Interannual Variability of the Tropical Indian Ocean Associated with Indian Ocean Dipole Events Co-occurred with El Niño

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ABSTRACT

The feature and evolution mechanisms of tropical Indian Ocean (TIO) SST anomalies during Indian Ocean Dipole events that co-occurred with El Niño are studied using SODA data sets and an ocean general circulation model. The vertical heat advection is the major contribution to the peak of southeastern TIO negative SST anomalies. The equatorial western TIO is warmed by surface heat flux, while horizontal and vertical heat advections are responsible for the off-equatorial warming. Then the negative surface heat flux anomalies and the negative vertical heat advection anomalies take over for the cooling of the western and eastern TIO, respectively.

KEY WORDS: Indian Ocean Dipole, El Niño, SST anomalies, heat budget, numerical simulation

INTRODUCTION

El Niño-Southern Oscillation (ENSO) and the IOD are two prominent modes of interannual variability that impact the IO (Schott, 2009). The interannual variations of SST of the tropical Indian Ocean (TIO) is a basin-wide warming signal associated with ENSO (Saji et al., 1999; Behera et al., 2000; Venzke et al., 2000). It emerges as the first empirical orthogonal function (EOF) model as the Indian Ocean SST variability. The second EOF mode represents the Indian Ocean dipole (IOD), with a weak warming over the western IO and a major cooling in the east off Java and Sumatra (Saji et al., 1999; Webster et al., 1999). The TIO gradually warms during an El Niño year, reaching a maximum during spring (March–May) about one season after NINO3 SST has peaked [Nigam and Shen, 1993; Klein et al., 1999; Liu and Alexander, 2007]. Klein et al. [1999] showed that much of this warming is caused by ENSO-induced surface changes in surface heat fluxes, particularly the wind-induced latent heat and cloud induced solar radiation fluxes. During El Niño, atmospheric convection is suppressed over the IO, and the resultant increase in solar radiation contributes to the IO warming. The processes that cause SST changes during IOD events in eastern and western TIO may differ significantly (Li et al., 2003). The southeasterly anomalies over the southeastern Indian Ocean seem to be responsible for the formation of cold SST anomalies (Hong et al., 2008). The southeasterlies off-Sumatra were strengthened during IOD year, causing anomalous surface latent heat flux and vertical temperature advection (Li et al., 2002; Li and Wang, 2003, Drbohlav et al., 2007). The eastern cooling is primarily induced by these processes and strongly regulated by the seasonal-dependent thermodynamic air-sea feedback (Li et al., 2003).

The warming in the western Indian Ocean has been ascribed to both local and remote forcings. Saji et al. (1999) suggested that the warming evolves as a result of the combined effects of weak winds reduced evaporation and reduced eastward transport induced by easterly anomalies. Ocean dynamics contribute greatly to the anomalous warming in the western Indian Ocean (Li et al., 2002; Li and Wang, 2003; Drbohlav et al., 2007; Hong et al., 2008). On the other hand, westward propagating Ekman ridge around 10°S that suppresses local up welling in the west (Prasad and McClean, 2004). During IOD events without ENSO the easterly anomalies are absent or weak, the anomaly in the western Indian Ocean seems to be the oceanic dynamical response to the anomaly in the east (Hong et al., 2008).

In the coincidence years when the Indian Ocean Dipole (IOD) is followed by the major El Niño during boreal autumn–winter season, surface dipole structure in the TIO tends to turn into the basinwide warm pattern in the November–December period. In contrast, the subsurface dipole keeps its structure from boreal autumn to winter (Tokinaga and Tamimoto, 2004). In this paper we find out the feature of SST anomalies and the mechanisms that are responsible for the SST anomalies during the coincidence years when the IOD and El Niño happens together. The rest of the paper is organized as follows. Section 2 describes the data sets and the model used in this study. Section 3 presents the SST anomalies associated with El Niño and IOD. Section 4 shows the model results and examines physical processes that generate the SST anomalies during the 1997-1998 IOD and El Niño. Section 5 provides a summary.

DATA SETS AND OCEAN MODEL

Data sets

Atmospheric variables in this study are monthly mean wind speed, net shortwave radiation, net longwave radiation, latent and sensible heat flux in the National Center for Environmental prediction/National Center for Atmospheric Research reanalysis products (NCEP/NCAR reanalysis;