Moisture Transport in the Asian Summer Monsoon Region and Its Relationship with Summer Precipitation in China*

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ABSTRACT

The characteristics of moisture transport over the Asian summer monsoon region and its relationship with summer precipitation in China are examined by a variety of statistical methods using the NCEP/NCAR reanalysis data for 1948–2005. The results show that: 1) The zonal-mean moisture transport in the Asian monsoon region is unique because of monsoon activities. The Asian summer monsoon region is a dominant moisture sink during summer. Both the Indian and East Asian monsoon areas have their convergence center, respectively. 2) Most moisture congregates in the lower troposphere primarily from the Bay of Bengal in the mid and upper layers, and the vapor flux comes from mid-latitude westerlies as well as the tropical western Pacific Ocean. 3) The moisture fluxes by the Indian monsoon enhance from May to July mostly in the zonal transport while those by the East Asian monsoon intensify mainly in the meridional transport from June to July. Both reach their maxima in July and then decrease from August. The sub-tropical westerly moisture fluxes south to the Tibetan Plateau across 90°E are strong in spring, while the mid-high latitude and tropical westerly vapor transfers change in phase and increase from January to July. The tropical westerly transport accounts for about 80% of the total moisture transport in July and only 18% from mid-high latitudes. 4) The moisture transfer and budgets over the Asian monsoon region undergo a substantial change after the South China Sea monsoon onset, especially over the Bay of Bengal, Indo-China Peninsula, and South China Sea. The northern boundary of the South China Sea is of great importance in providing abundant moisture for China mainland during summer. 5) The northward progress of the moisture transfer coincides with the seasonal march of the monsoon rainbelts very well. EOF1 of the moisture transport field basically depicts the consistent northward transport anomaly with an obvious decreasing trend over the East Asian monsoon region from 1951 to 2005. Further analyses suggest that this trend owing to the weakening of the East Asian summer monsoon is largely responsible for the decline of rainfall over North China. The EOF2 reveals that moisture flux convergence from northeast and southwest over the Yangtze River valley shows a slight increasing tendency from the 1980s and it is consistent with the fact of more frequently occurred heavy rainfall over there. The correlation analyses indicate that the interdecadal variation of the East Asian summer monsoon accounts for the main part of the variation.

Key words: Asian monsoon region, moisture transport, China summer precipitation

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1. Introduction

Moisture transport associated with the Asian summer monsoon is crucial for China rainfall distribution. Zhu (1934) elucidated that the East Asian summer monsoon was closely related to precipitation over China. It is necessary to reveal the relationship between Asian summer monsoon moisture transfer and China summer rainfall, which is of great significance for understanding water cycle and drought and flood prediction.

In the end of the 1950s, Xu (1958) estimated the moisture transport and water balance over East China in 1956 by using 33-station soundings. Yi (1995) contrasted the Indian monsoon with the Asian monsoon, and illustrated the existence of a three-dimensional

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unsymmetrical structure in the Asian monsoon and the anti-Hadley circulation. Huang et al. (1998), Fan and Liu (1992), Gao et al. (1999), and Xie et al. (2002) investigated the climatology of moisture transport over the East Asian monsoon region, North China, the Huaihe and Yangtze River valleys, respectively. Rosen et al. (1979) disclosed by calculating 5-yr global mean moisture transport that the Southern Hemisphere is the moisture and latent heat sources of the Northern Hemisphere at annual time scale. Chen (1985) analyzed the water vapor distribution during the first Global Atmospheric Research Program (GARP) Global Experiment (FGGE) and demonstrated that the non-divergent component represents the main feature of the moisture transport, and the Hadley and Walker circulations dominantly maintain the existence of the high moisture centers. Simmonds and Hope (1999) discussed the water vapor transfer and budget over eastern China with evidence showing that in Southeast China, the moisture carried by the Indian and Southeast Asian monsoon circulations originated from the Bay of Bengal and South China Sea, while in Northeast China, the moisture primarily came from the westerlies of mid latitudes.

A variety of rainfall cases have been discussed in detail. Xie and Dai (1959) found that the principal moisture resource is the South China Sea for the heavy rainfall over the Huanghe River basin in the summer of 1957. Ding and Hu (2003) and Hu and Ding (2003) suggested that the moisture of the torrential rainfall is usually converged from a considerably large area at lower levels, and the moisture from the South China Sea accounts mainly for the China precipitation.

As for the connection of moisture transfer and rain belts over China, Zhang (2001) pointed out that the Indian monsoon intensity has a negative correlation with the rainfall in the middle and lower reaches of the Yangtze River, while the East Asian monsoon shows a positive one. Tian et al. (2002) explained three anomalous patterns of precipitation and corresponding moisture features. Zhou et al. (2005) noticed that the moisture responsible for the anomalous rainfall over North China can be traced back to the western Pacific Ocean, which is different from some researchers' viewpoints.

From the past studies, a plenty of valuable results have been obtained, and these are helpful for understanding the links between moisture and rainfall, but many are limited to a short data period or a specific area. In this paper, the characteristics of Asian summer monsoon moisture transport and its relation with China summer precipitation are investigated based on long-term data.

2. Data and methods

This study used a global reanalysis dataset by NCEP/NCAR, which covers the period of 1948–2005, including specific humidity, zonal and meridional winds, and surface pressure on $2.5° \times 2.5°$ grids. CMAP data for 1979–2004 are also used together with monthly rainfall data of 160 weather stations over China (compiled by National Climate Center). Figures 1–6 are based on NCEP/NCAR daily data, and the others are on monthly data.

The calculation of moisture flux is based on Ding (2005). Unit column moisture transport integrated from ground surface to 300 hPa is (moisture above 300 hPa is neglected) defined as:

$$\boldsymbol{Q} = \frac{1}{g}\int_{300}^{p_s}(\boldsymbol{V}q)\mathrm{d}p. \tag{1}$$

The zonal and meridional components are

$$\boldsymbol{Q}_\lambda = \frac{1}{g}\int_{300}^{p_s}(uq)\mathrm{d}p, \tag{2}$$

$$\boldsymbol{Q}_\varphi = \frac{1}{g}\int_{300}^{p_s}(vq)\mathrm{d}p. \tag{3}$$

The moisture divergence is

$$Q_{\mathrm{div}} = \frac{1}{g}\int_{300}^{p_s}(\boldsymbol{V}q)\mathrm{d}p = \frac{1}{g}\int_{300}^{p_s}\boldsymbol{V}\cdot\nabla q\mathrm{d}p + \frac{1}{g}\int_{300}^{p_s}q\nabla\cdot\boldsymbol{V}\mathrm{d}p, \tag{4}$$

where the right two terms in Eq. (4) are moisture advection and moisture divergence by wind fields; g is the acceleration of gravity; $\boldsymbol{V}$ is two-dimensional wind vector; u and v are zonal and meridional wind speed; q is specific humidity; and p_{s} is surface pressure.

Stream function and potential function of moisture flux are based on Ding (1989) and Zhou et al.

(1999). According to the Helmholz theorem, moisture flux is given as

$$\boldsymbol{Q} = \boldsymbol{k} \times \nabla\psi + (-\nabla\chi) = \boldsymbol{Q}_{\psi} + \boldsymbol{Q}_{\chi}, \tag{5}$$

where ψ is moisture stream function, and χ is potential function. So Eq. (6) follows:

$$\begin{aligned} &\nabla^2\psi = \boldsymbol{k} \cdot \nabla \times \boldsymbol{Q} = \nabla \cdot \boldsymbol{Q} \times \boldsymbol{k}, \\ &-\nabla^2\chi = \nabla \cdot \boldsymbol{Q}. \end{aligned} \tag{6}$$

By solving the Poisson Equation (Eq. (6)), the moisture stream function ψ and potential function χ are obtained, then the non-divergent component $\boldsymbol{Q}_{\psi}$ and the non-rotational component $\boldsymbol{Q}_{\chi}$ are found.

3. Moisture transport features over the Asian monsoon region

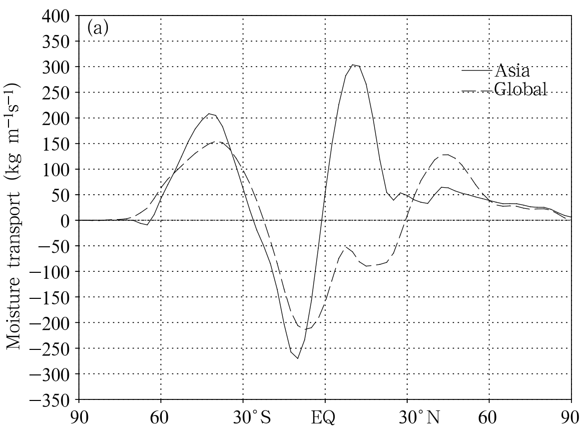
3.1 Climate features of zonal mean moisture transport

The summer (June-August) zonal moisture transport from 0° to 360°E and from 40° to 122.5°E, which denotes the Asian summer monsoon region, computed over 1948–2005, is given in Fig. 1. The solid line indicates effect of planetary trade wind zone. In the tropical region, the moisture is transferred by easterlies, while by westerlies in the mid-high latitudes, which is consistent with Rosen (1979) and Tian et al. (2002). In the Asian monsoon region, however, it is much different. It is noted that to the north of the equator, the moisture is carried by monsoon currents from west to east, which is especially strong in the tropics and over 300 kg m^{-1} s^{-1}. It can also be seen from Fig. 1b that the meridional moisture transport over the Asian monsoon region is more intense than that of the whole latitude mean, and the former is near 2 times larger than the latter in the equatorial areas.

3.2 The distribution of moisture source and sink

According to Eqs. (5) and (6), moisture stream function and potential function averaged over 1948–2005 are obtained (figure omitted). It is indicated that in the subtropical Pacific there is an anticyclonic moisture transfer center. In the equatorial Indian Ocean, there exists a strong monsoon flow. The moisture is constantly taken from the Pacific and Atlantic to southern Indian Ocean, then turns to north around the east coast of Africa and flows into the Somali jet, thus makes the vigorous moist Indian monsoon currents move continuously to the Indo-China Peninsula and South China Sea, subsequently northward into the eastern China mainland and further to Japan and Northwest Pacific. This is in accordance with Chen (1985) and Zhou et al. (1995).

The moisture stream and potential function render moisture convergence or divergence. A convergent center of about –300×10^6 kg s^{-1} over East China and West Pacific means that there is a huge moisture sink with moisture congregating from a large area (even a half globe), in which the moisture mostly comes from the Indian Ocean, and secondly from the Pacific



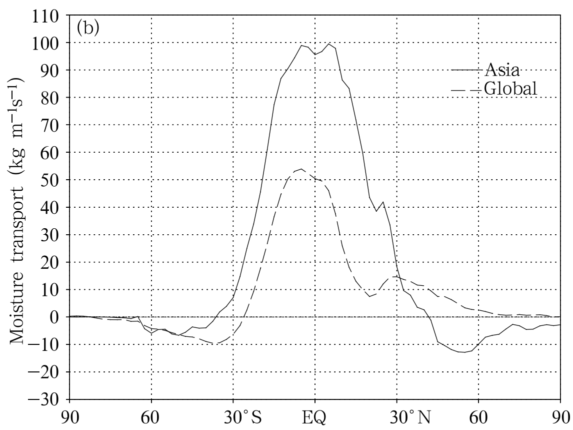


Fig. 1. Summer zonal (a) and meridional (b) moisture transport (kg m^{-1} s^{-1}) averaged over 40°–122.5°E (solid line) and 0°–360°E (dashed line) for 1948–2005.

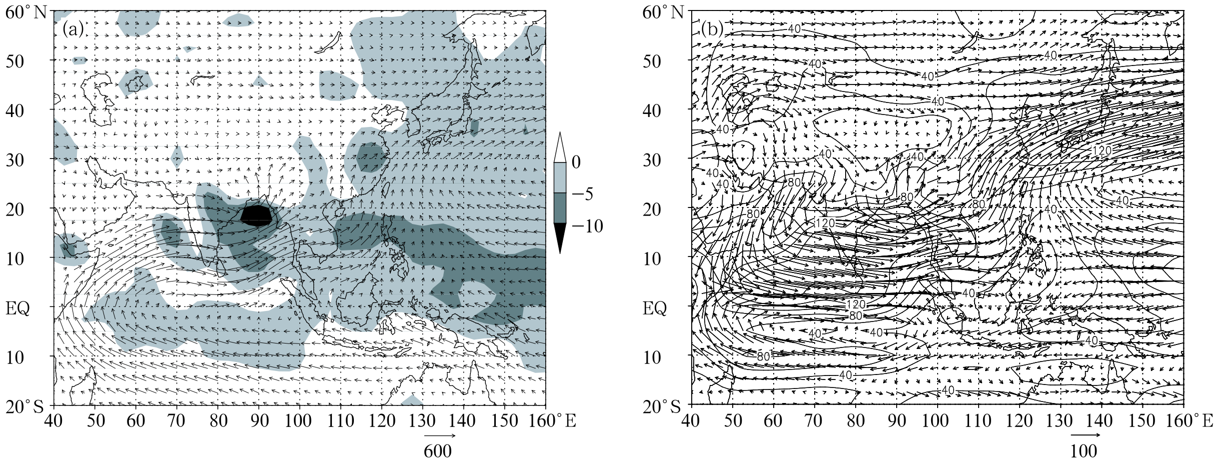


Fig. 2. Summer mean moisture flux vectors (kg m^{-1} s^{-1}) and its divergence (shadings; 10^{-5} kg m^{-2} s^{-1}) vertically integrated from surface to 300 hPa (a) and from 700 to 500 hPa (b) over 1948–2005.

Ocean. The moisture vectors in Fig. 2a clearly show that moisture from Somali by way of the Arabian Sea contributes more to the Indian summer rainfall, while more than one water vapor transport paths are responsible for the East Asian monsoon rainfall. This is also true in Huang et al. (1998). Shadings in Fig. 2 represent moisture convergence areas, where three high centers lie in the Indian Peninsula to the Bay of Bengal, South China Sea, and Yangtze-Huaihe River basin, respectively. The first is the strongest, which is primarily associated with the Indian monsoon rainfall, and the third basically attaches to the magnitude of Meiyu.

3.3 Distribution of moisture transport at different atmospheric layers

Moisture transport is concentrated in the lower troposphere due to rapid decrease of specific humidity with altitude. From the ground surface to 700 hPa, in eastern China, moisture chiefly comes from the Indian monsoon by southwest winds combined with a small part across the equator at 105°E. The two currents run northward together into South China with a maximum of about 120 kg m^{-1} s^{-1}, covering almost half of the total moisture content in a unit air column. The impact of moisture from the Pacific Ocean is confined to Japan and east ocean of Japan. From 700 to 500 hPa, the moisture in East China derives from the Bay of Bengal via Yunnan-Guizhou Plateau, and the rest passes through the Indo-China Peninsula and South China Sea. It is noted that the moisture by mid-latitude westerlies increases to 40 kg m^{-1} s^{-1}. From 500 to 300 hPa (figure omitted), the moisture carried by the Indian monsoon obviously reduces, while that by the westerlies remains, another moisture passage through West Pacific to South China Sea conducts moisture to the Yangtze River basin and into further northern areas. The vertical examination reveals that moisture sources notably differ from each other in the above three layers over eastern China.

3.4 Monthly evolution and seasonal change of moisture transfer at different latitudes

Figure 3 depicts the monthly differences of moisture transport. The moisture transport by the Indian monsoon currents strengthens from April to May (figure omitted), and even stronger from May to June (Fig. 3a). It is remarkable that the southwest flux from the Arabian Sea to South China Sea grows fast, meanwhile the southeast transport in the northeast of the Philippines has substituted the southwest transport along the flank of the subtropical high. From June to July, the anomalous transport from southwest winds over the Arabian Sea and Indian Peninsula, and the anomalous eastward transport over the subtropical Pacific south of Japan, Yangtze River valley, and South China are easily noticed, which indicate that the anomalous northward transport in North China and Northeast China is related to the subtropical high

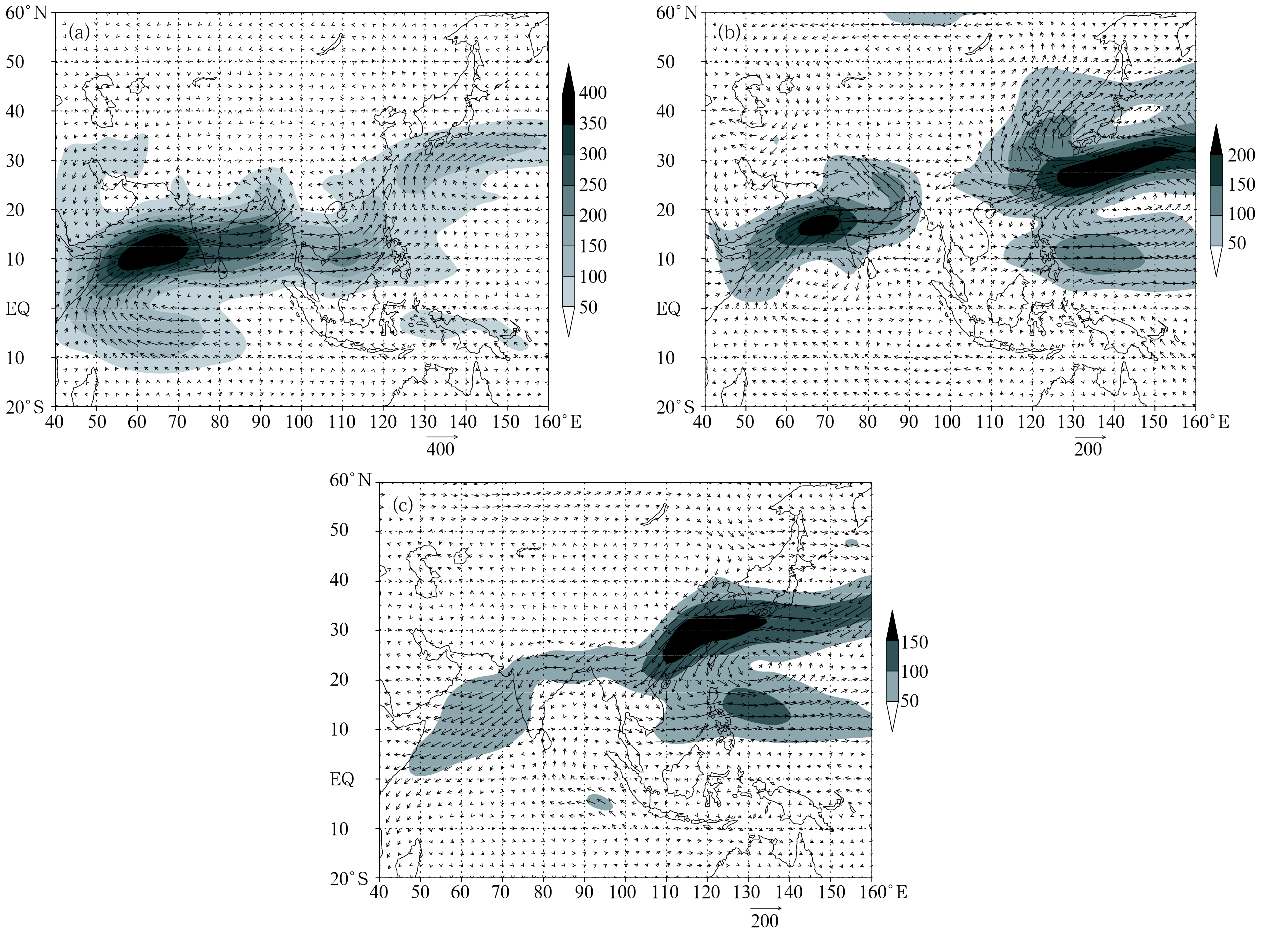


Fig. 3. Changes of the average monthly moisture flux (shadings; kg m^{-1} s^{-1}) over 1948–2005 for June minus May (a), July minus June (b), and August minus July (c).

over West Pacific. The southeast region of China, the northern part of the Indo-China Peninsula, Indian Peninsula, and the Arabian Sea are covered by anomalous northeast transfer from July to August, which means that the monsoon begins to weaken. In September, anomalous northerly transport over the east part of China, and anomalous easterly transport in the Indian monsoon region to South China Sea and the ocean east of the Philippines are evident, which is indicative of withdraw of the Asian summer monsoon from then on.

In order to understand the upriver moisture transport in different latitudes, the zonal transport across 90°E averaged for 40°–50°N, 20°–30°N, and 5°–15°N (which represent westerly transport of mid-high latitudes, subtropics, and tropics, respecitively) are computed. Among them, the mid-high latitude moisture transport is the weakest, while the tropics is the strongest. At 40°–50°N and 20°–30°N, moisture is transported by westerly winds all the year, while at 5°–15°N only for April to October. It is identified that the westerly transport in the tropics changes in phase with that of mid-high latitudes, with the latter amounts to 75 kg m^{-1} s^{-1} in July. The subtropical moisture supply in spring is around 100 kg m^{-1} s^{-1}, and starts to decrease to its minimum in August, and then increases through autumn and winter. The tropical moisture transport changes from westward to eastward in April, indicating the formation of the summer circulation pattern, and swiftly becomes powerful till July with a top value of about 350 kg m^{-1} s^{-1}. The reverse change occurs in October, and the strongest easterly transport begins in December, when the winter circulation pattern replaces that of summer.

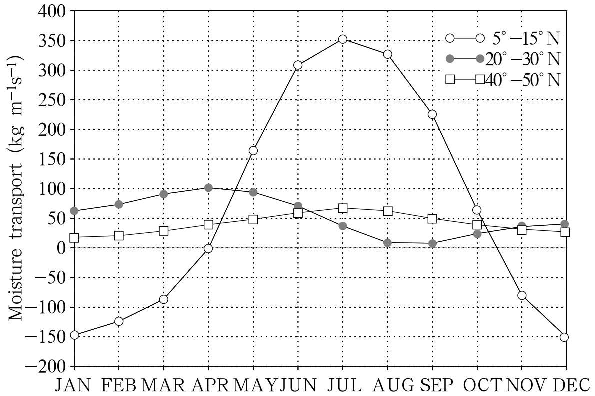


Fig. 4. Seasonal variations of zonal moisture flux (kg m^{-1} s^{-1}) across 90°E averaged over 40°–50°N, 20°–30°N, and 5°–15°N for 1948–2005.

According to the above discussion, before May the moisture in favor for rainfall in South China is generally provided by subtropical water vapor, while precipitation in the East Asian summer monsoon region is offered mostly by tropical westerly winds. The moisture from mid-high latitudes accounts approximately for 18% of the total.

4. Moisture transport and budget before and after the onset of the South China Sea summer monsoon

Lu and Gao (1983) found that moisture transport and circulation features are intimately linked to the march and withdrawal of monsoon. Fasullo and Webster (2003) defined a hydrology variable which described the onset and retreat of the Indian monsoon. To quantify the change in the vapor transport before and after the onset of the South China Sea summer monsoon (SCSSM), the period (1st pentad of April – 3rd pentad of May) prior to the onset and the period (5th pentad of May – 2nd pentad of July) are investigated. In Fig. 5, the moisture transport is overall weak except in the northern and southern fringes of the Pacific subtropical high, and southeastern China. It is shown that a westward transport over 20°–10°S exists and the transport across the equator is much scarce. After the onset, however, it is distinct that a moisture corridor of a planetary scale is established from the Southern Hemisphere across the equator to the Indian summer monsoon region and South China Sea. The most mighty transport appears over the Arabian Sea, Bay of Bengal, and South China Sea. All prove that moisture distribution undergoes a substantial variation during the monsoon onset.

Figure 6 displays the moisture budget. Before the monsoon onset, the budgets (Fig. 6a) in various areas are small, with the relatively large only in the northern brims of the Indo-China Peninsula and South China Sea, as well as in the east and west borders of southeastern China. The moisture in the South China Sea is on the whole from the West Pacific. In Fig. 6b, the stronger equator-crossing moisture is noticeable, especially in the southern edge of the Arabian Sea with the magnitude up to 256.9×10^6 kg s^{-1}, resulting in the largest moisture sink over there. The South China Sea changes from a moisture source to a sink with

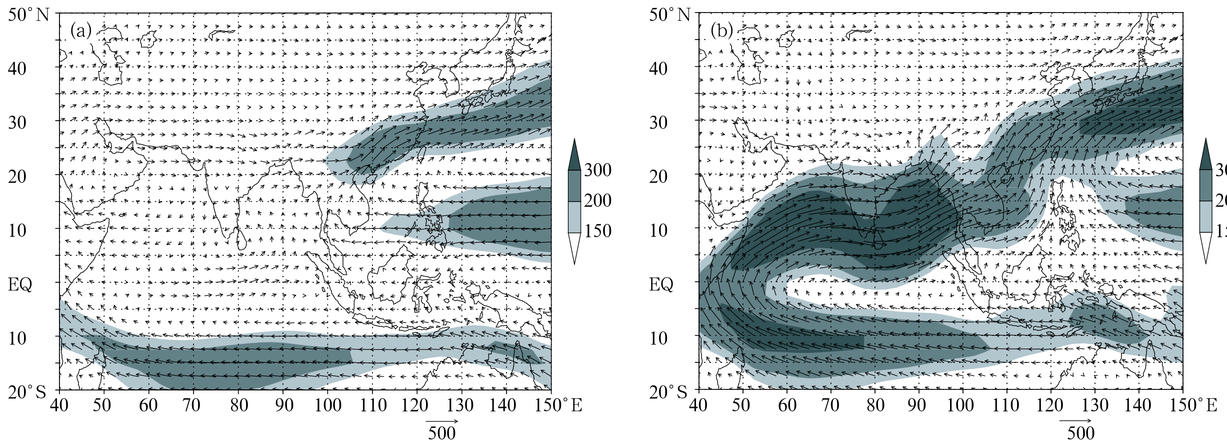


Fig. 5. Moisture transport (kg m^{-1} s^{-1}) over various monsoon areas averaged for 1948–2005. (a) Prior to the onset (1st pentad of April – 3rd pentad of May) and (b) after the onset (5th pentad of May – 2nd pentad of July) of the SCSSM.

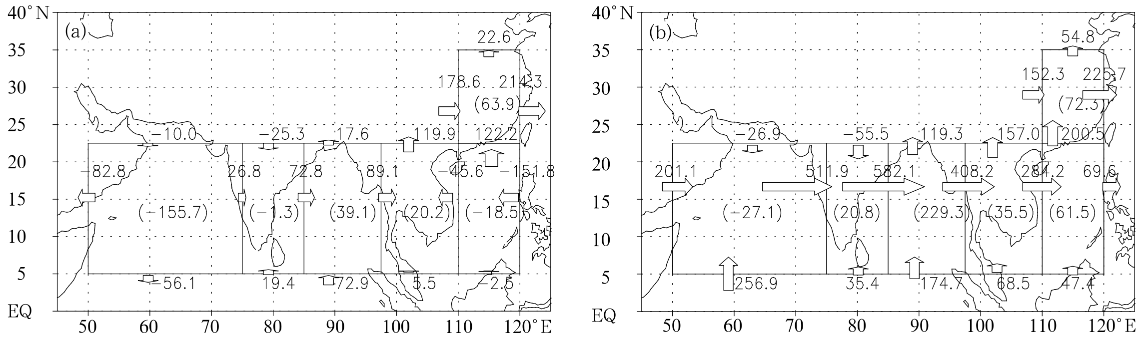


Fig. 6. Moisture budgets (10^6 kg s^{-1}) over various areas averaged for 1948–2005. (a) Prior to the onset (1st pentad of April – 3rd pentad of May) and (b) after the onset (5th pentad of May – 2nd pentad of July) of the SCSSM.

moisture coming from its western boundary. The moisture transport via the northern edges of the Bay of Bengal and South China Sea grow larger. The majority of moisture over the east part of China is from the South China Sea, and the minority is from the Indo-China Peninsula and Bay of Bengal. The vigorous eastward moisture transport within 5°–22.5°N obtains its top value over India and the Arabian Sea, exceeding 500×10^6 kg s^{-1}.

5. The relationship between moisture transport and precipitation over eastern China

5.1 The connection of progress of moisture transport and rainband in eastern China

With the onset of monsoon, the pattern of moisture transport alters totally, with its front edge coinciding with the progress of rainband. Figure 7 is pentad to pentad evolvement of moisture transport and rainfall averaged between 110° and 120°E during April-September for 1979–2004. From the second and last 10 days of April to the first and second 10 days of May, the largest moisture transport center at 25°N corresponds to the rainfall in the flood season of South China. The rainfall in South China goes up to its culmination in the middle of May after the onset of the SCSSM. Around the mid June, the curve marked 120 in Fig. 7a moves farther to 30°N and simultaneously the curve denoting a rainfall value of 8 mm day^{-1} extends to 30°N, which implies the commencement of Meiyu. The strong moisture transport moves forward to its northmost edge from the second and last 10 days of July to the beginning of August, and brings about the flood season in North China. After the first 10 days of August, the moisture transport and rainfall south of 35°N decrease sharply. In the beginning of

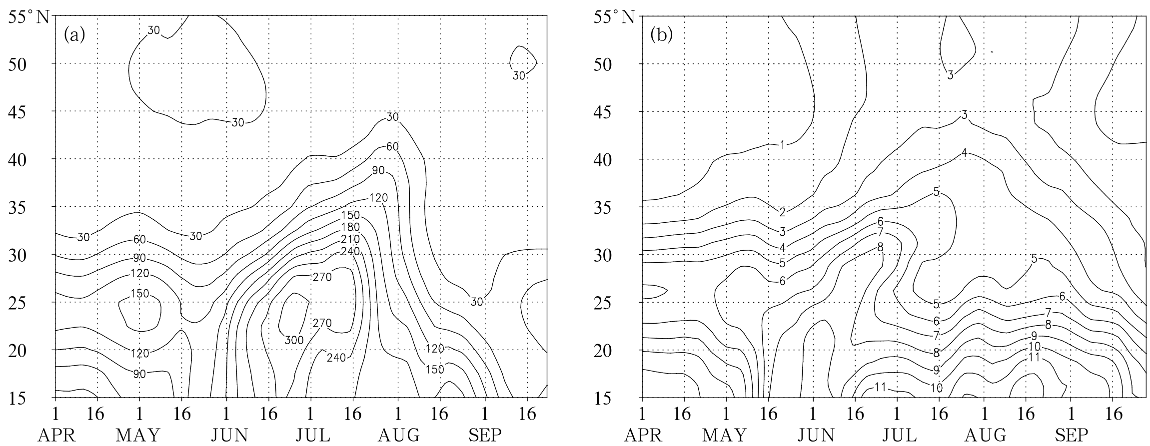


Fig. 7. The latitude-time (pentad) cross-sections of pentad mean (a) moisture transport (kg m^{-1} s^{-1}) and (b) precipitation rate (mm day^{-1}) averaged over 110°–120°E for 1979–2004.

September, the high-value centers of moisture transport and rainfall withdraw to the north part of South China Sea. It can be seen that from the monsoon onset to retreat, the march of moisture transport is in accordance with the migration pace of the Meiyu rainband.

5.2 Analysis of spatial-temporal features of moisture transport

To reveal the spatial and temporal structure of moisture transport, the Empirical Orthogonal Function (EOF) is applied to summer mean moisture transport over 1951–2005. The first (EOF1) and second (EOF2) EOF modes account for 17.6% and 10.6% of the total variance, respectively.

The first spatial pattern (Fig. 8a) portrays the most typical characteristic of moisture transport with uniformly positive (negative) departure located in the East Asian monsoon region. By looking at the time coefficients (Fig. 8b), it can be seen that more moisture from the Bay of Bengal, South China Sea, and western Pacific congregating in North China before 1974 is associated with strong monsoon years, and the opposite is true after 1974. The time coefficients manifest long periodic variations and exhibit a sudden jump in 1979 if examined by a running t-test, demonstrating that moisture transport shifts abruptly after 1979, namely, the northward moisture supply weakened remarkable by the end of 1970s.

Figure 9a shows the special pattern of EOF2. The

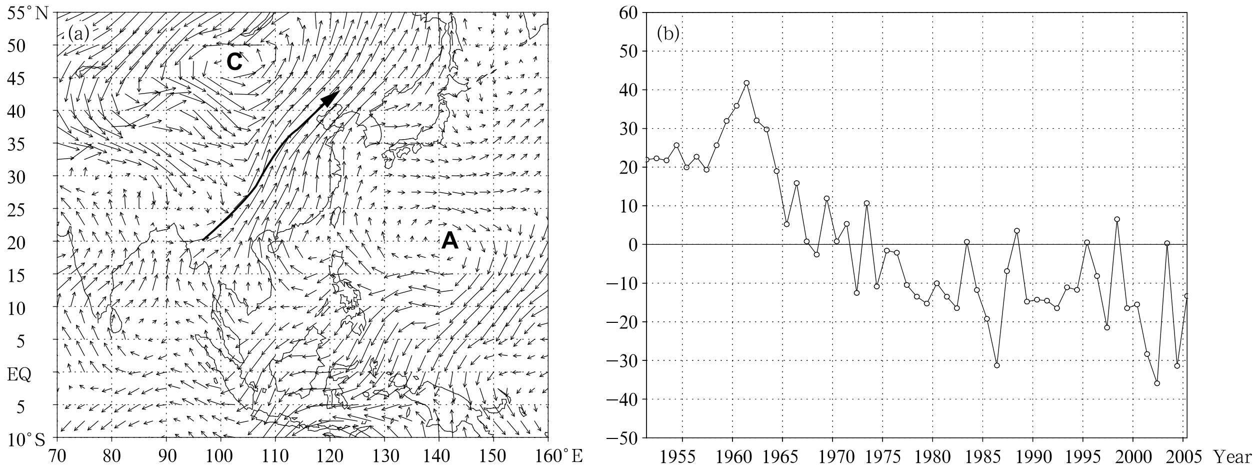


Fig. 8. The first EOF mode (EOF1) of the summer moisture transport field for 1951–2005. (a) Spatial pattern and (b) time coefficients.

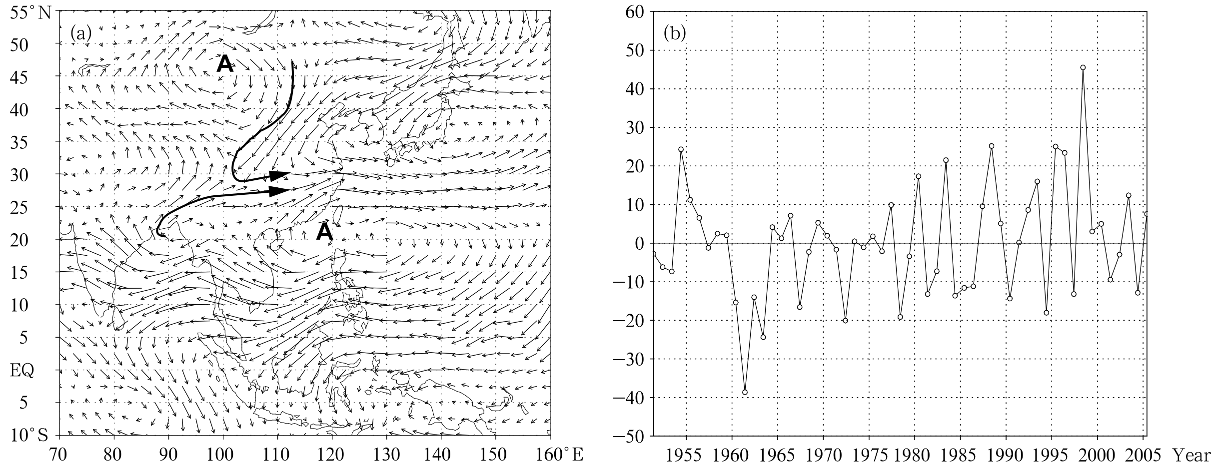


Fig. 9. As in Fig. 8, but for the EOF2 mode.

notable southwestward and northeastward transport departures lie on northern and southern sides of the Yangtze River during weak monsoon years. More than normal moisture is converged over Yangtze River basin when time coefficients of the year (Fig. 9b) are positive. The values of the curve in Fig. 9b are mostly positive after 1980, indicating that more moisture convergence occurs over the middle and lower reaches of Yangtze River then.

5.3 The relationship between moisture field and precipitation over eastern China

In order to figure out how the moisture transport exerts influences on precipitation over China, the two EOF modes of summer moisture transport are examined. The first mode in Fig. 10a illustrates a significant positive correlation area located in North China, suggesting a close relation between EOF1 and rainfall in North China. Sun and Ding (2002) demonstrated that the summer monsoon changed the large-scale moisture transport and its convergence, and further the distribution of the main rainbands. Figure 10b exhibits positive correlations over the 0.05 confidence level among the summer monsoon indices (Zhang et al., 2003), time coefficients of EOF1, and the rainfall anomalies in North China, and also a closer correlation on interannual than on interdecadal scale. The apparent decrease in mean values of the three series

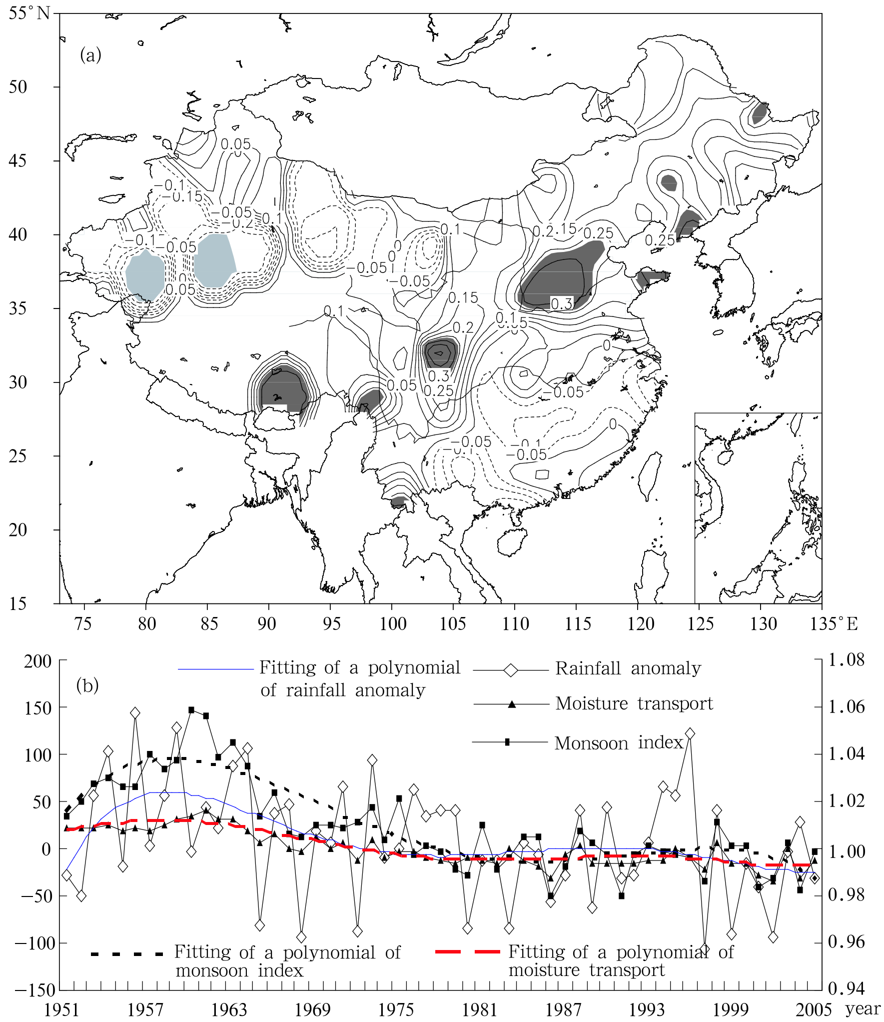


Fig. 10. (a) The correlation fields of EOF1 time series and summer rainfall (areas with confidence level over 0.05 are shaded). (b) The evolvement of the East Asian monsoon index (right: y-axis), EOF1 time series, and summer rainfall anomaly percentage in North China for 1951–2005.

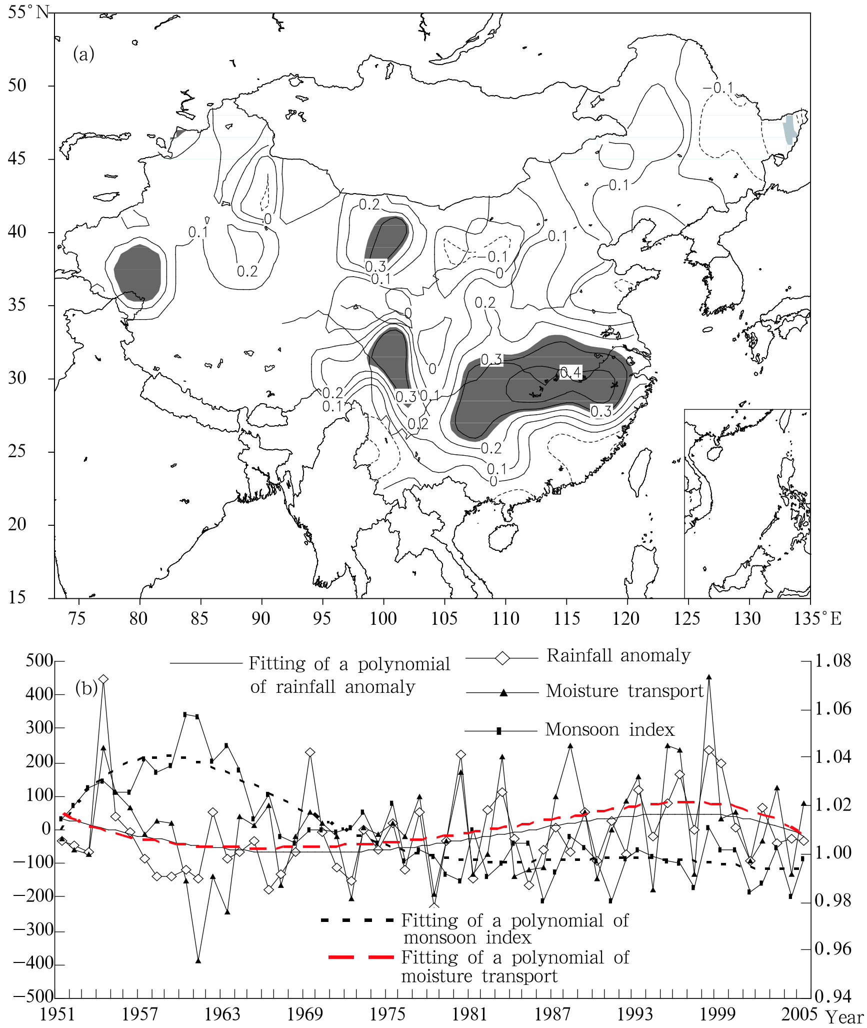


Fig. 11. As in Fig. 10, but for the EOF2 and the Yangtze River Valley.

appears around the end of the 1970s and manifests the weakening of northward moisture transport and the consequent reduction of rainfall in North China, which agrees with the previous study by Zhao et al. (2003).

Figure 11a shows the second EOF mode (EOF2). Significant correlation areas appear over the middle and lower Yangtze River valley. The correlation coefficient between the temporal coefficients of EOF2 and the anomalous precipitation over the middle and lower Yangtze River valley is up to 0.62 at the confidence level of 0.01 statistically. Several peak values in 1954, 1969, 1980, 1983, 1993, and 1998 denote flooding years, among which 1954 and 1998 are the most noticeable, and the pattern in 1998 with a maximum temporal coefficient resembles exactly the spatial structure of EOF2. The reason why the rainfall of 1998 is less than that of 1954 may be attributable to a number of factors. In 1954, there were 6 or 7 low pressure systems stepped eastward one after another from the eastern Tibetan Plateau into the Yangtze River, causing continuous heavy rain. While during 4–15 July 1998, the sub-tropical high jumped northward and led to an intermission of rain over the Yangtze River valley. In Fig. 11b, 1961, 1972, 1976, 1978, 1981, and 1994 are with the valley values and accompanied by dry years. From the 1980s, more than normal rain appeared over the Yangtze River valley, coincident with the station observations. Note that on the interannual scale, rainfall over the Yangtze River valley bears a significant positive correlation with the moisture transport. But on the interdecadal scale it shows a significant negative correlation at the 99% confidence level. A more complex relationship exists between the rainfall in the Yangtze River valley and the summer monsoon on the interannual than on the interdecadal scale. The fact that the heavy rainfall period replaced the less than normal period in the end of the 1970s is consistent with the previous study (Zhang et al., 2003).

It can be deduced that although the weakening of the summer monsoon on the interdecadal scale results in the change in distribution of moisture fields, followed by the decrease of rainfall in North China, more rainfall has dropped down the Yangtze River valley area, that is to say, monsoon exerts a key impact on rainfall, but it is not the only affecting factor.

6. Conclusions

The climatological features of moisture fields in the Asian summer monsoon region and the relationship between moisture transport associated with the Asian summer monsoon and rainfall over eastern China have been investigated based on the NCEP/NCAR reanalysis and station observations of rainfall. The main conclusions are as follows:

1) On global average, the tropical regions are characterized by easterly moisture transport, and the middle and high latitudes with westerly moisture transport. Contrarily, the Asian summer monsoon area north of the equator is featured with strong westerly transfer. As for the meridional transfer, the northward maximum moisture transport is located around the equator in the Asian summer monsoon region. The moisture gathering over the Asian summer monsoon region comes from the Atlantic, Pacific, and Indian Ocean via the summer monsoon circulation. The moisture from the last source plays the leading role, and the other two sources provide the southern Indian Ocean with moisture to strengthen the cross-equator water vapor flow collectively, thus result in a huge moisture sink in the Asian summer monsoon region, with two convergent centers above the East Asian and the Indian monsoon area.

2) Moisture transport is concentrated basically in the lower troposphere, and 70% of which under the 700-hPa level. The moisture sources change with the height in East Asia. In the middle and lower layers, moisture comes mainly from the Indian monsoon area, and in the upper layer primarily from middle Pacific and westerlies of mid-latitudes.

3) The period from May to July experiences the enhanced zonal moisture transport by the Indian monsoon. The meridional transfer by the East Asian summer monsoon intensifies during June and July. Both of them grow to the strongest in July, then start to withdraw from August, and eventually die away around September. Further analysis implies that the zonal moisture transport varies with latitudes, namely, the westerly flux is most significant in middle and high latitudes, and less significant is the subtropical area, which attains the maximum in Spring. The moisture transport in middle latitudes evolves in a manner that resembles tropics and reaches its peak in July. The latter accounts for about 80% of the total moisture across 90°E, while the former for about 18%.

4) The moisture transport varies significantly after the onset of monsoon. With the buildup of the water vapor corridor, the abundant moisture is brought into the Asian summer monsoon region and converged over there, especially in the Bay of Bengal, Indo-China Peninsula, and South China Sea. The majority of moisture inflow to China mainland comes through the northern boundary of the South China Sea.

5) The northward progress of the rainbands over eastern China synchronizes with the northward march of moisture transfer. The spacial-temporal analysis demonstrates that before the end of the 1970s northward moisture transport anomalies are found over most areas of North China, so is the increase of rainfall, and thereafter both are reduced distinctly. The analysis indicates that the weakening of the East Asian summer monsoon on the interdecadal scale is responsible for the decrease of the moisture to be delivered to North China and consequently the reduction of rainfall there. The EOF2 analysis typically reflects positive departure of precipitation over the Yangtze River valley with characteristics of two anomalous moisture flows from northeast and southwest joining together in the years of more than normal rainfall, and vice versa. The tops and valleys in the moisture transfer time series are well corresponding with those of rainfall. From the 1980s, the time coefficients keep at a higher mean value, in accordance with the observations of increased rainfall. The correlation analysis shows that on the interdecadal scale the contribution of the East Asian

summer monsoon is more significant for the evolvement of the precipitation over the above areas of China.

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