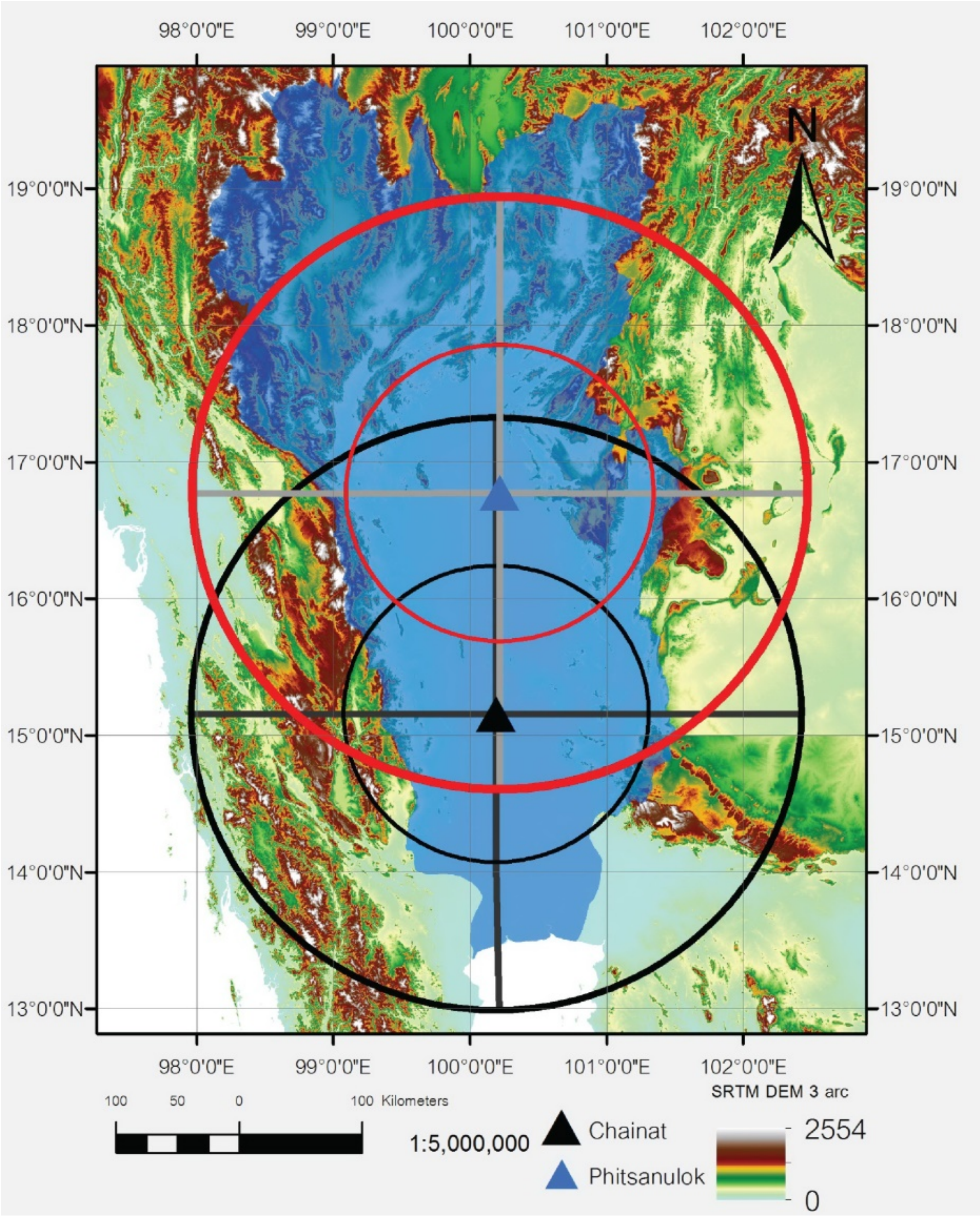

Figure 1 Study area over Chao Phraya River basin (shown in blue area) located in the middle of Thailand. Radar observation radius at Phitsanulok and Chainat stations with two observation ranges of 120 and 240 km, respectively, in the mode of 1st PPI (0.5°) provided by Thai Meteorological department.

The Phitsanulok radar site is located at latitude of 16°46'30.358"N and longitude of 100°13'4.312"E over the height of 47 m above mean sea level with tower height of 30 m. The Chainat radar is located in the middle of Chao Phraya River basin over the height of 18 m above mean sea level at latitude of 15°9' 27.898"N and longitude of 100°11'24.242"E which is in relative flat area comparing to Phitsanulok radar. Both radar data are observed by the TMD at four time per hour, while the data has been archived as images by Hydro and Agro Informatics Institute (HAII) at frequency of once per hour in format of GIF. The observation radius of the Phitsanulok and Chainat radar is 240 km observing in C-band frequency with beam width of 1°. In this study, the Plan Position Indicator (PPI) image of the first elevation at 0.5° from horizontal line have been collected and used in the analysis and radar data during influencing period of Sonca tropical storm on 26th July 2017 according to TMD warning announcement has been processed and investigated to develop RQI.

Methodology

The workflow of this study is shown in Figure 2. Quality index of mosaicked radars is developed to describe the quality of mosaicked radar reflectivity pixels. Three factors have been considered to develop the RQI. Python script was used during the development process for this study. An open source library of weather radar written in python, i.e. Wradlib [9], has been used in the analysis of beam-blockage fraction to simulate terrain obstructed for propagating beam. We have developed a method to detect the radar flares using Digital Image Processing (DIP) in computer vision technique by employing OpenCV (Open Source Computer Vision Library) using Python script interface.

To reconstruct of the propagating radar beam through the atmosphere, the spherical coordinate radar reflectivity was considered with the elevation above mean sea level (MSL) obtained from the SRTM Digital Elevation Model (DEM) V4 with resolution of 3 arc second [10] for each range bin at resolution of 1 km. The height of each range bin was calculated using the standard refraction relation from Eq. 1 [11].

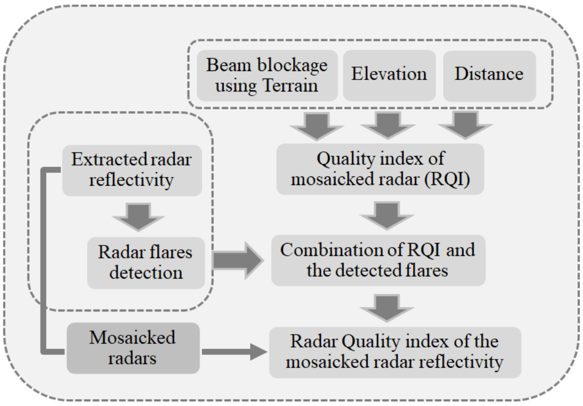

Figure 2 Flowchart of the developed radar quality index in assessment of the mosaicked reflectivity of two radars.

The first factor is the geometry of radar beam propagation which has been used to find area where beam blockage over 50% of beam width by considering with terrain data from SRTM DEM as equation (1). Second factor is the elevation of center radar beam as propagating through the air which has been included to the RQI calculation. The last factor is the distance of propagating radar beam which is also considered to realize the beam range to the end users. The combination of those mentioned three factors are simply integrated in the linear equation with initial weight based on reviews as shown in Eq. 2. Kajewski et al. [12] has concluded that using DEM in the prediction of radar beam occultation is a viable tool, as indicated by the good agreement of the calculated patterns of power loss with the actual long-term radar data. It is needed to quantify the beam blockage to realize the uncertainty of radar-rainfall products associated with the current scanning strategy and to design of future radar networks. Therefore, the beam blockage has been considered as the highest weights compared to the other two factors because the beam blockage can diminish the returned radar reflectivity and it may increase uncertainty of radar rainfall estimates. The computation of those three factors is done on the basis of single station afterward mosaicking the calculated factors.

The additional information of radar flares has been included to the RQI to inform the strong affected areas of radar reflectivity. The flares are not rain areas, but it occurs because of the interfering from other signal in communication sectors. The locations of radar flares usually change in both space and time. However, the radar flares are obviously detected over the Phitsanulok radar and the permanent flare location in the west of radar site is also detected after the radar beam crosses over the mountain in Sukhothai Province.

To detect the radar flares, there are two main steps in the python script developing [8, 13]. First, the morphological transformations have been applied to the extracted reflectivity to detect the flares. The extracted reflectivity is, then, converted to grey scale image to be ready to apply kernel convolution window. To eliminate small holes inside foreground objects, the morphological close is applied following with application of erosion morphology to separate each possible flare apart from the group of rain pixels. Second, in order to apply the process of flare detection, the eroded image in greyscale has been scanned for delineating the contour of the pixel objects. The contoured image is used as the main input in the next process. Before the flare detection, it is needed to identify rain coverage area for classifying the instantaneous scan of radar reflectivity into two classes which are small rain and large rain classes. The threshold is set at the rain area of 15% of radar coverage area. If the rain area is greater than this threshold, it will be classified as large rain class; otherwise, it will be classified as small rain class. The small rain class is applied to the automated flare detection later. After that, regional of interests has been applied to detect those flares in the small rain class. Eventually, the computed radar flares of the Phitsanulok radar have been included with the RQI.

$$H = \sqrt{r^2 + R'^2 + 2rR'sin\emptyset} - R' + H_0 \quad \text{(Eq. 1)}$$

where r is the range from the radar to the point of interest, ø is the elevation angle of the radar beam, H_0 is the height of the radar antenna, R' = 4/3R, and R is the earth's radius (approximately 6,374 km).

$$RQI = (0.25 * Distance) + (0.25 * Elevation) + (0.5 * Beam\,Blockage) \quad \text{(Eq. 2)}$$

Results and discussion

1) Mosaicked radars

To study of rainfall characteristics in mesoscale, the mosaicked multiple radars is needed because of the high spatiotemporal information. This information can be used in rainfall analysis over large watershed such the Chao Phraya river basin. However, the mosaicked radar product is not officially available for research in Thailand. Therefore, the public accessible radar reflectivity is used in this study. The Reflectivity data from two stations are simply mosaicked using maximum value of extracted radar reflectivity as shown in Figure 3(a).

The two areas of mesoscale moving clouds of stratiform and convective clouds are obviously shown. Those reflectivity data are observed at 5 minutes of time difference (11:25 and 11:30

am.) of local time as shown in Figure 3(b) and 3(c). In addition, the information of used cloud pixels in the mosaicking process has also been provided on pixel based basis in the Figure 4. The index map of used radar varies in time depending on the criteria of maximum intensity of considering pixels. It can be concluded that the reliability of mosaicked radar reflectivity is not yet provided in the index map of used radars. Therefore, the radar quality index must be further developed for end user.

Figure 4 shows the usage of radar reflectivity for both radar sites on the pixel-based basis. The method on mosaicked radar has been developed by using maximum value of reflectivity on 26 July 2017 at 11.30. This method can provide the information of used reflectivity in pixel location that informs the reflectivity in the overlapping area of these two radars. The results of the mosaicked radar reflectivity that provide to end user are varied in spatio-temporal dimension. We realized that the mosaicked results are subjected to the calibration of the weather radar instruments. Thus, TMD need to consider by including the standardization in their calibration procedures for the construction of radar composite products over the Thailand in the near future.

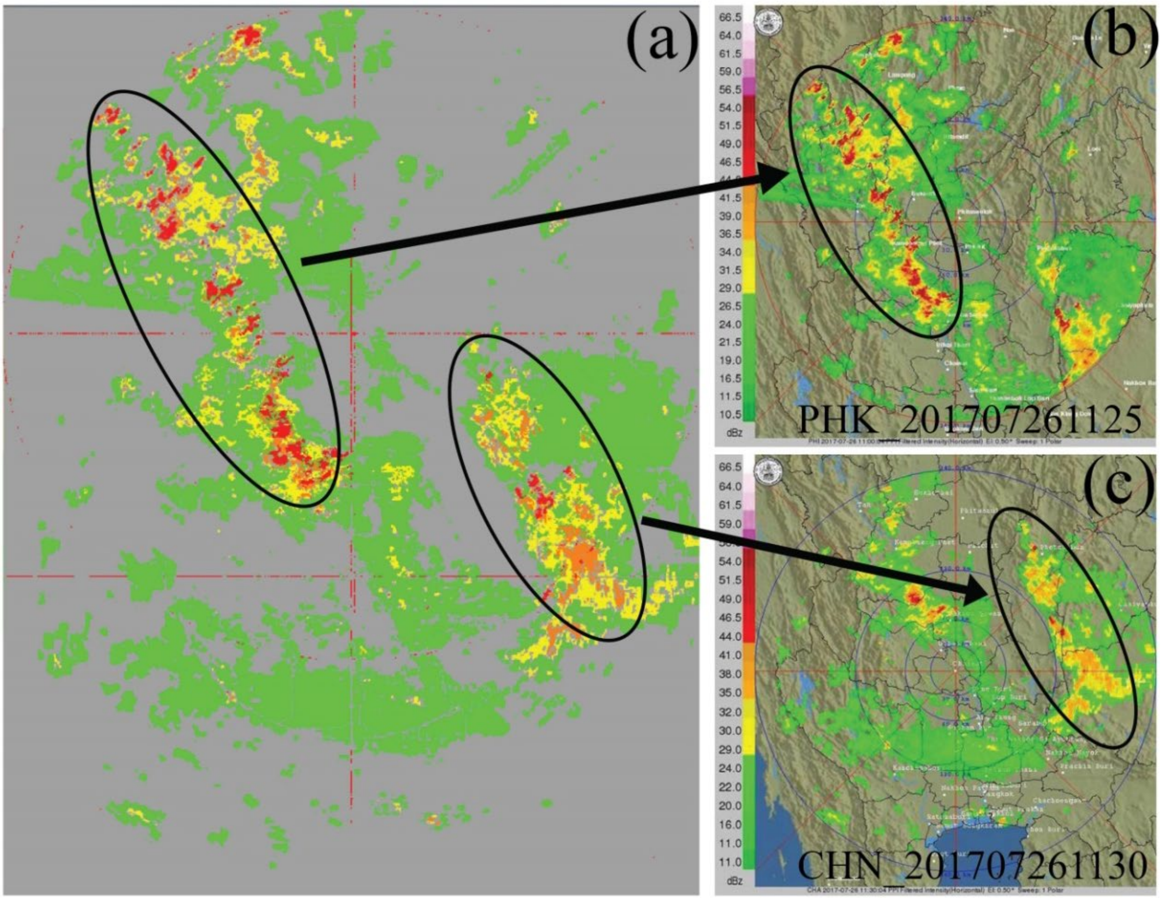

Figure 3 Results of mosaicked radar reflectivity of the 1st PPI on 26 July 2017 at 11.30 am. (a) the mosaicked map of the extracted radar reflectivity using Phitsanulok and Chainat stations (b) the original image of radar reflectivity at Phitsanulok and (c) the original image of radar reflectivity at Chainat.

Figure 4 Results of used radar on pixel-based location in the mosaicked radar reflectivity of the 1st PPI on 26 July 2017 at 11.30 am.

2) Beam blockage analysis

In step of calculation PBB using Wradlib library in Python script [9], simulation of beam propagation has been generated over the terrain of Phitsanulok radar coverage using 0.5° of elevation angle as shown in Figure 5. The strong affected beam on the west side of radar observation has been found with percent of blockage over half of beam width while it is propagating through the atmosphere as shown in Figure 5(a), 5(b) and 5(c). The isolate mountain named Khao Luang in Sukhothai province (Figure 5(c)) which is higher than 800 m.MSL, obstructs the propagating beam led to deteriorate the observation in the azimuth range of around 280° as shown in Figure 5(a) and 5(c). In addition, the beam-blockage fraction (BBF) has also shown over 50% in the east of Phitsanulok radar (Figure 5(b)). The simulated BBF over the east of the Phitsanulok radar caused by Phetchabun mountain range, which is prolongation of the southern end of the Luang Prabang Range, affecting the beam propagation over the 50% of beam width as shown in Figure 5(b). The usage of the first elevation radar observation over the eastern side of Phitsanulok, therefore, should be cautiously. By using multiple radar beams from the other radar sites located in the west and east sides of the Phitsanulok radar in the mosaicked procedure, the beam-blockage effects over the observed area can be mitigated.

Therefore, the highest impact factor for the radar quality index is the beam blockage information. In this study, the area of beam blockage at 50% by terrain information from SRTM DEM has been computed at pixel-based basis for each single radar as shown in Figure 6. The blocked beam by terrain for the first elevation at 0.5° is clearly shown over the west and east of Phitsanulok radars in Figure 6(a), while the Chainat radar has small areas of blocked beam over the west side of radar coverage as shown in Figure 6(b). The index map of beam blockage after mosaicking the two radars as shown in Figure 6c can be used to identify the unaffected area of beam blockage for both radars. The large area of beam blockage in the east of Phitsanulok site cannot be corrected by the mosaicking. In the east of Phitsanulok radar, several pixels indicate the unreliable returned radar reflectivity. This mosaicked beam blockage map is useful to fill the gap of beam blockage for increasing the reliability of mosaicked radar products.

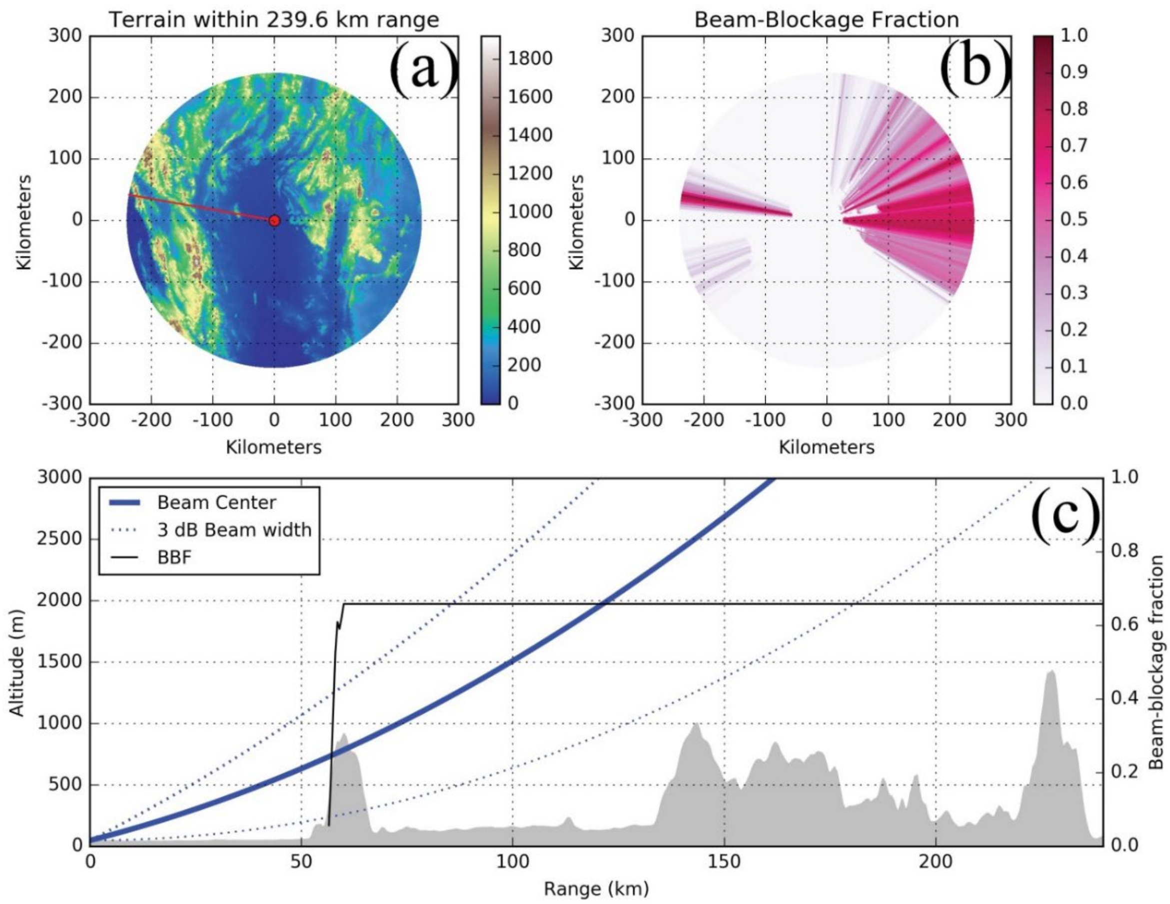

Figure 5 simulation of beam-blockage fraction using beam propagation equation implemented in Wradlib library over the terrain surrounding Phitsanulok radar of elevation angle at 0.5 deg. (a) terrain over the observed area and pointing azimuth direction shown in red line (b) beam-blockage fraction of each radar observation range and (c) simulated result of propagating beam at azimuth of 280°.

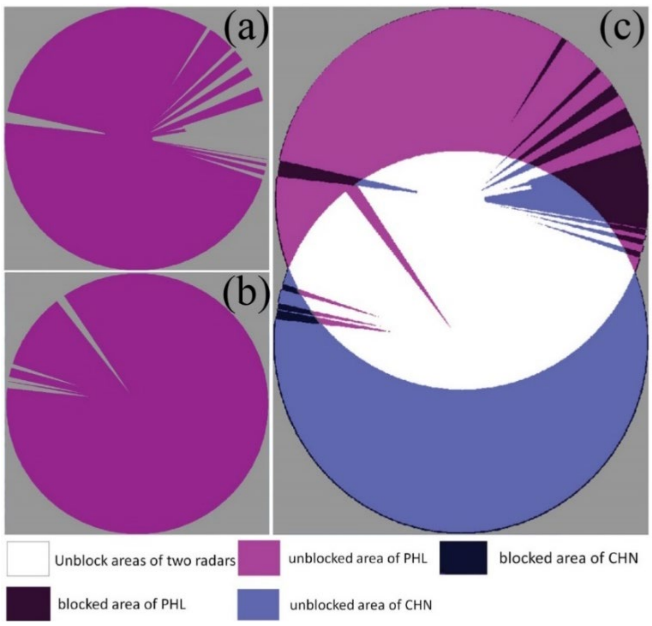

Figure 6 Beam blockage analysis with the surrounding terrain from SRTM DEM using threshold at 50% of beam width (a) Phitsanulok (b) Chainat and (c) The mosaicked map of beam blockage from two radars.

3) Radar flares detection

The development of automated radar flare detection has been applied on clearly seen flare on 23 June 2018 at 12:25 a.m. as shown in Figure 7(a). Using the best-fitting ellipse criteria and best-fitting rectangles, the automated radar flare detection is detected in the west and south east of Phitsanulok radar as shown in Figure 7(b). However, the radar flares will change from time to time of the observation due to the interfering on radar signal. Because the C-band frequency which is the main frequency usage for the meteorological observation, has also been used by other sectors.

4) Radar quality index fields

The beam distance and elevation have been repeatedly computed for each radar site and following by mosaicking of two radar coverage as shown in Figure 8. The far range from radar station may be either under-estimate or over-estimate rainfall when it is validated by gauge data at ground level. This two information are important for radar quality during the mosaicking process as weighting factors in the radar quality equation.

The three factors are combined into the linear equation of the radar quality index using initial weighting and it is defined as the RQI as shown in Figure 9(a). The interval of quality index indicates the reliability of mosaicked radar reflectivity in the sample scanning time. The west side of Phitsanulok radar is obviously recognized the low reliability at less than 20% due to beam blockage as also recognized by Mahavik and Tantanee [8]. However, the majority of the radar reflectivity pixels are in higher reliability at greater than 60%.

Finally, RQI which is the combination of the detected radar flares has been processed to include the strong influence of radar flares as shown in Figure 9(b). The result after applying RQI to the extracted radar reflectivity is recognized by the extended triangle toward the radar station of Phitsanulok as shown in Figure 9(c). However, the RQI varies from scan to scan due to unpredictable flare in their locations except the permanent flare located in the west of Phitsanulok radar. To understand the behavior of typhoons after their landing on the Indochina, [5] have attempted to experiment on numerical model by comparison the output to the mosaicked multiple radars from radar operated by national meteorological services of countries. The mosaicked multiple radars are very useful information to validate the simulated decaying stage of typhoon. The understanding of typhoon behavior can support the mitigation plan of meteorological disasters over the developing countries. The observed behavior of dissipating typhoon over the land of Indochina is so crucial as being pointed out by Asian Disaster Preparedness Center (ADPC) [14]. ADPC had observed flashflood/landslide in Uttaradit and Sukhothai provinces, northern region of Phitsanulok radar coverage, after low pressure caused by severe tropical storm named Chanchu on 21–23 May 2006. The provision of high spatio-temporal information of the dissipating typhoon is needed to monitor damaged area over the river basins.

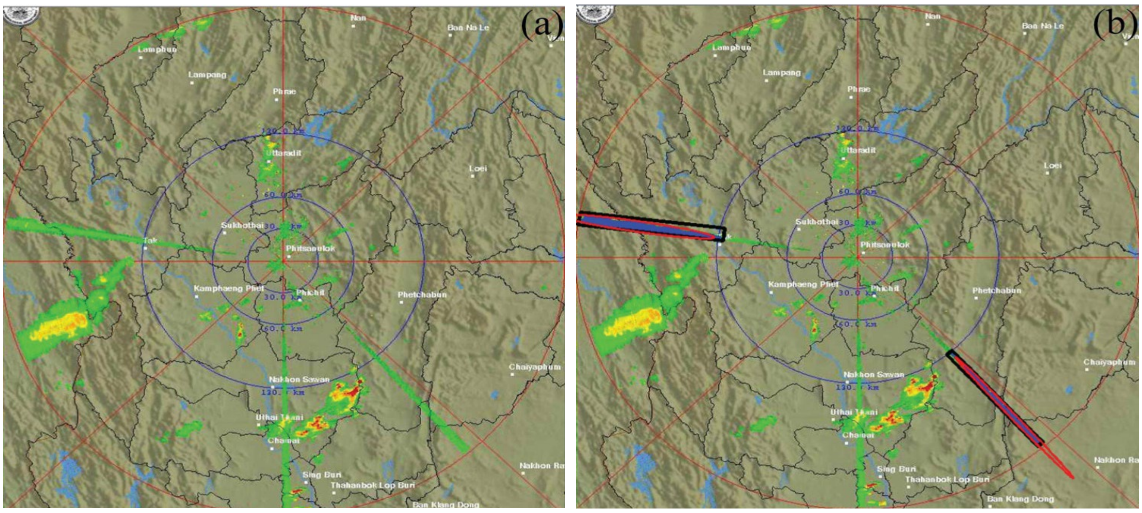

Figure 7 detection of radar flares (a) original radar reflectivity images from TMD on 23 June 2018 at 12:25 am. (b) detected radar flares by best-fitting ellipses and best-fitting rectangles.

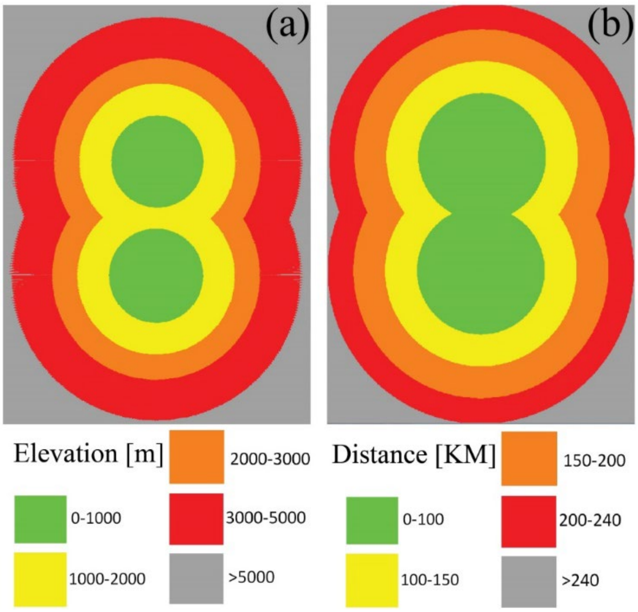

Figure 8 The mosaicked radar map for (a) elevation of radar beam propagation and (b) distance of radar beam

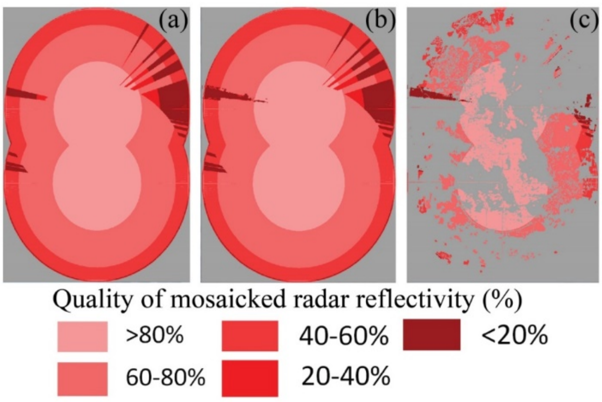

Figure 9 Radar quality index of (a) quality index (QI) from the three factors (b) including the detected radar flares to the QI and (c) results of applied the QIF to the extracted radar reflectivity on 26 July 2017 at 11.30 am.

It should be noted that the 1st PPI depends on several deteriorate factors of precipitation measurement. The overshoot of cloud in the far observation radar range normally occurs as shown in simulated beam propagation in Figure 5(c.) Radar rainfall estimates also depends on beam overshooting as comparing to observed rainfall at near surface [15]. The information of multiple elevation angles is usually used to observe severe storm to delineate the area of convective clouds i.e. [16–17]. The usage of Constant altitude plan position indicator (CAPPI) provides radar rainfall closed to the observed rain at ground during rainy season over the middle of Indochina by extracting raw information of weather radar in Vientaine, Lao PDR [18]. To process CAPPI, the reflectivity derived from multiple elevation angles of observed weather radars are needed over the region.

Furthermore, the observation from the mosaicked radar products needs to deliver with RQI to end user in order to be more accurate information for the decision maker. In the future work, the multiple weather radars of TMD will be included to correct data over the area of low quality based on RQI. In addition, the implementation of RQI in the Geographic Information System would improve the design of radar network to reduce uncertainty of radar observation as done in the US [12, 19].

Conclusion

A radar quality index (RQI) of mosaicked radar reflectivity has been developed in this study over area of Chao Phraya River basin, Thailand. The radar data from Phitsanulok and Chainat radar of the TMD has been used in the study. The geometry of beam propagation has been considered with the digital elevation model to find the beam blockage area. The beam blockage area is the highest influence factor to the developed linear radar quality equation. The elevation and distance of beam propagation has been calculated gridded Cartesian system to include initial weighting factors in the radar quality equation. The initial weight of the equation can be used to assess each returned radar reflectivity of a particular scanning time. The extracted radar reflectivity has been used as input information to detect a radar flare, non-precipitating area, over the single radar. Then, the radar flare can be added into the RQI field as the lowest reliability of mosaicked radar areas. From scan to scan, the RQI is repeatedly computed for each scanning data that is identical field due to the changing in space and time of the detected radar flares. The result of applied RQI field indicates the reliability of the mosaicked radar reflectivity for each pixel. In addition, the RQI field indicates radar coverage voids which is for the future process of gap-filling radars.

Future work will be the including of the validation process using a gauge network to assess the mosaicked radar products. The developed radar quality equation will also be investigated on sensitivity analysis of each factor. The error-related RQI field will provide more information to the mosaicked radar product toward the real-time operation and reanalysis data implementation over the Chao Phraya river basin.

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