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Observations of long-period waves in the nearshore waters of central west coast of India during the fall inter-monsoon period

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ABSTRACT

The waves measured in the eastern Arabian Sea during the fall inter-monsoon period (October) are examined at 4 locations during 2010–2015. Multi-modal features have been observed in measured wave spectra due to independent wave systems corresponding to long-period swells generated by remote storms, swells generated by nearby storms and locally generated wind waves. In October, the long-period waves (peak wave period > 18 s) appeared 5–7 times in different years and the significant wave height of these long-period waves are less than 1.4 m. The spatial distribution of peak wave period based on the numerical wave model shows that the presence of long-period swells along the 350 km stretch of the eastern Arabian Sea is almost in the same day. It is observed that the high waves (significant wave height > 4 m) generated in an area bounded by 40–60°S and 20–40°E in the south Indian Ocean reached the measurement locations in 5–6 days and resulted in the long-period waves. Relatively high percentage of long-period waves are observed in 2011 and 2015 compared to other years due to the reduction in short-period waves at the study location due to the influence of Indian Ocean Dipole.

1.Introduction

The wind pattern in the Arabian Sea (AS) changes between the boreal summer and winter monsoon (Shetye et al., 1985). During the summer monsoon (June to September), the winds are much stronger and during the transition period (October), the winds are weaker and these change in the wind pattern produce a similar shift in the waves in the AS (Kumar et al., 2012; Kumar and Anjali, 2015). Hence, the wave characteristics in the eastern AS undergo changes due to the seasonal reversal of monsoon winds (Anoop et al., 2015). The seasonal variations along the eastern AS have been well characterized and shown a monsoon-non-monsoon pattern and the general variations within a year are similar (Kumar et al., 2003, 2014). Studies on surface waves in the eastern AS has generally focused on the boreal summer monsoon (Kumar et al., 2000, 2011; Amrutha et al., 2015) and the period before the summer monsoon (Neetu et al., 2006; Vethamony et al., 2011; Amrutha et al., 2016a). Even though the annual wave characteristics of eastern AS are studied (Glejin et al., 2013; Kumar et al., 2014; Dora and Kumar, 2015), little attention has been given to the inter-monsoon period (October), which feature a short-lived and intense upper oceanic jet in the equatorial zone of the Indian Ocean (Hastenrath et al., 1993). The annual mean of the wind field through the equatorial Indian ocean is weak and westerly in nature with a strong semi-annual westerly component during both inter-monsoons (Schott and McCreary, 2001; Schott et al., 2009). Indian Ocean Dipole (IOD), an interannual mode of variability, is a major ocean-atmosphere coupled phenomena in the equatorial Indian ocean with cooler (warmer) sea surface temperature in the eastern (western) than the seasonal climatology (Saji et al., 1999). During IOD events Sea Surface Temperature anomalies are strongly coupled to surface wind anomalies in the central equatorial Indian Ocean (Saji et al., 1999). Surface winds reverse direction from westerlies to easterlies during the peak phase of positive IOD events (Rao et al., 2002). Since the wind is the major generating force of surface waves in the Ocean, the wind anomaly caused by IOD and El Niño Southern Oscillation (ENSO) (Schott et al., 2009) induce the change in wave climate. Recently Anoop et al. (2016) examined the impact of the IOD on the surface wind field of AS and its effect on the wave climate of eastern AS and reported influence of IOD on the surface wind field and a reduction in wind-seas in October during positive IOD years. Madden-Julian Oscillation (MJO) is a dominant intra-seasonal mode of oscillations which recurs every 30–60 days propagating eastward near the equator and an important factor of active and break phases of Indian and Australian monsoons (Madden and Julian, 1971) with intraseasonal and interannual variability (Mehta and Krishnamurti, 1988) and are seasonally phase locked (e.g. Saji et al., 1999).

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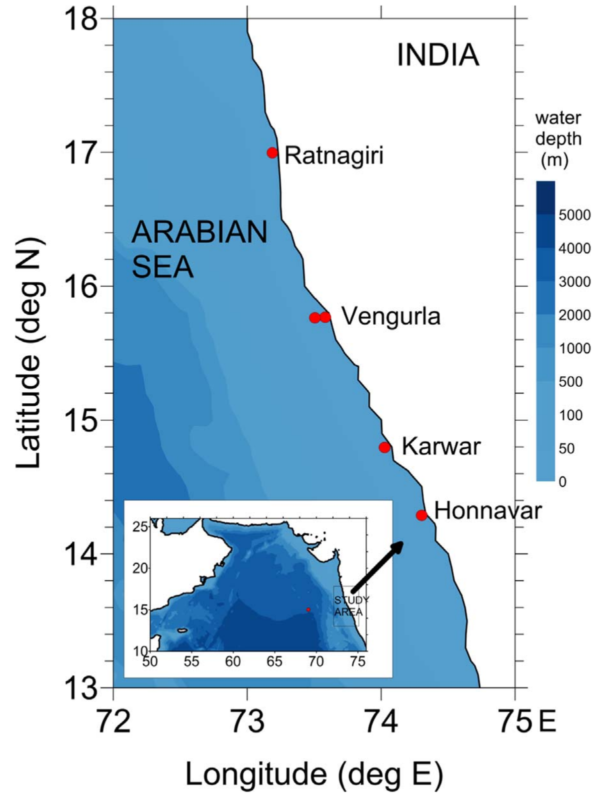

Fig. 1. Map showing the locations of wave measurement. The big circle represent the nearshore buoy and the small circle is the deep water buoy location.

Swells in the ocean surface can travel thousands of kilometres (Munk et al., 1963) and the identification of low-frequency swells propagating great distances from the generation region is important in wave hindcast studies (Ardhuin et al., 2009). Over the global ocean, 75% of the time, wave conditions are dominated by the swell (Semedo et al., 2011). Partially sheltered by the Africa continent, some of the Southern Ocean westerly swells could not reach the NIO. The annual climatology of swells and wind-seas indicates that the waves in NIO are dominated by swells (Semedo et al., 2011; Anoop et al., 2015) and the contribution of swells in the observed data ranged from 46% to 60% off the central west coast of India (Kumar et al., 2014). In the eastern AS, Glejin et al. (2016) observed low-amplitude (significant wave height < 1 m) long-period swells during 1.4–3.6% of the time in a year and are mainly during the non-monsoon seasons. The long-period swells cause significant heave motions of oil drilling rigs and interfere with other offshore operations (Gjevik et al., 1988). The ports exposed to open ocean, experience a reduction in efficiency of cargo handling operations and mooring line breakages due to long-period swells and its orientation with respect to moored vessel (McComb et al., 2009). Long-period swells (peak wave period, T_p > 15 s) are observed in the northern AS during 2009 (Kumar et al., 2011). Off the central west coast of India, southwest waves with T_p values greater than 18 s are observed (Kumar et al., 2014). During the summer monsoon, due to the interaction of monsoonal waves (immature swells) with long-period swells, the spectral peak frequency slightly moved towards the high-frequency region (Amrutha et al., 2015). Since the eastern AS becomes calm in October (Glejin et al., 2013), during this period, the presence of long-period swells is also expected. October-November is the period during which tropical cyclone is formed in the north Indian Ocean (NIO) (Pattanaik et al., 2013).

In this paper, we examine the characteristics of waves in the eastern AS during October based on data measured off Vengurla at 15 m water depth from 2013 to 2015 and at 5 m water depth during 2014 and 2015. The measured wave data at 3 other locations in water depth 9–15 m covering 350 km stretch of the eastern AS during 2010–2015 are also used in the study. The paper is arranged as follows. Section 2 contains the details of study area along with data and methodology employed in the study. Section 3 provides a discussion of the results, and Section 4 summarizes the conclusions.

2. Study area, data and methods

2.1. Study area

The study area is the nearshore waters of the central west coast of India (Fig. 1). During the spring tide, the tidal range in the area is ~ 2.3 m and during the neap tide, it is ~ 1.3 m (Amrutha et al., 2015). The ERA-Interim reanalysis data from European Centre for Medium-Range Weather Forecasts (ECMWF) at every 6 h interval with a spatial resolution of 0.5° during January, April, July, and October averaged over the years 2010–2015 is presented in Fig. 2 to show the seasonal variation of winds and waves in the AS. The waves in the AS show strong seasonal variation due to the variation in the winds similar to the earlier observations (Kumar et al., 2012; Anoop et al., 2015). During the non-monsoon season, the wave climate is primarily mixed sea and swell (Dora and Kumar, 2015). During July, the monthly average wind speed in the AS reaches 14–15 m/s with the significant wave height (H_{m0}) up to 5 m (Fig. 2). The average H_{m0} in the eastern AS during July varies from 2 to 4 m and the wave height increases from south to north (Glejin et al., 2012). The average H_{m0} in the present study area is 1.8–2 m during the summer monsoon period and is 0.6–0.8 m during the remaining period with an annual average value of 1–1.2 m (Kumar et al., 2014). Off Vengurla, Amrutha et al. (2015) reported seasonal average H_{m0} of ~ 2 m during the summer monsoon period and 1 m as the annual average value. During October, the wind speeds reach minimum value (< 4 m/s) over entire AS (Fig. 2). At Honnavar, the wave measurement location is 2.5 km from the west coast of India and at Ratnagiri, it is 2 km. The depth contours of 20, 50 and 100 m occur at 10, 30 and 75 km off Honnavar and at 6, 25 and 105 km off Ratnagiri. The study area is exposed to open ocean waves from northwest to south, and the nearest landmass is ~ 1500 km in the northwest, ~ 2000 km in the west, ~ 4000 km southwest and ~ 9000 km in the south (Amrutha et al., 2016a). Due to its exposure to the Sothern Oceans and the large fetch available, swells are present all year round in the study area and the swells are dominant during the non-monsoon period (Glejin et al., 2013). During February to May, due to the low wind-seas, the swells propagating from the southern hemisphere reach the eastern AS (Semedo et al., 2011; Glejin et al., 2013). Amrutha et al. (2016a) studied the changes in nearshore waves during the active sea/land breeze period (February-April) of the study area and reported that due to the influence of the land/sea breeze system, the range of the peak wave period in one day varied up to 8 s.