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Spatial and Temporal Variability of Sea Surface Height of Bay of Bengal Derived from Satellite Altimetry

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Abstract. The spatial and temporal variability of sea surface height anomaly of Bay of Bengal is derived from satellite altimeter observations for the period of 1993-2008. The data used are the weekly Maps of Sea Level Anomaly with 1/3 x 1/3 longitude and latitude resolution weekly files. Annual average of sea level anomaly field is estimated to understand the long term variability. Empirical Orthogonal Functional analysis has been carried out to derive the spatial structure and temporal amplitude of the variability. The first three modes of EOFs capture 80% of the total variance. The temporal amplitude clearly exhibits the influence of climate modes on the sea level of Bay of Bengal.

Keywords: Bay of Bengal, Sea Level anomaly, Variability

1. Introduction

Bay of Bengal, the north eastern arm of the Indian Ocean is receiving much attention as it is the fertile ground for generation of severe tropical cyclones. It is a semi-enclosed basin which experiences the monsoon winds and associated seasonal reversing circulation. In the northern part of the Bay, mighty rivers from Indian subcontinent discharges vast amount of fresh waters, this is highly contributing to the water characteristics and stratification. Wyrtki (1971)[1] presents a preliminary information of Bay of Bengal waters. Kumar et al (1993)[2] described the seasonal and inter-annual se surface height variations using TOPEX/POSEIDON altimeter data. The seasonal variation of hydrography and circulation of has been accounted in Varkey et al (1996)[3]. Recent studies[4,5,6] has reported surface circulation and mesoscale features in the Bay of Bengal. The propagation of Kelvin and Rossby waves in the Bay of Bengal is discussed in Benny and Mizuno(2000)[7]. Sadhuram et al. (2006)[8] found that the sea surface height variation of Bay of Bengal is well correlated to with the fluctuation of isothermal layer and cyclone heat potential.

Recent advances in satellite altimetry provide very accurate estimation of sea surface height, with high spatial and temporal resolution compared to with the in-situ observations. Satellite altimetry derived sea surface height data have been used to produce surface circulation and meso-scale features like fronts, eddies and the vertical motions. Moreover, the time series of Sea surface height data is available even form end of 1992, and it can be used for decadal scale variability studies. The present study determines the variability of sea surface height anomaly of Bay of Bengal during 1993-2008 using satellite altimetry observations and derives the spatial structures and temporal amplitudes of variability.

2. Data and Methodology

The satellite altimeter data used in this study are Maps of Sea Level Anomaly (MSLA) produced by the Collect Localisation Satellites (CLS), France for the period 1993-2008. The Maps of Sea Level Anomaly

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were obtained by merging JASON/ TOPEX/POSEIDON and European Remote Sensing Satellites ERS / Envisat data using optimum interpolation. Maps were produced every seven days since 1992 August with a resolution of 1/3° in both Latitude and Longitude.

To understand the spatial and temporal variations of sea level anomalies in the Bay of Bengal Empirical orthogonal functional (EOF) analysis has been carried out in the present study. EOFs were estimated by performing Singular Value Decomposition of the Time space data matrix. For a matrix X of dimensions M x N (M rows and N columns) there exists a triple product of Matrices, such that,

$$\mathbf{X = USV^T}$$

where, U is orthonormal and of size M x M

S is size of M x N and has elements not equal zero only on main diagonal (Singular values of matrix X)

V is orthonormal of size N x N

EOF analysis attempts to find a relatively small number of variables that describes as much of the original information as possible. It is a method that decomposes a signal or data set into a set of orthogonal basis functions. The goal of EOF analysis is to express the anomalies in terms of smaller number of EOFs, $e_m(x,y)$ which represent spatial variability, with amplitude $U_m(t)$ called principle components. The principal components, $U_m(t)$ tell us how the amplitude of each EOF varies with time. The first few EOFs may explain a majority of variance of the data. The first EOF explains the greatest fraction of the variance and the remaining EOFs for the remaining variances.

3. Results

The present study describes the annual average of Sea Level Anomaly (SLA) for sixteen years from 1993-2008. The long term variability and influence of climate modes are determined from first the first three EOFs and corresponding principal components.

3.1. Annual Average of SLA

The annual average SLA pattern shows much variation in the Bay of Bengal during 1993-2008 (Fig. 1). The SLA is almost between 10 and -10 cm in 1993 and the northern part exhibits positive anomaly whereas southern part with negative anomaly. In 1994, the SLA has again lowered except in the central part off west coast of India. Also, 1994 is reported as a positive Indian Ocean Dipole (IOD), this lowering corresponds to the cooling of eastern tropical Indian Ocean. But, in 1995 an increase in SLA is occurred in the Bay except in the eastern part. Again, SLA slightly decreased in1996. Conspicuous changes have been occurred in SLA during 1997, which is reported as the strongest El nino year. SLA has much decreased in the eastern part of the Bay and along the west coast of India. But, an increase in SLA is observed between 80 – 90E and 5-18 N. Minimum SLA of about -15 cm is observed off central west coast of India. Again, slight increase in SLA is displayed during 1998 and 1999 and 200-2001 and more increase in SLA especially in the eastern part of the Bay as well as the north eastern part. Again in 2002-2003 the SLA is almost normal. In 2003-2004 the SLA has increased except in the south western part of the Bay. This increase may be due to the negative IOD. Further, decrease in SLA is occurred in 2006 & 2007. But, 2008 is marked with a conspicuous rise over whole area of the Bay. This change also corresponds to the strong La Nina year.

3.2. Spatial and Temporal Variability

The EOFs derived from SLA estimated from satellite altimetry provide the spatial structures and temporal amplitudes of variation occurring in the Bay of Bengal (Fig. 2). The EOF 1 explains 60% of the total variance. The temporal amplitude is mainly dominated by annual cycle oscillation and unusually low value during 1997-1998 periods, when was the strong El Nino occurred. Thus, the temporal amplitude of EOF1 seems to be the composite signal of annual cycles and the climate modes like; El nino and Indian Ocean Dipole (IOD).

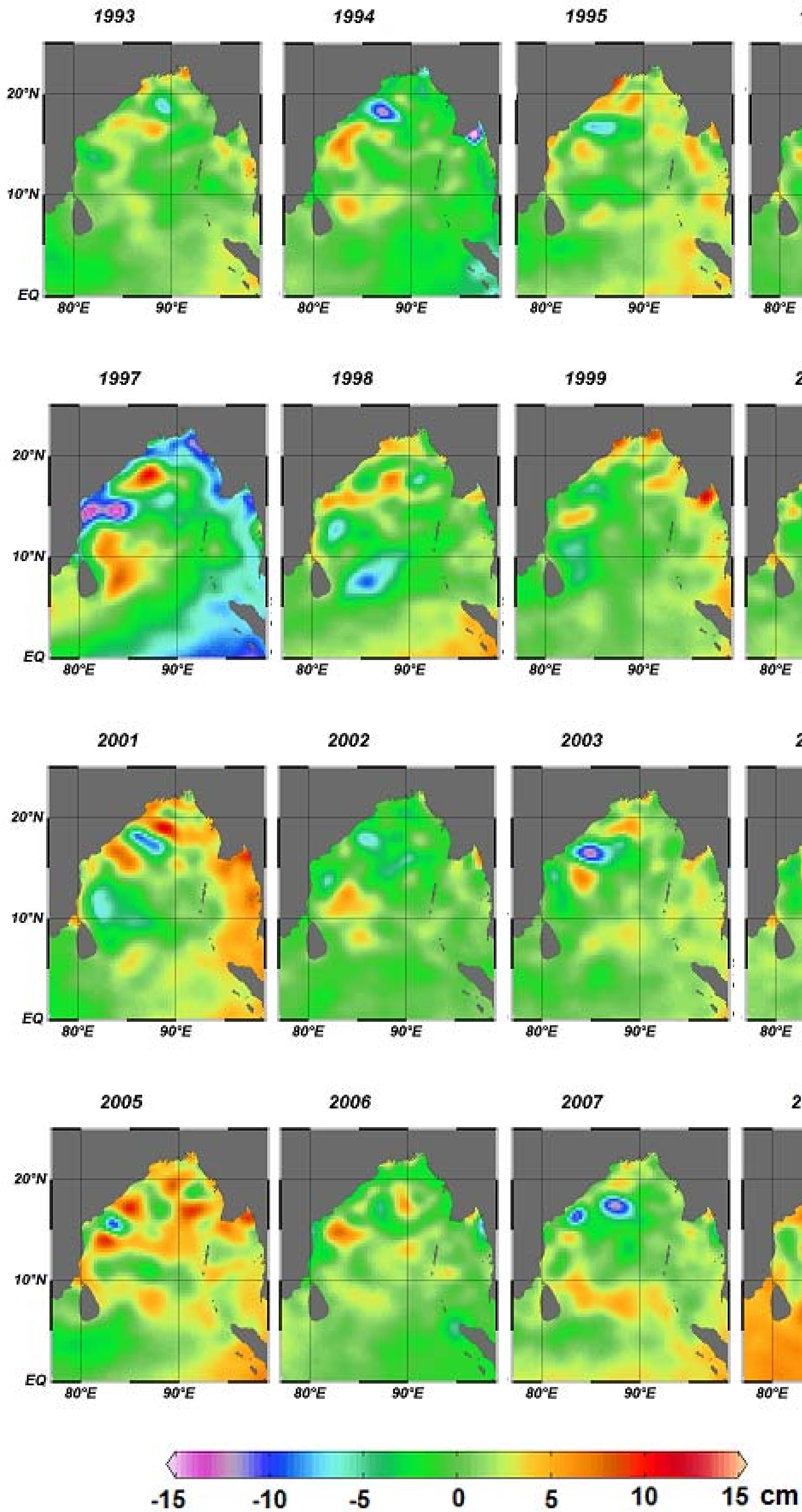

Fig. 1: Maps of sea level anomaly of Bay of Bengal from 1993-2008

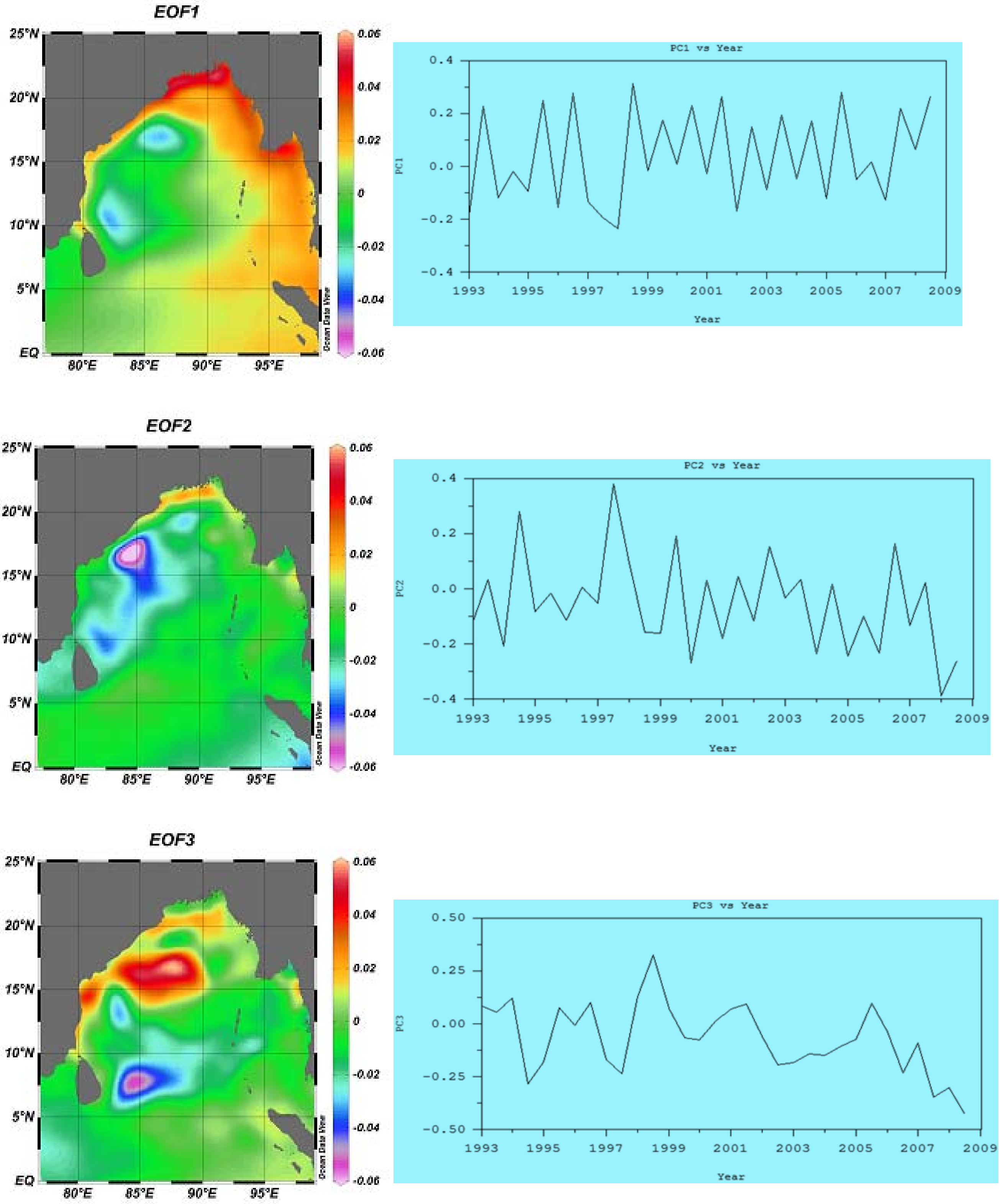

Fig. 2: Spatial structure and amplitudes of first three EOFs of sea level anomaly

The spatial pattern shows positive (increase) variations in the eastern part and along the western coastal regions of the Bay. Rest of the Bay exhibits negative (decrease) values. Decrease in SLA is occurring between 8 -18N and 80 -88 E region. Thus, rise in sea level is occurring in the northern and north eastern parts and west coastal regions, whereas a fall in sea level in the central part of the Bay.

The EOF 2 captures 15% of the total variance and which describes the annual oscillations as well as the climatic influences. Along the equatorial belt 0-5 N the eastern side shows negative values is the clearly indicating the Indian Ocean Dipole mode activity. The conspicuous characteristic in the spatial domain is low SLA between 15 and 20 N in the western region. The EOF 3 explains 5 % of the total variance. The spatial pattern depicts a dipole structure located off the west coast of India. The positive pole is around 16 N and 86 E and the negative pole at around 8 N and 84 E. Also, the strong variations along the west coast of India that indicates this mode correspond to the variability occurring due to the monsoon and related upwelling and sinking. In the Bay of Bengal, along the east coast of India, in response to the strong upwelling favourable south westerly winds, the sea surface height thickness decreases north of 10N [2]. Also, the larger variations in the northern end of the Bay are related to the trapping of huge river discharge[9].

4. Conclusion

The SLA distribution of Bay of Bengal exhibits significant spatial and temporal variations during 1993-2008. The annual average of SLA shows uneven increase and decrease. Conspicuous changes in SLA are occurred in 1997-1998 and 2007-2008 and these periods correspond to strong El nino and La Nina features respectively. The spatial structures obtained from EOF analysis demonstrate that the western and eastern parts changes in opposite way. The temporal amplitude of variability is dominated by annual cycle as well as the climate modes. Also, the slight inter-annal variations are consistent with the Indian Ocean Dipole mode.

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