

Storm Surge Forecasting In the Bay of Bengal and Arabian Sea

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Abstract

India and its neighborhood are threatened by the possibility of storm surge floods whenever a tropical cyclone approaches. About 300,000 lives were lost in one of the most severe cyclones that hit Bangladesh (then East Pakistan) in November 1970. The Andhra cyclone devastated the eastern coast of India, killing about 10,000 persons in November 1977. More recently the Orissa coast of India was struck by a severe cyclonic storm in October 1999, killing more than 15,000 people besides enormous loss to the property in the region. These and most of the world's greatest human disasters associated with the tropical cyclones have been directly attributed to storm surges.

Storm surge disasters cause heavy loss of life and property damage to the coastal structures and the losses of agriculture which lead to annual economic losses in these countries. Thus the real time monitoring and warning of storm surge is of great concern for this region.

The main objective of the present paper is to highlight the current activity in surge prediction in India. The paper also describes the mitigation measures for storm surge hazards.

Introduction

Storm surges associated with severe tropical cyclones constitute the world's worst coastal marine hazard. Storm surge disasters cause heavy loss of life and property, damage to the coastal structures and the losses of agriculture which lead to annual economic losses in affected countries. Death and destruction arise directly from the intense winds characteristic of tropical cyclones blowing over a large surface of water which is bounded by a shallow basin. As a result of these winds the massive piling of the seawater occurs at the coast leading to the sudden inundation and flooding of coastal regions.

Storm surges are extremely serious hazards along the east coast of India, Bangladesh, Myanmar and Sri Lanka. About 300,000 lives were lost in one of the most severe cyclones that hit Bangladesh (then East Pakistan) in November 1970. Recent Paradip Cyclone devastated the eastern coast of India, killing more

than 10,000 persons in October 1999. These two and most of the world's greatest human disasters associated with the tropical cyclones have been directly attributed to storm surges.

During the last 109 years, 263 cyclones had struck the east coast of India, leaving severe damage and casualties mostly because of the strong winds and storm surges. Statistics show that 37% of the total cyclones hitting the east coast of India have crossed the Orissa coast. Notable storm surges that have affected the Orissa coast have been during October 1967, October 1971, June 1982, October 1985 and October 1999 of which the recent Paradip cyclone of October 1999 was the worst. The storm surge due to the October 1999 event was more than 7 meters over and above the normal astronomical tide. The surge penetrated through Mahanadi river system and caused serious inland flooding. Thus the real time monitoring and warning of storm surges is of great importance to Orissa.

A detailed review of the problem of storm surges in the Bay of Bengal is given by Ali (1979), Rao (1982), Roy (1984), Murty (1984), Murty et al. (1986), Das (1994 a, b), Dube et al. (1997, 1999, 2000a) and Chittibabu (1999).

The purpose of the present paper is to give a review of recent developments in predicting the storm surges in the Bay of Bengal and Arabian Sea. A real time storm surge prediction system is also proposed here for disaster management (Dube et al. 1994).

Destruction Potential of Storm Surge

Although the frequency of tropical cyclones in the Bay of Bengal is not quite high, the coastal regions of India, Bangladesh and Myanmar suffer most in terms of loss of life and property caused by the surges. The reason besides the inadequate accurate prediction, are the low lands all along the coasts and considerably low-lying huge deltas, such as, Gangetic delta and Irrawaddy delta. Table I lists the number of deaths associated with several deadly cyclone disasters in India and Bangladesh where death tolls were in excess of 5000 lives. These major surges usually occurred unexpectedly.

There can be little doubt that the number of casualties would have been considerably lower if the surge could have been predicted, say, 24 hours in advance allowing effective warnings in the threatened area. The prediction, must, of course, be accurate enough so that one can distinguish between the dangerous surges and the surges that cause little harm, as people cannot be evacuated from exposed areas for every approaching storm. Some success has been achieved in predicting storm surges by computer oriented numerical models.

TABLE I
DEATHS IN TROPICAL CYCLONES

Year	Countries	Deaths
1970	Bangladesh	300,000
1737	India	300,000
1876	Bangladesh	200,000
1897	Bangladesh	175,000
1991	Bangladesh	140,000
1833	India	50,000
1864	India	50,000
1822	Bangladesh	40,000
1965	Bangladesh	19,279
1999	India	15,000
1963	Bangladesh	11,520
1961	Bangladesh	11,466
1985	Bangladesh	11,069
1971	India	10,000
1977	India	10,000
1960	Bangladesh	5,149
1973	India	5,000

Data Input for Surge Prediction Models

In order to achieve greater confidence in surge prediction in the Indian Seas one should have the good knowledge of the input parameters for the model. These parameters include the oceanographic parameters meteorological parameters (including storm characteristics) hydrological input basin characteristics and coastal geometry wind stress and seabed friction and information about the astronomical tides. It has been seen that in many casts these input parameters strongly influence the surge development.

Most of the northern Bay of Bengal is very shallow and is characterized by sharp changes in seabed contours. The shallowness of water may considerably modify the surge heights in this region. Therefore, accurate bathymetry maps are needed for improved surge prediction.

Operational Prediction Models

In India, the study of the numerical storm surge prediction was pioneered by Das (1972). Subsequently several workers attempted the prediction of storm surges in the Bay of Bengal (Das et al. 1974; Ghosh, 1977, John and Ali, 1980; Johns et al. 1981; Murty and Henry, 1983; Dube et al. 1985 etc.)

Operational numerical storm surge prediction models have been developed and are being routinely used for several coastal region of the world such as North Sea, the Gulf of Mexico and Atlantic coast, Hong Kong, China etc.

Most of the operational models require large computing power. Therefore for routine forecasting of storm surges, especially providing multiple forecast scenarios, the models cannot be used in the absence of access to sufficient computing facility. To overcome this difficulty, most of the forecasting offices use the nomogram methods of JELESNIANSKI (1972) for prediction of storm surges associated with tropical cyclones. The nomograms have been developed from modelling studies of a large number of bathymetries and approach angles.

Advent of powerful personal computers has set up a trend to run storm surge models in real time on PC-based workstations in an operational office. In fact, a PC-based work station (the Automated Tropical Cyclone Forecasting System, ATCF) is already in operation at the Joint Typhoon Warning Centre, Guam for the past many years. The Australian Bureau of Meteorology Research Centre, together with their Bureau Severe Weather Programme Office has also developed an Australian workstation for storm surge forecasting.

Meal Time Storm Surge Prediction System for the Bay of Bengal

In India, Dube et al (1994) described a real time storm surge prediction system for the east coast of India. The forecasting system proposed by the authors is based on the vertically integrated numerical storm surge models that were developed earlier by the group (Johns et al. 1981; 1983; Dube et al. 1985). Surface winds associated with a tropical cyclone are derived from a dynamic storm model (Jelesnianski and Taylor, 1973). The only meteorological inputs required for the model are the positions of the cyclone, pressure drop and radii of maximum winds at any fixed interval of times. The model can be run in a few minutes on a PC in an operational office. The system is operated via a terminal menu and the output consists of the two -dimensional and three-

dimensional views of peak sea surface elevations with the facility of zooming the region of interest. One of the significant features of this storm surge prediction system is its ability to investigate multiple forecast scenarios to be made in real time. This has an advantage because the meteorological input needed for surge prediction can be periodically updated with the inflow of data on fast telecommunication links. The model has extensively been tested with severe cyclonic storms, which struck the east coast of India during the period 1960-1999. Detailed case studies by using this model may be seen in Dube and Gaur (1995). This version of the model was tested in near real time during the cyclone periods of 1992-1993 (Dube and Gaur, 1995).

Validation Experiments

In order to validate the model, using the data of severe cyclonic storms hitting the east coast of India has performed several simulation experiments. An attempt has been made to compare the simulated sea surface elevations with observations from local tide gauges, wherever possible or with post storm survey estimates of India Meteorological Department. The model results reported in the present study are in good agreement with available observations/estimates.

In the present paper we will give the results of the model computed storm surges associated with October 1999 Orissa cyclone.

Real Time Prediction of Storm Surge Associated with 1999 Super Cyclone

A depression formed in the Bay of Bengal near 12° N and 98.5° E at 0600 UTC of 25th October 1999. It became a cyclonic storm in the early hours of 26th and located at 13.5° N and 96.5° E. The cyclone moved further in a northwesterly direction and lay centered at 16° N and 92° E. It became a severe cyclonic storm with a core of hurricane winds on 27th at 0300 UTC. The cyclone further intensified into a very severe cyclonic storm and lay centered at 17.5° N and 89.5° E on 28th. Cyclone crossed the Orissa coast of India close to Paradip between 0430 and 0630 UTC of 29 October. For the track land falling near Paradip the pressure drop is 97 hPa and radius of maximum winds is 40 km. The track of the cyclone is shown in Figure 1.

Forecast experiments were performed for the following scenarios:

Scenario I

In this case the expected landfall is near Puri. The numerical integration is carried out for 36 hours. A maximum surge of 4.6 m is predicted to the north of Konark. The region between Konark and Paradip is affected by a surge of more than 3 m (Fig. 2a).

Scenario II

For this scenario the landfall of the cyclone is now taken as Balasore. The maximum computed surge of 4.2m occurs 30km to the south of Balasore (Fig.2b).

Scenario III

For this experiment the tentative best track of the cyclone is taken from the IMD after the cyclone crossed few km south of Paradip. The model is integrated with 98 hPa and 40 km radius of maximum winds. Fig. 2 (c) shows the model computed peak surge envelope along the Orissa coast. It can be seen that a maximum surge of about 7.8m occurred close to the landfall point (Dube et al. 2000). The coastal region between Konark and Chandbali is affected by a surge of more than 5m. Post-storm survey reports also show that the surge is more than 7m, near Paradip.

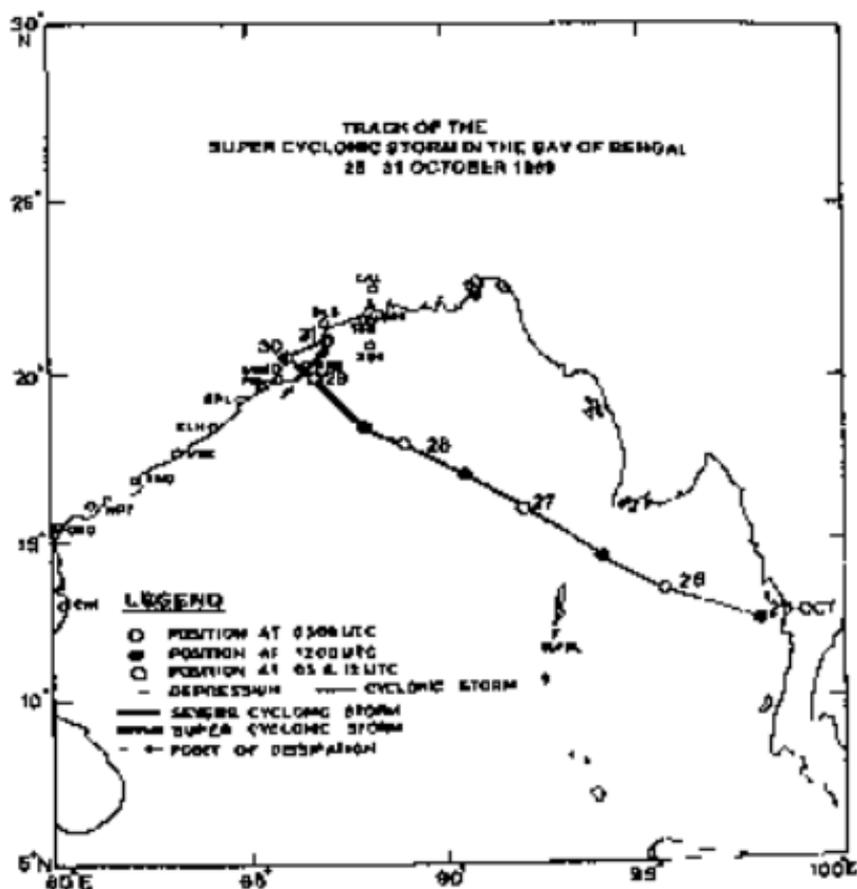


Fig. 1. Track of October 1999 Orissa Cyclone

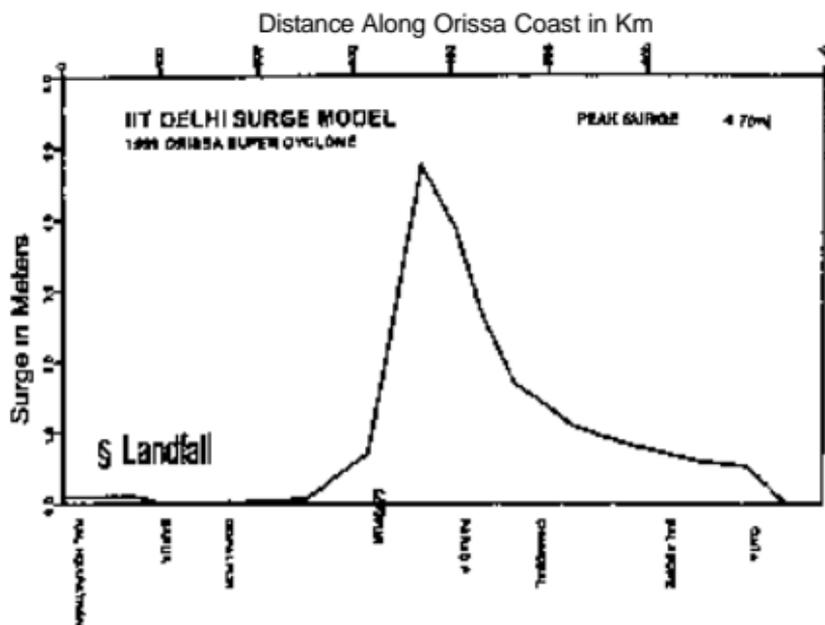


Fig. 2(a) Peak Surge -Scenario I :Landfall at Puri(Dube et al, 2000b).

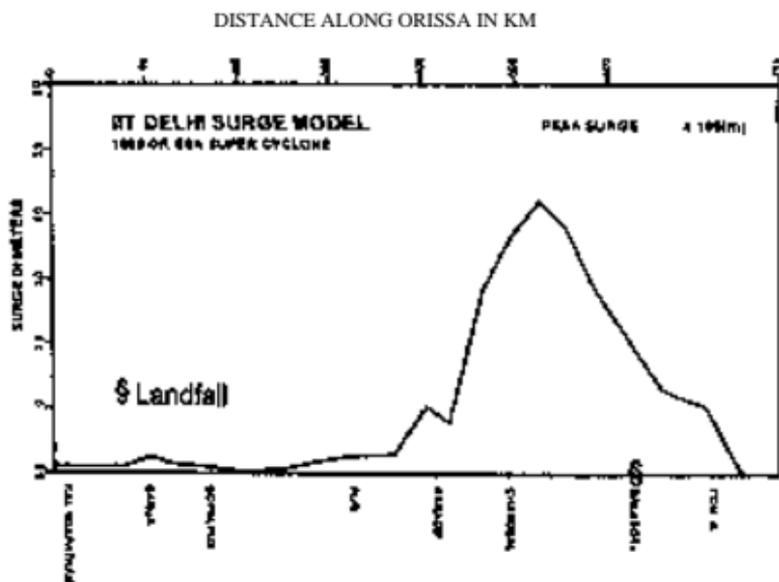


Fig 2(b) Peak surge- Scenario II :Landfall at Balasore (Dube et al, 2000b).

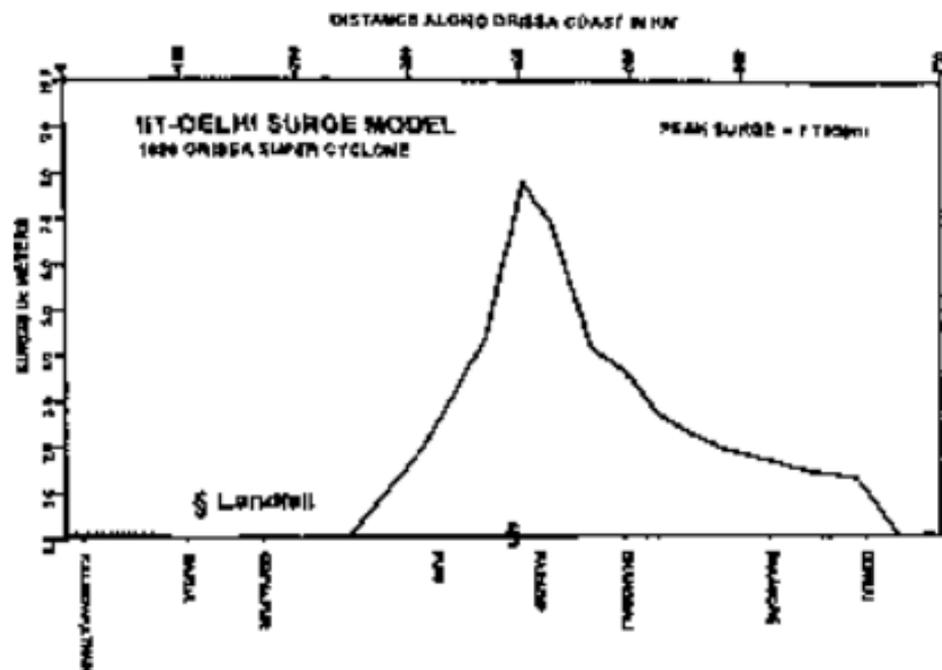


Fig.2(c) Peak surge envelop - Scenario III Actual Landfall at Paradep (Dube et al. 2000b).

Some Future Directions

The damage from cyclones is mainly due to two factors. About 90% of the damage is due to inundation of land by sea water and also flooding of the river deltas from the combined effects of tides and surges from the sea penetrating into the rivers, while at the same time excess water in the rivers due to heavy rains from the cyclone is trying to flow through the rivers into the sea. The balance 10% of the damage is from the very strong winds from the moving cyclones. At this time, science is not capable of controlling cyclones but is capable of eliminating practically 90% of the damage and the loss of life. The only recourse to minimizing the damage from the strong winds is to design buildings with stronger roofs, and wind - proofing electric power poles, etc. Still one has to expect damage to trees.

This general pattern of damage worldwide appears to apply for the recent event in Orissa as well. The cyclone of October 25 - 29, 1999 made landfall near Paradip in Orissa and the peak TWLE was about 12 meters.

It should also be noted that almost all the loss of life is due to inundation and flooding. Thus there is need for a plan, which should practically eliminate 90% of the damage but also eliminate almost all the loss of life as well. Following are some of the recommendations in this regard:

Use extremely sophisticated state of the art computer models to calculate maximum possible storm surge and maximum possible total water level envelope (MPTWLE) for the Orissa coast, under a variety of scenarios

Through very detailed soil surveys one can determine for each segment of the Orissa coastline which of the following protection measure is most appropriate

- | | |
|--------------------------|--|
| (a) Earth dykes | (d) Breakwaters |
| (b) Sea walls (concrete) | (e) Storm surge buffer zones (vegetation reed grass) |
| (c) Mangrove forests | (f) Sand dunes |

Sometimes a combination of two or three of the above may be more appropriate

To mitigate the damage from the overflow and flooding from rivers a combination of the following schemes, should be considered

- (a) Storm surge barriers to prevent the surge from the ocean to penetrate into the rivers
- (b) A system of dry canals for each river and estuary During a flooding event, excess water can be diverted into these

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Cyclone Tauktae that was the first Extremely Severe Cyclonic Storm in the Arabian Sea to make landfall in Gujarat in 130 years brought significant rains, as well caused considerable infrastructural damage, in Gujarat and several coastal states. The current cyclone, were it to fully form, will be called Yaas and is a name proposed by Oman. Last May, the cyclone Amphan that formed in the Bay of Bengal ravaged West Bengal as a 'Super Cyclonic storm', the most powerful in the IMD's intensity measuring scale. This year the IMD has forecast a 'normal monsoon.' Subscribe to Morning Filter & Evening Wrap newsletter. Submit. Storm surge of about 4 to 5 m (13 - 16 feet) above Astronomical Tide is likely to inundate low lying areas of south and north 24 Parganas and about 3 to 4 m (10 - 13 feet) over the low lying areas of East Medinipur District of West Bengal during the time of landfall. Tropical Cyclone "Amphan" at 04:06 UTC on May 20, 2020. Credit: Copernicus EU/Sentinel-3, Antonio Vecoli. Tropical Cyclone "Amphan" at 04:06 UTC on May 20, 2020. Credit: Copernicus EU/Sentinel-3, Antonio Vecoli. Tropical Cyclone "Amphan" on May 20, 2020. Credit: NASA Aqua/MODIS. Storm surges in the Arabian Sea: Although the frequency of storm surges is less in the Arabian Sea than in the Bay of Bengal, major destructive surges can occur occasionally along the Gujarat coast of India and Pakistan. Historic records show that surges are frequent in the Gujarat coast where astronomical tides are quite high and surge heights reach up to 2-3 m. The Saurashtra-Kutch coast too is vulnerable to storm surges, reaching 3 m in height. Very few storm surges are reported around Mumbai or Honavar. The Kerala and Goa coasts are almost free from storm surges. Surge prediction data and forecasting. The formable cyclone in the Bay of Bengal was approaching the country as recovery efforts continue after western parts of India were ravaged by Cyclone Tauktae, one of the strongest storms on record for the Arabian Sea, last week. The COVID-19 death toll in India surged past the 300,000 mark on Monday, making the country just the third in the world to reach the grim milestone. Only the United States and Brazil have recorded more fatalities throughout the duration of the pandemic. According to Reuters, 100,000 of those fatalities have occurred over the last three weeks amid a hard-hitting second wave.