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FURUNO White Paper
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Accurate and Reliable Rainfall Measurements using Multiple X-band Compact Radars

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Introduction

Recent serious threats to civilian lives due to localized heavy rains, larger typhoons and other meteorological events have been increasing. Many countries consolidate infrastructures that control rivers and sewage, They are creating systems to predict flow amounts and adding these capabilities to their existing weather observation and prediction systems. Each country deploys C-band and/or S-band radars to cover their nationwide area. Recent improvements include the addition of dual polarimetric observation function technologies to the weather radars.
The C-band and S-band radars can cover wider ranges, up to 400 km but have limited range resolutions due to pulse conditions. Also to observe longer range precipitation they have a gap-filling problem caused by earth curvature and other potential obstructions. The gap-filling problem is caused as range increases, coupled with the set elevation angle of the radar, effectively increasing the altitude in order to observe the longer range data. The FURUNO X-band compact/light weight Doppler weather radar features high spatial/temporal resolutions throughout all of its observation ranges and can fill these gaps. The higher resolution also provides high accuracy for rainfall observations and rivers or sewage flow estimates. In some instances X-band radars can have signal attenuation due to heavy rain at the radar location. This can cause some data loss at radar site location.
This paper describes a case study of accurate rainfall observations using multiple X-band weather radars with higher spatial/temporal resolutions in a domestic project demonstration in two Japanese cities.

X-band compact Doppler weather radar WR-2100

Demonstrations have been conducted under the domestic project (B-DASH) funded and support by the Ministry of Land, Infrastructure, Transportation and Tourism. This project uses the FURUNO WR-2100 X-band weather radars which measure the precipitation amounts. Figure 1 shows a photo of the WR-2100 and table 1 summarizes specifications of the radar. The radar can be installed easily with a small pedestal or tower on roof of buildings in

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an urban area. The WR-2100 radar's smaller size (1 m diameter) and light weight (68 kg) makes installation simple and easy. The dual polarimetric functions generate multiple parameters providing detailed information to identify what is happened in the precipitation phenomena.

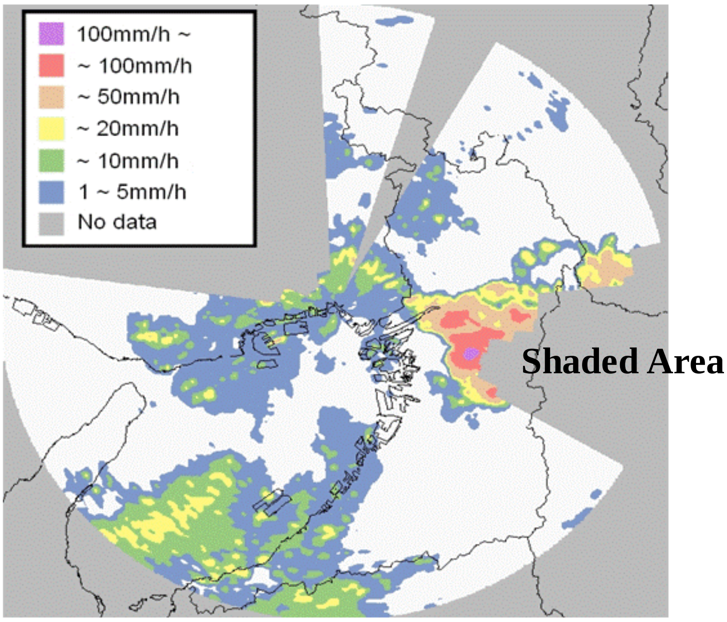
Figure 1 Photograph of Antenna Unit of WR-2100

Model name	**WR-2100**
Antenna Polarity	**Dual Polarimetric (Horizontal/Vertical) STAR(Simultaneous Transmission/Receiving)**
Radome size/weight	**Φ1085 mm/68 kg**
Operating Frequency	**9.4 GHz band**
Beam width of Antenna	**2.7 degree**
Peak Output Power	**100 W(Each polarization)**
Observation range	**70 km**
Power Supply	**100 – 240 VAC, Single Phase, 50/60 Hz**
Power Consumption	**650 W max.**

Table 1 Summarization of Specifications

Solution to avoid signal losses due to heavy rains

During the demonstration three (3) WR-2100 radars are deployed in Toyama and Fukui respectively. Propagations of X-band radio waves are gradually attenuated as rain intensities increase. This may cause some signal losses to occur beyond areas of strong precipitation as depicted in Figure 2 (Shaded area). In order to avoid these areas of potential signal losses FURUNO can offer multiple radar installations. Figure 3 shows the multiple-radar usage concept that overcomes the issue of heavy rain attenuation at individual radar site. When two or more radars are available another radar (ex: Radar B in Figure 3) can observe the heavy rain from the opposite side, providing full area coverage and eliminating the signal losses as shown in Figure 2. The distance between radars is set at 15 km to ensure proper sensitivity during rainfalls over 50 mm/h in the observed area.



The map is provided from the web site of Geospatial Information Authority of Japan.

Figure 2

Example of signal losses behind heavy rain (depicted as "Shaded Area").

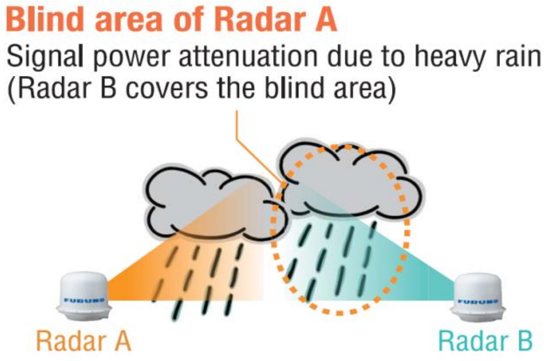


Figure 3

Concept of multiple radar observation.

Radar B can observe from the opposite side when Radar A has strong heavy rains in line of sight.

Multiple-radar operations and comparison to rain gauge data

Estimated rainfall data is converted into geographical grid meshes using a CAPPI (Constant Altitude Planning Position Indicator) of 500 m by Cressman interpolation. Rainfall estimations at a low altitude such as 500 m provide precise rainfall data and also characteristics of higher spatial and temporal resolutions.

The areas covered by radars are overlapped so using proper methods to synchronize radar data is important for precise estimates of precipitation amounts. Multiple techniques to estimate rainfall amounts within the overlaid area have already been discussed. The averaging method has an advantage which avoids discontinuities among the multiple radar signals around their range perimeters. However lost signal returns or attenuations of received signals can cause underestimations of rainfall amounts during heavy rain. Another approach is using a maximum value selection from the overlaid area’s data. Here the maximum value obtained from the three radars data is selected to avoid underestimations due to signal losses caused by heavy rain or other sources including ground clutter. This approach ensures all lost signal data caused by heavy rain is rejected however the possibilities of discontinuous radar echoes around the edge of observation range remain.

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Therefore estimated rainfall using both methods are compared with rainfall measured by rain gauges in Figure 4 (Fukui case) and 5 (Toyama case), respectively. The rain gauges used are located in the areas covered by the weather radars. We have two rain gauges for the Fukui case (Figure 4) and three rain gauges for the Toyama case (Figure 5).

Figure 4(a) shows a comparison between estimated rainfalls from radars using the average method and measured rainfalls of rain gauges for Fukui case. A relatively lower regression coefficient of 0.66 is obtained when average method is applied while an improved value of 1.04 is obtained by using the maximum value selection in Figure 4(b).

Figure 5(a) shows a comparison of estimated rainfalls from radars using the average method with the measured rainfalls of rain gauges for Toyama case. A lower regression coefficient of 0.68 is obtained when average method is applied while an improved value of 0.94 is obtained using the maximum value selection in Figure 5(b).

These comparisons imply that the maximum value selection is a much better way to ensure appropriate data collection in the overlaid area when using X-band multiple radars, even in persistent heavy rain conditions.

Good correlated coefficients for each case are also obtained for both city locations. In addition the FURUNO multiple radar system shows no data losses in heavy rain conditions during the demonstrations.

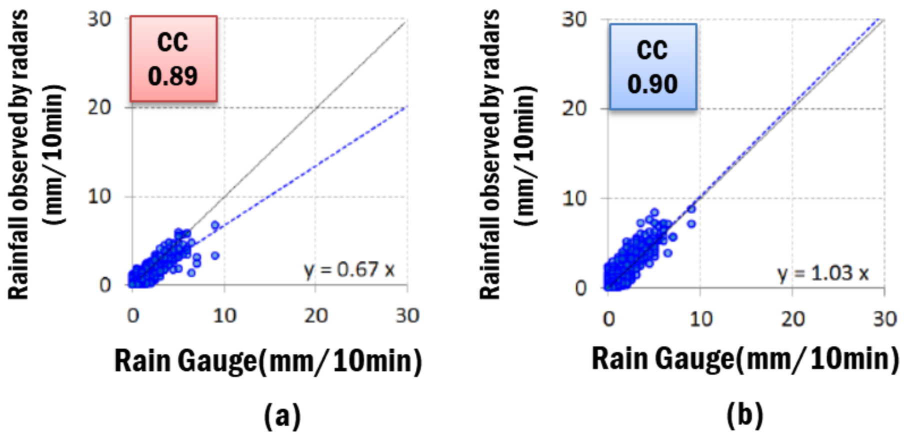

Figure 4

Estimated rainfalls by radars compared with rain gauge measurements in Fukui case.

(a) average method (b) maximum value selection

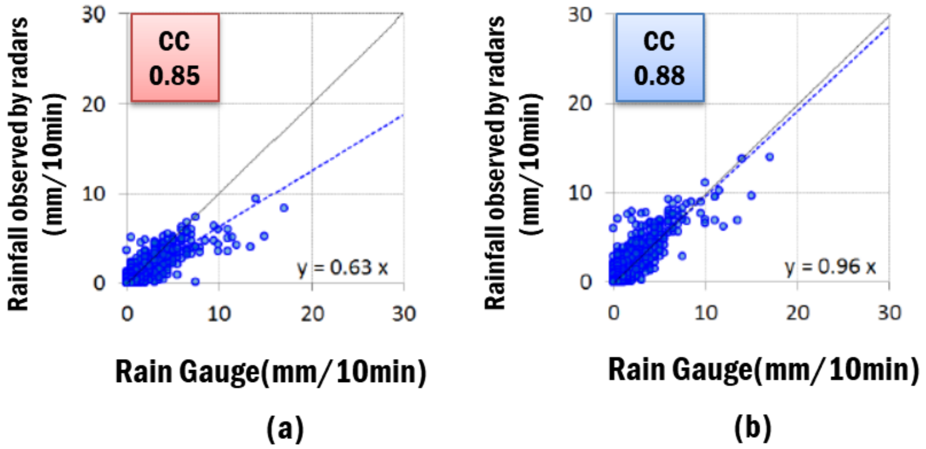

Figure 5

Estimated rainfalls by radars compared with rain gauge measurements in Toyama case.

(a) average method, (b) maximum value selection

Conclusions

Accurate observations in heavy rain conditions using our multiple FURUNO X-band radar network proved very effective during the demonstration supported and funded by MLIT (B-DASH project). The FURUNO multiple radars show good regression coefficients when compared to the collected rain gauge data. The high correlation coefficients are attributed to the relatively proximity of the radar installations and their maximum data selections within the overlapped areas. The FURUNO multiple radar network also shows very reliable observations due to their data loss mitigation capabilities in heavy rains during the demonstrations.