# Development and Observation of the Phase Array Radar at X band

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**ABSTRACT:** A new Phased Array Radar (PAR) system for thunderstorm observation has been developed by Toshiba Corporation and Osaka University under a grant of NICT, and installed in Osaka University, Japan. It is now well known that rapidly evolving severe weather phenomena (e.g., microbursts, severe thunderstorms, tornadoes) are a threat to our lives particularly in a densely populated area and is closely related to the production of lightning discharges. Over the past decade, mechanically rotating radar systems at the C-band or S-band have been proved to be effective for weather surveillance especially in a wide area more than 100 km in range. However, severe thunderstorm sometimes develops rapidly on the temporal and spatial scales comparable to the resolution limit (-10 min. and -500m) of typical S-band or C-band radar systems, and cannot be fully resolved with these radar systems. In order to understand the fundamental process and dynamics of such fast changing weather phenomena like lightning and tornado producing thunderstorm, volumetric observations with both high temporal and spatial resolution are required. The phased array radar system developed has the unique capability of scanning the whole sky with 100m and 10 to 30 second resolution up to 60 km. The system adopts the digital beam forming technique for elevation scanning and mechanically rotates the array antenna in azimuth direction within 10 to 30 seconds. The radar transmits a broad beam of several degrees with 24 antenna elements and receives the back scattered signal with 128 elements digitizing at each elements. Then by digitally forming the beam in the signal processor, the fast scanning is realized. After the installation of the PAR system in Osaka University, the initial observation campaign was conducted in Osaka urban area with Ku-band Broad Band Radar (BBR) network, C-band weather radar, and lightning location system. The initial comparison with C band radar system shows that the developed PAR system can observe the behavior of the thunderstorm structure in much more detail than any other radar system. The observed high temporal resolution images of the severe thunderstorm and lightning are introduced, showing the potential capabilities of the PAR and lightning location system.

## INTRODUCTION

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It is now well known that thunderstorms produces severe weather phenomena such as tornado, microburst, localized heavy rainfall, lightning and so on which are threat to our lives particularly in a densely populated area and the number of such phenomena tends to increase as a result of the global warming. One of the best ways to observe the thunderstorm and its related phenomena is the remote sensing using electromagnetic wave technology.

As a result of the recent advances on information and communication technology, rapid scanning technologies have been developed and applied to the radar remote sensing studies. One typical example of such innovations is the development of the Phased Array Radar (PAR) system. As is well known, lightning producing thunderstorm and its related phenomena such as tornadoes, flash floods etc. evolves rapidly and locally, and cannot be fully resolved by the conventional S or C band doppler weather radar system having large antenna. In order to discuss the mechanism on structure of thunderstorm and lightning discharges, rapid scanning radar like PAR is required, and a new Phased Array Radar (PAR) system for thunderstorm observation has been developed by Toshiba Corporation and Osaka University under a grant of NICT, and recently installed in Osaka University, Japan in 2012

In this report, a new remote sensing techniques for radar and lightning location system are reviewed and some recent results using PAR and a new LF lightning location system called BOLT are introduced.

## PHASED ARRAY RADAR

It is now well known that rapidly evolving severe weather phenomena (e.g., microbursts, severe thunderstorms, tornadoes) are a threat to our lives particularly in a densely populated area and the number of such phenomena tends to increase as a result of the global warming. Over the past decade, mechanically rotating radar systems at the C-band or S-band have been proved to be effective for weather surveillance especially in a wide area more than 100 km in range. However, rapidly evolving weather phenomena have temporal and spatial scales comparable to the resolution limit (-10 min. and -500m) of typical S-band or C-band radar systems, and cannot be fully resolved with these radar systems. In order to understand the fundamental process and dynamics of such fast changing weather phenomena, volumetric observations with both high temporal and spatial resolution are required.

Osaka University and Toshiba Corporation have started to develop a new Phase Array Radar (PAR) at X band under the grand of NICT in 2007, and installed at the top of the building in Osaka University, Osaka, Japan in 2012. The new phased array radar system developed (see Fig. 1) has the unique capability of scanning the whole sky with 100m and 10 to 30 second resolution up to 60 km. The system adopts the digital beam forming technique for elevation scanning and mechanically rotates the array antenna in azimuth direction within 10 to 30 seconds. The radar transmits a broad beam of several degrees with 24 antenna elements and receives the back scattered signal with 128 elements digitizing at each elements. Then by digitally forming the receiving beam in the signal processor, the fast scanning is realized.

## OBSEVATION AND COMPARISON

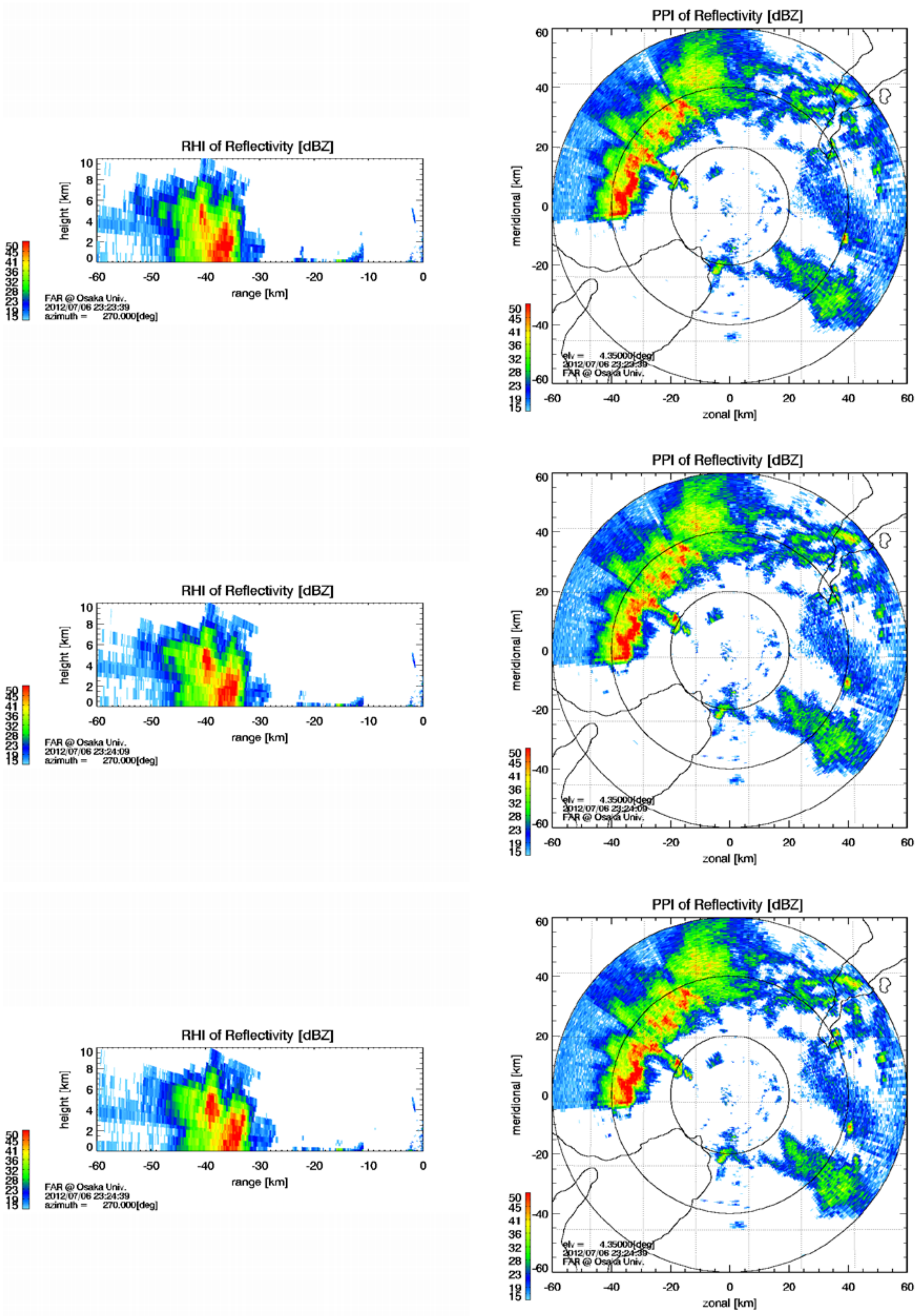
After the installation of the PAR system in Osaka University, the initial observation campaign was conducted in Osaka urban area with Ku-band Broad Band Radar (BBR) network, C-band weather radar, and lightning location system. One example of typical time series of the RHI and PPI image observed by the Phased Array Radar is shown in Fig. 2. In this observation, the PAR was operated to observe precipitation in 60 km range and in every 30 seconds. As shown in the left panel in the figure, the vertical structure of the thunderstorm is fully resolved from the 100 angles in elevation while the radar system achieves the 3 D volume scanning within 30 seconds. And, the times series of the observed images clearly show how the thunderstorm advects and evolves with 30 seconds and 100 elevation resolution, which could not be realized by the conventional radar system.

The initial comparison with C band radar system shows that the developed PAR system can observe the behavior of the thunderstorm structure in much more detail than any other radar system. In Figure 3, a typical time series of reflectivities observed by the PAR, BBR network, C band radar and disdromter, over the disdrometer site located about 15 km away from the PAR is shown. While the C band radar (Orange line) observes precipitation in every 10 min, the PAR and BBR network resolve the variation of reflectvities in less than 1 min. And the reflectivities calculated from disdrometer data matches very well with that observed PAR and BBR network. In addition to this, the observed CAPPI image at 3 km in height is shown in Figure 4. This simultaneous observation from these three radar systems at different frequencies show that the developed PAR work correctly although the scanning strategy is quite different from the conventional radar system using the dish type antenna. The correlation coefficient of the reflectivity in PAR with C band radar was about 0.8 in average and 0.9 with the BBR network.

## CONCLUSIONS

A new phased array radar using the digital beam forming technique were developed and evaluated. The radar system has the unique capability of scanning the whole sky with 100 elevation angles within 60 km in radius in 30 seconds. The initial observation results shows that the developed radar system can observe the thunderstorm evolution more explicitly than any other radar system due to its high temporal resolution and spatial resolution. The initial evaluation shows the developed system can observe the radar reflectivity comparable to other radar system though the system adopts the new imaging technique called digital beam forming.

Fig. 1 Photographs of the Phased Array Radar (PAR) at Suita Campus in Osaka University. Top left panel shows the installation of the PAR in May, 2012. Top right panel shows the antenna of the PAR system inside the Radar Dome. Bottom panel shows the overview of the PAR at the Electrical, Electronic and Information Engineering Department building in Osaka University.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height [km]
range [km]
FAR @ Osaka Univ.
2012/07/06 23:23:39
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PPI of Reflectivity [dBZ]
meridional [km]
zonal [km]
elv = 4.35000[deg]
FAR @ Osaka Univ.
RHI of Reflectivity [dBZ]
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elv = 4.35000[deg]
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Fig. 2 One example of time series of thunderstorm reflectivity observed by the PAR in RHI (Left panel) and PPI (Right panel) format. In this case, the radar images are in every 30 seconds.

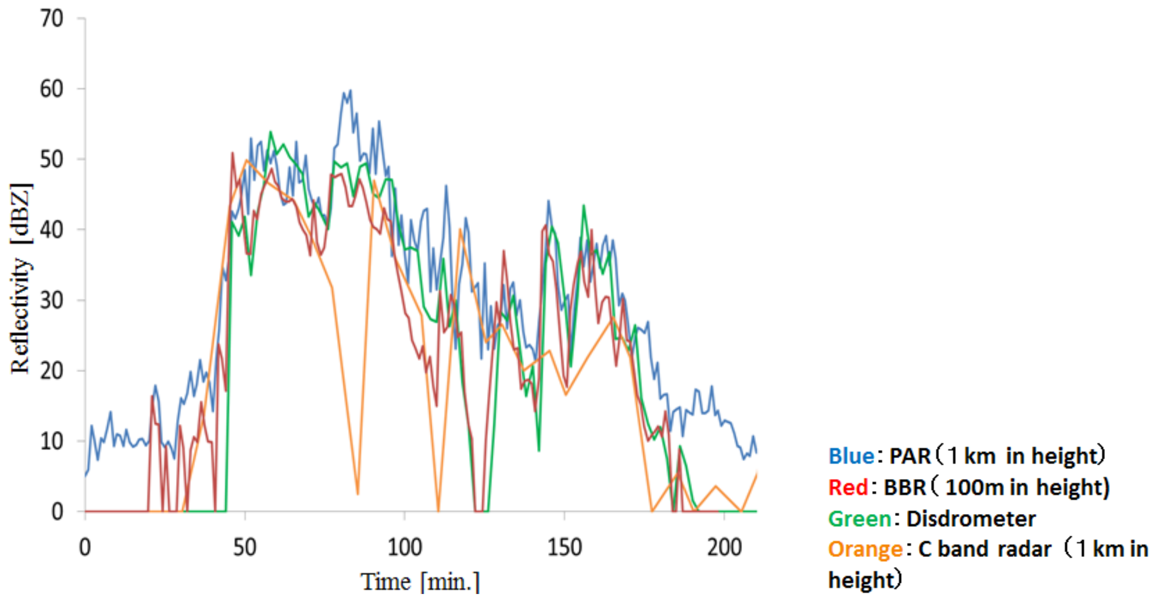


Figure 3 Typical time series of reflectivities from PAR, BBR network, C band radar and disdrometer. The disdrometer is located at about 15 km away from the PAR. Orange, green, red and blue lines show C band radar, disdrometer, Broad band radar network, and PAR, respectively.

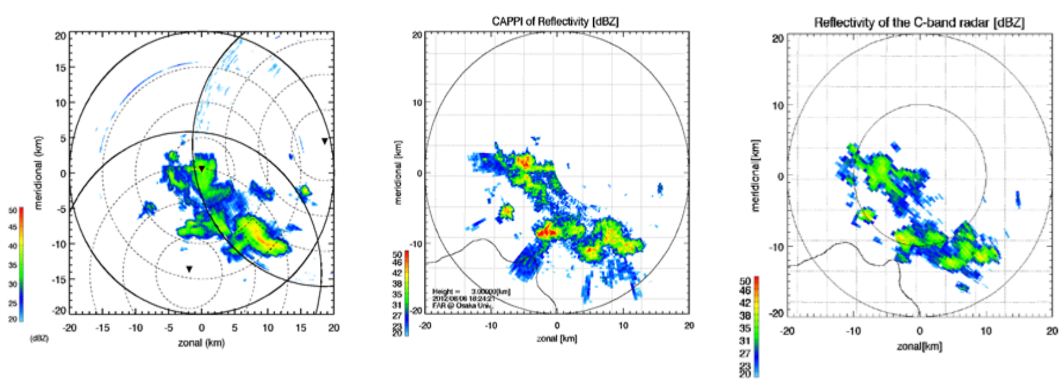


Figure 4 Initial comparison of the PAR with BBR network and C band radar. Left to right, the horizontal distribution of reflectivities at 3 km in height from the BBR network, PAR and C band radar

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