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The dynamic effects of barometric forcing on storm-surges in the Bay of Bengal

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ABSTRACT. The numerical model developed by Johns and Ali (1980a) has been used to study the dynamc contribution of atmospheric pressure anomaly on storm surges in the Bay of Bengal. The contribution due to this factor has also been compared with that due to wind-stress alone. It is found that dynamic effects of barometric forcing can to a reasonable approximation be represented by a statical corrections.

1. Introduction

Wind and atmospheric pressure anomaly are the two factors responsible for the generation of storm surges by supplying energy to the sea underneath. Wind is the main generating mechanism while pressure anomaly has a secondary effect. It has been a frequent practice to represent the effects of atmospheric pressure on storm surges by a statical law and to neglect its dynamical effects (*e.g.,* Heaps 1967, 1969; Banks, 1974). In a statical sense, the sea level rises by about 0.01 m per one millibar pressure drop. That the dynamical contribution of atmospheric pressure anomaly is small compared with that due to other forcing mechanisms has recently been shown by Prandle (1975). With these ends in view the dynamic effect of barometric forcing on storm surges in the Bay of Bengal has been neglected by Johns and Ali (1980a). However it was also mentioned by Johns and Ali (1980a) that an experiment supported the idea of statical correction, but the details of the results were not given.

It is intended here to present in somewhat more detail the dynamic contribution of barometric forcing in the generation of storm surges in the Bay of Bengal and to see the extent to which a statical correction is a reasonable approximation.

The present model is exactly the one developed by Ali (1979) and Johns and Ali (1980a).

The model area includes almost the whole of the Bay of Bengal, extending eastwards (outside the Bay) upto the easternmost coast of Burma and southwards as far as latitude 11 deg. N. This configuration is shown in Fig. 1. In the north-eastern sector of the Bay, the model has a representation of the *Ganges-Brahmaputra-Meghna* river system in Bangladesh. The schematic representation of the river system is given in Fig. 2. The rivers are marked 1, 2 and 3.

Two numerical experiments are performed: One with the wind forcing alone and the other with both the wind and barometric forcings acting simultaneously.

3. Basic equations

The dynamical processes in the Bay region are described by :

$$\frac{\partial \zeta}{\partial t} + \frac{\partial}{\partial x}(Hu) + \frac{\partial}{\partial y}(Hv) = 0 \qquad (1)$$

$$\frac{\partial}{\partial t}(Hu) + \frac{\partial}{\partial x}(Hu^2) + \frac{\partial}{\partial y}(Huv) - fhv$$

$$= -gH\frac{\partial \zeta}{\partial x} - \frac{H}{\rho}\frac{\partial P}{\partial x} + \frac{1}{\rho}(F_s - F_b) \qquad (2)$$
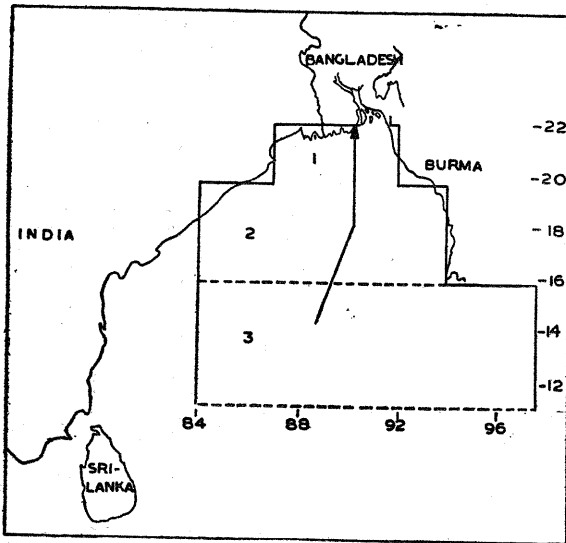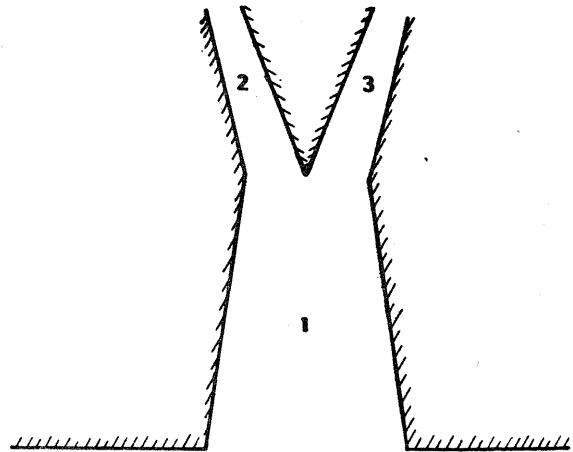
Fig. 1. The main analysis area and the cyclone track
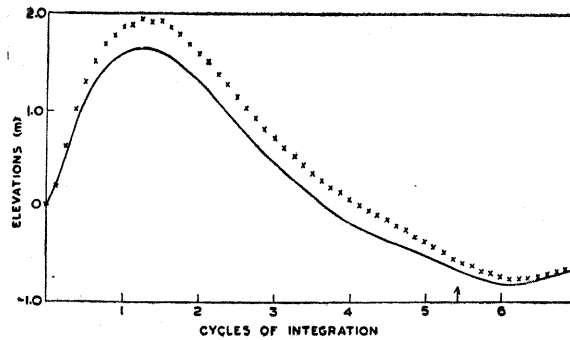

Fig. 2. Idealised river system

Fig. 3. Temporal variation of sea surface displacement at a
position in region 236 km east of its western boun-
dary and 18 km north of its southern boundary.
Continuous curve—wind stress; cross—wind stress
plus barometric forcing. The arrow indicates the
time of landfall

$$\frac{\partial}{\partial t} (Hv) + \frac{\partial}{\partial x} (Huv) + \frac{\partial}{\partial y} (Hv^2) + fhu$$

$$= -gH \frac{\partial \zeta}{\partial y} - \frac{H}{\rho} \frac{\partial P}{\partial y} + \frac{1}{\rho} (G_s - G_b) \quad (3)$$

where,

x, y, z : describe a system of cartesian
coordinates with x taken posi-
tive eastward, y northward and z
vertically upward.

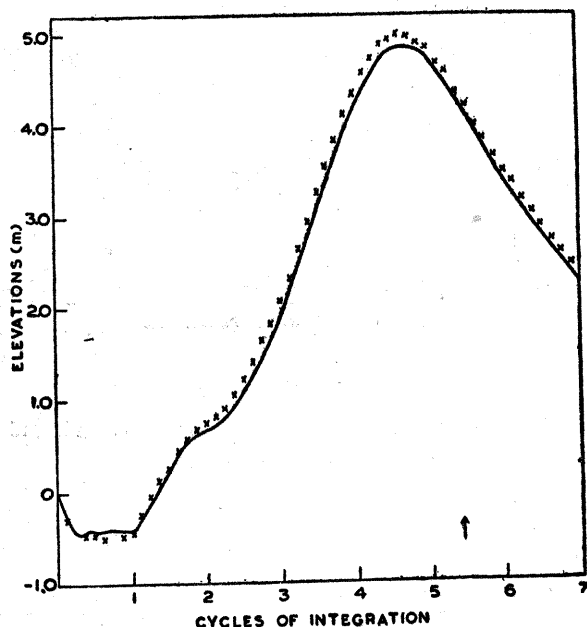|		
u, v	:	depth-averaged component of velocity in the x and y directions respectively
P	:	atmospheric pressure
ρ	:	density of water
f	:	Coriolis parameter
g	:	acceleration due to gravity
F_s, F_b	:	x-components of surface and bottom stresses respectively
G_s, G_b	:	y-components of surface and bottom stresses respectively.

Fig. 4. As in Fig. 3 except that position is on the eastern boundary of region 2 and 342 km north of its southern boundary
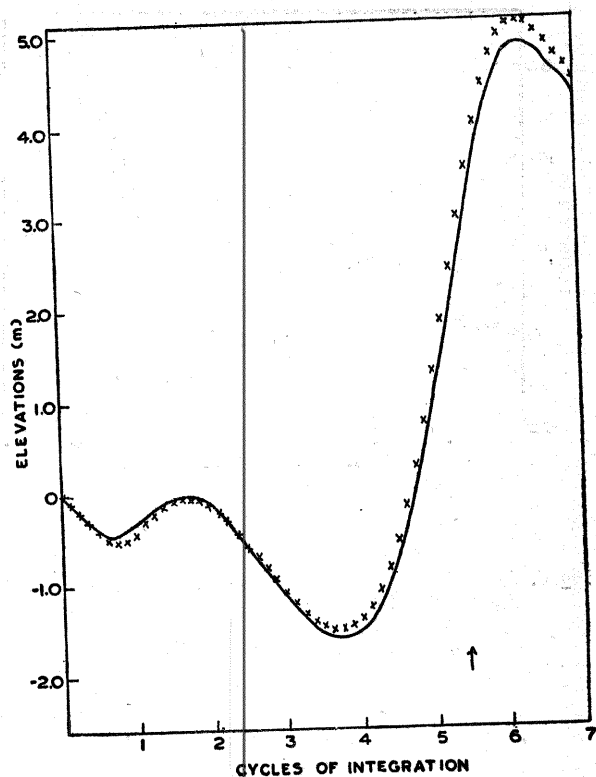

Fig. 5. As in Fig. 3 except that position is 18 km south of the northern boundary and 18 km west of the eastern boundary region 1

t :   time

z : $\zeta(x, y, t)$ corresponds to the free surface

z : $-h\,(x, y)$ is the floor

H : $h + \zeta$ is the total depth.

For the river model, the equations are :

$$b\,\frac{\partial \zeta}{\partial t} + \frac{\partial}{\partial y}\,(bHv) = 0 \qquad (4)$$

$$\frac{\partial}{\partial t}\,(bHv) + \frac{\partial}{\partial y}\,(bHv^2) =$$

$$-bgH\,\frac{\partial \zeta}{\partial y} - \frac{b}{\rho}\,G_b \qquad (5)$$

where $b = b(y)$ is the breadth of the river. In Eqns. (4) and (5), the variables are independent of x-coordinate.

The approximations involved in the derivation of the above Eqns. (1)-(5) have been discussed by Ali (1979) and Johns (1980). The surface and bottom stress terms are parameterised by conventional quadratic laws.

Both the river and the bay models are treated here as a single model and is called the Bay-River model.

Eqns. (1)-(5) are written in finite-difference form using the leap-frog scheme. The grids are staggered in space. The details of the numerical scheme are given in Ali (1979) and Johns and Ali (1980a).

The Bay region is divided into three sections, marked 1, 2 and 3 (see Fig. 1). Region 3 is covered by a coarser grid of length 72 km, and regions 1 and 2 by a finer grid of length 18 km. Grid lengths in the rivers are also 18 km.

3. Numerical experiments

Storm surge is generated in the model by an idealised cyclone of constant strength tracking across the analysis area (the track of the cyclone is shown in Fig. 1) with a constant speed. The pressure distribution in the cyclone is given by

$$P = P_a - \triangle P \exp(-r/R) \qquad (6)$$

where P_a is the ambient atmospheric pressure, P is the pressure drop in the centre, R is the e-folding radius and r is the radial distance of
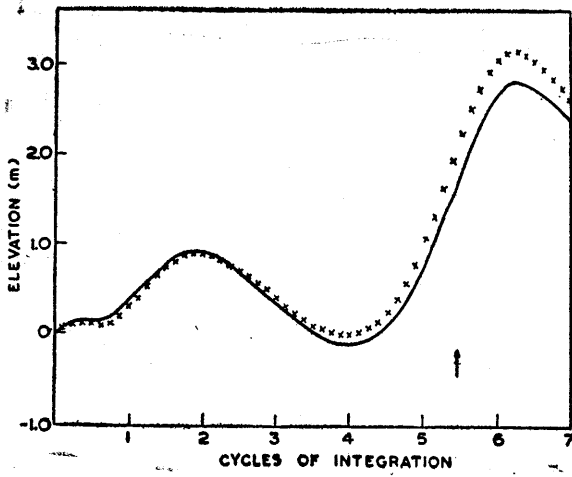
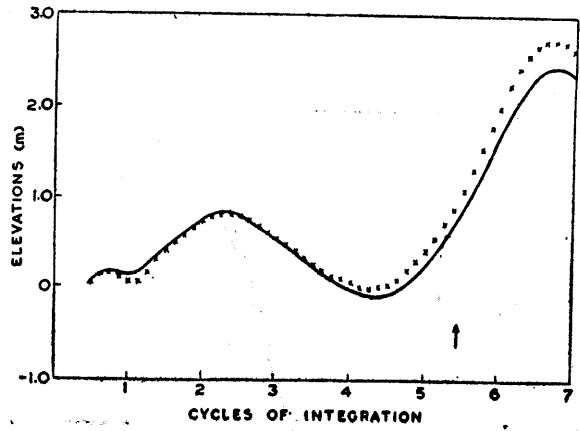Fig. 6. As in Fig. 3 except that position is at mid-point of the mouth of river 1

Fig. 7. As in Fig. 3 except that position is 162 km inland along river 1
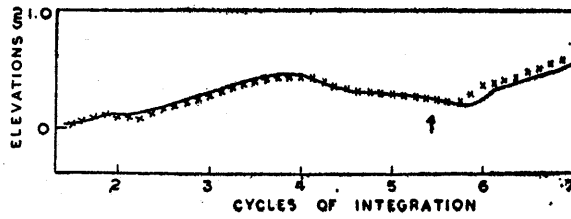
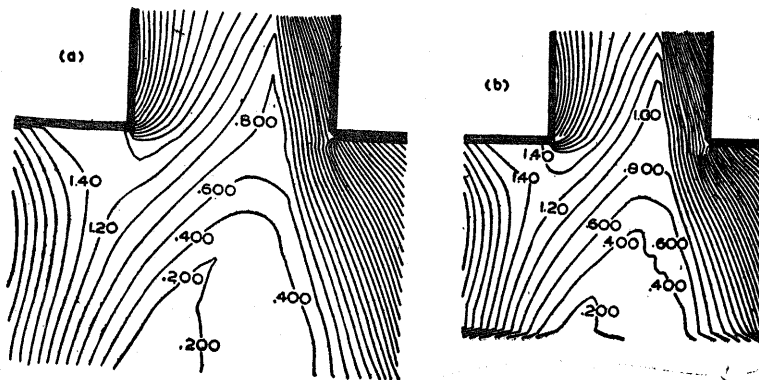Fig. 8. As in Fig. 3 except that position is 252 km inland along river 2

Fig. 9. Contours (in metres) of maximum surges in regions 1 and 2 corresponding to (a) wind stress alone and *plus* pressure forcing

any point from the centre of the cyclone. The wind distribution in the cyclone is calculated on the assumption of a gradient balance among the pressure gradient force, the Coriolis force and the centrifugal force.

The dimensions and the values of various parameters used in the model are exactly the same as those in Ali (1979) and Johns and Ali (1980 a).

It is worth mentioning here that detailed discussion on the use of the pressure formula given in Eqn. (6) and the choice of $R = 350$ km in the model have already been made by Ali (1979, 1980) and Johns and Ali (1980 b).

As mentioned earlier, two experiments are performed : One with the wind-stress alone and the other with the simultaneous presence of wind-stress and barometric forcing.

Since the main interest lies in regions 1 and 2 of the Bay model and in the rivers and since elevations are of prime importance, the results for region 3 and the depth-averaged currents will not be considered here. Again the results in river 3 are also not given because features in rivers 2 and 3 are more or less the same.

The time variation of storm surges at different points is shown in Figs. 3 to 8. In these diagrams, each cycle is equal to 12.4 hr. The general picture is that during the early stages of integration, the contribution due to atmospheric pressure anomaly seems to be negative (except in Fig. 3), tending to reduce the surge heights below the values obtained with wind-stress alone. In the later stages, the contribution is positive. The maximum positive contribution due to pressure forcing occurs around the peak surge. However the overall effect of barometric forcing is negligible compared with that due to wind-stress.

The spatial distribution of maximum surges in regions 1 and 2 for the two experiments is given in Fig. 9. The highest contribution (~ 0.6 m) from pressure forcing occurs in the deeper water of region 2. In this deep water region, the percentage increase in peak surge obtained with the combined forcings compared with that due to wind-stress alone is as much as 30 per cent at some grid points. Elsewhere, including river 1 (results not shown here), the percentage increase is around 12 per cent. Obviously this percentage increase is much less in rivers 2 and 3.

The inverted barometric law gives a maximum elevation of 0.5 m at the centre of the cyclone for a pressure drop of 50 mb (the value used in the experiment). So to a good approximation, the dynamic effect of atmospheric pressure anomaly may be neglected in the present model. This is consistent with Prandle's (1975) conclusion.

4. Conclusions

The numerical model developed by Ali (1979) and Johns and Ali (1980 a) has been used to investigate the dynamic effect of barometric forcing on storm surges in the Bay of Bengal. The study has shown that the contribution due to barometric forcing is quite negligible compared with that due to wind-stress. The dynamic effect of atmospheric pressure anomaly is further found to be representable by a statical correction. The omission of atmospheric pressure term also saves a significant amount of computational time.

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