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COMPARISONS BETWEEN DOPPLER AND SIMULATED FEATURES OF A SUPERCELL

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Abstract: Firstly, typical features of a supercell, which occurred in Guangzhou on August 11, 2004, are discussed by using the new generation weather radar data. V-notch, finger-echo, weak echo region, overhang and echo-wall are observed from reflectivity products. A vertical cross section of the radial velocity is made along the direction of the low-level inflow and across the maximum reflectivity core, which displays a part of strong updraft and downdraft. Secondly, a 3-D convective storm model is used to simulate the supercell. The maximum reflectivity and the core thickness of the simulated radar echo are 75 dBz and 14km, respectively. These values are more than the counterparts that are detected by radar. The reason is that attenuation is not calculated in the model. The wind field structure is also given when the storm is the strongest. Divergence, caused by thunderstorm outflow, is in the low level. In the middle and high level, convergence is dominant, but the plume is not simulated at the top. Finally, the evolution of the simulated vertical motion is documented. The interaction between the environmental wind and the updraft, which is formed by the convergence on the ground at the beginning, makes the storm stronger. Then, downdraft occurs and grows. When it becomes dominant, the supercell collapses.

Key words: supercell; mesoscale cyclones; weak echo areas; 3-D numerical model

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1 INTRODUCTION

With the deployment and construction of the next-generation Doppler radar network in China, many meteorologists have conducted intensive research into the severe convection. In their analysis of the typical characteristics of a supercell in Dong'ah, Shangdong province in 2002 with the products of CINRAD/SA in Jinan, Zhu et al.[1] put forward that storm tracking information (STI), hail index (HI), vertical integration of liquid water (VIL) and mesocyclone (M) were the products that identify and forecast severe convection well. Three-body scatter spike (TBSS) and tornado vortex signature (TVS) were first detected in China in May 2002 with a radar in Chang De, Hunan province, which were the indicators of giant hails and tornadoes, respectively, and confirmed by surface reports (Liao et al.[2]). A number of mesoscale and fine-scale weather data gathered by the Guangzhou radar were used to categorize the Doppler velocity and reflectivity factors and products derived based on them and various characteristics were statistically analyzed by the types of destructive weather systems (Wu et al.[3]). A process of supercell taking place in northern Anhui province in 2004 was studied using the measurements of a Hefei radar for features of outflow boundary, V-notch, weak echoes, overhang and mesocyclone (Zheng et al.[4]). They pointed out that conventional data, which had coarse spatial and temporal resolution, were not satisfactory in forecasting the potential of severe convective weather. More work was done on the techniques of measuring the mesoscale wind field with data of single-site Doppler (Wang et al.[5]). With the next-generation Doppler in Hefei, comparisons and experiments were carried out regarding three ways of quantitative precipitation estimation that were most

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commonly used, errors were analyzed and areas and methods of optimal precipitation estimation were determined (Zheng[6]).

On the other hand, numerical simulation of hail clouds has been performed by a number of Chinese meteorologists. Three-dimensional convective cloud models, which took into account the liquid-phase microphysics, were set up in 1990 respectively by Xu et al.[7] and Wang et al.[8]. A three-dimensional model for hail clouds was developed that included detailed ice-phase microphysics and a series of numerical simulations were conducted of hail clouds (Kong et al.[9]). Afterwards, a major improvement was made on the model with the microphysics adopting a more realistic scheme of spectral evolution that involved dual parameters, which can determine the concentration and liquid water content of frozen droplets and graupels, the embryos of hails; a catalytic intervention was added so as to study the dynamics and microphysical structure of severe storms and hails prevention by catalytic approaches (Hong[10]). A supercell storm that happened in Beijing June 29, 1996, was simulated, which gave typical details of a weak echo zone, overhang and echo-wall (Liu et al.[11]). A case of exceptionally heavy rain, which took place in Wuhan July 2, 1998, was simulated and cloud physics responsible for the process was studied (Xiao et al.[12]).

In the afternoon of August 11, 2004, a series of severe convective processes occurred in Guangdong province. One of the supercells seriously affected the city of Guangzhou. Belonging to the kind of tropical supercells, it showed hook echoes, mesocyclones, weak echoes and intense reflectivity core. It brought thunderstorms, strong winds and heavy precipitation to the area it passed. Hails, particularly, fell on a village in the Huadu District of the city, which lasted about 10 minutes. Typical characteristics of the supercell were discussed with the Doppler weather radar in Guangzhou. Then a three-dimensional cloud model for convective storms was used to simulate the echoes and flow field of the event, which were compared with the results of real radar measurements.

2 BRIEF ACCOUNT OF THE SUPERCELL

At 12:00 (L.T., same below) August 11, 2004, isolated storms formed on the border between Qingyuan and Shaoguan and northern Huizhou before intensifying and moving southward slowly. Some minutes past 13:00, some storms developed locally one after another over most of the Pearl River Delta area. At 13:33, a storm over Conghua and Huizhou showed signs of splitting. At 14:03, it broke into two intense cells that continued to move south, the western one being on its way to approach Guangzhou. At 14:27, it got stronger by merging with smaller cells and the low-level airflows interacted with intense low-level diverging outflow of a local weakening cell in Guangzhou to form an area of powerful convergence, making the dying cell to revive. At 15:21, the cell was at its full swing by showing many of the typical features. Then, the downdraft inside the supercell began taking the upper hand and weakened substantially at 16:03, showing signs of decaying.

3 NUMERICAL SIMULATION OF THE SUPERCELL

A three-dimensional cloud model for convective storms, developed at the Atmospheric Physics Institute of Chinese Academy of Sciences, was used in this work. The dynamic framework of the model consists of a complete elastic set of equations that are non-hydrostatic and compressible, which adopts a scheme of dual parameter spectral concentration for the physics of clouds and precipitation. The model includes microphysics of eight water substances (water vapor, cloud water, rainwater, ice crystal, snow, graupels, frozen droplets and hails). The model has a domain of computation of 36 km×36 km×18.5 km, horizontal

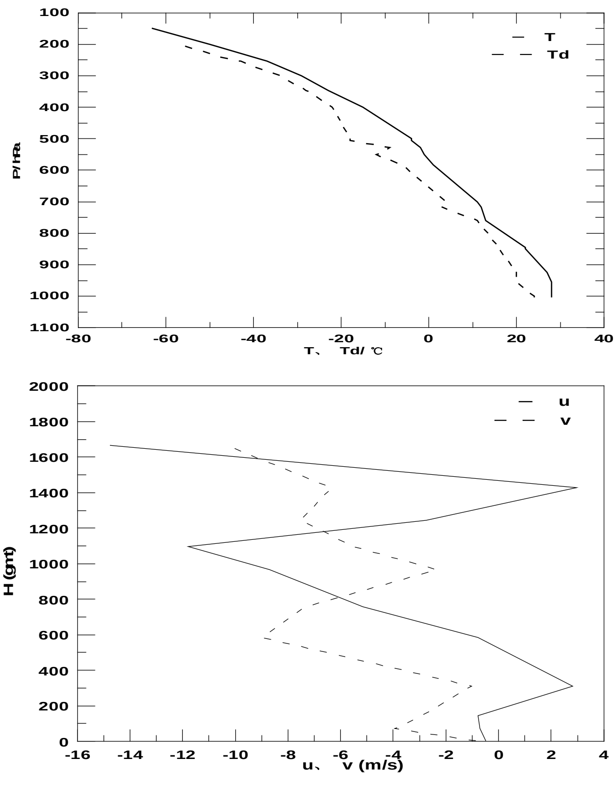

Fig.1 Profiles of temperature at Qingyuan at 08:00 August 11, 2004. a: the solid line for temperature T and dashed line for dew point T_d; b: the solid line for wind profile u and dashed line for v.

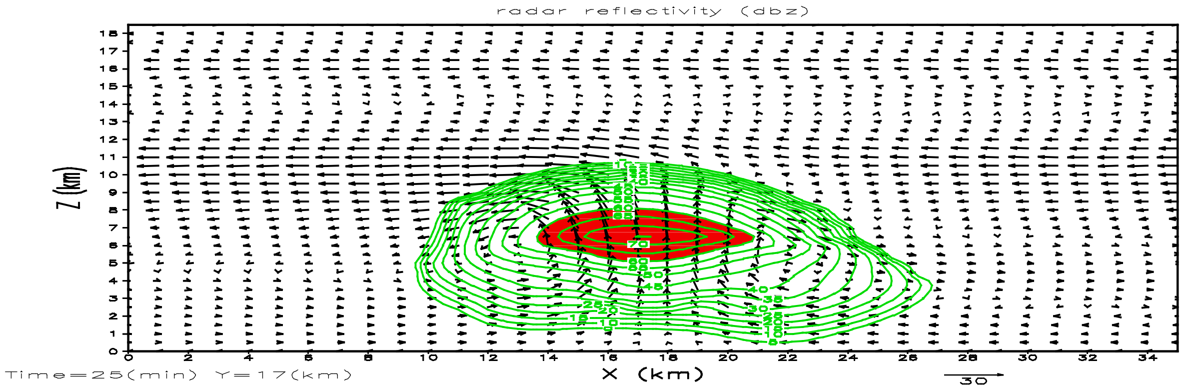

Fig.2 Radar echoes up to 75 dBz appeared in the simulated cloud at 25^{th} min.

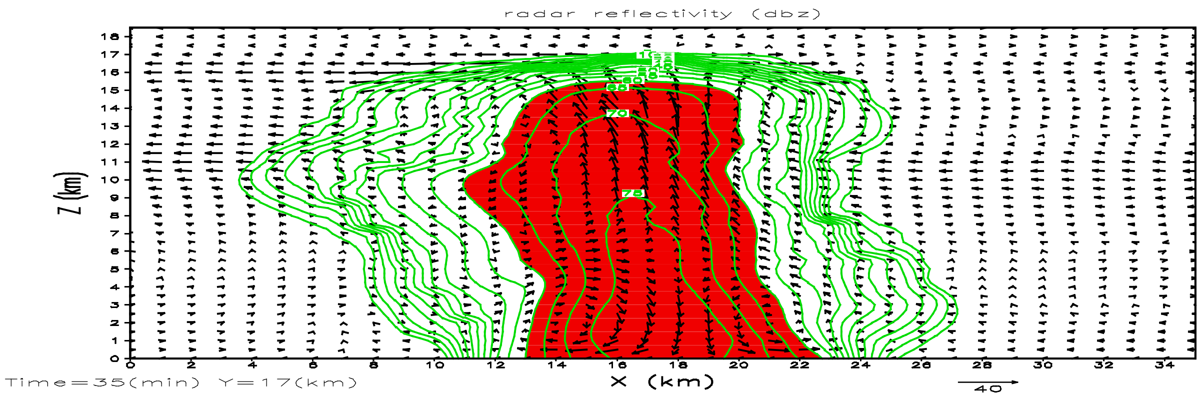

Fig.3 Radar echoes of the simulated cloud developed to its prime intensity at the 35^{th} min.

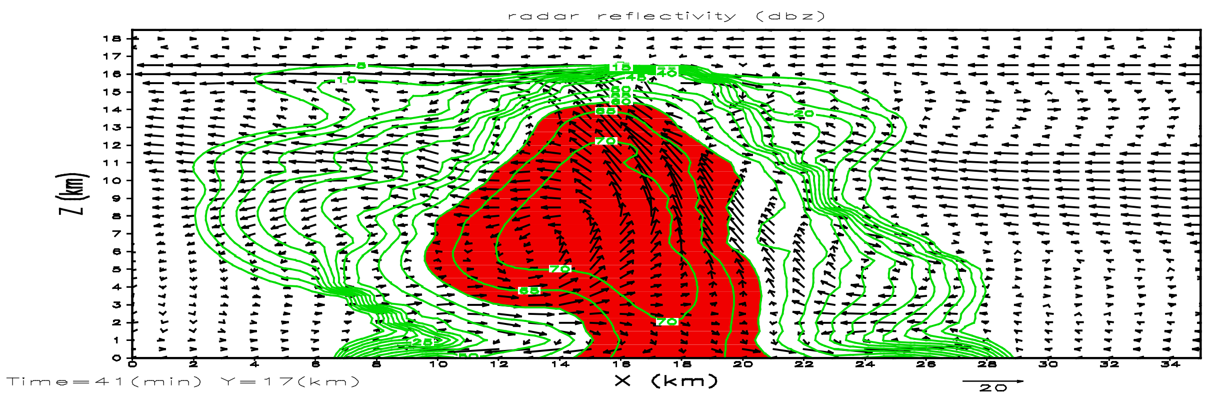

Fig.4 Radar echoes began to have weak zones inside the updraft on the right at the 41^{st} min.

gridpoint interval of 1.0 km and vertical gridpoint interval of 0.5 km. *i*, *j* and *k* depict the ordinal numbers of gridpoints on the axis of *X* (eastward), *Y* (northward) and *Z* (upward), respectively. Sounding data that have been corrected with surface observations are input to the model procedure of hail clouds. Convective clouds are started up using the humid thermal approach by assigning a disturbance of geopotential temperature symmetric about the axis and with an extreme of 1.5°C. With the central coordinates of 18, 18, 7, the area of disturbance is at the altitude of 3 km and has a thickness of 6 km. The simulation is 120 minutes long for the storm. Detailed three-dimensional numerical simulation of cloud physics has been made in this paper for the severe convective weather in Guangzhou on August 11, 2004 and the sounding data are from the Qingyuan Sounding Station on the same day (Fig.1).

At the 25^{th} min. of the simulation, with the convective cloud expanding both upward and downward, an echo center as strong as 75 dBz appears inside it and stays at the altitude of 6.5 km (Fig.2). By the 35th min., the supercell developed to its maximum intensity, with the 75-dBz echo touching the ground to form an echo-wall, the vertical thickness reaching nearly 9 km for the 75-dBz echo core and the 60-dBz echo top ascending to the altitude of 15.5 km (Fig.3). afterwards, the echo cell weakens and the echo top decreases. By the 41st min., the cell is still very strong with the 70-dBz core unchanged in thickness and the slant, upper-level updraft remained organized within it. In contrast, a weak echo area appears in conjunction with insignificant overhang in the updraft area in the front of the echo-wall that keeps contact with the ground, which is absent during the prime period of the supercell. It indicates that the simulated radar echo is strengthened once again (Fig.4). Then, the cell weakens quickly and comes to the end of its life cycle in nearly 50 min. For analyses of other aspects, refer to the Chinese edition of the journal.

4 CONCLUSIONS

The next-generation Doppler weather radar and a three-dimensional cloud model for convective storms are used to study the characteristics of a supercell that affected Guangzhou. Finger-echoes and mesocyclones are observed and weak echo areas, overhang and echo-walls were found in the vertical cross section of the reflectivity factors. According to the observation, the maximum reflectivity factor is 66 dBz and the echo top is almost 15 km high. In the numerical model, the intense upward and downward extension of the core of the supercell is simulated but the weak echo area and overhang are not well defined. The maximum reflectivity factor of the simulation is 75 dBz, which is higher than the observation. It can be resulted either from the lack of the attenuation effect or the presence of relatively large initial model disturbance and non-spherical particles.

While the velocity cross-section of the Doppler outlines a general picture of contrasting presence of updraft and downdraft, the numerical model gives what the stream field looks like when the supercell is at its maximum intensity. Diverging airflows dominate in the near-surface level, on top of which is the converging downdraft. The latter inclines with altitude but with insufficient rotational components so that the outflow that forms at the top merges into the ambient wind field without showing any anvils. Additionally, the evolution of in-cloud vertical motion is also simulated. Surface convergence at the initial moment forms the updraft, which then strengthens to interact with the ambient wind field to acquire the inclination. Then, downdraft appears in the cloud though the updraft still dominates. The strengthening downdraft is then taking control of the cloud to weaken the supercell. For other cases, however, more verification is to be made to see whether the model can accurately tell about the structure of wind fields inside the storm.

REFERENCES:

[1] ZHU Jun-jian. DIAO Xiu-guang, HUANG Xiu-shao. Study of CINRAD/SA products for a hail storm [J]. Journal of Applied Meteorology, 2004, 15(5): 579-589.
[2] LIAO Yu-fang, YU Xiao-ding, GU Qing. Case study of a series of severe convective storms based on China new generation (Doppler) weather radar data [J]. Journal of Applied Meteorology, 2003, 14(6): 656-662.
[3] WU Zhi-fang, YE Ai-fen, HU Sheng, et al. The statistic characteristics of mesoscale and microscale systems with the new generation weather radar [J]. Journal of Tropical Meteorology, 2004, 20(3): 391-400.
[4] ZHENG Yuan-yuan. YU Xiao-ding, FANG Chong, et al. Analysis of a strong classic supercell storm with Doppler weather radar data [J]. Acta Meteorologica Sinica, 2005, 62(3): 317-328.
[5] WANG Feng-yun, WANG Yan-xiong, TAO Zu-yu. The study of mesoscale wind field detection technique for single Doppler weather radar [J]. Journal of Tropical Meteorology, 2003, 19(3): 291-298.
[6] ZHENG Yuan-yuan, XIE Yi-feng, WU Lin-lin, et al. Comparative experiment with several quantitative precipitation estimator techniques based on Doppler radar over the Huaihe valley during rainy season [J]. Journal of Tropical Meteorology, 2004, 20(2): 192-197.
[7] XU Huan-bin, WANG Si-wei. A three-dimensional cloud-scale model suitable for compressible atmosphere [J]. Acta Meteorologica Sinica, 1990, 48(1): 81-90.
[8] WANG Qian, HU Zhi-jin. Three-dimensional elastic atmospheric numerical model and the simulations of a severe storm case [J]. Acta Meteorologica Sinica, 1990, 48(1): 91-101.
[9] KONG Fan-you. On 3-dimensional numerical simulation of hail clouds [D]. Beijing: Doctoral Thesis for Atmospheric Physics Institute, Chinese Academy of Sciences, 1991.
[10] HONG Yan-chao. A 3 d hail cloud numerical seeding model [J]. Acta Meteorologica Sinica, 1998, 56(6): 641-653.
[11] LIU Shu-yan, XIAO Hui, DU Bing-yu, et al. Three-dimensional numerical simulation of a strong convective storm in Beijing [J]. Chinese Journal of Atmospheric Sciences, 2004, 28(3): 455-470.
[12] XIAO Hui. WANG Xiao-bo, ZHOU Fei-fei, et al. A three-dimensional numerical simulation on microphysical processes of torrential rainstorms [J]. Chinese Journal of Atmospheric Sciences, 2004, 28(3): 385-404