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THE INTERANNUAL AND DECADAL VARIABILITY OF PRECIPITATION FOR YUNNAN PROVINCE IN RAINY SEASON AND ITS RELATIONSHIP WITH TROPICAL UPPER LAYER TEAT CONTENT

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ABSTRACT: Based on the monthly precipitation data of 126 observation stations from 1961 to 2000 in Yunnan Province, the interannual and decadal variability of precipitation in rainy seasons are studied by using wavelet analysis. It is shown that there is a 2-6 year oscillation at the interannual time scales and a quasi-30 year oscillation at the decadal time scales. These periodic oscillations relate to the distribution of tropical heat content. When the precipitation is much more (less) than normal, the upper seawater is colder (warmer) in almost all the tropical Indian Ocean, and warmer (colder) in the western Pacific as well as colder (warmer) in the eastern Pacific. The key areas of the anomaly heat content distribution that have significant correlation to the Yunnan precipitation in rainy season are in the southern hemispheric Indian Ocean with a dipole pattern in the winter as well as in the deep basin of the South China Sea (SCS) before the Yunnan rainy season begins. Therefore, the anomalous distributions of the heat content in the southern Indian Ocean and the SCS In winter are good indicators for predicting drought or flood in Yunnan Province in the following rainy season.

Key words: rainy season precipitation in Yunnan Province; interannual and decadal variability; tropical oceans; heat content

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1 INTRODUCTION

Locating in the southwest of China, the Yunnan province is featured by complicated terrain and subjected to climate of low-latitude subtropical and tropical monsoon and direct impact from the Indian Ocean to the south. There are two seasons in a year, the dry season (November to the coming April) and wet season (May to October). The southwest monsoon from the Bay of Bengal contributes much to the precipitation in the wet season.

It is well-known that SST anomalies in the tropics play an important role in global climate changes. Previous work concentrates on the relation between the SST and precipitation in the province[1], especially the relation between the precipitation and the teleconnection of SST anomaly field in the Indian Ocean[2] or El Niño in the tropical eastern Pacific[3]. With more understanding of tropical air-sea interations and new evidence in recent years, it is proved that the anomalous signals for SST in tropical eastern Pacific are actually caused by the eastward propagation of anomalous signals of the sub-surface layer of the western Pacific along the thermocline. Then SST is not the only factor when the effect of tropical oceans on global climate changes is studied. The consideration should be expanded to the variation of thermal condition in sub-surface layer of the ocean. It is possible that the anomalous variation of thermal oceanic condition affects the monsoon and global climate. In view of the fact that changes in the wetness of Yunnan are somewhat teleconnected with the tropical ocean, it is necessary to discuss the relation between the anomalous variation of thermal content in the upper layer of tropical ocean

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and the precipitation in raining season.

2 DATA AND METHODS

To depict the variations of rainfall in the raining seasons of Yunnan, the precipitation data used in the work are the monthly mean from 126 measurement stations across the province over a period of 40 years (1961 – 2000). The amount of precipitation averaged over the wet season (May to October) is used to constitute a 40-year time series and standardize it. The thermal content information for the top ocean layer comes from the Simple Ocean Data Assimilation (SODA) of the United States, which is assimilated over the surface ocean layer from 0 to 125 m across the globe. Spanning from January 1950 to December 1999, the data are about 1°×1° in space resolution. The upper-layer thermal content is defined as the vertical integration in unit of °Cm of depth multiplying temperature of seawater within 0 – 125 m.

To study the interannual and interdecadal variations of the wet season precipitation in the province, the wavelet method[6] is used to probe the distribution in both ranges of time and frequency. Taking the "Morlet" as parent wavelet, the work selects the wavelet-scale factor s in the manner presented below.

$$s_j = s_0 e^{j\delta j}, \quad j=0, 1, \ldots\ldots, J$$

in which $J = \delta j^{-1} \log_2(N\delta t / s_0)$, $s_0 = 2\delta t$, N is the number of sample and δt is the sample interval, which takes 0.1 here. For concrete algorithm of wavelets, refer to [6]. In addition, techniques of composition and correlation are also used to study the links between precipitation in Yunnan's wet season and surface layer oceanic thermal content.

3 VARIATIONS OF PRECIPITATION IN YUNNAN'S WET SEASON

Fig.1 gives the series of wet season precipitation varying with time in Yunnan province. It shows that it is marked with significant interannual variation, and the difference can be very large from year to year, corresponding to drought and floods. The year 1966 is one that receives the most rainfall in the 40 years while 1992 is the year that records the least, with significant interdecadal variations. In other words, precipitation was generally more before mid-1970's than

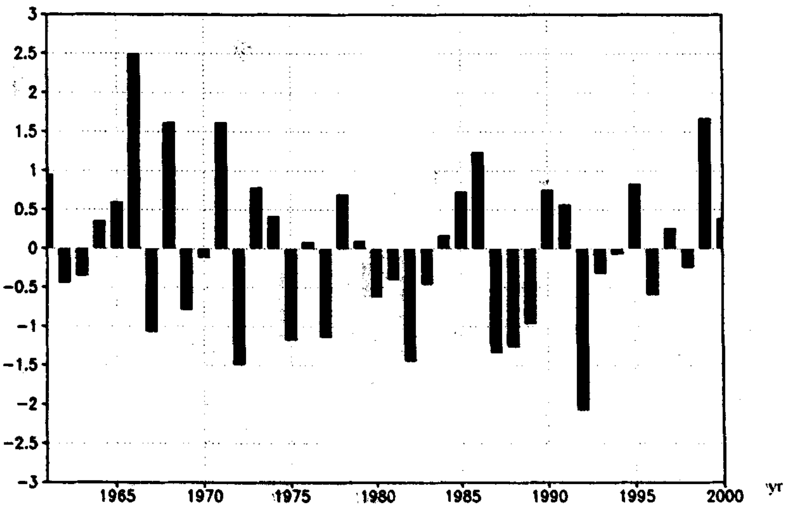

Fig.1 Variation of standardized precipitation with time in the wet season (May – Oct.) in Yunnan 1961–2000

after it. The falling trend stayed until early 1990's before rising again. It agrees with the drought / floods situation in the province.

To probe more into such multiple time scale variation of precipitation, Morlet wavelet transform is conducted of the above time series to know how it distributes over the ranges of time and frequency. From the distribution of overall variance of wavelet transform (being equivalent to power spectra, Fig.2a), we know that the total precipitation is characteristic of 2–3-year, 4–6-year and quasi-30-year oscillations. Examining the distribution of the real part of individual wavelet transform over the time and frequency ranges (Fig.2b), it is clear that interannual variations are the main features of the oscillation in Yunnan's wet season, with the main periods

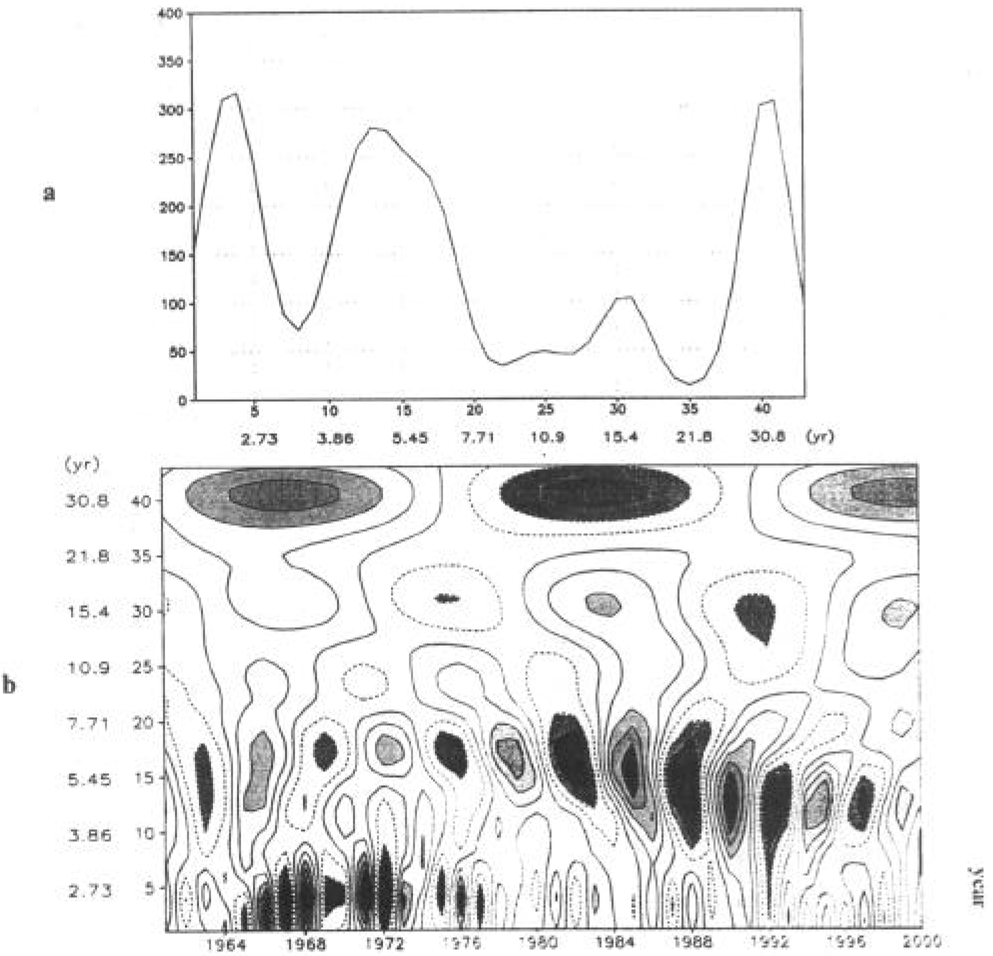

Fig.2 Distribution of overall variance (a) and the real part (b), of the wavelet transform, for precipitation in wet seasons of Yunnan. The abscissa in (a) is the scale of wavelet transform and the line underneath is the period in unit of year and the ordinate is the spectral value of variance of wavelet transform in unit of mm^2; the ordinate in (b) is the scale of wavelet transform and the column to the left is the period in unit of year.

from 2 to 6 years. It is noted that the most prominent period is 2-3 years before the mid-term of the 1970's. The quasi-2-year oscillation does not exist afterwards and is replaced by lower-frequency periodic variations from 4 to 6 years. The change from high to low frequency is more clearly shown in the distribution of power spectra of the wavelet (figure omitted). For the interdecadal variations, however, there is more precipitation before the mid-1970's point with the strongest center appearing in the middle and late stages of the 1960's. The precipitation is less over the period form mid-1970's to early 1990's, with the driest period occurring in mid-1980's, but precipitation increases again after 1990's. It seems the climate is having a shift from being dry to being wet. It agrees with the result of Duan et al. and goes quite well with the long-term variations of main precipitation modes in southwest China[2].

4 ANALYSIS OF COMPOSITE THERMAL CONTENT IN UPPER OCEANIC LAYER IN DRY AND WET YEARS OF YUNNAN

4.1 *Analysis of composite concurrent thermal content in upper oceanic layer in the tropics*

To understand the relation between the wet season precipitation and thermal conditions in the surface layer of ocean in the tropics, composite analysis is used. Following Fig.1, years in which standardized precipitation anomalies higher than 1 are grouped as wet years and those lower than –1 as dry years. By the definition, we thus have five wet years (1966, 1968, 1971, 1986 and 1999) eight dry years (1967, 1972, 1975, 1982, 1987, 1988 and 1992). The rest are all normal years. Thermal content in the top ocean layer (0 – 125 m) is then composed together for the tropical ocean over 30°S – 30°N respectively for the wet, dry and normal years (Fig.3).

Fig.3a gives the difference in thermal content wet years minus dry years in which shaded areas are where the *t*-test passes the 95% confidence level. It shows that key regions related to the wetness in Yunnan's raining seasons are over the entire tropical Indian Ocean, west Pacific warm pool, eastern Pacific off the South America coast and subtropics in south Pacific. When there is more precipitation in the wet season, land-sea contrast increases to strengthen the southwest monsoon from India except for coastal Somalia where it is cooler. It is similar to the work of Yan et al[2]. who address the relation between precipitation in raining season in southwest China and SST anomalies in the summer of the Indian Ocean. Over the Pacific Ocean, however, seawater is warmer than normal in the west Pacific warm pool while it is cooler in eastern Pacific in what we call a La Niña mode of the tropical Pacific. It is consistent with the relation between May precipitation in Yunnan and SST over the tropical Pacific, as what is studied by Wang et al[3]. The same is true otherwise. It is then known that the onset of dry or wet raining seasons in Yunnan not only connects closely with the thermal conditions in the upper layer of the Indian Ocean, but also responses to El Niño (La Niña), the strongest interannual signal over the tropical Pacific. Furthermore, the thermal content in the layer accounts for most of the SST signal.

To study the key waters resulting in the difference of thermal oceanic content in more details, anomalous variations relative to normal years are investigated respectively for the dry and wet years. Fig.3b gives the difference field of thermal content with the wet years minus normal years. When precipitation increases in Yunnan, relevant key waters are in the Arabian Sea and tropical Pacific where it is anomalously cold and south Pacific where it is positively anomalous. When precipitation decreases (Fig.3c), relevant correlative waters are mainly over the tropical Indian Ocean, which correspond to anomalous warmer upper layers of the Indian Ocean. It is then clear that the oscillation of precipitation intensity is mainly related with the thermal conditions of the upper layer of the Indian Ocean, which, via the changes in the layer, affects the intensity of the Indian summer monsoon and further affects the precipitation in Yunnan. In the meantime, the province's precipitation is also subjected to, to some extent, the oceanic thermal content in the Pacific Ocean. It is mainly reflected in the intensifying role displayed when season's precipitation increases. The mechanism may work through altering the Walker cell and Hadley cell to affect the summer monsoon in east Asia and thus plays a part in the precipitation in Yunnan.

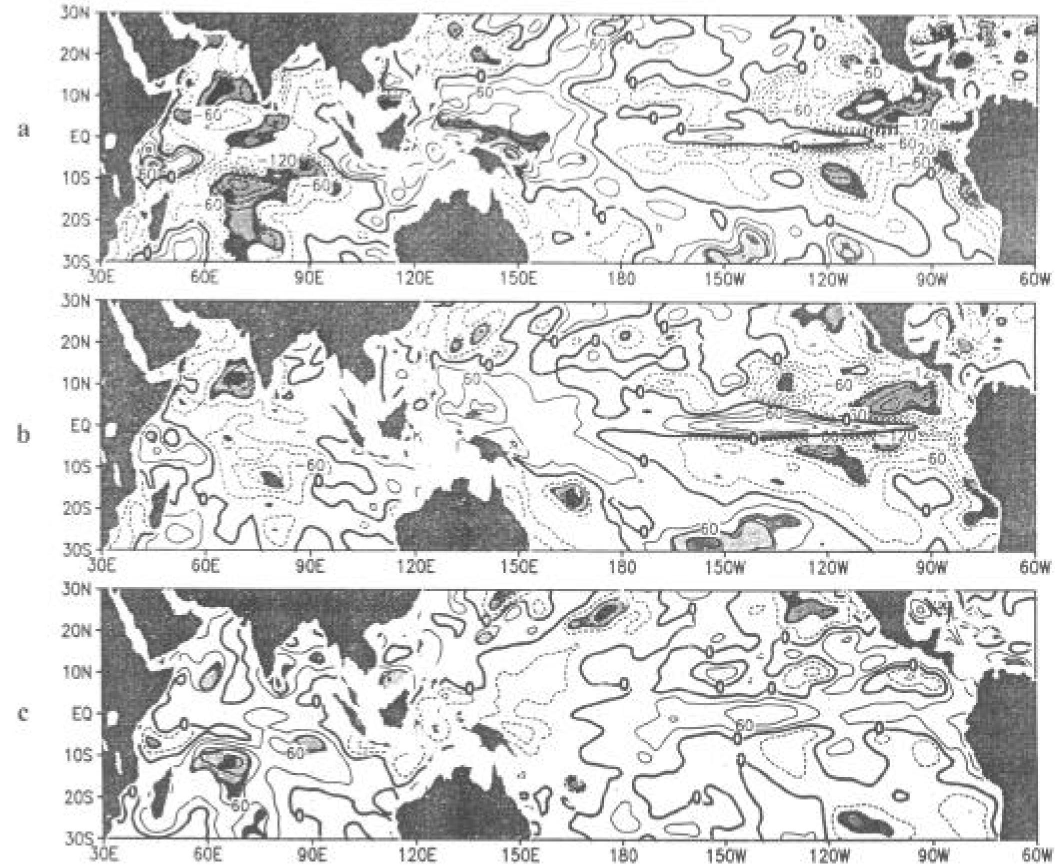

Fig.3 Composite distribution of thermal content in tropical oceans in the concurrent years of wet seasons (May – October) in Yunnan. (a) is the difference by subtracting dry years from wet years and shades stand for regions with confidence levels more than 90%, 95% and 99%, with isolines at intervals of 30°Cm, the solid, bold line the zero line, the solid line the positive area and the dashed line the negative area; (b) is the difference by subtracting normal years from wet years; (c) is the difference by subtracting normal years from dry years.

4.2 *Analysis of composite preceding thermal content in upper oceanic layer in the tropics*

As the ocean has a relatively long "memory", precipiation in Yunnan's wet season is not only related to the thermal content over the concurrent period, but also may associate with thermal anomalies in the tropical ocean in the preceding winter (DFJ). As shown in Wang et al. [2], who study it using the SST of the Indian Ocean over the DJF period and report high value for the forecast of the wetness in the raining season of the province. Fig.4 gives the distribution of thermal content in the surface layer of ocean composed for the wintertime DJF prior to the wet season in Yunnan. From Fig.4a, we know that the anomalous intensity of the precipitation is significantly correlated with the thermal content of the tropical ocean. The typical distribution over the Pacific is similar to the composite distribution over the simultaneous period except that that the positive anomalies in the west Pacific warm pool shifts obviously to the north. Apart from the findings, years with less precipitation tend to relate with the thermal conditions in south

Pacific (Fig.4c) while years with more precipitation with an anomalous colder equatorial eastern Pacific (Fig.4b). As for the relation between the anomalous precipitation in Yunnan and the Indian Ocean (Fig.4a), it differs from the concurrent relation in which it links with the entire Indian Ocean's anomalies; it shows a semi-concentric wave-like distribution that alternates positive phases with negative ones, which radiates outward centering around the equatorial southeast Indian Ocean. It travels from north Indian Ocean to the southwest on a route popular with the winter monsoon before turning northwest after crossing the equator, with more than one center of strong positive or negative on each loop.

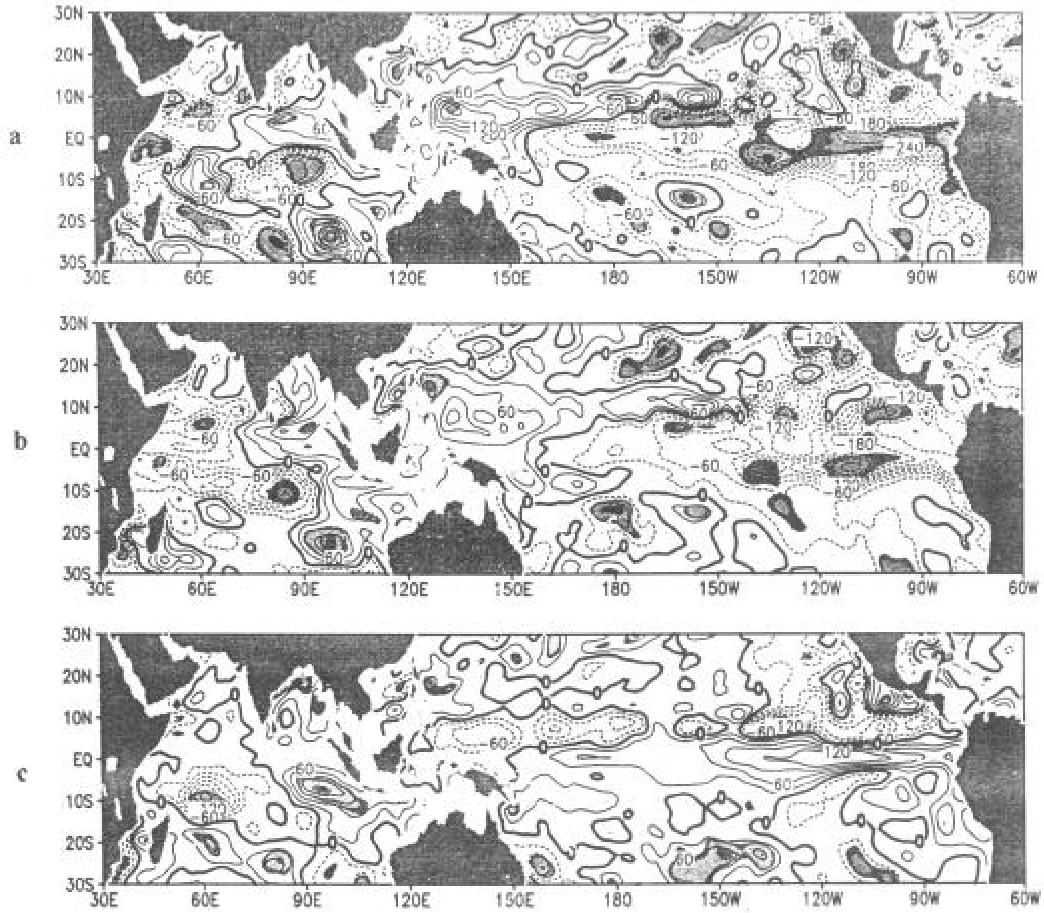

Fig.4 Same as Fig.3 but for the composite distribution of the preceding winter (DJF).

As shown in the alternative distribution of positive and negative centers, a pattern similar to what Webster (1999) put forward appears, namely, an east-west dipole appears. When precipitation increases in the season of Yunnan, it is northward in north Indian Ocean, accompanied by another couple of NW-SE positive-negative dipole in the Southern Hemisphere over southeast Indian Ocean (Fig.4b). When the precipitation decreases, the whole of the east-west dipole, lying over the Indian Ocean in the preceding winter, shifts to southern Indian Ocean (Fig.4c). When the anomalous distribution is colder in the west than in the east in equatorial Indian Ocean wintertime, winter monsoon is weakened over the northern part of the ocean, followed by increased rainfall in Yunnan's wet season. The same is true otherwise. Additionally, a saddle distribution appears over the southern Indian Ocean. The anomalous changes in the upper layer of the ocean thermal conditions makes it possible for the low-level Mascarene cold anti-cyclone to enhance and for the equatorial airflow crossing from the winter hemisphere to summer hemisphere near Somalia to weaken, i.e. the Indian winter monsoon weakens, then precipitation will increase in the Yunnan's raining season. Otherwise is true.

5 CORRELATION ANALYSIS OF RAINING SEASON PRECIPITATION IN YUNNAN VS. THERMAL CONTENT IN THE UPPER LAYER OF THE OCEAN

5.1 *Correlation between raining season precipitation in Yunnan and concurrent thermal content in the upper-layer of the ocean*

From the analysis above, we know that there are significant 2–6-year interannual variations and quasi-30-year interdecadal variations in the anomalies of the precipitation in the wet season of Yunnan; some links have been established between the extreme years of precipitation anomalies and anomalous distribution of thermal content in the upper layer of the ocean in the tropics, as shown in the composite analysis. It remains to be supported with evidence, however, how the overall changes in precipitation anomalies correlate with the thermal content.

Fig.5a gives the concurrent field of correlation between the time series of the season's precipitation in the province and the anomalies of the thermal content in the upper layer of the Pacific Ocean. It shows clearly that the equatorial west Pacific is significantly in positive correlation while the tropical eastern Pacific is an extensive region where negative correlation is dominating. Starting from the warm poll in the equatorial western Pacific, the positive correlation over the west Pacific is extending towards northeast and southeast in a right-recurvature of "V" shape by 90 degrees, consistent with the warm anomalies (i.e. El Niño), a typical SST distribution. For the Indian Ocean, however, almost the whole ocean is negatively correlated

a

b

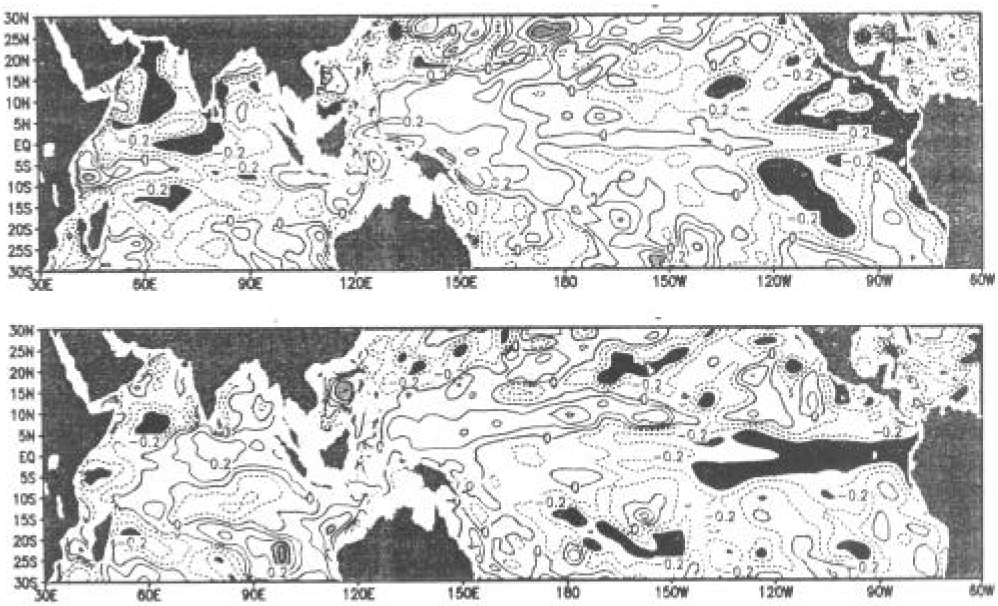

Fig.5 Correlation distribution between precipitation in the Yunnan wet seasons and the oceanic thermal content in the upper layer of ocean in the concurrent period (a) and preceding winter (b). The shaded areas are locations of significant correlation where the confidence level passes 95%.

except for the Somalia coast. The distribution of correlation agrees with the result of the composite analysis shown in Fig.3a. It indicates that some degree of correlation exists between the anomalous amount of precipitation in Yunnan's raining season and the thermal conditions in the upper layer of the tropical Pacific.

5.2 *Correlation between raining season precipitation in Yunnan and preceding thermal content in the upper-layer of the ocean*

Fig.5b gives the preceding field of correlation between the time series of the season's precipitation in the province and the anomalies of the thermal content in the upper layer of the Pacific Ocean. It shows that waters that relate most significantly, and negatively, with the precipitation anomalies in the province are mainly over the regions of equatorial central and eastern Pacific, while the equatorial regions of central and western Pacific are positively correlated; the distribution is more complicated over the Indian Ocean when it comes to the patterns of positive and negative correlation centers, which agree well with the results achieved with the composite analysis (Fig.4a). Being quite indicative to precipitation in the wet season, the anomalous distribution of Indian Ocean SST in winter is to be used with great care taken to select key regions sensitive to forecast, especially the east-west dipole patterns, which are similar to SST anomalies over the Indian Ocean, for they could cause anomalous variations of the precipitation by changing the winter monsoon system over India. Besides, it is noted that the spectral analysis of Wang et al. points out some kind of linkage between the precipitation in Yunnan and SST in the South China Sea[9], and the our results are further proof that the anomalous variations of the precipitation are showing significant positive correlation with the oceanic thermal content in the upper layer of the whole deep water basin throughout winter in the region of South China Sea. It is concluded that the anomalous variation of thermal conditions in the surface layer of the sea over the previous winter is also a key predictor of considerable weight in making long-term forecast of the wetness in raining seasons in Yunnan, though more work remain to do to probe into possible processes and mechanisms behind the relation.

6 CONCLUDING REMARKS

The precipitation in Yunnan's wet season is marked with significant interannual and interdecadal variations, the former being 2 – 6 years in periodic oscillations, specifically being 2 – 3 years before the point of the interdecadal climatic abrupt change in 1976 but 4 – 6 years after it. The interdecadal variation is, on the other hand, mainly of quasi-30-year oscillation; precipitation is more before the mid-point of the 1970's, followed by less precipitation from mid-1970's to early 1990's when the province receives less rain than before, and then by a period of increasing rainfall again since the 1990's, reversing the trend of getting drier to one of getting wetter in the climate.

The key regions of anomalous distribution of upper-layer of oceanicn thermal content that correlate with the Yunnan's seasonal precipitation are mainly ENSO-like patterns over the tropical Indian Ocean and equatorial Pacific. When precipiation is more in Yunnan, it is anomalously colder the whole Indian Ocean and anomalously warmer west Pacific warm pool but anomalously colder in eastern Pacific. Otherwise is true.

The anomalies of the oceanic thermal content in the upper layer of the Indian Ocean during the preceding winter of Yunnan's wet season, especially the anomalous thermal variation of the east-west dipole in southern Indian Ocean, are well correlated with the precipitation anomalies in the province over the time afterwards. In the meantime, the upper-layer oceanic thermal conditions in the deep water basin of the South China Sea over the preceding winter are positively correlated with the precipitation in the raining season of the concurrent year in the province. It is then known that the thermal conditions in winter over southern Indian Ocean and the South China Sea can well indicate the wetness of the raining season in Yunnan for a time to come.

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