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The Dynamical Effects of Divergent Wind on the Intraseasonal Variability of the East Asian Circulation

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ABSTRACT

In this paper, the dynamical effects of divergent wind on the intraseasonal variability of atmospheric circulation over East Asia are analyzed by using the function of Rossby–wave source and the energy exchanging function between divergent component and rotational component of the flow.

The results analyzed from the observed data show that the advection of vorticity by divergent wind caused by the heating due to the monsoon rainfall in the south to the Yangtze River and the strong convective activities around the Philippines may play an important role in the northward jump of westerly jet stream during the seasonal transition from spring circulation to summer circulation over East Asia. Due to the northward movement of the advection of vorticity by the divergent wind, the energy transformation from divergent component into rotational component can be caused over the Yellow River basin and Northwest China and will cause the intensification of the zonal flow there. Thus, the jet stream abruptly shifts northward to North China.

Moreover, the analysed results also show that the advection of vorticity by divergent wind caused by the heating due to the strong convective activities around the Philippines also plays an important role in the intraseasonal variability of the circulation over East Asia during the seasonal transition from summer to winter. With the southward movement of the advection of vorticity by the divergent wind, the energy transformation from divergent component into rotational component can be caused over East Asia, especially over the Yangtze–Huaihe River basin. Therefore, the jet stream gradually moves southward from North China to the Yangtze River basin.

Key words: Divergent wind, Rossby–wave source, Exchanging function.

I. INTRODUCTION

The diagnostic studies of vorticity budget are very important for the investigation of the evolution of atmospheric disturbances. Although Holton and Colton (1972), Fein (1977), Sui and Yanai (1986), Sardeshmukh and Hoskins (1985), Yang et al. (1992) have made a lot of fundamental work on the vorticity budgets, the conclusions about the functions of various terms in the vorticity equation were quite different in their investigations. These differences may be due to the different spatial and time scales as well as the different data sets used in their studies.

Sardeshmukh and Hoskins (1988) studied the generation of global rotational flow by steady idealized tropical divergence using the nonlinear vorticity equation. They proposed that because the advection of vorticity by divergent component of the flow is significant, the Rossby–wave source can be very different from the simple $-fD$ used often in the vorticity model.

However, a series of studies by Sardeshmukh and Hoskins (1985, 1987, 1988) (hereafter referred to as SH85, SH87 and SH88) mainly focused on climatological mean flow. In their studies, the properties of stationary or quasi–stationary Rossby–wave source were analysed, but the effect of divergent wind on the intraseasonal variability of atmospheric circulation has not been discussed yet. Moreover, the physical meaning of the advection of vorticity by divergent component of the flow included in the Rossby–wave source should be studied further. Therefore, it is necessary to investigate the dynamical effect of divergent wind on the variation of atmospheric circulation.

This paper aims at investigations on the dynamical effect of divergent wind caused by heating on the intraseasonal variability of the East Asian circulation. In order to investigate the dynamical effect of divergent wind on the intraseasonal variability of atmospheric circulation, the advection of vorticity by divergent wind included in the Rossby–wave source is used to analyse the variation of the flow and a so–called exchanging function $C(k_\chi, k_\psi)$ describing the energy exchange between divergent component and rotational component of the flow is also investigated. Moreover, the relationships between the jet stream, the advection of vorticity by divergent wind and the exchanging function $C(k_\chi, k_\psi)$ are analysed by using the observed data at 200 hPa in 1984.

In Section 2 of this paper, we present a simple explanation to the exchanging function $C(k_\chi, k_\psi)$ describing the energy exchange between divergent component and rotational component of the flow. In section 3, the observed data at 200 hPa in 1984 are used to calculate the advection of vorticity by divergent component of the flow over East Asia during the seasonal transitions, and the intraseasonal variation of the circulation over East Asia is explained by using the Rossby–wave source arising from the advection of vorticity by divergent wind. In section 4, the energy exchanging function $C(k_\chi, k_\psi)$ describing the energy exchange between the divergent component and the rotational component of the flow is presented. The relationships between the jet stream, the Rossby–wave source arising from the advection of vorticity by divergent wind and the energy exchange between the divergent and the rotational components are discussed.

II. EXCHANGING FUNCTION $C(k_\chi, k_\psi)$ DESCRIBING ENERGY EXCHANGE BETWEEN DIVERGENT COMPONENT AND ROTATIONAL COMPONENT OF THE FLOW

For a wind vector **V**, it can be divided into two components, i.e.,

$$\mathbf{V}(\lambda, \varphi) = \mathbf{V}_\psi(\lambda, \varphi) + \mathbf{V}_\chi(\lambda, \varphi) \,, \tag{1}$$

where $\mathbf{V}_\psi(\lambda, \varphi)$ is rotational component, and $\mathbf{V}_\chi(\lambda, \varphi)$ is divergent component of the flow. In this way, the relative vorticity ζ and divergence D may be written as follows:

$$\zeta = \nabla^2 \psi,$$
$$D = \nabla^2 \chi \,,$$

where ψ and χ are stream function and velocity potential of the flow, respectively. ∇^2 is the two–dimensional spherical Laplace operator. Therefore, the kinetic energy due to rotational component and the kinetic energy due to divergent component of the flow can be written as follows:

$$k_\psi = \frac{1}{2}\left[\left(\frac{\partial \psi}{\partial x}\right)^2 + \left(\frac{\partial \psi}{\partial y}\right)^2\right] = \frac{1}{2}|\nabla \psi|^2 \,,$$
$$k_\chi = \frac{1}{2}\left[\left(\frac{\partial \chi}{\partial x}\right)^2 + \left(\frac{\partial \chi}{\partial y}\right)^2\right] = \frac{1}{2}|\nabla \chi|^2 \,, \tag{2}$$

where ∇ is the gradient operator in a plane rectangular system, k_ψ and k_χ the rotational and divergent wind kinetic energy respectively. The equations of the atmospheric motion can be changed as

$$\frac{\partial u}{\partial t} = -\frac{\partial}{\partial x}(\Phi + e_k) + (f + \nabla^2\psi)v - \omega\frac{\partial u}{\partial p} , \tag{3}$$

$$\frac{\partial v}{\partial t} = -\frac{\partial}{\partial y}(\Phi + e_k) - (f + \nabla^2\psi)u - \omega\frac{\partial v}{\partial p} , \tag{4}$$

where Φ is the geopotential height, e_k the kinetic energy, ω the vertical pressure velocity. The thermodynamic equation can be written as

$$\frac{\partial C_p T}{\partial t} = -\mathbf{V} \cdot \nabla \ (C_p \ T) \ - C_p \omega \frac{\partial T}{\partial p} + \frac{RT}{p} \ \omega + Q + F_T \ . \tag{5}$$

From Eqs.(3)–(5), the following equations can be obtained (See Krishnamurti et al., 1982)

$$\begin{cases} \dfrac{\partial k_\psi}{\partial t} = B_\psi - f \ \nabla\chi \cdot \nabla\psi - \nabla^2\psi\nabla\chi \cdot \nabla\psi - \dfrac{1}{2}|\nabla\psi|^2\nabla^2\chi \\ \qquad - \omega J(\psi, \dfrac{\partial\chi}{\partial p}) + F_\psi \\ \dfrac{\partial k_\chi}{\partial t} = B_\chi + \chi\nabla^2\Phi + f \ \nabla\chi \cdot \nabla\psi + \nabla^2\psi\nabla\chi \cdot \nabla\psi + \omega J(\psi, \dfrac{\partial\chi}{\partial p}) \\ \qquad + \dfrac{1}{2}|\nabla\psi|^2\nabla^2\chi + F_\chi \\ \dfrac{\partial C_p T}{\partial t} = B_{p+i} - \chi\nabla^2\Phi + Q_{p+i} + F_T \ , \end{cases} \tag{6}$$

where Q_{p+i}, the term of potential energy generation, includes diabatic heating terms. B_ψ, B_χ and B_{p+i} are boundary flux terms; F stands for friction term, J the Jacobian operator. Therefore, the internal energy exchanging process can be understood from Eq.(6).

According to Eq.(6), the diabatic heating term determines the generation of potential energy, and the energy transformation from potential energy into the kinetic energy of rotational component of the flow must be firstly transformed from potential energy into the kinetic energy of divergent component of the flow. SH85's analysis showed that the friction term F is small almost everywhere on planetary scale, and this was further discussed in SH87 in some details. Sui and Yanai (1986) have suggested that on length scales of 1000 Km and less, the cumulus friction may be important in the vorticity budget in the tropical atmosphere. In this paper, we assume that the large scale cumulus friction is negligible in the areas and on the scales of interest. Moreover, at the level of interest ω is small enough and thus compared with the main terms in Eq.(6), the vertical advection is small and can be neglected. Therefore, from Eq.(6), the exchanging function $C(k_\chi, k_\psi)$ can be obtained as follows:

$$C(k_\chi, \ k_\psi) = -f\nabla\chi \cdot \nabla\psi - \nabla^2\psi(\nabla\chi \cdot \nabla\psi) - \frac{1}{2}|\nabla\psi|^2\nabla^2\chi \ . \tag{7}$$

It is obvious from (6) that the exchanging function $C(k_\chi, k_\psi)$ indicates the energy exchange between the energy of rotational component and the energy of divergent component of the flow. Moreover, the divergent component of wind field is very important, i.e., the divergent field acts as a medium in the energy transformation process. If $C(k_\chi, k_\psi)$ is positive, the energy will be converted from divergent component to rotational component. On the contrary, if $C(k_\chi, k_\psi)$ is negative, the direction of energy conversion will be from rotational component to divergent component.

III. THE EFFECT OF DIVERGENT WIND ON THE INTRASEASONAL VARIATION OF ATMOSPHERIC CIRCULATION OVER EAST ASIA

As shown in SH88, considering the advection of vorticity by divergent wind, the Rossby wave source S may be written as follows:

$$S \equiv -\nabla \cdot (\mathbf{V}_\chi \xi) = -\mathbf{V}_\chi \cdot \nabla \xi - \xi D \ , \tag{8}$$

where ξ is the absolute vorticity. Thus, if the vertical motion and friction are neglected, the nonlinear vorticity equation may be written as

$$(\frac{\partial}{\partial t} + \mathbf{V}_\psi \cdot \nabla) \ \xi = S \ . \tag{9}$$

Thus, it may be seen from Eqs.(8) and (9) that the advection of vorticity by divergent wind may play an important role in the variation of circulation. If the advection of vorticity by divergent wind is positive, i.e., the Rossby–wave source arising from the advection of vorticity by divergent wind is negative in a region, the cyclonic vorticity may decrease or anticyclonic vorticity may increase in the region.

As for the meaning and importance of the Rossby wave source, one can refer to the following deduction. According to Eq.(8), we obtain

$$\begin{aligned} \psi S &= \psi.[-\nabla \cdot (\mathbf{V}_\chi \xi)] \\ &= -\psi \nabla \cdot [\nabla \chi \ (\nabla^2 \psi + f) \ ] \\ &= -\nabla \cdot [\psi \ (f + \nabla^2 \psi) \ \nabla \chi] + \ (f + \nabla^2 \psi) \ \nabla \chi \cdot \nabla \psi \ . \end{aligned} \tag{10}$$

It can be seen from the above that the expression of Rossby wave source explicitly contains the information which is important in the exchange process of divergent wind kinetic energy and rotational wind kinetic energy. Furthermore, as shown above, if the Rossby wave source arising from the divergent advection is neglected in the definition of the source, the normal process of energy transference must be greatly travestied. Thus in this paper, we will analyze the first term in Eq.(8), i.e., the divergent advection term $-\mathbf{V}_\chi \cdot \nabla \xi$.

The Rossby wave source and the main part of $C(k_\chi, k_\psi)$ are closely related in the sense that averaged over the sphere,

$$\iint_A \psi S dA = \iint_A \ (f + \nabla^2 \psi) \ \nabla \chi \cdot \nabla \psi dA \ .$$

This constraint shows that the Rossby wave source is very important in the energy transfer process. But this is a global, not a local constraint, the first term of (10) also contains divergent wind and locally it is very important. For a horizontal area A bounded by a closed line L, we have

$$\iint_A \psi S dA = -\int_L \psi \ (f + \nabla^2 \psi) \ \nabla \chi \cdot \mathbf{n} dl + \iint_A \ (f + \nabla^2 \psi) \ \nabla \chi \cdot \nabla \psi dA \ .$$

In the following, the effect of divergent wind on the variation of circulation over East

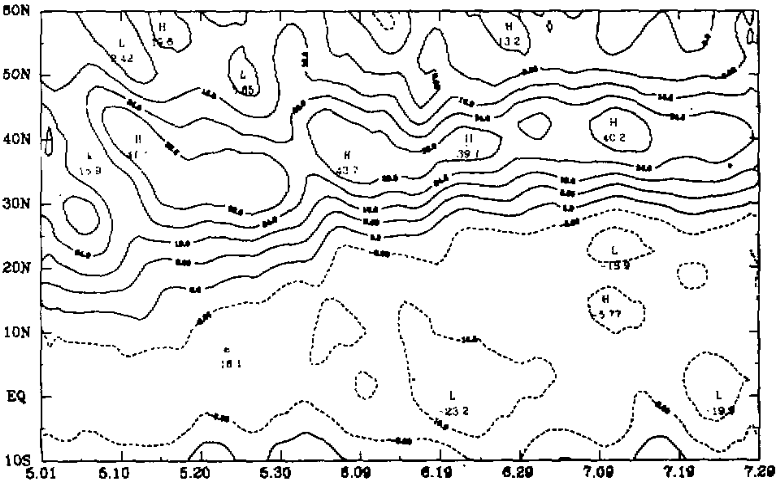

Fig.1. Latitude–time cross–section of the zonal wind averaged for 90°–130°E at 200 hPa during May–July, 1984. Units: m / s.

Asia during the seasonal transitions of circulation will be analyzed.

1). *During the Seasonal Transition from Spring to Summer*

Generally, the seasonal transition from spring circulation to summer circulation over East Asia occurs in early or middle June. Moreover, many investigations (see Yeh and Tao, 1959) showed that the characteristic of the seasonal transition in East Asia presents a kind of abrupt change behavior of the atmospheric circulation, accompanied by the northward jump of jet stream.

Fig. 1 is the latitude–time cross–section of the zonal wind averaged for 90°–130°E at 200 hPa during May–July, 1984. It can be seen from Fig. 1 that the jet stream abruptly shifted northward from 32°N to 38°N in early June. In the meanwhile, a strong easterly can be found over the tropics.

In order to explain the dynamical effect of the divergent wind on the jump of jet stream, we calculated the Rossby–wave source arising from the divergent wind, i.e., $-\mathbf{V}_\chi \cdot \nabla\xi$ by using the observed data at 200 hPa in 1984 analyzed by ECMWF. Fig. 2 is the latitude–time cross–section of $-\mathbf{V}_\chi \cdot \nabla\xi$ averaged for 90°–130°E arising from the divergent wind at 200 hPa during May–July, 1984. It may be found that the Rossby–wave source arising from the divergent wind was negative in middle latitudes during May–July, 1984 and therefore due to the dynamical effect of divergent wind, the anticyclonic vorticity would increase over East Asia, i.e., the South Asian high would be intensified at 200 hPa over East Asia. As a consequence, the strong westerly shifted northward, and the easterly was intensified over the tropics. Moreover, it is obvious that the large advection of vorticity by divergent wind abruptly shifted northward from 32°N to 40°N in early June. This may explain that the northward jump of the jet stream is associated with the northward shift of the negative Rossby–wave

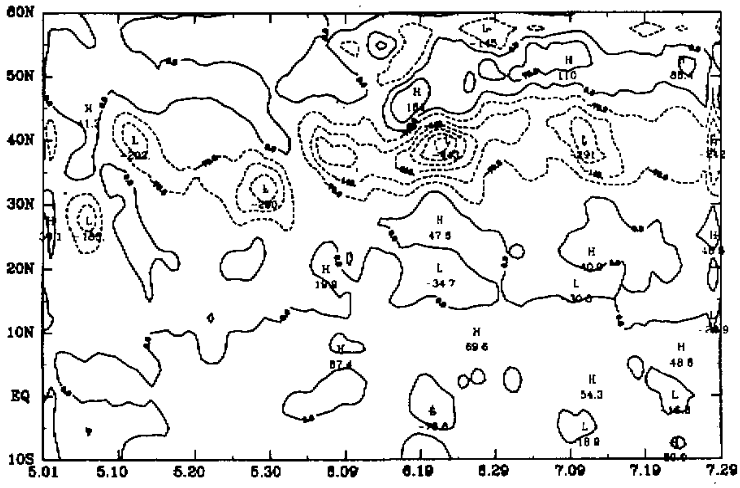

Fig. 2. Latitude–time cross–section of the Rossby–wave source arising from the divergent wind averaged for 90°–130°E at 200 hPa during May–July, 1984. Units: $10^{-12}s^{-2}$

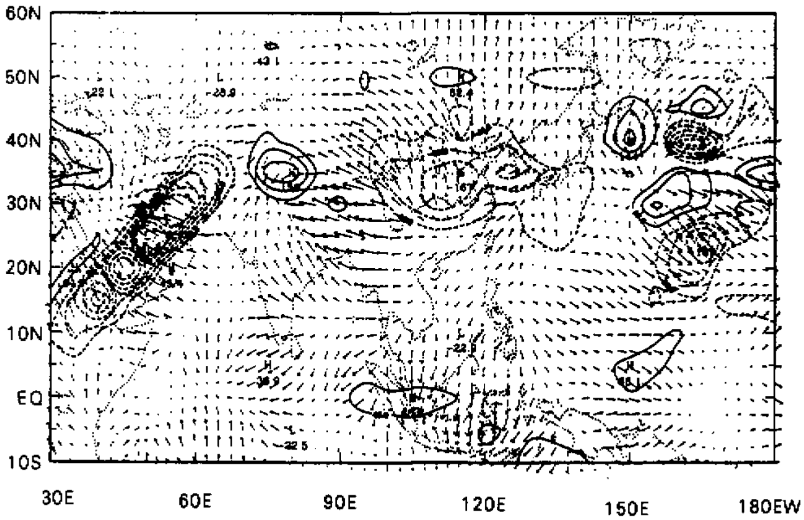

Fig.3. Distributions of the 5–day mean divergent wind and the 5–day mean Rossby–wave source arising from the advection of absolute vorticity by divergent wind averaged for the period from May 22 to 26, 1984. Units: $10^{-12}s^{-2}$

source arising from the advection of vorticity by divergent wind.

As an example to understand the dynamical effect of divergent wind on the variation of circulation over East Asia, Fig. 3 is the distributions of divergent wind and the Rossby–wave sources arising from the advection of vorticity by divergent wind averaged for the period from

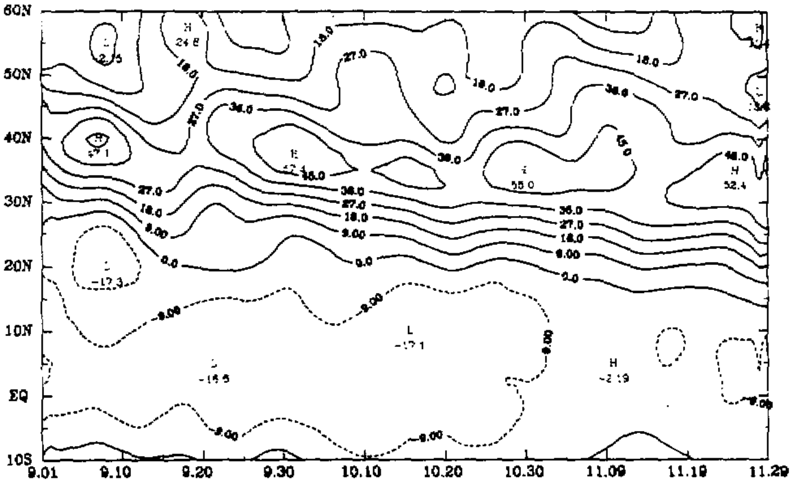

Fig. 4. Same as in Fig.1 but for the period from September to November, 1984.

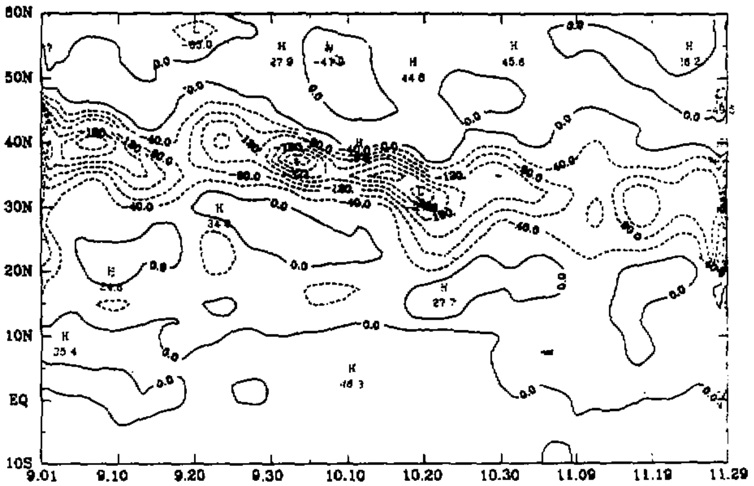

Fig. 5. Same as in Fig.2 but for the period from September to November, 1984.

May 22 to 26, 1984. (We have also analyzed many other 5–day averaged corresponding fields which due to the length of this paper cannot be presented here, but the results are generally the same.) Fig. 3 shows obviously that strong divergent winds flowed from the south to the Yangtze River and the Philippines to the Yangtze–Huaihe River basin, the Yellow River basin, Northwest China and the surroundings of the Tibetan Plateau. The divergent wind may be caused by the heatings due to the monsoon rainfall in the south to the Yangtze River and the convective activities around the Philippines.

Moreover, a center of large negative value of the Rossby–wave source arising from the advection of vorticity by divergent wind was located over East Asia during late May and the anticyclonic vorticity would increase over East Asia. That is to say, the South Asian high would be intensified at 200 hPa over East Asia. Thus, the jet stream moved northward to Northeast China and central Asia in early June, 1984, as shown in Fig.1. Huang and Gambo (1983) pointed out that the heating and dynamical effects of the Tibetan Plateau are the causes of formation of the South Asian high at 200 hPa during summer. However, It may be seen from the above–analyzed result that the divergent winds caused by the heating due to the monsoon rainfall in East Asia can also maintain the South Asian high at 200 hPa.

2. *During the Seasonal Transition from Summer Circulation to Winter Circulation*

Fig.4 is the latitude–time cross–section of the zonal wind averaged for 90°–130°E at 200 hPa during September–November, 1984. It can be seen from Fig.4 that the jet stream gradually shifted southward from 40°N to 30°N during September–November, 1984. The abrupt shift of the jet stream is not as obvious as that during May–July.

Fig. 5 is the latitude–time cross–section of the Rossby–wave averaged for 90°–130°E arising from the divergent wind at 200 hPa during September–November, 1984. It may be found that the Rossby–wave source arising from the divergent wind was also negative in middle latitudes during September–November, 1984. This may show that due to the dynamical effect of divergent wind, the cyclonic vorticity decreased over East Asia. Moreover, it is obvious that the large advection of vorticity by divergent wind gradually shifted southward from 40°N to 30°N during the period from September to November, 1984. This may explain that the southward movement of the jet stream is associated with the southward shift of the negative Rossby–wave source arising from the advection of vorticity by divergent wind.

Similarly, in order to analyze the dynamical effect of divergent wind on the intraseasonal variation of circulation over East Asia during the period from September to November, 1984, we choose another 5–day mean divergent wind and Rossby–wave source arising from the advection of vorticity by divergent wind during that period as an example.

Fig. 6 shows the distributions of divergent wind and the Rossby–wave source arising from the advection of vorticity by divergent wind averaged for the period from October 22 to 26, 1984. It may be clearly seen from Fig.6 that strong divergent winds flowed from the Philippines to East Asia, South Asia and the Southern Hemisphere in late October. Moreover, a center of large negative value of the Rossby–wave source arising from the advection of vorticity by divergent wind was located over the area from the Yangtze–Huaihe River basin to Japan. Due to the effect of $-\mathbf{V}_\chi \cdot \nabla\xi$, the cyclonic vorticity would decrease over East Asia from the Yangtze–Huaihe River basin to Japan. Associated with the corresponding exchanging function shown in Fig.10, the zonal flow was intensified over East Asia. Huang and Gambo (1982) pointed out that the formation of the stationary–trough over East Asia during the Northern Hemisphere winter may be due to the forcing by the heating and the dynamical effect of the Tibetan Plateau. In their investigations, the heating is caused mainly by storm–track over North Pacific. However, from the above–mentioned analysis, it is obvious that the strong convective activities around the Philippines may play an important role in the variability of the stationary–trough over East Asia through divergent wind. Therefore, the divergent wind due to strong convective activities around the Philippines may have a large effect on the atmospheric circulation over East Asia.

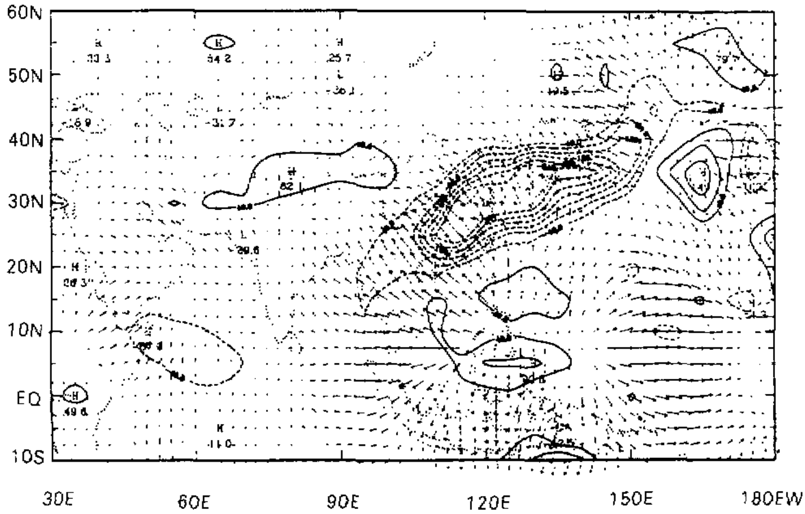

Fig. 6. Same as in Fig.3 but for the period from October 22 to 26, 1984.

IV. THE EFFECT OF DIVERGENT WIND ON THE ENERGY TRANSFORMATION IN THE INTRASEASONAL VARIATION OF CIRCULATON OVER EAST ASIA

In the previous section, the dynamical effect of the divergent wind caused by the heating due to the East Asian monsoon rainfall and the strong convective activities around the Philippines on the intraseasonal variability of circulation over East Asia has been investigated by using the first term of the Rossby–wave source. Moreover, in Section 2, we have discussed theoretically the physical role of the divergent component of wind field in the energy exchanging process with a function of energy exchange. Therefore, in this section, the physcial effect of the divergent wind caused by the heating due to the monsoon rainfall over East Asia and the strong convective activities around the Philippines will be analysed by using the exchanging function described in Section 2.

1. *During the Seasonal Transition from Spring to Summer*

Fig.7 is the latitude–time cross section of the exchanging term $C(k_\chi, k_\psi)$ averaged for 90°–130°E at 200 hPa during May–July, 1984. It may be found from Fig. 7 that in middle latitudes, the exchanging term $C(k_\chi, k_\psi)$ was positive during May–July, 1984. This shows that due to the physical effect of divergent wind, the energy was transformed from divergent component to rotational component. Moreover, it is also obvious that the larger value of energy exchanging term $C(k_\chi, k_\psi)$ abruptly shifted northward from 35°N to 43°N in early June. Compared with Fig.1, it is interesting to see that they are in good agreement. This may explain that the northward jump of the jet stream is associated with the northward shift of positive energy transformation.

Fig. 8 is the distribution of the exchanging function $C(k_\chi, k_\psi)$averaged for the period from May 22 to 26, 1984. As shown in Fig.7, One large positive value of $C(k_\chi, k_\psi)$ was located over the area from Japan to the Korean Peninsula and another was located over

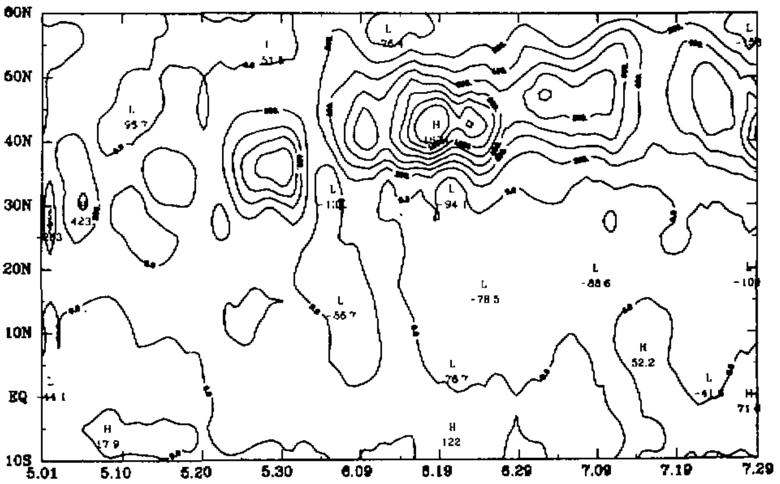

Fig. 7. Latitude–time cross–section of the energy exchanging funcion $C(k_\chi, k_\psi)$ averaged for 90°–130°E at 200 hPa during May–July, 1984. Units: $10^{-5}m^2s^{-3}$

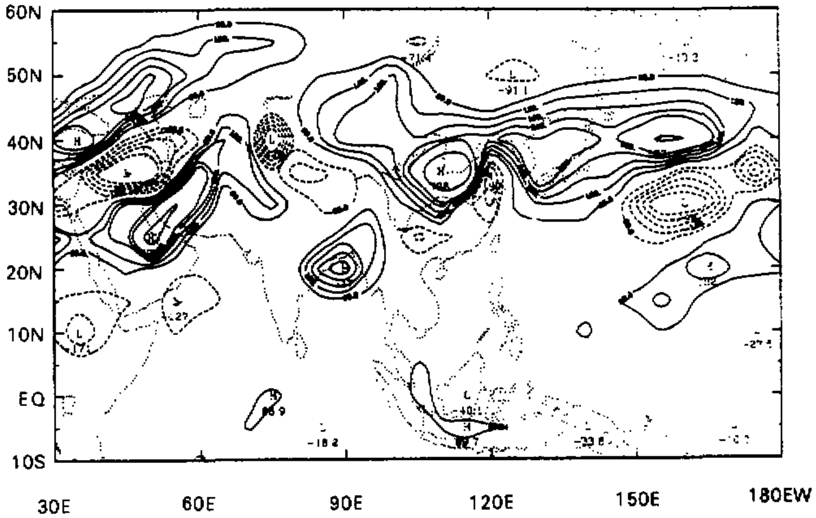

Fig. 8. Distribution of 5–day mean energy exchanging term $C(k_\chi, k_\psi)$ averaged for the period from May 22 to 26, 1984. Units: $10^{-5}m^2s^{-3}$.

the area from the Yellow River basin to Northwest China. These areas of large positive $C(k_\chi, k_\psi)$ were in agreement with the areas of large negative Rossby–wave source arising from the advection of vorticity by divergent wind. This may explain that the divergent wind caused by the heating due to monsoon rainfall in East Asia may play an important role in the energy exchange between divergent component and rotational component of the flow over the

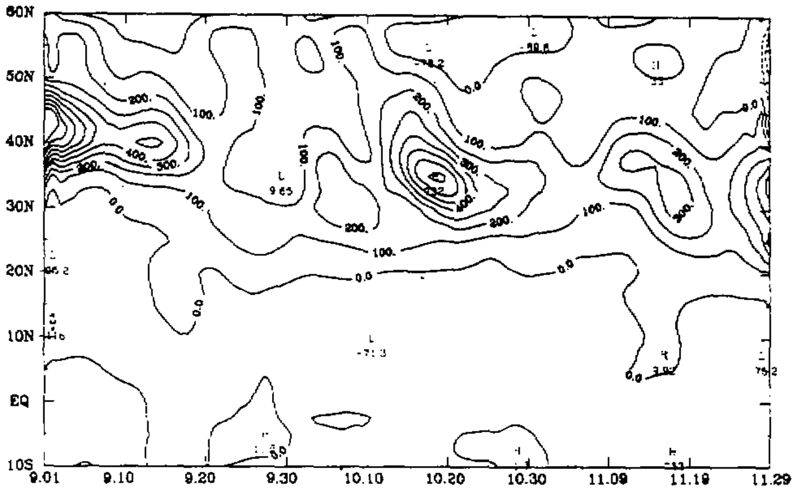

Fig. 9. Same as in Fig.7 but for the period from September to November, 1984.

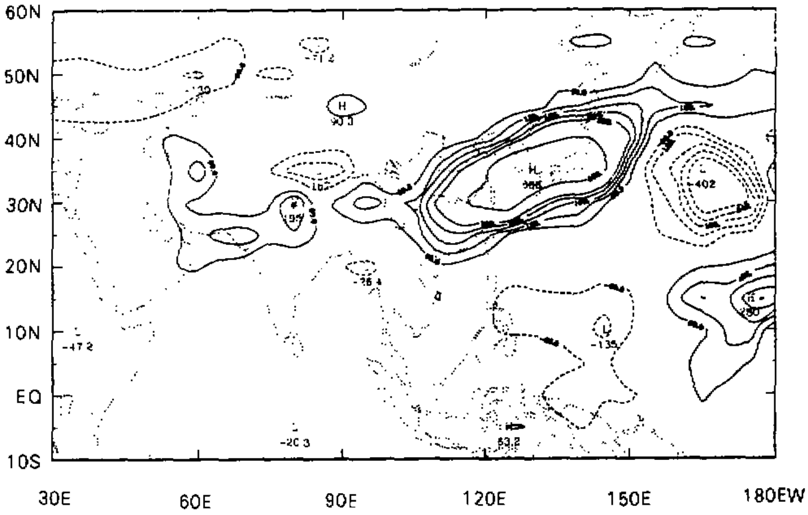

Fig. 10. Same as in Fig.8 but for the period from October.22 to 26, 1984.

Yellow River basin and Northwest China during the seasonal transition from spring circulation to summer circulation. In these areas, the kinetic energy was transformed from divergent component into rotational component of the flow. A direct consequence of the increase of the kinetic energy of rotational component of the flow was that the stream field was intensified in these areas. Compared with Fig. 1, these areas were just the positions of jet stream during early June, 1984.

The above–analyzed result shows that the divergent wind caused by the heating due to the monsoon rainfall in East Asia may play an important role for the northward jump of the jet stream over East Asia during the seasonal transition period from late May to early June.

2. *During the Seasonal Transition from Summer Circulation to Winter Circulation*

In this part, similarly as above, we will analyze the energy exchanging term $C(k_\chi, k_\psi)$ during the seasonal transition from summer circulation to winter circulation.

Fig. 9 is the latitude–time cross–section of the exchanging term $C(k_\chi, k_\psi)$ averaged for 90°–130°E at 200 hPa during September–November, 1984. It may be found in Fig. 9 that in middle latitudes, the exchanging term $C(k_\chi, k_\psi)$ was also positive during September–November, 1984. This shows that due to the physical effect of divergent wind, the energy was transformd from divergent component into rotational component. Moreover, it is also obvious that the large value of energy exchanging term $C(k_\chi, k_\psi)$ gradually moved southward from 42°N to 32°N. This may explain that the southward movement of the jet stream is associated with the southward movement of positive energy transformation.

In the following, the distribution of 5–day mean energy exchanging function $C(k_\chi, k_\psi)$ during September–November, 1984 will be analyzed as an example.

Figure 10 is the distribution of the exchanging term $C(k_\chi, k_\psi)$ averaged for the period from October. 22 to 26, 1984. It may be clearly seen from Fig.10 that a center of large positive value was located over East Asia from Japan to the Yangtze–Huaihe River basin. This area of large positive $C(k_\chi, k_\psi)$ was in agreement with the area of large negative Rossby–wave source arising from the advection of vorticity by divergent wind. Along with Fig. 6, it is clearly shown that the divergent wind caused by the heating due to convective activities around the Philippines must play an important role in the energy exchanging process between divergent component and rotational component of the flow over East Asia during the seasonal transition from summer circulation to winter circualtion. It means that the kinetic energy was transformed from divergent component into rotational component of the flow over East Asia during the seasonal transition in 1984 and this caused the increase of the kinetic energy of rotational component of the flow over East Asia. Consequently, in those areas with increased rotational wind kinetic energy, the stream function field will be intensified. Compared with Fig.4, this area was just the position of the jet stream during early November, 1984.

All the suspicions against the accuracy of the calculated divergence from current data sets notwithstanding, it can be shown from the above analyses that the divergent wind caused by the heating due to the strong convective activities around the Philippines can really function significantly to the intraseasonal variability of jet stream during the seasonal transition from summer circulation to winter circulation.

V. CONCLUSIONS AND DISCUSSIONS

In this paper, the dynamical effects of divergent wind on the intraseasonal variability of atmospheric circulation over East Asia during the seasonal transitions are analyzed by using the ECMWF data set in 1984 and by using the function of Rossby–wave source proposed by Sardeshmukh and Hoskins (1987) and the energy exchanging function $C(k_\chi, k_\psi)$ presented in this paper.

The analyzed results show that the advection of vorticity by divergent wind caused by the heating due to the monsoon rainfall in the south to the Yangtze River and the strong convective activities around the Philippines may play an important role in the northward jump of jet stream during the seasonal transition from spring circulation to summer circulation over East Asia. Due to the northward movement of the advection of vorticity by the divergent wind, the energy transformation from divergent component into rotational component can be caused over the Yellow River basin and Northwest China. Thus, the jet stream abruptly shifts northward and was located over North China.

Moreover, the analyzed results show that the advection of vorticity by divergent wind caused by the heating due to the strong convective activities around the Philippines is also important in the intraseasonal variability of the atmospheric circulation over East Asia during the seasonal transition from summer circulation to winter circulation. Due to the gradual southward movement of the advection of vorticity by the divergent wind, the energy transformation from divergent component into rotational component is also in the same pace over East Asia, especially over the Yangtze–Huaihe River basin. Therefore, the jet stream will gradually move southward.

The intraseasonal variability of the atmospheric flow over North America may be different from that over East Asia. The divergent wind caused by the heating over the area of the Gulf Current may have some impacts on the intraseasonal variability of the zonal flow over North America. However, the divergent wind over North America is much weaker than that over East Asia, but the high frequency variability is more significant than that over East Asia. The differences between the Rossby–wave source in North America and that in East Asia will be discussed in another paper.

From this study, we pointed out that the divergent winds caused by the heating due to the monsoon rainfall in East Asia and the convective activities around the Philippines may be very important in the intraseasonal variability of the atmospheric circulation over East Asia. However, the intraseasonal variability of the atmospheric circulation over East Asia can also affect the monsoon rainfall and the convective activities around the Philippines. Therefore, the interaction between the divergent wind and the circulation must be an interesting problem for further research.

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