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Dynamic Features and Maintenance Mechanism of Asian Summer Monsoon Subsystem①

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ABSTRACT

In the context of the dissociation of vertical shear flow and tropospheric mean flow based on 1980–1996 NCEP / NCAR re-analysis, study is undertaken of the barotropic and baroclinic development characteristics and kinetic energy maintenance mechanisms of Asian summer monsoon. Evidence suggests that the monsoon activity is marked by noticeable baroclinicity in three active regions of different dynamical characteristics, located in India, East Asian tropics and subtropics, respectively, with greatly differing maintenance mechanisms of barotropic / baroclinic kinetic energy.

Key words: Monsoon; Barotropic; Baroclinic; Maintenance

1. Introduction

Initially, monsoon was referred to the seasonal reversal of wind direction over the Indian Ocean, especially along the coastal belt of the Arabian Sea (Webster, 1987). With the increased understanding of monsoon behaviors, its definition and implication have been augmented. Based on previous studies and wind veering in January and July as the criterion of its definition, Ramage (1971) showed that the monsoon region includes Asian tropics / subtropics, Australia, Africa and their adjacent seas. With advances in monsoon research, meteorologists have expanded the Ramage's definition and are looking into the entity from a planetary–scale perspective. From the combination of wind direction and rainfall, the general criterion of the monsoon definition is its winter / summer reversal in wind direction and a wet alternation with a dry period on a seasonal basis. Following this criterion, Wang and Murakami (1994) presented their definition of Northeast Pacific monsoon. The most dramatic seasonal cycle on the globe emerges in the above monsoon regions, particularly the Asian ones ranking first in size and severity, which, however, differ substantially in land–sea distribution between India and east Asia, thus leading to greater discrepancy in land–sea thermal regime and pressure that are responsible for the difference in summer monsoon over the two sectors. Krishnamurti et al. (1976) first illustrated the interrelation in variation among Indian summer monsoon with its associated trough, South–Asian upper–air anticyclone, upper–level cross–equatorial southward flow, southern low–level Mascarene anticyclone and Somalian low–level jet—these members constitute an Indian monsoon circulation system. Yet

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the monsoons over China mainland, the South–China Sea and western Pacific have owed the origin and change to the Indian counterpart before.

Starting their study on East Asian monsoon as early as the 1940s–1960s, Zhu et al. (1934), Tu and Huang (1944), Tao et al. (1957) and Gao (1962) placed focus on the relationship of the East Asian summer monsoon to flood / drought events in China without addressing their relation to Indian monsoon. With active research of monsoon and tropical meteorology in China, not until the early 1980s did our meteorologists make a breakthrough in the East Asian monsoon study, demonstrating that the summer monsoon as well as its rainfall does not bear a close relation to the Indian counterpart. Tao and Chen (1987) proposed an East Asian monsoon system with its principal members determined in a definite way, indicating that the East Asian and Indian monsoon systems are both independent and interacting. Zhu et al. (1986) held that the East Asian system differs greatly from the South Asian counterpart in such a way that the former is composed of a tropical and a subtropical subsystem but the latter is solely under the effect of tropical monsoon. Based on analysis of vapor transfer, Xu, He et al. (1993) showed that the East and South Asian systems depend in relative independence on time scales, viz., they are independent as regards the change in intraseasonal oscillation but integrated as we look at the change in seasonal mean. Still more intensive studies showed that for both the systems, their inter–affecting systems in both the hemispheres are quite distinct in addition to the difference in northern circulations. For the East Asian monsoon system Huang et al.(1987) indicated that equatorial westerly can travel into East Asia from the Arabian Sea despite the westward propagation of circulations between 15–30°N. Numerical simulations have confirmed that the East Asian circulation pattern will be altered after the Mascarene high changes. In contrast, He et al. (1990) asserted that the East Asian monsoon of northern summer is related mainly to the circulations in the East Indian Ocean and Australia.

In the context of 1980–1996 NCEP / NCAR re–analysis, we performed study of the seasonal variation in circulations of the Asian monsoon subsystems. Fig.1 is a plot of 850 hPa circulation difference (July minus January) over the Asian monsoon region.

It is seen therefrom that conspicuous difference exists in seasonal variation between the East Asian and Indian monsoon circulations, as shown in the following: 1) the seasonal variation in circulations over the Indian monsoon region lies dominantly in the difference in the zonal wind (the maximum of 15 m s^{-1}); zonally westerly flow prevails in summer and easterly or weak westerly in winter; the meridional wind in the Bay of Bengal experiences significant seasonal variation (the maximum of 8 m s^{-1}); still stronger south wind blows in summer; the difference in seasonal variation of meridional / zonal winds has the same order of magnitude over the seaboard of east Africa and the western Arabian sea, affecting greatly the Indian monsoon, with the zonal (meridional) wind difference reaching the maximum of 20 (16) m s^{-1}, indicating that the region represents the maximum variation of both winds in Asian monsoon region on a seasonal basis; 2) for East Asian monsoon, its tropical circulations differ greatly from the subtropical counterparts, and the maritime continent zonal / meridional winds display pronounced seasonal variation, the former (latter) reaching 10 (8) m s^{-1}; for east China north of 20°N, its East / South seas, the Korean Peninsula, Japanese islands and their neighboring seas, the seasonal variation of circulations consists of meridional wind, the southerly (northerly) wind blowing in summer (winter).

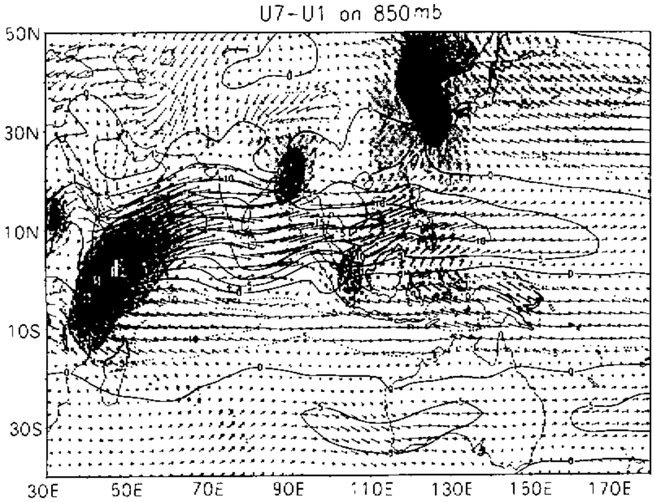


Fig. 1. 850 hPa circulation difference (July minus January) in the Asian monsoon region, where the isopleth denotes the difference in zonal wind and the areas of > 1 m s^{-1} difference in meridional wind are shaded, with the difference flowfield in vectorial form.

It follows that there emerges noticeable seasonality of Asian circulations in summer and winter, with greater difference between the East Asian and Indian monsoons in such a manner that the Indian monsoon exhibits mainly the difference in zonal wind, the east–Asian tropical monsoon equally–important difference in zonal / meridional winds, and the East Asian subtropical monsoon in meridional wind, on a seasonal basis. This reveals that the East Asian monsoon system is complicated in character.

2. Barotropic/ baroclinic dynamic features of the Asian summer monsoon system

Evidently, the view that the east–Asian and Indian summer monsoon systems are both independent and interacting is of great importance to the study of summer weather / climate causes for China. We can see that the Asian monsoon under the dynamic and thermal effect is a highly intricate climate system. Previous studies emphasized the difference in circulations and weather / climate anomaly between the East Asian and Indian monsoons. Evidently, the dynamic characteristics should be dealt with. Due to the fact that, covering tropics, subtropics and areas downstream of the Tibetan Plateau, and under the influence of land–sea thermal contrast both in N–S and E–W direction and the dynamic impact of the plateau, the East Asian summer monsoon is made a quite complicated system so that it is urgent to establish a fuller dynamic system of the monsoon.

Asian summer monsoon is characterized by pronounced altitude–dependent change in wind direction and speed, with the former reversed even in some cases, thus indicating strong baroclinicity, and the difference in magnitude between higher– and lower–level circulations even acts as the indicator of the interannual variation of the monsoon (Webster et al., 1992). In terms of the scheme developed by Wiin–Nielson (1962) for separating the barotropic from the baroclinic component, Xu et al. (1993) addressed low–frequency activities in the atmosphere and discovered noticeable baroclinicity of such activities in the tropical, particularly the Asian monsoon. In terms of the same dissociation scheme, Guan, Xu et al. (1997) indicated that the establishment and maintenance of the Asian summer monsoon are related to the growth of the baroclinic component in atmospheric motion there, with the change in the component indicative of the march and retrogress of the monsoon and the horizontal distribution of its intensity suggestive that the Asian monsoon is strongly baroclinic. Hence, we made the investigation of the dynamic structure of the monsoon by dint of the height–varying baroclinic component of the wind, extracted from circulation data, where, however, the unique barotropic / baroclinic structures of the East Asian monsoon, the mechanisms of baroclinicity genesis of the Asian summer monsoon and the interannual difference in the vigor for the different regions have not been attacked to full advantage. It is noted that the barotropic and baroclinic components are just numerical approximations, differing, to some extent, from the classic concept. In fact, the " barotropicity" mentioned here refers just to "equivalent barotropicity".

Atmospheric barotropic and baroclinic components are separated through the Wiin–Nielson method (Wiin–Nielson, 1962).

The means of u and v wind in vertical each have the form

$$\bar{u}=\frac{1}{p_s-p_t}\int_{p_t}^{p_s} u dp,\quad \bar{v}=\frac{1}{p_s-p_t}\int_{p_t}^{p_s} v dp,$$

where p_s denotes 1000 hPa and p_t (= 100 hPa) signifies the top boundary pressure so that $\bar{u}$ and $\bar{v}$ represent the tropospheric extent velocity–constant flow (simply called TEF hereafter) or the tropospheric mean flow in the related directions, serving as the barotropic component while the vertical shear flows u' and v' are taken as the baroclinic component. And we have

$$u'=u-\bar{u},\quad v'=v-\bar{v},$$

with the kinetic energy for barotropic motion of the form

$$K_m=\frac{1}{2}(\bar{u}^2+\bar{v}^2),$$

and the kinetic energy for baroclinic motion

$$K_S=\frac{1}{p_s-p_t}\int_{p_t}^{p_s}\frac{1}{2}(u'^2+v'^2)dp.$$

We made use of the 1980–1996 re–analysis to calculate u and v over the arrays at 1000, 850, 700, 500, 300, 200 and 100 hPa.

One can see therefrom that 1) there are three strongly active regions of baroclinic kinetic energy, two corresponding each to the planetary wind belt in the hemisphere and the remaining to the Asian monsoon region; 2) there emerge two strongly active sectors of Ks, each related to a hemispheric planetary wind belt, with almost zero of the energy for the Indian monsoon. The East Asian subtropical monsoon region (north of 20°N) shows stronger barotropicity, which, however, becomes the faintest in July when the monsoon is in its prime of development, leading, obviously, to the fact that the subtropical monsoon development is not under the full control of the northern planetary windbelt; 3) K_m is noticeably more than

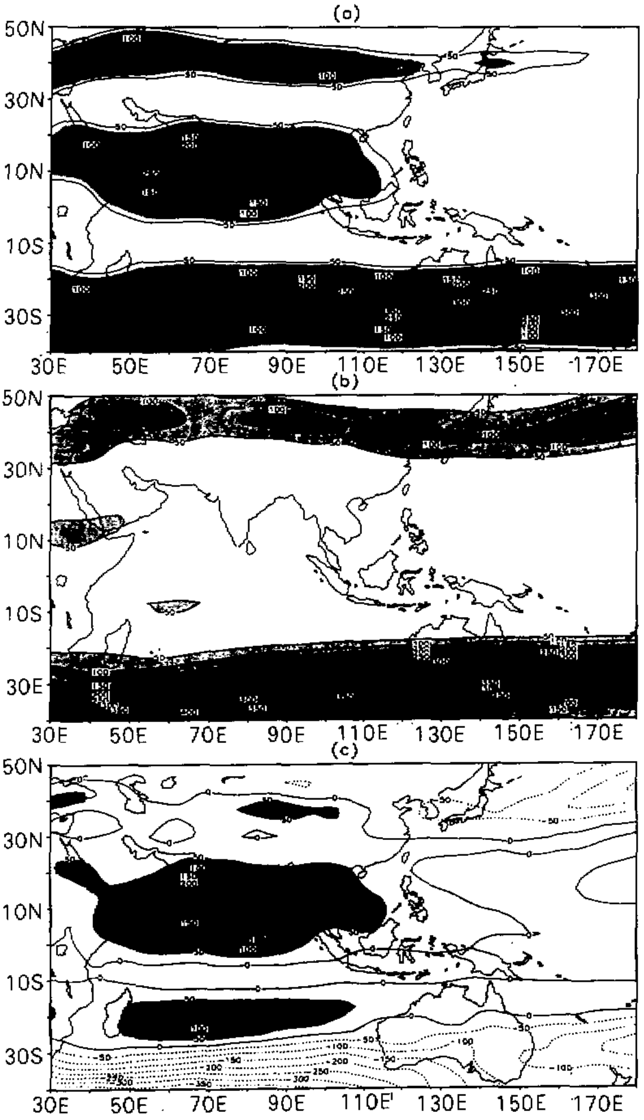


Fig. 2. Horizontal distribution of barotropic / baroclinic kinetic energy over the Asian summer monsoon region in July, a) K_s pattern where areas of > 50 m^2s^{-2} are shaded; b) As in a) but for K_m; c) The pattern of difference (K_s-K_m). Otherwise as in a).

K_s in the winter hemispheric planetary windbelt. The Indian monsoon region is entirely covered with baroclinic activities as the Asian summer monsoon is in the prime of development. The East Asian subtropical monsoon region shows comparable in strength barotropic / baroclinic kinetic energies that are quite feeble, representing a transition between the intensely baroclinic activities of the Indian monsoon and strong barotropics of the northern planetary windbelt. Like Indian summer monsoon, the East Asian tropic maritime continent is under the baroclinic effect except that the baroclinicity is much weaker as compared to the Indian monsoon center.

3. Role of zonal/ meridional wind shear in vertical over the Asian summer monsoon area

Look first at Fig.3, where the Indian monsoon baroclinic kinetic energy is almost under the full control of the baroclinic component of zonally vertical shear (u'), with the baroclinic kinetic energy (u_s) 10 times as large as v_s, of which the latter is dominant in the east of the N–S coastline, with a relatively higher–value region in the subtropical monsoon band that is

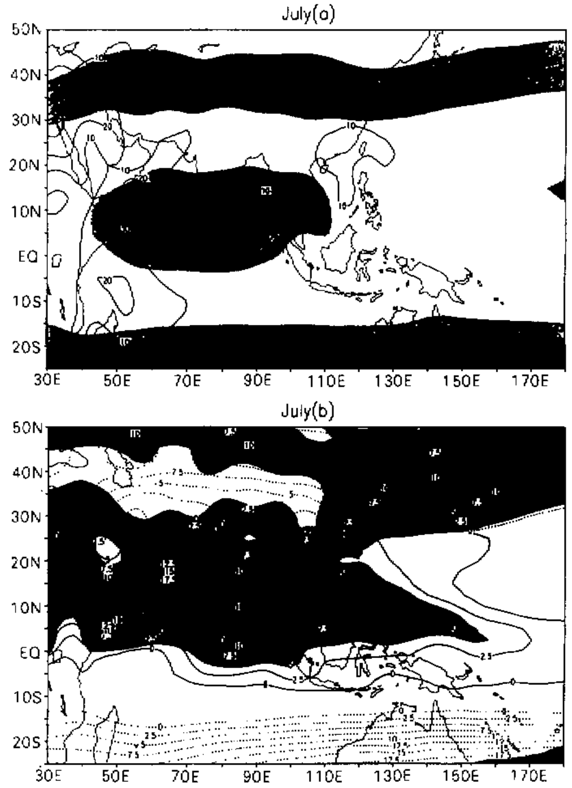


Fig. 3. Horizontal distribution of baroclinic kinetic energy of zonal/ meridional winds over the Asian summer monsoon region in July.

a) zonally baroclinic kinetic energy u_s with shaded areas of $>50\ \mathrm{m}^2\ \mathrm{s}^{-2}$ and isopleths denoting meridionally baroclinic kinetic energy v_s;

b) zonal component at 850 hPa with shaded areas of the wind of $>0\ \mathrm{m\ s}^{-1}$. Solid isolines give the distribution of u' and the dashed ones denote the zonal TEF.

just a low region of u_s, which hence contributes significantly to the subtropical monsoon activities.

Fig. 4 portrays that the Indian monsoon K_s is almost under the full control of the baroclinic component of zonal vertical shear (u'), with the u_s 10 times as large as v_s, which is dominant in the east of the N–S coastline with a relatively high–value area in the subtropical monsoon region that is just a low region of u_s, which hence contributes significantly to the subtropical monsoon activities.

At 850 hPa, zonal shear flow (u') is almost fully dissociated from the tropospheric mean ($\overline{u}$) which is related to zonal westerly (u) on a planetary scale. u' in the Indian monsoon region agrees completely with u on speed and direction, and the same is true of the maritime continent monsoon except for much smaller shear windspeed. The subtropical monsoon is between the Indian monsoon u' and northern planetary zonal westerly (u), passing through which are three zero lines of u, u' and $\overline{u}$ of the planetary windbelt. v' and $\overline{v}$ are by far smaller in the contribution compared to u except for their innegligible impacts on the east side of the coastline. On the other hand, in the East African offshore, Bay of Bengal and East China coastal belt, v' is relatively bigger and in agreement with v in these regions.

It is seen therefrom that u' is positive, meaning a westerly below 500 hPa, peaking at 20 m s^{-1} in 900 hPa, and negative, meaning an easterly, peaking at 30 m s^{-1} in 100 hPa, both located in the Indian monsoon area and showing greater gradients in vertical, in striking contrast to the gradients over the subtropical monsoon band; at 120°E, v' in the tropical and subtropical monsoon belts is the southerly below 700 hPa, maximizing at 10 m s^{-1} equatorially, and the northerly above 300 hPa with two centers of maximum wind, one situated at 200 hPa equatorially (20 m s^{-1}) and the other at 30°N (100 hPa) within the East Asian subtropical monsoon region.

It is easy to observe that K_s in the Indian monsoon depends entirely on u', whose gradients are great and baroclinicity with easterly shear is high; This is also the case in the tropical maritime continent monsoon belt except for small vertical gradients, responsible for weak baroclinicity. The subtropical monsoon region is extremely intricate in regime and serves as a transition from the Indian monsoon strong vertical shear flow into robust TEF ($\overline{u}$) of westerlies, where the barotropicity and baroclinicity of u are feeble, and v' is an useful indicator of baroclinicity, with northerly (southerly) in the upper (lower) troposphere.

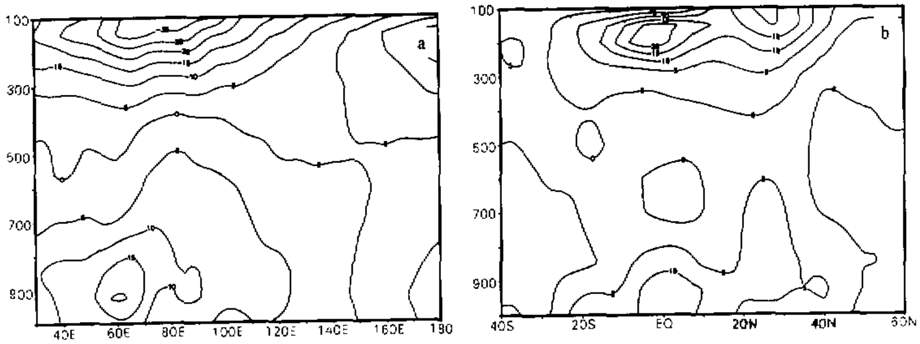


Fig. 4. Vertical distribution of u' and v', with u' at 15°N (a) and v' at 120°E (b).

4. Role of land–sea thermal contrast in the maintenance of the Asian summer monsoon

Fig. 5 depicts the distribution of temperature integrated over the troposphere (shaded area), indicating the land–sea heating regime in the Asian summer monsoon region. One can see that an intense warm center emerges around the Tibetan Plateau and Iranian highland in summer and peaks in July. In the Indian monsoon band to the south there appear u_s activities to match the center; whereas in the seaboards to the east of Africa and to the south of the Arabian Peninsula there arises considerable v_s, which is, however, out of phase with the condition in other two monsoon regions, i.e., along the East Asian coastal belt v_s peaks in June instead of in July.

Obviously, the land–sea thermal contrast is responsible for the baroclinicity in the monsoon region, leading to strong u' (v') in the Indian monsoon sector (East Asian seaboard).

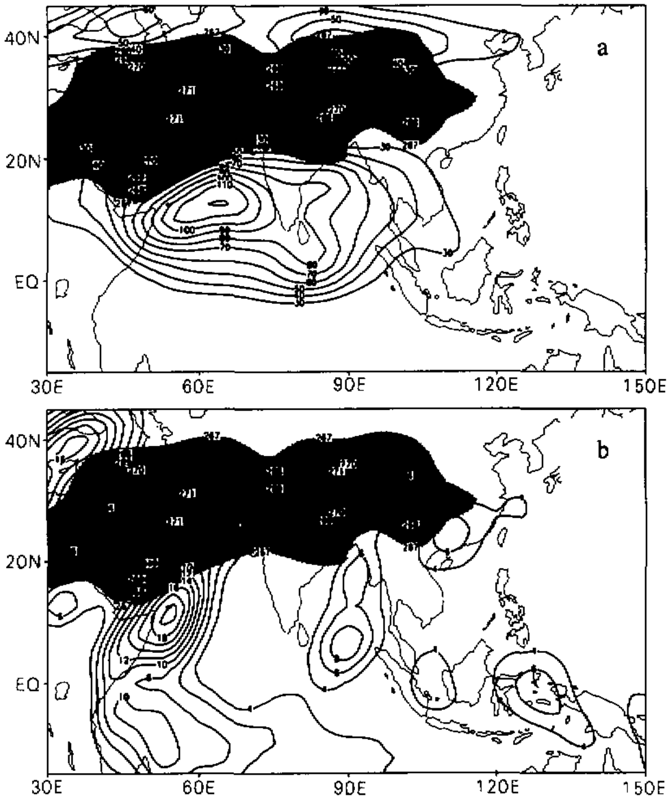


Fig. 5. Horizontal distribution of July temperature integrated over the troposphere (shaded area), and u_s (a) and v_s (isolines) in the Asian monsoon band.

From the thermal wind relation it follows that the vertical shear of horizontal windspeed is proportional to horizontal temperature gradient, i.e., the greater the gradient, the stronger the shear and baroclinicity. On the other hand, such gradients are inversely proportional to the Coriolis parameter f in such a way that robust meridional temperature gradients and small f will cause extremely vigorous u', such as in the Indian region, leading to strong u_s, as shown in Fig. 5. In midlatitudes to the north of the high temperature center where intense meridional temperature gradients are present, however the baroclinicity is much weaker due to the greater f.

To the east of the N–S coastline, zonal temperature gradients give rise to substantial v', causing feeble meridional baroclinicity owing to smaller zonal temperature gradients. In the East Asian subtropical seaboard, v_s is much weaker because of the greater f despite bigger zonal temperature gradients compared to the other monsoon areas.

From the horizontal distribution and dynamical relation, we see that the baroclinicity in the monsoon bands relates closely to the land–sea thermal contrast and the earth's rotation parameter f. But do the summer activities depend on other factors in addition to f and, particularly, the thermal contrast?

Fig. 6 presents the flowfield in July. At 850 hPa close similarity is shown in the shear (c) and total flowfields (a) over the monsoon regions of the tropical Indian ocean and west of the Philippines and such flowfields north of 30°N are almost reversed zonally, in good

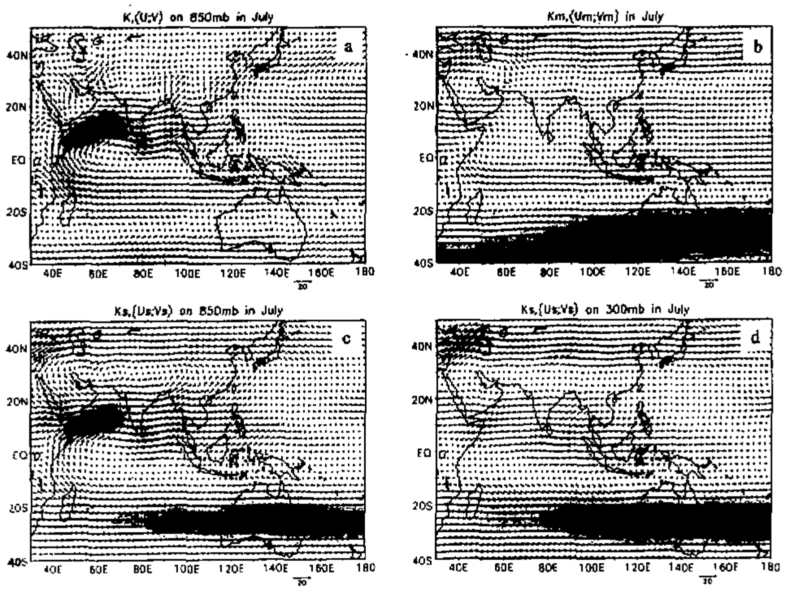


Fig. 6. Flowfield for July in the Asian monsoon region. a) total kinetic energy (shaded area) and flowfield at 850 hPa; b) kinetic energy (shaded area) and flowfield averaged over the troposphere; c) shear kinetic energy (shaded area) and shear flowfield at 850 hPa; d) as in c) but for 300 hPa.

accordance with the TEF flowfield. In the Australia region, the effect of meridional shear is discernible in such a way that the total flowfield (a) differs greatly from the shear one (c), but it bears resemblance to the tropospheric mean flowfield (b), and is under the joint effect of cross–equatorial northward flow and eastward TEF.

It is seen that the total flowfield (a) is in concord with the shear one (c) over the Indian and East Asian tropical monsoon areas, with the intensity depending on the land–sea thermal contrast; whereas they differ greatly in the subtropical monsoon region. Had the vigor been under the full control of the thermal contrast, the flowfield (a) there would have been covered with a southerly or southeasterly of the shear flow. But the total flowfield is actually covered with a SW wind that results from the combined effects of meridional shear and westerly jet on the north side of a subtropical high. As such, the total flowfield is not just a result of the thermal contrast but influenced by other factors as well.

Both the flowfields in (a) and (b) are well analogous to each other, displaying a stronger southerly flow in the southeast seaboards of China which are just between the tropical easterly of the TEF and the midlatitude westerlies and thus under noticeable influence of the thermal contrast zonally. This band is, of course, affected greatly by the western Pacific subtropical high.

In the equatorial western Pacific, besides, the shear flow at 850 hPa is westerly (c) and the TEF is easterly (b). Therefore, the occurrence of westerly anomaly there depends on the enhancement (reduction) of westerly shear (TEF easterly) flow. If the westerly shear flow is regarded as part of the Asian summer monsoon and the TEF easterly as the low–level trade wind, then we are allowed to reveal the truth of equatorial western Pacific westerly anomaly, which is the result of thermal and dynamic effects in combination, an outcome that is of high importance in understanding the interaction between Asian summer monsoon and ENSO.

By referring to the 300–hPa shear flowfield (d), we see the complete reserval in the pattern at high and low levels (b), suggestive of baroclinicity of the monsoon. In extratropics at lower levels, the shear flow is opposite in direction to the TEF such that zonal flow is extraordinarily weak, especially over Eurasia (a); whilst westerly jet emerges at high levels (figures not shown) due to the agreement of high–level shear flow (d) with the TEF (b) in direction.

5. Dynamic effect of barotropic–baroclinic kinetic energy conversion on Asian summer monsoon

The expression of total kinetic energy in P coordinates is

$$\frac{dK}{dt}=\int_{p_t}^{p_s}\int_s \omega\frac{\partial z}{\partial p}\,dSdp+\text{ other terms,}$$

where S denotes the integration area, and the "other terms" represent the terms of dissipation and cross–boudary transfer of K. As stated before

$$u=\bar{u}+u',\quad v=\bar{v}+v',$$

which are put into the equations of motion and after transformation and rearrangement we have, separately, the expressions of barotropic and baroclinic kinetic energy of the form

$$\frac{dK_m}{dt} = -\frac{p_{st}}{g}\int_s [\overline{V}\cdot\overline{D'V'} + (\overline{V}\times K)\cdot\overline{\zeta'V'}]dS + \int_{p_t}^{p_s}\int_{S'} \overline{\omega\frac{\partial \overline{z}}{\partial p}}dSdp + \text{other terms}$$

$$\frac{dK_s}{dt} = +\frac{p_{st}}{g}\int_s [\overline{V}\cdot\overline{D'V'} + (\overline{V}\times K)\cdot\overline{\zeta'V'}]dS + \int_{p_t}^{p_s}\int_{s} \omega\frac{\partial z}{\partial p}dSdp + \text{other terms}$$

where $D$and ξ denote, respectively, horizontal divergence and relative vorticity. The pressure difference $P_{st} = P_s - P_t$ with subscripts s and t denoting the surface and top level, respectively. The term of barotropic–baroclinic kinetic energy conversion has the form

$$(K_m, K_s) = -\frac{p_{st}}{g}\int_s \overline{V}\cdot\overline{D'V'} + (\overline{V}\times \overline{K})\cdot\overline{\zeta V'}]dS,$$

which means the conversion from baroclinic into barotropic kinetic energy for $(K_m, K_s) > 0$, favoring the growth of K_m. Its magnitude depends on two terms, one (the other) being the interaction between vertically averaged shear flow divergence (vorticity) transfer and the TEF, simply called a divergence (vorticity) factor.

Calculations of these terms are summarized in Fig. 7. It is seen from (a) that except the northern Bay of Bengal, Sri Lanka, Maldive Is. and the western Arabian Sea in the Indian monsoon area, the barotropic–baroclinic kinetic energy conversion is negative–valued, favoring the reduction (growth) of barotropic (baroclinic) kinetic energy; the East Asian tropical monsoon region is negative–valued except smaller positive values over the South–China Sea, a situation that contributes to baroclinic development; the subtropic monsoon band is covered with higher negative values, suggestive of higher K_s growth from K_m. Comparison reveals that the vorticity factor plays a crucial part in K_s maintenance in the Indian and East Asian subtropic monsoons (d); whilst the divergence factor is dominant in the East Asian tropical monsoon belt (c).

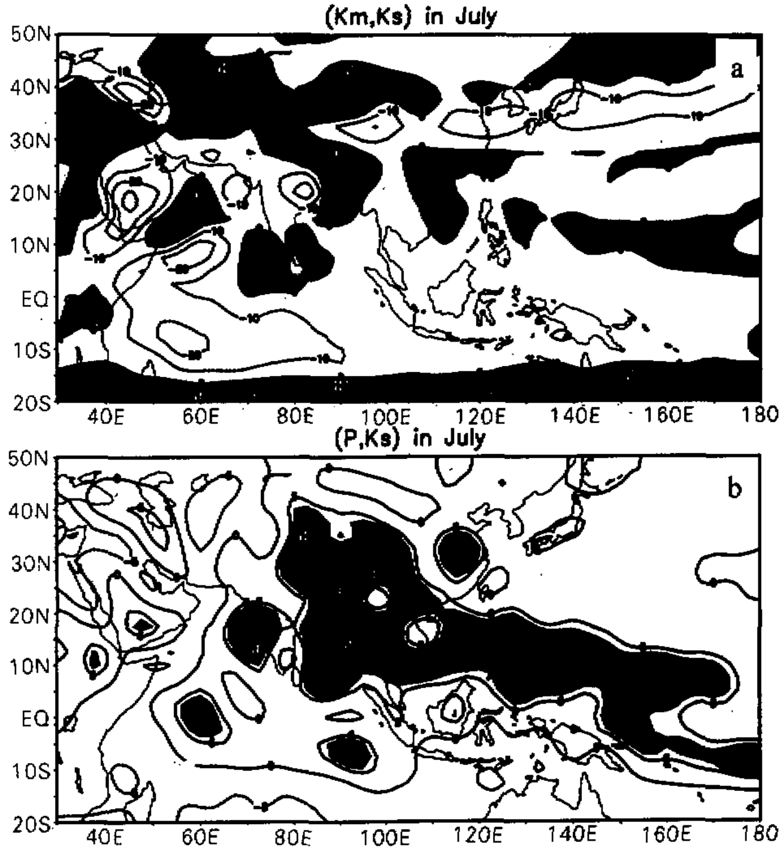
The term of potential energy conversion can influence the K_s development. In the Asian monsoon region as a whole, particularly the Indian and East Asian tropic subregions, the conversion of potential energy (b) is intense enough to be in favor of the reinforcement of the monsoon whereas the subtropical monsoon band presents a greatly different picture.

The foregoing analysis shows that there is vast difference in the maintenance mechansim of barotropicity / baroclinicity development in the three key sectors of the Asian summer monsoon. The K_s maintenance in the Indian and East Asian tropic monsoons depends mainly on potential energy conversion, whilst in the subtropical monsoon band the vorticity factor plays an innegligible role in the conversion of barotropic–baroclinic kinetic energy $(K_m - K_s)$ in addition to potential energy conversion. The $(K_m - K_s)$ transformation, though exerting smaller effect on the tropic monsoon, contributes to the intensification of baroclinic development. The Indian monsoon differs in maintenance mechanism from the East Asian tropic counterpart in such a way that the former depends dominantly on the vorticity factor and the latter on the divergence factor.

6. Concluding remarks

Based on the above analysis we come to the following:

1) barotropic kinetic energy (K_m) is greatly higher than baroclinic kinetic energy (K_s) in the winter hemispheric planetary windbelt. In the prime of the Asian monsoon development,



(Km,Ks) in July

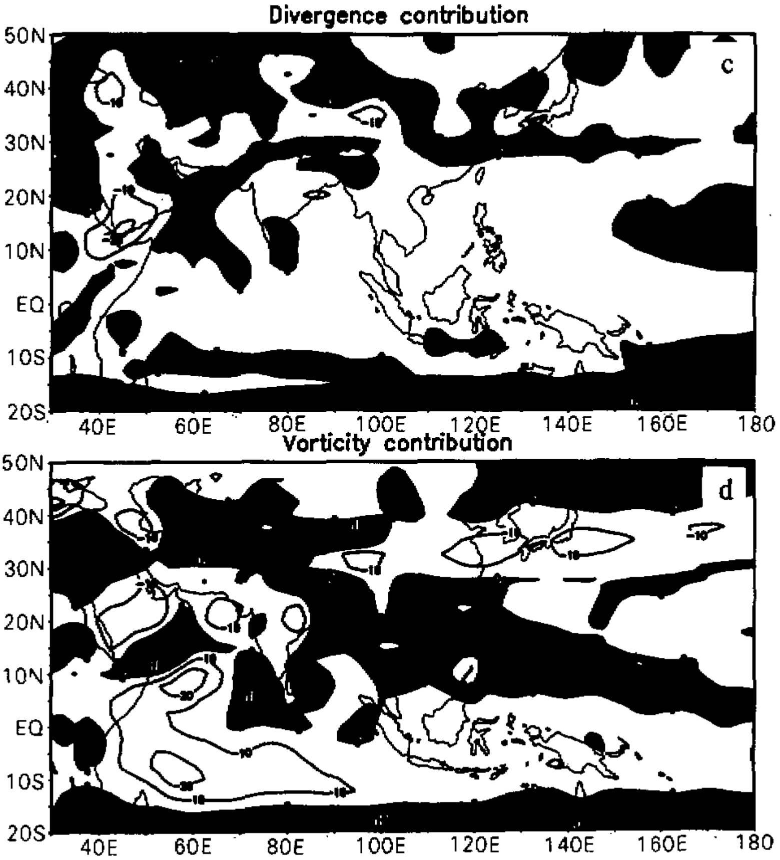
(P,Ks) in July

a) conversion of barotropic–baroclinic kinetic energy; b) conversion of potential energy;

the Indian sector is under the full control of baroclinic activities, with ignorable K_m. K_m and K_s are comparable at lower indensity in the subtropical monsoon band as a transition between the vigorously baroclinic development in the Indian monsoon and strongly barotropic activity in the northern planetary windbelt. The East Asian maritime continent falls into the sector of baroclinic development as does the Indian region except the baroclinicity much lower compared to that of the Indian monsoon center;

2) in the Indian monsoon, K_s depends entirely on zonally vertical shear (u'), and the bigger the vertical gradient, the higher the baroclinicity, with easterly (westerly) at higher (lower) levels. It is the case in the maritime continent monsoon band except for smaller vertical gradients and lower baroclinicity. Things are different in the East Asian subtropical monsoon belt, which is a transition between the strong vertical shear in the Indian region and robust TEF of westerlies with faint barotropicity / baroclinicity zonally, but meridional vertical shear (v') is a good indicator, with northerly (southerly) in the upper (lower) troposphere.

3) The baroclinic development bears a close relation to land–sea thermal contrast and the earth's rotation parameter f in the Asian summer monsoon. However, pronounced



c) divergence factor; d) vorticity factor.

Fig. 7. Horizontal distribution of the calculations of the terms in July.

difference arises among these monsoon subsystems. The total flowfield agrees with the shear counterpart, with the vigor dependent on the thermal contrast over the Indian and East Asian tropical areas while greater discrepancy exists between the flowfields, relying not just on the thermal contrast but other factors in the subtropical monsoon band;

4) As regards the maintenance mechanism of barotropic / baroclinic activities, the three important subregions differ greatly among themselves. The K_s maintenance relates mainly to potential energy conversion in the Indian and East Asian tropic monsoon bands and the vorticity factor plays an important part in the $K_m - K_s$ conversion over the East Asian subtropical monsoon band as well. The $K_m - K_s$ conversion, while having smaller influence on the tropic monsoon, acts to strengthen its baroclinicity. Besides, the Indian monsoon differs in maintenance mechanism from the East Asian tropical monsoon. The vorticity (divergence) factor has higher effect in the Indian (tropical) band;

5) Dynamically, the Asian summer monsoon has three key active regions in the Indian ocean, East Asian tropics and subtropics, the first two being more similar in characteristics.

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