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Characteristics Analysis of a Nocturnal Bow Echo

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***Abstract*—A nocturnal bow echo which occurred under the warm and moist environment in front of the upper trough caused short-term heavy rainfall and gust wind on 13-14 July 2012 in shanghai was analyzed based on the conventional data, radar data, lightning data and WRF simulation results. The analysis showed that: (1)The mid-level advection of dry and warm air which came from the southern subtropical high was the key environmental element that strengthened downdraft through evaporation and cooling. (2)The maintained strong downward sloping rear inflow jets (RIJ) together with the downdraft reinforced the pressure gradient at the leading edge of the bow echo were the main causes of the strong gust wind.(3) a vortex pair caused by strong outflow and strong environmental vertical wind shear caused the vertical development of the convection in the leading edge of the bow echo, which was the main mechanism of the bow echo's development and maintenance.**

***Keywords*—Bow echo; gust front; cold pool; RIJ; dry and warm air enrollment**

I. INTRODUCTION

Damaging surface wind is one of the most common severe weather. Types of windstorms which are responsible for damaging surface wind can vary widely, bow echo has long been recognized as one of the classical one. Bow echo is often connected with damaging straight-line winds and downburst [Nolen, 1959；Fijita, 1978；Przybylinski and Grey,1983], posing a significant hazard to life and property, and has been the research focus of severe convection.

Many observations and mechanism studies concerning about generation and development synoptic environment associated with bow echoes. Simulations of Weisman[1993] suggested that convective systems similar to the idealized bow echo may be generated in environment which the CAPE was at least 2000 $J\cdot kg^{-1}$ and the vertical wind shear was at least $20m\cdot s^{-1}$over the lowest 5 km AGL. In addition, the development of such systems was especially favored if most of this vertical wind shear was confined to the lowest 2.5 km AGL. However, some studies showed that the low-level (0-5 km) wind shear less than $20m\cdot s^{-1}$ could also generate the bow echo[Evans,2001；Coniglio et al.,2004], and high values of low level moisture was a major contributor to the warm season bow echo[Johns and Hirt,1987； Johns,et al,1990]. The general conclusion of these studies was that moderate to severe vertical wind shear and strong convective instability conditions were favored for the generation of bow echo.

The above research mainly aimed at the bow echo generated in instability conditions, while the observation and simulation of the bow echo in the relatively stable condition at night was relatively less. Observations [Trier and Parsons,1993]indicated that LLJ (Low Level Jets) intensified and veered during the night was favorable to the development of strong nocturnal mesoscale convective complexes (MCC). Numerical experiments [French and Parker, 2010] showed that nocturnal squall line system occurred in the stable boundary layer were closely related with the nocturnal LLJ, strong LLJ meant strong low level vertical wind shear, and the increase of the low-level vertical wind shear was favorable for the stronger lower lift condition. Wang et al. [2012] studied a long life time storm which developed from **s**upercell to bow echo, the results showed that since the bow echo generated at night, surface thermal instability was significantly reduced in the front of the bow echo's path, its self-organization structure and mutual interaction between the squall line and environment (high humidity in the low layer and strong vertical wind shear) were the dominant reason of its development and maintenance.

It is generally believed that there were two environmental conditions for the strong downdraft of thunderstorm: (1) a relatively dry layer in the middle troposphere; (2)large temperature lapse rate in the middle and low troposphere, the more close of the temperature lapse rate to the dry adiabatic, the more favorable for the strong downdraft.

However, in July 13-14, 2012, a nocturnal bow echo occurred in the moist and relative stable environment in front of the upper trough in the Yangtze River Delta region, which was different from typical bow echo background conditions. During the bow echo's lifetime, heavy rainfall of 15-28mm·h^{-1} (seven automatic station) and damaging surface winds of 7-9 levels (17 automatic station) were observed in western and northern areas of Shanghai. Using conventional weather data, QP-98D and WSR-88D Doppler radar data, automatic weather station data, lightning data and combined with numerical simulation results of Weather Research and Forecasting Model(WRF), the nocturnal bow echo over the Yangtze river delta region was analyzed, especially was its formation and maintenance mechanism.

The paper is organized as follows. Section 2 presents the synoptic and mesoscale environment observed on 13 July 2012, while section 3 provides a overview of the event and the damage that was observed. Detailed simulation results are analyzed in section 4 to better understand the bow echo, while section 5 summarizes the straight-line wind cause and bow echo's maintenance mechanism. Discussion and conclusions are finally presented in section 6.

II. SYNOPTIC AND MESOSCALE ENVIRONMENT

A. synoptical environment

At 500hPa in Fig. 1a, central East China was in front of a trough, southwesterly flow was observed with the speed of 8-16 m·s^{-1}. At 850hPa in Fig. 1b, easterly and southwesterly wind shear line was along northern Jiangsu province to central Anhui province, broad southwest flow was observed advecting humid and warm air into Yangtze River Delta area. On the surface, most areas of central East China were covered by a surface low. Weak easterly wind(1-2 levels) were observed in the Shanghai mesoscale automatic station observation network, and there was no obvious convergence and temperature front area.

Therefore, due to the warm and humid air ahead of the upper trough and along subtropical high edge, combined with low layer convergence lifting condition, strong convective weather such as short-time heavy rainfall may occur in the Yangtze River Delta area.

B. Mesoscale analysis

Fig.2 were the 1200 UTC sounding at Anqing(58424,2a), Baoshan(58362,2b), Hangzhou(58457,2c) and Quzhou(58633,2d). A relatively dry mid-tropospheric layer was observed in Hangzhou(Fig. 2c) and Quzhou (Fig. 2d) which allowed for large DCAPE (downdraft convective available potential energy) while Anqing(Fig. 2a) and Baoshan's(Fig. 2b) whole layer were humid (PWV were 71.2mm and 63.9mm respectively).Some convective indexes were shown in table 1. CAPE (convective available potential energy) value were low, the temperature lapse rate were 5.0□·km^{-1}、5.7℃·km^{-1}、6.0℃·km^{-1} and 7.7℃·km^{-1} at 700-1000hPa respectively. Since the convection occurred at night, the temperature lapse rate and CAPE value would not change significantly with no warming conditions.

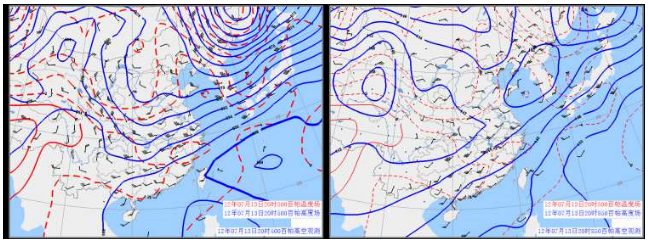

Fig. 1. The 1200 UTC 13 Jul. upper-air analysis at 500 and 850hPa. Solid and dashed lines show the geopotential height (dagpm) and temperature fields (°C) respectively. Winds are also shown (half barb 2 m·s^{-1}; full barb 4 m·s^{-1}; flag 20 m·s^{-1}).

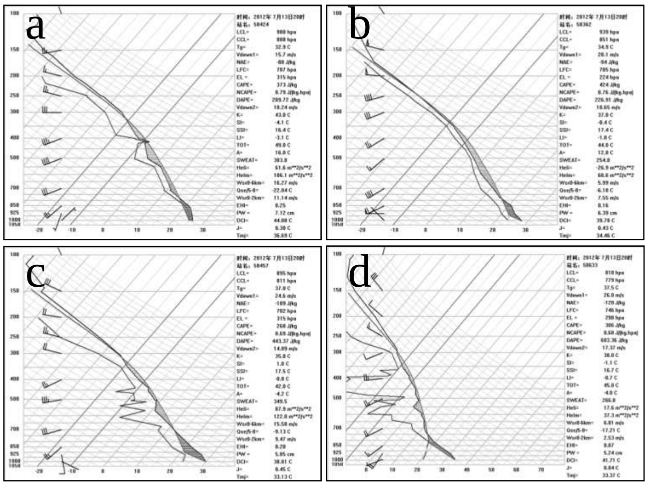

Fig. 2. Skew T-LogP sounding diagrams and convective indices for (a)Anqing, Anhui(b)Baoshan, Shanghai(c)Hangzhou, Zhejiang (d)Quzhou,Zhejiang 1200UTC 13 July 2012

Table1 convective parameters of Anqing,Baoshan, Hangzhou and Quzhou 1200 UTC 13July 2012

Parameters	Anqing	Baoshan	Hangzhou	Quzhou
CAPE(J· kg^{-1})	373.00	424.00	268.00	306.00
K(℃)	43.00	37.00	35.00	38.00
Li(℃)	-3.10	-1.80	-0.80	-0.70
DCAPE(J·kg^{-1})	209.72	226.91	443.37	603.36
Wmax(m·s^{-1})	10.24	10.65	14.89	17.37

The environmental wind change with the height often reveals the shape and trend of the thunderstorm's development. There are two methods for calculating the vertical wind shear, the bulk wind shear [Weisman and Klemp, 1986], and total wind shear[cumulative wind shear, Rasmussen and Wilhelmson,1983]. For the wind field which doesn't change with height, the total wind shear is always equals to the bulk wind shear, otherwise the total wind shear is higher than the bulk wind shear. 0-3km and 0-6km vertical wind shear calculation results are shown in table 2. Due to the weak wind speed at 500hPa in Baoshan(58632), the 0-6km bulk wind shear was only 5.99m·s^{-1}, but the total wind shear can reach to 27.06 m·s^{-1}. QP-98D radar wind profiler products (VWP) showed that 500hPa wind increased before the storm came into Shanghai (0-6km bulk wind shear increased to 12.17m·s^{-1}). Therefore, strong vertical wind shear conditions were favorable for the development and strengthening of the bow echo [Weisman, 1993].

Table 2 vertical wind shear of Anqing, Baoshan, Hangzhou and Quzhou 1200 UTC 13July 2012

shear(m·s^{-1})	**Anqing**	**Baoshan**	**Hangzhou**	**Quzhou**
0-3km Bulk wind shear	13.37	16.02	12.97	8.79
0-3km Total wind shear	17.83	16.88	17.38	11.68
0-6km Bulk wind shear	16.27	5.99	15.58	6.81
0-6km Total wind shear	20.84	27.06	20.61	13.68

III. CHARACTERISTICS OF THE BOW ECHO

During the identification time by WSR-88D SCIT algorithm, the storm evolved to deep convection in the earliest stages (1218UTC-1428UTC, Fig. 3.), Echo Top(ET) was 15km, VIL was 40 kg·m^{-2} at 1330UTC, which were the highest value during its life cycle. Corresponding lightning activity also reached its peak stage after 12min, positive lightning activities reached the peak value at the subsequent 12min, while vertical development of thunderstorm began to weaken, showing typical single thunderstorm evolution features during life cycle. However, despite echo top continued to decrease, VIL was still around 30 kg·m^{-2}, at 1500UTC the storm continued to develop, and lightning activity reached secondary peak. Before arrived in Shanghai, the height of storm and associated lightning activity continued to decrease, ET was 10km at 16:00UTC, strong echo (50dBz) fell to below 0℃ layer, therefore lightning activities began to weaken. After entering Shanghai, ET reduced to 6-8km, while the height of maximum reflectivity (HMR) was at 4-5 km.

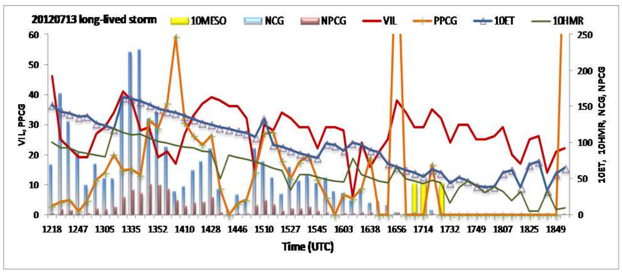

Fig.3. Time series of storm structure and lightning activity of a long-lived storm in the Yangtze River Delta in the evening of Jul. 13, 2012

The long-lived storm evolved into the bow echo at its late stage, mainly included the following stages: (1) at 1536 UTC, one linear multi-thunderstorm merged with another new initiated storms south of it in northern Zhejiang, moved east-northeasterly together,(2) RIJ was visible as a characteristic of the thunderstorm, the multi thunderstorm evolved into a bow echo at 1606 UTC,(3) at 1748 UTC, the bow echo had a outward apex, Rear Inflow Notch(RIN) were observed at the 0.5 °elevation reflectivity field, Rear Inflow Jets (RIJ) was visible at the maximum value. The apex of the bow echo caused southwest gust winds at Baoshan(14.4m·s^{-1}) ,Lingqiao(14.5 m·s^{-1}) , and Wusong (26m·s^{-1}).

A. *evolution from multi-storms to bow echo*

At 1200 UTC, thunderstorms began to initiate at southern Anhui and northern Zhejiang province, and moved east-northeasterly. At 1536 UTC, a linear multi-thunderstorm merged with another new initiated storms south of it, moved east-northeasterly together.

At 1548 UTC, the 26m·s^{-1} RIJ was first visible as a core of radial velocity at 2.4° elevation of QP-98D radar; at 1600 UTC, the RIJ increased to 40m·s^{-1} (the velocity ambiguity appeared) at 2.4° elevation. At 1606 UTC RIJ was 40m·s^{-1} at both 2.4° and 3.4° elevation(Fig. 4c, 4d), the height was about 2.1and 2.9km. RIJ caused the mid-level flow accelerated into the convection from rear, as a result, the convective cells propagated more quickly at the core of the system, helping to create the bow shape [Fujita, 1978]. Meanwhile, the maximum reflectivity of 60 dBz was observed, and also was large reflectivity gradient in the leading edge. The cross section showed the existence of weak echo region (WER, Fig. 4b white ellipse) in the inflow side, while echo top was above the WER, all of which were common features of bow echo. The reflectivity core (>=50dBz) was at the height of 5-6km, and echo top was at about 12km. The multi-thunderstorm evolved into the bow echo.

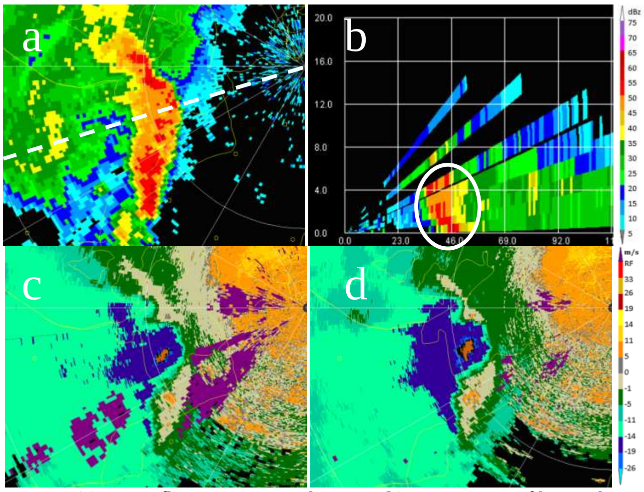

Fig. 4. (a)Base reflectivity at 1.5° elevation,(b)cross section of bow echo at 1.5° elevation, (c)radial velocity at 2.4°elevation, (d) radial velocity at 3.4° elevation 1606 UTC 13 July 2012 of QP-98D

B. *Bow echo's characteristics in mature stage*

After the multi-thunderstorm evolved into the bow echo, it continued to move east-northeasterly. At 1648 UTC, the leading edge of the bow echo had approach Western Shanghai, high reflectivity gradient were still visible, echo top was up to

8 km, and the VIL was 25-30 kg·m^{-2}. RIJ still existed and the convergence band were also observed at 1.5°- 2.4°elevation in the leading edge.

At 1706 UTC, since the weakening of the southern thunderstorm, the narrow band echo (southern gust front) along the leading edge of bow echo on reflectivity field was clear.

At 1748 UTC(Fig. 5b), compared with the previous time, the bow echo had a outward apex, while RIN was visible at the low level reflectivity field. However, since the bow echo located in the northwest of WSR-88D, and RIN directed to the northeast, which was perpendicular to radial direction, so the great value of RIJ was not observed correspond to the RIN. QP-98D radar showed that RIJ as a core of radial velocity was 47 m·s^{-1} at 2.4° elevation since 1712 UTC, then the area of the jet flow increased, reached to the maximum area at 1748 UTC, while the outflow was 26 m·s^{-1} at 0.5° elevation, and was 47 m·s^{-1} at 2.4° and 3.4° elevation. The apex of the bow echo caused southwest gust winds at Baoshan(14.4 m·s^{-1},1746 UTC) ,Lingqiao(14.5 m·s^{-1} 1748UTC) , and Wusong (26m·s^{-1} ,1749 UTC),which was consistent with weak echo channel may mean the downburst and possibly tornado caused by downburst [Przybylinski and Gery,1983].The reflectivity cross section of bow echo had no significant weaken or decline due to the bow echo fast moving (50km·h^{-1}). Since then, the bow echo moved eastward to the sea, continued to develop several hours due to the favorable sea temperature and humidity conditions.

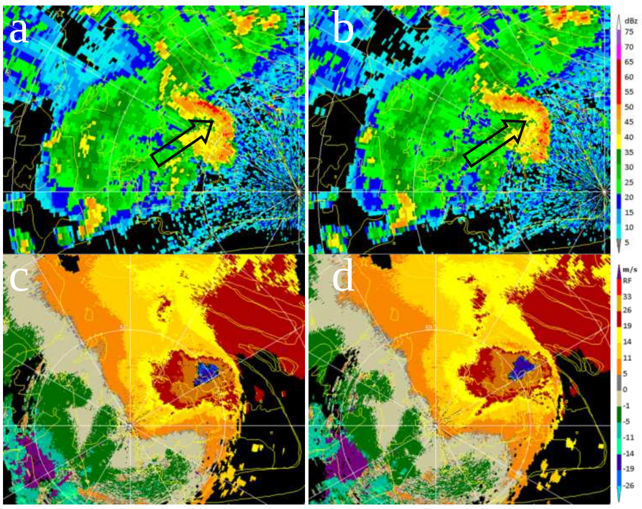

Fig.5. Base reflectivity at (a)1742 (b) 1748 BT 14 July 2012 at 0.5° of WSR-88D and radial velocity at (c) 1742 (d) 1748 UTC 13 July 2012 at 2.4° elevation of QP-98D

Since the warm updraft climbed onto the low layer cold pool, a mid-level mesolow formed behind the leading edge of the storm. Due to low-level divergence, convergence of compensation flow formed in the middle layer, which was the RIJ. RIJ is an important feature of the squall line system, which lead the dry and cold mid-level air to the ground, causing and strengthening downdraft of the convective storm[Smull and Houze,1987].

Weisman [1992] studied the effect of RIJ on the evolution of the mesoscale convective system in the long life history, and found that the strengths and the height of RIJ were influenced by CAPE and the environmental vertical wind shear. In this process, RIJ remained at the height of 2-4km and just descent to the surface in front of the gust front. The strong vertical wind shear(0-3km 16.88m·s^{-1})was the key to the maintenance of cold pool and the height of RIJ [Weisman, 1993]. Strong vertical wind shear at low level prevented the cold pool from quickly leaving the main storm, and the appropriate convective buoyancy made RIJ maintain at 2-4km, causing the storm maintained a long lifetime.

RIJ remained at a strong level of 26-47 m·s^{-1} was a distinct characteristic of this bow echo, the reason that contributed to the evolution and strength of RIJ still need to be researched.

Mid-altitude radial convergence (MARC) is a feature of the bow echo which is assumed to be transition zone from front to back strong ascending flow and RIJ [przybylinski, 1995], if velocity difference reaches the 25-50m·s^{-1}at 3-7km, the MARC feature is supposed to be significant. MARC (white circle) can be observed in this process ,with the height of 4-6km, the and velocity difference was 25 m·s^{-1}.

The results of the present study[Atkins et al.,2005；Wakimoto et al., 2006；Wheatley et al., 2006] provided clear observational evidence that, in addition to descending rear inflow at the bow echo apex, low-level mesovortices within bow echoes can produce damaging straight-line winds at the ground. The WSR-88D mesocyclone Detection algorithm (MDA) identified mesocyclone at 1706,1712, and 1730 UTC. However, these mesocyclone only last a short time and didn't cause severe damaging winds.

In addition, since strong reflectivity (>=50dBz) only covered the frontier area of bow echo, and fast moving of the bow echo, the maximum hourly precipitation and accumulated precipitation were only 28.0mm and 28.8mm. Because the reflectivity core (>=50dBz) was mainly concentrated under 5km,so the VIL value was only 25-30kg·m^{-2}(maybe underestimated due to its fast moving). The lightning activity was not intensive, since the reflectivity core 50dBz) was mainly concentrated under 5km(freezing level).

IV. WRF SIMULATION RESULTS ANALYSIS

In order to reveal the evolution mechanism of bow echo and reasons for thunderstorm damaging wind under the warm and humid, stable boundary layer and strong vertical wind shear environment conditions, The mesoscale numerical weather prediction model WRFV3 (2008.4 3rd Edition) was used to simulate severe thunderstorm events from 1200 UTC 13 July, 2012 in the Yangtze River Delta Region.

A. WRF simulation results overview

WRF model simulation results showed that thunderstorms initiated at 1300 UTC near the west -southwest jet axis which was on the south side of low level shear line, which was consistent with the Hefei radar observation, and moved in the direction of east-northeast. At 1750 UTC(Fig. 6f) the storm

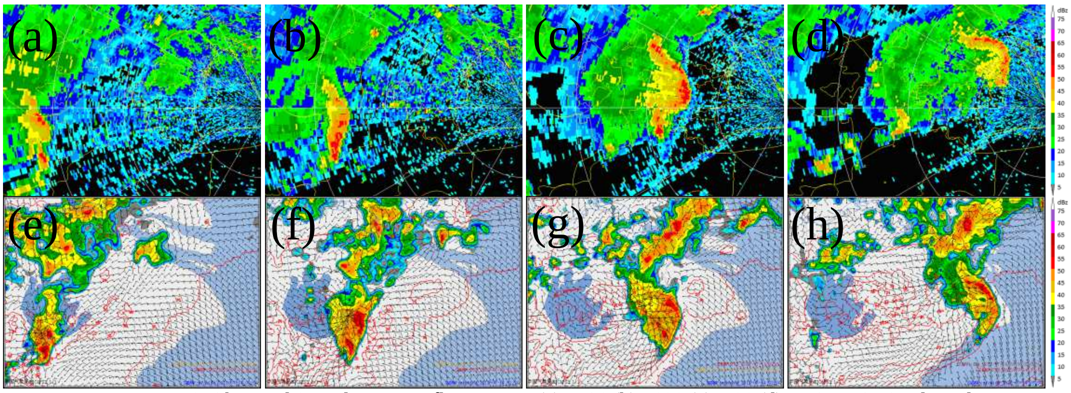

Fig.6. Observed 0.5° elevation reflectivity at (a) 1536 (b) 1606 (c)1706 (d)1748 UTC 13 July and WRF-3km simulated base reflectivity at 850 hPa (shaded) with ground temperature (red line , □) and surface wind (vector, m·s^{-1}) at (e)1650 (f)1750 (g)1850 (h)1950 UTC13 July 2012

a

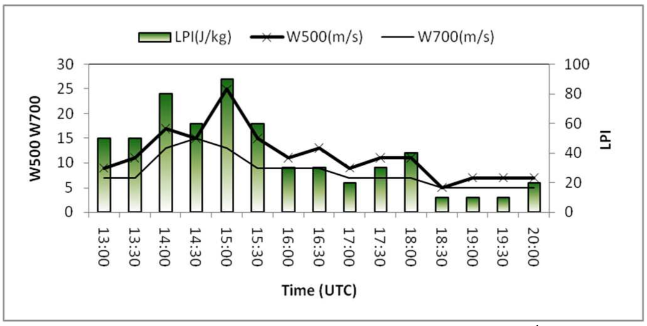

Fig.7. WRF model outputs of maximum vertical velocity (m·s^{-1}) at 500hPa and 700hPa and the maximum LPI (Lightning Prediction Index, in J·kg^{-1}) of the storm

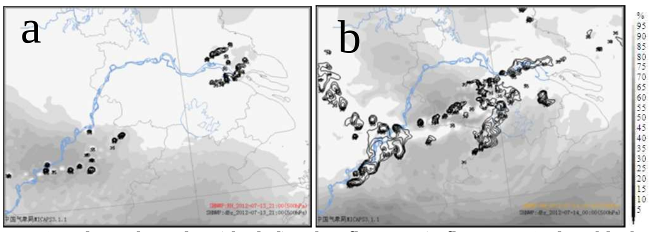

Fig.8. relative humidity (shaded)with reflectivity(reflectivity≥35dBz, black solid line) of 500 hPa at (a)1300 UTC (b)1830 UTC 13 July 2012

approached Shanghai, and evolved into the bow shape echo at 1850 UTC(Fig. 6g). Compared with the observation (Fig. 6a-d), the overall movement of the simulation is slightly south, and time-delayed due to the lack of radar assimilation.

Fig.7. was time series of maximum upward velocity at 500hPa and 700hPa of simulated storm center and the corresponding Lightning activity index (LPI),which was close to the observation (Fig.3). Fig.7 showed that LPI was severe at the early stage, while was gradually weak at the late stage. When the storm approached Shanghai (1600 UTC or 0200 BJT), lightning activity decreased significantly, so did the LPI index.

B Sorm environmnet features

When thunderstorm first initiated in the vicinity of 500 hPa moisture frontal zone, Shanghai's whole layer was in high humidity (Fig.8a). During thunderstorms eastward movement, a relatively dry area (relative humidity in 50%-70%) in the south of Hangzhou Bay continued to move northward (Fig.8b), which was from subtropical high(consistent with the sounding of Hangzhou (Fig. 2c) and Quzhou (Fig. 2d)) . The northeast advection of the dry and warm air can provide the dry air for strong evaporation precipitation for bow echo. In addition, the model forecast sounding showed that when the bow echo approached Shanghai, 0-3 and 0-6 km vertical wind shear (31.21 °N, 120.60°E)were about 18.3 m·s^{-1}.

C the evolution of storm structure

Convective storm initiated from northern Zhejiang mountain area firstly, with stratiform precipitation at the front. The storm moved east-northeasterly, its bow echo characteristics appeared at 1530 UTC (Fig. 9a). Cross section along the moving direction showed that (Fig. 10a), convective reflectivity core (>= 50 dBz) mainly located below 0℃layer, which was the dominant characteristics of warm cloud. Storm relative wind and relative humidity profile (Fig. 10b) showed that, a relatively warm and dry air from about 5 km height flowed into the middle layer at the rear side of the storm, continued to move downward and merged with the dry and cold downdraft and reached the ground together along the direction of the black arrow, forming a dry air channel (Fig. 10a,10b).

In warm and humid environment, high humidity was supposed not to be favorable for the precipitation evaporation, while precipitation drag effect was the main source of downdraft in the storm. The establishment of the dry air channel showed that the humidity of the middle layer was reduced, thus increased the evaporation of precipitation, reduced the temperature, increased the density of the air in the storm, and strengthened the downward movement together with the precipitation drag effect. Simultaneously, downward motion led more dry air arrived at the lower level of relatively warm and humid environment, significantly increased the negative buoyancy, thereby increased the downward movement of the storm in the original warm and humid environment.

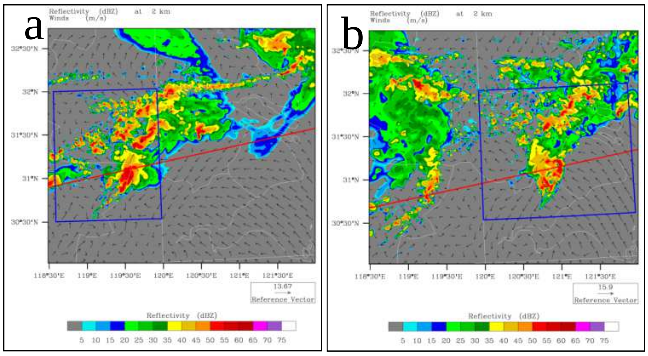

Fig.9. WRF-3km simulation of 2km reflectivity with surface wind (a) 1530 UTC (b) 1830 UTC 13 July 2012. Red lines represent storm motion and the cross section direction, and blue rectangles for enlargement

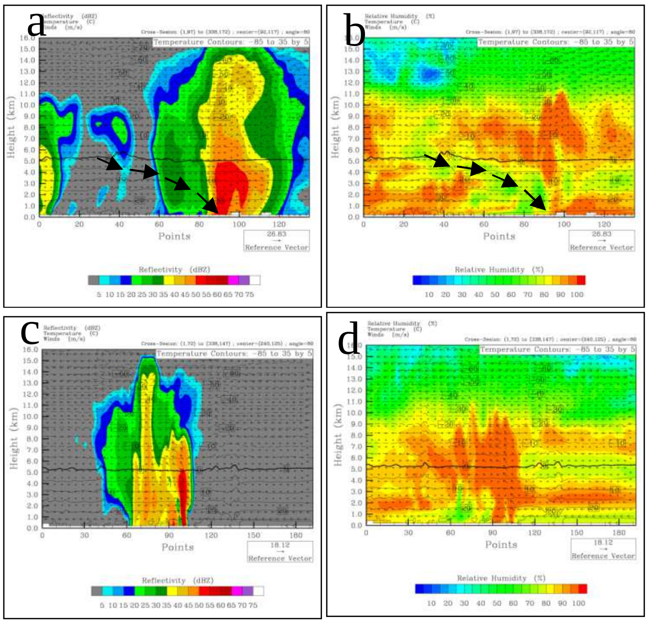

Fig.10. WRF-3 km simulation of temperature, storm-relative wind with (a,c)cross sections of reflectivity, and (b,d)with relative humidity, along the red line in fig. 9(a,b) at 1530 UTC and 1830 UTC 13 July 2012

Storm evolved to a medium scale convective system (Fig. 9b) with distinct bow echo characteristics at 1830(UTC). Fig.10c and 10d showed the storm structure and environmental characteristics at the moment. Strong reflectivity area(≥50dBz) in the front of the storm was still below 0□ layer, its low center of gravity as dominant characteristics of warm cloud maintained; the echo top of the main convective storm was up to 8km. In addition, the original relatively dry warm air in the middle layer at the rear of the storm had disappeared (Fig. 10d),and formed relatively dry area in the main precipitation area in the lower layer, corresponding to the strengthened cold pool.

V. ANALYSIS OF THE CAUSE OF GUST WIND AND MAINTENANCE MECHANISM OF BOW ECHO

A. reason of the gust wind

During the evolvtion of the bow echo, the temperature lapse rate was only 5.7℃·km^{-1} at 700-1000 hPa,and and it didn't change obviously because of the lack of ground heating, so the negative temperature difference between downdraft(in its downward warming process) and the environment was small,which was not conducive to the downdraft downward acceleration.

Strong reflectivity core (more than 50dBz) mainly concentrated under 5 km(freezing level), low center of gravity of warm cloud characteristics was obvious.Lightning activity was not dense,which indicated that the number of ice particles was not much, therefore melting, evaporation and endothermic effect of ice particles had not obvious contribution to the downward motion.

The intense downward sloping RIJ at the rear side was one distinct characteristics of the bow echo, and WRF simulation results showed that during the storm's eastward movement, another important feature was the northward advection of dry and warm air from southern subtropical high. Therefore, the relatively dry air entrained from the middle level of the southern subtropical high and led into the storm by RIJ, increased the particle evaporation, caused the decrease of the temperature in the storm, and intensified downdrafts together with precipitation drag effect. Downward movement caused more dry air reached the lower layer of warmer and more humid environment, increased negative buoyancy, thereby reinforced the downward movement of the storm in the original warm and humid environment, which was favorable to enhance the ground high at the bottom of the storm.

Therefore, advection of warm and dry air from the southern subtropical high and the continued intense RIJ, strengthened the nocturnal bow echo downdraft, intensified the ground high strength, thereby increased the pressure gradient at the front side of the bow echo, together with the speed of 50km·h^{-1},caused the nocturnal gust wind in Shanghai.

B. maintenance mechanism of the bow echo

Fig.11 was a conceptual model of mature nocturnal bow echo. Horizontal reflectivity distribution showed that strong echo and high gradient reflectivity area concentrated in the front of the system, while at the rear side also had the strong echo area. Among them were the weak echo, which corresponded to the storm dry downdraft zone, and located in front of the cold pool. Downdraft dry zone together with the cold pool's divergent air, strengthened downward motion in front of the cold pool, and constrained the elevated RIJ down to the ground, downward movement together with RIJ formed gust front.

The appearance of the gust front strengthened the front upward motion, which was similar to the normal squall line in Shanghai[Yao et al,2005].This type of convection often occurred below the middle and high level jet, which generated the key environment elements of strong vertical wind shear along the moving direction, and together with the formation of gust front, formed a pair of matching vortex which was opposite in direction, caused the vertical development of the convection in the leading edge.

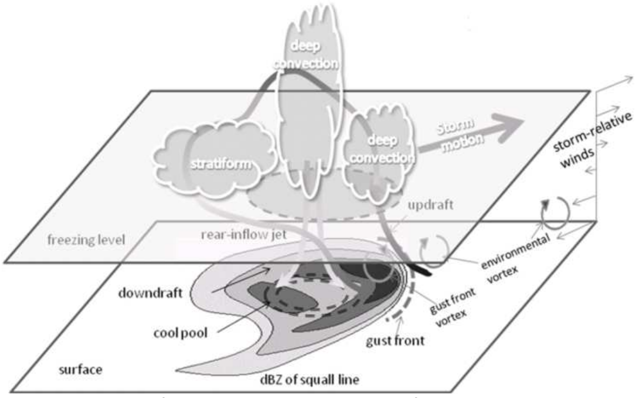

Fig.11 Illustration of structure conceptual model of a bow echo on 13 July 2012

VI. CONCLUSION AND DISCUSSION

The nocturnal bow echo occurred in the warm and humid environment ahead of the upper trough in 13-14 July,2012 was analyzed by using synoptic data, radar data, lightning data and WRF simulation results, the following conclusions can be obtained:

(1)Different from the typical bow echo generation environment and strong downdraft thunderstorm background, the bow echo occurred in front of the upper trough of warm and relatively stable boundary layer at night, with no lower heating effect, the CAPE value remained at a low level. Vertical wind shear were of large value; bow echo formed by the merging of two multi-cell thunderstorm, the height of the reflectivity core (>=50dBz) was below 5km, which was the dominant characteristics of warm cloud, and the VIL value was in the 25-30 $kg\cdot m^{-2}$, the lightning activity was not dense enough, which was different from the common features of bow echo structure.

(2)The advection of dry warm air from the southern subtropical high in the middle layer, strengthened the precipitation evaporation cooling effect, caused the significant increase of the downward movement, and was the key environmental factor of long swath of surface winds; the maintained forward downward sloping RIJ at the rear side of the bow echo system, together with the downward movement in the thunderstorms strengthened the pressure gradient in the front of the storm, which was the main cause of the gust wind.

(3)Strong low-level environmental vertical wind shear prevented the bow echo cold pool from leaving the storm quickly; and a pair of matching vortex opposite in direction which were generated by the downdraft and RIJ and low-level environmental wind vertical shear triggered the vertical development of new cell, was the key maintenance mechanism of bow echo.

The analysis of the nocturnal bow echo showed that, similar to the synoptic background as ahead of the upper trough, even if the instability energy is relatively low, close attention should paid to the low-level vertical wind shear and dynamic lifting condition; for squall line as bow echo, great concern should be paid to radar characteristics as RIJ (height, intensity)and gust front, which were the key elements of the system's development and maintenance, thus to improve accuracy and time efficiency of short-time forecast.

Compared with other studies, such as Srivastava's [1985] simulations using one dimension cloud model showed that, a higher relative humidity in the environment is conducive to stronger downdraft because the environment is then virtually warmer, which is opposite to the concept of higher relative humidity will reduce the evaporation potential, thus produce smaller downdraft velocity. Proctor [1989] got similar results using three-dimensional numerical simulation. The increase of humidity in the low layer atmosphere will increase the intensity of the downdraft, and the increase of humidity near the melting layer will slightly decrease downdraft intensity. That is to say, in addition to the high melting layer height and deep dry insulation layer, the dry air near the melting layer and low layer relative humidity environment will produce the strongest downdraft. In addition, the simulated intensity of the downburst will increase with the increase of surface precipitation intensity, mainly because there are more precipitation particles to absorb heat, and reduce the ambient temperature. Therefore, whether the whole high humidity environment is conducive to the intense downdraft, can also be further discussed through sensitive tests etc.

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