Kinematic and Dynamic Structures of Mesoscale Convective Systems over the Northern Taiwan Area by Using CAA Doppler Radar Data

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Abstract

On 4 June 1997, a quasi-stationary Mei-yu front moved forward and backward over the northern part of Taiwan and brought intense precipitation more than 120 mm/d. By using the Civil Aeronautics Administration (CAA) Doppler radar data, the kinematic and dynamic structures of mesoscale convective systems (MCSs) accompanying with the frontal system and the effects between the low-level jet and the MCSs were investigated. The preliminary findings are: (1) The extended velocity azimuth display (EVAD) scheme was a reliable tool for estimating the horizontal wind field in the vertical cross section below the midtroposphere after comparing with the sounding profiles. (2) The prevailing southwesterlies had a deceleration while approaching the multicell MCSs and a pronounced convergence accompanying with intense echoes occurred at the east side of the radar site. The interaction between the southwesterly wind along the northwest coast of Taiwan and the easterly flow over the inland seemed to trigger the intensification of the MCSs. (3) The downdraft inbound flow from the midlevel above 4 km in altitude penetrated the lower portion of the intense convection and the warm, moist outgoing flow climbed up over the inbound flow, demonstrating that the strong vertical shear occurred at the updraft portion of the deep convection. This flow patterns created a powerful instability and intensified the development of the system effectively.

1. Introduction

The Mei-yu front in the vicinity of Taiwan in May and June is relatively shallow (cold air depth ~ 1 km) and satellite pictures usually show a long stratiform cloud band along the front with vigorous convection embedded within the band (Chen et al., 1989; Chen, 1993; Chen, 1978; Wang et al., 1990). The primary mesoscale meteorological phenomena related to the Mei-yu front include the mesoscale circulation associated with the Mei-yu front, a density current, a low-level jet (LLJ), pre-frontal squall lines, mountain convection, mesoscale convective systems (MCSs), frontal deformation due to topography, terrain-induced mesoscale circulation, and a land-sea breeze. The low-level jet of wind speeds exceeding 12.5 m/s at 850 and 700 hPa is frequently observed in association with the Mei-yu front and often precedes heavy rainfall events by as much as 12 hours (Chen and Yu, 1988). The LLJ is commonly observed on the warm side of the Mei-yu front (Chen, 1977, 1983), and is highly ageostrophic (Matsumoto et al., 1971). The LLJ not only transports moisture into the frontal band, but also destabilizes the atmosphere, which provides a favorable environment for the development of heavy precipitation and MCSs. Mesoscale structures of the Mei-yu front and the accompanied convective systems over the Taiwan area were difficult to investigate due to lack of high resolution data before the conduction of TAMEX (Taiwan Area Mesoscale Experiment, 1987), which was designed to enhance the forecasting of heavy precipitation events through better understanding of the mesoscale circulation associated with the Mei-yu front and the effects of orography on the Mei-yu front and the MCSs during the spring of 1987 (Kuo and Chen, 1990). Li et al. (1997) noted that the existence of an orographically induced barrier jet was located at about 1 km in altitude and suggested that the interactions among the barrier jet, synoptic southwesterly flow and the Mei-yu front determined the regions most favorable for the development of MCSs. Hor et al. (1998) found a well-defined density current and MCSs accompanying with slight rising and sinking motions in a Mei-yu front leading edge and proposed that the intense horizontal pressure gradient force from rear to front in the cold core region and the moderate convective instability at the head of the system as well as the kinetic energy transport from the mean flow were the probable mechanisms for the propagation of the density current and the maintenance of the frontal system as well as the MCSs.

The "Heavy Rainfall Research in Taiwan Area" group executed an intensive observational and forecasting field experiment in May and June, 1997. Seven heavy rainfall IOPs (Intensive Operational Periods) were conducted during the period. One of the scientific objectives in the study of the research group is to improve the understanding of the dynamic and thermodynamic precipitation processes related to the heavy rainfall events in the Taiwan Mei-yu season (Jou, 1997). On 4 June 1997, a quasi-stationary Mei-yu front was located over the north part of Taiwan. Figure 1 shows the time series of the positions of the system determined by subjective mesoscale analysis between 0030 UTC 4 June and 0000 UTC 5 June. At 0030 UTC 4 June, it was propagating southward and then changed to the receding state after 1500 UTC 4 June. Figure 2 indicates the surface weather pattern at 1500 UTC on 4 June 1997. There were two meso-high systems over the island just located in front and at the rear of the frontal system, respectively, generating a pronounced convergence in the vicinity of the front. The maximum hourly rainfall reached 47 mm at Pan-chiao station and the 24h-accumulated rainfall was 124 mm at An-pu and 110 mm at Chu-tze-hu. With good coverage obtained by the Civil Aeronautics Administration (CAA) Doppler radar over land, this case offers a good opportunity to study the kinematic and dynamic structures of mesoscale convective systems accompanying with the Mei-yu front over the northern Taiwan area and examine the effects between the low-level flows and the MCSs which are closely related to the precipitation distribution.

2. Data sources and analysis procedures

a. Data sources

Figure 1 shows the location of the CAA C-band Doppler radar site. The radar echoes observed by the CAA radar every 15 minutes were used to monitor the inland evolution of the MCSs inside the frontal system. Surface data (temperature, pressure, relative humidity, wind and precipitation) were used to delineate the surface signatures associated with the frontal systems. The sounding data from Pan-chiao (46692) and Ma-kung (46734) stations were applied to realize the environmental situations inside and outside the frontal system, respectively. The GMS-5 satellite imageries were good evidences to separate the MCSs that were directly related to the frontal system or propagated northward from the warm, moist ocean.

b. Doppler radar data analysis procedures

Doppler data collected by the CAA radar from 1347 UTC 4 June to 1832 UTC 4 June 1997 were analyzed. The radar beamwidth is 0.86° . This means that the linear beamwidth at 20 km from the radar site (about the center of the MCS analyzed) would be about 300m. Thus, mesoscale perturbations with wavelengths of less than 1 km could not be resolved using the radar data. Ground clutter was removed, but no folded radial velocities were corrected due to that the unambiguous velocity is ±48 m/s which is much higher than the observed wind speed. Only those data with a high signal-to-noise ratio (a radar reflectivity above 10 dBZ) were accepted for analysis.

The extended velocity azimuth display (EVAD) technique developed by Srivastava et al. (1986) and modified by Deng and Jou (1995) was executed to obtain the horizontal wind field, divergence and deformation in the lower atmosphere in order to improve the insufficient sounding observations.

3. Results and discussions

Based on the CAA radar observations between 1347 UTC 4 June and 1832 UTC 4 June, a northwest-southeast oriented convective system with 40 km in length existed at about 20 km northeast of the radar site and kept moving toward northeast. The system reached its maximum intensity (between 40 and 50 dBZ) at 1502 UTC and became decayed later. The Pan-chiao station (46692) profiles showed that the energy supporting the parcel lifting in the atmosphere was not sufficient. The magnitude of convective available potential energy was 1348 m^2/s^2 at 1200 UTC 4 June. It means that the atmospheric thermodynamic condition was not a primary factor for the development of the MSC. Instead, the dynamic mechanism played significant roles.

The preliminary results in this case study show three important findings:

(1) The EVAD time series (time interval 15 min) for horizontal wind field between 1347 UTC 4 June and 1832 UTC 4 June in 15 km range (Fig. 3) delineated that the weak southeasterly wind with the maximum speed of 5 m/s was dominant in the lowest layer (lower than 500 m) and the prevailing southwesterly flow with the maximum speed of 12.5 m/s and on the warm side of the front zone occurred between 0.9 km and 3.3 km in altitude. Compared with the sounding profile of the Pan-chiao station at 2000 L of 4 June, the similar wind structure was obtained. It showed the EVAD scheme was a reliable tool for estimating the horizontal wind field in vertical cross section below the midtroposphere while the weather system was quite mature and well organized. Its high resolution determinations of horizontal wind field in temporal scale can improve the insufficient rawinsonde observations.

(2) During this IOP on 4 June, the CAA Doppler radar completed a volume scan

every 15 min with 10 elevation angles from 0.5° to 15.0° in the Doppler mode. The composited constant altitude plan position indicator (CAPPI) at the 0.5 km altitude (shown in Fig. 4) collected from the radar reflectivity (dBZ) and radial wind (m/s) data elucidated that the prevailing southwesterlies had a deceleration while approaching the multicell MCSs and a pronounced convergence accompanying with intense echoes greater than 40 dBZ occurred at the east side of the radar location. The interaction between the southwesterly wind along the northwest coast of Taiwan and the easterly flow over the inland seemed to trigger the intensification of the MCSs and made it propagate slowly toward northeast and lasted more than 2.5 hours. The intense inward flow over land was closely related to the local meso-high system over the northeastern tip of Taiwan (Fig. 2).

(3) The composited vertical cross section of the reflectivity and radial wind following the most intense precipitation echoes along the 90° azimuth (shown in Fig. 5) indicated that the downdraft inward flow from the midlevel above 4 km in altitude penetrated the lower portion of the intense convection and the warm, moist outgoing flow climbed up over the inward flow, demonstrating the strong vertical shear occurred at the updraft portion of the convection. This event might create a powerful instability and intensify the development of the system effectively.

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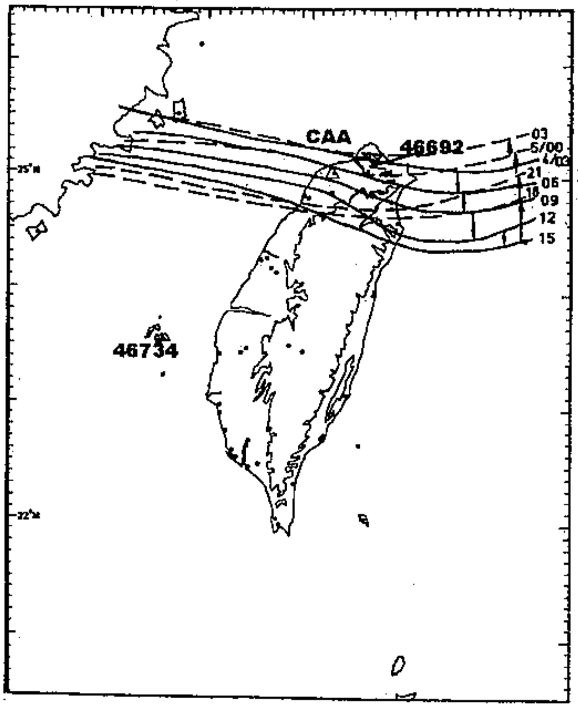

Fig 1. Evolution of the Mei-yu front from 0300 UTC 4 June 1997 to 0000 UTC 5 June 1997. The open triangle shows the location of the CAA radar station. Terrain contours go from sea level to 500m. The open circles denote surface stations. The solid lines (southward motion) and dashed lines (northward motion) indicate the positions of the surface fornt by subjective mesoscale analysis. The closed circles stand for the sounding stations of Pan-chiao (46692) and Ma-kung (46734), respectively.

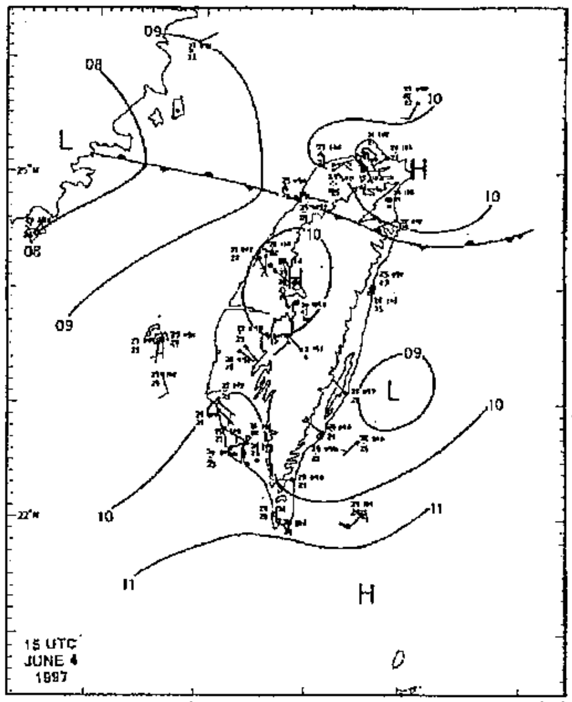

Fig.2 The surface weather chart by subjective mesoscale analysis at 15 00UTC (2300 L) on 4 June 1997.

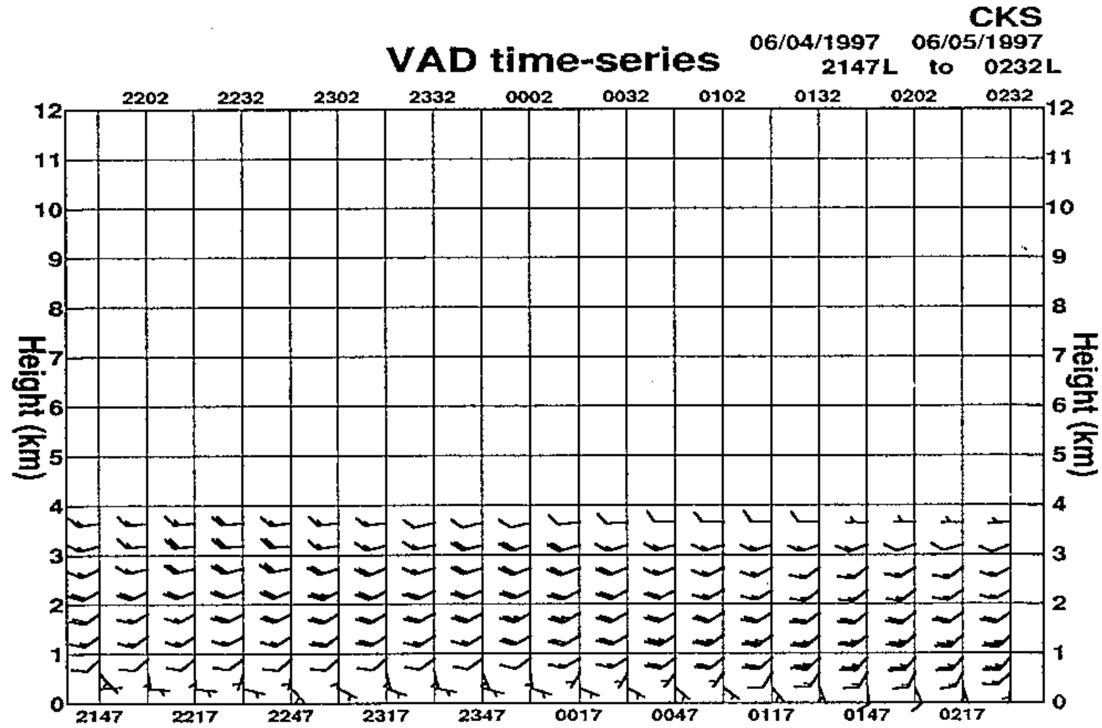

Fig.3 The extended velocity azimuth display (EVAD) time series from 2147 L on 4 June 1997 to 0232 L on 5 June 1997. The time interval is 15 min and the conducted radar data range 15 km.

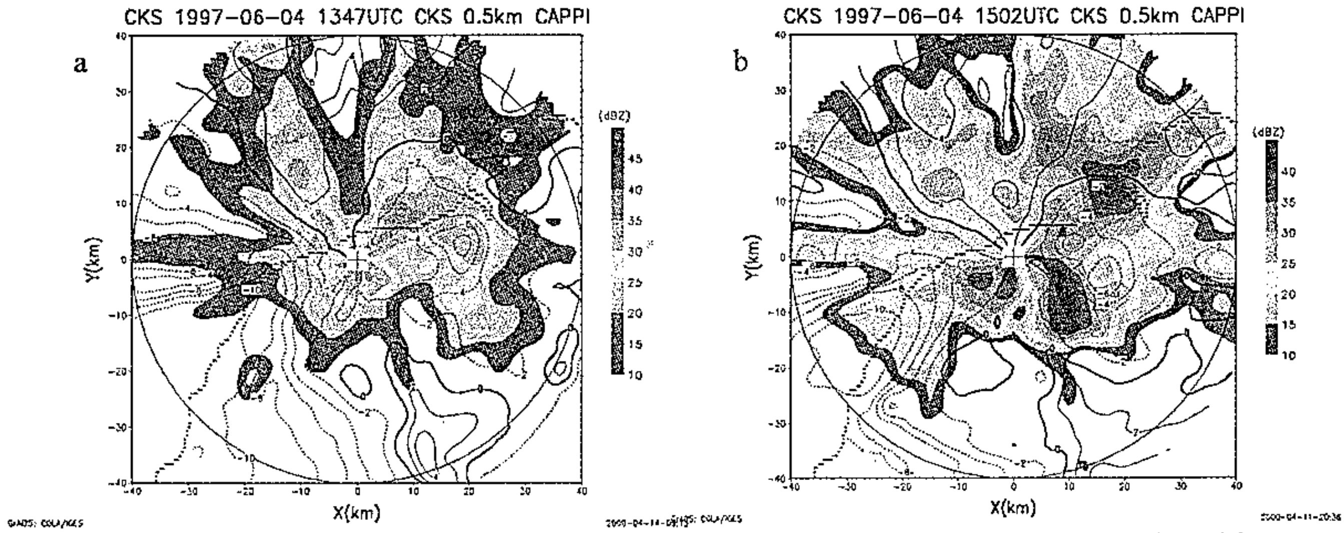

Fig.4 The composite constant altitude plan position indicator (CAPPI) at the 0.5 km altitude collected from reflectivity (dBZ) and radial wind (m/s) data of the CAA Doppler radar at (a) 1347 UTC on 4 June 1997 and (b) 1502 UTC on 4 June 1997. The symbol "+" represents the CAA radar site. The domain size in the figure is 80 km x 80 km.

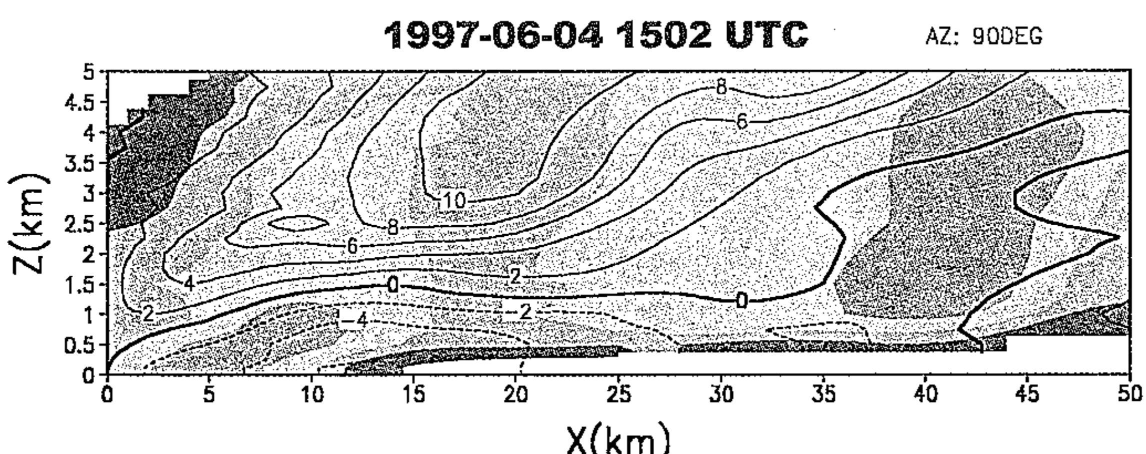

Fig.5 The composite vertical cross section collected from reflectivity (dBZ) and radial wind (m/s) data of the CAA Doppler radar along the azimuth angle of 90° at 1502 UTC on 4 June 1997. The scale in the abscissa (X axis) represents the distance from the radar.