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Single Doppler Radar Observation of Vortical Snow Storm on the Ishikari Plain, Hokkaido, Japan

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Abstract

The kinematic structure of a vortical snow storm, which had a horizontal scale of 30 km in diameter and developed on the Ishikari Plain on 3 February 1989, was studied using a single Doppler radar. To detect the horizontal wind field in the storm, a pseudo dual Doppler radar observation, named "Time-Lag-Dual method" in this study, was carried out, by applying two PPI displays at different times in observation with a single Doppler radar. Wind field calculations showed cyclonic circulation and strong wind gusts, which corresponded to the data from surface observations. As a result of these analyses, it can be concluded that a major cause of the vortical disturbance was a kinematic effect of topography around Ishikari Bay, but that a thermal effect took a minor part in the storm formation.

1. Introduction

A vortical snow storm of various horizontal scales was often observed during winter monsoon surges around the Sea of Japan. The vortical disturbances, which have a scale of several hundred kilometers, were identified as polar-lows and/or meso-cyclones; and analytical studies were carried out using satellite and radar images as well as synoptic charts (e.g., Asai and Miura, 1981; Ninomiya, 1989). Recently, Tsuboki and Wakahama (1991) clarified from data analyses of observations and from linear instability analysis that the mechanism causing polar-lows at 200-700 km in diameter is a kind of baroclinic instability.

Kobayashi et al. (1989) showed a detailed structure of a meso-scale vortex of several tens of kilometers in diameter, which developed off Haboro on the

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Sea of Japan, using a conventional weather radar. They showed a warm core structure in the echo-free area of the vortex, and revealed that a thermal effect of three different air currents generated the meso-scale vortex. A vortical structure of the snow storm was also often observed around the Ishikari Plain, however, the horizontal wind field and the internal kinematic structure of the vortex were barely observed by Doppler radars until recently.

On 3 February 1989, a meso-scale disturbance with a horizontal scale of about 300 km in diameter, according to a satellite image, developed off the Shakotan Peninsula on the Sea of Japan. In accordance with the development of the meso-scale disturbance, a vortical radar echo of about 30 km in diameter was observed on Ishikari Bay ; and we were able to observe the storm for two hours using a single Doppler radar. The radar reflectivity presented vortical shapes clearly and the Doppler velocity field showed significant features, therefore, a pseudo dual Doppler method was adopted with the intention of clarifying the velocity field of the storm.

2. Observations

Single Doppler radar observations were conducted around Sapporo on the Ishikari Plain, Hokkaido, Japan in the winter of 1989. Figure 1 shows an observational meso-network near Sapporo and the location of the radar site at Hokkaido University. The observational range of the radar was 63.5 km in radius and the range resolution was 250 m. To obtain a detailed structure of the fast moving radar echoes, sector PPI (Plan Position Indicator) observations of several elevation angles were conducted in 10 minute intervals. The sector PPI recorded data of a 180° azimuth range in 30 seconds. Surface meteorological data were also collected by several observation points, as shown in Fig. 1.

3. Time-Lag-Dual method

To analyze the horizontal wind field of the snow storm, the dual Doppler radar method (summarized by Doviak and Zrnic, 1984) was adapted to two sector PPI data of a single Doppler radar. Peace et al. (1969) have suggested that single Doppler radar data collected during two time periods could be used to analyze the horizontal wind field associated with a convective storm if the wind field was steady state in the reference frame of the storm. Bluestein and Hazen (1989) adopted this method to an rainband of a tropical cyclone. They concluded that synthetic dual Doppler analysis was a viable technique for

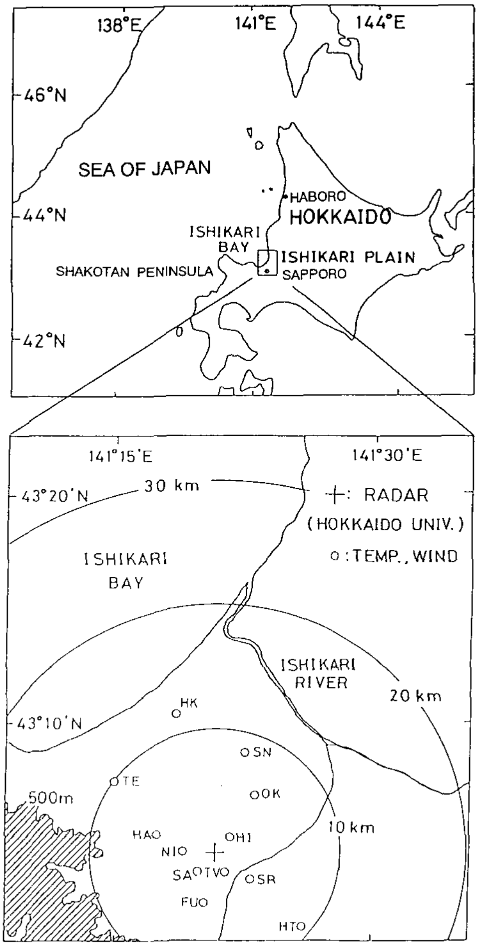

Fig. 1. Radar site (the symbol of +) and meso-network around the Ishikari Plain.

studying the meso-scale aspects of mobile cyclones. We adapted this method to a vortical snow storm and named it as the Time-Lag-Dual method in this study. Figure 2 shows conceptual drafts of the Time-Lag-Dual method in 2-dimensional display. In Fig. 2(a), the same radar echo was observed at the different times T_1 and T_2; and they were labeled E_1 and E_2, respectively. If the moving velocity of the echo is expressed by $\mathbf{V}$, the moving distance ($\mathbf{L}$) is considered to be

$$\mathbf{L}=(T_2-T_1)\mathbf{V}.$$

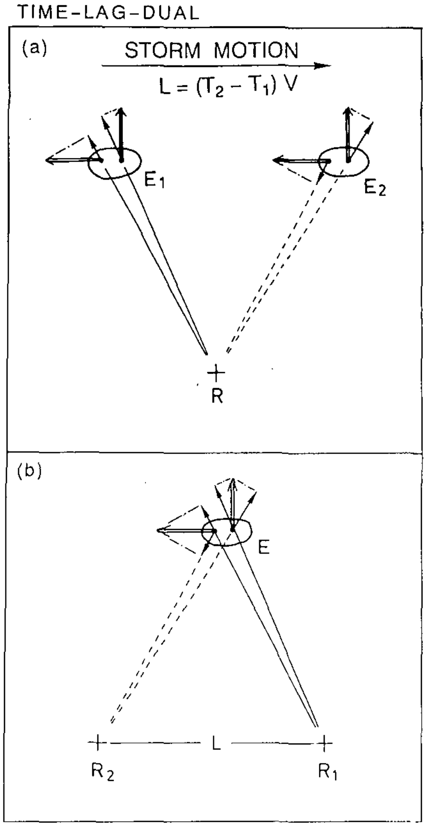

Fig. 2. Schematic illustration of the Time-Lag-Dual method. (a) Thick arrows indicate wind vectors in the echo (E_1 and E_2); and thin arrows are Doppler velocity components from radar site R. (b) Thick arrows are wind vectors composed by Doppler velocity of two observations. The baseline distance (**L**) is considered from moving velocity of radar echo (**V**) and time difference of two observations (T_2-T_1).

If the velocity pattern in the storm (shown by thick arrows) was not changed during the two observations, Doppler velocities of E_1 and E_2 could be obtained, as shown by thin arrows in Fig. 2(a). If we consider that the two observations had been conducted simultaneously from two different radar sites, the two data sets can be regarded as the equivalent to the dual Doppler radar observation of the baseline distance of **L** as shown in Fig. 2(b). In this case, the two radar sites of the dual Doppler analyses are denoted as R_1 and R_2, respectively. We then applied the dual Doppler method to these data, and wind velocities were calculated, as shown by the thick arrows in Fig. 2(b). The results were in agreement with the original wind velocities as shown in Fig. 2(a).

If we supposed that the whole radar echo had constant moving velocity, we are able to obtain data about the wind velocity field of the storm. To simplify the calculations, we did not take the vertical velocity into account and used a 1 km data grid obtained from only one PPI image on an elevation angle of 3.0° in this study. Bacause of this, an accurate value of vorticity and rotation was not acquired. The Time-Lag-Dual method is, however, practicable in suggesting an adequate velocity field in order to understand the whole aspect of a vortical storm under the winter monsoon condition.

4. Results

On 3 February 1989, a vortical echo of the snow storm, as shown in Fig. 3, passed over the radar site around 0730 JST. The echo began to organize at around 0640 JST on Ishikari Bay and it then moved to the Ishikari Plain, as shown by the sequence of radar reflectivity in Fig. 4. The vortical echo showed cyclonic rotation and new convective echo cells were developed in front of the cells movement. The moving velocity of the system was almost constant (from west-northwest to east-southeast in 10 m/s) and the figure of the echo showed no substantial change within each 20 minute interval.

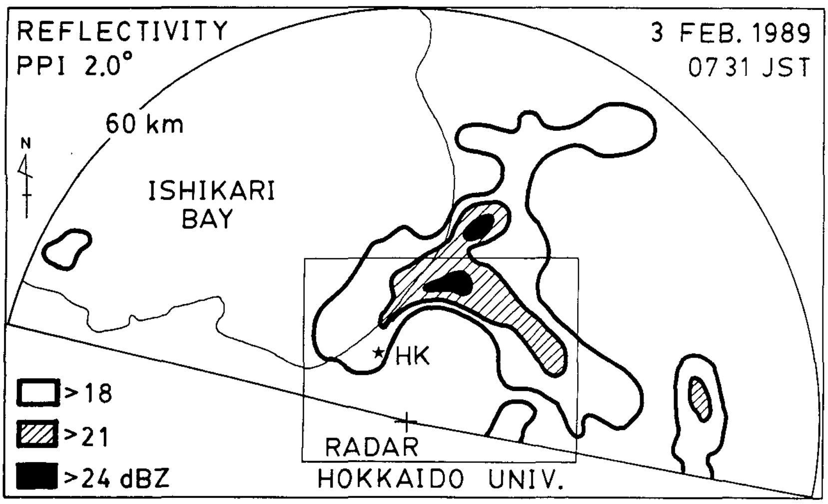

Fig. 3. Sector PPI display of radar reflectivity at 0731 JST on 3 February 1989. Elevation angle is 2.0° and the coastal line is drawn. Contours are drawn every 3 dBZ beginning at 18 dBZ.

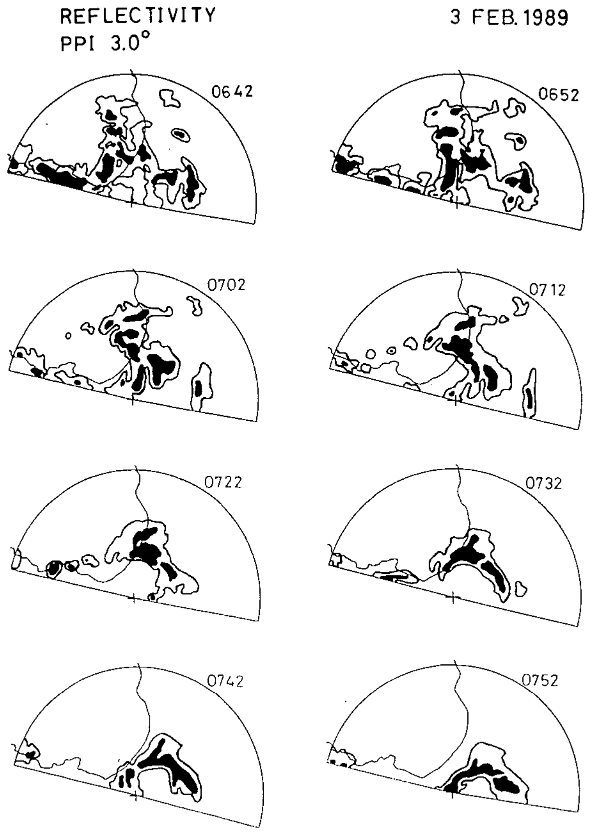

Fig. 4. Time series of sector PPI radar reflectivity from 0642 to 0752 JST. Elevation angle is 3.0°. Echoes over 18 dBZ are indicated and over 21 dBZ are shown by black areas.

Figure 5 shows the velocity field around 0730 JST corresponding to the rectangle in Fig. 3. The position of the radar site around 0730 JST is denoted by R_3. The area of radar reflectivity over 18 dBZ at 0732 JST was shown by a gray region. The wind vectors were calculated by the Time-Lag-Dual method from two displays of Doppler velocity at 0722 and 0742 JST. The moving distance of the echo was derived from matching radar reflectivity patterns. The positions of the radar site corresponding to the time of 0722 and 0742 JST are indicated by R_2 and R_4, therefore, the pseudo dual Doppler method of a 12 km baseline length was conducted in this case.

The calculated wind vectors showed that southerly or south-easterly wind blew at the center of vortex, and north-westerly wind gust was clearly indicated

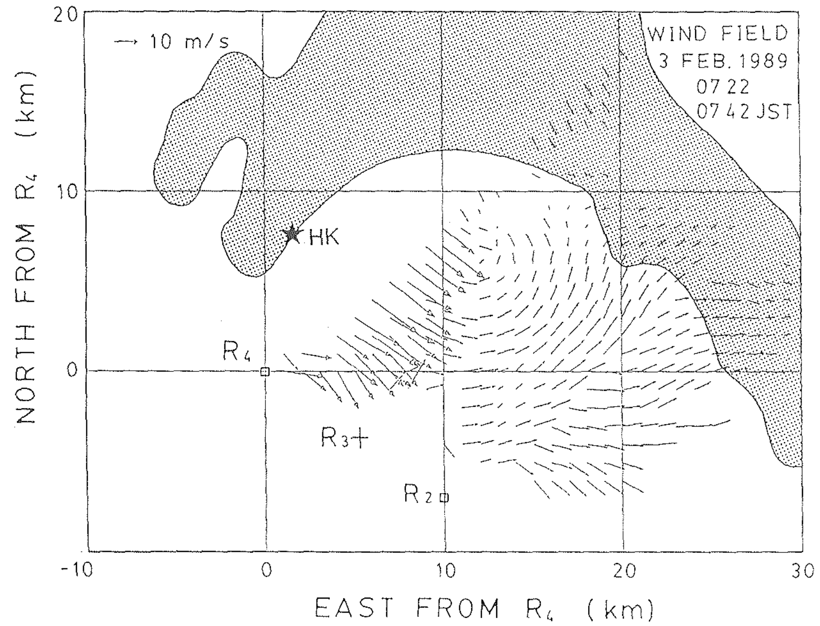

Fig. 5. Velocity field in the rectangle of Fig. 3 around 0730 JST calculated by the Time-Lag-Dual method. R_2 and R_4 indicate the estimated position of radar site at 0722 and 0742 JST for pseudo dual Doppler method. R_3 corresponds the position of radar site at 0732 JST. Reflectivity echoes over 18 dBZ at 0732 JST on the elevation angle of 3.0° are shown by a gray area.

in front of the northwest side echoes. The wind gust obtained by the Time-Lag-Dual method corresponded to the surface wind gust recorded at point HK, which is shown by a star mark in Figs. 3 and 5. Figure 6 shows instantaneous wind speed and direction at HK. As shown in the figure, a weak southwesterly breeze was recorded before 0725 JST ; and a strong northwesterly wind gust of 14 m/s was recorded at 0725 JST. After the gust passage, strong northwesterly wind was blowing continuously. These features coincide with the velocity field of the Time-Lag-Dual method described above. In contrast to the wind signature, the surface temperature shows no significant and systematic change through the echo passage, at all surface observational points ; e.g., a 0.1°C down at the point TE, a 0.6°C down at the point SN, and a 0.6°C up at the point HT.

5. Discussion and conclusions

The horizontal wind field was obtained by applying a synthetic pseudo dual

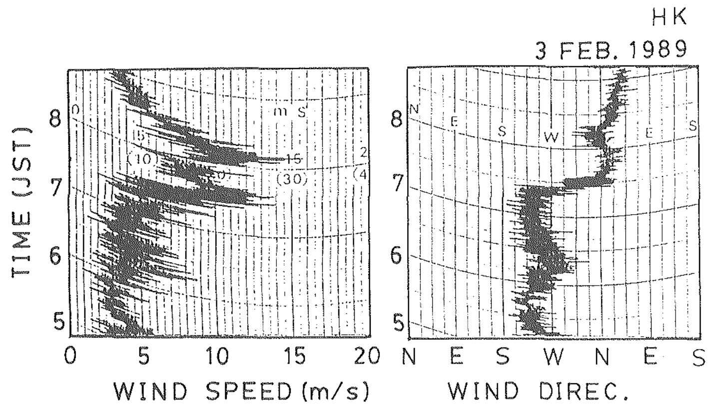

Fig. 6. Instantaneous wind speed and direction at HK on 3 February 1989.

Doppler method from two snapshots of PPI images taken in different time observations ; and the method was named Time-Lag-Dual method in this study. When the echo kept a constant moving velocity and was located in a suitable position in relation to the radar site, an adequate wind field was obtained by this method. Not only the features of a vortical system but a strong wind gust was also detected in detail. It is helpful to understand the detailed structure of the vortical snow storm.

Significant changes of the wind speed and direction were observed by surface observation data corresponding to the echo passage. Strong wind gusts in winter monsoon surges were identified as snowbursts and were well discussed by Shirooka and Uyeda (1990). The snowburst had a horizontal scale of about 10 km and accompanied by a significant temperature drop, which was explained by thermodynamic effects of strong downdrafts. On the contrary, significant and systematic temperature changes were not recorded corresponding echo passage at the surface observation points in the study. Strong wind gusts were, however, observed at the all surface observation points corresponding echo passage. The vortical snow storm did not have a warm core structure and a signature of the snowburst. Therefore, topographical effects around Ishikari Bay and kinematic effects such as strong vorticity of a meso-scale cyclone off the Shakotan Peninsula were more dominant than thermal effects, in the formation of the vortical snow storm in this case.

This method of detecting a wind field is suitable for snow clouds in winter monsoon surges, because the moving velocity of such a snow storm is relatively large and constant (e.g., about 10 m/s southeastward in this case). To investigate the kinematic structure of vortical storm in more detail, real dual Doppler observations using two or more Doppler radars are recommended. This method is, however, an easy and practical way in the case that only a single Doppler radar is available.

Acknowledgments

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