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Research Article

Evaluation of the radar-based quantitative precipitation estimation composite in Viet Nam

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Abstract: Real-time monitoring of quantitative precipitation distribution is essential to prevent natural disasters caused by heavy rainfall. Precipitation distribution by rain gauge network or combined with radar/satellite data is operationally used in Viet Nam. Previously, meteorological radar data was simply converted to precipitation amount using a simple Z-R relationship. To get accurate quantitative precipitation estimation (QPE) data, converted precipitation amounts from radar should be corrected by rain gauge data. In the ongoing JICA technical cooperation project, preliminary development of the QPE product has been conducted by utilizing the data from the automatic rain gauge network and meteorological radar network in Viet Nam. The fundamental part of this QPE algorithm has been used and updated by Japan Meteorological Agency (JMA) for more than 25 years. This is the first attempt to get quantitative precipitation distribution with a precise resolution by combining radar and rain gauge data in Viet Nam. This paper describes each process to introduce this QPE method to Viet Nam and indicates the results through the project. Future issues to improve its accuracy are also mentioned.

Keywords: Radar; Rain gauge; QPE; Quality Control, JICA.

1. Introduction

Weather radar is an effective system for monitoring precipitation, but various methods are needed for its quantitative use. Japan Meteorological Agency (JMA) has developed a system to calculate quantitative precipitation estimation (QPE) by combining radar and rain gauges [1–2]. Based on this QPE, JMA uses it for short-time precipitation forecasts and for calculating landslides, inundation, and flood indices that are directly related to the occurrence of these disasters. JICA initiated a technical cooperation project with the Viet Nam Meteorological and Hydrological Administration (VNMHA) to introduce these JMA methods to Viet Nam. Since June 2018, a bilateral cooperative project (hereinafter described as "Project") between JICA and the VNMHA named "Strengthening capacity in weather forecasting and flood early warning system in Viet Nam" has been conducted [3–4]. A basic QPE system was introduced in the first period of the Project, and an outline of the QPE in Viet Nam was reported [5].

For improvement of QPE, various kinds of issues should be considered. The priority is to improve the quality of the rain gauge and radar observation data used in the analysis. Second, the QPE algorithm needs to be improved to fit the situation in Vietnam. In the future, the utilization of dual-polarization radar is also an important theme. However, further efforts should be made to calibrate and maintain radar for the utilization of dual-polarization radar. Several improvements for QPE have been conducted in the second half of the Project from 2020 to 2023, and these trials are reported in section 2, and some evaluation results are summarized in section 3.

2. Materials and methods

2.1. Observation Data

In VNMHA, two types of rain gauge stations are under operation. One is manual rain gauge stations which are located at 186 locations. The staff on duty at the station measures the accumulated rain amount every six hours. The other is automatic rain gauge (ARG) stations located at around 500 points. In these ARG stations, 10-minutes of rainfall amount is recorded and transferred to the data center at the VNMHA headquarters. VNMHA also receives more than 1500 ARG data operating outside VNMHA and a total of more than 2000 ARG data is available.

There are many ARG sites, but the quality of some sites is problematic. The problems of some sites are as follows; poor data transmission rate, continuation of non-zero constant value, and significant differences from surrounding sites. In this QPE algorithm, rain gauge values are treated as true values, so any errors in the rain gauge cannot be corrected. Quality control is essential to identify poor-quality rain gauge data [6].

Currently, ten meteorological radars of VNMHA are operated by the Aero Meteorological Observatory (AMO). Their locations and maximum detection range are shown in Figure 1, and their characteristics are shown in Table 1. Several different generations and types of radars are under operation. The radar network consists of two S-band radars and eight C-band radars, which consist of five Doppler radars and five dual-polarized Doppler radars. These radars have been newly replaced since 2017 (including a minor upgrade of the signal/data processing unit). This radar network covers almost the whole country and surrounding sea except for some areas where the lower layer is difficult to detect in the mountainous region.

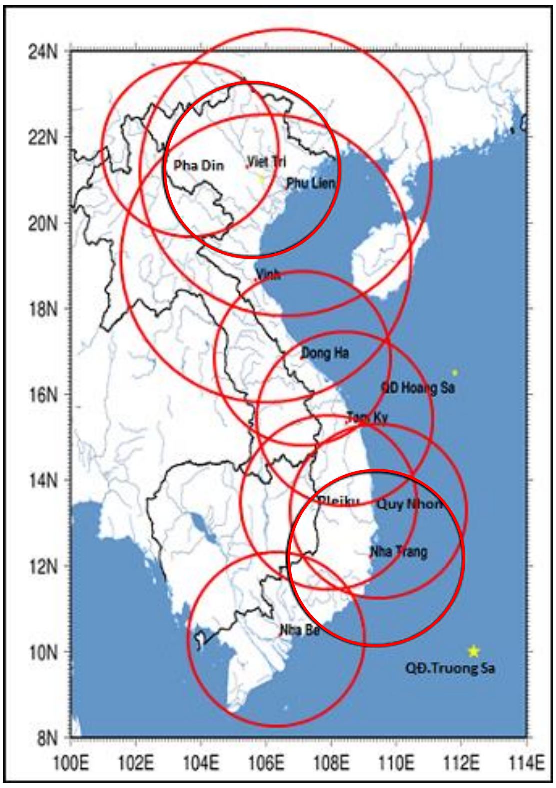

Figure 1. Meteorological radar network in March 2023. Larger circles represent Japan Radio Company (JRC) radars and other circles represent Vaisala radars.

Table 1. Characteristics of radars. D and S in the third column indicate dual-polarized radar and single-polarized radar, correspondingly. The first and second values in the detection range column show maximum detection range in intensity mode and Doppler mode respectively.

Radar Site	Height (m)	Type	Band	Detection Range (km)	Beam Width (deg)	Manufacturer
Phadin	1470	D	C	300/120	1.0	Vaisala
Viettri	154	D	C	300/120	1.0	Vaisala
Phulien	146	S	S	450/200	1.7	JRC
Vinh	92	S	S	450/200	1.7	JRC
Dongha	40	S	C	300/120	1.2	Vaisala
Tamky	52	S	C	300/120	1.2	Vaisala
Pleiku	842	D	C	300/120	1.0	Vaisala
Quynhon	582	D	C	300/120	1.0	Vaisala
Nhatrang	467	D	C	300/120	1.0	Vaisala
Nhabe	35	S	C	300/120	1.0	Vaisala

2.2. Method of QPE Calculation and its Improvements

The QPE value is obtained by combining the one-hour integrated radar value and the rain gauge value and applying a two-step correction process (primary correction and secondary correction). The basic algorithm is explained in [5]. A simplified version of the software made by JMA was installed. The essential calculation part is almost the same, but the part of the effect of beam altitude is not included.

After the software was implemented, various adjustments were made to fit the Vietnamese situation. In Vietnam, stable calculation of QPE required not only adjustment, but also improvement of the algorithm, optimization of the settings used in the calculation, and selection of rain gauges to be used. We comment on several important points below.

2.2.1. QPE algorithm

In the early stage of operation, QPE results were sometimes unstable. Especially when most of the echoes were at sea and only a few were on land, unstable results were often evident. Since the current algorithm uses a method of determining the primary correction factor for each radar in an area where multiple radars overlap by comparing each radar with the rain gauges in that area, it was found that the calculation results may vary over time if the number of valid rain gauges in this area is small.

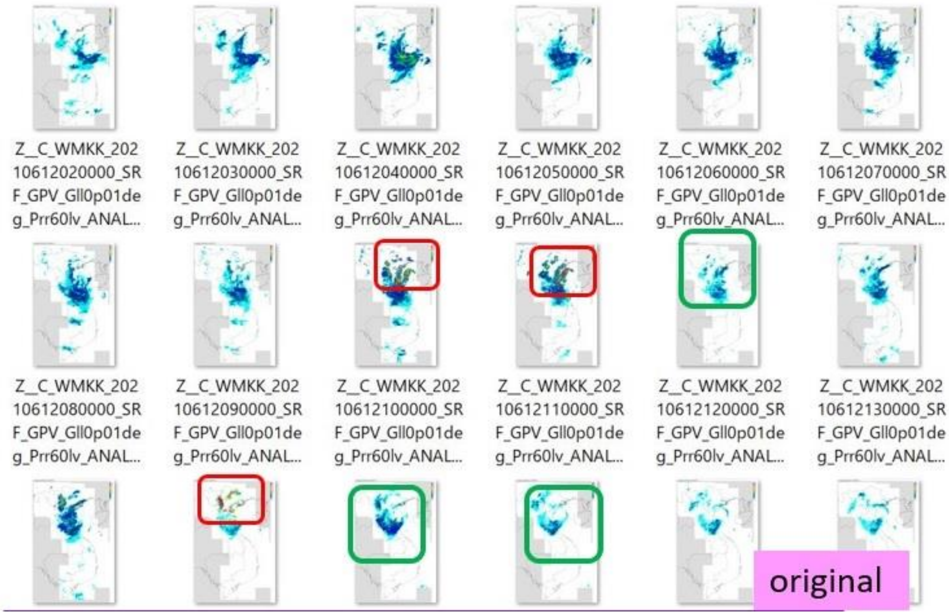

Figure 2. QPE results are based on the original algorithm.

The following changes were made to solve this problem.

- During the primary correction, if the average rainfall in the overlapping area is 10 mm or more, no correction is made, and the primary correction factor is set to 1.

- If there are less than 4 rain gauges of 5 to 10 mm in the overlapping area during the primary correction, no correction is made, and the primary correction factor is set to 1.

These modifications were made in March 2020.

These improvements suppressed overcorrections in the overlap region and stabilized the QPE calculation results. A comparison of Figures 2 and 3 shows the effect of this improvement. When focusing on the red square regions, the values are excessive in Figure 2 but not in Figure 3. On the other hand, this change has a side effect, which tends to suppress the area of intense rainfall. The green square regions in Figures 2 and 3 illustrate this characteristic.

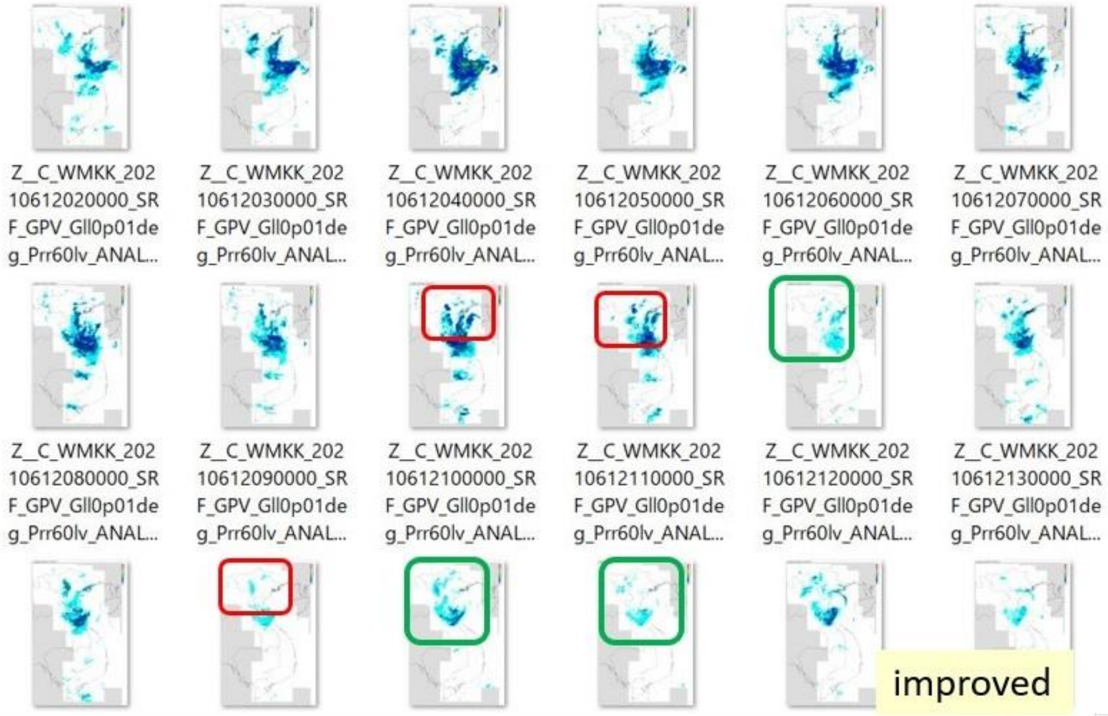

Figure 3. QPE results are based on the improved algorithm. Data are the same as in Figure 2.

2.2.2. Rain gauge list

Which rain gauge data to use is a critical issue in determining the accuracy of the QPE. Basically, the more rain gauge data, the more accurate the QPE. However, if the rain gauge contains abnormal observations, the accuracy of the QPE will drop dramatically.

Although there are more than 2000 ARG data in Vietnam, they include points with low data acquisition rates or problematic observations. A comparison of ARGs and human observations has been reported to verify the accuracy of ARGs [7]. There is also an attempt to combine several QC factors to validate and categorize the accuracy of ARGs [6]. This paper also evaluated the impact on QPE produced by each category.

In this paper, 805 sites were selected from 2000 sites that were determined to be normal based on their data acquisition rates and comparison with surrounding sites and used to calculate QPE.

2.2.3. PCAPPI table

The settings in the PCAPPI table also play an important role in the accuracy of the QPE. To calculate the QPE accurately, it is necessary to use radar observation data of good quality at as low altitude as possible. In mountainous areas, the radar beam is shielded or partially shielded, which reduces observation accuracy. Utilizing topographic data, the elevation angle to be used by azimuth is determined in relation to the altitude at which the radar is installed.

If the elevation angle to be used is calculated mechanically from topographic data, the angle may change within a narrow azimuth range. Figure 4a shows an example of the QPE distribution in the initial setup, but the distribution is discontinuous in the area circled in red. Such discontinuous distribution is due to the PCAPPI table being set with a fine azimuthal width. Figure 5 shows the PCAPPI table settings before and after the modification. By changing the settings in this way, discontinuity areas can be avoided as shown in Figure 4b.

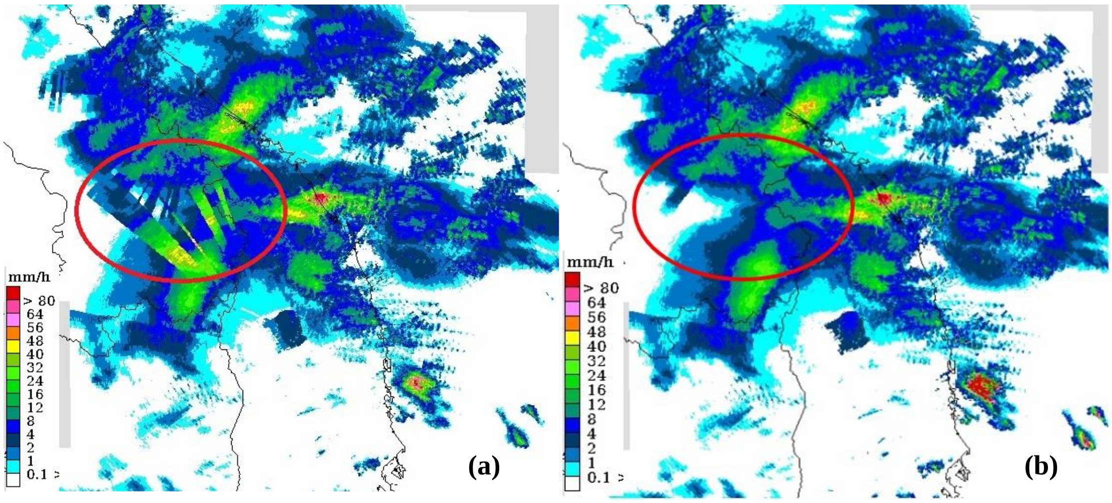

Figure 4. QPE distribution: (a) with initial PCAPPI settings; (b) with modified settings in the central region at 15LST 7 October 2020.

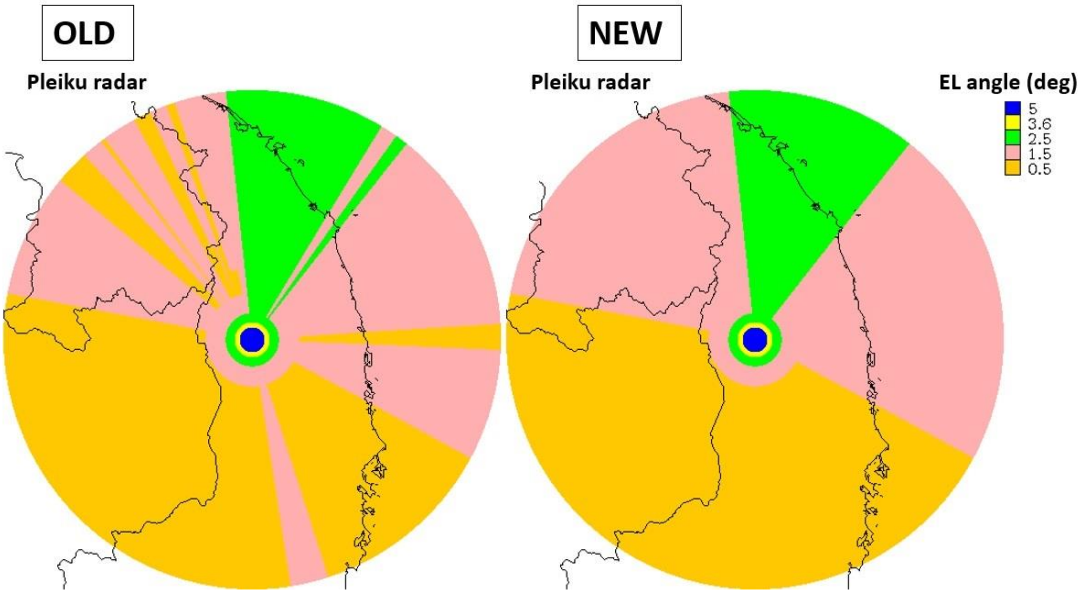

Figure 5. Initial (left) and modified (right) PCAPPI table of Pleiku radar.

When using the PCAPPI table, it is necessary to introduce smoothing processes such as interpolation between elevation angles in regions where the elevation angle changes. This method is used to avoid discontinuous distributions while taking advantage of lower altitude observation data will be possible. Figure 6 shows the difference between before and after introducing the smoothing processes when the PCAPPI table is updated. It shows that the wedge-shaped echoes in the previous image (a) changed to a more natural shape in the new image (b) due to the revised elevation angle and the use of smoothing.

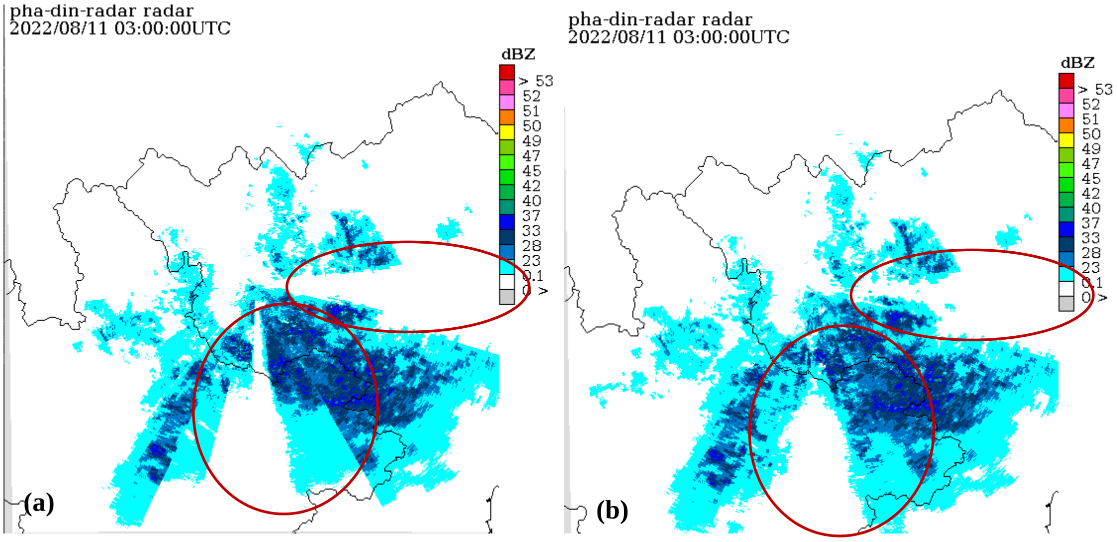

Figure 6. QPE distribution with initial PCAPPI settings in the Northwest region at 10LST 11 August 2022: (a) Old table with no smoothing; (b) New table with smoothing.

3. Results

3.1. Evaluation of QPE results and tendency of QPE products

Results of QPE products are evaluated from the whole country on around 800 rain gauge stations data with the exact grid points of QPE precipitation maps at each station. For this evaluation process, rain gauges not used for calibration are chosen. Scattergrams (Figure 7), statistical indicators, and time-series graphs evaluated the accuracy of QPE. The comparison was made for three statistical indicators, and the characteristics of QPE results are as follows. In Figure 7, the slanted solid line shows the most accurate result. From these four figures, the plot concentration, and the red slope of the regression line show that the accuracy of stations (b) and (d) is high.

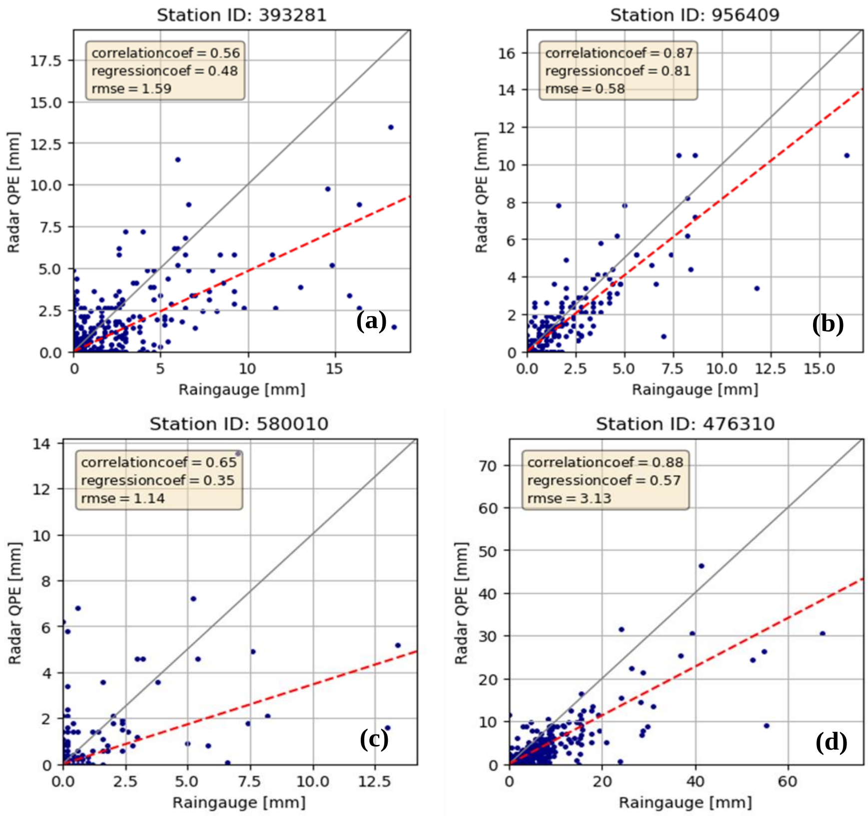

Figure 7. Hourly QPE vs rain gauge scatterplots of (a) Đạ Chais, (b) Phượng Mao, (c) Mường Mùn, and (d) Ba Điền stations.

- Correlation coefficient (CC): Correlation Coefficient (CC) is a statistical measure of the strength of the relationship between the two data sets, Radar QPE, and ground-based rain gauge. If the CC is closer to 1.0, the better the correlation between QPE and rain gauge.

- Root Mean Square Error (RMSE): RMSE shows differences between the model and the observation. The RMSE value is always non-negative and tends to be larger in the region with more rain. Therefore, using it for comparison in the same region is better.

The distribution of CC and RMSE are plotted on maps (Figure 8). The high CC are located in the Central coast area and Near Hanoi, while low CC is in the mountain area and Southern area. Most of the radar in Viet Nam is located near major cities along with the eastern coast and the altitudes are quite low. The beam angles are set higher to monitor the mountain area or to avoid ground clutters, and then the beam height is too high to catch the low clouds, especially in the western (mountain) side of the country. Some stations with low CC in the red areas are the stations with low data receiving since many of the AWS with high receive rate is used for the calibration.

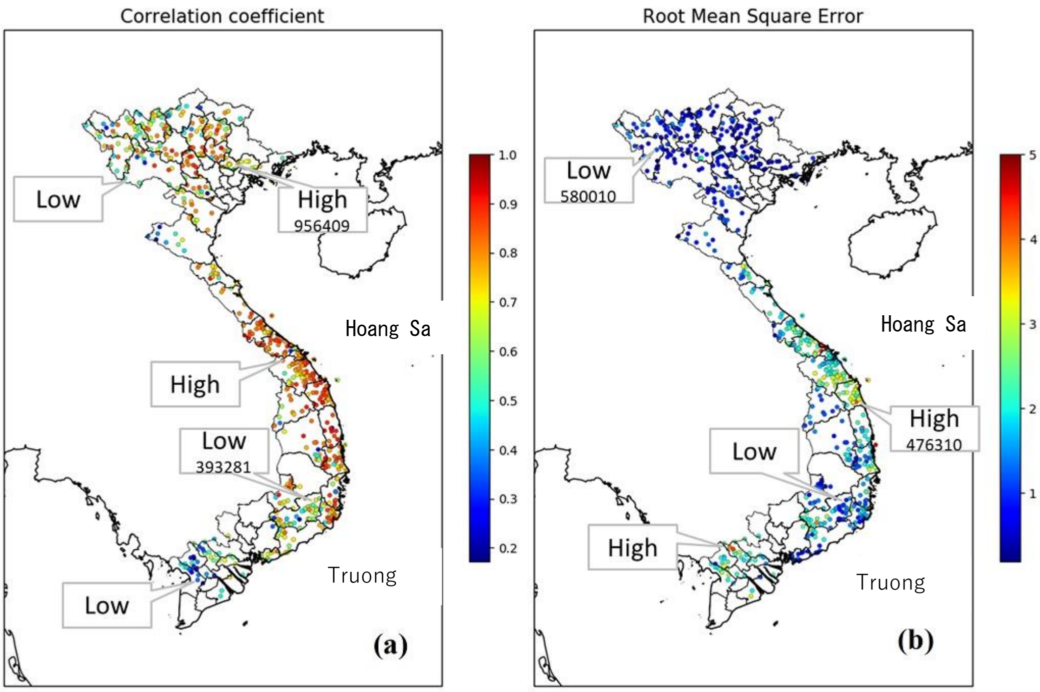

Figure 8. The distribution plot of statistical indicators: (a) correlation coefficient; (b) root mean square error.

There were some updates on the evaluation method between radar and rain gauge. In the first validation, the value from the grid right above the rain gauge was used, but now it is using the maximum value among the surrounding nine grids over the rain gauge (3km × 3km). This method takes into consideration the observation height and the rain carried away by the wind and is the same method as the Verification in the JMA-QPE package.

Figure 9 is the time-series graph from August 10 to August 13, 2022. The blue bar is rain gauge data, the red line is from radar QPE. The bottom time series graph Since wind advection is considered, the lower graph is more consistent with the rain gauge values since it uses the maximum value among the surrounding nine grids over the rain gauge.

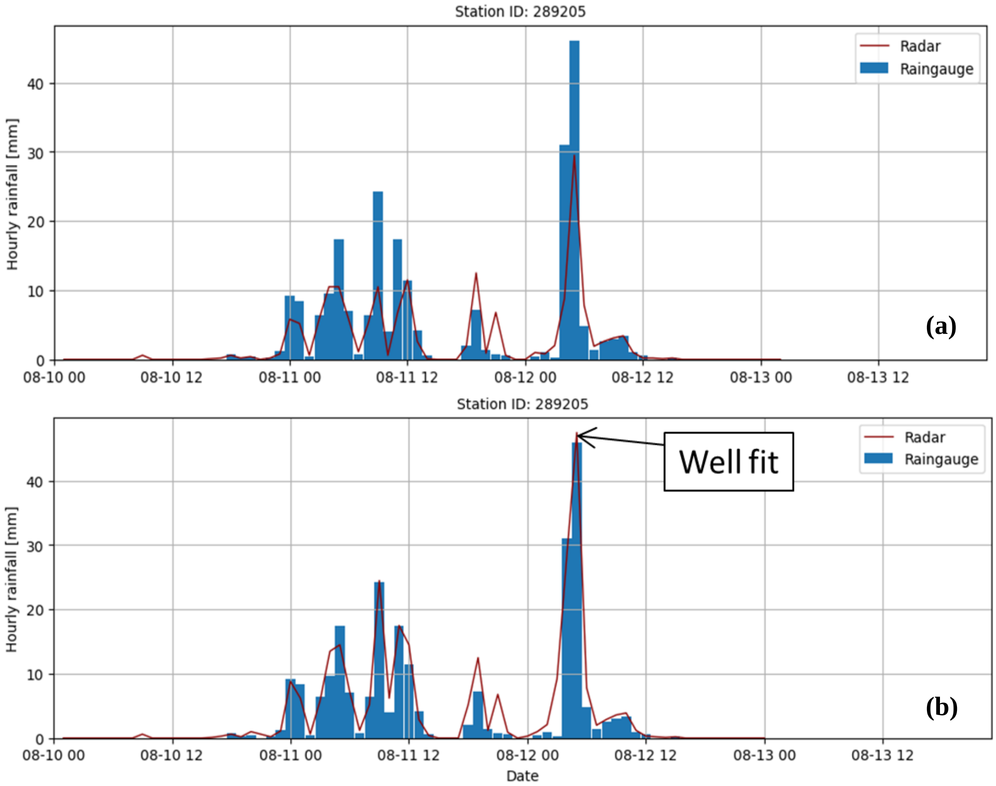

Figure 9. The time-series graph of statistical indicators at An Khánh station, Hà Nội: (a) using a single grid; (b) Using the maximum value among the surrounding nine grids over the rain gauge.

3.2. Further improvement of QPE product

3.2.1. Clutter map introduction and its calculation

A single polarization radar has functions to remove clutters, for example, reflectivity, velocity, and velocity width calculated by Fast Fourier Transform (FFT) based on spectral analysis of the orthogonal detection signal from receiving unit outputs. However, a single polarization radar cannot remove clutters, clear air echoes, chaffs, and so on (dual-polarization radar can discriminate and remove non-precipitation echoes using dual-polarization techniques). In JMA QPE software package has a function for clutter maps, and in 2021, clutter map calculation methods were developed.

Clutter map functions consist of "decrease" and "cut," and values of "decrease" and "cut" (Figure 10) would be calculated from observed echoes on non-precipitation examples at each radar site. Noises that clutter maps can effectively eliminate are removed through clutter maps, such as stationary ground clutters from static ground objects such as buildings and topography, stationary sea clutters (Sea clutters in strong wind conditions can be avoided by changing the PCAPPI table to use a higher elevation or by

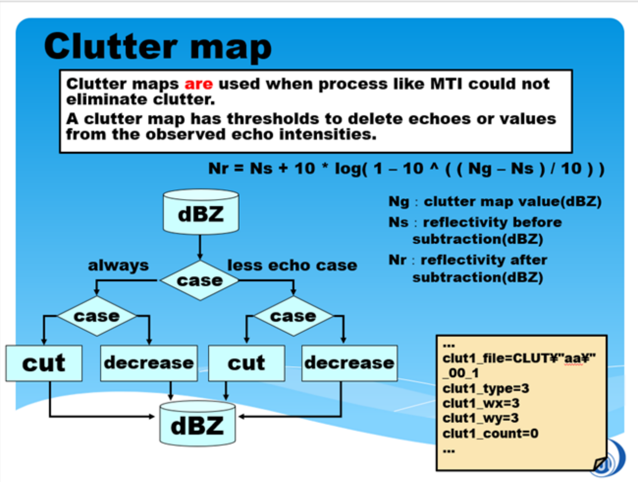

Figure 10. The process flow diagram of the clutter map.

changing the elevation itself.), and point clutters from wind turbines. In Figure 11, clutter due to topography shown inside the red circle in the left figure around Vinh's radar has been reduced in the right figure after the clutter map process.

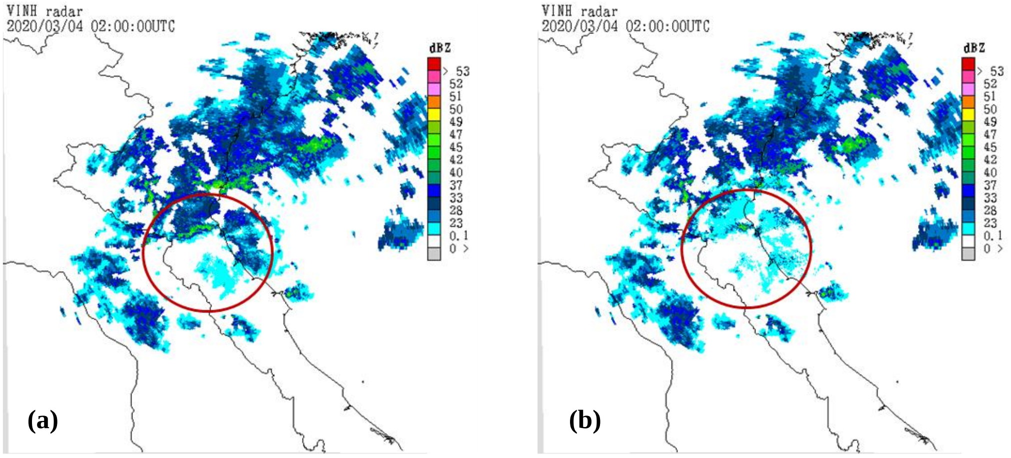

Figure 11. Before (a) and after (b) the clutter map is applied.

Recently, many wind farms have been planned and installed in Viet Nam to shift to clean energy sources. To remove reflections of wind farms, the 'pseudo-masking' method shown in Figure 12 is proposed. The method is PPI elevation in directions and distances where wind farms exist should shift to a higher elevation, not affected by wind farms.

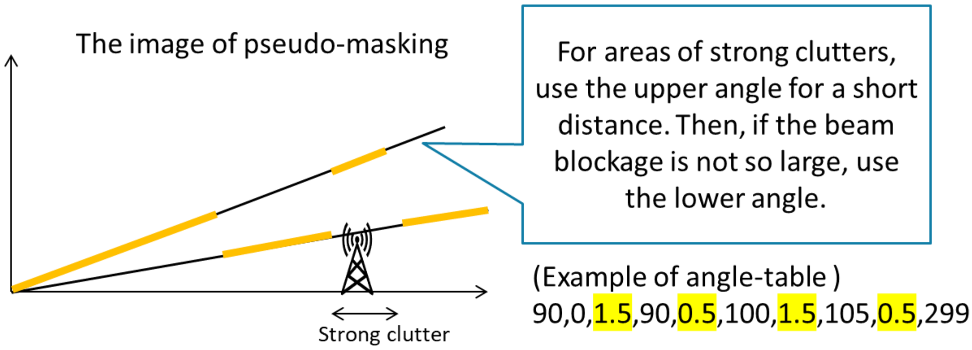

Figure 12. The time-series graph of statistical indicators at An Khánh station.

3.2.2. 10-minute interval QPE

QPE calculations are done initially once an hour using hourly rainfalls for both radar and rain gauges. But now, QPE can be updated at 10-minute intervals using the API's 10-minute rain gauge data. The main advantages of updating at 10-minute intervals are that it facilitates monitoring of short-duration heavy rainfall that dissipates in an hour or so. In addition, QPE can be updated at 10-minute intervals.

The short-interval version of the QPE uses 10-minute rain gauge observations from the API, so the quality of the rain gauge needs to be verified separately since there is a lack of data due to data transfer. Considering these circumstances, the conventional hourly QPE, which uses rain gauges that pass QC, is calculated in parallel.

3.2.3. Utilization of dual-polarized data

Usage of dual-polarization radar data is firstly quality check and removal of non-precipitation echoes. Dual-polarization radar has various products; for example, Differential Reflectivity (ZDR [dB]) calculated by the following formula attenuates precipitations in the background area of heavy rains shown in Figure 13.

$$Z_{DR}[dB] = 10\log_{10}\frac{Z_{HH}}{Z_{VV}} \quad (1)$$

When the particles are raindrops, Z_{DR} generally has a positive value or close to zero. Z_{DR} is effective but sensitive since it is the ratio between Z_h and Z_v, therefore the accuracy of Z_{DR} depends on the adjustment between Z_h and Z_v (Figure 14). Only a few people pay attention to Zv, but periodical calibration is essential to maintain the accuracy of dual-pol radar.

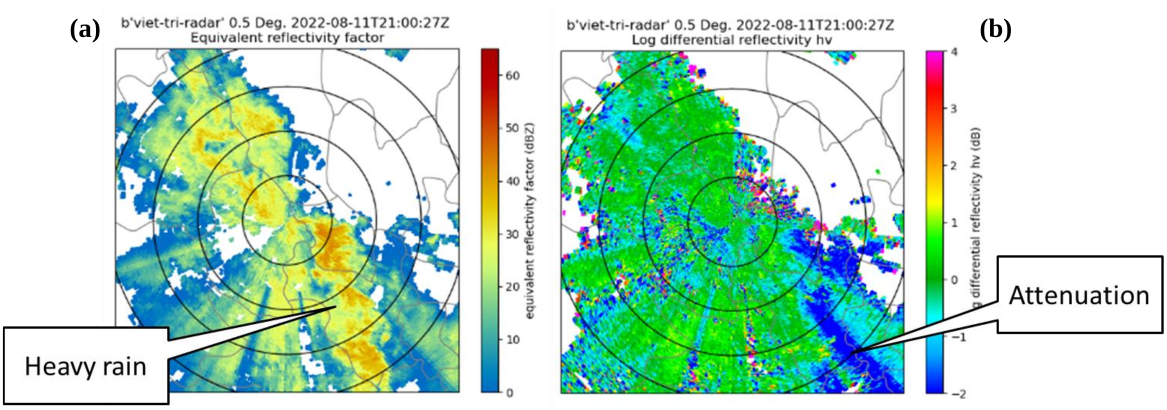

Figure 13. The PPI image of Z_h (a) and Z_{DR} (b) at 04 LST 12 August 2022.

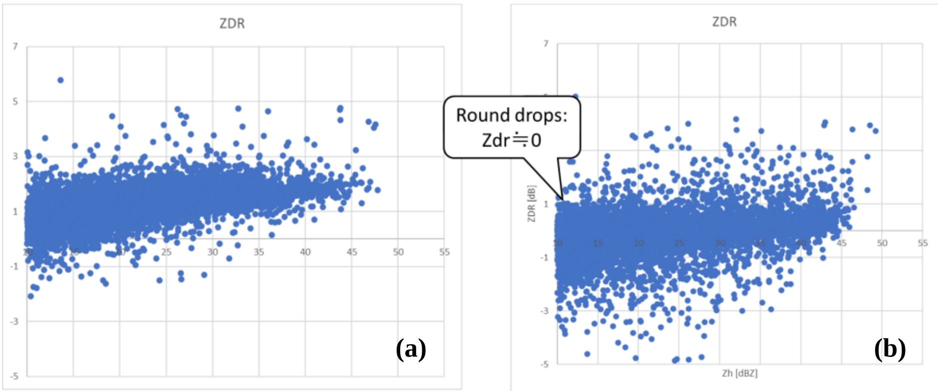

Figure 14. The scattergram of Z_h vs Z_{DR} of before (a) and after (b) the calibration.

4. Future issues

Various improvements have been made to QPE products to ensure stable operation and improve accuracy. However, the following actions are needed in each category to improve accuracy further.

4.1. Improve the quality of rain gauge data

- Necessary to introduce systematic checks, calibration, and maintenance for ARG to increase the reliability of ARG data.
- Necessary to introduce an improved QC method for ARG data to increase the availability of ARG data.
- Rain gauge network is not uniform: necessary to move or add some rain gauges to sparse areas, especially in the radar overlapping area and mountainous area.

4.2. Improve the quality of radar data

- Improve scan strategy and thereby the quality of radar;
- Improve calibration by using disdrometer;

- Combined utilization of Intensity mode with Doppler mode;
- Improve observation quality for mountainous areas;
- Utilization of dual-polarized data.

4.3. Improve the algorithm of the QPE product

- Introduce smoothing between adjacent ELs to calculate PCAPPI;
- Introduce beam height effect to calculate QPE;
- Improve algorithm to calculate primary correction factor when echo approaches from the sea.

5. Conclusions

Currently, ten meteorological radars and about 800 ARG data are combined to make hourly QPE products covering the whole Viet Nam. In the early stages of operation, QPE values sometimes became unstable, and abnormally large values were displayed. Enhanced quality control of ARG and radar data and improved calculation algorithms have made it possible to suppress such anomalous values. With these series of modifications, the QPE product is now stable and operational.

These QPE products can be easily checked on the website and are available to forecasters and other users, as well as to disaster management officials outside the VNMHA. The AMO also provides a system on its website that displays the risk of landslides in real time by accumulating these QPE values and combining them with information on the risk of landslide occurrence. This system is still experimental, but it is essential to continue improvements as an application of QPE.

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