4-8 Development of a 400 MHz-band Wind Profiler Radar with RASS

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Okinawa Subtropical Environment Remote-Sensing Center of the Communications Research Laboratory has developed a new 400 MHz-band Wind Profiler Radar (400M-WPR) since FY 1997 in a research and development project of remote-sensors for measuring subtropical environment. After construction of the Ogimi Wind Profiler Facility at Ogimi village in Okinawa, the 400M-WPR has continued wind velocity profiling with an altitude range from approximately 400 m to typically 13 km, and with an interval of a few minutes. We were successful for the wind profiling up to 16 km near the center of a typhoon Nari approached in September 2001. Besides, a RASS attached to the 400M-WPR could obtain virtual temperature profiles up to about 3 km.

Keywords
Wind profiler, Remote-sensing, Wind velocity, Temperature, Troposphere

1 Introduction

The Okinawa Islands belong to the Western Pacific Subtropical Zone, close to the eastern coast of the Asian Continent. Although they are located in the Subtropical High-Pressure Zone, their climate is humid and warm, due to the influence of the nearby Kuroshio. In this region, a southeastern wind in summer and a northwesterly wind in winter dominate. The islands are strongly influenced by the Asian monsoon and also experience characteristic meteorological phenomena such as Baiu, the rainy season, and typhoons. The Communications Research Laboratory (CRL) has developed three types of new remote-sensors to take measurements of the atmosphere and ocean dynamics in the Okinawa Subtropical Region, as part of a research and development project on measuring techniques for the subtropical environment begun in 1997. In this paper, we will describe one such remote sensor, a 400 MHz-band Wind Profiler Radar (hereafter referred to as 400 MHz-WPR). A type of ground-based Doppler radar, the 400 MHz-WPR measures the height profile of three orthogonal components of the wind velocity vector by measuring the speed of atmospheric turbulence and precipitation particles moving with the background wind fields, which are derived from the Doppler frequency shift in transmitting and receiving radio waves. By combining acoustic transmitters with the WPR, the Radio Acoustic Sounding System (RASS) is formed, which derives the height profile of the virtual temperature from the Doppler frequency shift in the radio waves scattered by propagating acoustic waves in the atmosphere. In RASS observations, it is necessary to obtain in advance the radial wind velocity, which is the projected component of the background wind velocity in the direction of the antenna beam, to find true acoustic speed. This is because the propagation speed of the acoustic wave obtained from the WPR's Doppler velocity of the acoustic waves is an apparent, not a true, speed caused by the superimposition of the true acoustic velocity and the radial wind velocity. The WPR that composes the RASS (hereafter referred to as WPR/RASS) is characterized by a time resolution of a few minutes, far better

Table 1 *Specifications for the CRL's 400 MHz-WPR*

Radar type	Monostatic pulse Doppler radar
Transmission frequency	443 MHz
Transmission power	20 kW (peak); 2 kW (average)
Antenna type	Electromagnetic coupling type coaxial linear array (24 elements×2 orthogonal columns)
Antenna dimensions	width: 10.4 m; depth: 10.4 m; height: 1.2 m
Antenna beam half power width	3.3˚
Antenna beam scanning range	azimuth 0˚-360˚ (electronic and mechanical scanning); zenith angle 0˚-15˚ (electronic scanning)
Range resolution	variable within 200 m-600 m
Observation altitude range	wind velocity: 350 m-16 km; temperature: 350 m-6 km

than those of conventional sensors designed for use in balloons, aircraft, or satellites. It is hoped that this device will contribute to the elucidation of meteorological phenomena on a more detailed level (i.e., the meso-scale).

2 The Structure of The System

Table 1 gives the specifications of our WPR. This WPR is a monostatic Doppler radar that serves as both transmitter and receiver. Its transmission frequency is 443 MHz, and an Active-Phased Array Antenna makes it possible to scan electronically in the direction of the beam. Peak transmission power is 20 kW, and maximum average transmission power is 2 kW, since the maximum duty ratio of the transmitter is 10 percent. The antenna is square-shaped with sides of 10.4 m. The width of the antenna beam is 3.3˚. To improve the signal-to-noise ratio of the received signals, our WPR uses pulse compression techniques that apply phase modulation codes devised by Spano et al.[1] (hereafter referred to as Spano Codes) to transmitted and received pulse trains. There are three pairs consisting of the width of each transmitted pulse (sub-pulse) and the number of sub-pulses, which constitute the transmitted pulse trains. We can select one from those three pairs, namely: width 1.33μs with 4 bits, width 2.00μs with 8 bits, and width 4.00μs with 4 bits. It is also possible to select Complementary Codes instead of Spano Codes for pulse compression, or to forego pulse compression and select a single pulse with width 1.33μs. Because the antenna consists of two sets of linear arrays, each with 24 elements along two orthogonal directions and because each element is connected to the independent transmission-and-reception switching module, the antenna beam can electronically scan in two vertical orthogonal planes.

The key feature of our WPR/RASS is that the azimuth of the antenna beam can point in any direction continuously, not just in four directions in 90˚-intervals. This significantly improves the altitude range for temperature measurements by RASS. In RASS observations using a monostatic WPR, the wave number vector of the transmitted radio wave must be 1/2 that of the transmitted acoustic wave, according to the Bragg condition. In the region to be observed, the antenna beam of the transmitted radio wave must be orthogonal to the acoustic wavefront. However, the space that satisfies the Bragg condition is not always at its zenith, but mostly limited to the windward direction, because the shape of the acoustic wavefront is affected by the background wind velocity profile. Therefore, we calculate in advance the propagation path of the acoustic wave, based on the background wind velocity and the temperature field. We then extend the altitude of the observation by predicting the space region in which the Bragg condition is satisfied and by scanning the antenna beam in that direction. Although this method basically came into practice with MU radar-RASS, we have also improved our WPR to introduce automatic control. To realize this RASS observation method, our WPR is capable of beam scanning in all directions of azimuth, by mounting the whole antenna plane onto a turntable and rotating it horizontally. Although a complete two-dimensional array antenna that electronically performs antenna beam scanning in all directions of azimuth would be ideal, the method of rotating the orthogonal linear array antenna appears to be a reasonable compromise, given construction costs.

As described in the following section, because our Wind Profiler is installed in an observation facility some distance from our research facility, we need to develop sophisticated software to control the radar and to obtain data without requiring a specialized operator onsite. Particularly for RASS observations, the key feature of our system is software that conducts automatic observations by estimating the propagation path of the acoustic wave transmitted from the transmitter by the ray-tracing technique, using the wind velocity and temperature profile obtained by online processing, and by calculating the appropriate observed parameters. The system is designed for use at the remotely located observation facility, is controlled by a Web browser interface and features a “quick-look” display allowing easy access to observed data.

3 Results of Initial Observations

(1) Ogimi Wind Profiler Facility

CRL built the Ogimi Wind Profiler Facility shown in Fig.1 in the north of Okinawa Main Island at long. 128˚09'32"E, lat. 26˚40'41"N, and 225 m above sea level as a base for operating various atmosphere-observation devices. Apart from a 400 MHz-WPR, this Facility is equipped with a 1.3 GHz-WPR, a Doppler Sodar, a GPS radiosonde, an ultrasonic anemometer, an optical rain gauge, a

Fig.1 *A view of the Okinawa Subtropical Environment Remote-Sensing Center (long. 128˚09'32"E, lat. 26˚40'41"N, and 225 m above sea level)*

The square antenna in front of the observation building is the 400 MHz-WPR. The reception antenna for the GPS radiosonde, the optical rain gauge, the disdrometer, and the ultrasonic anemometer are installed on the rooftop of the observation building. On the left of the observation building is the Doppler Sodar, and on the right are the ground-based weather observation system and 1.3 GHz-WPR.

disdrometer, and a ground-based weather observation system that measures atmospheric pressure, wind velocity vector, temperature, relative humidity, solar radiation, and rainfall near the surface. The observation building has an electric power generator that can operate continuously for up to 72 hours, which makes continuous observation possible despite frequent power failures, particularly when a typhoon is approaching. The data obtained at each observation device is collected at the server computer and transmitted to the data archive device at the main CRL building via the Okinawa Subtropical Environment Remote-Sensing Center of the CRL.

(2) Wind velocity profile for Typhoon No.16 (Nari) in 2001

Next, we will describe the observation results on the typhoon, Nari, which approached the Okinawa Main Island from September 7 to September 8, 2001. As shown in Fig. 2, the typhoon approached the Ogimi Wind Profiler Facility very slowly from the southwest. At its closest approach to the tip of the observation site at 18:00 on September 7, it was 40 km south. It subsequently turned toward the west. Fig.3 shows the results of continuous observation of the wind velocity profile obtained by our WPR during that period. The maximum observation altitude of the wind velocity profile increased as the typhoon approached, falling after reaching over 16 km near the center of the typhoon. This appears

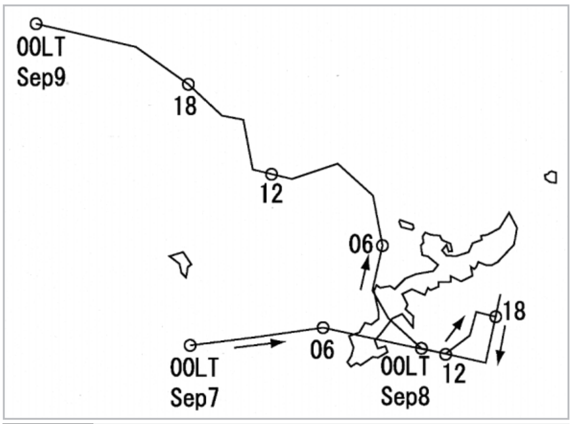

Fig.2 *The path of the typhoon Nari in 2001*

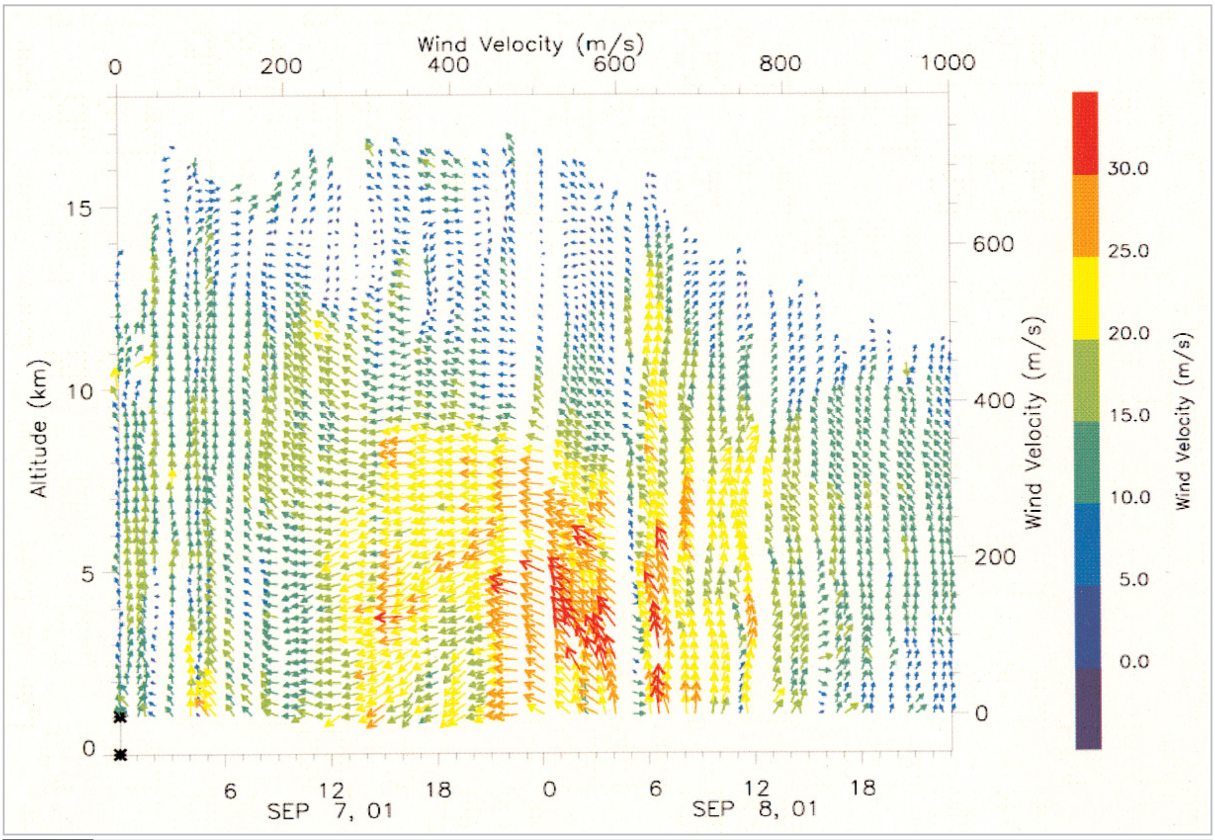

Fig.3 *The time-altitude distribution of the horizontal wind velocity vectors averaged over 30-minute intervals gathered by the 400 MHz-WPR*

The observation period, from September 7 through 8, 2001, coincides with the time during which the typhoon Nari approached.

to be due to radio scattering by precipitation particles in the cumulonimbus clouds that dominated at high altitude, close to the center of the typhoon. We detected vertical downward Doppler velocity during this period. The maximum observation altitude by our WPR was typically around 13 km. Since this is lower than estimates based on the radar equation, we are currently reviewing the operating conditions of the radar device.

(3) The RASS observation

Fig.4 shows the results of initial observations by RASS. The altitude distributions show a decrease in apparent acoustic velocity at high altitude, due to the fact that the RASS echo lay in the range between a Doppler velocity of 347 m/s and 340 m/s, and that temperature decreased with increasing altitude. The maximum observation altitude of the RASS echo varied greatly, depending on the direction in which the beams faced: 2.7 km for the beam facing south, and 1.6 km for the beam facing west, with the zenith angle 15˚. This indicates that the range of the observation altitude of RASS is extremely sensitive to the direction of the antenna beam.

Fig.5 is the altitude profile of the virtual temperature obtained by 10-minute RASS observations. The temperature fluctuations are confined roughly in the range of 1 K.

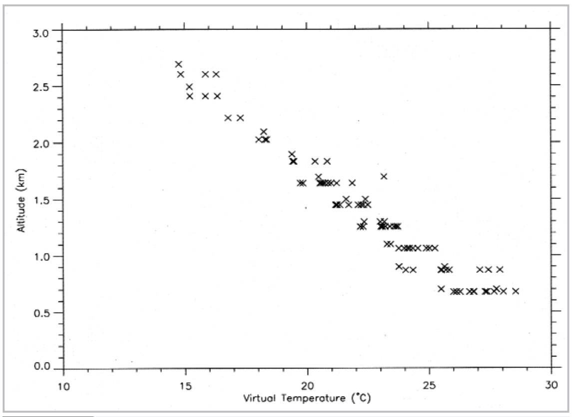

Fig.5 *The altitude distribution of virtual temperature obtained by 10-minute RASS observation*

4 Summary

The Okinawa Subtropical Environment Remote-Sensing Center of the CRL has developed a 400 MHz-WPR with RASS, which it has installed at the Ogimi Wind Profiler Facility on the Okinawa Main Island. We have improved the range of the observation altitude of RASS by mounting this radar antenna, the orthogonal linear array antenna, on a turntable, enabling the antenna beam to scan

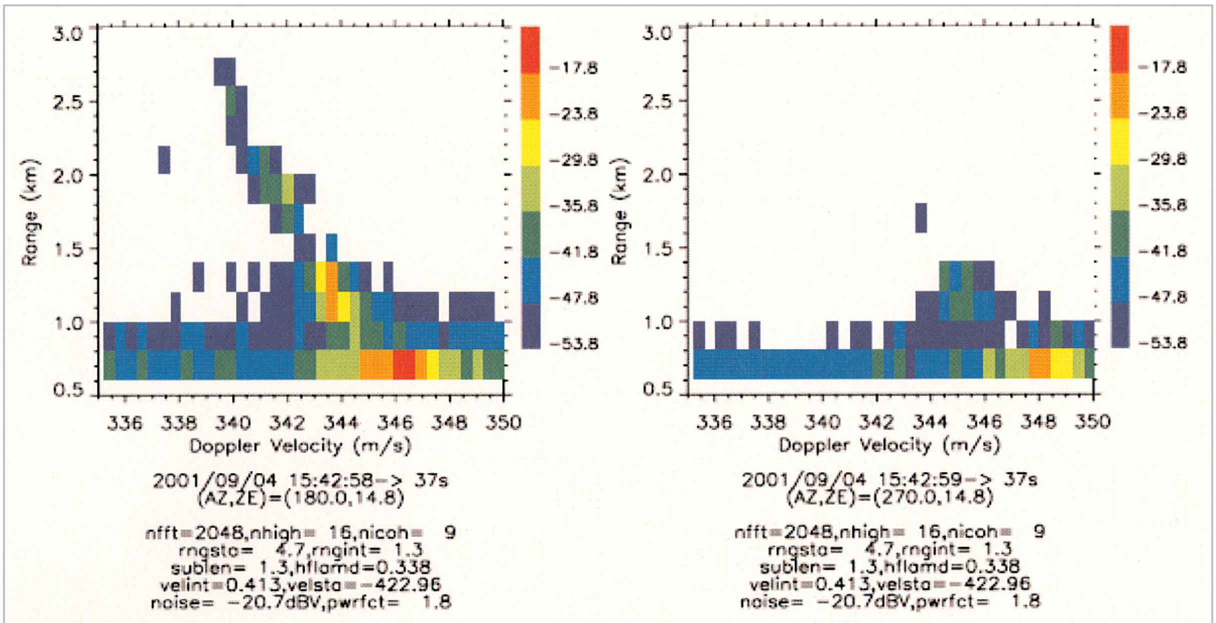

Fig.4 *The range-velocity cross-sectional view of the Doppler spectrum obtained by RASS observations*

The difference of colors reflects the intensity of received signals. The directions of the radar beams were: (azimuth, zenith angle) = (180˚, 14.8˚) for the left; (270˚, 14.8˚) for the right.

in all directions of azimuth. Measurements of wind velocity profile exceeded 16 km near the center of the typhoon Nari in 2001.

References

1 Spano, et al., "Sequences of complementary codes for the optimum decoding of truncated ranges and high sidelobe suppression factors for ST/MST radar systems ", IEEE Geosci. Remote. Sens., 34, pp. 330-345, 1996.

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