Doppler Radar Observations of a Quasi-Stationary Mesoscale Convective System and Associated Vortex

Ben Jong-Dao Jou
Department of Atmospheric Sciences
National Taiwan University

Abstract

Doppler radar observations of a mesoscale vortex associated with a quasi-stationary mesoscale convective system in the Taiwan Mei-yu season is presented. By using GBVTD technique, the mean tangential winds are retrieved. The results showed the vortex had a dipole structure in perturbed Doppler radial winds embedded within the prevailing southwesterly winds. Heavy rainfall occurred at downstream of the enhanced southwesterly flows induced by the mesoscale vortex.

1. Introduction

Observational studies show that a variety of mesoscale convectively generated vortices (MCVs) with horizontal scales ranging from tens to hundreds of kilometers and time scales ranging from hours to days can be generated within mesoscale convective systems (MCSs). These MCVs play a variety roles, from locally enhancing the strength of rear-inflow jets, which may contribute to the production of damaging surface winds, to initiating the development of long-lived, balanced midtropospheric circulations, which can help trigger new convective episodes on subsequent days (Smull and Houze 1985; Stirling and Wakimoto 1989; Brandes 1990; Johnson and Bartels 1992; Jorgensen and Smull 1993; Bartels et al. 1997). In most above-mentioned studies, observations indicated that mesoscale vortices are frequently found in the low to mid-troposphere of MCS stratiform precipitation regions. Stretching of planetary vorticity in response to latent heat release in the stratiform region was thought to be important mechanism for the formation and maintenance of the mesovortex (Skamarock et al. 1994). On the other hand, Yu et al. (1999) showed that, with an exceptionally moist atmosphere and moderate ambient vertical shear through a deep layer with much weaker shear and winds aloft, a mesovortex was formed within the convective precipitation region of a developing MCS. By using airborne Doppler radar data, they showed that vertical stretching in the convective region was a primary mechanism contributing to low-level development of the vortex and then vertical transport of low-level convectively generated vorticity acted to strengthen and extend the more widespread cyclonic vorticity at upper levels. In addition, the cyclonic vorticity originated along the mesoscale shear/convergence zone resulted from interaction of the large-scale southwesterly inflow with the relatively cool orographically-trapped northeasterly low-level flow aided the MCV's spin up at lower levels.

An early study on the mesolow in the Taiwan Mei-Yu season by Chen (1978) showed that a positive correlation existing between rainfall amount and mesolow frequency to the west of the Central Mountain Range (CMR). It was further suggested by Chen and Chi (1980) that mesolow over the northwestern Taiwan probably served as a mechanism for producing heavy rainfall through enhancing southwesterly flows. However, the questions such as detailed structure and dynamic processes relating to the formation of the mesolow as well as the specific dynamic link between the convection and the mesolow remain unanswered. A recent study conducted by Chen and Wang (1992) investigated the composite mesoscale structure of the mesolow at different life stages. The results showed that the deep convection and thus the heavy rainfall to the south of the low center were closely associated with the formation and intensification of the mesolow through the enhanced southwesterly flows and the boundary layer convergence. It was suggested the behavior of convection is heavily modulated by the surface boundary layer convergence.

The objective of this paper is to present observations of a mesoscale vortex embedded within a quasi-stationary MCS as captured by the C-band Doppler radar at CKS International airport. In May and June 1997, an observational and forecasting experiment was conducted to study the heavy rainfall events over the Taiwan area during the Mei-yu season. Intensive observations of meteorological data of 7 heavy rainfall cases were collected in the experiment. In late afternoon of 2 June, a heavy rain event occurred in Hsin-Chu area. Mesoscale surface pressure analysis showed that a mesolow was found over the region. A cyclonic circulation was also identified through surface wind analysis. From radar echo, it was shown that the convection was first found over the coast of central Taiwan and propagated northward along the sloping area west of CMR. The convection slowed down and became quasi-stationary while approached Hsin-Chu county. From 2 to 5pm, more than 120mm rain was collected by an automatic rain gauge in the area.

2. Data

During the period of heavy rainfall, intensive observations were conducted by a C-band Doppler radar located ~40 km north of MCS. Precipitation reflectivity and Doppler radial winds were obtained by the radar in a horizontal resolution of 1km X 1^0 and with 13 elevation angles in each volume scan and in time interval of 15 minutes. In this study, the Doppler radial winds were analyzed to reveal the mesoscale flow structure associated with the mesovortex by using GBVTD (ground-based velocity track display) technique developed by Lee et al. (1999).

3. Results and Discussion

A sequence of radar reflectivity maps from 11:47-15:47 LST June 2 1997 taken by CKS Doppler radar is given in Fig.1.

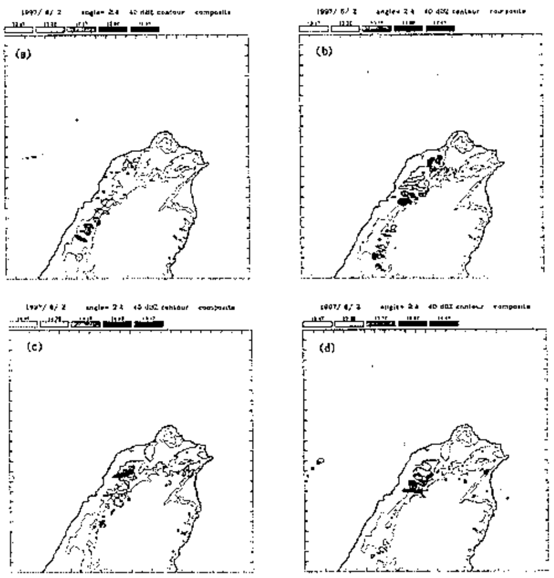


Fig.1. Radar reflectivity summary maps of (a) 11:47-12:47, (b) 12:47-13:47, (c) 13:47-14:47, and (d) 14:47-15:47 LST on June 2, 1997 observed by CKS Doppler radar. The elevation angle is 2.4^0. The closed contours indicate the isolines of 40 dBZ reflectivity intensity.

The closed contours indicate the isolines of radar reflectivity factor of 40 dBZ at elevation angle 2.4^o. Each closed contour is 15 minutes apart. It is shown that the convective system formed over the sloping area of central Taiwan in late morning and then gradually moved northward along the flat plateau at a height 200-500 m west of CMR. The convective system slowed down and became quasi-stationary near Hsin-Chu county in early afternoon. The convective system developed and became an organized mesoscale convective system (MCS) in this region. Fig. 2 showed the detailed terrain feature in the Hsin-Chu area. The numbers indicated in the figure are accumulated hourly rainfall amount (2:01-3:00pm) for each automatic rainfall stations. Hourly rainfall of 50 mm was measured by the station Da-Tei-Kun (DTK) and this station accumulated more than 100 mm rain between 2-5pm. It is worth to mention that the MCS slowed down when it approached the concave terrain feature in the county of Hsin-Chu. It seems that the MCS was trapped and became stationary because of the concave shape of the complex terrain. This feature is especially clear when mapping the centers of the associated vortex in sequence of time.

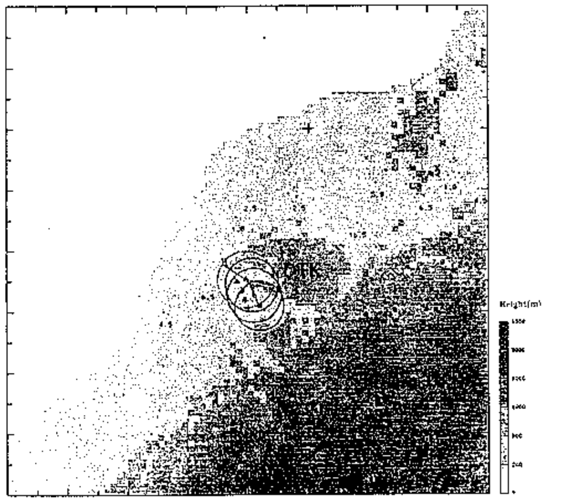


Fig.2. Detail terrain feature around Hsin-Chu area is given. The numbers in the figure showed the hourly rainfall of 1500LST for the stations in the area. Rainfall station Da-Tei-Kun is marked with DTK. The small circles indicated the radius of maximum wind and the center of the mesoscale vortex at different altitudes (from 2-5 km).

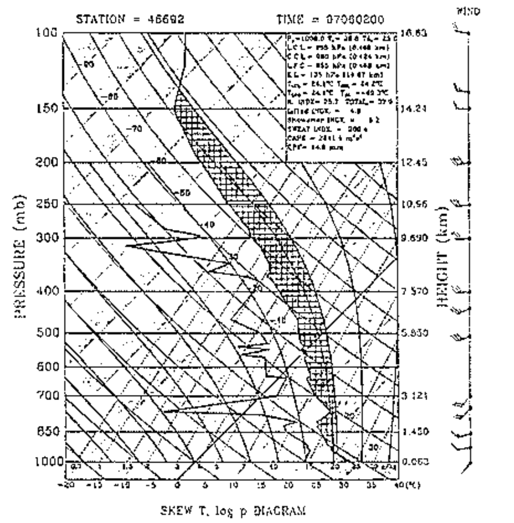


Fig.3. Upper air sounding from Pan-Chiao (46692) station on 00Z June 2 1997.

Sounding of Pan-Chiao on 00Z June 2 1997 is given in Fig.3.The well-mixed layer and high moist content below 950hPa is clearly shown. Pronounced inversion layer at 800hPa prohibited large area convective activity development. However, the huge amount of CAPE (~2800 m^2s^2) indicated great potential for convection development in this area. Vertical profiles of horizontal wind derived from CKS Doppler radar using VAD technique is given in Fig.4.

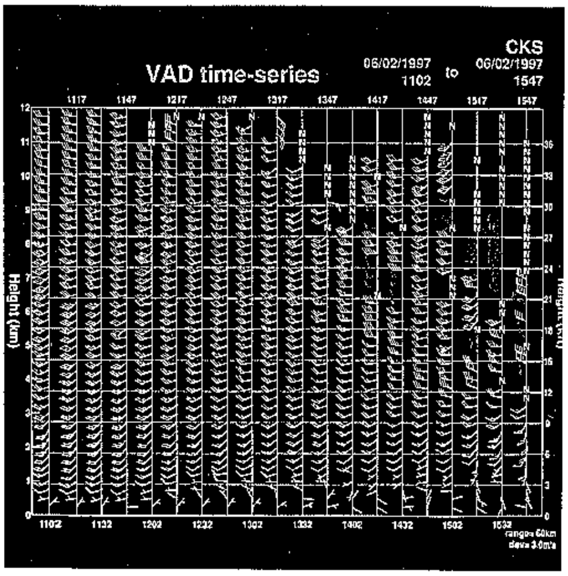


Fig.4. Time series of the vertical profiles of horizontal wind with 15 minutes interval derived from CKS Doppler radar using VAD technique.

The 15 minutes interval of vertical profiles of horizontal wind showed there is a moderate vertical wind shear in the lower atmosphere. A pronounced wind shift zone existed below 1 km height with southwesterly prevailed above and northeasterly down below, indicated the approach of surface frontal system. This feature is further confirmed by the wind measurements at the surface stations on the northwest coast of Taiwan. Surface analysis (Fig.5) indicated the existence of mesoscale cyclonic circulation over the Hsin-Chu and Miao-Li area.

Surface pressure analysis also showed the existence of a meoslow accompanying with the mesoscale cyclonic circulation as revealed in the local wind analysis. This result is similar to the results shown in Chen and Wang (1992) analyses. In their study, Chen and Wang (1992) showed the major precipitation and cloudiness distributions located in the area where enhanced southwesterly flow prevailed. As will be shown later, similar organization was also observed in this study however in a much finer scale.

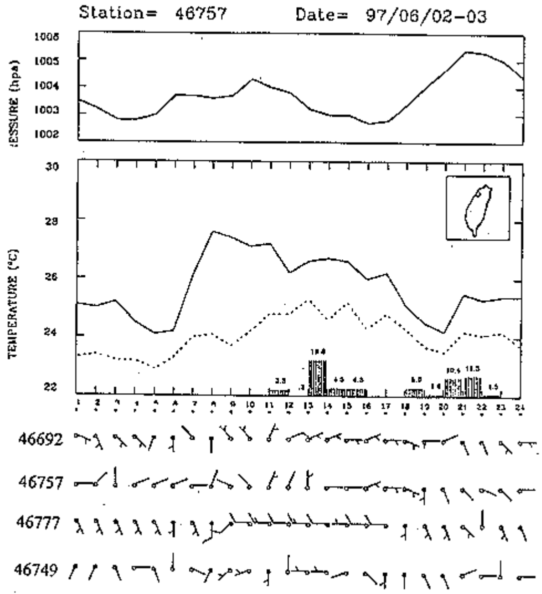


Fig.5. Time series of the surface pressure, temperature, dew point, precipitation, and winds at Hsin-Chu station(46757).Wind data at adjacent stations of Hsin-Chu is also given.

Radar reflectivity and Doppler radial wind at height 2 km on 2pm is given in Fig.6.

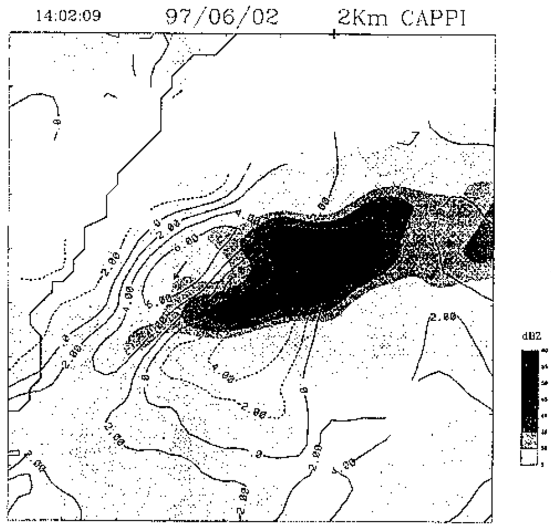


Fig.6. Radar reflectivity and perturbed radial wind at 2 km height on 1402LST June 2 1997.

The Doppler winds in this plot are the perturbation winds. The mean southwesterly flow component determined from the VAD analysis has been deduced from the total Doppler radial winds in order to show the disturbed wind pattern. In the figure, the dipole structure of the perturbed wind is vividly shown. This disturbance embedded within the prevailing southwesterly flows. This signature was not showed in the original Doppler wind pattern. The "+" sign at the top of the figure indicates the location of CKS radar.

The perturbed winds showed a maximum value of 6 m/s both on the approaching and the receding components. This dipole pattern of Doppler wind indicates a signature of cyclonic vortex motion in this region. The dipole pattern of the perturbed radial winds was not only observed at height 2 km but up to 5 km indicating the mesovortex is not only a boundary layer phenomenon.

The size of the vortex (~20 km in diameter) is much smaller compared to that of midlevel mesoscale vortex in the trailing-stratiform rain region of an asymmetric squall line (Houze 1993). The major reflectivity field was found to locate over the down stream of the southwesterly flow. In the region of perturbed northeasterly flow, the reflectivity field was a minimum. This organization indicates the importance of the intensifying warm and moist southwesterly flow on the development and maintenance of this mesoscale convective system.

By using pattern recognition method, Lee et al. (1999) demonstrated that GBVTD technique successfully reconstructs the horizontal tropical cyclone primary circulation from single Doppler radar radial winds. Detailed mathematical derivation and interpretation of the method can be found in Lee et al. (1999) and will not be repeated here. In this paper, we applied the GBVTD technique to analyze the mean and the disturbed winds associated with the vortex. In Fig.7, a sequence of mean tangential winds from 1302-1432 LST at height 2 km is given.

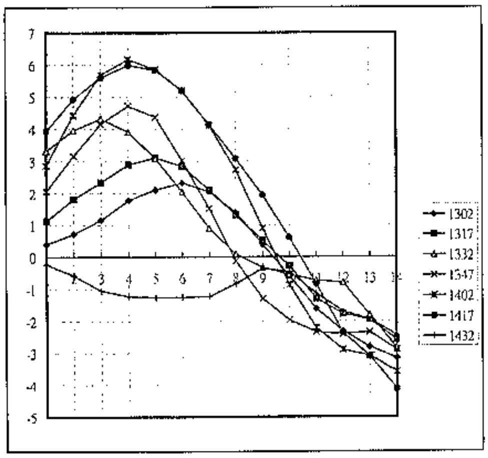
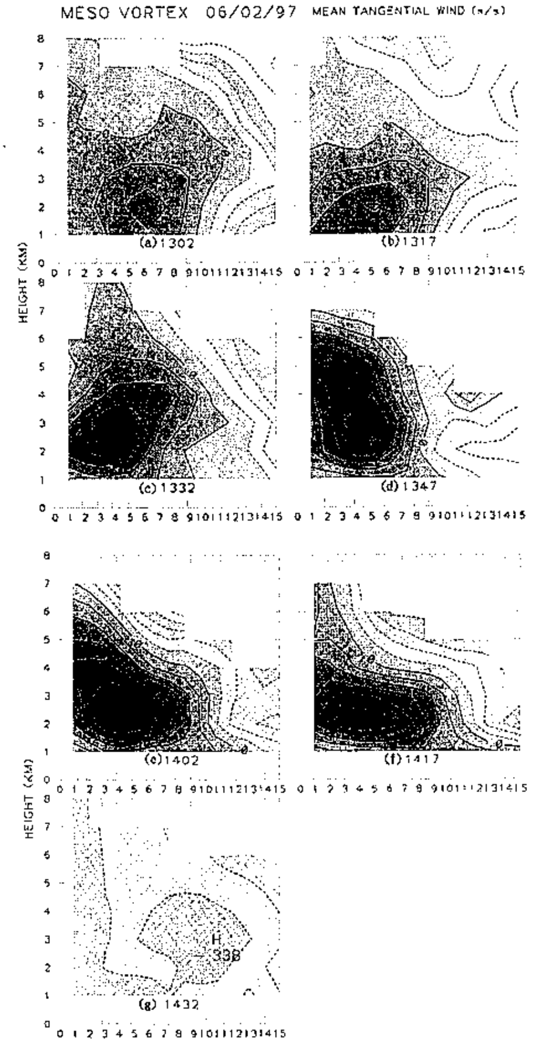


Fig.7. Time sequence of the mean tangential winds at 2 km height derived from the GBVTD technique.

The evolution of the mean tangential winds at 2km height showed the mean tangential wind increased its intensity from 2 m/s to 4 m/s in the early development stage and the radius of the maximum wind shrink from 6km to 3 km at the same time. The mean tangential wind intensified to 6 m/s and the mesovortex reached its mature stage. During this period, no apparent change of the radius of the maximum wind (RMW) was observed. The vortex dissipated rapidly after its mature phase. In Fig.8, evolution of the mean tangential winds at various height and radius were displayed in time sequence starting from 1302 to 1432 LST June 2, 1997. It is interested to note that orientation of the axis of the maximum mean tangential wind radius has been gone through a dramatic change from a straight-up-to-outward pattern (small RMW at the bottom and larger RMW at the top) to a downward-outward (reversed) pattern. In the intensifying stage, the RMW at upper portion of the vortex (at height 4 km, for example) shrunk from10 km down to 3 km. The mean tangential wind was strengthened rapidly from 3 m/s to 6 m/s at height 2 km and from near zero to 4 m/s at 5 km height. These features can be interpreted with the conservation law of



angular momentum. In the decaying stage, the strong mean tangential wind at upper level the vortex dissipated quickly and the vortex collapsed afterwards.

Fig.8. The mean tangential winds derived from GBVTD technique and at radius vs height displays.

4. Concluding remarks

It is interested to note the center of the vortex at different heights tilted toward southeast with altitude as indicated in Fig.2. The tilt is consistent with the direction of shear between 700 and 500 hPa. It is also interested to note that the maximum rainfall measured by the surface rain gauge station was at DTK and was located at downstream of the enhanced southwesterly flows induced by the mesoscale vortex. It is known the precipitation echoes of radar reflectivity were changing rapidly due to complex precipitation mechanisms involved. It is very difficult to trace back the history of each individual echo and make accurate precipitation forecast. However, the radial wind pattern with dipole signature has a much longer time memory. This dipole signature can be served as a pre-cursor of the heavy rain as indicated in this case study. More studies are needed to clarify the relationship between the mesoscale vortex and the MCS in which the vortex is embedded within.

Acknowledgement

This study is partially supported by National Science Council of R.O.C., under Grant NSC89-2111-M-002-019-AP6.

Reference

Bartels, D.L., J.M. Brown, and E.I. Tollerud, 1997: Structure of a midtropospheric vortex induced by a mesoscale convective system. Mon. Wea. Rev., 125, 193-211.

Brandes, E.A., 1990: Evolution and structure of the 6-7 May 1985 mesoscale convective system and associated vortex. Mon. Wea. Rev., 118, 109-127.

Chen, G.T.J., 1978: On the mesoscale systems for the Mei-yu regime in Taiwan. Proc.Conf. Severe Weather in Taiwan Area, NSC and Academia Sinica, 150-157.

Chen, G.T.J., and S.S. Chi, 1980: On the mesoscale rainfall and mesolow in the Mei-yu season in Taiwan. Atmos. Sci., 7, 39-48.

Chen, G.T.J., and C.C. Wang, 1992: The composite structure of mesolows accompanying heavy rainfall in the Taiwan Mei-yu season. TAO, 3, 533-556.

Houze, R.A.Jr., 1993: Cloud Dynamics. Aeademic Press, New York, 573PP.

Jorgensen, D.P., and B.F. Smull, 1993: Mesovortex irculation seen by airborne Doppler radar within a bow-echo mesoscale convective system. Bull. Amer. Meteor. Soc., 74, 2146-2157.

Johnson, R.H., and D.L. Bartels, 1992: Circulations associated with a mature-to-decaying midlatitude mesoscale convective system. Part II:Upper-level features. Mon. Wea. Rev., 120, 1301-1320.

Lee, W.C., B.J.D. Jou, P.L. Chang, and S.M. Deng, 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.

Skamarock, W.C., M.L. Weisman, and J.B. Kelmp, 1994: Three-dimensional evolution of simulated long-lived squall lines. J. Atmos. Sci., 51, 2563-2584.

Smull, B.F., and R.A. Houze, Jr., 1985: A midlatitude squall line with a trailing region of stratiform rain: Radar and satellite observations. Mon. Wea. Rev., 113, 117-133.

Stirling, J., and R.M. Wakimoto, 1989: Mesoscale vortices in the stratiform region of a decaying midlatitude squall line. Mon. Wea. Rev., 117, 452-458.

Yu, C.K., B.J.D. Jou, and B.F. Smull, 1999: Formative stage of a long-lived mesoscale vortex observed by airborne Doppler radar. Mon. Wea. Rev., 127, 838-857.