FORMATION OF HIGH AMPLITUDE COASTAL WAVES IN THE BAY OF BENGAL (EAST COAST OF INDIA) DUE TO CLIMATE CHANGE

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Abstract: This study emphasize on the genesis of high amplitude wave over the Northern Indian Ocean region near East coast of India (Bay of Bengal) Odisha and Andhra Pradesh state. The issue of unwelcome high amplitude coastal waves and its devastating nature in context to climate change. These waves are formed due to the change in water circulation pattern and storm surges over the Bay of Bengal. During September to November the littoral current is more pronounced and it diverges towards the near shore region and forming counterclockwise eddies with high surge. And sallow depth. These waves are more intensifies and destructive in nature if depression activities takes place in Bay of Bengal. From the last 30 years of tropical depression data studies indicates that the depression/cyclone genesis ground has been displaced towards the Odisha coast of India. These waves are more devastating in nature and it effects the coastal environment and changes the shore line. This paper discusses the genesis of high amplitude wave, using Oceanographic and Atmospheric variables such as Sea surface Height, Geostrophic current, Tropical depression and Wind Speed. Also explains the displacement of Cyclogenesis ground over the Bay of Bengal which triggers the high amplitude coastal waves from the last 30 years of the study.

INTRODUCTION

The High amplitude coastal waves were observed in the Northern Indian Ocean region near East coast of India (Bay of Bengal) i.e. Odisha and Andhra Pradesh coastal states. These types of waves are generally coastal based and regionally originated waves. Coastal waves are natural phenomena and have a significant impact on the coastline. These coastal high amplitude waves are in destructive in nature. The destructive wave spreads over multiple areas and different sections of coastline receive different amounts of surges in the form of heavy wave and causes erosion by removing sand and sediment from beaches (Figure1). Of late, the coastal erosion is triggered more along the

Figure1: Erosion at Puri in between Lighthouse & Sterling Hotel beaches (Odisha, India)

Odisha coast due to storm surges and even without storm surges. The 1930 land record shows an area of 320 sq km for the Satabhaya cluster of seven village near Paradip in Odisha. In the recent land records (Mahapatra, 2008) of 2000 indicate that this area has been reduced to 155 sq.km. Five of the seven villages have been swallowed by the sea. This has been caused due to the intrusion of the sea inland by about 2.5 km. constantly pushed back by the sea, the local residents find themselves in a unique situation. Technically they are encroachers as their legal documents show their lands are somewhere inside the sea. The state government is aware of the situation of these coastal villages. A proposal for the rehabilitation package for Satabhaya, Kanhapur and other nearby villages started long back in 1980's. A high-level state committee has suggested to carry out a scientific study (Mahapatra, 2006). A fishermen village on the southern region of State Odisha coast at Gopalpur in Ganjam district is completely submerged in the sea due to the sea wave and erosion (Pati, 2009). In my study I have discussed about the formation of high amplitude coastal wave and its genesis near the coastal region of East coast of India. Ocean waves usually have a spectrum of waves that depends on the variations in the wind speed and direction (Hasselmann *et.al.*., 1976 &1980). The unusual coastal waves and its hazardous impact over the coastal region cause damage to the socio-economy status of the country. Generally this kind of oceanic wave affects a few region of the northern Indian continent. This type of waves has been noticed along Andhra Pradesh and Odisha coasts for the last two decades. These two coastal states of eastern Indian continental region are being considered as non-depositional areas based on the occurrence of relict sediments and morphological features on the sea bed (Subba Rao,1964., Rao *et.al.*., 1980., Mohana *et.al.*.,1989., Murthy *et.al.*.,1987., Murthy,1989., Mohapatra *et.al.*, 1992., Mohana and Rao,1994). Morphological features such as reefs terraces, karstic structure over the outer shelf of the East coast of India and related them to eustatic sea-level changes (Rao *et.al.*., 1980). The two linear trends of Holocene mounds at 60-70m depth over the Visakhapatnam shelf (Murthy *et.al.*., 1987) while inferred Holocene transgression based on the sediment grain size parameters (Murthy, 1989). Demarcation of late Pleistocene regression level around 130 m water depth and different Sea-level strandlines during Holocene transgression based on the shallow seismic reflection data and radio carbon dates of the algal limestone (Mohana and Rao,1994). Similar studies (Mohapatra *et. al.*, 1992) and reported still stand zones over the eastern continental shelf of India. Afterwards studied in detail (Vivier, *et.al.*, 1999 and Politi,*et.al.*, 2000) the annual SSH signals into those associated with the steric height, baroclinic Rossby waves, time-varying topographic Sverdrup balance, and Ekman pumping response. While most of the above mentioned studies have focused on basin-scale features, some did mention regional phenomena. Important atmospheric and oceanic variables linked to formation of High amplitude coastal waves such as Wind velocity, eddies, Geostophic Current, Storm surges, etc. These physical factors are being influenced directly or indirectly by the different oceanic events and form the giant High amplitude wave. These waves are more pronounced in between September to November.

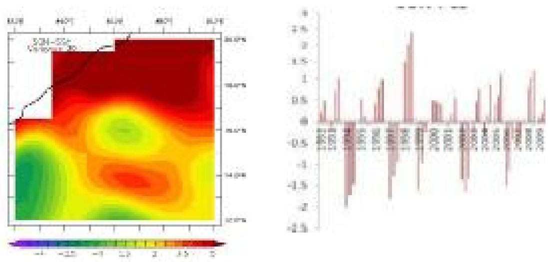
DATA AND METHOD

The variation of sea surface height in Bay of Bengal has been studied for the period of eighteen years from 1992 to 2009. The anomaly of Sea Surface Height (SSH), Wind speed(WS), Sea Surface Temperature(SST), Geostrophic current used for the study. Geostrophic current retrieved from SSH for the same period have been used for the study. Using EOF method, the most efficient decomposition of the data into representative modes is determined by empirically finding the eigenfunctions that best describe the information. It can be proved that the EOF method describes the data in the most compact form. This has been described below. The EOF eigenmodes can be ordered in terms of the percentage of the total variance to be described by each mode and, in addition, the modes are statistically uncorrelated with one another (Sirovich,1987). The method is useful in this regard for two reasons. First, retention of the only the first few modes may contain a significant portion of the total variance, leading to potentially significant storage savings if not all the variance is required. Additionally, each mode contains phenomena having differing spatial and temporal scales and thus can be isolated. They can then be associated with physical processes taking place. The method (also called principal component analysis or Karhunen–Loeve analysis) is empirical because the data are used to find their own optimum decomposition with no a priori assumptions on either spatial or temporal behavior. This optimization is found by formulating an eigenvalue problem involving the two-point spatial covariance matrix. In these studies monthly SSH data from AVISO, daily SST data from NOAA-OISST is used and converted into monthly, NCEP-Reanalysis wind data is used for the study. Simultaneously weekly SSH data is used for getting the geostrophic current. To study the formation of high amplitude coastal waves was studied only three months data from September to November of all the years.

RESULTS AND DISCUSSION

In general the high amplitude coastal waves are observing near Odisha and Andhra Pradesh coast during September to November (SON). These waves are more devastating in nature and actively associated with coastal erosion shown in figure1. In my studies I have focused on the ocean and atmospheric dynamics during the SON month. The EOF mode-1 and mode-2 of SSH explains about 30% and 21% of the variance during SON and is more dominant towards the northern region of the studied area which is shown in the corresponding Principal components (PC-1 and PC-2) (Figure: 2&3). The 3rd EOF mode explains 9% of the variance during the same period and the negative

SSH MODE-1 **SON PC-1**



SSH MODE-2 **SON PC-2**

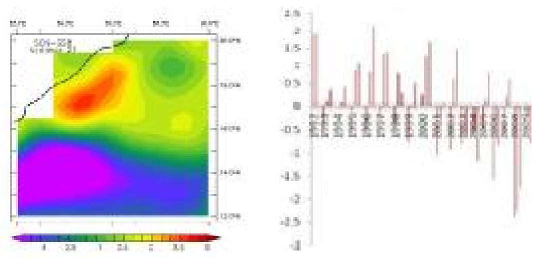


Figure2: EOF mode-1 of SSH (cm) corresponding to PC-1

Figure3: EOF mode-2 of SSH (cm) corresponding to PC-2

SSH MODE-3 **SON PC-3**

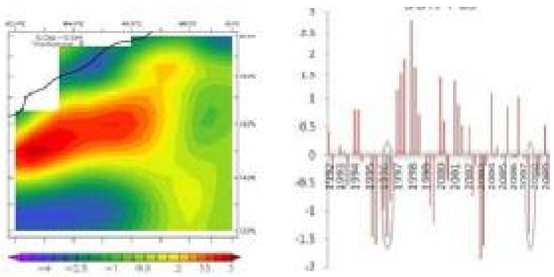
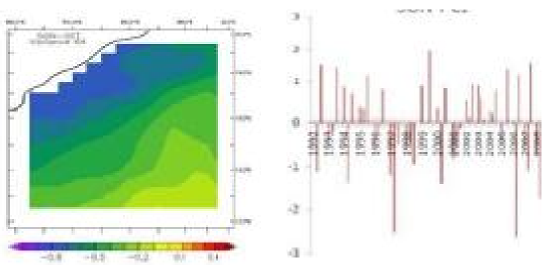


Figure4: EOF mode-3 of SSH (cm) corresponding to PC-3

anomaly of SSH peaks are more dominated towards the coastal region which is shown in PC-3 (Figure4). As per the existed case study report during 2007 a high amplitude wave was noticed near the Odisha coast and other years such as 1995, 1996 and 1999 from the local community information the major high amplitude waves were found near the coastal regions of the Odisha. In my study I have found negative anomaly of SSH for the above said years over the same region in PC-3. For the detailed study I did the analysis of SST, Wind Speed and Geostrophic Current. The EOF analysis of SST shows 64% of the variance in mode-1 and the negative anomaly of the SST is showing towards the coastal region. The negative anomaly of SST may be associated with major climatic events such as Indian Ocean dipole, ENSO etc. which is more dominated and found in the corresponding PC-1 (Figure5).

SST MODE-1 **SON PC-1**



SST MODE-2 **SON PC-2**

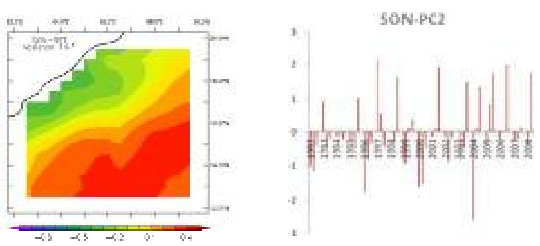


Figure5: EOF mode-1 of SST (°C) corresponding to PC-1

Figure6: EOF mode-2 of SST (°C) corresponding to PC-2

The second EOF mode shows a variance of 14.1% and negative SST anomaly is dominated over the coastal region. As per our case studies the negative anomaly of SST is showing for the same period and is showing in corresponding PC-2(Figure6). The EOF of wind speed for the period of SON shows a negative anomaly over the offshore region with variance 74.9% and the second EOF mode shows a negative anomaly over the offshore/ southern part of the studied area with variance 9.5% which shows in the corresponding PC-2 (Figure 7&8).

WC MODE-1 **SON PC-1**

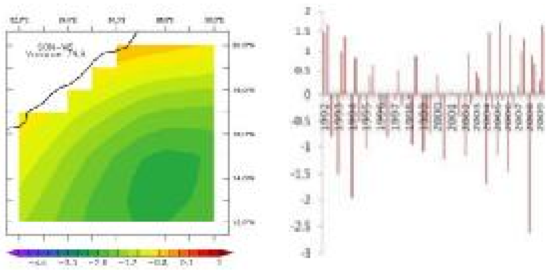


Figure7: EOF mode-1 of WS(m/s) corresponding to PC-1

WC MODE-2 **SON PC-2**

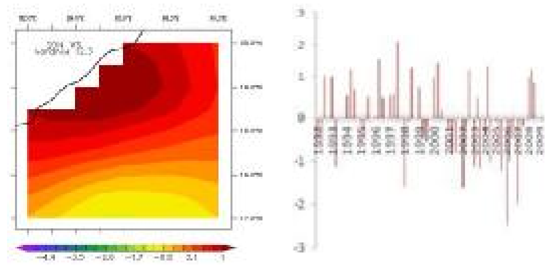


Figure8: EOF mode-2 of WS(m/s) corresponding to PC-2

Geostrophic current over the studied area indicates a circular pattern towards the coastal region (Figure9). This circulation pattern is counter clock wise and is a cold core eddies from the SST study. The localized eddies are generating due to the littoral current moving parallel to the coast which diverges from its original path and forming a circular pattern towards the coast. It has been noticed that a strong negative correlation is found between SSH and second EOF mode of Wind Speed (Figure10a) parallel to coast. It represents the wind action triggers the localized coastal eddies. In the second correlation between SSH and third EOF mode of SST (Figure10b) showing quite

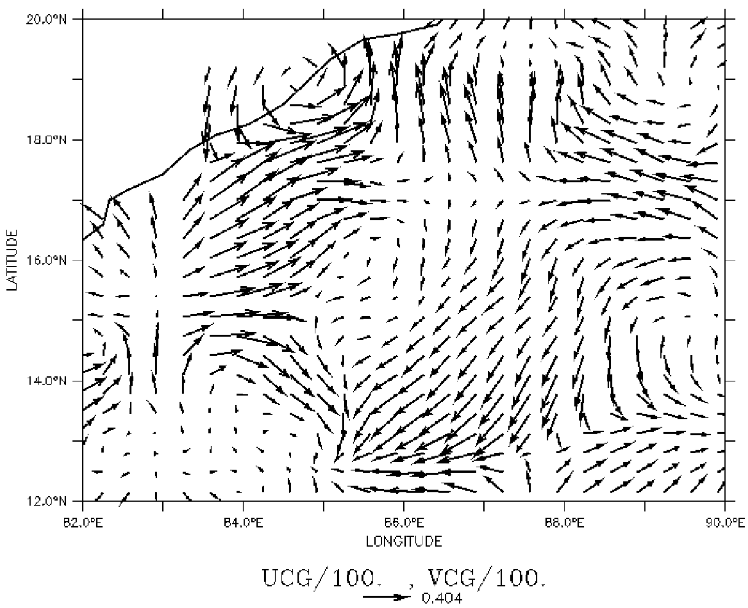


Figure9: Geostrophic current on October 2007

positive correlation nearer to the coast and is the indication counterclockwise eddies nearer to the coast. These eddies have surges to destroy the coastal region. From the special plots of the cyclogenesis ground it is positive

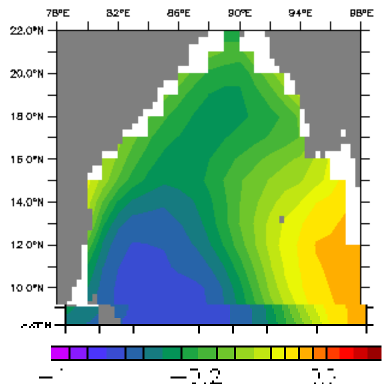


Figure10.(a): Correlation coefficient between WS and EOF mode-2of the SSH

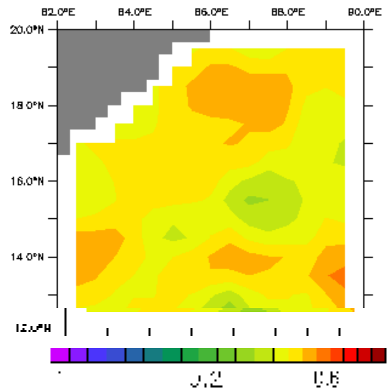


Figure10.(b): Correlation coefficient between SST and EOF mode-3of the SSH

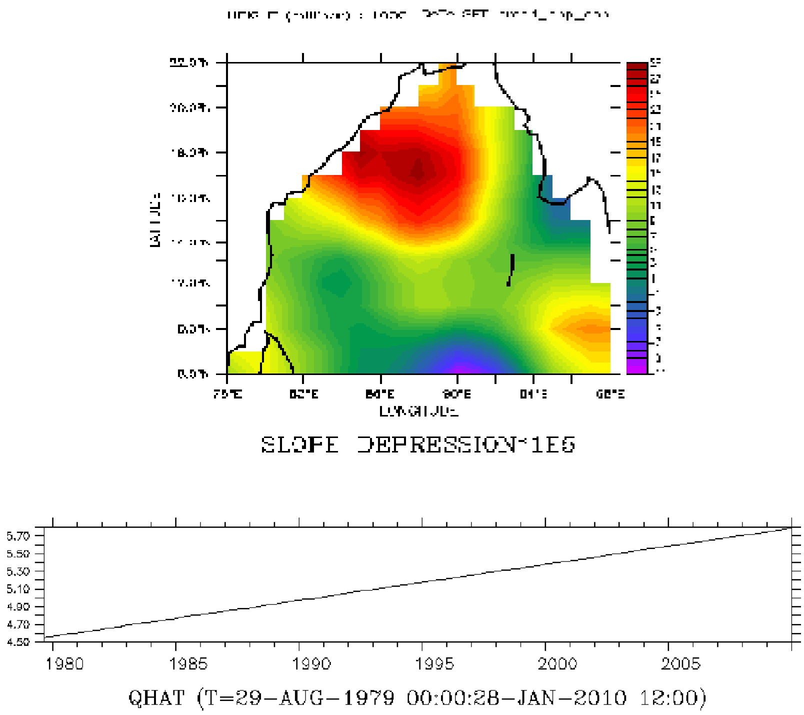


Figure11: Special plot for the Cyclogenesis ground during SON from 1979 to 2009 and trend plot.

towards the northern Odisha coast (Fig: 11). In the Bay of Bengal maximum Cyclogenesis period is between September to November which may be helpful for the littoral current to generate the cold core eddies.

CONCLUSION

The coastal high amplitude waves are most devastating in nature and it changes the shore line due to high insurgence and changes the shore line. The Northern part of Odisha coast has been swallowed around 2.5km landward and a fishermen village of Southern region of same state. These coastal waves are generates due to the formation of counterclockwise eddies which is noticed in Geostrophic current. In the SSH it is observed that negative anomaly over the near-shore region and correlation study between SSH and SST shows quite positive over the same region which indicates cold core eddies. This high insurgence coastal wave is found few years interval near Odisha coast and is more intensifies during cyclonic condition over the Bay of Bengal.

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REFERENCES:

Mahapatra, R., 2008. Climate change Stabhaya village in Orissa goes under, **Infochange News & Features** http://infochangeindia.org/200804287087/Environment/Features/Climate-change-Stabhaya-village-in-Orissa-goes-under.html

Mahapatra, R., 2006. Falling off the map Orissa submerged villages, **Infochange News & Features** http://infochangeindia.org/200605025762/Environment/Features/Falling-off-the-map-Orissa-s-submerged-villges.html

Pati, B.B., 2009. Orissa Paradeep port town the next Victim of Coastal Erosion, **Hotnhitnews** http://hotnhitnews.com/Orissa_Paradeep_port_town_the_next_Victim_of_Coastal_Erosion_906_90043.html

Hasselmann, K., Ross,D.B., Miller, P. and Sell, W., 1976. A parametric wave prediction model, **Jour. Phys. Oceanogr.**, **6**: 200-228.

Hasselmann, D. E., Dunckel, M. and Ewing, J.A., 1980. Directional Wave Spectra Observed during JONSWAP 1973, **J. Phys. Oceanogr. 10**, 1264

Subba Rao, M., 1964. Some aspects of continental shelf sediments of east coast of India, **Mar. GFeol.**, **V.1**, pp.59-87.

Rao , A.T., Acharyulu,K.V.S. and Rao, K.S, 1980. Aplite vein from charnockite pegmatite of Visakhapatnam, Andhra Pradesh. **J. Geol. Soc. India**, **21**, 204-205.

Mohana Rao, K., Rajmanickam, G.V. and Rao, T.C.S., 1989. Holocene marine transgression as interpreted from bathymetry and grain size parameters off Gopalpur, **Proc Ind. Aca.Sci.**,**V98**,pp173-181.

Murthy, K.S.R., Eao, T.C.S. and Sarma, K.V.L.N.S., 1987. Subbottom profiling over the innershelf off Visakhapatnam, east coast of India. **Ind.Jour.Ear.Sci.**,**V14(2)**, pp.110-113.

Murthy, k.S.R., 1989. Seismic stratigraphy of the ongole-Paradeep continental shelf east coast of India. **Ind. Jour. Ear. Sci., V.16**, pp.47-58.

Mohapatra, G.P., Rao, B.R. and Biswa, N.R., 1992. Morphology and surface sediments of the eastern continental shelf off PeninsularIndia. **G.S.I.Sp. Pub.No.29**,pp.229-243.

Mohana Rao, K and Rao, T.C.S., 1994. Holocene sea-levels of Visakhapatnam self, east coast of India. **Jour. Geol. Soc. Ind.**, **V44**, pp.685-689.

Vivier, F., K. A. Kelly, and L. Thompson, 1999. Contributions of wind forcing, waves, and surface heating to sea surface height observations in the Pacific Ocean, **J. Geophys. Res.**, **104(C9), 20**,767–20,788.

Polito, P. S., O. T. Sato, and W. T. Liu, 2000. Characterization and validation of the heat storage variability from TOPEX/Poseidon at four oceanographic sites, J. Geophys. Res., **105(C7), 16**,911 – 16,922.

Sirovich, L., 1987: Turbulence and the dynamics of coherent structures. Part I: Coherent structures. **Quart. Appl. Math.**, **45**, 561– 571.