Analysis of the Characteristics in a Supercell Storm Event in China

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ABSTRACT

A severe convective storm with thunder, shower and gust as well as hailstone in Hunan province, China on April 8, 2008 was investigated using the remote sensing data such as FY-2C satellite, Doppler radar and automatic surface weather network. The results show that 1. The previous warmer weather provided abundant unstable energy, and the vertical wind shear, thermo-dynamic factors are favorable for severe convection. 2. The mesoscale torrential rain clouds triggered by the tail of front-cyclone clouds caused the event. 3. The phenomenon that the thunder storm clouds were triggered by frontal cyclone clouds was revealed clearly by FY-2C satellite image. Cloud-Derived Wind image indicated the strong divergence at the high level. 4. The PPIs manifest as the isolated massive echoes, and the intense echo cores of storms is higher than 65dBz at the 3-6km altitude on reflectivity vertical section, the echo higher than 50dBz located at 9km high-level and the temperature is approximately - 30℃, the echo top height is higher than 12km. the PPIs at different levels show that the character of "three-body scattering spike" at 16:18, 16:36 and 16:54 respectively, namely typical character of hail echo. 5. For velocity, at the low and middle altitude, there were the cyclonic convergence and divergence at the high altitude.

Keywords: Analysis, Application, Remote Sensing Data, Storm

Introduction

As the most severe form of well developed local storm, the super cell often causes lots of losses and attracted the attention of meteorologists. Browning and Ludlam[1] , Stout and Huff [2] indicated that except the quasi-stable status, the other significant features of the super cell include Weak Echo Region (WER) or Bounded Weak Echo Region (BWER) , and hook echo at low altitude shown in the radar data. As a result of wide application of Doppler weather radar in research and operational forecast since 1970s, the traits of super cell were revealed much and the concept of mesocyclone promoted by Fujita[3] was widely accepted. The researches of new generation radar (Doppler weather radar) application on severe convection which covered the area of the super cell, multi-cell and squall line leading hailstone, tornado and gust, were conducted by Chinese meteorologists with lot of encouraging results.

The data of meteorological satellite provide many high tempo-spatial resolution products for weather surveillance and forecast, especially for the disasters such as severe convection, rainstorm, typhoon and sandstorm. By analyzing the satellite products, the mechanism of weather disaster genesis and evolution was better understood [4-6].

Hunan province lies in south to Yangtze river region of China with the capital of Changsha city, and hailstone is one of the major catastrophes in

Hunan province, not only does the hailstone harm the agriculture but it brings great hazard to transportation, construction and the security of property and human life, it is of great importance to forecast in time. There was a severe fast moving convection with lightning, hailstone and gust, and it caused lot of losses in Hunan on April 8, 2008.

1 Weather summary and losses

April 8, 2008, because of the low trough at high altitude, wind shear at mid altitude and cyclonic wave on surface, a severe convection swept Hunan. Limited by the meso-scale detection capacity, the rainstorm and gust was observed only by one conventional weather station and there was no hailstone record. According to witness report and disaster investigation, large hailstone, rainstorm and gust occurred in the central and east Hunan with buildings collapse, crops damage and one death. 13 towns were hit and the direct economic loss is RMB9.40 million including RMB1.2 million of agriculture loss.

Fig. 1 Destroyed building and agricultural facility

2 Weather background analysis

April 6-8, 2008, from surface to high altitude, Hunan was controlled by southwest air stream with increasing southwest jet at low level which hit the top at 16:00 BJT April 8, the values of wind speed at 850hPa of Changsha, Zhijiang and Chenzhou stations exceeded 20m/s and the values on surface of most of weather stations in Hunan exceeded magnitude 4 m/s, and there were 4 stations with gale of 17m/s in central Hunan with maximum of 21m/s in Lengshuitan. The temperature increased rapidly because of southwest stream from bottom to up air, all temperatures exceeded 30℃ and some went over 34℃ on April 7~8 except northwest part of Hunan, so abundant energy was stored for the convection. 08:00 BJT April 8 the low trough in south China leading the cold air mass went south. The mid air wind shear with strong north wind in the north part located in north Hunan, warm center at 700hPa was in Hunan, the warm wet southwest stream brought moist air toward Hunan in front of the trough. The surface chart indicates a front in Yangtze river gradually got down south to the north Hunan, and the cyclonic wave went southeast, 20:00 the front arrived in Xiangjiang river, the region swept by cyclonic wave saw hailstone, lightning, rainstorm and gust, the temperature difference between north and south of the front reached 10℃, the cyclone wave split at 15:00 and became smaller ones in Jiangxi province and south China. The front moved out of Hunan at 08:00 April 9 and the convections ended in Hunan.

3 Physical mechanism analysis

3.1 Thermo condition

3.1.1 Convective instability

The vertical distribution of pseudo potential temperature θse shows the convective instability of atmosphere. θse of 850~500hPa at 08:00 and 20:00 April 8 shows it decreased with the increasing altitude.

The convective instability $Ic=(\theta se)_{850}-(\theta se)_{500}$ was introduced, we find that Ic in Changsha at 08:00 April 8 was -15.01℃ and in Zhijiang it was -18.25℃, which means the atmosphere was instable and the reasons are: 1.there was clear cold advection at 500hPa and warm advection at low altitude in the hailstone hit area, and the stratification of dry-cold at high and wet-warm at low formed. 2. The lasting hot and wet weather previously heated the air on ground surface and the instable energy accumulated.

3.1.2 Indices

The indices of K, Si and instable energy of 3 sounding stations derived from T-lnP were listed in table 1. Index $K=(T_{850}-T_{500})+Td_{850}-(T-Td)_{700}$ represents the instability and moisture of low air. The indices show the high value located close to Changsha stretched from northeast to southeast and it matched the heavy loss area caused by the convection. K of 23~30℃ at 08:00 jumped to 28~46℃ at 20:00. According to statistics and analysis, the thunderstorm may occur as the Si is -6℃‹S‹-3℃. In this case, the values of Si in 3 stations were quite low, values in Changsha at both 08:00 and 20:00 were lower than -4℃ and the lowest is -6.2℃ with abundant instable energy, it is very likely to be convective.

Tab. 1 K, Si and CAPE in Changsha on April 8

		Changsha	Huaihua	Chenzhou
K	08:00	30	23	23
	20:00	46	43	28
Si	08:00	-4.7	-2.1	-1.0
	20:00	-6.2	-4.0	0.5
CAPE(J/kg)	08:00	-1003.7	-459.1	-175.5
	20:00	-1945.9	-1249.4	-1572.5

3.1.3 Temperature advection

The sounding data of Changsha show that wind shear turned clockwise vertically at low altitude with warm advection, while it was anticlockwise at mid level with cold advection and, turned back again at high altitude with warm advection. That means the cold air invaded firstly at mid level of troposphere and it is favorable to form a stratification of dry at high and wet at low.

Not only did the temperature advection cause instable stratification, but it led vertical movement also and played an important role in convection. As the cold invaded, the air above 700hPa was controlled by cold advection at 20:00 with a center at 500hPa, and the mid and low levels were warm advection with a centre at 850hPa (fig 2). The moisture also shows a configuration of dry at high level and wet at low level. The vertical temperature advection provided a suitable condition for severe convection. The cold air invaded at low level at 08:00 April 9, the atmosphere below 700hPa was cold advection and the air turned to stable, the convection ended.

3.1.4 CAPE

CAPE at 08:00 April 8 showed a high center close to Changsha with a maximum of $233.4J\cdot kg^{-1}$, and it increased to $440.7J\cdot kg^{-1}$ at 20:00, the hailstone occurred closed to the high center. The energy released out at 08:00 April 9, the CAPE value in the area with hailstone decreased to 0 and the convection ended, that means this convective event is tightly related to the release of CAPE.

3.2 Dynamics

3.2.1 Vertical velocity

Vertical diagram of vertical velocity shows, there were 2 ascending centers at 109°E and 114°E at 08:00 April 8, indicating the low pressure on the ground surface caused a certain updraft. The stronger was close to 114°E with a maximum of -6.0 hPa.s^{-1} at 500hPa. The strong updraft moved east to 118°E at 20:00 and the air in Hunan turned to descending and the convection ended.

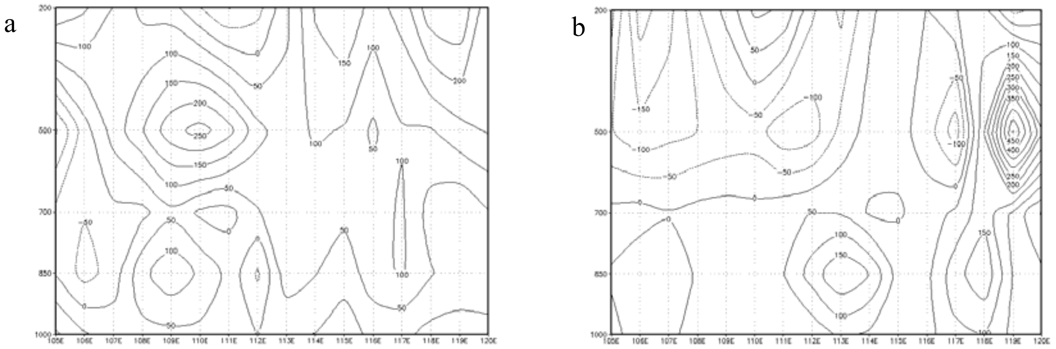

Fig. 2 Vertical diagram of temperature advection on April 8. (a: 08:00 b:20:00)

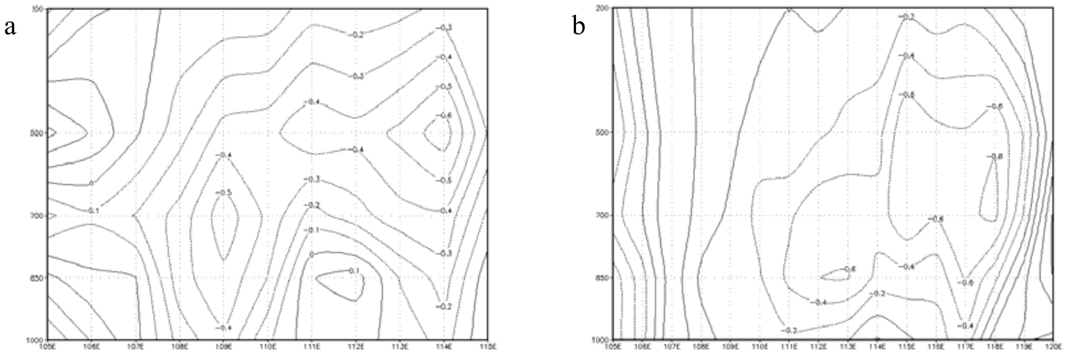

Fig. 3 Vertical diagram of vertical velocity on April 8. (a: 08:00, b: 20:00)

3.2.2 Divergence

The favorable vertical divergence distribution is divergent at high altitude and convergent at low level. The situation from 08:00-20:00 April 8 met the event well, there was a convergence in central Hunan at 850hPa (fig 4a) and turned to weak divergence at 200hPa, the divergence field matched the region where hailstone occurred. The vertical change of divergence (fig 4b) showed that during 08:00-20:00 the convergence layer at low level got thick and a strong divergence appeared at high level, which provided a good situation for convection.

3.2.3 Vorticity advection

Positive vorticity advection of up air is the dynamic factor to enhance the low pressure on the ground and severe hailstone is often triggered by the development of ground surface low pressure and up air divergence. It can be found from the vertical vorticity advection during on April 9, that there was positive vorticity advection above 850hPa between 108-112°E at 08:00 and the maximum located above 500hPa(fig 5a). Forced by the up air positive vorticity advection, the pumping effect at high altitude lead convergence of low level caused updraft, and triggered the violent convection with hailstone. The low trough passed away at 20:00 and the vorticity at 500hPa decreased to negative, and the convection ended.

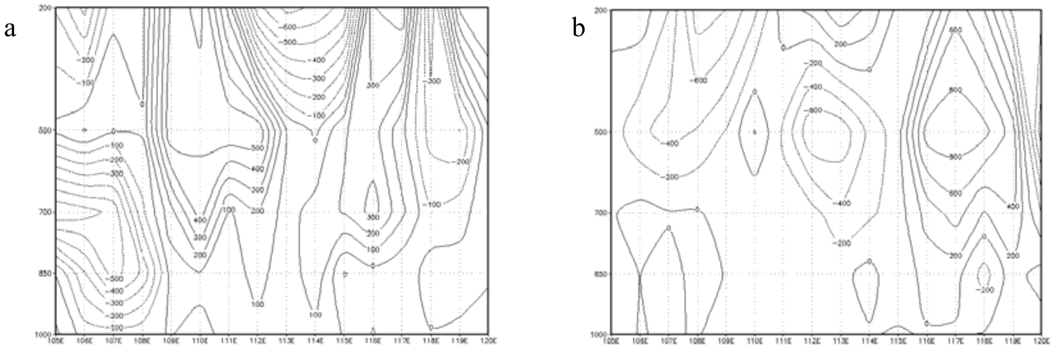

Fig. 4 Vertical diagram of vorticity advection along 28°N on April 8. (a: 08:00, b: 20:00)

4 Analysis with Remote Sense Data

4.1 Satellite and Intensive Detection Network

Satellite cloud images show a typical frontal cyclonic cloud system centering at the curve of the yellow river and northeast Hunan province located at the tail of the front, the meso scale thunderstorm clouds were triggered. The data of intensive meso scale meteorological detection network at 16:00, 17:00 and 18:00 revealed that, meso scale low pressure matched the quasi circle shape thunderstorm clouds. The cloud derived wind indicated strong divergence at high altitude, the divergence at up air and convergence at low level promoted the formation of thunderstorm.

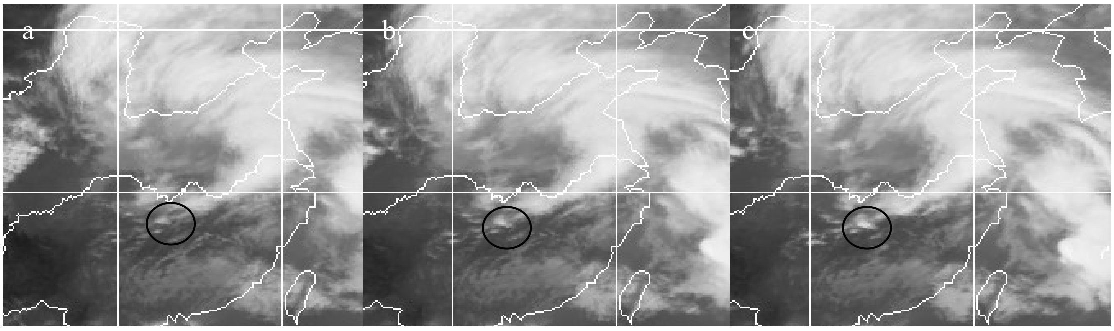

Fig. 5 Ir images of FY2 meteorological satellite. (a:16:00, b:17:00, c:18:00)

4.2 Radar Data

4.2.1 Reflectivity

4.2.1.1 Movement feature

The discontinuous echoes formed in direction ENE-WSW close to meso convergence line on the ground at 14:30 April 8, initially the intensities of the echoes were less than 30dBz but developed rapidly, the intensities increased to 50dBz with the top of 10km within 13min. The echoes merged together into a belt at 15:12 and moved northeast, the echoes in south evolved quickly and those in north changed little. At 16:00 the north echoes moved northeast and became a left moving storm, the intensities decreased gradually. The echoes in south turned southeast and became a right moving storm, the intensities increased violently and caused thunder, heavy rainfall, gust and hailstone in Changsha, Ningxiang and Loudi cities. There is the feature of left moving storm weakened and right moving storm increased. The right moving one went fast and reached Jiangxi province at 18:40 at a speed of 50-60km/h.

4.2.1.2 Structure feature

PPI shows isolate block shape echoes over 65dBz, with large gradient and V shape notch because of the side influx, the strong echoes of 65dBz located in 3-6km and those of 50dBz reached 9km, the temperature was -30℃ and the top of echo is 12km. The PPIs in different levels showed three-body scattering spike at 16:18(fig 6), 16:36(fig 7) and 16:54, but the heights and numbers are different. There was clear side lobe echo in vertical diagram (fig8) and, the overhanging echo appeared at mid level and weak echo at low level. The three-body scattering spike, side lobe echoes are the typical feature of hailstone, it is easy to classify that the event is a super cell storm by intensity, PPI and vertical diagram characters.

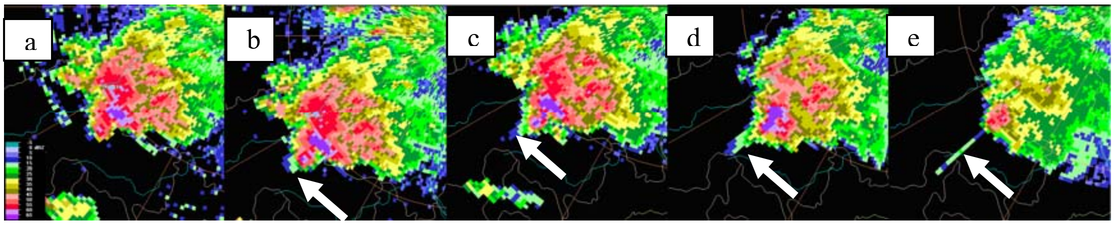

Fig. 6 "three-body scattering spike" at 16:18 April 8 2008
(a:2.4°, b:3.4°, c:4.3°, d: 6.0°, e:9.9°)

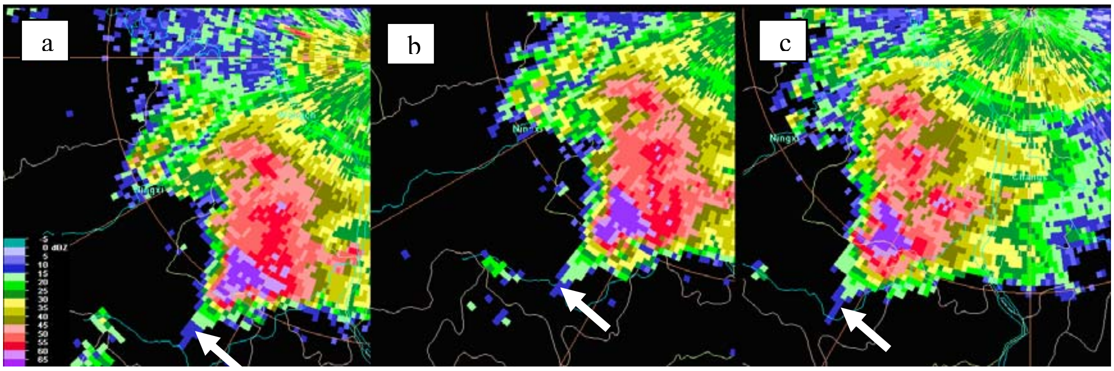

Fig. 7 "three-body scattering spike" at 16:36 April 8 2008 (a: 3.4°, b:4.3°, c: 6.0°)

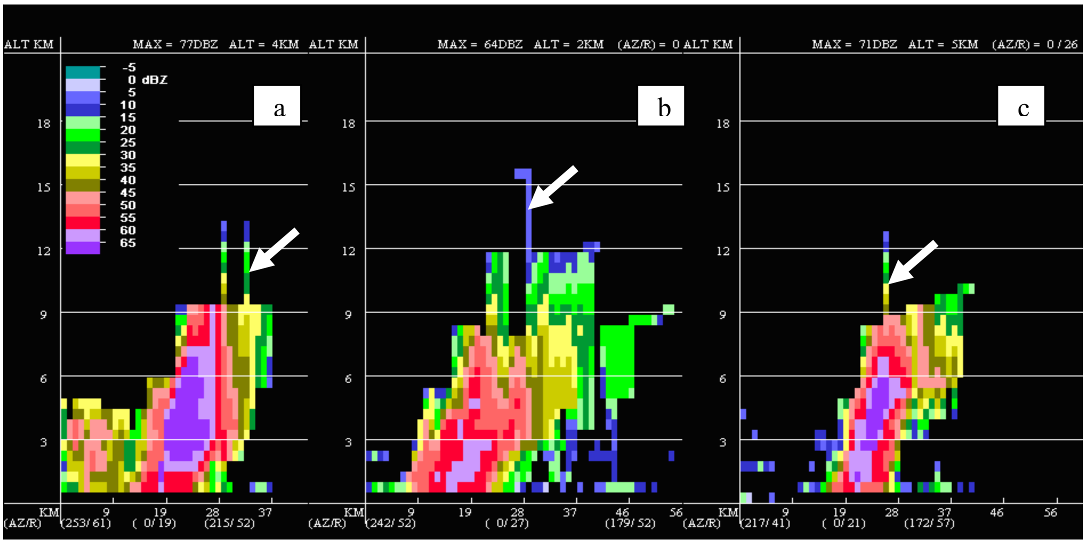

Fig. 8 Reflectivity vertical section (a: 16:18, b:16:30, c:17:00)

4.2.2 Doppler Velocity Structure

Doppler velocity images of intensive echoes (Fig 9a) showed that there is a convergent mesocyclone at low level (Fig 9b), a pure mesocyclone of directional symmetry positive and negative velocities at mid level (Fig 9c), and divergent velocities at high level (Fig 9d). So the velocity image of Doppler radar match the results of satellite and physical products of NWP, that is the storm is convergence at low level, mesocyclone at mid level and divergence at high level.

The vertical structure of velocity showed (Fig 10) that there is anticyclone after the strong echoes at 1-4km, which was caused by sinking stream of the high pressure after the severe thunderstorm and the stream led the gust. the mesocyclone appeared with the intensive echoes wall at 2-4km and the updraft is very strong, the strongest echoes emerged at 3-6km while at low level a weak echo area formed, and the hailstone cores got the chance to experience the dry-wet growth several times to become large hailstone.

We can find the thin long echo in the vertical diagram of base reflectivity but there is no corresponding echo in velocity image. That means the thin long echo is false side lobe.

The major characters at high level are gale core in the negative velocity area and it is different from the typical velocity feature of severe storm.

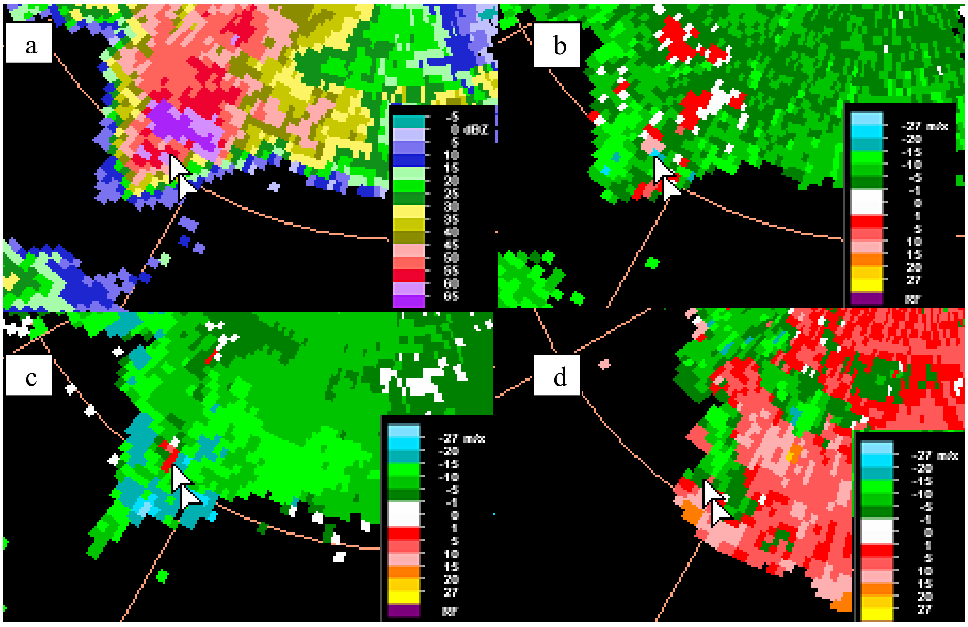

Fig. 9 Velocity images at 16:36. (a: 1.5°Reflectivity, b: 1.5°, c: 3.4°, d: 6.0°)

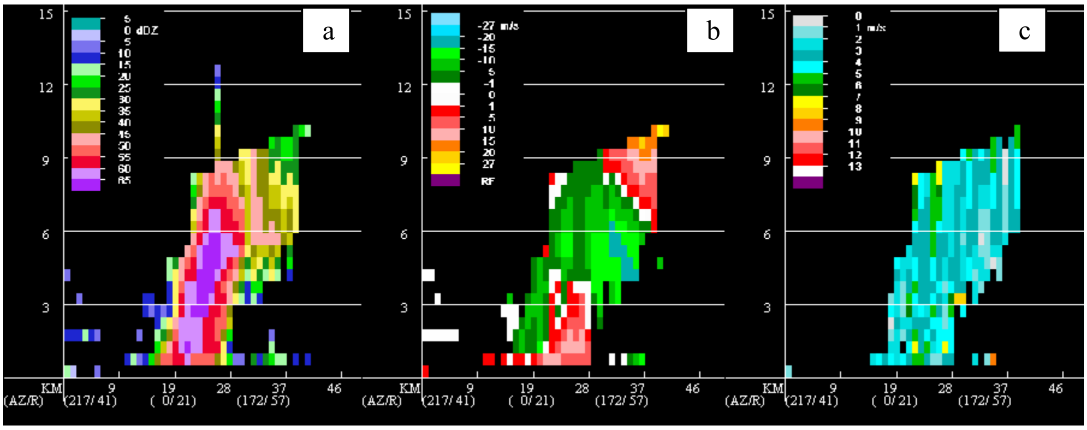

Fig. 10 Vertical diagram at 17:00 April 8 (a: Reflectivity, b: Velocity, c: Spectrum Width3.4°)

5 Results

1) Lasting warm days previously accumulated the energy, and the vertical wind shear, thermo-dynamic and vapor factors provided good condition for severe convection.

2) The satellite data revealed that meso scale thunderstorm clouds triggered by the tail of front cyclone clouds caused the local severe convection.

3) There are three-body scattering spikes but the number of elevations with the spikes and the heights are different, and there is side lobe, the typical feature of hailstone in vertical diagram. Velocity images show convergence at low and mid levels and gale core in the negative velocity area at high level that is somewhat different from the typical severe storm velocity character. In all it is a severe convection caused by super cell storm.

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