Interannual waves in the sea surface temperatures of the Pacific Ocean

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Abstract

Various oscillatory modes of sea surface temperatures (SSTs) observed over a period of 8.8 years with the NASA Nimbus 7 Scanning Multichannel Microwave Radiometer (SMMR) and for 13 years with the NOAA Advanced Very High Resolution Radiometer (AVHRR), the latter sensing in the thermal infrared band, are described for the Pacific Ocean. The various modes are isolated by a combination of techniques designed also to accommodate nonstationary phenomena. After detrending and removing the seasonal cycle from each grid map element of the data, singular value decomposition (SVD) is used to separate the data into spatial and temporal parts to facilitate the modal analysis. Empirical Mode Decomposition is then used to separate the temporal parts of the data into approximately seven intrinsic modal functions (IMFs) for the temporal parts of the first five principal components (PCs) resulting from the SVD. A filtered time sequence of SST grids is then obtained by selecting IMFs with periods longer than 1.5 years and then reconstructing the SST grid maps from the filtered PCs. The time sequence of SMMR SSTs in the Pacific Ocean shows El Nin˜o Southern Oscillation (ENSO) oscillations not only along the Equator, but also in both the North and South Pacific, with, in fact, even larger amplitudes than along the Equator. A similar analysis was applied to the SST record from the AVHRR instrument. During the period of overlap with the SMMR record, similarities occur in the equatorial region, but the records are by no means identical. The AVHRR SSTs do not show any strong oscillations in the South Pacific.

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Abstract. Various oscillatory modes of sea surface temperatures (SSTs) observed over a period of 8.8 years with the NASA Nimbus 7 Scanning Multichannel Microwave Radiometer (SMMR) and for 13 years with the NOAA Advanced Very High Resolution Radiometer (AVHRR), the latter sensing in the thermal infrared band, are described for the Pacific Ocean. The various modes are isolated by a combination of techniques designed also to accommodate non-stationary phenomena. After detrending and removing the seasonal cycle from each grid map element of the data, singular value decomposition (SVD) is used to separate the data into spatial and temporal parts to facilitate the modal analysis. Empirical Mode Decomposition is then used to separate the temporal parts of the data into approximately seven intrinsic modal functions (IMFs) for the temporal parts of the first five principal components (PCs) resulting from the SVD. A filtered time sequence of SST grids is then obtained by selecting IMFs with periods longer than 1.5 years and then reconstructing the SST grid maps from the filtered PCs. The time sequence of SMMR SSTs in the Pacific Ocean shows El Niño Southern Oscillation (ENSO) oscillations not only along the Equator, but also in both the North and South Pacific, with, in fact, even larger amplitudes than along the Equator. A similar analysis was applied to the SST record from the AVHRR instrument. During the period of overlap with the SMMR record, similarities occur in the equatorial region, but the records are by no means identical. The AVHRR SSTs do not show any strong oscillations in the South Pacific.

1. Introduction

Various oscillatory modes of sea surface temperatures (SSTs) observed over a period of 8.8 years with the National Aeronautics & Space Administration (NASA) Nimbus 7 Scanning Multichannel Microwave Radiometer (SMMR) and for 13 years with the National Oceanic & Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR), the latter sensing in the thermal infrared band, are described for the Pacific Ocean. The SMMR calibration and an earlier and very similar version of the technique for calculating the SSTs from SMMR radiances are described elsewhere (Gloersen 1984, Gloersen *et al.* 1992). The various modes are isolated by a combination of techniques designed also

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to accommodate non-stationary phenomena (Gloersen and Huang 1999). After detrending and removing the seasonal cycle from each grid map element of the data, the time sequence of gridded SSTs is subjected to a Hilbert transform to provide complex data that preserve phase information. The spatial and temporal parts of the Complex Empirical Orthogonal Functions (CEOFs) of the gridded SSTs are then obtained by singular value decomposition (SVD). Hereafter, the CEOFs will be referred to as Complex Principal Components (CPCs). The real part of the spatial component of CPC1 is illustrated in figure 1 and its temporal part in figure 2(*b*). Ratios of the first 20 CPC eigenvalues (weights) relative to the first one are plotted in figure 2(*a*).

Contrary to popular belief, the CPCs are themselves multi-moded, as is demonstrated by Empirical Mode Decomposition (EMD) (Huang *et al*. 1998) of the first ten CPCs, containing about half of the SST signal, into approximately seven intrinsic modal functions (IMFs) for each CPC. The IMFs of the real part of the

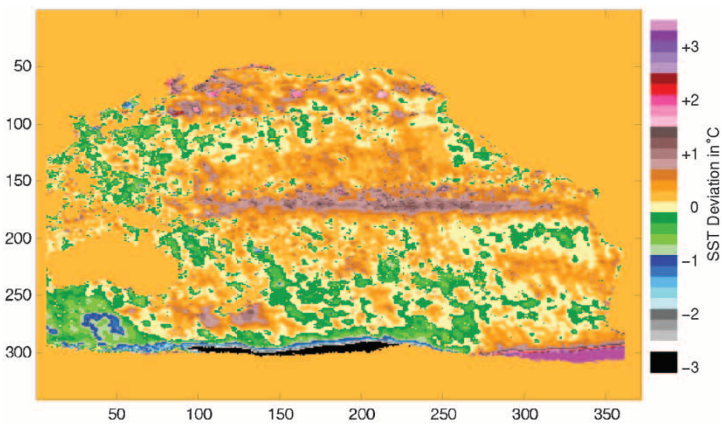

Figure 1. Pacific Ocean. Spatial component of the real part of the first Complex Principal Component of the nine-year record of detrended and deseasoned sea surface temperatures obtained from the NASA Nimbus 7 Scanning Microwave Radiometer (SMMR). *x*- and *y*-axes: grid map co-ordinates.

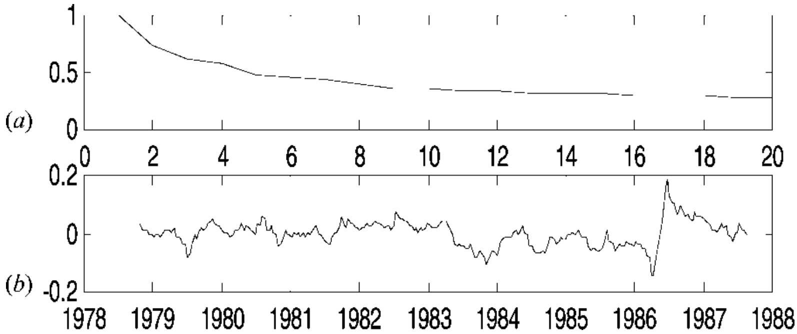

Figure 2. (*a*) Relative eigenvalues (weights) of the first 20 CPCs of the detrended, deseasoned Pacific SSTs of figure 1 and (*b*) temporal component of the first CPC of data of figure 1.

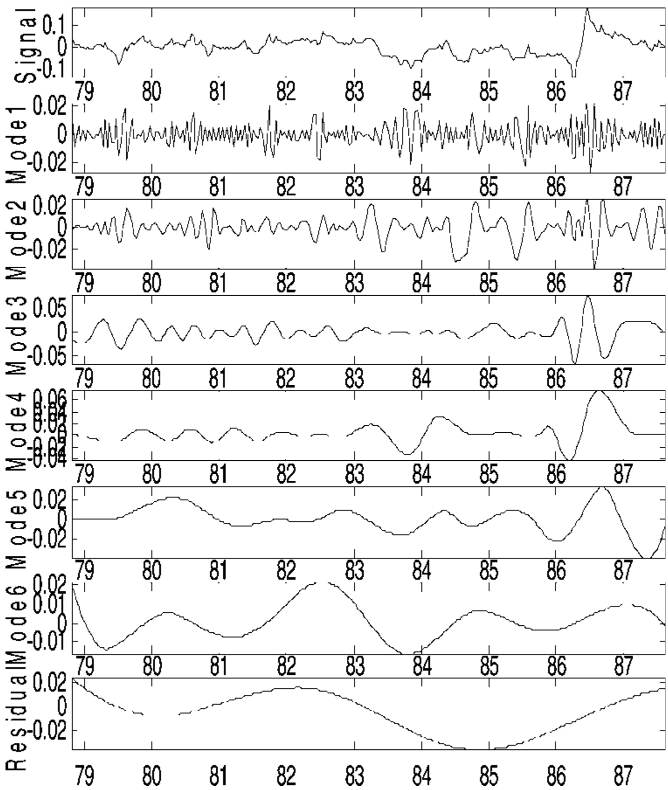

Figure 3. Intrinsic modes obtained from Empirical Mode Decomposition of the signal shown in figure 2(*b*) and in the top panel here.

temporal component of CPC1 are shown in figure 3. It is clear that the phenomena are indeed non-stationary, i.e. each mode is both frequency- and amplitude-modulated.

At this point, there is the opportunity to apply an elegant narrow-band filter by reconstructing the data from a single IMF or a combination of modes—in this case, Modes 5, 6 and 7 (the 'residual'), consisting of periods longer than one year. The seasonal signal is absent from the collection of modes as its average was removed from the data prior to the SVD. Modes 6 and 7 could be described as quasi-biennial and quasi-quadrennial modes, respectively, as are found in the El Niño Southern Oscillation (ENSO).

The filtered time sequence of SST grids is then obtained from the real part of the result of multiplying the spatial part of the CPCs by their weighted temporal parts. Time-lapse movies of the results of this procedure were taken and a sampling of the movie frames is shown in figures 4 and 5.

2. Analysis

The time sequence of SSTs in the Pacific Ocean (figure 4) shows ENSO oscillations not only along the Equator, but also in both the North and South Pacific, with, in fact, even larger amplitudes than along the Equator. The most prominent El Niño maxima occur in the frames labelled 1978.82, 1983.19 and 1987.30. It is noteworthy that the oscillations in the Southern Pacific are nearly in phase with those along the Equator, implying the existence of an atmospheric

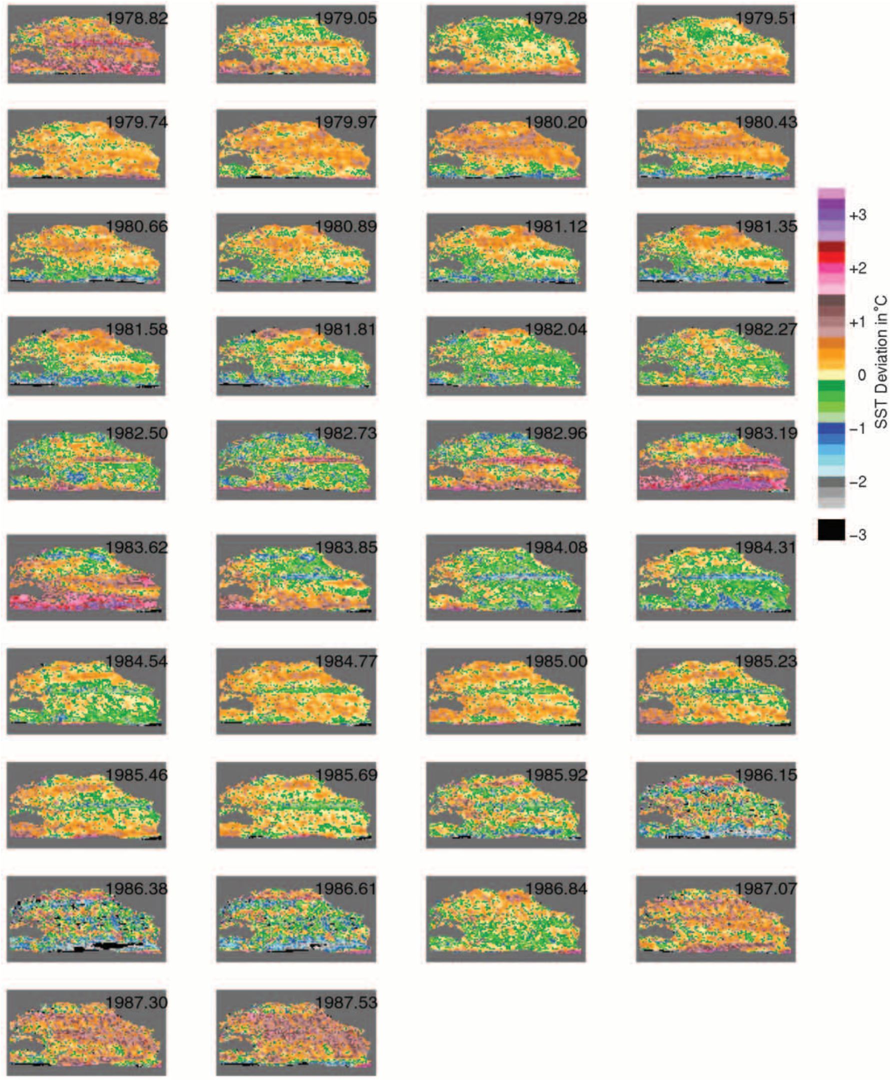

Figure 4. Time-lapse sequence of filtered SSTs from the Pacific Ocean obtained from SMMR data by reconstructing the time series using intrinsic modes with periods longer than one year of the first five CPCs. Note that during the 1978 and 1983 El Niños (1978.82 (day 82 of year 1978) and 1983.19 (day 19 of 1983)), there is an even stronger event in the Southern Ocean and a negative anomaly in the Bering Sea.

teleconnection, since oceanic signals propagate much more slowly. Such a strong signal in the South Pacific is not widely known. While plausible models for the oscillation along the Equator have been published, none have been for the South Pacific. Since the phenomena are essentially in phase, it cannot be determined empirically if one oscillation drives the other. In the Bering Sea, the oscillation appears to be about 180° out of phase with the Equatorial one.

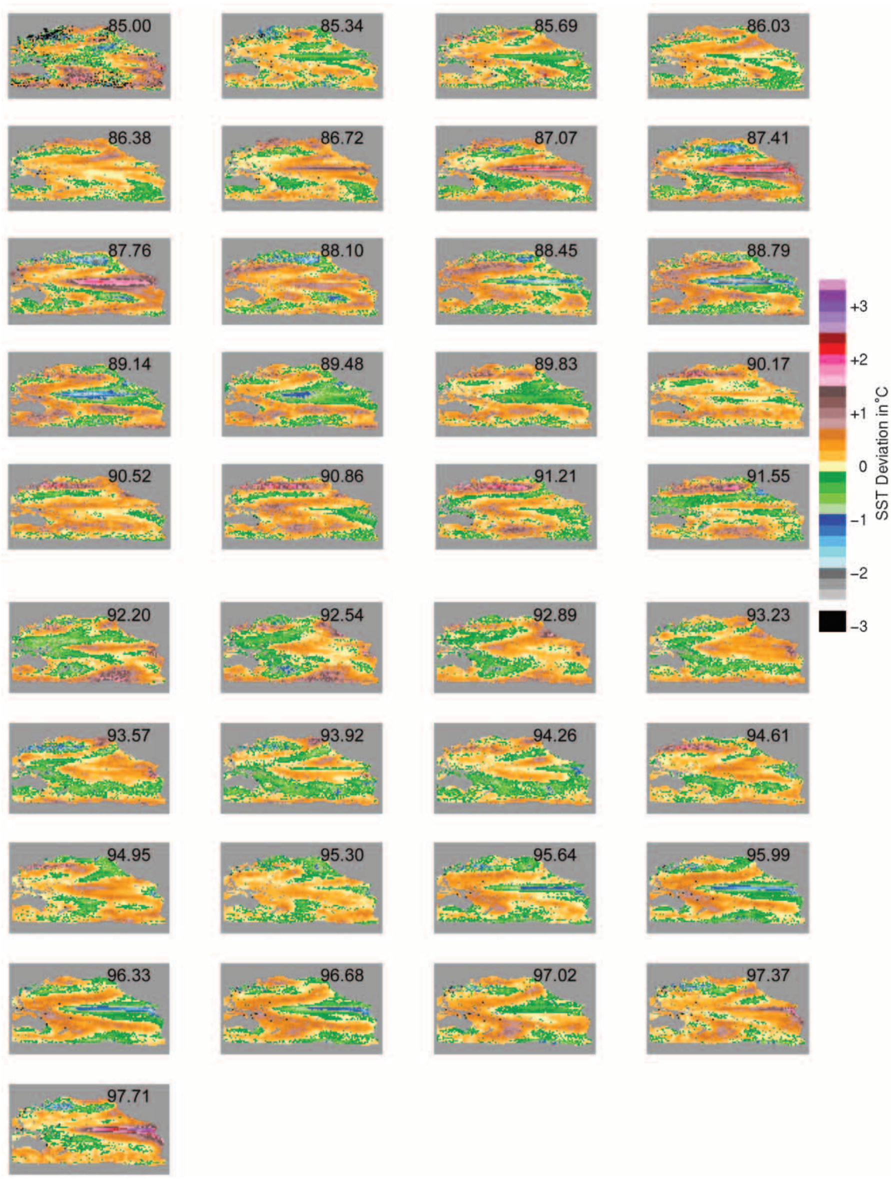

Figure 5. Time-lapse sequence of filtered SSTs from the Pacific Ocean obtained from NOAA AAVHRR data by reconstructing the time series using intrinsic modes with periods longer than one year of the first five CPCs. Note that the El Niño event in early 1987 is much more distinct than in the SMMR record. This is attributed in part to the different trend lines obtained for SMMR and AVHRR.

A similar analysis was applied to the SST record from the AVHRR instrument (figure 5). During the period of overlap with the SMMR record, similarities occur in the Equatorial region, but the records are by no means identical. For instance, for AVHRR, the maximum ENSO signal occurs in 1987 rather than 1983 as for SMMR. Since AVHRR and SMMR data cover different time intervals, their trend lines may differ considerably, which could account for this difference since both time series were detrended. The AVHRR SSTs do not show any oscillations in the

South Pacific. These differences are attributed somewhat to the differing oceanic skin depths observed by the infrared AVHRR channels and the 4.6 cm microwave channel of the SMMR but principally to the much greater sensitivity of the AVHRR to atmospheric interference, equal to or greater than the SST signal, which is especially severe in the South Pacific.

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