NUMERICAL STUDY ON EFFECTS OF THE QINGHAI–XIZANG PLATEAU ON FORMATION OF THE URAL BLOCKING HIGH

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ABSTRACT

By employing the improved T42L5 spectral model and utilizing the ECMWF data covering the period from 1 July to 7 July 1982, a numerical research on the formation of the Ural blocking system has been made. The results show that the model forecasts for the upstream Ural area turn out to be worse if the dynamic effect of the Qinghai–Xizang Plateau is not considered. The correlation coefficient between the model forecasts and observed 500 hPa geopotential height anomaly decreases by 9% for the 5–day mean, and their averaged root mean square (RMS) error increases 15 m. Due to the dynamic effect of the Plateau, the trough being on the northwest of the Plateau is barricaded and turns to be a transversal trough. Consequently southwest flow occurs along the northwest of the Plateau in front of the trough, while northeast flow prevails over the west of the trough, causing the formation of the blocking high over the Ural area. When the dynamic effect of the Plateau is not taken into consideration, the trough develops and moves southeastward and the Ural blocking high changes into a migratory high. All these result in the failure of the simulation. The dynamic effect of the Plateau helps to increase the negative vorticities over the Plateau and its north periphery as well as the Ural area, and also helps to increase the positive vorticities over the Black Sea and the Caspian Sea area. On the other hand, the thermodynamic effect mainly influences the Plateau and its downstream area and plays an less important role in the formation of the blocking high over the upstream Ural area.

Key words: Qinghai–Xizang Plateau, T42L5 spectrum model, numerical simulation, Ural blocking high, dynamic effect

I. INTRODUCTION

The blocking system influences the weather and climate over a large area. Blocking patterns often occur over Ural and Okhotsk (Sea) area in Asia, and the collapse of the Ural blocking system always leads to cold wave over a large area in East Asia. In recent years, many people have carried out numerical simulations of blocking system with general circulation models (GCMs), Such as Miyakoda et al. (1983), who has successfully simulated the blocking event over North America in January, 1977.

The Plateau influences the medium–range weather processes significantly in aspect(s) of dynamics and / or thermodynamics. Zheng and Liou (1986) studied the effects of the Plateau by using a seven-level spectral model. The results showed that the dynamic effect influenced the weather of East Asia significantly and played an important role in transporting negative and positive vorticities along the north and south periphery of the Plateau.

This paper aims to simulate the blocking process over Ural area in July 1982 and explore the impacts of the Plateau on the formation of the upstream blocking system by employing the developed T42L5 spectral model of NMC (Beijing) introduced from ECMWF. The T42L5 spectral model is described briefly in next section. In Section III, the designs of the experiments are presented. The results of the experiments are given in Section IV. Finally the conclusions are summarized.

II. BRIEF DESCRIPTION OF THE T42L5 MODEL

The improved T42L5 model in this paper consists of five levels vertically in the σ-coordinate, with $\sigma=0.1, 0.3, 0.5, 0.7$ and 0.9, respectively. The variables in the horizontal direction are truncated in triangle at wave number 42. The semi-implicit scheme is utilized in time integration with the time step is 30 min. The basic equations of the model are as follows:

$$\frac{\partial \zeta}{\partial t}=\frac{1}{a(1-\mu^2)}\frac{\partial(F_v+P_v)}{\partial\lambda}-\frac{1}{a}\frac{\partial(F_u+p_u)}{\partial\mu},$$

$$\frac{\partial D}{\partial t}=\frac{1}{a(1-\mu^2)}\frac{\partial(F_u+P_u)}{\partial\lambda}+\frac{1}{a}\frac{\partial(F_v+p_v)}{\partial\mu}-\nabla^2(E+\varphi+RT_0\ln P_*),$$

$$\frac{\partial T'}{\partial t}=-\frac{1}{a(1-\mu^2)}\frac{\partial}{\partial\lambda}(UT')-\frac{1}{a}\frac{\partial}{\partial\mu}(VT')+DT'-\dot{\sigma}\frac{\partial T'}{\partial\sigma}+\frac{R}{C_p}\frac{T_v\omega}{P}+P_T,$$

$$\frac{\partial q}{\partial t}=-\frac{1}{a(1-\mu^2)}\frac{\partial}{\partial\lambda}(Uq)-\frac{1}{a}\frac{\partial}{\partial\mu}(Vq)+Dq-\dot{\sigma}\frac{\partial q}{\partial\sigma}+P_q,$$

$$\frac{\partial}{\partial t}\ln P_*=-\int_0^1(D+\mathbf{V}\cdot\nabla\ln P_*)d\sigma,$$

$$\frac{\partial\varphi}{\partial\ln\sigma}=-RT_v,$$

and

$$F_u=V\zeta-\dot{\sigma}\frac{\partial U}{\partial\sigma}-RT'_v\frac{1}{a}\frac{\partial}{\partial\sigma}\ln P_*,$$

$$F_v=-U\zeta-\dot{\sigma}\frac{\partial V}{\partial\sigma}-RT'_v(1-\mu^2)\frac{1}{a}\frac{\partial}{\partial\mu}\ln P_*,$$

$$E=\frac{U^2+V^2}{a(1-\mu^2)},$$

$$T_v=T\frac{0.622+q}{0.622(1+q)},$$

$$T'_v=T_v-T_0,$$

$$T'=T-T_0,$$

$$\frac{\omega}{P}=\mathbf{V}\cdot\nabla\ln P_*-\frac{1}{\sigma}\int_1^{\sigma}(D+\mathbf{V}\cdot\nabla\ln P_*)d\sigma,$$

$$\dot{\sigma}=\sigma\int_0^1(D+\mathbf{V}\cdot\nabla\ln P_*)d\sigma-\int_0^{\sigma}(D+\mathbf{V}\cdot\nabla\ln P_*)d\sigma.$$

P_u, P_v are friction terms. P_t is diabatic heating term. P_q is the term of the vapour source. Other symbols in the equations follow the normal rules and are not detailed here.

Integral physical processes are considered in the model, which include mountains and the surface frictions, the impacts of the boundary layer, diffusions due to the sub-grid effects, large-scale condensation, sensible heat, effects of cloud and radiation, and cumulus convection. In the calculation of cloud and radiation, modeled water vapour and modeled diagnosing cloud scheme are employed. The surface temperature is calculated from the heat budget equation at the surface, and the sea surface temperature (SST) is yearly climatological normal of July.

The model initial fields are obtained by using the nonlinear balance equation initialization method described by Zheng (1987), and so the initial U and V fields fit the nonlinear balance equation well.

The variables are interpolated on the σ level, utilizing the iterative methods suggested by Zheng and Liou (1986) to reduce the transition error from p to σ-coordinate.

III. EXPERIMENT SCHEME

A blocking high generated and developed over Ural area during the period from 2 to 7 July, 1982. In this paper, the effects of the Qinghai-Xizang Plateau are studied according to the initial field of 12 UTC 1 July. The experiment designs are:

(1) The thermodynamic effect of the Plateau on the blocking system over the upstream Ural area is studied under the conditions of the presence of the mountains and the diabatic heating except the adiabatic process over the Plateau area.

(2) The dynamic effect of the Plateau on the formation of the upstream Ural blocking high is investigated by comparative numerical experiments A and B. In experiment A (EA), mountains and adiabatic process are involved in the model with the maximum height of the Plateau up to 5700 m. Conditions of experiment B (EB) are almost the same as those of EA except the inclusion of mountain just over the Plateau area.

Moreover, it should be announced that the Qinghai-Xizang Plateau referred in this paper includes the area containing Tibetan Plateau, Pamir Plateau, Altay mountains and Mongolian Plateau (hereafter referred as the Plateau).

IV. NUMERICAL EXPERIMENTS ON THE INFLUENCE OF THE PLATEAU ON FORMATION OF THE URAL BLOCKING HIGH

1. *The Thermodynamic Effect of the Plateau on Generation of the Upstream Ural Blocking High*

Fig.1 (a—d) demonstrates the discrepancy of the vorticities between the forecasts with diabatic heating and with adiabatic process just over the Plateau, under the same condition in the presence of the mountains.

The difference is small within the 24 h simulation. The distribution of centers of the positive and negative vorticity has occupied significant features since 48 hours. In the westerly zone of high and middle latitudes, the centers are concentrated mostly in the area from the east of the Plateau to the east coastal area of China. In the easterly of low latitudes the centers are distributed from the south of the Plateau to the Arabian Sea. There is little difference over Ural area positioned upstream of the Plateau. Besides, the distribution of the centers present zonality following the westerly and easterly, with the negative centers alternating with the positive ones. For example, at 72 hours and 144 hours (Figs.1c, 1d) the centers in high and middle latitudes extend from the Plateau towards east and northeast, while in low latitudes the centers display zonal distribution from the Philippines along the South China Sea and the Bay of Bengal

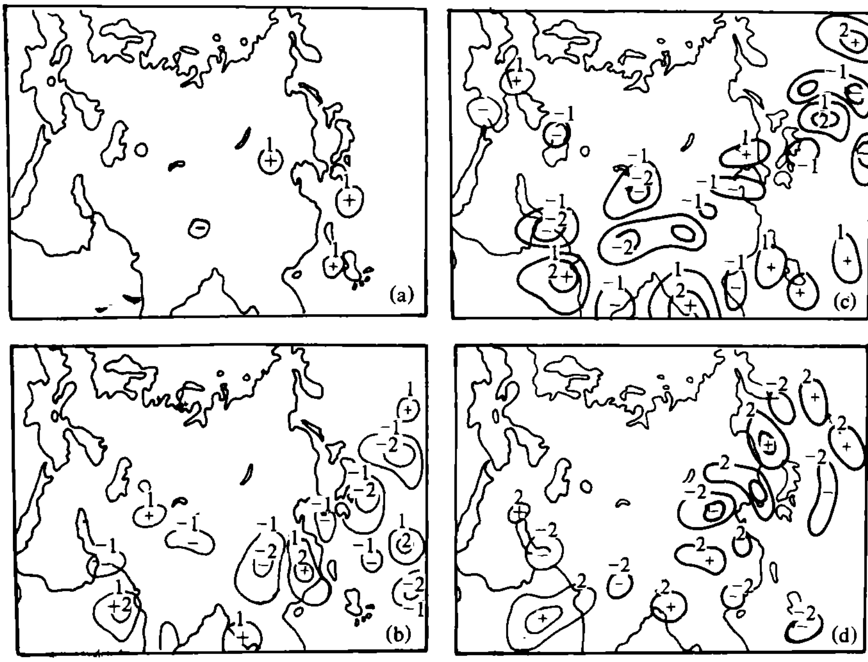

Fig.1. The vorticity differences (in 10^{-5} s^{-1}) between the forecasts with diabatic heating and with adiabatic process only over the Plateau area, both with the consideration of mountains: (a) for 24 hours; (b) for 48 hours; (c) for 72 hours; (d) for 144 hours.

to the Arabian Sea. Thus it is demonstrated that the thermodynamic effect of the Plateau mainly influences the Plateau and its downstream area through the transport of the westerly and easterly flow, and plays a little role in the westerly region upstream. It is concluded that the thermodynamic effect of the Plateau has little influence on the generation of the upstream blocking system in the medium– and short–time scale. But it should be noticed that the thermodynamic effects affect the upstream area through the meridional circulation and the easterly winds in low latitudes as time goes on. (It can be seen clearly in Fig.1 that the discussion is not affected though the zero lines are not drawn in the figure.)

2. *The Dynamic Effect of the Plateau on Simulation for Ural and Its Surrounding Areas*

It is known from above that the thermodynamic effect of the Plateau has little influence on the upstream westerly area (such as the area over which the Ural blocking high is generated). In order to describe the dynamic effect of the Plateau clearly, two kinds of numerical experiments A and B, presented in Section III, are carried out. The predictions for Ural and its surrounding areas are examined and compared then. The experiment results for the chosen region (45—75°N, 40—90°E) are given in Table 1.

In Table 1, r represents the correlation coefficient between the observed and predicted 500 hPa geopotential height anomaly. E_f and E_{per} stand for the root mean square errors between the model forecasts and observations, and between the persistence forecasts and the observations, respectively.

Table 1. The Prediction Errors of the Experiments (unit for E_f and E_{per} in gpm)

		24 h			48 h			72 h			96 h			120 h		
		r	E_f	E_{per}	r	E_f	E_{per}	r	E_f	E_{per}	r	E_f	E_{per}	r	E_f	E_{per}
500 hPa	(A)	0.81	37	59	0.88	39	82	0.88	44	86	0.88	50	97	0.93	47	104
	(B)	0.76	41	59	0.83	46	82	0.81	55	86	0.78	65	97	0.76	73	104
700 hPa	(A)	0.73	28	26	0.81	35	55	0.75	44	61	0.76	45	63	0.88	38	60
	(B)	0.62	34	26	0.70	43	55	0.57	59	61	0.53	65	63	0.57	63	60
850 hPa	(A)	0.84	49	91	0.93	41	144	0.93	50	132	0.92	62	153	0.94	61	170
	(B)	0.83	51	91	0.92	43	144	0.92	53	132	0.88	72	153	0.88	80	170

It is clear that the results of EA are much better than those of EB. At 500 hPa $E_f<A> - E_f<B>$ is 4.2, 7, 11, 15 and 26 gpm for five days respectively, while $r<A>-r<B>$ is 0.05, 0.05, 0.07, 0.10 and 0.17. It indicates that the influence of the dynamic effect on the upstream Ural area increases with the time. When the contribution of the mountain is not considered in the model, the RMS error for Ural and its neighboring area increases to 26 gpm on the fifth day, while the correlation coefficient reduces by 0.17 with the decrement of 0.09 for five-day mean. Consequently the simulation for the formation of the Ural blocking high comes to a failure. The results of EA are much better than those of EB, especially in middle and low layers.

3. *The Influence of Dynamic Effect on Formation of the Upstream Blocking Pattern*

The initial field of 500 hPa height is given in Fig.2.

In the initial field (Fig.2), the Ural blocking high was not established. A weak ridge lay over the Black Sea to Ural area, and the low was positioned over Lake Bajkal to the west periphery of the Plateau. Two centers of lows were located at the west of Lake Bajkal and at the south of the Balkhash Lake.

The observed 500 hPa geopotential height compared with the model forecasts for EA and EB on the first day of the prediction are given in Fig.3.

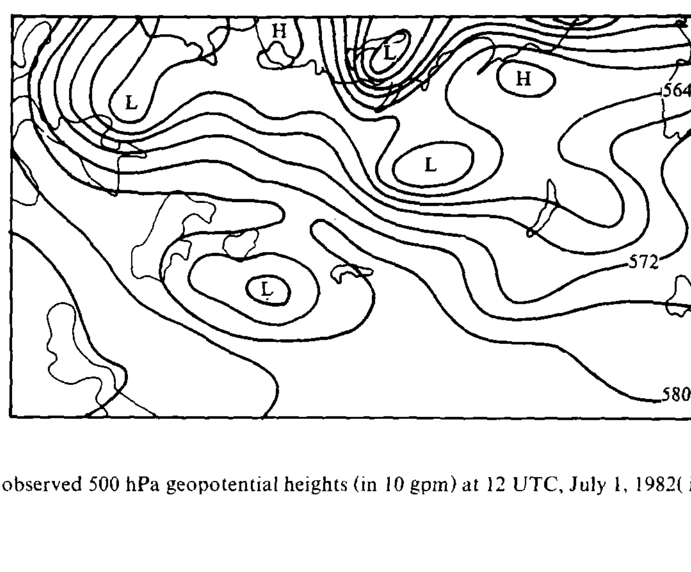

Fig.2. The observed 500 hPa geopotential heights (in 10 gpm) at 12 UTC, July 1, 1982(initial field).

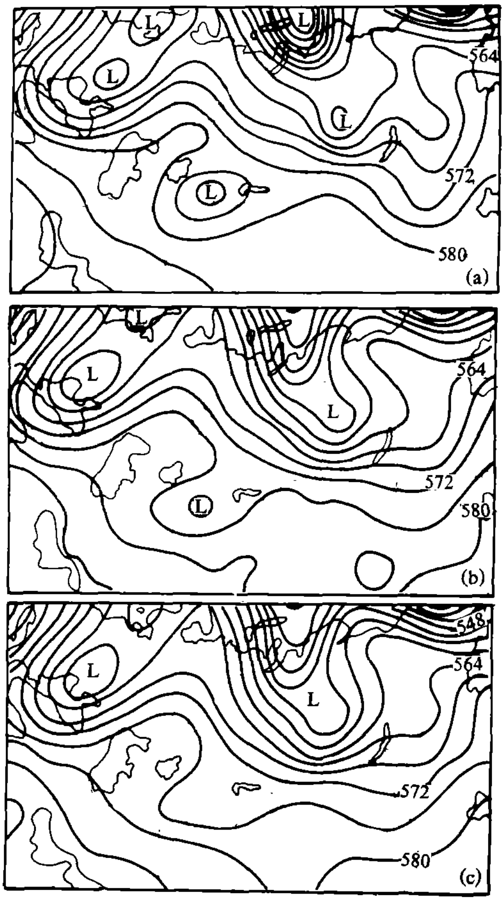

Fig.3. 500 hPa geopotential heights (in 10 gpm) at 12 GMT, July 2, 1982: (a) observations; (b) model forecasts of EA; (c) model forecasts of EB.

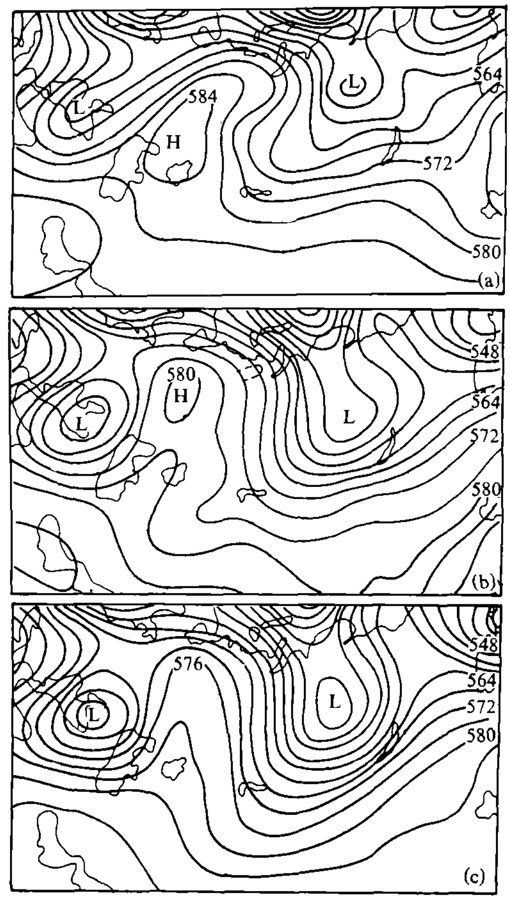

Fig.4. As in Fig.3, but for July 4, 1982.

Fig.3 shows that there is a high develops over the west of Ural, and the low stays on the northwest of the Plateau. These patterns are simulated correctly in both EA and EB. The simulations of the ridge over Ural for EA and EB have little difference because it is the first day of the prediction. It is simulated successfully in EA that the trough lying on the northwest side of the Plateau was at a standstill because the dynamic effect has been considered in the model, and as a result the southerly flow over the northwest periphery of the Plateau is significantly stronger than that in EB. In addition, the west and north flow dominates over the west of the Plateau in EB only due to that the dynamic effect of the Plateau is out of consideration.

The observed 500 hPa geopotential height and the simulations of EA and EB on the third day of the prediction are given in Fig.4.

It is known from Fig.4a and Fig.3a that the ridge over Ural area strongly develops and an anticyclonic closed circulation occurs, while a deep trough shapes from Lake Bajkal to the Balkhash Lake, and is detained at the west of the Plateau by the mountains. The west end of the trough line extends to the west of the Balkhash Lake. All these are simulated satisfactorily in EA. In EB, the deep trough shifts southwestward instead of staying on the west of Lake Bajkal,

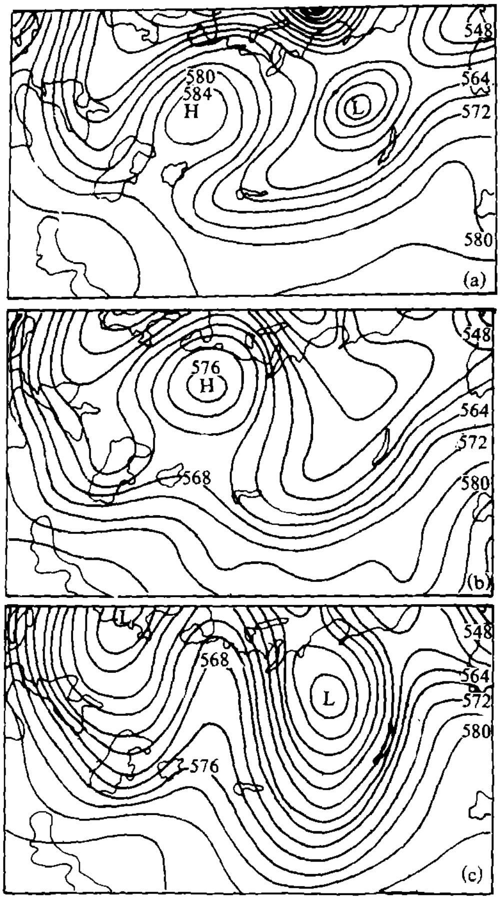

Fig.5. As in Fig.3, but for July 6, 1982.

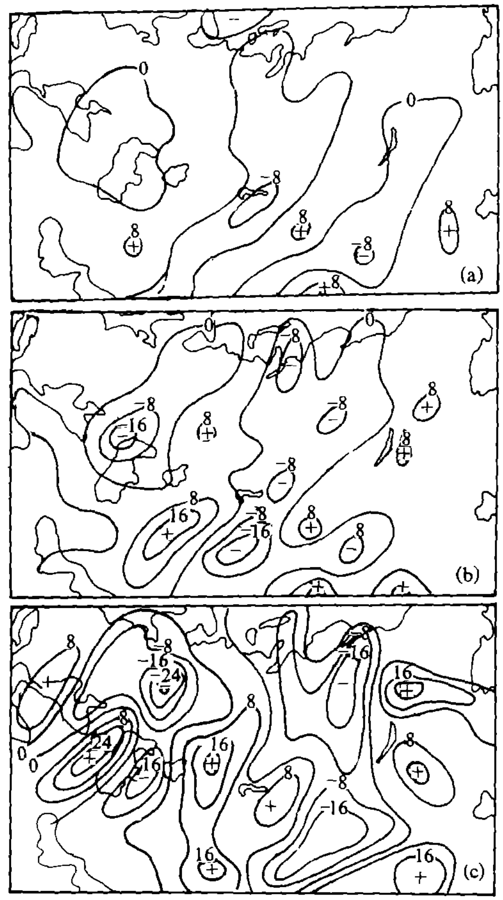

Fig.6. The distributions of vorticity difference (in $0.2 \times 10^{-5}\ s^{-1}$) between forecasts of EA and EB at 500 hPa: (a) for 24 hours; (b) for 72 hours; (c) for 120 hours.

and the trough line reaches between the Balkhash Lake and Lake Bajkal only because the Plateau is ignored in the model. Thus the Ural high turns into a migratory high and the anticyclonic closed circulation which indicates the generation of the blocking system does not appear.

It is shown from Fig.5a (the observations for the fifth day) that the deep trough maintains on the west of the Plateau and it turns into a typical transversal trough. The trough line is located on the west of the Plateau and its existence barricades the western system dynamically. So a typical blocking high forms over Ural area with the central intensity above 5840 gpm. This pattern is simulated well as expected in EA (Fig.5b) for the consideration of the mountains in the model. The predicated situation of the Ural blocking high, the circulation and the intensity of the blocking appear almost the same as those in the observations, so does the deep transversal trough on the northwest of the Plateau. Comparing Figs. 5b and 5c, it is clear that if the dynamic effect of the mountain is not considered, the trough shifts to the southeast due to the absence of the dynamic barrier effect of the Plateau on its northwest low (Fig. 5c). It is illustrated from the distribution of the flow over the northwest of the Plateau, that the transversal trough is situated between the Balkhash Lake and Lake Bajkal, and the southwest flow occupies the south of the Plateau in EA (Fig.5b). While in EB (Fig.5c), the trough line lies in south–north direction and moves nearly to Lake Bajkal. Its southern end reaches to the middle of the Plateau. Strong north flow prevails on the Plateau area facing the Balkhash Lake at east. Therefore, in Fig.5c, a migratory high ridge possesses the Ural area and no center of high occurs. The simulations of the Ural blocking high differ a lot which depend on whether the dynamic effect of the Plateau is taken into consideration in the model (other conditions are the same) or not. In EA, since the dynamic obstruction effect of the Plateau on the deep trough over Lake Bajkal to the Balkhash Lake is considered, the migratory trough turns into a stagnate transversal trough and the formation of the Ural blocking high is successfully simulated. While in EB, the simulation of the blocking high fails only due to that the mountain is removed in the model and then the dynamic barrier effect of the Plateau disappears.

4. *The Influence of the Dynamic Effect of the Plateau on the Streamline Field of the Upstream Blocking Event*

Fig.6 shows the distribution of the vorticity differences at 500hPa between EA and EB on the first, third and fifth day.

For the first day of the prediction, it can be seen that the difference of the relative vorticities between EA and EB is small (Fig.6a). The region of negative value occurs over the Black Sea area. There is also a negative belt extending from north to south over the northwest periphery of the Plateau.

On the third day, the dynamic effect of the Plateau is demonstrated by the difference between two experiments. The area of negative values of the vorticity difference maintains and strengthens over the northwest of the Plateau. This is attributed to the fact that the Plateau dynamically barricades the systems coming from northwest and stops the trough and weakens it. This favors the trough to change into a northeast–southwest–oriented trough. Then southwest flow shapes along the northwest of the Plateau in front of the trough. It is also shown in Fig.6 that the intensity of the negative region from the Black Sea to Ural is obviously strengthened, since a center with the intensity of $-3.2 \times 10^{-5}/s$ occurs on the north of the Black Sea. It can be seen from Fig.6c that on the fifth day a strong negative center with a value of $-7 \times 10^{-5}/s$ emerges over the area from north of the Black Sea to the west of Ural, and a region of positive value with the center value of $4.8 \times 10^{-3}/s$ appears from the Caspian Sea to the Black Sea, due to the difference between EA and EB. The area of strong negative value keeps on the west of the Plateau, and its center value reaches $-4.4 \times 10^{-5}/s$. It is concluded from the differences between EA and EB which are shown in Fig.6 that the dynamic effect of the Plateau makes it easy to strengthen negative vorticity over the northwest of the Plateau, which is associated with the air climbing up and bypassing when it meets the Plateau. The significant dynamic effect of the Plateau causes the obstruction of the trough on the northwest of the Plateau and helps the formation of the transversal trough extending in northeast–southwest direction (Figs. 5a, 5b). Strong southwest flows in front of the trough bypasses along the northwest of the Plateau, while northeast and east flows occupy the other side of the trough. A blocking high is formed over the Ural area finally, and a strong zone of the vorticity difference between EA and EB which is shaped like a dipole with negative in the north and positive in the south, as shown in Fig. 6c.

V. CONCLUSIONS

The influence of the dynamic effect of the Plateau on the formation of the Ural blocking high has been studied in this paper after the comparative numerical experiments A and B. The impact of the diabatic heating of the Plateau on the upstream flow has also been numerically investigated. The following conclusions can be drawn:

(1) The dynamic effect of the Plateau has significant influence on the results of the simulations for the upstream Ural and its surrounding areas. The correlation coefficient of EA between the model forecasts and observed 500 hPa geopotential height anomaly is 9% higher than that of EB for 5-day mean, while the RMS error is 15 m lower. The impact is larger on the height fields of lower levels.

(2) The mountains of the Plateau dynamically obstruct the western low system and turn it into deep transversal trough in 5 days. Thus the southwest flow dominates the west periphery of the Plateau in front of the trough while northeast flow occupies the other side, and these help to form the Ural blocking high. When the contribution of the mountains is not considered in the model, the formation of the Ural blocking pattern fails to be successfully simulated.

(3) Because of the dynamic effect of the Plateau, a strengthening northeast-southwest-oriented negative band of vorticity tends to be formed over the Plateau and its northwest periphery. A blocking system which is high in the north and low in the south generates in the end over the area from Ural to the Caspian Sea. The differences of the relative vorticity between EA and EB present a distribution of dipole, with negative in the north and positive in the south, over Ural area.

(4) The thermodynamic effect of the Plateau mainly affects the Plateau and its downstream area and has less impact on the formation of the upstream Ural blocking high.

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