NUMERICAL SIMULATION OF EURASIAN TELECONNECTION PATTERN IN ATMOSPHERIC CIRCULATION DURING THE NORTHERN HEMISPHERE WINTER

*K. Gambo** (岸保勘三郎), *Lu Li* (卢 理)

(Laboratary of Numerical Modelling for Atmospheric Sciences and Geophysical Fluid Dynamics, IAP, Academia Sinica, Beijing)

and *Li Weijing* (李维京)

(Lanzhou Institute of Plateau Atmospheric Physics, Academia Sinica)

Received February 13, 1987

ABSTRACT

In this paper, the anomaly of disturbance height field over Northern Hemisphere due to SST anomaly in the tropical Atlantic Ocean is simulated by using the general circulation model of IAP. A quasi-geostrophic, 34-level spherical coordinate model is also used to compute the distribution of atmospheric circulation anomaly when there is an anomaly of heat source over the tropical Atlantic. The computed results show that, owing to the heat source anomaly over the tropical Atlantic, the EU-pattern anomaly in the winter circulation may be caused. Namely, a ridge will be enhanced over the northwest Europe, a trough will be deepened over Siberia, but a positive anomaly of disturbance height field will be formed over the northeast China, Japan and other areas of East Asia. Moreover, the numerically simulated results show that the above-mentioned EU-pattern anomalies of circulation are due to the propagations of planetary wave train. About 15 days after an anomaly of the heat source over the tropical Atlantic is injected, the EU-pattern anomaly of atmospheric circulation is formed. This is in good agreement with the results analysed theoretically.

I. INTRODUCTION

During the past several years, it was found that the anomalous warming of SST in the low latitude might affect not only the zonal-vertical circulation in the low latitudes, but also the atmospheric circulation in the middle and high latitudes. Wallace and Gutzler (1981) computed the one-point correlation maps using the data of sea-level pressure at the 500 hPa height. They found that there were teleconnection patterns of atmospheric circulation, including the Pacific/North American Pattern (PNA), the West Atlantic Pattern (WA), the East Atlantic Pattern (EA), the Eurasian Pattern (EU) and the West Pacific Pattern (WP). Gambo and Kudo (1983), however, computed the one-point correlation maps using the data of disturbance height fields at 700 hPa. They clearly explained the structure of the EU-pattern wave trains. Kusunoki (1983) also investigated the time-space structure of the Eurasian Pattern.

The PNA teleconnection pattern has been studied by many scholars for a long time, such as Keshvamurly (1982), Shukla and Wallace (1983). Their results show that, due to the anomaly

* On the leave from Geophysical Institute, Faculty of Science in Tokyo University, Japan.

warming of SST in the equatorial Pacific, the PNA-pattern anomalies in the winter circulation over the Northern Hemisphere may be caused. Huang Ronghui (1986) theoretically and numerically explained that, owing to the heat source anomaly over the tropical Pacific, the PNA-pattern anomalies may be caused. However, the producing mechanism of the EU teleconnection pattern has not been studied so far. Yet EU teleconnection pattern in winter is important for the forecasting of long-range weather change over Asia, especially over China and Japan. Thus, it is valuable to study the physical mechanism of the EU teleconnection pattern.

II. OBSERVATIONAL FACTS OF EU TELECONNECTION PATTERN DURING THE NORTHERN HEMISPHERE WINTER

Gambo and Kudo computed the one-point correlation maps between 700 hPa zonally asymmetric height at the base grid point (75°N, 10°E) and 700 hPa zonally asymmetric height at every other grid point, respectively, based on the 10 winters data for 1969–1979. Their computed results show that there is a strong EU teleconnection pattern in winter circulation over the

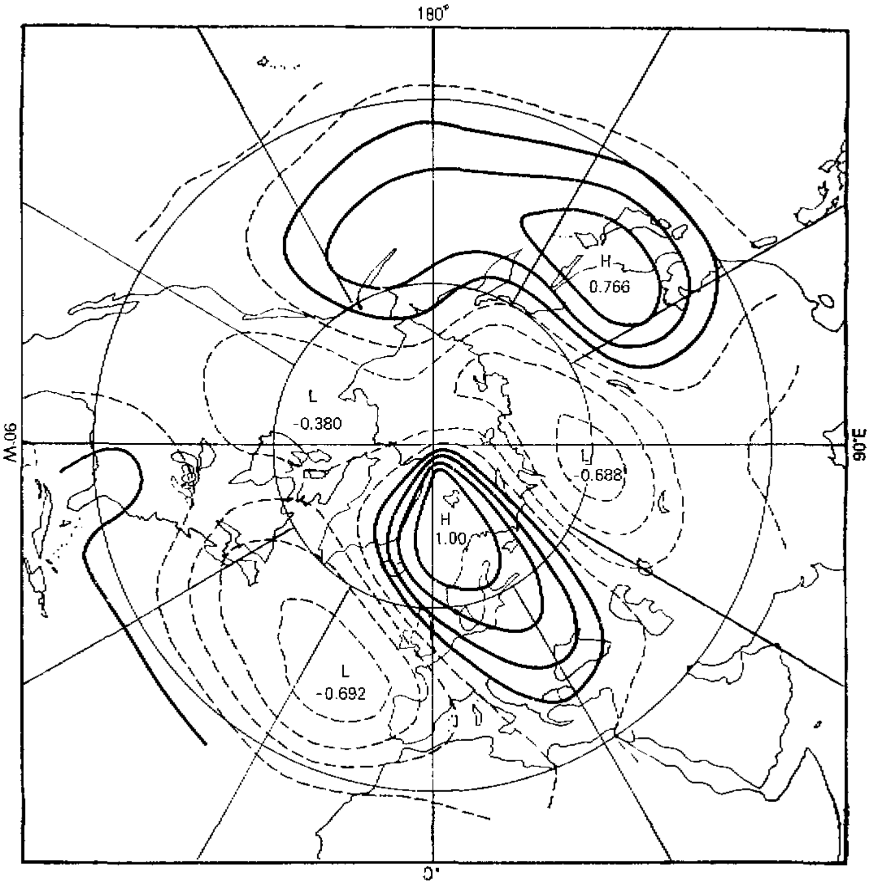

Fig. 1. Atmospheric circulation teleconnection during the Northern Hemisphere winters, based on the observational data for 1969–1979.

Northern Hemisphere. For the sake of discussion, we represent their computed results in Fig. 1.

From Fig. 1 we can see that there are a region of highly negative correlation over the north Atlantic; a region of highly positive correlation over the northwest Europe; a region of negative correlation over Ural and a large number of positive correlations over Asia, including Northeast China, Korea, Japan and the North Pacific, respectively, which, as a whole, constitute the so-called Eurasian teleconnection pattern. Namely, a high is enhanced over Northwest Europe, while a trough is deepened over Siberia. These may bring about a positive height anomaly in China and Japan. This teleconnection pattern may be utilized as one of the important tools for long-range forecasting in Asia.

III. NUMERICAL SIMULATION OF EU PATTERN IN WINTER CIRCULATION OVER NORTHERN HEMISPHERE BY USING GCM

Huang Ronghui (1986) analysed theoretically quasi-stationary planetary waves forced by heat source over low latitudes, which may propagate quasi-horizontally to the upper troposphere at high latitudes during the Northern Hemisphere winter. So the heat source anomaly in low latitudes may cause the anomalies of atmosphere circulation at middle and high latitudes. In order to investigate the real influence of SST anomaly over the tropical Atlantic on atmospheric circulation anomaly at middle and high latitudes in winter, we will simulate the influence of SST anomaly over tropical Atlantic on the EU-pattern anomaly of atmospheric circulation in winter by using the GCM of Institute of Atmospheric Physics, which was designed by Zeng Qingcun et al. (1986). This is a two-level global circulation model, in which the finite difference scheme of calculating the dynamics is unique, but the radiation heating, sensible and latent heat transfer from surface sea and land are similar to the two-level GCM of OSU (see Ghan, et al., 1982). The distribution of climatological mean SST used in this investigation is the same as Shukla and Wallace (1983).

In the model, we used directly the anomaly distribution of SST in the tropical Atlantic used by Rowntree (1972) (refer to Fig. 2). We can find from Fig. 2 that there is a region of positive SST anomaly in the western coast of Africa. The maximum anomaly is 2.5°C. For the sake of simplicity, we assume that the SST anomaly is invariable. We add the winter anomaly of SST as Fig. 2 to the distribution of SST over the globe and may obtain the distribution of anomaly SST over the Atlantic. Integrations, then, are performed for one month from an initial wind field and a height field, which had been obtained by integrating the

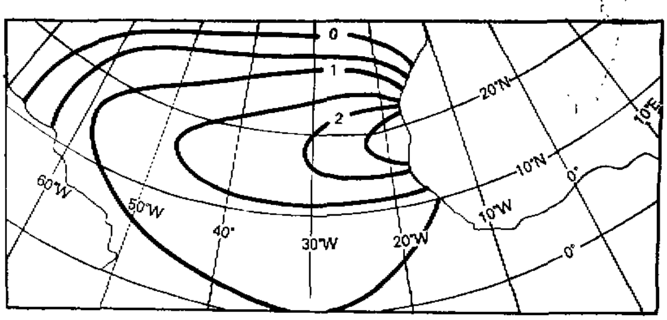

Fig. 2. The distribution of SST anomaly.

GCM of IAP until the 20th December of the next year. Moreover, we subtract the height values at the isobaric surface in the case obtained from the climatological mean distribution of SST from those in the anomaly case. Thus, the height anomaly at isobaric surfaces over the Northern Hemisphere, caused by the SST anomaly over the tropical Atlantic, is obtained.

Doberitz (1968) and Bjerknes (1969) showed that SST anomaly in the tropical ocean may not only enhance greatly the sensible heat transfer upward from sea surface, but also make stronger cumulus convection shift to a region of warming water from the observational data. It may be brought about that the precipitation anomaly is several mm/day. The latent heat release due to water vapour condensation may increase greatly because of the increase of the precipitation. Thus, the SST anomaly may cause the heat source anomaly over the tropics. As a consequence, a quasi-stationary heat source will be formed over the Atlantic at 15°N on the 8th day of the model integration. Fig. 3 shows the anomaly distribution of heat source averaged for 30 days of the model integrations. It can be seen from Fig. 3 that there is a positive anomaly heat source over the tropical and subtropical Atlantic, a maximum anomaly of heat source is 382 ly/day. We can obtain the quasi-stationary height anomaly using the model owing to the formation of stationary anomaly of heat source. Figure 4 shows that the computed distribution of 500 hPa height anomaly averaged for 30 days of the model integration. From Fig. 4, we can find that when the SST anomaly is caused in the tropical Atlantic, a negative anomaly of height field is found over West Europe and a region from the Black Sea to China with a positive anomaly center located over the northern part of Siberia. Besides, another positive anomaly center is located over Northeast China,

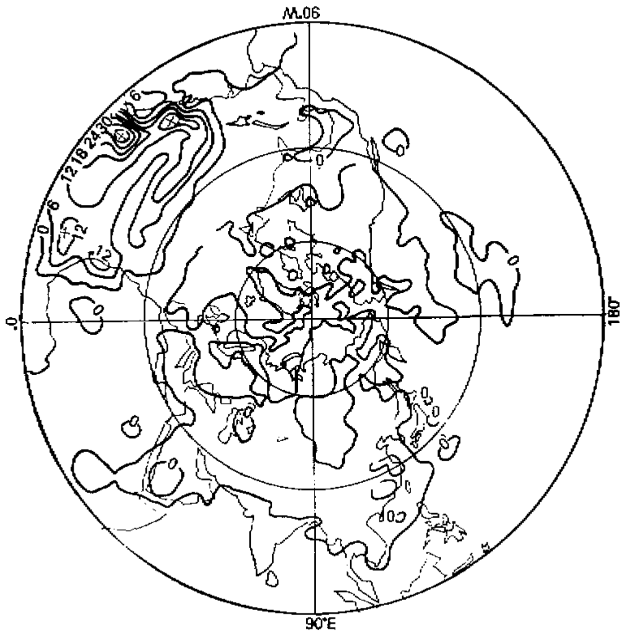

Fig. 3. The anomaly distribution of mean heat source averaged for 30 days of the model integrations (unit: 10 ly/day).

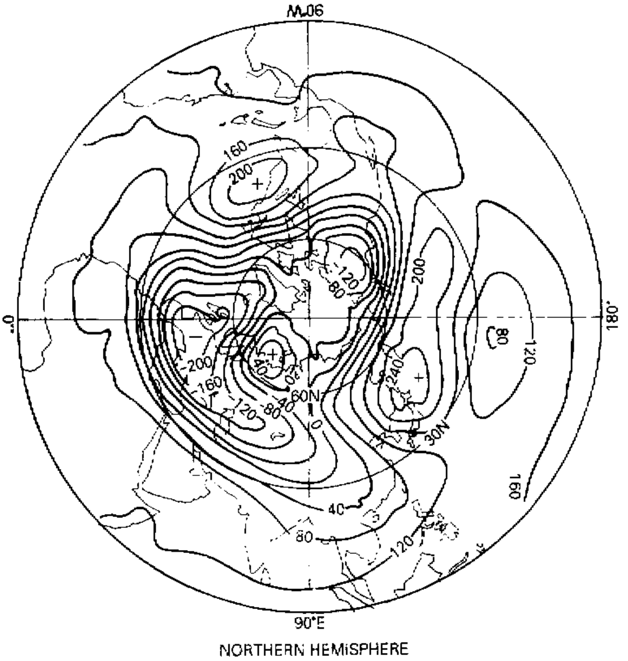

Fig. 4. The distribution of averaged 500 hPa height anomaly (unit: m).

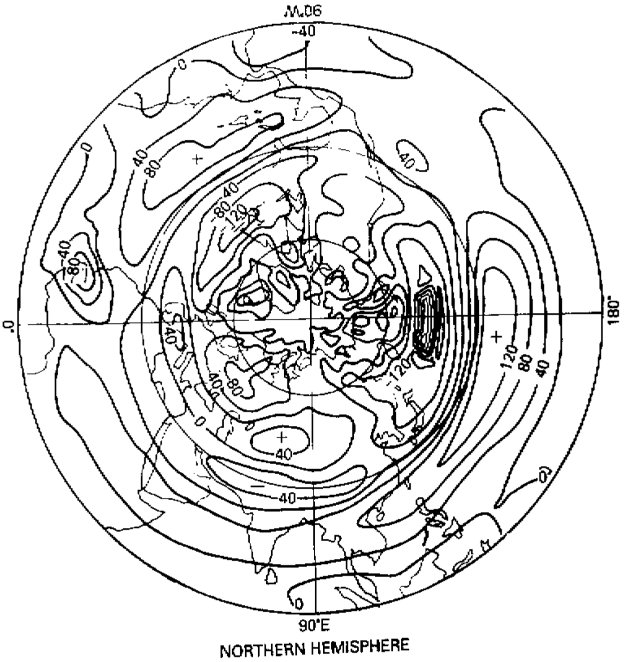

Fig. 5. The 30-day mean vorticity distribution at 400 hPa (unit: $10^{-6}s^{-1}$).

Japan and north Pacific. Rowntree (1972) simulated the change of atmospheric circulation over the Northern Hemisphere due to a SST warming in the tropical Atlantic by using a hemisphere primitive equation model. His results that are not in agreement with ours indicate a negative height anomaly located over East Asia, while a positive height anomaly is found over East Asia in ours. So, we compute the vorticity distribution at 400 hPa (refer to Fig. 5). We can see that there is a region of negative vorticity. This means that there is a high belt over the tropical Atlantic.

IV. THE STATIONARY MODEL COMPUTATION OF INFLUENCE OF HEAT SOURCE OVER THE TROPICAL ATLANTIC ON ATMOSPHERIC CIRCULATION OF EU PATTERN

In order to compare with the results simulated by using GCM, a quasi-geostrophic, 34-level spherical coordinate model with Rayleigh friction, Newtonian cooling effect and horizontal thermal diffusivity is utilized to compute the EU-pattern anomaly of atmospheric circulation caused by the anomaly of heat source over the tropical Atlantic. The model and parameters are the same as that of Huang Ronghui and Gambo (1982).

As mentioned in previous section, when a SST anomaly warming is caused in the tropical Atlantic, the heat source anomaly will be caused over the tropical Atlantic, i.e., the heat source will enhance. Thus, we assume that an idealized heat source anomaly is located over the tropical Atlantic and its horizontal distribution at 500 hPa is given by:

$$\Delta\hat{H}_0(\lambda,\phi)=\begin{cases}\Delta\hat{H}_0\left[\sin\left(\dfrac{\pi(\phi_1-\phi_2)}{(\phi_2-\phi_1)}\right)\sin\left(\dfrac{\pi(\lambda-\lambda_1)}{(\lambda_2-\lambda_1)}\right)\right]^2, & \begin{matrix}\lambda_1<\lambda<\lambda_2\\ \phi_1<\phi<\phi_2\end{matrix}\\ 0 & \text{otherwise}\end{cases}\tag{1}$$

Here the anomaly of heating rate $1/C_p\Delta\hat{H}_0=2.0\text{k day}^{-1}$, and the averaged anomaly of heating rate is 0.64 K day^{-1}. We take $\lambda_1=50°$W, $\lambda_2=20°$E, $\phi_1=0°$N, $\phi_2=30°$N. This corresponds to the maximum anomaly of heat source located at 15°N, 15°W. The domain of the heat source includes 5°N–25°N, 45°W–15°E. This is likely in agreement with Fig. 3. Moreover, we assume that the vertical distribution of this anomaly of heat source is

$$\Delta\hat{H}_0(\lambda,\phi,P)=\Delta\hat{H}_0(\lambda,\phi)\exp\left[-\left(\frac{P-\bar{P}}{d}\right)^2\right]\tag{2}$$

where d = 300 hPa, P = 500 hPa. This means that the vertical distribution of the idealized anomaly of heat source has a maximum at 500 hPa.

We add the anomaly of heat source to the winter climatological distribution of heat source over the Northern Hemisphere and may obtain the distribution of anomaly heat source over the tropical Atlantic. Thus, we can compute the stationary disturbance pattern at isobaric surface and the vertical distribution of amplitude and phase of waves.

In order to see clearly the EU-pattern anomaly of atmospheric circulation during the Northern Hemisphere winter due to the anomaly of heat source over the tropical Atlantic, we subtract the height values of stationary disturbance at isobaric surfaces in the normal case from those in the anomaly case of heat source over the tropical Atlantic in winter. Thus, we may obtain the circulation anomaly caused by the heat source anomaly over the tropical Atlantic during the Northern Hemisphere winter. Fig 6. is the anomaly distribution of 500 hPa height field caused by the heat source anomaly over the tropical Atlantic. From Fig. 6 we can see that when the heat source anomaly is caused over the tropical Atlantic, a positive anomaly of disturbance height field at 500 hPa is found over the tropical Atlantic and a negative anomaly of disturbance height field is found over the northwest part of Africa and the middle-latitude Atlantic. Besides, another positive anomaly is formed over the Scandinavia region of the northwestern Europe, while another negative anomaly is formed over Siberia regions of the eastern part from Ural. But a positive anomaly is formed over Northeast China, Japan and other areas of East Asia. Thus, it is shown that there is a strong positive correlation of 500 hPa disturbance height field between Northwest Europe and East Asia, but a negative correlation between Northwest Europe and Siberia.

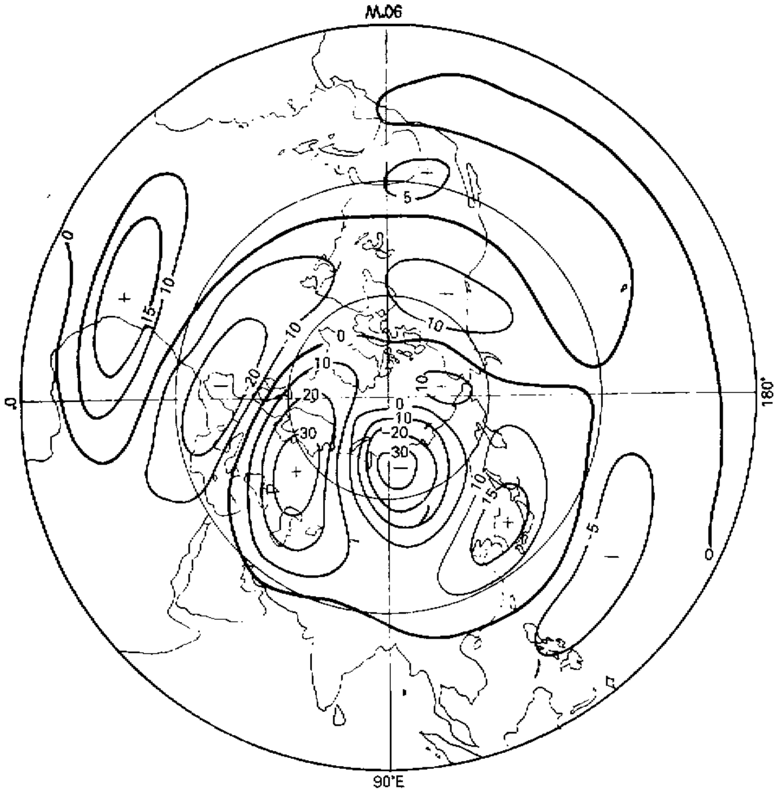

Fig. 6. The distribution of disturbance height anomaly at 500 hPa computed by using the steady-state model (unit: m).

From the computed results of 500 hPa height anomaly, we can find that when a heat source is intensified over the tropical Atlantic, a high may be formed over the tropical Atlantic, and another high may be formed over the Scandinavia region. But a trough will be deepened over Lake Baikal and the trough over Northeast China and Japan will be weakened. So, cold waves often intrude into China and cold surges brought in this country and the eastern part of Soviet Union.

V. THE PROPAGATIONS OF PLANETARY-WAVE TRAINS FORCING BY HEAT SOURCE OVER THE TROPICAL ATLANTIC

Hoskins et al. (1981) studied the propagation of planetary waves in a spherical atmosphere.

Huang Ronghui (1986) computed in detail the propagating ray of the quasi-stationary planetary waves in a winter basic flow forced by heat source in a spherical atmosphere and the time propagating from 15°N to the turning point was discussed in his paper. For the disturbance about wavenumber 1, the time propagating from the tropics to the vicinity of the polar regions is about two weeks; for the disturbance about wavenumber 2, this time is about one week. When it propagates from the tropics to middle latitudes, the group velocity of quasi-stationary planetary wave is slower than that when it propagates from middle latitudes to the vicinity of the poles. In our computed results, as discussed above, this case can be clearly seen. Figure 7 shows the results of the 5th day integrated by the GCM. From Fig. 7 we can see that a region of negative anomaly of disturbance height is found over North Africa and the Mediterranean;

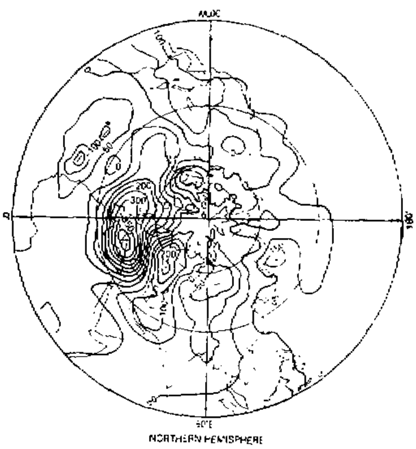

Fig. 7. The distribution of height anomaly at 500 hPa for the 5th-day (unit: m).

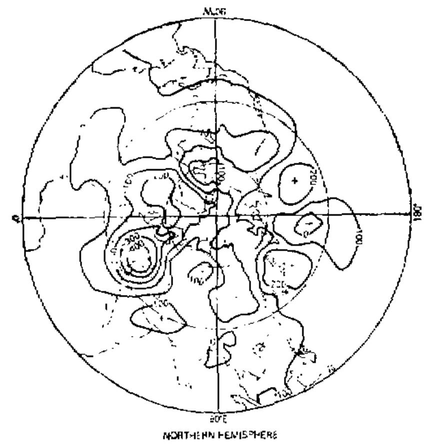

Fig. 8. As in Fig. 7, but for the 8th-day result.

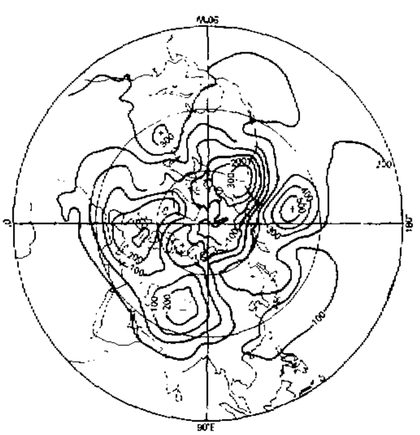

Fig. 9. As in Fig. 7, but for the 15th-day result,

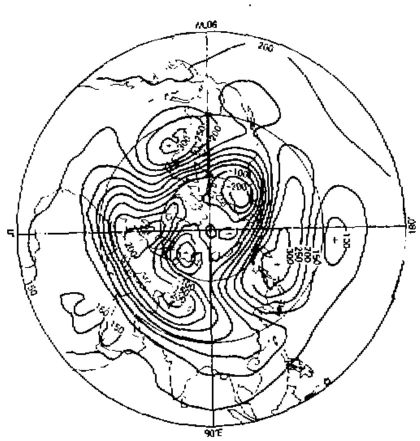

Fig. 10. As in Fig. 7, but averaged for the period from the 11th-day to the 30th-day.

a positive anomaly is formed over Europe and the Persian Gulf, respectively. In agreement with the theoretical results obtained by Zeng Qingcun (1983), the wave trains are divided into two branches: as shown in Fig. 7, a branch propagates to Asia, while the other propagates to Arabia. By the 8th day, as shown in Fig. 8, we can see that a region of negative anomaly of disturbance height is formed over the Black Sea and a region of positive anomaly is formed over the Ural region. By the 12th day, a region of positive anomaly is formed over the Scandinavia region and a region of negative anomaly is formed over the region from the Arctic Ocean to the northern part of Siberia. By the 15th day, as shown in Fig. 9, a region of positive anomaly is formed over Asia and the North Pacific. After the 15th day, a negative anomaly is maintained over Eurasia and a positive anomaly dominates from Scandinavia to Novaya Zemlya. Besides, another region of negative anomaly is located in the region from the Arctic Ocean to the northern part of Siberia and still another region of positive anomaly is formed over Northeast China, Japan and the Okhotsk Sea. Figure 10 shows the height distribution averaged for the period from the 11th-day to the 30th-day.

In order to see clearly the propagations of anomaly planetary wave trains due to the SST anomaly over the tropical Atlantic, we representatively select some points on Eurasia. Then, the evolution of height anomaly with time at these points is indicated in Fig. 11. The bottom line in Fig. 11 is the change of heat source with time. We can see that a wave train propagates from middle latitudes over the Atlantic toward Northwest Europe, then, propagates toward Asia and the Pacific. It is seen that a lag time between a larger negative anomaly over the Atlantic and a larger positive anomaly over Asia is about 5 days. The positive anomalies over Asia and Northwest Europe are stable after the model was integrated for 20 days. This result also agrees with that analysed theoretically.

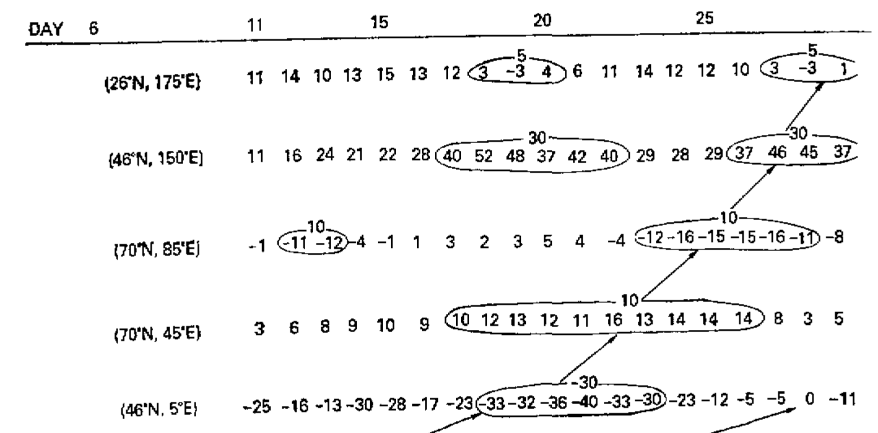

Fig. 11. The evolution of height anomaly with time at representative points at 500 hPa (unit: 10 m), and the change of heat source with time (unit: 10 ly/day).

VI. CONCLUSIONS AND DISCUSSIONS

In this paper, GCM of IAP and a quasi-geostrophic, stationary, 34-level spherical coordinate model are used to compute the distribution of the anomaly pattern during the Northern Hemisphere winter. The computed results show that in winter due to the heat source anomaly over the Atlantic, the EU-pattern anomaly may be caused, i.e., a ridge is enhanced over Northwest Europe and a trough is deepened over Siberia. A region of positive anomaly of height field is formed over Northeast China, Japan and other areas of East Asia. So, the cold wave often outbreaks to the Far East regions of Soviet and the north and centre of China.

According to the results of numerical simulation, we can see that when a heat source anomaly is caused over the tropical Atlantic, a planetary wave train will propagate toward the East Pacific and the United States. This wave train seems to form the PNA teleconnection pattern as shown in Fig. 10. Thus, PNA teleconnection pattern is not only caused by the heat source anomaly over the east tropical Pacific, but also may be due to other physical mechanisms. This problem needs to be further investigated.

The height anomaly computed by using GCM in middle and high latitudes is larger than the observational value, but the height anomaly over the tropics is weaker than the observational value. This may be due to the fact that in the model the dynamic characteristics of planetary wave can not be described correctly.

The authors wish to express their thanks to Prof. Zeng Qingcun, Director of IAP, for his valuable comments and suggestions. Thanks are due to Prof. Huang Ronghui for discussions and help throughout the course of this work. Thanks are also extended to Prof. Li Chongyin and Prof. Wu Guoxiong for helpful discussion.

REFERENCES

Bjerknes, J. (1969), Atmospheric teleconnections from the equatorial Pacific. *Mon. Wea. Rev.*, **97**:162–172.

Doberitz, R. (1968), Cross spectrum analysis of rainfall and sea temperature at the equatorial Pacific Ocean, *Bonn Meteor. Abh.*, **8**, 61.

Gambo, K. and K. Kudo, (1983), Three-dimensional teleconnections in the zonally asymmetric height field during the Northern Hemisphere Winter. *J. Meteor. Soc. Japan*, 61:36–50.

Chan, S. J., J. W. Lingaas, M. E. Schlesinger, R. L. Mobley and W. L. Gates (1982), A documentation of the OSU two-level atmospheric general circulation model, Climate Research Institute Oregon State University, Report No. 35.

Hoskins, B. J. and D. J. Karoly (1981), The steady linear response of a spherical atmosphere to thermal and orographic forcing. *J. Atmos. Sci.*, **38**: 1179–1196.

Huang Ronghui and K. Gambo (1982), The response of a hemispheric multi-level model atmosphere to forcing by topography and stationary heat sources. Part I, II, *J. Meteoro. Soc. Japan* **60**:78–108.

Huang Ronghui (1986), Physical mechanism of influence of heat source anomaly over low latitudes on general circulation over Northern Hemisphere in Winter. *Scientia Sinica* (series B) Vol. XXIX, No. 9, 970–985.

Kusunoki, S. (1985), An observational study of horizontal propagation of Rossby Waves in the troposphere. ph. D Geophysical Institute, University of Tokyo.

Rowntree, P.R. (1972), The influence of tropical east Pacific Ocean temperatures on the atmosphere. Quart. *J. Roy. Meteor. Soc.*, **98**:290–321.

Shukla, J. and J.M. Wallace (1983), Numerical simulation of the atmospheric responses to equatorial Pacific sea surface temperature anomalies. *J. Atmos. Sci.* **40**:1613–1630.

Wallace, J. M. and D. S. Gutzler (1981), Teleconnection in the geopotential height field during the Northern Hemisphere Winter. *Mon. Wea. Rev.*, **109**:784–812.

Zeng Qingcun (1983), The evolution and structure of Rossby wave packet in forced mean flow, IAMP-WMO Symposium on maintenance of the quasi-stationary components of the flow in the atmosphere and in atmospheric models, Paris, Aug. 29–Sep. 2, 1983.

Zeng Qingcun, et al. (1986), A global grid point general circulation model, Extended abstracts of paper presented at the WMO/IUGG International Symposium on short-and medium-range numerical weather prediction, Tokyo, 4–8 August, 1986,