NANSEN ENVIRONMENTAL RESEARCH CENTRE (INDIA)

A NON-PROFIT CENTRE WITHIN ENVIRONMENTAL AND CLIMATE RESEARCH IN THENANSEN GROUP OF RESEARCH INSTITUTIONS

ANNUAL REPORT 2010

REPORT FROM THE BOARD FOR 2010

Vision

Improve the understanding of climate change, its impact on the monsoon and ocean circulation and ecosystems in the Indian Ocean using measurements, satellite data and numerical ocean models. The influence of climate change on the coastal zone and its impact on socio-economy is also a research priority. Dissemination of our scientific results for the benefit of society and for the conservation of ecosystems is implemented.

Main scientific research focuses of NERCI are:

- Monsoon and ocean variability, Climate change, Sea level variations
- Marine Ecosystem studies, including algal blooms.
- Coastal Zone Management and Societal issues.

Organization

The Nansen Environmental Research Center India (NERCI) was established in 1999 as a joint venture between the Indian and Norwegian partners. NERCI conducts basic and applied research in ocean and atmospheric sciences funded by national and international agencies, organizations and industry. Core funding is received from the Nansen Centre and the Nansen Scientific Society, Bergen, Norway. NERCI is a non-profit research center within the Nansen Group of research centers, which includes:

- Nansen Environmental and Remote Sensing Center (NERSC), Bergen, Norway,
- Nansen International Environmental and Remote Sensing Centre, St. Petersburg, Russia.
- Nansen-Zhu International Research Centre, Beijing, China.
- Nansen-Tutu Centre for Marine Environmental Research, Cape Town, South Africa
- Nansen Scientific Society, Bergen, Norway
- Terra Orbit AS – a research company, Bergen, Norway.

NERCI capitalizes on the joint scientific expertise of the Nansen Group, which has more than 200 staff including 75 Ph. D and Master students.

Staff

The Centre has at present a staff of 14, which includes three full time scientists, four associate scientists, two project scientists, two full time and one part time Ph.D. students and two administrative staff.

Prof. Ola M. Johannessen and Lasse H. Pettersson of NERSC, Bergen and Prof. N. R. Menon and Prof. P.V. Joseph have been appointed as Associate Scientists of NERCI from 2010 and Dr. N. Nandini Menon, Sr. Scientist of NERCI is the Deputy Director.

Cover page: *The most prominent algae blooms in the Arabian Sea. Courtesy: N.R. Menon.*

Prof. N. R. Menon, one of the directors of NERCI has been selected as the Chairman, Research Advisory Committee of Ecology and Environment Committee. Kerala Govt. and is a Member, Assessment of Performance Appraisal of Centre for Marine Living Resources and Ecology, Ministry of Earth Sciences, Govt. of India and Vice-President, Marine Biological Association of India. Two scholars working under the supervision of Prof. N. R. Menon received Ph. D. in the Faculty of Marine Sciences from the Cochin University of Science and Technology in 2010, titled:

- Computer Vision Techniques in seafood quality control - Sri. S. Krishnakumar.
- Toxicant induced Antioxidant activity in *Oreochromis mossambicus* (Peter) – Sri. K. Kesavan.

Prof. P. V. Joseph was elected as the member of the International Advisory Panel in Meteorology of the Ministry of Earth Sciences, Government of India and continued to be Co-Chairman of the STORM Field Experiment's Implementation Committee. He is the elected President of the Ocean Society of India.

The NERCI Scientific Research Advisory Board monitors the research activities of NERCI and gives guidance for R&D activities as well as promotion of education and interaction with institutes in India and abroad.

Office and Environment

The office maintains an eco-friendly atmosphere for the staff to work.

An economy and environment committee has been constituted in 2010 with the Chairman, Vice chairman and the Executive Director as members, to support the management of the Center.

National and International Cooperation

Memorandum of Understanding (MoU) between Indian National Centre for Ocean Information Services (INCOIS) in Hyderabad, Nansen Environmental Remote Sensing Center, University of Bergen, Norway and NERCI signed in January 2008 is in operation. The MoU focuses on development of bilateral cooperation in operational oceanography and ocean modeling.

Under the MoU between Anna University, Chennai, India, Nansen Environmental and Remote Sensing Centre, Bergen, and NERCI implemented in 2007, Ms. Lakshmi Srikantha and Mr. Madhavan Narayanan, Ph.D. students from Institute of Remote Sensing, Anna University were trained at Mohn-Sverdrup Centre, NERSC, Bergen on HYCOM modeling applications for the Indian Ocean and geostatistical analysis of fish catch with remote sensing data respectively in 2010.

A renewal MoU with Cochin University of Science and technology (CUSAT), NERSC, UoB and NERCI was signed in February, 2010 providing Nansen fellowship, funded by the Nansen Scientific Society to three Indian Ph.D. students in ocean and atmospheric research, and also for inter faculty research.

MoU signing by NERCI with Cochin University of Science and Technology, (from left: Lasse H. Pettersson, Vice Chairman, NERCI, Dr. N. Chandramohana Kumar, Registrar, CUSAT and Prof. Ola M. Johannessen, Founding Director, NERSC, Bergen.

NERCI and NERSC has also signed MoU in February, 2010 with Toc H Institute of Science and Technology, J. C. Bose Center for Research and Advanced Studies, affiliated to CUSAT in the field of Environmental and Ecological Sciences for a period of five years.

Signing of MoU with TocH institution. (Starting from left: Dr. Job Kuruvila, Shri.K. Varughese, Prof. Ola M. Johannessen, Prof. P.J. Joseph and Dr. K. Ajith Joseph).

Dr. K. Ajith Joseph, Director of NERCI has been appointed as Associate Scientist at NERSC, Bergen, Norway from 2010.

Nansen Ocean colour group and Nansen Ocean modelling group were formed within the Nansen Group of Institutions.

Nansen Fellowship Program

Two full time and one part time Doctoral students are carrying out their studies at NERCI:

- Ms. Mary Swapna George - Validation of the HYCOM model for the Indian Ocean region and mesoscale ocean studies of the area.
- Ms. Smitha. A., has joined NERCI in 2010 as Senior Research Fellow as full time to work on Synergistic application of Scatterometer and OCM data for the studies of coastal upwelling, southwest coast of India.
- Mr. Chv. C. Jayaram who was working under this project has joined INCOIS in 2010 as Project Scientist and continue his Ph. D. work with NERCI as part time fellow to submit his thesis in 2011.

These studies are performed respectively at the Mohn-Sverdrup Centre at NERSC and University of Bergen, funded by Trond Mohn c/o Frank Mohn AS, Norway and at Cochin University of Science and Technology with funding from Space Application Centre – Indian Space Research Organization.

Outreach activities

NERCI conducted an international Ph.D. winter school from February 8 to 12, 2010 at Cherai, Cochin on the theme "*Indian Ocean: Challenges in Meteorology and Oceanography*" together with NERSC, Norway with financial support from Nansen Scientific Society. The details are available in the NERCI Technical Report No. 6, 2010. 48 students and 19 lecturers participated from India, Norway, France, South Africa and UK.

Financial Situation

NERCI is a non-profit research Center registered under Article 25 of the Company Act. NERCI was registered at the Consultancy Development Centre, of Dept. of Scientific and Industrial research (DSIR) in 2007. The authorized share capital of NERCI is INR 20,00,000.

The Nansen Center in Norway supported NERCI in financial year 2010-11 with a grant equivalent of INR.18,79,125 (29360 Euro). The total project grant received during the year 2010 is INR.21,79,125 from various projects and a net balance of INR 2,09,238/- is reserved for the financial year 2011.

Prospects for 2011

NERCI enters 2011 with plans for increasing their national and international cooperation, particularly strengthening the cooperation within the Nansen Group and the Indo-European research cooperation. Ph.D. candidates from India will visit NERSC, Bergen to work on ocean modeling and ocean color research.

The successful completion of UNEP project in 2010 and the ongoing national projects will help to get similar projects.

Cochin, 12th May 2011.

The Board of Directors

NANSEN ENVIRONMENTAL RESEARCH CENTRE (INDIA), COCHIN, FOUNDED IN 1999

http://www.nerci.in

SCIENCE REPORT FOR 2010

Intra seasonal variability of Ekman mass transport in the southeastern Arabian Sea using wind observations from OCEANSAT–2 Scatterometer

K. Ajith Joseph, Director, NERCI

Lasse H. Pettersson, Leading Scientist, NERSC

Smitha. A, Senior Research Fellow, NERCI

Ch.V. Chiranjivi Jayaram, Senior Research Fellow, NERCI

Prof. A. N. Balchand, Dept. of Physical Oceanography, CUSAT

Ekman transport occurs in the ocean due to winds often along the coast, causing upwelling or downwelling that influence the biological productivity of the ocean. The coastal areas of the Arabian Sea are major zones of upwelling during the southwest (SW) monsoon. Off the southwestern coast of India, upwelling starts even before the onset of the summer monsoon and continues till it ends in September. Here we have estimated the monthly Ekman mass transport in the southeastern Arabian Sea for the period from November 2009 to October 2010 using wind data from the scatterometer onboard the Indian Oceansat-2 satellite. The objective of this study is to monitor and understand the intra seasonal variability of Ekman mass transport in this region as a part of the Oceansat-2 data utilization programme funded by SAC-ISRO.

Major features of the upwelling are the upward displacement of the 20°C isotherm by nearly 100m and the invasion of nutrient-rich waters on the shelf off the west coast and the reduction of sea-surface temperature by 4-5°C with the development of rich phytoplankton blooms (Johannessen *et al*. 1987, Rao and Griffith, 1998). From the studies of Shetye *et al*. (1990) and Haugen *et al*. (2002), it was observed that the upwelling along the SW coast of India starts by February/March; however, chlorophyll-*a* concentration and the intensity of upwelling in this region strengthened with the onset of SW monsoon (Jayaram *et al*., 2010) emphasizing the importance of wind and Ekman pumping in the entrainment of subsurface nutrients towards the surface.

The study region (figure 1 and 2) is between 5-15°N latitude and 70-78°E longitude in the southeastern Arabian Sea off the southwestern coats of India. Winds over Arabian Sea reverse seasonally and are much stronger during the summer monsoon than during winter monsoon. March-April and October are months of transition between the monsoons, and winds are weakest at these times (Shetye and Gouveia, 1998). As the west coast of India is oriented along the meridional axis with an angle of 24° with north (Shetye, 1984), it is imperative to estimate the meridional Ekman transport for coastal upwelling. Also wind direction during the SW monsoon is north-northwesterly along the coast line to the south of 15°N.

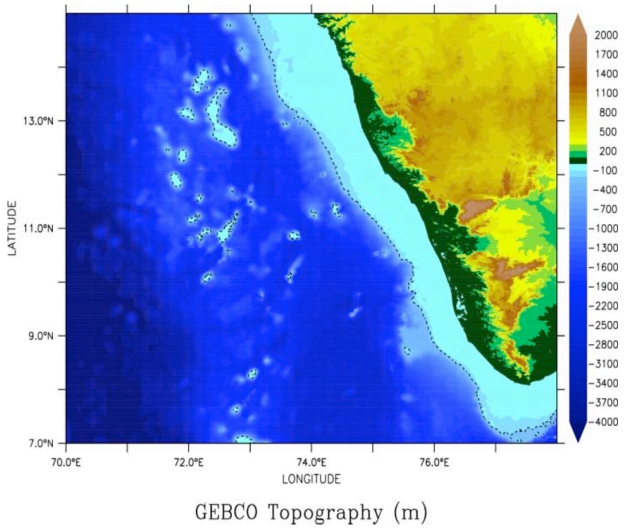


Figure 1. Bathymetry of the study region with 200 m depth contour shown in dotted line (south-eastern Arabian Sea).

Daily wind data at 50kmx50 km resolution (Level 3 data) were obtained from the Oceansat-2 portal of the National Remote Sensing Centre, Hyderabad. Ekman mass transport has been computed after calculating the monthly mean wind and a distance-weighted average remapping is applied to reduce the lacunas in the wind data records. Only the maps for December, February, June and August months are shown here (Figures 2 and 3 below).

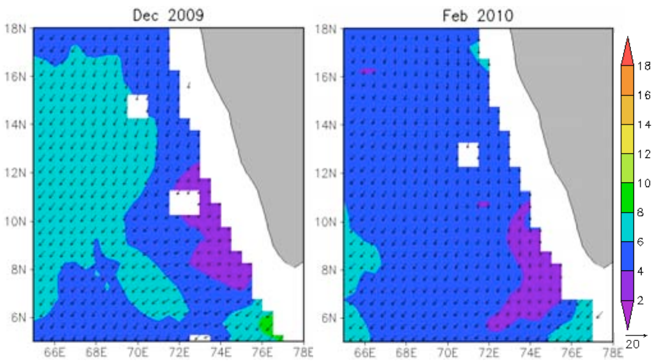


Figure 2a. Mean monthly wind (m/s) over the southeastern Arabian Sea during December 2009 and February 2010.

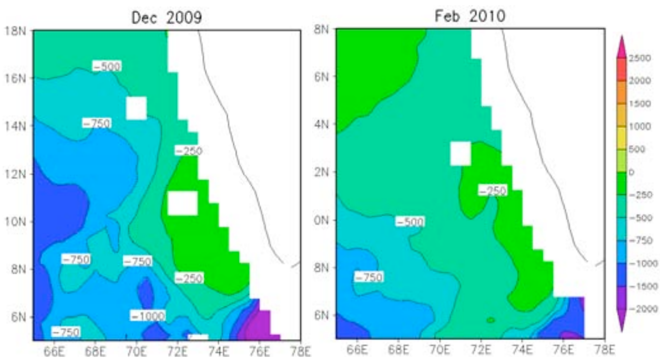


Figure 2b. Estimated monthly Ekman mass transport (kg/m^{2}s) in the southeastern Arabian Sea during December 2009 and February 2010.

Results

During November 2009, the mean wind was northerly above 12°N latitude, and northwesterly below. During this time offshore Ekman mass transport was observed all along the southwest coast with the strongest transport near 14°N latitude and off the southern tip of India. By December 2009, the wind becomes northeasterly (Figure 2a) and a slight decrease in the offshore mass transport was observed near the coast (Figure 2b) while it increased further west and off the southern tip of India. No much variation was observed during January 2010 except for an increase of negative Ekman mass transport in southwestern region. An overall decrease of wind speed was observed during February 2010 (Figure 2a) together with a decrease of offshore transport (Figure 2b) off the southern tip of India.

During March and April 2010 the wind was weak, and hence the Ekman mass transport was minimum in the southeastern Arabian Sea. By May, the wind get organized to northwesterly above 9°N latitude while in the south it was westerly and speed increased slightly. An increase of offshore mass transport was observed between 7°N and 11°N latitude, whereas positive Ekman mass transport was observed in the south.

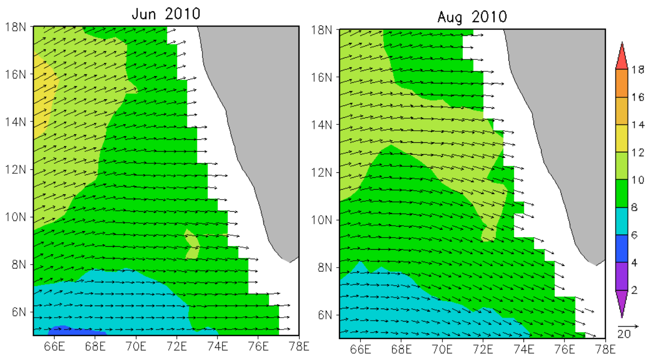


Figure 3a. Mean monthly wind (m/s) over the southeastern Arabian Sea during June and August 2010.

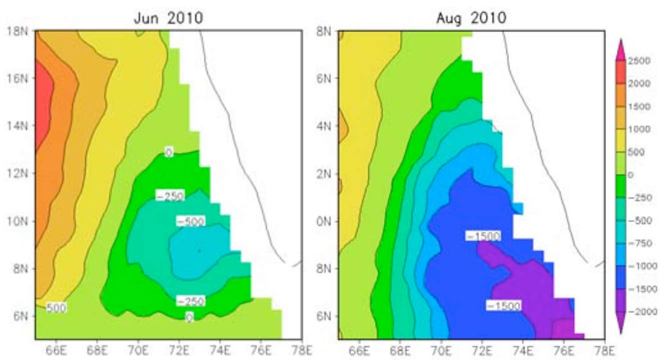


Figure 3b. Estimated monthly Ekman mass transport (kg/m^{2}s) in the southeastern Arabian Sea during June and August 2010.

During June 2010, when the wind was strong and west-northwesterly below 12°N latitude (Figure 3a), Ekman mass transport (Figure 3b) was negative (reached upto -750 kg/m^{2}s between 8-10°N latitude) thus inducing upwelling. Ekman mass transport becomes positive to the west of 68°E longitude. By July 2010, when the wind becomes westerly, offshore mass transport decreases and shifts southward. During August 2010, the wind turns northwesterly (Figure 3a) favoring strong offshore Ekman mass transport and upwelling that extend northward to 17°N latitude. Offshore mass transport of about -2000 kg/m^2s was located near the SW coast (Figure 3b). In September 2010, the wind turns westerly in the southern region while it remains northwesterly in the north. Offshore mass transport decreases in the southern part while north of 11°N latitude it was high, with the maximum of ~-1000 kg/m^2s located at 12°N latitude/ 68°E longitude. By October, wind speed decreases except near the southwest coast while the direction is generally north-northwesterly. Ekman mass transport increases below 10°N latitude with the maximum offshore transport of about -2500 kg/m^2s located in the south during this time.

Conclusion

Based on the analysis of Ekman mass transport, prominent region of upwelling along the southwest coast of India has been identified between 8°N and 14°N latitude. It has been observed that southwest monsoon from June to September is the major upwelling season in the southeastern Arabian Sea below 14°N latitude (near the southwest coast of India). The strongest offshore Ekman mass transport of about -2000 kg/m^2s was observed during August in this region due to the favorable wind conditions. The pre monsoon period is found to be a weak upwelling season when the wind is weak and variable with feeble offshore mass transport. Moderate offshore transport was observed along the southwest coast between November 2009 to February 2010 and October 2010. At the same time strong offshore transport was prevalent off the southern tip of India. Thus it is proved that scatterometer observations can be an effective tool for computing Ekman transport and monitoring associated coastal upwelling.

References:

Haugen, V. E., Johannessen, O. M., and Evensen, G., 2002, Mesoscale modeling of oceanographic conditions off southwest coast of India, *Proc. Ind. Acad. Sci. (Earth and Planetary Sci.)*, 111, No. 3, pp. 321-337.

Jayaram, C., Neethu Chacko, K. Ajith Joseph, and A. N. Balchand, 2010, Interannual variability of upwelling indices in the southeastern Arabian Sea: A satellite based study, *Ocean Sci. J.*, 45(1): 27-40.

Johannessen, O. M., Subbaraju, G. and Blindheim, J., 1987, Seasonal variations of the oceanographic conditions off the southwest coast of India during 1971–1975, *Fiskdirekt. Skr. Ser. Havunders*, 18: 247 – 261.

Rao, T. S. S., and Griffiths, R. C., 1998, Perspectives on oceanography, UNESCO, Paris, France, 187p.

Shetye, S. R., 1984, Seasonal variability of the temperature field off the south-west coast of India, *Proc. Ind. Acad. Sci. (Earth and Planetary Sci.),* 93: 399 – 411.

Shetye, S. R., Gouveia, A. D., Shenoi, S. S. C., Sundar, D., Michael G. S., Almeida, A. M., and Santanam, K., 1990, Hydrography and the circulation off the west coast of India during southwest monsoon 1987, *J. Mar. Res.*, 48: 359 – 378.

Shetye, S. R., Gouveia, A. D., 1998, Coastal circulation in the north Indian Ocean. Coastal segment (14, W-S), *The Sea*, Volume 11 (Allan R. Robinson and Kenneth H. Brink, eds.), John Wiley and Sons, Inc, Ch. 18, pp. 523–556.

Climate Change in India

P. V. Joseph, Professor Emeritus, Dept. of Atmospheric Science, CUSAT and Associate Scientist, NERCI

Introduction

There was Climate Change in India in several climatic elements during the most recent 150 years. This period had good observational networks to monitor the climatic change. The change in climate has been mainly of two types: (a) Type-1: Decadal change (a few decades of increase followed by a few decades of decrease in the climatic element, a sort of long period oscillation) and (b) Type-2: Long term increasing or decreasing trends in the climatic element. Observed climatic changes in Indian summer monsoon and cyclones are discussed in this paper.

Monsoon

India gets three fourths of its annual rainfall during the south west (summer) monsoon season taken as the period 01 June to 30 September. According to the India Meteorological Department, if the all India monsoon rainfall goes below 10% of its long term average in a year, it is declared as a drought year. All India monsoon rainfall had very little long term trend during the period of good rainfall measurements (1871 to date), but it had a prominent decadal change, first reported by Joseph (1976). This is a type-1 change as may be seen in figure 4 (taken from IITM web site www.tropmet.res.in).

During the 3 decade long DRY epochs 1901-1930 and 1961-1990, India had droughts on average once in about three years and tropical cyclones of Bay of Bengal had preferred northward movement. In contrast during the 3 decade long WET epochs 1871–1900 and 1931-1960 the frequency of droughts had been on average once in 10-15 years only and the Bay cyclones had preferred westward motion. Thus during the 120 years 1871 to 1990 we had regular 30 year epochs alternating between DRY and WET regimes. With a sparser network of rain gauge stations to monitor the monsoon, this regular 30-year epochal nature of the monsoon could be extended backwards to the 30 year period prior to 1871 which was a DRY epoch. Such a regular epochal pattern has undergone a climate change in recent years. The 30 year period 1991 to 2020 was expected to be a WET epoch. Although the decade 1991-2000 had no monsoon droughts, during the next decade beginning in 2001 we had three drought monsoons (years 2002, 2004 and 2009).

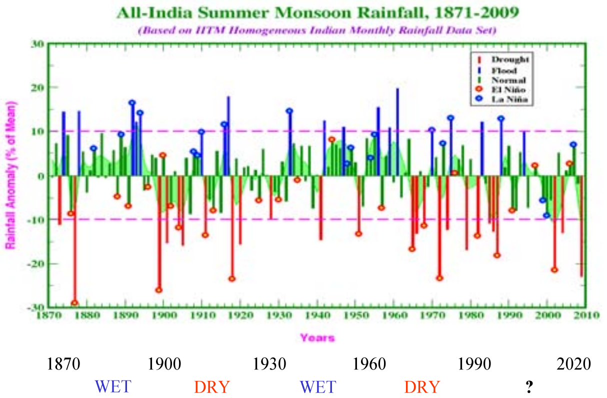


Figure 4. Alternate 30 year epochs of DRY & WET monsoons. Dry epochs have frequent drought years.

There is an interesting scientific finding named Tropospheric Biennial Oscillation (TBO) – Chang and Li (2000) and references in that paper. Soon after a year of DRY monsoon like 1972 (at times after two consecutive DRY monsoons like 1965 and 1966), the Sea Surface Temperature (SST) of the ocean around India develops a warm anomaly and the SST of west Pacific ocean a cold anomaly and the following Indian monsoon is normal or WET. This is very good for India and makes it different from Africa where drought years have occurred during successive years (10 to 15 years in a row as in the recent Sahelian drought incidences or the seven consecutive years of drought described in the Bible- Genesis 41). Indian food managers have to store food grains to meet the needs of one or at most two consecutive drought years only which is being done during the last three decades.

South west monsoon sets in over Kerala at the southern tip of India on 01 June (long term average of more than 100 years) and then moves north and covers about 90% of India in about a month. Monsoon onset dates over Kerala has considerable variability from year to year (earliest onset date was May 11 in 1918 and the most delayed one was June 18 in 1972). Monsoon onset date (Kerala) had a slow decadal (type-1) climate change. Around 1900s Kerala used to get monsoon onset during the second week of June. Slowly monsoon onset became earlier and in the 1950s and 1960s monsoon onset was around the middle of May. Monsoon onset is now back to the long term mean date of 01 June. Monsoon onset date had no long term trend (see figure 5 and Joseph *et al.*, 1994).

On 26 July 2005, Mumbai (in a large area of about 10 Km around its airport Santa Cruz) experienced a meteorological disaster - exceptionally heavy one day rainfall. The 24-hour rainfall recorded there was 94 centimetres on that day. A recent study by Goswami *et al* (2006) using the 1deg lat x 1deg lon gridded daily rainfall data showed that over central India *(lat 16.5^{o}N-26.5^{o}N, lon 74.5^{o}E-86.5^{o}E)*, instances of such very intense one day rainfall has had an increasing trend (type-2 Climate Change) during the period of study 1951 to 2003 as may be seen from figure 6, which is most likely the effect of global warming.

Some of the meteorological subdivisions of India namely Gangetic West Bengal, West Uttar Pradesh, Jammu and Kashmir, Konkan and Goa, Madhya Maharashtra, Rayalaseema, coastal Andhra Pradesh and north interior Karnataka have experienced significant long term (1901 to 2003) increasing trends (type-2 climate change) in monsoon rainfall and Jharkhand, Chattisgarh and Kerala significant decreasing trends (Guhathakurta and Rajeevan, 2008). The decreasing trend of monsoon rains over the slopes of the Western Ghats in south Kerala is much higher than the rest of Kerala as shown by the long rainfall records at Peermade (decrease of 2.6% per decade).

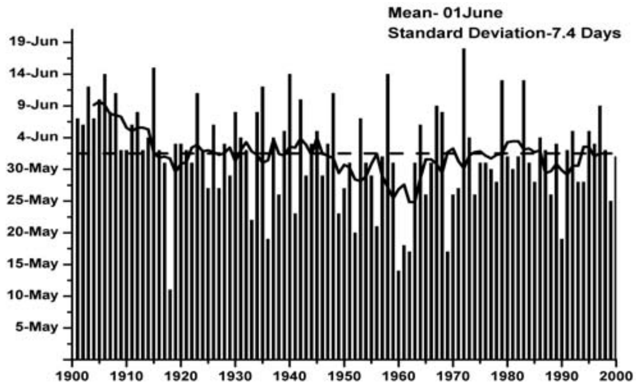


Figure 5. Subjectively determined IMD dates of onset of monsoon over Kerala 1901 to 2000. 100 year mean is shown by the broken line and the seven year moving average by the continuous line.

Monsoon Depressions are associated with large areas of heavy rainfall. These synoptic systems with life duration 5 to 7 days form over the head (north) Bay of Bengal and move in a west-north-west direction, at times taking the heavy rains of 20 to 30 centimetres per day in their south-west sector to Rajasthan in northwest India and even to Pakistan. The number of these depressions in a monsoon season has undergone a type-2 climate change during the last 120 years (see figure 7 from the ongoing study by Joseph, Krishnamohan and Mohankumar). The long term decreasing trend is marked in the figure. Around 1900s we used to get about 12 depressions during a monsoon season, now we get only about 4. A type-1 climate change (of period about 4 decades) in monsoon depression frequency is superposed on this long term trend.

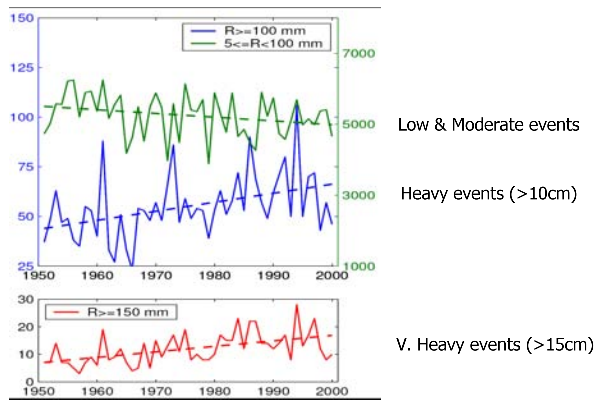


Figure 6. Trends in frequency of one day heavy rainfall over central India (lat 16.5°N -26.5°N, lon 74.5°E-86.5°E).Goswami, et al., (2006)

Tropical Cyclones

Tropical cyclones occur in Arabian Sea and the Bay of Bengal (north Indian Ocean) during the pre-monsoon season April and May and the post-monsoon season October to December. In a severe cyclone, an area extending radially about 60 kilometres from the cyclone center has very high wind and rain damage potential. The strong winds in this core area forces the sea surface to rise through 10 to 13 metres as the cyclone approaches some parts of the Indian coastline. This phenomenon called "Storm Surge" where the elevated sea enters and inundates the coastal area 15 to 25 kilometres inland is responsible for most of the human fatalities and a major part of the property damage. The sea level remains elevated for several hours in a storm surge unlike in a Tsunami. The Storm Surge is particularly disastrous when the storm approaches a coast at the time of high ocean tide which occurs twice a day (semi-diurnal oscillation of sea level).

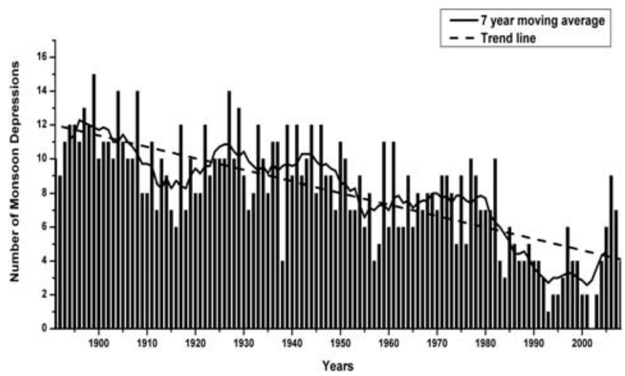


Figure 7. Number of Monsoon Depressions in a monsoon season (1891 to 2008) and their trend and seven year moving average.

In recent years, Orissa in India was hit by a super cyclone in October 1999. There was another one (named SIDR) in the Bay of Bengal of almost super cyclone intensity in November 2007. Arabian sea did not have a single super cyclone during the last 100 years but one such formed in 2007, the cyclone named GONU (the countries around Indian seas began naming cyclones only from 2004) which passed close to Oman coast and caused considerable destruction there.

On an average, about 6 tropical cyclones have genesis in a year in the Indian seas (north Indian Ocean). The annual number of tropical cyclones in the Indian seas had a prominent type-1 climate change– a Four Decade Oscillation (FDO). The temporal phases of the FDO in tropical cyclones and monsoon depressions are almost the same (maxima and minima are in about the same years) - taken from the ongoing work by Joseph, Krishnamohan and Mohankumar. During the last 120 years although the annual frequency of cyclones has shown only a weak decreasing trend, the intensity of cyclones has shown a marked increasing trend (type-2 climate change) most likely due to the increasing sea surface temperatures in global warming (see figure 8).

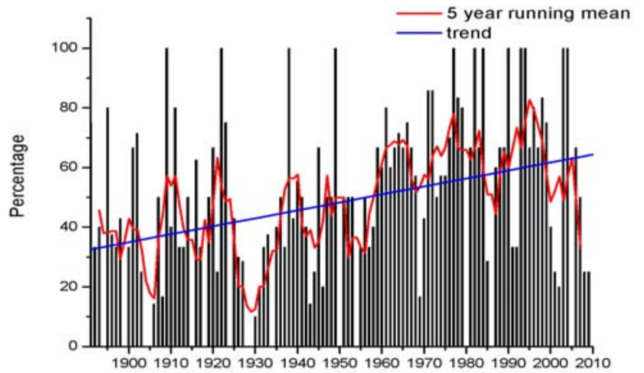


Figure 8. Percentage of annual number of tropical cyclones (wind 34kts & more) becoming severe Cyclones (wind 48 knots & more)– from ongoing study by Joseph, Krishnamohan and Mohankumar

Sea level rise

One of the major impacts of global warming is the sea level rise. Unnikrishnan and Shankar (2007) estimated sea level rising trends for the Indian ocean using the data spanning several recent decades of Aden, Karachi, Mumbai and Kochi in the Arabian sea and of Vishakhapatnam in the Bay of Bengal. The sea level rise estimated from these stations is between 1.06 and 1.75 mm per year with an average of 1.29 mm per year. The estimated trends are comparable with the global estimates as reported in IPCC reports. For instance, Douglas (2001) found a global mean of about 1.8 mm per year over a 70 year period using data of 25 stations chosen from stable land regions.

Summary

Available records of more than 100 years have shown that climate change of large amplitude has occurred in India in rainfall amounts, tropical cyclone frequency and in the height of sea level. One day very heavy rainfall occurrences that cause destruction of property in small areas have increased in frequency over a large part of central India. Frequency of severe tropical cyclones that cause widespread destruction of property and loss of life in coastal areas had an increasing trend. The study by Rajendran and Kitoh (2008) using a super high resolution

General Circulation Model (about 20 Kilometer spatial resolution) which has reproduced the monsoon rainfall of India and its climate change of the recent past realistically, has shown that the monsoon rainfall of June to September will have an increasing trend in most parts of India but a decreasing trend over the southwest coastal belt particularly in the rain rich Kerala State during the 21st century. They have also shown a clear shift to warmer surface air temperatures in most parts of India, towards the end of the same century.

References:

Chang, C. P., and Li, T., 2000, A theory for the tropical Tropospheric Biennial Oscillation, *J. Atmos. Sci*., 57: 2209-2224.

Douglas, B.C., 2001, Sea level change in the era of the recording tide gauge, in Douglas B.C., Keamey M.S. and Leatherman S.P. (Eds.), Sea vLevel Rise – History and Consequences, Academic Press, pp 37-64.

Goswami, B. N., Venugopal, V., Sengupta, D., Madhusoodanan, M. S., and Prince, K. Xavier, 2006, Increasing trend of extreme rain events over India in a warming environment, *Science*, 314: 1442-1445.

Guhathakurta, P., and Rajeevan, M., 2008, Trends in the rainfall pattern over India, *Int. J. Climatol*., 28: 1453-146.

Joseph, P. V., 1976, Climate Change in Monsoon and Cyclones 1891-1974, *Proc. of IITM symposium on Monsoons*, IITM Pune-5, India, pp 378-387.

Joseph, P. V., Eischeid, J. K., and R. J. Pyle, 1994, Interannual variability of the Onset of the Indian Summer Monsoon and its association with atmospheric features, El Nino, and Sea Surface temperature anomalies, *J. Climate*, 7: 81-105.

Rajendran, K., and Kitoh, A, 2008, Indian summer monsoon in future climate projection by a super high resolution Global model, Current Science, 95, 1560-1569.

Unnikrishnan, A. S., and Shanker, D., 2007, Are sea level rise trends along coasts of the north Indian ocean consistent with globaltimates?, Global and Planetary Change, 57, 301-307.

Role of Wind in the generation of chlorophyll-a in waters of south eastern Arabian Sea

Ch. V. Chiranjivi Jayaram, Ph.D Student, SAC-ISRO Project, NERCI-CUSAT

K. Ajith Joseph, Director, NERCI

Lasse H. Pettersson, Leading Scientist, NERCI/NERSC

Winds over the oceans play an important role in determining stratification – destratification processes that could influence the generation of chlorophyll-a associated with phytoplankton blooms. Stirring of upper layers by convective overturn and role of winds are the major mechanisms regulating phytoplankton growth (Cushing 1975, Kim *et al*., 2007). Conditions favourable for the blooms are often related to wind speed; though there exist a relation between wind stress and the timing of blooms, however the mechanisms that link them are still unclear (Kim *et al*., 2007). In order to understand these mechanisms, chlorophyll concentrations for the South Eastern Arabian Sea (SEAS) (see Figure 1) (Lat: 7º–15ºN; Lon: 70º-78ºE) are compared to wind stress during the upwelling season. Apart from wind and chlorophyll, mixed layer variations were also considered to study its role in upwelling that contributes to phytoplankton bloom.

The chlorophyll data for this study is obtained from SeaWiFS and MODIS-Aqua and wind stress is derived from QuikSCAT measured wind speeds. Gridded temperature and salinity profiles from CORIOLIS were used to compute mixed layer depth in the region based on Levitus (1982) density criterion. Data for the years 2000 to 2008 were considered to ascertain the temporal relation between wind stress and chlorophyll. Wind data is filtered using an 8-day moving average to match the temporal resolution of chlorophyll. A hypothesis is put forward, that chlorophyll begins to bloom as and when wind stress start weakening. Kim *et al*., 2007, found similar hypothesis for Japan/East Sea. The rationale behind this hypothesis is that, gradual decrease in wind stress, stabilizes the water column thereby upwelling nutrients, which are utilised by phytoplankton in the presence of sunlight resulting in enhancement of productivity. In this whole chain of events, however there should be a time lag between decrease in wind stress and increase in chlorophyll concentration, which allows phytoplankton cells to grow to a measurable density. The 8 day chlorophyll and wind stress were normalized with the maximum value for each year and plotted as a time series graph for respective years (Figure 9) so as to analyse the functional time lag.

Figure 9, shows a time lag, approximately 2 – 3 weeks between the occurrence of the highest peak of chlorophyll and decrease in wind stress during the southwest monsoon, only exceptions being the years 2004 and 2006. Years 2007 and 2008 were observed to be abnormal years with respect to chlorophyll concentration. It is observed that chlorophyll remained very low for the region but there were some unusual spurt in the concentration for a week in both the years, which resulted in vast decrease in the normalized values for the rest of the year. In-case if it was observed for only one particular year, it could be treated as an error in the data and could have been flagged, but this unusual spike was observed in the subsequent year of 2008 and therefore had to be considered.

Extensive quality check had been undertaken to confirm the values using data from SeaWiFS, MODIS onboard both Terra and Aqua and it is confirmed that the increase in chlorophyll concentration for a short period is indeed correct value and not an outlier. Another noticeable fact in chlorophyll pattern in all the years is that there exist two peaks except during 2006, 2007 and 2008 where there is no primary peak observed.

A close scrutiny of results from these figures explicitly reveals the existence of intra-seasonal oscillations, given that the area under study is limited alongshore the south west coast of India in comparison with numerous other upwelling regimes and is likely to carry an influencing factor in determining the extent of local fisheries. In order

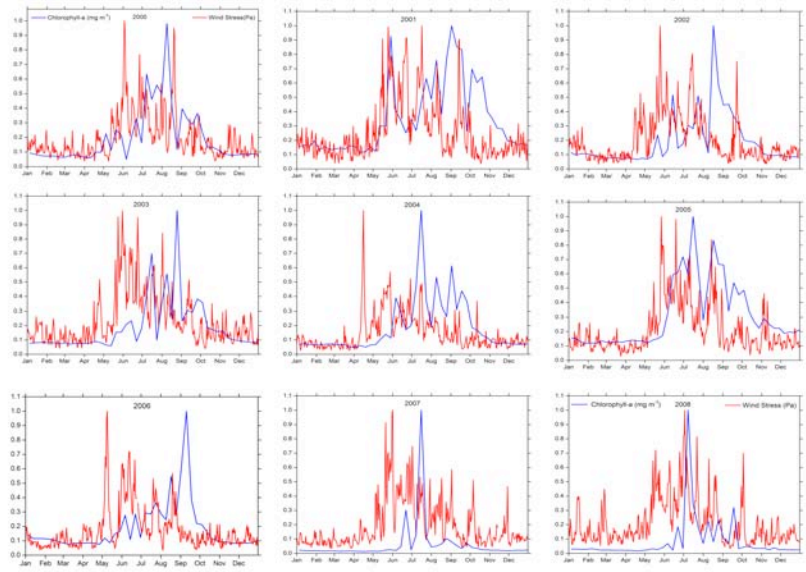


Figure 9.Time series graphs of 8 days average chlorophyll-a and wind stress in the South Eastern Arabian Sea.

to further understand the processes especially during the upwelling season between wind stress, mixed layer depth and chlorophyll-a, time series analysis is carried out (figure not given) for the SEAS during the southwest monsoon season.

It was noticed that, during all the years whenever the wind stress was high, the subsequent chlorophyll concentration was less and vice – versa. Similarly, whenever there is an increase in the wind stress, then the MLD deepened during the subsequent weeks and shoaled when a drop in the wind stress is observed. This proves our earlier hypothesis that increase in chlorophyll-a concentration is feasible with drop in wind stress, following thorough mixing and upwelling of nutrients to the surface. From the analysis of 8 years data, it is observed that chlorophyll concentration is appreciable in the SEAS region during 2000, 2001 and 2005, while 2007 was least productive among the monsoon period.

Conclusions

A time lag of approximately 2 – 3 weeks was observed between the occurrence of the highest peak of chlorophyll and decrease in wind stress during the southwest monsoon. Analysis of eight years of data revealed that chlorophyll concentration is appreciable in the SEAS region during 2000, 2001 and 2005 monsoon periods.

References:

Cushing, D. H., 1975, Marine Ecology and Fisheries, Cambridge University Press, Cambridge. 278pp.

Kim, H. C., Sinjae, Yoo, and Im Sang Oh, 2007, Relationship between phytoplankton bloom and wind stress in the sub-polar frontal area of the Japan/East Sea, *J. Mar. Sys.*, 67: 205 – 216.

Levitus, S., 1982, Climatological atlas of the world ocean, NOAA Professional Paper 13.

Sub Monthly Oscillation (SMO) mode of SST in the North Indian Ocean during boreal summer

A. Jayakumar, Scientist, NERCI,

Ola M. Johannessen, Founding Director, NERSC

The Indian Ocean has a unique tropical basin bounded by a continental landmass to the north. The combined effects of differential heating between the land and the ocean, convection and the Coriolis force resulting in a seasonal reversal of winds over this basin, make the Indian Ocean unique among other global Oceans. The interannual variability in the seasonal mean (eg. rainfall, wind) is modulated by variability in intraseasonal time scale. There are two clear peaks of atmospheric variability on the intraseasonal scale, namely the 10-30 day or Sub Monthly Oscillation (SMO) and the 30-90 day variability (associated with active-break monsoon cycle (Goswami, 2005) and Madden Julian Oscillation (MJO) (Madden and Julian, 1994). During summer, eastward propagating MJO signals are less coherent with the northward propagating 30-90 day variability in the North Indian Ocean. Several studies have looked at the importance of 30-90 day variability and its ocean response, but relatively less effort was given in the past to understand the SMO, which also influence the nature and intensity of monsoon rainfall (Chatterjee and Goswami, 2004).

Significant part of SMO comprises the 10-20 day variability or Quazi biweekly Mode (QBWO). This mode originates from the western Pacific and propagates westward to the Indian Ocean. Its horizontal structure exhibits a slight southwest-northeast tilt and vertical structure resembles the structure of the first baroclinic mode showing northwest tilt with height (Chen and Sui, 2010). The asymmetric distribution of this mode, with a 5° northward shift of the line of symmetry due to background flows which includes, mean summer atmospheric flow and easterly vertical shear, as well as large scale heating in the monsoon trough confined in the northern hemisphere (Chen and Sui, 2010). It has a low-level wind structure characteristic of double vortex structure with a westward phase speed of ~4.5m/s (Chatterjee and Goswami, 2004).

SMO can make significant 10–30 day variability in SST over different regions of Indian Ocean, which may explain about 30 to 50% of total intraseasonal SST variability (Han *et al*., 2006). But Han *et al*., (2006) studied only SST in the different boxes and not in the whole of Indian Ocean. A systematic study in the oceanic response to SMO over north Indian Ocean is lacking, which is the focus of this study.

North Indian Ocean SST response concurrent with the SMO

Regions of intra seasonal SST maxima in SMO mode are observed in STI (Southern Tip of India, 75°–78°E, 5°–9°N), Somalia (Somalia upwelling, 48°–58°E, 5°–11°N), NBoB (North Bay of Bengal, 80°–95°E, 15°–23°N) and Oman (Oman Upwelling, 54°–60°E, 17°–23°N) as inferred from the Standard Deviation (SD) of Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) SST during June-August period (Figure 10).

A normal SD of 10-30 day filtered SST mixes atmospheric-driven variability with smaller scale oceanic eddies and filaments. In order to isolate the atmospheric part only we have applied both a temporal (10-30 day) and spatial (retaining scales above 250km with a Laplacian filter) in the time series analysis. This method will help to retain the region where SMO response maximum during particular season. Spatial patterns of SMO variability are similar to those of 30-60 variability (Figure 10); there will be doubt in the readers that whether this SST response is a distinctive mode or a part of the tail of lower frequency variability (30-60 day).

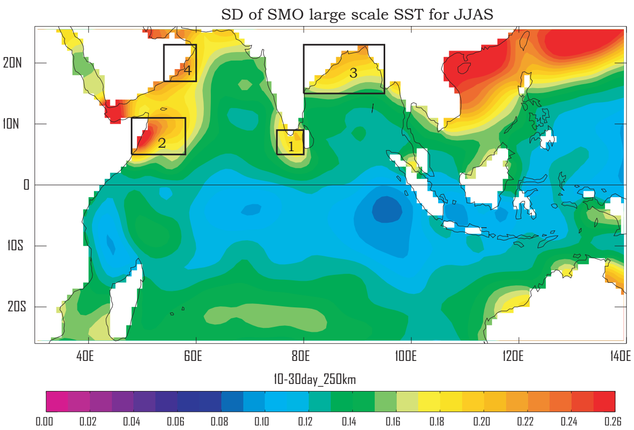


Figure 10. Standard Deviation (SD) of 10–30 day band passed SST during 1998–2007 using TMI SST observation for June-September period. The black boxes (1-4) respectively shows the region where maximum SD over Indian Ocean; STI [75°-80 °E, 5° -9 °N], Somalia [48°-58 °E, 5°-11 °N], NBoB [80°-95 °E, 15° -23 °N] and Oman [54°-60 °E, 17°-23°N]. We have applied both temporal (10-30 day) and spatial (retaining scales above 250km with a laplacian filter) filter on the data.

Figure 11 (a-d) is the power spectra of SST for the aforementioned regions, which are calculated for the June-September period separately for each year and then averaged it across all years for the given season. The null, 5% and 90% red noise significance levels are included. X-axis of Spectra is illustrated in frequency with log scaling and Y-axis as power times frequency. Spectral analysis pointed a distinctive mode of peak in SMO bands apart from the known 30–90 day mode documented in the previous studies (eg. Vialard *et al.*, 2011). Power in this high frequency band will be comparable in the two energy bands (both 10-20 and 20-30 day) with more than 90% significance level. Except Oman upwelling region, power of the spectrum is similar in other SST maxima regions. Ensemble of power spectra for wind field over these regions (figures not shown) corresponds to the dominant two peaks in the sub–monthly bands (10-20 days and 20–30 days) apart from the known 30–60 day band documented in the previous studies (Joseph and Sijikumar, 2004). This shows the importance of ocean dynamics associated with both sub–monthly wind fields in the Arabian Sea upwelling regions. But the Spectrum of the net heat flux shows significance peak only in the NBoB, where the AS upwelling region flux impact will be minimum in similar way with the monsoon active–break cycle in the study by Vialard *et al.*, 2011.

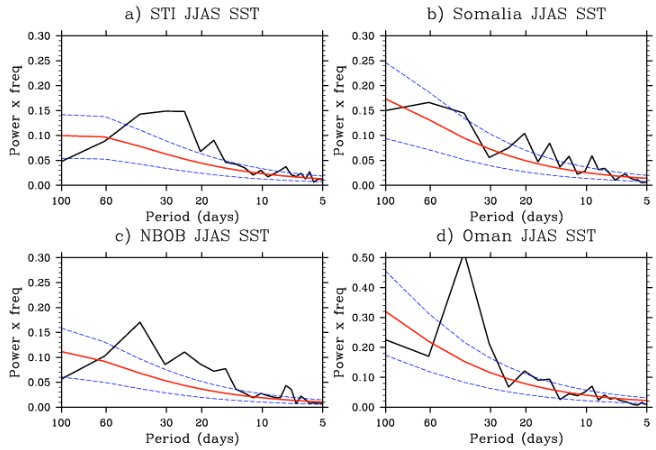


Figure 11. Power Spectra for the TMI SST for a) STI, b) Somalia, c) NBoB and d) Oman upwelling.

The amplitude and phase of SST associated with SMO over NBoB, Oman, Somalia and STI is represented in Figure 12. The maximum peak to peak amplitude in this mode is observed in NBoB and STI with weaker signatures in Oman and Somalia. The amplitude of regressed SST in NBoB (Figure 12a) is ~60% higher than during winter. Strong convective (~10Wm^{-2}) and wind speed (~1ms^{-1}) perturbations associated with sub monthly variability are observed in NBoB. Unlike the 30-90 day signals (Vialard *et al.*, 2011), Oman SST variability is much lesser compared to NBoB. This is evident in the net heat flux distribution in the different regions. Both NBoB (~25Wm^{-2}) and STI (~15Wm^{-2}) are influenced by the net heat flux, which is dominated by the shortwave flux contributions (Figure 12b). Unlike NBoB, upwelling regions in the Arabian Sea (both Oman and Somalia) are dominated by the latent heat flux as compared to short Wave flux.

To analyze the ocean response over north Indian Ocean following SMO, we used the simple SMO index constructed based on the 10–30 day Outgoing Longwave Radiation (OLR) averaged over the basin, 70°E–95°E, 10°N–25°N (Han *et al.,* 2006). Figure 13 shows the convection, wind field and SST signals in the North Indian Ocean based on this index. SST perturbation follows the north-westward propagation of associated convection and wind field. At the peak phase (lag=0 days) of the event, warm SST anomalies are observed near equatorial region with maximum around Somalia. This will be

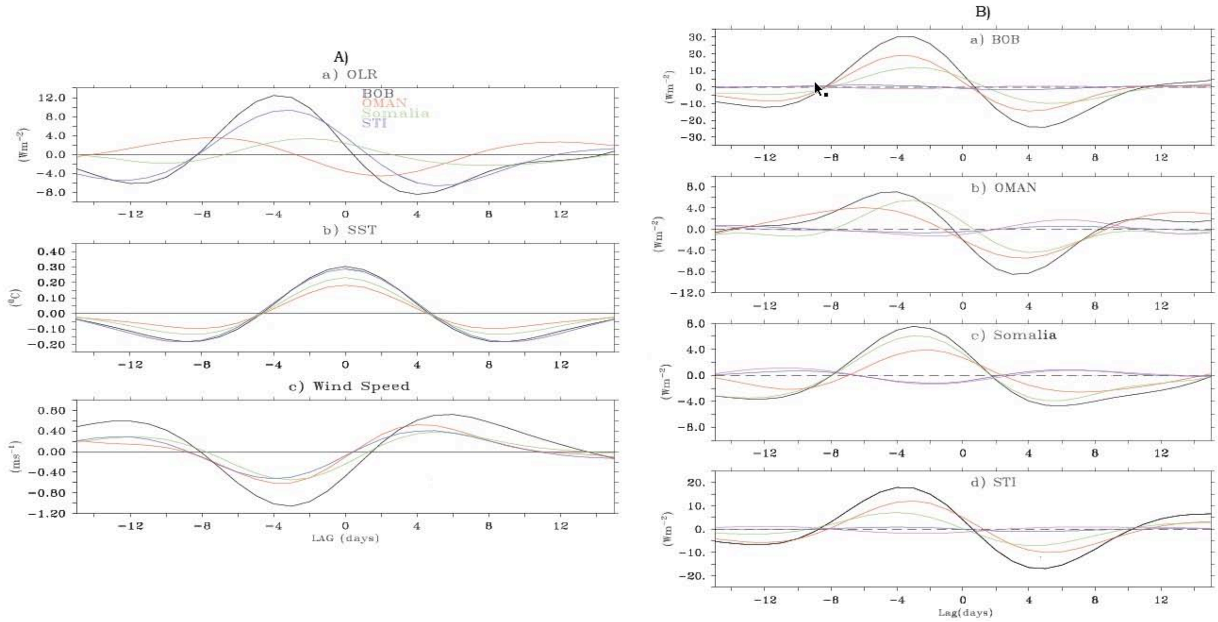


Figure 12. A) June-September intraseasonal (10-30 days) a) OLR, b) SST and c) Wind speed associated with typical SST perturbations in the four reference regions: NBoB (black), Oman (red), Somalia (green) and STI (blue). B) Regression of 10–30 days Surface net heat flux (black) and its components: Shortwave (red), Latent (green), Sensible (blue) and Long wave flux (pink) over aforementioned regions.

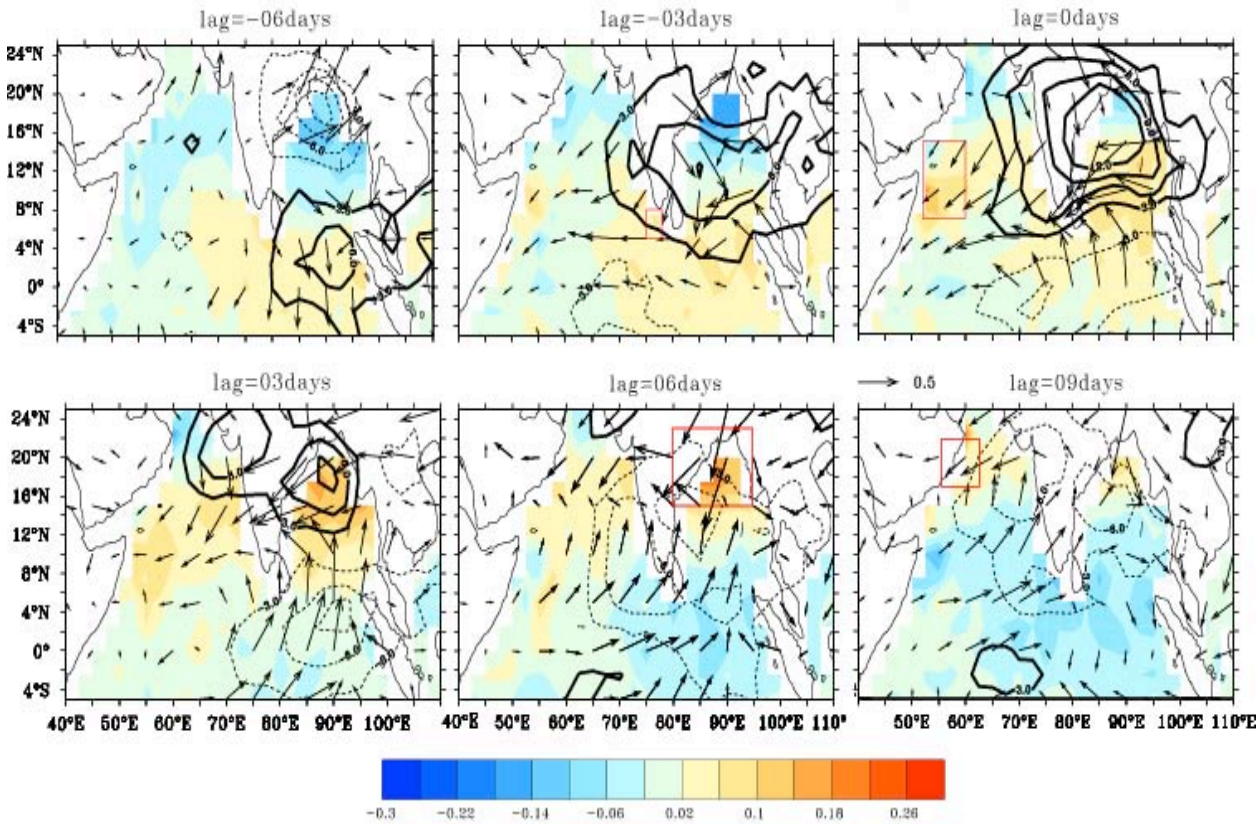


Figure 13. The regressed SST over NIO to SMO index. The red boxes represented the region over Oman, NBoB, Somalia and STI where SST response shows maximum amplitude for a particular lag.

concurrent with the SST anomalies in the break phase of monsoon intra seasonal oscillation (30–60 days) with north-easterly anomaly strengthened over western Arabian Sea. This will in turn change the Ekman transport in the Somalia upwelling region. 6 days prior to the peak event, negative phase of convection prevailed in the south of Indian mainland with warm SST anomaly observed in STI. At this phase strong convection is around NBoB, and the wind showing south-westerly pattern over Bay of Bengal. This will enhance the cooling in NBoB within 3 days (at lag -3 days). With the movement of SMO, dry phase of convection propagate to north and associated strong north-easterly anomaly (lag=3 days) dominated over NBoB. This in turn warm BoB in next phase (lag=6 days). SST anomaly is found to be extending along the north-western Arabian Sea especially over Oman upwelling region.

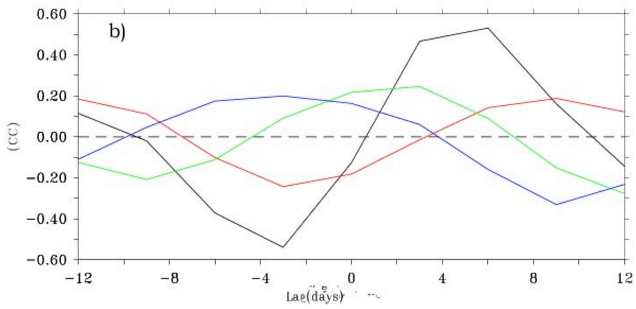


Figure 14. The correlation of average regressed SST over Oman (red), NBoB (black), Somalia (green) and STI (blue) to SMO index.

Figure 14 shows the correlation coefficient values of SST with respect to SMO index in the different regions. Warm SST anomalies first appear near the southern tip of India at lead of ~4 days with SMO index, and then in the Somalia upwelling region ~2 days lag. The warming in the northern Bay of Bengal follows the SMO index by ~4 days while the warming in the Oman upwelling appears last, ~7 days after. Stronger association is found to be seen in the BoB, which is identical to the monsoon active-break cycle response in this region. This shows a clear north-westward propagation of SST anomalies along the upwelling regions in Arabian Sea other than Bay of Bengal, but the signals are weaker as compared to BoB. So the SST signature associated with SMO cycle of monsoon in the Arabian Sea is weaker compared to Bay of Bengal.

Conclusions

Sea surface temperature in the Indian Ocean exhibits a prominent variability at the intra seasonal time scale (10–30 day and 30–90 day bands), both during boreal summer and winter. Ocean response in the 30–90 day band associated with monsoon active-break cycle during boreal summer is well documented, whereas limited attention was given to the 10-30 day (sub monthly) band, hence we conducted here a observational study in the sub–monthly oscillation (10–30 day) using satellite image for the period of 1998–2007.

Indian Ocean sub monthly SST signatures have higher imprints during boreal summer with respect to winter. Northern Bay of Bengal shows higher amplitude with stronger association with convective phases of SMO, whereas the upwelling regions in the Arabian Sea are dominated by wind stress associated processes. For the first time, we report a distinctive mode of intra seasonal SST peak in SMO bands apart from the known 30–90 day band region over the upwelling region in the Arabian Sea. The QuikSCAT winds over Somalia upwelling region shows higher power in the sub-monthly scale (both 10–20 days and 20–30 days) apart from the known 30–90 days variability. Concurrent with the Northwestward propagation of SMO, the SST variations appear first at the southern tip of India (day 0), in the Somali upwelling (day 4), Northern Bay of Bengal (day 6) and finally Oman upwelling region (day 9).

References:

Chen, G., and C. H. Sui, 2010, Characteristics and origin of quasiâbiweekly oscillation over the western North Pacific during boreal summer, *J. Geophys. Research*, 115, D14113, doi:10.1029/2009JD013389.

Chatterjee, P., and B. N. Goswami, 2004, Structure, genesis and scale selection of the tropical quasi-biweekly mode, *Q. J. R. Meteorol. Society*, 130, 1171–1194, doi:10.1256/qj.03.133.

Goswami B. N., 2005, South Asian Summer Monsoon: An overview: in The Global Monsoon System: Research and Forecast Eds. C.-P. Chang, Bin Wang, Ngar-Cheung Gabriel Lau, Chapter 5, pp 47, WMO TD No. 1266, WMO, Geneva.

Han, W., W. T. Liu, and J. Lin, 2006, Impact of atmospheric submonthly oscillations on sea surface temperature of the tropical Indian Ocean, *Geophys. Res. Letters*, 33, L03609,doi:10.1029/2005GL025082.

Madden, R. A., and P. R. Julian, 1994, Observations of the 40-50-day tropical oscillation: A review, *Mon. Wea. Review*, 122, 814–837.

Joseph P. V., Sijikumar, S., 2004, Intraseasonal variability of the lowlevel jet stream of the Asian summer monsoon, *J.Clim*.17:1449–1458.

Vialard, J., A. Jayakumar, C. Gnanaseelan, M. Lengaigne, D. Sengupta, and B. N. Goswami, 2011, Processes of intraseasonal sea surface temperature variability in the Northern Indian Ocean during boreal summer, *Clim. Dynamics*, DOI 10.1007/s00382-011-1015-3.

Investigations on the harmful algal blooms of the EEZ of India

N. R. Menon, Emeritus Professor, CUSAT/ Chairman, Scientific Research Advisory Board, NERCI

Lasse H. Pettersson, Leading Scientist, NERCI/NERSC

Various aspects of harmful algal blooms have been analysed during the period 2010. Since it is evident that nitrogen is a limiting factor for the growth of phytoplankton in the Northern Arabian Sea it was conceived that fixation of atmospheric nitrogen in the oligotrophic ocean is an important source of new nitrogen to surface waters stimulating phytoplankton productivity and fuelling the biological pump. In the tropical waters, the non-heterocystous cyanobacterium *Trichodesmium* is largely responsible for nitrogen fixation. Recent survey of phytoplankton covering an area of 1.2 x 10^5sq. km in the Northern Arabian Sea on board FORV Sagar Sampada has revealed some very interesting and intriguing ecology of a heterocystous cyanophyte *Richella intracellularis* living as a symbiont within the diatom *Rhizosolenia hebetata* (Padmakumar *et* *al*., 2010a). Around 60% of the cells of this diatom species harboured the endosymbiont. The cyanophyte occupied a position in between the plasmalemma and the cell wall of the diatom. The symbiotic relationship between these two species of totally different taxonomic placement is facultative. Viable cells of both the species have been recorded from phytoplankton samples collected upto 100 m depth. However, there was a predominance of the symbiont harbouring diatoms from surface to 30 m depth. Northern Arabian Sea is oligotrophic in nature with limited source of nitrogen during all the seasons but during the winter monsoon (Jan – Mar). Although convective mixing during winter monsoon is the main reason for nutrient enrichment, the role played by *Rhizosolenia – Richella* symbiotic association in the supply of inorganic nitrogen has to be reckoned with.

Excessive ponderance of *Noctiluca scintillans* in a region where a multispecies diatom bloom existed was recorded from the waters off Kochi (lat. 10°00' – 10°3' N and 75°32' E) during the peak monsoon months of August. The bloom was of brick red colouration and was spread over an area of 5 sq. km. The discolouration was caused by the predominance of *Noctiluca scintillans* (Padmakumar *et al*., 2010b).

Noctiluca formed around 56% of the phytoplankton and the rest was constituted of species belonging to 14 genera of diatoms. The single celled protest *Noctiluca scintillans* is highly bioluminescent and this quality is controlled by a luciferin-luciferase system located in numerous spherically shaped "micro sources". This protist is a voracious feeder of diatoms belonging to the genera *Thalassiosira* and *Pseudonitsczhia*. Among food items of *Noctiluca*, *Pseudonitsczhia* is found to produce toxins that can cause fish kill and lead to shellfish poisoning to humans, indicating that *N. scintillans* could be a vector for transfer of phyto-toxins to higher trophic levels. Blooms of *Noctiluca* are known to prevent aggregation of shoaling herbivorous fishes especially sardines. The waters where the bloom of *Noctiluca* was observed contained very high silicate (ca. 18.20 µmol/l), which probably indicates excessive secretion of silicate by this diatom feeding protest. High primary production along the west coast of India during the monsoons probably sets the stage for blooming of non-autotrophic forms like *Noctiluca.*

A series of blooms of *Trichodesmium erythraeum* was observed along the coast of Kerala during May-June months of 2009 from on board FORV Sagar Sampada (Figure 15). A qualitative analysis of the phytoplankton showed that about 90% of the surface phytoplankton was contributed by *T. erythraeum*. The distinct red or pink colouration of the sea water in the area was caused by the presence of phycoerythrin or dominant extracellular pigment leachate of this species. The presence of this pigment in the sea water signals the initial decay phase of *Trichodesmium*. As a rule the blooming of *Trichodesmium* occurs during hot weather with brilliant sunlight and stable high salinity (Padmakumar *et al*., 2010c). Normally *Trichodesmium* growth is not stimulated in classical upwelling areas. In this context the blooming of these filamentous algae during the monsoon period in an upwelling area would be considered quite unusual. Very high biomass of zooplankton (11.59 ml/m^3) clearly indicates the congenial conditions prevailing in the area for zooplankton growth. The fact that no fish mortality was observed in the bloom area probably opens up an area for further studies on the relationship between *Trichodesmium* bloom and zooplankton abundance. It is apparent that *Trichodesmium* blooms are ecologically significant to the productivity patterns of the south eastern Arabian Sea.

Figure 15. Trichodesmium bloom off Kochi (June 2009).

An analysis of the frequency of blooms of harmful algae during the period 1908-2010 (Figure 16) has shown that there has been an increase in the occurrence of blooms during the last decade. The reasons for this could be due to changing nutrient ratios in the coastal waters, dispersal of algal species through currents, storms and ship ballast waters combined with the increased awareness and augmented analytical capacity to understand harmful algal species and the related phytotoxins as reported by Padmakumar *et al*., 2010d.

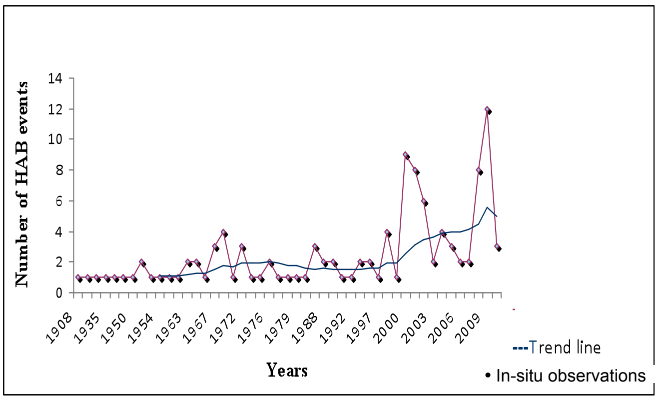


Figure 16. Harmful algal bloom events (actual observation) and trend line from 1908 to 2010 (1908-1996 – Secondary data, 1997 onwards – Primary data).

Conclusions

Based on analysis for data since 1908 an increase in the occurrence of harmful algal blooms has been observed during the last decade of period.

References

K. B. Padmakumar, N. R. Menon, and V. N. Sanjeevan, 2010a, Occurrence of endosymbiont *Richelia intracellularis* (Cyanophyta) within the diatom *Rhizosolenia hebetata* in Northern Arabian Sea, *Int. J. Biodivers. Conserv.*, 2 (4): 70-74.

K. B. Padmakumar, G. SreeRenjima, C. L. Fanimol, N. R. Menon, and V. N. Sanjeevan, 2010b, Preponderance of heterotrophic *Noctiluca scintillans* during a multi-species diatom bloom along the Southwest coast of India, *Int. J. Oceans Oceanogr.,* 4 (1): 45-53.

K. B. Padmakumar, B. R. Smitha, Lathika Cicily Thomas, C. L. Fanimol, G. SreeRenjimma, N. R. Menon, and V. N. Sanjeevan, 2010c, Blooms of *Trichodesmium erythraeum* in the South Eastern Arabian Sea during the onset of 2009 Summer Monsoon, *Ocean Sci. J.*, 45 (3): 151-157.

K. B. Padmakumar, N. R. Menon, and V. N. Sanjeevan, 2010d. Is occurrence of Harmful algal blooms in the EEZ of India on the rise? *Symposium on Indian Ocean Marine Living Resources*, 2-3 December 2010, organized by Centre for Marine Living resources and Ecology, MoES, Kochi. Book of Abstract, pp. 88-89.

Overview of the sources of chromophoric dissolved organic matter in an estuary

Nandini Menon N., Scientist, NERCI

Estuarine and coastal marine ecosystems are hot spots of Dissolved Organic Matter (DOM) cycling because of intense physical and biological activity. Chromophoric dissolved organic matter (CDOM) is operationally defined as the component of total DOM that absorbs light over a broad range of visible (blue light) and UV wavelengths. Sources of CDOM include rivers and groundwater, plankton and vascular aquatic plants, anthropogenic compounds in runoff, sewage discharge and other effluents such as hydrocarbons and agricultural waste (Coble, 2007).

CDOM strongly absorbs light, particularly at UV and blue bands, and its absorption exponentially decreases with increasing wavelength. This absorption is a primary factor controlling water colour in coastal and estuarine waters where high CDOM is often observed. It affects the quantity and quality of light available in estuarine ecosystems and the productivity of phytoplankton, sea grass and coral reefs.

In nearshore areas with strong river influence, mixing is the major factor controlling CDOM distribution, and an inverse linear relationship between CDOM and salinity is often observed. Physical factors have dominant role in the time scale of CDOM lifetimes within coastal waters. In the open ocean environment, however, in situ production is the primary source of CDOM. A number of studies have found that the lower trophic levels (primary producers, grazers, viruses, and bacteria) are important in production of CDOM in oceans, and in many locations CDOM is positively correlated with chlorophyll (Coble, 2007).

The present article is part of a study conducted to assess the sources and sinks of CDOM in the Cochin estuary and the adjacent coastal waters, in the south west coast of India (Figure 17).

Surface water samples from six representative stations (1 & 2 in the upstream estuary, 3 & 4 in the central estuary and 5 & 6 in the adjacent coastal waters) were collected at monthly intervals for one year (2007-2008). The samples were analysed (Table 1) for turbidity, salinity, temperature, chlorophyll a (Strickland and Parsons, 1972) and CDOM absorption (Bowers et al., 2000) using standard procedures. In the case of CDOM absorbance, the absorption co-efficient at 440 nm ($a_{CDOM440}$) is reported here. Remote-sensing studies in which the competition of CDOM with phytoplankton pigments for absorption in the blue is important often employ 440 nm (Nelson *et al*., 1998, Bowers *et al*., 2000), and this wavelength was chosen here for the same reasons.

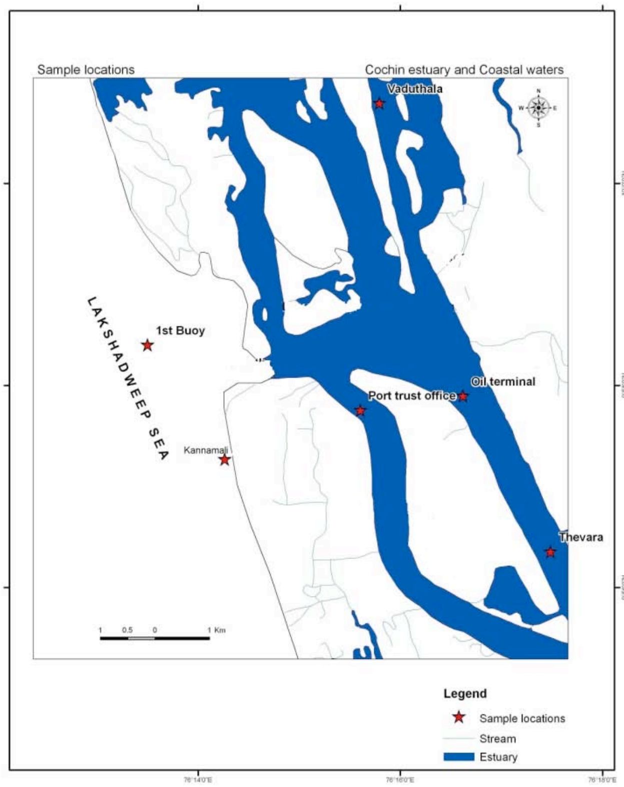


Figure 17. Study location showing the sampling stations.

The monthly results obtained were categorised into seasonal data such as monsoon, post monsoon and pre-monsoon because in tropical estuaries, the seasonal monsoon governed wet and dry periodicity is a pronounced feature.

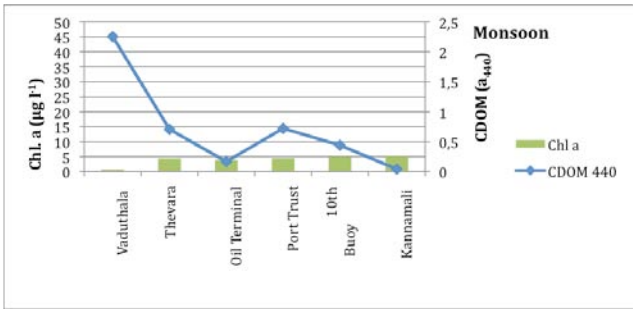
Spatially, CDOM absorbance increased from the lower to upper regions of the estuary, with the lowest values recorded in the coastal waters (range = 0.04 – 2.25 m^{-1}). The highest CDOM absorbance was observed during the monsoon period, when temperature and salinity were minimum and turbidity was maximum in the surface waters.

In Cochin estuary, CDOM absorbance was found to be strongly linked to seasonal cycles of water column mixing. During the south west monsoon, higher values of CDOM were recorded at the surface. This feature was probably due to the input of organic matter into the estuary due to fresh water runoff as shown by reduced surface salinity. Correlation studies revealed that CDOM showed strong negative correlation with salinity during post monsoon (R = $^{-}$0.98) and pre-monsoon (R = $^{-}$0.58), whereas in the monsoon season when fresh water filled the estuarine surface, correlation was weak (R = $^{-}$0.45).

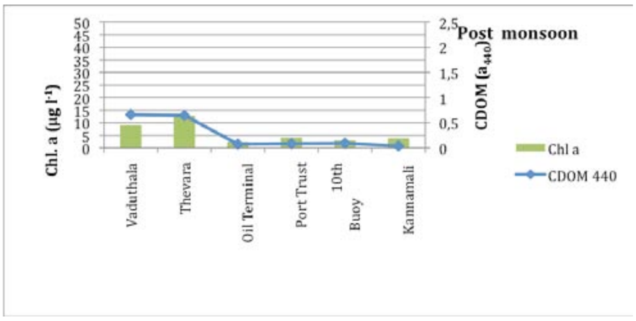
Table 1: Seasonal average of temperature (T^0C), salinity (S psu), turbidity (NTU), chlorophyll a (Chl. a µg l^{-1}) and CDOM absorbance at 440 nm (a_{CDOM} 440 m^{-1}) at the six sampling stations in Cochin estuary during monsoon (MON), post monsoon (POM) and premonsoon (PRM).

Parameter	Season	St.1	Stn.2	Stn.3	Stn.4	Stn.5	Stn.6
T ^{0}C	MON	26	27	27	27	27	28
	POM	29	29	28	28	28	30
	PRM	32	31.5	31	31.6	31.4	32
S psu	MON	0	0	0	0	1	8
	POM	5	10	28	24	29	30
	PRM	12	27	32	28	24	35
Turbidity NTU	MON	18.4	13.19	16.69	19.25	13.81	9.43
	POM	3.26	7.21	3.61	6.27	7.00	3.61
	PRM	8.39	5.85	7.50	6.45	3.3	2.07
Chl. a µg l^{-1}	MON	0.65	4.38	3.85	4.48	4.96	5.08
	POM	8.99	12.86	2.5	4.13	2.97	3.92
	PRM	10.46	44.14	22.56	4.99	4.11	5.9
a_{CDOM} 440 m^{-1}	MON	2.25	0.71	0.17	0.72	0.44	0.04
	POM	0.66	0.65	0.08	0.09	0.1	0.04
	PRM	0.61	0.52	0.40	0.1	0.07	0.04

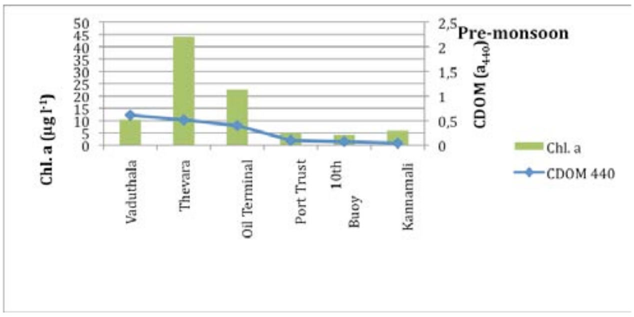
An examination of the contribution of chlorophyll a to CDOM (Figure 18 a, b, c) revealed that during post monsoon and pre-monsoon, there was significant positive correlation between CDOM and chl a (POM – R = 0.93, PRM – R= 0.64). Modelling study by Madhu *et al*., (2010) have shown that Cochin backwaters sustain surplus nutrients supporting chlorophyll production at consistently high level throughout the year. Pre-monsoon season is characterized by weakening of the estuarine flow, facilitating increased biological activities. Madhu *et al.*, (2007) have also observed that chlorophyll *a* increased from post-monsoon to pre-monsoon in Cochin estuary. Similar results were obtained in the present study also with respect to chlorophyll concentration. These facts coupled with the statistical analysis prove that biological production is the primary source of CDOM in the estuary during the lean months. A review by Coble (2007) states that field studies have demonstrated the involvement of all lower trophic groups (phytoplankton, grazers, viruses and bacteria) in the production of CDOM. Menon *et al*., (2006) have proved that in well mixed estuaries like Mandovi and Zuari, CDOM should be more than in a partially mixed estuary developed during post-monsoon season, but pre-monsoon season being a period of clear sky, the area receives maximum irradiance and highest sea surface temperature (SST), so that photo bleaching during this season reduce CDOM concentration.



(a)



(b)



(c)

Figure 18. Temporal and spatial variation in the CDOM-chlorophyll during (a) monsoon (b) post monsoon and (c) pre-monsoon

During pre-monsoon season, Cochin estuary is also in a well mixed condition and the SST is maximum, but the CDOM profile did not match with that of Menon *et al*., (2006). This may be because; rates of photobleaching vary among organic substances from different sources, with terrestrial humics typically bleaching much faster than organic substances originating in marine waters (Shank, 2007). Considering the fact that sampling for the entire study was done during the high tide period, the

CDOM in the estuary during pre-monsoon season could be more of marine origin than terrestrial.

It has been observed that in the estuaries along west coast of India, phytoplankton biomass during the SW monsoon remains well below expectation given copious macronutrients, most likely owing to light limitation of photosynthetic productivity arising from cloud cover and high water column turbidity (Shetye, *et al*., 2007). Same trend was observed in the case of present study also regarding chlorophyll concentration. Further, during monsoon, when primary productivity was the lowest, CDOM and chl a showed a significant negative correlation (R = $^{-}$0.92). During SW monsoon the water column turbidity ranged from 9-19 NTU. This leads to the inference that during monsoon, the primary source of CDOM is the terrestrial input from rivers.

Summary

The above results indicate the complexity of CDOM input into the estuary. The present study provides a glimpse of the influence of seasonal hydrodynamics of estuary in the spatial and temporal variability of CDOM. But more important from the biological and remote sensing points of view are its relations with primary productivity and turbidity. The observations clearly show the influence of CDOM as a major absorber of light over the same wavelengths favoured by phytoplankton, and at increasing levels, CDOM absorption can affect primary productivity and ecosystem structure by reducing the amount and quality of PAR to phytoplankton. Therefore, the ecological implications for phytoplankton photosynthesis in CDOM dominated estuary like the Cochin estuary requires further enquiry.

References

Bowers, D. G., Harker, G. E. L., Smith, P. S. D. and Tett, P., 2000, Optical properties of a region of freshwater influence (the Clyde Sea). *Estuar, Coast. Shelf Sci.,* 50; 717 -726.

Coble, P. G. 2007. Marine optical biogeochemistry: the chemistry of ocean color, *Chem. Rev.,* 107; 402–418.

Madhu, N. V., R. Jyothibabu, K. K. Balachandran, U. K. Honey, and G. D. Martin, 2007, Monsoonal impact on planktonic standing stock and abundance in a tropical estuary (Cochin backwaters - India), *Estuar. Coast. Shelf Sci*., 73; 54-64.

Madhu, N. V., Balachandran, K. K., Martin, G. D., Jyothibabu, R., Thottathil, S. D., Nair, M., Joseph, T. and Kusum, K. K., 2010, Short-term variability of water quality and its implications on phytoplankton production in a tropical estuary (Cochin backwaters-India), *Environ. Monit. Assess.*, 170(1-4); 287-300.

Menon, H. B., Lotliker, A, A., Nayak, S. R., 2006. Analysis of estuarine colour components during non-monsoon period through Ocean Colour Monitor. *Estuar. Coast. Shelf Sci*., 66(3-4), 523 – 531.

Nelson, N. B., Siegel, D. A. and Michaels, A. F., 1998, Seasonal dynamics of colored dissolved organic material in the Sargasso Sea, *Deep-Sea Res. Pt. I*, 45(6); 931–957.

Shank, C. G., 2007, General overview of CDOM chemistry and methods of breakdown, *Coloured dissolved organic matter (CDOM) workshop summary, Technical document 07-3,* Charlotte Harbor National Estuary Program, 11-15.

Shetye, S. R., Kumar, M. D., Shankar, D. (ed), 2007, The Mandovi and Zuari Estuaries. National Institute of Oceanography, Dona Paula, Goa, pp 49-58.

Strickland, J. D. H., and Parsons, T. R., 1972, A practical handbook of seawater analysis, *Fisheries Board of Canada Bulletin*. 167 (2nd Edn.), 295-300.

ONGOING AND FUTURE PROJECTS

NERCI has ongoing external funded projects from from Space Application Centre-Indian Space Research Organization (SAC-ISRO) under the Oceansat II Utilization program and two different projects under the Announcement of Opportunity for international partners by SAC-ISRO.

"Synergistic application of Scatterometer and OCM data from OCEANSAT – II for the studies of coastal upwelling in the Southwest coast of India"

Principal Investigator - Dr. K. Ajith Joseph

Co-PI - Prof. A. N. Balchand, CUSAT

The main focus of work is computing the upwelling index along the southwest coast of India from 8° to 15°N based on AVHRR SST and Oceansat-II scatterometer, ERS-1/2 and QuikSCAT wind stresses for the years from 1981 to till date.

"Water quality monitoring and low cost purification strategies for inland waterways of low-lying areas"

Principal Investigator- Dr. K. Ajith Joseph

Partner institute: Centre for Earth Research and Environment Management, Kochi, India

The project funded by UNEP - Asia Pacific Forum for Environment Development (APFED) Program, commenced in 2007, was completed successfully.

Wind induced aerator system for water quality improvement in canals and lakes developed by Dept. of Mechanical Engineering, TocH institute of Science and Technology in collaboration with NERCI under UNEP-APFED project.

ANNOUNCEMENT OF OPPORTUNITY PROJECTS BY SAC (ISRO)

"Algae Bloom monitoring and forecasting for the Norwegian waters using Oceansat-II data"

PI - Lasse H. Pettersson, NERSC.

Co-PI - Dr. K. Ajith Joseph, NERCI

The proposed work is in compliment to the ongoing HAB monitoring and forecasting for the Norwegian waters by NERSC over the last few years (http://HAB.nersc.no), which is highly beneficial to the Norwegian aquaculture and fishery industries. The methodology includes access to IRS-Oceansat II ocean colour level 2 data products for the study region by data downloading, processing, integration, analysis and assessment visualisation.

"Arctic monitoring and forecasting using Oceansat II Scatterometer data."

PI - Dr. Laurent Bertino, Mohn-Sverdrup Center at NERSC.

Co-PI- Prof. Stein Sandven, Lasse H. Pettersson and Dr. K. Ajith Joseph.

The proposed work is an enhancement of the TOPAZ monitoring and forecasting system for the Arctic Ocean. Scatterometer data from Oceansat-2 will be used to device sea-ice parameters (concentrations and type) and assimilated into the TOPAZ coupled ice-ocean system, in combination with or in replacement of pre-existing SSM/I and ASMR data.

INTERNATIONAL WINTER SCHOOL

An international winter school was organized at Cherai, Cochin in association with NERSC, Bergen and Nansen Scientific Society with the theme, Indian Ocean: Challenges in Meteorology and Oceanography from February 6-12, 2010. There were 48 student participants from different parts of the country and abroad.

Dr. N. Chandramohana Kumar, Registrar, CUSAT has inaugurated this five day event and Capt. D. Vijayakumar, Officer in charge, School of Naval Oceanology and Meteorology, Indian Navy delivered the keynote address. Eminent scientists like Dr. S. C. Shenoi (INCOIS), Dr. P. N. Vinayachandran (INCOIS), Dr. M. Rajeevan (NARL, ISRO), Prof. Ola M. Johannessen, Prof. Johnny A. Johannessen, Lasse H. Pettersson (NERSC) Prof. Trever Platt and Dr. Shuba Satyendranath (Plymouth Marine Lab, UK) were the key invited speakers to name a few among totally 19 international lecturers.

PUBLICATIONS IN 2010

Referred Journals

Jayaram, C., Neethu Chacko, **Ajith Joseph, K**., A. N. Balchand, 2010, Interannual variability of upwelling indices in the southeastern Arabian Sea: A satellite based study. *Ocean Sci. J.*, 45 (1): 27 – 40.

George MS, Bertino, L., **Johannessen, OM**, Samuelsen, A., 2010, Validation of a hybrid coordinate ocean model for the Indian Ocean. *J. Operational Oceanography.* 3 (2), p.25-38(14).

Padmakumar, K. B., **N. R. Menon,** and V. N. Sanjeevan, 2010, Occurrence of endosymbiont *Richella intracellularis* (Cyanophyte) within the diatom *Rhizosolenia hebetata* in Northern Arabian Sea. *Int. J. Biodivers. Conserv.,* 2 (4): 70-74.

Padmakumar, K. B., B. R. Smitha, Lathika Cicilly Thomas, C. L. Fanimol, G. SreeRenjima, **N.R. Menon,** and V. N. Sanjeevan, 2010, Blooms of *Trichodesmium erythraeum* in the south eastern Arabian Sea during the onset of 2009 summer monsoon. *Ocean Sci. J.*, 45 (3): 151-157.

Padmakumar, K. B., G. SreeRenjima, C. L. Fanimol, **N. R. Menon,** and V. N. Sanjeevan, 2010, *Preponderance of heterotrophic Noctiluca scintillans* during a muti-species diatom bloom along the Southwest coast of India. *Int. J. Oceans and Oceanography,* 4(1): 55-63.

Books

Joseph. P. V., 2010, Onset, advance and withdrawal of monsoon. In Monsoon Monograph, Vol. 1 (editors: Asnani. G. C., De U. S., Hatwar, H. R. and Mazumdar, A. B.), India Meteorological Department, p. 103-148.

Joseph. P. V., 2010, Synoptic systems during monsoon. In Monsoon Monograph Vol. 1 (editors: Asnani. G. C., De U. S., Hatwar, H. R., and Mazumdar, A. B.), India Meteorological Department, p. 205-237.

Menon, N. R., 2010, Effects of temperature on lower marine invertebrates In: Climate change and aquatic ecosystems. (A. Joseph, Bijoy Nandan and S. Arun Augustine (eds.), pp. 100-115.

Shadanan Nair, 2010, Challenges in solving the transboundary water disputes in India under a changing climate and environment. Hydrocomplexity: New tools for solving wicked water problems. IAHS publ. 338, 2010.

Conference proceeding papers

Balchand, A. N., **Nandini Menon, Ajith Joseph, K.**, 2010, Perspective on disruptions in biodiversity of Cochin backwaters along the south west coast of India. - Poster at the International Symposium on Integrated Coastal Management for Marine Biodiversity in Asia, organized by The Division of integrated Coastal Management of Kyoto University, January 14-15, in Kyoto City, Japan.

Jayaram C, Nandini Menon, Ajith Joseph, K., and Balchand, A. N. 2010, Monitoring of Trichodesmium blooms in Arabian sea using in situ and satellite products during the past decade —SAFARI Remote sensing and Fisheries International Symposium, 15-17 Feb 2010.

Joseph. P. V. 2010, Role of sea surface temperature (SST) gradient in producing monsoon convection (rainfall). In Proceedings of METOC – 2010 (National Symposium on Nowcasting to Forecasting – needs and challenges for naval operations), School of Naval Oceanology and Meteorology, Cochin, p. 6-11.

Lasse H. Pettersson, Anton Korosov, Torill Hamre, and Annette Samuelsen, 2010, Integrated monitoring and forecasting of harmful algae bloom events in coastal waters for use by aquaculture. SAFARI Remote sensing and Fisheries International Symposium, 15-17 Feb 2010.

Nandini Menon, Ajith Joseph, K., and Saramma, A. V. 2010, Fluorescence emission rations as a method for determining the source of CDOM in Cochin estuary, SW coast of India – SAFARI Remote sensing and Fisheries International Symposium, 15-17 Feb 2010.

Padmakumar, K. B., **N. R. Menon**, and V. N. Sanjeevan, 2010, Is occurrence of Harmful algal blooms in the EEZ of India on the rise? *Symposium on Indian Ocean Marine Living Resources*, 2-3 December 2010, organized by Centre for Marine Living resources and Ecology, MoES, Kochi. Book of Abstract, pp. 88-89.

Technical Reports/Special Reports

Ajith Joseph, K., and Leonid Bobylev, 2010, NERCI Technical report no.5 - Indo-Russian workshop on Regional climate change, March, 2010.

Ajith Joseph, K., Nandini Menon, N., Lasse H. Pettersson, and **Ola M. Johannessen,** 2010, NERCI Technical report no.6- Summary report on Nansen Winter school 2010 "Indian Ocean: Challenges in Oceanography and Meteorology, June, 2010.

Participants at the NERCI and Nansen Group Winter School at Cherai, Kerala in February 2010.

NANSEN ENVIRONMENTAL RESEARCH CENTRE (INDIA)

DIRECTOR: DR. K. AJITH JOSEPH
GOPAL RESIDENCY II FLOOR, THOTEKKAT ROAD
ERNAKULAM, KOCHI - 682 011, KERALA, INDIA
HTTP://WWW.NERCI.IN
PHONE: +91-484-2383351/94473-25564 FAX: +91-484-2353124
E-MAIL: NERCI@IPATH.NET.IN

A Partner in the **Nansen Group** of research institutes lead by Prof. Ola M. Johannessen, also comprising:

Nansen Environmental and Remote Sensing Center
Bergen, Norway
http://www.nersc.no

Nansen International Environmental and Remote Sensing Centre
St. Petersburg Russia
http://www.niersc.spb.ru/

Nansen-Zhu International Research Centre
Beijing, China
http://nzc.iap.ac.cn

Nansen-Tutu Centre for Marine Environmental Research
Cape Town, South Africa

Nansen Scientific Society
Bergen, Norway