Possible Influences of ITCZ in Asian Monsoon Regions on Rainy Season Anomaly of North China

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ABSTRACT

Vast convective activities over tropical zones are analyzed for both wet and dry summers in North China. An ITCZ synthesis index is designed using OLR data. The index can demonstrate quite clearly and objectively the seasonal features of deep convection in Asia monsoon areas. The differences of ITCZ activities in Indian as well as East Asian monsoon regions in winter–spring period are significant and so is the time–lagged correlation, which would be able to provide a new way to the long–lead prediction of summer rain in North China. The propagation characters of low frequency fluctuation are also different between wet and dry years. The intensity of low frequency fluctuation is stronger and the area is larger in wet years than that in dry years in both hemispheres. The fluctuation moves from south to north successively in wet years, which may lead to the leap of the subtropical high northwards, while it remains quasi–stationary in the Southern Hemisphere or the equatorial zone in dry years.

Key words: Drought / rainy summer in North China, OLR, ITCZ, Low frequency fluctuation

1. Introduction

Studies on precipitation anomalies of North China have been mainly focused on SST or ENSO or atmospheric circulation in recent years. Li et al. (1990) analyzed the relationships between summer rain of North China and circulation patterns. Ling and Yu (1993), Zhao (1995) studied the impact of El Niño on the precipitation of North China. Zhu and Zhang (1997) displayed the atmospheric anomaly patterns prior to rainy / dry summer. In recent years some authors discovered that the deep convective activities in the tropical region might as well have some influence on summer precipitation in the lower reaches of the Yangtse River. Huang and Sun (1994), Ye et al.(1996) pointed out that when warm phase appears in the western tropical Pacific, convection around the Philippines develops strongly, which leads to the western Pacific subtropical high moves further north with less rainfall in the Yangtes River and Huaihe River valley. Those studies give us a hint that possible connections are likely to exist between tropical convective activities and rainfall in North China. Though geographically located in middle latitudes, North China's rainy season (JJA) is generally dominated by summer monsoon which comes from low latitudes and can be identified to some extent by deep convection. In addition, Huang and Sun (1994) demonstrated the simultaneous relations between convective activities and precipitation, while this study tried to put

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emphasis on the possible time–lagged relations or the relations between summer rainfall and the prior tropical convection generally in winter–spring and especially in the Asian monsoon areas. Thus the result might be helpful for the long–lead forecast of rainy season in North China.

2. Data

OLR data used here are gained from NCEP with a 2.5°×2.5° grid, a range 30°N–30°S, 0°E–2.5°W and time series from 1975 to 1997 (without 1978). Monthly precipitation data are collected from 17 gauge stations including metropolitan cities of Beijing, Tianjin, and cities in Hebei, He'nan, Shanxi, Shandong Provinces, which are geographically located in the area of 112°–122°E, 35°–42°N. These 17 stations, defined by the executive expert group of the project Short–Range Climatic Prediction System of China (1997), can represent main characteristics of climatic conditions in North China. Time series of those data is also from 1975 to 1997.

3. Definition of ITCZ index

According to the conception of ITCZ by means of OLR given by Jiang (1990) the synthetic index has the form

$$I=(N+20)/L\times 100\ , \tag{1}$$

where I is the index, N stands for the geographical location of minimum OLR (typically from 20 to −20) and L represents the value of minimum OLR (generally from 180 to 240). It can be seen from Equation (1) obviously that if the minimum OLR appears at 20°S ($N=-20$), the index would be zero. So the index should be available only in the Northern Hemisphere.

At first we examine the seasonal variation of the index as shown in Fig. 1. The changes of the indexes are relatively smooth in winter with values between 12 and 18. An abrupt rise of

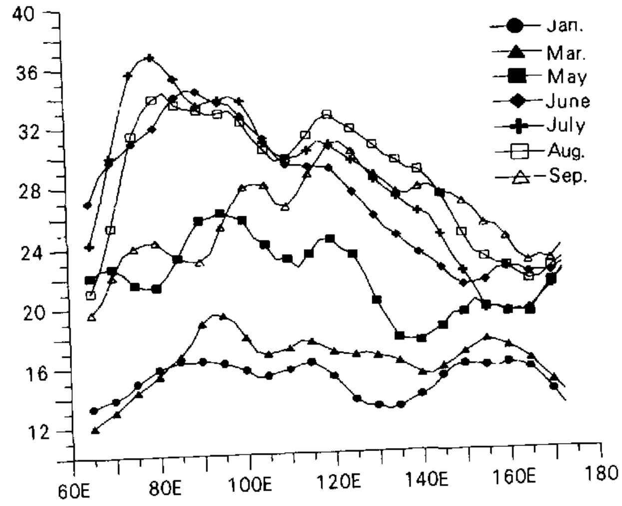

Fig. 1. Seasonal changes of ITCZ index (5 points running).

ITCZ index occurs in May especially around 90°–100°E which seems to demonstrate the breaking out of monsoon in the South China Sea. A sub–peak can be seen near 120°E which is possibly associated with the convective activities in the East Asian monsoon area. The highest point in June at 90°E is evidently the sign of Indian monsoon activity. In July the index is going further higher and achieves its highest point in an annual cycle around 80°E, and the second highest place is near 120°E reflecting the deep convection of East Asian monsoon. Deep convection of Indian monsoon begins to decline in Aug. while it is still developing further in East Asia, which confirms the point that the strongest amplitude of deep convection appears about a month earlier in Indian monsoon than in East Asian monsoon regions. The indexes start to decrease generally in Sept. It can be also seen from Fig. 1 that the indexes remain relatively lower throughout the annual cycle around 110°E which would be able to be recognized as the boundary of Indian monsoon and East Asian monsoon.

Combining the OLR minimum and its location the ITCZ index seems to be able to reflect the composite effect. But which is the dominant? Table 1 shows that the index is more sensitive to the location, so it is more likely to be used to describe the location of ITCZ.

Table 1. Average ITCZ index, OLR minimum and its location in Jan. and Jul.

Jan.								
Longitude (°E)	60	70	80	90	100	110	120	130
ITCZ index	4.39	4.48	6.80	6.88	7.53	7.62	7.59	4.92
OLR minimum	228	223	221	218	199	197	198	203
Minimum location	10S	10S	5S	5S	5S	5S	5S	10S
Jul.								
Longitude (°E)	60	70	80	90	100	110	120	130
ITCZ index	8.64	13.74	20.61	17.77	17.40	11.28	14.77	14.22
OLR minimum	231	218	194	197	201	222	203	211
Minimum location	0	10N	20N	15N	15N	5N	10N	10N

4. Characters of ITCZ in dry and wet years

Wet or dry summers are classified by the mean rain anomaly percentage. The wet year occupies a positive anomaly greater than 25%, while the dry year has a negative anomaly less than −25%. In this way the summers of 1976, 1978, 1990, 1994, 1996 (1978 is omitted for no corresponding OLR data) are considered wet ones or stronger rainy seasons and the summers of 1980, 1983, 1986, 1991, 1992, 1997 are regarded as dry summers or weaker rainy seasons. Considering the general differences between wet and dry years we define average anomaly percentage of ITCZ index of wet years as

$$\Delta \bar{I}_w = (\bar{I}_w - \bar{I}) / \bar{I} \times 100 \ ,$$

in which $\bar{I}_w = \frac{1}{5}\sum_{n=1}^{5} I_n$ stands for the average ITCZ index of 5 wet years for a certain month eg. Jan., $\bar{I}_w = \frac{1}{22}\sum_{i=1}^{22} I_i$ represents the average ITCZ index of 22 years for the corresponding month. In the same way we have the average anomaly percentage of ITCZ index of dry years:

$$\Delta \bar{I}_d = (\bar{I}_d - \bar{I}) / \bar{I} \times 100 \ ,$$

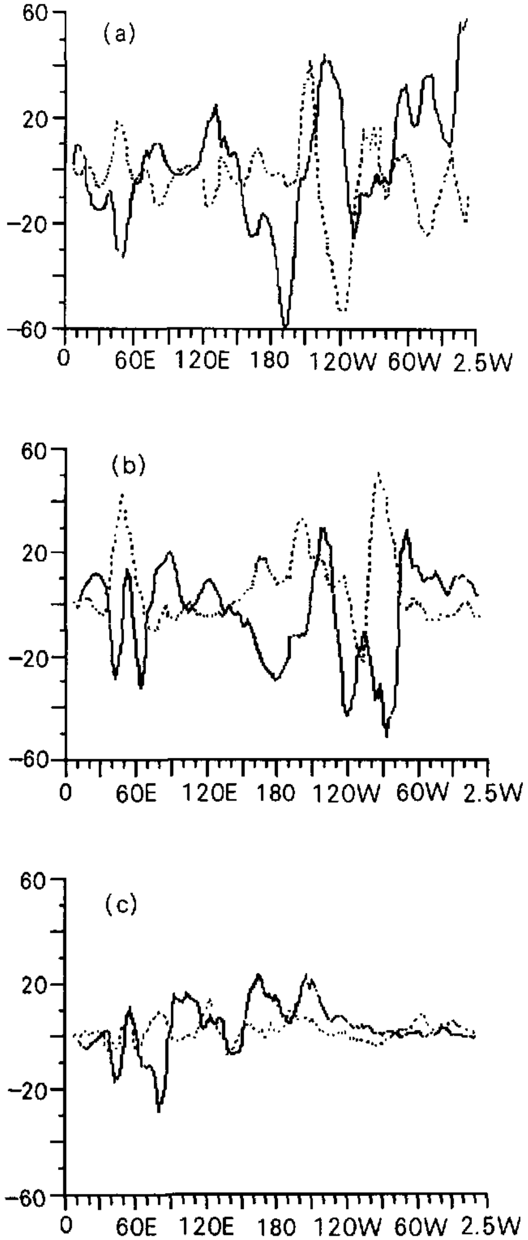

Fig. 2. Mean ITCZ index anomaly percentage of wet and dry years (5 points running). Heavier rainy seasons—, weaker rainy seasons ···, (a) Jan., (b) Mar., (c) May.

where $\bar{I}_d = \frac{1}{6}\sum_{m=1}^{6} I_m$ is the average ITCZ index of 6 dry years for a certain month. The average anomaly percentages for wet and dry years in Jan., Mar., May are displayed in Fig. 2 respectively. The first signs of the differences are already evident in Jan.–Mar. period around 90°E and 120°E respectively. The behavior of ITCZ in the central tropical Pacific is just opposite to that in the western Pacific area and the index anomalies are negative in wet years and positive in dry years. It is likely to be produced that the deep convective activities, instead of their original location over the western Pacific, appear eastward (near 180°E) in advance of a dry summer. That is the similar signal to an El Niño event (Ye et al. 1996). The peak value of the index anomaly is at 107.5°E in May ahead of wet summers, which should reflect stronger convection in the South China Sea.

5. Correlation between ITCZ index and summer rainfall in North China

As for the general time–lagged relations we calculate the correlative coefficients between convection and rainfall as follows:

$$C_l = \frac{\sum\limits_{m=1}^{22}(R_m - \bar{R})(I_{lm} - \bar{I}_l)}{[\sum\limits_{m=1}^{22}(R_m - \bar{R})^2 \cdot \sum\limits_{m=1}^{22}(I_{lm} - \bar{I}_l)^2]^{1/2}},$$

where C_l is the correlative coefficients between monthly ITCZ indexes (from Jan. to Aug.) at the longitudel and the average summer rainfall (JJA) of the 17 gauge stations in a certain month $\bar{R} = \frac{1}{17\times 22}\sum\limits_{m=1}^{22}\sum\limits_{i=1}^{17} R_{im}$ is the total average summer rainfall of the 17 gauge stations of 22 years, R_{im} is the average summer rainfall at one gauge station in year m; $\bar{I}_l = \frac{1}{22}\sum\limits_{m=1}^{22} I_m$ is the mean ITCZ index of 22 years in a certain month at a given longitude l,I_{lm} is the ITCZ index of year m in the corresponding month at longitude l,l is the longitude, e.g. 60.0, 62.5, 65.0, ……, 180.0°E, $i = 1,17$, $m = 1,22$. It is evident that C_l has different values at different longitude in different month. Time series used here is altogether 22 years from 1975–1997 (without 1978), and the results are shown in Fig. 3.

Two visible positive correlative regions can be discerned ($\alpha \leqslant 0.1$) in the Indian and East Asian monsoon areas (90°–100°E and 110°–120°E). Generally speaking, the remarkable period can be seen from Jan. to May. But if we go through carefully, we can find that the significant correlation appears about one month earlier in the Indian monsoon area than in the East Asian monsoon area. For example, the sign of $\alpha < 0.1$ emerges in February around 95°E, and then in March it can be seen about 115°E. But the most remarkable area is in the East Asian monsoon area from late March to April. This fact could undoubtedly come as a light of long–lead forecast of summer rain in North China.

It may be noticed from Fig. 3 that the simultaneous relations of precipitation and the indexes in summer (JJA) are not as significant as that of time–lagged, and negative relations occasionally even occur. This might be connected with the regular annual circle of ITCZ. According to the definition of ITCZ index in this study the convective activities only refer to those occurring within the tropical zone of 20°S–20°N. It is a well known fact that the convection in this region is active in winter–spring. In summer on the one hand the deep convection mainly appears further north and the average location of ITCZ axes is close to or north of

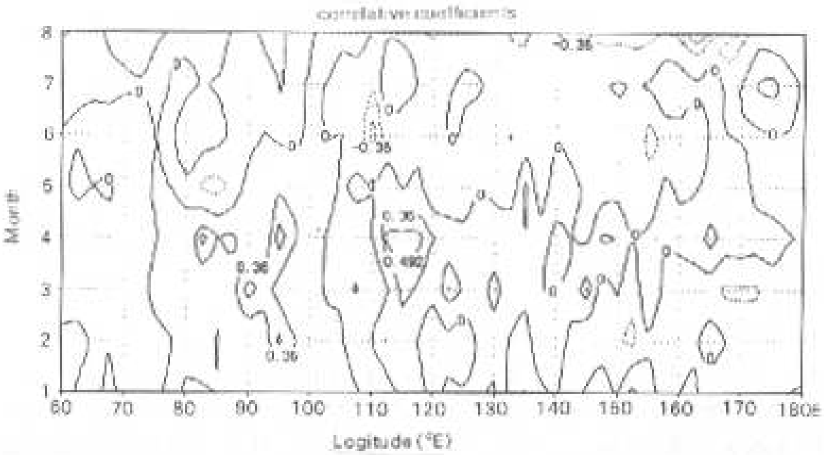

Fig. 3. Time–longitude distribution of the correlative coefficients between ITCZ indexes and summer rainfall in North China.

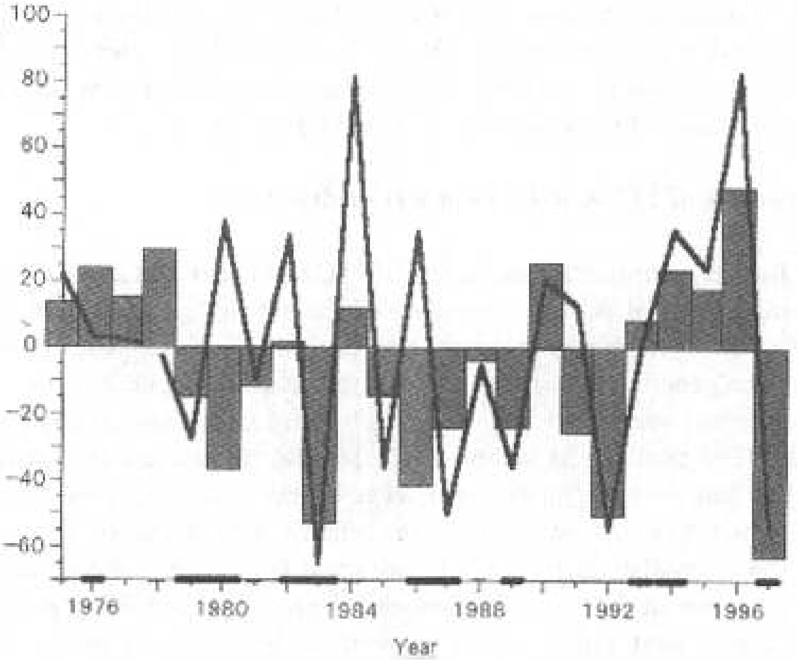

Fig. 4. Annual (1975–1997) normalized summer rainfall in North China and ITCZ indexes averaged over 80°–100°E from Feb. to Apr., Shaded area: rainfall, solid line: ITCZ index, Short thick bar: El Niño year, short thin bar: La Niña year.

20°N in the Asian monsoon area (Ding, 1991). On the other hand strong cross–equatorial flow in the Asian monsoon area might be likely to cause the generation of equatorial high. So the simultaneous relations between the index and precipitation is weaker than the time–lagged one or just the opposite some time. Zhu and Zhang (1997) found the PNA anomaly of circulation in Apr. prior to wet / dry summers of North China. This PNA pattern at 500 hPa means the energy transmission of Rossby waves along a large circle path (Hoskins, 1981). So the high time–lagged correlation between tropical convection and summer rain should be connected with the frequency dissipation of Rossby waves which no doubt needs time.

In order to study the relations further we look into them year by year. The variation trends of normalized summer precipitation in North China and average ITCZ indexes from Feb. to Apr. in the Indian monsoon area are generally consistent as shown in Fig. 4. Out of 22 years 19 years have identical symbols, i.e. 19 / 22 ≈ 0.86. The variations not only have a similar trend in terms of symbols (either positive or negative) but also have the tendency in proportion to the values. This result further testifies the relations between the two aspects.

Huang and Sun (1994) pointed out that in an El Niño year there is a general weakening of convection around the Philippines and a prevailing strengthening of convection near the dateline and dry summer often occurs in North China. While in a La Niña year convective activities seem to become stronger over the warm pool and North China might possibly has more rain than usual. Our work produces the similar condition not simultaneous but asynchronous. The time interval between these successive events make it practicable to make the long–lead forecast of summer rain in the light of OLR data. Compared with El Niño events North China's summer rain appears to be more coincident with the anomaly of ITCZ index in the Indian monsoon regions as depicted in Fig. 4. As far as the long–lead forecast is concerned it is more practicable and more feasible to use OLR than to discriminate whether there is an El Niño or not at the time or in the near future because the El Niño itself is hard to identify in time. Furthermore we think OLR, as the result of the interaction between atmosphere and oceans, should be able to include more information than the sea surface temperature does and have more influences on seasonal climate changes.

6. Pentad characters of ITCZ indexes in wet or dry years

In order to further examine the characters of ITCZ between wet and dry summers we produce accumulating curves of pentad anomalies of the indexes in the Indian (80°–100°E) and East Asian (100°–120°E) monsoon areas respectively for typical wet year of 1990 and dry year of 1983 (Fig. 5). The general tendency of the wet year is rising while it is just the opposite for the dry year. In the wet year from 1 to 27 pentads there were three ascending episodes. The first one started in 1–2 pentad, the second in 15–16, and the last in 24–25 pentads. It is obvious that the wet summer was significantly marked by the successive rising of 6 pentads from March to April, which was corresponding to the remarkable correlation shown in Fig. 3. During this period the anomalies in the Indian monsoon area appeared one pentad earlier and were stronger than those in the East Asian monsoon area. The last rising period was the most abrupt one which was inextricably bound up with the breaking out of the South China Sea monsoon and was about 10 days earlier than the average starting date of the monsoon (Chen et al. 1991). During this period and from then on the anomalies in the East Asian monsoon area came to be more remarkable than those in the Indian monsoon region. It should be pointed out that the increase episode in early spring was accompanied by an obvious positive anomaly of v–component of wind crossing the equator at 850 hPa from Feb. to Mar. (figure omitted). This cross–equatorial flow seems to have some relations with the stirring of the ITCZ anomalies. From the above analysis it is quite clear that in the wet year ITCZ came tobe more active than usual, and the positive anomaly emerged from the very beginning; the tendency curve kept rising continuously during mid–Feb. to mid–Mar., increased sharply in the first half of May and lasted till mid–summer.

While in the dry year the variation trend of accumulating pentad indexes is just the other way round compared with that in the wet year. It can be seen from Fig. 5 that the curve seldom rose until July in both Indian and East Asian monsoon area, and the former declined

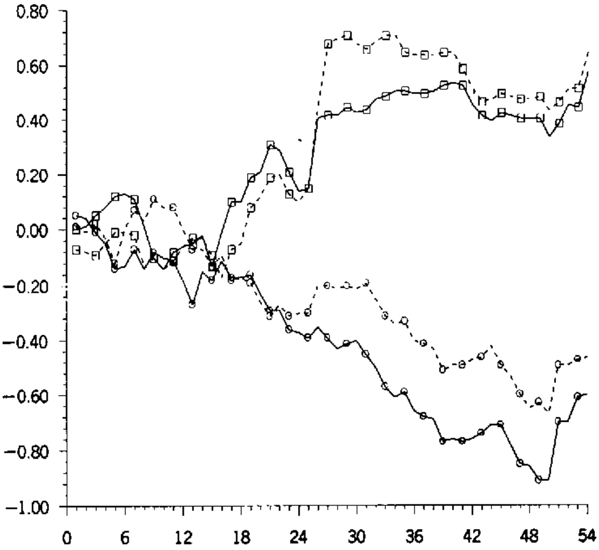

Fig. 5. Accumulating curves of pentad ITCZ index anomalies in typical wet and dry year. ○: 1983, □: 1990, solid line: Indian monsoon area, dashed line: East Asian monsoon area.

more sharply. There was almost no evidence for the onset of South China Sea monsoon. Furthermore the first significant difference between the dry and wet year occurred about 15 pentad, which, needless to say, hinted the anomaly of the following rainy season.

7. Characters of low frequency oscillation in wet and dry years

As pointed out previously, the summer rain in North China seems closely related to the convective activities in tropical regions. What is the possible link between them? Kawahara (1987) showed that the inter–annual and intra–seasonal variability of convective activities are more remarkable around the Philippines and Kurihara (1989) pointed out that the standard deviation of OLR is greater from the eastern Indian Ocean, South China Sea to the east of the Philippines. So our work focuses on the convection of these areas. Pentad data are used to produce the low frequent oscillation of OLR according to the method given by Nitta (1987):

$$c'_i = \bar{c}'_i + c'^{*}_i \ ,$$

where c_i is mean OLR at the pentad i, c'_i is the pentad anomaly which has been filtered the seasonal trend and annual circle and so stands for the sum of inter–annual and intra–seasonal variations, and $\bar{c}'_i$ is the summer mean value of c'_i (or any other seasons) representing inter–annual component for it has different value in different summer. Therefore intra–seasonal variation can be worked out from the difference between non–seasonal and inter–annual components:

$$c'^{*}_i = c'_i - \bar{c}'_i \ ,$$

in which c'^{*}_i is the intra–seasonal variation (ISV) of OLR.

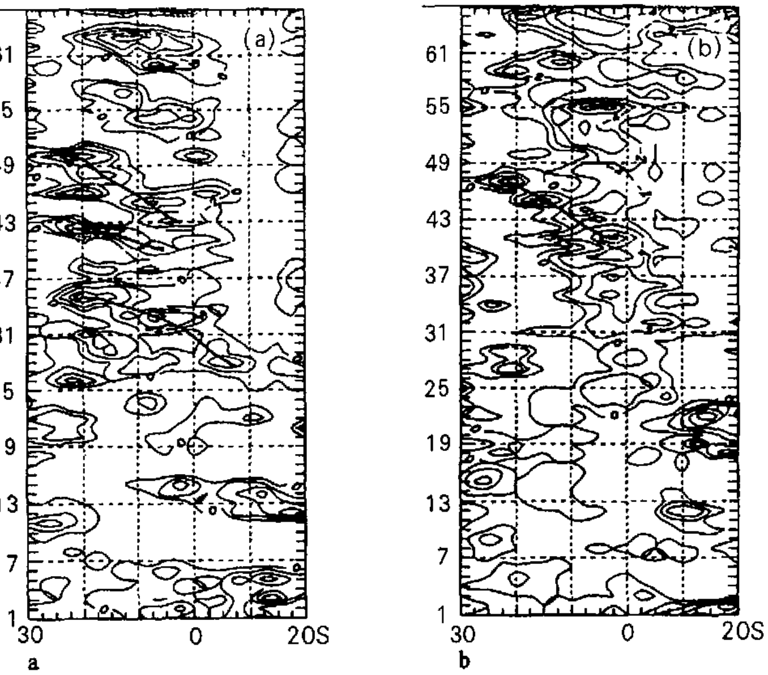

Fig. 6. ISV of OLR time–latitude profile along 120°E (30°N–20°S).(a) 1990, (b) 1983. Contour intervals: 2 W m^{-2}.

Figure 6 gives the ISV along 120°E from 30°N to 20°S in 1990 and 1983. There were two low frequent oscillation processes with periods of about 50 days from Jan. to Apr. in both hemispheres ahead of wet summer. Deep convection in the Southern Hemisphere occurred in 1–5 and 11–15 pentads respectively and transmitted northwards, while in the Northern Hemisphere deep convection appeared 5–8 pentads time lagged and with smaller space scale and less intensity. Comparing Fig. 5 and Fig. 6, it is quite obvious that the deep convection in the Southern Hemisphere in 11–15 pentads might lead to the positive anomalies of ITCZ indexes starting at 15 pentad in Asian monsoon areas. The second pentad of May started with a tendency of linking the two hemispheres' convection together. From the beginning of May to the first pentad of Sept. there were three processes of ISV propagating from south to north (arrows in the figure), which might be the cause of stirring East Asian monsoon occurrence and its moving northwards. On the contrary, before dry summer from Jan. to Apr. deep convection remained basically in the Southern Hemisphere, and from May to the end of Aug. there was only one process that the convection transmitted northwards from the equatorial zone (39–48 pentads).

A comparison analysis shows that the location of the subtropical high seems to have a consequent response to the transmission of low frequency oscillation. In 1990 the north boundary of the high jumped 8 latitudes from May to June while in 1983 it covered only 2 latitudes in the same period, and the average one is 5 latitudes. It is a well known fact that the location of subtropical high of the western Pacific dominates the rainfall in North China to a great extent, thus the propagation of ISV may play a linking role between the convective activities in tropical regions and summer rainfall in North China. This finding confirms the opinion given by Lau and Peng (1987) and Chen (1991).

8. Conclusions

The ITCZ index combining the intensity and location of ITCZ seems to hold a kind of capability to reflect objectively the annual circle of ITCZ. So it is reasonable to use the index to show the activities of Asian monsoon which might be associated with rainy season of North China.

The differences of ITCZ indexes between average wet and dry summers are visible in the early springs especially in Asian monsoon areas. The time–lagged correlation further demonstrates that the key period is from Feb. to Apr.. The time series curves of ITCZ index in the Indian monsoon area in winter–spring period and summer rain in North China show a rather coincident tendency. Rossby wave energy transmission might be connected with the correlation between tropical convection and North China's summer rain though the latter's geographical location is in middle latitudes. All those findings are no doubt of long–lead forecast meaning for summer rain in North China.

Pentad data analysis gives us a further detail image: before the wet summer positive anomalies of ITCZ indexes appear continuously during winter–spring, which might be possibly connected with the cross–equatorial flow and are triggered by the intra–seasonal variations coming from the Southern Hemisphere. And under such circumstances the onset of South China Sea monsoon is likely to be earlier and stronger than usual. The location of the subtropical high which strongly influences the summer rain in North China may respond to the constant propagation of low frequency oscillation and leap further north. So the North China's rainy season may be traced to the Southern Hemisphere, and the low frequency oscillation may play a part in linking ITCZ and precipitation. In the matter of dry summer those conditions are almost the other way round.

Both ITCZ and ISV are important components of tropical atmospheric circulation, and there are complex inner connections between them. The study of typical year shows that from May almost each time the low frequency oscillation comes into an active phase, the ITCZ is going to strengthen.

But the interactions between ITCZ and low frequency oscillation and their possible impacts on summer monsoon in Pan–Asian regions and then the effect on the subtropical high as well as the rainy season of North China are very complex. The low frequency oscillations might play key roles in the energy accumulation and operate triggering function for the onset of Asian summer monsoon, which are beyond the range of this work and should be further studied.

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亚洲季风区 ITCZ 对华北雨季异常的可能影响

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摘　要

分析了冬、春季亚洲季风区 ITCZ 活动对华北夏季降水的影响．用 OLR 资料定义了 ITCZ 综合指数，分析表明该指数能比较清晰、客观地综合反映出亚洲季风区深对流活动的强度和位置．用该指数分析了华北多雨年和少雨年前期热带大范围对流活动的变化特征．印度和东亚季风区的 ITCZ 活动在多雨和少雨年显示出明显不同．华北夏季降水与 2–4 月 ITCZ 综合指数的时滞相关性最明显．这种时滞相关可能与球面 Rossby 波的频散相联系，并可以为华北夏季降水的长期预报提供新的参考依据．低频振荡分析表明，多雨年南北两个半球的低频振荡强度较强，范围较大，并不断由南向北传播，这种传播很可能与副热带高压的北跳有关．而少雨年低频振荡在南半球或热带地区呈准静止状态。

关键词：华北雨季，OLR，ITCZ，低频振荡