



PREFACE

It is our pleasure to present to you the APEC Climate Center (APCC)'s Technical Report 2012, which reports the core outcomes of our research activities from the past year.

Since 2005, APCC, as a hub of climate information in the Asia-Pacific region, has strived to share our analysis and prediction of abnormal climate and to apply this information to regional development. The Center has established the most extensive Multi-Model Ensemble (MME) system for seasonal prediction in the world through its international science network and has provided value-added products to various stakeholders. Recently, APCC has expanded its mandate to include enhancing the capacity of APEC member economies to respond effectively to climate change and variability through better application of climate information.

In 2012, APCC continued to make an effort to improve the quality and quantity of our short-term climate forecasts and our online climate information systems, as information dissemination tools. Additionally, APCC began its endeavor to produce more applicable climate information through interdisciplinary research among various sectors, such as agriculture and hydrology. The following technical report provides more information about our research outcomes from 2012.

In 2013, following APCC's goal to enhance socioeconomic well-being through better utilization of climate information, APCC will continue to improve the quality and accuracy of its climate information, recognizing that the utility of this information is only as good as its quality. We would like to make the best use of our research outcomes in various scientific and application areas. We welcome any feedback on this report or on our services.

My best and warmest regards to all of you.

Dr. Chin-Seung Chung
Director/APEC Climate Center

CONTENTS

Analysis of Climatic Trends over South Asia

■ Dr. Sobhan Kumar Sahu

ResearchWork 1 Temporal Analysis of Marine Fisheries in Response to Climate Variation : A Case Study from Bangladesh

1. INTRODUCTION	32
2. Data and Methodology	34
3. Results and Discussion	35
3.1 Trends in Marine Fisheries related to Chl- <i>a</i> distribution in the region	35
3.2 Comparing the chlorophyll distribution with SST and SSH	37
4. Conclusion	39

ResearchWork 2 Formation of High Amplitude Coastal Waves in the Bay of Bengal (East Coast of India) and their Relationship to Climate Change

1. INTRODUCTION	48
2. DATA AND METHOD	51
3. RESULTS AND DISCUSSION	52
4. CONCLUSION	56
5. Acknowledgements	56

ResearchWork 3 Recent Trends of the Bay of Bengal (BOB) Tropical Depression and its Impact on Precipitation over the Region of India

1. Introduction	58
2. Data and Methodology	59
3. Results and Discussion	60
4. Conclusion	68

Analysis of Climatic Trends over South Asia

Dr. Sobhan Kumar Sahu

ResearchWork 1

Temporal Analysis of Marine Fisheries in Response to Climate Variation: A Case Study from Bangladesh

ABSTRACT

Both inland and marine fisheries are of key importance in Bangladesh in terms of provision of food security, livelihoods and national economy. Although it is an accepted fact that climate dynamics impact on marine fisheries, it is challenging to establish clear seasonal and annual trends. However, progression is being made because of the inter-disciplinary application of climate information. The present study describes the correlation between climatic variability and marine fish productivity for three different time periods: December to February; March to May and September to November in the years 1998-2009. The study integrates data from climatology, oceanography and the diversity of fish species in a catch, and is focused on the northern Bay of Bengal region; the marine territorial range of Bangladesh. Observed changes in the fisheries are closely related to observed changes in the oceanic climate. During the twelve year period, the close link between fish productivity, (expressed as fish catch per trawler) is best explained by the effect of the chlorophyll (Chl-*a*) gradient in a space-time continuum. Marine fish productivity fluctuates from about 20% to 17.5% of total fish production, and correlates significantly with the spatial distribution of Chl-*a* in the region. Chl-*a* concentration showed a marked decline of 0.055 mg/m³ between 1998 and 2009 during September-November [SON], compared to a decline of the order 0.012 mg/m³ during December-February [DJF] and of 0.033 mg/m³ during March to May [MAM] during the same temporal period. A decline in Chl-*a* is explained by an increasing sea surface temperature [SST] trend. It may possibly be concluded that, SST values show a positive trend of 0.07°C in DJF and SON. This analysis reflects a close correlation between increasing SST and an increasing trend in Sea Surface Height (SSH) in all the three seasons. The inverse trend of SST and SSH during MAM is explained on the basis of the local oceanic circulatory processes and currents, along with the influence of prominent land-sea-atmospheric phenomena, such as runoff and eddies. The study draws attention to the application of time series climate observations derived using evolving satellite remote sensing technology, in conjunction with ground-based observations, in order to understand the marine ecosystem complexity. It can be further concluded that the addressing of climate related concerns demands a collaborative inter-disciplinary effort between multiple sectors for the facilitation of decision making for the benefit of society.



1. INTRODUCTION

Bangladesh is a predominantly agricultural nation. Fisheries are the most important agriculture sub-sector and a significant driver of the Bangladesh economy; contributing an average of 5% of the country's annual GDP (Mome 2007). In recent years, worldwide fisheries have been troubled by a stagnation, and in places the collapse, of commercial fish stocks, due to a combination of regime shifts, climatic events, coastal degradation and mismanaged anthropogenic impacts (FAO 1994). Fisheries are an important source of revenue for livelihoods, and provide nutritional security. Reduction in the productivity of marine fish stocks, due to changing climate conditions, calls for an in-depth scientific understanding of climate-land-human interactions (Alam and Thomson 2001). Overland *et al.* (2010) studied the impact of climate variability and induced stress on natural ecosystems; underlining the importance of characterizing the spatial and temporal variability in the biophysical climatology of ocean ecosystems matched with their biological response, especially in the context of marine fisheries. Research into the seasonal dynamics of the Bay of Bengal using a mix of satellite derived images, onboard data collection, modeling and simulation techniques, has revealed the influence of oceanic hydrographic phenomena (such as upwelling, sea level anomalies and winds) and their coupling with biomass production (Shankar and Shetye 2001; Prasanna Kumar *et al.* 2002, 2004; Vinayachandran and Mathew 2003; Vinayachandran *et al.* 2005). Silas *et al.* (1985) and Choudhury *et al.* (2002) have, among other researchers, attempted to link satellite-derived ocean information to the study of trends in fisheries. However, there have been few attempts to map the long-term seasonal and temporal correlations with multiple climate variables.

Fresh water influx and its impact on the hydrography, thermodynamics and biological productivity of the coastal waters of the Bay of Bengal is illustrated by Gomes *et al.* (2000). Inter-annual variability in the primary productivity of the Bay of Bengal is mainly attributed to the influence of the monsoon; a fresh water input from major rivers such as the Ganges and Brahmaputra in addition to physical

circulations within the oceanic environment such as currents, gyres and eddies (Shetye *et al.* 1991, 1993). In addition to the impact of local oceanic phenomenon, such as Ekman pumping (wind driven mixing), eddies and the East India Coastal current (EICC), the region is also influenced seasonally by monsoon winds, rainfall and fresh water discharge (Vinayachandran and Mathew 2003). McCreary *et al.* (1993) drew attention to the influence of monsoonal winds on the annual cycle of the near-surface circulation at sea level. Shetye and Gouveia (1998) demonstrated that the salinity profile of the Bay of Bengal region is similar to that of the Arabian Sea. However, despite studies by Shetye *et al.* (1991), Bhat (2001), Vinayachandran and Mathew (2003) revealing the influence of internal and external forcing factors on seasonal variance, the primary productivity of the Bay of Bengal remains largely unexplained.

An exploration of the impact of climate variation on marine fisheries studies in the context of food and income security in a climatically vulnerable country such as Bangladesh. Observations on the seasonal and temporal climate dynamics and the resultant productivity of the Bay of Bengal could also help develop a wider understanding of its socio-economic application and improve science-based decision-making, with respect to the marine fisheries sector. Research by Prasanna Kumar *et al.* (2002), on the comparison between the monsoonal productivity during June to August (JJA) and the biogeochemical processes in the Bay of Bengal and the Arabian Sea, explains the coupling between physical forcing and the exhibited response in terms of biological productivity. The research further explained the seasonal dynamics of chlorophyll biomass, stating that high productivity occurs during the monsoon and post monsoon period (June to September), followed by winter (DJF) and the spring (MAM). Taking into account past scientific studies in the region, this present study focuses largely on seasonal observations (for three different time periods: September, October, November (SON); December, January, February (DJF); and March, April, May (MAM)). The period of June, July and August (JJA) has not been studied here because of the non-availability of Chlorophyll Satellite data, due to cloud cover. Earlier observations have been further developed and validated in this study with specific emphasis on the Bay of Bengal region and the marine fisheries



sector of Bangladesh. Bangladesh slopes gently from north to south, meeting the Bay of Bengal at the southern end where there is a flood plain delta with rivers and canals. The entire coast runs parallel to the Bay of Bengal, forming a coastline of 710 km (CZPo 2005). The southern part of Bangladesh is predominantly influenced by the discharge of numerous rivers, including the Ganges-Brahmaputra-Meghna (GBM) river system; creating one of the most productive ecosystems in the world. In this study, we analyze the marine region of Bangladesh, (i.e. the Northern Bay of Bengal from 88°E to 93°E and from 15°N to 19°N).

2. Data and Methodology

The schematic representation of the methodology (Fig.1) can be divided into two broad segments. The Fisheries' Analysis section considers temporal variations in the total annual fish catch and the species-level catch (1998-2009) data collected from the Department of Fisheries, Bangladesh. The marine fishing era is dominated by mechanized fishing. The information included in the second segment of the study was selected for detailed analysis and to showcase the fish productivity of the marine ecosystems with variance in climatic factors. The fish catch per trawler (for the period 1998-2009) is taken as a surrogate for the marine fish yield.

The declining rate of fish catch over the Bangladesh region, (i.e., the northern Bay of Bengal), is studied by interpreting the climatic variation and its effect on oceanographic parameters such as sea surface temperature (SST), sea surface height (SSH) and productivity, as measured by Chlorophyll-*a* (Chl-*a*). Data sets for the period 1998 to 2009 are integrated for analysis. The Sea-WiFS monthly Chl-*a* data were retrieved from <http://oceanwatch.pifsc.noaa.gov>. The SST data were derived from the NOAA-OISST (National Oceanic & Atmospheric Administration, Optimum Interpolation Sea Surface Temperature) and the SSH data retrieved from the Archiving, Validation and Interpretation of Satellite Oceanography (AVISO) from the site of the Asia Pacific

Data Research Center (APDRC). Data sets for three different periods (SON, DJF and MAM) are selected. All data sets are analyzed through Ferret graphical software, wherein all monthly anomaly data sets (of different periods) for SST, SSH and Chl-*a*, are subjected for trend analysis. A correlation between SST and Chl-*a*, SSH and Chl-*a* is then investigated. Marine environmental variables are subsequently correlated with yearly marine fish catch data and expressed as “fish catch per fishing trawl”.

3. Results and Discussion

3.1 Trends in Marine Fisheries related to Chl-*a* distribution in the region

During the period 1998-2009, marine fish productivity in Bangladesh witnessed considerable inter-annual variability, but its contribution to the total fish production (inland and marine catch) has shown a declining trend (Fig. 2). In the year 1998-1999, approximately 19% (300 metric tons) of the total fish production came from the marine sector. Of, about 1500 metric tons production in 1998-99, nearly 19% (300 metric tons) was produced from the marine sector, the percentage rising to closely 22% (about 455 metric tons) of the total fish production in 2003-04, but in 2009, of nearly 3000 metric tons, only about 500 metric tons (17.5%) was caught by the marine fishing sector. Studies relate the effect of climatic variability on marine fish productivity in the Bay of Bengal region to the atmospheric and hydrographical conditions impacting the Chl-*a* gradient, which in turn is impacted by SST and SSH. Observations on the seasonal atmospheric variability, in terms of mean Chl-*a* distribution from 1998-2009, show a declining trend over time during MAM and SON, and a relatively smaller decline in DJF. Fig. 3(b),(d),(f) illustrates a special trend plot of three different periods, revealing a negative trend of Chl-*a* anomaly towards the coastal region of the Bangladesh. Satellite observations recorded the highest Chl-*a* concentrations during SON, followed by DJF and MAM. It was also observed that Chl-*a* concentrations during SON decreased by almost half (from 0.95 mg/m³ in



September-1998 to 0.49 mg/m^3 in September-2009), while Chl-*a* concentration declined by 0.055 mg/m^3 (Fig.3 (a)).

The above observations can be explained in terms of the active blooming of Chl-*a* outside the mouths of the Ganga, the Brahmaputra and the Meghna Rivers (referred to as the GBM-effect), after the withdrawal of southwest monsoon, and following the flow of the East Indian coastal current off the northern part of the Indian coast towards the equator, (the high Chl-*a* region adheres to the coast (Chauhan *et al.* 2005)). When the current reverses, the Chl-*a* plume flows offshore, away from the coast into the open bay. During spring (MAM), this plume can be observed several hundred kilometers to the south, occasionally extending as far south as 17°N (Vinayachandran 2009). In the present study, a slight declining trend in Chl-*a* levels of 0.0121 mg/m^3 is noted during DJF (Fig.3(c)), while a declining trend of 0.033 mg/m^3 Chl-*a* is noted during MAM (Fig. 3(e)). There is a smaller concentration of Chl-*a* during DJF as a result of cooling in the northern Bay of Bengal, but this does not lead to winter convection due to the presence of low salinity surface waters. Away from the influence of low salinity waters, the stratification of the upper layers is weak and the moderate winter monsoon winds are able to initiate wind-mixing, facilitating the nutrient supply to the euphotic zone; indicating that eddies plays a vital role in enhancing biological productivity (Prasanna Kumar *et al.* 2004). In addition, the examination of the Chl-*a* distribution in the same region by Gomes *et al.* (2000) during the northeast monsoon (DJF), explains the increase in productivity in the northern part of the bay, especially along the coastal part, due to estuarine conditions and fresh water influx. In 1999 and 2007, high value of Chl-*a* are observed because of the moderate La Nina conditions (Fig.3(c)). Lower values of Chl-*a* concentration in the Bay of Bengal are observed during MAM. Prasanna Kumar *et al.* (2002) highlight the influence of fresh water influx from rivers and from oceanic precipitation under monsoon conditions, which then results in a strong stratification of the upper waters and low salinity waters during summer. These increase the stratification of the upper layers, that the strong monsoon winds are inept to break and initiate wind-driven mixing to supply subsurface nutrients to the euphotic zone.

An examination of the level of marine fish species (Bangladesh from 1999-2009) such as Hilsa (*Tenulosa ilisha*), Bombay duck (*Harpadon nehereus*), and Indian Salmon (*Oncorhynchus tshawytscha*) (in the eastward Bay of Bengal), shows that there is a relationship between seasonal trends in Chl-*a* and marine productivity at fish species level. While wide-ranging trends are observed at species level (Fig. 4), Bombay duck and Hilsa display comparatively greater temporal variance trends. Bhuiyan *et al.* (2008) state that the winter season is the most productive in terms of catch in the coastal areas of the Bay of Bengal, particularly for Bombay duck and shrimps. Fish catch statistics appear to support this, with, 27,480 metric tons of Bombay duck in 1999 to 36,980 metric tons in 2007-08 and a substantial increase to 58,260 metric tons in 2008-09. This increase can be explained by the seasonal (DJF) variations in Chl-*a* which peaked at 0.33 mg m^{-3} during the time period studied; whilst there was a general decline in seasonal Chl-*a* concentration over the temporal span from 1998-2009. The differential influence of Chl-*a* concentration in the northern region of Bay of Bengal during the three seasons, and the variance of the impact of this in near coast areas and in the shelf, clearly correlates with annual trends in marine productivity observed during the time period studied. In support of the above observations, a study by Mome [2007] suggests that southern patch of the marine fishing zone is more productive than other areas.

3.2 Comparing the chlorophyll distribution with SST and SSH

The decadal (1998-2009) pattern of climatology reflects a notable correlation between Chl-*a* and SST; Chl-*a* and SSH during MAM, although they are not correlated significantly during SON. During 1998-2009 the SSH during SON shows a drop equivalent to 0.87 cm, the decreasing value of SSH shown in special trend plot Fig.5(a),(b)). The observation supports the fact that turbidity is dominated by fresh water influx and extensive human activities that have accelerated the rate and amount of seashore erosion (Hussain and Hoq 2010). The SSH values during DJF and MAM show an increasing trend, with spatially derived values recorded as 1.31 cm and



2.09 cm (Fig. 5(c),(e)). The trend is a reversal of that of Chl-*a* gradient. Moreover, in the special trend plot there is an increasing trend in SSH values over the central and south-west region during DJF and over the central region during MAM (Fig. 5(d), (f)). A similar temporal trend is observed for SST. From 1998 onward, the SST index shows a positive incline that peaks during SON, thereby providing a clarification for the seasonal decline in Chl-*a* concentration, which in turns affects marine fish production., leading to food and livelihood insecurity in climatically vulnerable Bangladesh. These findings are in conjunction with the research of Venegas *et al.* (2008) from northern California, explaining the variability during seasonal cycles of circulation in SSH, SST and Chl-*a*. The SST values in the defined Bay of Bengal region during SON and DJF show a positive trend of 0.13°C and 0.07°C, while SST values in MAM show a negative trend of the order of 0.16°C (Fig. 6(a), (c),(e)). The special trend plot also clearly illustrates the ubiquitous SST value increase during SON, except in the extreme North-West region (Fig. 6(b)). While the SST values fluctuation less in DJF (Fig. 6(d)), as shown in the special trend plot of the random increase in the SST anomaly value, the SST value decreased in most areas studied (except for in the extreme northern region during MAM) (Fig. 6(f)). Species level catch variations in the different seasons correlate with fluctuations in sea-atmosphere-land dynamics; it is also noted that the fractional catch of Jawfish (Opistognathidae) nearly doubles, (from about 4.16 % of the total catch in 1999 to 8.31% in 2009), while those of the economically more important Hilsa shows a decline in representation in the total catch from 46.4% in 1999 to 43.89% in 2009 (Fig. 4). This is attributed to a change in salinity and hydrology, primarily resulting from the seasonal fresh water discharge from the GBM system. The broader concept of the statement has also been argued by Dwivedi (1993) in the context of Large Marine Ecosystems.

During SON, a negative correlation is observed between Chl-*a* and SST (Fig. 7(a)), except for in a few patches of the coastal region and in the southern zone of the Bay of Bengal. During DJF, there is a strong negative correlation over the central (Fig. 7(b)) region of the defined area. During MAM, a positive correlation towards

the coastal region of Bangladesh is observed, whereas the rest of the region indicates a more or less negative correlation (Fig.7(c)). There is a negative correlation between SSH and Chl-*a* during SON towards the central part and towards the south-west region of the area studied (Fig. 8(a)), but during DJF there is a strongly positive correlation in the eastern region of the Bay of Bengal, as well as in a few areas in the northern part of the region. No significant correlation is found towards the west of the study area (Fig.8 (b)). It has been observed that winds are favorable for coastal upwelling during December–March, favoring the development of blooms, as measured by increases in Chl-*a* levels (McCreary *et al.* 1996). MAM shows a strong positive correlation over the central region of the studied area (Fig. 8(c)).

4. Conclusion

Recent improvements in data and technological advances have facilitated the investigation of responses by different resource sectors to climate variability. In this study, the seasonal and temporal correlation of marine fish productivity with climate variables is quite apparent. Sea-WiFS data are commonly employed to calculate the spatial gradient of Chl-*a* concentrations. In the present study, remote sensing analysis depicts a decrease of Chl-*a* of nearly half its original amount within a span of 12 years (0.95 mg/m^3 in September 1998 to 0.50 mg/m^3 in September 2009). This observation adds to the global concern regarding threats to marine fish productivity arising from a mix of naturally driven and anthropologically induced land-atmosphere dynamics. The correlation of SST and SSH values with Chl-*a* concentrations improves our understanding of the dynamic processes governing climatic variation and the impact on marine ecosystems, especially that of fish production, with considerable spatial as well as temporal variation. While such observations are crucial in developing our understanding of ecosystem and socio-economic responses to climatic variability, further study can help decision makers and stakeholders use such information to prepare climate variation adaptation plans in a timely way.

**REFERENCES**

- Alam, Md.F., & Thomson, K. J. (2001). Current constraints and future possibilities for Bangladesh fisheries. *Food Policy, Volume 26, Issue 3*, 297-313.
- Bhat, G. S. (2001). Near surface atmospheric characteristics over the north Bay of Bengal during the Indian summer monsoon. *Geophysical Research Letters*, Vol. 28, No. 6, 987-990.
- Bhuiyan, A. S., Islam, S. N., & Bhiuyan, S. S. (2008). Seasonal occurrence of some copepods in relation to the physicochemical conditions of a fish pond in Rajshahi, Bangladesh. *Fishing Chimes* 28 : 39-41
- Chauhan, P., Nagamani, P.V., Solanki, H.U., & Nayak, S. (2005). Composite image of chlorophyll and Sea Surface Temperature (SST) using MODIS-AQUA. *Indian Society of Remote Sensing* 33(2), 177-180.
- Choudhury, S.B., Rao, K.H., & Rao, M.V. (2002). Satellite remote sensing for marine resources assessment. *Tropical Ecology* 43(1), 187-202.
- CZPo. (2005). Coastal Zone Policy Document, *Ministry of Water Resources, Government of the People's Republic of Bangladesh, Dhaka*.
- Dwivedi, S.N. (1993). Long-term variability in the food chains, biomass yield and oceanography of the Bay of Bengal Ecosystem. *American Association for the Advancement of Science (AAAS). Large Marine Ecosystems: Stress, Mitigation and Sustainability*. Washington, DC : AAAS Press : 43-52.
- FAO. (1994). Marine Fisheries and the Law of the Sea: A Decade of Change. *FAO Fisheries Circular No. 853*, 35.
- Gomes, H. R., Goes, J. I., & Saino, T. (2000). Influence of physical processes and freshwater discharge on the seasonality of phytoplankton regime in the Bay of Bengal, *Continental Shelf Res.*, 20, 313- 330.
- Hussain, M.G., & Hoq, M.E. (eds.). (2010). Sustainable Management of Fisheries Resources of the Bay of Bengal- Compilation of national and regional workshop reports. *Support to Sustainable Management of the BOBLME Project, Bangladesh Fisheries Research Institute. SBOBLMEP Pub./Rep. 2*. 122 .
- McCreary, J. P., Kundu, P. K., & Molinari, R. L. (1993). A numerical investigation of dynamics, thermodynamics and mixed-layer processes in the Indian Ocean, *Progress in Oceanography*, 31, 181- 244.
- McCreary, J.P., Kohler, K. E., Hood, R. R., & Olson, D.B. (1996). A four-component ecosystem model of biological activity in the Arabian Sea. *Progress in Oceanography*, 37, 193-240.
- Mome, M. A. (2007). "The potential of the artisanal Hilsa fishery in Bangladesh: An economically efficient fisheries policy." Reykjavik, ISK: *The United Nations University Fisheries Training Programme, E-publishing Inc*.
- Overland, E. J., Juergen, A., Andrew, B., James, H.W., David, M. L., & Miller, J.A. (2010). Climate controls on marine ecosystems and fish populations. *Journal of Marine Systems*.79 305-315
- Prasanna, K.S., Muraliedharan, P.M., Prasad, T. G., Gauns, M., Ramaiah, N., De-Souza, S. N., Sardesai, S., and Madhuratap, M. (2002). Why is the Bay of Bengal less productive during summer monsoon

- compared to the Arabian Sea? *Geophysical Research Letters*, 29(24).
- Prasanna, K.S., Nuncio, M., Narvekar, J., Kumar, A., Sardesai, S., De-Souza, S. N., Gauns, M., Ramaiah, N. & Madhupratap, M. (2004). Are Eddies nature's trigger to enhance biological productivity in the Bay of Bengal? *Geophysical Research Letters*, 31.
- Shetye, S. R., & Gouveia, A. D. (1998). *Coastal circulation in the north Indian Ocean: Coastal segment (14,S-W)*. *The Sea*, Chapter 18, Vol-11, 523-556.
- Shetye, S. R., Gouveia, A. D., Shenoi, S. S. C., Michael, G. S., Sundar, D., Almeida, A. M., & Santanam, K. (1991). The coastal current off western India during the northeast monsoon. *Deep-Sea Research*, 38 (12):1517-1529.
- Shankar, D., & Shetye, S.R. (2001). Why is mean sea level along the Indian coast higher in the Bay of Bengal than in the Arabian Sea? *Geophysical Research Letters* Vol. 28, No. 4, 563-565.
- Shetye, S. R., Gouveia, A. D., Shenoi, S. S. C., Sundar, D., Michael, G. S., & Nampoothiri, G. (1993). The western boundary current of the seasonal subtropical gyre in the Bay of Bengal. *Journal of Geophysical Research*, 98, 945- 954.
- Shetye, S. R., Shenoi, S. S. C., Gouveia, A. D., Michael, G. S., Sundar, D. & Nampoothiri, G. (1991). Wind-driven coastal upwelling along the eastern boundary of the Bay of Bengal during the southwest monsoon. *Continental Shelf Research*, 11, 1397- 1408.
- Silas, E.G., Rajagopalan, M., Fernando, A.B., & Dan, S. S. (1985). Marine turtle conservation & management: A survey of the situation in Orissa 1981/82 & 1982/83. *Marine Fisheries Information Service Technical & Extension Service* 50, 13-23.
- Venegas R. M., Strub P. T., Beier E., Letelier R., Andrew C. T., Timothy C., Corinne J., Luis S., & Carlos, C. (2008). Satellite-derived variability in chlorophyll, wind stress, sea surface height, and temperature in the northern California Current System. *Journal of Geophysical Research*, Vol. 113, C03015.
- Vinayachandran, P. N. (2009). Impact of physical processes on chlorophyll distribution in the Bay of Bengal. *Geophysical Monograph Series*, Vol. 185, 71-86.
- Vinayachandran, P. N., & Mathew, S. (2003). Phytoplankton bloom in the Bay of Bengal during the northeast monsoon and its intensification by cyclones. *Geophysical Research Letters* Vol-30(11), 1572.
- Vinayachandran, P. N., McCreary, J. P. Jr., Hood, R. R., and Kohler, K. E. (2005). A numerical investigation of the phytoplankton bloom in the Bay of Bengal during Northeast Monsoon, *Journal of Geophysical Research*, Vol-110, C12001.



Figures Legends

Figure 1 Schematic representation of the conceptual framework

Figure 2 Trends in marine fisheries: (a) The number of crafts used in marine fish catch is on the rise and the overall tonnage of total marine fish production shows a typical growth; (b) The pelagic fish catch has shown a decline over the same temporal period, as has the productivity; measured as catch per craft.

Figure 3 Trends in chlorophyll (Chl-*a*) concentration in three different periods (MAM, SON & DJF), together with a Special Trend plot from 1998 to 2009.

Figure 4 Decadal (1999–2009) variation in species-wise fish-catch in marine fisheries in Bangladesh.

Figure 5 Trend analysis from 1998 to 2009 for the analysis of Sea Surface Height distribution in three different periods (MAM, SON & DJF), together with Special Trend plot.

Figure 6 Trend analysis from 1998 to 2009 for the analysis of Sea Surface Temperature distribution in three different periods (MAM, SON & DJF), together with Special Trend plot.

Figure 7 Correlation studies between Sea Surface Temperature and Chlorophyll for three different periods: (a) SON, (b) DJF & (c) MAM.

Figure 8 Correlation studies between Sea Surface Height and Chlorophyll for three different periods: (a) SON, (b) DJF, & (c)MAM.

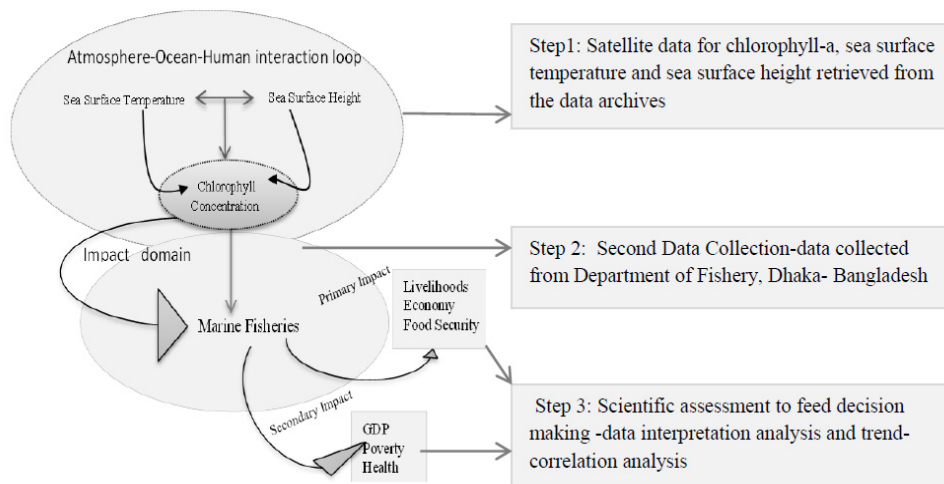


Figure 1 Schematic representation of the conceptual framework

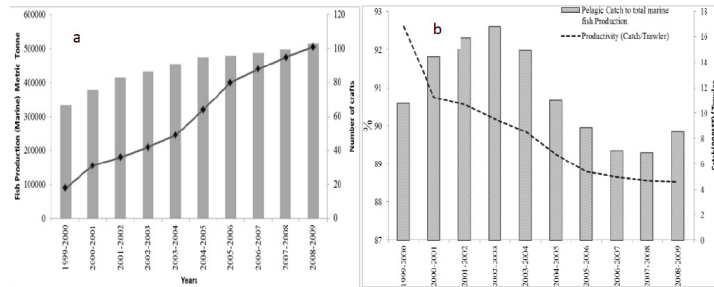


Figure 2 Trends in marine fisheries: (a)The number of crafts for marine fish catch is on rise and the overall tonnage of total marine fish production shows a typical growth; (b) The pelagic fish catch has shown decline in over the same temporal period as has the productivity, measured as catch per craft.

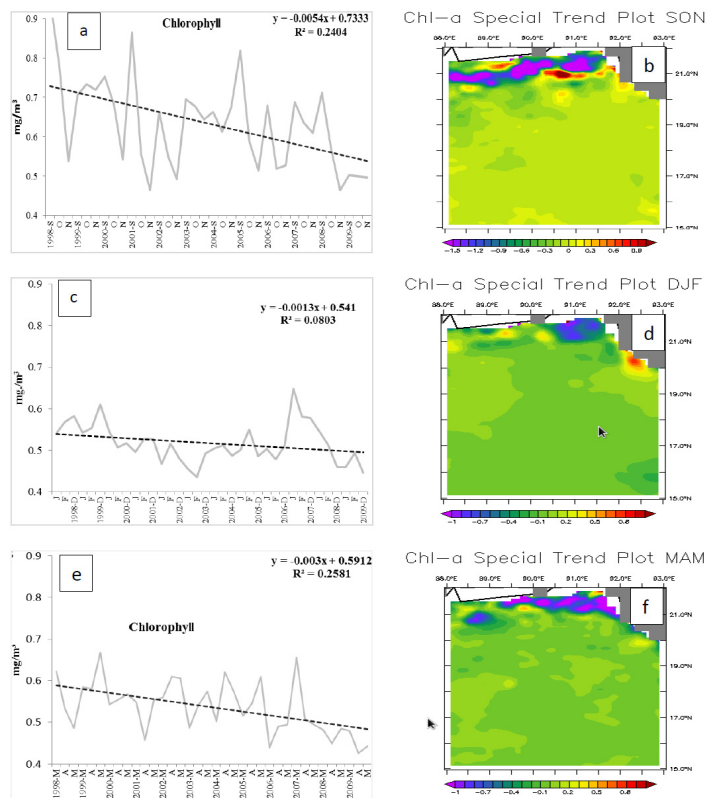


Figure 3 Trends in chlorophyll (Chl-a) concentration in three different periods (MAM, SON & DJF) along with Special Trend plot from 1998 to 2009

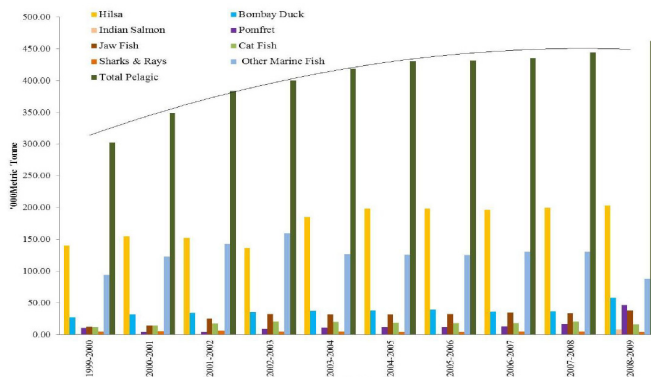


Figure 4 Decadal (1999-2009) variation in species-wise fish-catch in marine fisheries in Bangladesh.

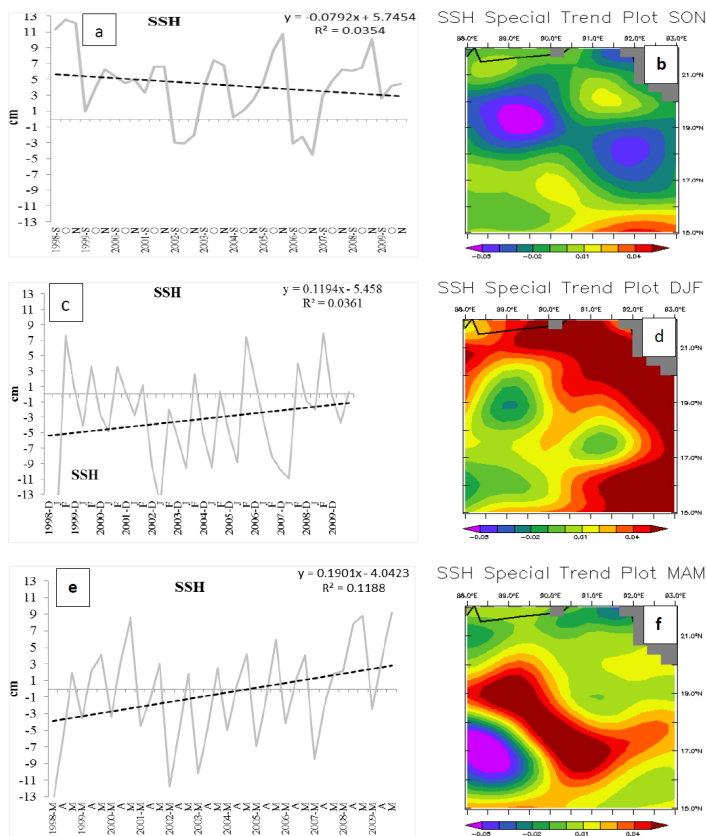


Figure 5 Trend analysis from 1998 to 2009 to understand Sea Surface Height distribution in three different periods (MAM, SON & DJF) along with Special Trend plot.

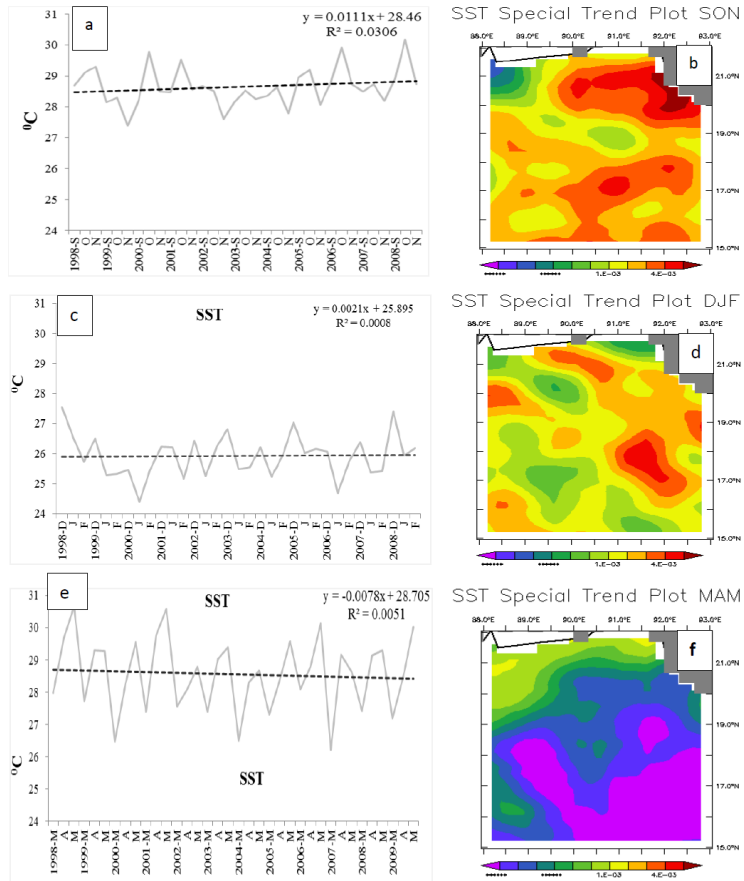


Figure 6 Trend analysis from 1998 to 2009 to understand Sea Surface Height distribution in three different periods (MAM, SON & DJF) along with Special Trend plot.

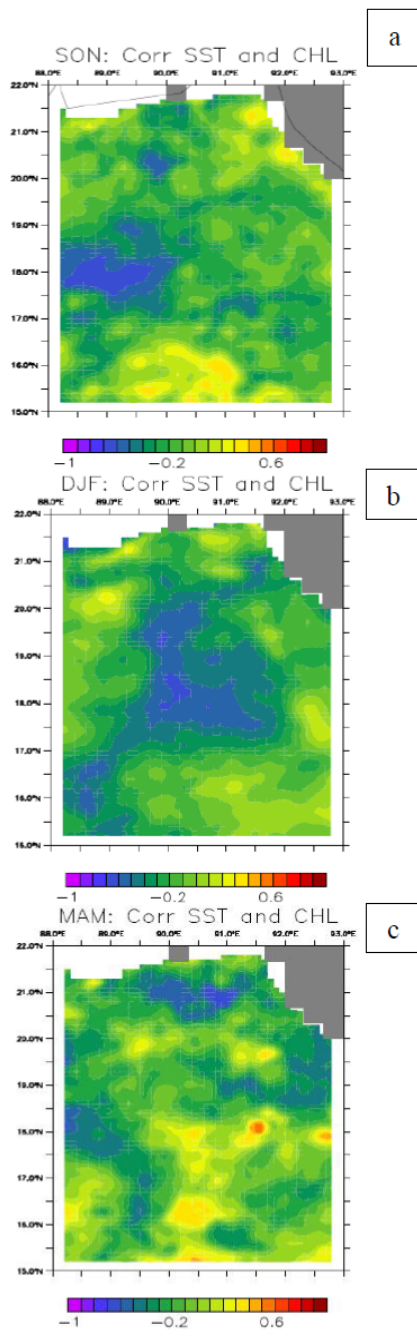


Figure 7 Correlation studies between Sea Surface Temperature and Chlorophyll for three different periods: (a) SON, (b) DJF & (c) MAM.

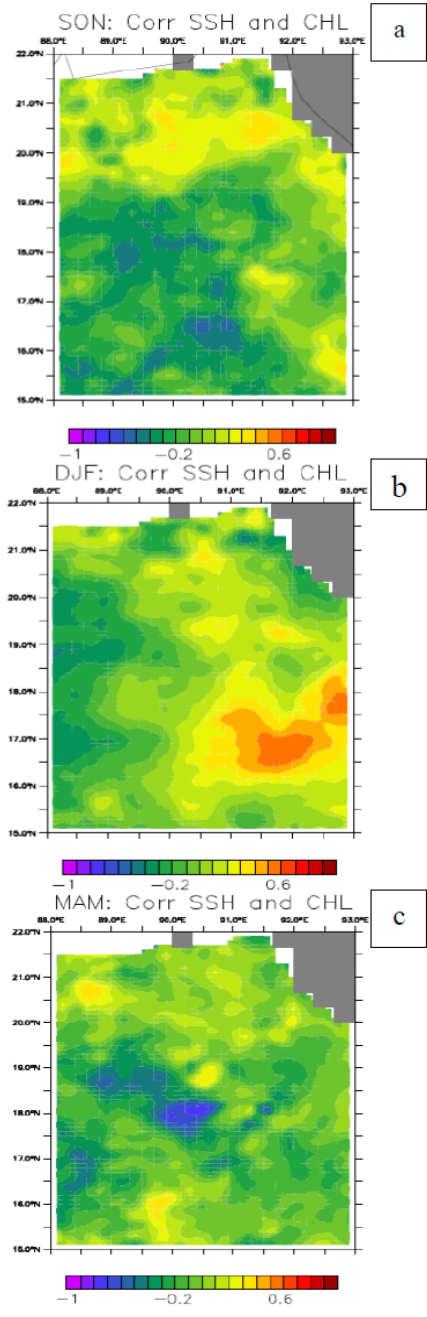


Figure 8 Correlation studies between Sea Surface Height and Chlorophyll for three different periods: (a) SON, (b) DJF & (c) MAM.



ResearchWork 2

Formation of High Amplitude Coastal Waves in the Bay of Bengal (East Coast of India) and their Relationship to Climate Change

ABSTRACT

This study emphasizes the genesis of high amplitude waves in the Northern Indian Ocean near the east coast of India (Bay of Bengal) (Odisha and Andhra Pradesh states). The issue of these high amplitude coastal waves and their devastating nature on the coastal environment and subsequent changes in the shoreline is seen in the context of climate change. These waves are formed due to the changes in the 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 forms counter clockwise eddy with high surges at shallow depths. During tropical depression activities in the Bay of Bengal, these waves become more intensified and destructive in nature. Tropical depression data studies over the past 30 years indicate that the area where the depressions and cyclones are formed has now been displaced towards the Odisha coast of India. These waves are more devastating in nature and it affects the coastal environment and changes the shore line. This paper discusses the genesis of these high amplitude waves, using oceanographic and atmospheric variables such as sea surface height, geostrophic current, tropical depression and wind speed. It also explains the displacement of the area of cyclogenesis over the Bay of Bengal, which triggers the high amplitude coastal waves using over the past 30 years data,

1. INTRODUCTION

High amplitude coastal waves are observed in the northern Indian Ocean near the east coast of India, in the Bay of Bengal (BOB) in the Odisha and Andhra Pradesh coastal states. This type of wave is generally coastal based and regionally originated. Coastal waves are natural phenomena and have a significant impact on the coastline. These high amplitude waves are, however, destructive in nature and affect multiple areas of the coastline, which receive different amounts of the surge in the form of heavy waves. This then causes excessive erosion by removing sand and sediment from beaches (Fig. 1). Recently and not always related to storm surge, the coast has been eroded to a great extent along the Odisha coast.



[Resource ICZM, Orissa Project report]

Figure 1 Erosion at Puri in between the Lighthouse & Sterling Hotel beaches (Odisha, India)

The 1930 land record shows an area of 320 km² encompassing the Satabhaya cluster of seven villages near Paradip in Odisha. However, in recent land records in 2000, (Mahapatra, 2008) the area is shown to be reduced to 155 km². Five of the seven villages had been swallowed by the sea with the intrusion of the sea over an area of approximately 2.5 km. The local residents are now finding themselves in a very difficult and unique situation; they are technically trespassers as their legal documents show their lands are somewhere inside the sea. One fishing village in the southern region of the State of Odisha at Gopalpur in the Ganjam district is completely submerged due to the wave erosion (Pati, 2009). However, the state government is aware of the situation, and in the 1980's instigated a proposal for the rehabilitation of Satabhaya, Kanhapur, and other nearby villages. A high-level state committee has suggested to carry out a scientific study (Mahapatra, 2006). A fishermen village on the southern region of Odisha coast at Gopalpur in Ganjam district is completely submerged in the sea due to the sea wave and erosion (Pati, 2009). In this study I have discussed about the formation of the high amplitude



coastal wave and their genesis near the coastal region of the east coast of India. Ocean waves usually have a variety of spectra that depend on variations in wind speed and the direction of the waves (Hasselmann *et al.*, 1976 & 1980). These unusual coastal waves have a hazardous impact over the coastal regions and also deteriorate the socio-economy status of the country. This type of wave generally affects a few region of the northern Indian continent and has been recorded along the Andhra Pradesh and Odisha coasts for the last two decades. However, these two coastal states of the eastern Indian continental region are considered to be areas of non-deposition, 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 reef terraces and a karstic structure over the outer shelf of the East coast of India relate such features to eustatic sea-level changes (Rao *et al.*, 1980). The two linear trends of Holocene mounds at a depth of 60-70 m over the Visakhapatnam shelf (Murthy *et al.*, 1987), infer a Holocene transgression, based on the sediment grain size parameters (Murthy, 1989). There is a demarcation of late Pleistocene regression at a level of approximately 130 m below sea level and shallow seismic reflection data and radiocarbon dating of the algal limestone of different sea-level strandlines indicates formation during the Holocene transgression (Mohana and Rao, 1994). Similar studies (Mohapatra *et al.*, 1992) have reported still stand zones over the eastern continental shelf of India. These were studied in detail afterwards (Vivier, *et al.*, 1999 and Politi, *et al.*, 2000), and it is apparent that the annual SSH signals are associated with such phenomena as 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 have mentioned regional phenomena and important atmospheric and oceanic variables linked to the formation of high amplitude coastal waves, such as wind velocity, eddies, geostrophic currents and storm surges. These physical factors are being influenced directly or indirectly by different oceanic events that form the giant high-amplitude waves that are more pronounced in between September to November.

2. DATA AND METHOD

The variation in sea surface height in the Bay of Bengal was studied over a period of eighteen years from 1992 to 2009. The anomalies of sea surface height (SSH), wind speed (WS), sea surface temperature (SST) and geostrophic current are used for this study. The geostrophic current was retrieved from the SSH during the same period have been used for the study. The most efficient decomposition of the data into representative modes have been done by using Empirical Orthogonal Function (EOF) method which 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 and is 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. Firstly, the retention of 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 with differing spatial and temporal scales and can thus be isolated and then associated with the physical processes taking place. The method (also called the principal component analysis or the Karhunen–Loeve analysis) is empirical because the data are used to find their own optimum decomposition with no a-priori assumptions of 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 and daily SST data from NOAA-OISST are used and converted into monthly data, along with NCEP-Reanalysis wind data. Simultaneously weekly SSH data is also used to obtain the geostrophic current. For the study of high amplitude coastal waves, data was used for a period of only three months from September to November in all the years.



3. RESULTS AND DISCUSSION

In general, the high amplitude coastal waves are observed near the Odisha and Andhra Pradesh coasts during September to November (SON). These waves are more devastating in nature and actively associated with coastal erosion as shown in Fig. 1. In this study, the ocean and atmospheric dynamics during the SON time period were focused. The EOF mode-1 and mode-2 of SSH explains about 30% and 21% of the variance during SON which is more dominant towards the northern region of the studied area, as shown in the corresponding Principal Components (PC-1 and PC-2) (Figs. 2 & 3). The 3rd EOF mode explains 9% of the variance during the same period and the negative

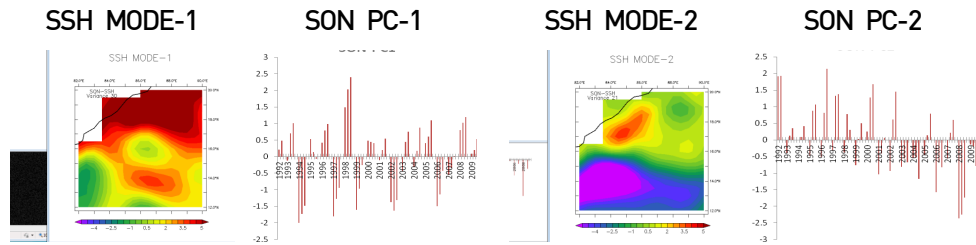


Figure 2 EOF mode-1 of SSH (cm) corresponding to PC-1 Figure 3 EOF mode-2 of SSH (cm) corresponding to PC-2

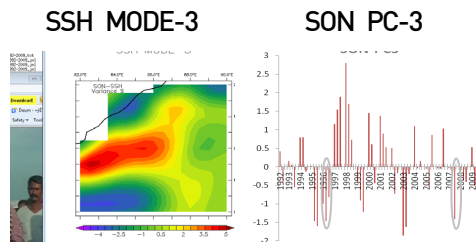


Figure 4 EOF mode-3 of SSH (cm) corresponding to PC-3

anomaly of SSH peaks are more dominated towards the coastal region which is shown in PC-3 (Fig. 4). As per the existing case study report of 2007, (from the local community information regarding major high amplitude waves near the coastal regions

of the Odisha), a high amplitude wave was noticed near the Odisha coast and in other years such as 1995, 1996 and 1999. In this study, I have found a negative anomaly of SSH for the above said years in the same region as shown in PC-3. SST, wind speed and geostrophic current were analyzed for the detailed study. The EOF analysis of SST shows 64% of the variance in mode-1 and a negative anomaly of the SST is evident towards the coastal region. The negative anomaly of SST may be associated with major climatic events such as the Indian Ocean dipole or the ENSO, which dominates, and is found in the corresponding PC-1 (Fig. 5).

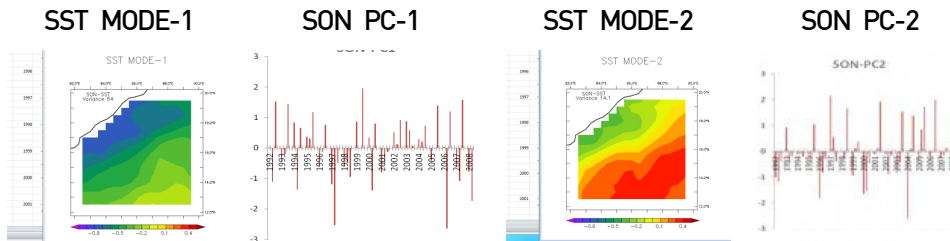


Figure 5 EOF mode-1 of SST [°C] corresponding to PC-1 **Figure 6** EOF mode-2 of SST [°C] corresponding to PC-2

The second EOF mode shows a variance of 14.1% and a negative SST anomaly is dominated over the coastal region. As per our case studies, the negative anomaly of SST is shown for the same period and is shown in the corresponding PC-2 (Fig. 6). The EOF of wind speed for the period of SON shows a negative anomaly over the offshore region with a variance of 74.9% and the second EOF mode shows a negative anomaly over the offshore, southern part of the studied area with variance of 9.5%, which is reflected in the corresponding PC-2 (Figs. 7 & 8).

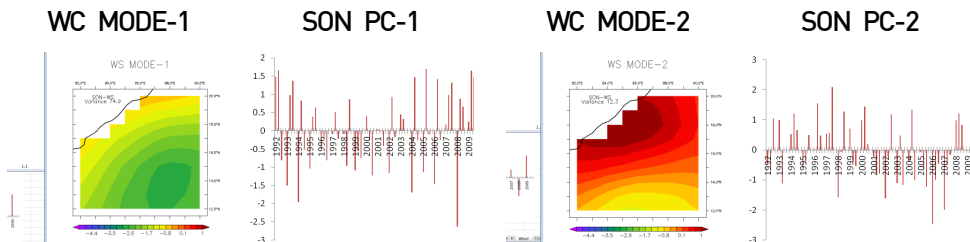


Figure 7 EOF mode-1 of WS(m/s) corresponding to PC-1 **Figure 8** EOF mode-2 of WS(m/s) corresponding to PC-2



The geostrophic current over the studied area indicates a circular pattern towards the coastal region (Fig. 9). This circulation pattern moves in a counterclockwise direction and is the cold core eddy from the SST study. The localized eddies are generated due to the littoral current moving parallel to the coast, which diverges from its original path and forms a circular pattern towards the coast. It has been noticed that a strong negative correlation is found between SSH and the second EOF mode of wind speed (Fig. 10(a)), parallel to the coast. This represents how the wind action triggers the localized coastal eddies. In the second correlation between SSH and the third EOF mode of SST (Fig. 10(b)), quite a positive correlation is shown nearer to the coast and is indicated by the counterclockwise eddies nearer to the coast. These eddies contain surges which destroy the coastal region and flow positively from the areas of cyclogenesis towards the northern Odisha coast (Fig. 11). In the Bay of Bengal the maximum cyclogenesis period is between September and November, which helps the littoral current generate the cold core eddies.

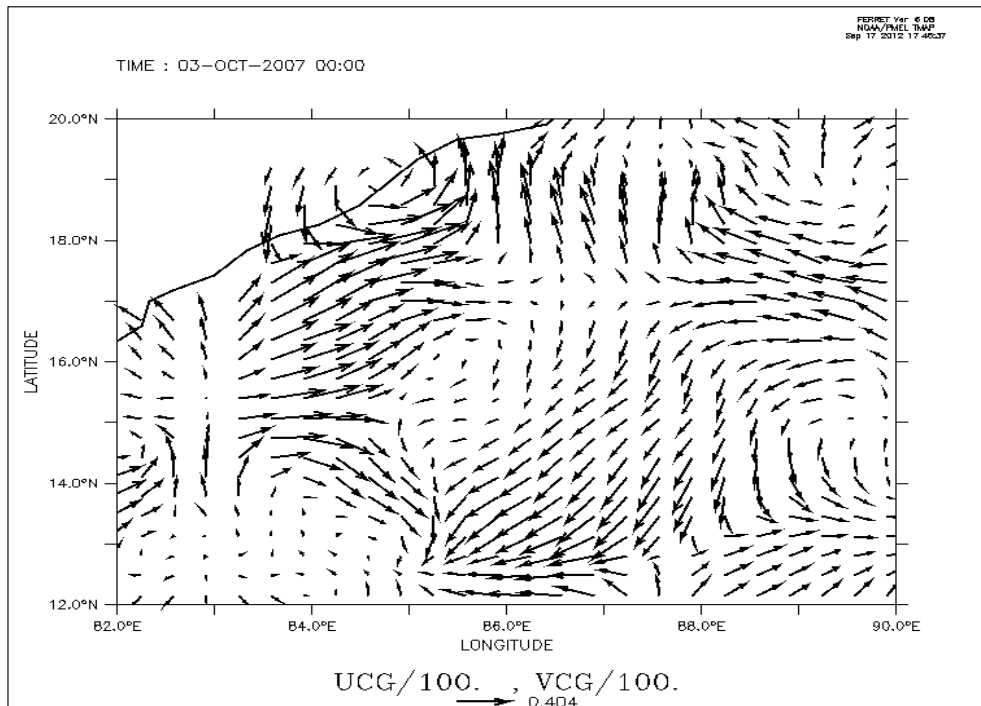


Figure 9 Geostrophic current on October 2007

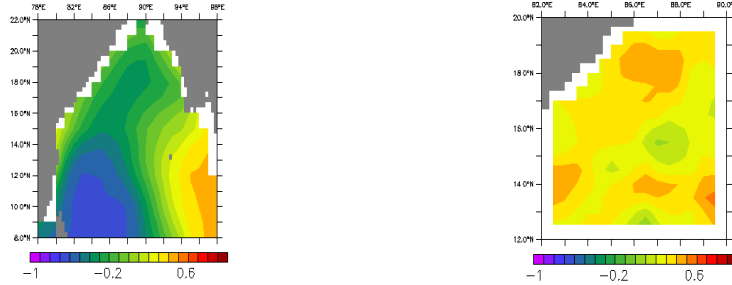


Figure 10(a) Correlation coefficient between WS and EOF mode-2of the SSH **Figure 10(b)** Correlation coefficient between SST and EOF mode-3of the SSH

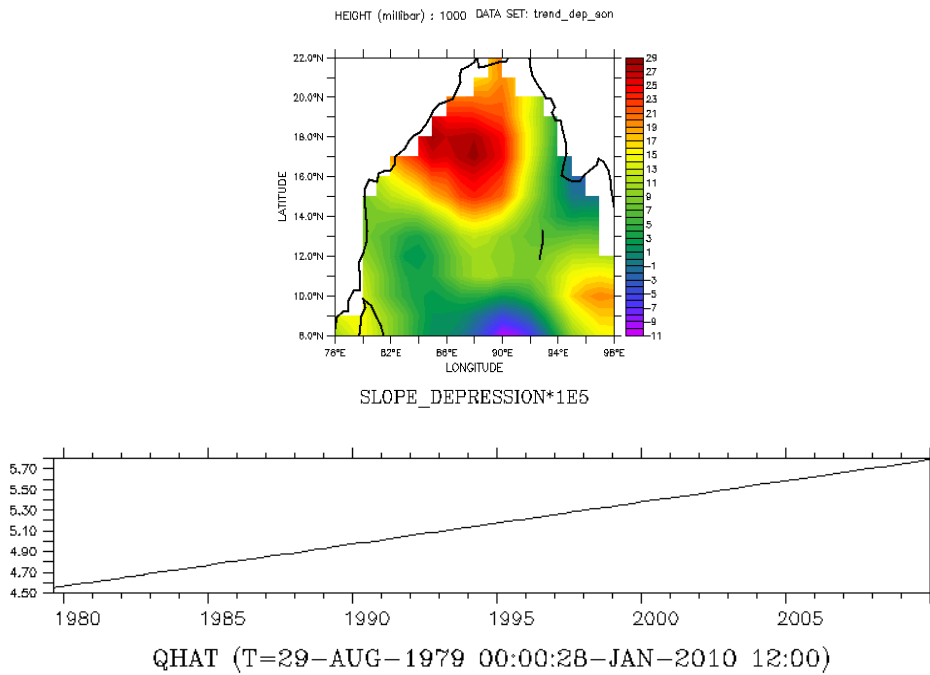


Figure 11 Special plot for the area of Cyclogenesis during SON from 1979 to 2009 and trend plot.



4. CONCLUSION

The high amplitude coastal waves are devastating in nature and change the shore line due to their high insurgence. Approximately 2.5 km of the northern part of the Odisha coast has been submerged, along with a fishing village in the southern region of same state. These coastal waves are generated due to the formation of counter-clockwise eddies which are noticeable in the geostrophic current. A negative anomaly is noticed in the SSH over the near-shore region and a correlation study between SSH and SST is shown to be quite positive over the same region which indicates the presence of cold core eddies. These high insurgence coastal waves have been observed for a few years near the Odisha coast and are intensified during cyclonic conditions over the Bay of Bengal.

5. Acknowledgements

This study was supported by the Director, APCC, South Korea. All data sources are duly acknowledged.

REFERENCES

- Hasselmann, D. E., Dunckel, M. and Ewing, J.A., (1980). Directional Wave Spectra Observed during JONSWAP 1973, *J. Phys. Oceanogr.* 10, 1264
- Hasselmann, K., Ross, D.B., Miller, P. and Sell, W., (1976). A parametric wave prediction model, *Jour. Phys. Oceanogr.*, 6: 200-228.
- 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-s-ubmerged-villges.html>
- 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>
- 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.
- 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.
- Mohapatra, G.P., Rao, B.R. and Biswa, N.R., (1992). Morphology and surface sediments of the eastern continental shelf off Peninsular India. *G.S.I.Sp. Pub.No.29*, pp.229-243.
- Murthy, K.S.R., Rao, 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.
- 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
- 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.
- 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.
- Sirovich, L., (1987): Turbulence and the dynamics of coherent structures. Part I: Coherent structures. *Quart. Appl. Math.*, 45, 561– 571.
- Subba Rao, M., (1964). Some aspects of continental shelf sediments of east coast of India, *Mar. GFeol.*, V.1, pp.59-87.
- Vivier, F., Kelly, K. A. and Thompson, L. (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.



ResearchWork 3

Recent Trends of the Bay of Bengal (BOB) Tropical Depression and its Impact on Precipitation over the Region of India

1. Introduction

It is evident that climate change has caused global temperatures to rise considerably, especially since the 1950's (Houghton *et al.*, 2001). Precipitation has also exhibited long-term changes in many places of the world (e.g., Wang *et al.*, 2000) on a regional basis. Although the long-term change in the annual mean precipitation is not as significant as that of surface temperature (Hu *et al.*, 2003), remarkable features are evident in the changes in summer precipitation (Yatagai and Yasunari, 1994). Many studies have been carried out on the variability of precipitation over Asia, especially during the summer monsoon (e.g., Yatagai and Yasunari, 1994; Chen *et al.*, 1998; Li *et al.*, 2005; Liu *et al.*, 2005; Goswami *et al.*, 2006; Su *et al.*, 2006). For the summer precipitation over India, Goswami *et al.* in 2006 detected positive trends in the frequency and magnitude of extreme precipitation events (>100 mm per day) and a negative trend in the frequency of moderate precipitation events over central India from 1951 to 2000. In addition, Ho *et al.* in 2003 reported an increase in the frequency of heavy precipitation over Korea in recent years. Furthermore, sea surface temperature (SST) affects the precipitation over Asia by changing large-scale atmospheric circulation patterns and providing atmospheric water vapor (Nitta and Hu, 1996; Yang and Lau, 1998; Yoo *et al.*, 2004; Huang *et al.*, 2007), particularly for tropical regions, while the impact of soil moisture is more important for arid regions (Xue *et al.*, 1996). A connection has recently been discovered between the changes in the tropospheric temperature and precipitation over eastern China (Yu *et al.*, 2004; Xin *et al.*, 2006; Yu and Zhou, 2007), and a large cooling trend has appeared over East Asia, most prominently in the upper troposphere. The cooling is accompanied by a southward shift of the upper tropospheric westerly jet stream and a weakening of the East Asian summer

monsoon, tending to decrease precipitation over northern China and increase the precipitation over the Yangtze River valley. In my studies I have observed an increase in the precipitation over the continental terrain region over the northern BOB. It has been observed from the last 30 years of precipitation data and simultaneously the tropical depression and cyclone activities are also actively increased over the BOB region. It has been discovered that the formation zone of tropical depressions and cyclones has been displaced at a northward direction to the BOB and that the ITCZ is also displaced towards the southern part of the BOB at around 5° over region of terrain in the eastern part of India. Due to the formation of active depressions during the summer monsoons, the precipitation has thus been increased over Bangladesh, Burma, the Philippines and the eastern region of India.

2. Data and Methodology

The schematic representation of the methodology can be divided into two broad segments. The section on precipitation analysis considers temporal variations in total seasonal precipitation (1979-2009) data collected from GPCP precipitation from the APDRC website. The second segment of the study was selected for a detailed analysis and to showcase the displacement of the cyclogenesis ground and the frequency of tropical depressions over the BOB region using a superior cyclonic data record from UNISYS weather and the ITCZ study was made using the outgoing long-wave radiation data from the APDRC site.

The increased rate of precipitation over Bangladesh, Burma, the Philippines and the eastern region of India, (i.e. Terrain part of above the northern Bay of Bengal), was studied by interpreting the climate variations such as SST, the area of cyclogenesis and wind vectors etc. Data sets for the period 1979 to 2009 were integrated for analysis. The SST data were derived from the NOAA-OISST (National Oceanic & Atmospheric Administration, Optimum Interpolation Sea Surface Temperature). Data



sets for the period June to September (JJAS) have been selected for the study. All data sets were analyzed using Ferret graphical software, wherein all monthly anomaly data sets (of different periods) for precipitation, SST, wind and OLR were subjected for trend analysis.

3. Results and Discussion

Recent studies of precipitation during JJAS, and indicated from the special plots of 30 years precipitation data, show an increase over the terrain region of northern BOB region, particularly in Bangladesh, Burma and over a few regions of eastern India (Fig.1). From the study area it can be seen that precipitation has increased at a rate of approximately 0.4 mm, as shown in Fig. 2. The northern region of the BOB was studied, (i.e. 84°E to 97°E longitude and 18°N to 26°N latitude) and it was found that the amount of precipitation has increased by 1.6 mm over the 30 years of the trend analysis (Fig. 3). The precipitation trend analysis of the whole region except the above said region shows a decreasing trend such as 1.26 mm (Fig. 4). It indicates that, during the summer monsoon, there has been a decrease in the amount of precipitation over the area studied, except for a few areas such as the western and eastern continental regions of India, Pakistan, Bangladesh and Burma.

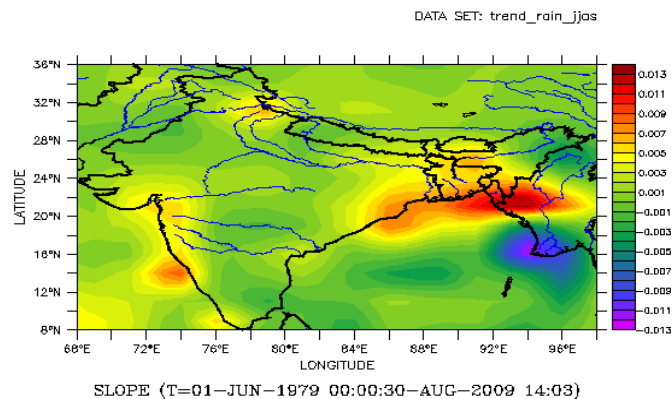


Figure 1 Special plot representing the trend slope

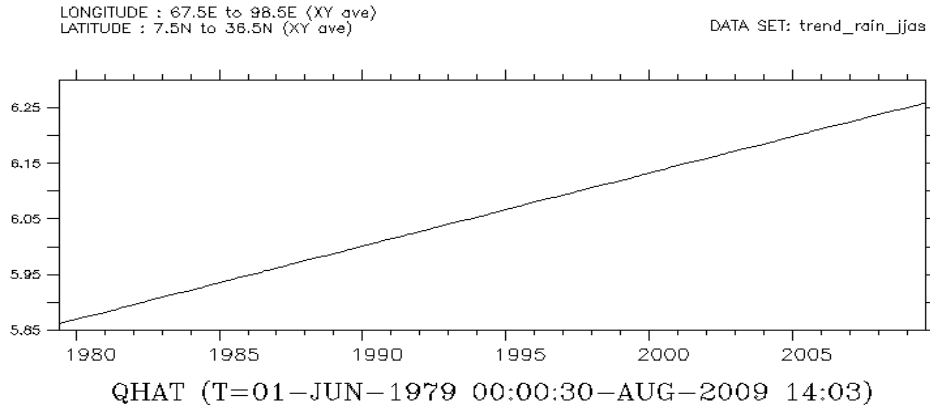


Figure 2 Trend plot of total study area

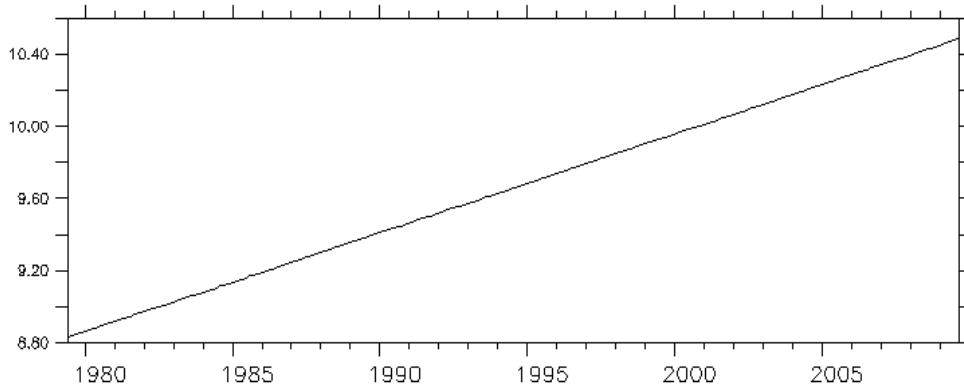


Figure 3 Trend plot of 84°-98°E and 18°-24°N

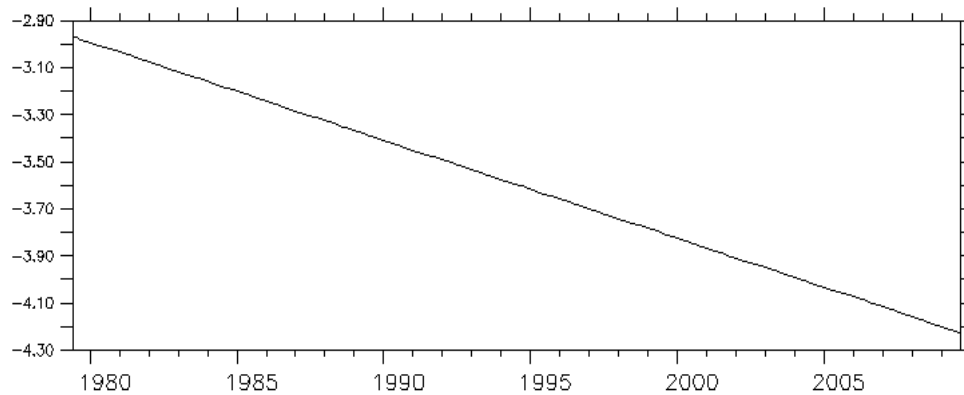


Figure 4 Trend plot of years except the domain 84°-98°E and 18°-24°N



From the EOF studies, it was found that the 1st EOF mode shows 24% of the variance and that the positive anomaly dominates over the region of terrain north-east of the BOB. The corresponding PC shows the inter-decadal oscillation pattern of precipitation (Fig.5).

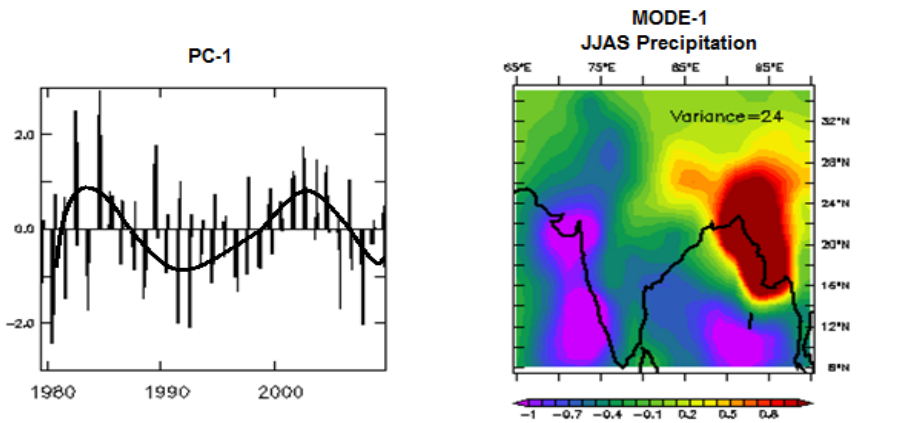


Figure 5 EOF 1st mode with corresponding PC

The 2nd EOF mode shows a variance of 18% and the dominant negative anomaly appearing in the south-west region of India and the north-east continent of BOB is represented in the corresponding PC-2 (Fig.6).

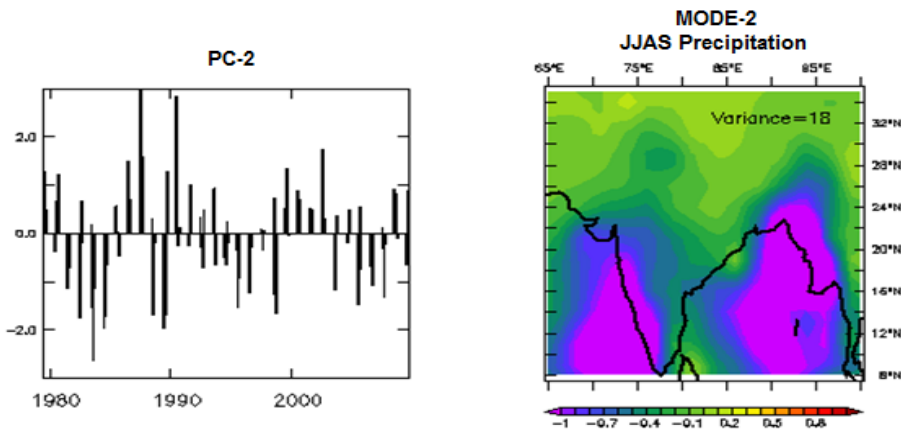


Figure 6 EOF 2nd mode with corresponding PC

The 3rd EOF mode explains about 10% of the variance. The dominated positive anomaly is showing over the northern terrain region of BOB. The corresponding PC of mode-3 shows a continuous increasing trend of the positive anomaly (Fig.7).

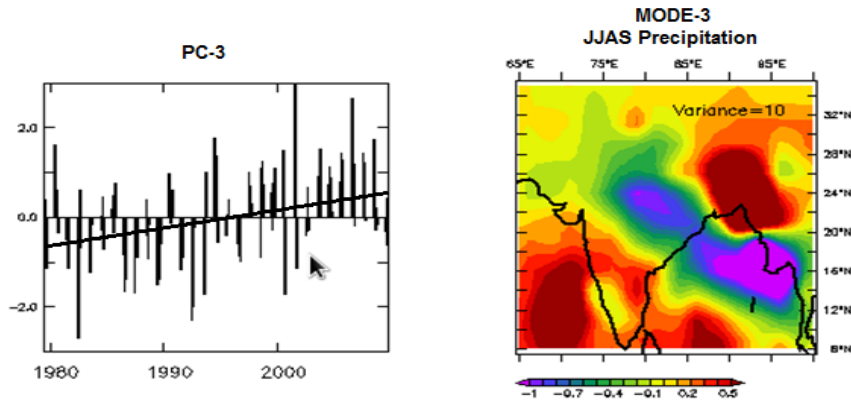


Figure 7 EOF 3rd mode with corresponding PC

To find the relationship between SST and precipitation we used a correlation study between different EOF modes of precipitation and SST. The first two modes showed limited correlation, but the 3rd EOF mode showed a good correlation of around 0.6. This indicates that the positive anomaly of precipitation towards the northern continent of the BOB is more dependent on the SST of BOB (Fig: 8).

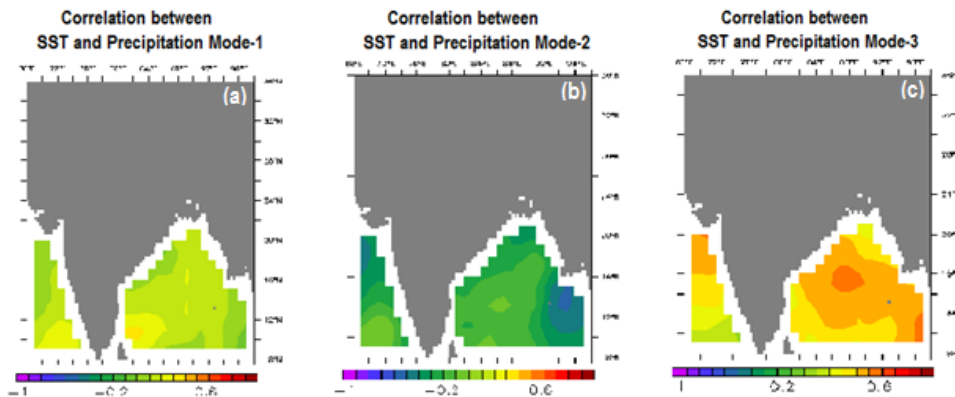


Figure 8 Correlation between SST and different Precipitation Modes

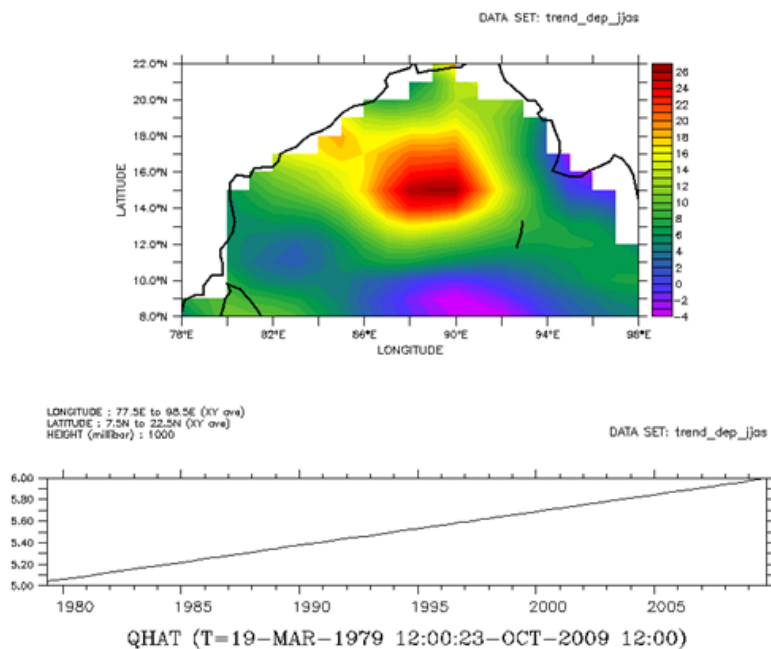


Figure 9 Special plot for the Cyclogenesis ground from 1979 to 2009 during the months of JJAS, for the same period

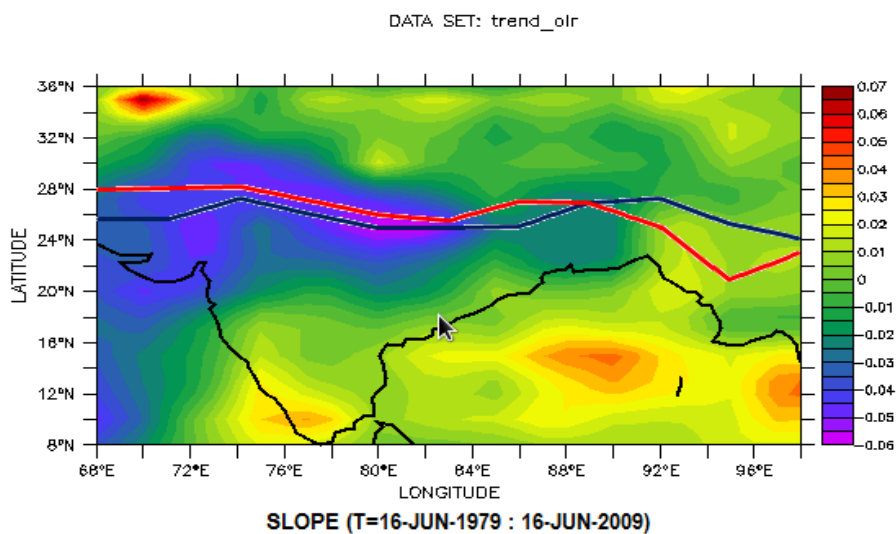


Figure 10 Displacement of ITCZ over the Indian region from 1979 to 2009

To study the wind convergence the OLR was analyzed for the same JJAS period over 30 years. In the special plot analysis, the negative value of OLR is apparent over the central Indian region. This indicates a greater convergence of wind has been taking place in recent years. From the 30 years of OLR studies, the trend analysis has found that the wind convergence position has been displaced; the western side of the studied region has been displaced to the north and the eastern region to the south. The recent position of wind convergence is displaced more towards the northern continent of the BOB at around 5° (Fig. 10).

We studied the vector plot of wind at 850Hpa. The anomaly of the wind components, such as u-wind and V-wind, (as per the averaged vector plot of the JJAS period for 30 years), indicates a pattern of circulation over the northern BOB region (Fig. 11).

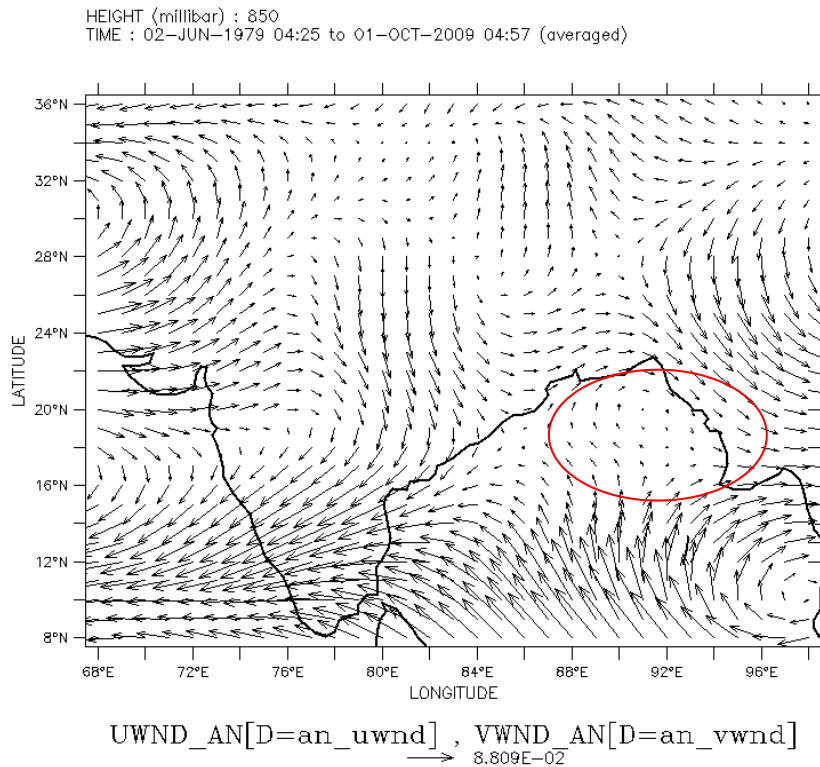


Figure 11 averaged vector plot of the JJAS for the period of 30 years



The special plot of zonal winds including humidity is positive towards the north-west of the region studied, as well as over the BOB and in the region of Burma. This shows that the zonal wind has carried more moisture towards the BOB in recent years (Fig. 12).

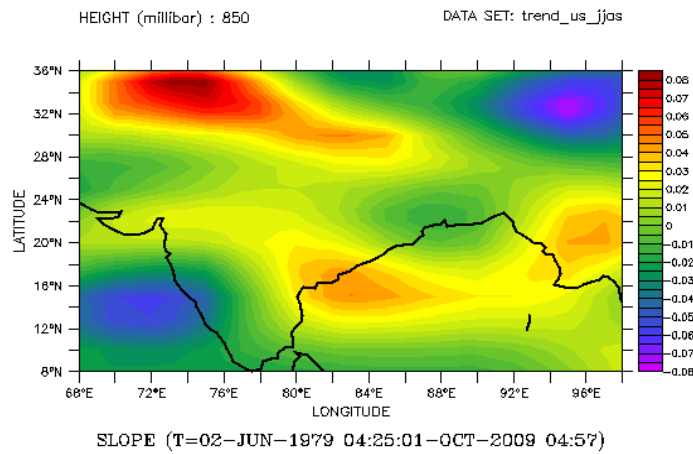


Figure 12 Special plot for the zonal winds including humidity

The SST study was made using the 30 years data, and the special plot of SST shows an increased trend of SST over the BOB region. The average SST change value is around 0.5°C (Fig. 13).

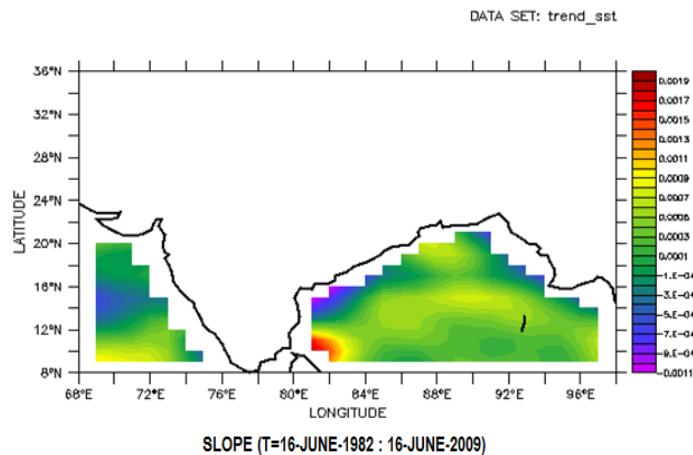


Figure 13 Special plot for SST

Due to the rise of SST and the formation of a prominent circulation pattern over the BOB region, depression activities were studied over the BOB for the period of JJAS over 30 years. In these studies it was noted that the depression trend has been showing positive over the BOB in recent years and that the cyclogenesis ground has been displaced upward (Fig. 14).

Correlation studies were made between different modes of precipitation, EOF and SST. The first and second modes of precipitation showed no correlation, but the 3rd EOF showed a good correlation with the central part of the SST in the BOB (i.e. 0.6° (Fig. 14)).

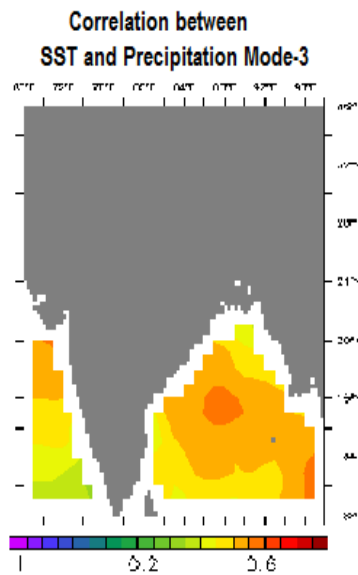


Figure 14 Correlation between SST and Precipitation Mode-3

The above results show that the increase in SST over the BOB enhances the zonal wind moisture transports towards the BOB and also wind convergence position is pulled towards the continent to the north of the BOB, which then leads to a depression over the BOB. The maximum precipitation therefore occurs over the terrain regions of Northern BOB.



4. Conclusion

The genesis ground of tropical depressions is displaced northwards over the Bay of Bengal. There has been an increase in the trend of tropical depression activities over the same region during the summer monsoons, which acts as a pooling action for summer monsoon precipitation over the terrain region of northern Bay of Bengal. From the OLR studies it was found that during summer solstices, the ITCZ over the eastern Indian region is displaced downward at around 5° from the trend analysis, which may trigger the recent tropical depressions over the Bay of Bengal. The tropical depression activities show an increasing trend in precipitation over Bangladesh, Burma, the Philippines and the eastern region of India from the 30 years of the observed precipitation data. The correlation studies between the 3rd EOF mode of precipitation and the SST shows a good correlation over the central part of the BOB (i.e. 0.6° (Fig 10)). The above results show that the increase in SSTs over the BOB enhance the zonal wind moisture transport towards the BOB and also the position of wind convergence is then pulled towards the continent to the north of the BOB, which leads to a depression over the BOB, and maximum precipitation occurs over the terrain regions of Northern BOB.



APCC **TECHNICAL REPORT** 2012-02

- Evaluation of Water Balance on a Regional Scale
- Analysis of Climatic Trends over South Asia
- Study of Aerosol Effect on Accelerated Snow Melting
- Aerosol Variability on Global and Regional Scales
- Evaluation of a Distributed Hydrologic Model

APEC Climate Center

12, Centum 7-ro, Haeundae-gu, Busan 612-020,
Republic of Korea
Tel: +82-51-745-3900 Fax: +82-51-745-3949
www.apcc21.org

바라봄



9 788997 333370
ISBN 978-89-97333-37-0
ISBN 978-89-97333-35-6 (세트)