Development of a Detection System of Heavy Rainfall using X-band Phased-Array Weather Radar

Kazuhiro Yoshimi[1] , Fumihiko Mizutani[1] , Nobuhiro Takahashi[2], Tomoo Ushio[3, 4]

[1]*Toshiba Infrastructure Systems and Solutions Corp., 1, Komukai, Toshiba-cho, Saiwai-ku, Kawasaki 212-8551 Japan*
[2]*National Institute of Information and Commuications Technology (NICT), 4-2-1, Nukui-Kitamachi, Koganei, Tokyo 184-8795, Japan*
[3]*Osaka Universtiy, 1-1 Ymadaoka, Suita, Osaka 565-0871, Japan*
[4]*Tokyo Metropolitan University, 6-6 Asahigaoka, Hino-shi, Tokyo, Japan 191-0065*

1 Introduction

Due to global warming and the rapid urbanization of emerging countries, torrential rain disasters occur frequently in various parts of the world and become social problems. Sediment disasters and flood damage are also frequent in Japan due to extreme weather phenomena such as super typhoon and torrential rain. Under such circumstances, the Government of Japan cites "Enhancement of societal resiliency against Natural Disasters" as one of the "Cross-ministerial Strategic Innovation Promotion Program (SIP)" led by the Cabinet Office. In preparation for natural disasters such as heavy rain and tornado, Industry-Academia-Government works together to establish a mechanism to share disaster information in real time, and is promoting realization of responding ability. This demonstration experiment is being conducting under the support of SIP from 2015 and TOSHIBA has been developing a detection system of heavy rainfall for users who conduct disaster prevention caused by rainfall

The purpose of this research and development is to aim at constructing a system based on user's view by conducting applied research on information obtained from heavy rain / tornado prediction technology. For the purpose of aiming at constructing a system based on such a user's perspective, we are conducting demonstration experiments to introduce a system to an actual site and to verify the problems for practical application.

2 Scheme of the developed system

2.1 Detection system of heavy rainfall

The developed heavy rain detection system (Figure 1) aims to distribute alarms as preliminary information of heavy rain to users such as municipalities. The heavy rain detection alarm is based on the information observed by the phased array weather radar (hereinafter, this is called “PAWR”) (Anraku et al, 2013/Wada et al, 2012/2014) and the information of the weather radar network called “XRAIN” distributed, by the Ministry of Land, Infrastructure, Transport and Tourism. Although rainfall prediction is carried out by many research institutes, the purpose of the detection system developed by TOSHIBA is to notify the heavy rain information more simply. Observation data delivered from each weather radar is processed in the cloud managed by TOSHIBA and delivered by e-mail and LED beacon as warning information of heavy rain. In addition, rainfall distribution is also delivered at the same time by the web display function which is one of the functions of the heavy rain detection system.

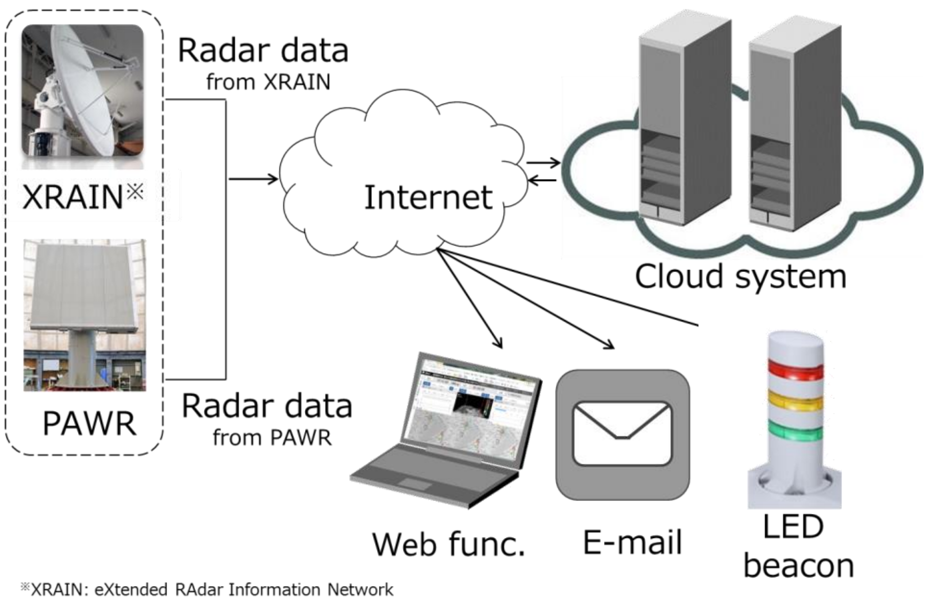

Figure 1: Conceptual diagram of the developed system

2.2 Definition of alarm

In this demonstration experiment, two types of alarms are distributed to the user as alarm information of heavy rain. The definitions of these alarms are as follows. In addition, a conceptual diagram of alarm notification is shown in Figure 2.

・WATCH alarm: early warning information to be announced based on predicted rainfall, VIL, ETOP
・WARNING alarm: current condition information to be reported when heavy rain is observed near the ground

where VIL: Vertical Integrated Liquid is the total mass of precipitation in the clouds (Hirano and Maki, 2010) and ETOP is the cloud top height. The predicted rainfall uses a prediction model that three-dimensionally tracks individual rain clouds.

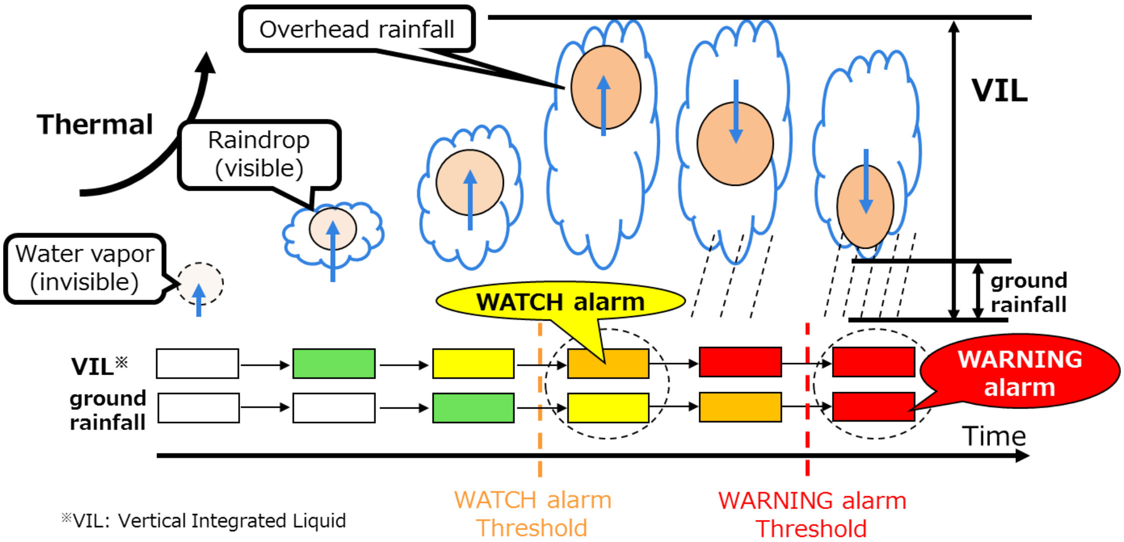

Figure 2: The conceptual diagram of the alarms

Next, we show the evaluation index of the demonstration experiment system in Table 1. "Threat Score (TS)", "False Alarm Ratio (FAR)" and "Undetected Error Rate (Ur)" with respect to alarm accuracy are defined as follows. True Positive is defined as the case where WARNING alarm is issued with WATCH alarm issued. Also, a state in which WATCH alarm is reported, but WARNING alarm is not reported is defined as False Positive. False Negative is defined as a state in which WARNING alarm is issued in a state where WATCH alarm has not been reported, and the other is defined as True Negative.

Table 1: Verification Indices for the two types of detection alarm

		WARNING alarm	
		Observed	NOT Observed
WATCH alarm	Forecasted	TP (True Positive)	FP (False Positive)
	NOT Forecasted	FN (False Negative)	TN (True Negative)

The threat score (TS) can be written as

$$\text{Threat Score (TS)} = \frac{\text{TP}}{\text{TP} + \text{FP} + \text{FN}} \quad (0 \leq \text{TS} \leq 1) \tag{1}$$

The false alarm ratio (FAR) can be written as

$$\text{False Alarm Ratio (FAR)} = \frac{\text{FP}}{\text{TP} + \text{FP}} \quad (0 \leq \text{FAR} \leq 1) \tag{2}$$

The undetected error rate (Ur) can be written as

$$\text{Undetected Error Rate (Ur)} = \frac{\text{FN}}{\text{TP} + \text{FN}} \quad (0 \leq \text{Ur} \leq 1) \tag{3}$$

2.3 Condition of alarm activation

The conceptual diagram of Figure 3 shows the distributed condition of WATCH alarm. The characteristic of the alarm using VIL and ETOP is that it uses three-dimensional rainfall information observed by PAWR. Therefore, in the demonstration experiment conducted in 2017, as mentioned above, an alarm was issued when VIL, ETOP, CAPE and 3D analysis exceeded the set thresholds. Table 2 shows the thresholds of the indices actually used as the alarm issued conditions. The thresholds of VIL and ETOP are supposed to follow the values of the demonstration experiment in 2016. Where, CAPE is an indicator of atmospheric instability and is very valuable for predicting serious weather. In addition, the threshold of CAPE was determined after analysis in all cases of past torrential rains in demonstration experiments (from 2015 to 2016).

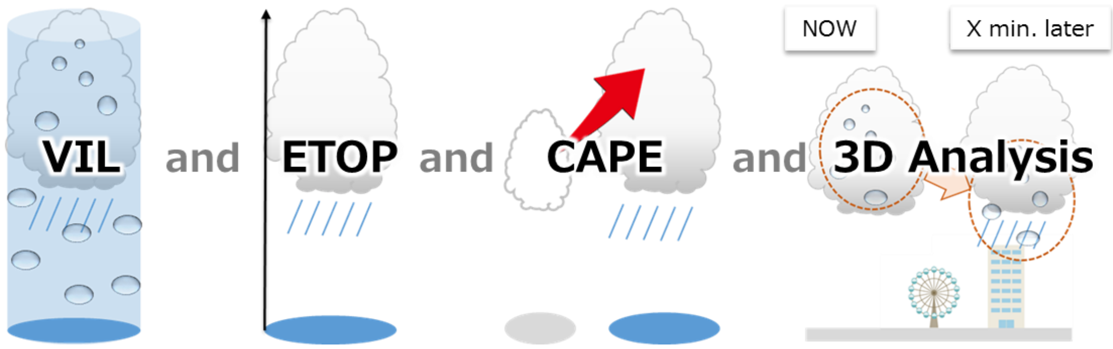

Figure 3: The WATCH alarm condition and its index

Table 2: The threshold of the index (VIL, ETOP, CAPE, 3D analysis)

Index	VIL [kg/m^2]	ETOP [m]	CAPE [J/kg]	3D analysis [mm]
Threshold	5	4000	800	8.33

3 Results of demonstration experiment using the system

3.1 Precipitation events and target site

Table 3 shows precipitation events where an alarm was distributed in the demonstration experiment conducted in the 2017. The total number of alarms reported from July to November during the period of the demonstration experiment was 15. When judging from the indicator expressing the state of the atmosphere and the weather chart, the case which can be defined as heavy rain was two cases occurred on August 18 and August 23. In other cases, an alarm was reported due to the heavy rainfall in the front line or torrential rain caused by the typhoon.

Moreover, in this demonstration experiment, we target users who may have flood prevention activities due to local heavy rain, such as sewerage division, park manager and road administrator. In showing the effectiveness of the observation data of PAWR, the following is example of the water park where remarkable results were obtained.

Table 3: Rainfall events during demonstration experiment in 2017(1/2)

No.	Period			Number		Remarks
				WATCH	WARNING	
1	2017/07/09 13:00	~	2017/07/09 21:00	20	36	Frontal rain
2	2017/07/17 21:00	~	2017/07/18 00:00	0	4	Frontal rain
3	2017/07/18 14:00	~	2017/07/18 21:00	2	4	Frontal rain
4	2017/07/26 01:00	~	2017/07/26 08:00	0	9	Frontal rain

Table 3: Rainfall events during demonstration experiment in 2017(2/2)

No.	Period			Number of times		Remarks
				WATCH	WARNING	
5	2017/08/07 15:00	~	2017/08/08 00:00	0	4	Typhoon
6	2017/08/08 12:00	~	2017/08/08 19:00	0	3	Typhoon
7	2017/08/18 05:00	~	2017/08/18 12:00	10	15	Torrential heavy rain
8	2017/08/23 13:00	~	2017/08/23 20:00	11	12	Torrential heavy rain
9	2017/08/26 03:00	~	2017/08/26 10:00	2	2	Frontal rain
10	2017/09/07 10:00	~	2017/09/07 15:00	0	8	Frontal rain
11	2017/09/12 03:00	~	2017/09/12 10:00	14	41	Frontal rain
12	2017/09/16 12:00	~	2017/09/17 00:00	0	1	Frontal rain
13	2017/09/17 17:00	~	2017/09/18 02:00	0	13	Typhoon
14	2017/09/28 04:00	~	2017/09/28 11:00	0	10	Frontal rain
15	2017/10/22 19:00	~	2017/10/23 00:00	0	1	Typhoon

3.2 Typical successful event

In the demonstration experiment in 2017, a water park managed by Osaka prefecture was also newly added as a target institution of the demonstration experiment. The water park is adjacent to the river, and a hydrophilic area where park users can freely access the riverside was constructed.

On the other hand, it is known that the water level of a river rises sharply due to sudden heavy rain in the hydrophilic area adjacent to urban areas. It is a very dangerous place for park users, as typified by a water accident at the Toga River.

In the demonstration experiment in 2017, in order to confirm whether alarms to such a hydrophilic area manager are useful, we asked the river administrator to use the system and whether alarm notification to the water park is useful. As a result, in the case of August 18, a case where the water level of urban river rose sharply was observed. We confirmed that alarm distribution in basin unit is effective not for local alarm distribution to targeted area. In other words, we showed that alarm distribution based on observation information of PAWR delivered in this demonstration experiment is effective for the water park (Figure 4).

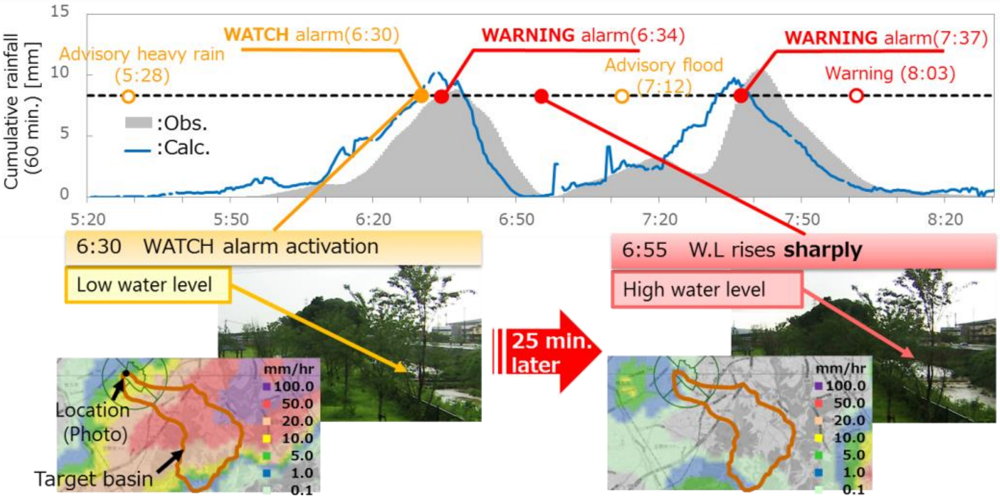

Figure 4: A successful case of alarm system at a water park in Osaka, Japan

3.3 Scores of the alarm in demonstration experiment in 2017

In this chapter, we show the results of the accuracy verification of the WATCH alarm for the heavy rain events in the demonstration experiment conducted in the 2017. As a result, it was found that the alarm distributing algorithm adopted in the demonstration experiment in 2017 showed that the frequent occurrence of the false alarm, which was the subject of the demonstration experiment in 2016, was greatly improved (Table 4). On the other hand, we found that the undetected error rate which was 0% last year was somewhat higher in score, 25.9%. Moreover, due to a large decrease in the false alarm ratio, the threat score has improved considerably compared with the demonstration experiment in 2016.

Table 4: Annual scores of the alarm

	2016 (num. of times)	2017 (num. of times)
TS	23.2% (38)	71.4% (20)
FAR	76.8% (126)	4.8% (1)
Ur	0% (0)	25.9% (7)

4 Discussions

As mentioned earlier, in the alarm distributing system of the demonstration experiment in 2017, it was found that the number of undetected error's cases of WATCH alarm increased while cases of torrential rain decreased. This is thought to be because the alarm was set to be distributed when all the indexes exceeded the threshold value, so that the alarm condition was too severe for the heavy rain case compared with demonstration experiment in 2016.

Therefore, as shown in Figure 5, We tried to improve the TS by permitting deterioration of the score of FAR, making a distinction between a judgment index based on measured value and a judgment index based on analysis value, and making it OR condition. There are two main reasons for roughly classifying. The first is to reduce the Ur by improving the alarm distributing algorithm in which an alarm is issued when any one of the determination indices matches. The second reason for roughly classifying judgment indicators is not only to report cases of heavy rain but also alarms for non-heavy rain cases. Because we hope users to utilize the demonstration experiment system in a wider sense for water defense activities. Here, the determination index based on the measured value is determined from the viewpoint of utilizing the observation information of the weather radar such as VIL and ETOP. Further, the analysis index based determination index is used as a determination index based on a so-called predicted value.

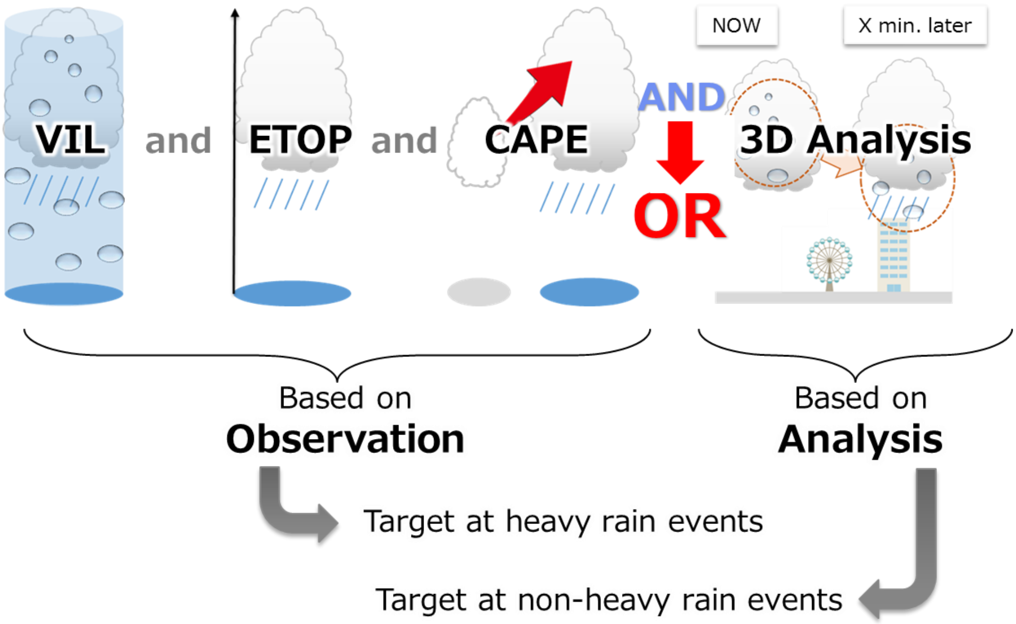

Figure 5: An improvement plan of the condition to distribute the alarm

5 Conclusions

TOSHIBA developed a heavy rain detection system based on observation data of the single polarized phased array weather radar and conducted a demonstration experiment using the system together with Osaka local governments. As a result, it was found that the three - dimensional rainfall information observed by PAWR is useful as the input of the system for securing the safety of the users of green space parks and water parks managed by municipalities. In addition, as a result of the demonstration experiments, we were able to obtain many cases where the alarm notification succeeded immediately before heavy rain. From the above, it is being acknowledged that local governments' flood prevention activities are carried out smoothly, and alarms are announced beforehand from heavy rain, which is an effective system for actual disaster prevention work. We will continue demonstration experiments from July in 2018, and verify the utility of PAWR data and the practicality of heavy rain detection system. Moreover, TOSHIBA has been developed high precision dual polarization phased-array weather radars which utilize solid-state transmitters which allow fast three-dimensional observation. In 2018, we will conduct demonstration experiments using observed data by this latest weather radar developed by TOSHIBA

Acknowledgement

This research is (partially) supported by the "Cross-ministerial Strategic Innovation Promotion Program (SIP)" from Japan Science and Technology Agency, JST.

References

Naoki Anraku, Fumihiko Mizutani, Masakazu Wada, Hironori Handa, Tomoo Ushio, Shinsuke Satoh, 2013: Development of Phased-Array Weather Radar system for 3D observation of cumulonimbus clouds. extended abstract, 36th Conf. on Radar Meteorology, Albuquerque, U.S, Amer. Meteor. Soc. 146.

Masakazu Wada, Naoki Anraku, Hiroshi Yamauchi, Ahoro Adachi, Ushio Tomoo and Shinsuke Satoh, 2014: Development of advanced radar technologies for weather application. ERAD 2014 - THE EIGHTH EUROPEAN CONFERENCE ON RADAR IN METEOROLOGY AND HYDROLOGY. Abstract ID 074.

Masakazu Wada, Naoki Anraku, Hiroshi Yamauchi, Ahoro Adachi, 2012: Operational usage of Solid-State Weather Radar. TECO 2012. WMO TECHNICAL CONFERENCE ON METEOROLOGICAL AND ENVIRONMENTAL INSTRUMENTS AND METHODS OF OBSERVATION.

Kohin Hirano and Masayuki Maki, 2010: Method of VIL Calculation for X–band Polarimetric Radar and Potential of VIL for Nowcasting of Localized Severe Rainfall – Case Study of the Zoshigaya Downpour, 5 August 2008 –, SOLA, 2010, Vol. 6, 089−092.