

Variations in tidal constituents along the nearshore waters of Karnataka, west coast of India

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Abstract

The characteristics of tidal constituents along the near-shore waters of Karnataka, west coast of India, are described. These are based on the sea level data measured at 3 locations using the Valeport wave and tide gauge, during the pre summer monsoon period. The objective of the study is to identify the tidal and non-tidal variations along the coast. Analysis shows that astronomical tides are responsible for most of the observed sea level variability along the Karnataka coast. 97% of the variation in measured sea level at Honnavar and Malpe and 96% of the sea level variation at Kundapur was due to tide. The observed non-tidal sea levels were related to local wind forcing. The study shows that when the wind from south was strong, a rise in sea level was observed and when the wind from the north was strong, a fall in sea level was observed. Correlation between alongshore component of wind and non-tidal sea level was 0.54 at Malpe and 0.48 at Honnavar. The non-tidal sea level variation was found to vary according to the significant wave height. High residuals of sea level were found during high waves. Amplification of shallow water constituents were relatively high compared to other constituents from south to north along the study area.

Key Words: Harmonic constants, tidal heights, sea level, atmospheric forcing, Karnataka coast, Arabian Sea

1. Introduction

Information on tides along the coast is important for estimating tide induced currents and planning shoreline management plans. The tide gauges record water level that is the sum of astronomical tides and fluctuations due to meteorological events. Tidal propagation in the Gulf of Khambhat and surrounding areas was studied by Unnikrishnan et al. (1999) and Nayak and Shetye (2003). The amplification of semidiurnal constituents of tides in the Gulf of Kutch was studied by Shetye (1999). Srinivas et al. (2003) studied the propagation of tides in the Cochin estuary. Sundar and Shetye (2005) studied the tides in the Mandovi and Zuari estuaries. Tides off Karnataka coast have not been studied in detail. Hence we examined the variations of the tidal constituents covering 100 km distance along the Karnataka coast, west coast of India, based on simultaneously measured sea level data at 3 locations for a period of 30 days during March-April 2008. This being the transition time between the northeast monsoon and the southwest monsoon, the large-scale circulation over India and the north Indian Ocean is generally weak during March-April (Shetye and Gouveia 1998). The data was collected for a period of 30 days because continuous observations for a period of 30 days are required to resolve the major tidal constituents. The objective of the study is to identify the tidal and non-tidal variations in sea level along the Karnataka coast and study the influence of atmospheric forcing on sea level.

1.1 Study area

The continental shelf off Karnataka has an average width of 80 km. The coastline at Honnavar and Malpe are inclined 17° to the west from the true north with the depth contours aligned approximately parallel to the coastline. Depth contours of 20, 50, 100 and 200 m occur at 10, 30, 75 and 100 km off Karwar and at 12, 48, 90 and 108 km off Malpe (Figure 1). There are a few islands off the coast, the major group being St. Mary's Island, 4 km off the coast near Malpe. The rivers joining the Arabian Sea along the Karnataka coast are Kali, Gangavali, Aganashini, Sharavathi, Hangarkatta and Gangolli. Sand bars are present in most of the estuaries. The coast is exposed to seasonally reversing monsoon winds, with winds from the southwest direction during the southwest (summer) monsoon period and from the northeast during the northeast (winter) monsoon period. The southwest monsoon winds are strong and the annual rainfall is around 3 m along the coast. Tides in the region are mixed and are predominantly semidiurnal. The tidal range slightly increases

from south to north. The average monthly sea level at Karwar varies from 1.06 m in September to 1.3 m in January. Based on the Indian Tide Table, the average tidal range at Karwar is 1.58 m during spring tide and 0.72 m during neap tide.

2. Materials and methods

Valeport Tide gauge (Valeport Limited, UK) was deployed to collect the hourly sea level data at locations C1, C2, C3 and C4. The location of measurement and the water depth are presented in Table 1. The Valeport tide gauge at location C4 was towed away from the moored location by fishing vessels and could not be traced at the moored location. Hence the instrument and data could not be recovered.

The measured sea level data was subjected to harmonic analysis to determine the amplitudes and phases of the tidal constituents (Emery and Thomson, 1998; Pugh, 1987). Tidal analysis was carried out using standard harmonic method, where a finite set of cosine functions with frequencies at the known astronomical forcing frequencies were fitted to the data using the least square method. Tidal Analysis Software Kit, TASK (Bell et al., 2000) developed by the Proudman oceanographic laboratory, UK was used for the analysis. Analysis was done with 24 independent constituents and 8 related constituents recommended for one month data of tides. Removal of tidal component from the sea level data leaves residuals of sea level that include contributions from direct wind forcing, indirect wind forcing and surface waves (Prandle, 1997).

Reanalysis data of zonal and meridional components of wind speed at 10 m height at 6 hourly intervals from NCEP / NCAR (Kalney et al., 1996) was obtained for the location (12.5° N; 72.5° E) close to the study area to know the influence of wind on sea level. These data are provided by the NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado at <http://www.cdc.noaa.gov/>. Relationship between wind forcing and residuals of sea level was studied by linear regression analysis. All directions use the oceanographic convention and indicate the direction towards which the wind is moving.

3. Results and discussion

The maximum tidal range during the measurement period was 1.8, 1.9 and 2.1 m at Malpe, Kundapur and Honnavar (Figure 2). As expected an increase in tidal amplitude from South to North along the coast was observed. Predominant tidal constituents are M2, S2, N2, K1, O1, Q1, J1 and M4 with constituent M2 (0.0805 cph) having the highest magnitude followed by K1 (0.0418 cph) constituent (Table 1). The form number, which is the ratio of the sums of the amplitudes of the diurnal constituents (K1 and O1) to that of the semidiurnal constituents (M2 and S2) is 0.71, 0.69 and 0.65 at Malpe (stn. C1), Kundapur (stn. C2) and Honnavar (stn. C3). The tides are thus classified as mixed and are predominantly semidiurnal in nature. The mean spring tide range i.e., $2(M2+S2)$ is 1.21, 1.3 and 1.41 m at Malpe, Kundapur and Honnavar and the mean neap tide range is 0.56, 0.61 and 0.66 m. Srinivas and Dineshkumar (2002) found the form number to be 0.80 for Beypore which is 270 km south of Malpe. Form number is found to increase from the north to the south along the coastline. The major tidal constituents are found to increase from south to north (Figure 3). The amplification of semidiurnal tidal constituents M2 and S2 is 1.17 (Figure 3a) from Malpe to Honnavar. Amplification of diurnal tidal constituent K1 is 1.07 and that of O1 is 1.09 (Figure 3b). Shallow water constituents are found to amplify more compared to other constituents (Figure 3c). The amplification of M4 is 1.39 and that of MS4 is 1.33 from Malpe to Honnavar (Table 2). The total contribution of diurnal constituents is found to decrease from 38 at Malpe to 36% at Honnavar, whereas the contribution of semi-diurnal constituents is found to increase from 56.7% at Malpe to 57.8% at Honnavar.

The non-tidal (residuals) sea level variation at all the three locations is similar (Figure 4a). Residuals of sea levels up to 18 cm are observed. Along the coast of India, seasonal sea-level changes due to atmospheric pressure variations vary from about 3 cm at Colombo to 13 cm at Paradip (Shankar, 2000). The non-tidal sea level variation along the study region is mainly due to the v-component (meridional) of wind. When the alongshore wind from south is strong, a rise in sea level is observed and when the wind from north is strong, a fall in sea level is observed (Figures 4a and 4b). Correlation between alongshore component of wind and non-tidal sea level is 0.54 at Malpe and 0.48 at Honnavar.

Strong winds on the water surface generate sea waves that can also affect the water level. A Datawell directional waverider buoy was deployed off Honnavar at 9 m water depth within

0.5 km distance from the deployed tide gauge. The significant wave height measured by the buoy is presented in Figure 4c. It is found that during Julian day 82 to 84, there is an increase in wave height and during the same period a rise in sea level is also observed.

4. Conclusions

Sea level data collected at 3 locations reveals that astronomical tides are responsible for most of the observed sea level variability during the pre-summer monsoon period along the Karnataka coast. During the measurement period, 97% of variation in measured sea level at Honnavar and Malpe and 96% of sea level variation at Kundapur is due to astronomical tide. The residuals of sea level upto 18 cm are measured and are due to atmospheric forcing. When the alongshore wind from south is strong, a rise in sea level is observed and when the wind from north is strong, a fall in sea level is observed. The amplification of tidal constituent M2 and S2 from Malpe to Honnavar is 1.17, whereas the amplification of K1 is 1.07 and that of O1 is 1.09. The amplification of shallow water constituent M4 from Malpe to Honnavar is 1.39 and that of MS4 is 1.33.

5. Acknowledgments

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6. References

- Bell, C., Vassie, J.M., Woodworth, P.L., 2000. POL/PSMSL Tidal Analysis Software Kit 2000 (TASK-2000), Permanent Service for Mean Sea Level, CCMS Proudman Oceanographic Laboratory, Bidston Observatory, Birkenhead, Merseyside L43 7RA, U.K.
- Emery, W.J., Thomson, R.E., 1998. *Data Analysis Methods in Physical Oceanography*. London: Pergamon Press, 634p.
- Kalney, E., and Coauthors, 1996. The NCEP/NCAR 40-Year Reanalysis Project. *Bulletin American Meteorological Society*, 77, 437–471.
- Nayak, R. K. and Shetye, S. R., 2003. Tides in the Gulf of Khambhat, west coast of India, *Estuarine Coastal Shelf Sciences*, 57, 249–254.
- Prandle, D., 1997. Tidal and wind driven currents from OSCR, *Oceanography*, 10 (2), 57-59.
- Pugh, D.T., 1987. *Tides, Surges and Mean Sea Level*. Chichester: John Wiley and Sons, 472p.
- Shankar, D., 2000. Seasonal cycle of sea level and currents along the coast of India. *Current Science*, 78(3), 279–288.
- Shetye, S. R., 1999. Tides in the Gulf of Kutch, India. *Continental Shelf Research*, 19, 1771–1782.
- Srinivas, C., Revichandran, P.A., Maheswaran, T.T., Mohammed Ashraf and Murukesh, N., 2003. Propagation of tides in the Cochin estuarine system, southwest coast of India. *Indian Journal of Marine Sciences*, 32(1) 14-24.
- Srinivas, K., Dinesh Kumar, P.K., 2002. Tidal and non-tidal sea level variations at two adjacent ports on the southwest coast of India. *Indian Journal of Marine Sciences*, 31(4), 271–282.
- Sundar, D. and Shetye, S. R., 2005. Tides in the Mandovi and Zuari estuaries, Goa, west coast of India. *Journal of Earth System Sciences*, 114(5), 493–503.
- Unnikrishnan. A.S., Shetye, S.R. and Michael, G.S., 1999. Tidal propagation in the Gulf of Khambat, Bombay High, and surrounding areas. *Proc. Indian Academy of Sciences. (Earth Planet. Sci.)*, 155–177.
- Shetye, S. R., Gouveia, A. D., 1998. Coastal circulation in the North Indian Ocean – Coastal Segment (14, S–W). In: *The Global Coastal Ocean: Regional Studies and Syntheses* (eds) Robinson A R and Brink K H, *The Sea* 11, 523–556.

Figure captions

Figure 1. Locations of measurement of sea level and wave

Figure 2. Variation of measured sea level and tide at (A) Malpe, (B) Kundapur and (C) Honnavar

Figure 3. Amplitude and phase angle of tidal constituents for locations Malpe (M), Kundapur (K) and Honnavar (H). (A) and (D) are semi-diurnal constituents, (B) and (E) are diurnal constituents and (C) and (F) are shallow water constituents

Figure 4. Variation of (A) residuals of sea level at Malpe, Kundapur and Honnavar, (B) alongshore wind speed and (C) significant wave height

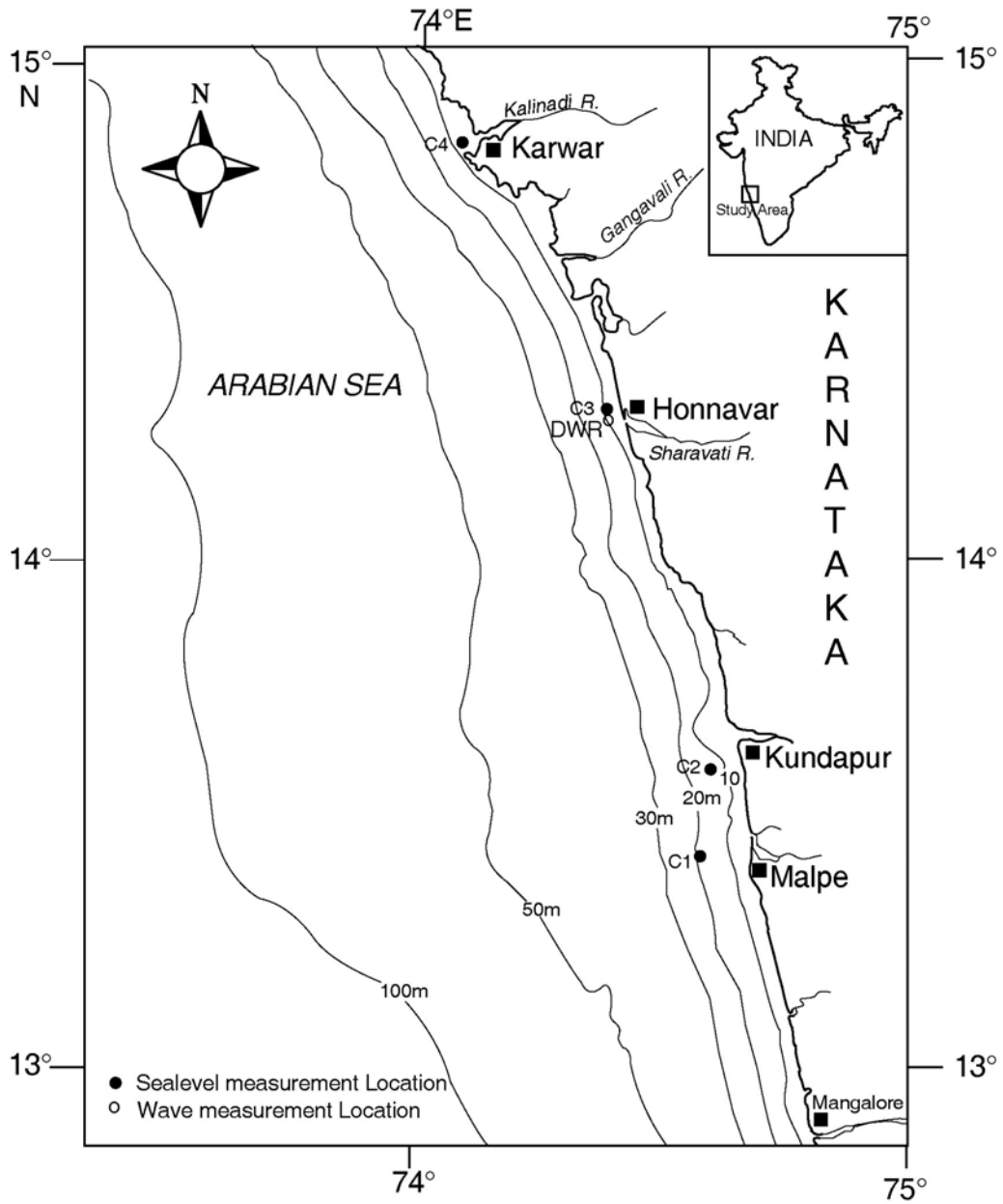


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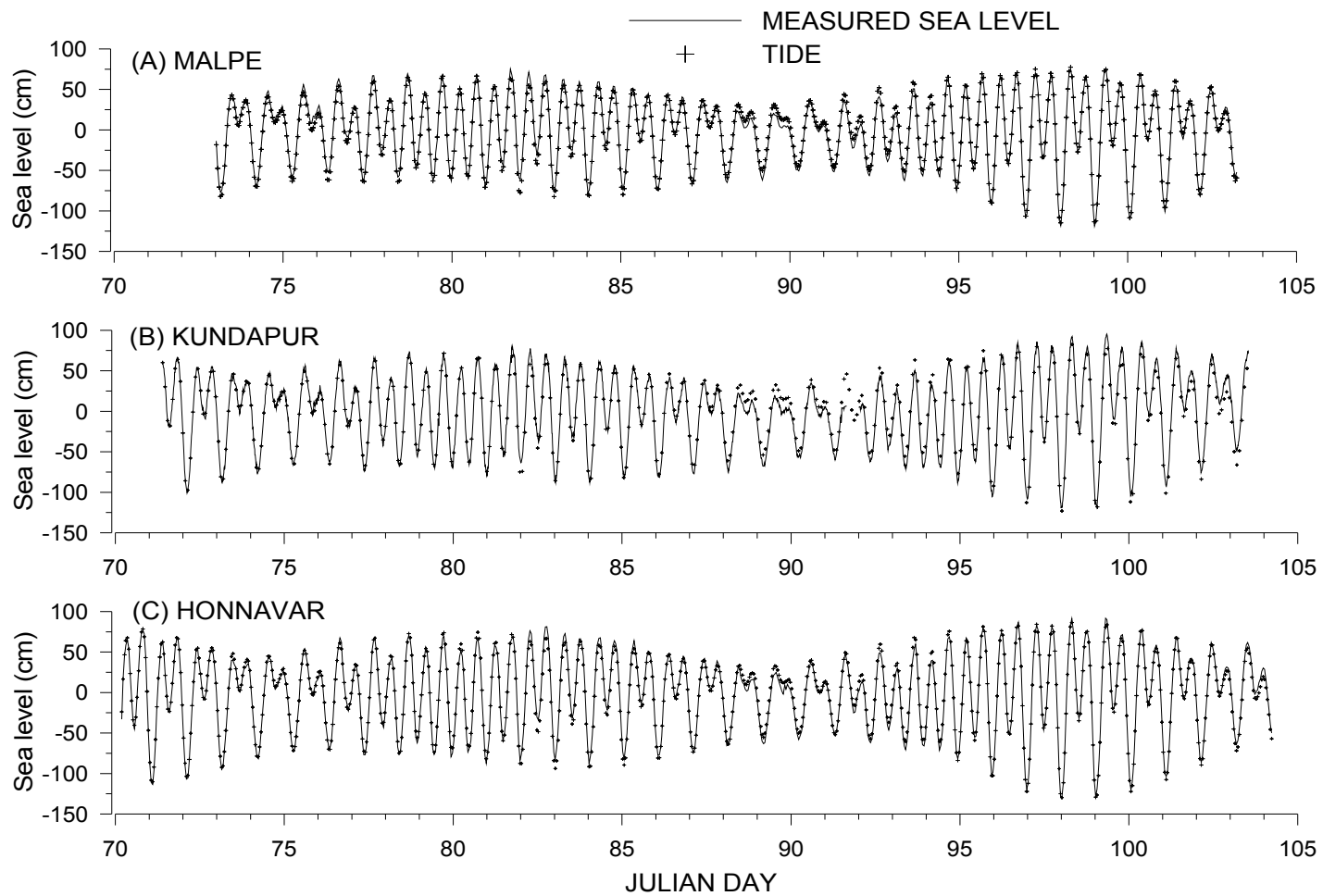


Figure 2. Variation of measured sea level and tide at (A) Malpe, (B) Kundapur and (C) Honnavar

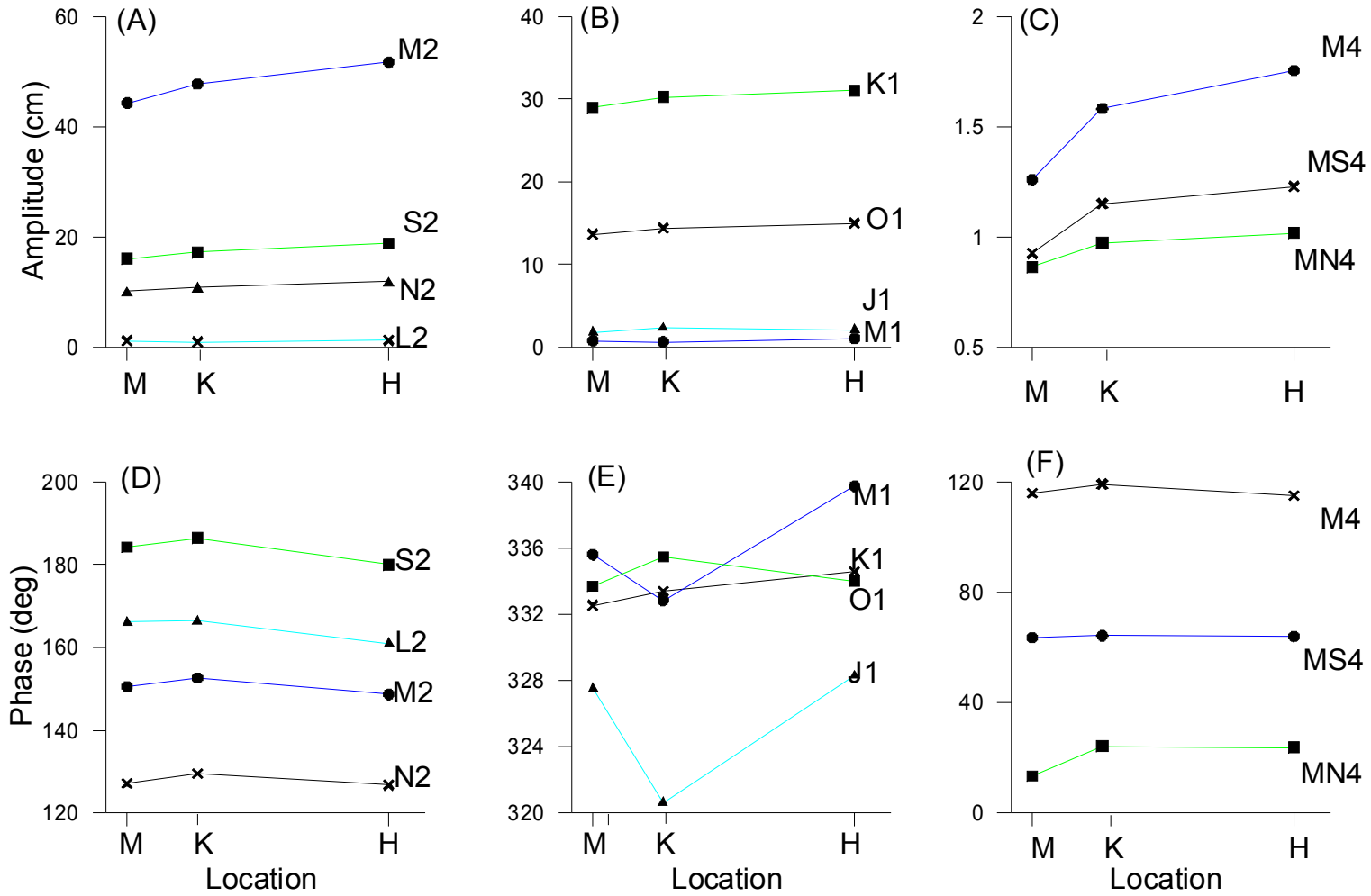


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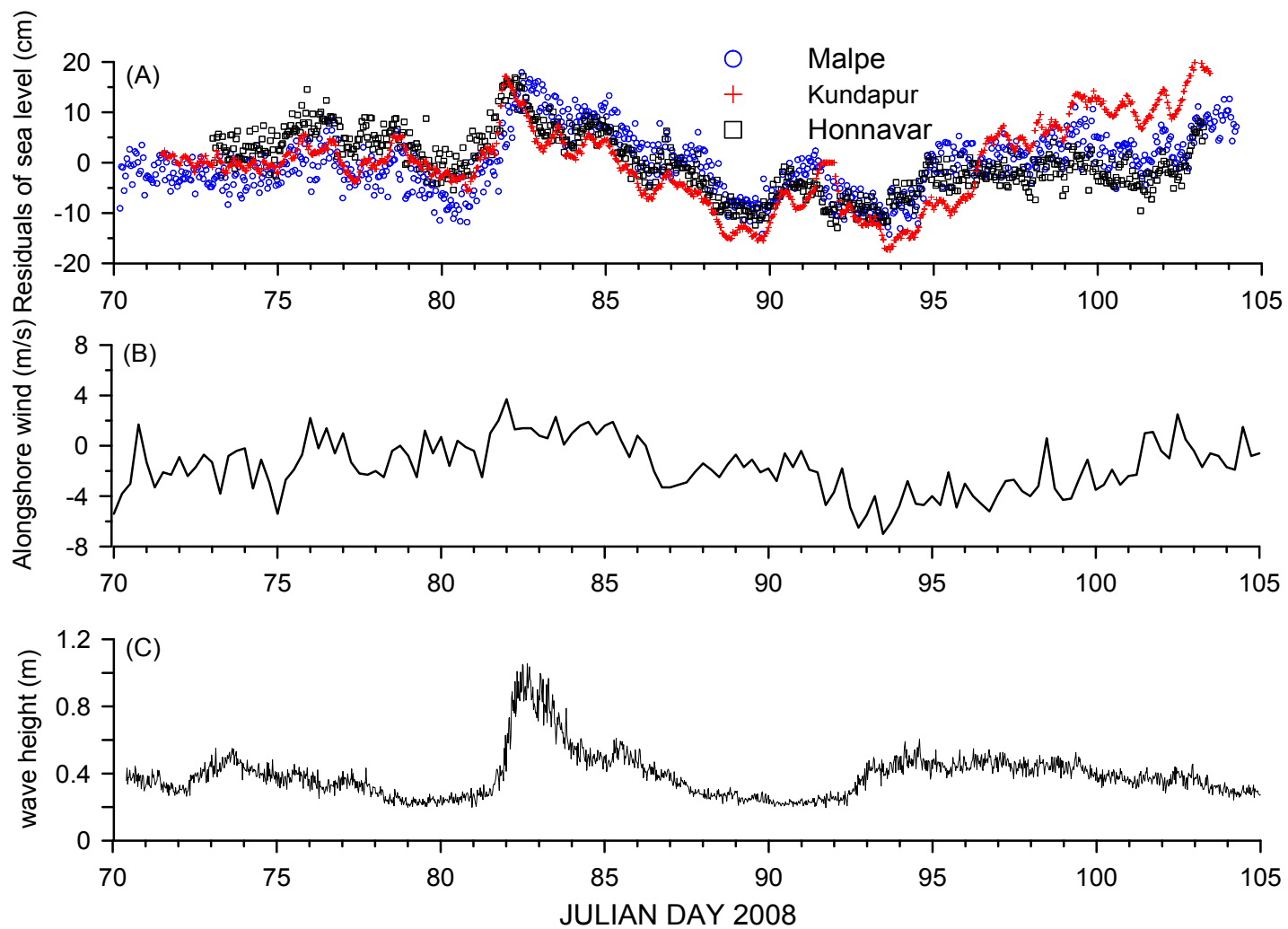


Figure 4. Variation of (A) residuals of sea level at Malpe, Kundapur and Honnavar, (B) alongshore wind speed and (C) significant wave height

Table 1. Locations considered in the present study along with period of measurement and water depth.

Sr No.	Location	Latitude	Longitude	Water depth (m)	Period of measurement
1	Malpe (C1)	13° 18.539'N	74° 40.384'E	10	13 March 2008 to 13 April 2008
2	Kundapur (C2)	13° 36.154'N	74° 37.923'E	10	12 March 2008 to 13 April 2008
3	Honnavar (C3)	14° 18.265'N	74° 23.407'E	10	11 March 2008 to 14 April 2008
4	Karwar (C4)	14° 49.452'N	74° 04.943'E	10	9 March 2008 to 15 April 2008

Table 2. Tidal constituents based on measured data at Malpe, Kundapur and Honnavar

Constituent	Speed (deg/hr)	Malpe (stn. C1)		Kundapur (stn C2)		Honnavar (stn C3)	
		Amplitude (cm)	Phase (deg)	Amplitude (cm)	Phase (deg)	Amplitude (cm)	Phase (deg)
Q1	13.4	2.8	352	2.9	4	2.9	345
O1	13.9	13.7	333	14.4	333	15.0	335
M1	14.5	0.8	336	0.7	333	1.0	340
K1	15.0	29.0	334	30.2	335	31.0	334
J1	15.6	1.8	328	2.3	321	2.1	328
OO1	16.1	1.5	10	1.7	18	1.7	18
MU2	28.0	0.1	356	0.2	284	0.2	355
N2	28.4	10.2	127	10.9	130	11.9	127
M2	29.0	44.3	150	47.7	153	51.6	149
L2	29.5	1.2	166	1.0	166	1.3	161
S2	30.0	16.1	184	17.3	186	18.9	180
2SM2	31.0	0.2	146	0.2	145	0.2	152
MO3	42.9	0.2	42	0.2	57	0.1	82
M3	43.5	0.4	17	0.4	14	0.3	32
MK3	44.0	0.1	78	0.2	90	0.0	179
MN4	57.4	0.9	13	1.0	24	1.0	24
M4	58.0	1.3	64	1.6	64	1.8	64
SN4	58.4	0.3	10	0.4	40	0.4	36
MS4	59.0	0.9	116	1.2	119	1.2	115
2MN6	86.4	0.1	252	0.0	298	0.2	292
M6	87.0	0.2	327	0.2	311	0.2	289
MSN6	87.4	0.1	292	0.2	241	0.5	229
2MS6	88.0	0.2	49	0.3	317	0.7	295
2SM6	89.0	0.1	22	0.3	35	0.7	30