Article ID: 1006-8775(2003) 01-0057-07

RELATIONSHIP BETWEEN WEST PACIFIC SUBTROPICAL HIGH AND ENSO AND ITS INFLUENCE ON RAINFALL DISTRIBUTION OF RAINY SEASON IN FUJIAN

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ABSTRACT: Relationship between the variations of West Pacific subtropical high indices in the summer half of the year and preceding SST in North Pacific was examined based on a data set of 1951 – 2000. The correlation between the subtropical high indices and preceding SST in the equatorial East Pacific was the strongest among the others, and has great persistency from last autumn to spring. It is indicated that ENSO events appeared about six months earlier than the change of the subtropical high activities, and the subtropical high intensities enhanced (weakened) and western ridge point was westward (eastward) in the year of El Nino (La Nina) events. It was also observed that there were similar interdecadal oscillation and abrupt variations between Nino3 SST, subtropical high intensities and rainfall of rainy season in Fujian. Therefore, experiments were made on rainfall distribution of rainy season in Fujian. The results showed that the distribution was directly affected by the subtropical high activities, pronouncedly caused by ENSO effect.

Key words: ENSO; West Pacific subtropical high; rainy season; rainfall distribution

CLC number: P434.4　　　**Document code:** A

1 INTRODUCTION

In summarizing climotological factors for precipitation in the raining seasons of China, Li et al. presented five anomalies that could affect the seasonal precipitation, namely, SST in the equatorial eastern Pacific, thermal conditions over the Qinghai-Tibetan Plateau, Asian monsoon, mid-latitude blocking high and West Pacific subtropical high. Not only subject to the direct effect of maritime thermal conditions of the West Pacific, the subtropical high is also influenced by the general circulation and underlying surface from the other four factors. Complicated interactions thus form. As early as in the 1950's, people were interested in the relationship between the subtropical high and droughts and floods in China and the focus shifted to the links between the subtropical high and the SST in the equatorial eastern Pacific[1-3]. In spite of the effort, no sufficient knowledge has been secured about the variation of the high, which includes seasonal zigzags, patterns of persistent anomalies and causation. The success of raining season precipitation forecast depends much on whether there are accurate estimates of the subtropical high in the same year. Its prediction is still the core issue in the forecasting of summer precipitation trends. More discussions will be held on the high's intensity, north-south location swings, westward extension and the relationship between the equatorial eastern Pacific SST and the ENSO event on the one hand, more diagnoses will be made of the relationship between the subtropical high and the precipitation distribution in Fujian's raining season, on the other. It is believed to help improve the forecasts of the subtropical high for better trend prediction of precipitation during the season. With the NCEP 2°×2° SST data for 1951 – 2000 provided by

Received date: 2002-07-08; **revised date:** 2003-05-30

Foundation item: Research on short-term climate prediction model for rainfall in raining seasons of Fujian Province –A Natural Science Foundation project for Fujian Province (D9810010)

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the National Climate Center of the United States, the warm and cool episodes of ENSO is defined following the standards of air-sea integration index as given in [4].

2 TELECONNECTION STRUCTURE OF NORTH PACIFIC SSTA AND KEY ZONES AFFECTING THE SUBTROPICAL HIGH

It is seen from derived correlation distribution, which is based on long-term SST series, between an equatorial cold water zone that sets (0°, 120°W) as the fundamental point and all gridpoints over the North Pacific (figure omitted) that there is a large positive correlation area near the kuroshio current region of the West Pacific and a high-confidence negative correlation area north of it, the so-called westerly drift and surrounding waters, in addition to a high-confidence positive correlation zone in the equatorial eastern Pacific (Niño 3 and Niño 1 & 2). Such anticorrelating, zigzagging oscillations of SST in the north-south direction in the North Pacific reflects the basic features of its ENSO cycle in the region.

To analyze the key zones of SST that govern the variation of the subtropical high, we conducted a statistic study of the distribution of subtropical high intensity indexes in preceding winters (January – February) in correlation with the characteristic quantities of the subtropical high in the summertime (June – August). The two quantities have the most significant relationship. It is clear from the figure (omitted) that they are quite consistent with the teleconnection patterns in North Pacific, in which the highest positive correlation is in the equatorial eastern Pacific region, making the Niño 3 and Niño 1 & 2 zones all at the 0.001 significance level. The other positive correlation region is over the kuroshio and warm pool, though the significance level is lower than the former region. The highest negative correlation is found over the westerly drift with the center at the 0.001 significance level, too. It is obvious that it is of the typical distribution pattern of El Niño SST. Zhao[5] makes an intensive statistical study of month-to-month variance changes for the equatorial cold water zone (Niño 3: 5°S – 5°N, 150°W – 90°W), westerly drift zone (35°N – 45°N, 160°E – 160°W) and kurishio (35°N, 140°E – 150°E; 25°N – 30°N, 125°E – 150°E) and the results show that the SST variance of Niño 3 is much larger than those of the westerly drift and kuroshio zones, which is above 0.5 all the year round and largest (1.0) in November and December. It suggests that the equatorial cold water area have the largest discrete variation of SST in the North Pacific and the strongest signals about the subtropical high activity in summertime.

3 RELATIONSHIP BETWEEN SUBTROPICAL HIGH AND EQUATORIAL EASTERN PACIFIC SST

In view of the reasons stated above, we focused our effort on three relatively independent characteristic quantities that reflect the monthly correlation (Tab.1) among the intensity of the subtropical high, its north-south and east-west locations. They are, namely, the area index of the high, location of the westernmost ridge point, ridge line location and Niño 3 SST. In general, the area index is most significantly correlated with the SST with 77% of the monthly area indexes having a 0.001-significance-level positive correlation with the SST over the time from preceding September to the current year. High correlation concentrates in the preceding period of winter and spring (December – March) and the 0.001 significance level is satisfied throughout the whole wintertime. The westernmost ridge point is all negatively correlated with the SST with 57% of the monthly correlation from the preceding September to the current year having the 0.01 significance level and maximum negative correlation concentrating in February – March that have just passed. The correlation between the ridge line location and the SST is far less significant than the area and westernmost ridge point, and June and July are the only time when the correlation maintains from the preceding September to the current period at a 0.05

significance level. The high correlation with the SST still concentrates over the winter and spring that have just passed. The correlation is the least significant between the ridge line and SST in August, but negative correlation resumes the 0.05 significance level in September between the ridge line and the SST after the preceding spring. The above study shows that for the effect of thermal conditions in the equatorial eastern Pacific on the subtropical high in the summertime, especially the intensity and the longitude to which it extends, the validity can be traced as backward as the preceding autumn, being particularly significant in winter and spring. A basic pattern can then be summed up like what follows: When warm water appears over the equatorial eastern Pacific in autumn and winter, the subtropical high is stronger and more westward in the summertime of the succeeding year and the ridge line more southward in early summer; when cold water appears over the region, otherwise is true with the subtropical high and ridge line.

Tab.1 Coefficients of correlation between characteristic quantities of the subtropical high and preceding Niño 3 SST from March to September in 1951 – 2000

	month	9	10	11	12	1	2	3	4	5	6	7	8
Area index	3	0.64	0.66	0.67	0.69	0.68	0.68	0.67					
	4	0.60	0.64	0.68	0.70	0.71	0.71	0.71	0.68				
	5	0.41	0.45	0.49	0.51	0.53	0.55	0.55	0.52	0.45			
	6	0.42	0.50	0.57	0.59	0.60	0.61	0.59	0.52	0.44	0.32		
	7	0.35	0.42	0.48	0.51	0.53	0.52	0.50	0.48	0.45	0.38	0.28	
	8	0.48	0.51	0.54	0.56	0.57	0.58	0.59	0.55	0.48	0.37	0.25	0.15
	9	0.37	0.44	0.50	0.52	0.51	0.50	0.47	0.40	0.32	0.23	0.18	0.14
Western ridge long.	3	-0.52	-0.54	-0.56	-0.58	-0.59	-0.60	-0.57					
	4	-0.47	-0.48	-0.49	-0.51	-0.53	-0.56	-0.58	-0.57				
	5	-0.41	-0.44	-0.47	-0.49	-0.51	-0.54	-0.52	-0.44	-0.29			
	6	-0.33	-0.39	-0.44	-0.47	-0.49	-0.53	-0.51	-0.43	-0.28	-0.16		
	7	-0.19	-0.24	-0.27	-0.28	-0.31	-0.33	-0.35	-0.34	-0.29	-0.22	-0.15	
	8	-0.37	-0.37	-0.38	-0.37	-0.38	-0.39	-0.40	-0.35	-0.27	-0.20	-0.17	-0.15
	9	-0.24	-0.29	-0.33	-0.33	-0.34	-0.33	-0.33	-0.28	-0.21	-0.13	-0.10	-0.08
Ridge line lat.	3	0.20	0.19	0.19	0.22	0.21	0.22	0.18					
	4	0.21	0.19	0.19	0.22	0.21	0.23	0.20	0.14				
	5	0.00	-0.01	-0.03	-0.02	-0.01	0.01	-0.03	-0.13	-0.23			
	6	-0.39	-0.41	-0.45	-0.50	-0.52	-0.52	-0.49	-0.41	-0.33	-0.26		
	7	-0.28	-0.28	-0.29	-0.29	-0.30	-0.31	-0.33	-0.34	-0.34	-0.27	-0.21	
	8	0.08	0.04	0.01	0.02	0.01	-0.02	-0.04	-0.07	-0.10	-0.16	-0.21	-0.21
	9	-0.14	-0.18	-0.21	-0.22	-0.21	-0.21	-0.25	-0.26	-0.30	-0.33	-0.39	-0.39

As we know, the intensity and location of the West Pacific subtropical high can both persist and turn over obviously. To discuss the relationship between the persistence and transition and SST, we use the index of subtropical high area to study the transition process, based on the principle that anomalies in at least four out of six months prior to the transition period have signs opposite to those in at least four out of six months after it. Nine processes of weak anomalies turning over to strong anomalies are found in July 1953, November 1957, November 1965, March 1969, October 1972, October 1976, May 1982, October 1986 and July 1997; six processes

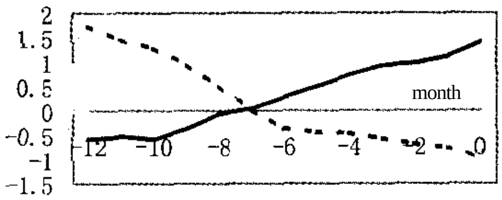

Fig.1 Composite SST anomalies in the Niño 3 area during the 12 months prior to the transition of the subtropical high in the nine strengthening processes (solid line) and six weakening processes (dashed line).

of strong anomalies changing to weak anomalies are found in November 1966, October 1970, October 1973, June 1984, November 1988 and January 1999. As a matter of fact, they belong to the starting year or developing stage of the ENSO warm or cold episodes[4]. For the nine processes in which the subtropical high strengthens, the SST anomalies in the Niño areas have a leading time varying from four to nine months in the transition from negative to positive anomalies, averaging at 6.7 months; For the six processes in which the subtropical high weakens, the SST anomalies in the area have a leading time varying from five to eight months in the transition from positive to negative anomalies, averaging at 6.5 months. Fig.1 compares the composite SST anomalies in the Niño 3 area during the 12 months prior to the transition of the subtropical high in the nine strengthening processes and six weakening processes. It is seen that the months for the zero anomalies on the two curves are also indicators of the leading time of SST turns, generally consistent with the mean number of leading months as described above. It shows that the ENSO episode affects the intensity of the subtropical high for approximately six months.

4 SUBTROPICAL HIGH CHARACTERISTICS IN EL NIÑO AND LA NIÑA YEARS

From what Tab.1 has revealed, we now know the basic patterns in which preceding periods of warm water and cold water in the equatorial eastern Pacific affect the subtropical high in the summertime. To study the activity of the high in typical ENSO episode years, the standard formulated by the ENSO monitoring office at the National Climate Center is used to determine typical El Niño and La Niña years. Seventeen years in which there are typical El Niño episodes are 1951, 1953, 1957 – 1958, 1963, 1965, 1969, 1972, 1976, 1983, 1987, 1991 – 1992, 1993, 1994, 1997 – 1998; twelve years in which there are typical La Niña episodes are 1954 – 1955, 1964, 1967, 1970 – 1971, 1974, 1975, 1985, 1988, 1999 and 2000. Fig.2 compares the mean of

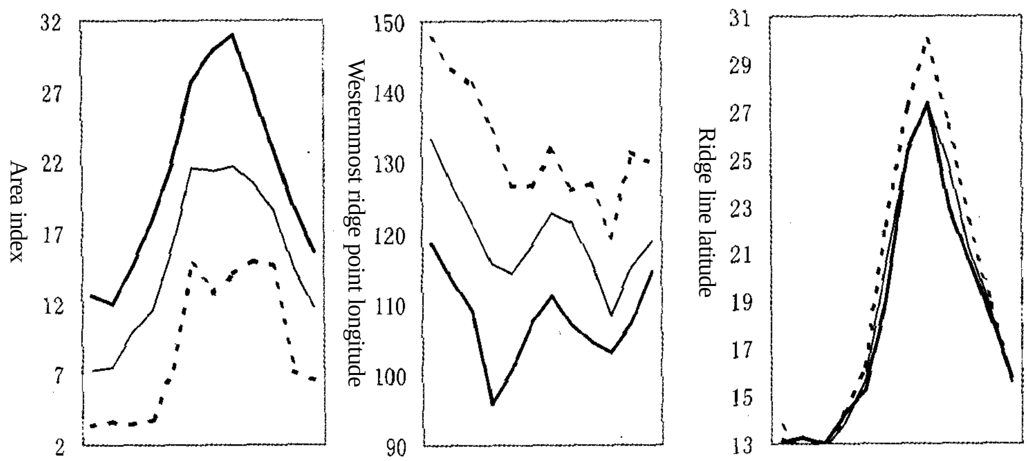

Fig.2 Mean curves for each of the three characteristic quantities of the subtropical high among the typical El Niño years (bold line) , La Niña years (dashed line) and normal years (fine line).

each of the three characteristic quantities of the subtropical high between the typical El Niño years and La Niña years. It is obvious that in both typical years the area and westernmost longitude of the ridge tend to be totally opposite to each other and so is the ridge line latitude in summertime, though less dramatic than the former two. It is consistent with the analysis results above but highlighting the anomalies of these typical years.

5 INTERDECADAL OSCILLATION OF ABRUPT CHANGE TIME OF SUBTROPICAL HIGH, SST AND RAINING SEASONS IN FUJIAN

Fig.3 is the year-to-year accumulative variation of the area index anomalies of the subtropical high and SST anomalies in the Niño 3 area all the year round and standard variable of precipitation of Fujian in the raining season of May and June. It is easy to see that the former two variations tend to be consistent and the latter one also goes in phase with them. Since 1951, the three variations have experienced a climatic jump around the mid-and late- point of the 1970's (1975 – 1978) —the Niño 3 SST is low most of the time before the turning point when the subtropical high is weak and the seasonal precipitation is more in Fujian; the Niño 3 SST is high most of the time before the turning point when the subtropical high is strong and the seasonal precipitation is less in Fujian. The oscillation is interdecadal, which is sound proof that the three variations have experienced more or less the same long-periodic oscillation since 1951.

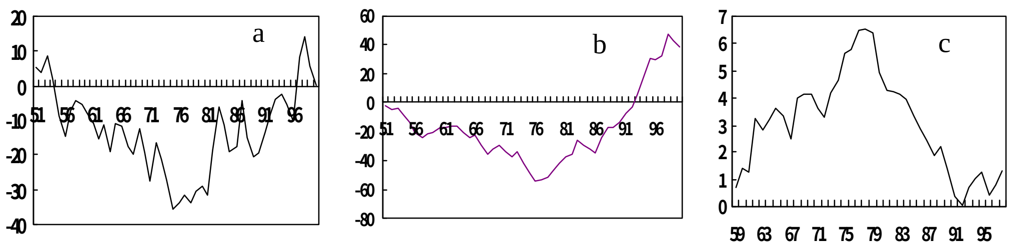

Fig.3 Year-to-year accumulative variations of SST anomalies in the Niño 3 (a), area index anomalies of the subtropical high (b) and standard variable of precipitation of Fujian in the raining season of May and June (c).

6 EFFECT OF SUBTROPICAL HIGH ANOMALIES ON PRECIPITATION DISTRIBUTION IN FUJIAN'S RAINING SEASON

The subtropical high is a general circulation system that affects most directly the location of rain bands during raining seasons in China. To study its effect on the precipitation distribution during the time (May – June), the three factors of area index, westernmost longitude of ridge and ridge line latitude, which are independent between themselves, are again taken (Tab.2) for statistical study of simultaneous correlation with the first three characteristic quantities of EOF in the precipitation of the yearly first raining season (with the variance contribution being 0.48, 0.17 and 0.06, respectively). As shown in the statistical result, the EOF_1 and EOF_3 have little relationship with the subtropical high while the EOF_2 has large correlation with it, because both its negative correlation with the area and positive correlation with the westernmost ridge longitude reach the 0.01 significance level. From the spatial distribution of the first three eigenvectors of the EOF (figure omitted), we know that the EOF_1 is positive throughout the province (being of the same vector sign), the EOF_2 is negative in the north but positive in the south (being of reversed vector sign in the north-south direction) and the EOF_3 is positive in the east but negative in the west (being of reversed vector sign in the coast-inland direction). It is obvious that the variation of the subtropical high is mainly in the north-south distribution of the precipitation, i.e. it mainly affects the location of rain bands. In the EOF_2 time coefficient series, take five largest anomalous years (1960, 1965, 1972, 1986 and 1997) versus five smallest anomalous years (1969, 1970, 1982, 1988 and 1995) for a composite study of standard variable of precipitation (Fig.4). It shows that most of the contours have alignment of WSW-ENE with the zero contours in the middle. It is obvious that precipitation variation is entirely different in the EOF_3 anomalous years —precipitation increases in the south but decreases in the north in large-value years and otherwise is true in small-value years. It can be verified by looking up relevant tables that the large EOF_2 years are all with a relatively weak, eastward and northward subtropical high while the small EOF_2 years are all with a relatively strong, westward and southward subtropical high. It implies that the a more northward and eastward subtropical high makes it possible for the summer monsoon to develop and advance north, the monsoon rain bands to rapidly move to the northern boundary of the middle and lower reaches of the Changjiang River, the ITCZ to be more active, contributing to more precipitation in southern Fujian; a more southward and westward subtropical high makes it difficult for the summer monsoon to develop, resulting in a stagnating rain band over the southern part of the middle and lower reaches of the Changjiang River and eventually leading to more precipitation in northern Fujian.

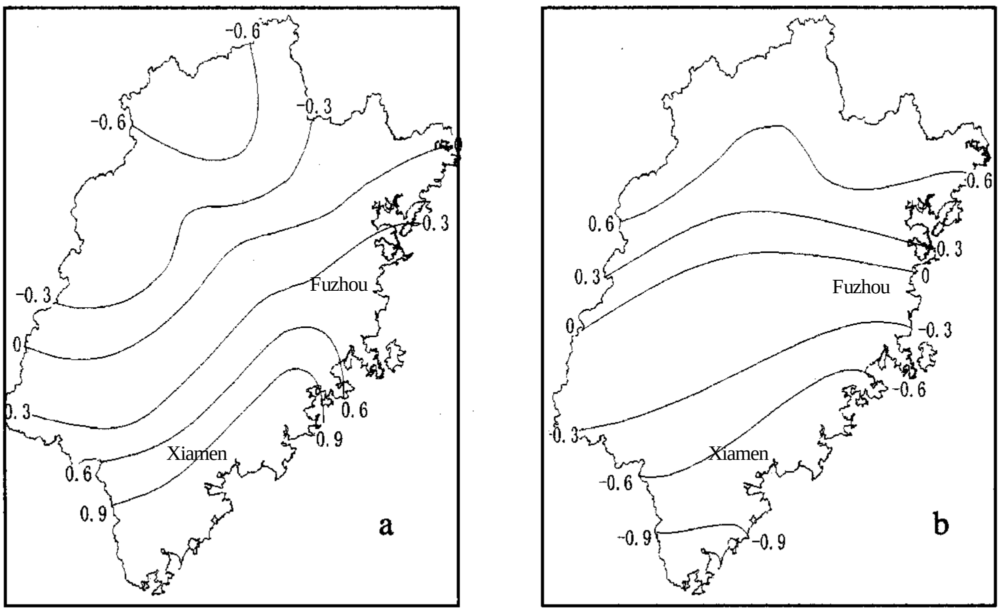

Fig.4 Composite study of standard variable of precipitation between largest anomalous years (a) and smallest anomalous years (b) in the EOF_2 time coefficient series.

On further study, we find that for the EOF_2 coefficient for four anomalously large years and five anomalous small years are in the stages of persistently weak and persistently strong subtropical high, which are respectively the developing stage of the cold and warm episodes of ENSO. As we know, the anomalies of the subtropical high are subject to more than one factor and as a significant factor the ENSO affects the subtropical high to cause anomalies in the precipitation of raining seasons. It is then known that the SST anomalies of the equatorial eastern Pacific and information on ENSO in preceding time have important implication for the forecast of summertime subtropical high, especially its intensity and westernmost ridge longitude, and the prediction of distribution tendency of raining season precipitation in Fujian.

Tab.2 Coefficients of correlation between raining season precipitation EOF in Fujian and simultaneous characteristic quantities of the subtropical high

	EOF_1	EOF_2	EOF_3
area	-0.16	-0.35	0.03
west-extending	-0.07	0.39	0.11
ridge line	-0.12	0.23	-0.11

7 CONCLUDING REMAKKS

a. The equatorial eastern Pacific, westerly drift and kuroshio where there are SST anomalies are three key zones indicating the anomaly of the subtropical high activity, with the preceding precursory information from the equatorial eastern Pacific being the most significant. The effect of the regional SST on the summertime subtropical high, especially its intensity and longitude to which the westernmost ridge point reaches, can have a leading time as far back as to the preceding autumn, with the winter and spring the most significant.

b. The generation of ENSO episodes affects the transition of the subtropical high for about six months; out-of-phase anomalies are quite typical in the characteristic quantities of the El Niño and La Niña years, especially with the intensity (area) and westernmost ridge longitude, followed by the ridge line latitude.

c. Since 1951, the subtropical high, equatorial eastern Pacific SST and precipitation variation have experienced large-scale oscillations for about half a century, with the interdecadal oscillation in basically consistent periods with historical abrupt changes, which took place in 1975 – 1978.

d. The anomalies of raining season precipitation in reversed north-south variations seen in the Fujian Province are resulted from direct influence by the subtropical high activity; the anomalies of the latter is in turn affected by ENSO.

Acknowledgements: Mr. CAO Chao-xiong, who works at the Institute of Tropical and Marine Meteorology, CMA, Guangzhou, has translated the paper into English.

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