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MEAN SQUARE DEVIATION ANALYSIS OF INTERANNUAL SST VARIABILITY IN TROPICAL PACIFIC AND INDIAN OCEAN

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ABSTRACT: Using the SST data series in tropical ocean (20°N ~ 20°S, 50°E ~ 80°W) during 1951 ~ 1997 to calculate its monthly mean square deviation, the work obtains results showing that interannual SST variability of the Pacific is more significant than that of the Indian Ocean, especially near the central and eastern equatorial Pacific (165°W～90°W, 6°N～6°S), where it ranges from 2°C to 4°C. The interannual SST variability is obvious in November and December but small in March and April. The interannual variability of “warm pool” SST is not so obvious as that of the eastern equatorial Pacific. However, interannual SST variability of the Indian Ocean ranges from 1°C to 2°C or so, being smaller than that of the Pacific. In the Indian Ocean, interannual SST variability of the Southern Hemisphere is more obvious than that of the Northern Hemisphere. According to above characteristics of interannual SST variability, the key sectors are determined.

Key words: mean square deviation; SST field; high-value sector

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1 INTRODUCTION

Receiving the most solar radiation across the globe, the tropical ocean is the region that is of special position in the energy budget and provides the atmospheric heat engine with most of the fuel. In the tropics, atmospheric motions at various scales are subject to air-sea interactions and in turn exert their influence on the changes in weather and climate in the mid- and high- latitudes, by way of the general circulation. It is then seen that the tropical ocean is specially important in storing the heat as the surface has the largest area of all waters, playing an specially important role in heat storage. During the process, the sea surface temperature and its anomaly (SSTA) are importantly shown in the oceanic effect on the atmospheric ocean, posing great influence on the general circulation and climate.

Through some observational studies, people have found that the change in the thermal conditions of the ocean can affect the general circulation and climate, particularly so in a number of key regions. They include the equatorial eastern Pacific waters where the El Niño event takes place and the "warm pool" of the equatorial western Pacific Ocean where the SST is the highest. Global-scale anomalies of weather and climate are usually resulted in the years of anomalously warm or cold SST in the tropics —the higher the SSTA, the more anomalous the weather and climate will be. It is true otherwise. It is therefore important for the study of climatic change to include the analysis of the interannual variation of the tropical SST.

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In much of the previous research[1-13], emphasis were on the relationship between the change of temperature over tropical ocean surface and the interannual variation of the general circulation and climate, with the subject of temporal and spatial distribution of the interannual variation of SST much intact. It is with this observation that the current work deals with it from the point of mean square deviation for identification of key areas in which the interannual variation of tropical SST is the maximum and for better understanding of the effects of the SSTA in low-latitude tropical Pacific and the Indian Ocean on the weather and climate in eastern Asia.

2 DATA AND METHODS

Regional monthly mean 5°×5° gridpoint data are used in the work. They are extracted from the Specific Climatic Dataset, by the code of 96-908-04-08, of the Research on Short-term Climate Prediction System in China, by the code of 96-908, a key scientific and technological project in the 9th five-year economic development plan of China. From the tropical domain of waters bounded by 20°N ~ 20°S, 50°E ~ 80°W, a total of 368 gridpoints have been selected in the monthly SST field from 1951 to 1997 and mean square deviation of the interannual variation is calculated for each of them with the following equation of:

$$S=\sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{x})^2}{n}}$$

where S is the mean square deviation, x_i is the monthly mean SST and $\overline{X}$ is multi-year mean, at the gridpoint, and n is the length of the sample. The mean square deviation at the gridpoint shows the magnitude of the interannual variation of SST. It is then graphically presented in spatial distribution charts for individual months. By studying these charts, we may be able to seek the temporal and spatial patterns in the interannual variation of SST and to identify the key areas where the variation is the largest.

3 ANALYSIS OF MEAN SQUARE DEVIATION OF SST

3.1 *Analysis of mean square deviation of the Pacific SST*

As shown in Fig.1, the SST varies between 1.2°C and 6.0°C across the interannual range for the entire region of the Pacific Ocean, with the maximum in May over waters at 2.5°S ~ 7.5°S, 85°W ~ 80°W and maximum mean deviation as high as 1.74 (Fig.1), the minimum in November over waters at 12°N ~ 20°N, 85°W ~ 80°W and maximum mean deviation as small as 0.29.

Examining the mean square deviation chart for all of the 12 months, we find that there is a region (175°W ~ 95°W, 6°N ~ 6°S) of significant interannual variation of SST near the equator with the mean square deviation higher than 0.8 all over it, which is called a high-value sector here. The regional maximum occurs in November with the mean square deviation as high as 1.69 (Fig.1) and over 1.0 in extensive portion of the waters.

Moving with season, the strip-shaped high-value sector weakens significantly in January ~ April, dropping to its minimum in both area and central value in April. Regions with the February mean square deviation are located separately in (180° ~ 100° W, 5.5°N ~ 8.5°S) and (168°E ~ 178°E, 2.5°N ~ 2.5°S). There are two centers in (180° ~ 170° W, 0° ~ 3°S) and (160°W ~ 120° W, 3°N ~ 4°S). The high-value sector are split into two in March, one in (170° ~ 180°W, 3° ~ 3°S) and the other (180° ~ 125°W, 6°N ~ 6°S). In April, high values are shown in two smaller

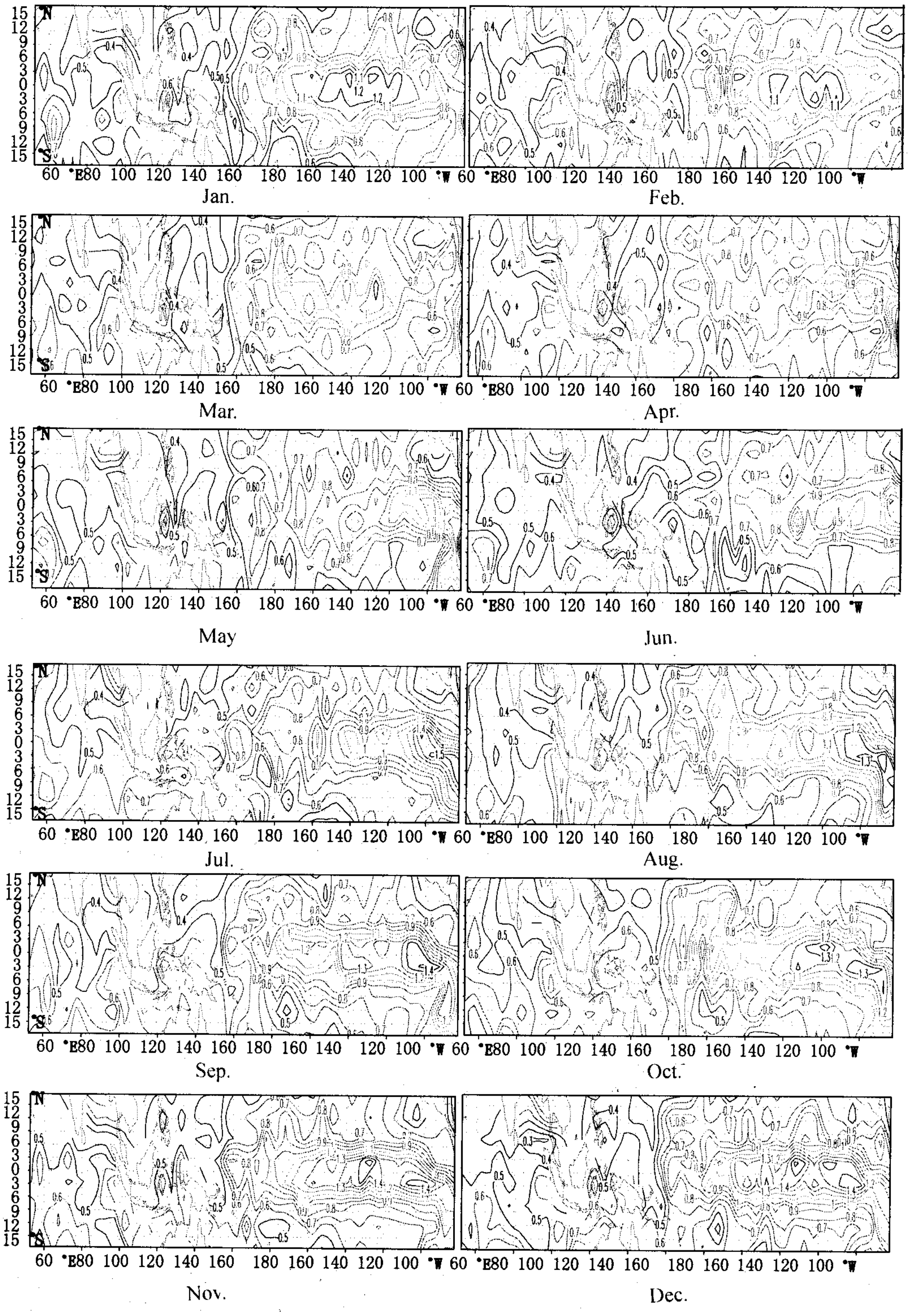

Fig.1 Distribution of mean square deviation from January to December of the SST in the equatorial Pacific and Indian Ocean.

regions near the equatorial eastern Pacific (120°W ~ 110°W, 0° ~ 5°N and (105°W ~ 95°W, 0° ~ 5°S). The high-value region is larger in area and magnitude in May, locating in waters (120°W ~ 80°W, 5°N ~ 6°S). In June, the high-value sector expands westward to 150°W with little change in the mean square deviation; its July area remains virtually unchanged though with increased magnitude. Another small region of high value appears to the west of what is originally the June sector (165°W ~ 155°W, 6°N ~ 4°S). Compared with July, the smaller high-value region has merged with the larger one in August, without much change in the core.

Autumn is the season when the high-value sector evolves from a stable phase to an all-out strengthened one, which is a time of abrupt change. In September and October, the sector develops full-stretched with the western part expanding to 180° and well-marked variation in the core. A maximum central area for October appears east of 140°W and a sector in which the mean square deviation is greater than 1.0 is present from 180° to 140°W. Winter is the full-swing season of high-value sectors. In November, it extends to 180° to the west and 80°W to the east, with three central areas concentrating from 160°W to 90°W. In December, the value of mean square deviation reaches the maximum, being the strongest in the year, again without much change in the location of the core, though with the magnitude and area larger than those in November. In January, the high-value sector begins to weaken and withdraws to 175°W to the west and 100°W to the east, with the core in a complete piece, which is reduced in magnitude.

Tab.1 presents the maximum mean square deviation of SST within the high-value sectors of the Pacific Ocean for all months. It is shown that it is smaller in January ~ May than in June ~ December, an indication that the SST varies within a small (large) range of the interannual cycle in the first (second) half year.

Tab.1 Max. mean square deviation of SST within the high-value sectors of the Pacific for all months

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.	1.36	1.31	1.25	1.59	1.35	1.63	1.62	1.47	1.41	1.53	1.69	1.55

By comprehensive analysis of the distribution of mean square deviation of SST, we know that the region (80°W ~ 90°W, 3°S ~ 9°S) has the maximum value for the entire tropical Pacific. It begins to expand from March. By June, it has enlarged westward to 105°W while the eastern core starts shrinking. The westward expansion is seen at 110°W in July and 135°W in August. The area decreases gradually in the three months of September, October and November with the maximum shifted westward to places between 120°W and 100°W, reducing to the minimum in December and almost disappearing all together in February.

Besides, there are two regions in the Pacific in which the SST is relatively stable, one in 110°W ~ 80°W, 10°N ~ 20°N, ranging from 1.2°C to 2.5°C, with the maximum mean square deviation of 0.62 appearing separately in March and June and the minimum of 0.34 in January, the other in 180° ~ 145°W, 10°N ~ 20°S, ranging from 1.2°C to 2.4°C, with the maximum mean square deviation of 0.63 appearing in February and the minimum of 0.33 in November (Fig.1).

3.2 *Comparison of mean square deviation between western Pacific warm pool and equatorial eastern Pacific*

It is noteworthy that there are all together 13 El Niño and 11 La Niña events between 1954 and 1997. The El Niño event starts mostly in the spring and sometimes in the summer and autumn. Its major positive anomaly can last as long as 1 year or longer and the maximum positive

SST anomaly usually occurs in November ~ December, with the average of more than 1°C and extremes of 4°C in some localities. In the El Niño years, the SST would persistently rise in anomaly over the entire waters of the equatorial eastern Pacific as well as anomalies on the coast of Peru. When the positive anomaly of SST is persistently large over the former region, an El Niño event is said to happen. It is observed that the mean square deviation is large on the Peruvian coast from April to August and the spring value is higher than the summer one while it is quite large near the equator in central Pacific. It coincides with the usual waters in which the El Niño event takes place. We have also observed that the interannual variation is insignificant from month to month in the SST in and around the "warm pool" of the equatorial western Pacific, with the mean square deviation staying around 0.5°C, which is just half that over the waters of the equatorial eastern Pacific.

3.3 *Analysis of the mean square deviation of the SST field in the Indian Ocean*

It is generally the case that the SST varies in a more stable way in the Indian Ocean than in the Pacific Ocean. Its range of interannual change is between 1.2°C and 4.8°C over the entire region. The maximum occurs in January in waters of 12°S ~ 15°S, 107.5°E ~ 112.5°E with the mean square deviation as high as 1.20 and the minimum, less than 0.3, appears in December in waters of 4°N ~ 9°N, 80°E ~ 100°E.

The high-value sector of the Indian Ocean consists of two areas, one in the Northern Hemisphere and the other in the Southern Hemisphere. The area and mean square deviation are larger in the Southern Hemisphere. For the entire Indian Ocean, the SST field varies more in the Southern than in the Northern Hemisphere. See Fig.1.

For the Northern Hemisphere, the high-value sector is over waters of 80°E ~ 100°E, 10°N ~ 20°N and the mean square deviation varies within a range of 0.50 ~ 1.20. See Fig.1. The area changes with the season such that it reduces in autumn with September having the minimum and retrains within 100°E ~ 105°E, 12.5°N ~ 20°N but it strengthens to its strongest in winter.

Tab.2 Maximum mean square deviation of SST within the high-value sectors of the Indian Ocean for all months

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.	0.96	1.09	1.20	0.96	0.78	0.71	0.76	0.83	0.74	0.66	0.82	0.95

For the Southern Hemisphere, the high-value sector consists of two regions, one in the eastern part of the Indian Ocean and the other in the western part. The eastern region is stationary over waters in 50°E ~ 80°E, 3°S ~ 20°S and the western one in 90°E ~ 120°E, 0° ~ 20°S. During the summer and autumn, the two high-value sectors merge into one. In spring, the eastern high-value sector is weak. It then crosses the equator in summer to expand northward, most dramatically so in July (Fig.1). It becomes stronger in winter with a maximum of 0.84 in January. The western sector varies little in spring with the maximum in July. Its strongest period occurs in autumn when it expands to the west to join with the eastern sector.

Comparing the monthly maximum of mean square deviation of the high-value sectors in both hemispheres, we know that it is larger in magnitude but smaller in area in the Northern than in the Southern Hemisphere.

There is an additional region in which the SST is stable in the Indian Ocean, which is located in 50°E ~ 100°E, 12°N ~ 3°S. The minimum mean square deviation (0.28) also occurs in August in 100°E ~ 105°E, 2.5°N ~ 7.5°N. It should be noted that the region of waters is just where the seasonal change is the smallest in the Indian Ocean.

Tab.3 Same as Tab.2 but for the Southern Hemisphere

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.	0.87	0.92	0.79	0.77	0.78	0.82	0.83	0.82	0.73	0.77	0.79	0.88

In summary, the SST varies steadily in the Indian Ocean. Comparatively, waters in the Southern Hemisphere are more unstable than those in the Northern Hemisphere, especially so in autumn, because the high-value sector is smaller in the Northern Hemisphere while the eastern and western high-value sectors have joined together in the Southern Hemisphere. In the other three seasons, the high-value sector in the Southern Hemisphere is split into two, with the magnitude largely the same as in the Northern Hemisphere.

3.4 *Comparison between the Pacific Ocean and the Indian Ocean*

In general, the mean square deviation is larger in the SST field of the Pacific Ocean than that of the Indian Ocean, whether it is judged from the maximum value or the area. For the maximum mean square deviation, the Pacific Ocean is 1.74, appearing in May and the Indian Ocean is 1.20, appearing in March. Regions with the value larger than 0.80 (175°W ~ 95°W, 6°N ~ 6°S) can be found in the Pacific all the year round but they are largely non-existent in the Indian Ocean.

Tab.4 Comparison of max. mean square deviation between the Pacific Ocean (P.O.) and Indian Ocean (I.O.)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
P.O.	1.36	1.31	1.33	1.59	1.74	1.62	1.53	1.14	1.41	153	1.69	1.55
I.O.	0.96	1.09	1.20	0.96	0.77	0.79	0.89	0.83	0.93	0.77	0.82	0.88

With the change in time, the spatial field of the SST mean square deviation changes in the Pacific and Indian Oceans, though the effect is more significant in the former than in the latter. For the high-value sector near the equator, it is over the equatorial eastern Pacific in the spring and summer but the equatorial central and eastern Pacific in the autumn and winter. The western coast of the Indian Ocean is where the high-value mean square deviation prevails and stays consistently through all seasons. The seasonal change is, however, insignificant in central Indian Ocean south of the equator so that waters with relatively large variation of SST are stationary in the central Indian Ocean south of the equator and around Indonesia.

4 CONCLUDING REMARKS

a. Over the course of a year, the maximum interannual variation of SST occurs in the second half while remaining relatively small in the first half.

b. There is a strip-shaped high-value sector of mean square deviation over the equatorial ocean surface of the Pacific, which varies significantly on the interannual scale.

c. With the shift of season, this high-value sector also changes, by the smallest margin in April with the location in 140°W ~ 80°W but by the largest margin in December with the location from 180° ~ 80°W, covering extensive waters.

d. Compared with the equatorial eastern Pacific, the "warm pool" in the western Pacific has small mean square deviation. In other words, the interannual change is less than that in the equatorial eastern Pacific for all individual months.

e. For the whole year, the mean square deviation of SST is always smaller than that of the Pacific Ocean in the simultaneous period. In other words, the interannual variation of SST is less significant in the Indian Ocean than in the Pacific Ocean.

f. In the Indian Ocean, the SST has a larger interannual variation in the Southern than in the Northern Hemisphere.

g. Comparisons have been carried out between our findings and much of previous efforts concerning the effect of tropical SST on weather and climate[1-13], showing that the waters having the most impact on weather and climate are the key regions that have the maximum interannual variation of mean square deviation of the SST.

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