Evaluation of the applicability of radar rainfall information to operational hydrology

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Abstract This paper proposes a framework for evaluating usefulness of radar rainfall information by different usage, and discusses prospect and limitation of further development of the radar system. The authors pointed out the primal reason for quantitative evaluation for observation accuracy of radar raingauge not being established was that we couldn't obtain true value to be compared. In addition, the authors found it appropriate to evaluate usefulness of radar rainfall from the viewpoint of user not radar developer or researcher and implemented evaluation for their each purpose. Then the authors came to the conclusion that radar raingauge is highly effective to comprehend rainfall averaged over the river basin which is important for flood forecast, reservoir management and so on and rainfall observation system which is the combination of ground raingauge and radar raingauge is the best way.

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

INTRODUCTION

How accurate does radar raingauge observe? How much can we expect its accuracy to improve? It has been more than 50 years since the concept of precipitation observation with radar was established and more than 30 years since it started to be fully studied and operated in Japan. But it is still difficult to find an answer for this simple and ultimate question. The reason is that the true values to test the rainfall accuracy observed with radar cannot be gained. We normally define rainfall depth measured with ground raingauge as rainfall. However, the ground raingauge only provides amount of rain pours on raingauge only about 20 cm in diameter and does not measure midair widespread rainfall observed with radar. True value to compare cannot be known. Therefore the accuracy of radar is always evaluated with assumption or guess and different depending on comparing condition or case so quantitative evaluation of observation accuracy was difficult.

In this paper, rainfall observation accuracy of radar raingauge was tried to clarify from the viewpoint of radar data user. Because required performance and accuracy of radar observation vary according to purpose 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 if it is practical. First, an appropriate evaluation method for observation accuracy according to each usage purpose was suggested. Second, the authors demonstrated case studies to show advantages of the use of different evaluation methods according to usage purpose and evaluated the usefulness of the radar rainfall system from multi-functional aspects. The authors also researched how effective the calibration of radar rainfall with ground rainfall data is for a variety of operational applications.

Evaluation methods for each purpose

The radar rainfall is used for disaster-preservation purpose and requirements of rainfall observation differ for each purpose. While sediment disaster warning and traffic management requires the point rainfall accurate in a small area, the precise areal averaged rainfall in large area ranging in river basin is the important point for flood forecast and reservoir management.

The authors abstracted point and areal rainfall observation accuracy as the methods to evaluate the precision of observations for different purpose.

Calibration of radar data

Main calibration method, depending on their own interpolation, are uniform correction method, Ninomiya and Akiyama's method (1978), range weight method (RWM) (Brandes, 1975), dynamic window method (DWM)(Yamaguchi *et al*., 1993) and kriging method (Yoshino *et al*., 1988). RWM and DWM are in practical use now in Japan.

Japan Meteorological Agency (JMA) has been working to put calibration to practical application and provides Radar-AMeDAS rainfall, combination of weather radar and AMeDAS ground rainfall (JMA, 1995). Radar-AMeDAS rainfall is calculated with RWM. Value of calibration coefficient f for each radar mesh is calculated by giving weight W which is 'range weight', becomes smaller as ground raingauge is far, multiplied by 'radar rainfall ratio weight', gives more weight to the mesh with the gained rainfall data close to radar rainfall of correction mesh. Maximum 10 of AMeDAS observation meshes used to correct target mesh are all located within 70 km in radius from target mesh.

Ministry of Construction (MOC) (reorganized in 2001 to Ministry of Land, Infrastructure and Transport (MLIT)) had not distributed calibrated data because they have been developing radar to be precise as raingauge by itself and incompleted calibration system may wrongly correct rainfall intensity or spatial fluctuation of rainfall at points with no ground raingauges. However, DWM providing prospect in secure precision and spatiotemporal decomposition capacity of data improved enabled them to start distributing calibrated data from 2001. DWM is a method to decide most appropriate sampling area by balancing variation of estimation accuracy caused by changing number (area) of sample and the one owing to spatial fluctuation of rainfall (calibration coefficient *f*). In fact, rainfall intensity affects the variation of rainfall (calibration coefficient) and figure *f* to be averaged is also changed depending on rainfall intensity. Calibration is carried out by averaging inverse number of spatial fluctuation coefficient (relation of variation between observation rainfall and mesh areal averaged rainfall) as weight (Yamaguchi *et al*., 1993).

Originally, calibration of radar rainfall data with ground rainfall data has been used to make radar rainfall closer to ground rainfall. However, calibration improves homogeneity of spatiotemporal accuracy and precision for reference value of radar rainfall and its veritable meaning is rather to provide areal rainfall close to its true value by combining both advantages "point rainfall observation accuracy" of ground raingauge and "spatiotemporal decomposition capacity of rainfall distribution observation" of radar raingauge. Therefore, it is the efficient method rather when accurate areal rainfall is needed such as flood forecast than when point rainfall observation accuracy is required.

Evaluate hardware error on radar raingauge system

Before subjective observation accuracy with radar raingauge is considered, the error on its hardware itself has to be understood quantitatively. Ishizaki *et al*. (1986) analyzed electrical and mechanical error of MOC's radar raingauge hardware focusing on radar instrument specific resolution, a range of electric loss, noise etc. Consequently, except for the attenuation due to the water film formed on the radome, raingauge error of hardware was about 1.0 dB as amount of electric wave fluctuation, which corresponds about less than 15% as rainfall observation error with radar constant β=1.6.

Ground raingauge also has various measurement errors. Point rainfall observation error of ground raingauge tested and properly placed on flatland with no shielding according to the installation standard can be within 3% of verification tolerance, but when it is strongly affected by wind, observation accuracy changes largely. Koschmieder (1934) compared values of raingauge in the ground not affected by wind and the one installed without any guard having receiver 1.1 m high from the ground and approved that the difference between two observed values became huge as wind velocity v got strong. According to his research, gained value from underground raingauge was about 1.4 times the value of other raingauge's when v=8 ms^{-1}, twice as much at v=12 ms^{-1} and about three times at v=15 ms^{-1} (Kawabata *et al.*, 1972).

Accuracy from the view of point-rainfall observation

Nakao *et al.* (2001) analyzed MOC's radar rainfall data all over Japan from June to October 1999 and determined correlation and total rainfall ratio (TRR) between ground point rainfall and the mesh radar rainfall right above the ground station. According to this analysis, correlation coefficient r of hourly rainfall was more than 0.6 at most of the points and even more than 0.8 at many points. In addition, r showed a tendency to become higher as rainfall intensity got stronger. Although his result gives an indication of current radar observation accuracy, raindrop drift by wind in midair should be considered to evaluate point rainfall accuracy in this way.

Nakao (1999) analyzed observation result of MOC's Mt. Takasuzu radar raingauge during the rainstorm in August 1998 and proved that even at the point with bad correlation (r=0.71) between ground rainfall and the mesh radar rainfall right above the ground station, if comparing area is expanded to include some radar meshes around the point, mesh on the windward side always has the ones highly correlate with ground rainfall (r=0.85-0.98). Ishizaki *et al*. (1986) researched r and average deviation between ground raingauge data and its right above the ground station and eight meshes around based on observation data obtained by high density ground raingauge observation in Kurihashi area with 24 ground raingauges installed in range of 15 km^2. However, it was proved that neighborhood meshes have the mesh with high correlation, but not corresponding to wind direction and velocity in all cases.

The feature of sediment disaster owing to heavy rain is that it takes long to build up danger by rainfall but the time to evacuate is hardly left once sediment disaster occurs. It is important to give proper warning and order a evacuation at the most opportune time because people will have difficulties with evacuation for this sort of disaster.

Local authorities set up rainfall depth (reference rainfall) for each stream endangered by debris based on MOC guideline (scheme) (1984) to provide warning and evacuation order against debris flow disaster. This is set with 'rainfall intensity - rainfall depth' as a measure using data of when debris flow occurred and it did not in the past. In practice, warning and evacuation order are announced when snake line reaches WL (Warning Line) and EL (Evacuation Line) but there are some problems such as difficulty in dealing rainfall which exceeds largest record or a failure in decision.

Introduction of rainfall observation and forecast value based on radar rainfall data was considered for improvements but it still has the problem that spatial resolution (few km mesh) of radar information is too rough for sediment disaster occurrence scale (250-500 m). Yamaguchi *et al*. (1993) considered application of radar by reviewing rainstorm caused debris flow disaster in southern part of Kyoto in 1986. He illustrated the radar calculated rainfall with high regional fluctuation near mountain stream which had debris flow with 3 km×3 km mesh averaged value so that it was underestimated.

Accuracy from the view of point-rainfall observation with calibration

Yamaguchi *et al*. (1993) examined advantage of calibration with DWM for aforementioned debris flow disaster in 1986. He reported that calibration improved entire observation accuracy of rainfall distribution, but in sediment disaster area, cumulative rainfall changed too little before and after calibration because of low ground raingauge density to improve underestimation of radar compared with point rainfall.

Nakao *et al.* (2001) applied RWM and DWM to MOC's national radar data and researched improvement of point rainfall observation accuracy by calibration. Both of methods improved TRR for ground rainfall up to about 1.0. Also, there was not big difference of accuracy between two methods. They also confirmed real time calibration has better accuracy than extrapolated time calibration.

To use rainfall forecast data based on radar rainfall for sediment disaster warning, Yamakoshi *et al*. (2001) is developing new method to produce snake line by calculating effective rainfall from short-term precipitation forecast data(1 hour, 10 minutes；2.5 km mesh) by Japan Weather Association. However short-term precipitation forecast was found reasonably applicable for sediment disaster measure, the benefit of every 10-minute short-term precipitation forecast is new information updated every 10 minutes rather than observation accuracy of effective rainfall. Additionally, Hara *et al*. (2001) and Watari *et al*. (2002) approved efficiency of method to avoid underestimation with process applying maximum value from about nine neighboring meshes includes mesh right above the ground with observation target point as forecast value.

Accuracy from the view of areal averaged rainfall observation

It is essential for flood forecast and reservoir management to know rainfall averaged over the river basin precisely. But there is a problem that areal rainfall cannot be gauged to use as true value for evaluation of radar rainfall. Many researches to figure out rainfall averaged over the basin from ground point rainfall accuracy etc. are in progress.

Hashimoto (1977) discussed accuracy and reliability of areal rainfall estimated from ground point rainfall data by using sample design method (SDM). In this discussion, he integrated extant studies and research result with thinning-out method (TOM) from inside and outside of nation and approved that relation between raingauge control catchment and estimated error is different from basin to basin. Also, he applied SDM which regards whole rainfall ranging in basin as a population and ground point rainfall as sample from this population and defined that areal coefficient of variation *Cv* increases as basin area expands, *Cv* dose not depend on rainfall if it is large enough and *Cv* becomes bigger when rainfall duration is short. He illustrated relation among basin area, number of rainfall observation station and average relative error bearing the area with poor rainfall data in mind (Hashimoto, 1974). It shows, for instance, in 1,000 km^2 basin area, average relative error is less than about 15% with eight rainfall observation stations and is less than 10% with 20 stations.

Ishizaki *et al*. (1986) applied TOM and SDM for the result of high density ground rainfall observation in Kurihashi area. He approved that for the rain with more than certain rainfall intensity, one point raingauge representing average rainfall in range of 15 km^2 had 40-60% of error and about 10% of error for six points. Also, with SDM, estimated relative error was 6-8% and about 13% in thunderstorm with 24 observation stations at risk rate 2 α=50%. He considered basin average rainfall estimation error by radar rainfall data with TOM using each 900 km^2 of Kurihashi area and Shimokubo-dam area in mountains district as objects. The result was compared with the one of ground precision rainfall observation in Naka-gawa river basin by Public Works Research Institute and it was defined that necessary number of average mesh is smaller than average raingauge's at same risk rate, with allowable error when radar one mesh corresponds one ground raingauge. The difference gets larger as allowable error becomes smaller, which means estimate accuracy of areal rainfall by radar is decent.

Accuracy from the view of areal rainfall observation with calibration

Matsuura *et al.* (2001) figured out improvement effect of areal rainfall observation accuracy by DWM with rainfall in Syounai-gawa river basin (A=1,010 km^2) in August 1996. The result showed that TRR of ground areal rainfall and radar areal rainfall was 0.7 and r=0.95 before it was corrected but the former improved nearly 1.0 after the correction. He also focused on rainfall averaged over the river basin in times of flood concentration which is important for flood forecast and compared radar and ground rainfall in 2000 Tokai storm to evaluate their accuracies. When he estimates ground rainfall averaged over the river basin regarding all ground rainfall data from JMA AMeDAS, MOC telemeter and Aichi prefecture ground raingauge as homogeneous and check out the figure against previous result from Hashimoto (1974), ground rainfall averaged over the river basin is estimable with less than 10% error. First, Matsuura *et al*. (2001) compared Thiessen method and Kriging method as the procedure to gain rainfall averaged over the river basin from ground rainfall data in those 20 points and found little difference between these two. Efficiency of number and location of raingauges in this basin is obvious from it. Then, he compared areal rainfall calculated with MOC's radar data, which was calibrated with MOC telemeter rainfall data at 12 points in river basin and areal averaged rainfall calculated from 20 ground raingauge data with changed averaged area up to 100-600 km^2. The result was that $r \geqq 0.95$ in all of averaged case and TRR=1.00±0.06. Also the closer values of them compared using cumulative rainfall within times of flood concentration shows that areal average rainfall of radar raingauge is accurate.

CONCLUSION

Availability and limited capacity of radar rainfall for disaster-prevention has been discussed from the viewpoint of user in this paper. It was proved that radar raingauge is effective to estimate rainfall averaged over the river basin for flood forecast and so on. On the other hand, pinpoint rainfall prehension, for example, in each dangerous mountain stream still needs to be improved its accuracy. However, as radar is the practical method to assess rainfall at points where no ground raingauge is installed, it is necessary to establish and maintain the rainfall observation system which is the combination of ground raingauge and radar raingauge. Also, data provision system and format should be constructed actually for user considering the usage as well as accuracy.

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