4-3-2　Renewal of the Radars of Rainfall Information System: Tokyo Amesh

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Abstract
Bureau of Sewerage of Tokyo Metropolitan Government has a radar rain gauge system, "Tokyo Amesh". Rainfall information system is used to make the operation of pump stations and wastewater treatment plants more efficiently. The rain radars of Tokyo Amesh have worked for a long time. We are replacing the rain radars because of the aging of the facilities. Observations of additional meteorological parameters with the newly developed radars would increase the precision and relativity. As future efforts, methods to rapidly detect urban heavy rain and to decrease cost of maintenance of ground rain gauges will be addressed.

Keywords
Radar rain gauge system, X-band radar, dual polarization radar, urban heavy rain

1. INTRODUCTION

Bureau of Sewerage of Tokyo Metropolitan Government is in charge of the speedy removal of rainwater from land surface to public water body through pipes and pumps in order to guard cities in Tokyo against floods. Urbanization of Tokyo has altered our rainfall environment. The rainwater no longer permeates into the ground easily due to the decrease of unpaved grounds. The rainwater mostly flows into sewerage pipes. Because of the low permeation rate, concentrated heavy rain causes immediate water rush-in to pumping stations and wastewater treatment plants. The accurate and real-time information of rainfall conditions is essential to respond unstable rainfall with stable operation. In addition, most of pump stations in Tokyo are remote controlled from centralized monitoring room in distant wastewater treatment plant or pumping station. It enables us to operate pumps by fewer workers. However, operators need to understand rain information in each distant pumping stations. For these reasons, we have a radar rain gauge system, "Tokyo Amesh". The radars are used to measure rainfall intensity and location. Accurate rainfall information enables appropriately operate.

However, several operational problems are occurring due to deterioration of the radars after the long period of service. To enhance reliability of the rainfall information, we replace the current rain radars with X-band MP radars (dual polarization radars using X-band), which can obtain data of additional metrological parameters.

Moreover, in recent years, increased frequency of urban heavy rain, which brings much rain localized to a small area in short period of time, increases a risk of floods. We address to rapidly detect urban heavy rain with the new radars.

Ground rain gauges are used for calibrating some error originated in the uncertainty of the shape and density of raindrops. The new radars do not require the calibration. The maintenance cost of ground rain gauges would decrease by using the new radar.

In this paper, the efforts of Tokyo Metropolitan Government to prevent floods through replacement Tokyo Amesh radars will be shown.

2. TOKYO AMESH

A radar beam travels straight and reflects on the surface of an object. The property enables radar to measure the location and the dimension of the object. The Radar Rainfall Gauge system gathers rain signals, omitting the reflection from buildings, mountains or structures (See Figure 1).

The antenna receives the echo and measures the power, which indicates the rainfall intensity.

Conversion coefficients between the signal power and the rainfall intensity determined empirically include some error because of the uncertainty of the shape of raindrops. The calibration with the ground rain gauge data contributes to the minimization of the error.
To apply effective calibration, ground rain gauges are arranged densely over Tokyo land area. 106 gauges of Bureau of Construction are used as well as 44 gauges of Bureau of Sewerage for the calibration.
Tokyo is mostly covered by the two radars. Each of the radars has the observation area of 50km-radius. In addition, Tokyo Amesh also shares the rainfall information with the neighbouring local governments, successfully enhancing accuracy and extending observation range. Radar's observation is obstructed by strong rain near the antenna. The effect rainfall Attenuation occurs because beam weakens while passing through rain. The attenuation is complemented in the allied system with the neighbouring local governments.

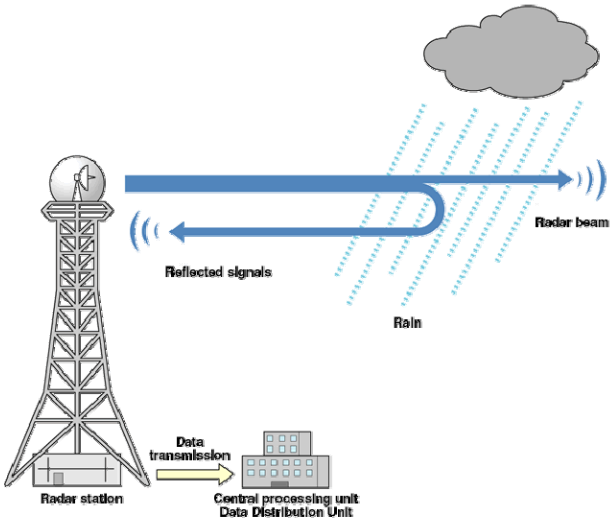

Figure 1. Radar rainfall information measurement

Tokyo Amesh system consists of five radar stations, 150 ground rain gauges, central computer for processing and data distributing, and over 100 information terminals (See Figure 2).
Based on the measured data with the radars and ground rain gauges, the central computer calculates the intensity of the rain and sends the results to terminal stations. At a terminal station, the information is shown on the graphical interface suited to plant operation (See Figure 3). As the information obtained from Tokyo Amesh is open to the public via Internet and Cellular phones, it is popular among Tokyo Metropolitan citizens.
(Our web site: http://tokyo-ame.jwa.or.jp/en/index.html)

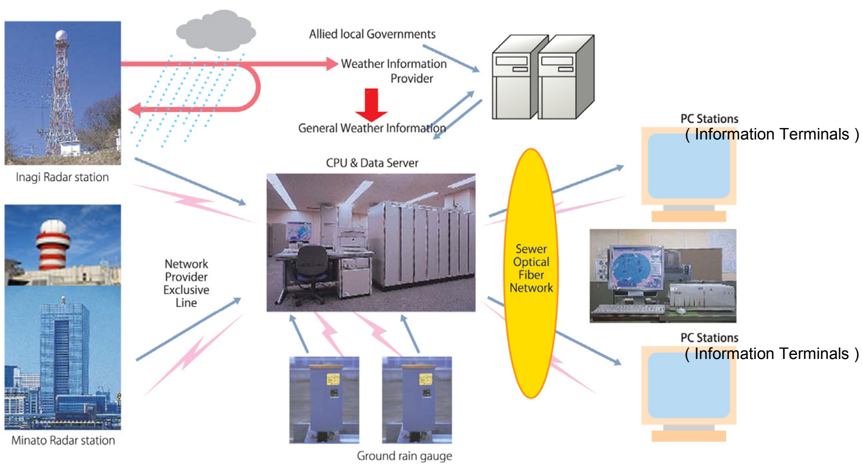

Figure 2. System configuration of Tokyo Amesh

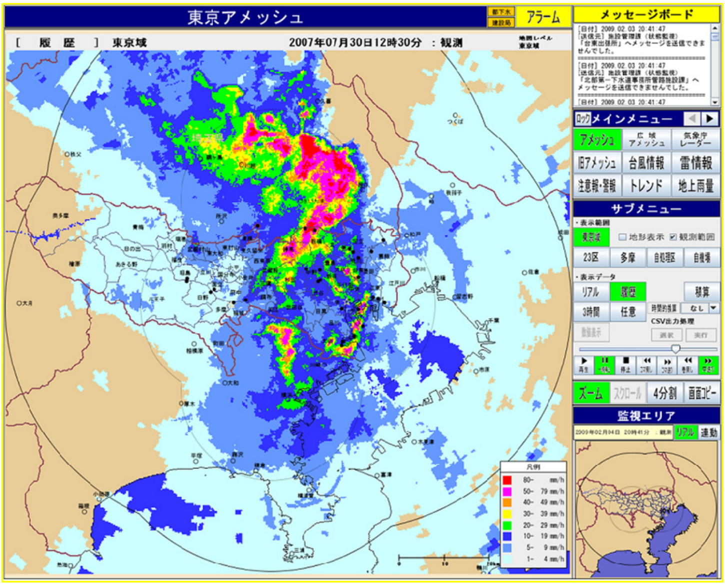

Figure 3. Main surveillance screen of Tokyo Amesh

3. REPLACEMENT OF RADARS

Current radars were put into operation in 2002. System troubles caused by mechanical failure sometimes occur in recent years. In the management plan 2013, Bureau of Sewerage of Tokyo Metropolitan Government made a decision to replace the decrepit radars as one of the countermeasures against floods. The plan aims to increase precision of the rain information system to increase safety of pump operation against heavy rain.

X-band MP radars will be installed as new radars. Features and advantages of the new radars are shown in this chapter.

3.1 Principle of X-Band MP Radar

Current rainfall radars measure rainfall intensity with received signal strength of only horizontal polarimetric wave. On the other hand, X-band MP radars enable to identify the shape and the diameter distribution of raindrops by measuring rainfall with both horizontal and vertical polarimetric wave (See Figure 4).

The major parameters measured with the new radars are shown in Table.1.

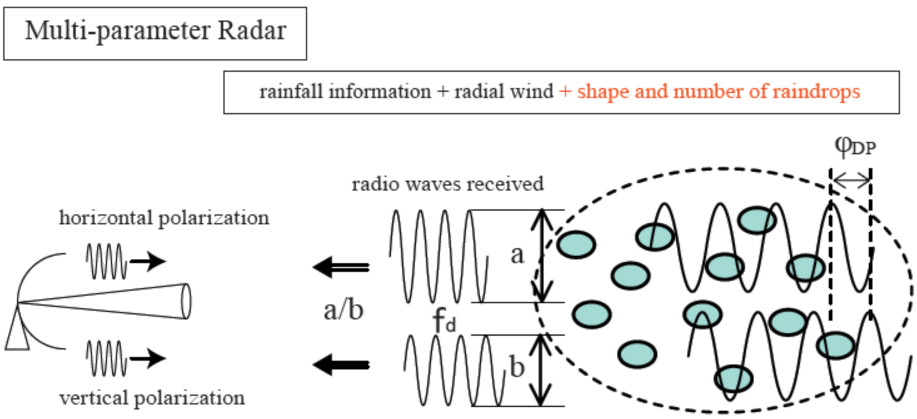

Figure 4. Conceptual diagram of MP radar (NIED, 2005)

Table 1. Major parameters of X-Band MP radar

Parameter	Symbol	Description
Horizontal Reflectivity Factor	Z_H	To estimate rainfall intensity.
Differential Reflectivity	Z_{DR}	To identify the shape of raindrops (spherical or flattened) with the ratio of horizontal reflectivity factor (Z_H) and vertical reflectivity factor (Z_v).
Differential Propagation Phase	φ_{DP}	To estimate ellipticity of raindrops with the phase difference between horizontal and vertical polarimetric wave.
Co-Polar Correlation Coefficient	ρ_{HV}	Calculated with a correlated function of received signals of horizontal and vertical polarimetric wave. To identify the raindrop type (rain, snow or hail) in combination with differential reflectivity ratio.
Specific Differential Phase	K_{DP}	Differential propagation phase per unit distance. To estimate rainfall intensity, being less interfered by rain attenuation.
Radial Velocity	V_D	To measure wind direction and wind velocity with the radial velocity of raindrops.
Spectrum Width	W	To indicate accuracy of the measured radial velocity.
Doppler Velocity Unfolding	V_H	Radial velocity corrected for folding effect.
Doppler Velocity Spectrum Width	W_H	Spectrum width of Doppler velocity unfolding.

3.2 Solid-State Transmitter

Magnetron transmitters, which can transmit at a high output power, are used in the current radars. However, the short mechanical life of about 1 year and the occasional occurrence of sudden failure make its maintenance cost higher.

In the new radars, solid-state transmitters are used. Solid-state transmitters offer longer mechanical life, less maintenance cost and stable continuous rainfall monitoring. Although the output power of solid-state transmitter is less than that of magnetron transmitter, the output power is enhanced by assembling eight solid-state transmitters. The assembled transmitters enable us to deliver equal performance to the conventional transmitter at a smaller output power by applying for pulse compression. Comparison of magnetron and solid-state transmitter specification are shown in Table 2.

Table 2. Comparison of magnetron and solid-state transmitter specification

	Magnetron	Solid-State
Type	Coaxial Magnetron	Gallium Nitride Device
Replacement Frequency	Approximately 1-year	No Regular Replacement
Transmitter Power	70kW	1.2kW (Eight 200W Devices Assembled)
Pulse Width	2μs	0 to 7.5 km 1 μs 7.5 to 80 km 48 μs
Pulse Compression	Inapplicable	Applicable
Minimum Detectable Signal	-109dBm	-110dBm

3.3 New Radar Specification

Comparison of specifications between the current radar and the new radar is shown in Table 3.

Table 3. Specification comparison between current and new Radar

		Current Radar	New Radar
Operation Range		0～80km (0～50km : Quantitative Monitoring) (50～80km : Qualitative Monitoring)	0～80km (0～50km : Quantitative Monitoring) (50～80km : Qualitative Monitoring)
Antenna	Diameter	Φ3m Circular Parabolic	Φ3m Circular Parabolic
	Polarization	Horizontal	Horizontal, Vertical
	Beam Width	Less than 1.4°	Less than 0.8°
	Gain	More than 43dB	More than 43dB
	Rotation	3 min^{-1}	3 min^{-1}
Transmitter	Peak Power	70kW	1.2kW
	Frequency	9710MHz (Minato Radar) 9730MHz (Inagi Radar)	9710MHz (Minato Radar) 9730MHz (Inagi Radar)
	Pulse Width	2μs	Short Pulse 1μs Long Pulse 48μs
	Type	Coaxial Magnetron	Solid-State
	Pulse Repetition Frequency	450pps	1200/1500pps （Dual Type）
	Minimum Detectable Signal	Less than -109dBm	Less than -110dBm
Data Processing Capability	Range Resolution	250m	150m
	Spatial Resolution	1.4°	0.8°
	Update Frequency	1 minute	1 minute

Parameters	Horizontal Electric Wave Signal (Pr-NOR), Horizontal Electric Wave Signal(Pr-MTI), Horizontal Reflectivity Factor (Z-NOR), Horizontal Reflectivity Factor (Z-MTI), Rainfall Intensity (Rr-MTI), Rainfall Intensity (Rr-NOR)	Horizontal Electric Wave Signal (P_H-NOR), Vertical Electric Wave Signal (P_V-NOR), Horizontal Electric Wave Signal (P_H-MTI), Vertical Electric Wave Signal (P_V-MTI), Horizontal Reflectivity Factor (Z_H), Vertical Reflectivity Factor (Z_V), Differential Reflectivity (Z_{DR}), Differential Propagation Phase (Φ_{DP}), Co-Polar Correlation Coefficient (ρ_{HV}), Specific Differential Phase (K_{DP}), Radial Velocity (V), Spectrum Width (W), Doppler Velocity Unfolding (V_H), Doppler Velocity Spectrum Width (W_H), Rainfall Intensity (Rr)

Note: NOR (Normal) is a raw value from the radar. MTI (Moving Target Indicator) is a value corrected for interfering reflected wave from the moving target.

3.4 Advantages of X-Band MP Radar

Due to the installation of X-band MP radars, some advantages are expected. Some observation errors tend to occur with the current radars, as below. It is expected to improve precision of estimate rainfall intensity by decreasing the errors with the new radars.

(1)Effect by the shape of raindrops
As intensity of radar beam is affected by ellipticity of raindrops by air resistance, error tends to occur by the uncertainty of the shape of raindrops. To identify the shape of the raindrops by measuring rainfall with both horizontal and vertical polarimetric wave using X-band MP radars could be estimated more precisely.
(2)Overestimating by Bright Band
Radar waves are reflected strongly at the layer of melting rain cloud, which is called the bright band. Bright band makes received signal stronger than actual and overestimate the rainfall intensity.
Combining differential propagation phase (φ_{DP}) and co-polar correlation coefficient (ρ_{HV}) enables distinguishing whether the strong signal is from raindrops or from melting layers and prevents to the overestimation of the rainfall intensity.
(3)Underestimating by Rain Attenuation
X-band radar is susceptible to rain attenuation due to the short radar wave length. Decline of radar wave by rain attenuation causes an underestimation of the rainfall intensity. X-band MP radars calculate specific differential phase (K_{DP}) with horizontal and vertical polarimetric wave phase and

estimate rainfall intensity with specific differential phase (Maki et al., 2005). As phase of radar wave is not affected by the rain attenuation, it can estimate rainfall intensity less susceptible to rain attenuation. To calculate specific differential phase with the new radars prevents more effectively to underestimate rain intensity.

In addition, it is difficult to observe low rainfall (less than 1 mm/hr.) with the current radars. To estimate rainfall more precisely with the new radars would contribute to identify low rainfall from about 0.3 to 1 mm/hr.

3.5 Data Distribution during Replacing

Since the rainfall information cannot be obtained during replacing the radars, alternative rainfall data collection methods are required in order to operate pump as usual. As we allied with Ministry of Land, Infrastructure, Transport and Tourism, the rainfall data of them will be available. That data enable us to offer rainfall information as accurate as the current system to its users without any interruption during the transition periods.

4. FUTURE EFFORTS

Bureau of Sewerage of Tokyo Metropolitan Government continues to address the following challenges with the new radars.

4.1 Rapid Detection of Urban Heavy Rain

Rainfall radars can identify rainfall only after the rainfall starts. Detecting early signs of urban heavy rain is essential to be ready for a pump control.
During the initial stage of urban heavy rain, strong downdraft known as microburst occurs (See Figure 5). If X-band MP radars can detect microburst with Doppler measurement technology, the radars would provide sufficient time to prepare for urban heavy rain.
We will develop detection technology as one of the next challenges with the new radars.

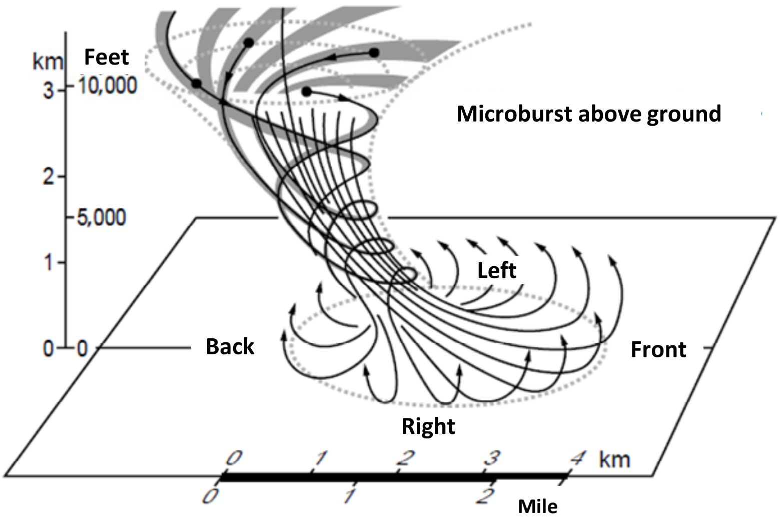

Figure 5. Conceptual diagram of microburst
(Translated based upon data from Adachi and Sato, 2000)

4.2 Reduction of Maintenance Cost of Ground rain gauges

As Amesh system is aimed to monitor inflow amount of rain water to sewage facilities, it is important to estimate the actual amount of precipitation. As mentioned above, the rainfall intensity estimated by the radars is calibrated with the rainfall data of ground rain gauges.

The X-band MP radar provides more precise rainfall estimate. The calibration with ground rain gauges will become less important than before, indicating possible reduction of the number of ground rain gauges.
Operation of ground rain gauges requires maintenance cost which includes fees for periodic certification test. We address to reduce the number of ground rain gauges in order to reduce the maintenance cost maintaining the precision of rainfall monitoring.

5. SUMMARY

Bureau of Sewerage of Tokyo Metropolitan Government is replacing the decrepit radars as one of the countermeasures against floods. Due to the installation of X-band MP radars, improvement of precision of estimates is expected. In addition, the methods to detect urban heavy rain rapidly and to reduce maintenance cost of ground rain gauges by decreasing its number will be addressed.

6. REFERENSE

(i) Bureau of Sewerage of Tokyo Metropolitan Government, Tokyo Amesh, available at: http://tokyo-ame.jwa.or.jp/en/ (accessed 28 May 2013)
(ii) National Research Institute for Earth Science and Disaster Prevention (NIED), 2005 Rainfall Observation by X-Band Multi-Parameter Radar, available at: http://www.bosai.go.jp/kiban/radar/PDF%20Files/PDF%20File%20-%20English/nied_brochure_e.pdf (accessed 28 May 2013)
(iii) Maki, M., Park, S-G., & Bringi, VN. 2005 Effect of Natural Variations in Rain Drop Size Distributions on Rain Rate Estimators of 3 cm Wavelength Polarimetric Radar, *Journal of the Meteorological Society of Japan VOL. 83, NO. 5*, p.871-893
(iv) Adachi, H. & Sato, Y. 2000 Special Issues: Radio Wave Application Technologies and Systems, *Toshiba Review, 2000, VOL.55, NO.5*, p.27-30