Regional Studies in Marine Science 3 (2016) 67–75

Contents lists available at ScienceDirect

Regional Studies in Marine Science

journal homepage: www.elsevier.com/locate/rsma

Comparison of long-term variability of Sea Surface Temperature in the Arabian Sea and Bay of Bengal

P.K. Dinesh Kumar [a,*], Y. Steeven Paul [b], K.R. Muraleedharan [a], V.S.N. Murty [b], P.N. Preenu [a]

[a] Council of Scientific and Industrial Research (CSIR) – National Institute of Oceanography, Regional Centre, Dr. Salim Ali Road, Kochi – 682 018, Kerala, India

[b] Council of Scientific and Industrial Research (CSIR) – National Institute of Oceanography, Regional Centre, Visakhapatnam – 530017, India

HIGHLIGHTS

- Examined, Arabian sea and Bay of Bengal long-term SST variability during 1880–2010.
- SST time series revealed a clear upward trend in Bay of Bengal than Arabian Sea.
- Delineated the major processes that led to the warmer SSTs in the Bay of Bengal.
- Semi-annual and annual forcing control SST in AS whereas, the annual forcing in BoB.
- SST responses were in phase to the climatic events with stronger impacts in AS.

ARTICLE INFO

Article history:
Received 29 December 2014
Received in revised form
18 May 2015
Accepted 18 May 2015
Available online 21 May 2015

Keywords:
Sea surface temperature
Arabian Sea
Bay of Bengal
India
Climate change

ABSTRACT

Long-term variability of Sea Surface Temperature (SST) in the Arabian Sea (AS) and Bay of Bengal (BoB) during 1880–2010 is examined using all the available data sets of monthly SST, wind speed, incoming solar radiation, cloud cover, long wave radiation, latent heat flux, net surface heat flux and surface currents. SST time series reveal an upward (increasing) trend (warming) after 1940 in both the basins. Wavelet analyses of the SST time series reveal that AS SST is controlled by semi-annual and annual forcing while the BoB SST is influenced predominantly by annual forcing. The SST responses in both the basins are in phase to the climatic events such as El Niño, La Niña and Indian Ocean Dipole, but a stronger impact is noticed in the AS SST. The climatic events affected the seasonal peaks of SST warming (April–May) and cooling (August–September) in both the basins. Time series of SST anomaly also showed in phase responses to the climatic events and an upward trend from 1960 to 2010 in both the basins. Long-term decreasing trends observed in surface wind speed, latent heat flux and advective process *via* the weakened surface currents, together with the long-term increasing trend in P — E (Precipitation, P minus Evaporation, E) contributed to the SST warming trend in both the basins. In association with the upward trend in P — E, the Simple Ocean Data Assimilation (SODA) Reanalysis Sea Surface Salinity time series exhibited freshening (a decreasing trend) and enhanced the salinity stratification in the BoB, thus modulated the BoB SST warming. These cumulative processes led to the warmer SSTs in the BoB compared to that in AS.

1. Introduction

The northern Indian Ocean basin is entirely different from other world oceans due to its confinement within the tropics and lack of connection to the northern polar region. The Indian peninsula divides the north Indian Ocean into two basins—the AS and the BoB which experience the semi-annually reversing southwest (SW) and northeast (NE) monsoonal winds. Accordingly, the wind driven surface circulation in both the basins undergoes seasonal reversal (Dietrich, 1973; Murty et al., 1992; Conkright et al., 1994; Varkey et al., 1996). The current systems in the northern Indian Ocean are characterized by the seasonally changing monsoon gyre. The circulation is stronger and steadier during the SW monsoon than during NE monsoon which has no parallel in other oceans.

The Sea Surface Temperature (SST) is a direct measure of the energy balance which drives the circulation and ultimately defines the climate. The energy transferred between the ocean and the atmosphere is to a large extent dependent on SST and functions of SST such as the sensible heat flux, latent heat flux, and radiative

* Corresponding author. Tel.: +91 484 2390 814; fax: +91 484 2390618.
E-mail address: dineshku@nio.org (P.K. Dinesh Kumar).

http://dx.doi.org/10.1016/j.rsma.2015.05.004
2352-4855/

flux at the sea surface. SST is an important physical property of the ocean to understand the features like current flows, precipitation, biological production, properties of surface air over the ocean, upwelling, etc. SST is influenced by the parameters such as net incoming shortwave solar radiation, net long wave radiation, and the turbulent air–sea heat fluxes (the latent heat and sensible heat fluxes), wind stress curl, mixed layer depth, advection of eddies and ocean currents (Rao et al., 1994; Wilson-Diaz et al., 2009).

In both the AS and BoB, the annual variation of SST exhibits bi-modal character (Colborn, 1975) exhibiting surface warming in April–May and October and surface cooling during SW monsoon and winter months. However, the AS cools more during SW monsoon than does the BoB. Earlier studies suggested that the AS SST is important because of its possible role in the inter-annual variability of Indian summer monsoon (Li et al., 2001; Vinayachandran, 2004; Wilson-Diaz et al., 2009). Ellis (1952) showed that the floods of 1920 and the droughts of 1933 over a large area of the Indian sub-continent were well correlated with the AS SST anomalies. The AS SST exhibits a distinct spatial gradient, with lower SST in the west compared to that in the east (Rao, 1988) during the southwest monsoon. During April–May, the north Indian Ocean becomes the warmest area among the world oceans (Joseph, 1990). Soon after the onset of monsoon in June the surface winds strengthen, latent heat flux increases, SST decreases and the AS cools rapidly (Shenoi et al., 2002), though this cooling is not uniform in all parts of the AS (Ramesh Babu and Sastry, 1984). In the BoB, the lesser SST cooling is due to the heavy precipitation and fresh water runoff and the associated near-surface stratification during the SW monsoon (Shenoi et al., 2002).

The AS SST has a large influence on the wind patterns over India (Shukla and Misra, 1977; Ramesh Babu and Sastry, 1984; Vinayachandran, 2004) and on the Indian monsoon rain fall (Prasanna Kumar et al., 2009). Winds are strong over the AS due to the presence of Findlater Jet (Shenoi et al., 2002) compared to that over the BoB during the SW monsoon. Stronger winds cause increase in evaporation, upwelling and spreading of coastal cold waters off Arabia and Somalia coasts, resulting in wide spread of colder SST waters into the central AS. Onset of monsoon (Vinayachandran, 2004) and the biological production (Murtugudde et al., 2007) in the AS are closely related to the SST. The heat transfer between the atmosphere and ocean is dependent upon SST. Joseph (1990) studied the relation of warm pool and onset of summer monsoon, while Rao and Sivakumar (1999) studied the variation in SST. A mini-warm pool with higher SST (∼31 °C) occurs in the south-eastern Arabian Sea prior to the onset of SW monsoon (Vinayachandran et al., 2007; Nyadjro et al., 2012). Molinari et al. (1986) reported that much of the SST variability in the AS can be predicted by the surface fluxes alone but in coastal areas the horizontal advection of heat and entrainment of subsurface water are to be considered.

The BoB receives more extensive fresh water from precipitation and river run off than the AS (Varkey et al., 1996; Shenoi et al., 2002) and hence the former is less saline. Saji et al. (1999) have pointed out that Indian Ocean gives birth to a unique coupled ocean–atmosphere mode categorized as the manifestation of the tropical air–sea interaction. A shift in SST was reported in the Indian Ocean after 1976–77 (Terray, 1994; Terray and Dominiak, 2005) and a clear shift of SST in the AS after 1995 (Prasanna Kumar et al., 2009).

Long-term perspective of variations in SST in the AS and BoB and their comparison are required for a range of purposes. This knowledge would help in assessing whether the future climate scenario shows a continuation of recent variability or shows extreme case. It would also be required to overcome the inherent variability of climate models. In this direction, in the present study we have attempted to compare the long-term variability in SST in the AS and BoB using the long-term data records over a period of 130 years from 1880 to 2010. The goal of this study is to gain some insight into the processes controlling the forcing by utilizing all the available gridded data sets and raise questions about the climate change in response to natural and anthropogenic sources. Primarily using the ERSST, this study details the SST/SST anomalies from 1880 to 2010 for the Arabian Sea (AS) and Bay of Bengal (BoB) and using various heat flux components the mechanisms causing the SST variability are brought out. The paper is organized as follows: Section 2 describes various data sets and methods used. Detailed analyses of long-term variability in SST and SST anomaly in the AS and the BoB are presented in Section 3.1. In Section 3.2 we investigate the linkages between the SST anomaly variability in the AS and BoB and the climatic events such as the Indian Ocean Dipole (IOD), El Niño and La Niña. Section 3.3 deals with the long-term variation of the air–sea interaction parameters and surface currents in the AS and BoB. A summary and discussion of our findings are presented in Section 4.

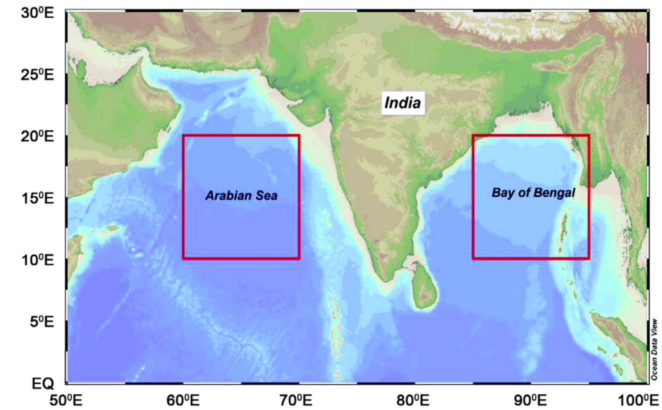

Fig. 1. Study area showing the boxes of investigation in the Arabian Sea (AS) and Bay of Bengal (BoB).

2. Materials and methods

For the present study, the region between 10°–20°N and 60°–70°E in the AS and the region between 10°–20°N and 85°–95°E in BoB are considered (Fig. 1). Monthly mean SST data was extracted from the NOAA extended reconstructed monthly Sea Surface Temperature (ERSST), version 3, from 1880 to 2010 (http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.ersst.html). This ERSST product contains the SST estimates from satellites, ships and buoys merged using a weighted sum of the different inputs, with weights inversely proportional to the noise estimate for each type (Smith et al., 2008). The monthly analysis extends from January 1854 to the present, but because of sparse data in the early years, the analysed signal is weak before 1880. After 1880, the strength of the signal is more consistent over time (Ihara et al., 2008). Hence, the data were selected from 1880 to 2009. ERSST is suitable for long-term global and basin wide studies; local and short-term variations have been smoothed in ERSST. By fitting to a set of spatial modes, the high-frequency SST anomalies have been reconstructed. For checking the quality of the data set, the ERSST data is compared with the Conkright et al. (1994) monthly temperature data.

Parameters such as SST, wind speed, shortwave radiation, long wave radiation, latent heat flux, and cloud cover were analysed using the monthly data from National Centre for Environment Prediction (NCEP)/National Centre and Atmospheric Research (NCAR) reanalysis 1 product for the period from 1948 to 2011 with 2.5° × 2.5° resolution. The recently developed new global Tropical air–sea heat Fluxes (TropFlux) data products (Praveen Kumar et al., 2012a) on improved air–sea heat fluxes, reconstructed solar