Ocean Engineering 163 (2018) 599–608

Contents lists available at ScienceDirect

Ocean Engineering

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

Wave transformation in the nearshore waters of Jeddah, west coast of Saudi Arabia

Alaa M.A. Albarakati*, V.M. Aboobacker

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

ARTICLE INFO

Keywords:
Wave spectra
Red sea
Diurnal variability
Wave transformation
Jeddah coast
SWAN

ABSTRACT

Many specific problems in the coastal zones require an accurate description of the wave field and knowledge of wave parameters. The studies on the spectral characteristics of wind-waves in the Red Sea are very much limited. In this study, the spectral characteristics of nearshore waves in the central Red Sea, specifically the Jeddah coast has been investigated utilizing a third generation spectral wave model, SWAN. The model results were validated against the available measured data. The seasonal and monthly characteristics and the diurnal variability of wave spectra were analysed and discussed. The wave transformation between deep, intermediate and shallow water depths were assessed at three transects – northern, central and southern regions off Jeddah. The results indicate that multi-directional swells are present in the Jeddah nearshore regions, which are propagated from the northern and southern Red Sea. The diurnal variability in the wave spectra is persistent throughout the year, although it fluctuates among the seasons according to the prevailing wind conditions. Significant attenuations in wave heights were identified in the intermediate and shallow waters, with the highest attenuation occurred in the central Jeddah coast.

1. Introduction

The Red Sea is a semi-enclosed basin located in a narrow, elongated rift valley between Africa and the Arabian Peninsula. It is approximately 2250 km long and 350 km wide at the widest part. It has three distinct depth zones; shallow shelves of less than 50 m, deep shelves having depths between 500 and 1000 m, and the central axis with depths between 1000 and 2900 m (Rasul et al., 2015). The Large scale wind patterns in the Red sea are primarily controlled by the seasonal characteristics and the surrounding orography (Patzert, 1974; Clifford et al., 1997; Sofianos and Johns, 2003). In the northern Red Sea (north of about 20° N) the north-westerly wind blows all around the year. In the southern Red Sea the intensity and direction of winds are mainly controlled by the Arabian Sea monsoon; with dominant south-easterlies in winter (November–April) and north-westerlies in summer. There exists a convergence zone in the central Red Sea (south of Jeddah) during winter, where the north-westerlies converge to the south-easterlies that lead to very low wind speeds (Ralston et al., 2013). These peculiarities in the wind systems reflect on the wave characteristics of the Red Sea (Langodan et al., 2014; Saad, 2010; Zubier et al., 2008).

Ocean wave spectra refer to the distribution of the total wave variance over frequency and direction. Continuous measurements of wave spectra are difficult due to operational constraints, whereas the validated spectral wave models can be considered as an alternative to resolve the spectral transformation in the offshore and nearshore regions. The *in situ* wave data are very much limited in the Red Sea. NDBC provides wave parameters from a met-ocean buoy (reference number 23020) deployed in a deep water location in the central Red Sea. This data have been utilised in the previous investigations, especially for the validation of offshore wave model results (e.g., Shanas et al., 2017a; Aboobacker et al., 2016). Eventually, numerical wave models were applied to study the seasonal and long-term characteristics of the wind-waves in the Red Sea. The Red Sea basin often experiences the superposition of multiple wave systems and hence the basin has been categorized into distinct regions based on the dominance of superimposed/non-superimposed/co-existing waves (Shanas et al., 2017b). The Jeddah coast (Fig. 1) is one among the regions, where the wind seas are often superimposed over the swells. Here, the swells are predominantly from the northern Red Sea and a small contribution is from the southern Red Sea, while the local winds are usually in the form of sea breeze and land breeze. Our focus is to elaborate on the spectral wave characteristics off Jeddah using a calibrated nearshore spectral wave model. The region is particularly interesting because of the availability of measured wave spectra for model validation and due to the complex wave-wave and wave-bottom interactions. In this perspective, we have carried out numerical wave simulations for the Jeddah coast using the Simulating

* Corresponding author.
E-mail address: alaa7@yahoo.com (A.M.A. Albarakati).

https://doi.org/10.1016/j.oceaneng.2018.06.041
Received 8 October 2017; Received in revised form 28 May 2018; Accepted 13 June 2018
0029-8018/

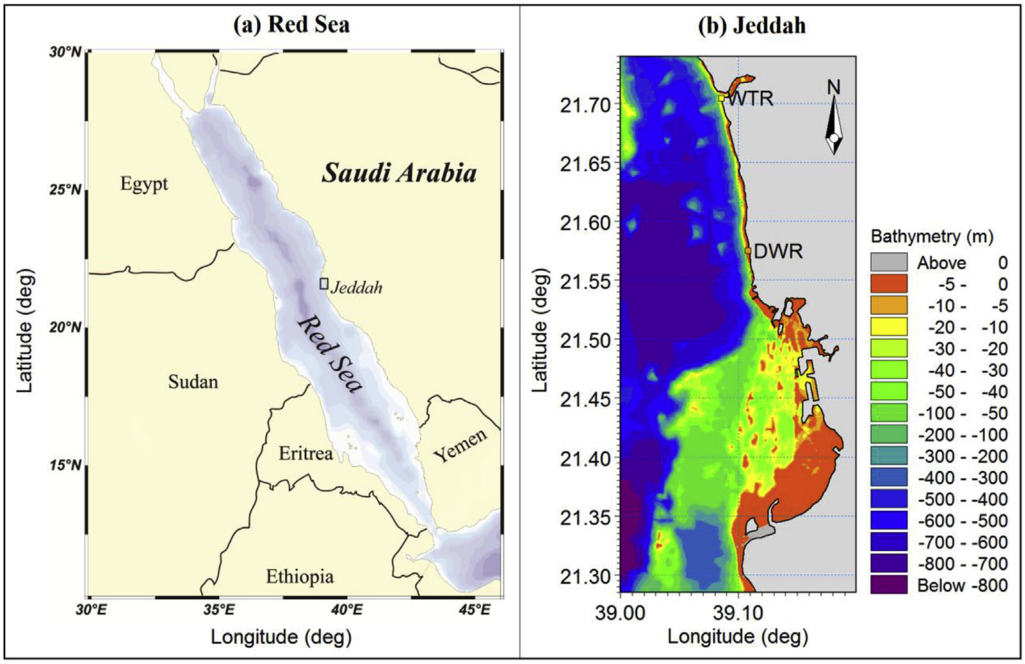

Fig. 1. (a) The Red Sea and (b) the Jeddah model domain and bathymetry. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Waves Nearshore (SWAN), a spectral wave model specifically designed for nearshore applications.

The studies based on wave model results in the Red Sea were mainly focused on the total wave parameters rather than the component waves such as wind seas and swells. Saad (2010) used the WAM model for hindcasting the waves in the Red Sea with a relatively coarse spatial resolution. The WaveWatch III (WW3) model has been widely applied in the Red Sea for short-term and long-term wave hindcasting (e.g. Langodan et al., 2014; Aboobacker et al., 2016; Shanas et al., 2017a, 2017b). The SWAN-based models were also used for short-term wave analysis (e.g., Zubier et al., 2008; Ralston et al., 2013; Fery et al., 2012, 2015); they are capable of resolving the shallow water processes more accurately than the offshore wave models (Booij et al., 1999).

Saad (2010) gives an overall idea of the wave conditions in the Red Sea. This study marked the under-estimations of wave heights, which are primarily due to the coarse resolution of model grids and input winds. Better predictions were obtained in the later hindcasts in the Red Sea with proper treatment of the source functions (Langodan et al., 2014), which leads to reliable assessment of wave power (Aboobacker et al., 2016) and understanding of short-term and long-term variability (Shanas et al., 2017 a; b). Zubier et al. (2008) customized the SWAN for the first time in the Red Sea with a focus to implement an operational wave prediction system. The follow-up study analysed the sea states along the Jeddah coast (Fery et al., 2015). A comprehensive analysis of the wave conditions in the Red Sea were made by Ralston et al. (2013), which examined the impact of Tokar winds in the central Red Sea. Although the wave conditions in the Red Sea are vastly described, localised features are yet to be well-understood.

Fery et al. (2015) analysed the wave parameters measured off Jeddah and used them for the verification of a Red Sea wave model. The reported average wave heights in these locations are 0.6 m and 0.4 m, respectively, whereas the maximum wave heights are 2.2 m and 1.2 m, respectively. They identified distinct diurnal variations in the wave patterns. Pronounced diurnal variability are limited to the coastal regions, which are due to the sea breeze – land breeze systems and their influence diminishes towards the offshore regions (Ralston et al., 2013; Shanas et al., 2017b). Recently, Shanas et al. (2018) analysed the measured wave spectra off Jeddah for a limited period of time (during summer) and studied the wind sea and swell characteristics. This data has been used in the present study for the validation of SWAN model results. Nonetheless, the spatial and temporal characteristics of the wave spectra in the nearshore regions of Jeddah are yet to be understood. Previous studies lack the discussion on the wave transformation from deep to intermediate and shallow regions off Jeddah coast. In this context, the present study aims to explore the spectral wave characteristics off the Jeddah coast using the spectral wave model SWAN. The monthly and seasonal features have been discussed. Diurnal variability of the wave spectra has been particularly addressed. The transformation of wave parameters from the deep to intermediate and shallow depths have been analysed considering three cross-shore transects.

The paper has been organised as follows: Section 2 describes the area of study, Section 3 explains the data and methodology that consists of the description on the wave data collection, wave model setup and validation of model results, Section 4 demonstrates the results and discussions, and Section 5 summarises the important results.

2. Area of study

The Jeddah coast lies in the central part of the Red Sea along the west coast of Saudi Arabia (Fig. 1). The winds are predominantly from the NW/WNW throughout the year; however, local breezes from the N to E directional sector and occasional desert winds from the SE are also accountable. The convergence zone developed in the south of Jeddah (around 18° N) during winter has several implications on the met-ocean parameters in the central Red Sea; e.g., resulting in low wind speeds and weakens the local wind seas. During summer (especially during Jul and Aug), the Tokar gap winds developed in the Tokar mountain ranges in the Sudan blow as westerlies across the Red Sea. These wind systems can generate high waves in the central Red Sea and propagate towards the Saudi coasts. A portion of these waves occasionally reaches the Jeddah region.

The bathymetry off Jeddah coast is complex due to the steep gradients in water depths and by the presence of coral reefs (Fery et al., 2015). The coral and island reefs significantly reduce the wave propagation towards the coast. The orography of the Jeddah bay helps to