Case Study on the Characteristics of Bow Echoes off the Southern Coast of Taiwan in the 2003 Mei-yu Season

Tai-Hwa Hor[1], Chih-Hsien Wei[2], Mou-Hsiang Chang[2] and Wen-Chau Lee[3]

1 General Education Center, Lunghwa University of Science and Technology Taoyuan, Taiwan, Rep. of China
2 Department of Applied Physics, Chung Cheng Institute of Technology, National Defense University, Taoyuan, Taiwan, Rep. of China
3 Atmospheric Technology Division, National Center for Atmospheric Research Boulder, Colorado, USA

Abstract

On 7 June 2003, an eastward propagating mesoscale convective system was captured by the Taiwan Doppler weather radar network after initiating in the northern South China Sea and exhibited similar patterns to bow echoes in the mid-latitude continental area during spring and summer seasons.

Radar reflectivity collected by Chigu, Kenting and Green Island Doppler radars characterized its bend-shaped convective line (line echo wave pattern, LEWP) in the leading edge and widespread stratiform precipitation in the rear area. The system lasted more than 7 hours. Moreover, between the convective rainband and the stratiform cloud, there was a region of weak echo. The maximum Doppler velocity in the rear of convective line went up to 24 m/s as a rear inflow jet embedded in the stratiform area. Although the vertical wind shear (7.5 m/s between surface and 850 hPa) was quite weak in the lower atmosphere, the mid-altitude radial convergence (MARC) feature was identified. An apparent Doppler velocity gradient was associated with the convective line in the horizontal, revealing the remarkable shearing along the convective line. Also, it was obvious that a negative-positive velocity couplet occurred within the apex of the convective line and was comparable with the mesoscale convective vortex (MCV).

Key words: Bow echoes, rear inflow jet, mesosclae convective vortex

1. Introduction

Bow echoes are longer-lived and larger-scale convective windstorm and usually occur in the mid-latitude continental area during spring and summer seasons. They are most easily identified by their characteristic bow-shaped pattern of high reflectivity on radar images, with kinematic features which include a strong leading-line updraft, cold outflow accompanied by rear inflow jet and a weak-reflectivity region behind the apex of the bow echo (Burgess and Smull, 1993; Przybylinski, 1995). Additionally, a dominant cyclonic vortex and weaker anticyclonic vortex are existed behind the northern and southern ends of the convective line (Weisman, 1992). Literatures concerned the occurrence of bow echoes in the subtropical Taiwan are rare largely due to radar sampling limitations and the lack of high resolution thermodynamic observations near bow echoes. Chen and Chou (2001) found a fast moving bow echo with a high CAPE, dry mid-troposphere, and significant vertical wind shear in the northern part of Taiwan on 6 June 2000.They concluded that the twisting mechanism due to strong downdraft accompanied by the strong rear-inflow jet and the strong vertical shear was responsible for the formation and maintenance of the book-end vortices.

On 7 June 2003, eastward propagating mesoscale convective systems (MCSs) initiated over the Southern China and northern South China Sea area were captured in relays by the Chigu, Kenting and Green Island Doppler weather radars and presented a bow-shaped line of convective cells embedded with MCSs. It gives a good opportunity to realize the evolution and structure of bow echoes, construct a conceptual model over the subtropical Taiwan area and compare their features with those over the midlatitudes.

2. Radar Data Collection and Analysis

The Doppler radar data used in the study were collected by the Gematronik Meteor-1000S Doppler weather radars Chigu and Kenting and EEC (Enterprise Electronic Corporation) DWSR-92C Doppler weather radar located at Green Island. Due to the topographic blocking of radar beam in viewing angles of 0.4 deg, 1.4 deg and 2.4 deg, the Kenting radar had to be operated in sector scanning strategy at the first three elevation angels. However, there was no similar problem for the Chigu and Green Island radars fortunately. There were two scanning strategies and two range resolutions being employed during the surveillance of Chigu and Kenting radars (every 10 minutes and 8 minutes for each volume scan, respectively): the Doppler mode scanning strategy with range of 230 km and resolution of 250 m as well as the non-Doppler mode scanning strategy with range of 460 km and resolution of 1 km. The non-Doppler mode scanning strategy with range of 480 km and resolution of 2 km was executed every 15 minutes and the Doppler mode scanning strategy with range of 120 km and resolution of 500 m was executed every 30 minutes at the Green Island radar. The relative locations of these three Doppler weather radars are shown in Fig. 1, including the interesting area bounded by the dashed line.

After the necessary data analysis, plan position indicator (PPI), constant altitude plan position indicator (CAPPI) and vertical cross section are the primary products in order to identify the three dimensional variations of the bow echoes in this study.

3. Characteristics of Bow Echoes

Based on the non-Doppler mode PPI of 0.5 degree in elevation angle at the Chigu radar, the MCSs off the southeast coast of Taiwan possessed intensive echoes with reflectivity larger than 40 dBZ in the eastward fast moving speed of 14-16 m/s and featured the line echo wave pattern (Fig. 2). Its intensity seemed diminished after the northern portion of the system moved inland, but the southern part kept moving eastward with original appearance. It could last more than 7 hours in life duration. At 0428 UTC of 7 June 2003, the line echo wave pattern had more pronounced bow echo features just located at south of Kenting radar site between x = -10 ~ 10 km and y = -55 ~ -75 km displayed on the 2 km CAPPI of reflectivity and radial wind (see Fig. 3). The rear inflow jet could reach more than 24 m/s in the stratiform cloud region and there was a severe gradient of wind speed as well as wind direction in the bow echo area, suggesting an organized cyclonic vortex there.

Fig. 4 illustrates the vertical cross section between x = -140 km and x = -200 km along y = 7.5 km collected from reflectivity (dBZ) and radial wind (m/s) data of the Kenting Doppler radar at 0300 UTC on 7 June 2003. The arrows stand for the wind directions at the altitude between 4 km and 9 km and specify the signature of mid-altitude radial convergence (MARC) in a mature MCS, implying the precursor to the initial onset of damaging downburst winds (Schmocker 1996). The bow-shaped line brought 12 mm rainfall at Heng-chun weather station during its passage between 0342 and 0354 UTC and the wind direction shifted from southwesterly to westerly.

After the dual-Doppler analysis, the total wind field could be retrieved reasonably. Fig. 5 gives the CAPPI at the 1 km altitude synthesized from reflectivity (dBZ) and radial wind (m/s) data of the Kenting and Green Island Doppler radars at 0500 UTC on 7 June 2003. The symbol "+" represents the Kenting radar site and the domain size is 100 km x 100 km. The mesoscale cyclonic vortex can be easily identified by wind arrows between x = 30 ~ 70 km and y = 20 ~ 70 km.

4. Conclusions

After the surveillance in relays operated by the Chigu, Kenting and Green Island Doppler weather radars, a bow-shaped line of convective cells embedded with MCSs on 7 June 2003 initiated over the Southern China and the northern South China Sea area were investigated carefully and detailedly. It helps us see the evolution and structure of bow echoes, and compare their features with those over the midlatitudes. The preliminary results are:

1. The mesoscale convective systems existed in the southern and southeastern region of Taiwan exhibited elongated, bow-shaped structure while the Mei-yu front still stayed at the northern part of Taiwan. The development and maintenance of elongated, bow-shaped convective systems were probably due to the wind shear induced by the confluence of westerly and southwesterly flows (low level jet). The characteristic of this feature seems to be similar to that of wind shift line which is associated with Mei-yu front over the northern Taiwan.
2. The features of bow-shaped convective systems over the southern Taiwan area were similar to those observed at the midlatitude continental regions, including LEWP, MARC, MCV, and rear-inflow jet. However, the intensity (~24 m/s) of rear-inflow jet was much less than that (~40 m/s) observed in midlatitudes. Also, the altitude of the bow echo systems (~ 8 km) is lower than the midlatitude ones (~ 12 km). This could be related to the weak CAPE (611 J/kg) and mild vertical wind shear (7.5 m/s between surface and 850 hPa) in this subtropical case.
3. While the passage of the bow-shaped system, it brought heavy rainfall over land, but no derecho phenomenon (a windstorm accompanying with bow echoes defined by Johns and Hirt, 1987) was determined by the ground weather stations, probably due to that the moving speed (14-16 m/s) of the system was too fast and the primary part of bow echo systems didn't pass over land.

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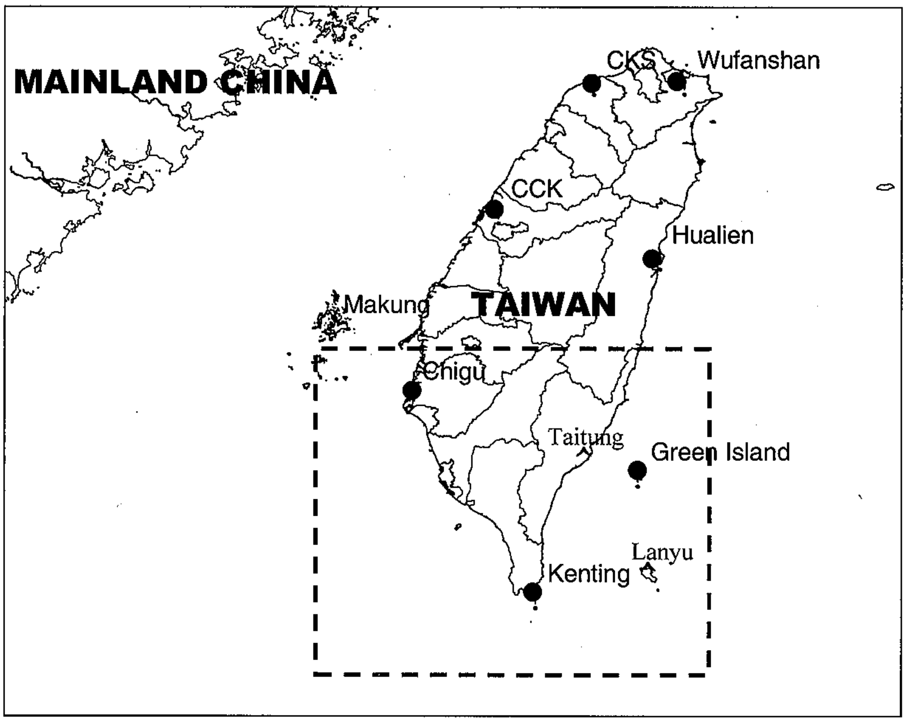

Fig. 1 The operational Doppler weather radar network in the Taiwan area. The dashed area shows the interesting region in this case study. The black spots stand for the radar sites at Chigu, Kenting, Green Island, etc.

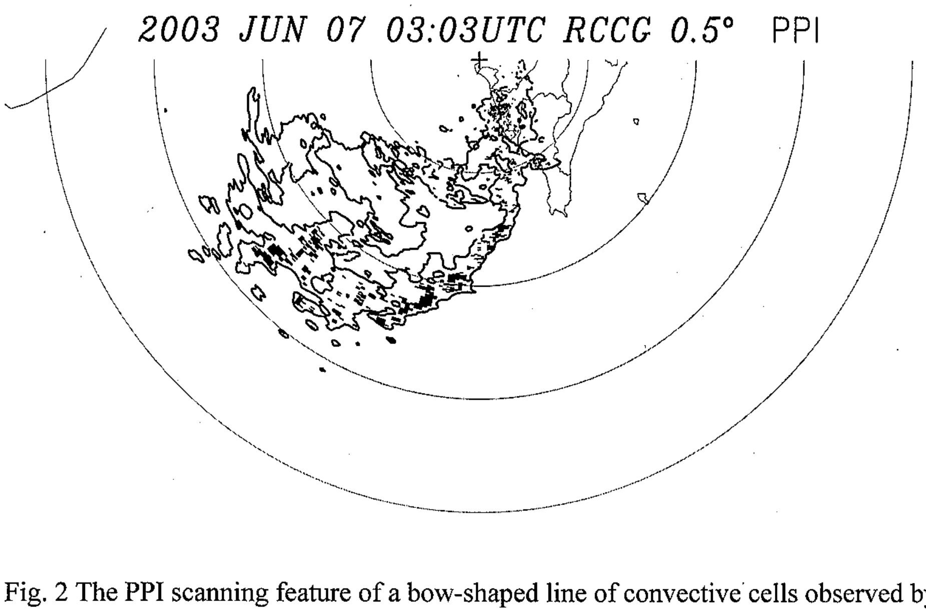

Fig. 2 The PPI scanning feature of a bow-shaped line of convective cells observed by the Chigu Doppler radar in the elevation angel of 0.5 degree at 0303 UTC on 7 June 2003. The symbol "+" represents the radar site. The contoured area shows the reflectivity intensity larger than 20 dBZ.

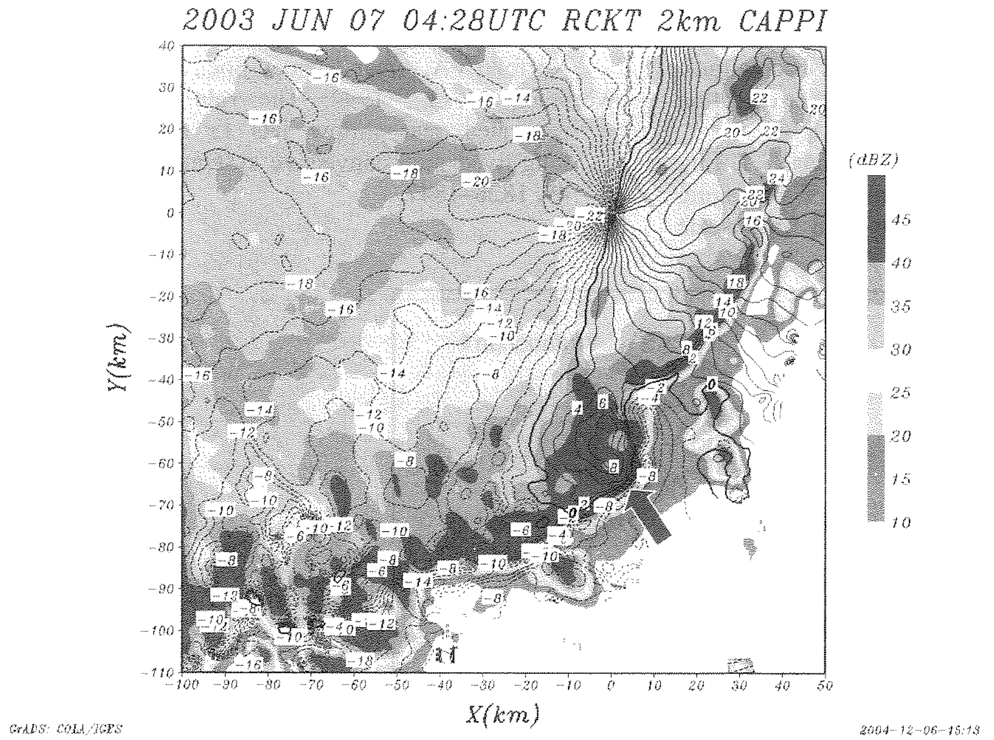

Fig. 3 The composite constant altitude plan position indicator (CAPPI) at the 2 km altitude collected from reflectivity (dBZ) and radial wind (m/s) data of the Kenting Doppler radar at 0428 UTC on 7 June 2003. The symbol "+" represents the radar site and the bold arrow stands for the location of bow echo. The domain size is 150 km x 150 km.

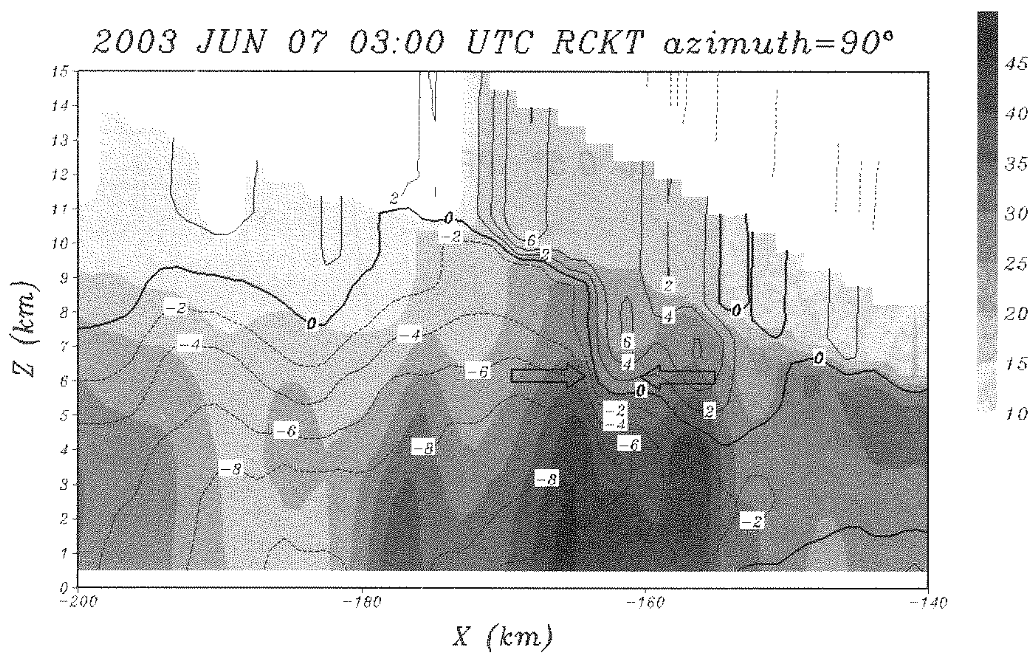

Fig. 4 The vertical cross section between x = -140 km and x = -200 km along y = 7.5 km collected from reflectivity (dBZ) and radial wind (m/s) data of the Kenting Doppler radar at 0300 UTC on 7 June 2003. The arrows stand for the wind directions at the altitude between 4 km and 9 km and specify the signature of mid-altitude radial convergence (MARC) in a mature MCS.

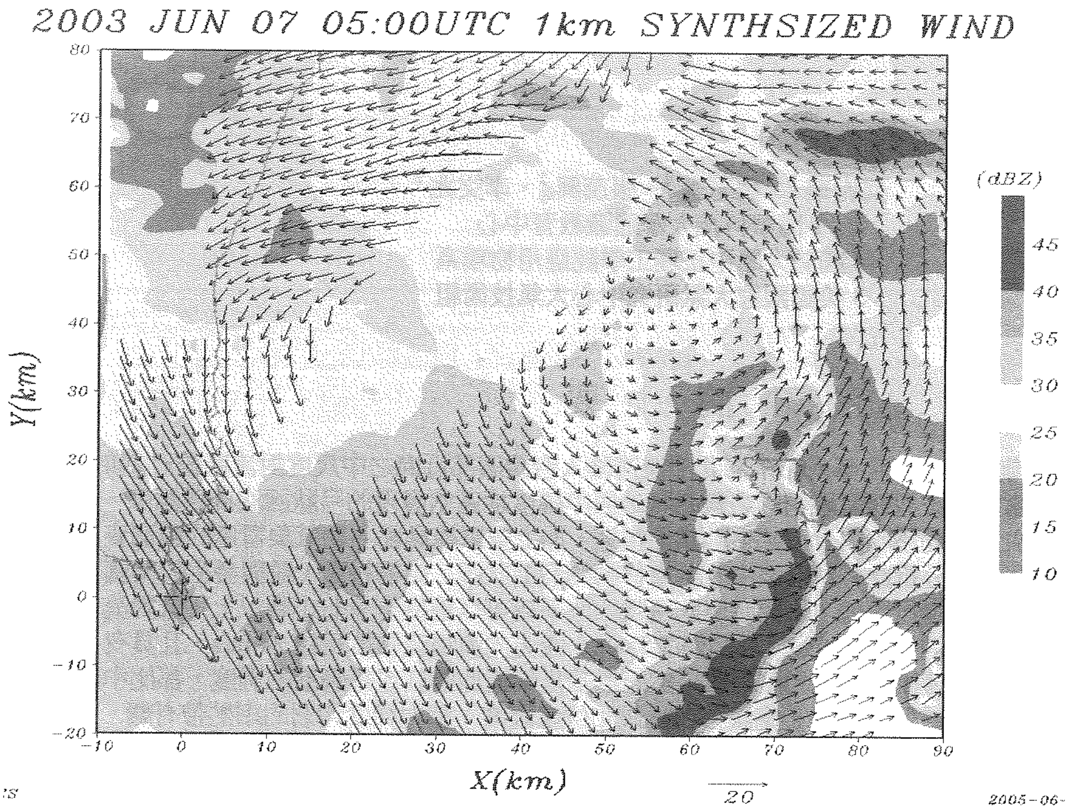

Fig. 5 The composite constant altitude plan position indicator (CAPPI) at the 1 km altitude synthesized from reflectivity (dBZ) and radial wind (m/s) data of the Kenting and Green Island Doppler radars at 0500 UTC on 7 June 2003. The symbol "+" represents the Kenting radar site. The domain size is 100 km x 100 km. The mesoscale convective vortex can be identified by wind arrows between x = 0 ~ 70 km and y = -10 ~ 70 km.

2003 年梅雨季臺灣南部近海弓狀回波的個案分析

何台華[1]、魏志憲[2]、張茂興[2]、李文兆[3]
1 龍華科技大學通識教育中心
2 國防大學中正理工學院應用物理系
3 美國國家大氣研究中心大氣技術組

摘　　要

在 2003 年 6 月 7 日自華南和南海北部快速移入台灣南部近海之中尺度對流系統，其前緣強對流區的雷達回波型態呈現明顯之彎曲狀，與中緯度地區常發現的弓狀回波極為類似。本研究利用中央氣象局墾丁與七股都卜勒氣象雷達，加上空軍綠島都卜勒氣象雷達的觀測資料，以接力賽的方式分析此弓狀回波由西至東移動的發展狀況、結構特徵，並與發生於美國地區之弓狀回波系統進行比較。研究發現此弓狀回波系統可以維持至少七小時以上，低對流層垂直風切甚小，從地面至 850 hPa 之間僅 7.5 m/s，後方內流噴流強度可達 24 m/s，且具有中高度徑向輻合、對流渦旋的中尺度特徵，然而無論是噴流的強度或是渦旋的渦度，都比中緯度陸上地區所觀測的個案為弱，應與移速過快和位處溫度、壓力梯度均弱的副熱帶有關。

關鍵字：弓狀回波、後方內流噴流、中尺度對流渦旋