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THE CORRELATION BETWEEN THE PACIFIC SEA SURFACE TEMPERATURE (SST) and PRECIPITATION OVER NW CHINA

WANG Cheng-hai (王澄海)[1], WANG Shi-gong (王式功)[1], YANG De-bao (杨德保)[1], DONG An-xiang (董安祥)[2]

(1.*College of Resource and Environmental Science of Lanzhou University, Lanzhou*, 730000 *China*: 2. *Meteorological Bureau of Gansu Province, Lanzhou*)

ABSTRACT: With the singular value decomposition (SVD), correlation analysis has been conducted between the Pacific Ocean sea surface temperature (SST) and northwestern China precipitation over March – May (MAM). The result shows that there is good relationship between the North Pacific and spring precipitation in northwestern China. When the SST is of the peak El Niño phase, precipitation is less over this part of the country except for the Qinghai-Tibetan Plateau; when the SST for the months DJF is of the mature El Niño phase, precipitation is more over the region in the subsequent March – May; when the North Pacific SST for DJF is of the La Niña pattern, precipitation is less over the plateau in the subsequent March – May. For the Pacific SST, the westerly drift, kuroshio current, Californian current and north equatorial current are all significantly correlating with the March – May precipitation in northwestern China. Specifically, the SST in DJF over the kuroshio current region is out of phase with the precipitation in northern Xinjiang, i.e. when the former is low, the latter is more. In northwestern China, regions in which March – May precipitation response to the variation of SST in the Pacific Ocean are northern Xinjiang, the Qinghai-Tibetan Plateau and areas off its northeastern part, the desert basin and western part of the Corridor of the Great Bend of Yellow River valley (Corridor).

Key words: precipitation of Northwest China; Pacific sea surface temperature (SST); singular value decomposition (SVD)

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1 INTRODUCTION

For more than a decade, the air-sea interactions have become a well-known core subject of climate research. Large amount of facts and theoretic research have shown that the ocean is playing an essential role in climate changes on virtually all time scales[1, 2]. Tropical oceans are major suppliers of energy for global atmospheric motion. The area of ocean takes up more than 70% of the Earth's surface and variations of the tropical ocean contribute much to the interannual variation of the general circulation and climate[3]. It has been acknowledged that the anomaly of the Pacific SST brings about changes to the climate in China in general, and relates to sustained low temperature in northeastern China, precipitation in raining seasons in eastern China, western Pacific typhoons and west Pacific subtropical high, in particular[4]. As shown in some studies, the anomaly of the Pacific SST is also affecting the precipitation in northwestern China. Most of the study so far documented has done difference tests of meteorological elements for the El Niño and non- El Niño years, on the annual scale. It is obvious that the efforts are still short of what is needed for two of the reasons below: (1) If only the warm episode is taken into account, the life

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Biography: WANG Cheng-hai (1961 –), male, native from Qin'an County of Gansu Province, professor, mainly undertaking the study land surface processes and climate change.

cycle of ENSO is 18 – 24 months long on average[1, 2]. As a result, the coupling with the atmosphere varies over different stages of the ENSO evolution; (2) five stages, of initial conditions, initial phase, peak phase, transitory phase and mature phase, are divided based on the work of Rasmusson et al[12]. During the five stages, the SST is distributed variably over all parts of North Pacific. Similarly, the effect of the ENSO episode on the climate change differs regionally. Only through the analysis of the correlation between SST and various stages of climate fields can we have a full picture of the coupling relationship between the Pacific SST and climate.

The spring drought for March – May is one of the important damaging weather phenomena in northwestern China, for the rainfall over the time is directly affecting whether there is agricultural harvest in the region. With the SVD technique, the current work attempts to isolate objectively areas of high correlation between the SST fields in North Pacific and spring precipitation in northwestern China for both simultaneous and preceding periods, study the correlation between the two fields and discuss the precursory signs for the forecasting of highly correlated areas.

2 METHODS AND DATA

With the SVD technique, Wallace et al[13]. study the relationship between the North Pacific SST and 500 hPa geopotential height field. Jiang et al. probe into the relationship between the anomalies of North Pacific SST and those of summertime precipitation in China. Wei et al[9]. diagnose the couplings between the anomalies of North Pacific SST and summertime temperatures in China. The results have shown that the SVD is an efficient tool in understanding air-sea couplings and the interactions and mutual feedbacks between any two meteorological fields. After the SVD study, the relationship between spring precipitation in northwestern China and Pacific SST is statistically tested for significance.

For the North Pacific (10°S - 50°N, 120°E - 180°) SST, the SST is taken from gridpoint reports of 5°×5° (286 gridpoints in all). The data span from 1960 to 1998. The left field consists of preceding SST for DJF (equivalent to the mature phase of ENSO) and current SST for MAM (equivalent to the peak phase of ENSO) and right field is the MAM (spring) precipitation field from 1961 to 1998 for 84 weather stations across the region of northwestern China. Following the REOF result[14], the spring precipitation is divided into six sensitivity regions of northeastern plateau, Qinghai Plateau, Tianshan (northern Xinjiang), western Great Bend of the Yellow R., southern Xinjiang and desert basin.

3 CORRELATIONS BETWEEN SPRING PRECIPITATION IN NORTHWESTERN CHINA AND PACIFIC SST

3.1 *Simultaneous relationship*

Tab.1 gives the percentages of the first six couples of singular vectors variance taking up the total variance, accumulative variance percentages and correlation coefficients for the spring (MAM) SST and simultaneous precipitation in northwestern China. It shows that the first three couples of singular vectors have accounted for 64% of the total variance, with each of them having a coefficient that passes the significance test of $a = 0.001$ ($r_{a=0.001} \approx 0.5013$). In the meantime, the Monte Carlo method is used for verification, in which the temporal sequence of the precipitation field is randomly altered for 30 times to have 30 times of mean correlation coefficient of R_{avg}, which are listed in the table. Efforts are mainly spent on the characteristics of the spatial distribution patterns of the first three couples.

Fig.1 gives the spatial distribution pattern for the first couple of singular vectors. It is known from the left field (of the Pacific SST, as shown in Fig.1a) that the negative value is extensive over the westerly drift and areas near the Dateline with the center close Hawaii; the Niño3 region on both sides of the Equator is of positive value, which extends all the way to the Californian current off the Californian coast, with the center value of 0.48. It is similar to the peak phase situation as given by Rasmusson et al. for a composite chart of SST anomalies in the life cycle of El Niño. In the right field corresponding to it (Fig.1b), the northwestern China is all covered with negative values with the center in the Corridor and the value above –0.4, passing the significance test of $a = 0.01$ ($r_{a=0.01} \approx 0.4032$). In other words, when the SST is low in the westerly drift and North Pacific current and high in the Niño3 region in the equatorial eastern and central Pacific, i.e. when the ENSO evolves to its peak phase, simultaneous precipitation will be less in the Corridor and eastern and southern parts of Gansu province.

Tab.1 The percentage, sum percentage of the first 6 singular vectors to total variance and correlations between left and right vector fields of the first 6 singular vectors

K	SCF_k /%	$CSCF_k$ /%	$R(a_k, b_k)$	$R_{avg}(a_k, b_k)$
1	44.5	44.5	0.58	0.49
2	12.0	56.5	0.71	0.52
3	7.4	63.9	0.66	0.45
4	6.1	70.0	0.74	0.72
5	4.7	74.7	0.74	0.76
6	3.2	77.9	0.88	0.77

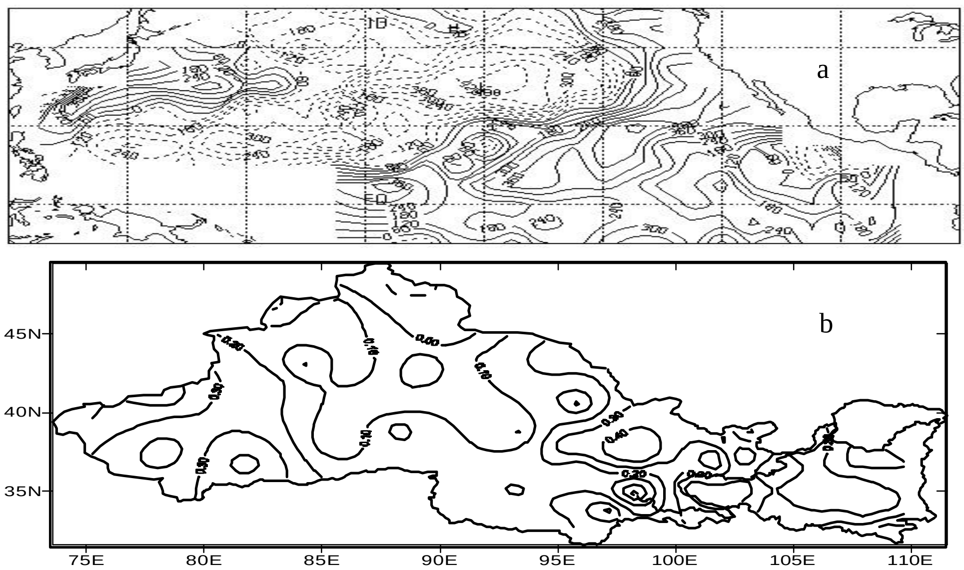

Fig.1 The first SVD couple pattern between Pacific SST and precipitation in NW China.

Fig.2 gives the spatial distribution pattern for the second couple of singular vectors. It is known that a negative region prevails over the warm pool and the oceans north of it, the kuroshio, the northern equatorial current and the Californian current, with the center around Hawaii and the central value more than 0.5; a positive region is over the westerly drift region. The left field (Fig.2b) is corresponding to northern Xinjiang and the Corridor where the distribution is positive and the central value over the former is greater than 0.40 (passing the significance test of $a = 0.01$). In other words, when SST is low over the kuroshio region but high over the central part of North Pacific and westerly drift, precipitation will be more in northern Xinjiang (north of the Tianshan Mt.) and the Corridor.

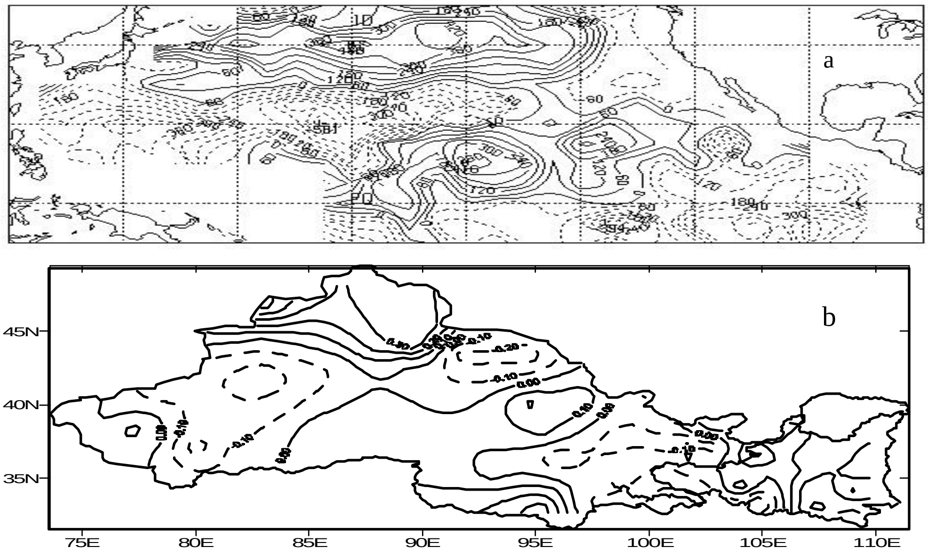

Fig.2 The second SVD couple pattern between Pacific SST and precipitation in NW China.

The spatial distribution of the third couple of singular vectors explain 74% of the total variance and the coefficient is 0.66. In the left field (Fig.3a), the northern equatorial return current is positive and the kuroshio is negative, with the central value greater than 0.4 and the El Niño3 region in the negative territory. The right field (Fig.3b) is negative, which is for the Takelama Arid Desert basin, the Qinghai Plateau and the Corridor. In other words, when the SST is low over the kuroshio region, high over the northern equatorial return current region and low over the El Niño3 region, precipitation will be less over the desert basins, the Corridor and the Qinghai Plateau.

3.2 *Successive relationship*

Like Section 3.1, Tab.2 gives the percentages, accumulative percentages and coefficients of the first six couples of singular vectors variance, in addition to mean correlation coefficients, obtained with the Monte Carlo method. It is shown in the table that the variance of the first six couples of vectors fits 81.1% of the total variance while that of the first three couples fit 67.5%. The correlation coefficients of corresponding singular vectors all pass the significance test of $a = 0.001$.

Tab.2 The percentage, sum percentage of the first 6 singular vectors to total variance and correlation between left and right vector fields of the first 6 singular vectors

K	SCF_k /%	$CSCF_k$ /%	$R(a_k, b_k)$	$R_{avg}(a_k, b_k)$
1	42.7	42.7	0.52	0.52
2	13.5	56.2	0.66	0.56
3	11.3	67.5	0.70	0.60
4	5.9	73.4	0.77	0.48
5	4.3	77.7	0.60	0.65
6	3.4	81.1	0.81	0.68

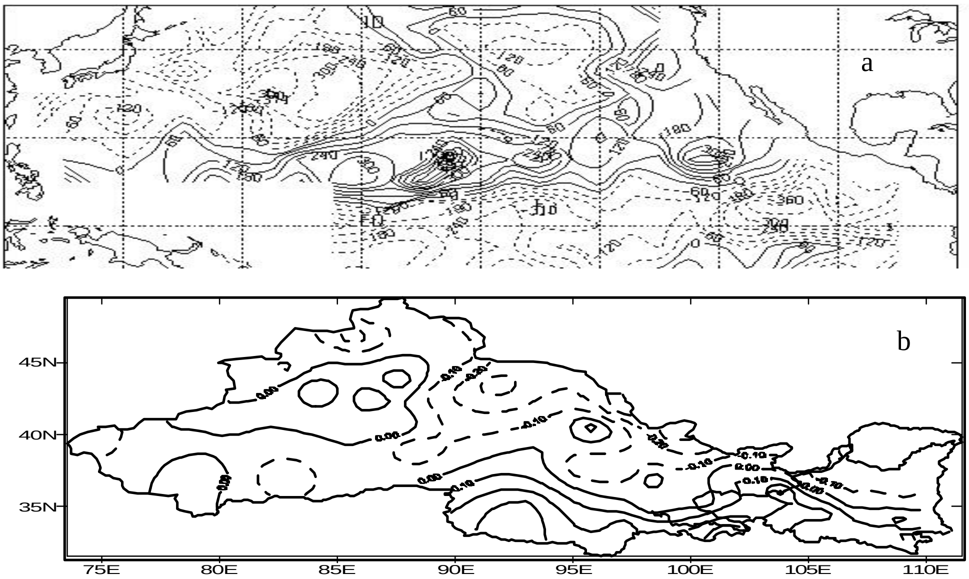

Fig.3 The third SVD couple pattern between Pacific SST and precipitation in NW China.

Fig.4 is the distribution pattern of the first couple of spatial vectors of SST in the months of DJF and precipitation in MAM over northwestern China. For the left vector field (Fig.4a), positive values prevail over the Niño3 region and the eastern part of Niño4 region striding across the Equator while negative values, with the center larger than –0.6, are present in the westerly drift and Californian current. The distribution is similar to the mature phase chart of El Niño as given by Rasmusson et al[12]. in their composite phase work. For the right vector field (Fig.4b), positive values are throughout the northwestern part of China with major areas of high values on the northeast side of the plateau and the central value higher than 0.45. In other words, precipitation will be more over the region in subsequent MAM months if the El Niño evolves to its mature phase.

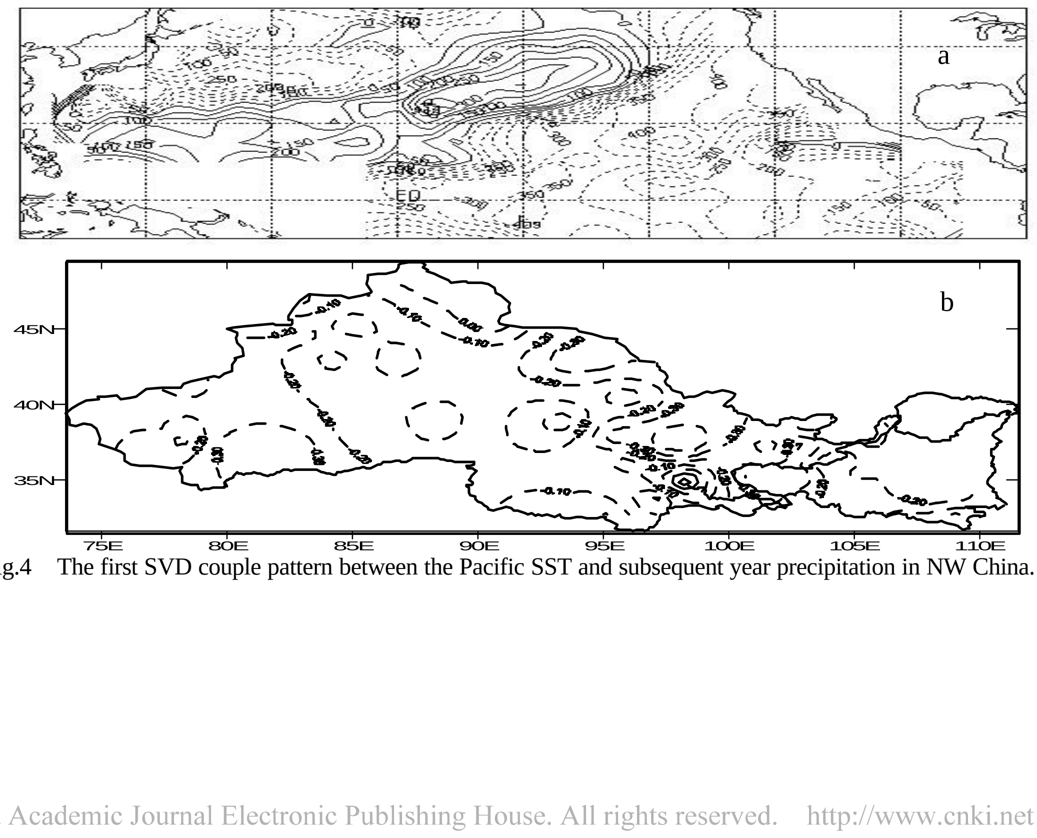

Fig.4 The first SVD couple pattern between the Pacific SST and subsequent year precipitation in NW China.

The second couple of singular vectors explain 13.5% of the total variance and the correlation coefficient is 0.66 for pattern coupling. For the left vector field (Fig.5a), positive values are found in the kuroshio and westerly drift regions while negative values are widely seen in the SST of the central and eastern parts of North Pacific and Californian current. For the right vector field (Fig.5b), however, positive values are observed in the south of the Qinghai Plateau, eastern Gansu, the Corridor and northern Tianshan Mt., though the main positive zones are located in northern Xinjiang north of the mountains with a central value higher than 0.4. In other words, precipitation will be more in areas north of the Tianshan Mt. if the SST is high over the kuroshio but low over central Pacific and Californian current.

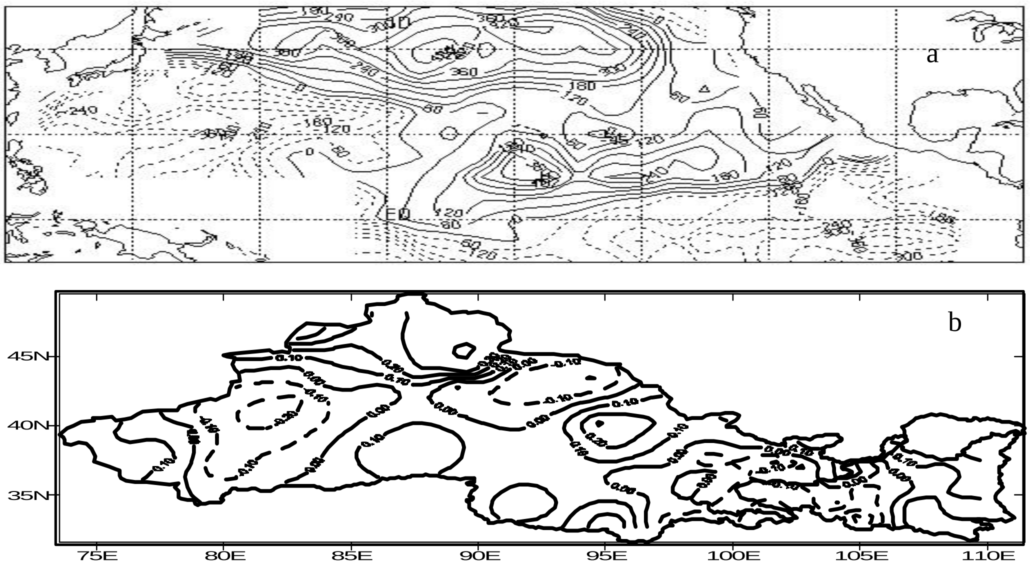

Fig.5 The second SVD couple pattern between Pacific SST and subsequent year precipitation in NW China.

As shown in the coupling pattern for the third couple of vectors (Fig.6), negative values are found in the kuroshio and vast regions in eastern Pacific, including El Niño3 and El Niño4 regions while positive values are present in the warm pool and areas north of it. In other words, when the La Niña pattern, which is increasing from east to west in the SST distribution of the Pacific Ocean, appears, the right vector field is the corresponding pattern, with strong positive zones of precipitation over the Qinghai Plateau (with the central value over 0.3) and the desert basin. In other words, precipitation will be more over the plateau region when the SST increases from east to west in the Pacific Ocean.

4 SIGNIFICANCE TESTS FOR SPRING PRECIPITATION IN NW CHINA AND SST ANOMALIES IN THE PACIFIC

As shown in the analysis above, the kuroshio and westerly drift are also two regions that are well correlated with spring precipitation in northwestern China when the SST is in some specific morphology near the equatorial Pacific region. A significance test is conducted of the time coefficient (RPC) determined by the REOF division for northwestern China over both El Niño and La Niña years and the results are compared with the interannual variation of SST for the kuroshio and westerly drift regions.

4.1 *Tests*

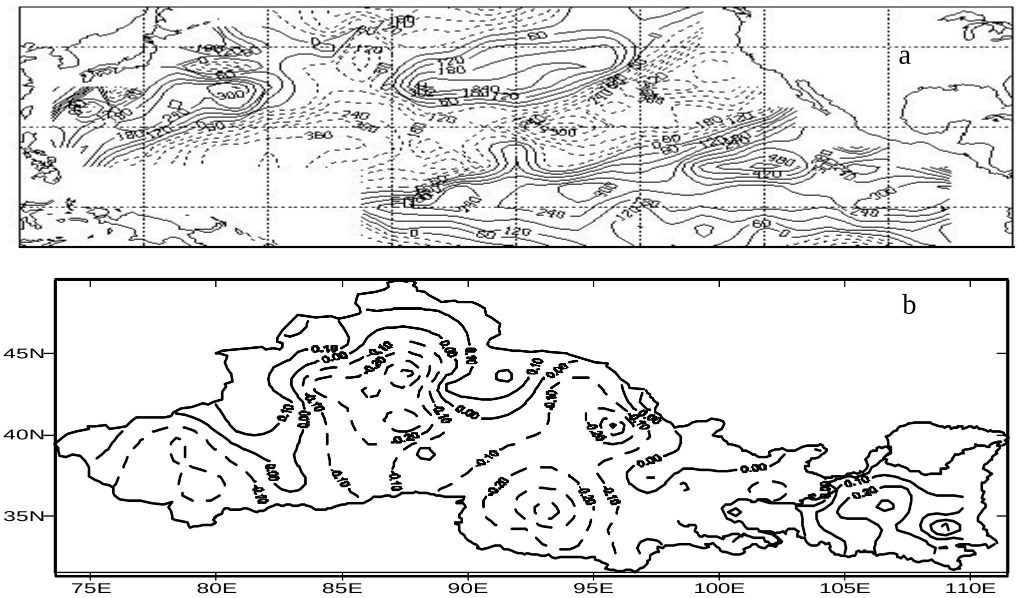

Fig.6 The third SVD couple pattern between Pacific SST and subsequent year precipitation in NW China.

The years in which El Nino takes place during 1961 – 1998[12] are 1963, 1965, 1968, 1969, 1972, 1976, 1982, 1983, 1986 – 1987, 1988 – 1989, 1991 – 1992, 1993, 1994, 1995, 1998. To verify the significance of precipitation difference in March – May in northwestern China in both El Nino and non- El Nino years, we use

$$t=\frac{\overline{x_1}-\overline{x_2}}{\sqrt{n_1 s_1^2+n_2 s_2^2}}\sqrt{\frac{n_1 n_2(n_1+n_2-2)}{n_1+n_2}}$$

in which $\overline{x_1}, s_1^2$ and $n_1, \overline{x_2}, s_2^2, n_2$ are precipitation mean, variance and number of samples for El Nino and non- El Nino years, respectively.

The expression above is used to determine the t tests for the spring precipitation in MAM months in the region in both El Nino and non- El Nino years. They show that $t > 1$ in the desert basin, the Corridor and northern Xinjiang and the $a = 0.10$ significance test has been passed. It indicates that the region of interest has strong response to the El Nino episode, suggesting difference of RPC for the pattern of desert basin between the El Nino and non-El Nino years, with $t = 1.9886 > t_{a=0.05}$.

The same technique is used to determine the t tests for the El Nino years and the spring precipitation in subsequent MAM months in the region. Apart from southern Xinjiang, the entire region has a t value greater than 1.00 and passes the $a = 0.10$ significance test. The difference is especially obvious in the desert basin where $t > 1.89$ and the $a = 0.10$ significance test is also passed. Correspondingly, Tab.3 gives the difference of RPC for the El Nino and non-El Nino years in the six anomalies-sensitive regions derived from REOF analysis of the spring precipitation in northwestern China. It also reveals stronger response to the El Nino episode by the Corridor, northern Xinjiang and desert basin, each of which corresponds to RPC.

Tab.3 *t*-test value between El Nino and non-El Nino

RPC	1	2	3	4	5	6
t	-0.3896	-0.7303	1.0926	-1.4476	0.8552	1.9886
$\alpha(t>t_\alpha)$			0.25	0.20		0.05

4.2 *Indicative meaning of the kuroshio and westerly drift for precipitation in NW China*

For the regions of kuroshio and westerly drift, the coverage is defined based on the work of Li[15] and Tang[16]. Fig.7 (a & b) gives the interannual variation and second-order tendency curves in the kuroshio region (20°N –30°N, 120°E – 150°E) and the westerly drift region (35°N – 45°N, 170°E – 175°W) in the MAM and DJF months. Fig.7 (c & d) gives the RPC interannual variation, 5-year running mean and second-order variation tendency for the MAM precipitation in northern Xinjiang and northeastern part of the plateau. The figures show that for the 5-year running mean and second-order variation tendency, the northern Xinjiang precipitation generally goes out of phase with the SST in the kuroshio region but goes in phase with the northeastern plateau precipitation. Nearly out-of-phase variations are also observed in the relationship between the northern Xinjiang and northeastern plateau precipitation and the kuroshio SST. It is also an indicator of the regionality and complexity of the precipitation in northwestern China. The figures also show that the SST experienced a change in the mid-1970's in the two regions, particularly so in the variation in DJF, which goes through a cycle of being warm, cold and warm again. It demonstrates that the La Nina episodes become less active while the El Nino episodes more active from the 1980's onwards, a conclusion agreeable with the result by Wei et al[15].

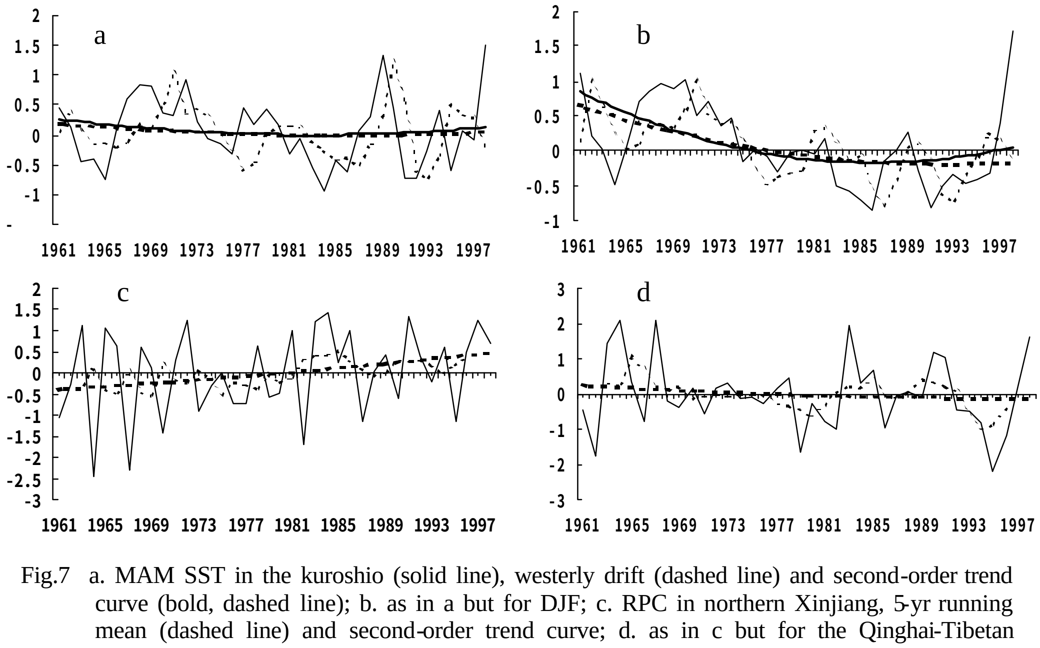

Fig.7 a. MAM SST in the kuroshio (solid line), westerly drift (dashed line) and second-order trend curve (bold, dashed line); b. as in a but for DJF; c. RPC in northern Xinjiang, 5-yr running mean (dashed line) and second-order trend curve; d. as in c but for the Qinghai-Tibetan Plateau.

5 CONCLUDING REMARKS

a. The SST anomalies of North Pacific SST is well correlated with the precipitation in the spring of northwestern China (from March to May). When the DJF Pacific SST is in the mature El Nino phase, precipitation is more in northwestern China; when the North Pacific SST in MAM is in the peak El Nino phase, however, precipitation is less over extended parts of the region; when the North Pacific SST in DJF is in the La Nina pattern, precipitation is more over the Qinghai Plateau region in MAM.

b. Apart from Nino3 and Nino4 regions, the SST in the westerly drift, kuroshio, Californian current and north equatorial current and their relative change are having significant correlation with the precipitation over the northwestern China in MAM. Specifically, the kuroshio SST varies out-of-phase with the northern Xinjiang precipitation but nearly in-phase with the northeastern plateau precipitation. In other words, low kuroshio SSTs are accompanied with more precipitation in northern Xinjiang.

c. The regions in which the MAM precipitation in northwestern China responds to the variation of Pacific SST are mainly in northern Xinjiang, the Qinghai Plateau and its northeastern part and the Corridor.

Spring is a season in which the general circulation is adjusting itself. Because of it, the 500-hPa ridge over Xinjiang is relatively weak and temperature increases slowly so that the spring precipitation in northwestern China can be quite special and complicated. The precipitation differs much in space and time in the onset and distribution. It therefore needs more study in the aspect of matching it temporally with strong signals such as the El Nino episode.

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