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Interannual and interdecadial variability in the North Pacific SST*

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Abstract. In the present paper, two methods are used to analyze the SST data from the ECMRWF and the NCEP/NCAR datasets. The first is a classical EOF (Empirical Orthogonal Function) analysis, which allows reconstructing the El-Nino, the La-Nina events with a good accuracy only by the first few EOF. However, the periods between these events need much more EOF for the reconstruction. The variability in midlatitudes is also not separated because of a strong signal in the tropics. Therefore, for the separation of these signals, the cluster method is used. The results obtained show that except a signal in the tropics, there exists a clearly marked signal in the subpolar gyre and the Kuroshio Extension with the interdecadal modulation.

1. Introduction

The Pacific Ocean is a source of the climatic variability influencing the atmospheric processes not only in local, but also in global scales. The strongest signal is the El-Nino-South Oscillation (ENSO) representing the inter-annual variability in the tropics. At the same time, in midlatitudes there exists an inter-decadal signal, the so-called Pacific Decadal Oscillations (PDO) centered over the Pacific Ocean and North America [1–3]. This variability can be analyzed in the sea surface temperature patterns after some statistical processing. The data were the ECMRWF and the NCEP SST datasets. The chosen domain for the SST analysis was bounded [112.5E, 70.5W] and [29.5S, 60.5N]. In the present paper, two methods are used. The first is the classical EOF analysis, which allows reconstructing the El-Nino, the La-Nina events with a good accuracy only by the first few EOF. However, for such a reconstruction the periods between these events need a greater number of the EOF. The variability in midlatitudes is also not separated because of the strongest signal in the tropics. Therefore, for separation of these signals including the PDO, the cluster method is used. The clusters were organized as well-correlated regions in space as well as in time [4]. This allows us to classify the SST data and separate some typical as well individual zones in the Pacific. The results obtained show that except a strong signal in the tropics, there exists a distinct signal in the subpolar gyre and the Kuroshio Extension with the inter-decadal modulation.

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2. Data sources

1. European Center of the Middle-Range Forecast (ECMRWF) dataset. The period 1981–1999.
2. NCEP/NCAR dataset. The period 1948–2002.

3. The EOF analysis of the SST

The Empirical Orthogonal Functions analysis for the period of 1981–1999 was made on the basis of a classical approach of calculations of eigennumbers and eigenvectors of a covariance matrix of the monthly averaged data. The treated Pacific Ocean domain was chosen as embedded to the rectangular [122.5E–70.5W, 29.5S–60.5N]. In this case, we have 11325 points with respect space and 218 steps with respect to time. The monthly averaged SST data were taken from the ECMRWF dataset. The period under investigation is characterized by occurrence of the El-Nino events (the warm phase – 1982, 1987, 1997) as well as the La-Nina event (the cold phase – 1988).

Analysis of the calculated EOF shows that maximum a contribution is given by the first and the second modes. The first mode describes a climatic state and is constant in time, whereas the second has the annual period and describes a seasonal variation. In order that we come to studying the variability of anomalies, these two harmonics were extracted from the initial data. Then, the EOF analysis for anomalies was conducted once again. After that, the SST field was reconstructed with the use of the

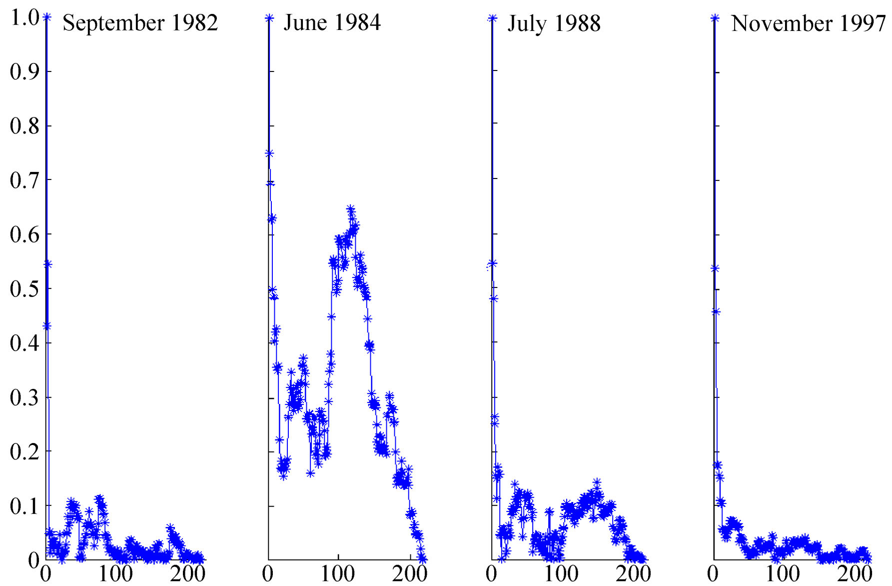

Figure 1. The share of the EOF to the SST anomaly field in different periods

obtained EOF. The results obtained show that during the periods of the extreme events (El-Nino, La-Nina) the anomalies fields in the tropics can be reconstructed by the first four EOF with a high accuracy. However, in the periods between the extreme events (for example, that of 1984), the reconstruction of the anomalies needs a greater number of harmonics for attaining a satisfying accuracy. The share of the EOF to the reconstruction of the anomalies fields at the point [110W, 0.5N] is presented in Figure 1.

The accuracy of the reconstruction in the midlatitudes is sufficiently low, because of damping by a stronger signal in the tropics. This fact initiates us to use the second method to separate a signal in the midlatitudes – the cluster analysis.

4. The cluster analysis of the SST for the period of 1948–2002

The cluster analysis is a method for combining the data according to the correlation criterion between the spatial points or the time points. The cluster analysis method allows us to solve the following problems:

- To classify objects with allowance for the main features of the objects;
- To check a hypothesis about occurrence of a certain structure in the aggregate of objects;
- Creation of a new classification for poorly investigated events, when it is necessary to establish relations in the aggregate and to introduce some structure into it.

For the cluster analysis, the monthly averaged SST data were adopted from the NCEP/NCAR dataset for the period of 1948–2002.

4.1. Spatial classification. The objective is to divide our set, consisting of n temporary series $F(t, x_i)$, $i = \overline{1, n}$, into some number of $k \ll n$ subsets (classes) in such a way that each realization $F(t, x_i)$ would belong to some class p ($p = \overline{1, k}$). All these classes should consist of the well-correlated realizations. To each class, one can attribute the "center" of the class as some "ideal" point $Z_p(t)$, which represents its class, each point of the class being correlated with this point better than with any other point. The next step is the so-called "cleaning". We choose some level of correlation in classes (for example, 0.7) and extract all the points in each class with correlation with the center of the class lower than this level. As a result, all the points of the Pacific Ocean will consist of k domains, for which each center will represent a temporary variability in this class. The relation between classes may be investigated by making a correlation between their centers.

The algorithm is recursive. First of all, two classes are formed, then three classes, etc. In Figures 2, 3, the division into two classes without

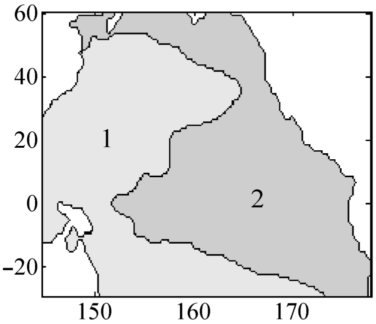

Figure 2. Spatial distribution of two classes

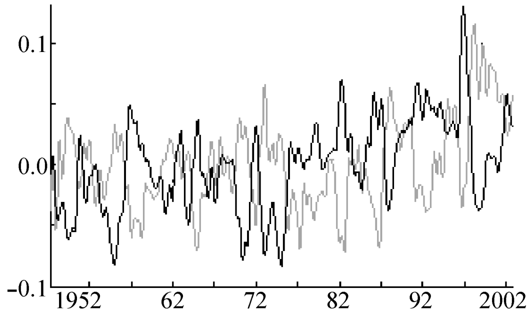

Figure 3. Temporal behavior of two classes: Class 1 – light, Class 2 – dark

"cleaning" is presented. Figure 2 represents the spatial distribution of the classes, whereas Figure 3 describes a temporary behavior of the centers. One can see that the eastern and the western parts of the Pacific Ocean are negatively correlated.

Finally, the number of classes was chosen to be equal to ten. In Figure 4, the distribution of ten classes after "cleaning" is represented. One can see that there are separated a few classes of the tropical zone, the eastern upwelling zone and a number of classes in the subtropical zone. The correlation analysis for the centers of the classes gives the highest correlation between the classes in the tropical zone (0.79), the positive correlation with the tropics and the eastern coastal upwelling zone (0.42) and a weak negative correlation between the eastern tropics and the Kuroshio Extension region (−0.32).

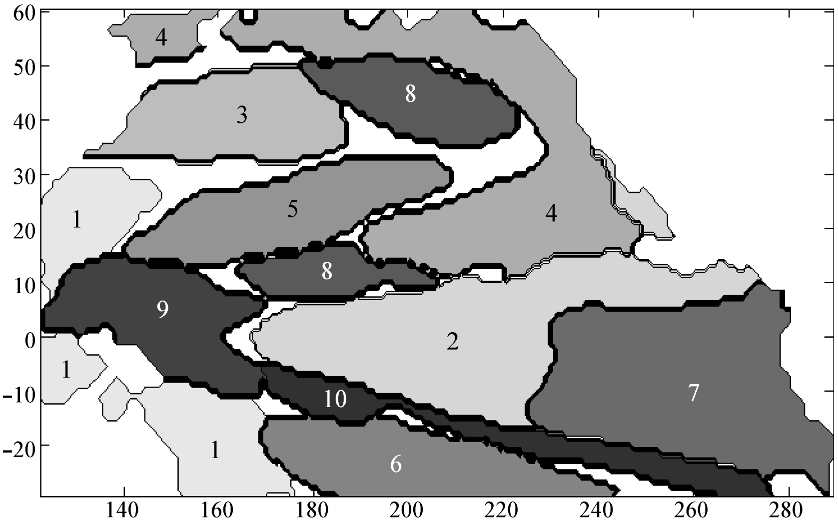

Figure 4. Distribution of ten classes according spatial classification

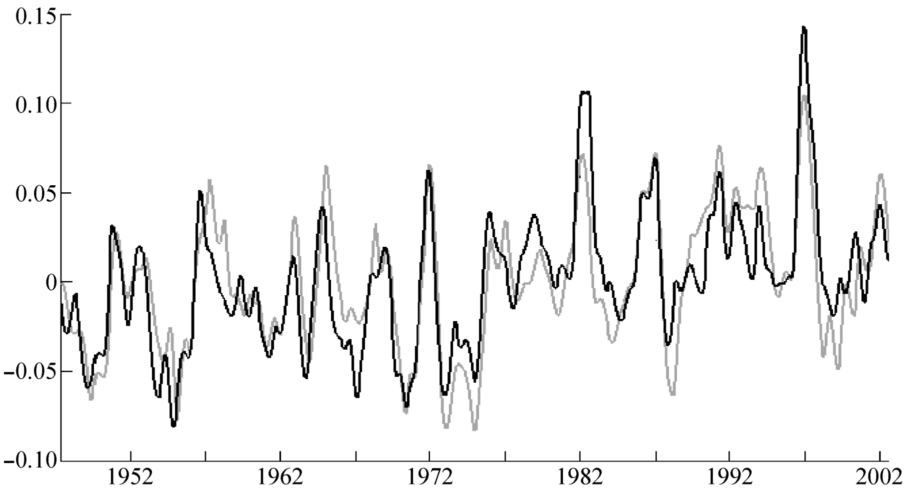

Figure 5. Temporary behavior of two neighboring classes in the eastern tropics: Class 2 – light, Class 7 – dark

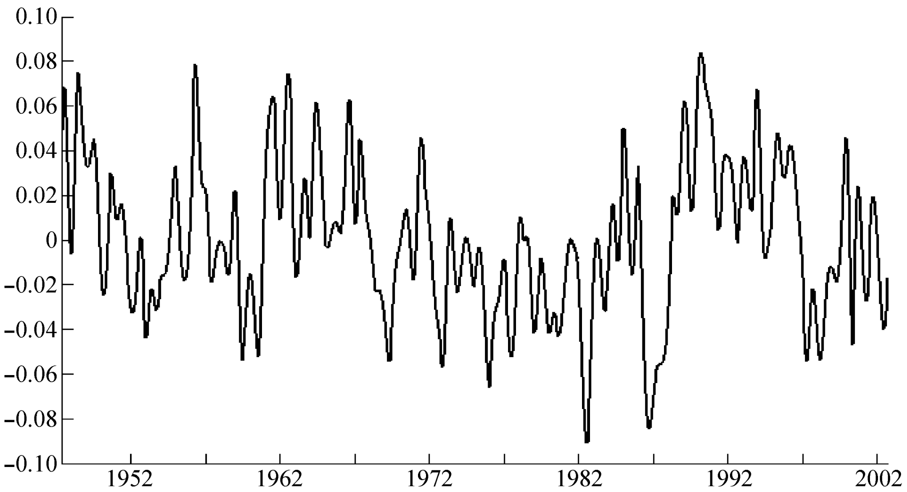

Figure 6. Temporal behavior of the subpolar region (Class 8)

Figure 5 represents the temporary behavior of the center of two classes in the eastern tropical Pacific (Classes 7 and 2). One can see that a high correlation is provided by a very similar behavior of the SST in these classes with some lag. The maximum values of these functions correspond to the El-Nino periods (1957, 1964, 1972, 1982, 1987, 1997). The minimum values – the La-Nina events (1950, 1955, 1968, 1973, 1975, 1988, 1999).

In Figure 6, the temporary behavior of the subpolar region (Class 8) is presented. The diagram shows marked interannual variations, which are probably associated with shifting the subpolar front. More interesting is

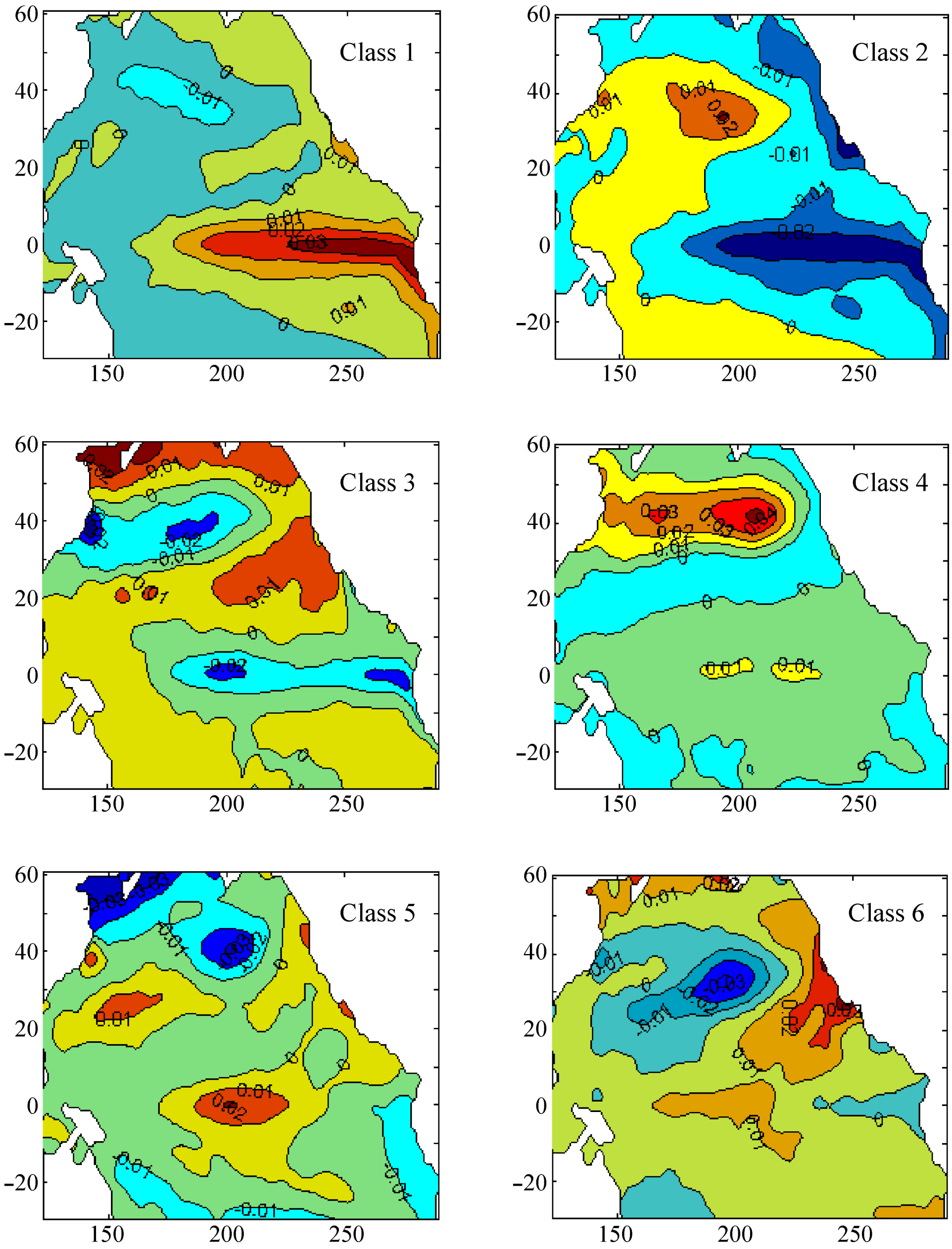

Figure 7. Six classes of temporal classification

the low-frequency part of the diagram, which represents the interdecadal variability in this region with the period that is approximately equal to twelve-fifteen years.

4.2. Temporal classification. If one represents the SST information as m spatial maps consisting of n points corresponding to the time points t_j, $j = \overline{1, m}$, i.e., replaces the temporal and the spatial variables t and x_i, and classifies the array $T_t(x_i)$, then from the mathematical point of view this problem will have the same type as the previous one. In this case, a set consisting of m maps $T_t(x_i)$ – the spatial distribution SST – is divided into some number of k classes consisting of the "most similar" maps with the number p ($p = \overline{1, k}$). Like in the spatial case, for each class the "ideal" map $Z_p(x_i)$ of this class can be found, i.e., the map most accurately representing the SST field in the class p. Figure 7 presents six temporal classes. The first and the second classes represent the El-Nino and the La-Nina events. Classes 3 and 4 describe a decrease and an increase of the SST in the Kuroshio region. Classes 5 and 6 describe the episodes of decreasing the SST in the subpolar and the subtropical gyres. The temporal diagram for Class 7, obtained in the spatial classification, is shown in Figure 8. The numbers under the diagram indicate to the kind of a class dominating in this period. One can see that Classes 1 and 2 corresponding to the El-Nino and the La-Nina events are distributed exactly in the periods when these

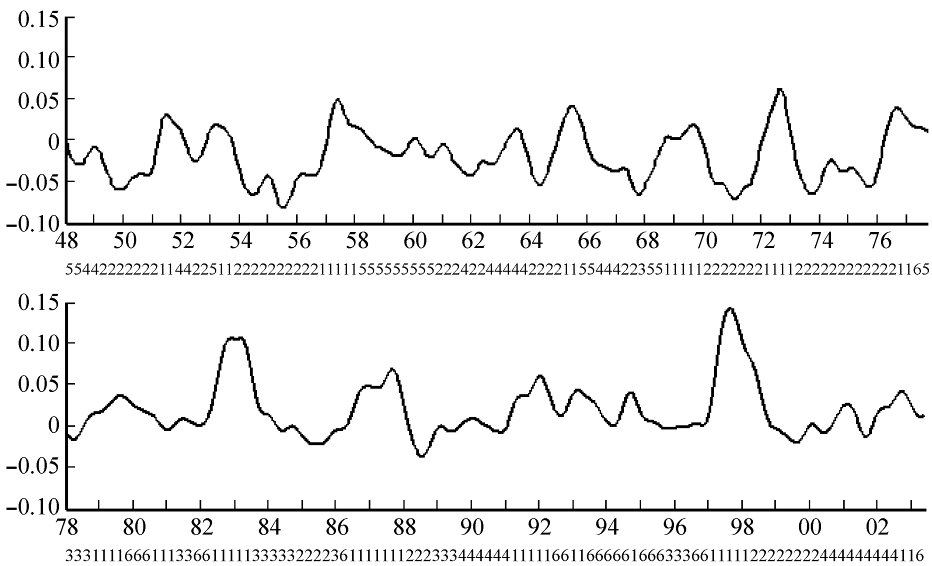

Figure 8. Temporal behavior of Class 7 obtained according to the spatial classification with indication below the diagram to the number of temporal class dominating in each period

events occur. Classes 4 and 5 correspond to the periods without the El-Nino, La-Nina events and describe anomalies processes in the subtropical and the subpolar regions.

5. Conclusion

The EOF analysis enables us to separate the strongest signal in the Pacific Ocean and to reconstruct it with a few first harmonics. The periods between the El-Nino and the La-Nina events need a greater number of harmonics for reconstruction of the anomalies. This indicates that the state in these periods is governed by the first two climatic harmonics and finer processes form the anomalies. The PDO variability in the subtropics and in the subpolar regions is damped by a stronger tropical signal.

The spatial-temporal cluster analysis allows us to separate the typical structures in the SST variability, to indicate the variability in the subtropical and the subpolar regions and to establish relations between the regions. It also allows us to indicate a marked signal of the inter-decadal variability in the subpolar-subtropical zones.

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