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NUMERICAL SIMULATION OF TIDE, WIND AND STORM INDUCED CURRENT OFF CHENNAI COAST

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KEYWORDS

Tide
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Cyclone tracks and parameters
MIKE 21 Hydrodynamic module and Toolbox
Chennai coast

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ABSTRACT

Due to the enormously growing population in a short period, the maritime activities along the coastal stretches off Chennai have increased tremendously. The study of tide, wind and storm induced currents in this context is very essential to have a sustainable development of coastal needs. Though a few studies were made earlier, the problem is still not completely resolved and some more studies in different angles and with different methods are essential for understanding this problem in a holistic manner. So the authors attempt to study the hydraulics parameters (viz. tide, wind and current) off Chennai coast, using the advanced numerical modeling tool of the Danish Hydraulics Institute's MIKE 21 Hydrodynamic module and MIKE 21 Toolbox. The tides in this region are of semi diurnal type with an average spring tidal range of 1.01 m and a neap tidal range of 0.41 m and these tide levels vary with respect to Chart Datum (CD). Along with this seven tidal constituents off Chennai coast were also carried out. While the magnitudes of simulated tide induced currents were observed to be around 0.119 m/s for all the time, the directions of tide induced currents during the flood and the ebb phases of tides were observed to remain almost same. The order of magnitude of M_2 and S_2 tidal constituents (0.078 m/s and 0.024 m/s) were reduced. A good agreement was observed between the simulated tides and the Predicted tides. The wind roses were prepared and presented to understand the wave climate off Chennai. The winds during the summer monsoon months were from south and southwest and their weighted mean magnitude was 8.9 m/s and the winds during the winter monsoon off Chennai were from northeast with a mean magnitude of 6.9 m/s. The time variations of simulated shore parallel currents, at nearly 10 m water depth off Chennai, were observed to be 0.24 m/s and 0.18 m/s respectively. But in this region, the wind induced current was towards south during the winter monsoon and towards north during the summer monsoon. The present simulation shows that the storm induced current is approximately 0.70 m/s.

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INTRODUCTION

At present the Coastal Engineers are interested on the influence of currents in the nearshore and offshore structures for their engineering activities. In this context the study of tide, wind and storm induced currents are very essential. Cyclonic storms and storm surges are more frequent along the East Coast of India (ECI) than along the west coast of India (WCI). Storm surges are common along ECI due to the occurrence of severe cyclones. Many available records in this coast on surges are based on surveys conducted after the passage of storms. The records of storm parameters also are not based on instrument recordings, as they are often indirectly derived from observations on atmospheric parameters. Reliable estimates from measured data of cyclone parameters are also not available for many past cyclones. In the present study, the authors simulated different hydraulic parameters and compared them with earlier results. Several studies were carried out earlier on 1977 Andhra Cyclone (Das, 1972; Jhons and Ali, 1980; Jhons *et al.,* 1981; Jossy *et al.,* 1996) using finite difference methods for surge simulation while others (Subbaramayya *et al.,* 1979; Murty, 1984; Sharma and Murty, 1988) analyzed this cyclone critically in other respects. But in this paper simulation of storm induced nearshore current generated by 1977 Andhra cyclone was made using Danish Hydraulic Institute MIKE 21 Hydrodynamic module and MIKE 21 Toolbox taking the input data of Ghosh (1981) and assuming the track of cyclone is perpendicular to the coast. The DHI-MIKE 21 model is the latest tool and technique and has not been applied to this subject area earlier. Therefore, this model has been used in the present study to compare with the earlier works that were made using the other methods.

Study area, data and methodology

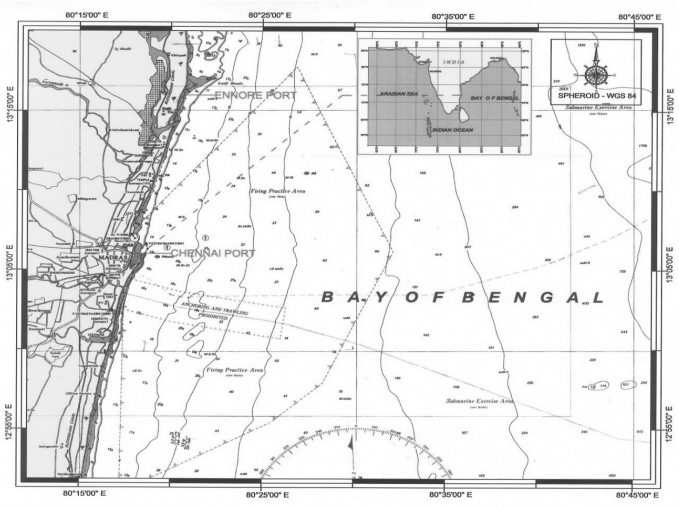

Figure 1: Study area - Hydrographic chart

Study area

The landfall of Cyclone is in the coastal area off Chennai and the study area is shown in Fig. 1.

Input data and model domain

The larger and coarser resolution grid module with the grid spacing of 1 km ×1 km in both the X and Y directions is given in Fig. 2. The bathymetry of the study area was extracted from three sources. They are DHI - MIKE-C-MAP data base, Indian Naval Hydrographic Charts and measured bathymetry data of INDOMER. For the Hydrodynamic module setup, the input parameters of track of Andhra cyclone - 1977, maximum pressure drop, and radius of maximum wind were obtained from Ghosh (1981) and "*Cyclone e Atlas, IMD"* respectively. The cyclone track of Chennai and the points (X,Y) of calculation of currents is presented in Fig. 2.

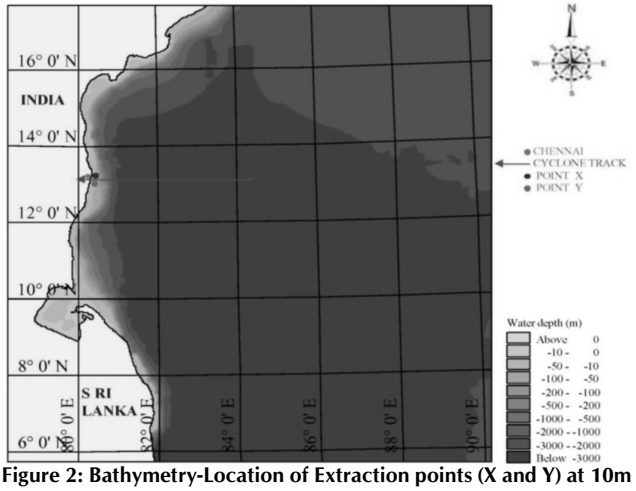

Figure 2: Bathymetry-Location of Extraction points (X and Y) at 10m depth

MATERIALS AND METHODS

The MIKE 21–HD module is an advanced tool for two dimensional (2D) free-surface flows. This HD module forms the basic module and a part of DHI- MIKE 21 Model suite developed by Danish Hydraulic Institute. It provides the hydrodynamic basis for the computations performed in the Environmental Hydraulics modules. The output of the hydrodynamic (HD) module is also used as input for many of the other MIKE 21 modules viz., Advection-Dispersion module (AD), Sediment Transport module (ST) Particle tracking and the Environment module. The HD module is the basic module that calculates the depth-averaged hydrodynamic variables in the area, which is essential for the water levels and the water fluxes between the grid cells. Water depths and depth averaged current velocities and directions can then automatically be derived from these variables, so that the basic equations governing the tide induced flow field in marine environment are the continuity and momentum conservation equations. These equations in terms of vertically integrated mass fluxes, (q_x, q_y), in Cartesian coordinate system are,

$$\zeta,t + q_{x,x} + q_{y,y} = 0 \quad (1)$$

$$q_{x,t} + H^{-1} q_x q_{x,x} + H^{-1} q_y q_{x,y} - fq_y + gH\zeta_{,x} + \rho^{-1} (Hp_{a,x} - \tau_{ax} + \tau_{bx}) = 0 \quad (2)$$

$$q_{x,t} + H^{-1} q_x q_{y,x} + H^{-1} q_y q_{y,y} - fq_x + gH\zeta_{,y} + \rho^{-1} (Hp_{a,y} - \tau_{ay} + \tau_{by}) = 0 \quad (3)$$

Here the origin of the co-ordinate system is chosen at the undisturbed sea surface and z is measured positive upwards. The suffixes preceded by comma indicate partial derivatives. The pressure is assumed hydrostatic and the astronomical tide generating forces are neglected. The u, v are components of velocity in the x, y direction respectively and t, time. $H = h + \zeta$ is the total depth of water, h is the undisturbed depth of water and ζ is the elevation of the sea surface measured from the undisturbed sea surface. P_a is the atmospheric pressure, f is the Coriolis parameter, ρ is the density of seawater and g is acceleration due to gravity. (τ_{ax}, τ_{ay}) are wind stresses acting at the air-sea interface in the x and y directions and (τ_{bx}, τ_{by}) are the stresses in the x and y directions at the sea bottom.

In order to estimate the surge height, the distribution of the wind and pressure fields induced by the cyclone have to be specified over the Bay of Bengal (BOB) near the study area. As the wind and pressure fields induced by the moving cyclone are assumed as circular here, they are described in terms of a smaller number of storm parameters in the MIKE21 module. The parameters used to describe the wind field associated with the cyclone are:

- Radius to maximum wind, R_m,
- Maximum wind speed, W_{max},
- Cyclone track, forward speed V_f and direction,
- Central pressure, P_c and
- The ambient pressure, P_{am}

At a distance R, from the center of the cyclone, the rotational wind speed W_r is given by,

$W_r = W_{max} (R/R_m)^7 \exp [7(1-R/R_m)]$ for $R < R_m$ (4)

$= W_{max} \exp [(0.0025R_m + 0.005) (1-R/R_m)]$ for $R < R_m$

Where R and R_m are in kilometers. Cyclone induced wind rotates anti-clockwise in the northern hemisphere and clockwise in the Southern hemisphere. The direction of the wind at a distance R from the centre of the cyclone is deflected towards its centre by friction at the air-sea interface. The deflection angle θ with respect to the tangent to the circle at a particular location R from the centre of the cyclone is given by,

$\theta = 10°$ for $R < R_m$

$= 10° + (R - R_m)/(0.2R_m)15°$ for $R_m < R \le 1.2R_m$

$= 25°$ for $1.2R_m < R$

Finally, the pressure, P, at a particular location is given by,

$P = P_c + (P_{am} - P_c) \exp (-R_m/R)$

RESULTS AND DISCUSSION

The seven tidal constituents (M_2 to Q_1) slowly decreases at Chennai are given below.

The simulation study reveals that the tide induced current pattern for Chennai is 0.119 m/s for all the time, but it reduces the order of magnitude of M_2 and S_2 tidal constituents (0.078 m/s and 0.024 m/s), which is in good agreement with that of Chandramohan *et al*. (2010) who estimated it as 0.115 m/s.

Station name/ Constituent	Amplitude (m) M_2	S_2	N_2	K_2	K_1	O_1	Q_1
Chennai	0.311	0.138	0.057	0.026	0.059	0.025	0.002

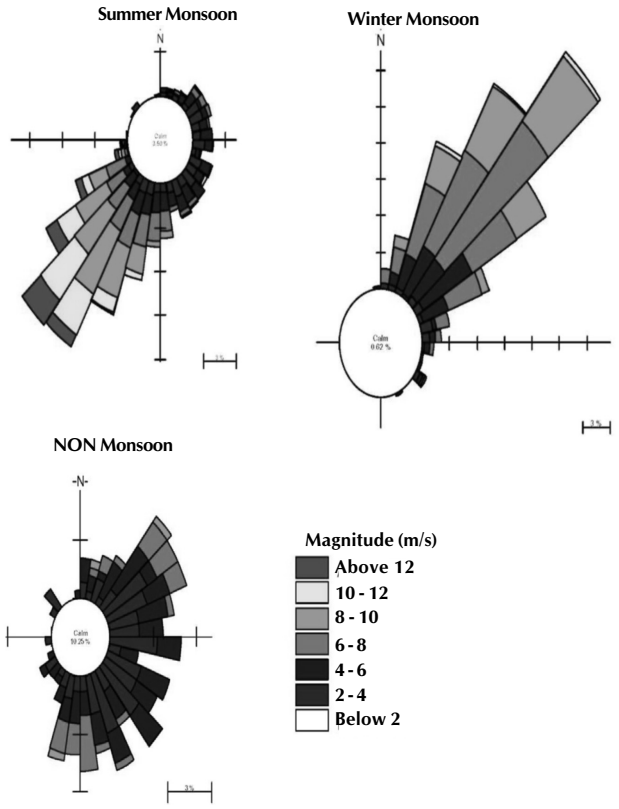

Figure 3: Rose diagram for wind

The directions of tide induced currents during the flood and the ebb phases of tides were observed to remain almost same. During the summer monsoon months, winds were blowing from south and southwest directions (Fig. 3) and their weighted mean magnitude was 8.9 m/s. During the winter monsoon, winds off Chennai were blowing from northeast (Fig. 3) with a

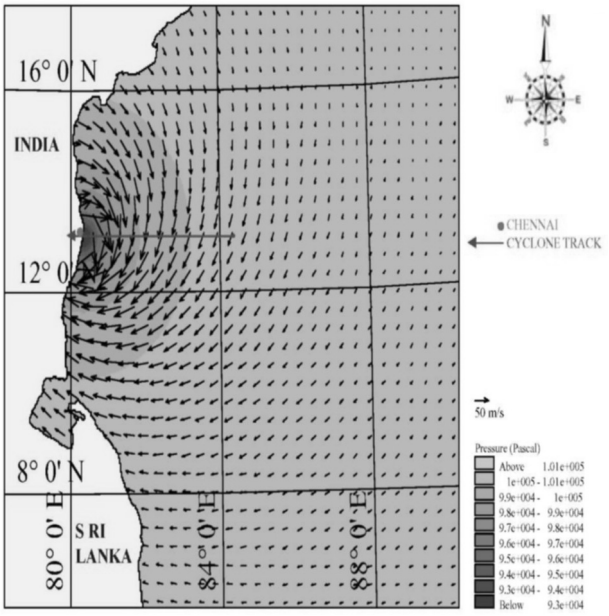

Figure 4: Wind field one hour before the landfall of the cyclone

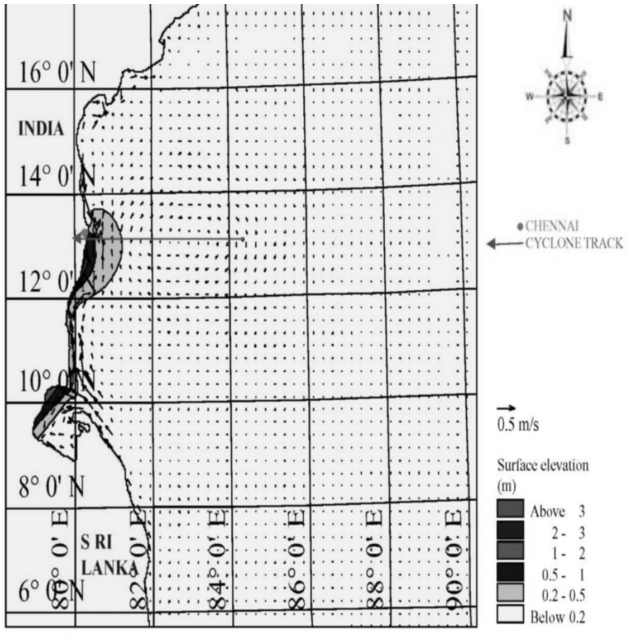

Figure 5: Strom surge height at the time of land fall of cyclone

mean magnitude of 6.9 m/s. The maximum simulated steady state current during the summer monsoon was 0.24 m/s, and during winter monsoon was 0.18 m/s. But, in this region the wind induced current was towards south during the winter monsoon and towards north during the summer monsoon. The present study revealed that the wind induced current pattern for Chennai has a good agreement with that of Chandramohan *et al*. (2010) who estimated as 0.22 m/s and 0.15 m/s for both the summer and winter monsoons while Sundar and Sundaravadivelu (2005) estimated the long shore current velocity as 0.75 m/s off Chennai. The latter study appears to be over estimated. It is also found that the shore parallel currents were found to increase with time and reach

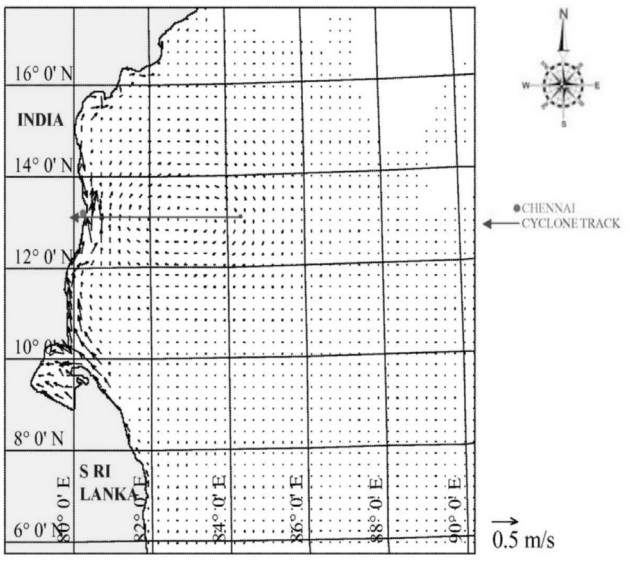

Figure 6: Storm induced currents in the nearshore waters one hour before the cyclone landfall

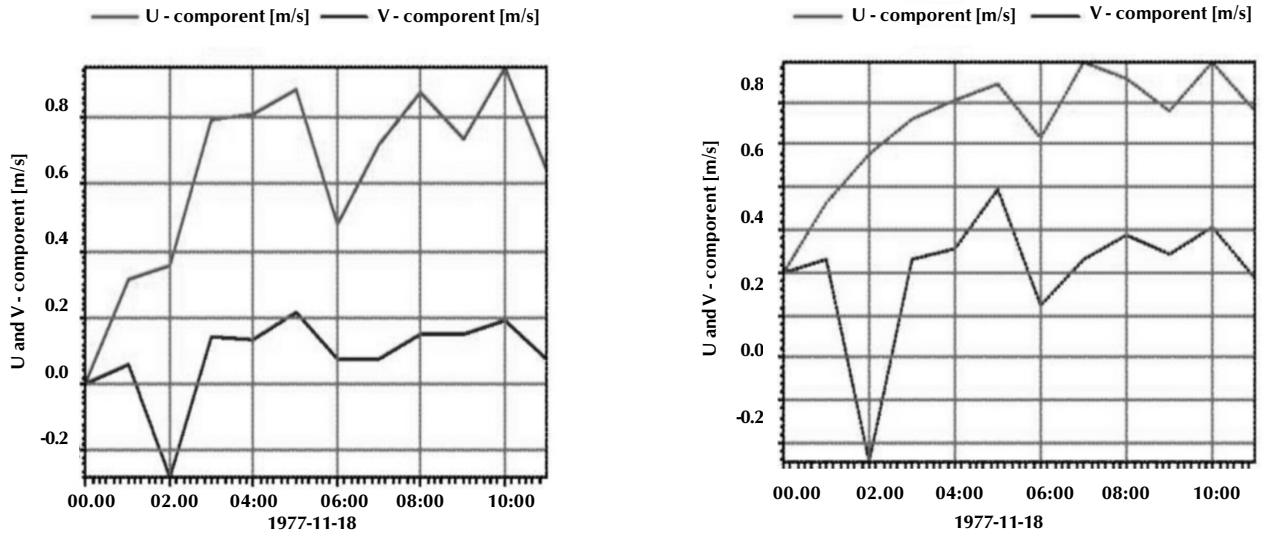

Figure 7: Time variation of currents at point X and Y of landfall

the steady state within nearly 8 h. So it should be noted here that as the wind vectors do not remain constant at any coastal region, to forecast the offshore currents, continuous measurement of wind field is required.

The storm induced currents, surge height were also simulated and presented in the Figs. 5 and 6. The wind field, one hour before the landfall of the cyclone, was presented in Fig. 4. The track of the storm and the landfall point were indicated as arrow and dot in Figs. 4 to 6. The model was first calibrated by simulating surges for different values of wind stress coefficients Ka. The simulated storm surge height at the time of land fall of 1977 Andhra cyclone is shown in Fig. 5. For the value of Ka = 3.4×10-3, the model predicts a peak surge of 2.11 m on the northern side of the landfall point (Fig. 5). Fig. 6 shows the flow field in the nearshore waters one hour before the landfall of the cyclone. The flow in the foreshore is stronger than the off shore. The simulation shows that the storm induced current is approximately 0.70 m/s. The time variation of x- and y-components of currents in 10 m water depth, at two points one on the north and the other on the south of the landfall point (Fig. 2), was shown in Fig. 7.

CONCLUSIONS

The accuracy of model results could be improved when fine spatial resolution winds are used. The results of this study are very useful for the design of break waters, jetty, groin and other coastal activities planned in this region. So, it should be noted here that as the wind vectors do not remain constant at any coastal region, to forecast the offshore currents, continuous measurement of wind field is required. The sufficient studies on estimations of storm induced nearshore currents off Chennai coasts are not available. So the present study gives a general idea of currents developed along Chennai when cyclones cross the coastal stretch. This study also gives an attempt to show that how far the MIKE-21 model demonstrated the results off Chennai coast. In the absence of direct measurements, this method and the model appear to be the best tool for estimation of coastal circulation.

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