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ACCURACY OF COMPOSITE WIND FIELDS DERIVED FROM A BISTATIC MULTIPLE-DOPPLER RADAR NETWORK

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1. INTRODUCTION

A bistatic multiple-Doppler radar network as described in Wurman *et al.* (1993) is comprised one transmitting Doppler radar and one or more passive low-gain, non-scanning receivers at remote sites. The bistatic multiple-Doppler radar network is excellent in its easy and inexpensive installation as compared with a traditional monostatic multiple-Doppler radar network. Furthermore, it is useful to measure a short-time change of wind fields in a rapidly evolving storm because all radial velocities measured from individual volumes simultaneously. However, low-gain antennas of the bistatic receivers are less sensitive to weak echoes, and are more sensitive to contamination of transmitter sidelobes. To reduce these limitations, it is effective to expand multiple bistatic receiving sites. More accurate vector wind fields in lager area will be obtained from these multiple radial velocities, provided that a suitable composite method of overdetermined velocities is developed.

In this study, practical composite method is investigated using actual observed data on May 30, 1997. The experiment was conducted using NCAR S-POL radar and three bistatic receivers, which were deployed in Kansas as part of the Cooperative Atmospheric Surface Exchange Study (CASES-97). Fig.1 shows locations of them and general dual-Doppler analysis areas.

2. BISTATIC GEOMETRY

Fig.2 shows a schematic diagram of the bistatic geometry. A bistatic receiver can measure delay time of *t*, where $t=(R1+R2)/C$, C is the light speed. Surfaces of the constant *t* form ellipsoids with foci at the transmitter and the receiver. Measured Doppler velocity vector (V_{DR}) by the receiver is oriented perpendicular to the ellipsoids. The direction of V_{DR} is represented by ∇t vector, and its angle is $\beta/2$. The V_{DR} is proportional to the difference in pathlength between two successive pulses, which time interval is Δt (see Fig.2). If we consider the V_{DR} as a unit vector, the difference in pathlength is $2\times\cos(\beta/2)$. In the case of monostatic Doppler radar, the difference in pathlength is 2. Therefore, an expansion velocity factor (a ratio of bistatic Doppler velocity to monostatic) is $(\cos(\beta/2))^{-1}$.

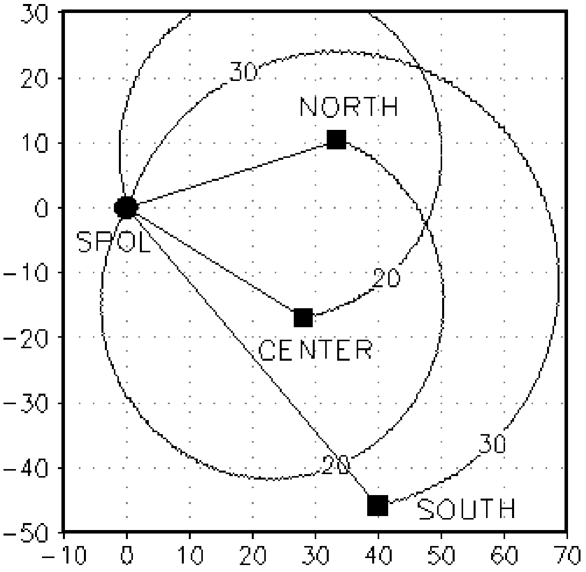

Fig.1 Locations of main radar (SPOL) and three bistatic receiver sites (NORTH, CENTER, SOUTH). Line between SPOL and each bistatic site indicate a baseline. Circles show dual-Doppler analysis areas by scatter angles.

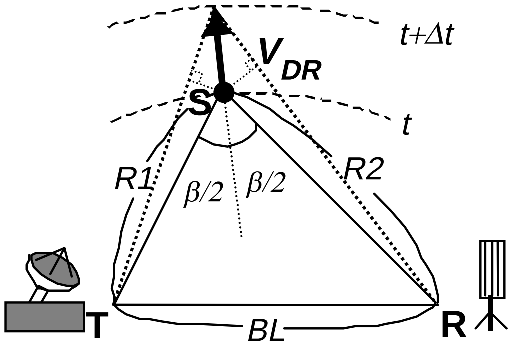

Fig.2 Schematic diagram of transmitter(T)-scatterer(S)-receiver(R) geometry and Doppler velocity vector (V_{DR}) measured by a bistatic receiver. Where, β is the angle between the transmitter-scatterer and receiver-scatterer directions. *R1* is the distance between the transmitter and scatterer, *R2* is the distance between the receiver and scatterer, *BL* is the distance of a baseline between the transmitter and receiver. Dashed lines indicate constant time surfaces. Thick dotted lines indicate the path of T-S(at $t+\Delta t$)-R at the next pulse.

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The expansion factor is also expressed by $|\nabla t| \times C/2 = 2\times(\sqrt{2}(1+\cos\beta))^{-1}$. The angle of β is expressed as $\cos\beta=(R1^2+R2^2-BL^2)/(2\times R1\times R2)$. Doviak and Zrnic (1993), Protat and Zawadzki (1999) also describe explanation of the bistatic geometry.

3. PARAMETERS RELATED TO ACCURACY

Accuracy of vector wind synthesis from bistatic dual-Doppler data is depend on the following three parameters:

(1) scatter angle ; $\beta/2$,
(2) velocity expansion factor ; $(\cos(\beta/2))^{-1}$
(3) Normarized coherent power (NCP).

The scatter angle in the bistatic geometry is a half of a scatter angle of a monostatic dual-Doppler geometry. Therefore, on the baseline, the bistatic scatter angle is 90 deg. Similar to Lhermitte and Miller (1970), the variance (σ_u, σ_v) of the estimates of (u,v) are expressed by

$$(\sigma_u^2+\sigma_v^2)/(\sigma_1^2+\sigma_2^2)=1/\sin^2(\beta/2),$$

where σ_1 and σ_2 are variances of observed Doppler velocities, $\beta/2$ is the bistatic scatter angle.

Due to the bistatic geometry, however, Doppler velocity resolution reduces near the baseline according to the velocity expansion factor, while unambiguous velocity expands. The resolution reduction leads to error. While, expansion of resolution volume lengths influences an error when a gradient of either velocity or reflectivity is large (Wurman,1994).

The normarized coherent power (NCP) of a bistatic receiver is used an index to distinguish effective Doppler velocity, because mean Doppler velocity estimated from data in small coherency may not be accurate. The NCP distribution from a bistatic receiver indicates the antenna pattern when a scatterer distribution is quite uniform within the observation range. Fig.3 shows NCP on the R-θ coordinates of the north bistatic site. Since the observation data shows almost uniform stratiform echo (see Fig.4), the NCP distribution on the R-θ coordinates indicates the antenna pattern of the bistatic receiver. In Fig.3 (b), the regions of averaged-NCP $\geq$ 0.5 extend from 100 deg to 220 deg in azimuth. This is similar to the effective beam width of the slot array antenna.

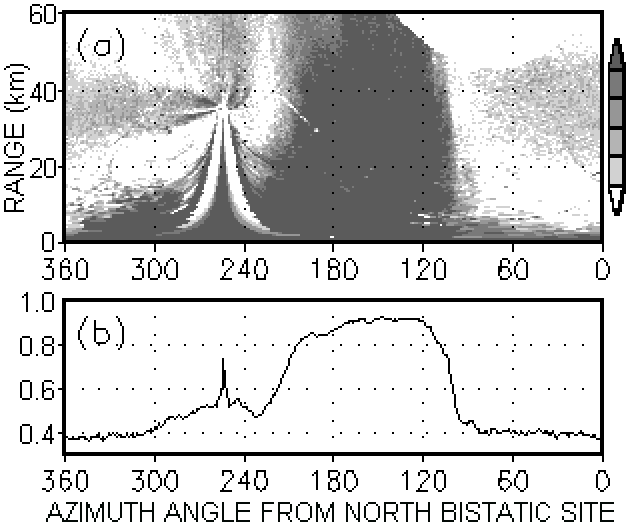

Fig.3 (a) Normarized coherent power (NCP) on a radar coordinate of the bistatic site of north. (b) Averaged NCP in the range direction.

4. PROCEDURE OF WIND VECTOR CALCULATIONS

4.1 Unfolding Doppler velocity

Beforehand, observed bistatic Doppler velocities are divided by the velocity expansion factor to keep a constant folded (Nyquist) velocity. Following the correction process of unfolding, the expansion factor multiplied by the unfolding velocity.

4.2 Dual-Doppler processing

Although the formulation of bistatic wind field synthesis described by Wurman *et al.* (1993), it is basically the same as monostatic dual-Doppler formulation except using bistatic scatter angles. In this paper, vertical velocity is not taken into consideration, because low elevation angle data are used.

4.3 Coordinates conversion from R-θ into X-Y

Since a bistatic Doppler observation carries all data on a radar coordinate (R-θ) of the main radar, the dual-Doppler processing is permitted on either R-θ or Cartesian (X-Y) coordinates. However, when the coordinate conversion includes such averaging process as Cressman scheme, a dual-Doppler processing on the R-θ coordinates may reduce error compared with it on the X-Y coordinates. In this study, a nearest grid point scheme is applied to the coordinates conversion to make clear the cause of error. Range and azimuth resolution are 0.15 km and 0.9 deg, respectively. Cartesian grid size is 0.5 × 0.5 km. All calculations are done on a PPI plane with a constant elevation angle.

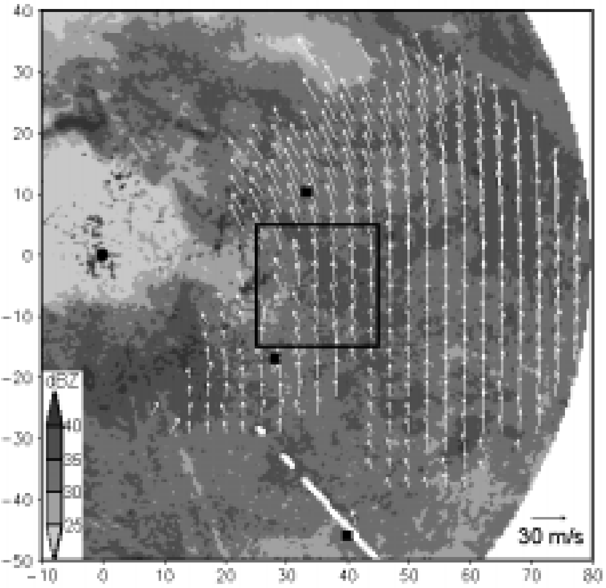

Fig.4 Composite wind vectors superimposed on reflectivity distribution in a PPI plane in an elevation angle of 0.5 deg. A rectangle shows a domain of Fig.5.

4.4 Composite wind vectors

To make composite the wind vectors calculated from multiple dual-Doppler processing, the accuracy parameters described above are used. Fig.4 shows composite wind vectors calculated from three dual-Doppler pairs (SPOL-NORTH, SPOL-CENTER, and SPOL-SOUTH). Here, three threshold values, that are $\beta/2 \geq 25$ deg, $(cos(\beta/2))^{-1} \leq 3$, and NCP≥0.5, are used as the accuracy parameters. Also, a bistatic antenna pattern estimated in Fig.3 is used to eliminate the wrong data scattered from strange locations. On the overdetermined region, wind vectors (*u,v*) of a largest scatter angle are adopted.

5. COMPARISON AMONG THREE KINDS OF WIND FIELDS

Fig.5 (a), (b), and (c) show the wind fields derived from three kinds of dual-Doppler pairs. Fig.5 (d) and (e) are distribution of the magnitude vector differences. The difference of NORTH-CENTER is small as a whole. The large difference distributes over a region of small scatter angles (Fig.5 (a) and (b)). While, The

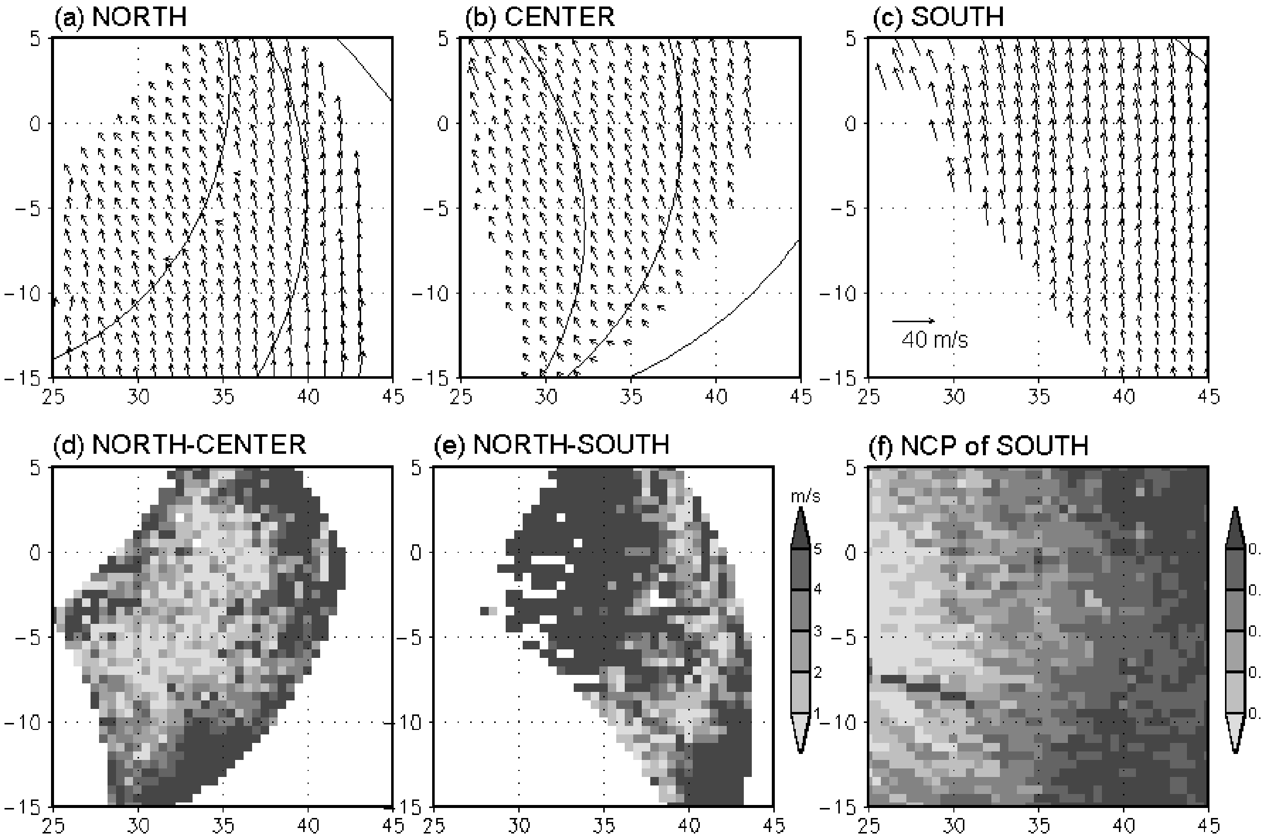
(a) NORTH
(b) CENTER
(c) SOUTH
(d) NORTH-CENTER
(e) NORTH-SOUTH
(f) NCP of SOUTH

Fig.5 Comparison among three wind fields from (a)SPOL-NORTH, (b)SPOL-CENTER, (c)SPOL-SOUTH. Contours represent scatter angle ($\beta/2$) of 20, 30, and 40 deg. Magnitude of the vector difference between (d)SPOL-NORTH and SPOL-CENTER, between (e)SPOL-NORTH and SPOL-SOUTH. (f)NCP of SOUTH bistatic receiver.

difference of NORTH-SOUTH is large over the left half of the displayed domain. In this region, the scatter angle is enough large in both NORTH and SOUTH (Fig.5 (a) and (c)). However, the NCP distribution shown in Fig.5 (f) indicates that the large difference region overlapped with the small NCP region. The small NCP seems to be caused by weak signals. The longer baseline (~60 km) of SOUTH bistatic site will lead to not enough sensitivity. Also, the velocity expanding effect is a possible contribution to the error because this region is close to the baseline.

Fig.6 shows a scatter diagram of magnitude vector difference against the smaller scatter angle ($\beta/2$). The smaller scatter angle is the dominant parameter for the inaccuracy of wind vector synthesis. The scatter diagram clearly presents the effect of the scatter angle.

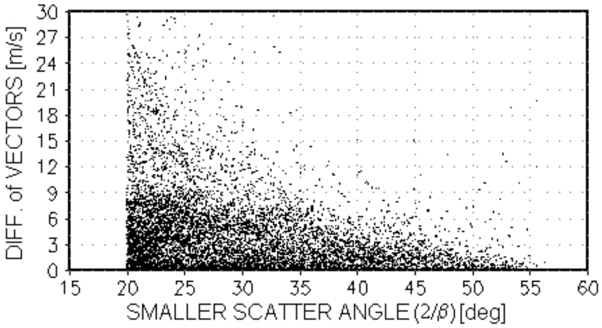

Fig.6 Scatter diagram of magnitude vector difference against the smaller scatter angle ($\beta/2$).

6. CONCLUSION

This paper has described the practical composite method based on both the actual observation data and the bistatic geometry. Accuracy of composite wind vectors is controlled by three parameters, which are the scatter angle, the velocity expansion factor, and the NCP. The scatter angle seems to be most useful parameter to represent the accuracy of wind vector synthesis. Both the velocity expansion factor and the NCP are useful to eliminate wrong data of Doppler velocities from each bistatic receiver. The NCP is also used to estimate the bistatic antenna pattern assuming a uniform scatterer distribution. The result of comparison among three wind fields showed that these parameters dominate the accuracy of wind vector synthesis.

In Fig.4, a simple composite method using only magnitude of the scatter angle ($\beta/2$) was applied. However, we have to develop better composite method to satisfy both accuracy and continuity at a boundary of over-determined region. A weighting function as one or more parameters related to accuracy will effective measures. Of course, it will be useful to apply minimizing error using a variational method described by Protar and Zawadzki (1999). In this paper, only one set of observation data was used for the examination. However, we should use variable observation data, which includes strong convective system with complex structure, to confirm and to improve the composite method. Also, the strong echo will lead to contamination of transmitter sidelobes. The sidelobe contamination is expected to appear on an ellipsoid, that is a constant time surface described in the bistatic geometry (section 2).

It is possible to calculate dual-Doppler synthesis between two bistatic receivers' data. Although the analysis area will be small because the bistatic receiver antenna looks toward a main dual-Doppler lobe, the precise wind vectors in the small area may improve the accuracy as a whole of composite wind fields.

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