Analysis of Predictability of a Large-scale Short-duration Heavy Precipitation Process in Nanchang City

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Abstract Based on the observation data of automatic stations and sounding data, the circulation characteristics and physical quantities of a large-scale short-duration heavy precipitation process in Nanchang City on July 7, 2020 were diagnosed and analyzed, and the ability of several numerical forecasting products to predict this process was tested. The results show that the short-duration heavy precipitation process was triggered in the process of the subtropical high changing from lifting to the north to retreating to the south under the weather background of the confrontation between the northerly flow behind the trough and the strong southwest warm and wet flow on the north side of the subtropical high. The strong southwest warm and wet flow provided abundant water vapor, and the southern pressing of the lower energy front and the invasion of the cold air near the surface layer provided unstable energy and dynamic conditions for the heavy precipitation. The changing trend of the subtropical high from lifting to the north to retreating to the south during 08:00 to 20:00 on July 7 was not predicted by numerical forecast, and there was a large deviation in the forecast of the time and intensity of the southern pressing of the northerly flow behind the trough, so the guidance of numerical forecast for heavy precipitation was not strong, which was not conducive to the prediction of the short-duration heavy precipitation. It was predicted that the subtropical high would move slightly to the south on July 6 compared with the previous day, and the forecast adjustment of the high-level weather system can be used as a sign of the forecast change, which needs to be paid certain attention in the daily forecast.

Key words Short-term heavy precipitation; Predictability; Test; Evaluation

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As an important type of strong convection weather, short-duration heavy precipitation with hourly precipitation greater than or equal to 20 mm has the characteristics of precipitation concentration and high intensity, and is easy to cause urban waterlogging and water accumulation in farmland. In areas with relatively fragile geological conditions, it is prone to natural disasters such as mud-rock flow, mountain flood and landslide, bringing huge losses to the national economy and people's lives and property. In order to reduce the loss of national economy and people's life and property as much as possible, Chinese meteorologists have conducted relevant studies on the temporal and spatial distribution characteristics and extremes of short-duration heavy precipitation[1-6], and also analyzed the relationship between short-duration heavy precipitation and rainstorm and the causes of their generation[7]. As the causes of short-duration heavy precipitation and rainstorm are relatively complex and it is difficult to forecast them, Chinese meteorologists have also carried out a lot of analysis and research on the causes, and have analyzed the analysis of individual cases of forecast failure, as well as forecast deviation and its predictability[8-21].

Jiangxi is located in the subtropical monsoon climate zone, which is one of the provinces with frequent flood disasters. In particular, geological disasters such as mountain floods and urban waterlogging caused by short-duration heavy rainfall are extremely serious. Meteorologists in Jiangxi have carried out many studies on heavy rainfall, some of which focus on the characteristics, causes and forecast models of flood causing rainstorm[22-23], while others focus on the study of the temporal and spatial distribution characteristics of heavy rainfall process and extreme precipitation based on daily data of precipitation series[24]. However, the study of short-duration heavy precipitation focuses on the analysis of process cases[25-26]. On July 7, 2020, a large-scale short-duration heavy rainfall process occurred in Nanchang City, Jiangxi Province, resulting in obvious urban waterlogging and certain economic losses. In this paper, the large-scale short-duration heavy precipitation process in Nanchang City on July 7, 2020 was analyzed, and the forecast based on numeric forecasting products was tested to discuss the predictability of this process.

1 Process profile

From 16:00 on July 7 to 01:00 on July 8 in 2020, there was an obvious short-duration heavy precipitation process in Nanchang City. During this period, short-duration heavy precipitation with hourly rainfall exceeding 20 mm (hereinafter referred to as short-duration heavy precipitation) occurred in a total of 235 stations, and hourly rainfall exceeded 50 mm in 12 stations. The maximum appeared in Qiaole station of Anyi County, up to 61.6 mm/h, followed by Maogang Primary School, Xishan Township, Xinjian District (60.8 mm/h). From 16:00 on the 7th, the short-duration heavy precipitation process intensified significantly from 20:00 to

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23:00, appearing in more than 31 stations. It was the strongest at 22:00, and happened in 46 stations. It weakened at 01:00 on the 8th (Fig. 1). During the period, the city's cumulative precipitation averaged 111.5 mm, and was more than 100 mm in 68 stations. It exceeded 250 mm in 3 stations, and the maximum appeared in Wanli No. 1 Middle School station, up to 265.2 mm.

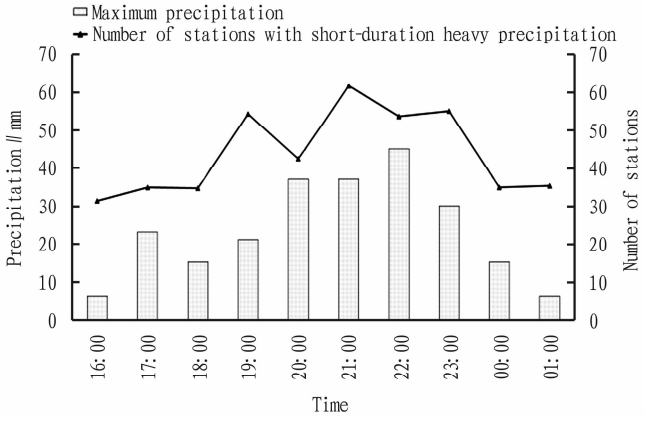

Fig. 1 Temporal distribution of short-duration heavy precipitation from 16:00 on July 7 to 01:00 on July 8, 2020

Seen from the hourly precipitation of Wanli No. 1 Middle School station from 16:00 on July 7 to 01:00 on July 8, 2020 (Fig. 2), short-duration heavy precipitation began to appear at 17:00 on July 7, and lasted for 6 consecutive hours from 19:00 on July 7 to 00:00 on July 8. It was the strongest from 21:00 to 22:00 on July 7, and the maximum of hourly rainfall intensity reached 50.7 – 56.2 mm/h. The heavy rainfall gradually weakened at 01:00 on August 8.

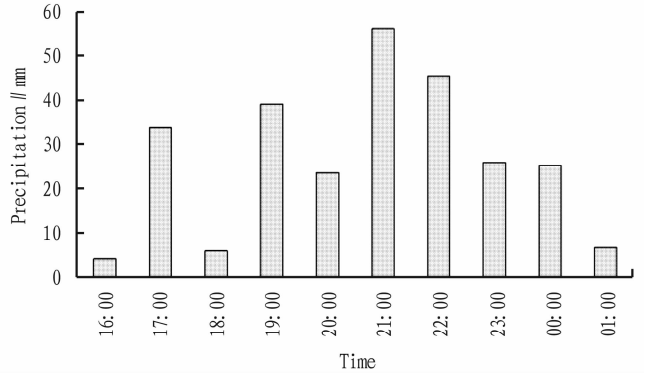

Fig. 2 Hourly precipitation in Wanli No. 1 Middle School station from 16:00 on July 7 to 01:00 on July 8, 2020

2 Circulation background and diagnosis and analysis of physical quantities

2.1 Circulation nackground From the circulation situation at 500 hPa, from 08:00 on July 6 to 08:00 on July 7, 2020, the subtropical high gradually moved northwards from South China to the south of the Yangtze River. However, since 20:00 on July 7, the subtropical high stopped moving northwards, and stayed in the north of Jiangxi. There was one trough and one ridge over Eurasia, and North China was controlled by the northerly air flow behind the coastal trough. The air behind the trough guided cold air to move southwards in the lower reaches of the Yangtze River, and South China and the south of the Yangtze River were controlled by the subtropical high. The subtropical high controlled the north of Jiangxi, and the strong southwest warm and humid air to the northwest of the subtropical high and the northerly air behind the trough formed a confrontation near 29° N in Jiangxi, which was conducive to the occurrence and development of this short-duration heavy precipitation process.

2.2 Water vapor condition From 14:00 to 20:00 on July 7, 2020, there was a water vapor transport channel in the lower atmosphere from southwestern China to the south of the Yangtze River, among which a high-value water vapor flux area of 18 – 20 g/(s · cm · hPa) appeared in Nanchang at 700 hPa, larger than the average 16 g/(s · cm · hPa) in the flood season.

At the same time, in terms of the divergence of water vapor flux, an obvious water vapor flux convergence zone was formed at 850 hPa in the north of Jiangxi. During the occurrence of heavy precipitation, the divergence of water vapor flux in Nanchang was negative, exceeding -0.8×10^{-5} g/(cm^2 · hPa · s), and there was obvious water vapor flux convergence, which provided abundant water vapor conditions for the short-duration heavy precipitation process.

2.3 Unstable conditions In order to reveal the unstable conditions of the short-duration heavy precipitation process, the θ_{se}, which comprehensively reflects the characteristics of atmospheric temperature, pressure and humidity, can be analyzed to reveal the energy distribution in the atmosphere over the strong rainfall area and the change of unstable energy. The longitudinal profiles of θ_{se} at 14:00 and 20:00 were drawn along 116° E. It is found that from 14:00 to 20:00 on July 7, 2020, an energy front area over the short-duration heavy precipitation area moved southwards from about 31° N to around 28° N (Fig. 3), and the low-energy area at the lower level invaded and combined with the high-energy area at the middle and upper levels to form unstable stratification. It provides favorable unstable stratification conditions for the short-duration heavy precipitation process.

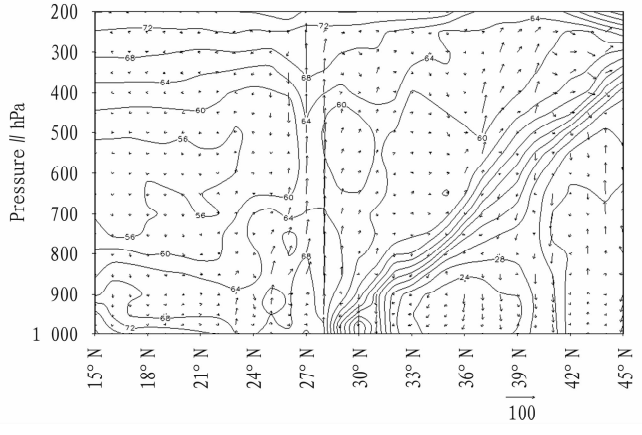

Fig. 3 Longitudinal profile of θ_{se} along 116° E at 20:00 on July 7, 2020 (unit: ℃)

2.4 Dynamic conditions Seen from the longitudinal profiles of vertical velocity and meridional wind in the short-duration heavy precipitation area along 116° E (Fig. 4), there was a deep ascending movement area near 28° N at 20:00 on July 7, and there was a large-value area (−1.2 hPa/s) at 700 hPa. Meanwhile, a dense vertical distribution zone of meronal wind inclined from south to north in the middle and low layers. There was a center of 12 m/s above 700 hPa and a center of −8 m/s in the low layers, and it intruded southwards to 29° N, indicating that warm and cold air met and gradually moved southwards. The incursion of cold air near the surface layer provided favorable dynamic lifting conditions for the short-duration heavy precipitation process.

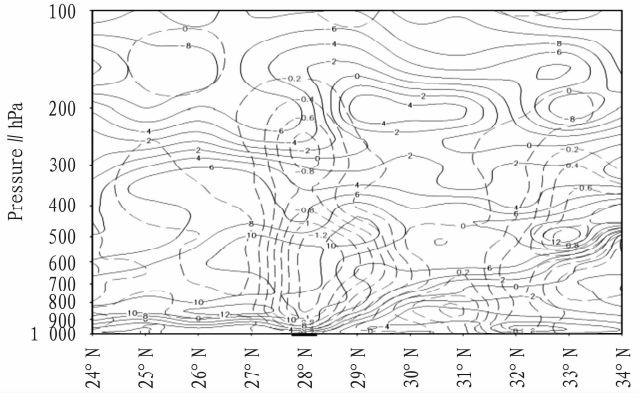

Fig. 4 Longitudinal profile of vertical velocity (dashed line, unit: hPa/S) and v component (solid line, unit: m/s) along 116° E at 20:00 on July 7, 2020

3 Predictability analysis

3.1 Prediction test of position of the subtropical high Seen from the analysis of the EC forecast field on the forecast of position of the subtropical high, the results of EC forecast show that the subtropical high gradually increased and moved to the north during July 6 − 7, 2020; it retreated southwards rapidly from 08:00 to 20:00 on the 8th. The forecast on July 5 reveal that the subtropical high was the strongest at 20:00 on July 7, and moved northwards to areas along the river in the north of Jiujiang. Nanchang City was controlled by the subtropical high. The forecast on July 6 also indicates that it was the strongest at 20:00 on July 7, but compared with the forecast of the previous day, the position of the northern lifting of the subtropical high was slightly to the south, only to the south of Jiujiang. Nanchang City was on the edge of the subtropical high.

From the comparison and analysis of the forecast and actual position of the subtropical high at 08:00 on July 7, 2020, it can be found that the position of the subtropical high at 08:00 on the 7th predicted on July 5 − 6 was more accurate, and it was predicted that the subtropical high moved northwards to the south of northern Jiangxi. Seen from the comparative analysis of the forecast and actual position of the subtropical high at 20:00 on July 7, 2020, the forecast position of the subtropical high at 20:00 on July 7 predicted on July 5 − 6 was stronger and more northerly than the actual position. Especially on July 5, it was also predicted that the subtropical high would control northern Jiangxi at 20:00 on July 7. In fact, the subtropical high had retreated to the south of northern Jiangxi at this time.

From the forecast test of position of the subtropical high, the forecast position of the subtropical high at 20:00 on the 7th by EC was more northerly and stronger, and especially the turning trend of the subtropical high changing from northern lifting to southern retreat was not predicted.

3.2 Forecast test of wind field From the comparison and analysis of the forecast and actual situation of wind field at 500 hPa from 08:00 to 20:00 on July 7, 2020, it can be found that under the influence of a large coastal trough, the northerly air flow behind the trough moved to the south rapidly in the lower reaches of the Yangtze River at 500 hPa from 08:00 to 20:00 on July 7. However, it was predicted that it moved to the south on the 8th. The predicted wind speed of the northerly wind behind the trough was smaller, and the predicted position was more southerly. Therefore, the predicted time of the southward movement of the northerly air flow behind the trough was late, and EC had a large deviation in the prediction time, intensity and speed of the northerly air flow behind the trough.

3.3 Test of precipitation forecast The precipitation from 08:00 on July 7 to 08:00 on July 8 was predicted by EC during July 5 − 6. The forecast results show that the main rain belt would appear from Hubei to Anhui to the north of the Yangtze River, and there was mainly light rain in Nanchang City. The forecast results on July 5 reveal that on the daytime and night of the 7th, precipitation would be only 5 − 20 mm in the north of northern Jiangxi, 20 − 30 mm along the river in northern Jiangxi, and only 0 − 5 mm precipitation in Nanchang City. On July 6, the precipitation from 08:00 to 20:00 on July 7 and from 20:00 on July 7 to 08:00 on July 8 was predicted. It was predicted that there was a slight increase in rainfall, but the main rain belt of rainstorm would be from Hubei to Anhui to the north of the Yangtze River. From 08:00 to 20:00 on July 7, precipitation would be 10 − 30 mm in the north of northern Jiangxi; the precipitation center of Jiangxi would be in the north of Shangrao and the north of Jingdezhen, and it was 40 − 50 mm in some areas. The precipitation in Nanchang City would be 0 − 6 mm. On the evening of the 7th, the precipitation in the north of northern Jiangxi would be 10 − 30 mm; the precipitation center in Jiangxi would be in the northeast of Jiujiang and the northwest of Shangrao, and the local precipitation was 40 − 60 mm. The precipitation in Nanchang would be 10 − 18 mm in the north and 3 − 10 mm in the south.

The precipitation from 08:00 on July 7 to 08:00 on July 8 was also predicted by GRAPES-GFS during July 5 − 6, and the prediction results were similar to those of EC. That is, the main rain belt of rainstorm would be from Hubei to Anhui to the north of the Yangtze River, and there was mainly light-to-moderate rain in Nanchang City; a heavy rain would appear in some areas from 20:00 on July 7 to 08:00 on July 8. The results of prediction on July 5 show that the precipitation center during the daytime and night of the 7th would be in the west of northeast Jiangxi (west of Shangrao and Jingdezhen).

During the daytime of July 7, rainfall would be 20 − 40 mm

in the heavy precipitation center, 50 – 55 mm in some areas, 5 – 20 mm in the north of northern Jiangxi, and 1 – 5 mm precipitation in Nanchang City. On the night of July 7, rainfall would be 30 – 40 mm in the heavy precipitation center, 50 – 60 mm in some areas, 5 – 20 mm in the north of northern Jiangxi, 1 – 5 mm precipitation in Nanchang City, and 10 – 20 mm in some areas of northeast China.

The results of precipitation from 08:00 to 20:00 on July 7 and from 20:00 on July 7 to 08:00 on July 8, which were predicted on July 6, were different from the forecast results on July 5. The rain belt would extend from southwest to northeast, and rainfall would also increase, but the main rain belt would be from Hubei to Anhui to the north of the Yangtze River. It was predicted that from 08:00 to 20:00 on July 7, precipitation would be 10 – 20 mm in the north of northern Jiangxi, 20 – 30 mm in northern Jiujiang and northern Shangrao, and 2 – 10 mm in Nanchang City. From 20:00 on the 7th to 08:00 on the 8th, precipitation would be 20 – 40 mm in the north of northern Jiangxi, and the precipitation center in Jiangxi would appear in the east of Jiujiang and the northwest of Shangrao, with the rainfall of 40 – 60 mm. In Nanchang, precipitation would be 18 – 36 mm in the north and 4 – 18 mm in the south.

From the above analysis, it can be seen that EC and GRAPES-GFS did not provide a good reference forecast for the short-duration strong convection weather in Nanchang.

In order to study the ability of four commonly used model precipitation forecast products such as EC, GRAPES-GFS, GRAPES-MESO and East China regional model to predict this short-duration heavy precipitation, the TS scores of the short-duration heavy precipitation forecast in Jiangxi Province from 08:00 to 20:00 on July 7 and from 20:00 on July 7 to 08:00 on July 8 based on the four models were tested (Table 1 and Table 2). The test results show that the TS scores of the short-duration heavy precipitation forecast from 08:00 to 20:00 on July 7 and from 20:00 on July 7 to 08:00 on July 8 based on EC were all 0, that is, the short-time heavy precipitation process was not predicted by EC. The TS scores of the short-duration heavy precipitation from 08:00 to 20:00 on July 7 based on GRAPES-GFS were all 0, and the short-duration heavy precipitation from 08:00 to 20:00 on July 7 was not predicted by GRAPES-GFS. Although the forecast from 20:00 on the 7th to 08:00 on the 8th had a certain score at 08:00 on the 5th and 20:00 on the 6th, while the score was 0 in intermediate time. That is, there were fluctuations in the score at different times, indicating that there were large fluctuations in the short-duration heavy precipitation forecast at different times, and the guidance for the short-duration heavy precipitation forecast was not strong.

The forecast of short-duration heavy precipitation from 08:00 to 20:00 on July 7 and from 20:00 on July 7 to 08:00 on July 8 based on GRAPES-MESO had a certain score at 20:00 on the 5th and 08:00 on the 6th, but the other scores were 0. There were also fluctuations in the short-duration heavy precipitation forecast at different times, which seriously affected the guidance of the short-duration heavy precipitation forecast.

The score of short-duration heavy precipitation forecast from 08:00 to 20:00 on July 7 based on East China regional model was 0 at 20:00 on the 6th, but it showed an increasing trend in the first three times, which has certain guidance for the forecast of short-duration heavy precipitation. For the short-duration heavy precipitation from 20:00 on July 7 to 08:00 on July 8, the score ranged from 42.42% to 51.52% in the last three times, which had good guidance for the forecast of heavy precipitation.

Table 1 TS scores of short-term heavy precipitation forecast based on various models %

Forecast time	Starting time	EC	GRAPES-GFS	GRAPES-MESO	East China regional model
From 08:00 to 20:00 on July 7	08:00 on July 5	0	0	0	10.00
	20:00 on July 5	0	0	23.53	5.00
	08:00 on July 6	0	0	16.67	33.33
	20:00 on July 6	0	0	0	0
From 20:00 on July 7 to 08:00 on July 8	08:00 on July 5	0	29.17	0	0
	20:00 on July 5	0	0	31.03	42.42
	08:00 on July 6	0	0	32.14	51.52
	20:00 on July 6	0	12.50	0	51.35

From the above analysis, it can be seen that EC did not forecast the turning trend of the subtropical high from northward lifting to southward retreat from 08:00 to 20:00 on the 7th. The predicted time of the southward movement of the northerly air flow behind the trough was late, and EC had a large deviation in the prediction time, intensity and speed of the northerly air flow behind the trough. The guidance of EC, GRAPES-GFS, and GRAPES-MESO models for the forecast of this short-duration heavy precipitation process was not strong, and the East China regional model only predicted the short-duration heavy precipitation process from 20:00 on July 7 to 08:00 on July 8.

Seen from various types of forecast data, the subtropical high would move slightly to the south on July 6 compared with the previous day, which needs to be paid attention to in the daily forecast.

4 Conclusions

In this study, based on the observation data of automatic stations and many numerical forecasting products, a large-scale short-duration heavy precipitation process in Nanchang City on July 7, 2020 was analyzed to obtain some conclusions as follows.

(1) The short-duration heavy precipitation process was a typical short-time heavy precipitation process triggered in the process of the subtropical high changing from lifting to the north to retrea-

ting to the south under the weather background of the confrontation between the northerly flow behind the trough and the strong southwest warm and wet flow on the north side of the subtropical high. In this process, the southwest warm and wet flow provided abundant water vapor, and the southern pressing of the lower energy front and the invasion of the cold air near the surface layer provided good water vapor, unstable energy and dynamic conditions for the heavy precipitation.

(2) The test of the numerical model products shows that due to the error in the forecast of the subtropical high position from 08:00 to 20:00 on July 7, the change of the subtropical high from lifting to the north to retreating to the south was not predicted, and there was also a large deviation in the forecast of the time and intensity of the southern pressing of the northerly flow behind the trough, which was not conducive to the prediction of the short-duration heavy precipitation.

(3) The test results of precipitation forecast reveal that the heavy precipitation process was not predicted by EC, and the forecast of the heavy precipitation based on GRAPES-GFS and GRAPES-MESO at different times had a large fluctuation, so the guidance of heavy precipitation forecast was not strong, while the East China regional model had certain guidance for the heavy precipitation forecast.

(4) Seen from various types of forecast data, the subtropical high would move slightly to the south on July 6 compared with the previous day, and the forecast adjustment of the high-level weather system can be used as a sign of the forecast adjustment, which needs to be paid some attention in the daily forecast.

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