ELBOW-SHAPED ECHO PATTERN AND THE MEI-YU FRONTAL RAINBANDS

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1. INTRODUCTION

Two cases of convective rainbands along the Mei-Yu fronts (24-25 June 1987 and 22 May 1988) are investigated in this study. The common phenomena of these two cases is the elbow-shaped precipitation echoes observed by CAA Doppler radar while the rainbands approached to the northwest coastal region of Taiwan island. The strength of the prefrontal low level jet stream and the behavior of the postfrontal cold air are important factors in the formation of this distinct feature of precipitation echoes. In this study, three other cases without the presence of the elbow-shaped precipitation echoes are also examined. In section 2, the data used is described. The synoptic conditions and the composited radar reflectivity maps are described in section 3. The horizontal and vertical structures of the elbow-shaped convective rainbands are analyzed for both cases in section 4 and discussion of their formation follows.

2. DATA

Data used in this study are taken from a C-band Doppler weather radar at CKS International airport of the Civil Aeronautic Administration of Taiwan (CAA Doppler radar). The radar is located at northwest coast of Taiwan. Time interval of 10 or 20 minutes of radar reflectivity and radial wind data are gathered. Soundings of Panchiao station (46692) and surface weather station data over northern Taiwan are also used. Detailed data processing procedures were described in Jou (1994).

3. CASE DESCRIPTION

Surface weather charts of 24-25 June 1987 (June case) showed that the surface front (Mei-yu front) passed through northern Taiwan slowly. The low-elevation angle PPI radar reflectivity maps composited from several selected times found that the radar echoes observed by CAA Doppler radar revealed a distinct line-shaped echo pattern while the rainband was still some distance away from the coast and the rainband turned into an elbow-shaped echo pattern while appraoched to the island. The drop of air temperature and dew point, the rise of surface pressure, and the change of surface wind from southerly to northerly recorded at the airport surface station during this period (Fig.1a) all provided evidence of a surface cold front passage at about 4 am of June 25 1987. Accompany with passage of the surface cold front, intense precipitation was observed. The rainfall intensity weakened rapidly after the front passed the station.

The composited radar reflectivity map of 22 May 1988 (May case) also showed elbow- shaped echo pattern while the surface front approached to the northwest ocean of Taiwan. Surface data of temperature, pressure, dew point, and winds all revealed a signature of surface cold front passage at around 2 pm of 22 May (Fig.1b). The synoptic conditions of May case were similar to that of June case in which the surface front located at a position very close to northern Taiwan. However, there are some differences. In May case the surface front passed Taiwan during the daytime and in June case it was during the nighttime. The former had a faster speed and the latter slower. Soundings of Panchiao (Fig.2) showed deep moist layer in May case, nevertheless, a pronounced mid-level dry layer shown in June case.

There are two interesting points worth of mention. Firstly, the precipitation echo patterns evolved from line-shape into elbow-shape while the convective rainbands moved closer to the coastal region. The

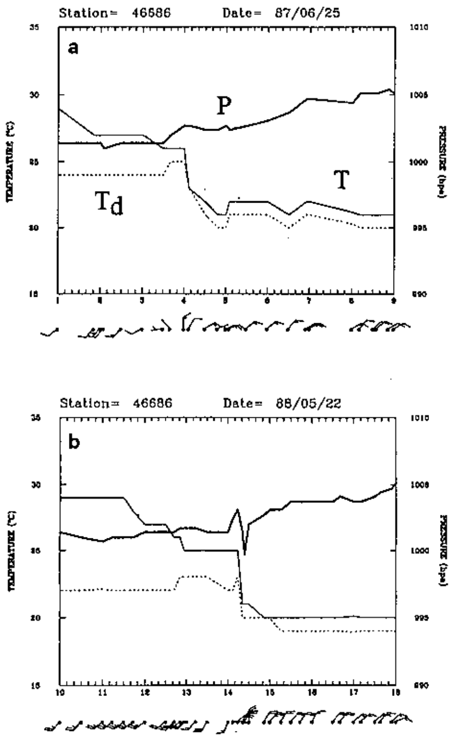

Fig. 1. Surface observations of pressure, temperature, dew point, and winds at CKS station (46686). (a) 25 June 1987 and (b) 22 May 1988.

elbow-shaped echoes broke into scattered weak echoes while landed. This observations suggest the northwest ocean of Taiwan is a preferable location for the elbow-shaped precipitation echo to form. The explanation is not clear yet, however, the preferable location of occurrence suggests that the pronounced Taiwan topography may play an important role in formation of the elbow-shaped precipitation echoes. Secondly, from surface observational data, it indicated that the air in the postfrontal region in May case was colder and heavier than in June case. The prefrontal surface winds in May case were also stronger than in June case. The prefrontal soundings of Panchiao indicated that the lower tropospheric winds in May case had a stronger intensity (60 knots at 850 hPa) than that in June case (40 knots at 900 hPa). The precipitation measured by raingauges also showed much heavier rain in May case (51 mm/hr) than in June case (14 mm/hr). All these observations suggest that the May case is a stronger convective frontal rainband system in terms of temperature contrast, strength of prefrontal low-level winds, and rainfall intensity than that of the June case.

4. SINGLE DOPPLER ANALYSIS OF THE RAINBAND STRUCTURE

4.1 Low-elevation angle reflectivity and radial winds

A sequence of low-elevation angle reflectivity and radial wind maps focused on the ocean northwest of Taiwan island with time interval of 20 or 30 minutes are given in Fig. 3 for June case and in Fig.4 for May case, respectively. In these figures, the isolines are radial winds with positives recede from the radar and negatives approach to the radar. Since the mean low-level prefrontal winds were southwesterlies for both

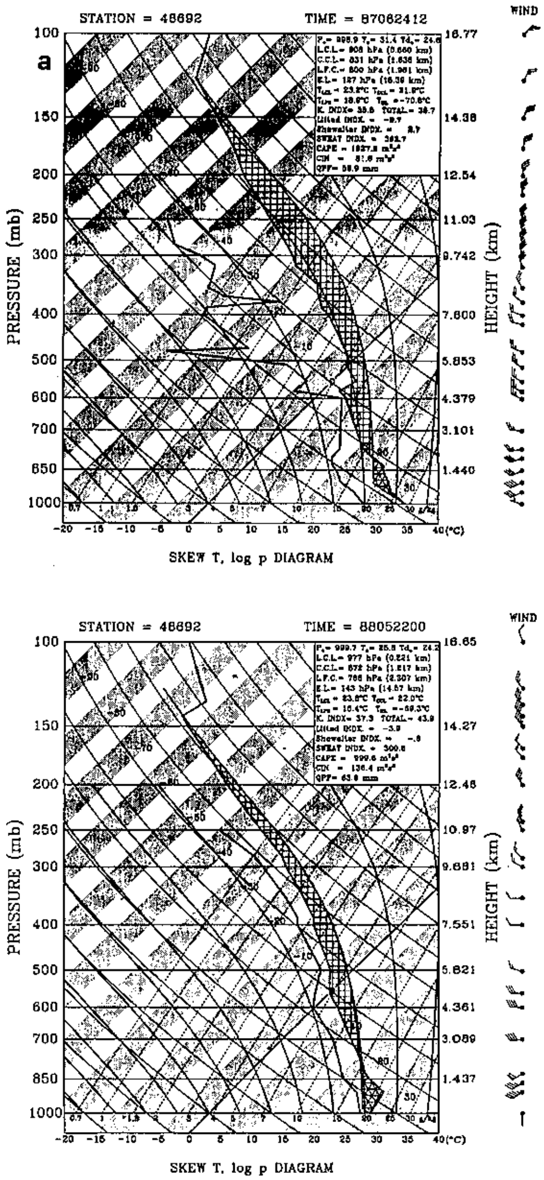

Fig. 2. Skew T-log P plots of soundings from Panchiao (46692). (a) 12Z 24 June 1987 and (b) 00Z 22 May 1988.

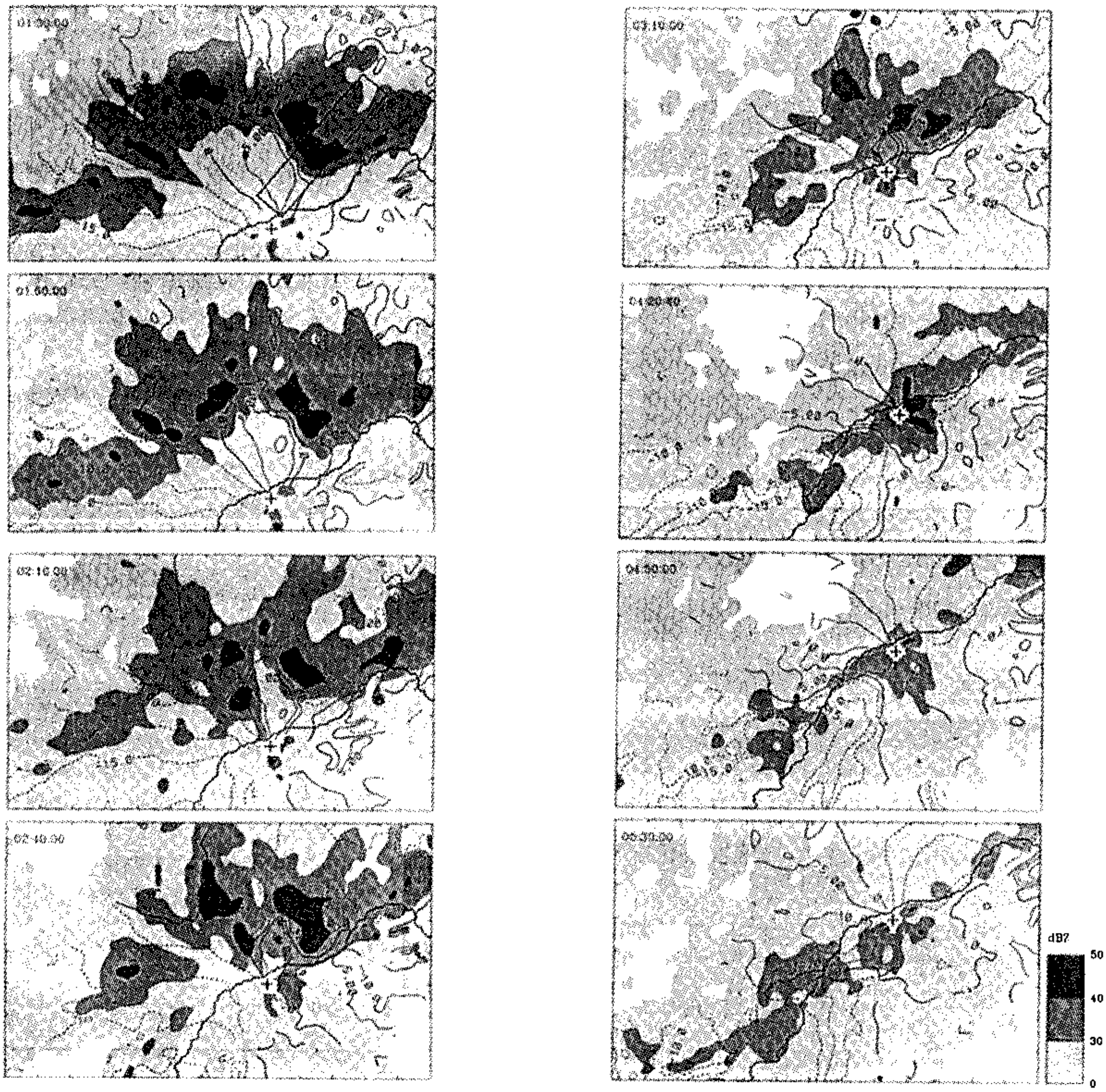

Fig. 3. Low-elevation angle reflectivity and radial wind maps of 25 June 1987 taken from CAA Doppler radar observations. The shading is echo intensity in dBZ and the isolines are radial winds. Positives (negatives) are winds receding from (approaching to) the radar (marked by +).

cases (see Fig.2), the radial winds observed by CAA Doppler radar revealed most of the mean winds while the radar beams aligned along the directions nearly parallel to NE-SW. It is noted earlier that the surface cold front passed CAA radar station at around 4 am for June case and at around 2 pm for May case. The passage of surface cold front was identified by the shift of surface winds from southwesterly to northeasterly. Thus, the zero radial wind lines north and northeast of the radar in both Figs.3 and 4 were wind shift lines associated with the surface cold front. It is also noted that the low-level wind speed in May case was much stronger than that in June case. This result is consistent with what was found by sounding data of Panchiao.

In terms of precipitation echoes, it was found that in both May and June cases, strong echoes colocated well with the zero radial wind line north of the radar. The echoes organized into elbow shape along the low-level wind shift line while the wind shift line approached to the coast. Comparing with the surface observations shown in Fig.1, the passage of wind shift line at the radar site observed by radial winds is consistent with

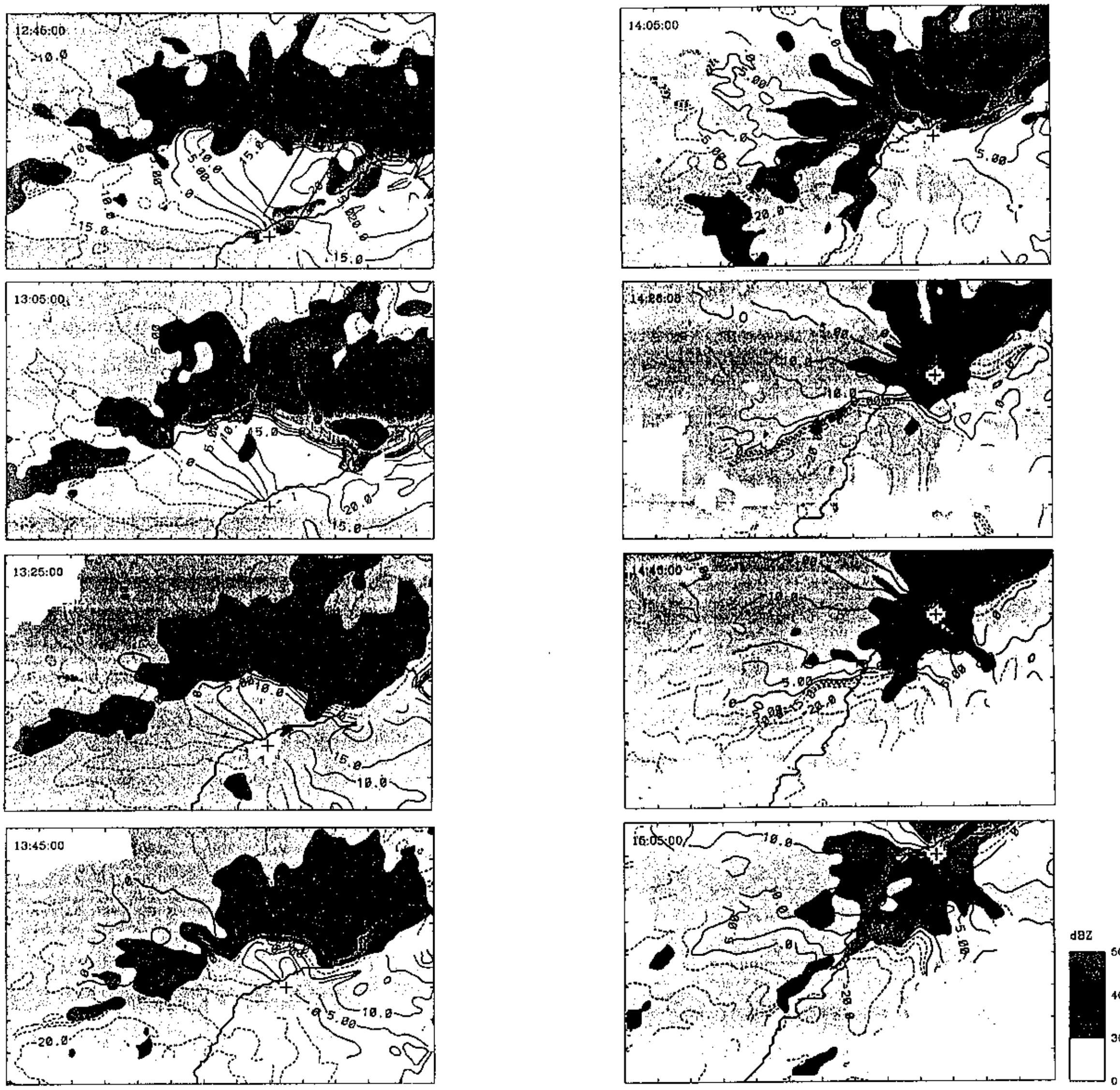

Fig. 4. Same as Fig. 3 but for 22 May 1988.

that observed by the surface station. This finding is to confirm that the convective rainbands north of radar in both June and May cases were associated with the surface cold front. The propagation speed of the rainband is the same as the wind shift line observed by the Doppler radar.

4.2 Vertical cross-section of reflectivity and radial winds

Figs.5 and 6 show the averaged structure of reflectivity and velocity component parallel to the long axis of rectangles across the surface cold front (in NE-SW direction) as shown in Figs. 3 and 4 for the June and the May cases, respectively. Most noticeably is the southward penetration of northerly flow at the lowest level (from right to left). The depth of the northerly flow was no more than 1 km in height. Winds shifted to strong southerly flow and pronounced horizontal convergence existed at the leading edge. As discussed in previous section, the low-level wind shift line is the position of surface cold front. Thus, the depth of the northerly flow can be viewed as the depth of surface cold front. The surface cold front was rather shallow as revealed from the Doppler radar observations. This finding is similar to what was observed by Trier et al. (1990) during TAMEX (Kuo and Chen 1990). In the prefrontal region, deep southwesterly flow prevailed at low and middle troposphere with strongest wind at low levels. At the leading edge of the wind shift line, the low-level winds weakened rapidly and the strong southwesterly flow was lifted to a higher altitudes. For example, in June case, the height of strong low-level winds was lifted from 1-1.5 km to 2-2.5 km, and in May case it was lifted from 0.5-1 km to 2 km.

In Figs.5 and 6, the horizontal divergence and vertical velocity calculated by using anelastic approximation and two-dimensionality assumption are also given. The estimated vertical velocity had its maximum intensity at low altitudes for both cases. In June case, it was 2m/s at 2 km height and in May case it was 4 m/s at 1.5 km height. This structure of vertical velocity within the convective frontal rainbands was very different from what was estimated in the prefrontal squall line (Wang et al. 1990) or the prefrontal convective rainband (Lin et al. 1992; Jou and Deng 1992) during TAMEX. In both above mentioned cases, the maximum vertical velocity was found at middle or upper troposphere instead of at lower troposphere. This structure difference of vertical

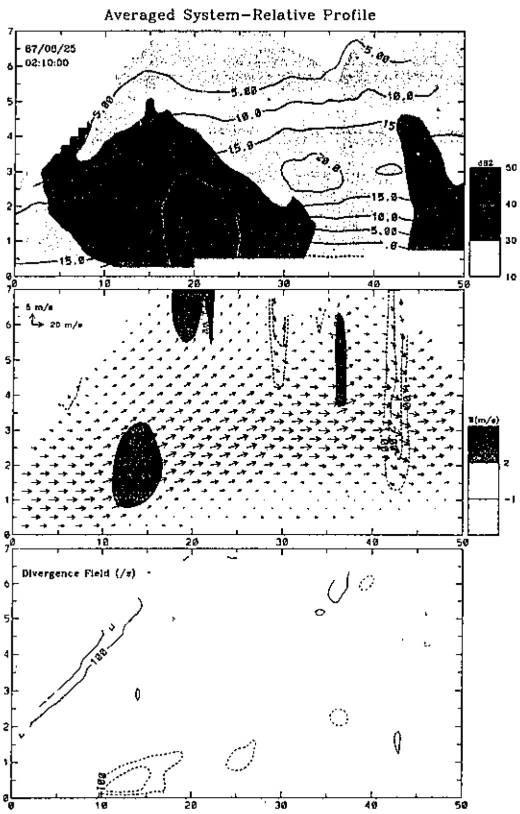

Fig.5. Vertical cross-sections of reflectivity and radial winds (upper panel), wind arrows and vertical velocity (middle panel), and estimated horizontal divergence (lower panel, $10^{-6}\,s^{-1}$) of 2:10 am 25 June 1987.

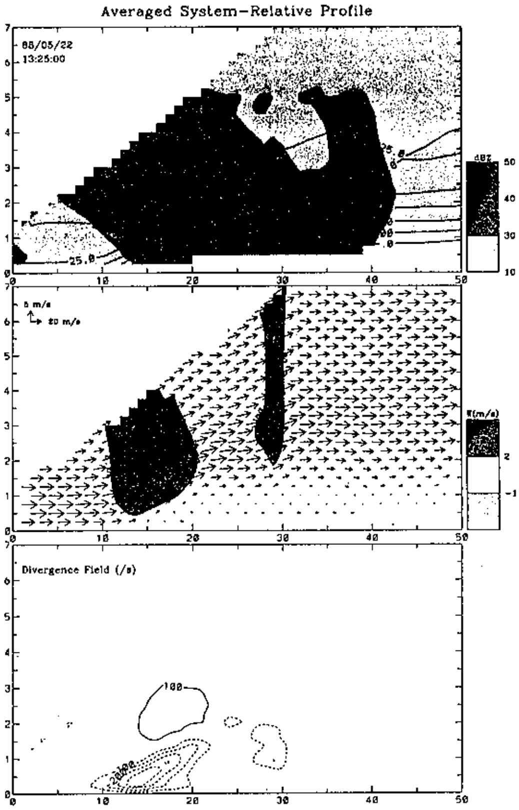

Fig. 6. Same as Fig.5 but for 1:25 pm 22 May 1988.

velocity indicated there is a fundamental difference in formation mechanism associated with the convections.

The maximum vertical velocity colocated well with the low-level wind shift line. In terms of reflectivity, the precipitation echoes spreaded all over the frontal zone. However, the maximum echoes located at the postfrontal region just behind the wind shift line. Thus, there was a phase difference between the maximum reflectivity field and the maximum vertical velocity. The vertical extent of the intense precipitation echoes (>30dBz) reached about 4 km height. Comparing with the mesoscale convective systems observed in the Taiwan Mei-Yu season (Chen and Chou 1993; Wang et al. 1990; Lin et.al. 1992; Jorgensen et al. 1991; Chen et al. 1991; and Jou 1994), the vertical extent of reflectivity of these frontal rainbands is shallower than the prefrontal squall lines, oceanic convections, and mountain convections.

5. DISCUSSION

By using a two-dimensional nonhydrostatic cloud model, Parsons (1992) studied the dynamics of the narrow cold-frontal rainbands and suggested that the maintenance of the intense frontal updrafts at the leading edge of the cold air mass were associated with a strong upward-directed pressure force and not associated with significant parcel buoyancy. By performing a series of numerical sensitivity experiments, he concluded that the conditions for intense updrafts and heavy precipitation to occur in the simulations are 1) strong deep cold pools, 2) a prefrontal environment that contains deep layers of air that are nearly saturated with a lapse rate that is nearly neutral to moist ascent, and 3) intense low-level vertical shear in the cross-frontal component of the horizontal wind. These conditions favored for updraft maintenance are typical of maritime surface cold fronts. In current study, two cases of convective frontal rainbands associated with the surface cold fronts in Taiwan Mei-Yu season are presented. As discussed earlier, the prefrontal low-level strong winds and intense temperature contrast across the wind shift line are the common observed phenomena in both cases. These common observed features are consistent with the conditions required to form narrow cold-frontal rainbands as suggested by Parsons (1992). Three other cases of frontal rainband without the presence of the elbow-shaped precipitation echoes observed by CAA Doppler radars are also examined (see Table 1). It can be seen that the strength of low-level vertical wind shear was much weaker for those rainbands without elbow-shaped echo patterns.

The formation of elbow-shaped echo patterns over the northwest ocean of Taiwan may closely relate to Taiwan topography. As suggested by Chen and Li (1994) from observational study and Sun et al. (1991) from numerical study, a barrier jet may exist over the ocean northwest of Taiwan while southwesterly flow passed through the Central Mountain Range. If this were the case, then the existence of strong low-level winds over the ocean northwest of Taiwan is a very localized phenomenan. This is different from the synoptic and subsynoptic low-level jet stream as discussed in many other studies (for example, Chen and Yu 1988). On the other hand, the formation of elbow-shaped echo patterns may also closely relate to the distortion of surface front while it passed through the complex terrain region over northern Taiwan. According to Wang (1989), under certain synoptic conditions, the frontal surface would be distorted and separated into two branches while the front passed over northern Taiwan. On the east coast of Taiwan, the front moved faster and on the west coast of Taiwan and Taiwan strait, the front moved slower. Partly due to surface friction, over the western coastal region, the front moved even slower than that in the Strait. Thus, the frontal surface distorted to become orient into NE-SW direction. This orientation is consistent with what revealed by the radar reflectivity. Local frontogenesis

Table 1. Some characteristics of the Mei-Yu frontal rainband.

Case	1	2	3	4	5
date	Jun. 24-25 1987	May 22 1988	May 28-29 1989	Jun. 8-9 1990	May 2-3 1993
Local time of frontal passage (CKS station, 46686)					
	03-04	14-15	02-03	05-06	02-03
Elbow-shaped echo pattern					
	yes	yes	no	no	no
Low-level jet at height (km)/intensity ($m\ s^{-1}$) derived from VAD method					
	1.2/21	1.6/32	1.0/15	1.5/23	2.4/20
Low-level vertical wind shear ($m\ s^{-1}\ km^{-1}$)					
	5.2	6.0	1.5	4.1	2.5
Cold air depth (m)					
	800	1300	1000	>1500	400

processes occurred in some very localized regions over the northwest part of Taiwan.

6. SUMMARY

Formation of elbow-shaped precipitation echoes is closely related to the surface front behavior over northwest portion of the island and the flow interaction with the Central Mountain Range. To understand these mesoscale processes by observational diagnosis and numerical simulations in the near future is fundamentally important to advance our understanding of the development and organization of convections in the Mei-Yu fronts.

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REFERENCE

Chen, C.S., W.S. Chen, and Z.S. Deng, 1991: A study of a mountain-generated precipitation system in northern Taiwan during TAMEX IOP8. Mon. Wea. Rev., 119, 2574-2606.

Chen, G.T.J., and H.C. Chou, 1993: General characteristics of squall lines observed in TAMEX. Mon.Wea. Rev., 121, 726-733.

Chen, G.T.J., and C.-C. Yu, 1988: Study of low-level jet and extremely heavy rainfall over northern Taiwan in the Mei-Yu season. Mon. Wea. Rev., 116, 884-891.

Chen, Y.-L., and J. Li, 1994: Characteristics of surface airflow and pressure patterns over the island of Taiwan during TAMEX. Workshop on Weather Research in Taiwan Area. Taipei, May 26-28, 1994, 1-8.

Jorgensen, D.P., M.A. LeMone, and B.J.D. Jou, 1991: Precipitation and kinematic structure of an oceanic mesoscale convective system. Part I: Convective line structure. Mon. Wea. Rev., 119, 2608-2637.

Jou, B.J.D., 1994: Mountain-originated mesoscale precipitaion system in northern Taiwan: A case study 21 June 1991. Terrestrial, Atmos., and Oceanic Sciences (TAO), 5, 169-197.

Jou, B.J.D., and S.-M. Deng, 1992: Structure of a low-level jet and its role in triggering and organizing the moist convection over Taiwan: A TAMEX case study. TAO, 3, 39-58.

Kuo, Y.H., and G.T.J. Chen, 1990: Taiwan Area Mesoscale Experiment: An Overview. Bull. Amer. Meteor. Soc., 473-478.

Lin, Y.J., R.W. Pasken, and H.W. Chang, 1992: The structure of a subtropical prefrontal convective rainband. Part I: Mesoscale kinematic structure determined from dual-Doppler measurements. Mon. Wea. Rev., 120, 1816-1836.

Parsons, D.B., 1992: An explanation for intense frontal updrafts and narrow cold-frontal rainbands. J. Atmos. Sci., 49, 1810-1825.

Sun, W.Y., J.D. Chern, C.C. Wu, and W.R. Hsu, 1991: Numerical simulation of mesoscale circulation in Taiwan and surrounding area. Mon. Wea. Rev., 118, 2449-2470.

Trier, S.B., D.B. Parsons, and T.J. Matejka, 1990: Observations of a subtropical cold front in a region of complex terrain. Mon. Wea. Rev., 118, 2449-2470.

Wang, S.T., 1989: A study of orographic influences on the east-west and northeast-southwest oriented fronts in TAMEX. Preliminary Scientific Results, Taipei, Taiwan, 292-299.

Wang, T.C.C., Y.J. Lin, R.W. Pasken, and H. Shen, 1990: Characteristics of a subtropical squall line determined from TAMEX dual-Doppler data. Part I: Kinematic structure. J. Atmos. Sci., 47, 2357-2381.