P3.33 AIRFLOW STRUCTURE OF CLEAR-AIR AND PRECIPITATION ECHOES OBSERVED BY AN X-BAND DOPPLER RADAR OVER THE NOBI PLAIN IN JAPAN IN THE SUMMER OF 2010

Mariko Oue* [1], Hiroshi Uyeda[1], Tadayashu Ohigashi[1], Takeharu Kouketsu[1], and Fumihiko Mizutani[2]

1. Hydrospheric Atmospheric Research Center, Nagoya University, Nagoya, Japan

2. Toshiba Corporation, Kawasaki, Japan

1. INTRODUCTION

Detection of airflow and turbulence associated with precipitation clouds is important for understanding formation and structure of the precipitation clouds. The airflow and turbulence are observed not only as precipitation echoes, but also in clear air by precipitation radars (Battan, 1973). Clear-air echoes caused by fluctuations of refractive index is detectable by precipitation radars in moist environments.

Many researchers have attempted to detect clear-air echoes using X-, C-, or S-band Doppler radars. The clear-air echoes were sometimes detected by these radars in association with a sea breeze front (e.g., Atlas, 1960). Around the Nobi Plain in Japan, a sea breeze front markedly develops in summer (Tsunematsu and Kai, 2004), and then convective clouds develop (Sano and Tsuboki, 2006). Takeda and Murabayashi (1981) conducted observations of clear-air echoes in the Nobi Plain using X-band radars. They showed echo patterns in clear air. However, Doppler velocity in clear air has been rarely observed by X-band Doppler radars in the Nobi Plain. It is considered to be possible to measure the airflow and turbulence by X-band Doppler radars, by increase of pulse repetition frequency (PRF).

The purpose of this study is to capture structures of airflow and turbulence in precipitation clouds and clear air in summer by an X-band Doppler radar. During a summer season from August to September 2010, we made an attempt of clear-air and precipitation observations using the X-band Doppler radar in Nagoya located in the Nobi Plain. The Nobi Plain is located on the Pacific side in the central parts of Japan and faces the Ise Bay to the south. In this study, we analyzed wind field in clear air and precipitation echoes in the Nobi Plain during a summer season of 2010 and discussed possibility of clear-air observation using an X-band Doppler radar.

2. OBSERVATION AND DATA

The clear-air observation was carried out using a Nagoya University's X-band polarimetric radar (NUPol). The NUPol radar was placed

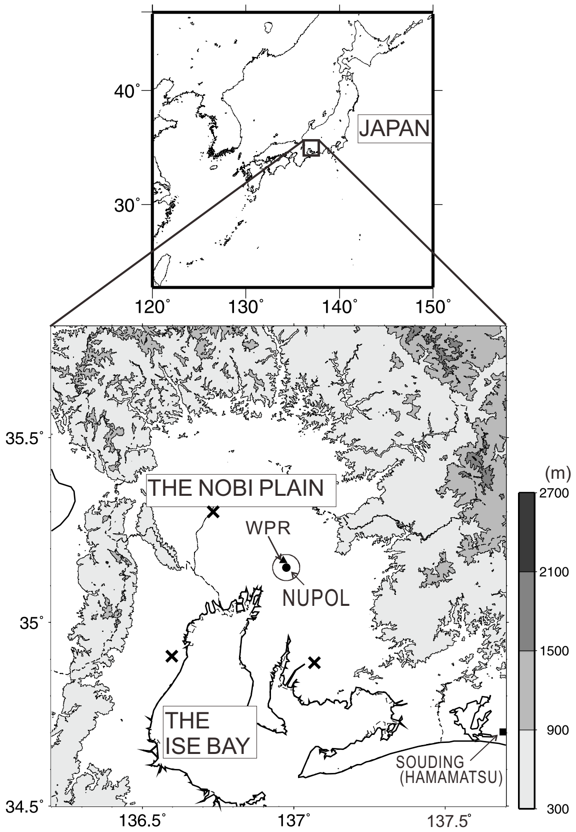

Fig. 1. Locations of the Nobi Plain and observation sites. The filled circle, triangle, and cross marks show the locations of the NUPol radar, a JMA wind profiler, and MLIT X-band radars, respectively. The large circle shows the radar range of 4.2 km in radius. The filled square represents a sounding observation site at Hamamatsu. Topography is shown by gray shade from 300 m every 600 m.

*Corresponding author address: Mariko Oue, Hydrospheric Atmospheric Research Center, Nagoya University, Furo-cho, Chikusa-ku, Nagoya, 464-8601, Japan; e-mail:oue@rain.hyarc.nagoya-u.ac.jp

at Nagoya University located in the Nobi Plain (Fig. 1). The radar was operated in high-PRF mode to gain a large number of pulses for integration. Settings of the high-PRF mode are shown in Table 1. The PRF was 20,000 Hz, and the Nyquist velocity was 10 m s^{-1}. The number of pulses for integration was 40,000, and the antenna rotation rate was 0.1 rpm. The pulse width was 1.0 μs. For the observation reported here, the NUPol radar performed plan position indicator (PPI) scans at an elevation of 4 degrees. The observation range is 4.2 km in radius. In the high-PRF mode, the radar transmits only horizontally polarized wave. The production data by the radar in the high-PRF observation were power spectra of Doppler velocity for each range bin. The received power, Doppler velocity, and velocity dispersion were calculated from each spectrum. Non-meteorological signals such as ground clatter were removed from the spectrum. A sharp peak around the 0 value of Doppler velocity in a spectrum is considered to be caused by ground clatter. Therefore, data within adequate width centering around the 0 value were removed from each spectrum. Horizontal wind at constant height was estimated from Velocity-Azimuth Display (VAD; Browning and Wexler, 1968).

Data of a wind profiler operated by Japan Meteorological Agency (JMA) were used for validation of Doppler velocity measured by the NUPol radar and for obtaining environment over the radar observation area. The wind profiler is located 1.9 km north-northwest of the radar along the 343 azimuth angle. Data of X-band polarimetric radars operated by Ministry of Land, Infrastructure, Transport and Tourism (MLIT) were subsidiarily used to detect convective precipitation echoes.

3. RESULT

The high-PRF observation was performed in the day time for 17 days during the observation period from August to September in 2010. A case of 25 August 2010 was chosen as a typical case of pressure pattern of summer with southerly wind in Japan, and sufficient data of radar observations were collected on that day. To compare that case to another case that northerly wind prevailed in contrast to summer, a case of 17 September 2010 was chosen. On 25 August and 17 September, radar observations were performed for 17 scans (4 hours) in succession and 1 scan, respectively. We analyzed the observational data on those days in detail.

Table. 1. Plan position indicator (PPI) setting of high-PRF observations by the NUPol radar.

Elevation angle	4.0°
Radar coverage	4.2 km in radius
Rotation rate	0.6° sec^{-1} (0.1 rpm)
Range gate spacing	150 m
Beam width	1.2°
Pulse width	1.0 μs
Pulse repetition frequency	20,000 Hz
Number of integration pulses	40,000
Nyquist velocity	10.0 m s^{-1}
Transmitter pulse	horizontally polarized wave

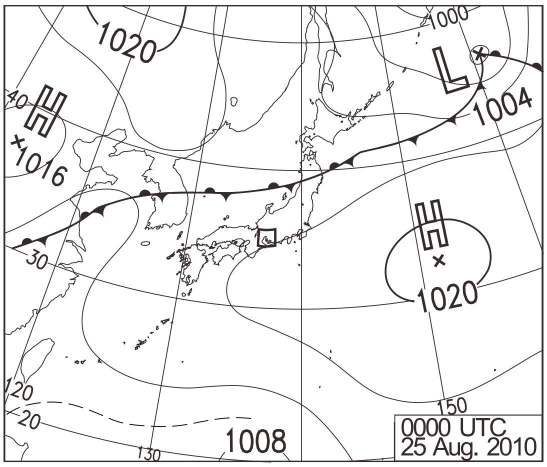

Fig. 2. A surface weather chart at 0900 LST on 25 August 2010. The open square represents the location of the Nobi Plain.

3.1 A case of 25 August 2010

On 25 August 2010, the Nobi Plain was located on the west edge of an anticyclone exiting over the Pacific Ocean (Fig. 2). Relative humidity measured by sounding at Hamamatsu at 0000 UTC on that day showed greater than 75% at altitudes below 2 km. The high PRF observations were performed for 17 scans from 0954 LST (= UTC + 9) to 1354 LST on that day. Figure 3 shows time variation of vertical profile of horizontal wind measured by the JMA wind profiler. Southerly wind near the surface was clearly found from 1310 LST. The southerly wind probably corresponds to a see breeze from the Ise Bay.

The radar observations were performed

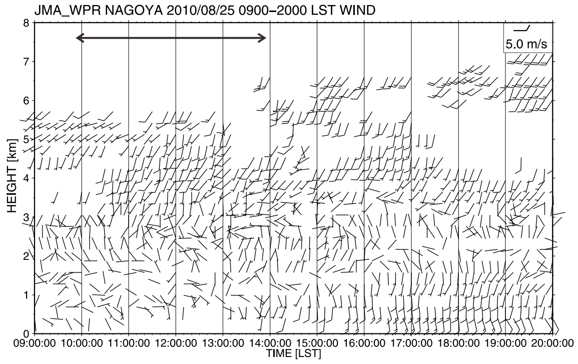

Fig. 3. Time-height cross section of horizontal wind (barb) measured by wind profiler operated by JMA on 25 August 2010. The arrow represents a high-PRF observation period.

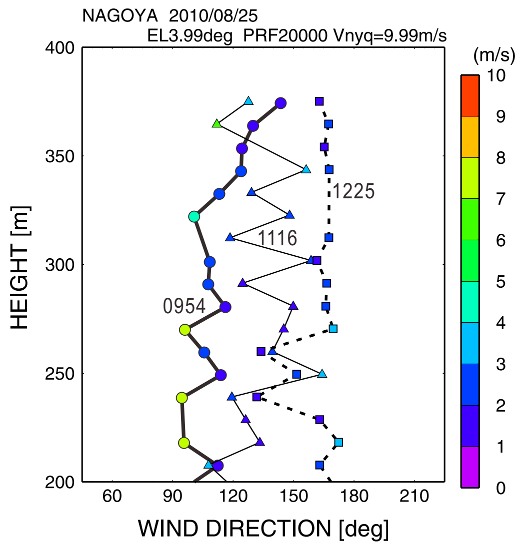

Fig. 4. Vertical distributions of wind direction (line) and wind speed (color) estimated from each PPI by the VAD method. Thick line, thin line, and dashed line represent PPI scan at 0954 LST, 1116 LST, and 1225 LST, respectively.

when the southerly wind measured by the wind profiler was indistinct. Vertical profiles of horizontal wind observed by the NUPol radar were estimated from VAD (Fig. 4). Doppler velocity observed as clear-air echo by the radar showed that prevailing wind shifted from easterly wind to southerly wind between 0954 LST and 1230 LST. The southerly wind from ocean was approximately 3 m s^{-1}. The time when the southerly wind predominated in the radar observation range is in good agreement with the beginning time of a development of southerly-wind layer shown in a vertical distribution of wind observed by the JMA wind profiler (1200−1300 LST in Fig. 3). The shift from easterly wind to southerly wind is considered to be inflow of the sea breeze.

Precipitation echoes were found in the NUPol's observation area by the MLIT radars at around 1230 LST (Fig. 5). The precipitation echoes was possibly a convective cell forming in the sea breeze front. The precipitation echoes developed at about 1220 LST, and almost stayed at the same place. After 1240 LST, the precipitation echoes gradually dissipated. Meanwhile, the NUPol radar observed the precipitation echoes and wind field associated with the precipitation echoes. Figure 6 shows horizontal distributions of Doppler velocity at an elevation of 4.0 degrees by the NUPol radar. The precipitation echoes were found at about 3.5 km south of the radar at 1225 LST. In and around the precipitation echoes, there was turbulence embedded in a southerly wind (Fig. 6a). Assuming a couple of visible convergence and divergence regions of radial velocity in Fig. 6a to a scale of turbulence, a horizontal scale of turbulence was estimated to be 0.5−1 km.

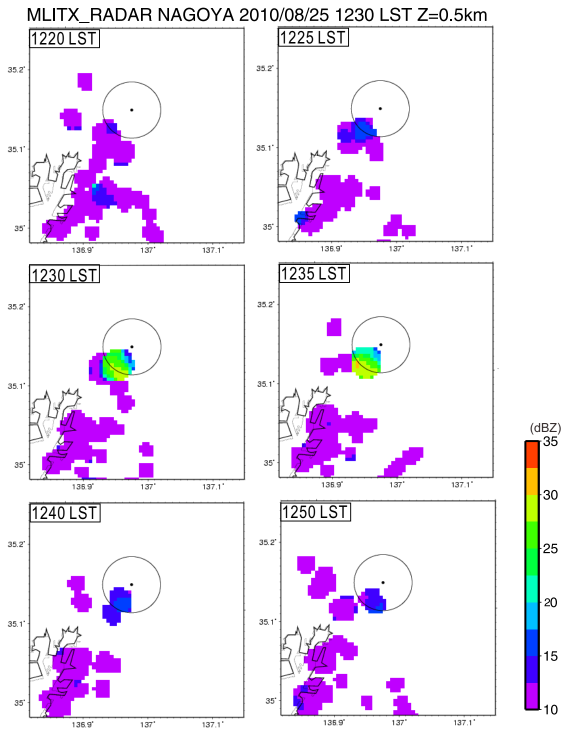

Fig. 5. Horizontal distributions of radar reflectivity at an altitude of 0.5 km in constant altitude PPIs observed by the MLIT's radars at 1220, 1225, 1230, 1235, 1240, and 1250 LST. The dot and open circle in each panel represent the location of the NUPol radar and the radar observation range (4.2-km radius), respectively.

After the precipitation echo dissipated (1250 LST), Doppler velocity observed by the NUPol radar showed turbulence regions to the south of the radar at 1252 LST (Fig. 6b), even though there was very weak echo less than 10 dBZ by the MLIT radars in the NUPol's observation area.

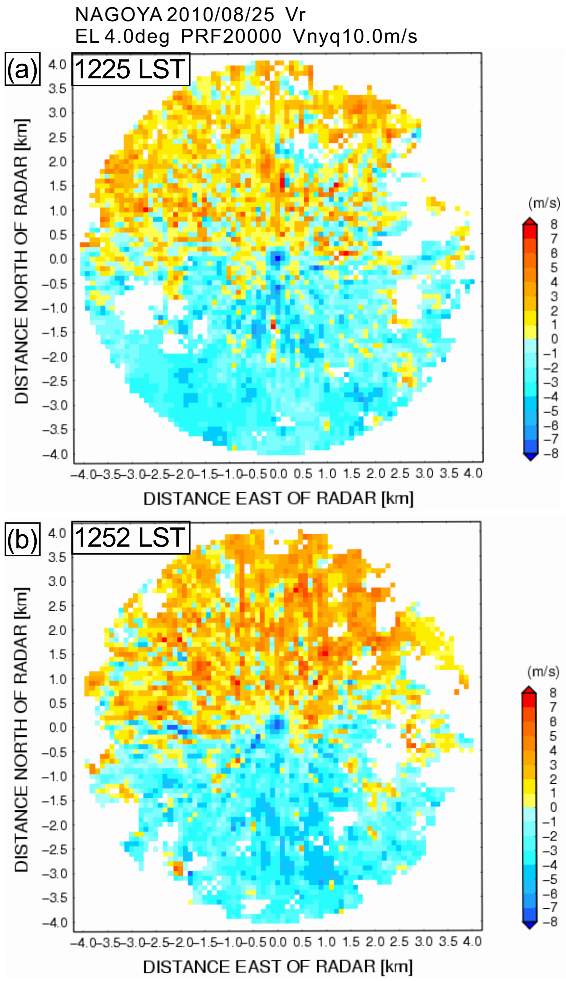

Fig. 6. Doppler velocity of a PPI observed by the NUPol radar at (a) 1225 LST and (b) 1252 LST. Scan elevation is 4.0 degrees. Negative values denote approach to the radar.

3.2 A case of 17 September 2010

On 25 August 2010, the Nobi Plain was located in the rear of a low pressure exiting to the east of Japan (Fig. 7). For this pressure pattern, northerly wind was likely to prevail at the surface around the Nobi Plain. Relative humidity measured by sounding at Hamamatsu at 0000 UTC on that day showed less than 70% below an altitude of 2 km. No precipitation echo was detected by the NUPol and MLIT radars in the NUPol's observation area.

Time variation of vertical profile of horizontal wind measured by the JMA wind profiler was shown in Fig. 8. Northwesterly wind was predominant near the surfase during that day as a whole. The high-PRF observation was performed at 1312 LST. A vertical profile of horizontal wind estimated from the VAD method using the high-PRF scan data was shown in Fig. 9. The horizontal wind observed by the NUPol radar showed approximately northwesterly wind above an altitude of 250 m. The wind direction was roughly in consistent with that by JMA wind profiler. However, wind speed in Fig. 9 shows underestimation compared to the JMA wind profiler. The inaccuracy was possibly because the VAD estimation was insufficient due to weak signals and small amount of data for the calculation in the PPI. The weak signals were thought to be due to the northwesterly wind including less water vapor compared to that of southerly wind on 25 August 2010. This suggests that in the dry air from northwest clear-air echoes were hard to detect by the X-band radar.

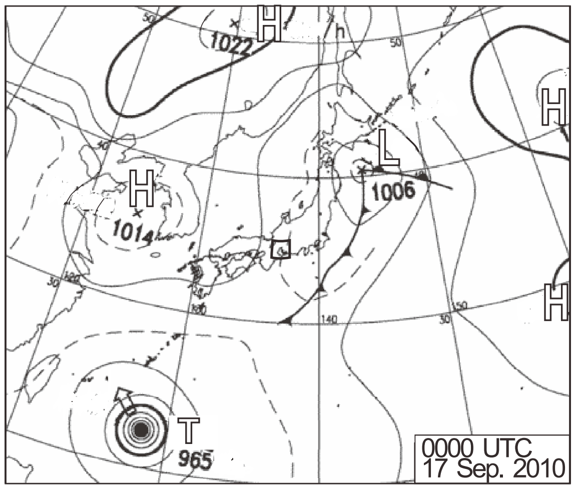

Fig. 7. As in Fig. 2, but for on 17 September 2010.

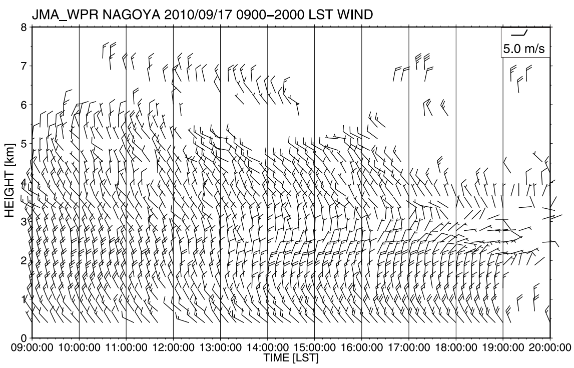

Fig. 8. As in Fig. 3, but for on 17 September 2010.

5. SUMMARY AND CONCLUSIONS

X-band Doppler radar observations were performed in the Nobi Plain during a summer season from August to September 2010. To observe clear-air echoes, the observations were performed with high pulse repetition frequency

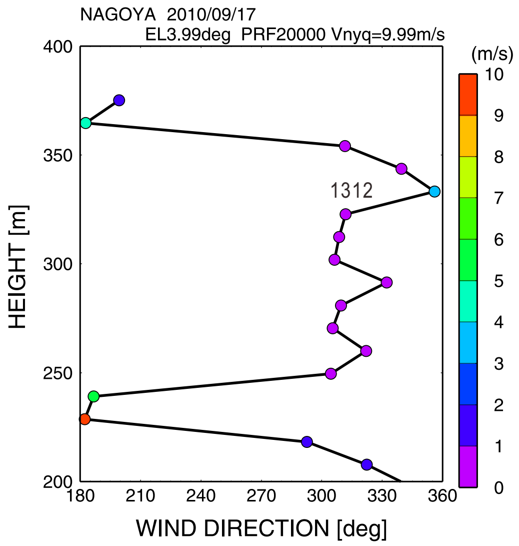

Fig. 9. As in Fig. 4, but for at 1312 LST on 17 September 2010.

(PDF) of 20,000 Hz and slow antenna's rotation rete of 0.1 rpm.

On 20 August, Doppler velocity in a clear air and precipitation echoes were observed. Wind direction estimated from VAD of the Doppler velocity shifted from east to south between 0954 LST and 1354 LST. The change of wind direction was considered to be an inflow of sea breeze. Precipitation echoes were observed when the southerly wind was distinguished. Around the precipitation echoes, the NUPol radar detected turbulence.

On 17 September, Doppler velocity in a clear air was observed. Horizontal wind estimated from VAD showed dominance of northwesterly wind. The signal of clear-air echoes on 17 September were not clear compared to that on 25 August.

The high-PRF observations by the X-band Doppler radar were valid for observation of horizontal wind in clear air, even though the dry air in the northwesterly wind prevailed in the Nobi Plain. In particular, the observations were effective for the southerly wind including moisture to detect turbulence associated with precipitation and clear-air echoes.

Acknowledgments: The authors appreciate Ministry of Land, Infrastructure, Transport and Tourism (MLIT) for providing data of MLIT's X-band polarimetric radar to the research consortium on technological development of MLIT's X-band multi-parameter radar. They are also thank Dr. Masakazu Wada of Toshiba Corporation for his valuable suggestions. This study was partly supported by a Grant-in-Aid for Scientific Research of the Japan Society for the Promotion of Science and the program "Formation of a virtual laboratory for diagnosing the earth's climate system."

References

Atlas, D., 1960: Possible key to the dilemma of meteorological ängelëchoes. *J. Meteor*, **17**, 95–103.

Battan, L. J., 1973: Radar observation of the atmosphere, revised edition. *The University of Chicago Press, Chicago*, 324pp.

Browning, K. A. and R. Wexler, 1968: The determination of kinematic propaties of a wind field using Doppler radar. *J. Appl. Meteor.*, **7**, 105–113.

Sano, T. and K. Tsuboki, 2006: Structure and evolution of a cumulonimbus cloud developed over a mountain slope with the arrival of sea breeze in summer. *J. Meteor. Soc. Japan*, **84**, 613–640.

Takeda, T. and S. Murabayashi, 1981: Observation of Clear-air echoes with 3.2-cm radars. *J. Meteor. Soc. Japan*, **59**, 864–875.

Tsunematsu, N. and K. Kai, 2004: Time variation of cloud distribution near surface wind convergence zone in the Nobi Plain during daytime on summer sunny days. *J. Meteor. Soc. Japan*, **82**, 1505–1520.