VIETNAM JOURNAL OF
HYDROMETEOROLOGY

Research Article

Quantitative Precipitation Estimation by Combining Rain gauge and Meteorological Radar Network in Viet Nam

Chiho Kimpara[1], Michihiko Tonouchi[2], Bui Thi Khanh Hoa[3], Nguyen Viet Hung[3], Nguyen Minh Cuong[3], Kenji Akaeda[4,*]

[1] Japan Weather Association, Tokyo170–6055, Japan; kimpara.chiho@jwa.or.jp
[2] Japan Meteorological Business Support Center, Tokyo101-0054, Japan; tono@jmbsc.or.jp
[3] Aero–Meteorological Observatory, Hanoi 10000, Vietnam; khanhhoa303@gmail.com; truongphi115@gmail.com; nguyenminhcuong_T59@hus.edu.vn
[4] Japan International Cooperation Agency, Tokyo102–0084, Japan; akaeda191@yahoo.co.jp
* Correspondence: akaeda191@yahoo.co.jp; Tel.: +84–82–976–1096

Received: 17 July 2020; Accepted: 20 August 2020; Published: 25 August 2020

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 by using simple Z–R relationship. In order to get the accurate quantitative precipitation estimation (QPE) data, converted precipitation amount 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 in Japan Meteorological Agency (JMA) for more than 25 years. This is the first attempt to get quantitative precipitation distribution with 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 some preliminary results. Several issues to improve its accuracy is also proposed.

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

---

1. Introduction

Natural disasters such as landslides, floods, and inundations caused by heavy rainfall occur in Viet Nam every year. These disasters cause not only human damage but also economical loss to the country. To mitigate these damages, it is necessary to statistically analyze hydrological and geological relationship between precipitation amount and the occurrence of disaster. Based on these relationships, accurate and prompt meteorological information and/or warning should be issued before a disaster occurs. As an indicator for precipitation monitoring, quantitative precipitation estimation (QPE) plays a central role and therefore should be calculated and monitored in real–time.

Since June 2018, a bilateral cooperative project between the Japan International Cooperation Agency (JICA) and the Viet Nam Meteorological and Hydrological Administration (VNMHA) named “Strengthening capacity in weather forecasting and flood early warning system in Viet Nam” has been conducted. This project is related to the quantitative utilization of S–band radars that were installed at Hai Phong (Phu Lien) and Vinh in September 2017 by another grant aid project. Detailed reviews of this JICA project are given by Tonouchi et al. (2020) [1]. One of the main targets of the JICA project is the quantitative utilization of these radar data and precipitation estimation.

Three observation systems are used to estimate precipitation distributions in VNMHA; (1) meteorological radar, (2) meteorological satellite and (3) rain gauge. Each system has its strengths and weaknesses as follows. First, the major remote sensing tool for precipitation land is the meteorological radar. Key topographic uncertainties in radar observation are due to the curvature of the Earth and radar beam broadening with detection range; moreover, precipitation estimation is expected to be the most accurate where the radar beam is close to the ground. Therefore, scanning strategy is important to get observational data close to the ground while avoiding beam blockage by the mountain. Other sources of uncertainties in radar precipitation estimation include radar reflectivity–rain rate (Z–R) relations resulting from variable drop size distributions, lack of consistent radar hardware calibration, evaporation of raindrops as they fall through the air, and horizontal advection below the radar sampling volume due to wind shear. Improvements are also needed on quality control (QC) of radar data to remove ground/sea clutter, biological targets, and other non–precipitation echoes.

While generally acknowledged to have significantly greater uncertainty than radar, precipitation estimation from satellite data provides continuous spatial coverage and can be valuable where radar data are unavailable or known to be unreliable. Various techniques have been developed to estimate precipitation from infrared (IR) and microwave satellite observations [2]. IR data corresponds to cloud top feature which is not directly related to precipitation amount. Passive microwave sensors provide a stronger indicator of precipitation than IR sensors, although microwave instruments are presently available only on limited satellites with a typical sampling frequency of twice per day per satellite and a spatial resolution on the order of 15 km. Satellite estimates also need to be quality controlled to screen out non–precipitating clouds.

In situ rain gauges provide direct measurement of point precipitation as well as a surface reference for adjustment and evaluation of, and merging with, remotely sensed precipitation. Because of the various limitations of radar and satellite estimations as described earlier, rain gauge data secures the accuracy of QPE. Improved precipitation products must draw from each system's strength in an optimal way. In particular, meteorological radar can provide high–quality estimation in regions of appropriate observation conditions. Satellites are the secondary source of data followed by radars. Detailed description of the characteristics of these three observation systems are referred [3].

In Viet Nam, radar reflectivity data is previously converted to precipitation amount by simple Z–R relationship by assuming Marshal–Palmer size distribution. This relation is commonly used as an averaged raindrop size distribution and therefore estimation error becomes large when the drop size distribution is different from Marshal–Palmer's. In order to get the accurate precipitation amount, converted precipitation amount from radar should be corrected by rain gauge data. In this paper, new method of combining radar and rain gauge is applied [4–5] and shows some preliminary results.

2. Observation network in Viet Nam

In VNMHA, two types of rain gauge stations are under operation. One is manual rain gauge stations which are located at 370 locations as shown in Figure 1a. The staff on duty at the station measures the accumulated rain amount every six hours. The other is automatic rain gauge (ARG) stations located around 1400 points as shown in Figure 1b. In these ARG stations, 10–minutes rainfall amount is recorded and transferred to the data center at the VNMHA headquarter every hour. However, different ARG systems have been installed depending on the organization that installed them, such as VNMHA, the World Bank, Italy and South Korea. Their data formats and data monitoring/controlling systems differ, depending on their manufacturers.

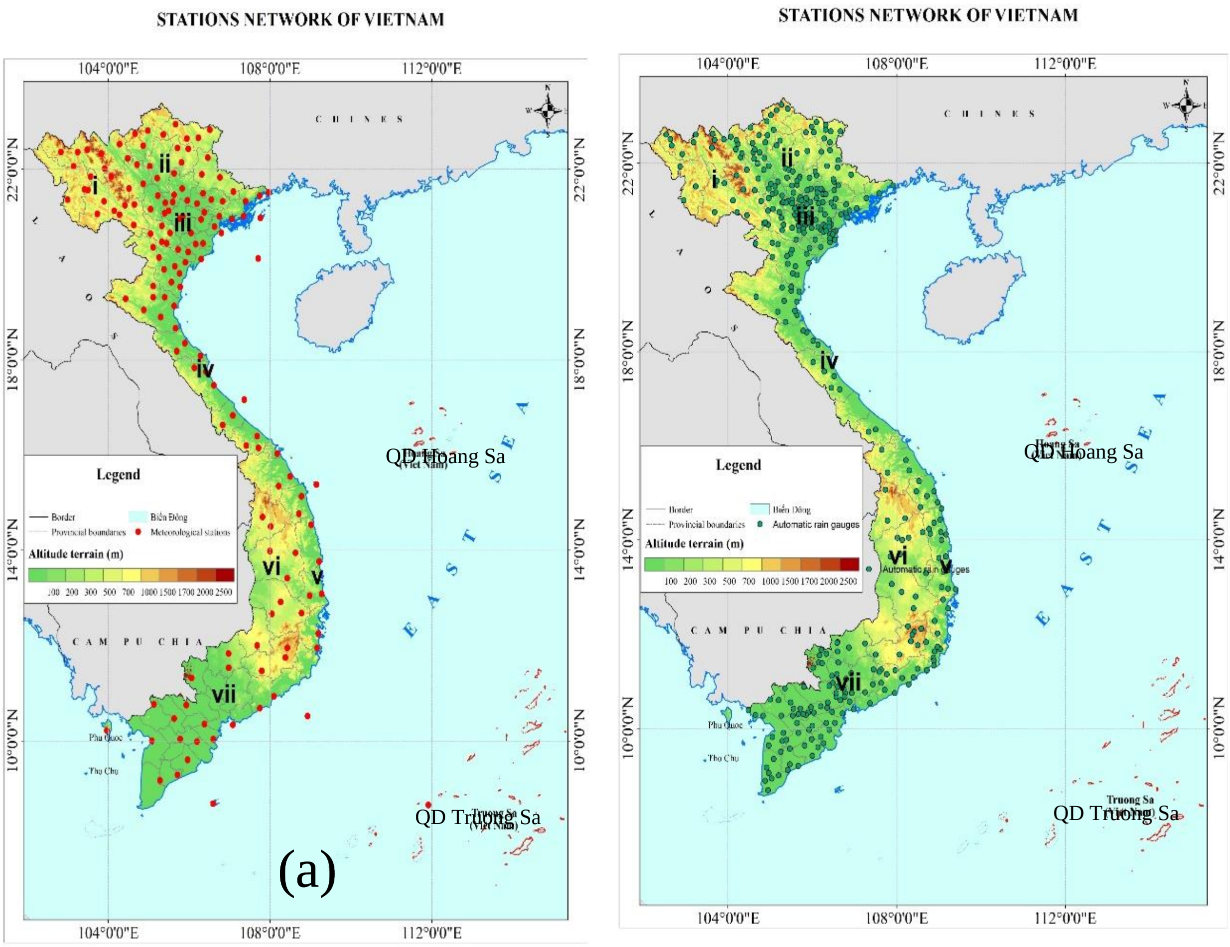

Figure 1. Surface rainfall observation network in Viet Nam: (**a**) Meteorological stations; (**b**) Automatic rain gauge (ARG) stations.

Currently, ten meteorological radars of VNMHA are operated by the Aero–Meteorological Observatory (AMO). Their locations and maximum detection range are shown in Figure 2 and their characteristics are shown in Table 1. Several different generations and types of radars are operated. The radar network consists of two S–band radars and eight C–band radars, and consists of one conventional radar, six Doppler radars, and three dual–polarized Doppler radars. Eight radars are newly replaced ones (including a minor upgrade of signal/data processing unit) in the past few years and the remaining two radars are scheduled to be replaced shortly. These radars almost cover the whole country and surrounding sea except some undetectable areas in the northwestern mountainous region.

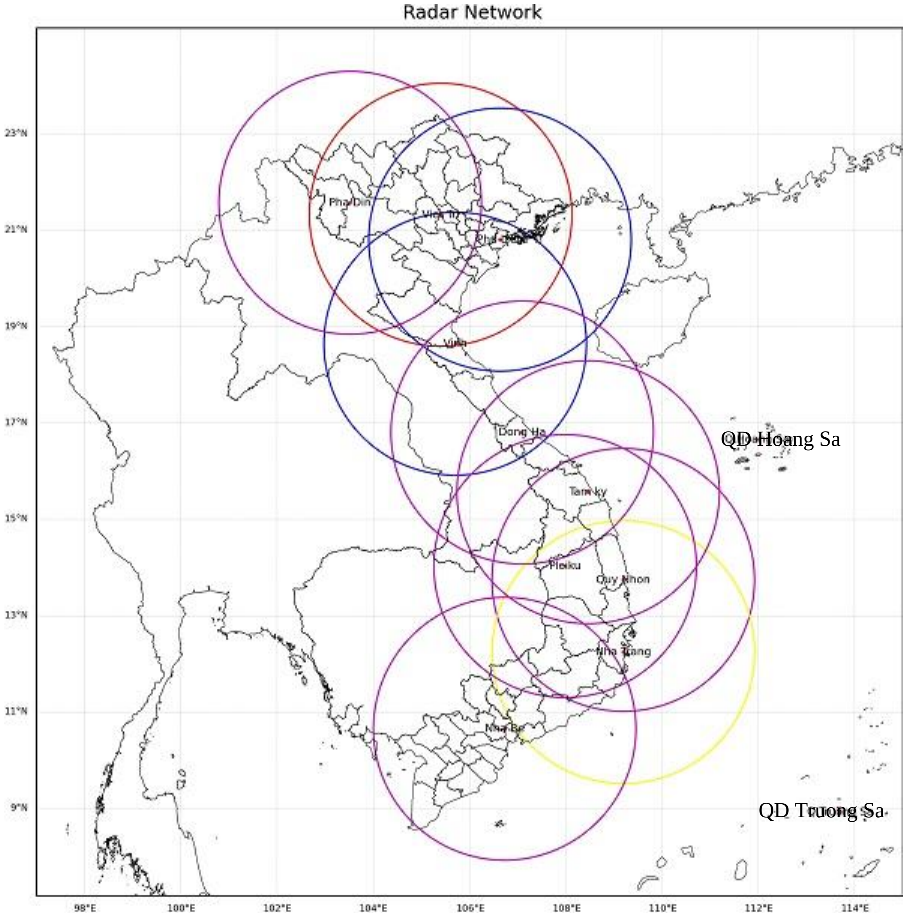

Figure 2. Meteorological radar network in March 2020. Purple circles represent Vaisala radars, blue circles as Japan Radio Company (JRC) radars, red circle as Thompson radar and yellow circle as Enterprise Electronic Corporation (EEC) radar.

Table 1. Characteristics of radars. D and S in the third column indicate dual–polarized radar and single–polarized radar, correspondingly. 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**
Pha Din	1470	D	C	300/120	1.0	Vaisala
Viettri	40	S	C		1.1	Thompson
Phu Lien	146	S	S	450/200	1.7	JRC
Vinh	92	S	S	450/200	1.7	JRC
Dong Ha	40	S	C	300/120	1.2	Vaisala
Tam Ky	52	S	C	300/120	1.2	Vaisala
Pleiku	842	D	C	300/120	1.0	Vaisala
Quy Nhon	582	D	C	300/120	1.0	Vaisala
Nha Trang	57	S	C	240/120	1.0	EEC
Nha Be	35	S	C	300/120	1.0	Vaisala

3. Method of quantitative precipitation estimation

As mentioned in the introduction, rain gauge and radar have both strengths and weaknesses to estimate precipitation distribution. Rain gauges can measure accurate precipitation amounts, but they provide only point measurements. In case of convective rain, precipitation intensity changes within the scale of several kilometers. Therefore, numbers of rain gauges are necessary to estimate the distribution of precipitation. On the contrary, radar can estimate qualitative precipitation distribution with the resolution of 1 km. Radar measures the intensity of return echoes from targets (hydrometeors) but therefore it does not have direct relationship with the amount of precipitation. The physical unit of precipitation amount is related to the third power of raindrop diameter, but echo intensity is proportional to the sixth power of raindrop diameter. To link these two parameters to derive precipitation amount, Z–R relationships are used but various drop size distributions of the precipitation are assumed as one. In this project, one from Marshall–Palmer's observation is used. When radar–derived precipitation is calibrated with rain gauges, more accurate QPE is available while compensating weakness of radar and rain gauges.

In this project, one–hour accumulated rain gauge data and one-hour accumulated radar intensity are combined based on the method developed by JMA [4]. Rain gauge data and radar intensity data have different characteristics such as the difference between point data and spatial data or surface data and low–level not surface data. In order to calculate QPE stably, data accumulation is necessary. By using this method, the QPE product with 1 km resolution is calculated every 1 hour for 1 hour accumulated rainfall amount.

The algorithm of QPE is summarized in Figure 3. This algorithm consists of five major processes, 1) quality control and one hour accumulation of rain gauge data, 2) convert from radar volume scan intensity data to lowest level distribution and one–hour accumulation, 3) 1st calibration by rain gauge data, 4) 2nd calibration by rain gauge data, 5) produce a national composite map.

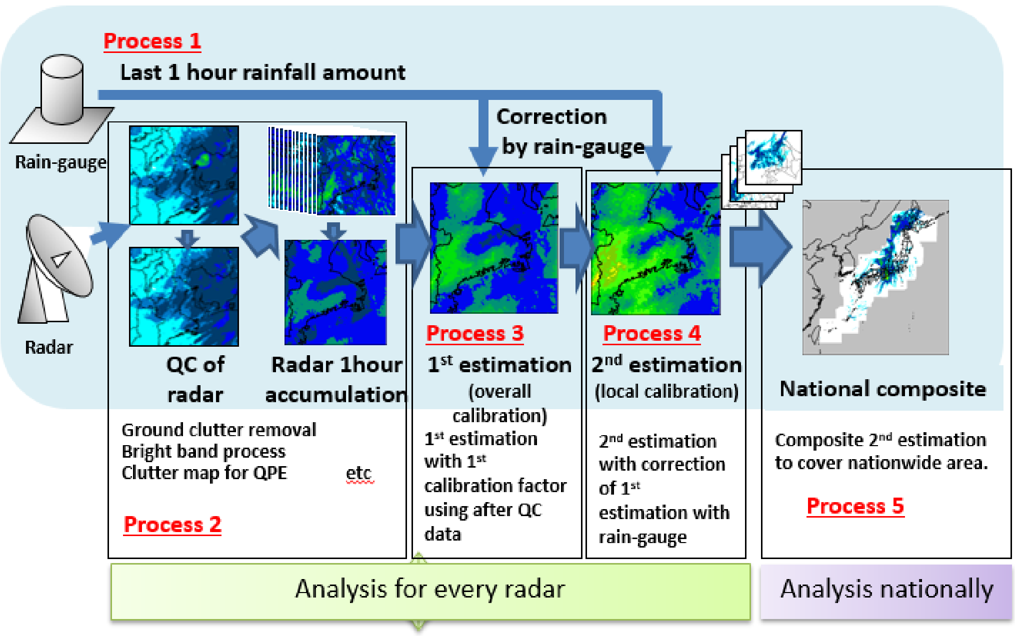

Figure 3. Schematic algorithm for QPE.

Even if several radars observe the same grid mesh, the values of one–hour accumulated precipitation may not be the same. Also, the values of one–hour accumulated precipitation right above a rain gauge may not be the same as the one–hour precipitation amount of the rain gauge. This is because of the following reasons;

- Error due to the assumption in Z–R relationship.
- The mechanical characteristics of the receiving sensitivity in each radar.
- Radio wave attenuation due to precipitation in the transmission path and wet radome.
- Error due to the different rain distribution between the upper air and the ground. The higher the radar beam passes through, the larger the error will be.

Therefore, one–hour accumulated precipitation E_0 from the radar must be calibrated to fit the value of the rain gauge. The calibrated one–hour accumulated precipitation value is called the 1st calibrated value E_1, and the correction quantity is called the 1st (precipitation) calibration factor. Several conditions to determine the 1st calibration factor σ are as follows,

- The factors for the errors differ in each radar and time, therefore the 1st calibration factors σ are determined in each radar and in each hour.
- The 1st calibrated precipitation E_1 should take the same value at the area where two neighboring radar overlap.
- The 1st calibrated precipitation E_1 should be corresponding to the amount of the one–hour precipitation from rain gauge.

For estimating the 1st calibration factor σ, first we determine 1st calibrated precipitation E_1 as in below.

$$E_1 = \sigma E_0 \quad (1)$$

From Condition 1, σ is the function of time t, which can be written as $\sigma(t)$. From Condition 2, assume that there is common observation area A and B, and at the certain point, the calibrated precipitation from both radars should be the same value. But in actual cases, it will not be the same. Therefore, we need to consider the residue δ_1 as;

$$\delta_1 = (\sigma_a (E_{ab}) - \sigma_b (E_{ba}))^2 \quad (2)$$

where E_{ab} is the reflectivity from Radar A and E_{ba} is from Radar B at the certain point.

From Condition 3, where $\langle R_{ab} \rangle$ is defined as the mean value of 1–hour precipitation among rain gauges in area A∩B, and mean values from the radar are defined as the figure, it can be written as;

$$\sigma_a \langle E_{ab} \rangle = \langle R_{ab} \rangle,\ \sigma_b \langle E_{ba} \rangle = \langle R_{ab} \rangle, \quad (3)$$

But in actual cases, they will not be as the equation. Therefore, we need to consider the residue δ_2 as below.

$$\delta_2 = (\sigma_a \langle E_{ab} \rangle - \langle R_{ab} \rangle)^2 + (\sigma_b \langle E_{ba} \rangle - \langle R_{ba} \rangle)^2 \quad (4)$$

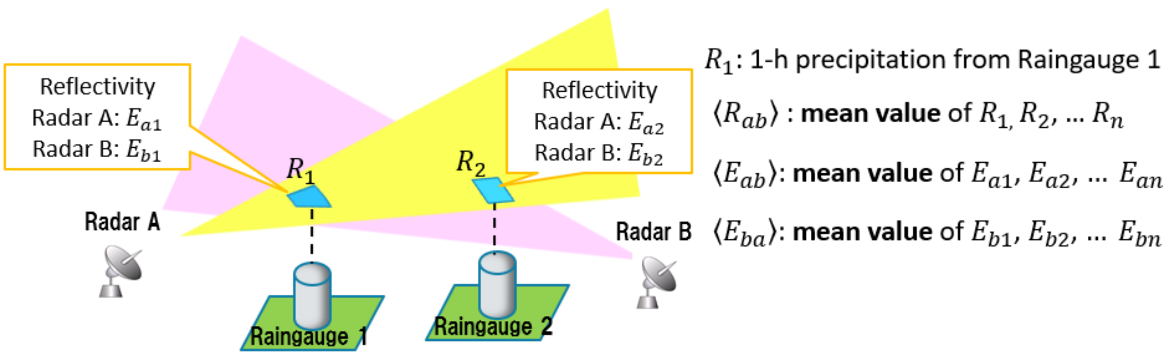

Figure 4. Schematic view of parameters for estimating 1st calibration factor σ.

Residue δ_1 and δ_2 are summed up in Equation 5 as residue Δ, where α is a parameter.

$$\Delta \equiv \delta_1 + \alpha \delta_2 \tag{5}$$

When δ_1 and δ_2 take the optimum value, residue Δ takes the minimum value. First calibrated factor may be determined by solving the simultaneous partial differential equation for σ_a and σ_b on this residue Δ.

Second calibration is a process to calibrate locally to each rain gauge sites. The 2nd calibration factor is determined at each rain gauge mesh by comparing 1st calibrated precipitation and rain gauge one–hour precipitation. At the grid of raingauge, the ratio of 1st calibrated precipitation and 1–hour rainfall of the rain gauge is set as the temporal 2nd calibration factor.

When $R(\vec{r})$ is 1–hour rainfall of the rain gauge at point $\vec{r}$ and $E_1(\vec{r})$ is 1st calibrated precipitation at that grid, temporal 2nd calibration factor at point $\vec{r}$ is described as below.

$$\varphi(\vec{r}) = \frac{R(\vec{r})}{E_1(\vec{r})} \tag{6}$$

When the temporal 2nd calibration factor is set at the grid of rain gauge, 2nd calibration factor at the other grid is calculated by interpolating the temporal 2nd calibration factor $\varphi(\vec{r})$. The 2nd calibration factor $\chi(\vec{r_0})$ at the grid $\vec{r_0}$ can be described when using $\varphi(\vec{r_i})$ as the temporal 2nd calibration factor at rain-gauge i grid $\vec{r_i}$, parameter ϖ and weight w_i

$$\chi(\vec{r_0}) = \exp\left\{\frac{\sum_i(\varpi w_i + 1)\ln\varphi(\vec{r_i})}{\sum_i(\varpi w_i + 1)}\right\} \tag{7}$$

where

$$w_i = w_D \times w_R \tag{8}$$

This calculation will be repeated three times to make well–fit and smooth interpolation. Finally, these 2nd calibration factors at each rain gauge mesh are interpolated to make a distribution of 2nd calibration factor. The weighting factor for interpolation is a function of distance between the target mesh and rain gauge and precipitation type. By using the 2nd calibration factor, 1st calibrated precipitation E_1 is converted to 2nd calibrated precipitation E_2, which is the result of the QPE. Detailed explanations on this QPE algorithm are given in [4–7].

4. Characteristics of rain gauge data and quality control

The total number of ARG stations is around 1400 from the station list. In order to keep a qualified QPE product, quality control of rain gauge data is vitally important. There are three types of errors affecting rain gauge data such as trouble of rain gauge system, transmission error, and environmental change surrounding rain gauge. Before the test operation of QPE started in July 2019, all ARG data with the present format were temporarily checked. Since ARG did not have enough data for the rainy season, the main targets were to detect the transmission error and abnormal values to remove suspicious ARG stations. We used the following simple conditions to check the quality of each ARG.

The ratio of missing data is less than 5% or not

Comparing rain amount with an adjacent station located around 5 to 10 km and both observational values are not so different

By using the observation data between December 2018 and June 2019 at about 950 ARG stations, we checked the missing rate. Figure 5 shows the distribution of the missing rate. 745 stations have less than 5% of the missing rate. Figure 6 shows the locations of high missing stations. They distribute extensively in the country and need to know the cause of these missing stations to improve the quality of rain gauge data.

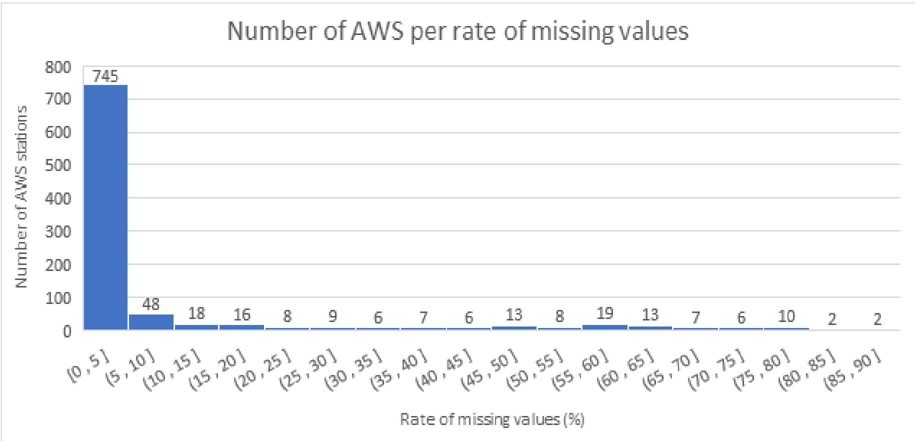

Figure 5. Number of ARG per rate of missing values.

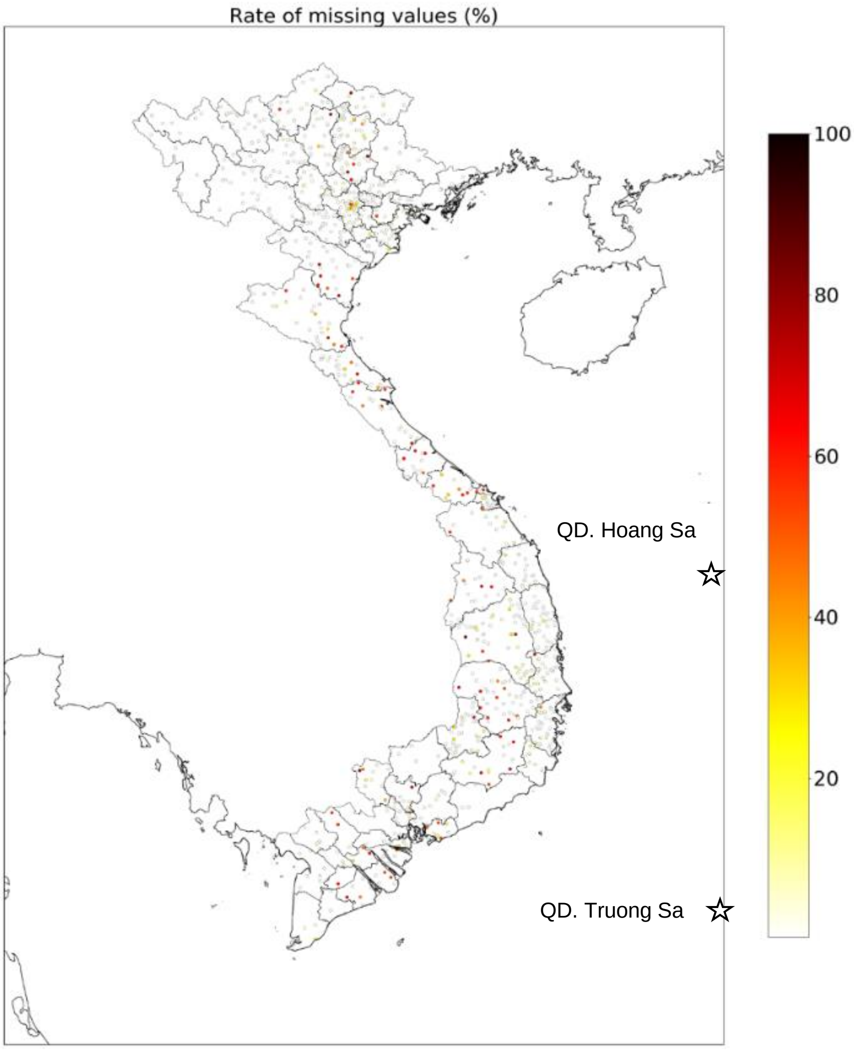

Figure 6. Distribution of ARG missing rate.

Some stations have unnatural low value compared with nearby ARG. Figure 7 shows an example of comparing the time change of precipitation amount at three nearby stations. Their distances are 5–10 km. In this case, precipitation amount at station No.23584 is much less than station No.731750 and station No.92510. Therefore, the data from station No.23584 is not used for QPE calculation. Similarly, several other stations are not used according to the manual check.

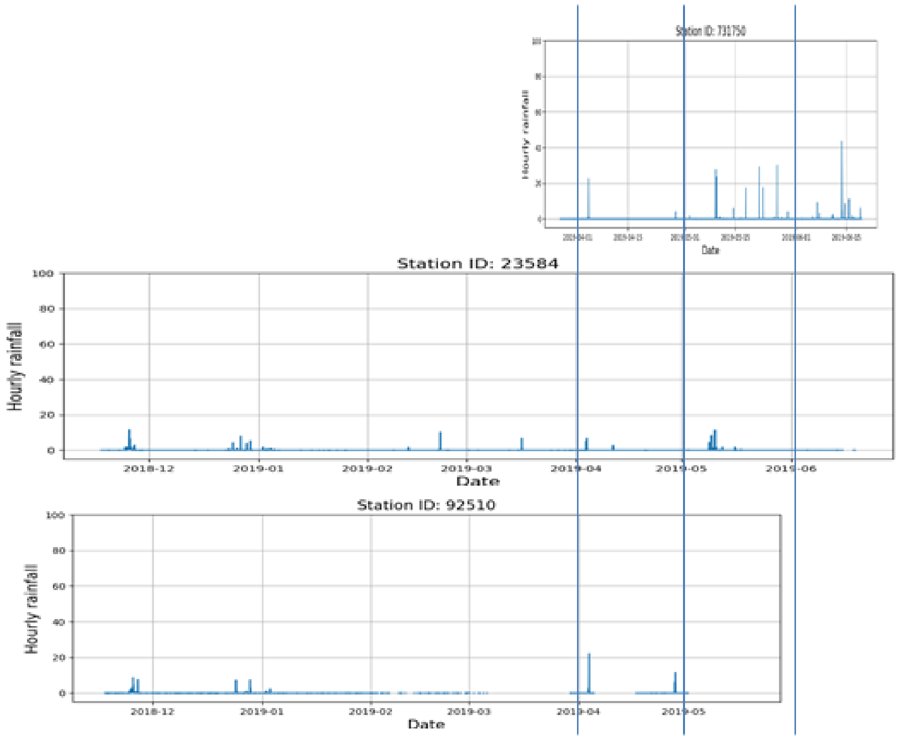

Figure 7. Time changes of three ARG stations located nearby within the distance of 5–10 km.

Based on these two conditions, we finally selected 750 ARG stations for QPE calculation. (The final number of stations increased more than 745 by adding other type of ARG data.) About half of the ARG data are not used for QPE calculation. In order to improve the accuracy of QPE, the cause of errors should be checked and the number of qualified ARGs should be increased.

5. Characteristics of radar and QPE product

Each radar scans in Intensity mode or Doppler mode. Intensity mode is a type of observation with low Pulse Repetition Frequency (PRF) and can detect with a longer range than Doppler mode. Vaisala radar has a maximum detection range of 300 km and JRC radar of 450 km in Intensity mode. Several specifications of these observation modes are summarized in Table 1. In this QPE calculation, Intensity mode data is used.

Radar scans with a sequence of multiple elevations in six to ten minutes. In order to get precise precipitation distribution, echo intensity data at the lowest altitude is necessary. Low elevation scans are often affected with ground clutter, sea clutter, or non–precipitation echoes. A combination of different elevations depending on the surrounding situations around the radar, is determined as a composite table. This method is called “Pseud Constant Altitude Plan Position Indicator (PCAPPI)” in this QPE algorithm.

Figure 8 shows the PCAPPI elevation table of three radars. In order to avoid the effect of ground clutter, some radars located close to the mountainous region have a complicated table. Statistical quality control of PCAPPI data is useful to check the effect of beam cut by mountain or interference. For quality control of PCAPPI data, accumulation of PCAPPI data for appearance frequency and intensity are two important indicators to determine whether the echo is from precipitation or not. Figure 9 shows examples of these accumulations. Table 2 indicates the meanings of each category. Precipitation echo shows high frequency and high intensity. Area of beam cut shows low frequency and low intensity and partial beam cut shows high frequency and low intensity. Interference shows high frequency and extremely high intensity and extremely high frequency area becomes a linear shape.

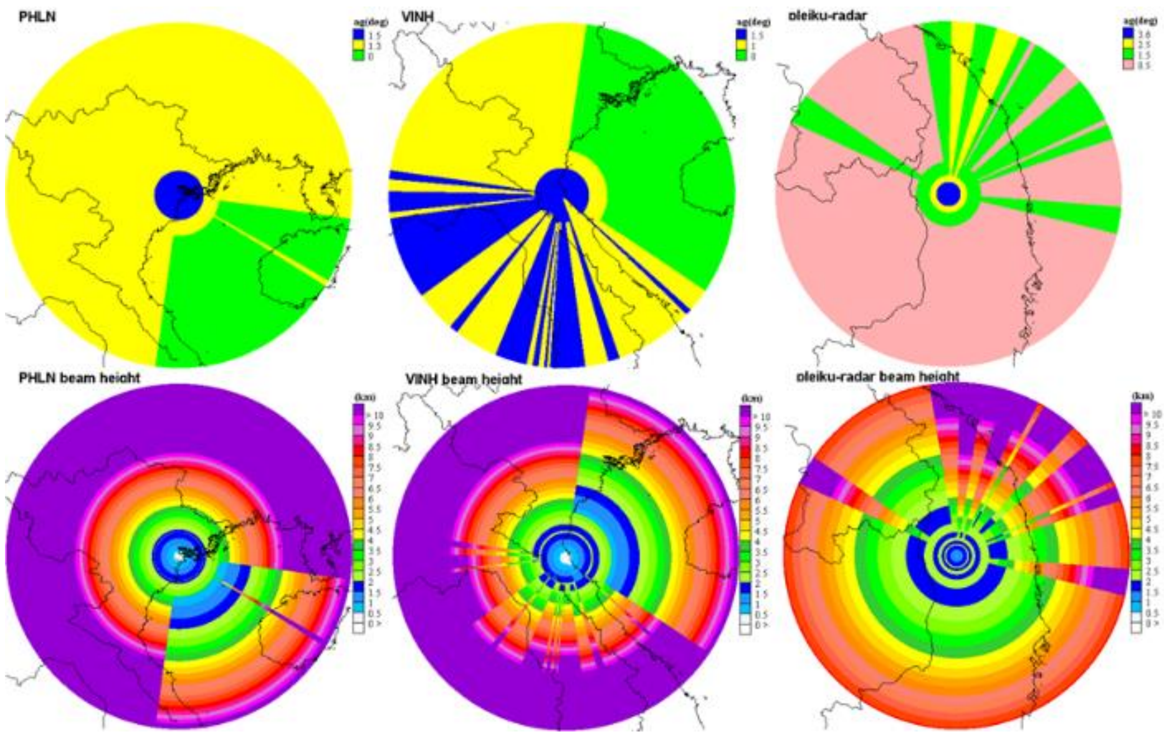

Figure 8. PCAPPI elevation settings for Phu Lien, Vinh and Pleiku radars (from left to right).

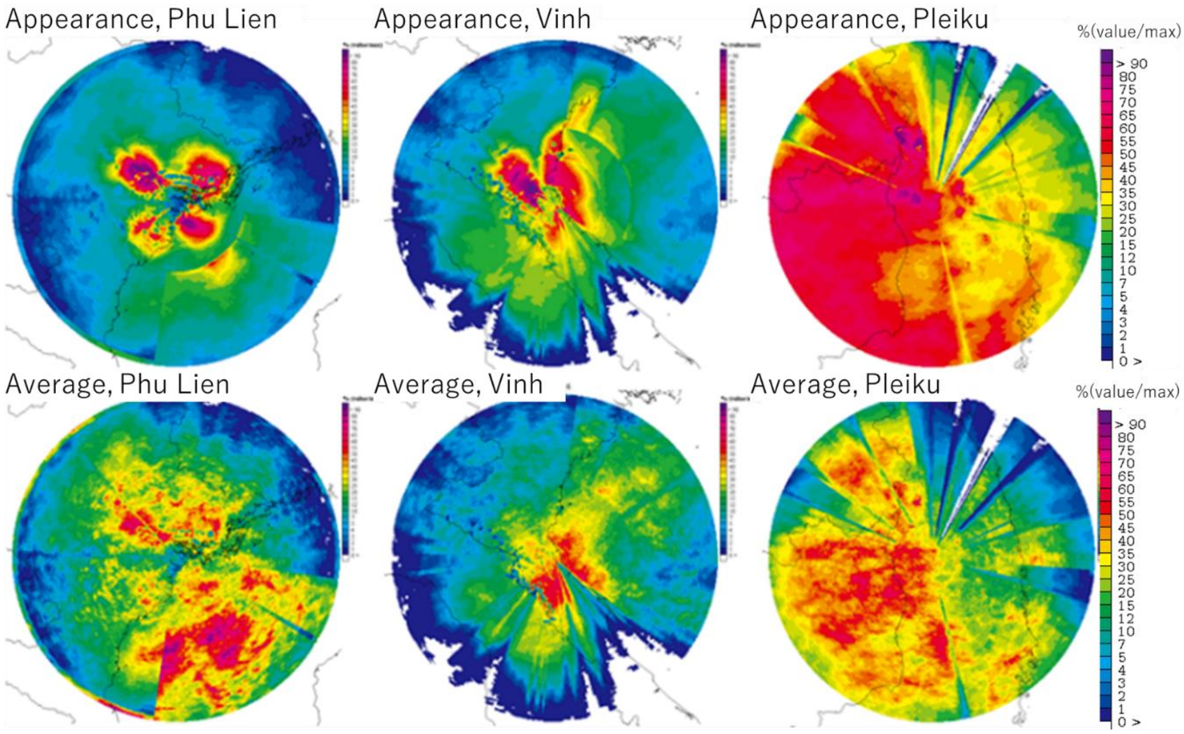

Figure 9. Appearance frequency (upper row) and average reflectivity (lower row) of one–month accumulated PCAPPI data from September 1st to 30th, 2019.

Table 2. Characteristics of several noisy situation

	Appearance frequency	Average reflectivity	Echo pattern
Beam blockage	Low	Low	Wedge
Low–frequency interference	Low	High	Wedge
High–frequency interference	High	Low	-
Strong interference or clutter	High	High	-

Based on this statistical check, elevation settings for the PCAPPI products are optimized in each radar to make them less influenced by clutters or beam blockage. By combining PCAPPI and rain gauge data, a preliminary QPE product is created. Time sequence of QPE calculation is shown in Figure 10.

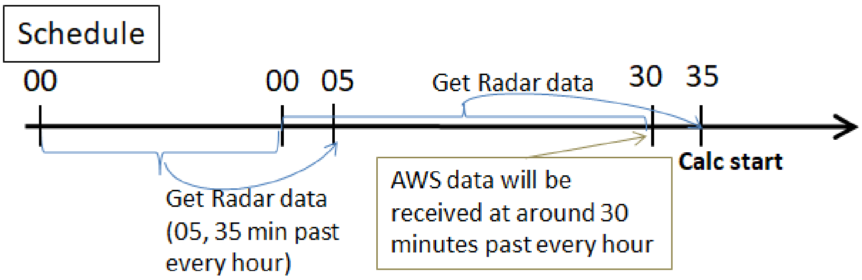

Figure 10. Calculation schedule of QPE.

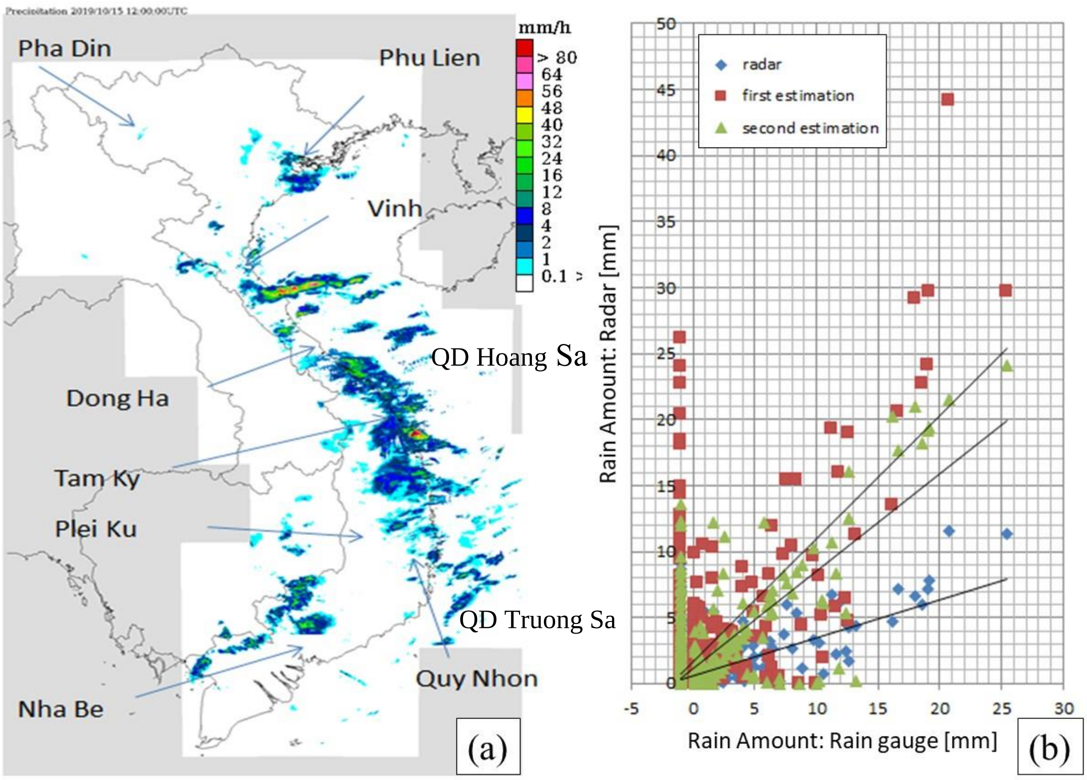

Figure 11. (a) Sample result of QPE; (b) Evaluation of three types of estimated precipitation. (1) Estimation only by radar, (2) 1st calibrated precipitation, (3) 2nd calibrated precipitation.

The first version of QPE calculation started its operation from July 2019. At this stage, two JRC radars and four Vaisala radars were used for QPE calculation. After the number of Vaisala radars increased to six, the algorithm has been improved for several issues. Finally, the current version of the calculation was started from March 2020. The detailed installation process is referred to [8].

Figure 11a shows an example of a QPE product. QPE results can be overlaid on satellite data by using the Satellite Animation and Interactive Diagnosis (SATAID) system. Figure 11b shows the result of the preliminary evaluation of QPE products. Accuracy of the precipitation improves from estimation only by radar to 1st calibrated precipitation and further to 2nd calibrated precipitation. In this case, rain gauge data used in the calculation are employed for evaluation.

6. Improvement of scan strategy of JRC radars

As mentioned in introduction, scan strategy is one of the important issues to improve the quality of QPE. JRC radar's scan sequence has three elevation angles for Intensity mode and 10 elevation angles for Doppler mode. QPE calculation uses only intensity mode data and the quality of this mode is important to keep the accuracy of QPE. There are enough volume scans for Doppler mode, but only three elevations for Intensity mode. Furthermore, two scan angles in Phu Lien radar are so similar such as 1.3 degree and 1.5 degree, which means not enough scan angles for Phu Lien radar as intensity mode. In order to make optimal PCAPPI products avoiding the effect of ground clutter, sea clutter and non–precipitating echo, it is essential to have the choice of elevations in Intensity mode. Vaisala radar changed its scan strategy from August 2019 and increased the number of elevations for Intensity mode to four or five angles.

Table 3 and Figure12 show the current scan sequence and proposed new ones. In the new scan sequence, four elevations for intensity mode and 10 elevations for Doppler mode with different angle settings from the current scan sequence. The merits of the new scan sequence are as follows:

- The number of elevation angles for intensity mode increases and have a better choice of elevation for PCAPPI product
- Qualified of low elevation angle data with combining Intensity mode and Doppler mode data
- Higher vertical resolution in the range between 200 to 300 km
- Smoother change of vertical resolution in the range between 0 to 200 km
- Improvement of detectability of high-altitude echo close to the radar site

Table 3. Elevation angle table of current scan sequence (upper 2 lows) and newly proposed scan sequence (lower 2 lows) for JRC radars (unit is degree). Phu Lien radar currently uses 1.3 degree in the second elevation in Intensity mode and Vinh radar uses 1.0 degree.

Int	0.0	1.3 1.0	1.5							
Dop	0.0	0.5	1.0	1.5	2.0	3.0	4.0	6.0	9.0	12.0
Int	0.0	0.5	1.0	1.5						
Dop	0.5	1.0	1.5	2.5	3.6	5.0	7.2	10.4	15.0	21.5

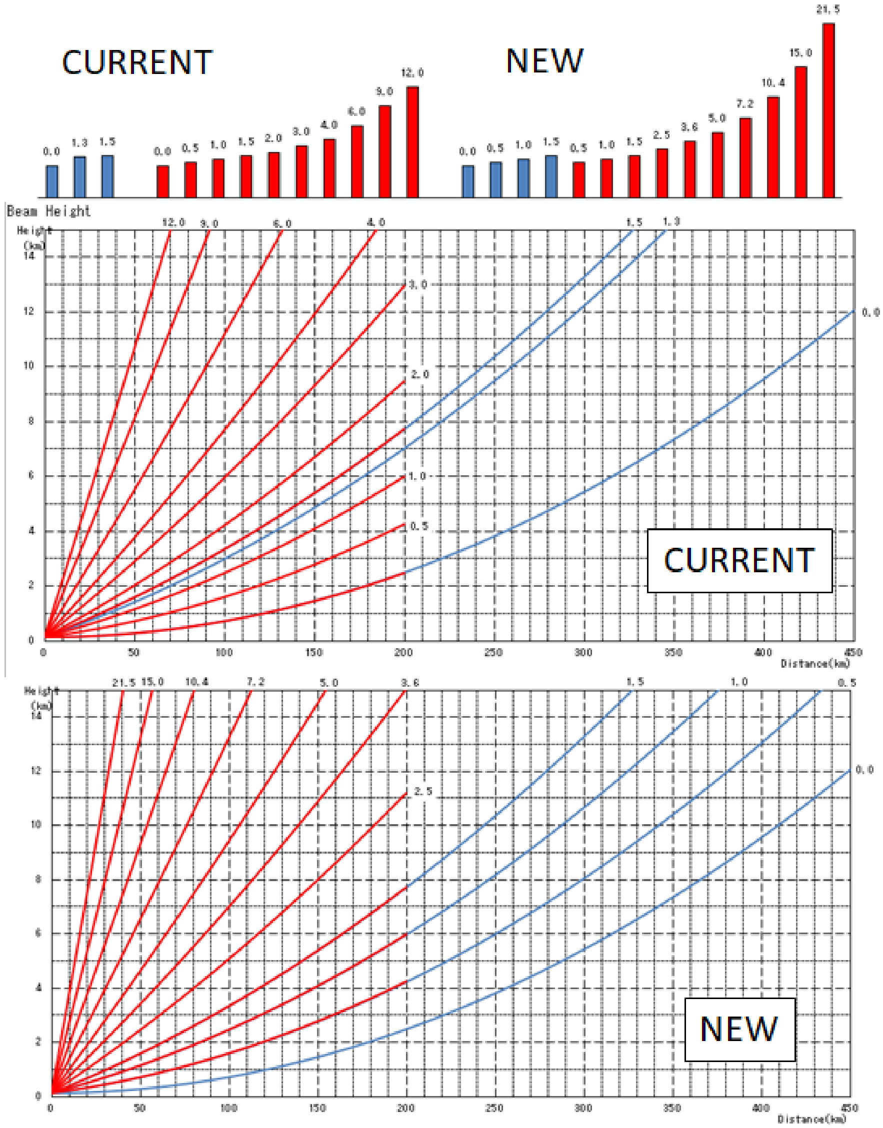

Figure 12. Current scan sequence and newly proposed scan sequence on Phu Lien radar.

7. Summary and future issues

Currently eight meteorological radars and about 750 ARG data are combined to make hourly QPE product. In the early stage, sometimes there were sudden increases in QPE value. Several improvements were made such as correction of locations of radar and ARG, quality control of radar and ARG data, optimal parameter settings of the QPE algorithm and suppression of these abnormal values. Even if these improvements increased the stability of calculation, there still are several issues regarding the optimal setting of radar and QPE software, quality control of ARG and radar data to further improve the accuracy of QPE. Detailed issues are listed as follows:

- Increase reliability and availability of ARG data
- Optimal elevation setting in PCAPPI
- Improvement of scan strategy of JRC radars
- Proper setting of clutter maps
- Evaluation of QPE product with independent ARG
- Optimal parameter setting of QPE algorithm

Radar estimated precipitation amount without rain gauge correction has sometimes large errors. This is due to the Z–R relation based on Marshal–Palmer distribution tend to correspond to stratiform precipitation. In case of convective precipitation, drop size distribution is different from Marshall–Paler and varies with different convective cases. Radar estimated precipitation for convective cases underestimate the amount. By using QPE method with rain gauge correction as proposed in this paper, heavy rain events are expected to estimate accurately. Evaluation of QPE product is necessary for various types of precipitation.

Accurate QPE data is a base of various information for disaster prevention and there are two major ways to further utilize QPE data. One is an application to various indexes of disaster risk prediction. Usually precipitation amount is used to predict the occurrence of disaster, but in order to improve the prediction indexes including other factors such as soil water for land slide and runoff for flood are necessary. Archive data set of QPE with the occurrence of disaster is useful to formulate the relationship between these indexes and the occurrence of disaster. The other is an application to quantitative precipitation forecast (QPF). There are several techniques for QPF and the merging of extrapolation of QPE with forecast by numerical weather prediction (NWP) model is one of the useful methods.

Author Contributions: Conceptualization, C. Kimpara and M. Tonouchi; methodology, C. Kimpara, N.V. Hung and N.M. Cuong; software, C.Kimpara and B.T.K. Hoa; validation, C.Kimpara, M.Tonouchi and B.T.K. Hoa; formal analysis, K. Akaeda; writing–original draft preparation, C.Kimpara and B.T.K. Hoa; writing–review and editing, All authors have read and agreed to the published version of the manuscript.

Funding: This study is supported by the JICA project for strengthening capacity in weather forecasting and flood early warning systems in Viet Nam.

Acknowledgments: The authors thank the Japan Meteorological Agency for providing the package for calculating QPE products and their support for the installation. Also, authors thank Nguyen Vinh Thu, Director of the Aero Meteorological Observatory for his support and suggestions to this project. Thanks are extended to Nguyen Quang Vinh of the Aero Meteorological Observatory for his technical support to various radar analysis.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Tonouchi, M.; Kasuya, Y.; Tanaka, Y.; Akatsu, K.; Akaeda, K.; Nguyen, V.T. Activities of JICA on disaster prevention and achievement of JICA project in Period 1. *VN J. Hydrometeorol*., **2020**, *5*, 1–12.
2. Vicente, G.; Scofield, R. A.; Mensel, W.P. The operational GOES infrared rainfall estimation technique. *Bull. Amer. Meteor. Soc.* **1998**, *79*, 1881–1898. doi: 10.1175/1520-0477(1998)079<1883:TOGIRE>2.0.CO;2
3. Vasiloff, S.V.; Seo, D.J.; Howard, K.W.; Zhang, J.; Kitzmiller, D.H.; Mullusky, M.G.; Krajewski, W.; Brandes, E.A.; Rabin, R.M.; Berkowitz, D.S.; Brooks, H.E.; Mcginley, J.; Kuligowski, R.J.; Brown, B.G. Improving QPE and very short term QPF. *Bull. Amer. Meteor. Soc.*, **2007**, *88*, 1899–1911. doi: 10.1175/BAMS–88–12–1899

4. Makihara, Y. A method for improving radar estimates of precipitation by comparing data from radars and rain gauges, *J. Meteor. Soc. Japan*, **1996**, *74*, 459–480. doi: 10.2151/jmsj1965.74.4_459
5. Makihara, Y. Algorithms for precipitation nowcasting focused on detailed analysis using radar and rain gauge data, *Technical Reports of the MRI*, **2000**, *39*, 63–111. doi:10.11483/mritechrepo.39
6. Observation Department. Radar/rain gauge-analyzed precipitation, *Weather Radar Application Technology at the Japan Meteorological Agency*, 2017, pp. 62–70.
7. Makihara, Y. Quantitative Precipitation Estimation, Training for QPE derived from the combination of radar and rain gauge data, Hanoi, *Training Material*, 2020, ##5.
8. JICA and JMBSC. The Project for Strengthening Capacity in Weather Forecasting and Flood Early Warning System in Vietnam, *Final report (First period)*, 2020, pp. 147.