ERROR COMPARISON OF WIND FIELD RETRIEVAL FROM SINGLE AND DUAL–DOPPLER RADAR OBSERVATIONS

Tao Zuyu (陶祖钰)

National Laboratory for Severe Storm Research, Department of Geophysics, Peking University, Beijing 100871

Received January 1, 1994; revised April 18, 1994

ABSTRACT

The error distributions of the wind fields retrieved from single and dual–Doppler radar observations are given in this paper. The results indicate that the error of dual–Doppler retrieval depends on the position in the scan region of the dual–Doppler radar. The error of single–Doppler retrieval by using velocity azimuth processing (VAP) technique depends on the angle between the directions of wind and the radar beam. Generally, the winds retrieved from single Doppler radar are close to those retrieved from dual–Doppler radar. But, the error distribution of the single–Doppler retrieval is different from the dual–Doppler retrieval. We simulate the retrievals of single Doppler observation by the use of the output wind data from a 3–D numerical model of severe convection. The comparison of the simulated single– and dual–Doppler retrievals shows that the VAP may be a suitable technique for the operational analysis of mesoscale wind fields. It can also be used as a supplement to wind field retrieval in the field experiment.

Key words: Doppler radar, wind field retrieval, velocity azimuth processing (VAP) technique

I. INTRODUCTION

The chief object of Doppler radar observation is to obtain mesoscale wind fields. Since only the radial component of wind vector (the radial velocity) can be measured by Doppler radar, the combined observation of two Doppler radars is necessary to obtain the mesoscale wind field. The wind vector can be compounded by two radial velocities measured by two separated Doppler radars.

The wind error estimation of dual–Doppler retrieval (Doviak et al. 1976) shows that the retrieved winds with small error are available only in two separated regions located on both sides of the dual–Doppler radar baseline. The area of effective region is about one fourth of the radar scan area. Hence, the dual–Doppler retrieval is not suitable for the operational analysis of mesoscale wind fields.

Because of the limitation of dual–Doppler radar wind field retrieval, the techniques of single–Doppler retrieval have been suggested, such as velocity volume processing (VVP) technique by Waldteufel (1979), uniform wind (UW) technique by Persson (1987) and velocity azimuth processing (VAP) technique by Tao (1992).

In order to infer the horizontal velocity vector from one field of Doppler velocity, an assumption about the wind field is necessary. The VVP technique is under the assumption of linear wind field in a limited volume. The weakness of VVP technique is that the precision and the space resolution of the retrieved wind field are poor. The case study shows that the retrieved wind field by VVP technique is not good enough (Koscielny et al. 1982). Therefore, VVP technique was not accepted as a conventional technique to retrieve wind fields from single–Doppler observation.

The UW technique is under the assumption that the winds are uniform in a limited interval of the azimuth. As the winds are uniform, the tangential component V_t of velocity can be inferred from the gradient of the radial component V_r with azimuth

$$V_t = -\frac{\partial V_r}{\partial \theta}. \tag{1}$$

For the 100 km scale wind field, it is reasonable to assume that the winds in the space resolution of 1—3 km are uniform. Because the tangential component in Eq. (1) is very sensitive to the variation of the radial component with azimuth, the noise of Doppler radar measurements will be amplified greatly. In order to get reasonable wind fields, the UW retrieved wind fields have to be modified by dynamical control, such as imposing horizontal non–divergence (Hagen 1989). But, most of mesoscale features of retrieved wind fields will be missed after the modification.

The VAP technique is another kind of uniform wind technique for single–Doppler retrieval (Tao 1992). The direction α and velocity V of the wind can be derived from the radial velocity V_{r2} and V_{r1} at two contiguous azimuth ($\theta+\Delta\theta$, $\theta-\Delta\theta$) in the velocity azimuth profile as follows:

$$\mathrm{tg}\alpha = \frac{V_{r2} - V_{r1}}{V_{r2} + V_{r1}}\mathrm{ctg}\Delta\theta, \qquad V = \left|\frac{V_{r2} + V_{r1}}{2\cos\alpha\cos\Delta\theta}\right|, \tag{2}$$

where α is the angle between the wind direction and the radar beam. The first results with the VAP technique show that the mesoscale features can be found in the retrieved wind field (Tao 1992). Hence, the VAP technique may be a suitable technique to derive the mesoscale wind fields from single Doppler radar observation.

In order to further confirm the feasibility of single–Doppler retrieval through VAP, the errors of wind field retrieved from single– and dual–Doppler radar observations will be compared in this paper.

II. ERROR DISTRIBUTIONS OF DUAL– AND SINGLE–DOPPLER RETRIEVAL

1. *Dual–Doppler Retrieval*

Since there are no observation data of a mesoscale wind field which can be used to examine the error of the retrieved wind field, the error is usually discussed by the retrieval formula theoretically. The error distribution can be given only for a simple wind field (Doviak et al. 1976). The quality of the wind field retrieved from the Doppler radar measurements is usually examined by the comparison of wind field to the radar echo distribution and individual sounding data (Koscielny et al. 1982; Tao 1992).

For the simple wind fields, the theoretic error distribution of the dual–Doppler retrieval is given in Fig.1 (after Doviak et al. 1976). For the wind perpendicular to the dual–Doppler baseline (x–axis), the error of v component is very large around the baseline. For the wind parallel to the baseline, the error of u component is increasing with the distance to the center of baseline. Obviously, it is because the beams of two radars are nearly parallel in those regions. As a result, the difference of Doppler velocity of two radars is very small, and the results of dual–Doppler retrieval are calculated mainly from the noise of Doppler radar observation. So, the error of wind field retrieved from dual–Doppler observations depends on the location of the retrieving area relative to the radar position.

For complex wind fields, the error distribution can not be given by a theoretical analysis. It also can not be given by the real case study because the real wind field is not available for calculating the error distribution of the retrieved wind field. The only way to obtain the error distribution for the complex wind field is by the simulative retrieval, in which the "real" wind field is given artificially. The simulative Doppler observations are calculated from the "real" wind

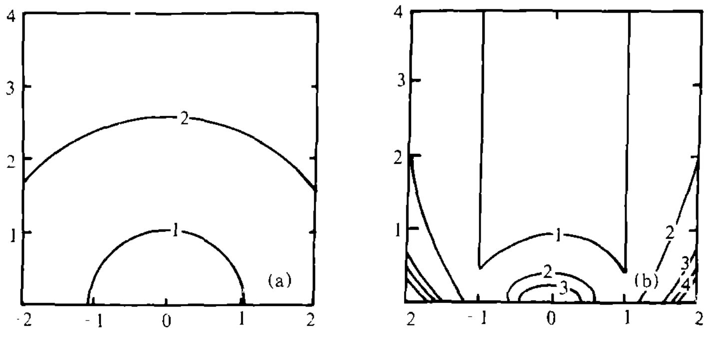

Fig. 1. Horizontal distribution of the relative error of the dual–Doppler retrieval of a simple wind field (adapted from Doviak 1976): (a) for u component, (b) for v component. The x–axis is the baseline of dual–Doppler radar. Two radars are located at $x = +1$ and -1, respectively. The isolines are the ratios of the standard variance of the retrieved values to the observations.

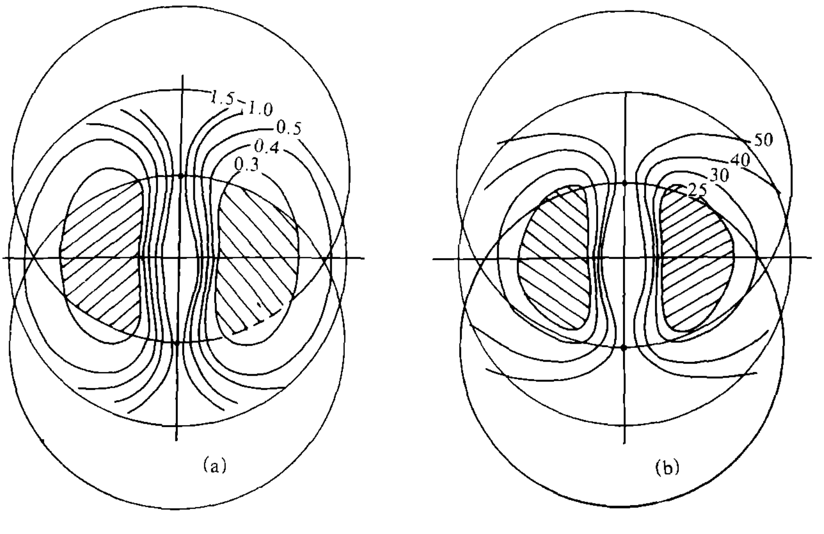

Fig. 2. Error distribution of simulative dual–Doppler retrieval of a complex wind field (adapted from Kong 1993): (a) relative error of wind velocity, (b) error of wind direction in degrees. Dots denote the radar locations. The distance between two radars is 100 km.

fields. Hence, the error of retrieval can be calculated from the difference between the "real" and retrieved wind fields. Kong (1993) used the 35×35 grid wind data from a 3–D mesoscale convective numerical model as the " real" wind field. The simulative dual–Doppler measurements are converted from the rectangular grid "real" wind field by interpolation. The distance between two radars is 100 km.

The results of dual–Doppler simulative retrieval show that the error distributions of u and v components are similar to Fig.1. It means that the features of error distribution for the complex wind field are consistent with the simple wind field in the dual–Doppler retrieval. Figure 2 gives the error distributions of the wind velocity and direction of simulative dual–Doppler retrieval. It can be seen that both are distributed symmetrically about the baseline. The area with the relative error of wind velocity less than 0.3 and the area with wind direction error less than 25 ° are about one fourth of the radar scan area.

2. *Single–Doppler Retrieval*

According to Eq. (1), the error of UW technique is only related to the resolution of azimuth. The theoretic calculation indicates that the error of the tangential component retrieved by UW technique will reach 5 m / s everywhere when $\Delta\theta = 1°$ and the noise of Doppler measurement is 0.2 m / s (Hagen 1989).

For the single–Doppler retrieval of VAP technique, the error distributions of the simple wind fields ($u\equiv 0$ and $v\neq 0$) can be calculated from the following formula (Tao 1992):

$$\mathrm{d}\alpha = \frac{\mathrm{d}x}{1+x^2}, \qquad \mathrm{d}V = \frac{\mathrm{d}(V_{r2}+V_{r1})}{2\cos\alpha\cos\Delta\theta}, \tag{3}$$

where

$$x = \frac{V_{r2}-V_{r1}}{V_{r2}+V_{r1}}\,\mathrm{ctg}\Delta\theta.$$

Figure 3 is the error distributions of meridional wind field when $\Delta\theta = 1°$ and the noise of Doppler velocity is 0.2 m / s. It can be found that the features of error distribution for single–Doppler retrieval are different from the dual–Doppler retrieval. The error of the wind velocity is small in most area, but very large around the x–axis where the radial components are close to zero. This means that the error of wind velocity is very large where the wind direction is perpendicular to the radar beam. The reason is that when the wind direction is perpendicular to the radar beam, the Doppler velocity is very small and the wind velocity is mainly retrieved from the noise of Doppler velocity.

The error distribution of wind direction (Fig. 3b) is different from the wind velocity. The direction error is very small around the x–axis, and larger around the y–axis. It means that the error of wind direction is larger where the wind direction is parallel to the radar beam and the radial velocity is maximum. The reason is that the gradient of Doppler velocity with azimuth ($\partial V_r / \partial\theta$) is close to zero. Figure 3 shows the wind velocity retrieved by VAP method is unacceptable only in a very small region, and the error of the wind direction is smaller than 30°. Hence, the precision of single–Doppler retrieval by VAP method is similar to the dual–Doppler retrieval. As the error of single–Doppler retrieval depends on the angle between the wind direction and the radar beam, but is not related to the distance to the radar, the effective area of the single–Doppler retrieval could cover most of the radar scan region. It means that the

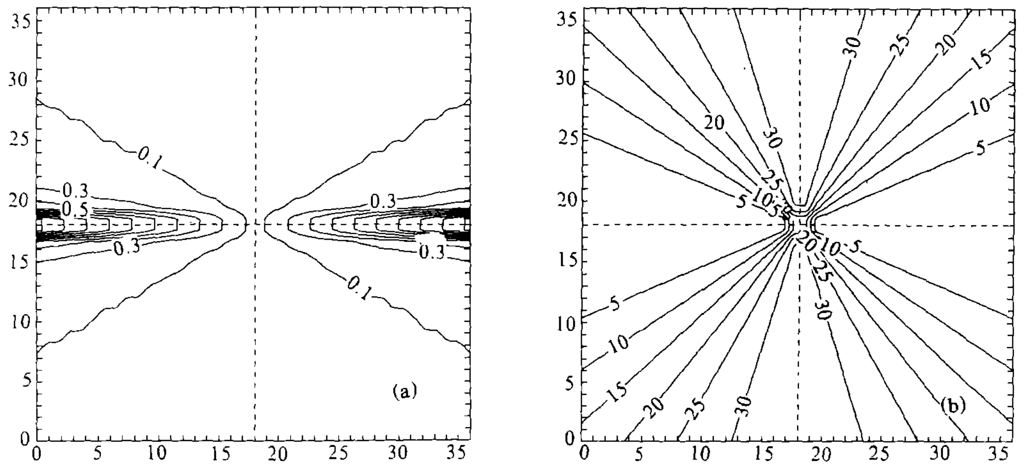

Fig. 3. Error distribution of single–Doppler retrieval of a simple wind field by VAP method. (a) relative error of wind velocity, (b) error of wind direction in degree.

effective area of the single–Doppler retrieval is larger than the dual–Doppler retrieval.

It has to point out that $\Delta\theta$ must be not less than 1 ° in VAP technique. Hence, the space resolution of retrieved wind field by VAP method is limited. But, the space resolution of dual–Doppler retrieval could be improved with the width of radar beam. Generally, the resolution of single–Doppler retrieval is 1—3 km, and 0.5—1.0 km for dual–Doppler retrieval.

III. COMPARISON OF SIMULATIVE RETRIEVAL BETWEEN SINGLE– AND DUAL–DOPPLER

In order to test the effectiveness of single–Doppler retrieval by VAP technique, the simulative retrieval is conducted based on the 35 × 35 rectangular grid data of Kong with 1.0 km grid distance of the wind fields produced by a 3–D numerical model of severe convection. The simulative measurements of the Doppler radar with 0.333 km distance interval and 1.0 degree azimuth interval are converted from the rectangular grid data of the wind field through Cressman interpolation. The simulative radar is sited at the center (18, 18) of the wind field. Then, the wind fields are retrieved by the VAP technique from the simulative Doppler measurements.

Figures 4a and 4d are the modeled and retrieved wind fields at 0.25 km and the 48th minute respectively. It can be seen that the northerly background wind and two convergent lines associated with convection are retrieved successfully. The considerable differences between the retrieved and "real" wind fields are mainly in the wind direction, located near the convergence line and the x–axis. Comparing the distributions of radial velocities of Figs. 4b and 4c, we find that considerable wind direction errors are located around the extreme value of radial velocity and the regions with dense contours of radial velocity. Obviously, the larger error of direction around the extreme value of radial velocity is consistent with the feature of the error distribution of VAP technique (see Fig. 3b). The larger error of direction in the regions with dense contours of Doppler velocity may be due to the fact that the noise of Doppler velocity is larger in that

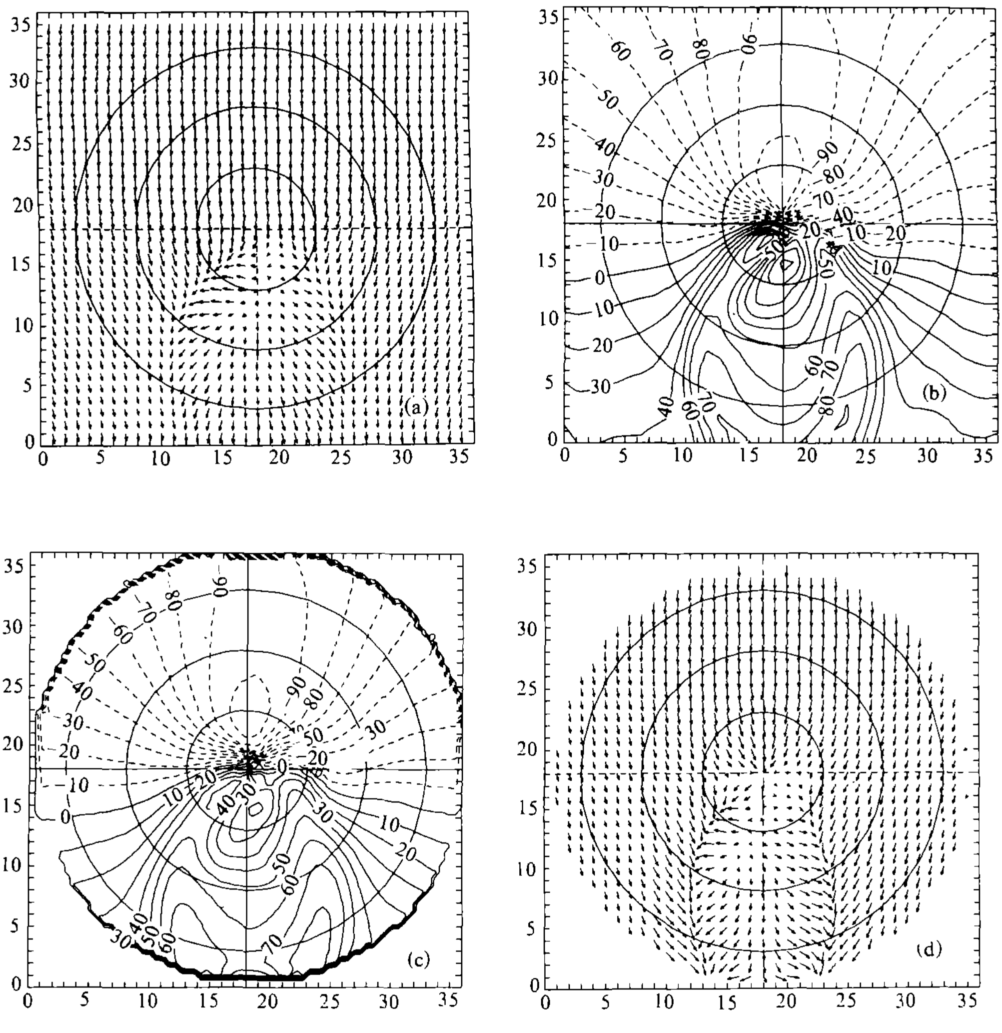

Fig. 4. Wind field at 0.25 km the 48th minute (grid distance is 1.0 km). (a) 35 × 35 wind vectors of numerical model output, (b) radial component of (a) in m / s, (c) simulative Doppler velocity interpolated from (b), (d) wind vectors retrieved from (c) by VAP method.

regions. Comparing Fig.4c with Fig.4b, we can find that the simulative Doppler velocity field (Fig. 4b) is not exactly same as the distribution of the radial component of "real" wind. So, the larger noise in those regions may be caused by the interpolation.

It is necessary to point out that no very large velocity of retrieved wind can be found in Fig.4d. It does not mean that the VAP technique do not cause large error in wind velocity anywhere. In fact, the error of wind velocity is very large near the zero contour of Doppler velocity. No very large velocity of wind can be found in the retrieved field of Fig. 4d. This is due to the fact that the velocity of winds is forced as a certain extreme value when the retrieved wind velocity is greater than a criterion.

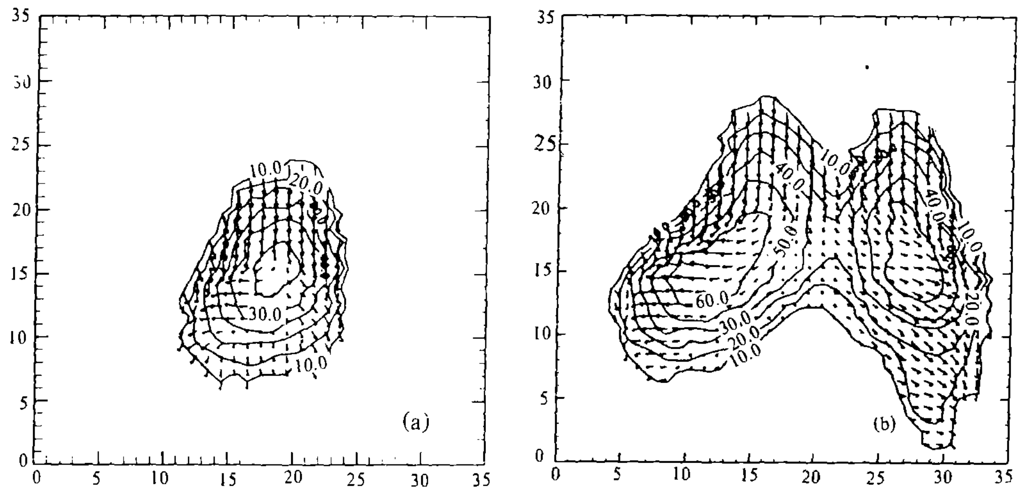

Fig. 5. Wind fields at 0.25 km height retrieved from simulative dual–Doppler observation (Kong 1993). (a) the 48th minute, (b) the 80th minute.

In order to compare the results of the single– and the dual–Doppler retrieval, the wind fields retrieved by dual–Doppler are given in Fig. 5. For the wind field at the 48th minute, the wind fields of the single– and the dual–Doppler retrieval are very similar. For the wind fields at the 80th minute, the result of the dual–Doppler retrieval is better than that of the single–Doppler retrieval (given in Fig.6), especially in wind dirqection. The dual–Doppler retrieval was quite good because the baseline of simulative dual–Doppler is considerably longer than the length of the retrieved wind field (100 km and 35 km respectively) and the retrieval region is located on the region with smaller dual–Doppler retrieval error. The comparison between Fig. 5 and Fig. 4d and Fig. 6d also shows that the effective dual–Doppler retrieval area with small error is considerably smaller than that the single–Doppler retrieval. The reason is that the dual–Doppler retrieval can obtain better results only when the beam of one radar is nearly perpendicular to another.

IV. CONCLUSIONS

According to the analysis of the error distributions and the comparison of the wind field retrieved from the simulative single– and dual–Doppler radar measurements, the conclusions are as follows:

(1) The error of dual–Doppler retrieval depends on the location of the retrieving region relative to the radar position. There are two effective regions with smaller error, the relative error of wind velocity less than 0.3 and the direction error less than 25 °, located symmetrically about the baseline of dual–radar. The area of two effective dual–Doppler retrieval region is about one fourth of the radar scan area. The space resolution of the retrieved wind field from dual–Doppler measurements could reach 0.5 km. Hence, the dual–Doppler retrieval can be used to analyze the mesoscale system in the effective retrieval regions during the field experiments.

(2) The error of the single–Doppler retrieval by VAP technique depends on the angle between the wind direction and the radar beam. The error of the retrieved wind velocity is largest

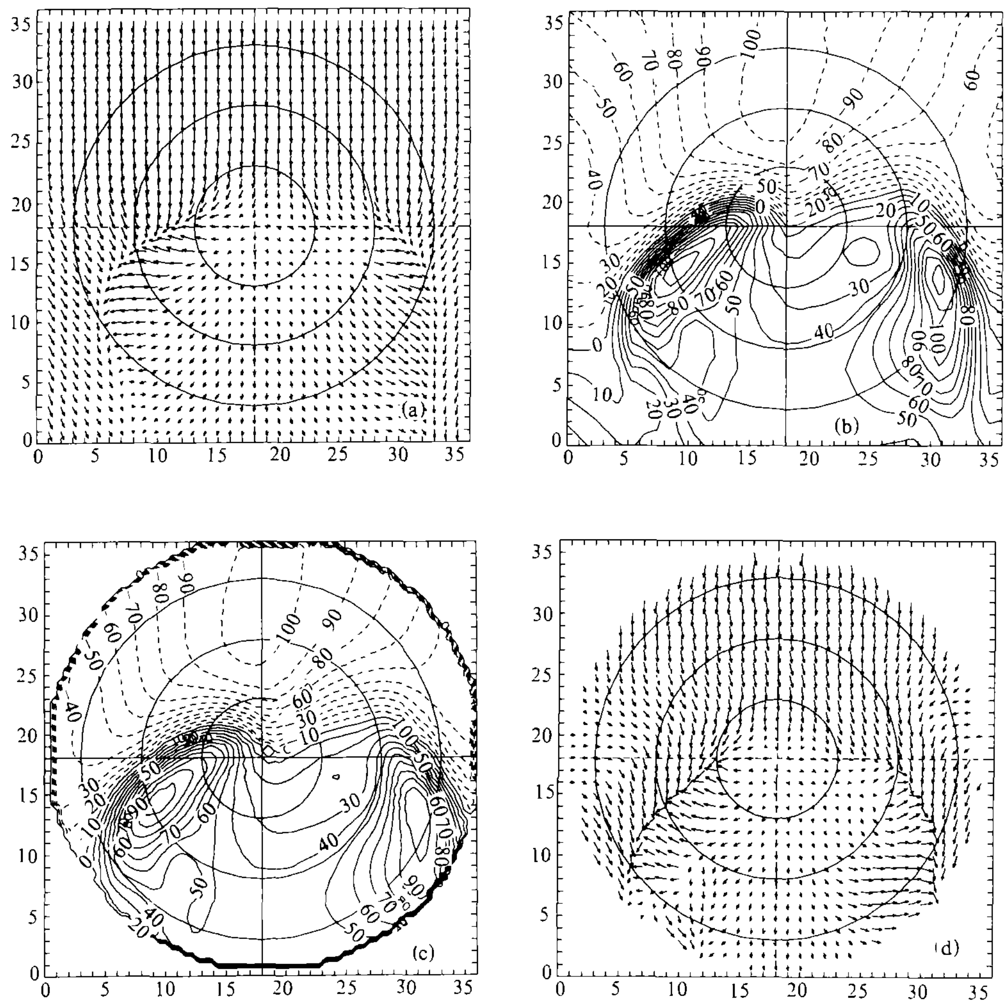

Fig. 6. Same as Fig.4, but for the 80th minute.

where the wind direction is perpendicular to the radar beam (i.e. around the zero contours of Doppler velocity); the error of retrieved wind direction is largest where the wind direction is parallel to the radar beam (i. e. around the extreme of Doppler velocity). For the most part of the radar scan region, the precision of the single–Doppler retrieval (VAP method) is close to the dual–Doppler retrieval. Hence, the VAP method of single–Doppler retrieval is suitable for the operational use on the analysis of a mesoscale wind field. It also can be used as a supplemental method in field experiments.

The author is indebted to Dr. F. Y. Kong for his grid data of the numerical model wind field, and to Prof. J. Egger of the University Munchen for reviewing the manuscript.

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