

# SEA AND SWELL ALONG WEST COAST OF INDIA: STUDY BASED ON MEASURED DATA

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## ABSTRACT

Separation of sea and swell from the measured data is important for studying the wind wave dynamics and in the design of coastal and offshore structures. The wave data collected using Datawell directional waverider buoy at a deep-water location and at shallow water location off the Goa coast during pre-monsoon period was used in the present study. Sea and swell components were separated for deep and shallow water locations and compared. The study shows that the conditions in the deep water are influenced by swell with 62%, whereas in the shallow water, the influence of wind seas with 68% is dominating in most of the period. The wind data shows that the wind direction was predominantly from sector between north to west at deep water and the sea was in the direction of the wind. Mean swell direction was  $168^\circ$  at deep water and  $187^\circ$  at shallow water. The spectra was narrow band in the deep water and relatively broad in the shallow water.

## INTRODUCTION

A real sea state is commonly a combination of two or more wave systems, i.e. the wind sea and the swell. This can be easily identified through wave spectra. Conditions in the open ocean are most often influenced by swell. Near the coast pure wind seas are more commonly observed. During the fair-weather period, swells are also observed in the coastal regions. Separation of sea and swell from the measured data is important for studying the wind wave dynamics, in planning safety of marine operation and in the design of coastal and offshore structures. Harish and Baba (1986) found a swell dominated wave climate during non-monsoon period and the main peak was shifting towards high frequency during June to September when the monsoon is active. Based on the data collected off Cochin at 15 m water depth, Baba et al. (1989) observed multiple peaks at approximately 1.5 or 2 times the frequency of the main peak. Wang and Hwang (2002) proposed a method for separation of the sea and swell from the ocean wave spectra and verified the results based on the data collected in the Gulf of Mexico and off the California coast. Kumar et al. (2003) found that at shallow water locations along the Indian coast, about 60% of the wave spectra observed had two peaks but they were mainly single peaked when the significant wave height was higher. The double peaked spectra observed were mainly swell dominated with average value of the ratio of these two spectral peaks around 0.6 and the average value of the difference between peak frequencies as 0.09 Hz. Violante-Carvalho et al. (2004) examined the influence of longer (swell) on shorter, wind sea waves using an extensive database of directional buoy measurements in deep water in the South Atlantic.

Based on the data collected at deep water and shallow water along west coast of India during pre-monsoon period, a study was carried out to examine the influence of sea and swell in the wave characteristics.

## MATERIALS AND METHODS

The data collected using Datawell directional waverider buoy (Stephen and Kollstad, 1991) at deep water location (2700 m water depth) and at shallow water location (30 m water depth) off the Goa coast during 18 to 30 April 2005 was used for the analysis. The data were recorded for 20 minutes duration at a frequency of 1.28 Hz. The wave spectrum was obtained through Fast Fourier transform (FFT). FFT of 6 series, each consisting of 256 measured vertical elevations of the buoy data, were added to obtain the spectra. The high frequency cut off was set at 0.58 Hz and the resolution was 0.005 Hz. The significant wave height ( $H_s$ ) and the mean wave period ( $T_{m02}$ ) were obtained from the spectral analysis. The period corresponding to the maximum spectral energy is referred as spectral peak period ( $T_p$ ) and is estimated from the wave spectrum. The sea and swell from the measured data was separated through the method described by Wang and Hwang (2002). Other parameters obtained were spectral peakedness parameter,  $Q_p$  (Goda 1970), spectral width parameter based on spectral analysis,  $\epsilon$  (Cartwright and Longuet-Higgins, 1956), the maximum spectral energy and the spectral energy at the secondary peak.

## RESULTS

During the study period, the significant wave height was less than 1 m at deep and shallow water (Figure 1A). The mean wave period was higher ( $T_{m02}$  varied from 3.8 to 7.5 s) at deep water than at shallow water ( $T_{m02}$  varied from 3 to 5.7s) indicating the presence of swells (Figure 1B). The ratio of  $H_s$  of sea ( $H_{sw}$ ) to that of swell ( $H_{ss}$ ) was 0.8 at deep water and 1.6 at shallow water (Figure 1D). At shallow water the high waves were due to locally generated waves (Figure 2A). The contribution of swell in the measured wave was predominant in deep water (Figure 2B). At shallow water, the contribution of sea was predominant. The average value of swell height reduced from 0.6 m at deep water to 0.4 m at shallow water. The average percentage of sea in the measured wave was 38 at deep water and 68 at shallow water.

During the measurement period, the average wind speed was 3.9 m/s and the maximum wind speed was 11.6 m/s. The wind direction was predominantly from sector between north and west. The direction of sea was also mostly from sector between north and west.

Average value of the ratio of the spectral density at secondary peak to that at the primary peak was 0.17 at deep water and 0.78 at shallow water. The spectral energy at secondary peak was large at shallow water than at deep water (Figure 3). The wave spectrum at deep water is narrow with a large peak ( $Q_p = 1.1$  to 3.3) compared to that at shallow water ( $Q_p=1$  to 2.4). Spectral width parameter was high in deep water compared to shallow water. The maximum spectral energy varied from 0.3 to 1.9 in deep water whereas it varied from 0.2 to 0.8 at shallow water.

Table 1. Wave statistical parameters at deep and shallow water

Wave parameter	Deep water		Shallow water	
	Range	Average	Range	Average
Significant wave height, $H_s$ (m)	0.5 - 1.0	0.7	0.5 - 1.1	0.7
Significant wave height of sea, $H_{ss}$ (m)	0.3 - 0.7	0.5	0.3 - 1.0	0.6
Significant wave height of swell, $H_{sw}$ (m)	0.4 - 0.7	0.6	0.3 - 0.5	0.4
Mean wave period, $T_{m02}$ (s)	3.8 - 7.5	5.1	3.0 - 5.7	4.0
Peak wave period, $T_p$ (s)	5.3 - 16.7	13.0	3.5 - 15.4	10.7
Spectral peakedness parameter, $Q_p$	1.1 - 3.3	1.7	1.0 - 2.4	1.5
Spectral width parameter, $\epsilon$	0.7 - 0.9	0.8	0.6 - 0.8	0.7
Mean wave direction of sea, $\theta_{se}$ (deg)	90 - 347	296	112 - 325	287
Mean wave direction of swell, $\theta_{sw}$ (deg)	125 - 199	168	124 - 210	187
Ratio of $H_s$ of sea to that of swell, $H_{ss}/H_{sw}$	0.4 - 1.3	0.8	0.7 - 2.7	1.6
Maximum spectral energy ( $m^2/Hz$ )	0.3 - 1.9	0.8	0.2 - 0.8	0.3

Mean direction of the swells were from  $168^\circ$  in deep water and  $187^\circ$  in shallow water (Figure 4). At deep water, the high peak in the spectrum lies in the low frequency region and the second peak in high frequency region. The low frequency waves were from south and the high frequency waves were from northwest (Figure 5).

At shallow water, most of the time, the primary peak is in the high frequency part of the spectrum (Figure 6). The mean wave directions at the higher frequencies align with the north-westerly wind direction and gradually shift to south-westerly swell direction at lower frequencies.

## CONCLUSIONS

The study shows that the conditions in the deep water are influenced by swell, whereas at the shallow water, the influence of wind seas is dominating in most of the study period. The average percentage of sea in the measured wave was 38 at deep water and 68 at shallow water. The wind data shows that the wind direction was predominantly from sector between north to west at deep water and the wind sea was in the direction of the wind. Swells were approaching mainly from the south with mean swell direction of  $168^\circ$  at deep water and  $187^\circ$  at shallow water. The spectra was narrow band in the deep water and relatively broad in the shallow water.

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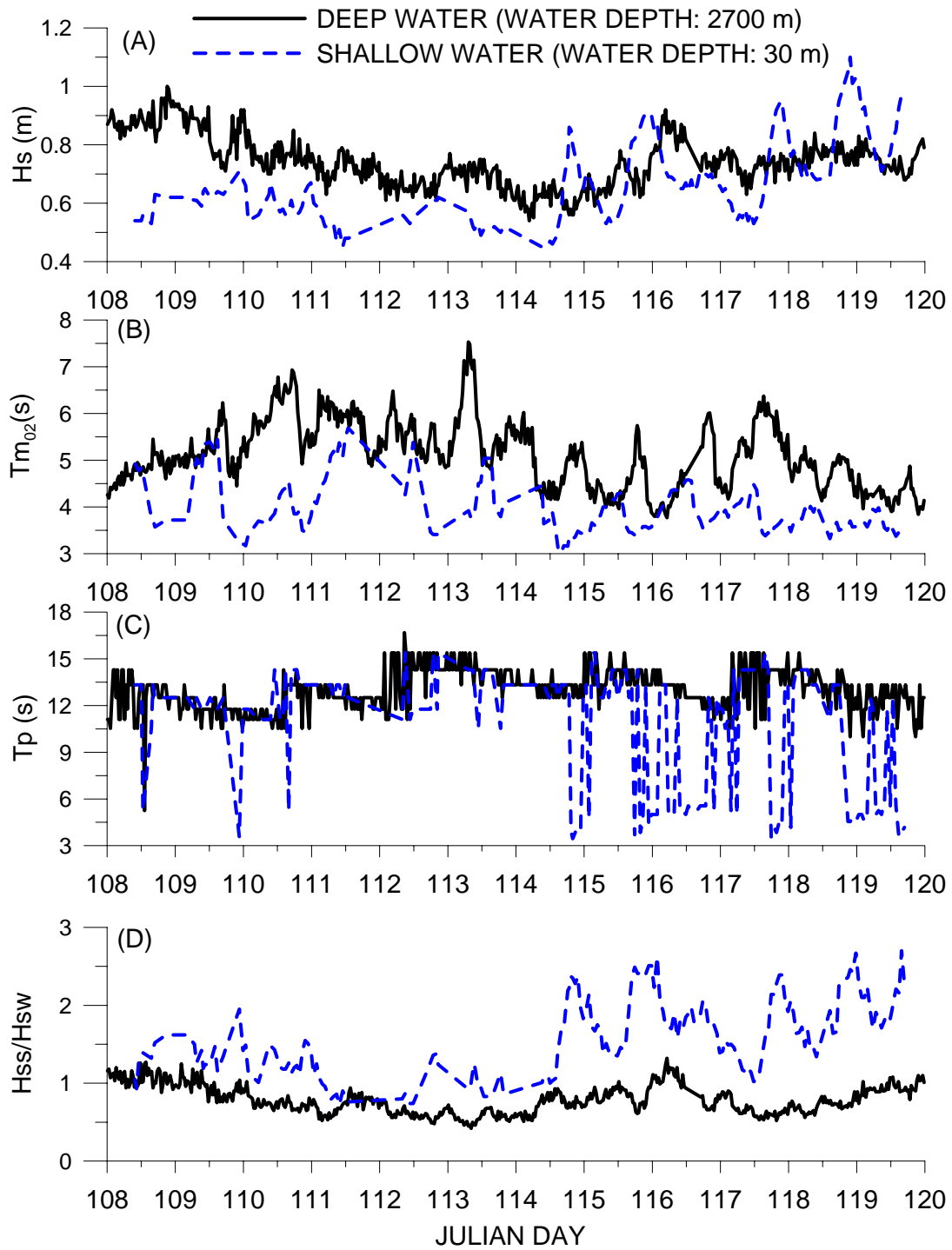


Figure 1. Time series plot of (A) significant wave height, (B) mean wave period, (C) peak wave period and (D) ratio of  $H_s$  of sea and swell at deep water (black line) and shallow water (blue line)

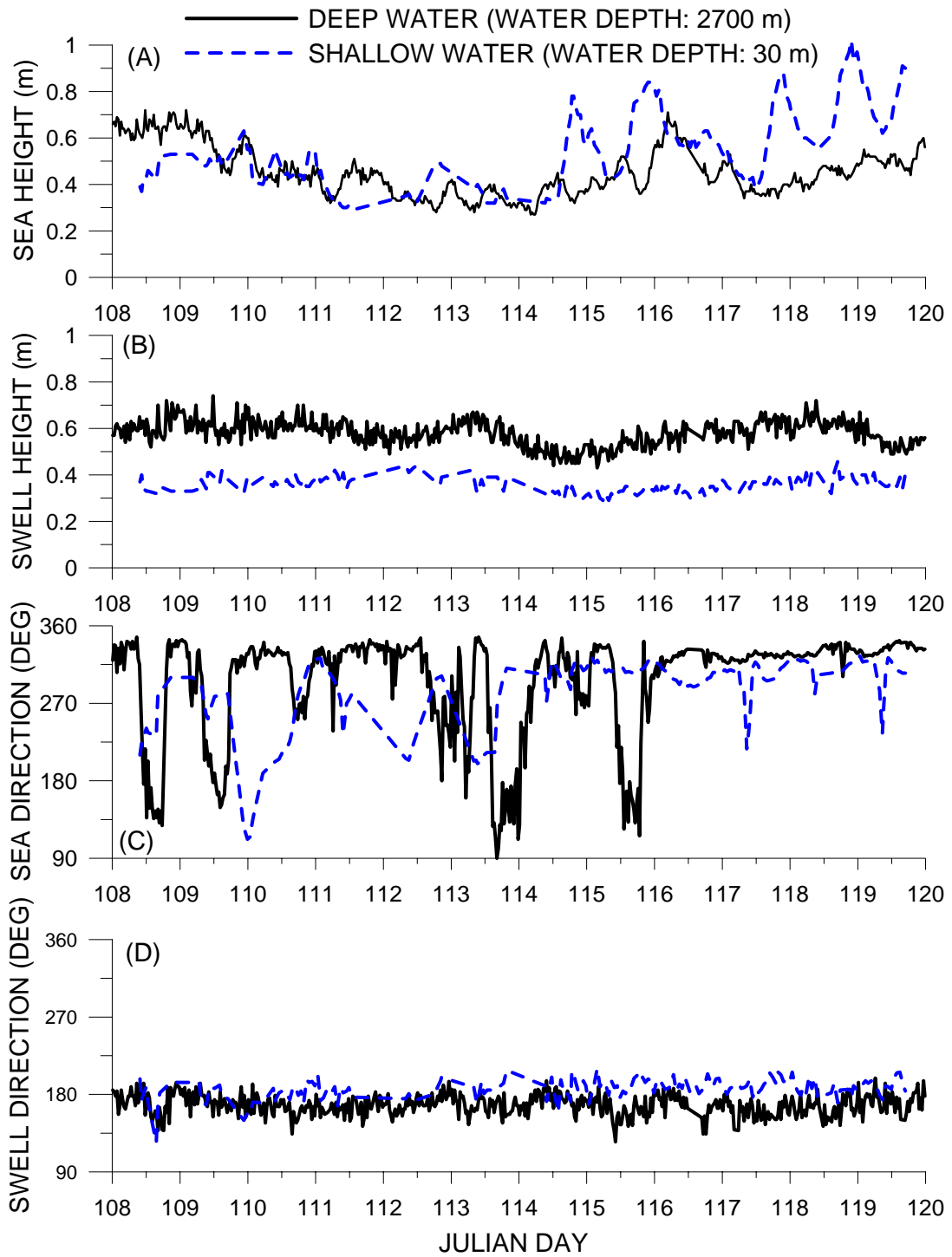


Figure 2. Time series plot of (A)  $H_s$  of sea (B)  $H_s$  of swell (C) mean wave direction of sea (D) mean wave direction of swell at deep water (black line) and shallow water (blue line)

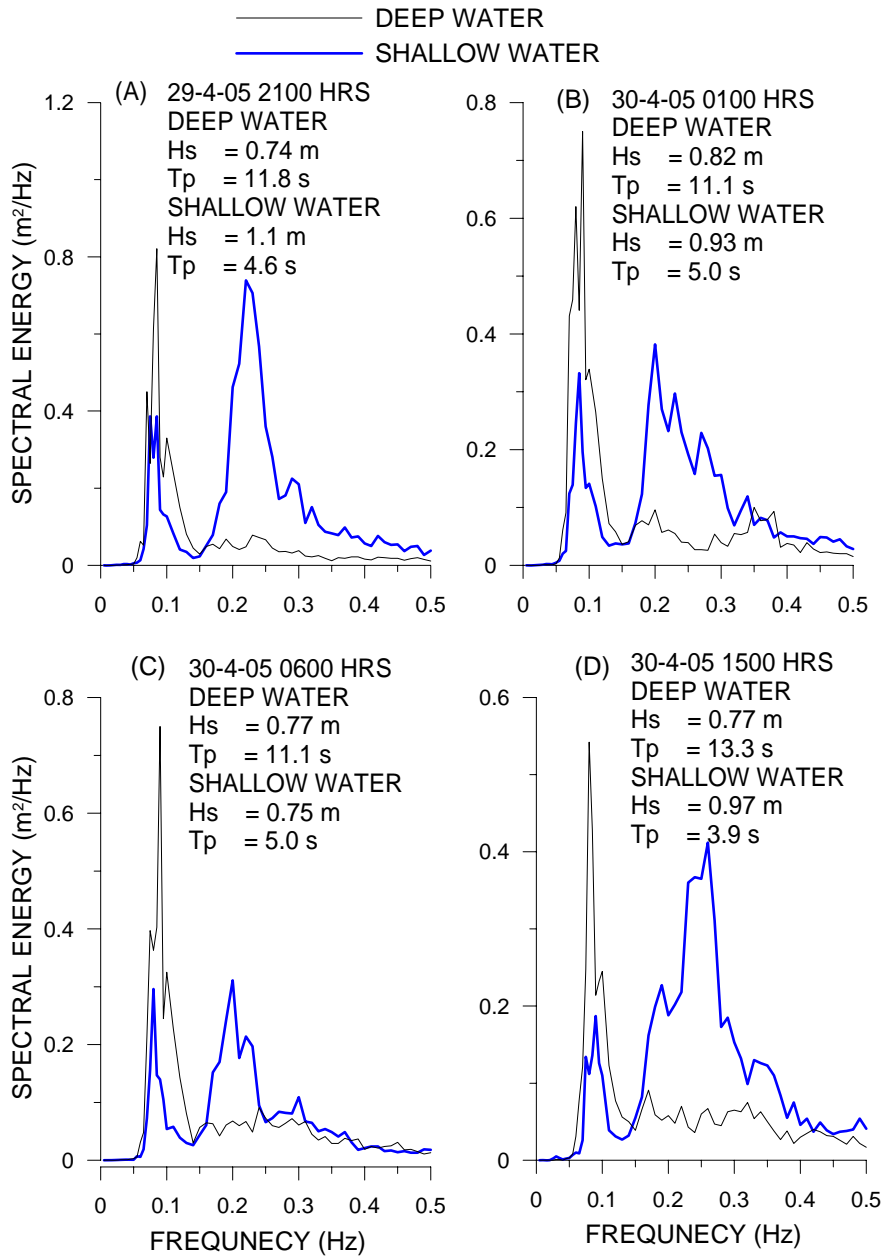


Figure 3. Typical wave spectra estimated based on measured data at deep water (black line) and shallow water (blue line)

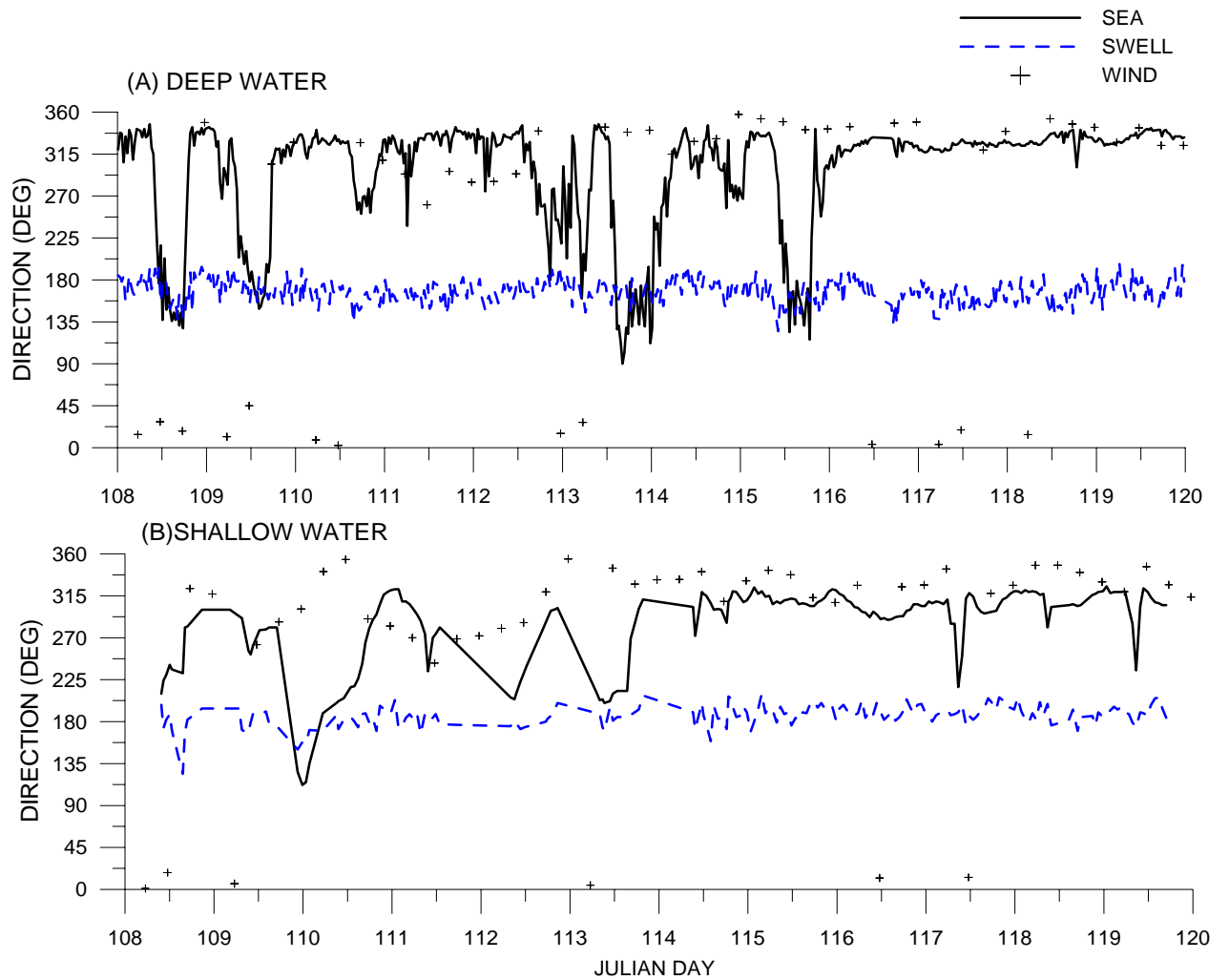


Figure 4. Time series plot of (A) mean direction of sea, swell and wind direction at deep water (B) mean direction of sea, swell and wind direction at shallow water



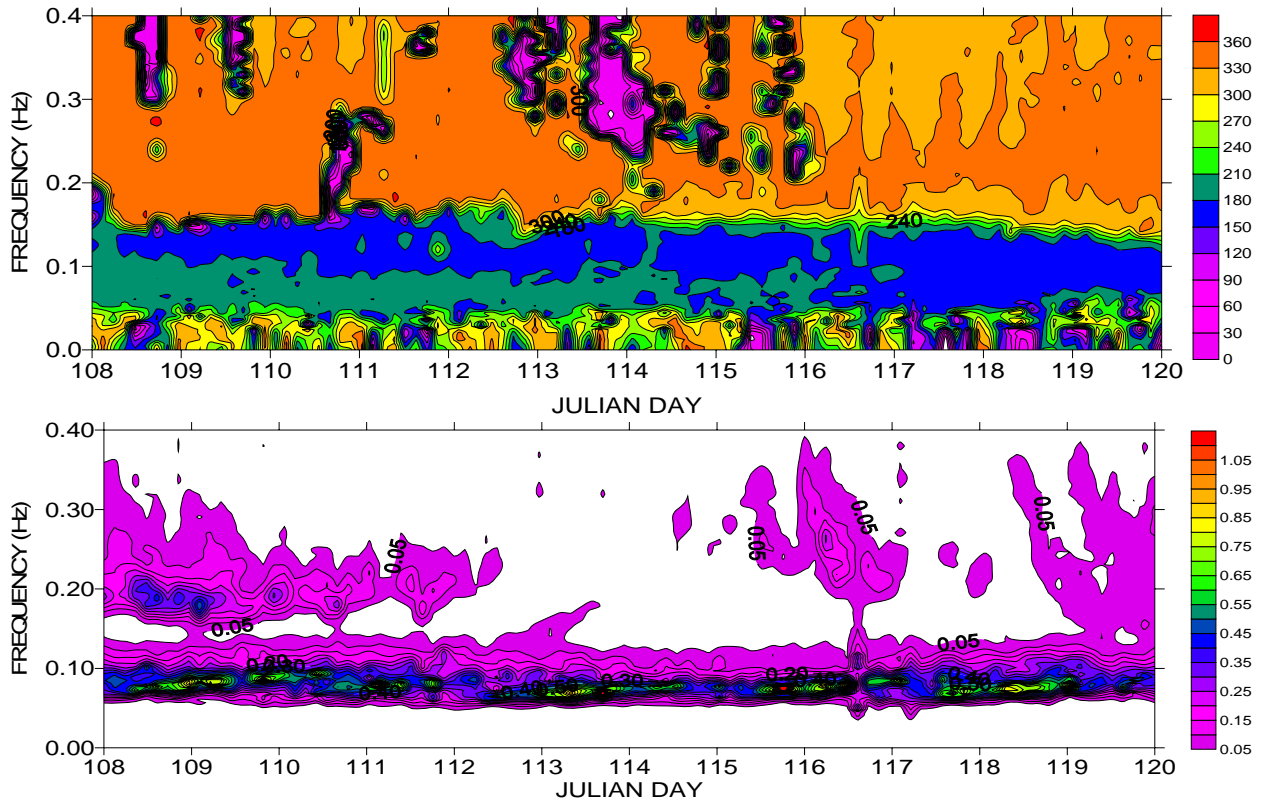


Figure 5. Variation of (A) mean wave direction (deg) over frequency and time (B) spectral energy ( $m^2/Hz$ ) over frequency and time at deep water

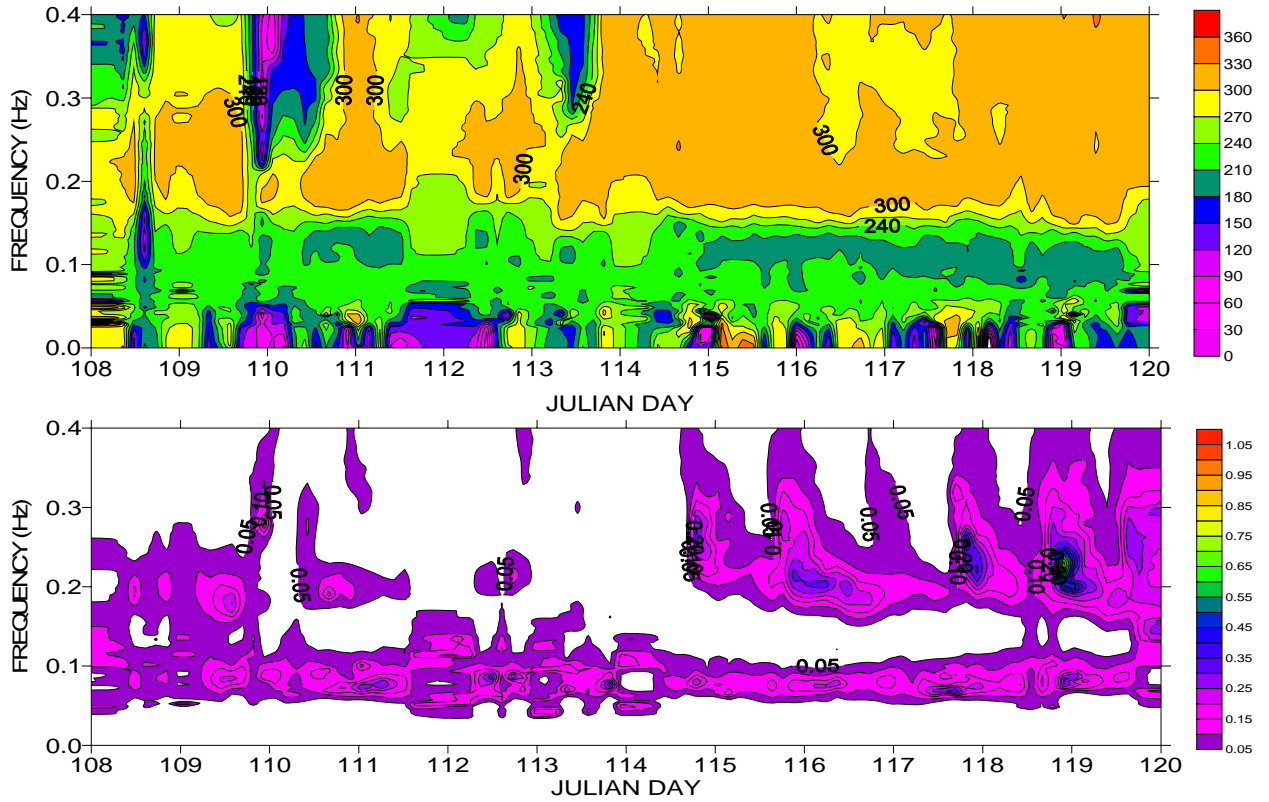


Figure 6. Variation of (A) mean wave direction (deg) over frequency and time (B) spectral energy ( $\text{m}^2/\text{Hz}$ ) over frequency and time at shallow water