Ocean Modelling 119 (2017) 105–117

Contents lists available at ScienceDirect

Ocean Modelling

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

Climate driven variability of wind-waves in the Red Sea

P.R. Shanas*, V.M. Aboobacker, Alaa M.A. Albarakati, Khalid M. Zubier

Faculty of Marine Sciences, Department of Marine Physics, King Abdulaziz University, P.O. Box 80207, Jeddah 21589, Saudi Arabia

ARTICLE INFO

Keywords:
Red Sea
Wind waves
Inter-annual variability
Climate indices
Wave modelling

ABSTRACT

Wind-wave variability in the Red Sea has been studied over a period of 32 years (1979–2010) by hindcasting the wind-waves using a third generation spectral wave model, WaveWatch III, forced with the Climate Forecast System Reanalysis (CFSR) winds. The wave model results have been validated against the satellite observations and available measurements in the Red Sea. The study reveals robust spatial and temporal variability of wind speed and significant wave height in the Red Sea. The role of climatic indices on the wind-wave variability has been assessed. The highest extreme wave heights (99th percentile) are centered at three regions; around 23° N, 19° N, and 15° N latitudes, while the 90th percentile and mean significant wave heights are scattered in the deep waters of the Red Sea. Contrasting trends of the significant wave heights such as negative trends in the northern Red Sea during summer and positive trends in the southern Red Sea during winter are the highlights, where the trends are significant and comparable with the trends at few marginal seas around the globe. A clear distinction exists between the two parts of the Red Sea in response of the variability due to climatic indices. Among the climatic indices, the North Atlantic Oscillation (NAO) and the El Niño-Southern Oscillation (ENSO) show significant positive and negative correlations with the characteristic wave heights in the northern and southern Red Sea.

1. Introduction

This paper presents the estimated trends and variability of wind waves in the Red Sea. The Red Sea is a semi-enclosed basin with a narrow opening at the south (Fig. 1). It is assumed that the swells from the Indian Ocean have negligible influence on the Red Sea due to the geometry of the basin that impedes the monsoon waves to enter the Red Sea (Ralston et al., 2013; Langodan et al., 2014). It has been identified in semi-enclosed basins, for instance at the Baltic Sea that the wave climate is one among the most sensitive indicators of local wind climate (Zaitseva-pärnaste, 2009). The wind climate in the Red Sea is subject to reversing monsoons (Jiang et al., 2009; Patzert, 1974), and the variations due to climatic signals are generally reflected on the predominant monsoons – southwest and northeast (Ralston et al., 2013). In addition, the occurrence of Tokar gap winds and the convergence are crucial in controlling the waves in the central Red Sea (Langodan et al., 2014, 2015; Aboobacker et al., 2016). Even though the Red Sea is relatively small, the local wind and wave climate needs to be assessed to understand the regional variability and its dependence with the global climate indices.

Globally, a number of studies have described the trends and variability of wind waves; based on the past data such as satellite observations (e.g., Young, 1999; Young et al., 2011; Izaguirre et al., 2011), visually observing ships data (e.g. Gulev and Grigorieva, 2004, 2006) and the wave hindcasts (e.g., Cox and Swail, 2001; Dobrynin et al., 2015, 2012; Wang and Swail, 2006). Based on the past observations, Young et al. (2011) identified significant trends in extreme wave conditions globally. Increasing trends in wind speed and wave height were identified regionally over the last few decades, especially in the Pacific (Allan and Komar, 2000; Durrant et al., 2014; Hemer et al., 2011; Seymour, 2011), in the East and North Atlantic (Bertin et al., 2013; Gulev and Grigorieva, 2006), in the Southern Ocean (Bhaskaran et al., 2014) and in the North Indian Ocean (Anoop et al., 2015; Hithin et al., 2015; Kumar et al., 2013; Shanas and Kumar, 2015). Future projections take into account of the carbon emissions, although uncertainties exist among different scenarios for the 21st century (e.g., Hemer et al., 2013a; Semedo et al., 2013; Wang and Swail, 2006). The projected changes in the annual mean wave heights are leading to decreasing trends in the sub-tropics and increasing trends in the Southern Ocean (Hemer et al., 2013b). The CMIP5-based statistical projections show significant increase in wave heights in the tropics and in the high latitudes of the southern hemisphere (Wang et al., 2014).

Inter-annual variability is the most striking phenomenon associated with the climate change. Several studies have shown that the climate variability has a significant impact on the wind wave conditions all over the globe, with large inter–annual variability correlated with climate

---

[*] Corresponding author.
E-mail addresses: sputhuveetil@stu.kau.edu.sa (P.R. Shanas), amohamad@kau.edu.sa (V.M. Aboobacker), aalbarakati@kau.edu.sa (A.A. Albarakati), kzubier@kau.edu.sa (K. Zubier).

http://dx.doi.org/10.1016/j.ocemod.2017.10.001
Received 28 September 2016; Received in revised form 1 October 2017; Accepted 11 October 2017

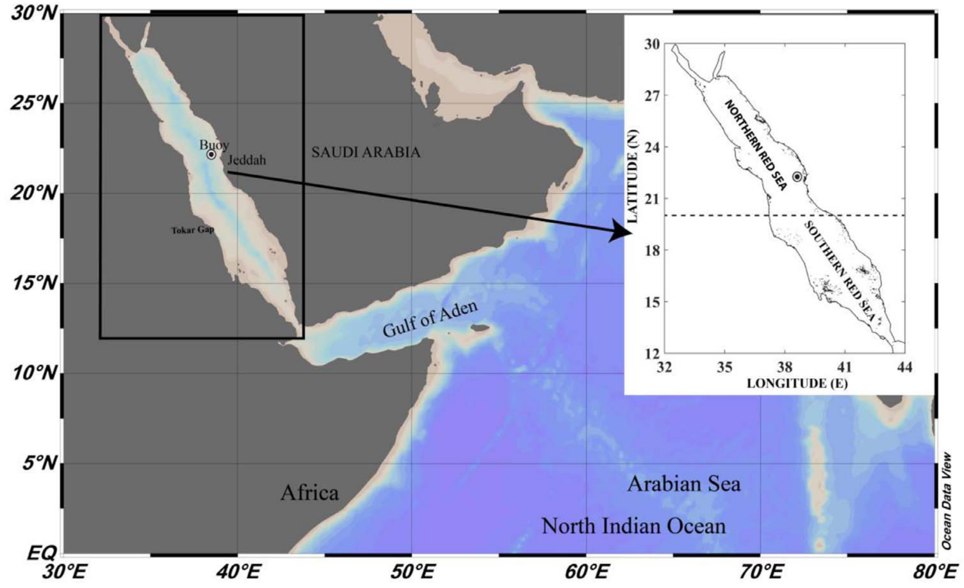

Fig. 1. Study area showing the buoy location and model domain (12°–30°N, 32°–44°E).

indices (Anoop et al., 2015; Gulev and Grigorieva, 2004; Lionello and Sanna, 2005; Méndez et al., 2006). For instance, the wind-wave variability in the Atlantic has a strong resemblance with the North Atlantic Oscillations (Cotton, 1999; Woolf et al., 2002; Gulev and Grigorieva, 2004; Bertin et al., 2013; Gulev and Grigorieva, 2006). The El Niño-Southern Oscillation (ENSO) has a strong influence on the wave climate in the Pacific (Gulev and Grigorieva, 2004; Izaguirre et al., 2011; Hemer et al., 2011; Stephens and Ramsay, 2014). The Dipole Mode Index (DMI), a measure of Indian Ocean Dipole (IOD) has significant impact on the inter-annual variability in the wave climate over the Arabian Sea (Anoop et al., 2016). The East Atlantic - West Russia patterns (EAWR) can also influence the wind-wave variability in global and regional seas (Izaguirre et al., 2011).

The wave climate variability in the semi-enclosed and marginal seas are prominently conditioned by the regional storminess as well as the orographic and topographic influence (Mirzaei et al., 2013; Hailun and Yao, 2016; Liang et al., 2013; Stefanakos and Athanassoulis, 2004; Appendini et al., 2014; Senafi and Anis, 2015). At the same time, the wind wave variability in most of the marginal seas has strong links with the global climate that leads to spatial and seasonal variability in trends (Lionello and Sanna, 2005; Räämet et al., 2010; Arkhipkin et al., 2014; Valchev et al., 2012; Groll et al., 2017; Zaitseva-Pärnaste et al., 2011; Patra and Bhaskaran, 2016). This indicates that regional wind-wave variability studies can give more insight on the native contribution to the global climate.

In the Red Sea, there are no long-term studies on wind-wave variability so far; primarily because of the non-availability of long-term in situ measurements. Seasonal characteristics of wind-waves in the Red Sea were studied based on short-term observation and modelling (Langodan et al., 2014, 2017; Ralston et al., 2013). Here, the in situ measurements are available only at one buoy location (see Fig. 1). The satellite altimetry coverage is shorter and less frequent across the basin, which is insufficient for a reliable long-term analysis for the entire basin, although it can be used for the model validation. The previous studies provide an overview of the wave conditions in the Red Sea. The waves are generally moderate with an observed maximum significant wave height of 4.0 m at the buoy deployed in the central Red Sea by the King Abdullah University of Science and Technology (KAUST) (Ralston et al., 2013). The average significant wave height varies spatially between 0.6 and 1.2 m while the average peak wave periods are between 4 and 6 s. Extreme events such as tropical cyclones were not reported in this region, however, the Saudi coast along the Red Sea experiences moderate storms (Prakash et al., 2015).

Well calibrated third generation wave models are suitable to hindcast the wind-waves for long-term periods (Sterl et al., 1998; Wang and Swail, 2002). In the Red Sea, third generation models were applied to hindcast the wind-waves for various period lengths (Fery et al., 2015; Langodan et al., 2014, 2015, 2016; Aboobacker et al., 2016; Saad, 2010; Ralston et al., 2013; Zubier et al., 2008). In the present study, we have carried out the hindcasting of wind-waves in the Red Sea during 1979–2010 (32 years) using the well-known third generation spectral wave model, WAVEWATCH-III (WW3 hereafter) (Tolman, 2014). The model results have been validated against satellite observations and available measurements. Long-term characteristics such as trends, variability and the role of climatic indices have been assessed.

The paper is organized as follows: Section 2 describes the features of the study area and Section 3 details the methodology, including the setup and validation of wave model results. Section 4 describes the results and the discussion is divided into 3 subsections which explain the trends, variability and role of climatic indices. The main conclusions of this study are summarized in Section 5.

2. Study area

The Red Sea is an elongated basin, oriented in SE to NW direction between 12°N and 30°N latitude, and 32°E and 44°E longitude (Fig. 1). It features a unique combination of relatively small size with a rather complex bathymetry. Several characteristics of global oceans are observed in the Red Sea such as convective and subductive water mass formation, interaction with adjacent semi-enclosed basins, small scale mixing process, etc. (Eshel and Naik, 1997; Eshel et al., 1994). The sea splits in the north into the western shallow Gulf of Suez and the eastern deep Gulf of Aqaba (Manasrah et al., 2006). Complex orography with the mountain ranges bordering along the eastern and western coasts of the Red Sea has a profound influence on the local wind regime (Jiang et al., 2009).

Two dominant wind regimes are present in the Red Sea (Al-Barakati, 2004). In summer (June–September), the north-northwest winds are predominant in the major part of the Red Sea with an average magnitude of 5–7 m/s. At the southern regions, the Red Sea winds merge with the SW monsoon winds of the Indian Ocean. In winter (December–March), the northerly winds dominate in the northern Red Sea (north of 20° N), while the south-southeast winds are prevalent in the south of 20° N which are due to the turning of NE monsoon winds (Clifford et al., 1997; Langodan et al., 2014; Patzert, 1974; Ralston et al., 2013; Sofianos and Johns, 2003). An intermediate zone of weak