11A.4 Single-Doppler Radar Analysis of a Mesocyclone in the Taiwan Strait

Zhao Kun*[1] Ben Jong-Dao Jou[2]

[1]Key Laboratory for Mesoscale of Severe Weather/MOE, and Department of Atmospheric Sciences, Nanjing University, Nanjing, China

[2] Department of Atmospheric Sciences, National Taiwan University, Taiwan

1. INTRODUCTION

It is well known that the mesocyclone in the severe storms, such as supercell, is often accompanied with tornado. During the past few decades, the conventional and Doppler radar studies have revealed the important structure and kinematic patterns of the mesocyclone in supercell (Lemon and Doswell 1979). The typical mesocylone in supercell forms at midlevel (5-8km AGL), and a tangential velocity profile resembles that of a Rankine combined vortex. In addition to the observations, many numerical simulations have significantly advanced our understanding of the mechanism and dynamics of the mesocyclone in supercell (Klemp and Rotunno (1983), Rotunno and Klemp (1985) and Davies-Jones and Brooks (1993)). It is well know now that the midlevel mesocyclone usually formed as a result of tilting of low-level horizontal vorticity associated with strong vertical shear of the environmental winds. However, the formation of low-level mesocyclone is due to the titling of horizontal voriticity generated solenoidally by a baroclinic zone.

Recently, a few high-resolution single Doppler radar observations, such as Funk et al. (1999) have shown that the quasi-linear convective systems (QLCSs), such as squall lines and bow echoes, are often associated with low-level mesovortices (2-20km), some of which met mesocyclone criteria. However, their structure features have seldom been studied because of absence of dual-Doppler radar observations.

On 10 September 2004, an intense mesocyclone was embedded in a QLCS near northern Taiwan coast. This mesocylone located only about 60km from the CAA (Civil Aeronautic Administration) 5-cm Doppler radar at the Chiang Kai-Shek (CKS) International Airport in northern Taiwan, which provided an unique opportunity to study the structure of the mesocylone*. The purpose of this paper is to delineate the evolution and fine structure of the mesocyclone by applying the GBVTD (Ground Based Velocity Track Display) (Lee et al.1999a) techniques to single Doppler radar data collected by the CKS radar.

* *Corresponding author address:* Zhao Kun, Dept. of Atmospheric Sciences, Nanjing University, 22, Han- kou Rd. , Nanjing ,China, P.R.C.; e-mail : zhaokun@nju.edu.cn

2. SYNOPTIC CONDITION

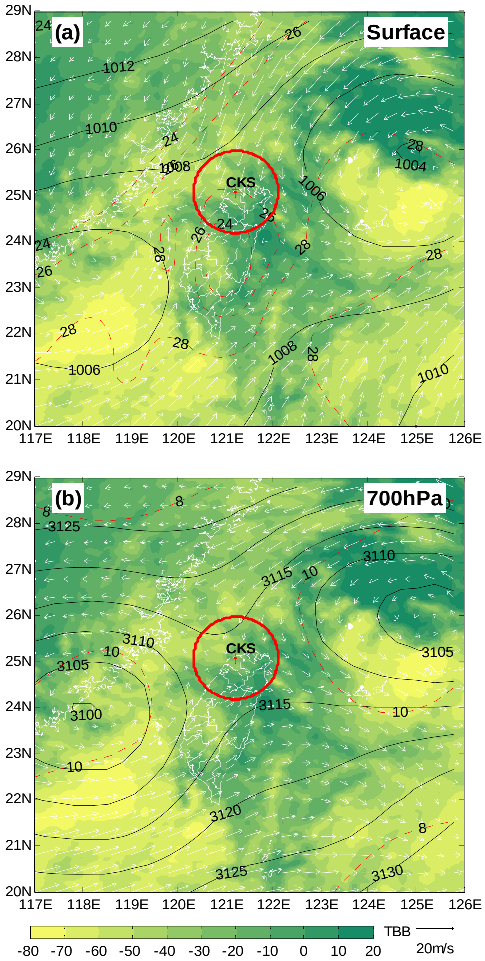

Fig.1 The surface (a) and 700hPa (b) upper-air analysis from FNL model on 10 Sep. 2004 at 0600UTC. The infrared image from GEOS9 also plotted with shaded color in (a) and (b).

On the beginning of 10 September 2004, the synoptic environment of Taiwan was on the influence of deep southwesterly monsoon flows. Embedded within there were two tropical depressions, one at the South China Sea southwest of Taiwan and the other at the East

China Sea northeast of the island. These two tropical depression systems moved northeast and northwest respectively. The surface analysis in Fig.1a shows that the northwest coast of Taiwan was on the convergence/shear zone set up by these two tropical depression systems at 0600UTC. The northeast flow prevails from the middle of Taiwan Strait to East China Sea. Also a surface ridge oriented in south-north direction located near eastern China coast northwest of Taiwan. Under the effect of this ridge, the northeast wind was accelerated to converge into the northwest coast of Taiwan. Since there are few surface observation station in the Taiwan Strait, specially at the northern part, the characteristic and environment of convergence/shear zone can't be further confirmed and investigated. Fortunately, a QuickScat observation provided complete sea wind distribution over the Taiwan Strait at 1035UTC (not shown). Based on this observation, a convergence/shear zone, which was associated with northeasterly wind at the north and easterly wind at south, was clearly identified. At 850hPa (not shown),a front, characterized by a wind shear line separating the southeasterly winds ahead of it and northeasterly winds behind it, located over the Taiwan Strait. This front extended up to about 700hPa (Fig.1b) and tilted toward the northwest. The warm and moist advections accompanied with the southwesterly flow ahead of the front provided the convective unstable energy for the development of the organized convective systems. At 500mb (not shown),a weak short-wave trough was located at the northwest of Taiwan Strait, which provided a favorable dynamic condition for the development of the convection.

From the prefrontal sounding taken at Ma-Kung (over the Taiwan Strait) on 0000UTC September 10,2004 (not shown),it can be seen that the atmosphere was quite moist and unstable with the convective available potential energy (CAPE) of 1613 J Kg^{-1}. The low-level (surface to 850hPa) wind shear was southeast with magnitude of 6.2 m s^{-1}. The wind shear through a deeper layer of 5km was almost uniform with magnitude of 12ms^{-1}. The lifting condensation level (LCL) was at 984hPa (~0.2km),while the level of free convection (LFC) was at 952hPa (~0.5km). Previous numerical and observational studies have shown that environments of QLCSs in midlatitude are often characterized by large CAPE and moderate to strong low-level shear (Carbone et al. 1990; Weisman 1993). Jorgensen (1997) revealed the similar environment condition in tropical region except for a relative smaller CAPE and wind shear compared with the midlatitudes. In comparision with these previous studies, the current case is situated at a more moderate CAPE and weaker shear regime.

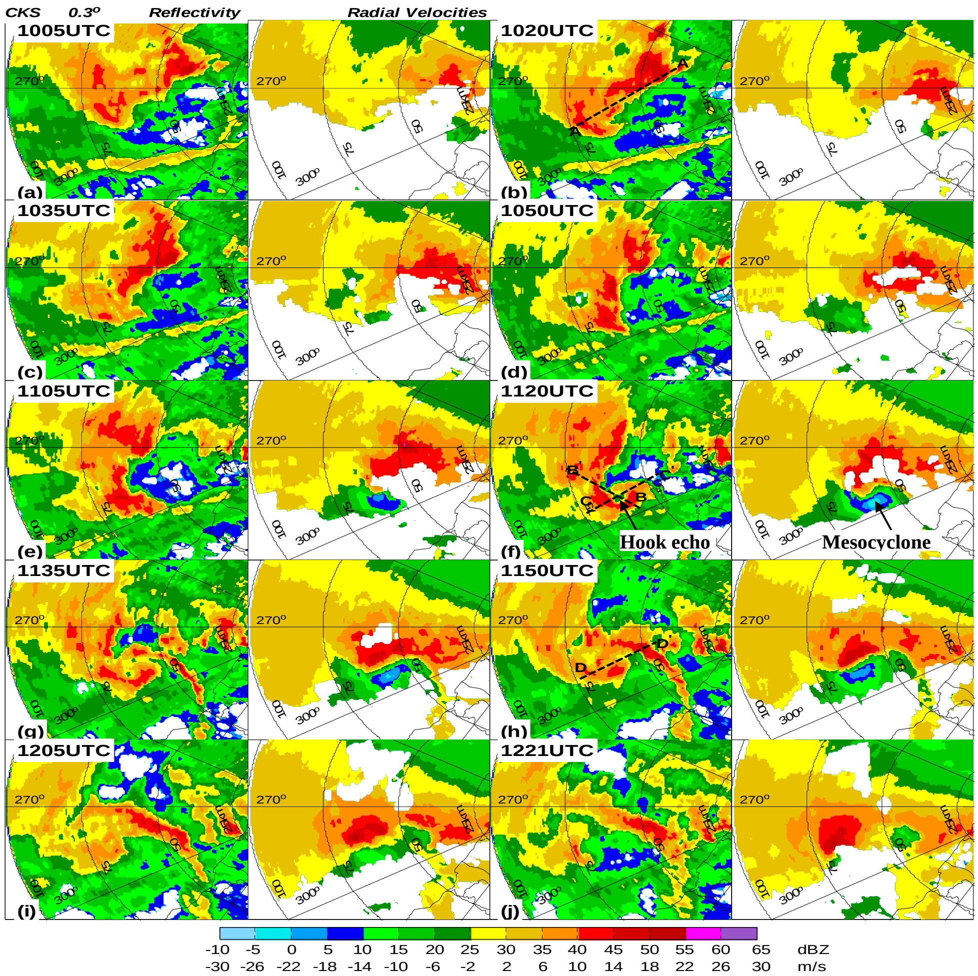

Fig.2 Times series of radar reflectivity and storm-relative radial velocity from CKS radar on 0.3°elevation

3. Mesocyclone Structure

In Fig.2,a sequence of low-level reflectivity and radial wind with interval of 15 minutes(at 0.5^o elevation, from 1020-1221 UTC September 10,2004) observed by a C band Doppler radar at CKS International airport is given. The quasi-linear convective system oriented in a NE-SW direction with strong echo over southeast corner at 1005UTC (Fig.2a). The radar located at (0.0, 0.0), i.e. on the right (east) of the diagram. The echo at the southern end of the convective system was getting stronger and bulged during 1005UTC~1050UTC (Fig.2b~d). Subsequently, the bulged echo continued its development and then curved into a cyclonic curvature, and the first indication of a storm-relative circulation is evident in radial velocity (Fig.2e). At 1120UTC (Fig.2f),the classic rotational couplet in Doppler velocities indicative of the mesocyclone circulation(Brown et al.1979) can be clearly seen and is accompanied by a hook echo in radar reflectivity. The hook echo is apparent as a ring of high reflectivity surrounding a weak echo hole. The mesocyclone intensifies and reaches its peak value at 1135UTC and is characterized by a classic rotational couplet embedded within the hook echo (Fig.2g). At the east edge of the hook echo, a new linear convection with the convex curvature developed. Following the development of the linear convex convection, the original hook echo convection dissipated quickly (Fig.2h~j).

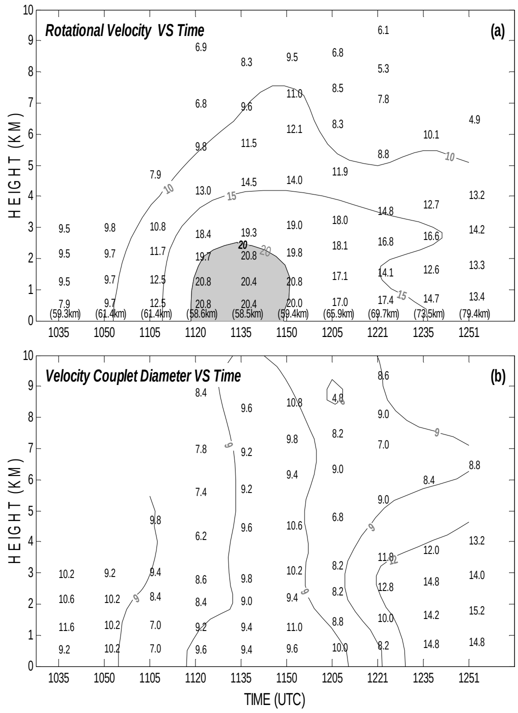

Fig.3 Time-height profiles of mesocyclone (a) rotational velocity and (b) couplet diameter. The rotational velocity values are contoured every5ms^{-1},with value greater than 20ms^{-1} shaded gray

The time-height profiles of mesocyclone rotational velocity and couplet diameter (Definition similar to Atkins et al. 2004) estimated from the single Doppler radar radial velocity data (Fig.3) shows that this mesocyclone formed initially at low level, then deepened and strengthened rapidly into mature stage with the vertical depth deeper than 8km and later decayed rapidly. The mesocyclone lasted for about 2 hour. It is also worth to note that the maximum rotational velocity was confined to the low levels. Thus the evolution and structure of the mesocyclone is similar to that observed within a non-supercell thunderstorm noted by Wakimoto and Wilson 1989.

The GBVTD-derived axisymmetric structures of the mesocyclone at its mature stage from 1120UTC~1150UTC are presented using radius–height plots of the azimuthal mean quantities in Fig.4. It can be clearly seen that at 1120UTC(Fig.4a),the radius of maximum wind (RMW) of the mesocyclone was about 5~6 km with the maximum tangential wind about 18m/s at lowest retrieved level. This is consistent with the location of maximum mean reflectivity field. The axis of RMW tilted inward to the center of the mesocylone with increasing altitude. The mean radial wind field was characterized with a low-level inflow inside RMW and outflow outside RMW respectively. The strongest reflectivity was associated with stronger updraft near RMW, and weak downdraft was located at the center of the cyclone. Between 1120~1135UTC (Fig.4b),the axismmetric tangential wind strengthened and reached its maximum intensity with a value about 20 ms^{-1}. The axis of RMW turned to tilt outward. The downdraft and reflectivity near the mesocyclone center strengthened obviously, accompanied with the low-level outflow, strong updraft as well as high reflectivity extending outside RMW. Subsequently, the axismmetric tangential wind decreased obviously with its maximum value about 18ms^{-1} (Fig.4c). Correspondingly, the axis of the RMW continued to tilt outward with tilting angle beyond 50^o. The downdraft and reflectivity near the mesocyclone center, as well as the low-level outflow continually strengthened. It is worth to mention that the axisymmetric circulation characteristics of the mesocyclone at its mature stage resemble a feature very similar to that observed in a mature typhoon (Lee et al. 2000). However, there are significant differences, i.e., the size is much smaller, the life time is much shorter, and the downdraft in the center is produced by precipitation instead of compensating subsidence.

The asymmetric structure of the mesocyclone indicated the relative tangential wind initially exhibited a wavenumber 1 asymmetric structure with the maximum wind region at the left portion of the cyclone and shifted counterclockwise with height (Fig.5a). After that the wave-1 asymmetric structure redeveloped with the maximum wind at the left-front of motion (Fig.5b, c).

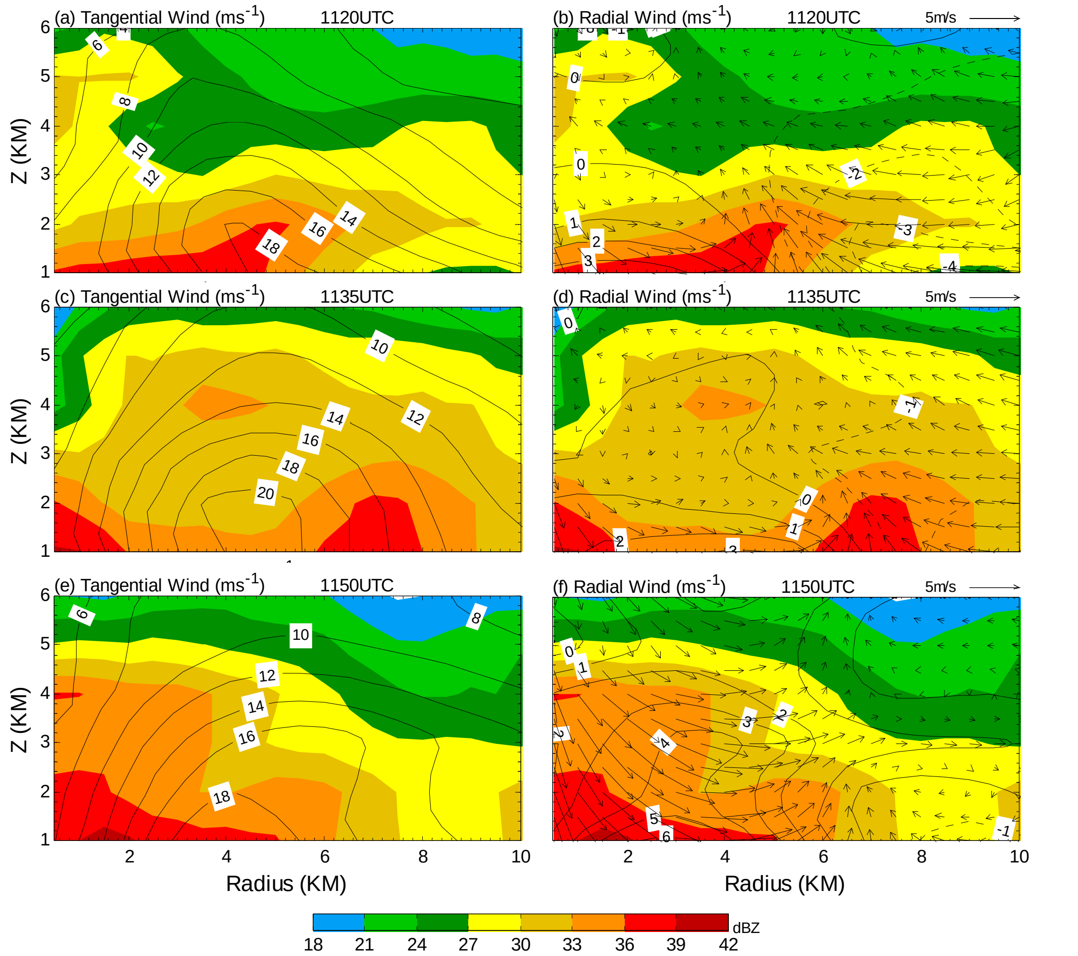

Fig.4 The retrieved axisymmetric structure (radius-height) of the mesocyclone from 1120 to 1150UTC ((a)、(c)、(e) tangential wind at 1120、1135 and 1150UTC respectively. (b)、(d)、(f) radial wind and vertical velocity at 1120、1135 and 1150UTC respectively. The axisymmetric reflectivity is in color shades.)

4. SUMMARY

In this case, we have been using the GBVTD technique to retrieve the kinematic structure of the mesocyclone accompanied with the QLCS, not only the mean axis-symmetric component but also the asymmetric components. The capability of retrieving the location and intensity of strong winds, which was not possible to be identified in the original Doppler radial velocity, is very helpful to the explanation of the formation of the mesocyclone.

The evolution and structure of the mesocyclone in this study is similar to that observed within a non-supercell thunderstorm previously observed (Wakimoto and Wilson 1989). It is also worth to mention that the axisymmetric circulation characteristics of the mesocyclone at its mature stage resemble a feature very similar to that observed in a mature typhoon (Lee et al.2000). However, there are significant differences, i.e.,the size is much smaller, the life time is much shorter, and the downdraft in the center is produced by precipitation instead of compensating subsidence.

Acknowledgments

This work is supported by the National Natural Science Foundation of China. (Grant No. 40505004.)

References

Atkins, N. T., J. M. Arnott, R. W. Przybylinski, R. A. Wolf, and B. D. Ketcham,2004: Vortex structure and evolution within bow echoes.Part I: Single-Doppler and damage analysis of the 29 June 1998 derecho. *Mon. Wea. Rev.,* **132,** 2224–2242.

Carbone,R. E.,J. W. Conway,N. A. Crook, and M. W. Moncrieff,1990: The generation and propagation of a nocturnal squall line. Part I: Observations and implications for mesoscale predictability. *Mon. Wea. Rev.,* **118,26**–49.

Davies-Jones R. P., and H. E. Brooks, 1993: Mesocyclogenesis from a theoretical perspective. The Tornado: Its Structure, Dynamics, Prediction and Hazards,Geophys Monogr,No.79,*Amer. Geophys. Union*, 105–114.

Funk T. W., K. E. Darmofal, J. D. Kirkpatrick, et al., 1999: Storm reflectivity and mesocyclone evolution associated with the 15 April 1994 squall line over Kentucky and southern Indiana. *Wea. Forecasting*, **14**, 976–993.

Jorgensen, D. P., M. A. LeMone, and S. B. Trier,1997: Structure and evolution of the 22 February 1993 TOGA COARE squall line: Aircraft observations of structure, circulation, and near-surface energy fluxes. *J. Atmos. Sci.,* **54, 1961**–1985.

Klemp, J. B., and R. Rotunno, 1983: A study of the tornadic region within a supercell thunderstorm. *J. Atmos. Sci.,* **40,** 359–377.

Lee W. C., J. D. Jou, P. L. Chang, et al.,1999: Tropical cyclone kinematic structure retrieved from single-Doppler radar observations. Part I: Interpretation of Doppler velocity patterns and the GBVTD technique. *Mon. Wea. Rev.,* **127**, 2419–2439.

Lee, W. C., J. D. Jou, P.L. Chang, and F. D. Marks, 2000: Tropical cyclone kinematic structure retrieved from single-Doppler radar observations. Part III: Evolution and structure of Typhoon Alex(1987). *Mon. Wea. Rev.,* **128,** 3982–4001.

Lemon L. R., and C A. Doswell, 1979: Severe thunderstorm evolution and mesocyclone structure as related to tornadogenesis. *Mon. Wea. Rev,,* **107**, 1184–1197.

Rotunno R., J. B. Klemp, and M. L. Weisman, 1985: On the rotation and propagation of simulated supercell thunderstorms. *J. Atmos. Sci.,* **42**, 271–292.

Wakimoto R. M., and J. W. Wilson, 1989: Non-supercell tornadoes. *Mon. Wea. Rev.*, **117**, 1113-1140.

Weisman, M. L., 1993: The genesis of severe, long-lived bow-echoes. *J. Atmos. Sci.,* **50,**645–670.

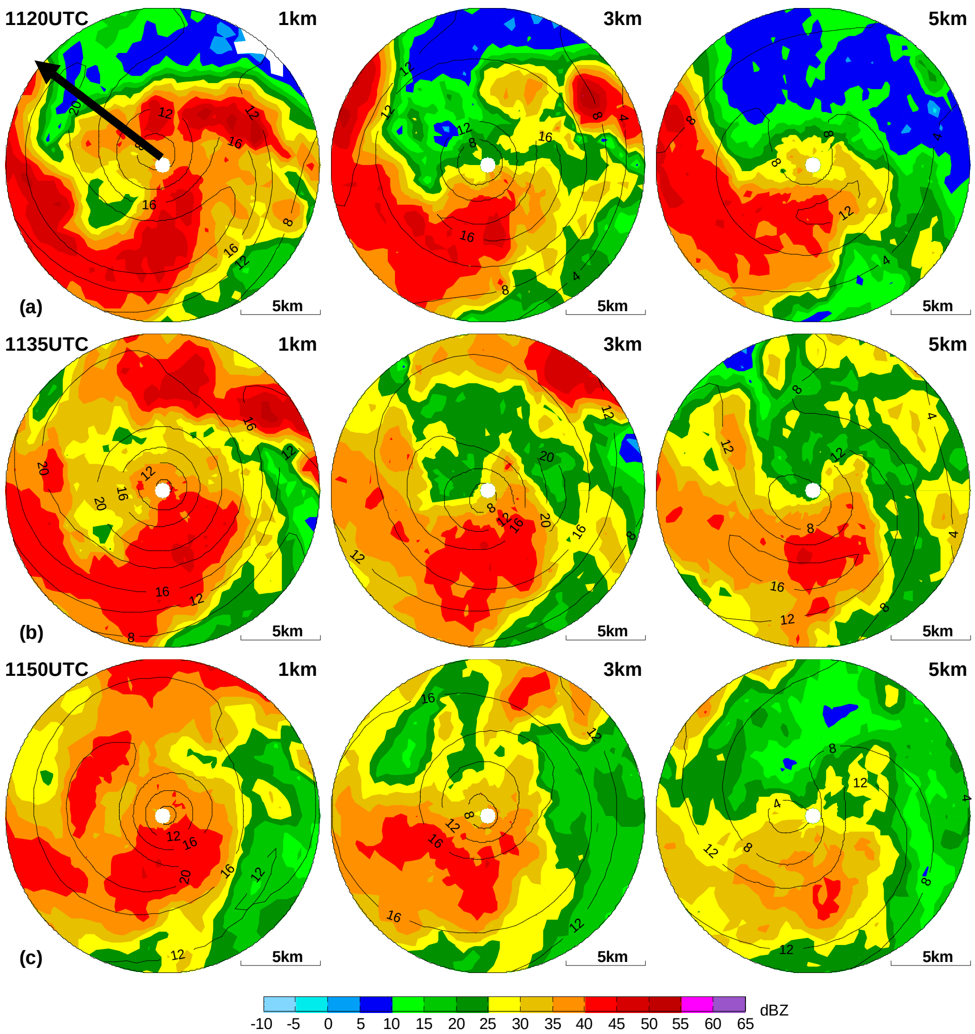

Fig.5 The GBVTD-derived tangential winds of mesocyclone at (a)1120、(b)1135 and (c) 150UTC on 10 Sep. 2004. The black arrow in (a) represents the storm motion.