Influence of coast line on upper ocean’s response to the tropical cyclone

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[1] A 3-dimensional Princeton Ocean Model has been configured for the east coast of India, which is applied to study the transformation of the upper ocean’s response in the near-coastal waters to the 1999 Orissa super cyclone in the Bay of Bengal at the time of landfall. It is well known that the sea surface temperature (SST) cooling is more towards the right of the storm track, because of the dominant wind stress forcing there. Consequently, the model simulated SSTs showed more cooling to the right of the storm track. However, it is found to be true only in the open ocean. The coastal dynamics transformed the scenario as the cyclone translated over the coastal waters owing to the impedance of the coast-line to the circulation and shifted the region of maximum surface cooling to the left of the cyclone track. The satellite imageries during the period also endorsed the model simulations. Citation: Mahapatra, D. K., A. D. Rao, S. V. Babu, and C. Srinivas (2007), Influence of coast line on upper ocean’s response to the tropical cyclone, Geophys. Res. Lett., 34, L17603, doi:10.1029/2007GL030410.

1. Introduction

[2] The Sea Surface Temperature (SST) is known to be a very crucial parameter in the genesis and intensification of the tropical cyclone. The ocean and the cyclone mutually respond to each other. During the genesis, the ocean supplies energy to tropical cyclones, causing the storm to intensify as long as it remains over warm enough sea water. The central low pressure and the strong winds due to the cyclone produce intense mixing and divergent flows in the upper layers of the ocean, forcing in the redistribution of waters through entrainment and upwelling, resulting in a cooling of surface layer. The cooling of the sea surface near the core of the storm results in the reduction in the total heat flux and energy production into the atmosphere, tending to dampen the storm intensity. Thus, the cyclone induced sea-surface temperature drop leads to a negative feedback, because the SST is a limiting factor for the attainable strength of a cyclone. The SST anomalies forced by the tropical cyclone have been observed to vary from 1 to 6°C [Black, 1983; Sadhuram, 2004]. The SST cooling also depends upon the translation speed of the cyclone. The observations on the tropical cyclones, grouped as “slow, medium and fast” moving result in a surface cooling of “high, medium and low” respectively [Bender et al., 1993].

[3] The occurrence of tropical cyclones is a regular feature in May (pre-monsoon) and October (post-monsoon) over the Bay of Bengal. The passage of a moving tropical storm with strong localized surface wind stress is an epitome of strong interaction between the atmosphere and the ocean. The typical time-scale for the forced stage response is of the order of half a day. The energy of the mixed layer currents is dispersed in the spreading wake of internal waves [Geisler, 1970; Gill, 1984] that penetrate into the thermocline [Shay and Elsberry, 1987] leaving behind a baroclinic geostrophic current along the storm track.

[4] The super cyclone during 25–31 October 1999 became the most intense and the deadliest cyclone in the last hundred years for the state of Orissa. It started as a disturbance and by 26 October, it assumed the dimension of a cyclone. The system had been moving northwesterly and by 27 October, it got intensified to a severe cyclonic storm. It was further upgraded to the stage of very severe cyclonic storm by late 27 October and moved in a west northwesterly direction. It attained peak intensity just before landfall, close to and south of Paradip on 29 October. The minimum central pressure at landfall was estimated to be 912 hPa with sustained winds peaking to an estimated 260 kmph at the time of crossing the coast. It practically remained stationary over the same area for more than 24 hours and weakened later [Bhatia et al., 2000]. The cyclone generated high storm surge along a long stretch (100–150 km) of the coastline (maximum of over 6 m) north of the landfall point [Simon et al., 2001].

[5] Oceanic processes associated with tropical storms are as important as intensity, track prediction and the associated rain fall, for, everything associated with the tropical cyclone heavily relies on the underlying ocean state. With the advancement in observation technology, especially weather satellites and buoys, there is considerable improvement in the quantum and quality of data in general and around a tropical system such as cyclones/depressions. Contrary to the consensus conviction, the Tropical Rainfall Measuring Mission Microwave Imager (TMI) satellite imagery from http://www.remss.com/tmi during the 1999 Orissa super cyclone depicted sea surface cooling to the left instead of right of the cyclone track over the coastal waters.

2. Model

[6] To elucidate and investigate the above feature, a three-dimensional Princeton Ocean Model as described in detail by Blumberg and Meller [1987] and Meller [1992] has been configured for the east coast of India. It is a free surface ocean model with a turbulence closure scheme of Meller and Yamada [1982]. The momentum equations are nonlinear and incorporate β-plane approximation. The model uses an orthogonal curvilinear grid and a terrain following sigma coordinates in the vertical. The boundary conditions in the vertical are no-slip condition at the bottom and no through flow at the surface, i.e., ω = 0, (ω is the
vertical velocity component normal to the sigma surfaces) for the continuity equation. For the momentum equations, the boundary conditions are suitably specified using the surface and bottom turbulence momentum fluxes. The boundary conditions for velocities include radiation conditions at the lateral open boundaries. The details of the model set up and the methodology is given by Babu et al. [2007]. The input fields are the climatological monthly data of temperature and salinity as initial density for the concerned month of October, derived from Levitus94. The model is forced with wind stress forcing, derived from NCEP/QSCAT winds. A suitable amplification factor is used to overcome the scatterometer limitations for maximum winds and assume the maximum wind speed occurred during the cyclone period, as reported by India Meteorological Department and Unisys Weather Hurricane/Tropical data (http://weather.unisys.com/hurricane/indian Oc/1999/index.html). The model is utilized to investigate the thermal response of the ocean during the cyclone period. The cyclone moved very fast over the ocean and slowed down and became a super cyclone just prior to the landfall. The model simulated SST is in qualitative agreement with the available 3-day mean TMI satellite imagery.

3. Results and Discussion

Owing to the extreme barometric pressure drop of about 90 hPa at the centre, intense wind stress forcing and cyclonic winds, the tropical cyclone is expected to produce sea surface cooling along its track. Further, it is the consensus opinion of many workers that the SST cooling is more towards the right of the storm track, because of the dominant wind stress forcing there. The model simulated SSTs also show the same feature of more SST cooling to the right of the storm track. However, it’s found to be true only in the open ocean, for, the scenario gets transformed as the cyclone translates over the coastal waters, particularly when the bathymetry is shallow.

The results from the model simulations and the 3-day mean TMI satellite imageries are presented in Figure 1. In Figures 1a and 1c the model simulated sea surface temperature (contours) and sea surface current (vectors) are shown for Day 3 and Day 4.5 corresponding to 28 October 1999 0600 hrs and 29 October 1999 1200 hrs IST respectively. The colour code in Figure 1 clearly indicates that the temperature drop in Day 3 for about 3.5°C to the right of the cyclone and for Day 4.5 about 3.0°C but to the left of the cyclone. The TMI SSTs are shown in Figure 1 (b) and (d) for day ending 28.10.1999 and 29.10.1999 respectively. The SST cooling is less than that depicted by the TMI imagery. This is because; apart from the magnitude, the NCEP winds do not show the true cyclonic feature. The surface current is also shown to be increased about four times compared to Day 1 (not shown) near to the coast as the cyclone advanced for the land fall. A plausible
explanation as why the maximum cooling is to the left of the storm track is given below.

As a tropical cyclone approaches the east coast, the winds along the front edge of the hurricane are northerly and hence, the net Ekman transport of water would be towards the coast. However, as the cyclone approaches the coast further, on-shore transport continues to its right, while to the left, off-shore transport develops. The off-shore transport and upwelling favorable winds to the left of the cyclone causes more SST cooling to the left. Thus, serving as an obstacle to Ekman transport, causing piling up of waters, the coast is responsible for the transformation of the region of maximum sea surface cooling from right to left during the time of landfall. This is also supported by the well established opinion that the piling up of waters due to the on-shore transport that gets manifested as storm surge is more to the right of the landfall. However, due to the paucity of observations around the cyclone in general and the limitations of the in-situ data, in it’s not being able to offer an over all impression over a region of concern, this attribute of the coast influencing the upper layer thermal structure in a limited region has not been focused so far. However, with the advent of the satellites information and the TMI imageries, we can have a bird’s eye view that clearly shows that the sea surface cooling is more to the left than to the right in the near coastal region.

4. Conclusion

The life cycle of a tropical cyclone, viz., the genesis, deepening, maturity and decay is heavily dependent on the underlying sea surface temperature and the ocean state. Although there are limitations in our simulations for instance, using the climatological inputs for temperature and salinity (or density fields) and using amplification factors for bringing the QSCAT/NCEP wind close to maximum cyclonic wind but the result confirms our speculation that the maximum cooling occurs to the left of the storm track particularly when the cyclone is translating over the coastal waters in contrast to the common beliefs that the maximum cooling always occurs to the right of the cyclone. The model simulated results confirms qualitatively to the 3 Day mean TMI satellite imagery and hence, the upper layer oceanic response to the passage of Orissa super cyclone is well simulated by numerical modelling.

References


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