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INFLUENCE OF SEA–AIR INTERACTION ON THE DISCHARGE OF FLOOD SEASON IN THE UPPER REACHES OF THE CHANGJIANG RIVER

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ABSTRACT: On the method of correlation analysis the paper begins with searching the SST (Sea Surface Temperature) and circulation features of some regions with close correlation to the discharge of the flood season (from June to September) in the upper reaches of the Changjiang (Yangtze) River, then discusses the characteristics of sea–air interaction and the relations between the sea–air interaction and the discharge of the flood season, after that analyzes the possible mechanisms through which the main sea regions affect atmospheric circulation, and of the influence of the circulation changes on the discharge of the flood season.

KEY WORDS: upper reaches of the Changjiang River, discharge of flood season, atmospheric circulation, sea–air interaction

I. CORRELATION BETWEEN THE DISCHARGE OF FLOOD SEASON IN YICHANG STATION AND SST OF THREE OCEANS

The discharge from June to September in Yichang Station of the upper reaches of the Changjiang River can basically reflect the plenty or deficiency of the flood season in that region. The relative anomaly percents of discharge (QY) from June to September in Yichang Station are used to indicate the degree of the plentiful or deficient discharge in the upper reaches of the Changjiang River. The analyzing results are shown in Fig.1.

The four years that have the maximum values are chosen as the plentiful years: they are 39.2%(1954), 13.7%(1965), 17.1%(1968), and 19.3%(1974) more than the average year respectively. The four years that have the minimum values are chosen as the deficient years: they are 20%(1959), 19.4%(1969), 18.3%(1971) and 25.1%(1972) less than the average year respectively.

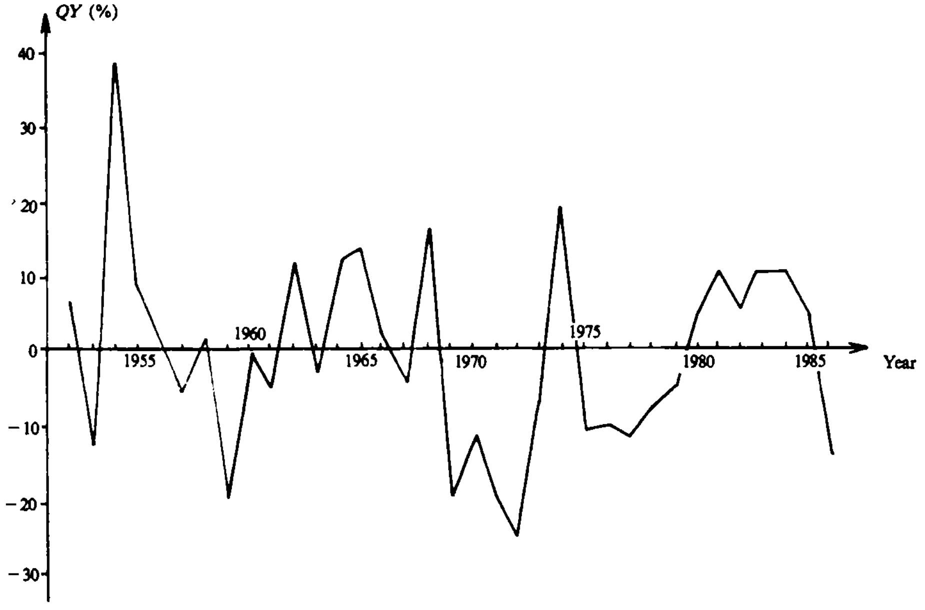

Fig.1 Annual change of the relative anomaly percents of discharge (QY) from June to September in Yichang Station

SST data were taken from the North Atlantic Ocean (from January 1951 to December, 1980), the North Pacific Ocean (from January 1951 to December 1986) and the Indian Ocean (from January 1964 to December 1977).

The range of 500 hPa altitude data included $5° \times 10°$ latitude–longitude grids of the whole Northern Hemisphere, and the period was from January 1951 to December 1986.

The results of correlation analysis show that there are good correlations between QY and SST of the stage of the main current regions over the North Atlantic Ocean, the North Pacific Ocean and the Indian Ocean. From January of the year to May of the second year, the position of the main correlation centers which come up to the marked level are less moveable, and there are more times of emerging. All of that illustrate that the current regions over oceans are the important regions which influence the plentiful or deficient discharge of the flood season in the upper reaches of the Changjiang River to a certain extent.

Fig.2 displays the correlation field of the different time lags between QY and SST of the three oceans. Considering the greater heat inertia of oceans, the SST data were calculated by the average of the continuous two months. In the figure, January represents the average of January and February, and March represents the average of March and April.

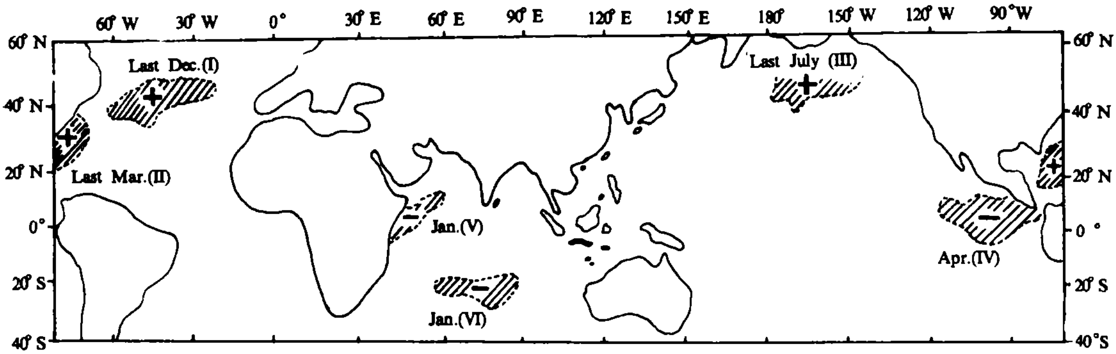

Fig.2 Correlation field of different time lags between QY and SST of the three oceans (The confidence limits of the shaded parts exceed 0.05)

The analyzing results indicate that:

(1) Starting from January of the last year there were the marked correlations between QY and SST of the west wind drift region (region I) and of the Gulf Stream region (region II) over the North Atlantic Ocean, and then the correlations of the two regions were enhanced continuously. The high correlation region in the Gulf Stream began to shrink from May, and at last disappeared. However the high correlation range of region I continuously expanded and strengthened, and became the strongest in November. The correlation between QY and SST of region I began to weaken slowly from January of the second year.

(2) Over the North Pacific Ocean, high correlation center mainly appeared in the west wind drift region (region III) from January to September of last year. Although the correlation regions of achieving the marked level also appeared in the other sea regions, their stabilities were poor. The high correlation center began to be strengthened, and the range expanded in the east parts of the equatorial Pacific Ocean (region IV) from January to May of the second year.

(3) Over the Indian Ocean, the stable and motionless negative correlated regions appeared in the east coast of Africa (region V) and the subtropical sea region of the south Indian Ocean (region VI) from January of the second year and the November of the last year respectively.

The influence of the earlier stage SST of the every main sea region on QY is different. Here the range of 35 ° N–45 ° N, 30 ° W–45 ° W represents region I; that of 5 ° S–5 ° N, 80 ° W–95 ° W does region IV; that of 5 ° S–5 ° N, 45 ° E–50 ° E does region V and that of 20 ° S–30 ° S, 55 ° E–65 ° E does region VI. There are the longer durations of correlations in the four sea regions which have good indicative significance. Fig.3 gives the correlations between QY and SST of the earlier stage (from December to June) of the flood season in these four sea regions.

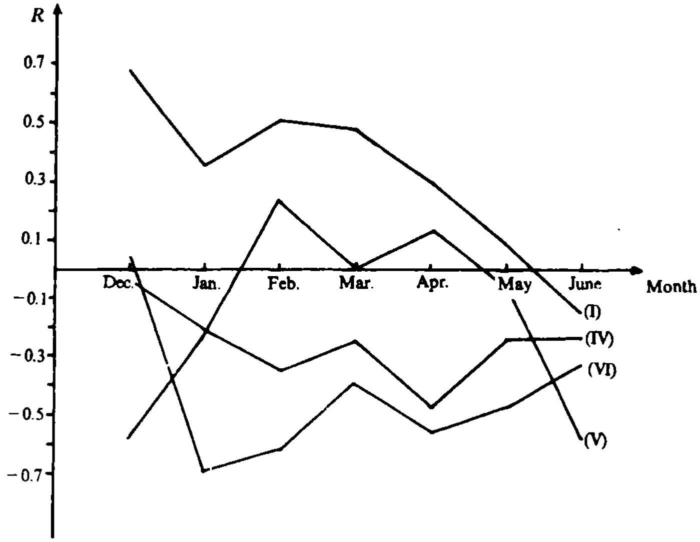

Fig.3 Correlation coefficients of different time lags between QY and SST anomalies of every sea region

The closest correlation between QY and SST in December appeared in region I. The correlation coefficient reached 0.67 (the confidence limit exceeds 0.001), and that from January to March reached 0.35, 0.5 and 0.47 respectively (the confidence limits reach 0.05 , 0.01 and 0.01 respectively), which showed that SST of region I had continuous influence on the discharge of the flood season of Yichang Station.

The correlation coefficients between QY and SST of region IV in February and April were −0.35 and −0.47 (the confidence limits reach 0.05 and 0.01 respectively).

The correlation coefficients between QY and SST of region V in December and June were all −0.56 (the confidence limits reach 0.05).

The correlation coefficient between QY and SST of region VI in January was −0.69

(the confidence limit reaches 0.01), and coefficients in February and April in this region were −0.61 and −0.55 respectively (the confidence limits reach 0.02 and 0.05 respectively).

Two significant results could be obtained by Fig.3:

(1) The influence of the mean SST change of every sea region during the earlier winter on QY are the most remarkable.

(2) The influence of SST of every sea region on QY have the obvious double humped characteristics, which show that the change of SST self has the oscillatory features of several months scale.

II. RELATION OF ATMOSPHERIC CIRCULATION WITH DISCHARGE OF FLOOD SEASON IN YICHANG STATION

By means of calculating the correlated relations from January of last year to the corresponding period between QY and 500hPa altitudes we obtained 18 figures that reflected the features of temporal and spacial variation about the correlated relations.

Marking the position of the maximum absolute values in the correlated regions that the confidence limits all reached 0.05 for every figure we got the spread chart of the positions of the maximum correlated center points which were relatively concentrated in the sky of the mid–high–latitude of the North Atlantic Ocean, of the European west coast, of the Arctic Ocean nearby 180 ° E, of the north equatorial current in the Indian Ocean, and of Burma–Laos–Yunnan region (abbreviated BLY region). Especially, the points of the latter among these regions were the most. By means of calculating monthly variation of mean correlation coefficients (Fig.4) of BLY region (25 ° N–30 ° N, 95 ° E–105 ° E), we can see that there are the closest correlation during the last summer, and good correlation in the corresponding period. We will see that the region plays an important role for the transport of moisture from the Bay of Bengal later on.

In order to analyze the features of the correlation field synthetically we had calculated the monthly point number N of high correlation coefficients that the confidence limits reached 0.05, and monthly mean square of the extreme values of the correlation coefficients *R*①(Fig.4). We can see that:

(1) The variations of *N* and *R* have a good synchronism, namely the more the correlation point number, the greater the mean square of the extreme values of the correlation coefficients.

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① $R=\sqrt{(\sum r_i^2)/n}$, *n* is the total of the correlation regions of having the great–range same signs; r_i is the correlation coefficient of having the maximum absolute values in the i–th correlation region.

(2) N and R have the cycle vibration of 5 months, or called as the rhythm. Long-term weather process is different from the mid-short-term weather process which gradually evolves from far to near. The long-term process has the rhythm phenomenon. The cause of producing 5 months rhythm is thought probably relating to the double cycles constituted by the autovibration of westerlies circulation of having 73 days cycle[1].

After analyzing the high correlation point number N and R, we found that there was also similar rhythm phenomenon in the process of SST variations. The close connection separated from a few months between the anomalies of SST or circulation and the discharge trend of the later stage reflect that there are the cycle vibrations of a few months in the sea-air coupling system to a certain extent.

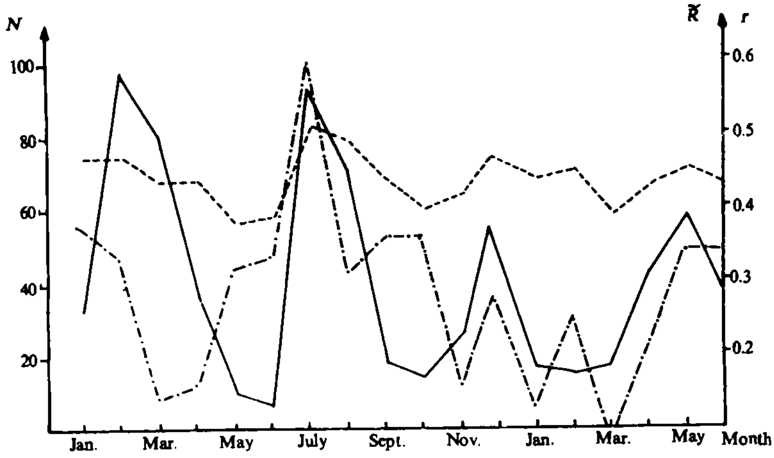

Fig.4 Monthly change of high correlation point number on 500hPa (N), mean square of the extreme values of the correlation coefficients (R) and mean correlation coefficients of BLY region (r). solid line:N; dash line:R; dot-dash line:r

III. INFLUENCE OF SEA-AIR INTERACTION ON THE DISCHARGE

1. Influence of Sea-Air Interaction over the North Atlantic Ocean on the Discharge

After analyzing the distributional situations of mean SST anomalies over the North Atlantic Ocean during the earlier stage of the plentiful and deficient discharge of the flood season in the upper reaches of the Changjiang River, we found that there was the negative correlation to a certain extent between the two distributional situations (Fig.5).

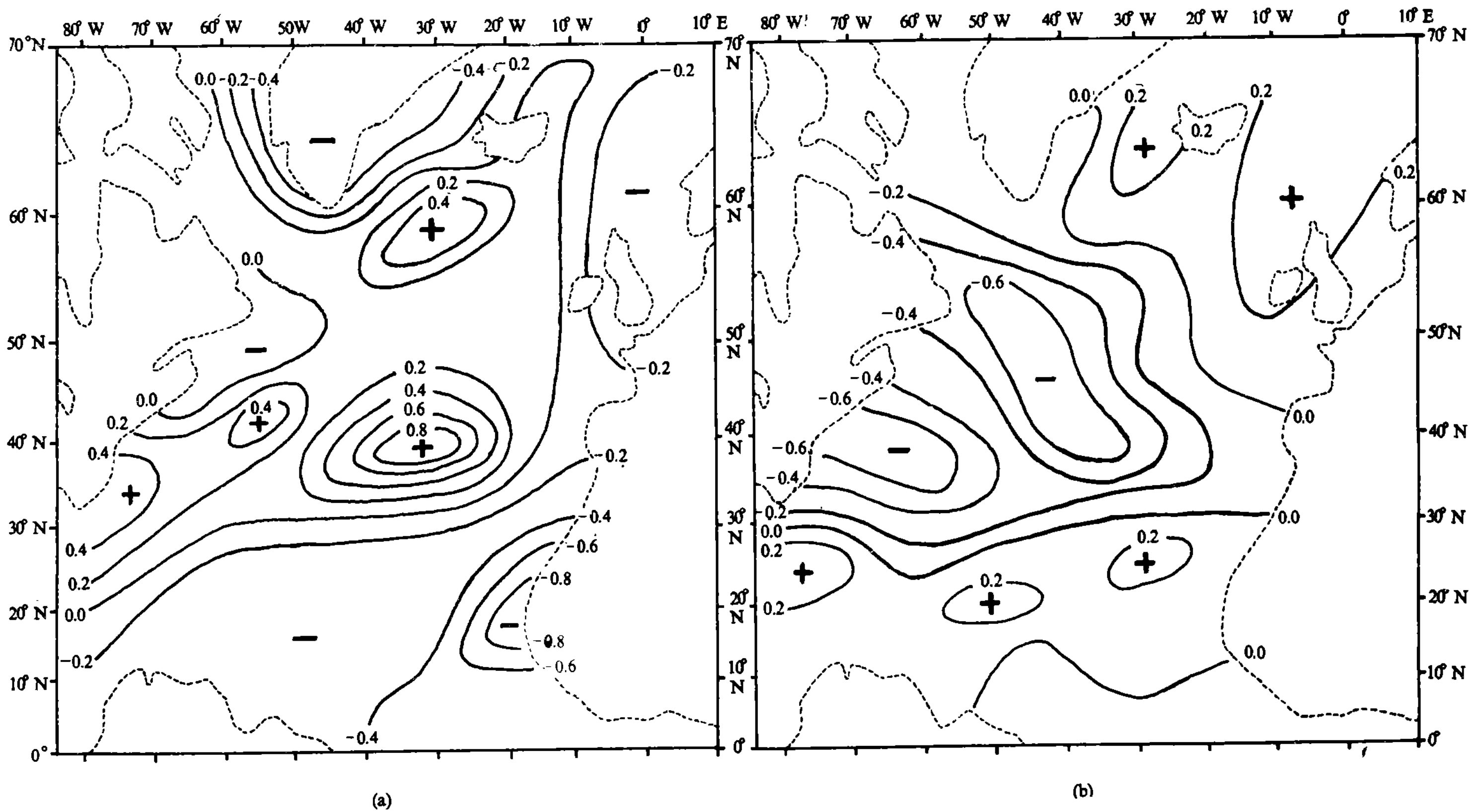

Fig.5 Distributional types of mean SST anomalies on the North Atlantic Ocean during the earlier stage (from Dec. to Mar.) of the plentiful and deficient discharge of the flood season. a: plentiful discharge year; b: deficient discharge year

The high and low latitude zones on the North Atlantic Ocean were occupied by the negative SST anomalies in the plentiful year, and by the positive SST anomalies in the deficient year; the mid–latitude zone was occupied by the large positive SST anomaly values in the plentiful year, and by the large negative SST anomaly values in deficient year. The correlation coefficient between two different SST anomaly fields is −0.3, the confidence limit exceed 0.005.

The distributional type of Fig.5a is defined as the plenty type, and that of Fig.5b as the deficiency type. By calculating the correlation coefficients between the mean SST anomaly field on the North Atlantic Ocean during the earlier stage (from Dec. to Mar.) of every year and the plenty type (or deficiency type), we found that, the discharge of Yichang Station increased if the SST anomaly distribution on the North Atlantic Ocean during the earlier winter (from Dec. to Mar.) was similar to the plenty type, and the discharge decreased if the distribution was similar to the deficiency type (the confidence limits exceed 0.005).

Therefore, when the SST of region I is anomalously higher during the earlier winter of plentiful year, the northward warm advection strengthens the ridge occupied in the sky of the European west coast, the longitudinal gradient of circulation is enhanced, and that during the corresponding later stage in the mid–latitude zone of East Asia is enhanced too. So, the activities of cold air in the region of the upper reaches of the Changjiang River are frequent, which is of benefit to the precipitation in the upper reaches of the Changjiang River, and the discharge of the flood season is plentiful.Conversely, when the SST of region I is anomalously lower during the earlier winter the discharge of the flood season is deficient.

2. Influence of Sea– Air Interaction over the North Pacific Ocean on the Discharge

The strength of the subtropical high over the west Pacific Ocean and the position of the ridge point extending westward have obvious influence on the precipitation in the upper reacher of the Changjiang River. The calculating results show that the mean position of the subtropical ridge points extending west ward over the west Pacific Ocean during June to August is at 129 ° E in the plentiful year, and at 124 ° E in the deficient year. There are close relations between the strength of the subtropical high and the positions of the ridge points extending west ward[2]. The position of the ridge point is by west as the subtropical high is strong, and by east as weak.

The SST anomalies on the east parts of the equatorial Pacific Ocean is an important cause of influencing the strength of subtropical high over the Pacific Ocean. There is the marked positive correlation between the two. When the SST on the east parts of the equatorial Pacific Ocean (region IV) is anomalously higher, the temperature gradient of south–north direction is increased, the more energy are provided to the rising branch of the Hadley cell, and the Hadley cell is strengthened. Therefore the subtropical high is also enhanced, the discharge of the flood season in the upper reaches of the Changjiang River is decreased; conversely, the discharge is increased.

It is well known that, north wind is prevailing in the lower layer of the troposphere and south wind is prevailing in higher layer during the winter half year, which is the typical Hadley cell. During the summer half year south wind is prevailing in lower layer of the troposphere and north wind is prevailing in higher layer. The cell is one part of the Hadley cell in the Southern Hemisphere which is called as the monsoon longitude circulation. April is the starting month of the transition from the Hadley cell of winter season to the monsoon longitude circulation of summer season, which is a possible cause why SST on the east parts of the equatorial Pacific Ocean in April have the strongest influence on the discharge of the flood season (Fig.3).

3. Influence of Sea–Air Interaction over the Indian Ocean on the Discharge

The influence of SST of the region V on the discharge of the flood season in the upper reaches of the Changjiang River has the rhythm relation about a half year (Fig.3). The cause of producing the relation probably relates to the store and release of the heat quantity, as well as the sea–air interaction of the sea active layer. The Indian Peninsula is controlled by a heavy heat low during summer, the southwest monsoon is prevailing, which leads to the upwelling of the cold sea water situated on the east coast of Africa and produces the Somalia cold current. The temperature gradient of land–sea is strengthened, the southwest monsoon is more developed during summertime; the south–north passageway formed in the mountain system of the east parts of Burma leads to the powerful northeast monsoon from the strong polar anticyclone to Southeast Asia during winter. Along the west parts of the equatorial Indian Ocean, the wind blows forward the land from the sea, and the sea water down wash, therefore the Mozambique warm current is strengthened. This season change probably is a cause about the rhythm of 6 months.

Fig.6 gives the variation of SST anomalies on the region V from last December to July in the plentiful year and deficient year.

It can be seen that there are not the sustain positive or negative SST anomalies on the region V during the earlier stage of the plentiful year or deficient year. The differences of both are clear in December and January of winter, as well as June of summer. All of that not only show that there is the negative correlation of a certain extent between SST of region V and the discharge of the flood season in the upper reaches of the Changjiang River, but also provide the evidences for the six–month rhythm.

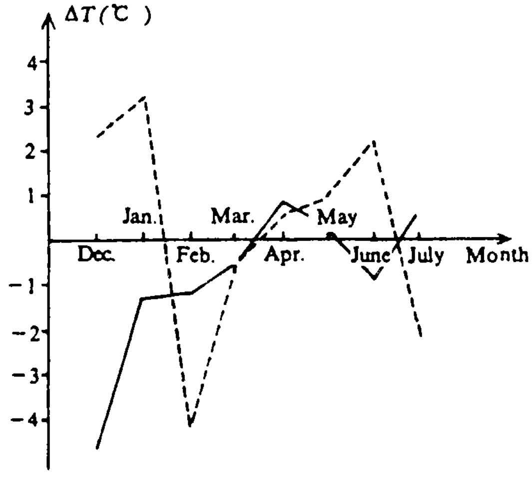

Fig.6 Variation of mean SST anomalies on the region V during the earlier stage of the plentiful year and deficient year solid line: plentiful year; dash line: deficient year

Ramage indicated that [5], the east part of the upper level monsoon trough that corresponded to the Indian low pressure during summer was situated in the north parts of the Bay of Bengal which was the source region of the monsoon low pressure. In the preceding part, we have pointed that there is the marked positive correlation between QY and 500hPa altitudes of BLY region. The establishment of the relation is based on the fact that when the 500hPa altitudes of BLY region are higher than the average, the pressure gradient formed between BLY region and the monsoon trough is strengthened and the southwest monsoon is also strengthened. So the moisture carried to the upper reaches of the Changjiang River is increased, which will be of benefit to the increase of the precipitation in that region. This process is related to the eruptively north ward development of the monsoon cloud cluster originated from the tropic Indian Ocean and Bay of Bengal[6]; conversely, when the altitudes of BLY region are lower, the southwest monsoon is weakened, which will be not of benefit to the precipitation, so the discharge of the flood season is decreased.

The influences of the Southern Hemisphere on the weather and climate of the Northern Hemisphere are related to the exchanges of the various physical quantities (atmospheric mass, heat quantity, moisture) during summer. Here the influence of SST of region VI on QY is briefly analyzed. Table 1 is the variations of the SST anomalies in region VI in the plentiful and deficient year.

Table 1 Variations of mean SST anomalies in region VI during the earlier stage of the plentiful and deficient year (unit: ℃)

Item	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Plenty year	−2.4	−2.6	−4.0	−1.1	−4.5	−1.3	−0.2	−0.7	−3.1	−1.1
Deficiency year	1.7	1.7	1.2	1.1	0.6	1.7	2.1	2.1	3.2	1.0

Region VI was occupied by the negative SST anomalies corresponding to the plentiful year, and the positive SST anomalies corresponding to the deficient year. There was the negative correlation between the SST of region VI and the discharge in the upper reachers of the Changjiang River. The analytical results show that [1],[7]region VI is situated in the western part of the south equatorial current. Along the region, the south equatorial current is divided into two branches of south and north. The southdown branch, together with the west wind drift and the Australia current, forms a counter–clockwise circulation cell; the northup branch supplies to the Somalia current through region V. During the half winter year, if SST of region VI is higher than the average the heat quantities are stored in the deep layer of sea by the downwash sea water. The heat quantities stored during winter are released by the upwelling when the southwest monsoon erupts. So SST of region VI is higher, SST of region V is higher also because the heat quantities transport to the north. The result would lead to the southwest monsoon weakened, which is not of benefit to the precipitation in the upper reaches of the Changjiang River according to the discussions above. On the contrary, if SST of region VI is lower, the precipitation in the upper reaches of the Changjiang River would be heavier. SST in January, February, April and May in region VI have ominous significance for the discharge of the flood season in the upper reaches of the Changjiang River according to Fig.3 and this influence is continuous.

IV. DISCUSSION

(1) From the analyses above, it can be seen that, the SST anomalies of the North Atlantic Ocean, the North Pacific Ocean and the Indian Ocean affect the discharge change of the flood season in the upper reaches of the Changjiang River mainly by the forcing of atmospheric circulation, which reflects that, as the important cold or heat source, SST change of the oceans must lead to the corresponding change of atmospheric circulation. The currents play an important role in the process. Almost all the important correlation regions are situated in the current regions on the three analyzed oceans, and the periods are mainly during the winter and spring seasons. However the forcing between the ocean and

atmosphere is mutual in the sea–air system, not merely the oceans exert the influence on the atmosphere. The atmosphere also affects the oceans. Apart from SST the atmospheric circulation is also affected by the other factors. The changes of the unknown factors probably strengthen or weaken the forcing of oceans. So the obtained relation above is merely a statistical relation which may be destroyed when the other factors intensely change.

(2) The variations of the currents and circulations of any ocean among three oceans are respondent to that of the other two oceans by means of the adjustment of atmospheric circulation. So having the global scale in mind, simultaneously considering the SST variations of three oceans is better than solely considering that of one ocean for the long–term hydrologic forecast of the upper reaches of the Changjiang River, with a drainage area of 1 million square kilometers.

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