A Mechanism Analysis on Thermo-Dynamical field of a short-term Suddenly Intensifying Storm from Mountains with Radar Data 4DVar

Xiao Xian[1] Wang Yingchun[2] Chen Mingxuan[1]

1 Institute of Urban Meteorology, CMA, Beijing 100089, China

2 Beijing Meteorological Bureau, Beijing 100089, China

1. Introduce

On average, storms spreading from mountains to plains, which are some single severe weather hazard, including squall line, tornadoes and hurricanes, bring poverty damage which top to more than 1,000,000 Renminbi a year in North China. The most usual spreading path of severe weather is from mountains to plains. An odd problem that make the problem puzzling for forecasters, involves deciding whether convective storms that are extrapolated to move from mountains to the plains will intensify, keep stable or dissipate. During 5 years, it is founded that more or less 20% of storms which is scattered storms or lines of stratiform precipitation storms suddenly intensified into convective lines as they approached the foothills, but then most of them dissipate as they approached onto the plains(Jim,2008).

With the development of 4D-VAR technology which includes continuous 4DVAR cycling procedure, direct assimilation of radar data on constant elevation angles, addition of an analysis background, inclusion of mesonet data, and modification of the boundary conditions, the advantage of the 4DVAR technique over other simpler techniques is that it can retrieve not only the three-dimensional wind and convergence but also thermodynamical fields that can also be input to the Auto-Nowcaster(Chen,2009)which helps to improve the nowcasting skill and capture the evoluti on of storms for forecasters.

VDRAS is a cloud –scale mode with 4D-VAR technology which enable it to read and assimilate radar data on constant elevation levels in the vertical. The procedure of VDRAS was that the length of the assimilation window in each analysis cycle is 12 min, consisting of three radar volumes. Only the analysis fields at the final time of the assimilation window are written to disk and displayed(Sun,2008).

Beijing city on a plain with an elevation of no more than 30m open to moist air from the Bohai sea, is located at the foothill of Yanshan mountains which have an average altitude of 1.5-2.5km and extend roughly in a southwest-to-northeast line to the west and north of Beijing urban area. To improve Beijing forecast skill and meet the forecast challenge of Beijing 2008 Olympiad, BMB(Beijing meteorology bureau) has set up more than 100 high resolution AWS and 2 radio station and adopt severally different method to improve data quality control.

2. Case study:

On the afternoon of 1 August 2009, several scattered storms generated on the mountains, because there is connective lift in the mountains. They propagated gradually from mountains to plains, suddenly intensifying and forming a connective line at the foothill of Yanshan mountains like a squall line. However, when it propagated to the plains, the connective line abated and even dissipated quickly. It is evident that the line storms went through rapid development from 12:53LST to 20:05LST, and rapid dissipation after approaching the plains only lasting only 1.5 hour after it propagate to the plains(Fig 1).

The sounding at 08：00UTC and 12:00UTC at Beijing 54511 station, and at 12:00UTC at Zhangbei meteorological observation station(NO. 54401)on August 1 all showed there were little wind-shear below 4m/s between the ground and 3km or 6km and little Cape not above 50 J/km for initiation of storms or revisiting storms.

So there is a puzzling question why the scattered storms could rapidly intensify on the weak weather conditions(little cape and wind shear), and dissipate quickly after approaching the plains.

In the case of study, the VDRAS analysis domain covered an area of 180*180km^{2,} centered at Beijing meteorological observation station(NO.54511). The domain covered almost north China, including Beijing city, Tianjing city and most of Heibei province, with the depth of 8.3km at the interval of 0.5km in the vertical. The grid resolution of the analysis domain was 3 km in the horizontal.

We ran VDRAS from 10:00UTC, which is little later after small clusters storms generating on the mountains. In each analysis cycle, the minimization was halted at 50 iterations. Continuous assimilation cycles are performed in which the analysis from the previous cycle is used as the background. The inflow boundary conditions are given by a combination of the background wind and the radial velocity observations.

Helicity and wind shear are useful index for challenge nowcasting. Wind shear was calculated between 0-3km and 0-6km, the helicity is calculated in the below equation.

$$H = \iiint V \bullet \nabla \times V d\tau \qquad (1)$$

3.Result

To illuminate explicitly the development of the severe weather process, we partition the course of the severe weather into two stages: 1.before storms approaching at the vicinity of the foothill， and 2. after approaching the plains. In our researches, we use perturbed temp, temp gradient, wind-shear, and helicity to describe the change of dynamics and thermodynamics field in the development.

A. before storms approaching at the vicinity of the foothill

In the case, we set from 12:53LST to 17:30UTC as stage 1. The key for successfully forecasting the retriggering of the storm near central Beijing urban area is the identification of cold pools(marked H) produced by the cumulus cloud (fig 2,4). Through VDRAS wind and temperature analyses, the cold pools and their leading edges are clearly shown by the perturbation temperature field and the horizontal convergence field, respectively.

Figure 2 illustrates the dynamic and thermodynamics fields of the cold pools by showing the perturbation temperature field overlaid with the horizontal convergence contours greater than 0.2 m/s/km and the horizontal wind vectors at 14:29LST. The cool pool is identified by the temperature perturbation of -2.5 degree. It is showed that the horizontal wind direction was south direction on the plains, while it was west on the mountains. And at the south edge of cool pool, since the obstacle effect of cool pool to the environment wind field, the wind direction changed from south to west direction at the edge of cool pool H. The obstacle effect is relative to the temperature gradient. And the turning wind collided with south wind at southern the edge of the cool pool, that is why convergence located near the southern edge of cool pool(fig 2).

The cross section of temperature and wind distribution along the line AB and BC in fig 2, showed clearly the dynamics and thermodynamics structure of cool pool. It showed that on the mountains, the temperature was relative high because of thermal radiation from sun, while on the plains, there was relative low temperature(cool pool), with the temp of the center of which is below -3.5 degree, the height of which is above 6km. The fig also showed the wind field both on the mountains and the plains, that was, in the upward side of the mountains， because of effect of the thermodynamic lift and terrain lift, causing to the vertical wind, with the max value of which was above 4m/s; while; while on the plains, because of the cooling effect of cool pool, the down motion dominated the area, with the max value of vertical wind speed is between -1m/s and -2m/s. Significantly, at the edge of the cool pool, warm and moist wind rush from mountains to the cool pool, with warm tongue inserting the root of the cool pool, resulted in several ascending area at the leading edge of cool pool with the max convergence of 0.1-0.3m/s/km and great temperature gradient, which helped to the propagation of storm or the initiation of new storm. Furthermore, from fig 2a and 2b, it is clearly showed that the wind direction and speed except for the vicinity of the edge of cool pool stay stable from low to high, so the wind shear is relatively low on the plains(wind shear isoline(blue line) was straightened upward) which is not beneficial for storms revisiting, but at the edge of the cool pool, because of the obstacle effect to the environment wind, it result in ascending motion, and components of horizontal wind was changed to vertical components. So this formed to relative high wind shear(fig 2a,b blue lines)(isoline down) in the low layer which was conducive to the initiation of storms or the revisiting of storms near the edge of cool pool.

At 14:29LST, it show relatively high wind shear in the mountains higher than 6m/s and relatively low wind shear in the plains, that is low than 3m/s, which is not conducive to storm initiation in the Fig.3. But as analysis of preceding paragraph, at the edge of the cool pool, there is relative high wind-shear, which help to initiation of new storms or propagation of storms. Two factors lead to the result, namely, 1: temperature gradient, ---, larger temperature gradient of cool pool resulted relatively high wind shear.2: as the preceding paragraph mentioned, the obstruction effect of the cool pool resulted relatively high wind shear: the direction of shear wind is southwest, which is the same as the direction of leading air, helping to the propagation of old storms from the mountains to the plains. And helicity is the same as wind shear: low value except for at the edge of cool pool. All index meant the condition of plains was not conducive to the propagation, but cool pool yet produced good condition for storms propagations.

With the propagation of scattered storms, at 16:05LST, the storms approached near the foothills. The temperature in total the domain is as the same as the last time, with the higher temperature in the southeast, and the strength of cool pool(marked H) on the plains is a litter weaker than fig 4. But the obstacle effect still stayed stable leading to more or less unaffected convergence of 0.4m/s/km. Besides, in the south of mountains, the scattered storms produced two cold pool with a magnitude of -4 degree, marked T1, T2.

The wind field showed the main south wind direction was also as the same as fig 2. With the approaching of three cool pool, the outflow of cool pools collided with environment wind resulted in the warm air lifted and the enhancement of the convergence in the area south of the Beijing border with the magnitude of 0.6m/s/km. As a result, the old weak convective system located north re-intensified rapidly and new storms generated between T1 and T2. And the collision of the three gradually triggered the two storms collision. But the scattered storm located at the west south(in the circle in fig 1) of T1 gradually dissipated because of no effect of the collision of cool pool.

The cross section of temperature and wind distribution along the line AB was showed in fig 4. In the fig, it was clearly showed that, to be in conformity with the analysis in last paragraph, the downdraughts dominated the area of cool pool of H and T2, with the strength of -4m/s. But between the two cool pool, because of the squeezing of the outflow of the two cool pool, it resulted in upward wind above 4m/s, the decaying storms re-intensified(white line). And as well as the last time, the collision of cool pool also lift the upward wind and increased the speed at the high layer, forming relative high wind shear while low wind shear over the cool pool. All this supplied dynamics conditions for intensifying of the storms.

Fig 5 show the helicity and wind-shear of the total domain., which is calculated between 0-3km and 0-6km. with the propagation of storms, at 15:06LST, it also showed low wind shear on the plains smaller than 4m/s, which is not conducive to storm initiation. But at the edge of the cool pool, since the effect of cool pool, there is relative high wind-shear, with 8m/s which help to initiation of new storms or propagation of storms. And the direction of wind shear is the same as the leading air, so it is availed to the propagation of storms. The change trend of helicity is similar as the wind shear. On the edge of the cool pool, because of the effect of cool pool, there was higher helicity nearly 100m/s^2, reaching the category of storms revisiting. Otherwise, with low helcity, the southern storms dissipated. Besides, between the cool pool, the squeezing of the cool pools resulted in high wind shear and helcity, separately 10m/s, 16m/s and $80m/s^2$,proiving good condition for collision of storms.

In a word, mechanism of cool pool could produce good condition for storm generating or propagating, and the interaction of cool pool also help to storm propagating in the stage. So on the conditions, the old northern storm re-intensifying and with the collision of cool pool, the scattered storms formed line storms, with the max over 60dBZ and gusty. But the southern storms dissipated because of no cool pool in the propagating path.

B. after the storms approaching the plains

At 19:17LST(Fig.6), the line storm had developed into mature stage. And the cooling effect of lasting precipitation, induced the descending of cool air at the backward of the line storms and intensified the cool pool. At that time, three cool pool of last stage had merged into a strong and big cool pool, with a magnitude of -7 degree and height of 7km, before which, there was relatively warm area on the plains. The wind field also showed that it was similar as the last stage on the plains. One thing to be mentioned is that for the rapid intensifying of cool pool, the outflow intensified conspicuously, so there was leaning incline at fig 6, with the speed over 20m/s, proved by the observation of moneset. But the fig clearly showed that the strong outflow had gradually left the main line storm, and so we forecast that storm would go to the dissipating stage. The outflow of the cool pool collided with the southern warm wind from the Bohai Bay and the collision formed convergence area with 0.4m/s/km, so they leaded to new storms initiating(fig1 white line), which hided back warm inflow and was not conducive to propagation of storms.

Form the cross section(fig 6 AB), it was clearly showed that at the under parts and rear ward of the line storms, the cool air intensified further, the temperature reduced to -5 degree above 2km, and there was conspicuously inflow in the middle and low layer(RIJ). When the inflow rushed down to the leading edge of the cool pool, it produced brief thunder. And the main upward wind had blown away the major storm which is not conducive to the revisiting of the old storms.

The fig 7 showed clearly wind shear and helicity. As preceding paragraph showed, on the plains, there was little weak wind shear because of no obstacle effect of cool pool, except for the vicinity of the storms for the pollution of storms. According to RKW(Weisman,2000), because there was no equilibrium between cool pool and wind shear, so the outflow would rapidly left the main of storms leading to the dissipation of the storms. The helicity also exhibited similar situation, that is, no enough helicity to revisit the propagation of storms, as well because of no obstacle effect of cool pool.

Consequently, thermodynamics and dynamics field forecast the storms would dissipate, and the observation of radar proved it.

In a conclusion, although the outflow of the line storms collide with the warm southern wind form Bohai bay, which is conducive to storms revisiting, since there was no obstacle effect of cool pool, it formed to weak wind shear and helicity, leading the disequilibrium of cool and wind shear, which resulted in the dissipating of the line storms.

4. Conclusion:

On the basis of local improvement of VDRAS model, we analysed a case of the propagation of storms from the mountains to the plains, with the use of convergence filed , temperature, temperature gradient, and dynacis in the low layer., and some forecasting index, namely helicity, wind shear, and so on.

We found that in weak weather condition, the cool pool between mountains and plains play important role for storms initiation and propagation:

(1) .The cool pool hindered the environment wind so that the obstacle effect leaded to wind convergence, wind shear and helcity, the strength of which was related with the temperature gradient. All they were conducive to the propagation of storms.

(2). The scattered storms produced cool pool, the collision of new cool pool and old cool pool intensified scattered storms into line storms.

(3) When the line storms approached into the plains, because of no cool pool to form high wind shear and helicity, the line storms dissipated rapidly.

Reference:

Wilson J，E. Ebert, T. Saxen, R. Roberts, C. Mueller, M. Sleigh,C. Pierce, and A, 2004. Seed. Sydney 2000 Forecast Demonstration Project: Convective storm nowcasting. Wea. Forecasting, 19, 131–150.

Sun J, Chen M X, Wang Y C. 2010. A frequent-updating analysis system based on radar, surface, and mesoscale model data for the Beijing 2008 Forecast Demonstration Project. Wea. Forecast, 25: 1715-1735.

Weisman M L, Rotunno R. 2000. The Use of Vertical Wind Shear versus Helicity in Interpreting Supercell Dynamics [J]. J. Atmos. Sci., 57: 1452-1472.

Chen M X, Gao F, Kong R,et al. 2009. A system for Nowcasting Convective Storm in Support of 2008 Olympics. The World Meteorological Organization Symposium on Nowcasting and very Short Range Forecasting(WSN09),Whistler,Canada.

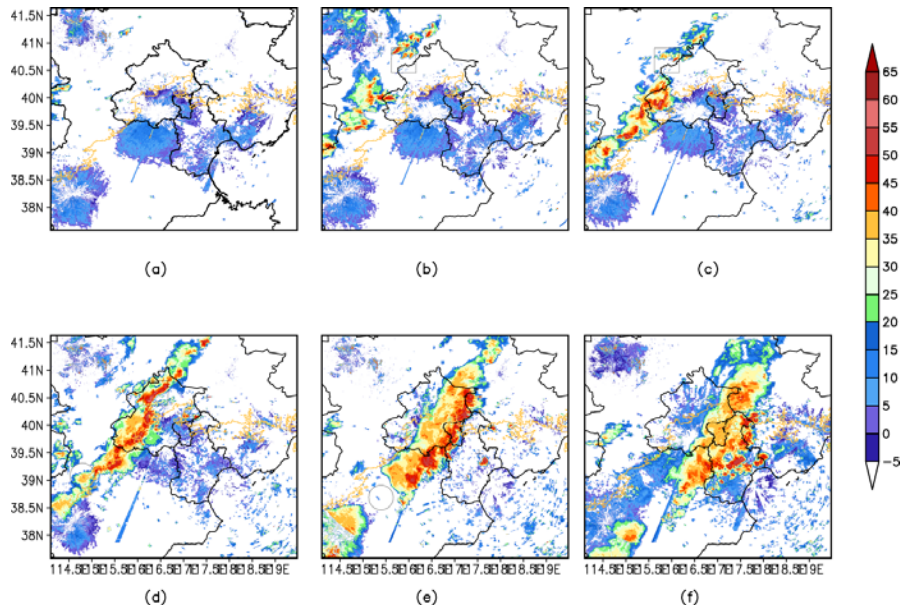

Fig.1 Composite reflectivity mosaic from 6 CINRAD radar observations (color shaded), at 12:53（a）、15:05（b）、16:05（c）、17:17（d）、19:17（e）and 20：05（f）. The abscissa and ordinate are longitude and latitude, respectively

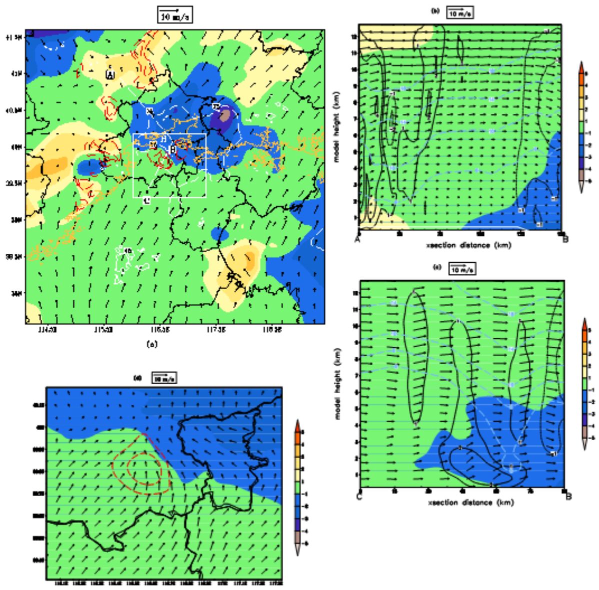

Fig. 2 Simulated perturbation temperature field at the initial storm phase（color shaded ）and wind fields (vectors) at lowest model level 250 meters with relative humility(white dashed line) and Composite reflectivity mosaic(white contour) over 45DBZ.Convergence field over $0.2\times10^{-3}\cdot s^{-1}$ with the interval of $0.2\times10^{-3}\cdot s^{-1}$. The abscissa and ordinate are longitude and latitude, respectively.

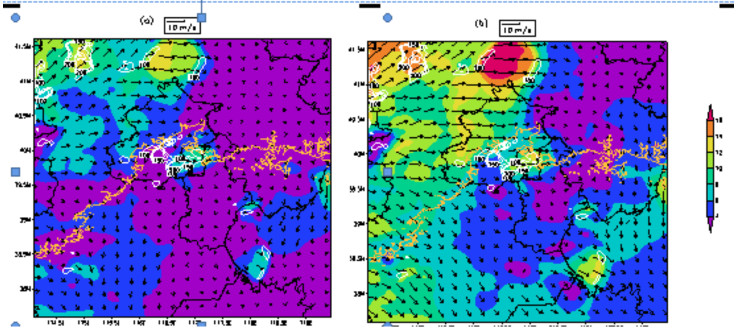

Fig 3 wind-shear between 0 and 3km and 0 and 6km(color shade), helicity(contour),wind-shear vector(vector)

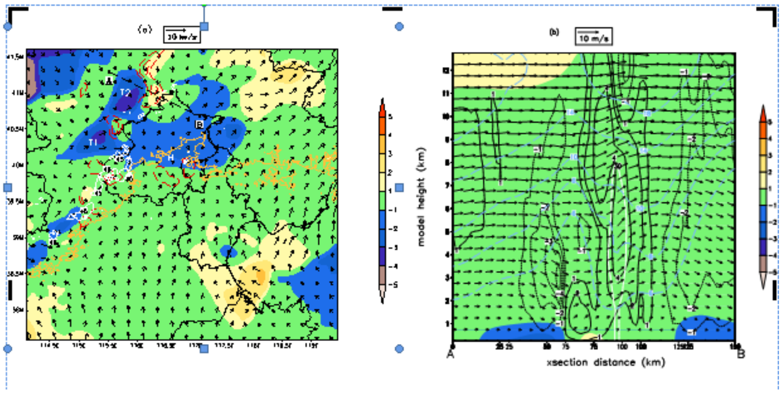

Fig. 4 Simulated perturbation temperature field at the initial storm phase（color shaded ）and wind fields (vectors) at lowest model level 250 meters with Composite reflectivity mosaic(white contour) over 45DBZ.Convergence field over $0.2\times10^{-3}\cdot s^{-1}$ with the interval of $0.2\times10^{-3}\cdot s^{-1}$. The abscissa and ordinate are longitude and latitude, respectively.

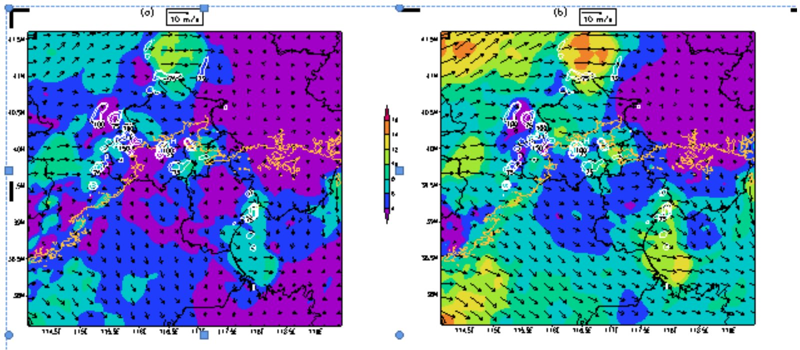

Fig 5 wind-shear between 0 and 3km and 0 and 6km(color shade), helicity(contour),wind-shear vector(vector)

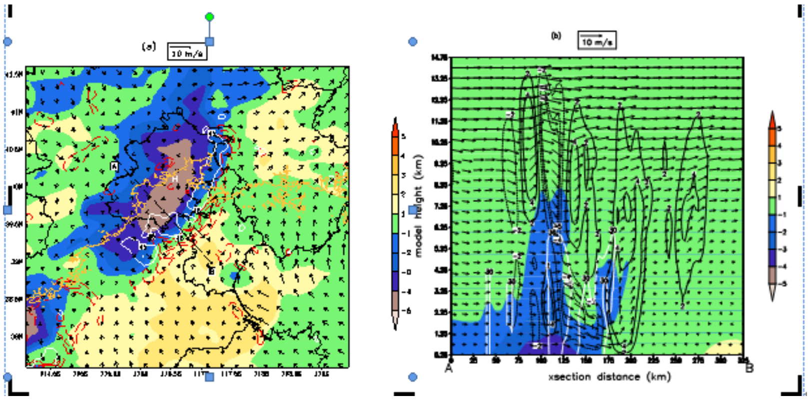

Fig. 6 Simulated perturbation temperature field at the initial storm phase（color shaded ）and wind fields (vectors) at lowest model level 250 meters with Composite reflectivity mosaic(white contour) over 45DBZ.Convergence field over $0.2\times10^{-3}\cdot s^{-1}$ with the interval of $0.2\times10^{-3}\cdot s^{-1}$. The abscissa and ordinate are longitude and latitude, respectively.

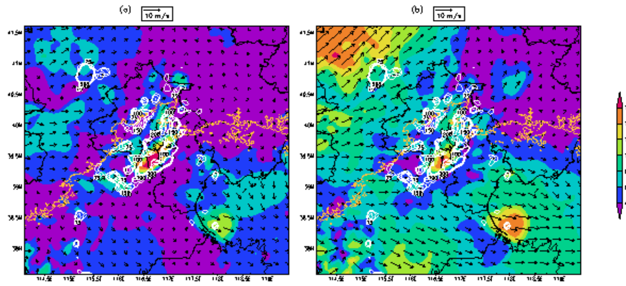

Fig 7　wind-shear between 0 and 3km and 0 and 6km(color shade), helicity(contour),wind-shear vector(vector)