Observation and initial comparison of the Phased Array Radar at X band

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1. Introduction

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.

2. Phased Array Radar at X band

Osaka University and Toshiba Corporation have started to develop a new Phase Array Radar at X band under the grand of NICT from 2007. The 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 beam in the signal processor, the fast scanning is realized.

3. Observation

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 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 while the radar system achieves the 3 D volume scanning within 30 seconds.

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 Fig. 4, 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 Fig. 5. 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.

4. Clutter mitigation

Although the phased array radar system using the digital beam forming technique can estimate the 3 dimensional structure of the precipitation system within 10 to 30 seconds with 100 meter resolution, the observation results also shows the received signal was seriously contaminated by the relatively high received power from ground clutter and strong precipitation echoes through the side lobes of the transmitting beam. In fig. 6, PPI images at 0.0 and 4.35 degree in elevation from the PAR are shown. At the 0.0 degree in elevation, the strong echoes appear in south direction, where the many tall buildings are in Osaka down town area, and these strong echoes are probably from these tall buildings. However, at the 4.35 degree in elevation angle, there are still remaining reflectvities probably from these tall buildings. These echoes are through the high side lobe of the broad transmitting beam.

To avoid this problem, a beam forming technique using the MMSE (Minimum Mean Square Error) formulation was proposed and tested. This approach can adaptively mitigate the masking interference that results from the standard digital beam forming method in the vicinity of ground clutter and strong precipitation area. The proposed method is compared with the standard beam forming technique by applying to the huge raw IF signal data digitized at each 128 antenna elements. The results show that the proposed technique can correctly estimate the precipitation echo within a few dB even in the presence of a strong ground clutter that is more than 20 dB higher than the precipitation echo with 15 pulse repetition number. The MMSE based technique is shown to be superior to the standard DBF scenarios under the small number of pulse repetitions to achieve the rapid scanning. Much more detail of this technique is described in Yoshikawa et al. (2013)

Fig. 1　Phased Array Radar at the top of the building in Osaka University.

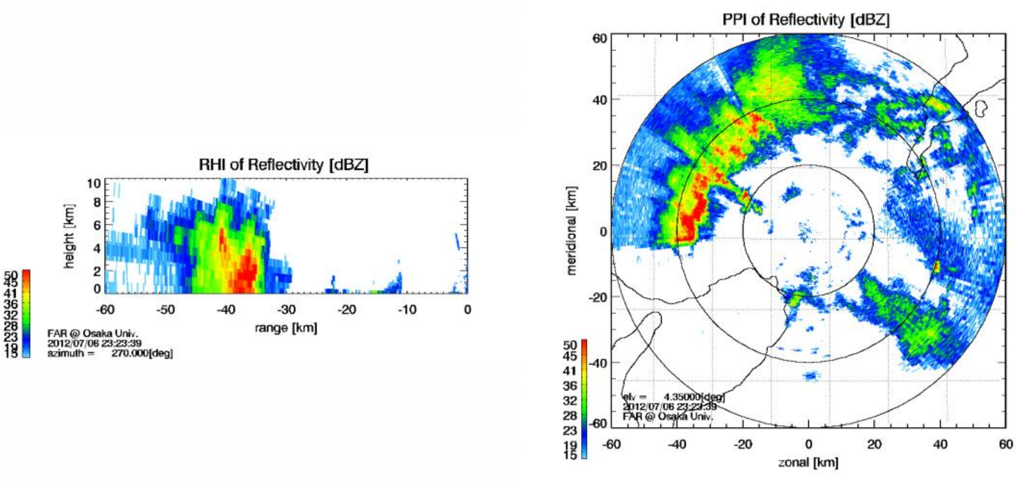

Fig. 3 One example of the RHI and PPI image observed by the Phased Array Radar in Osaka University.

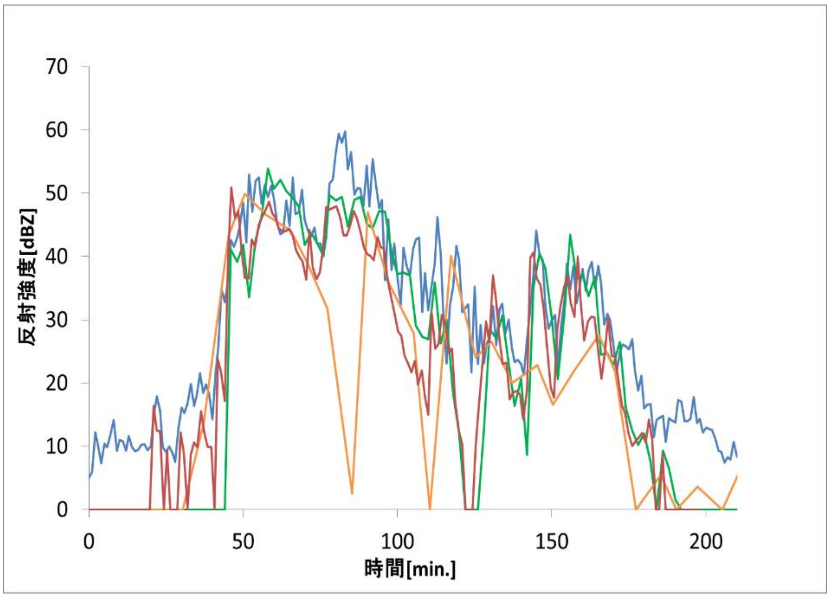

Fig. 4 Typical time series of reflectivities from PAR, BBR network, C band radar and disdrometer. The disdrometer is located at about 15 km away from the PAR. Orange, green, red and blue lines show C band radar, disdrometer, Broad band radar network, and PAR, respectively.

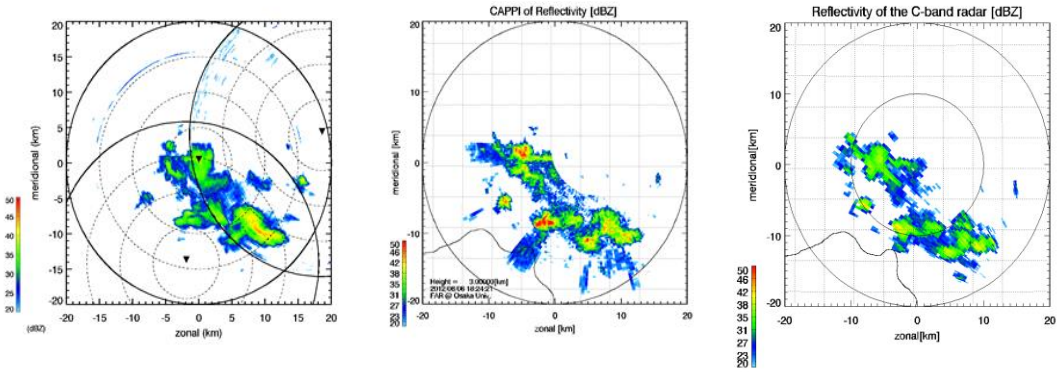

Fig. 5 Initial comparison of the PAR with BBR network and C band radar. Left to right, the horizontal distribution of reflectivities at 3 km in height from the BBR network, PAR and C band radar

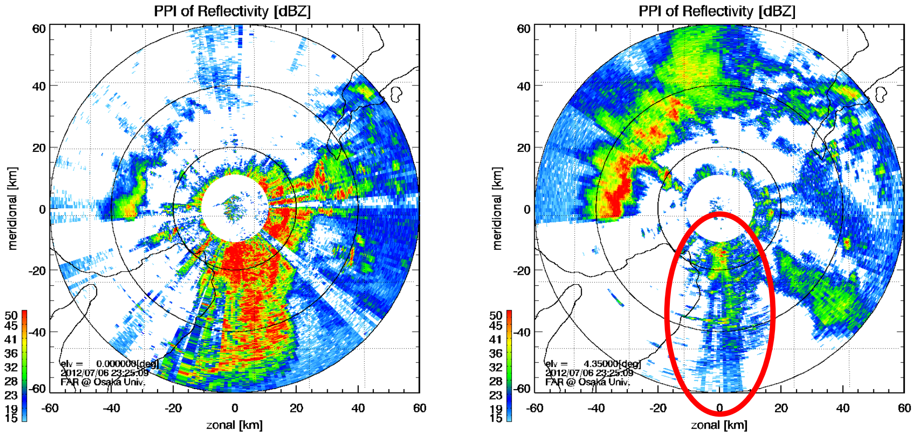

Fig. 6 PPI images observed the PAR. Left panel shows the reflectivity distribution at 0 degree in elevation, and right panel shows the 4.35 degree in elevation.

Reference

Yoshikawa, E., T. Ushio, Z-I. Kawasaki, S. Yoshida, T. Morimoto, F. Mizutani, and M. Wada, MMSE Beam Forming on Fast-Scanning Phased Array Weather Radar, *IEEE Trans. Geosci. Remote Sens.*, Vol. 51, Issue 5, pp. 3077-3088, 2013