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PRELIMINARY RESEARCH OF THE PACIFIC-INDIAN OCEAN SSTA MODE AND DEFINITION OF ITS INDEX

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ABSTRACT: Applying the empirical orthogonal function (EOF) analysis to the sea surface temperature (SST) field of the tropical Pacific and Indian Oceans for determination of the first eigenvector field, the current work reveals that there are significant zonal gradients of SST in all seasons of the year in the northwestern and eastern Indian Ocean and equatorial central and eastern Pacific and western Pacific. It is also found that the variance contribution rates of the first EOF mode of every season is more than 33%. This shows that this kind of spatial distribution of the SST is stable. This pattern is named Pacific-Indian Oceans SSTA mode. Through careful analysis and comparison, an index of the mode was defined.

Key words: Pacific Ocean; Indian Ocean; SSTA mode; Index

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1 INTRODUCTION

As early as in the 1960's, Bjerknes[1, 2] began to study the ENSO phenomenon, a significant event in air-sea interaction across the world. Since then, its effect on the global climate has become an issue widely addressed in climate research, setting off a huge amount of work. The effort reveals anomalous changes of SST not only in the Pacific Ocean but also in the warm pool of the western Pacific and Indian Ocean on the interannual scale, apart from tropical oceans due to the ENSO. The anomalous changes are also responsible for anomalies of the general circulation and weather / climate. In the work of Yan et al. [3] in 2000, with the aid of the GCM IAP9L at the Institute of Atmospheric Physics of the Chinese Academy of Sciences, it is found through simulation that the warm (cold) SSTA in the equatorial low-latitude regions of the Indian Ocean may generate wavetrains of winter or summer teleconnection patterns in the mid- and higher-latitude regions of the Northern Hemisphere, similar to PNA or EAP, which play important roles in the anomalies of circulation or weather / climate in the mid- and lower-latitude areas of the Asian monsoon region. As shown in some of the more recent work, the dipole oscillations are also present at the ocean surface near the equator in addition to those of the SST in both the eastern and western parts of the Pacific Ocean. Chen et al. had earlier noticed that the zonal gradient of Indian Ocean SST would affect the summer precipitation in China. Li[4, 5] and Xiao et al.[6] also showed in their study that the Indian Ocean dipole affected the climate change significantly. In fact, the Indian Ocean dipole closely links with the Pacific ENSO, as the variation of SST in the tropical ocean is not an isolated phenomenon. Li et al. analyzed the

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temporal and spatial distribution of SST in the Indian Ocean during the ENSO episodes and Yan et al. compared SSTA of the Indian Ocean during two phases of the ENSO cycle. Both of them suggest good correlation between the variation of SST in the Indian Ocean and that in the equatorial eastern Pacific area and significant dipole oscillations during the ENSO episodes. It has been shown through observation and study over the past few years that the equatorial western Pacific is much similar to the eastern Indian Ocean, especially in the SST and its anomalous variation. As shown by Chen et al.[8 – 10] and Wu et al.[11], the Indian Ocean SST not only varies significantly on the annual scale but also correlates positively with the eastern equatorial Pacific SST, this correlation made possible by considerable gear-like couplings between the zonal monsoon circulation above the equatorial Indian Ocean and Walker cell above the Pacific Ocean; the ENSO and dipole actually represent a mode associated with the Walker cell in the Pacific and Indian Oceans respectively. It is then, in addressing the effect of SSTA of the two oceans on weather and climate, necessary to view the ENSO and dipole as a unified anomalous mode of the SST. It is just based on this consideration that the current work treats the Pacific ENSO and Indian Ocean dipole as a unified mode and seeks scientific definition of the index of the mode in addition to analyzing its spatial distribution.

2 DATA AND MAIN METHODS OF COMPUTATION

For the study, the reanalyzed monthly 2°×2° SSTA dataset of Reynolds that covers the period from 1951 to 2001 was selected[12].

The Empirical Orthogonal Function (EOF) is applied to decompose the SST field for the region of tropical ocean (40°E – 90°W, 20°S – 20°N) between 1951 and 2001.

3 SPATIAL DISTRIBUTION OF SSTA MODE OVER PACIFIC-INDIAN OCEANS

An El Niño episode took place in 1997, the strongest ever in the 20th century, yet it was not accompanied by serious droughts over the Indian subcontinent as it was usually seen in years of El Niño and instead, saw anomalous SST as high as 2°C over the equatorial western Indian Ocean. It attracts great interest in the SSTA in the Indian Ocean and potential roles it plays. It is also why the variation of SSTA over the Indian and Pacific Oceans is treated as an integral process by the authors. The anomalous distribution of global SST for October 1997 is shown in Fig.1.

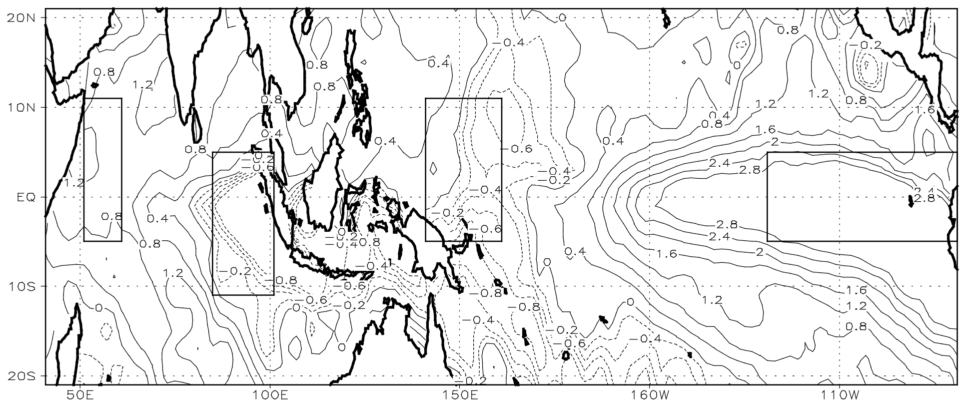

Fig.1. The pattern of global sea surface temperature anomaly in October 1997. The dashed lines are contours below zero and the solid lines contours above zero. The boxes are the key areas of the Pacific-Indian SSTA mode as defined in the text.

Fig.1 shows that there is a well-defined warm tongue in the equatorial east Pacific and positive SSTA in the northwestern Indian Ocean region while there are large negative SSTA in the equatorial western Pacific and eastern Indian Ocean region. It illustrates how the mode of SSTA distributes across the Pacific-Indian Oceans — there are significant zonal gradients of SST in northwestern and eastern Indian Ocean, equatorial central and eastern Pacific and western Pacific. When SST is high (low) in the northwestern Indian Ocean and equatorial central and eastern Pacific Ocean, the SST in the Warm Pool of western Pacific and eastern Indian Ocean is low (high). Previous studies on the interactions between the atmosphere and ocean mainly focuses on the equatorial eastern Pacific. As shown in Fig.1, however, the variation of SST in this region and the western Pacific warm pool and Indian Ocean is an inter-linked complete system, which is named the Pacific – Indian Oceans SSTA mode. It has more extensive spatial distribution compared to the ENSO in the traditional sense.

4 EOF DECOMPOSITION OF SSTA IN TROPICAL OCEANS

A concept has been put forward for the SSTA mode in the Pacific-Indian Oceans. The question is whether it actually exists. Either it occurs regularly or it is simply a particular case occurring during a specific period. In order to investigate this question, an EOF decomposition was run for the tropical ocean (40°W – 90°W, 20°S – 20°N) and the results are presented in Fig.2.

From the first eigenvector field of SST for individual seasons that have been EOF-decomposed (Fig.2), a similar phenomenon is found — there are significant zonal gradients of SST in all seasons of the year in the northwestern and eastern Indian Ocean and equatorial central and eastern Pacific and western Pacific. When SST is high (low) in the northwestern and eastern Indian Ocean and equatorial central and eastern Pacific Ocean, the SST in the Warm Pool of western Pacific and eastern Indian Ocean is low (high). It agrees very well with the spatial distribution of SSTA across the Pacific and Indian Oceans proposed by the authors. The variance contribution rates for seasonal EOF decomposition are 42%, 38%, 34% and 38% respectively for winter, spring, summer and autumn. It is noted that the variance contribution of the eigenvector is larger than 33% in all of the seasons, which suggests that the structure of the tropical SST field is stable and the proposed SSTA mode is realistic.

From the corresponding time series (Fig.3), it is seen that the mode was mainly of negative phase before the mid-1970's but of positive phase after 1977. As shown in the distribution of the anomaly in individual seasons, there was consistent and significant interdecadal variation in the mid- and late-stages of the 1970's. Compared to traditional ENSO, the mode has not only larger spatial scale but also larger temporal scale. For ENSO, it is the interannual variation that is of most interest[13]; for the mode, however, it is the interdecadal variation that is most important. It is also noted that at such larger temporal and spatial scales, the La Niña episodes usually occurred during the negative phase of the mode (from early 1950's to the mid-1970's) while the El Niño episodes during the positive phase of the mode (from the mid-1970's to the present).

5 PRELIMINARY STUDY OF DEFINITION OF THE INDEX OF PACIFIC-INDIAN OCEANS SSTA MODE

With the Pacific-Indian Oceans SSTA mode determined, a good index is needed to describe it. First, the temperature anomalies for global SST in October 1997 are used to define the index (to be called PIMI1) to be the sum of SST difference between the area (50°E – 65°E, 5°S – 10°N) and the area (85°E – 100°E, 10°S – 5°N) and SST between the area (130°W – 80°W, 5°S – 5°N) and the area (140°E – 160°E, 5°S – 10°N) is defined as the index of the mode (as shown by a rectangular block in Fig.1).

To test whether the index PIMI1 is truly describing the mode, correlation analysis is applied to the SSTA fields in individual seasons (Fig.4).

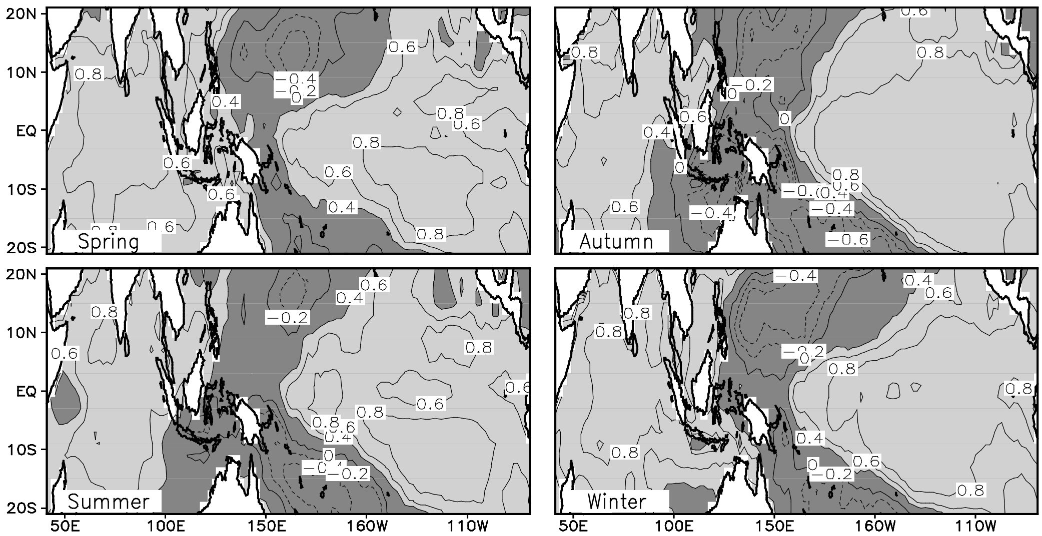

Fig.2 The first eigenvector field of SSTA in the tropical ocean (40°E – 90°W, 20°S – 20°N) in the four seasons.

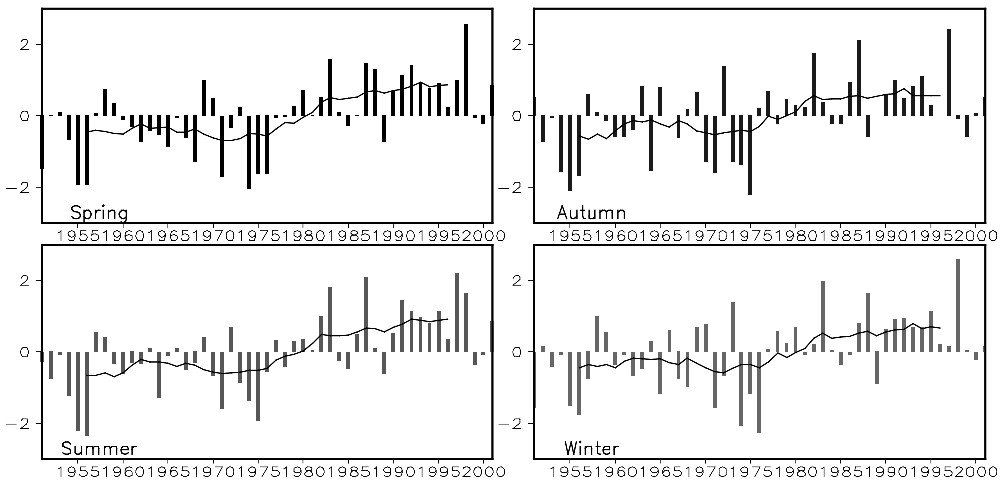

Fig.3 The time series for the first eigenvector field of SSTA in the tropical ocean (40°E-90°W, 20°S-20°N) during the four seasons.

From Fig.4, it is seen that in all seasons of the year there is a large area of significant positive correlation over the Indian Ocean and equatorial central and eastern Pacific and a large area of significant negative correlation in western Pacific. In other words, with a high (low) index, the SST is significantly higher (lower) in the northwestern Indian Ocean and equatorial central and eastern Pacific but much lower (higher) in the western Pacific. Our definition of the PIMI1 index seems to describe the mode well by picking up information of both the ENSO in the Pacific and dipole oscillations in the Indian Ocean.

An important issue needs to be considered here. Can the time series of the EOF decomposition of the SSTA in the Pacific-Indian Oceans, which describes the variation of the mode with time, be directly used as the index describing the mode? To address this issue, the temporal coefficient for the first eigenvector of the SSTA field is used as the index of the mode (to be called PIMI2 hereafter) and is analyzed for its correlation with seasonal SSTA in the region bounded by 40°E – 90°E, 20°S – 20°N (Fig.5).

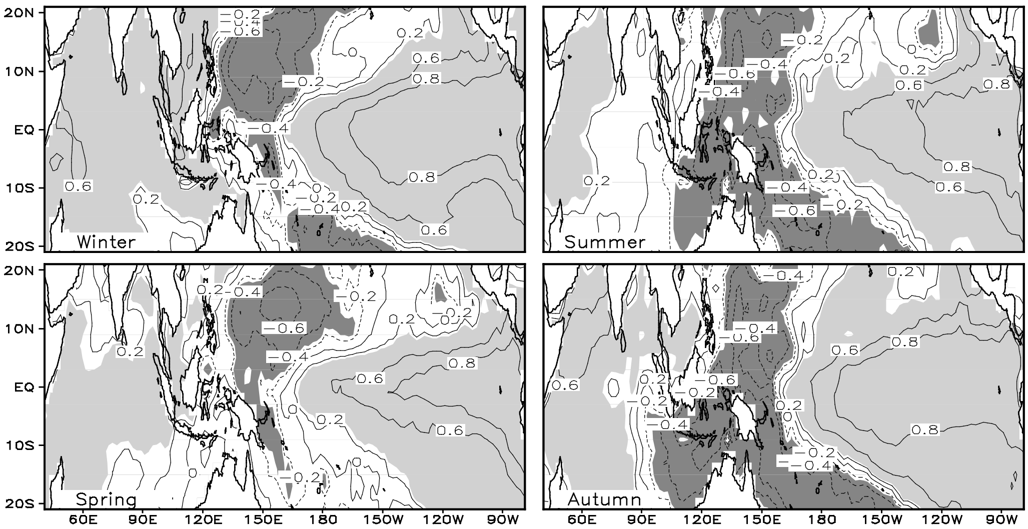

Fig.4 The correlation between PIMI1 and SSTA field in the tropical ocean (40°E – 90°W, 20°S – 20°N) of the four seasons during 1950-2001. The dashed lines show contours below zero and the solid lines show contours above zero, with the values above the 0.05 significance level shaded.

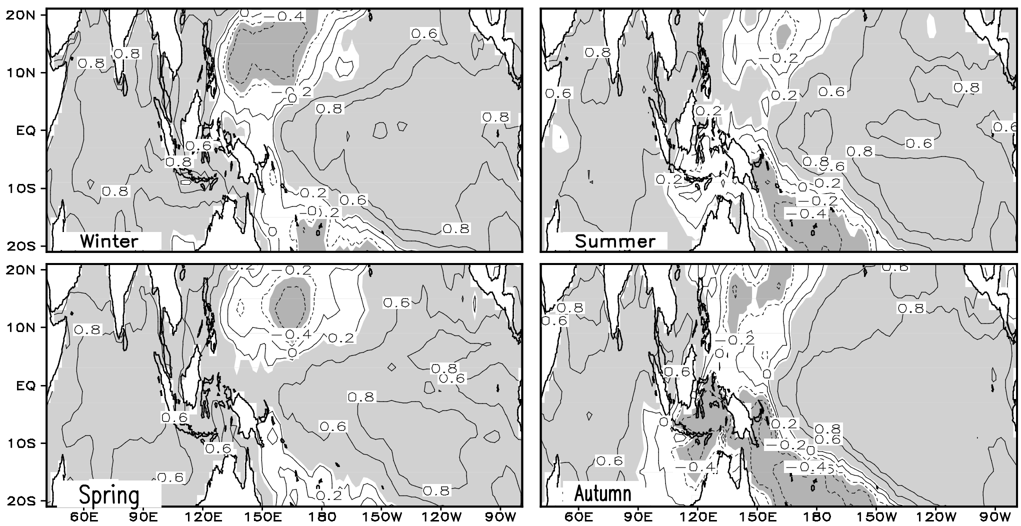

Fig.5 The correlation between PIMI2 and SSTA field in the tropical ocean (40°E – 90°W, 20°S – 20°N) of the four seasons during 1950-2001. Other captions are the same as in Fig.4.

It is seen from Fig.5 that there are extensive areas of significant positive correlation in all seasons in much of the Indian Ocean and equatorial central and eastern Pacific but only extended areas of significant negative correlation in western Pacific in autumn and summer. It means that with a high (low) index, the SST is significantly higher (lower) in the northwestern Indian Ocean and equatorial central and eastern Pacific but much lower (higher) in the western Pacific only in autumn and summer. If the temporal coefficient of the first EOF-decomposed eigenvector is used as the index of the mode, then the PIMI2 will be an insufficiently accurate indicator for winter and spring seasons. Although the index is quite objectively selected, it is only the time component of the first eigenvector of the SSTA field. In fact, the variation of SSTA in the Indian Ocean is not as significant as that in the equatorial eastern Pacific. It results in much stronger signals of the Pacific ENSO in the EOF eigenvector so that the signal of the Indian Ocean dipole is not fully reflected in the first mode. However, the zonal thermal contrast is of comparable magnitude in both the Indian Ocean and the Pacific Oceans[4, 10, 11]. Yan et al.[14] studied the temporal and spatial characteristics of the SSTA field of the Indian Ocean during the recent 50 years and concluded that the variation of the second eigenvector of EOF reflects the zonal difference of the SST change in the Indian Ocean. The variation of the zonal difference is linked to some degree to that of the SST in the equatorial eastern Pacific. This is why the authors propose not to use the temporal coefficient of the first eigenvector that is decomposed with EOF as the index of the mode.

The above analysis shows that it is more appropriate to choose PIMI1 as the index of the SSTA in the Pacific – Indian Oceans. From the derived correlation coefficients between the seasonal indices PIMI1 and Niño3 – SSTA, it is known that all of the correlation coefficients have passed the 99% significance test. Under such circumstances, does PIMI1 really take care of the characteristics of zonal gradient distribution of SST of both the Pacific and Indian Oceans while differing from Niño3 – SSTA? To differentiate PIMI1 from the ENSO index, Niño3 – SSTA is studied for its correlation with the SSTA field for the region of the tropical ocean at 40°E – 90°W, 20°S – 20°N (Fig.6).

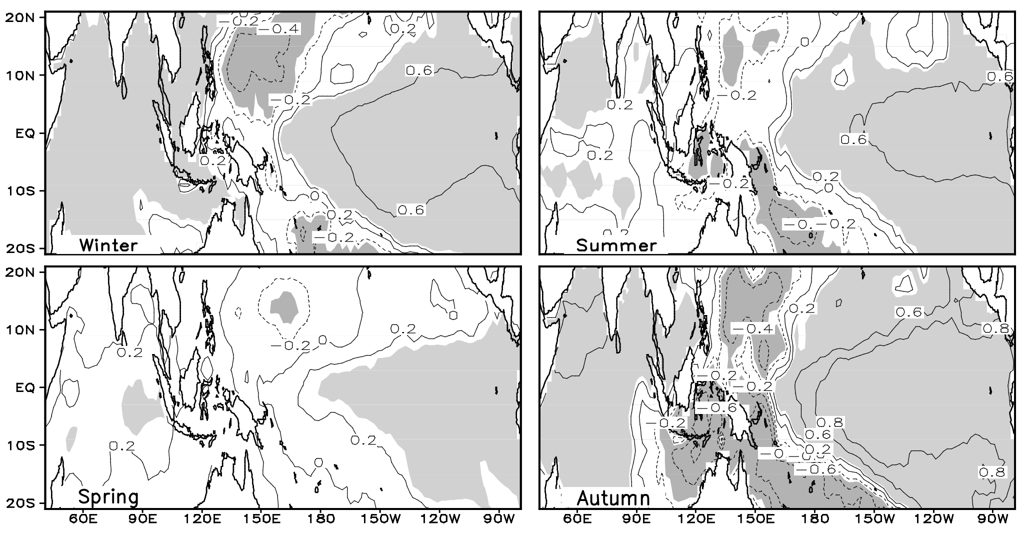

Fig.6 The correlation between Nino3-SSTA and SSTA field in the tropical ocean (40°E – 90°W, 20°S – 20°N) of the four seasons during 1950 – 2001. Other captions are the same as Fig.4.

Fig.6 shows that the index Niño3 – SSTA mainly reflects the information of the Pacific ENSO so that large areas of significant positive correlation can be present in much of the Indian Ocean and equatorial central and eastern Pacific and large areas of significant negative correlation can be found in western Pacific in summer. The correlation of SST, however, is less significant between the Indian Ocean and west Pacific in winter and spring, especially in winter, when the previously mentioned characteristics of the Pacific – Indian Oceans SSTA mode are almost absent.

From the comparison of Fig.4 – Fig.6, it can be concluded that the PIMI1 index is an appropriate measure of the mode, because it is selected in such a way that it takes care of the characteristics of zonal SST gradients of both the Pacific and Indian Oceans while differing from pure ENSO information and the index does well in describing the mode in all seasons.

6 CONCLUDING REMARKS

By comparing, analyzing and studying the SSTA mode of the Pacific – Indian Oceans, the characteristics of the spatial distribution of the mode have been clearly demonstrated and its index defined. The following preliminary conclusions can be drawn:

a. Quite similar characteristics are found in the first eigenvector field of seasonal SST that is decomposed with EOF. There are obvious gradients of SST in the northwestern and eastern Indian Ocean and equatorial central, eastern and western Pacific. When it is high (low) in northwestern Indian Ocean and equatorial central and eastern Pacific, it is low (high) in the Warm Pool of western Pacific and eastern Indian Ocean. This distribution of the SST mode is called the Pacific – Indian Ocean SSTA mode. For individual seasons, the variance contribution rates of the EOF-decomposed mode are 42% for winter, 38% for spring, 34% for summer and 38% for autumn, respectively. It suggests stable distribution of the mode and supports our view that the distribution of SSTA in both the Pacific and Indian Ocean has a unified mode.

b. From the computational analysis, significant interdecadal variations of the Pacific – Indian Ocean SSTA mode are found. The phase changed from negative to positive in the mid-1970's.

c. From our comparisons and analyses, the sum of SST difference between the regional mean at (50°E – 65°E, 5°S – 10°N) and another mean at (85°E – 100°E, 10°S – 5°N) and the sum of SST difference between the regional mean at (130°W – 80°W, 5°S – 5°N) and another mean at (140°E – 160°E, 5°S – 10°N) is defined as the index of the mode. It is thought to be appropriate to take PIMI1 as the index of the mode, because it is selected in such a way that it takes care of the characteristics of zonal gradient distribution of SST of both the Pacific and Indian Ocean while differing from pure ENSO information and the index does well in describing the mode in all seasons.

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