Monitoring and Forecasting the Biogeochemical State of the Indian Ocean

Kunal Chakraborty, Ph.D.

Indian National Centre for Ocean Information Services (INCOIS),
Ministry of Earth Sciences, Hyderabad, India
(kunal.c@incois.gov.in)

Modelling for Ocean Forecasting and Process Studies

Indian Ocean Global Ocean Observing System (IOGOOS)
International Training Centre for Operational Oceanography (ITCOocean)

December 09, 2021

Outline of the Talk

- ✓ India's Ocean Observation Network
  - -Biogeochemical (BGC) Argo Floats
  - -BGC Sensors in the OMNI Mooring
  - -Coastal Water Quality Buoy Network
- ✓ Operational Modeling Framework
  - -Ocean General Circulation Modeling (OGCM)
- ✓ Modeling physical-biological interactions in the Indian Ocean
  - -Biogeochemical State of the Indian Ocean (BIO)
  - -Ocean Data Assimilation
- ✓ An application - Potential Fishing Zone Forecasts

OCEAN OBSERVATION NETWORK

- Argo
- XBT/XCTD
- Current meter network
- Wave rider buoy network
- Tsunami buoy
- Tide gauge
- Ship based weather station
- Mooring network

How the observational needs are met?

INCOIS

Data Sources

- Argo Floats
- Wave Rider Buoys
- Wave Height Meter
- HF Radars
- Tide Gauges
- BPRs

- Moored Buoys
- Drifting Buoys
- Ship-borne AWS

- XBT/XCTD
- EQ Current Moorings
- Coastal ADCPs
- CTD from MoES Ships

- NOAA 18,19
- METOP A, B
- Oceansat-2
- Suomi–NPP

- Oceansat-1
- TRMM
- Quikscat
- SeaWIFS
- Altimeter

- *Real Time Data*
- *Offline Data*
- *Maps*

- COMAPS
- ICMAM
- CTCZ
- Cruise Summary Reports
- *Geotraces-India*
- *SIBER*

- Topographic Maps- Nellore-Machipatnam (1:25,000 Scale)
- CRZ Maps Land Use (1:25,000),
- Aqua Culture and Wet lands (1:50,000)
- CRZ Land Use Maps - Gujarat Coast
- (1:25,000 Scale)

India's Ocean Observation Network
(Present Status)

Objectives

- **Ocean observation network** has been established to collect sustained long term marine meteorological and oceanographic data from open ocean and coastal waters of the tropical Indian Ocean to facilitate
  - Ocean Information and Advisory **Services**
  - **Data assimilation** in the ocean and atmospheric models
  - **Validation** of operational nowcast / forecast of ocean state.
  - Understanding **oceanographic processes** and air-sea interactions
- Conduct **Field Campaigns** for Process Specific Studies to
  - Quantify **mixing processes**
  - Validate the performances of existing **parameterization schemes** used in the OGCM
  - **Fine-tune** the existing parameterization scheme or develop new schemes.
  - Fine-tune and refine the bulk flux algorithm
- **Capacity building**, education, and training and inter-institutional project.

INCOIS Observations

Open Ocean

- Argo Float Network (50 per year)
- Drifting Buoy Network (25 in last 3 years)
  - Wave and oil spill drifter
- XBT/XCTD Transects (3 shipping lines)
- Glider Transect (2 transects)
- Tsunami Buoy Network (4 locations)
- AWS Network on Research Vessels (34)
- Wave Height Meter (1)
- Equatorial Current Meter Moorings (3)
- Flux Mooring in the Bay of Bengal
- BGC Sensors on Arabian Sea OMNI Mooring
- RAMA Network (until 2017)
- Process Specific Observations: uCTD, VMPs, ASIMET, LADCP, ECFS, Radiometers

Coastal

- Tide Gauge Network (36)
- GNSS and SMA Network (35)
- Wave Rider Buoy Network (16)
- Coastal ADCP Network (17)
- Coastal Water Quality Buoy Network (6)
- SATCORE Observations (11)

NIOT Observations

- OMNI Buoy & Tsunami Buoy Network (3)
- HF Radar (5) & RAMA Network (Since 2017)

Argo Profiling Float Network

Argo Programme is a component of GOOS

- INCOIS is leading the Indian Argo Programme
- Complement the other in-situ ocean observation in the Indian Ocean - IndOOS / IOGOOS
- Deploy 50 Floats per year (3:2 of TS and Bio Argo)
- INCOIS serves as the Regional Argo Centre (RAC) in the Indian Ocean and also serves as National Data Assembly Centre (DAC)

Variables

- Vertical profile of Temp, Sal, Chl-a, DO, Backscatter and Nitrate up to 2000 m with 10 day typical mission

Applications

- Improve Ocean and Climate forecasting
- Understand ocean-atmosphere interactions
- Predict seasonal to decadal climate variability
- Wide range of applications for high-quality global ocean analyses
- Data Assimilation in OGCM

Data availability

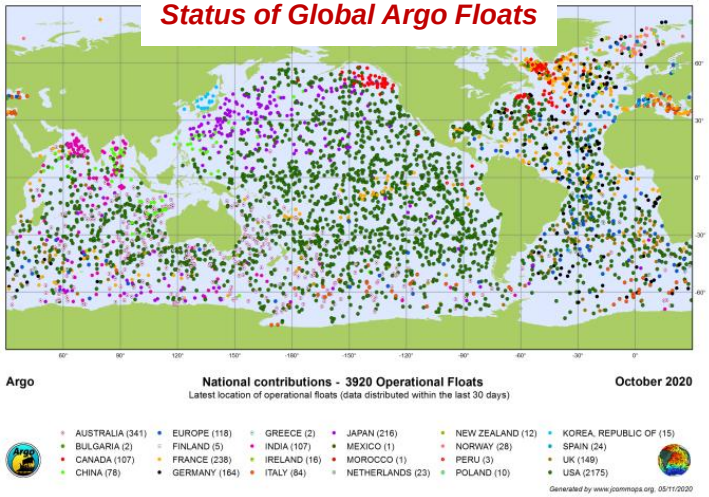
- GTS and INCOIS website in near real time
- Real-time data for operational purpose and Delayed-mode data for research purpose
- Derived Data products are available online

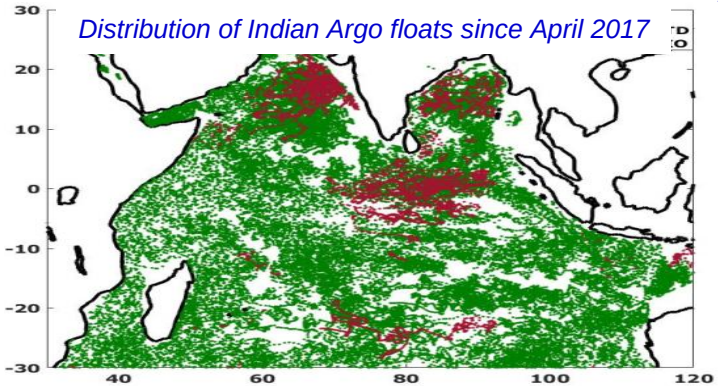
Current Status

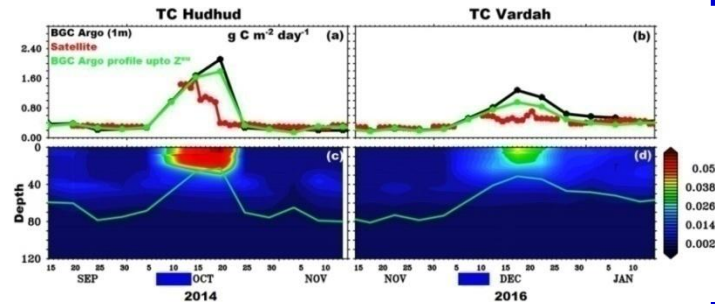
- 75 Floats (51 TS + 24 BGC) deployed during 2017-20

Future Plan

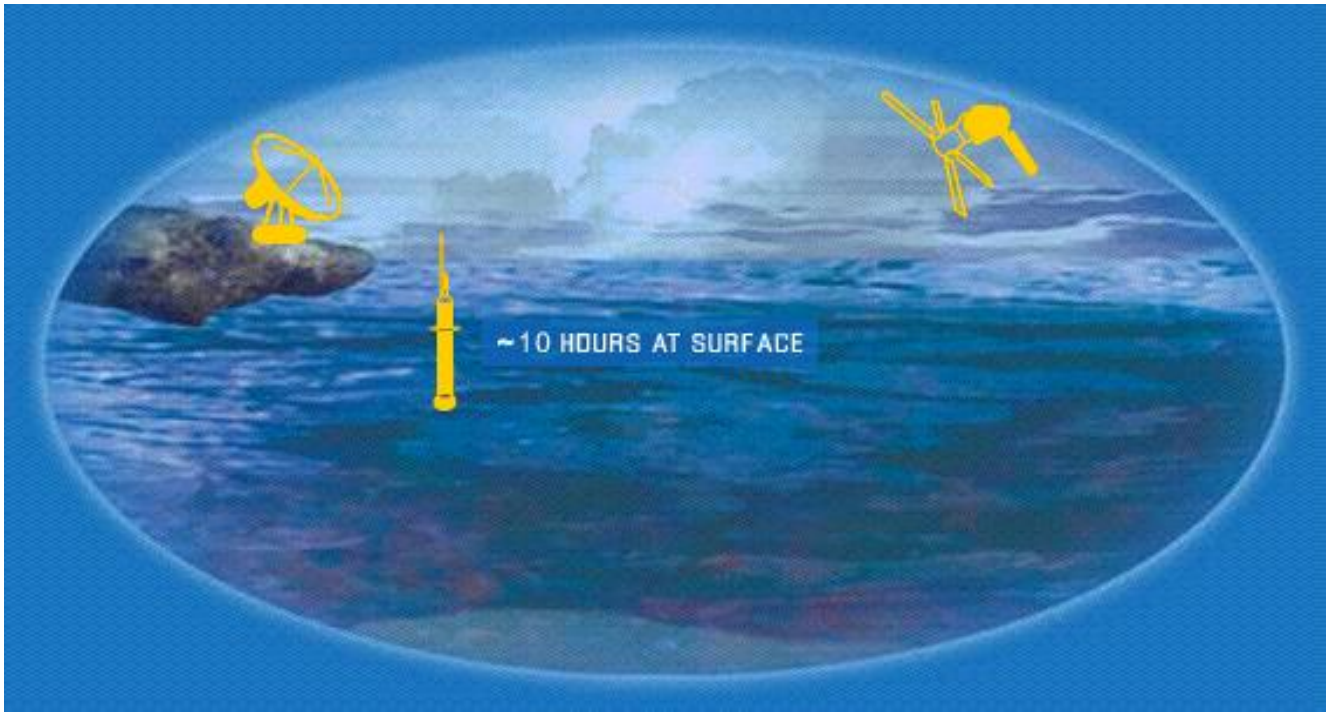
- 50 floats/year at least one float in 3x3 grid (33 floats with Temperature and salinity +17 Bio floats with CHL, DO and backscatter)

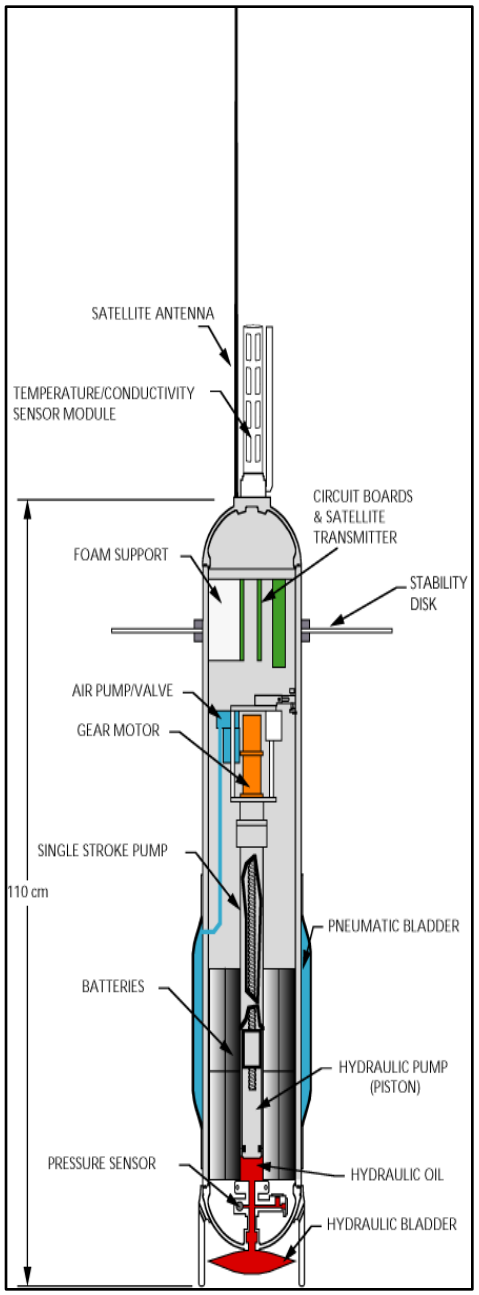




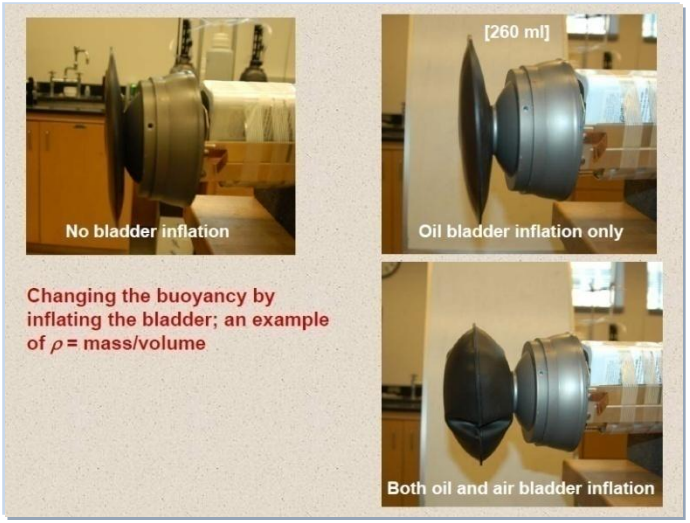


Argo Cycle and Cross Section





- Drifting Depth: **1000 m**
- Profiling Depth: **2000 m**
- 10 Days/Cycles



BGC sensors in the OMNI Mooring

Variables

- Time series of (~3hr) Temperature, Salinity, Chlorophyll, Dissolved Oxygen and Optical backscatter

Applications

- Generate long-term continuous BGC observation
- Understand short-term variability of BGC parameters
- Understand response of ecosystem to global warming
- Understand role of the Indian Ocean in global carbon cycle
- Validation the ecosystem model outputs
- Calibration and validation of remote sensing geophysical parameters

Data availability

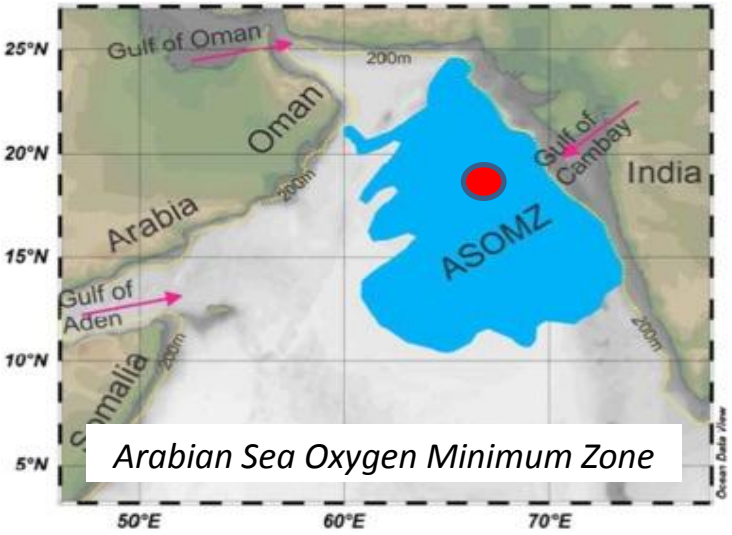
- Delayed-mode (after the recovery of the mooring)

Current Status

- Sensor installed on NIOT-OMNI Buoy AD06 for collection of time series observations for a year 2018-19

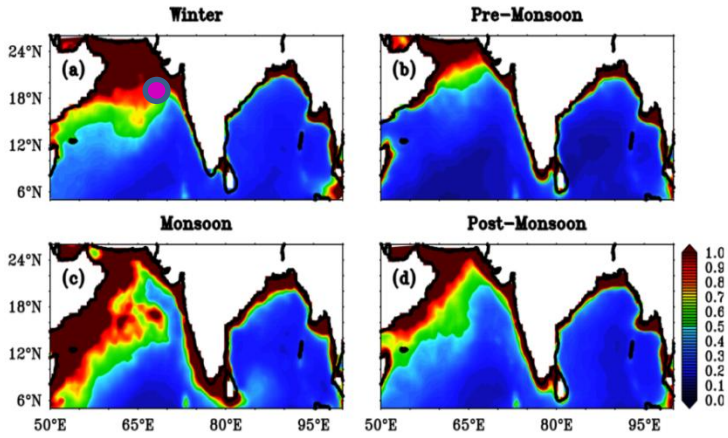
Future Plan

- Enhance the network with (2021-2026)
- DO and Chlorophyll in the DCM
- DO and Nitrate in the OMZ.
- Surface water and atmospheric pCO_2
- Surface water pH



Arabian Sea Oxygen Minimum Zone

Seasonal variability of chlorophyll



Coastal Water Quality Buoy Network

Variables

- Temp, sal, current, Chl-a, DO, scattering, turbidity, pCO2, pH, inorganic nutrients, CDOM, etc.

Applications

- Long-term changes in coastal water quality
- Understand coastal hypoxia, eutrophication, Ocean acidification and species shift.
- Calibrate/validate satellite data and develop/improve semi-analytical algorithms.
- Validation / tuning of high-resolution coastal biogeochemical model
- Provide water quality services such as Algal bloom information, jelly fish aggregation and Trophic state index

Data availability

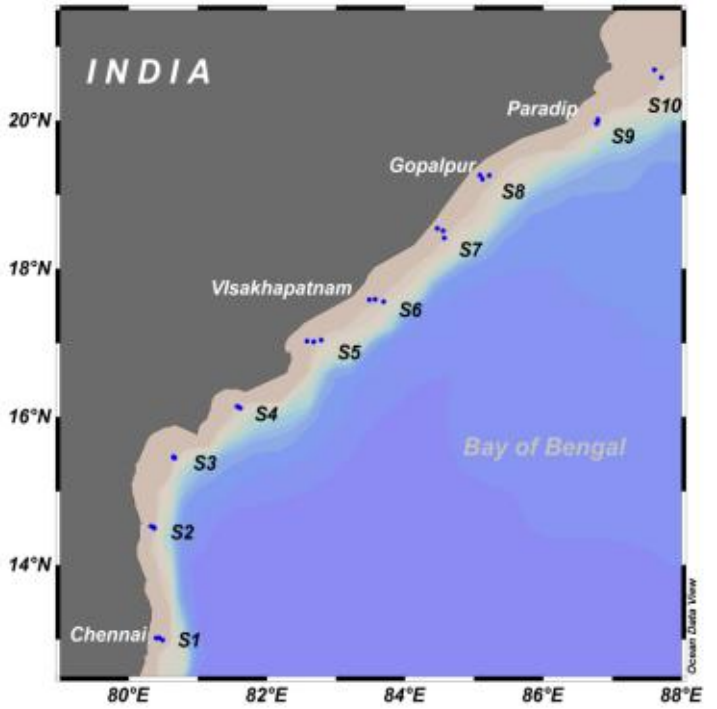
- Real-time

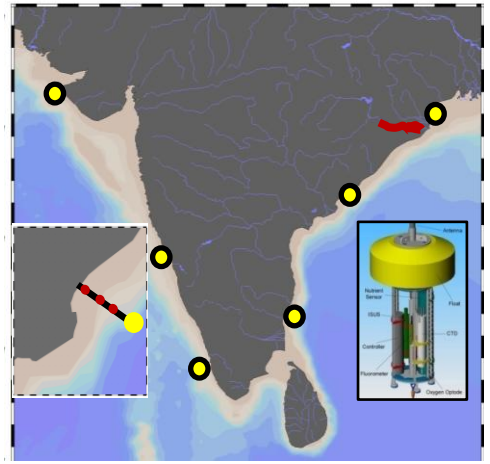
Current status

- Procurement of two observatories are in process
- Initiated water quality sampling at proposed location in collaboration with CSMCRI, NIO-Goa, NIO-Kochi, NIO-Vizag

Future plan

- First phase deployment off Kochi and Visakhapatnam
- Second phase deployment at other locations
- Continue with in situ manual sampling

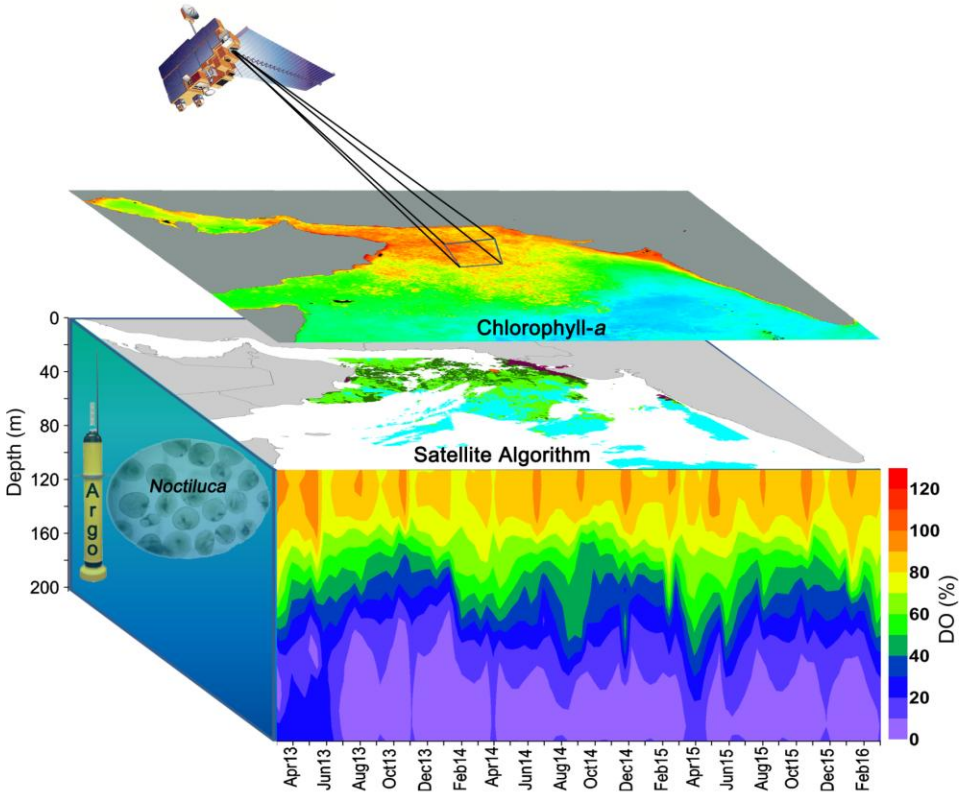


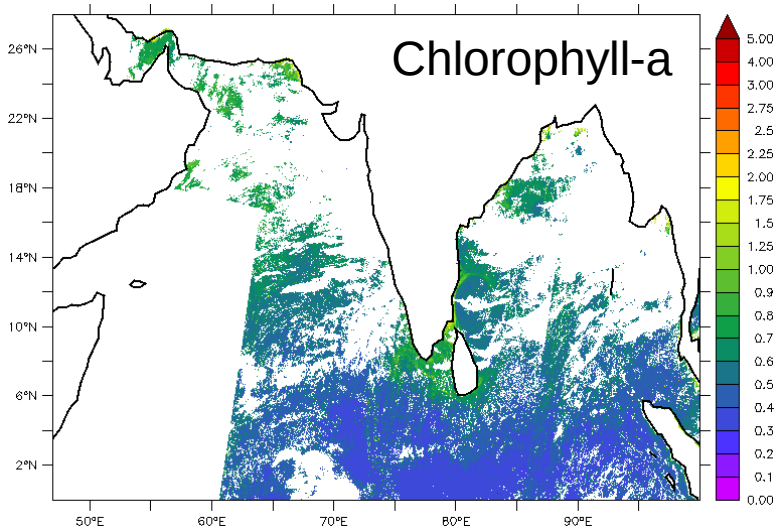


Remote Sensing Data Products

Sensor	Variables	Application
Ocean Color (MODIS (Aqua, Terra), VIIRS (Soumi NPP), OCM-2 (Oceansat-2)	Chlorophyll-a, Kd_490, etc.	Primary productivity, Biogeochemical model, Phytoplankton functional type, Coastal processes
SARAL Altika	Sea Level Height	Assimilation in numerical models, Sea level variability, etc.
AVHRR (NOAA 18/19), (MODIS (Aqua, Terra), ATOVS/Metop -1,2	Sea Surface Temperature	High resolution thermal front demarcation, Assimilation in numerical models, etc.
Scatterometer (SCATSat)	Winds	Primary productivity and Biogeochemical modeling

Merged data products are combined from multiple mission observations into a single data product with better spatial and temporal coverage than the individual missions.





Operational Modeling system at INCOIS

High-resolution Operational Ocean Forecast and reanalysis System (HOOFS) [Francis et al., 2020]

- Global : INCOIS-GODAS (MOM4.0+3DVAR)
- Regional: ROMS v3.6 + LETKF
- Coastal : ROMS v3.6

INCOIS Tentral Ocean Prediction System for Indian Ocean (ITOPSI)

- Global : HYCOM (HYCOM+TSIS)
- Regional: HYCOM (HYCOM+TSIS)

Wave Forecasts

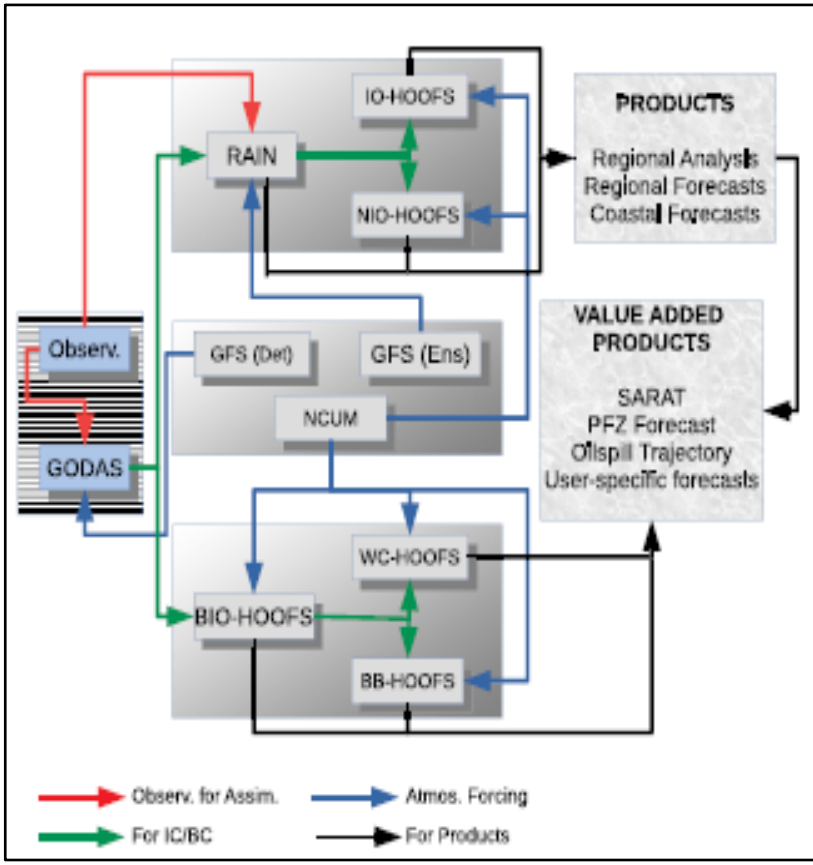
- Global : WAVEWATCH III
- Regional: WAVEWATCH III
- Coastal : SWAN

Tsunami

- Global: ADCIRC
- Regional: Tunami N2 (Scenario based)

Storm Surge

- Regional: ADCIRC+ SWAN

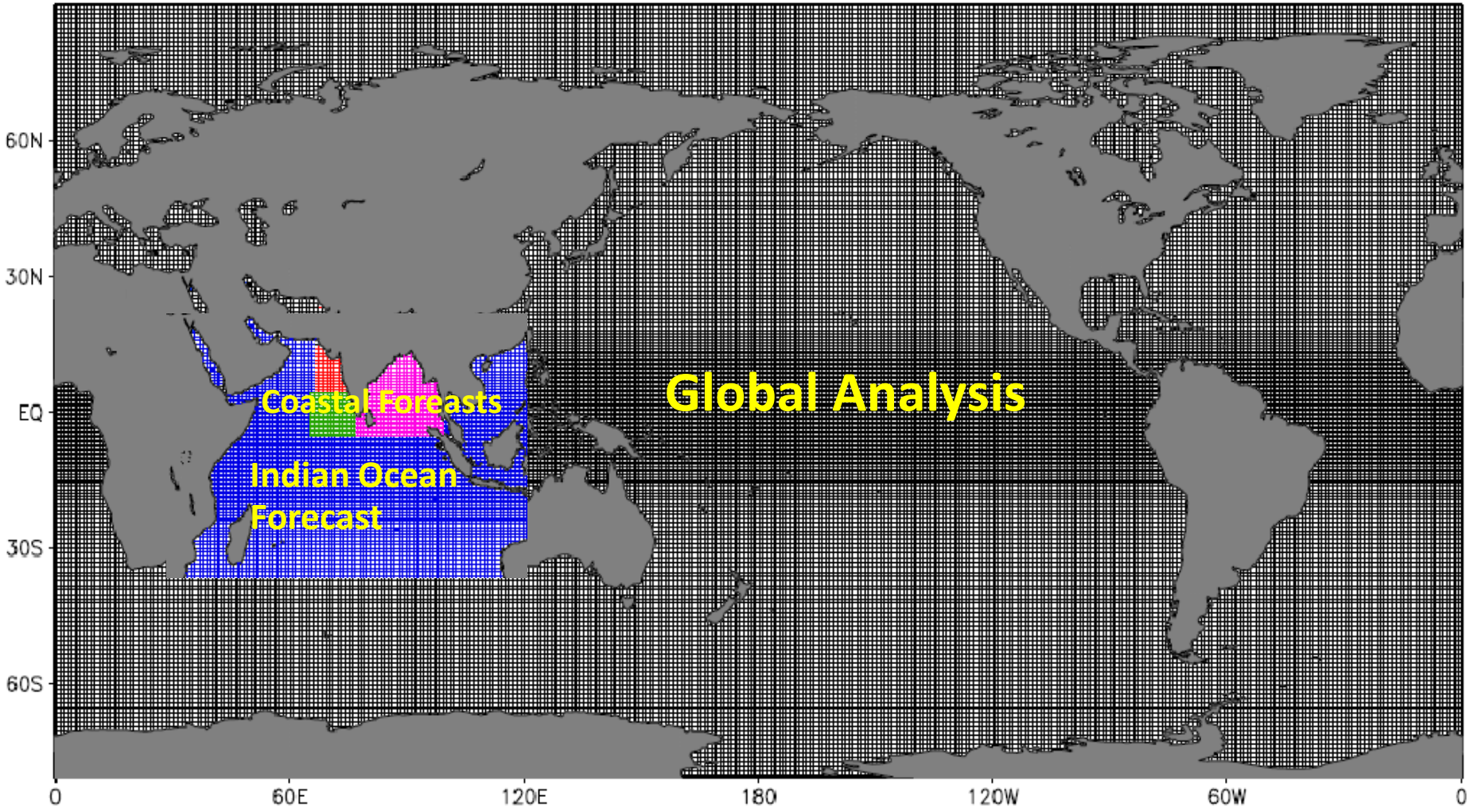


BAMS Article

High-Resolution Operational Ocean Forecast and Reanalysis System for the Indian Ocean

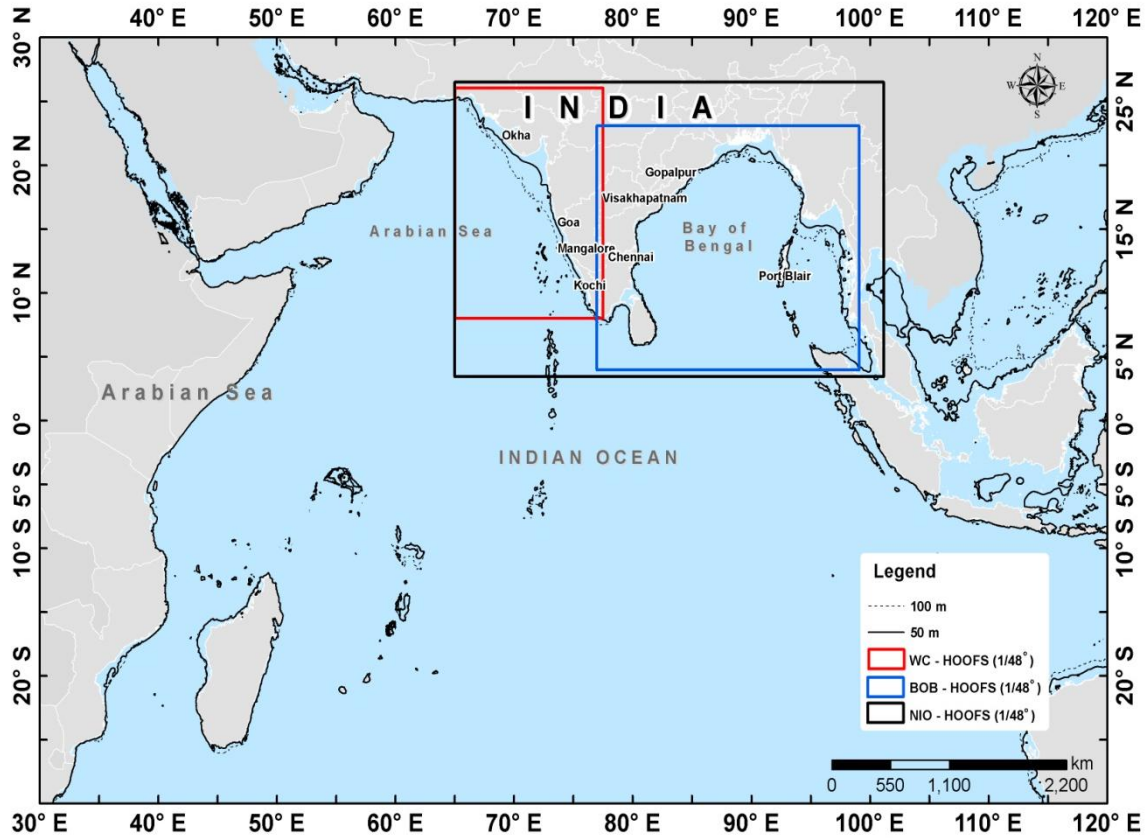
P. A. Francis, A. K. Jithin, J. B. Effy, A. Chatterjee, K. Chakraborty, A. Paul, B. Balaji, S. S. C. Shenoi, P. Biswamoy, A. Mukherjee, P. Singh, B. Deepsankar, S. Siva Reddy, P. N. Vinayachandran, M. S. Girish Kumar, T. V. S. Udaya Bhaskar, M. Ravichandran, A. S. Unnikrishnan, D. Shankar, A. Prakash, S. G. Aparna, R. Harikumar, K. Kaviyazhahu, K. Suprit, R. V. Shesu, N. Kiran Kumar, N. Srinivasa Rao, K. Annapurnaiah, R. Venkatesan, A. S. Rao, E. N. Rajagopal, V. S. Prasad, M. D. Gupta, T. M. Balakrishnan Nair, E. P. R. Rao, and B. V. Satyanarayana

Ocean General Circulation Models - INCOIS



Global : GODAS (@ variable spatial resolution, MOM4p0d + 3DVAR)
Indian Ocean : ROMS (~9.5 x 9.5 km) with LETKF& HyCOM with red. KF(~ 7 x 7 km)
Coastal Ocean : ROMS (~ 2.25 x 2.25 km)

Biogeochemical State of the Indian Ocean (BIO)



The biogeochemical state the ocean, which includes following major variables, is regularly updated by the BIO system:

1. Nitrate, Ammonium, Chlorophyll-a
2. Dissolved Oxygen etc.
3. Carbon Fluxes

Major Application:

Development of PFZ Forecasts System

- Biogeochemical State of the Indian Ocean (BIO) is a high resolution, coupled physical-biogeochemical modeling system developed at INCOIS **to study the evolution of biogeochemical state of the Indian Ocean at both short and long time scale**.
- To address the operational and scientific needs, a suite of high resolution, coupled physical-biogeochemical models have been configured.
- **The models run for 5 days in hind-cast mode followed by 5 days in forecast mode thereby regularly updating to generate daily analysis of biogeochemical state of the Indian Ocean.**

Assessment of the model simulations

Journal of Sea Research 146 (2019) 63–76

Contents lists available at ScienceDirect

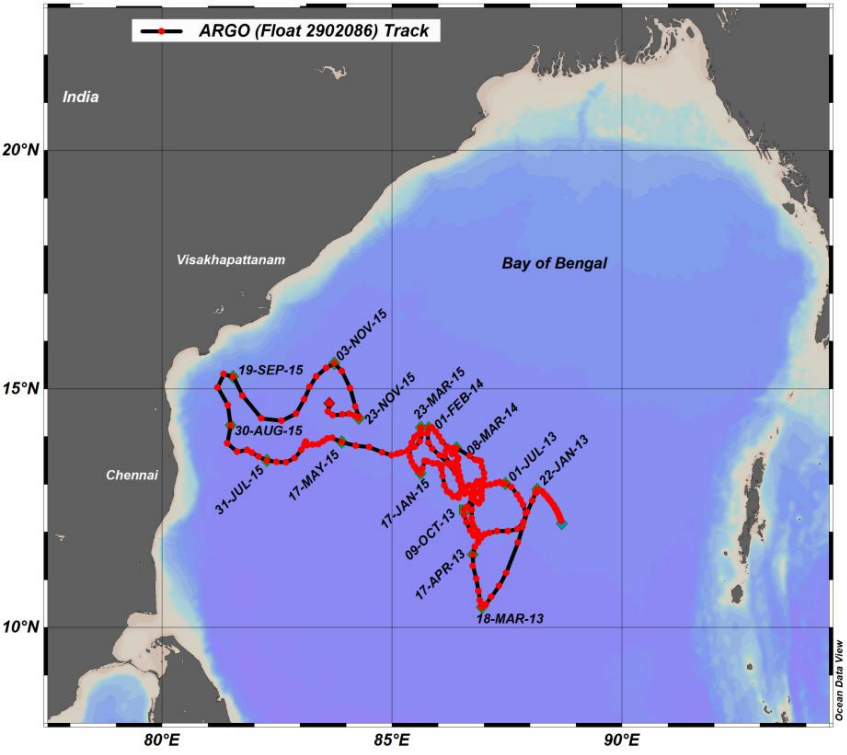
Journal of Sea Research

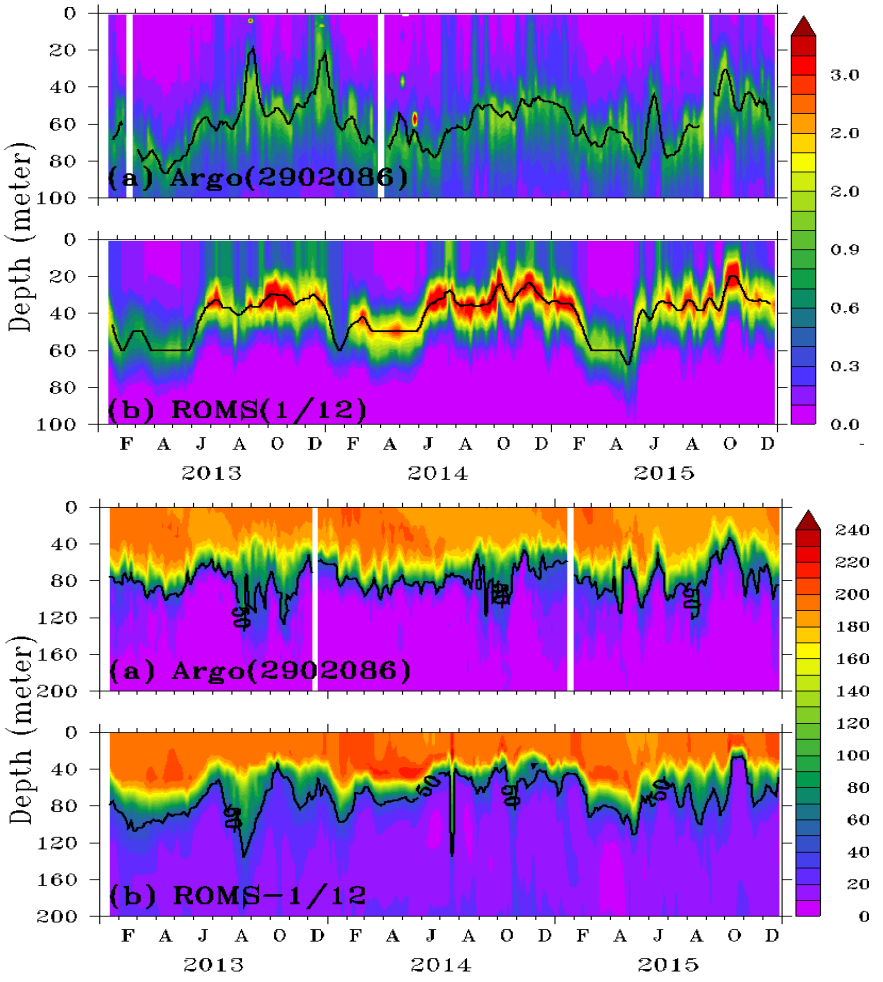
journal homepage: www.elsevier.com/locate/seares

Assessment of model-simulated upper ocean biogeochemical dynamics of the Bay of Bengal

Kunal Chakraborty[a,*], Aneesh A. Lotliker[a], Sudip Majumder[b,c], Alakes Samanta[a], S.K. Baliarsingh[a], Jayashree Ghosh[a], P.P. Madhuri[d], A. Saravanakumar[e], N.S. Sarma[f], B. Srinivas Rao[g], P. Shanmugam[h]

[a] ESSO-Indian National Centre for Ocean Information Services, Hyderabad, India
[b] Cooperative Institute for Marine and Atmospheric Studies, University of Miami, Miami, FL, USA
[c] Atlantic Oceanographic and Meteorological Laboratory, National Oceanic and Atmospheric Administration, Miami, FL, USA
[d] Indian Institute of Space Science and Technology, Thiruvananthapuram, India
[e] Centre for Advanced Studies in Marine Biology, Annamalai University, Parangipettai, Tamilnadu, India
[f] Department of Physical and Nuclear Chemistry & Chemical Oceanography, Andhra University, Visakhapatnam, India
[g] Centre for Studies on Bay of Bengal, Andhra University, Visakhapatnam, India
[h] Department of Ocean Engineering, Indian Institute of Technology Madras, Chennai, India





To facilitate the analysis the model outputs are extracted nearest grid point of Argo profiling float at the time and at the location (nearest grid point) of Argo profiles.

Assessment of the model simulations

JOURNAL OF OPERATIONAL OCEANOGRAPHY
2019, VOL. 12, NO. 2, 116–142
https://doi.org/10.1080/1755876X.2019.1588697

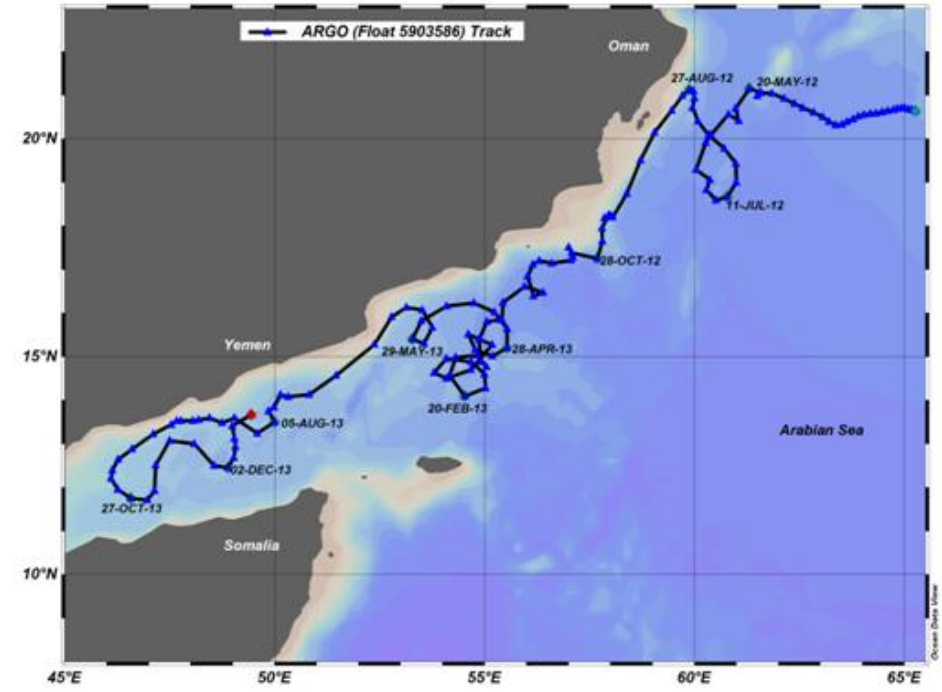
Taylor & Francis
Taylor & Francis Group

Check for updates

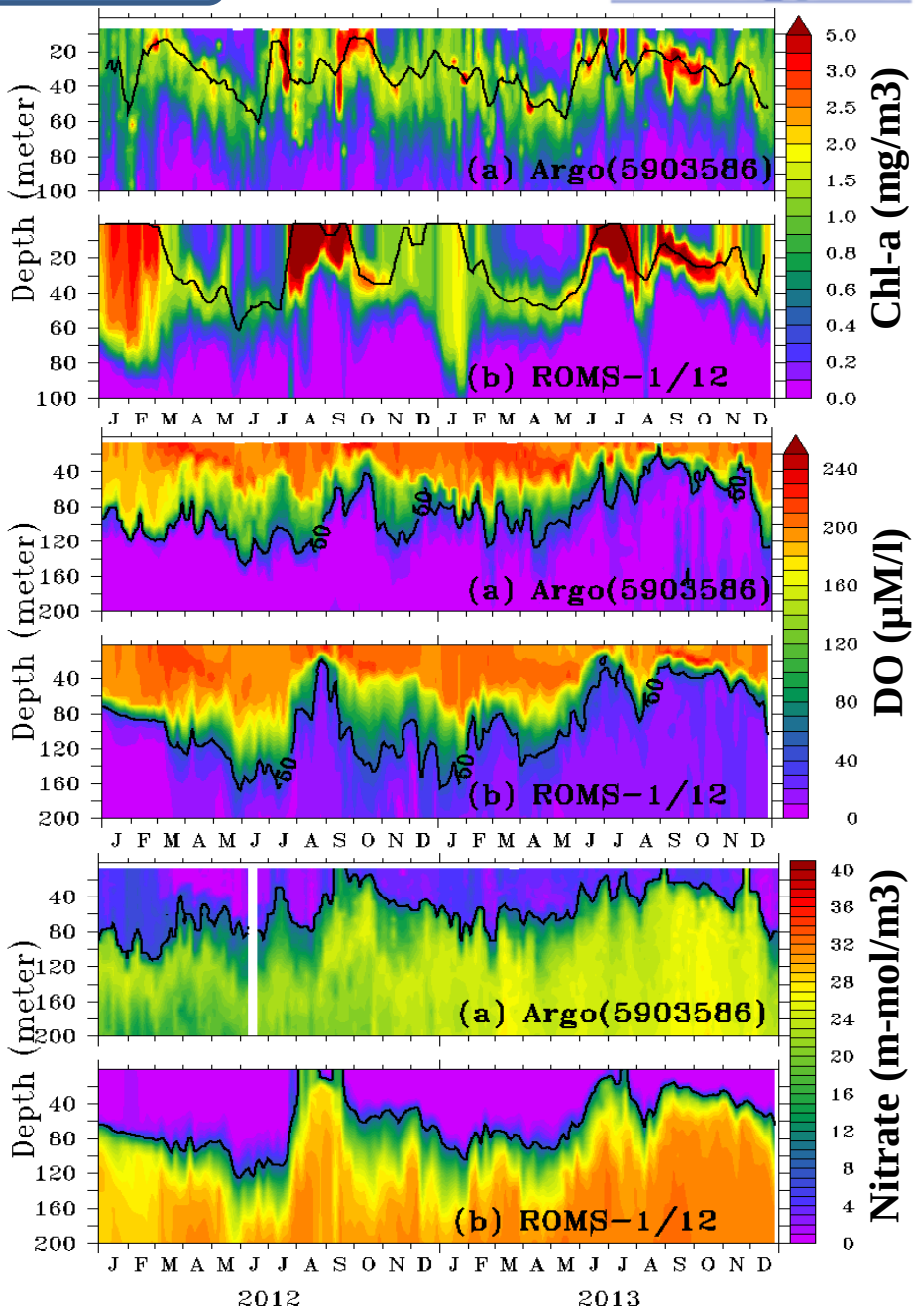
Assessment of the impact of spatial resolution on ROMS simulated upper-ocean biogeochemistry of the Arabian Sea from an operational perspective

Kunal Chakraborty [a], Nimit Kumar [a], M. S. Girishkumar[a], G. V. M. Gupta [b], Jayashree Ghosh [a], T. V. S. Udaya Bhaskar[a] and V. P. Thangaprakash [a]

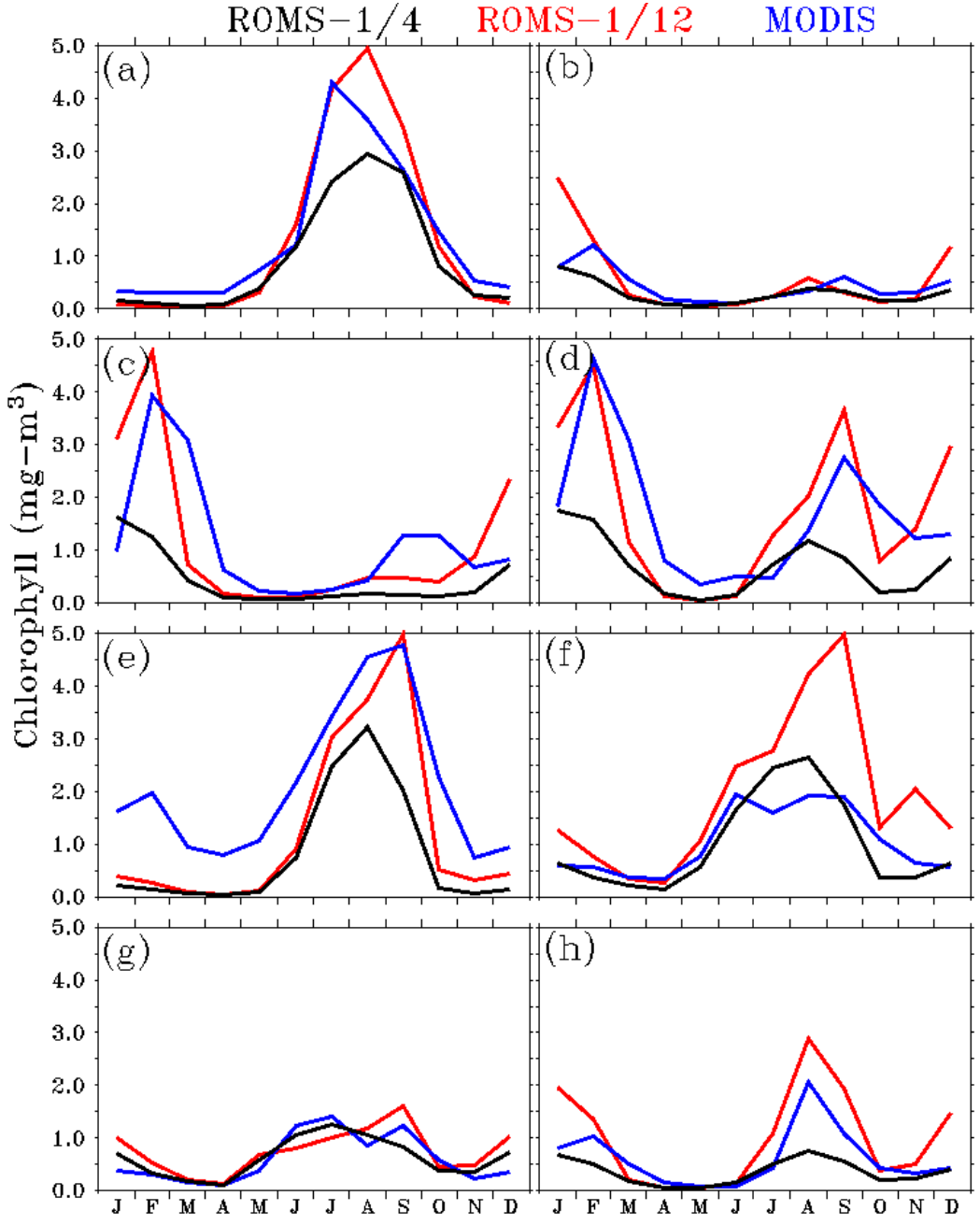
[a]Indian National Centre for Ocean Information Services, Ocean Valley, Pragathinagar (BO), Nizampet (SO), Hyderabad, India; [b]Centre for Marine Living Resources and Ecology, Ministry of Earth Sciences, Kochi, India

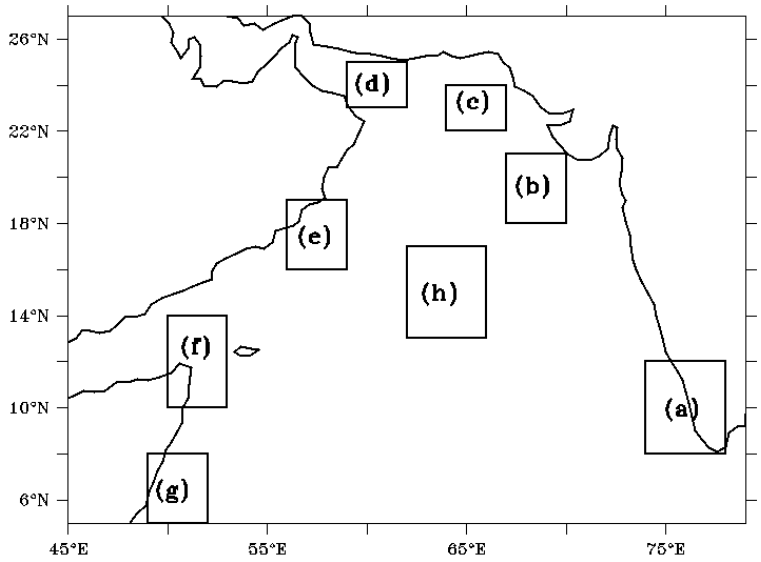


BGC Argo data has been used to evaluate the capability of the model in capturing the inter-annual variability of the biogeochemical (nitrate, chlorophyll and dissolved oxygen) state of the Arabian Sea.



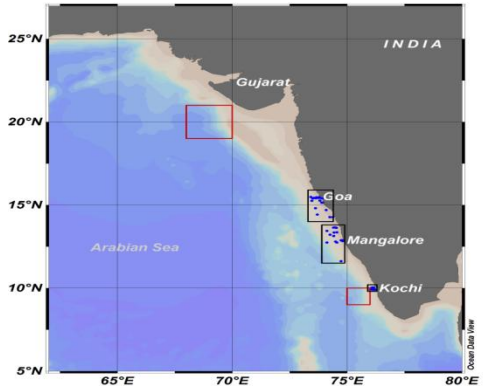
Assessment of the model simulations





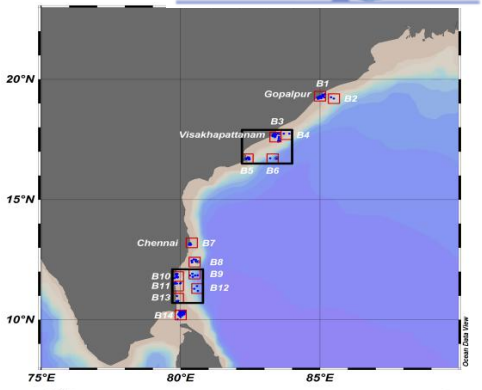
Box ID	Latitudinal Extent (°N)	Longitudinal Extent (°E)
(a)	8-12	74-78
(b)	18-21	67-70
(c)	22-24	64-67
(d)	23-25	59-62
(e)	16-19	56-59
(f)	10-14	50-53
(g)	5-8	49-52
(h)	13-17	62-66

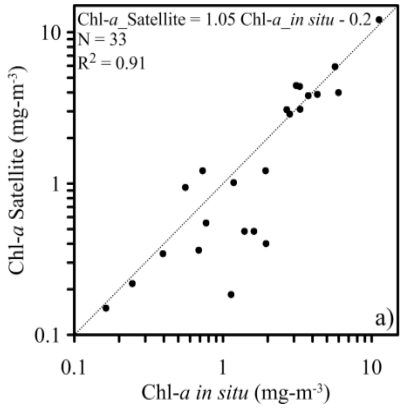
Assessment of the model simulations

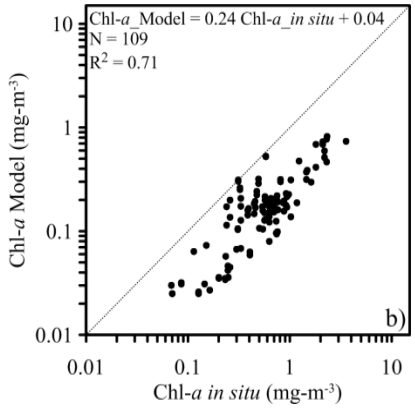


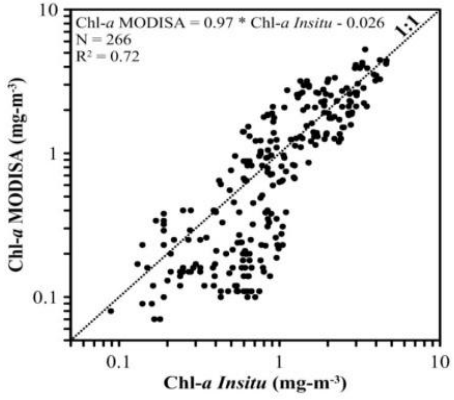
AS	MODIS-A	ROMS-1/4
N	33	109
Slope	1.06	0.24
I	-0.2	0.04
R	0.95	0.84
R^2	0.91	0.71
r	1.44	3.85
Log_{10} *RMSE*	0.24	0.58

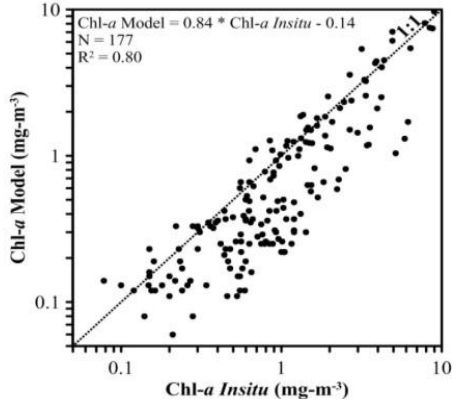
BOB	MODIS-A	ROMS -1/12
N	266	177
Slope	0.97	0.84
I	-0.026	-0.24
R	0.84	0.89
R^2	0.71	0.80
r	1.77	1.92
Log_{10} *RMSE*	0.33	0.32

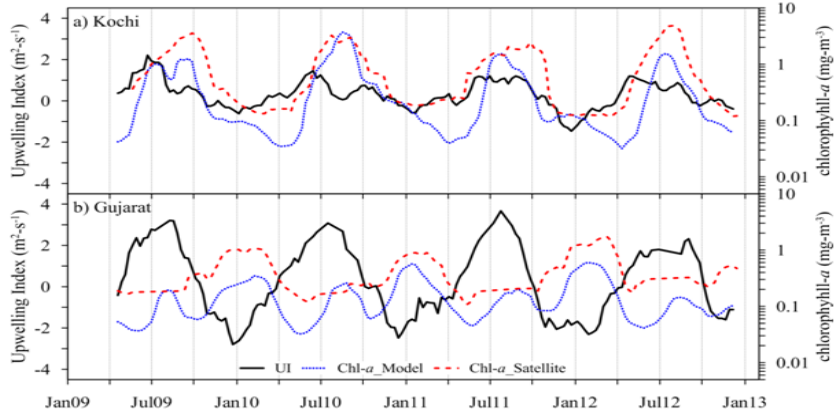


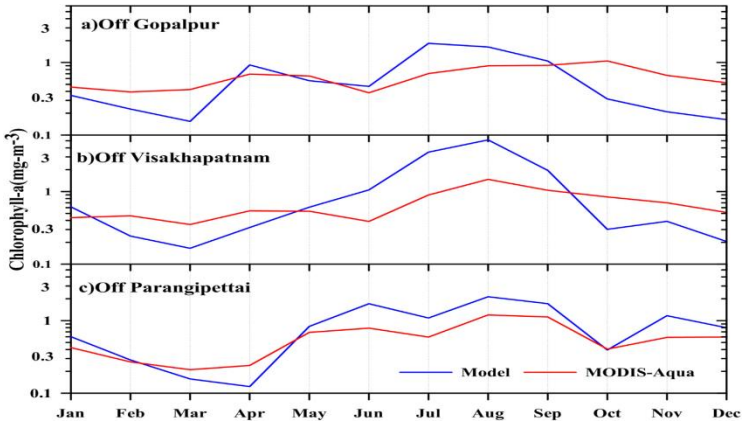








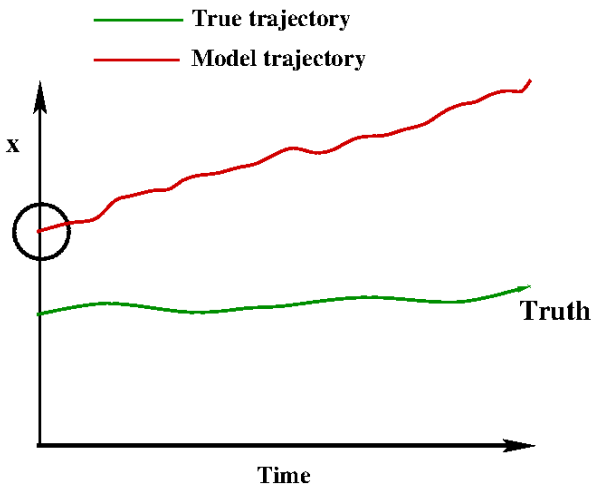


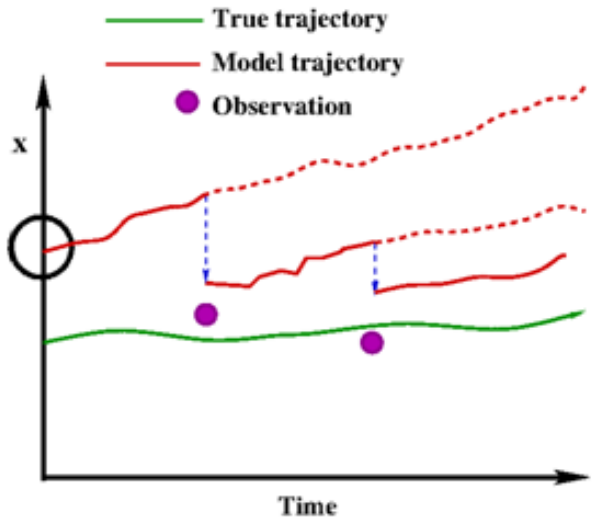


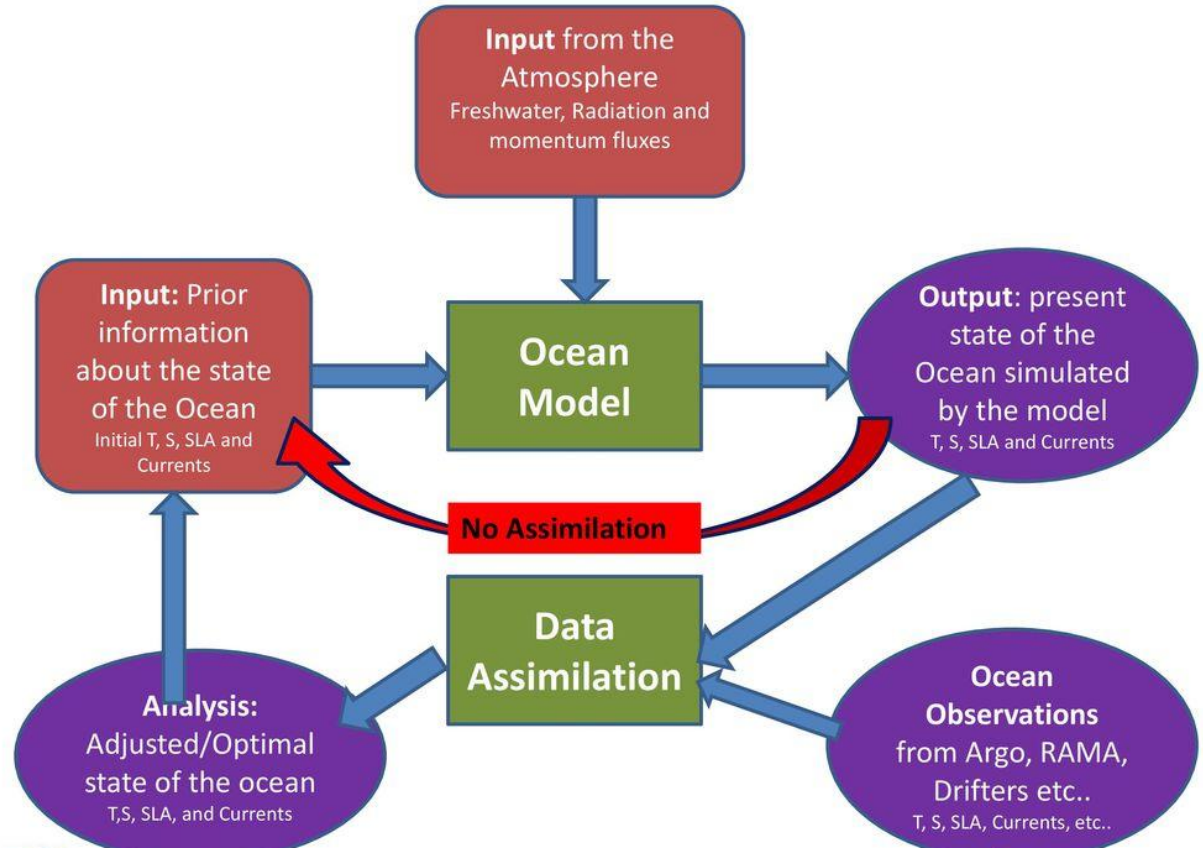
Chakraborty et al., 2016; Estuarine, Coastal and Shelf Science (Elsevier)

Chakraborty et al., 2019; Journal of Sea Research (Elsevier)

What does Data Assimilation do?







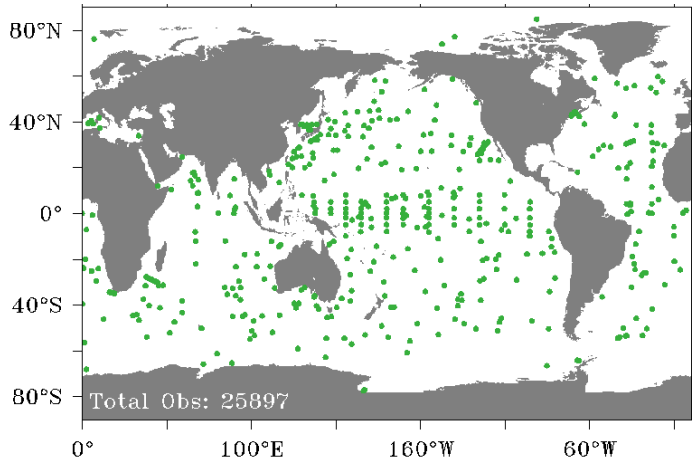
Data assimilation is the process that combines ocean observations with numerical models in order to provide an improved initial model state which subsequently gives the best estimate of the ocean state.

Data Assimilation in INCOIS Ocean Models

OBSERVATIONS

Physical Variables

1. In-situ Temperature
2. Salinity Profiles (RAMA moorings, NIOT buoys and Argo floats)
3. Sea surface temperature (Satellite track data : AMRSE)

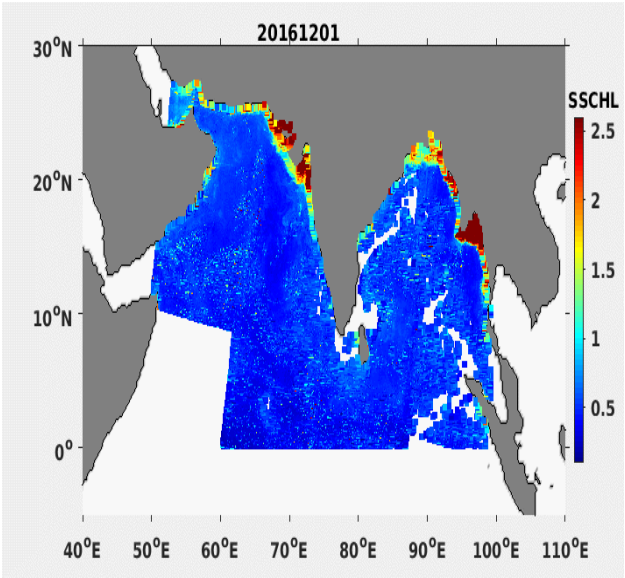


Temperature & Salinity profiles

RAIN (Regional Analysis of Indian OceaN) is a data assimilation system developed at INCOIS

Biological Variables

1. Chlorophyll from satellite
2. In-situ chlorophyll from BGC Argo floats
3. In-situ Oxygen from BGC Argo floats



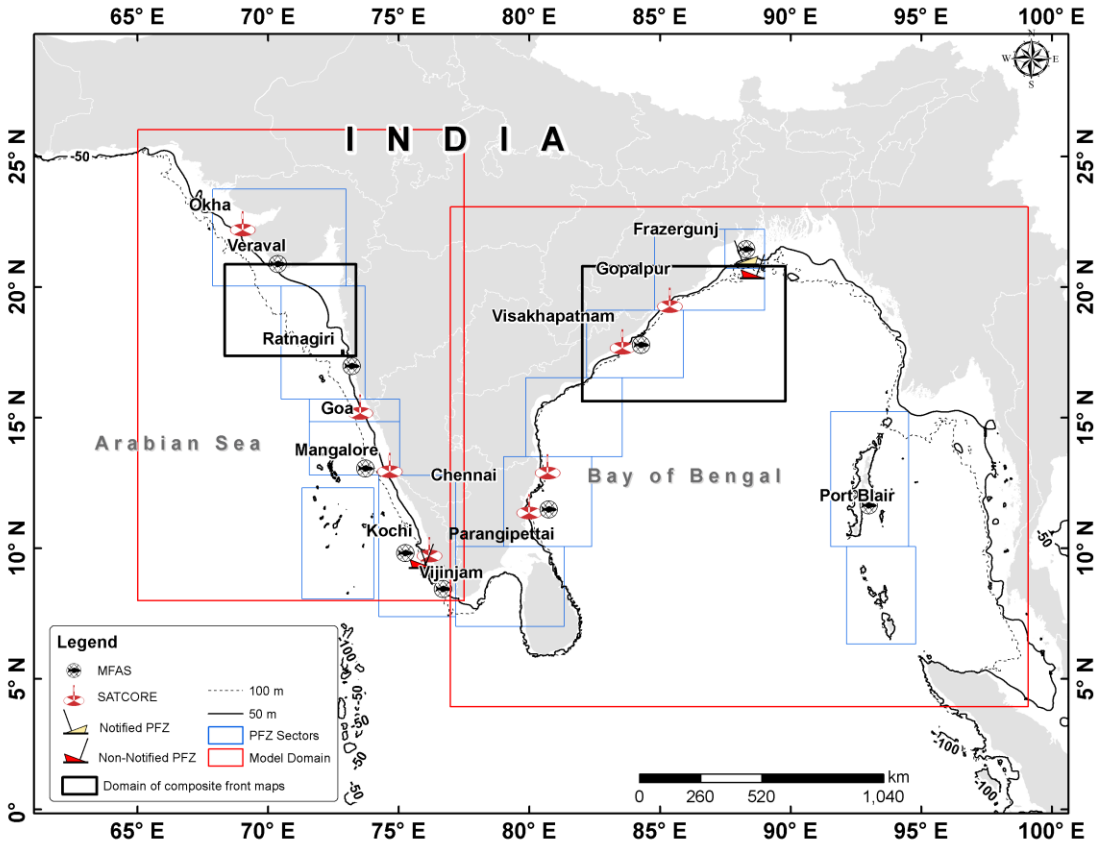
Surface chlorophyll-a from satellite

Under Development

Marine Fishery Advisory Service (MFAS)

Potential Fishing Zones (PFZs) are identified as the relatively narrow zones in the ocean where horizontal gradients of physical and/or biological properties are enhanced.

The advisories are provided to fishermen on a daily basis using remotely sensed sea surface temperature (SST) and chlorophyll-a (Chl-a) data from **NOAA-AVHRR and MODIS-AQUA and/or Oceansat-2 satellites**, respectively.



To demarcate PFZs –

As a first step, the thermal fronts are identified using the algorithm prescribed by **Cayula and Cornillon (1992).**

The Chl-a fronts are detected using **Canny (1986) algorithm**.

The frontal vectors thus delineated from satellite SST and Chl-a are superimposed to identify the common fronts.

Outstanding Issues in Generating PFZ Advisories – Relevance of an Ocean-Ecosystem Model

- **Presently, MFAS uses satellite data of SST and chlorophyll, which is hindered with cloud cover. The problem becomes acute during monsoon time.**

- **Other key parameters like dissolved oxygen is not available through remote sensing. A ocean-ecosystem model simulated oxygen can complement the service need.**

- **The sub-surface properties of the ocean such as deep chlorophyll maxima and oxycline can help determine fishing depth – a value addition to PFZ and very useful information for the fishing operation.**

- **The PFZ advisories are disseminated by the end of the day, and is also being used for multiday fishing. Due to poor or non-existant offshore communication, fresher PFZs can't be obtained for the later days of the trip. Graduating PFZ advisories into PFZ forecast with the help of an ocean-ecosystem model certainly solve this issue as fisher obtains data for next 2-3 days while beginning the fishing trip.**

- **An ocean-ecosystem model simulation is useful towards developing strategies to manage coastal resources in a changing climate.**

Forecasts of PFZs using Numerical Models

JOURNAL OF OPERATIONAL OCEANOGRAPHY
2019, VOL. 12, NO. S2, s157–s175
https://doi.org/10.1080/1755876X.2019.1574951

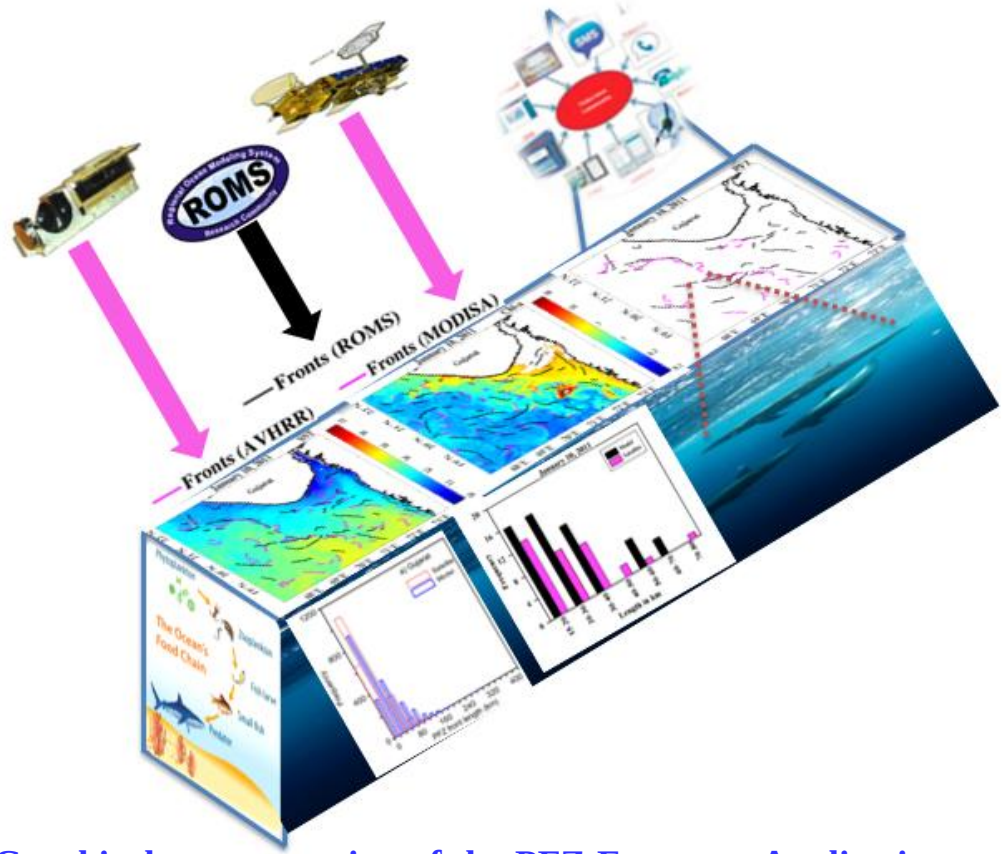
Taylor & Francis
Taylor & Francis Group

OPEN ACCESS Check for updates

Modelling of marine ecosystem in regional scale for short term prediction of satellite-aided operational fishery advisories

Kunal Chakraborty, Sourav Maity, Aneesh A. Lotliker, Alakes Samanta, Jayashree Ghosh, Nagaraja Kumar Masuluri, Naga Swetha and Rose P. Bright

ESSO-Indian National Centre for Ocean Information Services, Hyderabad, India



Graphical representation of the PFZ Forecasts Application developed using BIO Modelling System (high resolution, coupled numerical models) configured at INCOIS.

- **A suite of high resolution, coupled, regional ocean-ecosystem models capable of simulating ocean features leading to PFZs has been developed.**
- **Operational difficulties in generating PFZ advisories such as non-availability of data due to Cloud Cover have been resolved.**
- **3 days Forecasts of PFZs to carry out the pelagic fishing activities in deep seas which requires multi-day fishing.**
- **Forecasts of PFZ lead to both economic (and therefore social) and environmental developments.**

Summary/Conclusions

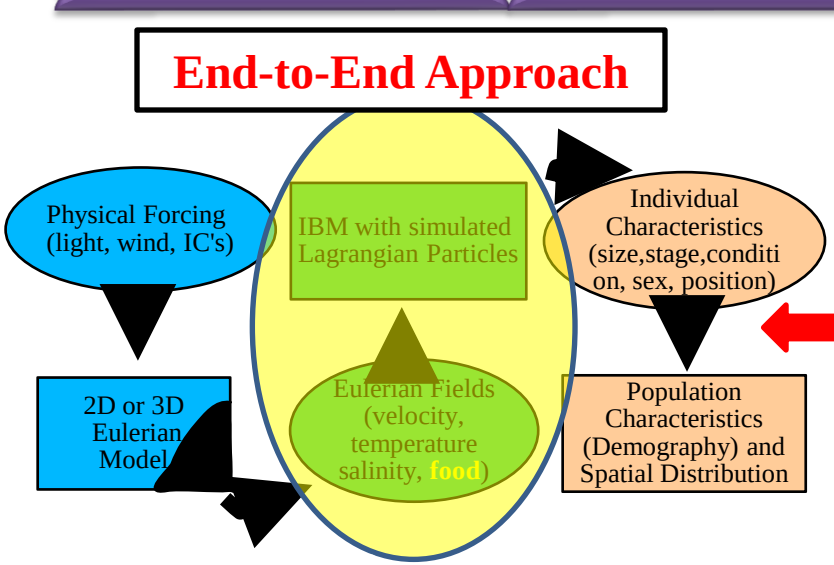
INCOIS

ECOSYSTEM MODELING

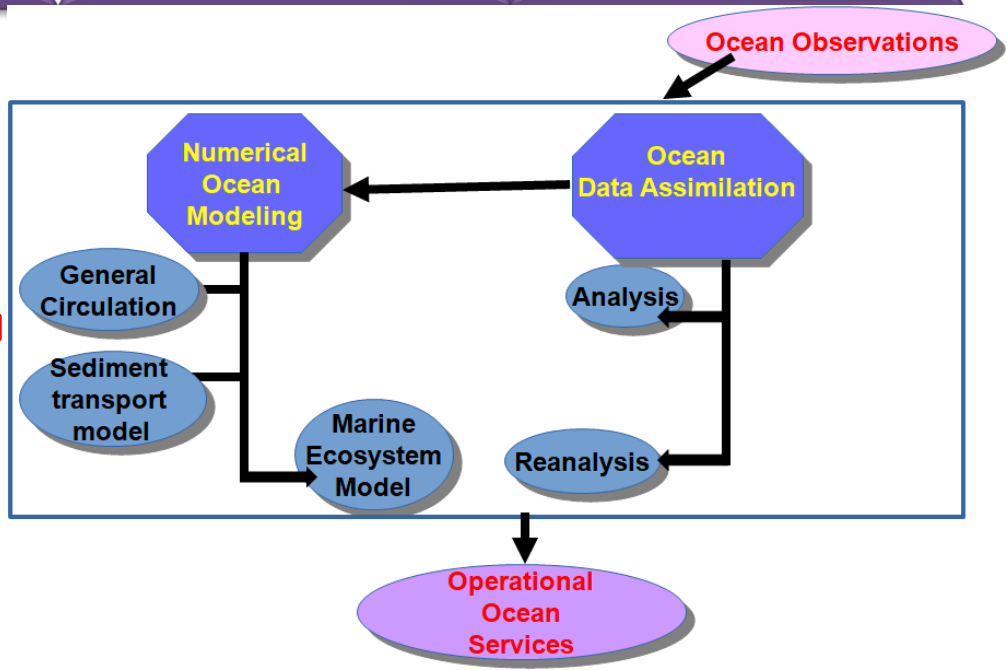
Exploring Potential Applications of an Ocean-Ecosystem Model

- To graduate the existing PFZ advisories to PFZ forecasts
- Forecasting of biogeochemical State of the NIO
- Mesoscale processes governing primary productivity
- To estimate air-sea CO_2 fluxes over the NIO
- Processes and associated dynamics of the oxygen minimum zones in the NIO
- Assessment of the Indian Ocean acidification in a changing environment
- Forecasting of Harmful Algal Blooms in the NIO
- Environmental conditions associated with interannual and intra-seasonal modes controlling variability in fish populations

End-to-End Approach



Eulerian-Lagrangian Coupling Offline/Online



Thank You for your attention