AN ANALYSIS OF MESOSCALE FEATURES IN A HEAVY RAINFALL PROCESS ON 10 JULY 2004 IN BEIJING

Mao Dongyan*, Qiao Lin, Chen Tao and Yang Keming
National Meteorological Centre, China Meteorological Administration, Beijing, China

1. INTRODUCTION

A heavy rainfall occurred in Beijing on 10 July 2004. The rainfall was so strong in a short time that it brought very serious effect on the local traffic. The heavy rain event started at 08UTC and ended at 12UTC, only lasting for about 4 hours. Within this short time there are many stations with the rain amount surpassing 50mm. The maximum rain is 52mm in one hour and 23mm in 10 minutes. So it has evident mesoscale features, such as short time, big intensity and strong localization.

A dynamical and mesoscale analysis for the heavy rainfall process is performed by using the routine and densified observation, NCEP/NCAR reanalysis data and radar images.

2. WEATHER BACKGROUNDS AND PHYSICAL QUANTITY ANALYSIS

2.1 500hPa Synoptic Situation and Main Systems

Before the rain happened, at 500hPa a cold vortex maintained in the Western Siberia, from which short-wave troughs continuously spit and moved eastward along the mid-latitude frontal zone. At 00UTC on 9, a short-wave trough split and merged with a plateau trough during its moving eastward and formed a deep trough at 06UTC on 10, in the north of which a vortex formed (Fig. 1a). Fig. 1b is the 850hPa wind and low-level jet at the same time as Fig. 1a. The shaded area means the low-level jet with the wind velocity of more than 12m·s\(^{-1}\). Prior to the rain occurrence the SW airflow gradually became stronger and the north border of it extended from 30ºN to 35ºN. A warm shear formed between the SW air and the SE air in the north of Huanghuai area and connected with the vortex in the north of Hetao area. Thus the situation of vortex and shear set up. In surface a cyclone matched with the vortex. Beijing lied in the warm sector in front of the cold front. SE air prevailed between Beijing and Bohai Gulf. Thus, the 500hPa westerly trough, vortex and shear line in mid- and low-level and the surface cold front are 3 main systems that led to the rainfall occurrence.

2.2 Dynamic Conditions

Fig. 2 is the time-height cross section of vorticity and divergence at the point of (116ºE, 40ºN), which is very near to Beijing. Before the rain occurred, vorticity in the whole levels was negative because at that time Beijing was controlled by a high ridge. After 06UTC, the vorticity turned into positive above 500hPa and still remained negative below it. This situation is not good for the rain occurrence. Before the rain happened, the divergence in the whole levels was weak. Convergence mainly happened between 600-700hPa and divergence in low level. With the occurrence of the heavy rain, the convergence area extended to the low levels.

So the dynamic condition is not favorable for the rainstorm occurrence, which is probably connected with the time that dynamic condition set up and the low resolution of the data compared with the scale of the rain system.

* Corresponding author address: Mao Dongyan, National Meteorological Centre, CMA; e-mail: maody@cma.gov.cn.
Fig. 1  (a) 500hPa high field and (b) 850hPa wind field at 06UTC on 10 July 2004 (Shaded areas mean the wind velocity of more than 12 m·s\(^{-1}\), with the interval of 4 m·s\(^{-1}\)).

Fig. 2  Time-high cross section along (116ºE, 40ºN) for (a) vorticity and (b) divergence (unit: 10\(^{-5}\)s\(^{-1}\)).

2.3 Water Vapor Conditions

As we know, water vapor is one of the key factors that influence the rain intensity. It includes two parts, the local water vapor and the water vapor transport.

Fig. 3a is the 850hPa specific humidity distribution at 06UTC on 10 July. The NW of the North China was a dry area and others in the North China, humid area. Beijing just lied in the front of the big value of specific humidity gradient, with the water vapor content of 11 g·kg\(^{-1}\). Water vapor transport is very important for the duration of rain. For this case the water vapor transport mainly happened below 800hPa and focused on 925hPa. So the wind and water vapor transport in this level is selected (Fig. 3b). There were two passages for the transport of water vapor for Beijing. One was from SW jet with the big value of water vapor flux mainly lying in the south of 35ºN and did little contribution for Beijing. The other was the SE air in the north of the warm shear line, which transported the water vapor from Bohai Gulf to Beijing. Here neither of these two water vapor transports was evident, which may be one of the reasons that the heavy rain only lasted for a short time.

2.4 Instability Conditions

For this case, it’s necessary to study the condition of instability energy.
Fig. 3  (a) 850hPa specific humidity field (unit: g·kg⁻¹) and (b) 925hPa water vapor flux (unit: g·s⁻¹·cm⁻¹·hPa⁻¹) and wind at 06UTC on 10 July 2004

Before the heavy rain occurred, the profile of $\theta_{se}$ in the upper of Beijing showed the bow-shape. $\theta_{se}$ decreased variously from 900hPa to 750hPa, which reflected that in this level the atmosphere was instable. Time-longitude cross section of CAPE along 40°N is displayed in Fig. 4b. Before 00UTC, CAPE was weak in Beijing and its western areas. In the following 6 hours, it began to increase and reached maximum at 06UTC, with the big value center in the west of Beijing. With the rain occurrence, the energy released. This indicates that CAPE quickly accumulated in a short time prior to the rain occurrence and released after 06UTC.

Fig. 4  (a) Vertical distribution of $\theta_{se}$ along (116ºE, 40ºN) at 06UTC on 10 July 2004 (unit: k) and (b) time-longitude cross section for CAPE along 40°N (unit: J·kg⁻¹)

3. MESOSCALE FEATURES OF SURFACE ELEMENTS

In this part the surface elements are used to study the mesoscale features of the heavy rain event by using the Barnes objective analysis approach.

3.1 Mesoscale Features of Surface Rainfall

Mesoscale rain cluster is defined as the rain area with hourly precipitation more than 10mm, lifespan more than 1 hour and range more than 10km. Here the rain rate in one hour came from the automatic rain station. The hourly precipitation distribution from 08 to 11UTC is analyzed.

From 07-08UTC, the rain range was small and the rain area was scattered. One mesoscale rain cluster was in the west of the downtown area of Beijing, which
corresponded with the strong rain of 31mm in Mentougou. For the next one hour, the rain range obviously enlarged and the rain intensity increased. The mesoscale rain cluster in the previous one hour weakened. Moreover another one occurred in the east of the downtown Beijing with the scale of 25 km *15km and the maximum rain of 42mm which lied in Tian-an-men, just in the center of the rain cluster. After that the rain area was divided into two parts, the east and the west part. For the east one, comparing with the previous one hour, it moved northeastward and the intensity decreased, with the corresponding strong rain of 40.5mm in the north of the rain cluster. The west one was another new mesoscale rain cluster. Although the rain range was small, the intensity was strong, with the strong rain of 51.9mm in Feng-tai, which is the maximum hourly precipitation in the heavy rain process. For the last one hour, the east rain area reduced and the intensity decreased. The range of the western one varied little, but the rain center moved northward, with the strong rain of 33.5mm in Shi-jing-shan.

The mesoscale rain clusters are summarized in Table 1. There’re 3 main mesoscale rain clusters during the heavy rain process. They have evident meso-ß scale characteristics with about 100km horizontal scale and 2-3 hours lifespan. Since the rain clusters appeared in a small area repeatedly, it resulted in the local strong precipitation in the downtown of Beijing.

<table>
<thead>
<tr>
<th>No.</th>
<th>Range</th>
<th>Time of Initiation and decay (UTC)</th>
<th>Lifespan (hour)</th>
<th>Position of Maximum Rainfall</th>
<th>Maximum Rainfall (mm h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(116.08-116.21°E)</td>
<td>15-17</td>
<td>2</td>
<td>Men-tou-gou (116.12°E, 39.92°N)</td>
<td>31.0</td>
</tr>
<tr>
<td></td>
<td>(39.87-39.97°N)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>(116.26-116.51°E)</td>
<td>16-19</td>
<td>3</td>
<td>Tian-an-men (116.38°E, 39.9°N)</td>
<td>42.2</td>
</tr>
<tr>
<td></td>
<td>(39.85-40.02°N)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>(116.14-116.28°E)</td>
<td>17-19</td>
<td>2</td>
<td>Feng-tai (116.25°E, 39.87°N)</td>
<td>51.9</td>
</tr>
<tr>
<td></td>
<td>(39.83-39.97°N)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

3.2 Mesoscale Features of Surface Stream Field

Surface stream field is analyzed by using surface densified observations. The orographic height isopleth with 50m interval is added in Fig. 5.

Before 09UTC on 10 July, the eastern wind prevailed in the south plain of Beijing. Then the southern part of it increased. At the same time, the southern wind maintained in the west of Hebei Province. At 09UTC (Fig. 5a), an evident mesoscale convergence line set up in the south plain of Beijing, with the scale of about 100km and the direction of north-south. In the next one hour (Fig. 5b), the convergence line disappeared and was replaced by a small anti-cyclone. Accordingly the surface rain decayed.

4. ANALYSIS OF RADAR DATA

Radar data has its own advantages to study the mesoscale weather systems because of its high resolution. So the mesoscale features are further revealed by using the Doppler Radar images of Beijing Municipal Meteorological Bureau. The radar’s temporal resolution is 5 minutes and the scan radius is 150km.

Some basic results from the reflectivity charts are as follows.

(1) At 0700UTC some scattered convective echoes appeared in the southwest of radar station with the maximum reflectivity of more than 50dBz. The one that was nearest to the radar station gradually developed and became stronger, which corresponded with the mesoscale rain cluster one. The other two echoes moved northwestward, then turned northeastward and merged. At 0843UTC and 0948 UTC, another two convective echoes began to move into Beijing from the...
northwest of Hebei and about one hour later brought weak rain there.

(2) At 0805UTC a small convective echo appeared in the southeast of radar station, became stronger by merging with the echoes from Langfang and moved northwestward. This echo corresponded with the mesoscale rain cluster 2. 

(3) At 0910UTC the above two echo bands from Northeast-Southwest and Northwest-Southeast directions merged, corresponding with the mesoscale rain cluster 3. Accordingly the precipitation reached its peak within this hour. 

It was very clear that in the radial velocity charts, at about 0840UTC a mesoscale convergence line appeared in the west of radar station and reached its peak at 0910UTC. This is correspondence with the merging of two echo bands.

5. CONCLUSIONS AND DISCUSSIONS

The main results are as follows.

(1) The local heavy rain occurred under a relatively favorable synoptic background. The 500hPa westerly trough, vortex and shear line in mid- and low-level and the surface cold front are 3 main systems that led to the rainfall occurrence. The unstable atmosphere and in situ abundant moisture provided the favorable conditions before the rain occurred, but little contributed to the rainfall by the dynamical conditions and water vapor transport.

(2) The spatial and temporal distribution of the precipitation over the downtown of Beijing is highly inhomogeneous due to the movement of 3 main mesoscale rain clusters. The rain clusters have evident meso-ß scale characteristics with about 100 km horizontal scale and 2-3 hours lifespan. Since the rain clusters appeared in a small area repeatedly, it resulted in the local strong precipitation in the downtown of Beijing during the short time. 

(3) The initiation, development, merging and decay of Radar strong convective echoes was found to accompany the whole heavy rainfall process. It shows that the precipitation mainly resulted from the in-coming echoes, among them 3 from Zhuozhou and 1 from Langfang, Hebei province. However, the precipitation reached its peak value because of the merging of 2 echo bands from Northeast-Southwest and Northwest-Southeast, and the mesoscale convergence line triggered the heavy rainfall event. 

Both the subjective and objective forecasts had predicted the precipitation process successfully, but the amount was less than the actual value. This implies that it still exist difficulties in forecasting this kind of localized heavy rain event associated with the mesoscale system mentioned above. It also shows that only depending on the conventional observations and model outputs cannot meet the needs of operational prediction, the high resolution observations...
from Radar or satellite as complementary measurements need to monitor and trace the movement of the mesoscale systems. Thus, we can try to do the prediction about 1-2 hours ahead and offer more instant and accurate information for the disaster defending.

Reference