Analysis of the characteristics in a typical thunderstorm gale event in South China*

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Abstract

Using the data of conventional sounding, surface observation, NWP products ,auto- meteorologic stations of Hunan and Doppler radar in Changsha ,a typical thunderstorm on April 17, 2007 in Hunan province, China was investigated and the results show: 1. Warm days before the event provided abundant instable energy, instable stratification and wind vertical shear were favorable for severe convection. 2. The small trough in the Qinghai-Tibet plateau merged with another trough from east and got deep which led the cold air on the ground surface moving south rapidly and the dynamics was transported from high to low altitude, the weather background for gust event was set. 3. The disturbance kinetic energy at 850hPa, the uneven distributed disturbance temperature at low altitude which caused front-genesis and instable stratification of dry at high and moist at low altitude were the triggers for the event. Even though the strong ascending movement caused by convergence at low altitude,but the pumping effect at high altitude was not strong enough and that may be the reason of severe convection with short duration and limited precipitation. 4. Low centroid echoes without weak echo region were the main feature for the event. Comparing with the super cell storm, the updraft was weaker. It was a typical gust echoes in this event that cold air poured rapidly, the high area of VIL above 20kg/m^2 moved southeast. 5. The cold front on the ground surface, meso-convergence at mid-low altitude, adverse wind area were the major systems for the event, and the divergence in the north of narrowband echo was benefit for the thunder- gust.

Keywords: thunder-gust, radar, analysis

1. Preface

Since the building of the new generation weather radar network of China in 1999, Chinese meteorologists acquired good foundation for convection study thanks to the high sense and velocity detection capabilities. The new generation weather radar is widely used for disastrous weather events, especially the convective and rainfall related meteorological hazards [1]. Focusing the operational demands, the corresponding researches were conducted such as work of YU et al. [2], which analyzed a tornado in Wuwei county Anhui province in the night of July 8, 2003 and found that the meso-cyclone which triggered the tornado was confined to the air below 4 km and the reflectivity showed a typical super-cell characters, work of ZHENG et al.[3] investigated a super-cell event in north Anhui province on May 27, 2002 and found that outlet boundary, reversed V shape structure, weak echo, echo wall and meso-cyclone. Work of ZHANG et al. indicated that the radar products are capable for understand the evolution of severe convection and hailstone identification with the data

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of Pinglian in Gansu province. Studies[5-8] show that with the different radar products, the ability to monitor and forecast the convection with hail, thunder and heavy rainfall can be improved.

Hunan province has a subtropical monsoon moist climate; the warm wet air from the south often meets the clod dry air from the north in Hunan, together with the complex geography, thunder, rain storms and hailstone, gust occurs from time to time. Severe rainstorm shows a very high probability in Hunan especially from March to September with heavy loss of human life and various industries. April 16-17, 2007, a convection occurred with gust, hail and short time heavy rain in Hunan from north to south, the gust of magnitude 8 recorded in 34 weather stations with the maximum of 36m/s(ChengBu), the hailstone of diameter over 5mm(ChaLing) was observed and the maximum precipitation was 37.2mm(SuiNing).

2. Weather situation

08:00 of July 15, 2007（(Beijing time, similarly hereinafter)）there were 2 troughs which located in the east China sea and mid-high latitude of Eurasia and 1 ridge over the mid and high latitude of Asia.Hunan lay in the ridge which was back to east Asia trough with a high meridional circulation.The wind speeds of Changsha, Huaihua, Chenzhou reached 28, 24 and 22 m/s at 500 hPa. Controlled by warm low pressure at ground surface the temperature rose in the clear sky. 08:00 of April 16, a short wave from the Qinghai-Tibet plateau moved east, at 850hPa the low vortex was in the central of Sichuan basin and shear lay from south of Chongqing to north of Hunan. The temperature in Hunan kept high and over 24℃ in most of weather station and some even reached 30℃ in the south part on April 16, the instable energy was prepared for severe convection. A cold air moved south from inner Mongolia passing Ningxia-Gansu-Sichuan.

20:00 April 16 the trough moved and split，southwest jet at 700hPa enhanced quickly, the wind speeds at Changsha and Huaihua reached 16 m/s, the low vortex at 850hPa arrived in north of Sichuan basin, and the shear-convergence got intensive in the north Hunan. On the ground surface, there was a clear cyclone-genesis from the mid reach of Yangtze River to the south of Sichuan basin and a large area of strong north wind. About 02:00 April 17 the cold front on the ground surface effected north Hunan.08:00 April 17, the cold trough coming from the plateau combined with the short wave trough and moved to west Hubei to Guiyang. The southwest stream intensified to 20～28 m/s at 500hPa, the shear from mid to low altitude lay in northeast to southwest of Hunan with a strong convergence, cold front moved to south Hunan. As the trough at 500hPa moved ahead of shear at mid and low altitude, the cold advection intensified and lead the cyclonic wave on the ground moved from north to south, and thunderstorm hit Hunan (fig 1). 20:00 April 17 the trough in up air moved to southwest China area close to sea, the cold high pressure moved down and the weather in Hunan turned fine.

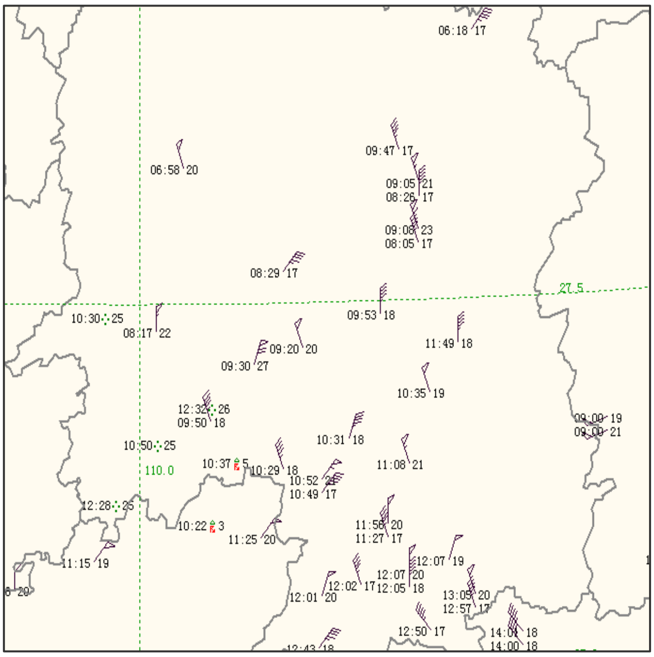

Fig 1. weather phenomena in Hunan from 20:00 April 16 to 20:00 April 17

It can be found from sounding data at 08:00 April 16 that, the winds in 3 weather stations of Hunan turned clockwise from low to high altitude before the convection, which means there was medium level of wind vertical shear with warm advection. Tab 1 shows that the negative energy and negative Si indices indicating instable structure appeared in Huaihua in west Hunan and Chenzhou in south Hunan at 20:00 April 16. there was severe convection in Huaihua from 08:00-10:00 April 17 while K index there was pretty high and Si was -4～-7 indicating very instable air structure and easy to lead convection. For Chenzhou, convection appeared from 12:00 to 13:00 April 17 and the CAPE increased from negative to a high positive number and K index was 36. 20:00 April 17 as the convection ended the instable energy, K index decreased rapidly and Si turned to positive, the air structure changed into stable.

Tab 1. CAPE, K and Si index from 20:00 April 16 to 20:00 April 17

Index	Date	Changsha	Huaihua	Chenzhou
CAPE （J/kg）	20:00, 16	1551.4	-81.5	-977.7
	08:00, 17	2815.7	3356.8	-1893.5
	20:00, 17	6497.7	5534.5	6144.1
k	20:00, 16	29	41	32
	08:00, 17	26	41	36
	20:00, 17	6	15	32
Si	20:00, 16	4	-4.1	-3.1
	08:00, 17	5.2	-6.7	-1.4
	20:00, 17	16.6	10	18.5

3. Disturbance analysis

Using global model T213, limited area elements such as disturbance energy, disturbance temperature, and disturbance humidity were calculated. Since the average values were neglected, it can better describe the characters of meso-scale weather and find out the mechanism for the storm event.

3.1 Disturbance temperature

The negative disturbance temperature appeared at 20:00 April 16 in north Hunan and positive center in south Hunan (fig 2a), the north part of central Hunan showed a high temperature gradient which means the cold front on the ground surface. 08:00 April 17 the high temperature gradient area moved to south to the central Hunan indicating the cold front moved south and the radar data showed the intensive echoes, the severe convection developed and got intensified (fig 2b). 20:00 the center of disturbance temperature moved to Jianxi and south of Fujian provinces while the cold front on ground surface moved to the south boundary of Hunan, the convection ended(fig 2c).

The vertical distribution of disturbance temperature shows (fig3a,3b), the main disturbance lay below 700hPa and the maximum appeared at 1000hPa, and the value was low at the high altitude, the positive disturbance moved continuously south.20:00 April 17, the positive disturbance temperature center moved to 23°N just ahead of cold front on ground surface, the cold down stream controlled Hunan and the sky turned clear(fig 3c).

It can be conducted that the uneven distribution at low altitude was one of the major factors for the front-genesis.

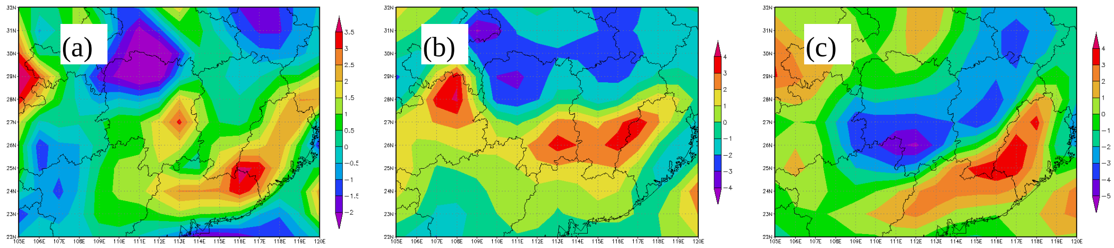

Fig 2. temperature disturbance at 1000hPa (a: 20:00 April 16, b: 08:00 April 17, c: 20:00 April 17）

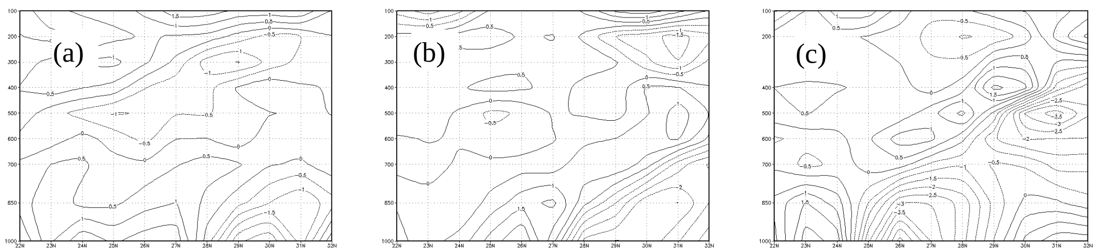

Fig 3. Vertical diagram of temperature disturbance. (a: 20:00 April 16, b: 08:00 April 17, c: 20:00 April 17)

3.2 Disturbance kinetic energy

The maximum of disturbance kinetic energy located in north Hunan at 08:00 April 17, 2007 (fig 4a) and moved south, it arrived in central Hunan at 14:00(fig 4b), and moved out of Hunan at 20:00, it got fine in Hunan then(fig 4c). The moving feature of high center of disturbance kinetic energy matched the echoes of severe convection in radar, even a little north to the convection, it was a good indicator for convection developing and moving. The vertical distribution of disturbance kinetic energy it can be found that the maximum was below 850hPa. Taking account of mass decrease of air mass as the height increased, the value of disturbance kinetic energy at low altitude was bigger, so the disturbance kinetic energy at 850hPa may be one of the trigger mechanisms.

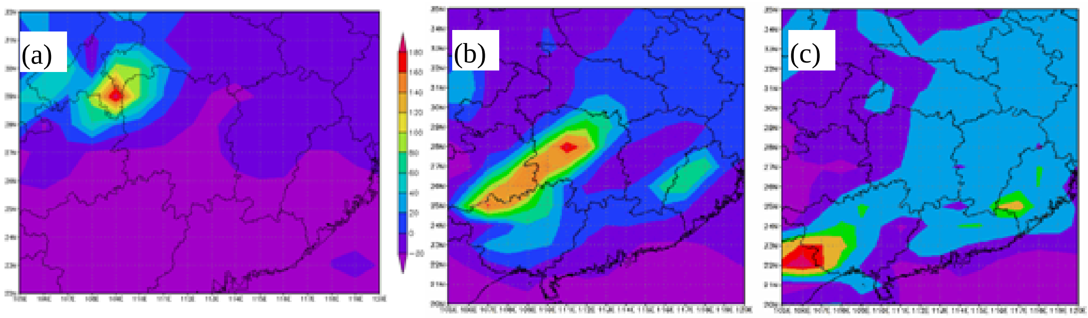

Fig 4. disturbance kinetic energy at 850hPa (a: 20:00 April 16, b: 08:00 April 17, c: 20:00 April 17）

3.3 Disturbance humidity

The disturbance humidity at 08:00 April 17 (fig 5a) shows the humidity was over 80% all around Hunan and higher in west and south Hunan. Vertical diagram of Humidity shows the maximum located around 850hPa with the value of 100%, generally speaking dry at high and moist at low altitude (fig 5b). The humidity at 20:00 (fig 5c) shows decreasing distribution from south to north and the most part of Hunan was less than 80%. Humidity was 85% in southeast of Hunan where the rain occurred. Because of the vertical distribution of dry at high and wet at low altitude, the vertical structure was instable that was favorable for severe convection. The humidity of 80%～90% in south Hunan at 850hPa was favorable for hailstone and lead hail in some areas. Even though there was good humidity at low altitude, the cold air moved rapidly and the humidity decreased from north to south, rainfall was not too significant for all the province and the main phenomena were thunderstorm and gust.

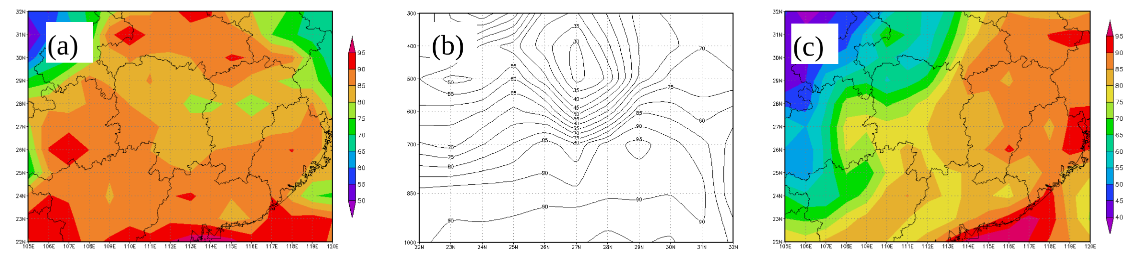

Fig 5. Humidity at 850hPa. (a: 08:00 April 17, c: 20:00 April 17)and
vertical diagram at 08:00 April 17 along 111°E (b)

3.4 Diversity and vorticity

Just as we known,the situation of convergence at low, divergence at high altitude and positive vorticity advection at high altitude is favorable condition for severe convection. The vertical diagram of convergence (fig 6a) shows convergence below 700hPa and the maximum at 850hPa while above it was a divergence with the center at 500hPa, an instable vertical structure of convergence at low, divergence at high altitude formed, but the pumping effect at high altitude was not strong that lead the short duration and limited amount of precipitation. Vertical diagram of vorticity (fig 6b) shows there was positive maximum center below 700hPa in south Hunan, which means there was better dynamic left condition for convection.

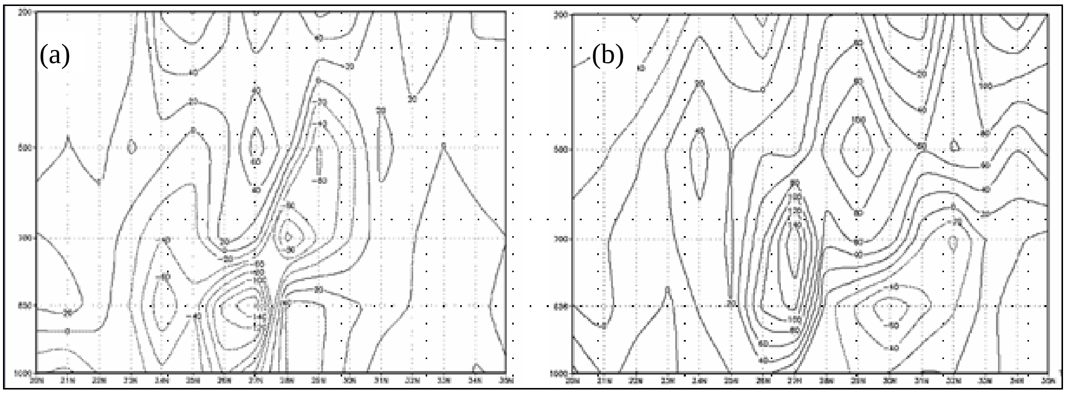

Fig 6. vertical diagram along 111°E at 14:00 April 17. (a: divergence b: vorticity)

3.5 Vertical velocity

Velocity at 14:00 April 17 (fig 7a) shows that updraft center moved from north to south Hunan, and the maximum located at 700hPa (fig 7b). The updraft reached the tropopause that means it was strong enough for severe convection while a weak down draft in north Hunan means a turning for good weather there.

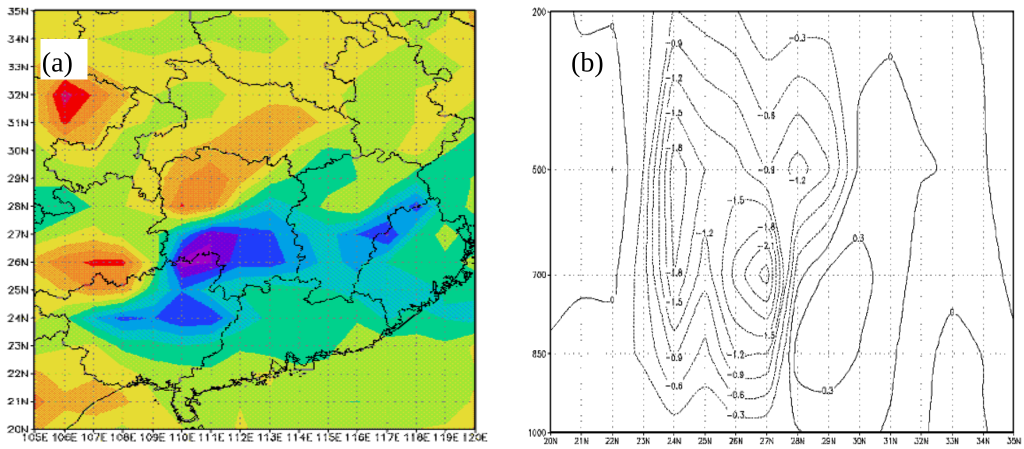

Fig 7 velocity at 14:00 April 17 (a: 850hPa, b: vertical diagram along 111°E)

4. Radar data analysis

4.1 Base reflectivity

Separated narrowband echoes extended for several hundreds kilometre with width of 10～20km that showed no sign of intensify were observed at 0.5° and 1.5° by radar in Changsha(fig 8a,8b), the areas of echoes increased at mid layers of 1.5°—4.3°(fig 8c,8d), and reached maxima at 5～7km, or about 2 times of that at low layers, then the areas decreased above. The echoes went southeast at high layers showing the effect of northwest wind at high altitude. The cold air at high altitude sank rapidly at the leading flanks of echoes and caused the gust, thunder and rain there. The vertical diagrams (fig9, 10) show that the tops of clouds were about 10km, intensive echoes with the values above 50dBz lay below 5km, it means the echoes were low centroid, and there was no weak echo. Comparing with the storm of super cell, the updraft was relatively weak, and the sinking cold caused thunder and gust but it was not easy to caused large area hailstone and torrential rainfall. The VILs were 10-30 kg/m^2, and the area of high value above 20kg/m^2 moved rapidly southeast, which was the typical character of thunderstorm gust echoes

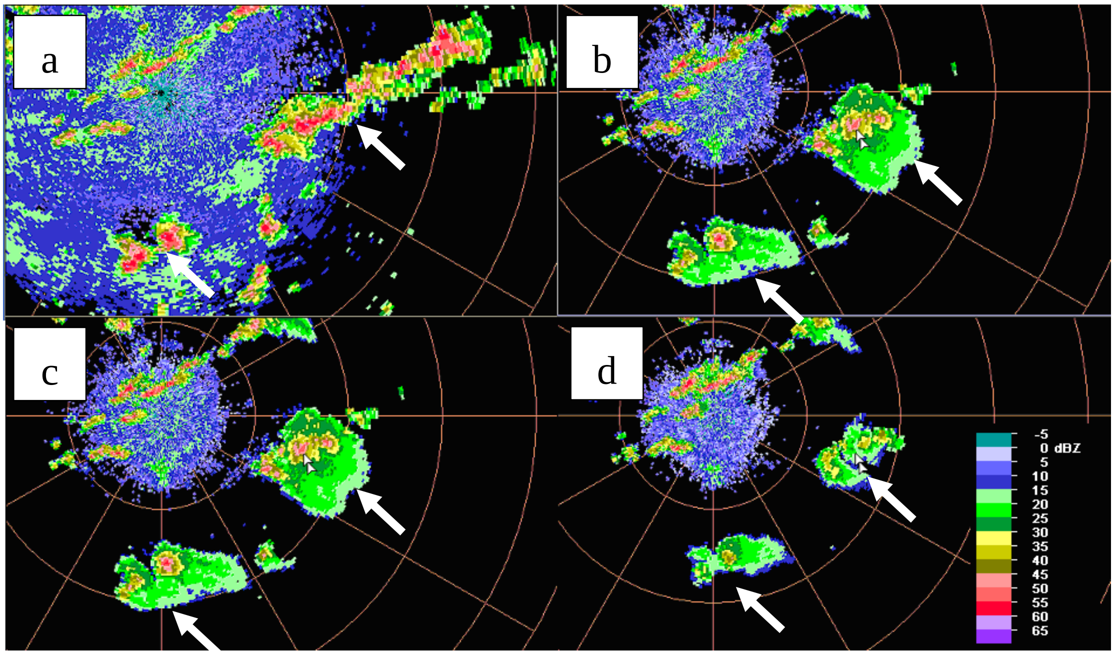

Fig.8 Radar image at 5:47 April 17, 2007 (a: 0.5°, b: 3.4°, c: 4.3°, d: 9.0°)

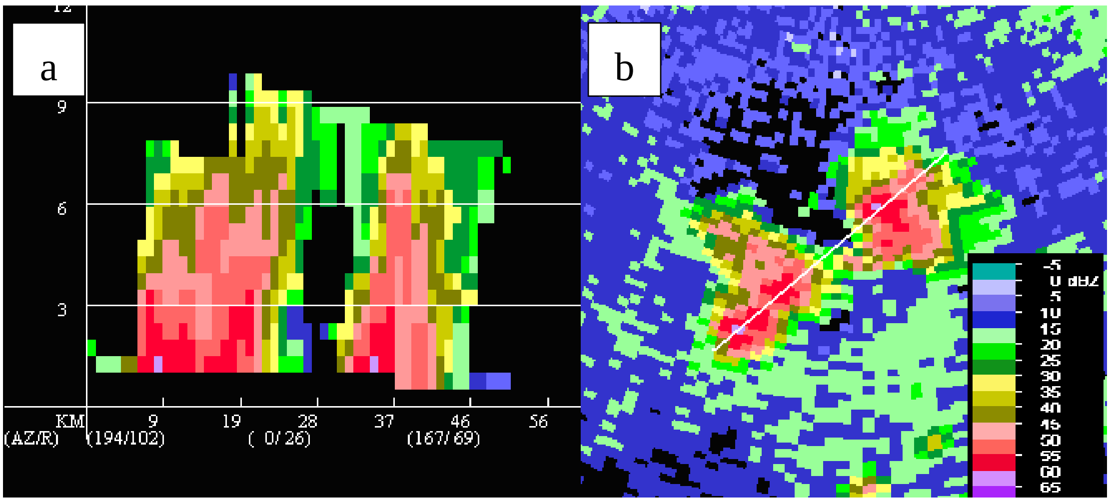

Fig 9. radar data at 5:47 April 17, 2007（a: vertical diagram, b: base reflectivity at 0.5°）

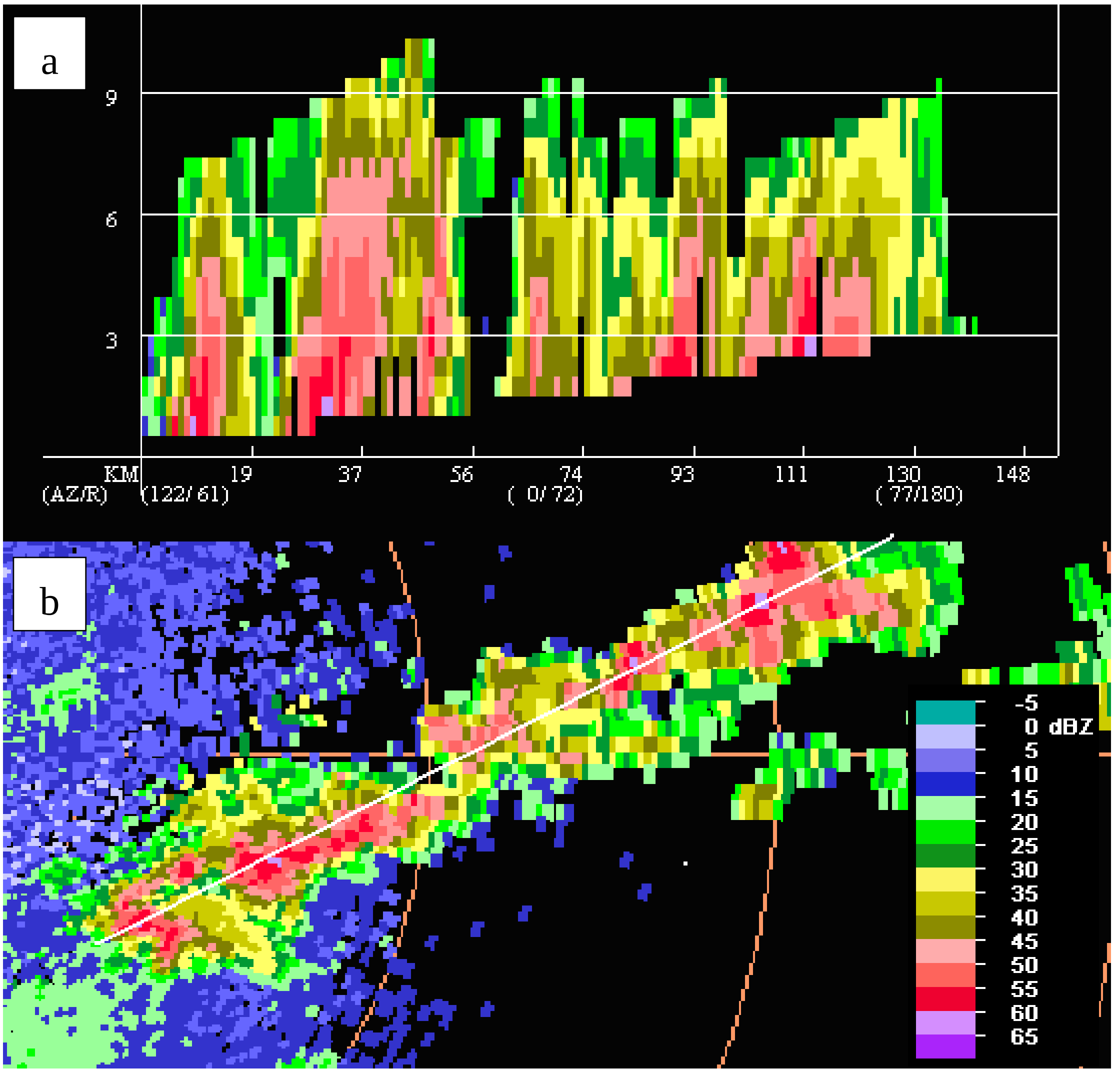

Fig 10. radar data at 5:47 April 17, 2007（a: vertical diagram, b: base reflectivity at 0.5°）

4.2 Doppler velocity

The 2 convective cells in the southwest of narrowband echoes (fig 9, 11a, arrowheads point the same position) were well developed. In the Doppler velocity images, corresponding to the intensive echoes, there was meso-convergence with meso-vortex but it did not meet the standard of meso-cyclones at low layer (fig 11b) . While at medium layer, there was adverse wind area (fig11c) which can generates certain convergence-divergence in some area. At high layer there was divergence (fig 11d). Since there was co-operating effect of different layers, the 2 cells evolved quickly and the dangerous weather of thunderstorm and rainfall occurred on the ground.

The convection was relatively weak in northeast section of narrowband echoes (fig 10,12a,arrowheads point the same position), and there was no clear divergence-convergence caused by wind direction at low layer (fig 12b) in Doppler velocity image, but with the high difference of velocity, meso-divergence-convergence caused by wind speed was remarkable. There was a small adverse wind area at mid-high layer (fig 12c,d) but no significant divergence. Another feature in the Doppler velocity field was an obvious meso-divergence line (shown by arrowheads of fig 12) at low, mid and high layers; the strong divergence was favorable for gust on the ground.

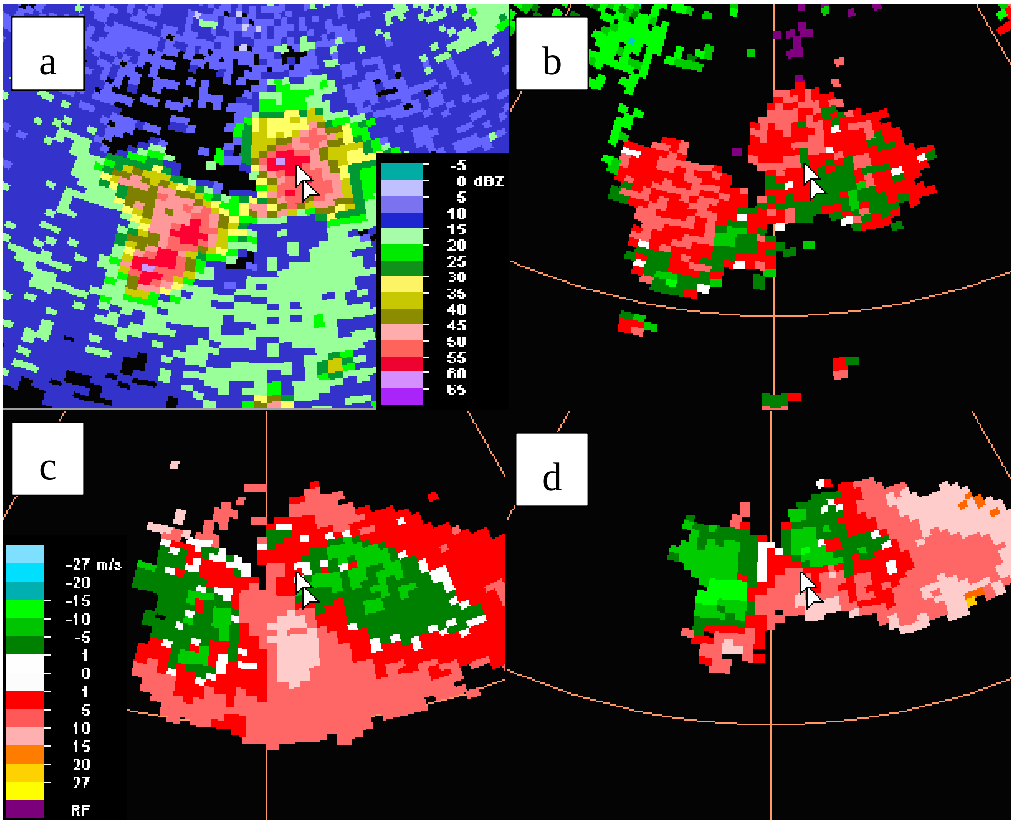

Fig 11. radar images at 5:47 April 17, 2007 (a: base reflectivity at 0.5°, b: velocity at 1.5°, c: velocity at 4.3°, d: velocity at 6.0°）

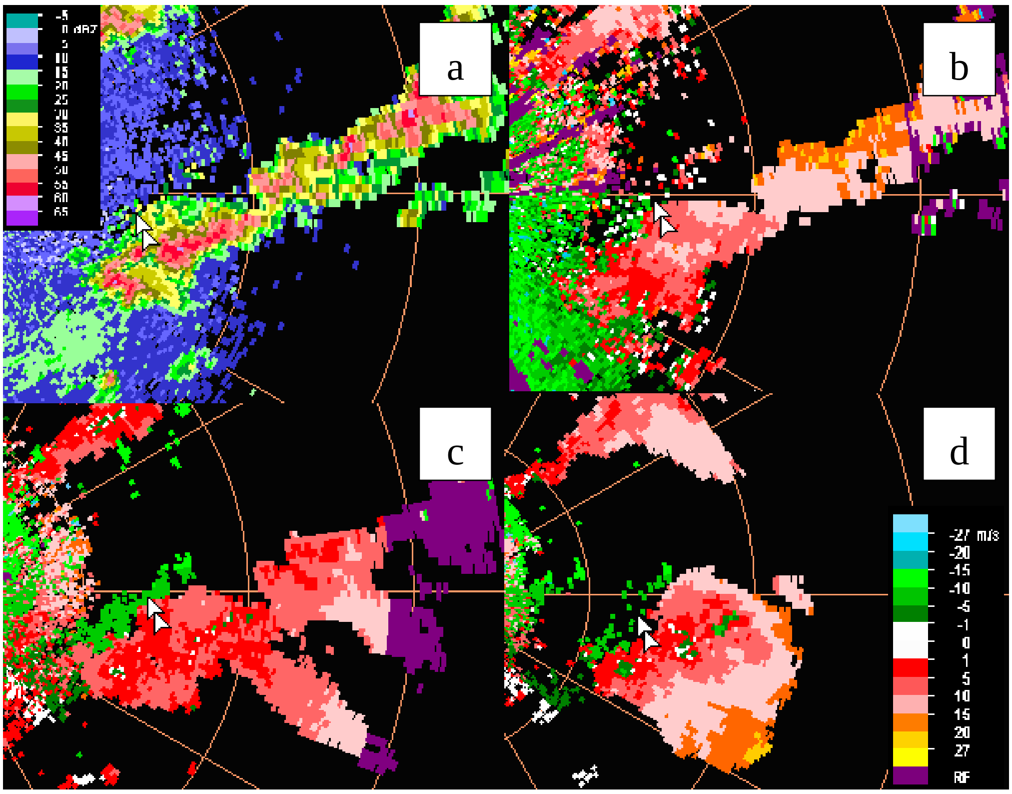

Fig 12 radar images at 5:47 April 17, 2007 (a: base reflectivity at 0.5°, b: velocity at 1.5°, c: velocity at 2.4°, d: velocity at 4.3°）

The analysis above shows that the cold front on ground surface, mid-low layer convergence line and adverse wind area were the main systems for the event, and the divergence in the north of narrowband was favorable for the thunderstorm and gust. Because of the fast moving speed of the echoes, even though the high intensity, duration was limited, so the amount of precipitation was not too much and the major phenomena were gust and thunderstorm.

5. Summary and discussion

Using the data of conventional sounding, surface observation,NWP products,auto- meteorologic stations of Hunan and Doppler radar in Changsha ,a typical thunderstorm on April 17, 2007 in Hunan province, China was investigated and the results show:

1) Warm days before the event provided abundant instable energy, instable stratification and wind vertical shear were favorable for severe convection.

2) The small trough moving from Qinghai-Tibet plateau combined with a south moving trough and got deeper, which led the cold air on the ground surface moving south and caused the kinetic energy transmitted toward low altitude and trough-genesis on the ground surface, which intensified the convection.

3). The disturbance kinetic energy at 850hPa, uneven disturbance of temperature at low altitude caused the front-genesis on the ground surface, together with the vertical configuration of dry at high and wet at low altitude. All above were the trigger for the convection event. Even though the strong ascending movement caused by convergence at low altitude,but the pumping effect at high altitude was not strong enough and that may be the reason of severe convection with short duration and limited precipitation.

4) Low centroid echoes without weak echo region were the main feature for the event. Comparing with the super cell storm, the updraft was weaker. It was a typical gust echoes in this event that cold air poured rapidly, the high area of VIL above 20kg/m^2 moved southeast.

5) The cold front on the ground surface, meso-convergence at mid-low altitude, adverse wind area were the major systems for the event, and the divergence in the north of narrowband echo was benefit for the thunder- gust.

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