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REMOTE SENSING AND GIS IN MARINE FISHERIES MANAGEMENT

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Abstract

This chapter outlines the use of modelled and satellite remote sensing (SRS) data in supporting the research, technology-development and management of marine fishery resources. Numerical models are useful for studying fish and other aquatic invertebrate larval transport. SRS data are used to locate fish stocks, locate areas of reef stressand delineate areas of high productivity in the wake of cyclone paths. Coupling SRS with models helps to manage fishery resources on an ecosystem scale, generate potential fishing zones (PFZ), forecast ocean state (OSF), detect meso-scale features such as eddies and track cyclones threatening coastal resources. Modelled, SRS and in situ data sets in combination can be used in the estimation of potential fishery resources in the exclusive economic zone (EEZ), which in turn can help in fishing fleet management. Globally, there is considerable potential for phytoplankton data to serve in futureas a proxy for estimation of fish biomass. Usually, investigations in fisheries biology lack environmental timeseries or other biological data sets. Data from SRS, numerical modelling and their combinations can leadto robust conclusions.Numerical simulation is an attempt to supplement the existing decision support systems. The biological relevance of numerical modelling and SRS at present is restricted to a few operational activities in fisheries. But the issues are complex and there are many uncertainties. The role of coastal processes in fish and shell fish production and dynamics deserves further investigation with improved time series sampling of early life stages in marine organisms. But in the years to come, numerical modelling, SRS and their coupled usage will provide major technological advances supporting operational fisheries research and management.

Keywords: Ecosystem, modelling, SRS, data, marine resource management, fisheries

1. Introduction

India is a world leader in satellite technologies and remote sensing. We hope that in the future a satellite dedicated entirely to marine fisheries will be made available soon. Integrating remote sensing into marine fisheries for the establishment of 'e-infrastructure' is an exciting possibility. While we have been utilizing coastal resources thus far, technology will aid us in exploring oceanic areas for resources. India's marine fisheries sector is poised for greater opportunities as well as challenges in the years to come. On the benefit side, India is contemplating extension of EEZ up to 350 nautical miles from the present 200 nm which will result in a physical operating environment much larger than the land mass of India. This will increase our resource base tremendously which needs to be quantified scientifically by way of exploratory surveys and remote sensing for sustainable utilization and management of the resources. We envisage mariculture as the future of the marine fisheries sector of India and list the opportunities for the development of mariculture in the country. Opportunities exist in expanding the number of species that can be cultured, standardizing seed production technologies, production of small sized live feed and development of bio-secure brood fish facilities. Opportunities exist for the production of 'ready-to-use' algae which can go a long way in making mariculture a viable venture. Expansion of sea cage farming with the support of GIS-based tools and appropriate legislation is the need of the hour.

The developments in the marine fisheries sector and the advent in space and Information Communication Technology will benefit fishermen and fish farmers only when they get better returns from their profession. A Sophisticated Market intelligence and Information System using a combination of real time data and ICT needs to be established. It has now been recognized globally that fish and fisheries are only a part of the marine ecosystem which provides us with innumerable goods and services. This paved the way for "Ecosystem Approach to Fisheries

Management" which aims at development and management of fisheries while considering the health of the marine ecosystem. India too needs to shift from traditional single species management approach to EAFM for sustainable ecosystems. EAFM addressing ecological and human wellbeing with good governance has proved to be an effective option for sustaining the fisheries in several cases. EAFM involves identifying and prioritizing issues and threats, developing and implementing plans with quality checks and adapting. An EAFM approach would address our concerns regarding production from over-burdened coastal stocks, production from under-utilized off-shore and non-conventional resources, pollution of the seas, overcapitalization of coastal fisheries, biodiversity loss and so on.

We need a 'tool' for effectively delivering EAFM in the marine context. Marine Spatial Planning (MSP) is such a 'tool' that maps the varied uses of the marine environment and increases the efficiency of EAFM. It is a strategic plan for regulating, managing and protecting the marine environment that addresses the multiple, cumulative and potentially conflicting uses of the sea. MSP will serve both as a framework and a process for more integrated decision making. Its goal is a fully comprehensive, integrated, plan-led system of management for the present and future exploitation and development of marine resources and for the use of contested space. The most important task for marine fisheries in an MSP regime is establishing the broad aim of MSP and elaborating this through a coherent set of more specific objectives with reference to fisheries.

2. Geo-Physical Datasets From Satellite Remote Sensing (SRS) in the Context of Marine Fisheries Research and Management

SRS datasets are often used in empirical or semi-analytical validated models, either to extrapolate regional datasets in space or to generate derived geo-physical products. A simple example for this can be the summation of thermal signals from different wavelengths for generation of Sea Surface Temperature (SST). In a similar way, some of the most useful and relevant environmental properties in fisheries research such as sea surface salinity (SSS), wind speed and wind direction, sea surface height (SSH), chlorophyll-a (Chl-a) and Chl-a derived primary production (PP) are available online as processed and unprocessed geo-physical datasets. These datasets can be used to advantage in various fisheries research and management programmes. A few such case studies are illustrated below:

2.1 SRS chlorophyll data providing cues on fish stock variability

Variations between years in the seasonal cycle of SRS Chl-a have been implicated in fluctuations in fish stock variability (Platt et al. 2003). In this section we describe the results of an analysis of Chl-a with Indian oil sardine in the coastal waters of India. Fishing effort in the coastal waters of India changed little in the period 1998-2006, with 238,772 fishing craft in 2005 (CMFRI 2005) in comparison with 239,000 craft in 1997 (Sathiadhas 2006). Thus, the variability in sardine landings during the study period, despite steady fishing effort, indicates that other factors such as environment or food to the sardines are involved. A correlation analysis between available environmental factors (SST, sea bottom temperature, surface salinity, surface dissolved oxygen, bottom dissolved oxygen, pH, nutrients, chlorophyll, zooplankton, rainfall, multivariate El Niño Southern Oscillation index, coastal upwelling index, and derived SST) and sardine catch from the study area emphasised the high significance of chlorophyll compared with other environmental factors in explaining the variability in sardine catch (Krishnakumar and Bhat 2008). Using their fine branchial apparatus, sardines feed predominantly on phytoplankton and zooplankton. In a given area, Chl-a is a good index of the food availability to sardines. Summer surface Chl-a from the study area lies in the range 0.1 to 5 mg/m3, and can be very high, from 5 to 10 mg/m3, during bloom periods (Raghavan et al. 2006). Given the wide dynamic range of chlorophyll concentration in the coastal waters of southwest India and the dominant role of chlorophyll as a determinant of variability in sardine stocks, it seems likely that much will be gained in studying this link in detail.

Algal bloom in the study area often occurs during upwelling. Upwelling in the waters of the southwest coast of India (5 to 150N latitude) and the variability in local physical parameters drives changes in the chlorophyll concentration (Smitha et al. 2008). Physical processes affect not only the magnitude of the plankton biomass, but also its species composition (Huntsman et al. 1981), which may in turn affect larval fish feeding and survival (Lasker 1975; Simpson 1987). According to the Hjort-Cushing match-mismatch hypothesis (Hjort 1914; Cushing 1974; 1990), the survival rate of fish larvae is a function of the match between timing of hatching of eggs and initiation of spring phytoplankton bloom. The advent of SRS provides information at the appropriate temporal and spatial scales for testing this hypothesis (Platt et al. 2007). With SRS, it is possible to characterize the spring bloom objectively based on the timing of initiation, amplitude and duration. The statistical moments of all of these properties, and their inter-annual variation, can be calculated and the results used to analyze the effect of ecosystem fluctuations on exploited fish stocks (Platt et al. 2003).

The case study presented below deals with the interannual variability of Indian oil sardine (*Sardinella longiceps*) stock in the southwest coastal waters of India and its relationship with the phytoplankton bloom characteristics computed from SRS, with a view to explain larval survival and interannual variability at the synoptic scale (Grinson et al. 2012).

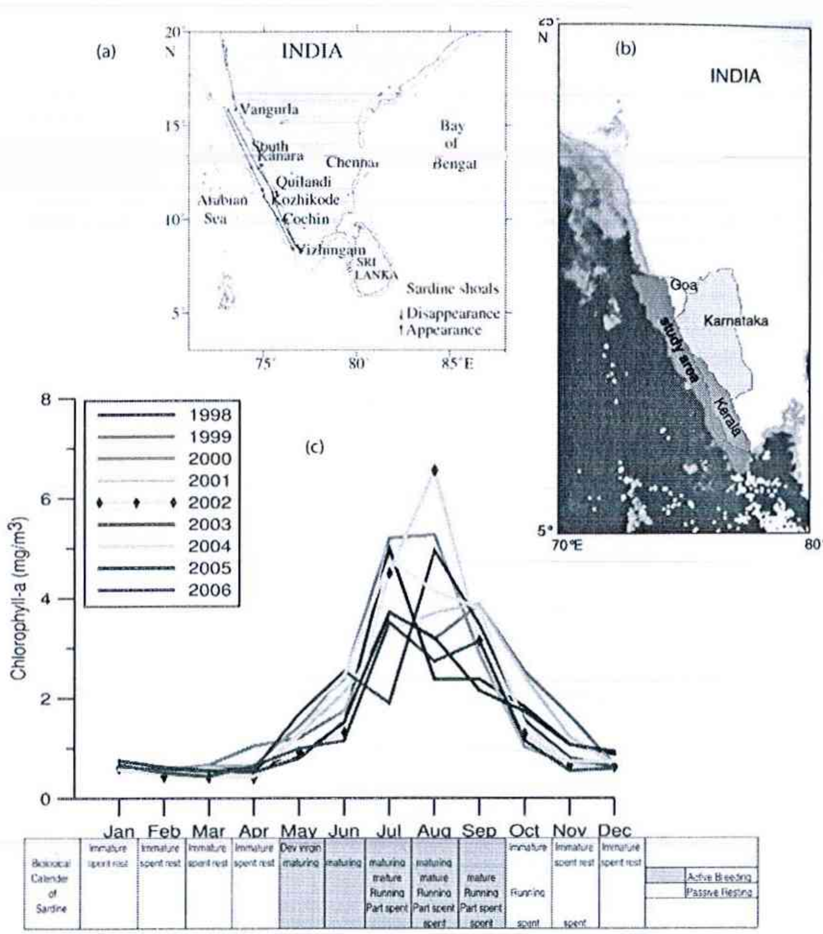

Fig. #.1 Indian oil sardine migration (Fig. (#.1.a)), and SeaWiFS satellite chlorophyll (Fig. ((#.1.b)) peaks utilized for explaining the trophic link between the upwelling bloom biology (Fig. ((#.1.c)) and sardine interannual variability along the south west coastal waters of India (Source: Grinson et al. 2012)

The life cycle of sardines includes an active breeding season from May to September. This coincides with the high chlorophyll concentration seen during May to September every year (Fig. #.1). Thus, we find a probable connection between the life history of sardines and phytoplankton bloom dynamics. This supports the finding that the fish itself times its breeding and adjusts its migration to exploit the productive southwest monsoon period. In this study, magnitude of the bloom during initiation month is selected for characterization of bloom, which naturally falls in the month of May every year. May is the most critical month for sardines because both bloom initiation and the beginning of sardines' active breeding phase occur during this month. A delay in the initiation of bloom in the area results in a delay in the onset of suitable conditions for survival of sardine larvae (Grinson et al. 2012).

2.2 Reef Health Advisories Using SRS Derived SST

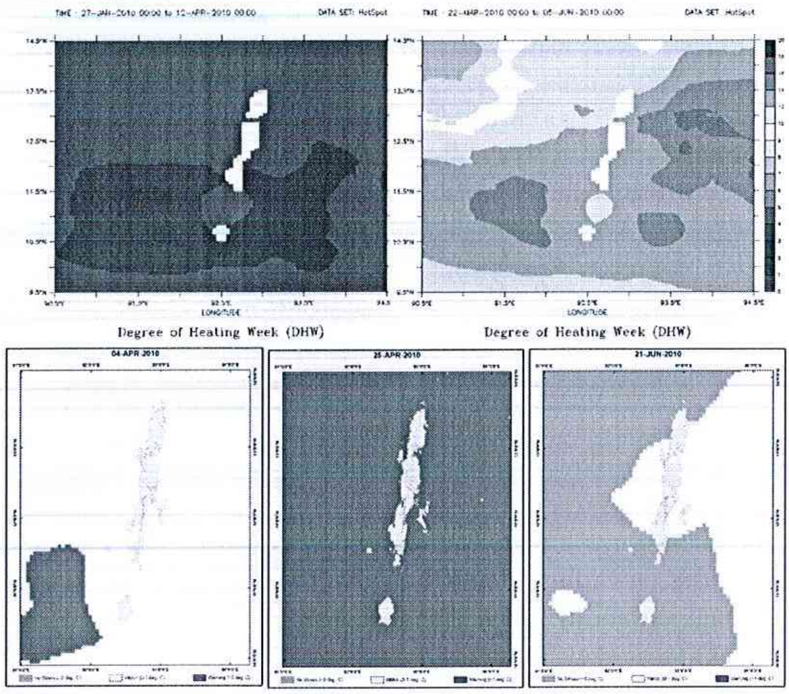

Fig. #.2 HS and DHW generated during the bleaching events in 2010 in Andaman Sea indicating the stress levels reefs faced (provided as advisory by INCOIS)

Globally, there are several instances of mass coral bleaching incidents leading to heavy reef mortality (Krishnan et al. 2011). The application of SRS provides synoptic views of the global oceans in near-real-time for monitoring the reef areas (Liu et al. 2003; Bahuguna et al. 2008; Mahendra et al. 2010). SST during night time is an important parameter for assessment of the thermal conditions inducing the bleaching. SRS provides SST information during day and night routinely, facilitating the development of a coral reef bleaching warning system to generate early warning advisories/bulletins in near realtime. The estimation of monthly maximum mean using night time SST climatology retrieved using NOAA, AVHRR is used for generating reef health advisories to eliminate the effect of solar glare and reduce the variation in SST caused by the heating during day time. Threshold hotspot (HS) and daily heating week (DHW) values for a region are calculated the advisory (Mohanty et al. 2013). Depending on the intensity of HS and DHW there can be advisories such as 'no stress'; 'watch'; 'warning' and 'alert levels-I & II' which progressively indicate the severity of a potential bleaching event. Based on this study INCOIS offers reef stress advisories (Fig. #.2) to alert the reef managers to take appropriate measures to reduce the damage caused to reefs during bleaching events.

2.3 SRS Data for Cyclone Tracks Creating Productive Fishing Grounds

Even though cyclones are devastating, there are some positive effects of cyclones on the fishery. Study of the effect of tropical cyclones on biological processes has gained momentum in the recent past. In thermally-stratified coastal waters, cyclones trigger the breaking up of nutrient-depleted surface waters and bring in nutrient-rich sub-surface waters inducing sudden algal blooms and enhancing the regional scale PP. The effect of physical forcings on PP, its variation and associated hydrography in the southwestern Bay of Bengal during the southwest monsoon (July) and post-cyclone period (November) of 1999 was studied by Madhu et al. 2002. In the postcyclone period, the combined effects of well-mixed coastal waters and freshwater injection from the land runoff associated with the cyclone brought nutrients to the mixed layer, which enhanced PP. Potentially, such enhancement of PP results in improving the regional fishery. But cyclone tracks alone will not provide the information on enhanced PP. SRS is able to detect the environmental changes caused by tropical cyclones. Geo-physical data sets from SRS are useful in such studies for indicating possible productive fishing grounds after a lag following the cyclone (Rao et al. 2006).

2.4 Demarcation of Ecological Provinces in Support of an Ecosystem Approach to Fisheries Management

Globally, the ecosystem approach to fisheries management (EAFM) is preferred as a basis for sustainable management of fish stock (Garcia at al. 2003). In this context, it is useful to have a spatial structure for global oceans defined on the basis of ecological provinces rather than geo-political considerations. There are various approaches for classifying the global oceans into ecological provinces (Ekman 1953; Margelef 1961; Yentsch and Garside 1986; Cushing 1989; Fanning 1992; Sathyendranath et al. 1995). The classification by Longhurst et al., 1995 is the most comprehensive, identifying some 50 biogeochemical provinces globally (Longhurst et al. 1995). Some other methodologies require huge data sets for demarcating ecological provinces (Hooker et al. 2000; Li et al. 2004; Alvain et al. 2005; Sherman et al. 2011). But there is lack of *in situ* data to suppport these approaches. As oceanic realms are dynamic, there are logistic issues in sampling. Consequently, SRS data are very useful to clasification protocols. PP derived from SRS can be a very useful input as PP provinces subsume many oceanographic forcing mechanisms on synoptic scales (Platt and Sathyendranath 2008). These ecological provinces are useful in fisheries management as the physical processes and the ecosystems in each province support characteristic fisheries different from those in nearby provinces (Stuart et al. 2011). Beyond static partitioning, there is a further goal for dynamic bio-geography at regional scales that would incorporate complexities of a dynamic marine environment and their effect on the phytoplankton. SRS will be an invaluable source of inputs in case of such partitioning. Changes in spatial extent of the ecological provinces arising from temporal variations in physical forcing can be captured in a SRS climatology of ocean colour.

3. Coupling Modelled and SRS Data for Effective Fishery Management

So far, we have discussed the usage of environmental data sets from models and SRS for various aspects in fisheries research and management. But lack of environmental time series data sets pointed to the need for more data. Coupled with SRS, numerical modelling is an alternative tool to generate environmental and biological datasets, which can help to mitigate problems arising from data gaps. Some relevant case studies are described below:

3.1 Trophic Modelling Using SRS Data as an Ecosystem Approach To Fisheries Management

Trophic levels in the marine ecosystem are similar to those in terrestrial systems starting with primary producers and ending in scavengers. But, the trophic structure in marine systems is web like, rather than a linear food chain. Fishing often alters the ecosystem structure. Trophic webs will respond differently to fishing depending on whether the target species is a predator or prey species. Single-species fish stock-assessment models ignore food web interactions. Ecosystem based fish stock assessement is offered as another option. EAFM models often resort to SRS-based PP as an input for forcing at the base of the food web to investigate energy transfers and biomass in an ecosystem without fishing, from lower to upper trophic levels (Chassot et al. 2011).

3.2 Generating Potential Fishing Zones (PFZ) and Their Dissemination along With Ocean State Forecasts (OSF)

Identification of PFZ involves an understanding of oceanic processes and interaction of hydro-biological parameters (Desai et al. 2000). The forage base and the physical gradients of temperature and Chl-a help the predatory fish to locate their prey and the same cues are used by fishermen. A number of studies have examined the use of SRS as an aid to locate more productive fishing areas (Waluda et al. 2001). Indian Remote Sensing Satellite P4 Ocean Colour Monitor (IRS P4 OCM) derived chlorophyll concentration and National Oceanographic Aerospace Administration Advanced Very High Resolution Radiometer (NOAA AVHRR) derived SST images have been used to characterise the relationship between the biological and physical variables in coastal waters and it was observed that chlorophyll concentration and SST were inversely correlated with each other (Solanki et al. 1998). The relationship between these two parameters was estimated by a clustering technique called ARNONE (NCAER, 2010) and the matching features were selected for generating integrated PFZ forecasts from the composite images on the basis of latitude and longitude (Solanki et al. 2005; NCAER 2010).

Validation of studies of PFZ forecasts have shown that the forecast may lead to substantial increase in fish catch (Solanki et al. 2001; 2003; Nayak et al. 2003). PFZ forecasts in near-real time indicating the likely availability of fish stocks for the next 2 days are disseminated in the Indian EEZ by INCOIS (Fig. #.3) to about 225 nodes for operational use (Nayak et al. 2003). A significant increase in total catch by following PFZ forecasts has been documented from ANI (Grinson-George et al. 2011, 2013).

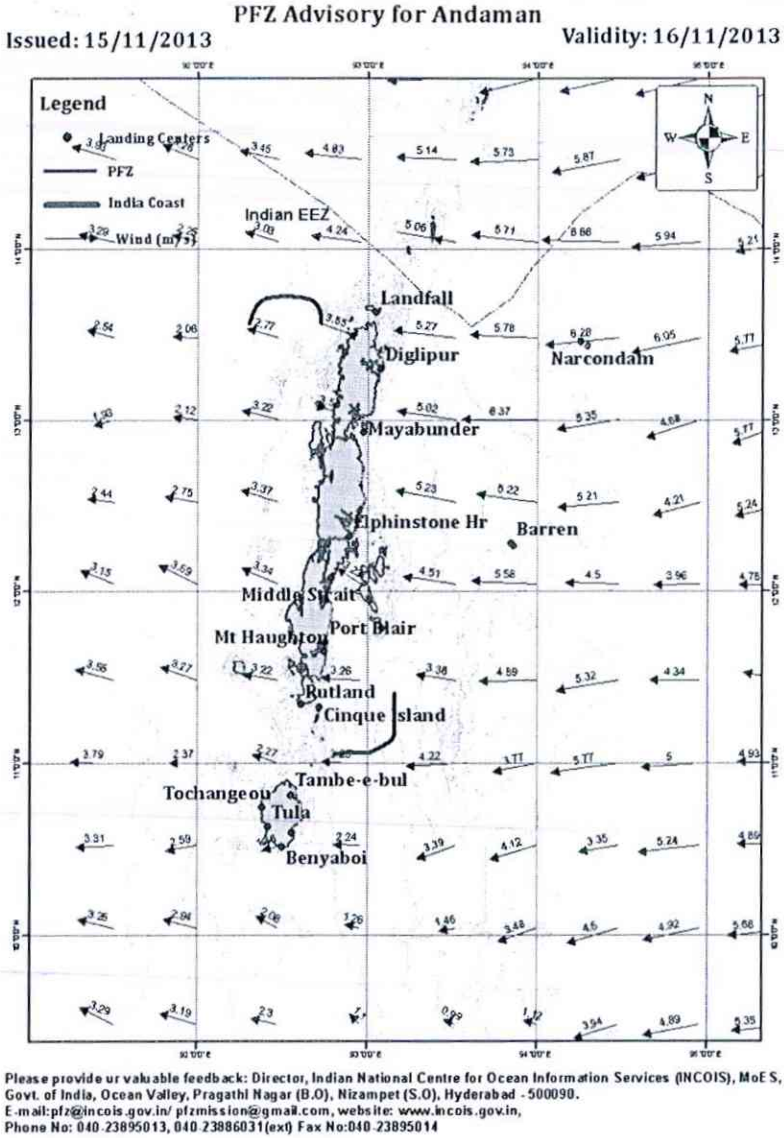

Fig. #.3 An INCOIS PFZ imagery for Andaman group of Islands

3.3 Detection of Meso-Scale Features Such as Eddies and Fronts that may Indicate Productive Fishing Grounds

Oceanographic features such as eddies, currents and meanders are pervasive features in the world's oceans. These conspicuous hydrographic features influence the horizontal and vertical distributions of the chemical (e.g. nutrients), physical (e.g. SST) and biological (e.g. Chl-a) properties in pelagic systems (Yoder et al. 1981, Seki et al. 2001). Eddies have been found to be localized regions of higher PP leading to aggregation and development of forage species base communities. The presence of mesoscale eddies and their detection by the fishing fleet is an important factor in fishery performance, leading to increased catch per effort for most pelagic species (Laurs and Lynn 1977; Laurs et al. 1984). The influence of mesoscale processes at fronts, such as the formation of rings, meanders and streamers arising or breaking off from these dynamic current systems, has also been shown to be important in shaping the distribution of pelagic fish and shellfish (Waluda et al. 2001). Studies linking the physical oceanographic processes with fish have been carried out around the major boundary currents and related mesoscale processes, such as in the fishing grounds associated with Kuroshio frontal regions (Yokouchi et al. 2000), mesoscale eddies and pelagic fisheries off Hawaiian waters (Seki et al. 2001), upwelling and longline fishery of Portuguese waters (Santos et al. 2006), Atlantic tuna and Gulf of Mexico circulation (Block et al. 2005), oceanographic conditions of spawning grounds of bluefin tuna in the NE Indian ocean (Matsuura et al. 1997), bluefin and frigate tuna spawning along the Balaeric archipelago (Garcia et al. 2003) and tuna exploitation near the mesoscale processes near the Sechelles (Fonteneau et al. 2006).

The chlorophyll-SST based advisories depend on the surface manifestation by algal blooms and thermal fronts which result from eddies and upwelling. Using altimetry data however, one would be able to follow the evolution of feature from inception to maturation and dissipation with time. There is a time lag between physical upwelling of nutrients to the ocean surface and development of phytoplankton blooms, and subsequently the aggregation of planktivorous and piscivorous fish. Altimetry data helps to identify the fish-aggregating meso-scale features from the outset giving valuable time to forecast and exploit the consequences. Difficulties in getting cloud free imageries sometimes limits the scope of this approach. Altimetry data, especially the SSH have been useful to study the physical oceanography and mesoscale circulation. Advances in SRS altimetry are making it possible to extend the information to the coastal areas where the fishermen are most active. Inputs from the altimetry data on the mesoscale features can be used to augment the PFZ advisories and also provide data during cloud cover.

3.4 Forecasting Cyclones and Ocean State to Reduce Impacts on Coastal Fisher Folk and Resources

Apart from elucidating the areas of likelihood of fish/ shellfish distributions during the PLD phase, the wind models used for generating wind inputs in simulation of physical process can be utilized for studying cyclone tracks. Fisheries is one of the sectors with high occupational hazard. The extent of direct mortality caused by storms at local or regional scales is severe (Gardner et al. 2005; Done 1992). OSF derived as products of numerical models are provided as input to fishermen to mitigate this risk. OSF provides wave and swell height as well as period, WS as well as wind direction (WD), Tsunami and rough sea warnings and coastal current details. To ensure safe navigation and operations at sea, and to forewarn the fishermen community, INCOIS started the OSF service in 2005 by issuing forecasts seven days in advance and at three hourly intervals, with daily updates. Fishermen utilize these forecasts to guide their daily operational activities and to ensure safe navigation. Though international agencies such as National Centres for Environmental Prediction (NCEP), USA and European Centre for Medium-Range Weather Forecasts (ECMWF) and UK issue sea state forecasts based on models such as WAVEWATCH III and WAM, these forecasts are for the open ocean. The INCOIS model provide accurate location-specific forecast in the coastal waters using high resolution local bathymetry, and tuning them using observed wave measurements. Real-time and on-line validation of the forecast products is disseminated through various means by INCOIS (Nair et al. 2013).

Cyclones also render coastal resources vulnerable. The ecological effects of cyclones on coral reefs have been reviewed by Harmelin-Vivien (1994). Tropical storms cause severe damage to the reefs; their impacts include the removal of reef matrix, scouring and fragmentation (Rogers et al. 1991; Done 1992), deposition of loosened material onto beaches above sea level or transporting it into deeper sub-reef environments (Done 1992). The reefs in Andaman and Nicobar Islands (ANI) suffered severe damage following a tropical cyclone in the Bay of Bengal off Myanmar coast during 13–17 March 2011 (Krishnan et.al. 2012). The investigation exposed the vulnerability of the reefs to oceanographic features which generally remain unnoticed unless they directly affect the life or the property of coastal inhabitants. The wind tracks of cyclone were generated using weather research and forecasting (WRF) models (Fig. #.4) which clearly indicated the passage of cyclone where reefs suffered damage.

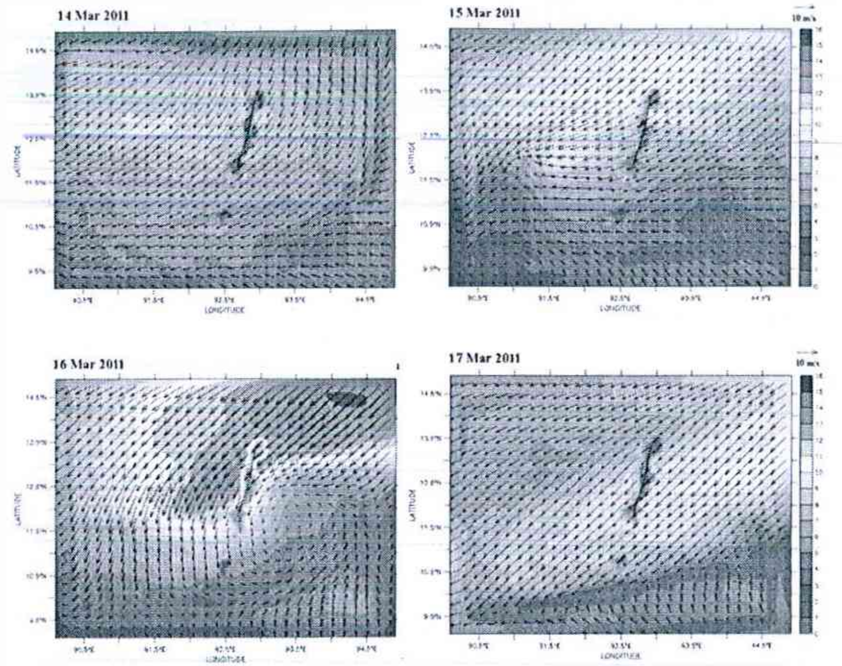

Fig. #.4 Tropical cyclone wind climatology modelled using WRF for studying the reef damages in Andaman Sea

3.5 Estimation of Potential Fishery Resources of an Exclusive Economic Zone (EEZ) for Fishing Fleet Management

Global marine fish production increased from less than 20 million tons per year in early 1950's to average around 90 million tons per year during the last decade. If the unreported and discarded catches are also taken into account, the global catches will be around 120 million tons per year (Zeller et al. 2005). The general trend in shortfall from traditional fishing grounds in the EEZ's of developed countries is compensated by the increasing exploitation of resources in developing countries (Pauly and Watson, 2003). The United Nations Convention on the Law of the Sea (UNCLOS) bestows the coastal states with the right to exploitation and responsibility for management of fishery resources of their EEZs. Observations are of paramount importance for managing the resources, and there is a need to establish acccurate catch data collection systems. Fish captured are considered to reflect fish abundance in coastal waters. From marine fish catch data, we can estimate the potential harvestable fish by plotting the catch effort curve, and estimate the maximum sustainable yield (MSY). But, mere post-mortem analysis of landed fish may lead to imperfect estimates as fish catch data without geotags of catching locations may not provide samples representative of the stock in the sea. Therefore, an estimate of harvestable fish based on *in situ* water productivity, taking into account the tropho-dynamics in the EEZ may afford very useful complimentary information.

Chlorophyll, which is an index of algal biomass (ML-3) present in a water column (L) is a prerequisite for primary production and subsequent fish production (ML-2T-1) which is the annual rate of production of fish biomass per unit area of sea bed. The importance of the potential link between PP and fish was understood decades ago (Ryther 1969), but the advent of SRS Chl-a and modelled PP data sets now available on global and meso-scale prompted policy planners to utilize this for estimation of fishery potential in the EEZ. Past studies relied on *in situ* datasets resulting from different sampling and processing methods and were generally characterized by low spatiotemporal sampling coverage. SRS Chl-a data are now basic to cross-trophic-level analyses of ecosystem production, structure, and function because of the easy and free availability of a wide-ranging, high resolution, and consistent sampling framework (Platt et al. 2007) at a reliable accuracy.

4. Conclusion

India is a global leader in satellite technology which can be effectively utilized for managing marine fisheries sector. Deploying a dedicated satellite for marine fisheries will provide several opportunities and applications for the fisheries sector. At present, the Potential Fishing Zone Advisories present a good example of integration of Satellite Remote Sensing (SRS) and fisheries. SRS can also be used for establishment of "e-infrastructure" in the marine fisheries sector. The concept of "e-infrastructure" deals with establishment of infrastructure (hardware and software) for greater data sharing and connectivity. The same principle can be used for SRS in marine fisheries in India. The data collected by SRS on synoptic temporal and spatial scales on various ocean parameters along with *in situ* data can be validated at dedicated data centres in the country. The advisories sent out by data centres can then be used by various management agencies or de-centralized agencies like Panchayats for effective management of resources. Guided fishing using SRS technology in turn can play a major role in precise fish stock assessments and management practices. Studies on fish larval transport are already underway which would give us a better estimate of future fish recruitment which will again increase the precision of stock assessments. SRS data can be used for trophic modelling and EAFM. Ocean health can also be monitored by SRS data and is currently being used for coral reef health advisories. SRS can be integrated with Geographic Information Systems for Marine Spatial Planning. Mapping the various users of marine ecosystems and their real time occurrences will play a big role in EAFM in India. The Vessel Monitoring and Surveillance (VMS) will increase the effectiveness of management. Identification of appropriate environment in the ocean from SRS data for release of fish juveniles as well as for inoculation of algal species for algal bioengineering of the oceans is also a possibility. Identification of suitable off-shore mariculture sites where culture will have minimal impacts on ocean health is also possible with SRS data.

A GIS-based site selection, by taking into account the social logistics, is an immediate requirement for the expansion of cage farming. In the context of potential extension of Indian EEZ from 200 to 350 nautical miles, it is necessary to develop offshore cage farming technologies including submersible cages by developing suitable cage designs and mooring systems. Further, policy for leasing suitable sites, bank finance, and governmental support through subsidy assistance is the need of the hour. Several tropical countries in the region are adopting advanced regulations, legal and policy framework for effective management of fisheries sector. Learning from these countries will give valuable information to manage our fisheries. Collaboration with survey agencies for information and infrastructure support, fishing industry for skilled human resource for exploration and harnessing of offshore resources is important. For integration of remote sensing in fisheries and spatial management, collaboration with the space research agencies, oceanographic laboratories and numerical modelling groups are needed. With novel technologies to be integrated into the marine sector, we need upgradation of skilled human pool in scientific research for seamless integration in areas such as remote sensing in fisheries management

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