

Impact of shamal winds and swells on the coastal currents along the west coast of India

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Wind, wave and current data collected at/off Ratnagiri, west coast of India were analysed to study the wind-wave-current interaction along the west coast of India (WCI) during shamal events. Shamal winds which originate in the Persian Gulf region during winter (November-March) generate swells in the northwestern Arabian Sea, and these swells propagate towards the west coast of India with distinct wave direction (northwest) and increase in wave heights. It is observed that during these events, the de-tided current data present a distinct change in the current direction and increase in current speeds (approximately from 0.08 m/s to 0.15 m/s). It can be inferred from the analysis that the waves which propagate from NW and the currents which flow towards north oppose each other, resulting in intensification of currents off Ratnagiri. In order to understand the intensity of shamal effect on the existing current system, we have also analysed winds and currents before, during and after the events.

[Keywords: Waves, Currents, Shamal wind, The Indian Ocean, Winter monsoon]

Introduction

In coastal and shelf regions, winds, waves, tides and currents are the primary driving forces which determine the physical processes of the system. The co-existence of the physical processes and their interaction with each other has significant influence on ecology and coastal geomorphology. Wind-wave impact on circulation is an important aspect of coastal hydrodynamics. When winds and waves propagate on an existing current system, several mutual interactions occur. Studies show that waves contribute to local current, sea level changes and mixing. Wind and wave induced currents are variable, and can be either reinforced or interfered with tidal currents, depending on the phase of the tide. Although there have been a number of studies on the individual processes for the last several decades, how these processes influence one another is still an important issue in coastal modelling and wave-current interaction problem.

Many studies¹⁻⁸ has been carried out to study the coastal currents off west coast of India (WCI) using measurements and also, numerical modelling. Some of the studies carried out for this region emphasised the importance of local and remote forcing in the Arabian Sea⁹⁻¹⁶. Shetye⁸ found that off Goa during March-April, the west India coastal current (WICC)

was driven by local winds only at periods less than 10 days, with remote forcing contributing at longer periods. Shetye¹⁷ studied the circulation along the west coast of India and concluded that during winter monsoon, currents along the WCI flow against the winds blowing from northeast. The surface currents are found to be poleward during the northeast (NE) monsoon which is in contrast to the equatorward currents in the southwest (SW) monsoon or summer monsoon.

Waves along the WCI primarily depend on the wind conditions prevailing over the Indian Ocean during the different seasons: southwest monsoon (June-September), northeast monsoon (NE) (October-January) and pre-monsoon (February-May). Northeast winds are weaker than the southwest winds. Waves of southwest monsoon (SW) follow the swell pattern as they are generated in the Arabian Sea/southern Indian Ocean by the strong SW monsoon winds^{18,19}. During pre-monsoon and NE monsoon seasons, waves follow either swell or wind sea pattern depending on their dominance. However, during the pre-monsoon season, wind seas play a major role in controlling the wave characteristics²⁰. Rashmi *et al.*²¹ made an attempt to study the coexistence of wind seas and swells along the west

coast of India during non-monsoon season. The study proved that the swells are predominant (61%) along the northwest coast of India during post-monsoon season, and wind seas are predominant (48%) during late post-monsoon and early pre-monsoon seasons. Vethamony *et al.*^{22,23} studied the wave characteristics off Goa, and found that co-existence of locally generated wind seas and pre-existing swells results in typical diurnal variation in wave parameters during the pre-monsoon season. Another study²⁴ showed the impact of swells generated during an extreme event in the south Indian Ocean propagating towards the north Indian Ocean. These swells did propagate in the NE/NNE direction towards the north Indian Ocean, and wave characteristics of the Arabian Sea were least influenced by these waves compared to that of Bay of Bengal.

The general wave conditions in the Arabian Sea during the pre monsoon period also depend on the swells coming from the far northwest Arabian Sea because of the northwesterly blowing shamal winds²⁵. Shamal winds normally occur in the Arabian Peninsula during winter (November to March) and summer (June to August). The onset, duration and strength of the shamal winds vary depending on the dynamic interaction of upper air jet streams and distribution of lower tropospheric pressure zones²⁶. The winter shamal is associated with mid latitude disturbances travelling from the west to the east, which has a high impact on the meteorological conditions over the Arabian Peninsula²⁷. It usually occurs following the passage of cold fronts, and is characterized by strong northwesterly winds. Rao *et al.*²⁰ reported that 51% of shamal days occurred from May to July compared to the winter months of November–March. The associated wind speeds can reach up to 20.0 m/s, and this can generate surface waves as high as 3.0 to 4.0 m in the Arabian/Persian Gulf²⁷. These winds are often strong during the day, but they decrease at night. The summer shamal events are longer in duration compared to the winter shamal events. Glejin *et al.*²⁸ studied the variation in the existence of summer shamal swells and wind sea propagation along the west coast of India, during the late pre monsoon (May) and strong Indian summer monsoon (June–August) seasons. Aboobacker *et al.*²⁹ has briefly studied the wave transformation and attenuation along west coast of India due to wind wave's interaction with swells coming from N, NW and SW during different seasons in the Indian Ocean.

The aim of this present work is to establish a better understanding of influence of waves generated by shamal winds on the existing current system along the west coast of India, with the perspective of studying the wave-current interactions before, during and after the shamal events. Here, we present only the preliminary results of changes in existing current system due to shamal winds/ swells in the Arabian Sea.

Materials and Methods

Wave measurements were carried out off Ratnagiri (Fig. 1) during 24 January-25 February 2008 at a water depth of 35 m. Datowell Directional Waverider buoy DWR-MkIII (Barstow and Kollstad 1991) was used for the measurements. The Wave rider buoy measures wave height in the range of ± 20 m; periods between 1.6 and 30.0 s and wave direction in the range of 0–360°. Data were recorded for 30 min duration at a frequency of 1.28 Hz for every half hour. The collected time series were subject to standard error checks for spikes, steepness and constant signals. Simultaneously, current data were collected at the same location at every 10 minutes interval using RCM current meter. The RCM9 speed sensor has an accuracy of $\pm 2\%$ of the recorded speed; current speed range is 0 to 3 m/s; the accuracy of current direction is $\pm 5^\circ$. Also, the wind measurements were recorded at Ratnagiri coastal station using an Autonomous Weather Station (AWS) of the National Institute of Oceanography (NIO), Goa. The AWS provided wind speed and direction at 10 minutes interval. The accuracy of AWS is: 0.2 m/s for wind speed in the range 0–60 m/s and 3° for wind direction in the

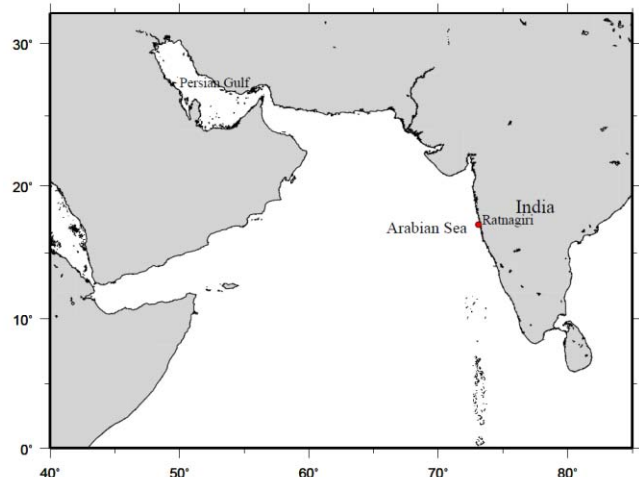


Fig. 1—Study area

range 0–360°. Reanalysis data from European Centre for Medium-Range Weather Forecast (ECMWF) Interim winds (U and V components) of $0.75^\circ \times 0.75^\circ$ resolution at every 6 h-intervals, were used for analyzing the wind patterns during the shamal events in the Arabian Sea and the Persian Gulf.

Results and Discussions

Available wind, wave and current measured data were analysed to study the impact of waves generated in the Persian Gulf due to shamal winds propagating towards the west coast of India on the existing current system in the region. Based on the features of the shamal winds, we identified the shamal events (Table 1) which occurred in the Persian Gulf. For this ECMWF Interim wind data was downloaded and plotted spatially for the non-shamal and the shamal periods (Fig. 2). Fig. 2 clearly depicts the propagation of shamal winds towards the west coast of India. The AWS wind data was also plotted to check the presence of these shamal winds in the coastal region (Fig. 3). Fig. 3 shows that wind speed reached upto 8 m/s during the shamal events. As studied by Aboobacker et al. (2011a), the effect of shamal winds on the waves in the Arabian Sea, in

this study we are trying to understand the impact of these shamal waves on the existing currents off Ratnagiri. Waves measured (Fig. 4) during shamal events showed a shift in wave height and wave direction when compared to those of non-shamal events. The shamal swells propagating from the Persian Gulf to WCI influence the wave characteristics with increase in the wave height and change in wave direction from NW or N.

The currents along the west coast of India are primarily driven by tides and the reversing winds. The winds over the Indian Ocean reverse the direction twice in a year: in the summer season (May – Sept), the winds blow from southwest and in the winter season (Nov- Feb), from northeast over the north Indian Ocean. In other months (March –April and October), winds are weak. These seasonally reversing monsoon winds over the north Indian Ocean, force a seasonally reversing circulation in the upper ocean. Therefore, the available measured current data was first converted into alongshore and cross shore velocity components. Then, using the TASK software (Tidal Analysis Software Kit)³⁰ the alongshore and cross-shore velocity components were de-tided. Removal of tidal constituents from the current data gives us residual currents, which are primarily due to winds, surface waves and density gradients. The obtained residual component was plotted separately in order to mark the changes in the currents during the events (Fig. 5).

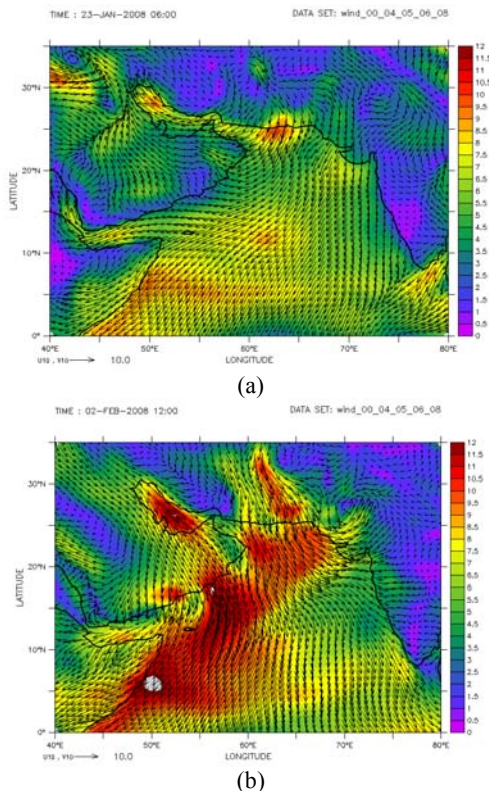


Fig. 2—Wind pattern from ECMWF during (a) non-shamal and (b) shamal period.

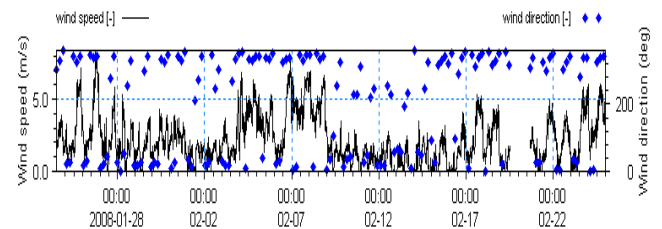


Fig. 3—AWS measured wind speed and direction at Ratnagiri during Jan-Feb 2008

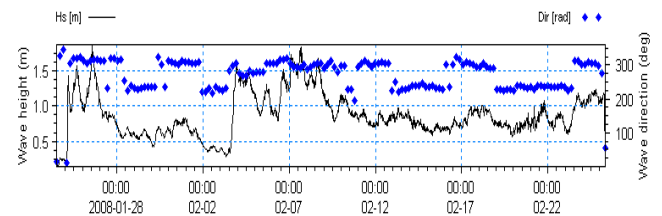


Fig. 4—Time series of significant wave height and direction off

Ratnagiri during Jan-Feb 2008

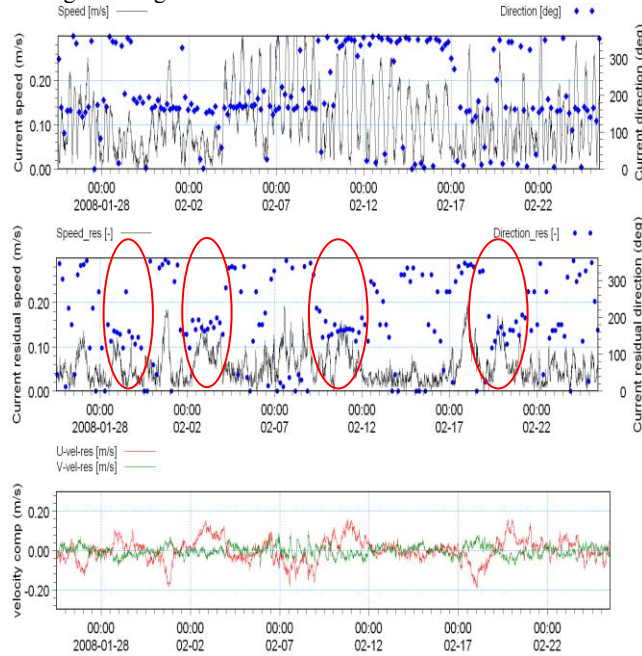


Fig. 5—Time series of (a) current speed and direction (b) residual current speed and direction (circle represents the increase in current speed during the shamal events) and (c) u and v current components off Ratnagiri during Jan-Feb 2008

Based on the study of Aboobacker *et al.*²⁵ the numbers of shamal events were identified (Table 1) from the available wind and wave data and these are used with corresponding current data to study the impact of shamal winds and shamal swells on the existing current system. It was observed that the existing currents which flow northward, change their direction to southeast when shamal winds (from NW) approach the coast (Fig. 5b). It can be inferred that the residual currents remained very weak in the region dominated by tides. But, during the shamal events the maximum residual current speed reached upto 0.15 m/s (Fig. 5b), and there is an increase (0.07 m/s) in the current speed during the shamal event compared to non-shamal period (Fig. 5b). This change is more evident in the residual plot of velocity components also (Fig. 5c), especially in the alongshore component during the shamal events. This is supported by many studies³¹⁻³⁶ which state that when wave and current are perpendicular and following each other, there is reduction in the current intensity and contrary occurs for opposing waves and currents. During shamal events, the waves propagate from N/NW and, when currents flow towards north, they oppose each other, and intensify the currents. This is what we see when the

shamal winds/swells interact with currents off Ratnagiri.

Table 1—Shamal events listed from the ECMWF wind data.

Sr. No.	Event Duration
1	31 Jan – 3 Feb 2008
2	4 Feb 6:00 – 8 Feb 06:00
3	19 Feb 18:00 – 23 Feb 00:00

In the present study, we intend only to prove that there is an effect of shamal winds and waves on the existing current system. Systematic numerical experiments are being planned by coupling waves and currents to study wave-current interaction, particularly to understand the impact of currents on wave system along the west coast of India during shamal events.

Conclusions

In the present study, the available wind, wave and current data have been analysed to study the impact of waves generated by shamal winds on the existing current system along the west coast of India. It is observed that there is prominent change in the direction and magnitude of currents due to interaction with the swells generated by shamal winds in the Persian Gulf. Numerical modelling is being planned to study the wave-current interaction during the Shamal events by coupling the wave and circulation models.

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