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Utility of Sea Surface Height anomaly (SSHa) in determination of Potential Fishing Zones

by

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Abstract (100 words)
Physical processes in the oceans can be monitored by altimeters well before a radiometer can in terms of temperature or chlorophyll concentration. Herein we show the importance of Sea Surface Height anomaly (SSHa, retrieved with altimeter) in demarcating potential fishing zones. We also show how SSHa can help predict tuna movements, horizontally as well as vertically in the water column. Moreover, we prove these prediction with positively correlating SSHa to tuna hooking rates. In the end, we list out present and potential future sources from where SSHa can be retrieved in order to provide improved fishery advisories.

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ABSTRACT

Physical processes in the oceans - such as eddies, gyre, currents and upwelling - have a spatial scale of 10-100 km and lifespan ranging from few days to weeks. Most of these processes are driven by seasonal cycles and often occur at the basin scale. Such episodes determine spatial and vertical structure of water mass in the region with reference to many other properties such as temperature and salinity. As a result sharp thermal &/or salinity gradients are formed. Upwelling is a phenomena that brings nutrient rich deeper waters into photic zone (well-lit surface waters). Upwelling and cyclonic eddies form deeper mixed layer which facilitates nutrient entrainment across otherwise stratified waters. These nutrients are lifeline for marine food web. Phytoplankton consume it and blooms (increase in size and numbers) in such favorable conditions. Zooplankton feed upon phytoplankton and planktivorus fishes, on both of these. Such small (forage) fishes are preyed upon by bigger ones and so on. Nutrients retain along the frontal structure and these areas are proven to be good fishing zones.

Such processes can be monitored via altimeters well before a radiometer can detect the same in terms of temperature or ocean color (chlorophyll concentration). With multiple active sensors, current times are best opportunity to harness capabilities of satellite altimetry. Herein we show the importance of Sea Surface Height anomaly (SSHa, retrieved with altimeter) in demarcating potential fishing zones. We also show how SSHa can help predict tuna movements, horizontally as well as vertically in the water column. Moreover, we prove these prediction with positively correlating SSHa to tuna hooking rates. In the end, we list out present and potential future sources from where SSHa can be retrieved in order to provide improved fishery advisories.

1. Introduction

1.1 History of PFZ

Indian marine capture fishery is a typical multi-species tropical fishery (Pillai N.G.K., 2004). First major rise in annual marine fish production occurred in 1960s with introduction to mechanization of fleet (Planning Commission Study??? Ramakrishnan Korakandy, 1994). However, fishery remained mostly individual affair and till date it has not taken any significant corporate shape. This had inhibited the fleet from venturing away from the shore in many parts of the country till early 1990s when primary studies started towards locating resources with the help of satellite. Fishery research organizations with the help of Indian Space Research Organization (ISRO) laboratories took up primary studies with encouraging results (Dwivedi et. al. 2005, Shailesh Nayak, et. al., 2003, Solanki, et. al. 2001a, 2001b, 2003, 2005, 2008). Such efforts were utilizing satellites by US and European countries such as NOAA, MetOp and MODIS, SeaWiFS for SST and Chlorophyll, respectively.

However, towards the end of the '90s, India launched its first satellite for the study of oceans – IRS-P4, known as Oceansat-1. Oceansat-1 with sensor Ocean Color Monitor (OCM) onboard started providing Chlorophyll data. This has followed by initiation of Potential Fishing Zone (PFZ) advisory program, as a free of cost service to Indian fisher community within Indian EEZ (Exclusive Economic Zone). Initially this service used SST data from NOAA series of satellites. Eventually data from more satellite such as MODIS and MetOP were also incorporated. The service initiated as a one-day delay product made available weekly-twice, is now being provided in Near-Real Time mode on daily basis. Today the Indian Marine Fishery Advisory Services (MFAS) is a unique program with decade-plus long experience and data-archive, reaching to estimated 100,000 fishermen (≈10% of active marine fisher-folk) on daily basis. Validation experiments carried out in 2000s shown mostly positive and encouraging results (Tummala, S K, 2008, Das et al, 2010; Pillai. V.N, 2010, Deshpande et al 2011, Nammalwar et.al. 2013, S. Subramanian, 2014). Similarly from fishermen feedback, PFZ advisories are found to be beneficial in obtaining more profit by reduction in searching time (and fuel consumption) for shoals. This in turn helps improving Indian's footprint by cutting carbon emissions per unit mass of fishes caught (NAIP AR 2011-12, E. Vivekanandan et.al. 2013, Shubhadeep Ghosh et.al. 2014, Renju Ravi, 2014).

1.2 Physical processes & Biogeochemistry

Productivity of oceans depends on nutrient availability in sun-lit upper waters known as, euphotic zone (Behrenfeld and Falkowski, 1997; Platt and Sathyendranath, 1988). Oceanographic phenomena such as upwelling help contribute to much of this requirement, by entraining nutrients above mixed layer depth and in turn, allowing phytoplankton to sustain food-web with the help of photosynthesis. Stronger the upwelling, deeper the upper mixed layer of oceanic water column. This allows colder nutrient rich waters to surface and resultantly lowering Sea Surface Temperature (SST). Thus, SST provides handy signature in detecting upwelling zones with the help of remote-sensing data. Productive waters may initially attract only planktivorous fishes but eventually, also to bigger fishes which prey upon them. This is the very reason how SST was harnessed as a tool towards first of fishery resource predictions (Choudhury S.B., 2007,). Commercially-important species such as Tuna, are believed to have temperature specificity (Zainuddin et al, 2004; 2006). This has reflected in studies which show positive correlation of specific temperature range with better hooking rates (Kumari B, 2009, Santos, 2006).

Ocean-color missions have provided more than one dimensions to our understanding of ecosystem-level interactions in ocean. Cooler SST signature with higher concentration with chlorophyll, relative to surrounding waters, indicates upwelling-induced productivity (Anukul B et. Al., 2010, Tummala, SK, et. Al, 2009) and has been correlated with higher Catch per Unit Effort (CPUE) (Onitsuka et al., 2009, Fiedland et al, 2012).

1.3 Operational hurdles

Limitation in satellite data availability can impact a service such as PFZ. This becomes more important post-ISM (Indian Summer Monsoon) period - approximately September and October - when government imposed fishing ban is over and fishing season starts. Coincidently, that is the same time when fishermen expects higher fish-catch, but receding monsoon often cloud cover limits satellite data coverage. In this regard, gap free data is much important. Also as fishermen are to be provided a realistic forecast, it has to be based on the ocean property that triggers productivity.

1.4 SSHa vs SST & Chl products

Altimeter gives the information on Sea Surface Height (SSH). Ocean being a dynamic medium, processes result in anomalies in the SSH. Hence, SSHa can be used as a proxy for detection of many of the phenomena such as upwelling or eddy. Such phenomena scale on 10-100km spatially and from days to weeks temporally. Even though along track product of sea surface height has very narrow swath, models/tools have been successfully developed to optimally interpolate/merge satellite data with in-situ observations. On the other hand, ocean color sensor operate in visual range of spectrum and thus, does not have night view facility. AVHRR sensors that provide sea surface temperature does have night view facility. However, both of these sensor performance gets hampered with presence or cloud. In other words, these sensors do not have see-through capabilities and for a tropical country such as India - surrounded by two vast basins and peninsula that experience two distinct monsoon seasons - these prove to be a great setback in seamless service delivery. Moreover, physical processes lead to the biogeochamical and biological response in the region - in that order. With sea surface height information, forecasting can be possible in short-time period as fishery advisories have need. In this way, from gap-free and advanced information aspects, anomaly maps of Sea Surface Height can address both of these.

2. Data and Methods

2.1 PFZ Data (line, point)

Productive areas in Indian seas were identified with the help of GIS and represent SST gradients, high-Chlorophyll region or often, combination of both. These features are archived as polyline shapefile. With each of the line-vectors attributed a unique ID it is possible to keep track of a feature even when it is clipped into smaller lines or converted into points. Line-vectors were converted into string of points spaced at regular interval of 1.5 km.

2.2 Tuna telemetry experiments (SATTUNA)

Pop-Up Satellite Archival Tags (PSAT) were used for studying yellowfin tuna movements. PSATs purchased from M/s Microwave Telemetry (MT), USA with product name X-Tag. had light sensor (for position estimations), pressure sensor (for depth calculation) and temperature sensor. Fishes were caught within India EEZ with Long-line fishing method and brought on-board with a specially prepared cradle. Only healthy fishes with minimum 90cm length (to avoid any interference from tag on normal behavior) were tagged along with umbrella type of darts. Processing of movement tracks at CLS was availed only for the tags that spent minimum 40 days at sea.

2.3 Tuna fish-catch data

Tuna fish-catch data from FSI vessels operated from Mumbai, Goa, Chennai and Port Blair were used. These vessels carry out fishing with the method named, long lining. A total of 2700 records were used spanning all the seasons during year 2005-2012. The database comprised of fishing date, location, number of fishes caught and number of hooks set. Hooking rates were calculated using the later two.

2.4 Sea Surface Temperature (SST) data

SST data in the form of daily satellite passes were collected from INCOIS ground station. The data is derived from AVHRR (Advanced Very High Resolution Radiometer) sensor onboard NOAA series (N-18, N-19) and ESA satellites (MetOp-1 & MetOp-2). The satellites provide data at spatial resolution of approx 1.1 km (≈1100 m). SST data were available for the period of 2006-2012. A total of 570 points were found to have data. Pixel values were extracted in order to correlate with tuna catch records.

2.5 Sea Surface Height anomaly (SSHa) data

SSHa relative to the geoid (mean ocean surface of the Earth if the ocean is at rest) is derived from satellite altimeter measurements. Altimeter measures the time taken by a radar pulse to travel from the antenna to the surface and back to the receiver. Combined with precise location data, altimetry measurements yield sea-surface heights. For operational purposes, anomaly of these observations are more useful to study various oceanographic phenomena. Altimeter outputs are either along track or merged product. Operational Geophysical Data Records (OGDR), Intermediate (IGDR) or GDR products are made available with delay of approx 10-24 hours, 7-10days or 30-40days, respectively.

(a) AVISO data

AVISO (Archiving, Validation and Interpretation of Satellite Oceanographic) provides SSHa observations (along with other oceanographic products) from multiple satellites.

(b) CCAR data

Colorado Centre for Astrodynamic Research (CCAR), USA provides SSHa and other oceanographic products. CCAR generates gap-free SSHa product that uses satellite observations and merges them optimally. Keeping in mind narrow swath and low-repeativity that altimetry observations offer, such product is very useful for spatial correlation of discrete events such as fishing. SSHa data from CCAR for years 2005 to 2012 was collected. Values from raster images were extracted for corresponding latitude and longitude values of fish catch data as well as along the PFZs. Values from corresponding date and location were extracted for all available (2700) catch data and PFZ records.

3. SSHa Trend along PFZ

Potential Fishing Zones (PFZ) demarcated using high-SST gradients and high chlorophyll regions have been archived for more than a decade. As we hypothesize that physical processes avail the nutrients that sets up a local food chain, occurrence of PFZs should follow a trend with reference to SSHa. As a proof of concept, we took PFZ data for the year 2014 and extracted SSHa values along these for various months. The data was available for all the regions for all the months.

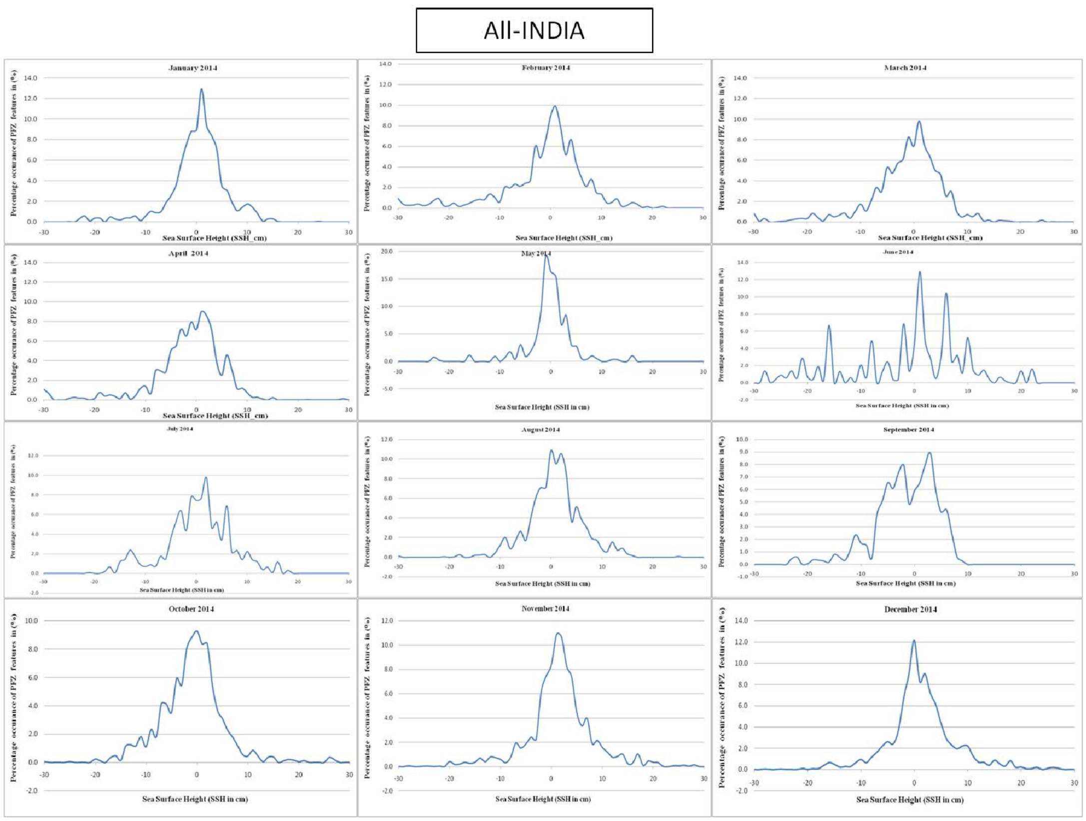

Figure1. Month-wise distribution of PFZ across SSHa (cm, X-axis) within Indian EEZ

As evident from the trends, occurrence of PFZ follows typical Gaussian distribution on either (positive and negative) sides of anomalies. Also, trends vary throughout the year due to seasonal forcing. However, such forcing may vary region-wise and thus, peculiar trends can be studied. We divided mainland EEZ in four quarters. Andamans' were studied separately.

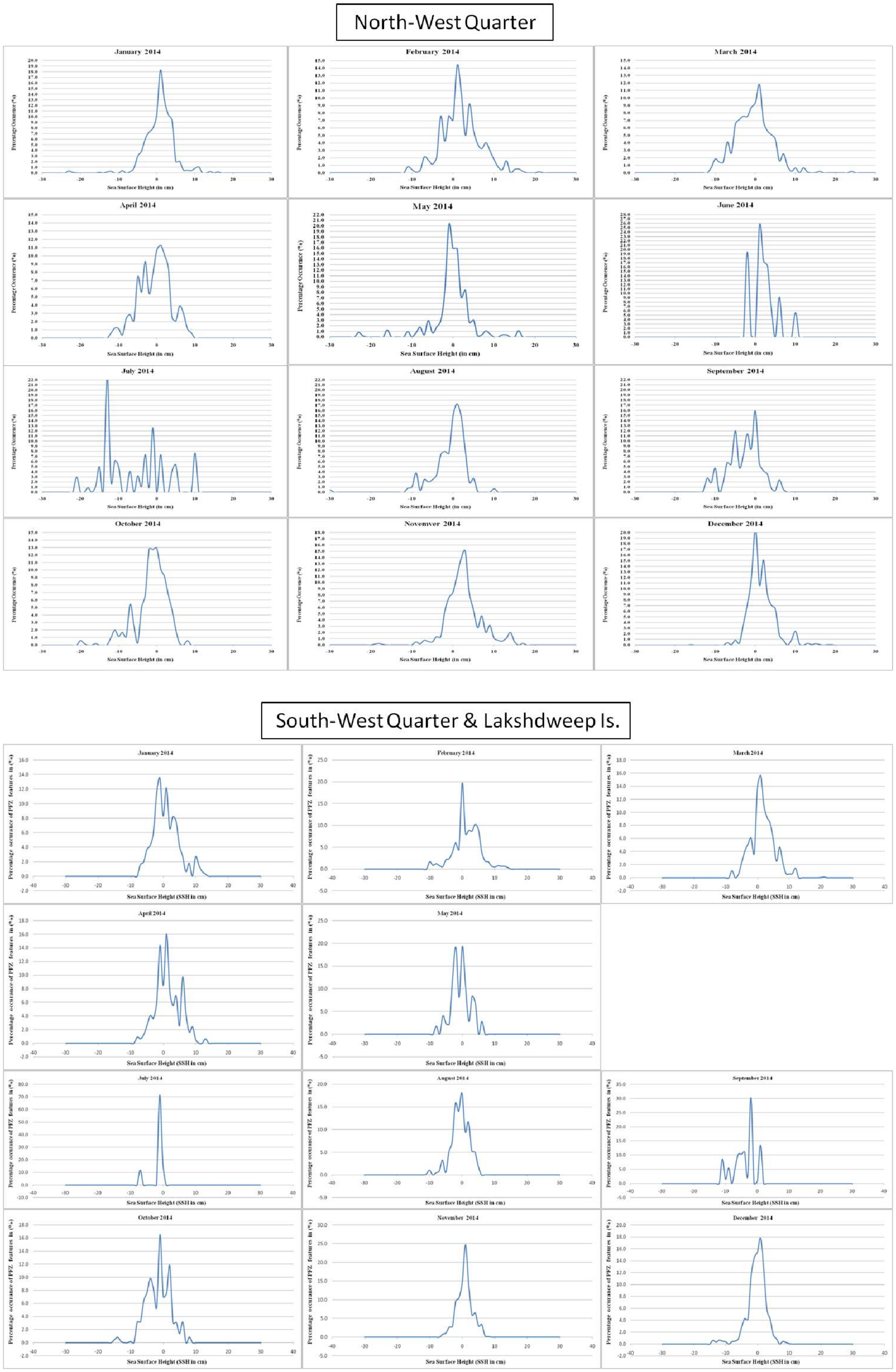

Figure2. Month-wise distribution of PFZ across SSHa (cm, X-axis) Arabian Sea

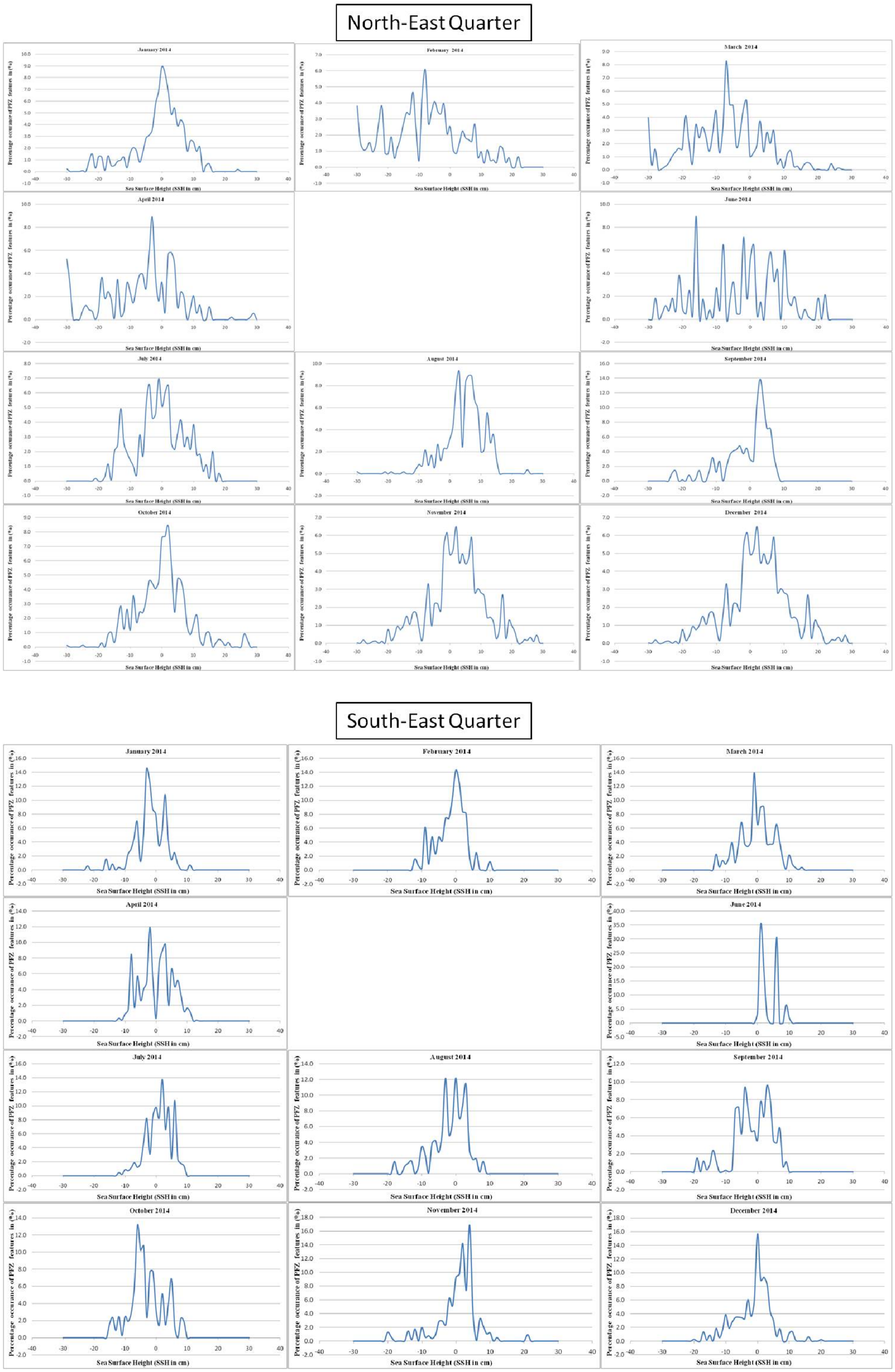

Figure3. Month-wise distribution of PFZ across SSHa (cm, X-axis) in Bay of Bengal

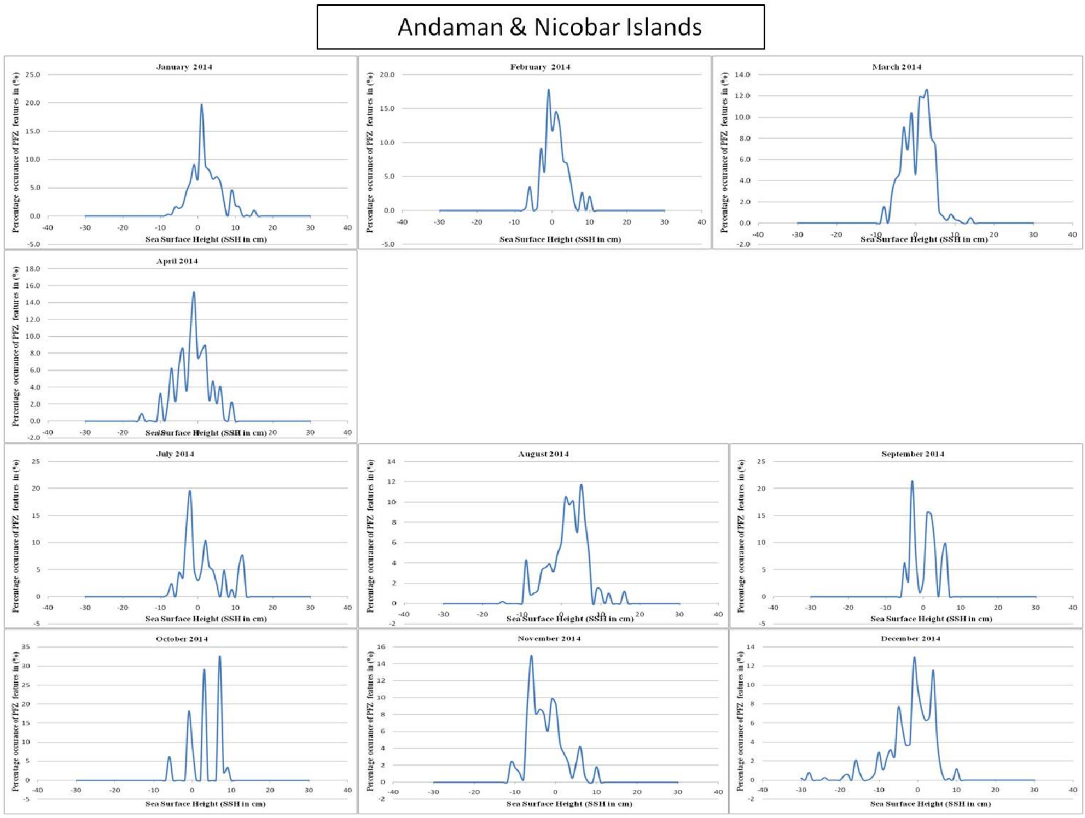

Figure4. Month-wise distribution of PFZ across SSHa (cm, X-axis) in A&N islands region

Data were not available for months of May and/or June with exception to northwest quarter of the Indian EEZ (northeast Arabian Sea). All the regions shown distinct distribution for various seasons. Arabian Sea have shown in general high coherence of SST-Chlorophyll distribution driven by processes that also contribute to anomaly in sea level. Whereas in Bay of Bengal, southern half of the basin shown better coherence in compare to its northern counterpart. Northeast quarter of Indian EEZ (comprising off West Bengal, Odisha and northern parts of Andhra Pradesh coasts) usually shown broad distribution, while often providing indistinct patterns, especially for Feb-June period. This is the time of the year where major rivers from Himalayas pour significant amount of colder, fresh water into the bay. Most of this bulk stays in the northern part and some portion travels on western boundary as EICC (East Indian Coastal Current). Salinity fronts generated due to freshwater influx do not have coherence with processes such as upwelling and thus, nor with SSHa.

4. SSHa Trend and Yellowfin Tuna Movements

Tuna is an endothermic species, known for high metabolic rate with an aptitude of adaptations for high ventilation rates [Bushnell et al, 1992]. Although tuna movement often exhibit oscillatory pattern to balance energy conservation and foraging, it prefers staying in the upper thermocline, mostly close to the base of mixed layer depth (MLD) zone [Block et al, 1997] to avoid deeper cold water. It has been argued that temperature plays a dominant role in defining the migration of tuna [Brill, 1994]. Since the deeper cold water is also associated with low dissolved oxygen (DO) and it is well established that presence of oxygen deficient water significantly influence shaping marine ecosystem niche [Naqvi et al, 2006; Seibel et al, 2011], it becomes important to understand which parameter among temperature and DO regulates the movement patterns of Tuna. To understand this, and advancing upon previous tag-based studies [Brill et al, 1999; Beenakumari et al, 1993, Yesaki et al, 1992], tagging experiment were carried out wherein yellowfin tuna were tagged using recovery-independent pop-up satellite archival tags in the Indian Ocean. Such tags provide three dimensional movements of fishes, enabling us to correlate spatio-temporal patterns in the light of oceanographic conditions.

Tuna telemetry studies employ either acoustic tracking or archival tagging approach. Such studies have yielded insight towards its diving behavior, spatial movement and temperature preferences [Brill et al, 1999]. Tuna hooking rates are well-correlated with Sea Surface Temperature (SST) [Beenakumari et al, 1993] and thus, temperature became a proxy for tuna resource monitoring. Most of the telemetry studies were conducted in the Pacific or Atlantic Oceans. Efforts in the Indian Ocean date back to 1990 (in Maldivian waters) [Yesaki et al, 1992] with major initiative been taken by IOTC under project IOTTP (Indian Ocean Tuna Tagging Programme) during 2002-09. These studies used conventional plastic tags, which being highly recovery-dependent, could yield limited knowledge with recovery rates no more than 18%.

In this context, here are the first in-wild observational evidence of tuna's movement preferences with reference to the oxycline depth. A typical marine dissolved oxygen profile shows higher concentration in upper mixed layer with fluctuations pertaining to the degree of mixing. Deeper waters experience removal of dissolved oxygen during decomposition of organic matter. This gradient sharpens linearly with stronger stratification, resulting in cold deeper waters rich with inorganic nutrients but with lower oxygen concentration. Resurfacing of these waters, through upwelling, fuel nutrients back to the local food-web at upper ocean. Upwelling processes can be detected with the help of satellite derived SST values. Divergence (upwelling coupled and otherwise) translates in lowering Sea Surface Height, which can be observed through satellite altimetry (negative SSH-anomaly/SSHa) and is strongly correlated with oxycline depth [Satya Prakash et al, 2013].

If tuna movements are induced only based on food availability, it would be spending maximum time in core of upwelling regions, but it has been reported using correlation between its movement patterns and SST that it tends to stay along the fronts [Laurs et al, 1984]. Analysis of tagged yellowfin tuna movements with reference to SSHa shows that the fishes tend to spend more time (~70%) in the periphery of divergence zones (between ±5cm SSHa) (Fig5) with frequency peak slightly towards negative side (Mean=-1.1, Median=-1.1). This supports to the SST-based observations that show frontal adherence and also that yellowfin tuna is attracted to an extent, with the presence of food induced by divergence and upwelling. However, the fact that the fishes avoid going further towards core of divergence, suggests that there could be driving forces other than food, which might control yellowfin tuna horizontal movements. When compared with remotely-sensed SST and Argo float gridded data temperature profiles, spatial or vertical movements of tagged yellowfin tuna did not show significant temperature specificity.

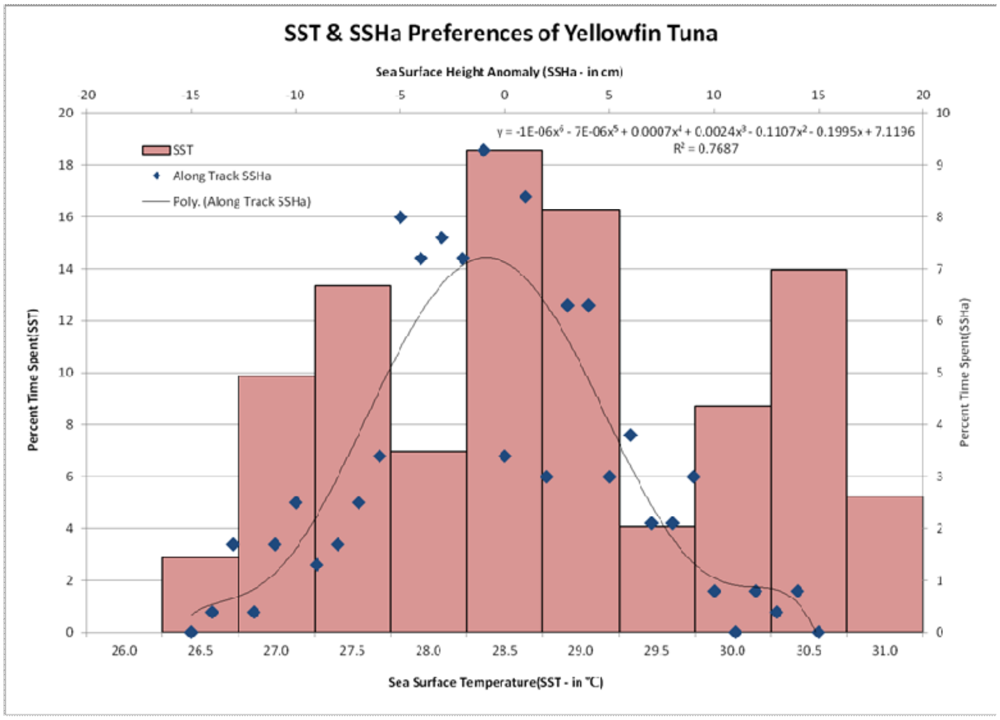

Figure5. SST and SSHa preference for yellowfin tuna movements

However, many earlier studies have argued that that temperature (by affecting cardiac output through red-muscle oxygen consumption) is a limiting factor probably because all the movements recorded were in mid-to-high latitudes and thus, observed that most of the movements were restricted to the upper thermocline regions [Block et al, 1997; Brill et al, 1999]. For example, in California bright the tuna vertical distribution was reported to be restricted in the upper thermocline zone (T>17.5C; [Block et al, 1997]) and in Hawaii the tagging experiment indicated a marked preference from near mixed layer temperature (19-26°C; [Block et al, 1997]). In concurrence with earlier observations, our analysis also shows that yellowfin tuna tend to spend most of the time in the upper 100 m which is however, relatively shallower than expected considering the oceanographic conditions of the tropical northern Indian Ocean where the sub-surface (near thermocline) waters are relatively warmer (>20°C). Notably, while these tropical waters are sub-oxic [Naqvi et al, 2006], earlier studies were conducted in regions where oxygen concentration was relatively (> 4 ml/l|) high and thus, it may not have been detected as a limiting factor. Evident from the fact the fishes avoid going deeper despite favoring temperature condition therefore, suggests that there could be other driving forces such as DO.

The northern Indian Ocean *i.e.*, the Arabian Sea and Bay of Bengal is characterized by the presence of oxygen minimum zones at intermediate depths. Despite being located at similar latitudes and being affected by seasonally reversing monsoon, the productivity pattern in these two basins is markedly different: former being more productive. However the export flux in both these basins is still comparable owing to high flux of dissolved organic matter through river discharge in the bay. This leads to high oxygen demand in the intermediate depths, which coupled with sluggish circulation as both the basins are landlocked by the Eurasian landmass in the north, leads to depletion of dissolved oxygen concentration at the mid depths. In this context, the present experiment provided a unique opportunity understand tuna movements from DO perspective [Naqvi et al, 2006, Seibel et al, 2011].

Unavailability of dissolved oxygen data with high spatial and temporal resolution in this part of the oceans was a major hindrance in understanding its role on migration pattern of Tuna. Recent deployments of few oxygen sensor laden ARGO floats have provided a new avenue in this context. However, considering the areal extent of Northern Indian Ocean, oxygen data from these floats are limited in time and space, to be used for direct correlation. To overcome this limitation we used empirical relationship [Satya Prakash et al, 2013] to estimate depth of oxygen deficient water, through oxycline, in the northern Indian Ocean using satellite derived SSHa. The correlation between oxygen concentration along the track and depths of Tuna movement certainly indicates that availability of DO restricts movement of tuna to deeper depth despite having favorable condition with respect to water temperature (Fig6). Limited studies within tropics have also suggested [Cayre et al, 1993] oxygen being a limiting factor instead of temperature, despite refuting this possibility in own earlier studies [Cayre, 1991].

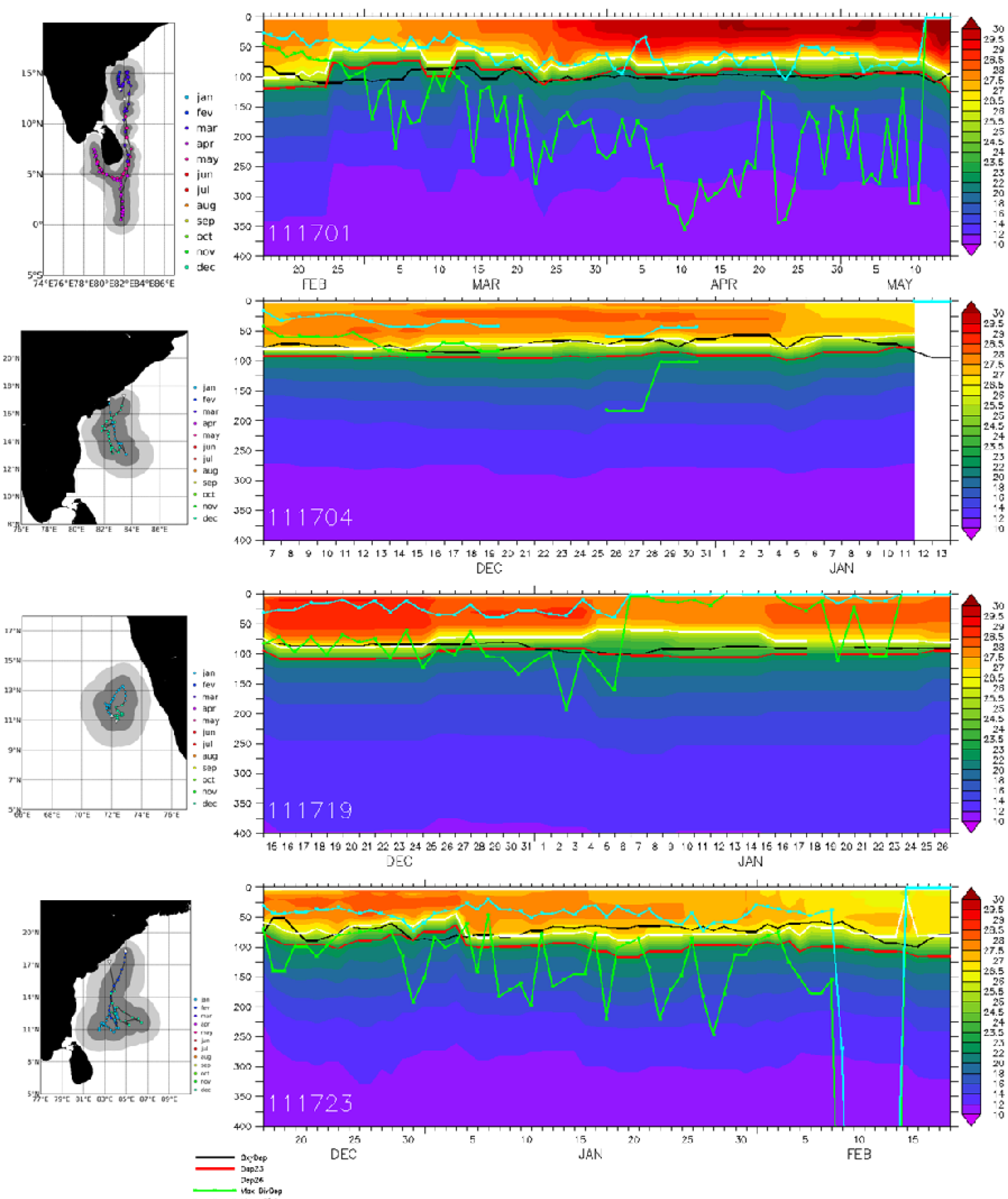

Figure6. Tuna vertical movements (cyan) against along track Temp, and Oxycline (black)

5. SSHa Trend and Yellowfin Tuna Hooking Rates

Tuna hooking rates were correlated with remotely-sensed sea surface temperature values. Most records were within 27°-30°C. Except some observations in lower temperature waters, high hooking rates were found to fall in 24-25°C, for 26°C and between 28-29°C waters.; with overall poor correlation between temperature and hooking rates.

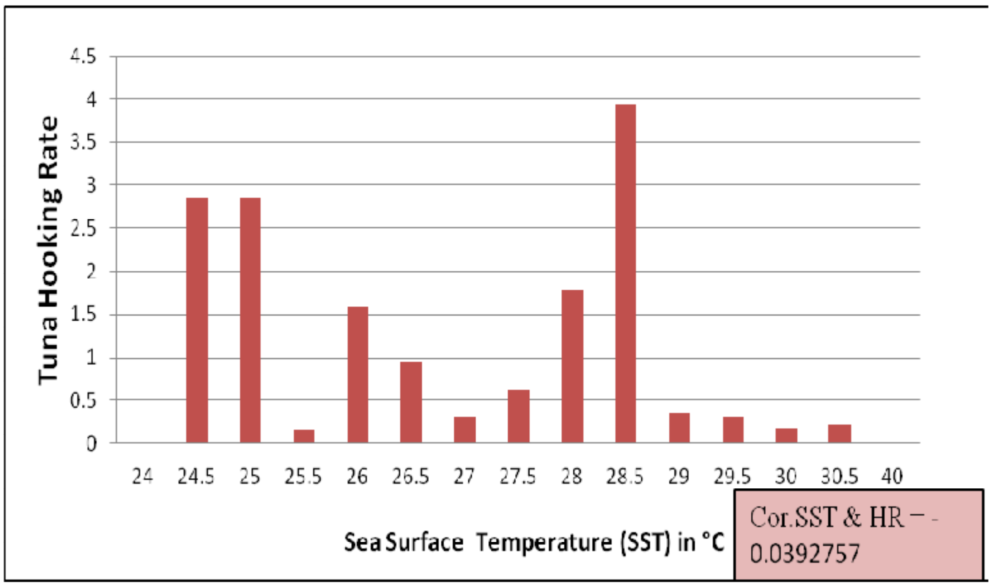

Figure7. Tuna catch correlation with satellite based SST

Moreover, SSHa data for the particular day was derived for all the respective fishing points. The distribution of SSHa across those points provided quasi-Gaussian trend on the either side. Majority (77%) of the catch locations were within +5 to -5 cm range. This indicates that tuna prefers to stay in moderate SSHa region. This can be understood with the fact that downwelling zones (positive height regions) will be having less food (low productivity due to nutrient consumption). On the other hand, upwelling zones (identified with negative height values) are productive but will be having less clear waters due to presence of plankton. So even though this area may have maximum abundance of the forage fishes, it will be less preferred by tuna due to being non-clear water. Hence, being in the moderate SSHa regions, tuna can access maximum of the food while staying in relatively clear waters.

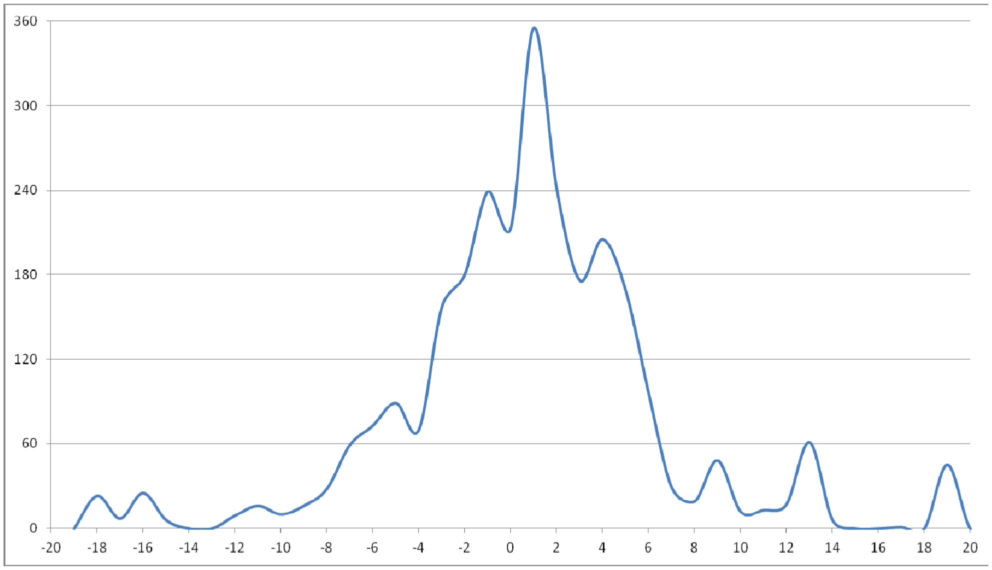

Figure8. Trend of SSHa (cm, X-axis) among the tuna catch locations (y-axis: no. of records)

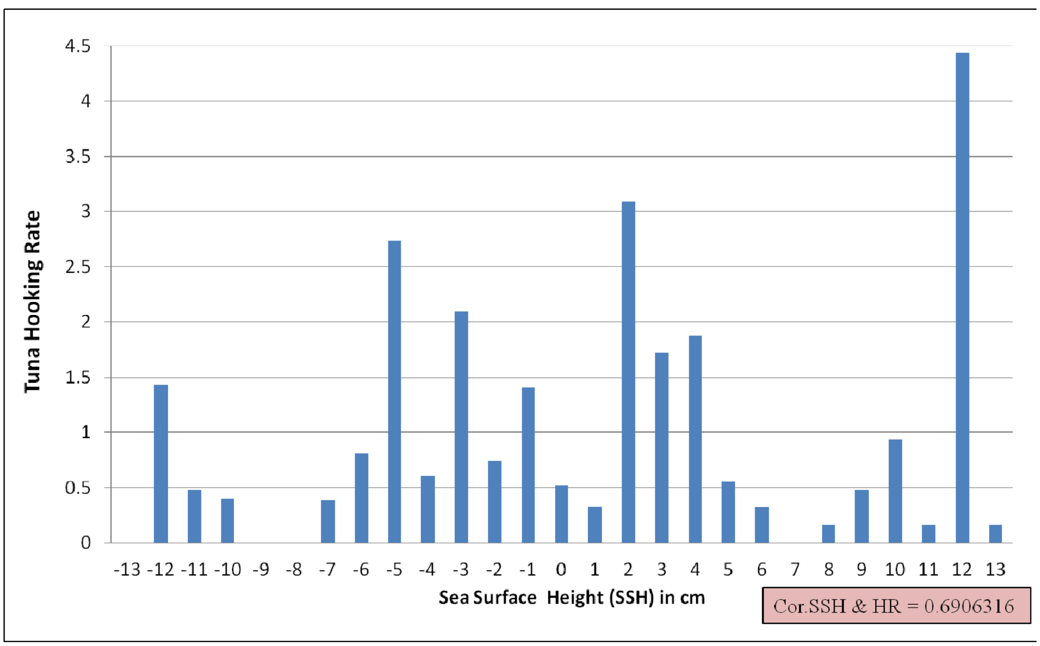

Figure9. Tuna Hooking rates correlated with Sea Surface Height

To test this hypothesis correlation was attempted between tuna hooking rates and SSHa values at those locations. It is observed that favorable SSHa values range between +5 to -5cm. Additionally, correlation was found to be better (0.69) in compare to SST (0.039). This suggests that in tropical ocean scenario where temperatures do not vary at magnitudes as on higher latitudes (where temperature has been correlated well with tuna hooking rates), SSHa could be a promising parameter to locate tuna resources. To further investigate how SSHa trends vary over time, data were segregated for each of the twelve months. It was observed that winter and spring time tuna catch locations were having inclined distribution towards positive values. However, as the season progresses the distribution skews towards negative side. In the post monsoon period (esp. September), it reaches to the extreme and then starts swinging back. This indicates that during spring time when many parts of northern Indian Ocean witnesses bloom (high chlorophyll) conditions, the food availability extends further away from upwelling zones and eddies due to lateral mixing. From this it is understood that tuna may spend more time in the region with overall positive SSHa areas. Such conditions change as summer approaches, and now tuna need to venture relatively closer to the core of eddies or upwelling zones. As Indian EEZ has distinct characteristics on either side of the peninsula as well as along the latitude, data for mainland EEZ was further segregated in four quarters of EEZ while Andaman & Nicobar Islands were made a separate group.

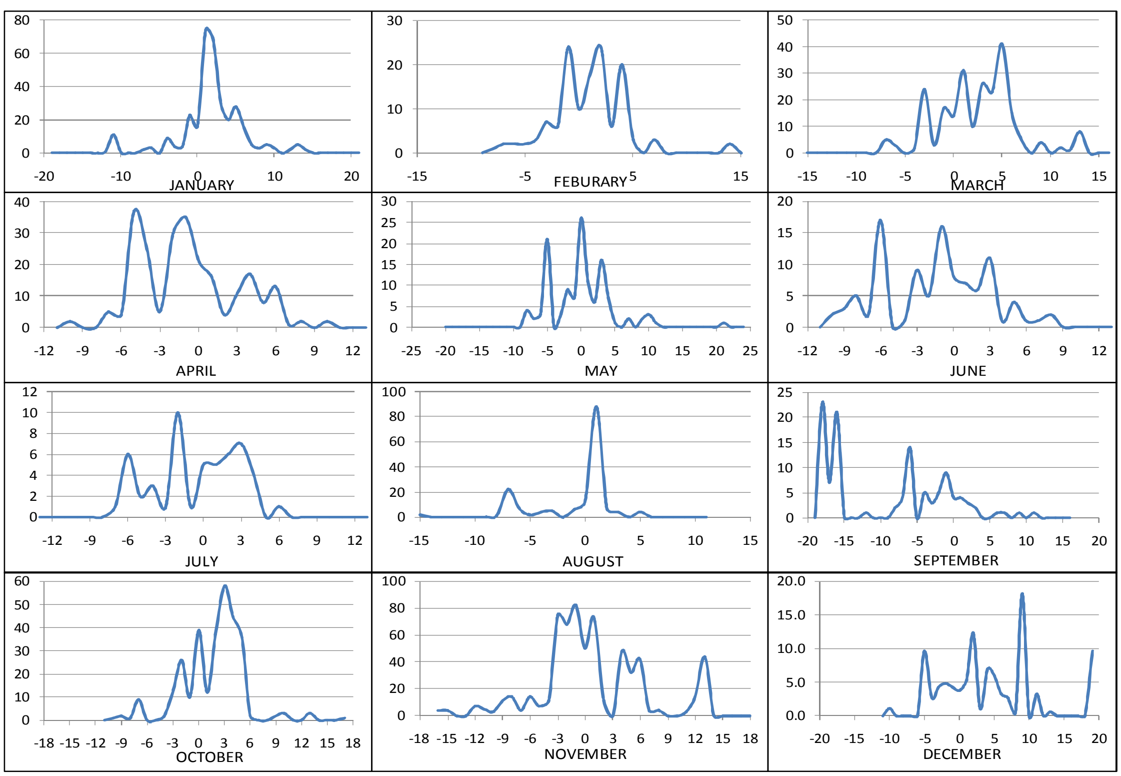

Figure10. Month-wise correlation of tuna catch with SSHa (cm, X-axis) within Indian EEZ

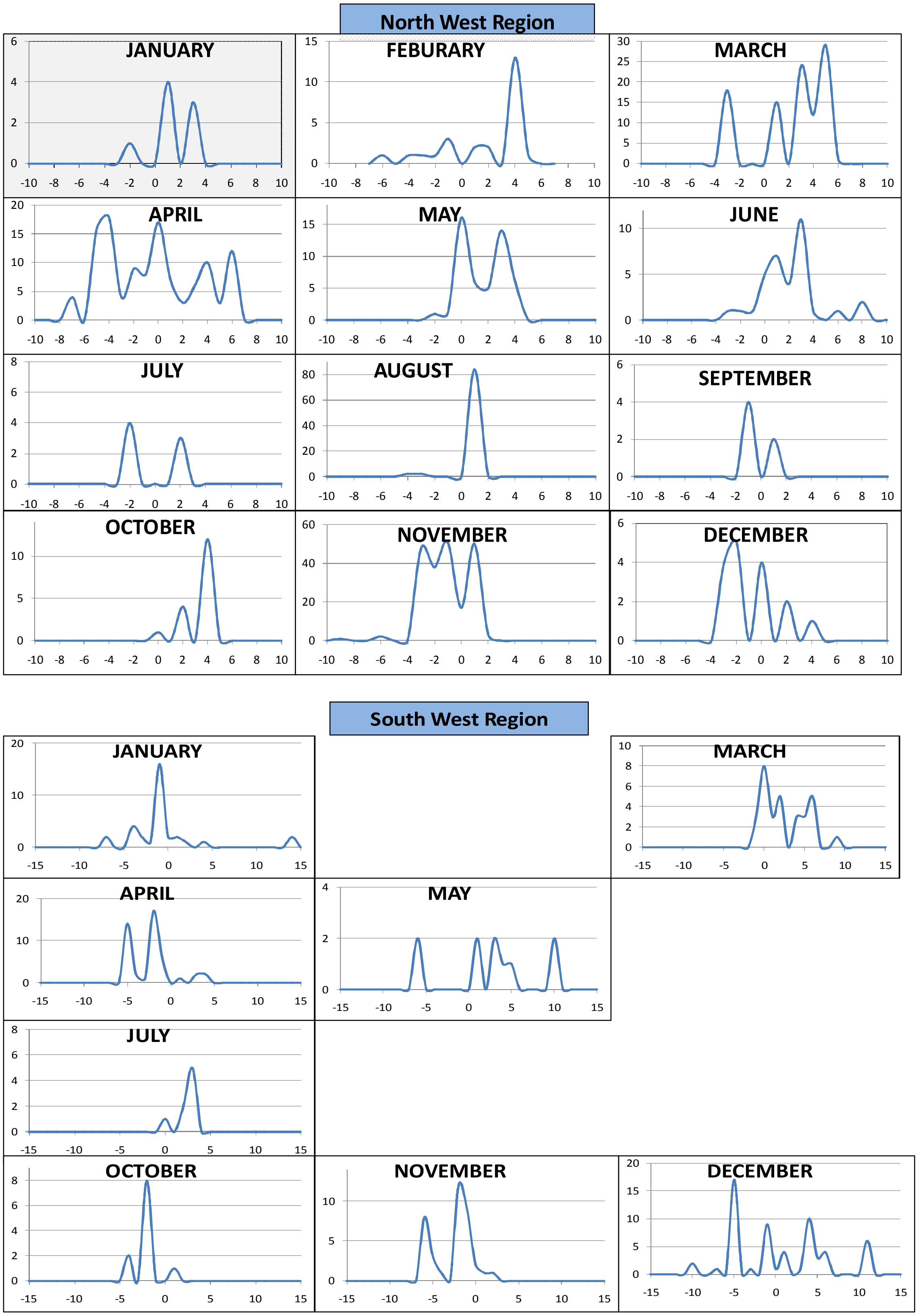

Figure11. Month-wise correlation of tuna catch with SSHa (cm, X-axis) in Arabian Sea

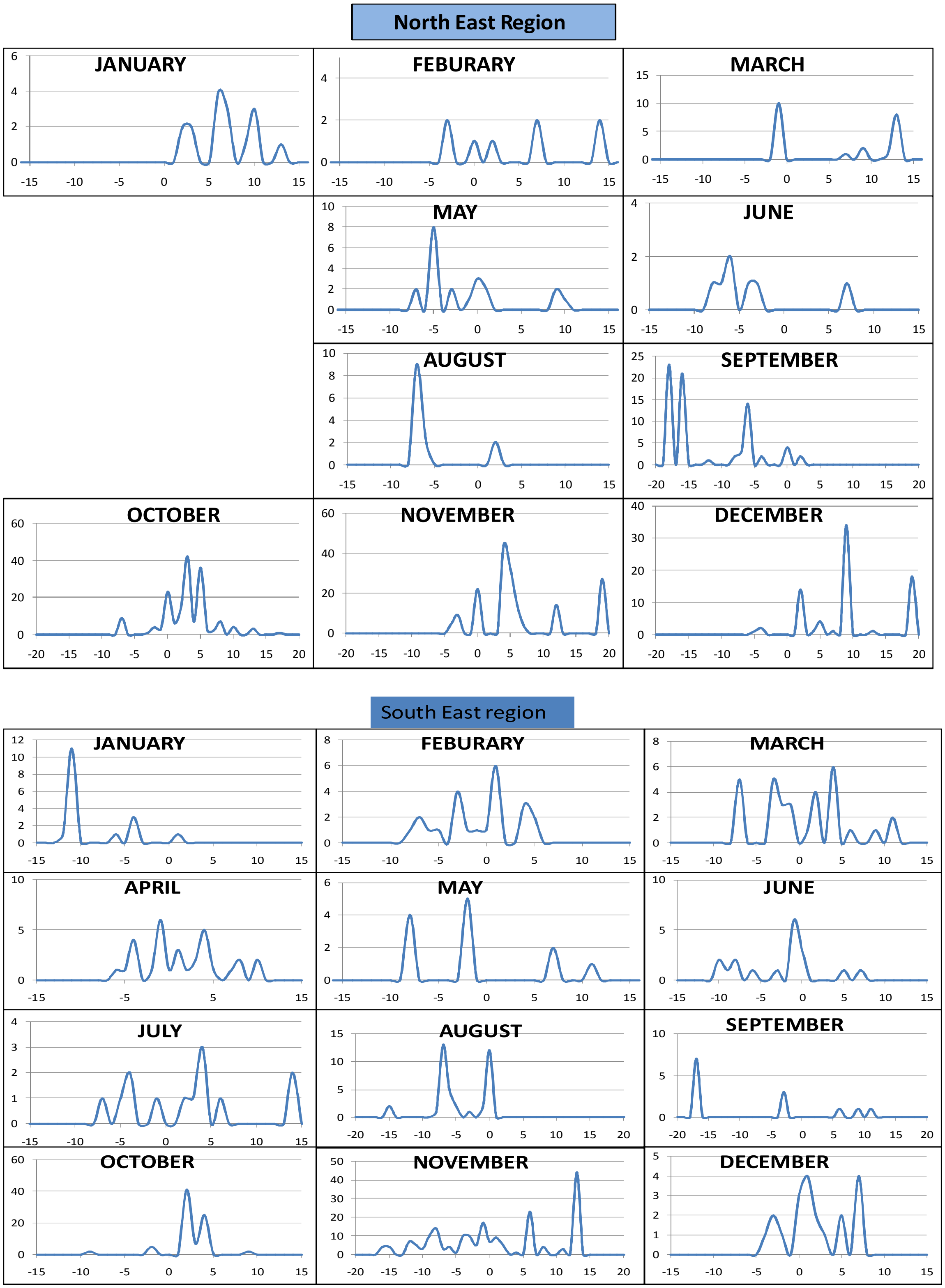

Figure12. Month-wise correlation of tuna catch with SSHa (cm, X-axis) Western BoB

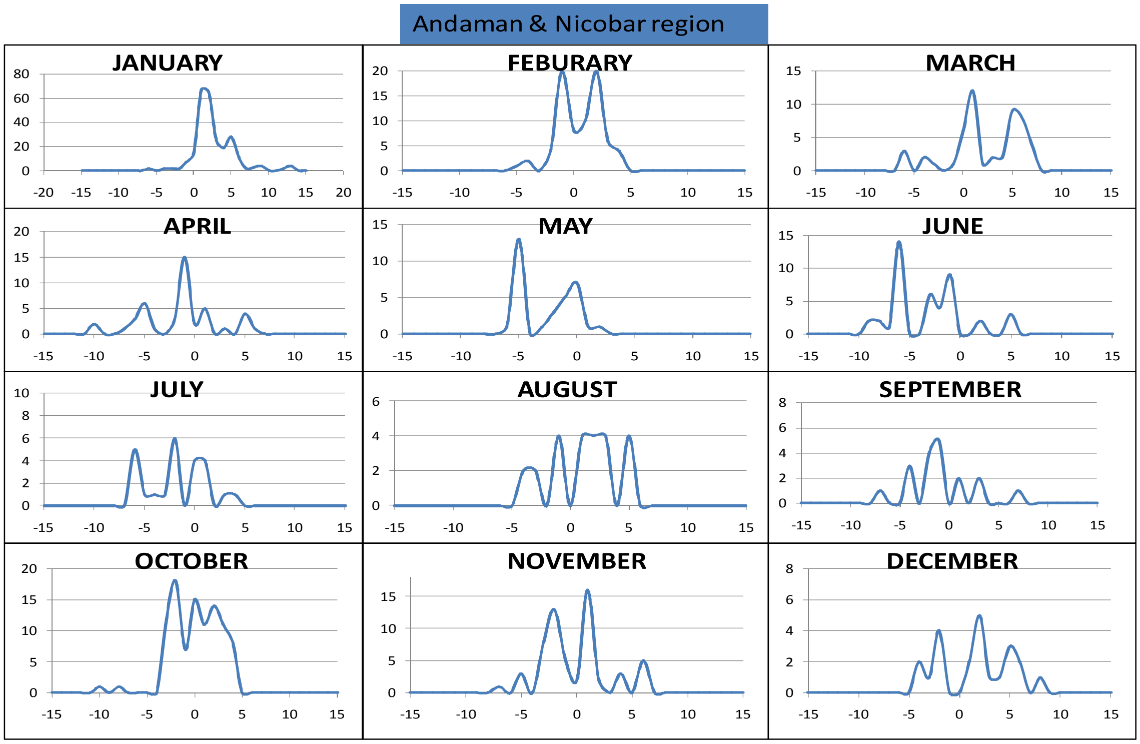

Figure13. Month-wise correlation of tuna catch with SSHa (cm, X-axis) in South-East BoB

No catch-data were available for some months within southwest (Kerala, Karnataka) and northeast (Odisha, WB) quarters. Prominent seasonality (high catch records) were found for northwest (Feb-May, Aug-Nov), southwest (Nov-Apr), northeast (Sep-Dec), southeast (Aug-Nov) and for A&N region (Oct-Apr). Most peculiar observation was for northeast and southeast region with high frequencies during September and October months, respectively. This suggests of stock moving within these quarters in consecutive months and needs to be investigated further with reference to monsoon retreat. Similar spike was observed for Andaman & Nicobar Islands during the month of October as well, further indicating to the potential basin-wide phenomena leading to the such observations.

Further investigations that focus on weather/climate parameters (along with standing stock information) can lead to the seasonal prediction of harvestable proportion of the stock as well as can provide insights on stock exploitation status.

6. Operational alternatives for SSHa Products

6.1 AVISO Products

Apart from standard OGDR, IGDR and GDR products, AVISO provides a range of global altimeter products such as MSLA (Maps of Sea Level Anomaly), MADT (Maps of Absolute Dynamic Topography) and absolute geostrophic velocities, along-track SLA and ADT etc.

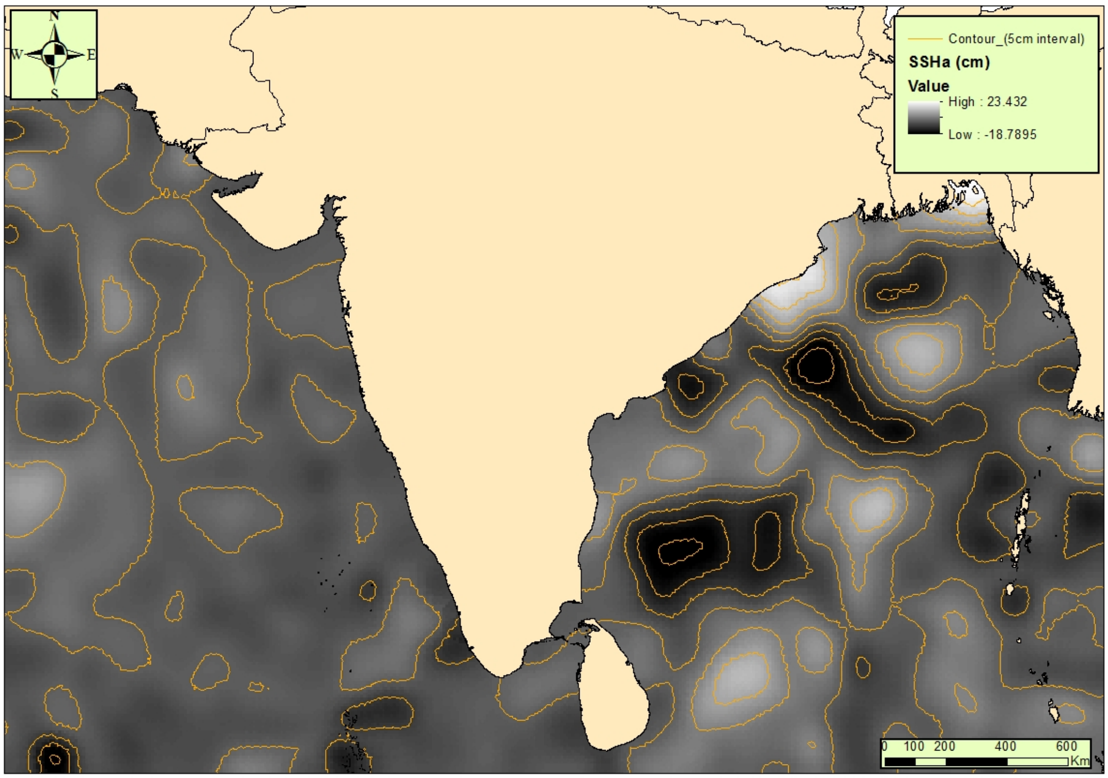

Figure14: An example of SSHa gridded-data product from AVISO

As shown in example above, AVISO data are one of the standard products available internationally. However, NRT (near-real time) global gap-free product is updated three-times. First day (D0) product is called preliminary NRT product, the same will be updated on D3 as intermediate NRT map and once again updated on D6. As a result, the same data is not available after three days. This is difficult for operational purposes because the quality of data used for hindcasting with historical fish-catch data or used for training a model is different from the quality of the operational (D0) product.

6.2 CCAR Products

CCAR data are made available to INCOIS via special FTP access since year 2013 when other alternatives for historical gridded data products were not availed due to various reasons. The global data is available in a daily file form for years 2002 onwards. Due to these reasons, CCAR data is being used at INCOIS for all the hindcasting and similar research exercises with reference to fish catch and fish movements.

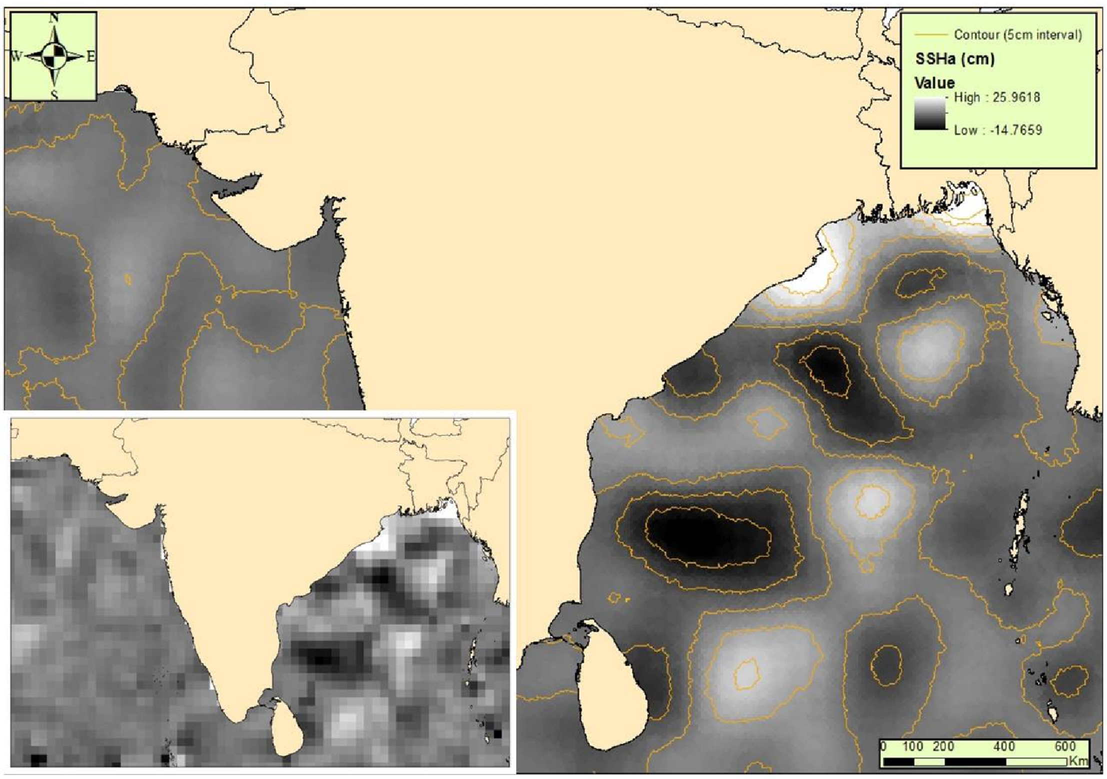

Figure15: An example SSHa data from CCAR before (inset) and after krigging interpolation

This gap-free, optimally merged, multisatellite product is being updated every evening itself. Original spatial resolution of the product is 1/4 degree (≈25 km) but after applying krigging (geospatial interpolation tool) the product resolution can be achieved to ≈8 km. As shown in an example data of the same date, the krigged product provides mesoscale features very similar to AVISO data and satisfies present operational requirements. In this way, we have found this product presently most suitable for the operational purposes.

7. Future Prospects

7.1 MOM (Modular Ocean Model)

A one-way nested Indian Ocean regional model is recently developed at INCOIS. The model combines the NOAA-GFDL Modular Ocean Model (MOM4p1) at global (nominally one degree) and a regional Indian Ocean MOM4p1 configuration with 25km resolution. Along from other properties, SSHa was validated with altimeter observations as follows.

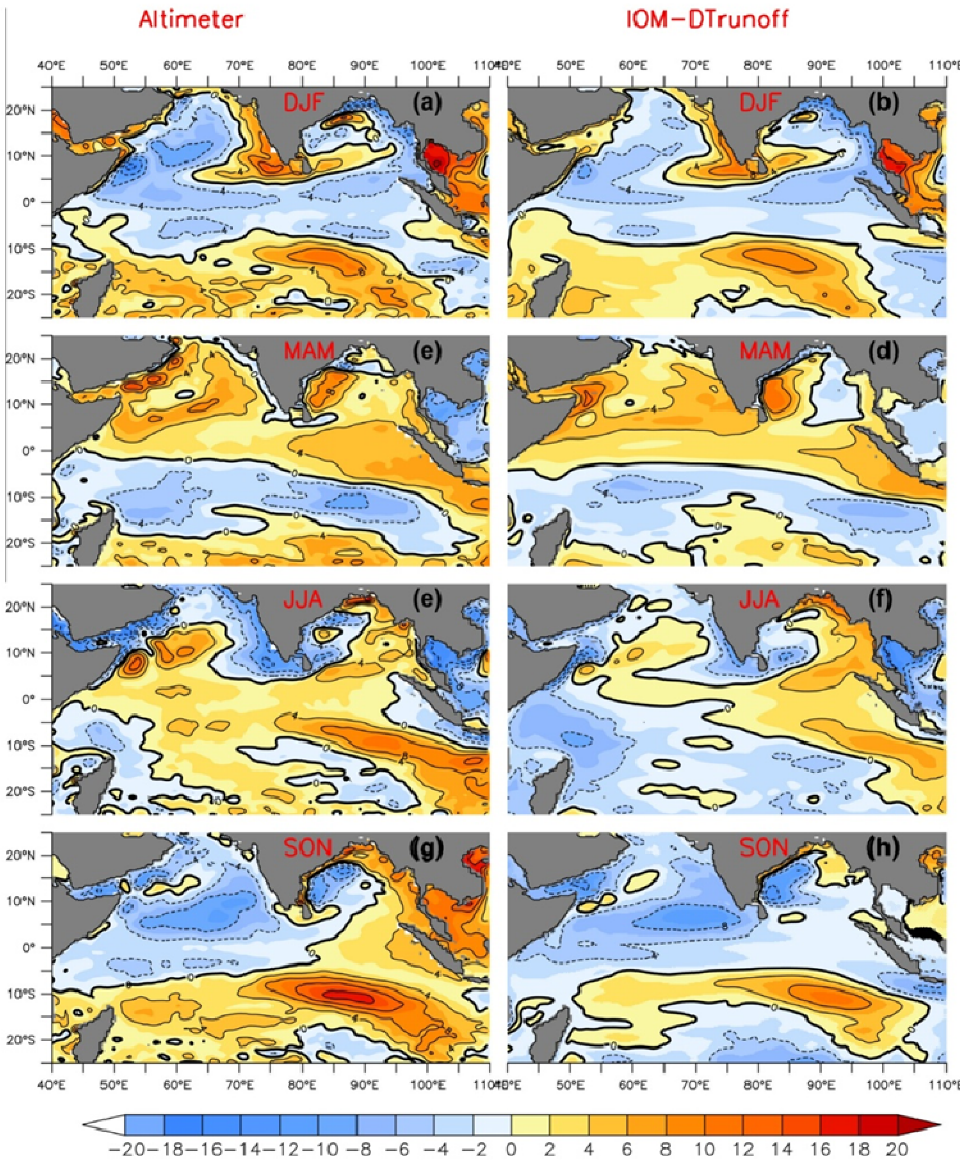

Figure16: SSHa (cm) seasonal climatology maps from altimeter and one of the three model product-versions (adapted from Rahman et al, 2014)

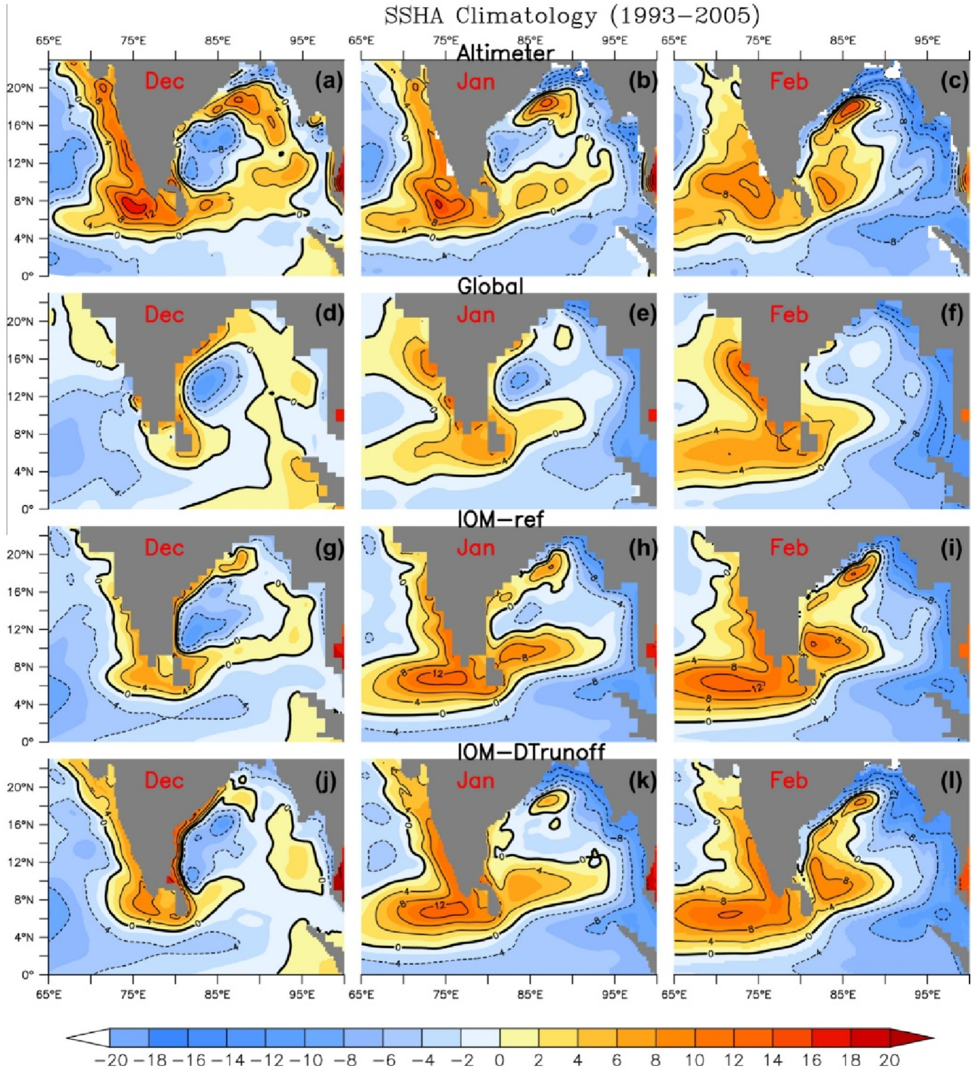

Figure17: SSHa (cm) monthly climatology maps for Dec-Feb from altimeter and various model product-versions (adapted from Rahman et al, 2014)

The model simulated major surface dynamics in the Indian ocean at satisfactory level. When it comes to its utility in determining potential fishing zones, instead of present 1/4 degree resolution, 1/8 or 1/16 degree resolution will be better and sufficient wrt to SSHa. Additionally, forecast products (with prior well-documented validations) should be made operational. This will help the operational team to forecast Potential Fishing Zones, instead of limited nowcast that is possible presently with the help of merged observation products such as from CCAR.

7.2 ROMS (Regional Ocean Modeling System)

High-resolution coastal model of ROMS for the west coast of India (WC-HOOFS) has been setup at INCOIS as a pilot experiment to assess feasibility to improve the prediction of coastal features, particularly the coastal circulation, well in advance. Domain of the model setup is shown in the following figure - presently available only for the west coast of India.

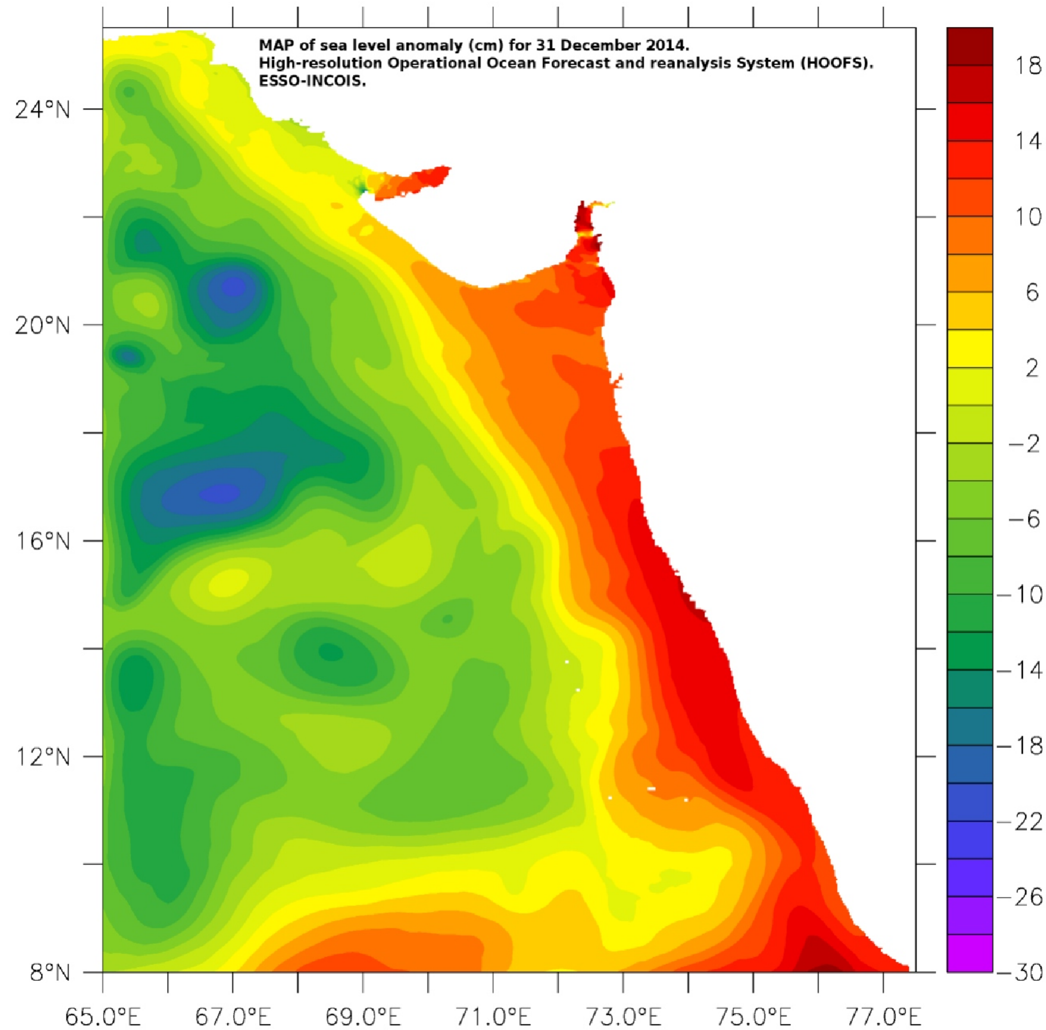

Figure18: An example map of SSHa (cm) from Hi-resolution ROMS setup

The model has a spatial resolution of 1/48 degree (≈2km) and has 40 vertical layers out of which half are within 200m to simulate upper ocean effectively. With well-documented validation, operational model for whole of Indian EEZ may be useful for PFZ demarcation.

8. Summary & Conclusion

Sea Surface Height anomaly (SSHa) can be a parameter equally useful for demarcation of Potential Fishing Zones and for generation of tuna fishing advisories. We recommend using gap free products that overcome limitation of satellite observations such as cloud cover. Also, this will enable INCOIS to provide PFZ as a zone (polygon) instead of a line that is currently being provided. Suitable ranges (eg 70-90% of data distribution) that vary over months and across quarters may be determined as per operational requirements and feasibility. Northeast region of Indian EEZ should be studies with further subdivision of the quarter in order to understand the uncertainties are throughout the region or only for part of the same. Correlation with tuna movements as well as tuna hooking rates both show SSHa immensely useful for determination of tuna fishing zones. Additionally, oxycline depth derived from SSHa using conversion proposed by Satya Prakash et al (2013) can help in generation of 3D advisories, which informs fisher optimum depth range of fishing. Among present alternatives, CCAR data proves to be less complicated to absorb in the operational process chain and for the hindcasting exercises. We strongly recommend to harness a validated model output as and when it is made available (within institute or from other source globally) due to SSHa having potential to become foundation stone towards forecast mode of PFZ advisories.

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