

NUMERICAL MODELLING OF TIDES AND TIDAL CURRENTS IN THE GULF OF KUTCH

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ABSTRACT

An application of a two-dimensional tidal model to study the tidal regime in the Gulf of Kutch is made. This is with a view to synthesise various information on tides and currents that are available in the Gulf. A comparison of surface elevations obtained from the model simulations at the locations Sikka, Mundra, Kandla and Navalakhi shows that the model reproduces the amplitudes and phases close to the observations. The modelled currents are also found to be accurate in magnitudes and phases, when compared with the moored current meter observations at a few locations such as off Navinar and Vadinar. The model results are used to study the tidal circulation in the Gulf. These results encourage us to look into the dynamical aspects such as the momentum balance and causes of amplification of the tides, which are dealt in a future paper.

INTRODUCTION

The Gulf of Kutch is characterised by high tidal ranges and the circulation in the Gulf is dominated by tides. Tidal range increases from mouth to head. Near the mouth, at Okha (Fig.1), the mean spring range is 3.06 m. Near the head, at Kandla, it is 5.88 and at Navalakhi, it is 6.43. Peak surface currents have been reported to be in the range of 1.5 -2.5 knots at the mouth and 3-5 knots in the central portion of the gulf (Anon., 1985).

The effects of construction of a proposed tidal barrage in the Hansthal creek was studied by observational and modelling studies by the Central Water and Power Station (Anonymous, 1985, Shaligram et al, 1988 etc.). In the 1990 s, the National Institute of Oceanography conducted several moored current meter observations off Vadinar, Navinar, Sikka, Kandla etc. during different periods. In the present study, we make use of the model results to make a synthesis of these observations and describe the tidal circulation in the Gulf.

MODEL

The following 2D model, originally developed for the French estuaries, by Salomon (1976) is used in the present study (see also Mariette et.al. (1982) for details). The model makes use of the implicit in alternate direction scheme developed for the propagation of tides in estuaries by Leendertse (1970). Salomon modified it by the inclusion of viscosity terms in the

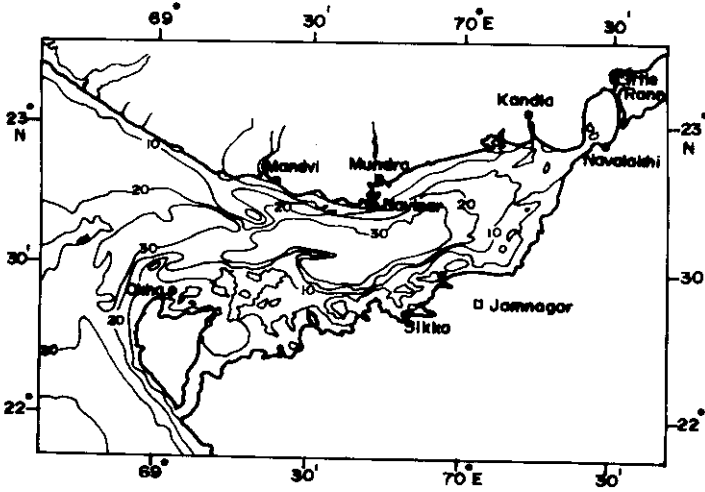


Fig.1 Gulf of Kutch

momentum equations Eqns (1) to (3) are the vertically averaged equations of momentum in x and y directions and the equation of continuity.

$$\frac{\partial U}{\partial t} + U \frac{\partial U}{\partial x} + V \frac{\partial U}{\partial y} - fV + g \frac{\partial \zeta}{\partial x} + gU \frac{(U^2 + V^2)^{1/2}}{C^2 H} + \frac{\tau_{sx}}{\rho H} + \epsilon \Delta U = 0 \quad (1)$$

$$\frac{\partial V}{\partial t} + U \frac{\partial V}{\partial x} + V \frac{\partial V}{\partial y} + fU + g \frac{\partial \zeta}{\partial y} + gV \frac{(U^2 + V^2)^{1/2}}{C^2 H} + \frac{\tau_{sy}}{\rho H} + \epsilon \Delta V = 0 \quad (2)$$

$$\frac{\partial \zeta}{\partial t} + \frac{\partial (HU)}{\partial x} + \frac{\partial (HV)}{\partial y} = 0 \quad (3)$$

where U and V are the depth averaged velocity components, ζ is the water surface elevation. The integration is carried out over a total depth, $H=h+\zeta$, where h is the still water depth. C is the coefficient of Chezy and ϵ is the coefficient of viscosity. τ_{sx} and τ_{sy} are the wind stress components, ρ is the density of water, f, the Coriolis parameter and g is the acceleration due to gravity.

The bottom friction is parameterised in terms of the coefficient of Chezy based on the hypothesis of Prandtl by the following relation

$$C = 7.83 \text{Log}(0.37H/z_0) \quad (4)$$

The stability of the numerical scheme is governed by the following relation.

$$\Delta t < \frac{2g(\Delta x)^2}{C^2 HU} \quad (5)$$

RESULTS AND DISCUSSION

In the application to the Gulf of Kutch, the model domain extends from the Okha region near the mouth to about 12 km upstream of the Navalakhi port inside the Hansthal creek and about 7 km upstream of Kandla in the Kandla creek. The grid resolution is 1460 m and there are 96 and 60 grid points in the x and y directions respectively. A time step of 100 secs is chosen, the value of z_0 is 0.01 cm. The values of Chezy obtained by (5) were multiplied by 1.2 for all the grid points to tune the model. No river run off is prescribed in the model. Wind stress is not included in the present simulations.

Most of the observations that are available to us on currents are at different epochs and there are no simultaneous observations for simulating the tides and currents. Hence, we planned to conduct a series of numerical experiments for simulating the tides and currents at different epochs. For the prediction of the tide, amplitudes and Greenwich phases of the four major constituents M_2 , S_2 , K_1 and O_1 at Okha were used to construct a composite tide by the Admiralty method as described by Glenn (1977). A total of 25 constituents including the four major constituents are considered in this method, in which the other components are taken by admittance. The predicted tide at Okha is used for prescribing open boundary conditions along the open boundary.

One numerical experiment was conducted for the period starting from 12 June 1996 for a period of about 6 days. In this period, observations were conducted by the National Institute of Oceanography by moored current meters for a period of about one month off Sikka and Mundra. At both these locations, surface elevations were obtained, while the current data was obtained off Sikka only. The current observations were made at the surface, mid depth and bottom. We chose the values at the mid depth for comparison with the model results. The model was run from 12th June onwards and the results are shown after 72 hours, a time sufficiently long enough for the spin up. Fig.2 shows our prediction for Okha as well as the comparison with the observed in the other stations. For the comparison of surface elevations, the observed values were used off Sikka and Mundra, while at Kandla and Navalakhi, the predicted tides from the Indian Tide Tables were taken. On an average, the computed elevations have an accuracy within 10 cm. and their phases are consistent with those observed.

Fig.3. shows a comparison of velocity components between the observed and modelled off Navinar and Vadinar points respectively, obtained after making separate runs for the periods

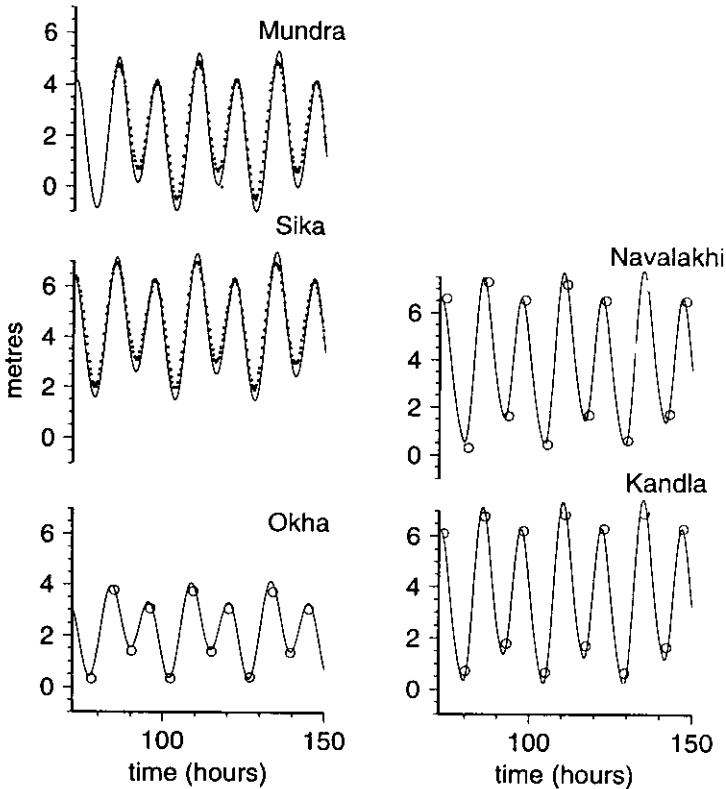


Fig.2. Comparison of the model results with the predicted tide at Okha , observed tides at Sikka and Mundra and the predicted tide at Kandla and Navalakhi. The time 72 hours corresponds to 00 hours on 15 June 1996. The continuous line corresponds to the model results, dotted line, the observed and the circles indicate the predicted values obtained from the Indian Tide Tables.

during which observations are available for comparison..The amplitudes are fairly accurate . At Navinar, the observed currents occur earlier than the modelled during flood, while during ebb, their phases are consistent. In general, the agreement is quite good.

As far as the magnitudes are concerned, at Navinar, for instance, the spring-neap variations in the u -component are between about 0.50 and 0.80 m/sec with the v component not exhibiting much changes. At Vadinar, the magnitudes are slightly less than those at Navinar. These locations are fairly close to the coast and higher intensities are found in the central region of the Gulf.

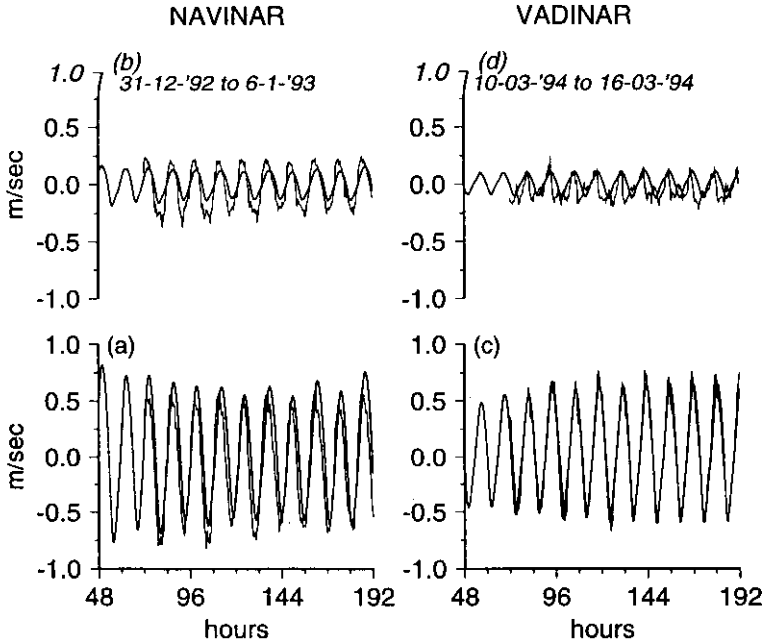


Fig.3. A comparison of model results of currents with observations off Navinar (22.735 N, 69.711 E) and Vadinar (22.422 N, 69.675 E). Fig.3a,c show the u component, while b,d show the v component. The continuous line indicates the model results and the dotted line, the observed. u is positive eastward while v is positive northward.

The simulated tidal circulation during a spring tide is shown in Fig.4. The currents are shown at two hours before the occurrence of high tide at Okha. At this hour, flood currents attain maximum intensities. In the central region of the lower Gulf, magnitudes are about 1.5 m/sec, with maximum reaching upto 1.75 m/sec. Upstream of Sikka, the maximum intensities are about 1.0 m/sec.

CONCLUSION

We have shown that the 2 dimensional model accurately simulates the surface elevations and currents in the Gulf of Kutch. The utility of a barotropic model in simulating currents accurately in a tidally dominated region is very well illustrated in the present work. The fact that the model reproduces the observations closely encourages us to study other dynamical features such as momentum balance and causes of amplification of tides in the Gulf. These aspects will be dealt in a future paper.

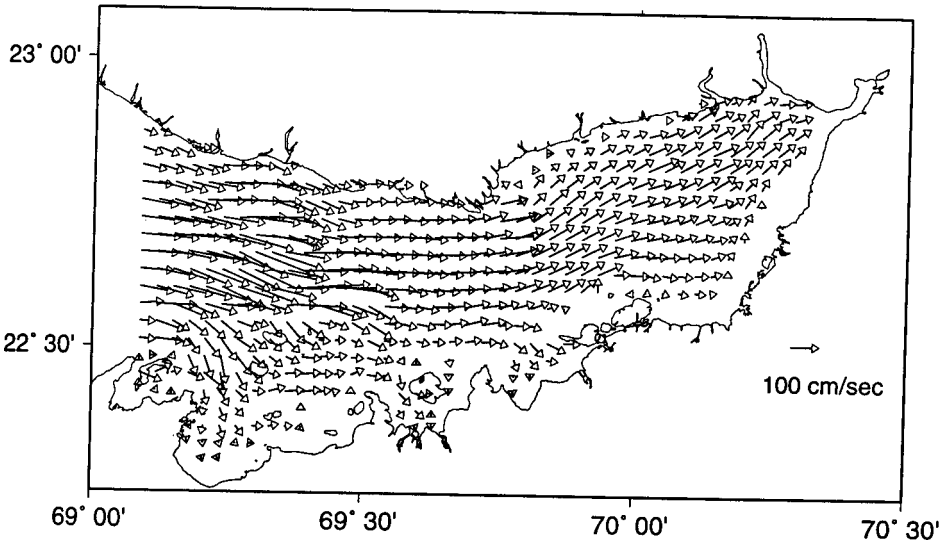


Fig.4. Tidal circulation in the Gulf of Kutch. The diagram is shown at two hours before the occurrence of high tide at Okha on 15-06-1996 at 11.04 hours.

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