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Evaluation of the applicability of radar rainfall information to operational hydrology

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Abstract This paper proposes a framework for evaluating the usefulness of radar rainfall information by different usage, and discusses the prospects and limitations of the further development of the radar system. The authors evaluate the usefulness of radar rainfall from the viewpoint of the user, not the radar developer or researcher, and they implement evaluations for each purpose. It was found that the radar raingauge is highly effective in estimating rainfall averaged over a river basin, which is important for flood forecasting and reservoir management; and a rainfall observation system composed of combination of ground raingauges and radar raingauges should be established for further development of the radar system.

Key words calibration; evaluation method; flood forecast; radar rainfall

INTRODUCTION

It has been more than 50 years since the concept of precipitation observation with weather radar was established, and more than 30 years since the radar system was fully studied and operated in Japan. However, it is still difficult to answer the questions: how accurately does the radar raingauge observe and how much can we expect its accuracy to improve? This is because the true values to test the rainfall accuracy observed with radar cannot be obtained. We usually define rainfall depth measured with the ground raingauge as rainfall. However, the ground raingauges only provide the amount of rain that pours on the raingauge of only about 20 cm in diameter, and does not widely measure distributed rainfall in the atmosphere. The true value to be compared cannot be known. Therefore, the accuracy of radar is always evaluated with an assumption or guess, and is different depending on various conditions or case studies, and thus quantitative evaluation of observation accuracy is difficult.

In this paper, rainfall observation accuracy of the radar raingauge was attempted from the viewpoint of radar data users. Because the required performance and accuracy of radar observation varies according to the purposes, such as weather forecast, flood forecast, sediment disaster warning, traffic management, and reservoir management, it is necessary to estimate accuracy and capability for each purpose to decide whether radar information is practically effective or not. For example, point rainfall information is required for sediment disaster warning and traffic management, while areal averaged rainfall in a large area in a river basin is important for flood forecasting and reservoir management. At first, an appropriate evaluation method for observation accuracy according to each usage is proposed. Secondly, the authors demonstrate case studies to show the advantages of the use of different evaluation methods according to usage and to evaluate the usefulness of the radar rainfall system from multi-functional aspects. The authors also evaluate the effectiveness of the calibration of radar rainfall with ground rainfall data for various operational applications.

CALIBRATION OF RADAR DATA

Calibration methods such as the uniform correction method, Ninomiya & Akiyama's method (1978), the range weight method, RWM (Brandes, 1975), the dynamic window method, DWM (Yamaguchi *et al.*, 1993a) and the kriging method (Yoshino *et al.*, 1988), have been proposed. The RWM and DWM methods are used in Japan.

The Japan Meteorological Agency (JMA) has worked to develop a practical application of radar observation and has provided Radar–AMeDAS rainfall, which is generated from the combination of weather radar and AMeDAS ground rainfall information with RWM (JMA, 1995). Values of calibration coefficient f for each radar mesh are calculated by giving range weight W, which takes a smaller value as ground raingauges are far from the radar mesh.

The Ministry of Construction (MOC) (Ministry of Land, Infrastructure and Transport, MLIT from 2001) had not provided the calibrated radar rainfall, because the radar system has been under development and the incomplete calibration system may produce erroneous rainfall intensity, while from 2001, MLIT began to distribute the calibrated radar data by using DWM, a method to decide the most appropriate sampling area by balancing variation of estimation accuracy. The calibration is carried out by using the averaged inverse number of spatial fluctuation coefficient (relation of variation between observed rainfall and radar rainfall) as the weight factor (Yamaguchi *et al.*, 1993a).

Traditionally, radar rainfall data have been calibrated to make the radar rainfall closer to the point ground rainfall observation. However, the DWM calibration method proposes to improve the accuracy of areal rainfall by combining both the advantages of point observation accuracy with ground raingauges and spatio-temporal observation ability with a radar raingauge. The calibration method is more appropriate when accurate areal rainfall is needed, such as flood forecasting, than when point rainfall observation accuracy is required.

EVALUATION OF HARDWARE ERROR ON RADAR RAINGAUGE SYSTEM

Before observation accuracy with radar raingauges is discussed, the error in the hardware itself has to be understood quantitatively. Ishizaki *et al.* (1986) analysed electrical and mechanical errors of the MOC radar raingauge hardware, focusing on a specific resolution of a radar instrument, a range of electrical loss and noise, etc. The results showed that, except for the attenuation due to the water film formed on the radome, a radar raingauge error of the hardware was about 1.0 dB as the amount of electrical wave fluctuation, which corresponds to less than about 15% of rainfall observation error when the radar constant $\beta = 1.6$ was used.

A ground raingauge also has various measurement errors. A point rainfall observation error of a ground raingauge properly placed on the flatland with no shielding, according to the installation standard, can be within 3% of verification tolerance, but when it is strongly affected by wind, the observation accuracy changes to a large extent. Koschmieder (1934) compared values of a raingauge under the ground not affected by wind and a gauge installed without any guard 1.1 m above the ground. The difference between the two observed values was large when wind velocity v was strong. According to the research, the observed value of the underground raingauge was about 1.4 times larger than the value of the other raingauge when $v = 8\ \mathrm{m\ s^{-1}}$, twice when $v = 12\ \mathrm{m\ s^{-1}}$, and about three times when $v = 15\ \mathrm{m\ s^{-1}}$ (Kawabata *et al.*, 1972).

ACCURACY FROM THE VIEW OF POINT RAINFALL OBSERVATION

Nakao *et al.* (2001) analysed the MOC radar rainfall data all over Japan from June to October 1999, and calculated the correlation and the total rainfall ratio (TRR) between ground point rainfall and radar rainfall right above the ground stations. According to the analysis, the correlation coefficient r of hourly rainfall was higher than 0.6 at most of the stations and higher than 0.8 at many stations. In addition, r showed a tendency to become higher as rainfall intensity was stronger. Although the result gives an indication of current radar observation accuracy, raindrop drift effect by wind in the atmosphere should be considered to evaluate the point rainfall accuracy.

Nakao (1999) analysed radar data observed at the MOC's Takasuzu radar raingauge during the rainstorm in August 1998. He proved that the correlation value r between ground rainfall and the mesh radar rainfall right above the ground station was 0.71, while the correlation between the ground rainfall and the mesh radar rainfall on the windward side always showed higher values ($r = 0.85$–0.98). Ishizaki *et al.* (1986) examined correlation and average deviation between ground gauged data and radar data right above the ground station and eight neighbourhood meshes by using the high density ground raingauge observation in the Kurihashi area with 24 ground raingauges installed in an area of 15 $\mathrm{km^2}$. In the research, it was shown that neighbourhood meshes had high correlation, but they did not correspond to wind direction and velocity in all cases.

The feature of sediment disaster caused by heavy rainfall is that there is almost no time left to evacuate once sediment disaster occurs. It is important to issue an effective warning and order for evacuation at an appropriate time because people have difficulties with evacuation for this sort of disaster. Local governments set up in guidelines of rainfall amount for each stream to issue evacuation warning and order against debris flow disaster based on the MOC guideline (1984). In practice, the warning and evacuation order are announced when the snake line (time series of rainfall intensity–rainfall depth relation) reaches WL (warning line) and EL (evacuation line), but there is some difficulty in giving the precise rainfall because of the sparse density of ground raingauge networks in cases of small-scale debris flow disaster.

The introduction of weather radar was expected to resolve the problem, but there is a difficulty in that the spatial resolution of radar information (several km) is too coarse for the scale of sediment disaster (250–500 m). Yamaguchi *et al.* (1993b) examined the radar data when rainstorm caused debris flow disaster in the southern part of Kyoto in 1986. They showed that the radar estimated rainfall intensity was an averaged value at 3 km resolution, which could not observe high regional variation of precipitation in a mountainous area; thus, the radar estimated rainfall could be underestimated in small-scale rainfall variation.

ACCURACY FROM THE VIEW OF POINT RAINFALL OBSERVATION WITH CALIBRATION

Yamaguchi *et al.* (1993b) examined the advantage of the calibration with DWM for the aforementioned debris flow disaster in 1986. They reported that the calibration improved the entire observation accuracy of rainfall distributions, but in the sediment disaster area the cumulative rainfall changed too little before and after the calibration. The ground raingauge density was too low to improve the underestimation of rainfall.

Nakao *et al.* (2001) applied RWM and DWM to MOC's radar data and examined the improvement of point rainfall observation accuracy by the calibration method. Both of the methods improved TRR for ground rainfall up to about 1.0, and there was a small difference in the calibration performance between the two methods. The research also showed that real-time calibration had better accuracy than extrapolated time calibration.

To use rainfall forecast based on radar rainfall observation for issuing sediment disaster warning, Yamakoshi *et al.* (2001) developed a new method to produce the snake line by calculating effective rainfall from short-term precipitation forecast data (1 h 10 min time resolution and 2.5 km spatial resolution) predicted by the Japan Weather Association. Hara *et al.* (2001) and Watari *et al.* (2002) improved the efficiency of the method to avoid underestimation by applying the maximum radar rainfall from about nine neighbouring radar meshes, including the mesh right above the study area as a forecast value.

ACCURACY FROM THE VIEW OF AVERAGED AREAL RAINFALL OBSERVATION

It is essential for flood forecasting and reservoir management to obtain averaged rainfall over river basins. However, there is a problem that areal rainfall cannot be gauged to use as a true value for the evaluation of radar rainfall.

Hashimoto (1977) discussed the accuracy and reliability of areal rainfall estimated from ground point rainfall data by using a sample design method (SDM). In the discussion, he reviewed the extant studies and research results with the thinning-out method (TOM) from within and outside of countries and found that the relation between the raingauge control area and the estimated error was different from basin to basin. He also illustrated the relation among the basin area, the number of rainfall observation stations and the average relative error (Hashimoto & Satou, 1974). It shows that in a 1000 km^2 basin, for instance, the relative estimation error of the basin average rainfall is less than about 15% with eight rainfall observation stations, and less than 10% with 20 stations.

Ishizaki *et al.* (1986) applied TOM and SDM for the high-density ground rainfall observation data in the Kurihashi area. They showed that, for the rainfall with more than certain rainfall intensity, the estimated error for representing average rainfall in a range of 15 km^2 by one point raingauge station was 40–60% and by six stations was about 10%. Also, with SDM, the estimated relative error was 6–8% and about 13% in thunderstorm with 24 observation stations at risk rate $2\alpha = 50\%$. Ishizaki *et al.* (1986) investigated the basin average rainfall estimation error by radar rainfall data with TOM at 900 km^2 in the Kurihashi and Shimokubo-dam areas in a mountainous district. The result revealed that the areal rainfall by radar was good.

ACCURACY FROM THE VIEW OF AREAL RAINFALL OBSERVATION WITH CALIBRATION

Matsuura *et al.* (2001) clarified the improvement effect of the areal rainfall observation accuracy by DWM with rainfall in the Syounai-gawa River basin (A = 1010 km^2) in August 1996. The result showed that TRR of ground areal rainfall and radar areal rainfall was 0.7 and correlation r was 0.95 before the radar data were calibrated, while TRR was improved to nearly 1.0 after the calibration. The paper also focused on rainfall averaged over the river basin in the 2000 Tokai heavy rainfall disaster. The rainfall amount averaged over the river basin using all ground rainfall data from JMA AMeDAS, MOC telemeter and Aichi prefecture was estimated, and the estimated value was compared against the previous result obtained by Hashimoto (1974). The ground rainfall averaged over the river basin was estimated with less than 10% error. First, Matsuura *et al.* (2001) compared the Thiessen and kriging methods for obtaining the averaged rainfall over the river basin using 20 stations and found little difference between these two methods. Then, they compared the areal rainfall amounts (up to 100–600 km^2) calculated using 20 ground raingauge data with the ones using MOC's radar data, which were calibrated with MOC telemeter rainfall data at 12 points in the river basin. The result was that the correlation r was larger than 0.95 in all averaged cases and TRR was 1.00 ± 0.06. Also it was shown that the difference between the values of cumulative rainfall during the flood period was quite small.

CONCLUSION

Availability and limitations of radar rainfall estimation for disaster prevention purposes have been discussed from the viewpoint of users. It was found that the radar raingauge was effective to estimate rainfall averaged over the river basin for flood forecast. On the other hand, point rainfall estimations in each mountain stream need to be improved in accuracy. As radar observation is the practical method to obtain rainfall where no ground raingauges are installed, it is necessary to establish and maintain the rainfall observation system composed of the combination of ground raingauge and radar raingauges. In addition, the data dissemination system and data format should be established to meet the various requirements of users.

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