[EN-I-085] Development of 3D Rapid Scanning High Resolution X-Band Phased Array Weather Radar

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+Taro Kashiwayanagi, Kazuomi Morotomi, Osamu Sato and Hiroki Sugawara

Japan Radio Co., Ltd.
Saitama, Japan
[kashiwayanagi.taro | morotomi.kazuomi | sato.osamu | sugawara.hiroki]@jrc.co.jp

Abstract: Urban areas in Japan suffer from more and more disasters by severe weather such as heavy rain fall or tornadoes recently. Particularly around Tokyo in summer season, rapidly developing cumulonimbi produce heavy rain; occasionally causing floods. To observe developing stage of cumulonimbi for analyzing and predicting severe weather, Japan Radio Co, ltd. have developed X-band phased array weather radar. With this radar, it takes only 30 seconds to finish volume scan of the cylindrical space with a radius of 80 km and height of 15 km. And more, this radar outputs radar parameter such as reflectivity with high spatial resolution of 50 m. The radar was installed in Chiba city and the experimental operation was started from the summer of 2015. This paper describes the overview of the radar system and observation results of heavy rain cases.

Keywords: phased array weather radar.

1. Introduction

In recent years, urban areas in Japan suffer from more and more severe weather disasters such as heavy rain or tornadoes. Particularly around Tokyo in summer season, rapidly developed enormous cumulonimbi produce localized heavy rain; occasionally causing floods [1].

For analyzing and predicting severe weather, weather radars are required to operate for whole three-dimensional volume scan with high spatial and temporal resolution, because cumulonimbus cloud tops sometimes develop over 10 km above the ground in only 10 minutes and tornados move several kilometers in only 10 minutes [2,3]. With conventional weather radars equipped with parabolic antennas, however, it takes five to ten minutes to finish a volume scan of limited elevation angles.

Japan Radio Co., Ltd. independently developed a prototype of phased array weather radar (Figure 1). With this phased array weather radar, it takes only 30 seconds to finish a volume scan of the cylindrical space with a radius of 80 km and height of 15 km.

This paper introduces our new phased array weather radar. Chapter 2 explains the volume scan way of our phased array weather radar. Chapter 3 explains the system components and specification. Chapter 4 shows the observation results obtained by this radar.

Figure 1. Appearance of JRC's phased array weather radar.

2. The volume scan of JRC's phased array weather radar.

Fig. 2 shows differences of volume scan ways between our phased array weather radar and conventional weather radars.

Conventional radar mechanically rotates a parabola antenna for azimuth scans. In each azimuth scan, the radar mechanically changes elevation angle of the antenna. X-band radars generally rotate at a speed rate of

3 r.p.m., operating for the volume scan of 15 elevation angles in 5 minute.

Our radar also mechanically rotates in azimuth direction, but, by using phased array antenna, operates for a lot of vertical electrical scans during rotation. Therefore, the volume scan of our radar finishes after just one rotation. Our radar is capable of rotating at maximum speed of 6 r.p.m.; therefore, the shortest cycle of the volume scan is just 10 second.

Our phased array antenna system adopts digital beamforming technique. With this technique, the radar simultaneously forms multiple pencil receive beams in a fan-shaped transmit beam (Fig.3). By electrically changing elevation angle, single vertical scan of almost whole elevation angles finishes in just a moment.

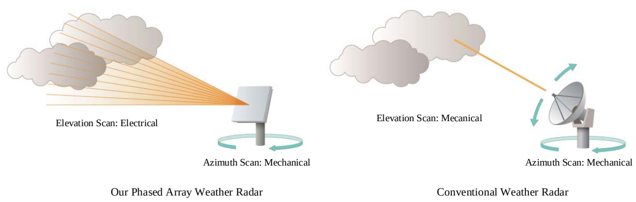

Figure 2. Differences of volume scan between phased array weather radar and parabolic weather radar.

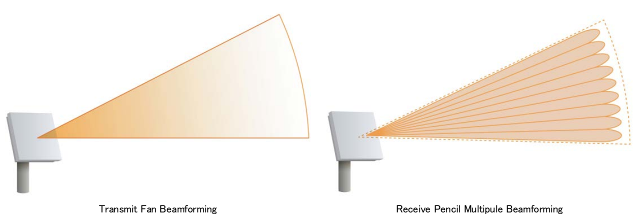

Figure 3. Transmit and receive beamforming.

3. System Components and Specification

Our radar system consists of just two components: the radar antenna equipment and the data processing workstation (Fig. 4).

The radar antenna equipment, along with small cubicle rotation control box, contains 16 transmit and 126 receive slot array antennas on the front side, solid state transmitters to output a total peak power of 1600W, receivers and digital boards on the back side. Radar echoes received by the antennas are downconverted, digitized and converted to IQ data. All IQ data are transferred through an optical fiber cable to the data processing workstation.

The data processing workstation converts the IQ data to radar parameters such as reflectivity. This conversion process includes the digital beamforming. In addition, the workstation includes radar control and quick-view software which draws PPI, CAPPI, RHI in real time.

Table 1 shows the specification of our radar. The detection range depends on the rotation speed because increase of the rotation speed decreases the pulse hit number so that accuracy of the radar parameters degrades. Therefore, the radar is supposed to normally scan the cylindrical airspace with a radius of 80 km and height of 15 km on 30-second cycle operation, or with a radius of 30 km and height of 15 km on 10-second cycle operation.

This radar operates for volume scan not only with high temporal resolution but also with high spatial resolution. The minimum range resolution of the transmit pulse is 75 m and the process resolution for the radar parameter output is 50 m. The number of the elevation scans is normally 360 every rotation.

Table 1. Specification of phased array weather radar.

Parameter	Value
Transmit Frequency	9.4 GHz
Rotation Speed	6 r.p.m. Max.
Volume Scan Space	height : 15 km adius : 30km at 6 r.p.m radius: 80 km at 2 r.p.m
Total Transmit Peak Power	1600 W Max
Range Resolution	75 m/100m/150m
Process Resolution	50 m
Number of Elevation Scans	normally 360 for every volume scan
Beam Width	Horizontal: About 1 deg Vertical : About 1 deg (for receive)
Detection Elevation Angle	Up to 87
Polarization	Single, Horizontal
Size	2.5 m ×1.8 m ×3 m

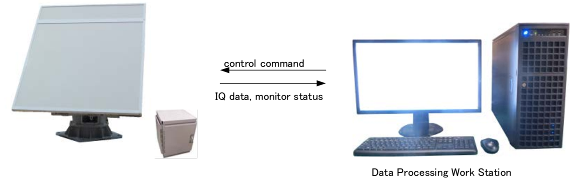

Figure 4. System components.

Figure 5. The radar installed in Chiba city (left) and observation area.

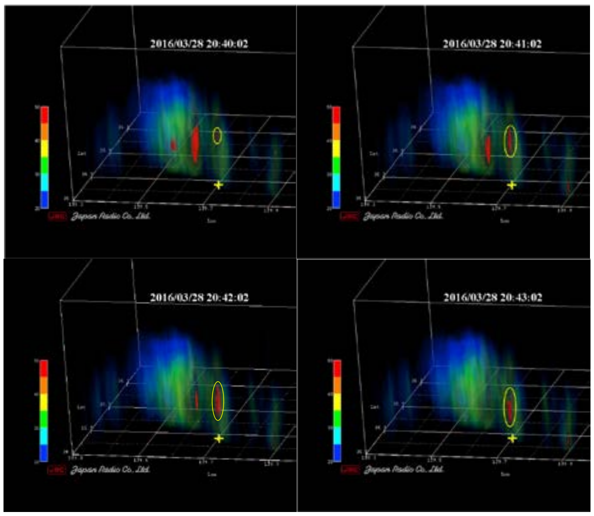

Figure 6. Time-series 3D images of reflectivity of a thunderstorm on March 28, 2016. The marker indicates Shinjuku.

As for antenna configuration, our radar forms the receive beams with horizontal and vertical beam width of about 1 degree. Because of the beam tilt of the slot array antenna, the elevation scan range is up to 87 degree. Therefore, the scan area is almost whole of the cylindrical airspace just except small area near the zenith. The detection elevation range of the narrowest fan transmit beam is 10 degree. The polarization is single, horizontal.

4. Observation Results.

We installed this radar in the summer of 2015 then started experimental operation in Chiba city about 45 km east away from the Central Tokyo (fig. 5).

In the summer of 2015, to evaluate the radar, we operated the radar for 30 km-radius volume scan on 30-second cycle operation.

One of the severe storm cases was hail on March 28, 2016 (Fig. 6). The echo above Shinjuku rapidly became stronger and fell in just few minutes. At this moment, hail was observed around Shinjuku. Therefore, this observation implies the possibility that this strong echo was produced by hail. Our radar succeeded in detecting the temporally detailed lifecycle of rapid raindrop growth and fall in the severe storms which it is difficult with conventional radars.

Another severe storm case was a thunderstorm storm on July 4, 2016 (Fig. 7). The storm moved from mountain region of Kanagawa to the Tokyo bay area, where the echo top reached above 15 km height. Inside of the storm, there was a strong wind shear that stood up toward the point of echo top (Fig. 8). This implies there was a mesocyclone which generate strong up draft.

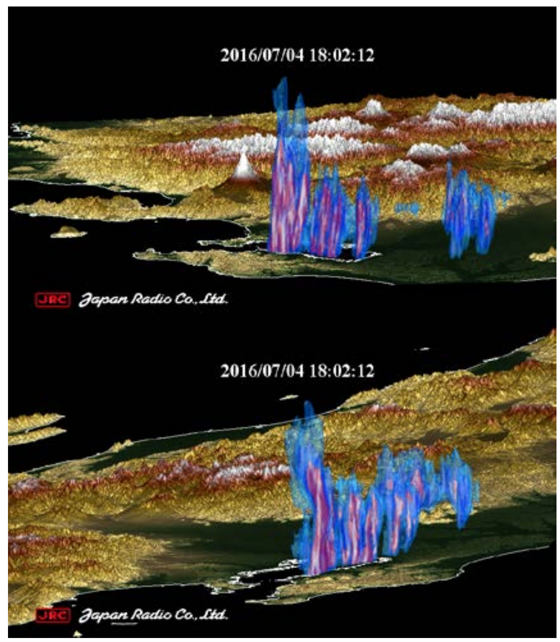

Figure 7. 3D images of reflectivity of a thunderstorm on July 4, 2016.

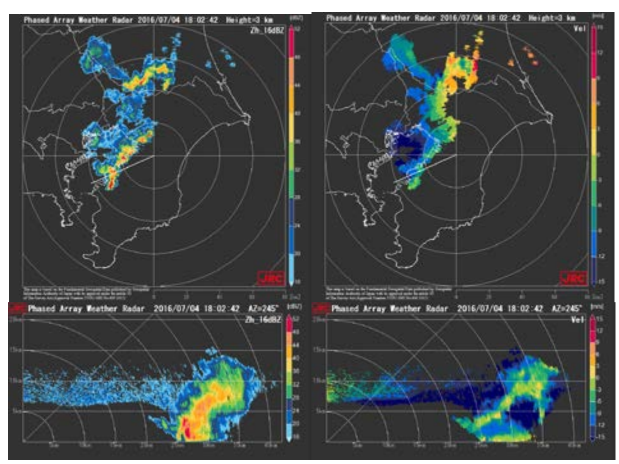

Figure 8. CAPPI at 3 km and RHI at 246 deg of the convective system, July 4, 2016. Figures of left side indicate the reflectiviy and figures of right side indicate the doppler velocity.

5. Summary

In this paper, we introduced JRC's phased array weather radar. With our new phased array radar, it takes only 30 second to finish almost whole three-dimensional volume scan in just 30 seconds within a radius of 80 km and height of 15 km with high spatial resolution. In the experimental operation, we succeeded in observing rain cases, where temporal and spatial transition of developing cumulonimbi was clearly revealed. By analyzing observed data, our radar will contribute to issue faster severe weather alert with accurate location.

We have started a collaborative research with Electronic Navigation Research Institute about use of observation data of the phased array weather radar for safe operation of aircraft. This research plan to investigate the efficient data delivery and integration of the 3D observation data into the next generation air traffic system, "System Wide Information Management".

6. References

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