Dynamics of Tidal and Non-Tidal Currents along the Southwest Continental Shelf of India

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Abstract

The tidal regimes over the continental shelves are often less documented due to lack of coastal water level data. This is of concern since continental shelves rule the global dissipation of tidal energy. The tides along the Southwest Indian shelf are predominantly mixed, semidiurnal in nature. Motion over any continental shelf is governed by the tide-driven oscillatory flow. In this paper, tidal and non-tidal characteristics of the waters of Southwest continental shelf of India are assessed using the observed time-series of water level collected during November- December 2005, from four tide gauge stations distributed along the southwest shelf of India. The tidal amplitudes showed a general decrease from north to south. Harmonic analysis of the tidal constituents showed the prominent tidal constituent to be M_2 followed by K_1, S_2 and O_1. The non-tidal sea-level along the shelf, showed a northward propagation with periodicities of several days. Local wind patterns and pressure systems play an increasingly important role in controlling the non-tidal circulation in this region.

1. Introduction

The continental shelf region, unlike the open ocean forms an extraordinary energetic system. Variations in water temperature, sea level and currents are amplified along the shelf than at further distance offshore. The dynamics of shelf circulation is quite different from "blue water" physical oceanography in many ways, and also differs from river hydraulics. Shelf dynamics usually extends from the coast or nearly 10 km from the shore, up to the shelf break.

Observations and knowledge on the oceanographic and meteorological factors is still sparse for the tide-gauge stations located along the coastline of the Indian subcontinent **(Shankar, 2000).** The present study deals with analysis of tides and their residuals along the southwestern continental shelf of India. The main endeavour is to provide an insight into the variability of tides, their speed and nature of propagation along the continental shelf.

2. Materials and Methods

The southwest Indian continental shelf **(Fig.1)** stretches roughly from 8^0 N to 20^0 N making an angle of 24^0 with true north. To have a proper insight into the tidal dynamics during the Northeast monsoon season, a water level survey spanning one month was initiated along the south west shelf of India during November 2005. Four tide gauges were deployed at specific locations along the continental shelf from which an extensive set of data was recorded **(Fig.1)**.

Water level time series obtained from all gauges were quality controlled and subjected to harmonic analysis. The length of the time series were 30 days and the measurements were made at half an hour intervals. The data was analysed to determine the amplitude and phase lag of the tidal constituents using TASK-2000 (Tidal Analysis Software Kit 2000) of the Permanent Service for Mean Sea Level, Proudman Oceanography Laboratory, UK **(Bell et al 1998).**

3. Results and Discussion

The shelf dynamics is largely controlled by tides, large-scale circulation, local winds and bathymetry. The results derived from harmonic analysis of water level data are presented in this paper. Studies pertaining to the tidal and non-tidal dynamics on the southwestern continental shelf are very singular.

4. Tides

It is the tide-driven oscillatory flow that predominate the motion over any continental shelf. The tides along the southwest coast of India are predominantly mixed, semidiurnal in nature. The amplitudes of deduced constants for 30 days are tabulated in Table-1 for comparison. The amplitudes of important 24 tidal constituents and 8 related constituents are presented. All the computations are referred to the Greenwich Mean Time, which lags the Indian Standard Time by 5 hours and 30 minutes.

Energy of each tidal constituent can be considered as proportional to square of amplitude of each constituent **(Cheng and Gartner, 1985).** At station Verem, M_2 is the most dominant constituent followed by K_1, S_2 and O_1. The sum of the dominant constituents M_2, S_2, K_1, O_1, N_2 accounts for 96% of the tidal energy, and P_1 is the largest minor constituent which contributes 2.2%. Computations of tidal energy for other three stations showed that prominence of minor constituents increased towards south. The energy of the minor constituents showed an increase towards Kollam, the southern most station whereas the energy of the major tidal constituents showed a general decrease towards the southern side.

According to **(Defant, 1958)** form number, F, for tides, $F= (O_1+K_1) / (M_2+S_2)$, can be used to characterize the tides. If F is less than 0.25, the tide is referred to as semi-diurnal, and if F is greater than 3.0 the tide is diurnal. Values of F between 0.25 and 3.0 are considered as mixed tides. The form numbers computed for the tides along the southwest Indian shelf show that tides become more and more of mixed in nature, as we go northwards from Kollam. The value varies from 0.63 at Verem through 0.78 and 0.87 at Kannur and Kochi respectively and reaches a value of 0.94 at Kollam.

Time-series of demeaned sea level at the four locations is shown in **Fig 2.** From figure it is obvious that the tidal range is highest at Verem and decreases towards the southern most station, Kollam.

5. Residuals

Residuals or non-tidal components are the differences between predicted and actual tides recorded. Predicted (or astronomical) tides assume that normal meteorological conditions prevail, whereas actual tides include influences from atmospheric conditions at the time of measurement. Even though tidal variations can be removed from the analysis, there could be energy in the tidal frequencies because of small timing errors in the gauges and weak interaction between tides and surges (**Pugh, 1987**).

Residuals are difficult to measure due to their small magnitudes compared to tidal signals. Even residual currents very small in magnitude, can play a major role in the long-term distribution of water properties. The main factors controlling the generation of residual signals is the wind impinging on the sea surface or the laterally varying density gradients due to non-uniform salinity and temperature distributions.

In order to obtain a quantitative assessment of the non-tidal contributions in the observed sea level, the daily mean residual sea level elevation for all the four stations were estimated. **Fig.3** shows the residual sea level from tidal time series of 30 day duration for all the four stations. There is a striking similarity in the residual sea level march along the four stations. The arrow in the figure shows the time lag in the occurrence of residuals between stations, indicating the propagation of residuals from south to north. The residuals are very small in range, (less than 0.3 m) at all the four stations. The time-dependence of the residual elevation and its relationship with the corresponding daily mean values of atmospheric pressure, along-shore wind, and cross shore wind were also estimated. There is a lag between the atmospheric pressure and residuals.

The residuals contain signatures of both oceanographic and meteorological signals. However no attempts have been made to quantify the effect of each component.

6. Conclusion

The tides along the southwest shelf of India are predominately mixed, semidiurnal in nature. The prominent tidal constituent being M_2. The demeaned tidal amplitude was maximum at Verem, and the least amplitudes recorded at the southern most station, Kollam. The major tidal constituent amplitudes decreased southwards where as the minor constituent, showed an increase towards the southern stations. The residuals were of less than 0.3 m in range at all stations. The residuals showed propagation from south to north.

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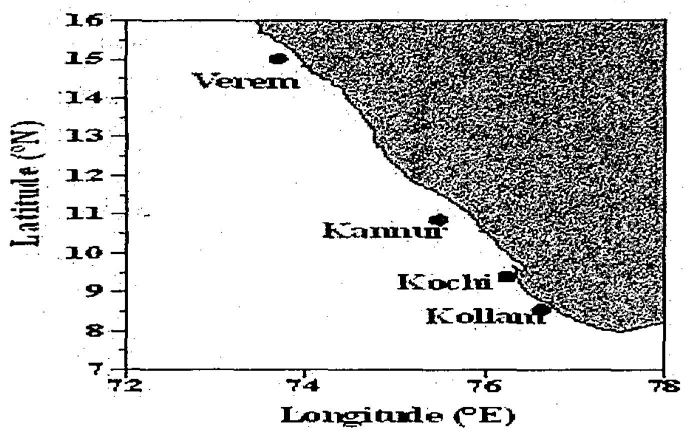

Fig.1 Station locations

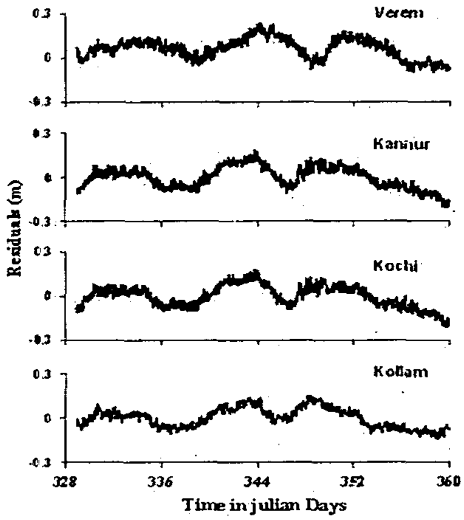

Fig 3. Time-series of residuals along the southwest shelf during Nov-Dec 2005.

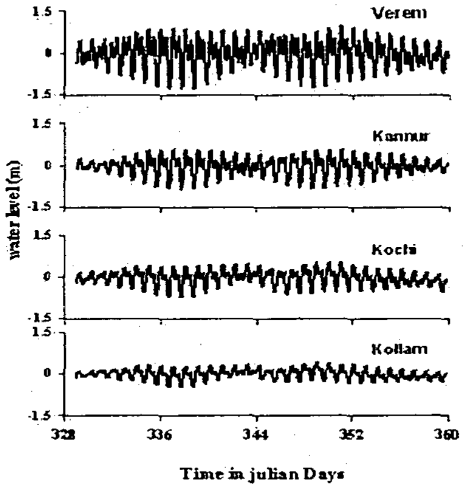

Fig 2. Time-series of water level along the southwest shelf during Nov-Dec 2005.

Tidal Constituents	Verem	Kannur	Kochi	Kollam
	Amplitude (cm)	Amplitude (cm)	Amplitude (cm)	Amplitude (cm)
Q1	2.75	3.79	1.82	0.84
O1	14.85	11.57	8.52	6.35
M1	0.94	1.03	0.39	0.56
K1	29.81	21.27	17.64	11.82
J1	1.78	2.89	1.48	0.72
OO1	1.33	0.69	0.86	0.29
MU2	0.69	0.90	0.39	0.2
N2	11.45	6.99	4.64	2.88
M2	52.86	34.93	21.98	13.47
L2	01.77	2.44	0.92	0.07
S2	17.87	13.07	8.02	5.96
2SM2	0.37	2.10	0.02	0.16
MO3	0.47	0.62	0.29	0.21
M3	0.31	0.37	0.39	0.23
MK3	0.39	0.57	0.94	0.47
MN4	0.38	0.67	0.32	0.39
M4	0.97	1.48	0.68	0.65
SN4	0.15	0.44	0.07	0.14
MS4	0.55	0.39	0.47	0.53
2MN6	0.29	0.21	0.01	0.18
M6	0.43	0.49	0.1	0.15
MSN6	0.21	0.33	0.16	0.21
2MS6	0.55	0.51	0.38	0.22
2SM6	0.11	0.16	0.04	0.11
PI1 (K1)	0.57	0.40	0.34	0.22
P1(K1)	9.87	7.04	05.84	3.91
PSI1(K1)	0.24	0.17	0.14	0.09
PHI1(K1)	0.42	0.29	0.25	0.17
2N2(N2)	1.52	0.93	0.62	0.38
NU2(N2)	2.22	1.35	0.9	0.56
T2(S2)	1.05	0.77	0.47	0.35
K2(S2)	4.86	3.55	2.18	1.62

Table.1 Tidal constituents along the southwest Indian shelf during Nov-Dec 2005