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On the co-existence of high-energy low-frequency waves and locally-generated cyclone waves off the Indian east coast

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ABSTRACT

The evolution of wave energy spectra obtained from a directional waverider buoy at the landfall location (Gopalpur) of the very severe cyclonic storm Phailin in the Bay of Bengal is discussed. The study reveals that swells generated approximately 8600 km away from the buoy location in the southern ocean (at 12 UTC on 3 October, 2013) travelled at a speed of 15.6 m/s and contributed to create a complex wave field at Gopalpur during cyclone Phailin. The rare co-existence of the low-frequency (0.055 Hz), high-energy (21.37 m^2/Hz) southern ocean swells with local cyclone-generated swells during the period (8–12 October, 2013) is reported.

1. Introduction

Investigation of wave field characteristics during extreme conditions, such as Tropical Cyclone (TC) events, is of paramount importance as the associated extreme waves have a direct impact on safe navigation at sea as well as the lives and properties of coastal communities in the affected areas. Prior knowledge about these extreme waves is very important to many areas including the fishing industry, navy and coastguard, ports and harbours, offshore oil industry, and the state administration for emergency preparedness and mitigation planning. Though routine wave forecasting has reached a satisfactory skill level (Komen et al., 1994), forecasting during a TC is a challenging task even today, as cyclone-generated wave fields can interact with the locally- or remotely-generated waves already existing at the location, thus forming a very complex wave field. Such complex wave fields can be studied through the analysis of observed wave spectra in the cyclone affected areas. Furthermore, results from complex TC-generated wave field studies can lead to regional wave model source term improvements and thereby better wave forecasts.

With this intention, the shallow water wave energy spectra off Gopalpur, has been analysed during the very severe cyclonic storm (VSCS) Phailin for the period from 8 to 12 October, 2013. Data from the Directional Wave Rider Buoy (DWRB) (Barstow and Kollstad, 1991) deployed offshore of Gopalpur, in the north-western Bay of Bengal is used for the analysis. Bay of Bengal (BOB) is prone to cyclones especially during the months of October–December (Alam et al., 2003). VSCS Phailin was the first such BOB disaster occurring during the 2013 cyclone season. Swells from the Indo-Australian sector of the Southern Ocean (extending from 30°E to 120°E and 60°S to 30°S, henceforth SIO) resulting from extra tropical storms reach Indian coastal waters (Alves, 2006; Bhowmick et al., 2011; Kumar et al., 2009) . A striking feature associated with the advection pattern of these swell systems is that they propagate towards the south-eastern coasts of Indonesia and Australia apart from the coastal areas of Myanmar and India (Alves, 2006).

The propagation of swells along great circle paths was studied by many researchers in the past (Munk et al., 1963; Barber and Ursell, 1948). It is understood that swells can traverse distances of the order of thousands of kilometres without much dissipation and reach the coastal areas with considerable energies. Aboobacker et al. (2011) showed that shamal swells interact with local wind seas in the Arabian sea during winter monsoon season. Studies of Nayak et al. (2013) describe the modulation of local wind sea due to the southern ocean swells. There have been individual reports of very low-frequency swell observations at various coastal stations around the globe. Shillington (1981) and Harris et al. (1973) reported the occurrence of very low frequency (0.045–0.05 Hz) waves in Cape Waters. Consideration of energy distribution in frequency–time space revealed that these swells originated around 100 nautical miles away, which was confirmed by the presence of a storm in the synoptic weather chart. Their

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result is an observational evidence of the modulation effects of remote forcing on locally generated wind sea. No such attempt has been made so far in the Indian coastal waters using measured wave spectra for the estimation of distant swell sources.

The objectives of this study are (1) to describe the complex wave fields observed during the VSCS Phailin, (2) to estimate the contribution of SIO swells towards the total wave energy at Gopalpur, and (3) to investigate the source and initiation of the low-frequency, high-energy component in the wave energy spectra observed at Gopalpur before and during Phailin, using'ridge analysis'. Ridge analysis is based on linear wave theory (Snodgrass et al., 1966). The basic paradigm on which this analysis is done is the fact that there will be a linear increase of swell frequency with time, if the storm is assumed to be a point source.

2. Data and methods

2.1. In-situ observation

Earth System Science Organization (ESSO)-Indian National Centre for Ocean Information Services (INCOIS) has established a DWRB network at 10 different locations along the Indian coastal waters including off Gopalpur, Odisha (19.28°N, 84.97°E at 12 m water depth, 2 km away from the coast; see Fig. 1 for location). This network is primarily meant for validating the wave models and understanding the in-situ wave characteristics at these locations. This DWRB was recording high waves at Gopalpur, the landfall location of Phailin until 6 UTC of 12 October, 2013, after which it drifted due to cyclone-generated high waves and strong currents.

The directional buoy measures horizontal (roll and pitch) and vertical (heave) accelerations using accelerometers and an onboard flux gate compass to give the directional displacements in horizontal and vertical axes. With this information, displacements of the buoy in the horizontal and vertical directions are calculated. Records of 256 heave samples were collected by the buoy every 200 s, at a sampling frequency of 1.28 Hz. Using sequences of 8 such records, the wave spectrum was obtained through Fast Fourier Transform (FFT) of these vertical displacements. Resulting spectra included the frequency interval 0.025–0.58 Hz at a resolution of 0.005 Hz. Integral wave parameters such as significant wave height (Hs), peak wave period (Tp) and peak wave direction (Dp) were computed from the spectrum. Other parameters like directional spread (σ), spectral peakedness (Qp) and spectral narrowness (υ) were also computed (Goda, 1970). The data were received in real-time at ESSO-INCOIS through Indian National Satellite System (INSAT) and also through the High Frequency (HF) system.

The wave measurements obtained from the three moored buoys viz, BD08 (18.14°N, 89.67°E), BD11 (13.49°N, 83.98°E) and BD14 (7.03°N, 87.99°E) deployed by the Earth System Science Organization (ESSO)-National Institute of Ocean Technology (NIOT) were also used in this study to verify the presence of Southern ocean swells in the study area during the period of study. The time reference in this paper is UTC.

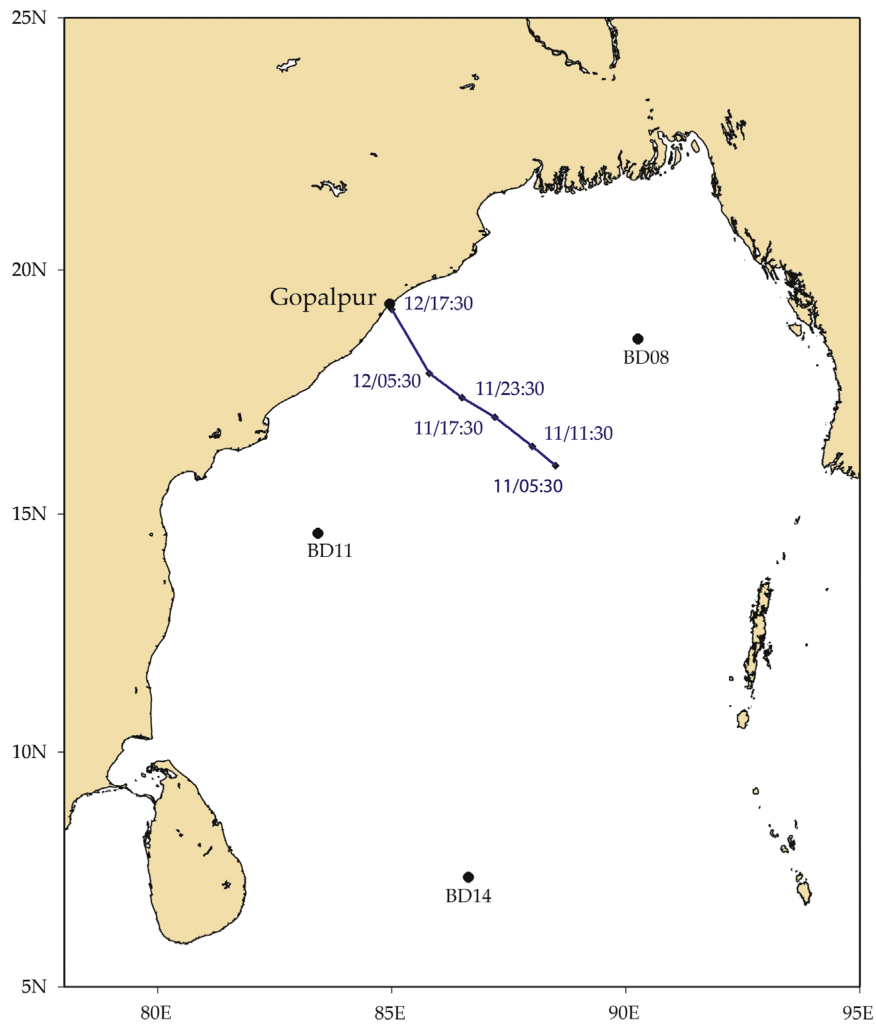

Fig. 1. Figure showing study area and Gopalpur buoy location. The track of Phailin is also shown.