

INDian Ocean FOrecast System (INDOFOS)

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Indian Ocean Forecast System-Overview

Ports | Shipping | Offshore energy



Fishermen
Coastal Community
Disaster Management



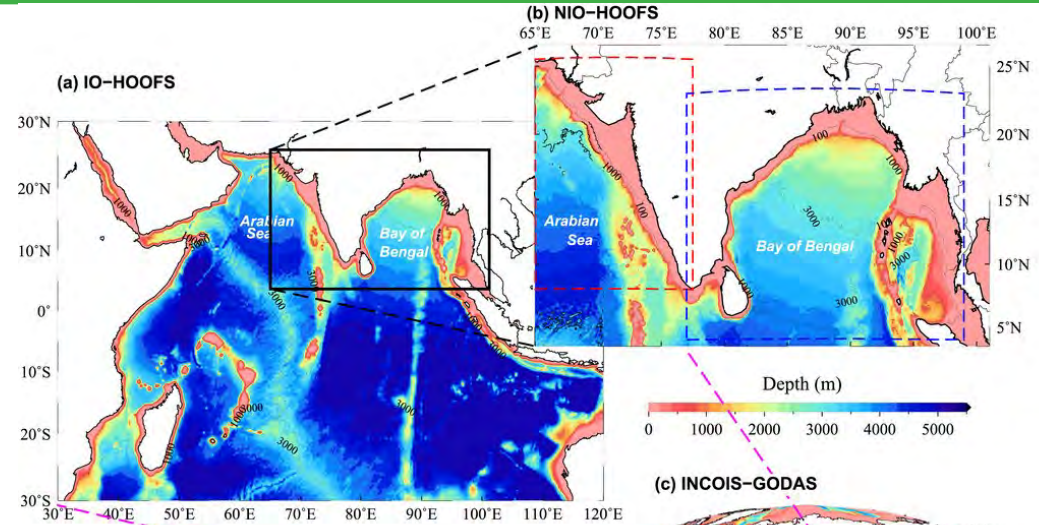
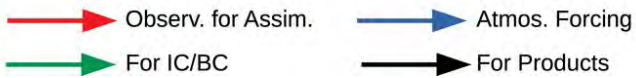
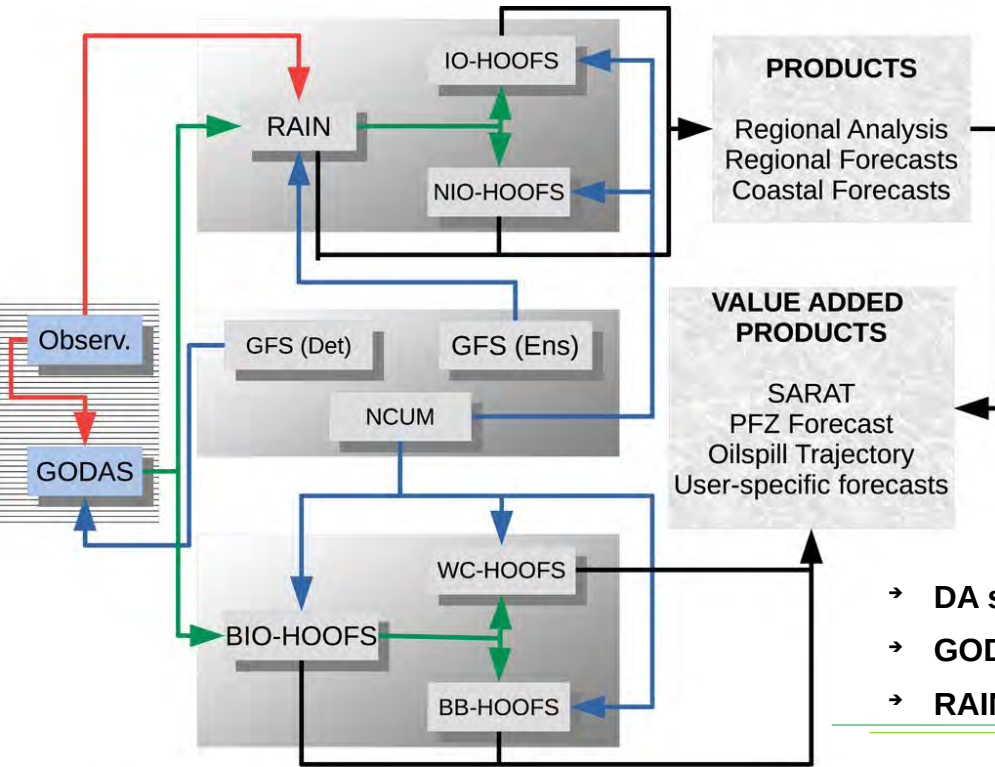
- ✓ Waves
- ✓ Tides
- ✓ Currents
- ✓ Water Quality
- ✓ Temperature



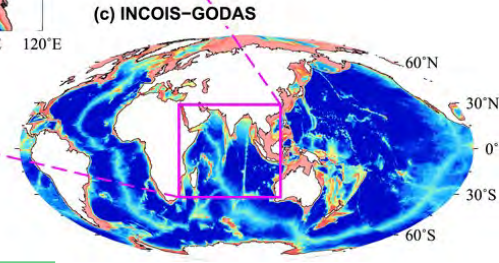
Navy | Coast Guard | Met Service

- ✓ Tsunami
- ✓ Storm Surge
- ✓ Swell Surge
- ✓ High waves

Indian Ocean Forecast System-Overview



- ➔ DA systems
- ➔ GODAS: 3D-VAR (profiles)
- ➔ RAIN: LETKF (profiles, SST, SLA)



BAMS
Article

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

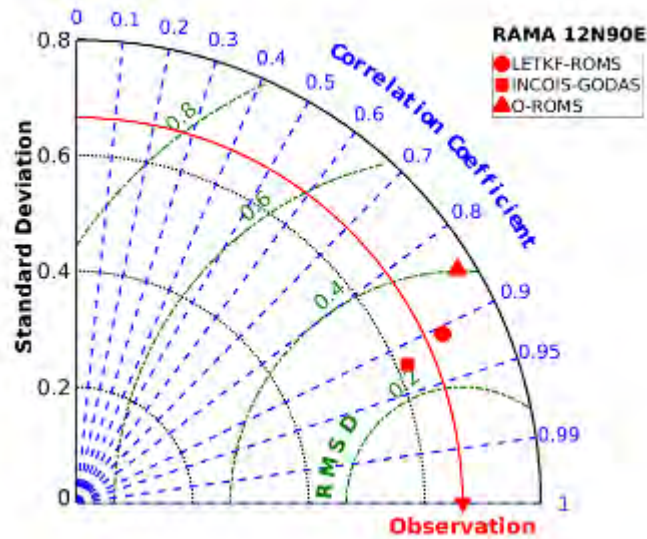
P. A. Francis, A. K. Jithin, J. B. Effy, A. Chatterjee, K. Chakraborty, A. Paul, B. Balaji, S. S. C. Shenoi, P. Biswamoy, A. Mukherjee, P. Singh, B. Deepsankar, S. Siva Reddy, P. N. Vinayachandran, M. S. Girish Kumar, T. V. S. Udaya Bhaskar, M. Ravichandran, A. S. Unnikrishnan, D. Shankar, A. Prakash, S. G. Aparna, R. Harikumar, K. Kaviyazhah, K. Suprit, R. V. Shesu, N. Kiran Kumar, N. Srinivasa Rao, K. Annapurmalah, 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



- ◆ **GODAS- Global Ocean Data Assimilation System**
- ◆ **RAIN- Regional Analysis for Indian Ocean**
- ◆ **HOOPS: High-resolution Operational Ocean Forecast System**

HOOFS: Some Performance Indicators

SST at 12N, 90E



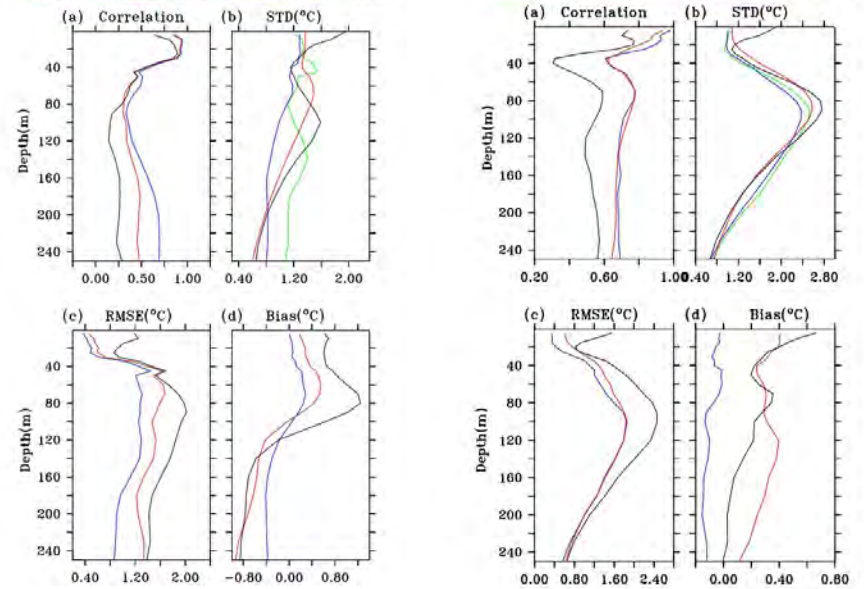
Temperature: AS (Left); BoB (Right)

Arabian Sea (Temperature)

Bay of Bengal (Temperature)

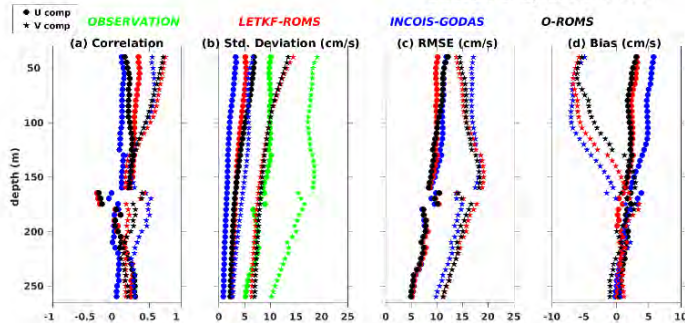
Observation LETKF-ROMS INCOIS-GODAS O-ROMS

Observation LETKF-ROMS INCOIS-GODAS O-ROMS



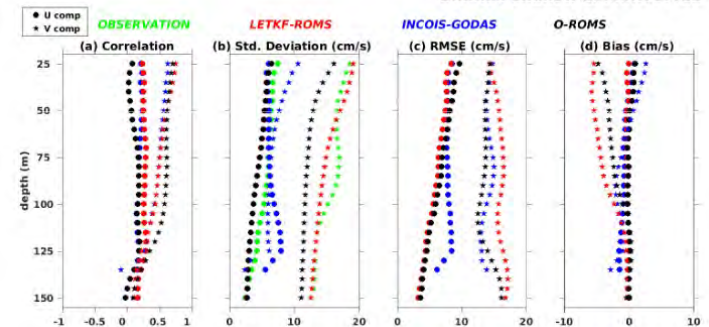
Currents at Bhatkal Slope (WC)

Bhatkal Deep 13.6N73.24E



Currents at Bhatkal Shelf (WC)

Bhatkal Shallow 13.88N73.41E



Present Operational Systems

- **High-resolution Operational Ocean Forecast and reanalysis System (HOOFS)** [Francis et. Al 2020.]
 - Global : INCOIS-GODAS (MOM4.0+3DVAR) | Varying resolution [2010-present]
 - Regional: ROMS v3.6 | 1/12 degree| Indian Ocean + LETKF [2016-present]
 - Coastal : ROMS v3.6 | 1/48 degree| North Indian Ocean [2017-present]
- **INCOIS Tentral Ocean Prediction System for Indian Ocean (ITOPSI)**
 - Global : HYCOM (HYCOM+TSIS) | 1/4 degree [2017-present]
 - Regional: HYCOM (HYCOM+TSIS) | 1/16 degree | Indian Ocean [2018-present]
- **Wave Forecasts**
 - Global : WAVEWATCH III | 1 degree [2013-present]
 - Regional: WAVEWATCH III | Indian Ocean: 1/2 degree | Northern Indian Ocean | 1/4 degree [2013-present]
 - Coastal : WAVEWATCH III| 1/24 degree [2013-present]
- **Tsunami**
 - Global: ADCIRC | unstructred [2014-present]
 - Regional: Tunami N2 (Scenario based) [2007-present]
- **Storm Surge**
 - Regional: ADCIRC+ SWAN | unstructured [2014-present]

INCOIS- RSMC of WMO



**Regional Specialized Meteorological Centre (RSMC)
for Numerical Ocean Wave Prediction
and Global Numerical Ocean Prediction**
Indian National Centre for Ocean Information Services (INCOIS)



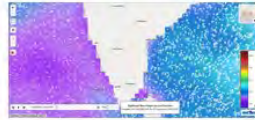
[Home](#) [Publications](#) [Waves](#) [Ocean Prediction](#)

The Indian Ocean is a vast stretch of seawater and a source of sustenance and livelihood for millions of people in the countries that border it. The marine resources of the Indian Ocean and the concept of the blue economy play a significant role in supporting the socioeconomic development and well-being of the populations living in this region.

Indian National Centre for Ocean Information Services (INCOIS) is an autonomous organization under the Ministry of Earth Sciences, Government of India. It was established in 1999 and has provided various ocean-related services since then. INCOIS started its wave forecast services from (25-05-2006) and augmented it with essential ocean variables from ocean general circulation models from (03-03-2015). INCOIS generates early warning advisories based on the state of the seas surrounding the Indian subcontinent and serves several island countries. These services are critical for the operational activities of offshore sea goers and onshore activities such as coastal tourism, ports and harbors etc.

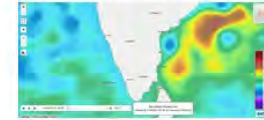
INCOIS operationally runs a suite of wave and ocean general circulation models at different resolutions to provide early warning services to maritime stakeholders. Users of forecasts are equipped to take informed decisions based on the sea state conditions, avoiding loss of life and property. Thus, INCOIS services extensively contribute to the development of the blue economy in the region through its forecasts and advisory services. Forecasts of essential ocean variables at different time scales are thus crucial for a broad spectrum of users ranging from fishermen to offshore industries. Recognizing the role played by INCOIS in issuing forecasts for the region, the WMO Executive Council at its seventy-sixth session (EC-76) adopted the designation of RSMC Indian National Centre for Ocean Information Services (INCOIS) (India) for numerical ocean wave prediction and global numerical ocean prediction.

Waves



[View](#) [Data Download](#)

Ocean Prediction



[View](#) [Data Download](#)

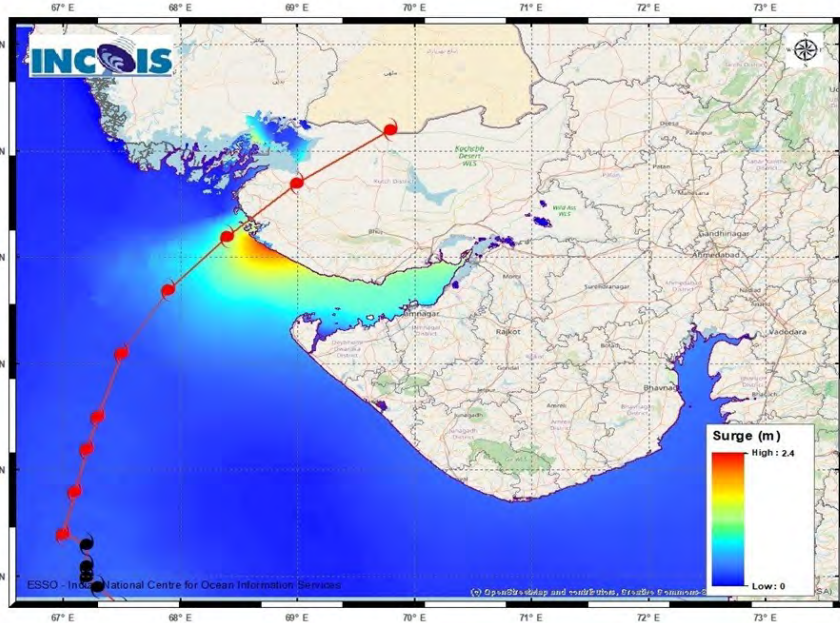
Model Name	Domain	Resolution	Forcing	Mixing	DA	Model Name	Domain	Resolution	Forcing	Mixing	DA
WAVEWATCH-III	Four nested grids covering Global Ocean	Global Ocean (1 x1 deg), Indian Ocean (0.5 x0.5 deg), Northern Indian Ocean (0.25 x0.25 deg) and coastal (10 Km x10 Km)	ECMWF forecast winds (0.25x0.25deg)	NA	Optimal Interpolation method; Assimilates Sig. Wave Height (SWH) from SARAL/AltiKa, Jason-3, Sentinel-3a and Sentinel-3b and all available in-situ SWH observations in the Indian Ocean	Hybrid Coordinate Ocean Model (HYCOM) version-2.35	20E-120E & 43S-30N	6.9 km (1/16) degree nested to a 25 km (1/4) Global Hycom	Atmospheric forcing: GFS Rivers: NRL climatology	KPP mixing	Method: Tendral Statistical Interpolation (Reduced Order Kalman Filter) Variables: AVHRR-SST, + L2 & L3 Along Track altimeter data. Argo profiles of Temperature & Salinity

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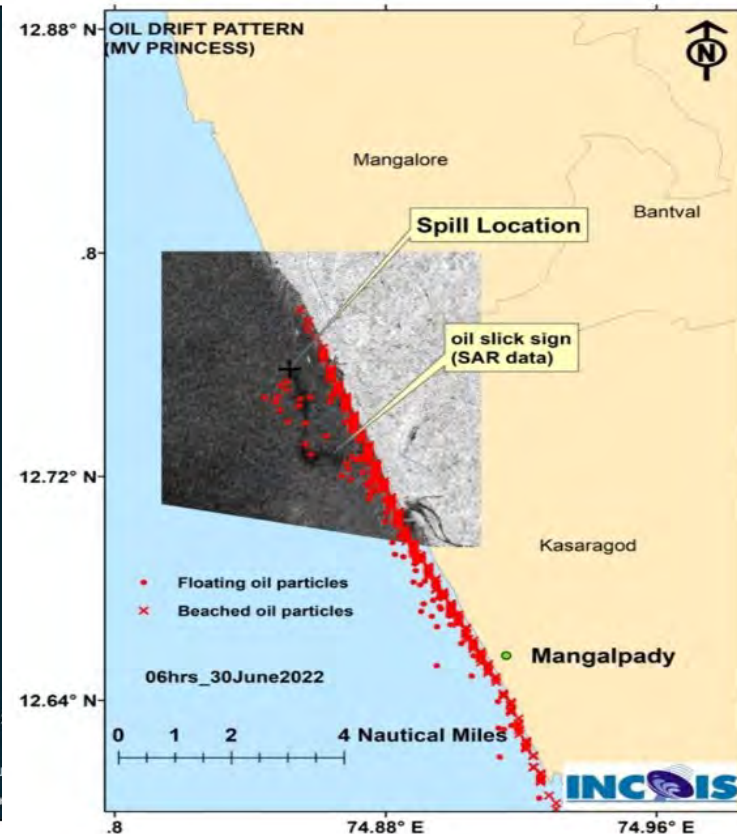
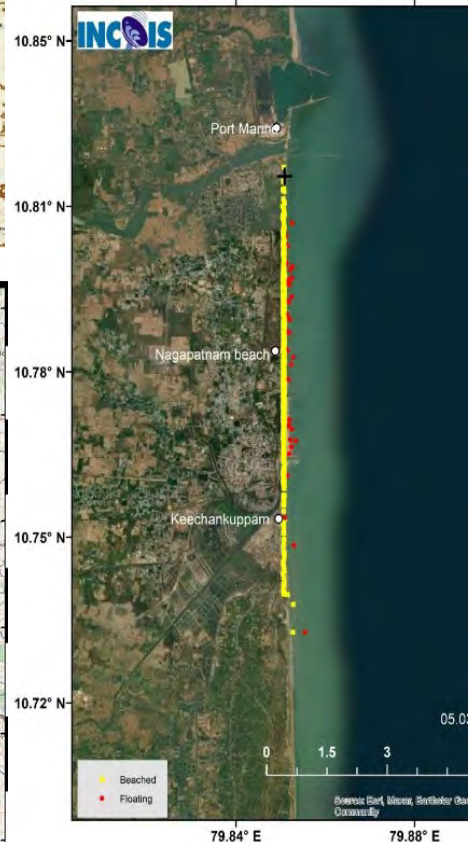
Forecast Examples

Storm Surge Prediction



Storm surge predicted during the landfall of the Tropical Cyclone Biporjoy (June-2023)

Oil Spill Trajectory Predictions



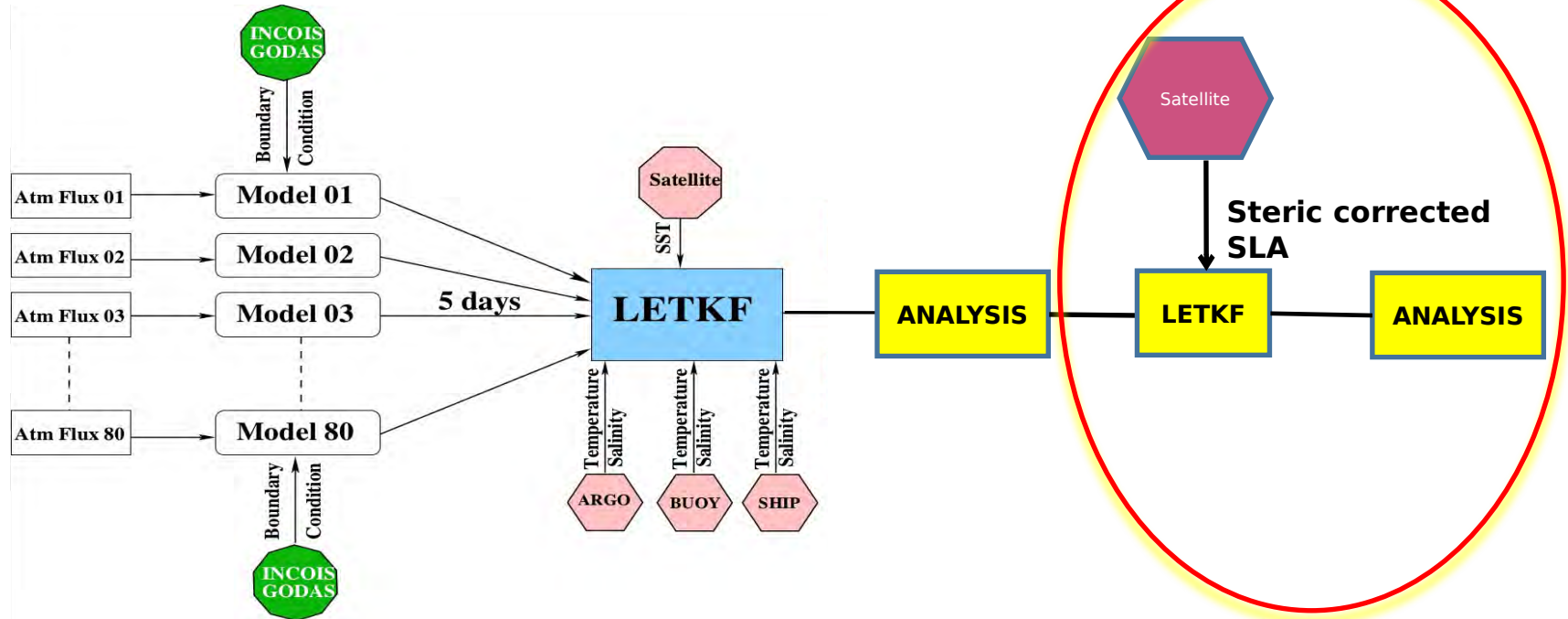
Predicted trajectories of oil spills.
Left: Bay of Bengal (Feb-Mar 2023);
Right: Arabian Sea Jun-Jul 2022

Impact of SLA Assimilation

The existing operational data assimilation system (ROMS+LETKF) is augmented with sequential assimilation of SLA.

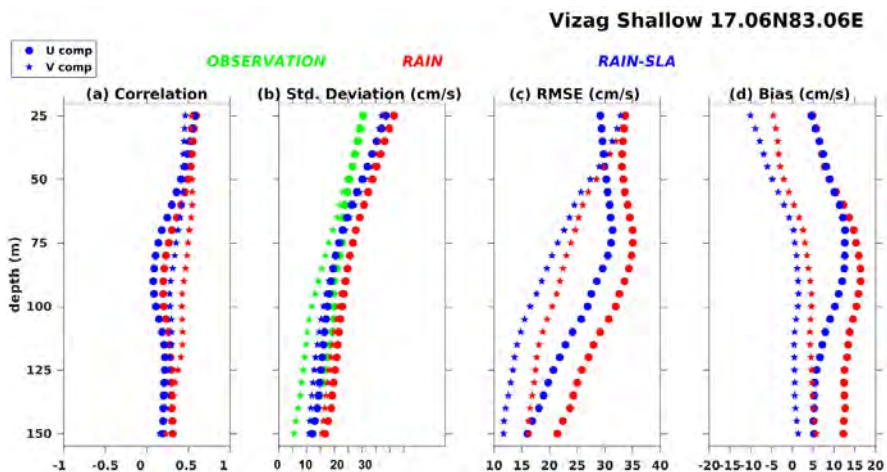
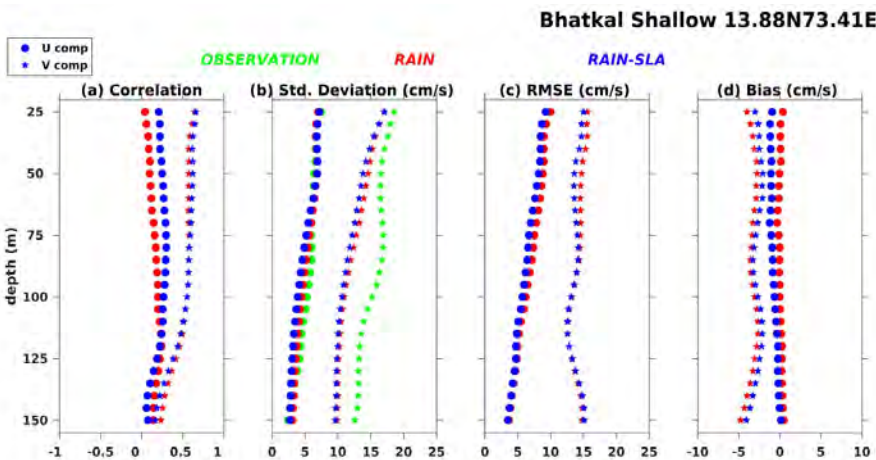
This assimilation has been done in two steps:

1. Assimilate all available in-situ temperature and salinity profiles along with satellite track data of SST.
2. SLA observations with steric correction were assimilated.



Impact of SLA Assimilation

Comparison with coastal ADCP Observations

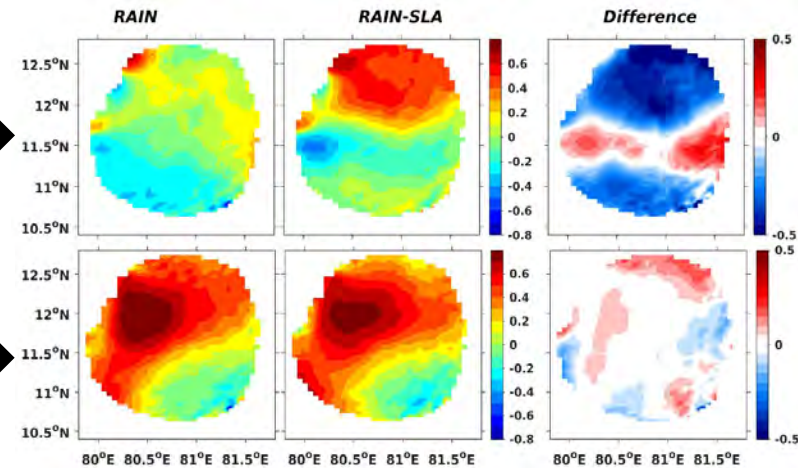


Comparison with TN CODAR Observations

U Current
Correlation



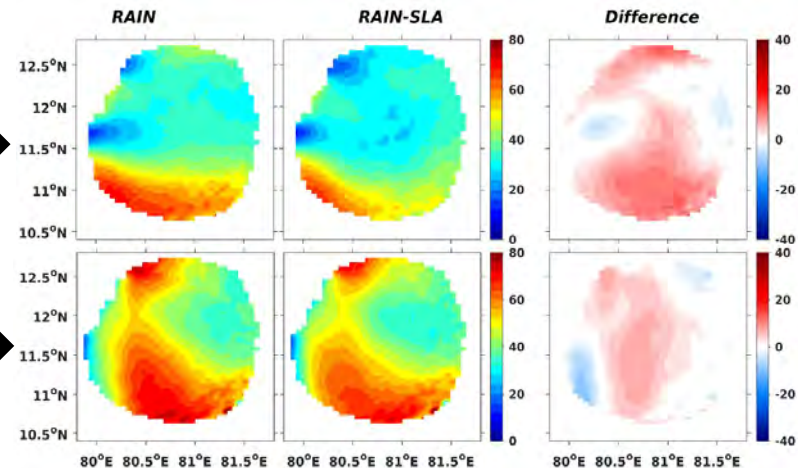
V Current
Correlation



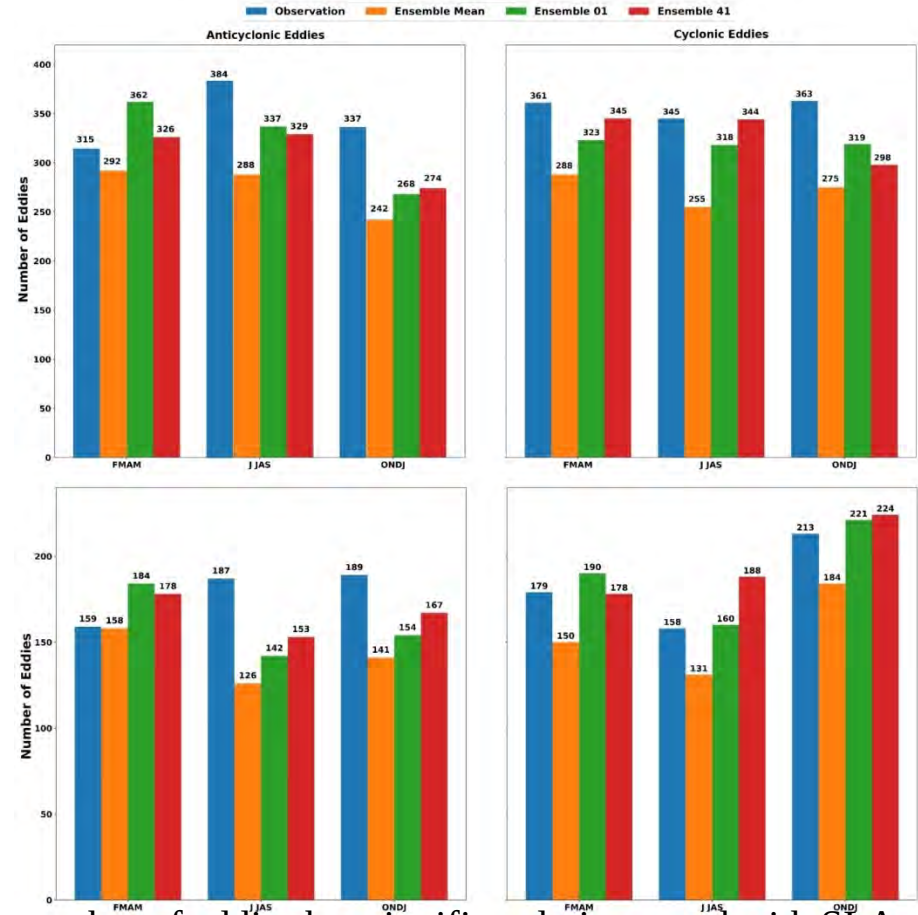
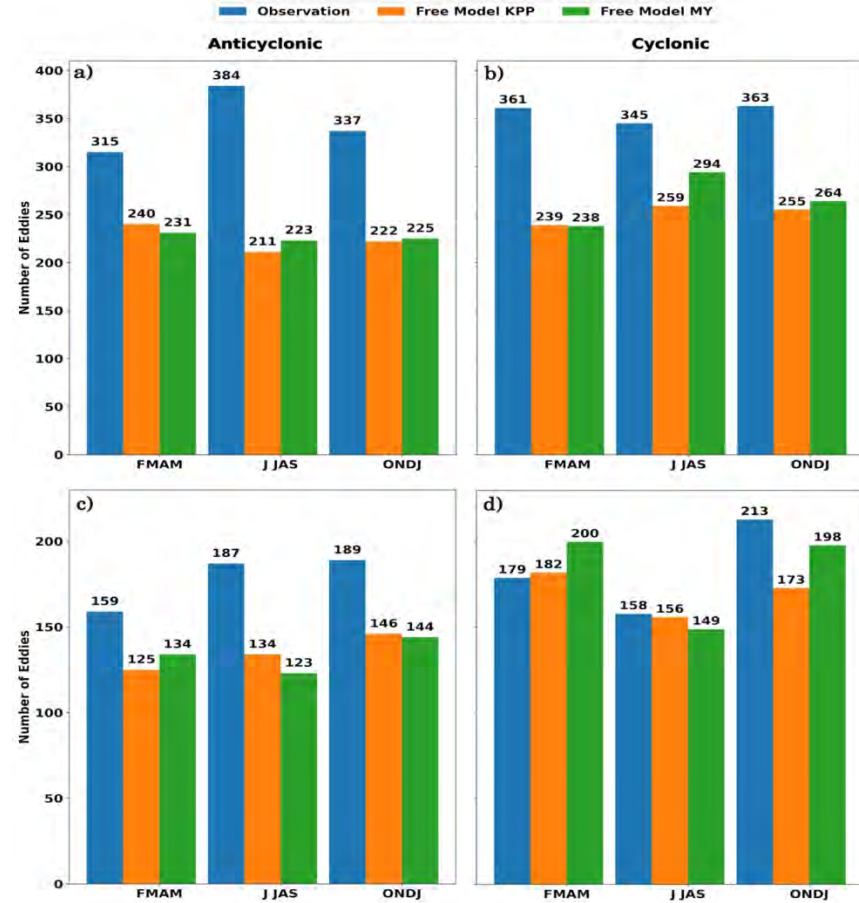
U Current
RMSE (cm/s)



V Current
RMSE (cm/s)



Impact of SLA Assimilation



- Free KPP (MY) model generated 67.7% (70%) of eddies in AS
- In BB, Free KPP (MY) model identified 84.4% (87.4%) eddies.

- The number of eddies has significantly increased with SLA assimilation.
- Assimilated KPP (MY) member produced 91% (91.5%) eddies in AS, while in BB models identified 96.8% (100%).

A New Quality Check for Ocean Data

Existing QC

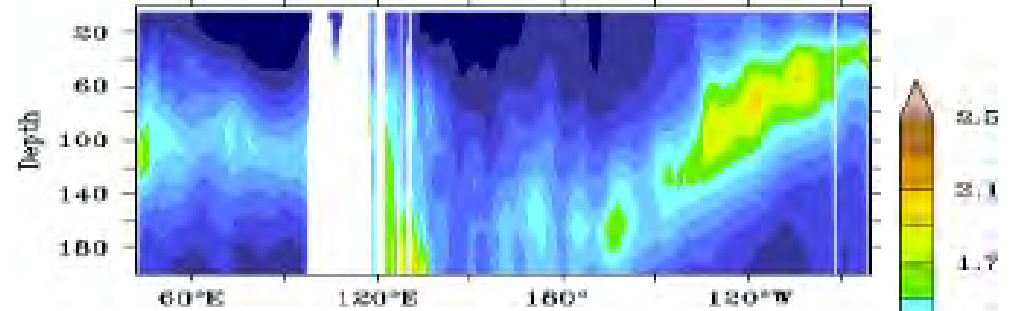


New QC

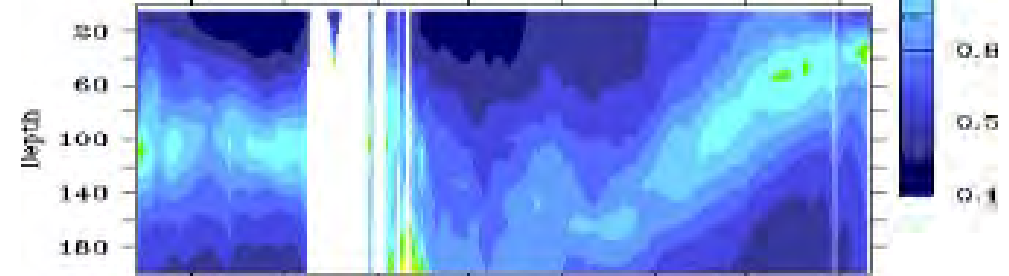


- The quality checks which INCOIS-adopted initially was very strict and hence much of the data was not going into the analysis.
- A new QC procedure was worked out and the ocean analysis is re-generated for the period 1999-present.

OLD QC



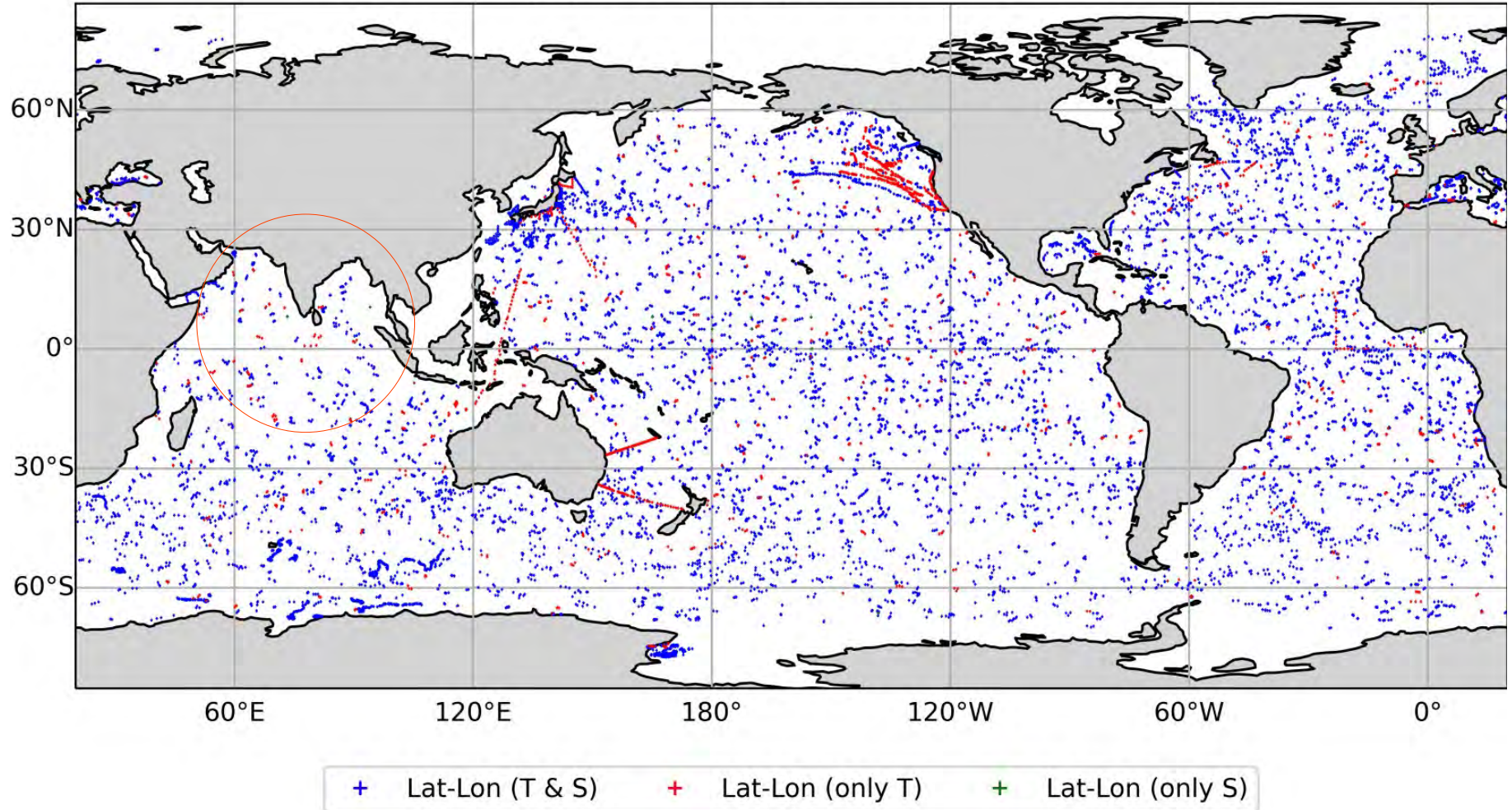
NEW QC



- ◆ Comparison of RMSE of temperature along the equator from INCOIS-GODAS using observations based on existing QC and new QC.
- ◆ The RMSEs are calculated with respect to monthly ECMWF-ORAS5 and NCEP-GODAS for the period 1999-2018.
- ◆ Global ocean analysis updated for the period 1999-present

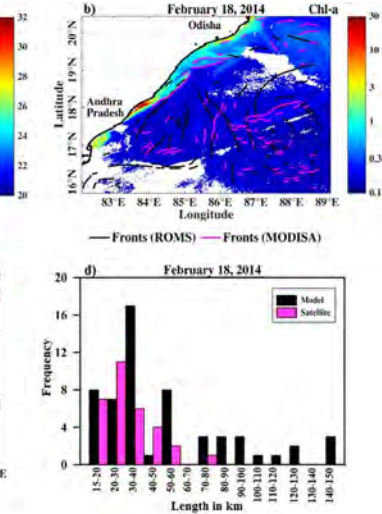
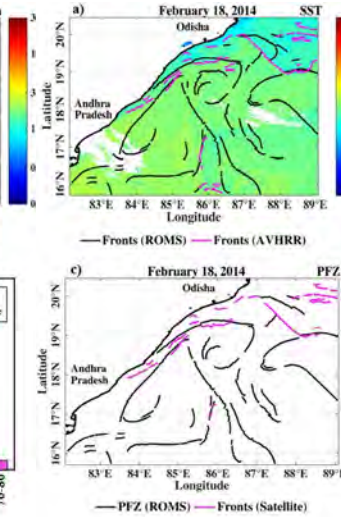
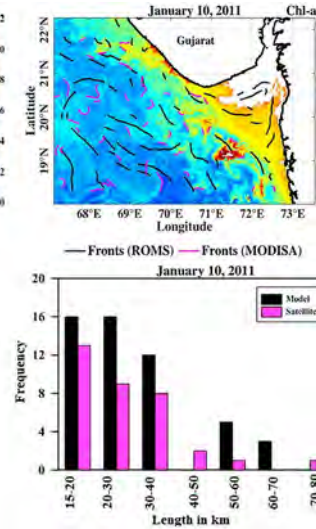
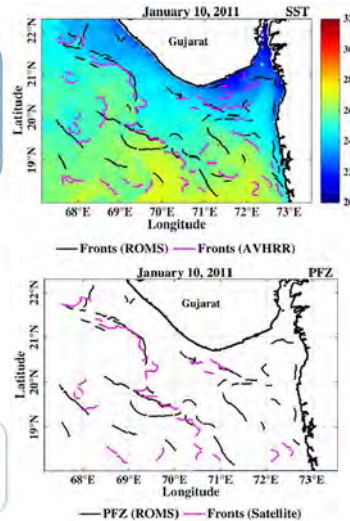
Argo data availability

GODAS Assimilation data locations 2023-04-01 to 2023-04-28



INCOIS is taking action to increase the Argo data coverage in the N. Indian Ocean

Potential Fisheries Zone- Advisory & Forecast



- PFZ advisories make use of the satellite measured SST and Chlorophyll concentration to identify potential regions of fish availability.
- Regions with large SST gradients and high Chl-a concentration are found to have better fish availability
- One of the challenges is the non-availability of satellite track data during cloudy days.

Explored the possibility to make use of model forecasts of SST and Chl-a to identify PFZ regions

Advantage is continuous data availability and possibility for predicting the PFZs.

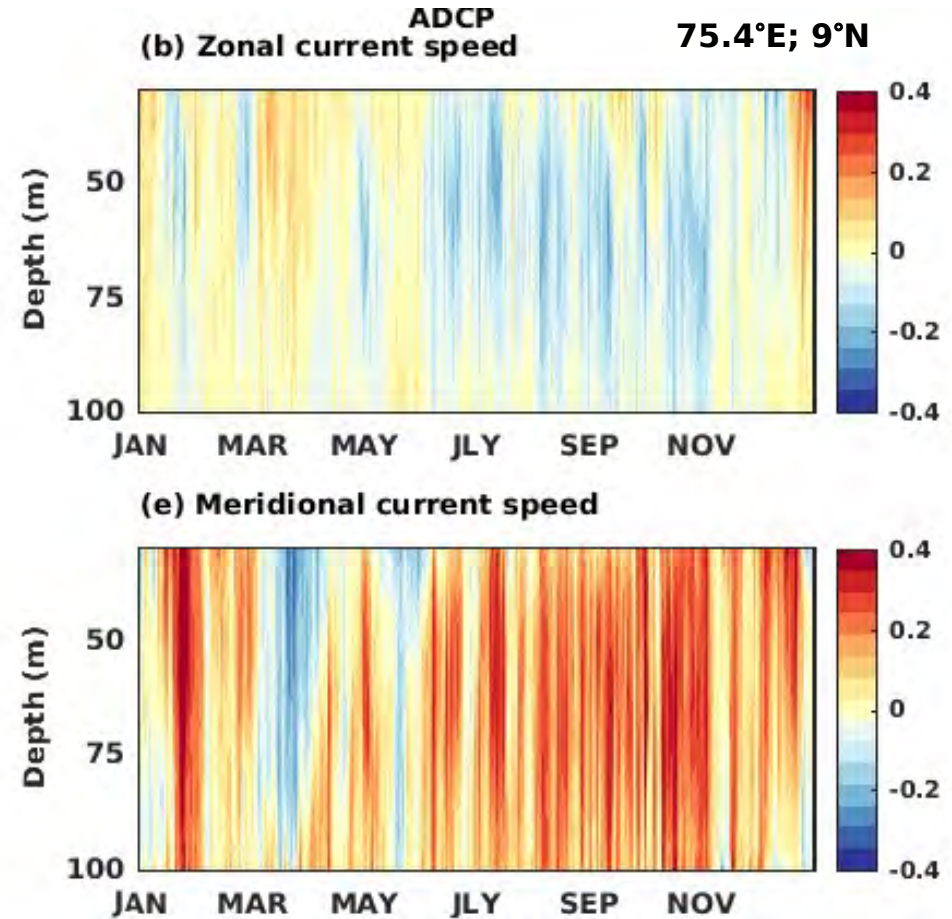
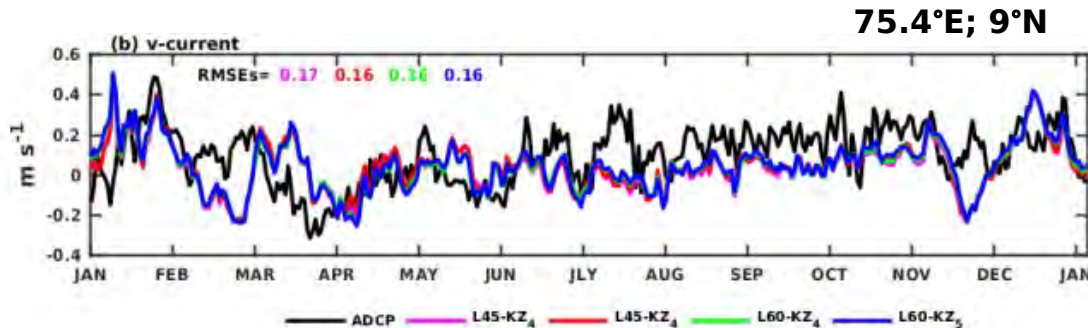
Only partially successful and large false alarms.

SST assimilation deteriorated the signals further

Exploring the possibility to develop a probabilistic PFZ prediction system from the ensembles

Prediction of Coastal Circulation

- 18 Major ports & 200+ minor ports
- 95% of transport by volume via sea route
- Most users of operational products (shipping, off-shore energy, fisheries, tourism etc.) operate in the shallow waters (~ 70m).
- Users need predictions of coastal currents, ocean state etc.
- Regular users are more concerned about short term variations in the coastal features, while policy makers and industry require long term variation as well.



Clearly, models need considerable improvements to cater to the needs of user community

Major Goals

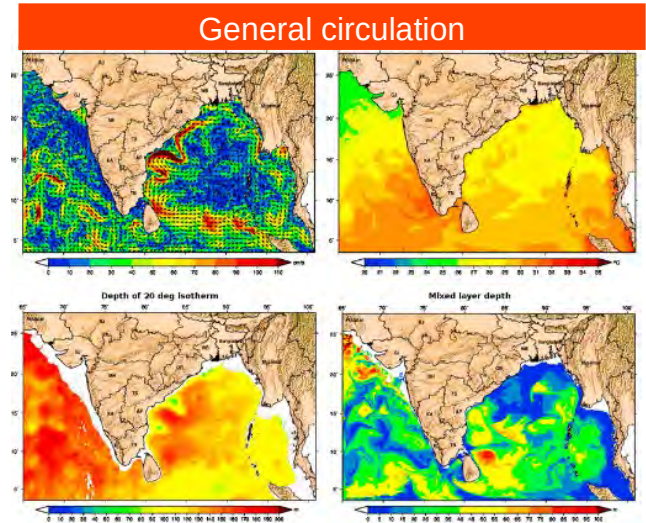
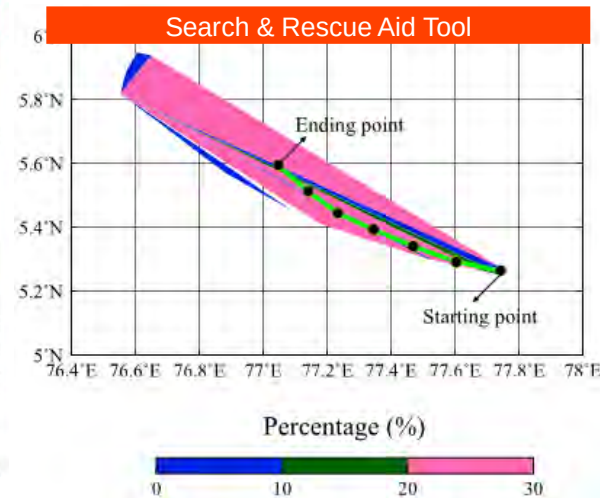
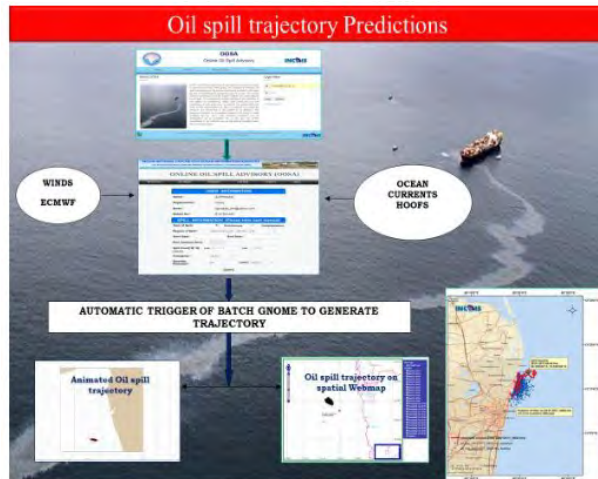
- Regional Ocean analysis
- Regional and coastal ocean forecasts
- R&D



Indian Ocean Forecast System

Regional Ocean Analysis

Regional and coastal forecasts



Major Goals

- ❑ Global Ocean reanalysis for climate studies
- ❑ Ocean climate indices
- ❑ Global Ocean analysis for initializing seasonal monsoon forecast model (IITM-CFS)
- ❑ Global Ocean initial conditions for extended range predictions by IITM CFS
- ❑ I/C and B/C for regional forecast models



Global Ocean Data Assimilation System

Ocean Initial Conditions

Ocean Analysis & Reanalysis

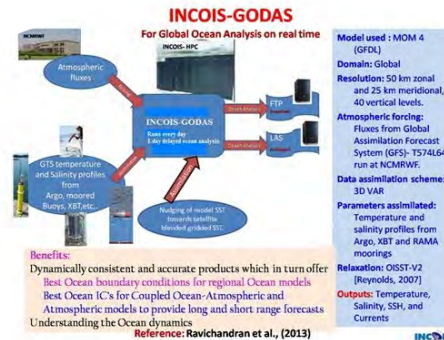
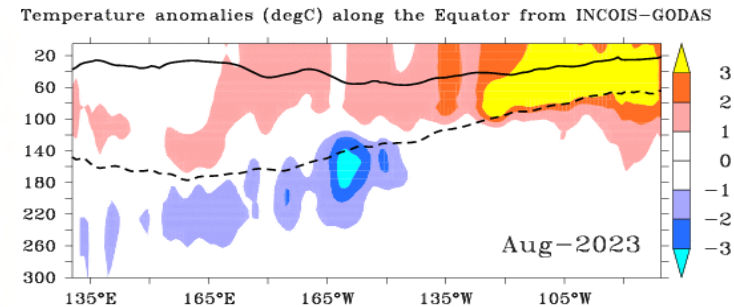


Figure Schematic diagram of INCOIS-GODAS



Major Goals

- ❑ Advisories on the decadal-to-long term projections, trends and coastal impacts:
 - ❑ Sea Level Change
 - ❑ Intensity & frequency of tropical cyclones
 - ❑ Extreme waves and coastal erosion
 - ❑ Storm surge and inundation hazard
 - ❑ Primary productivity, harmful algal blooms and coastal hypoxia
- ❑ Modelling and Deep Ocean Observations
- ❑ Multi-hazard Vulnerability Maps for the coastal regions of India
- ❑ Climate assessment report



DEEP OCEAN MISSION



Ocean Climate Change Advisory Services

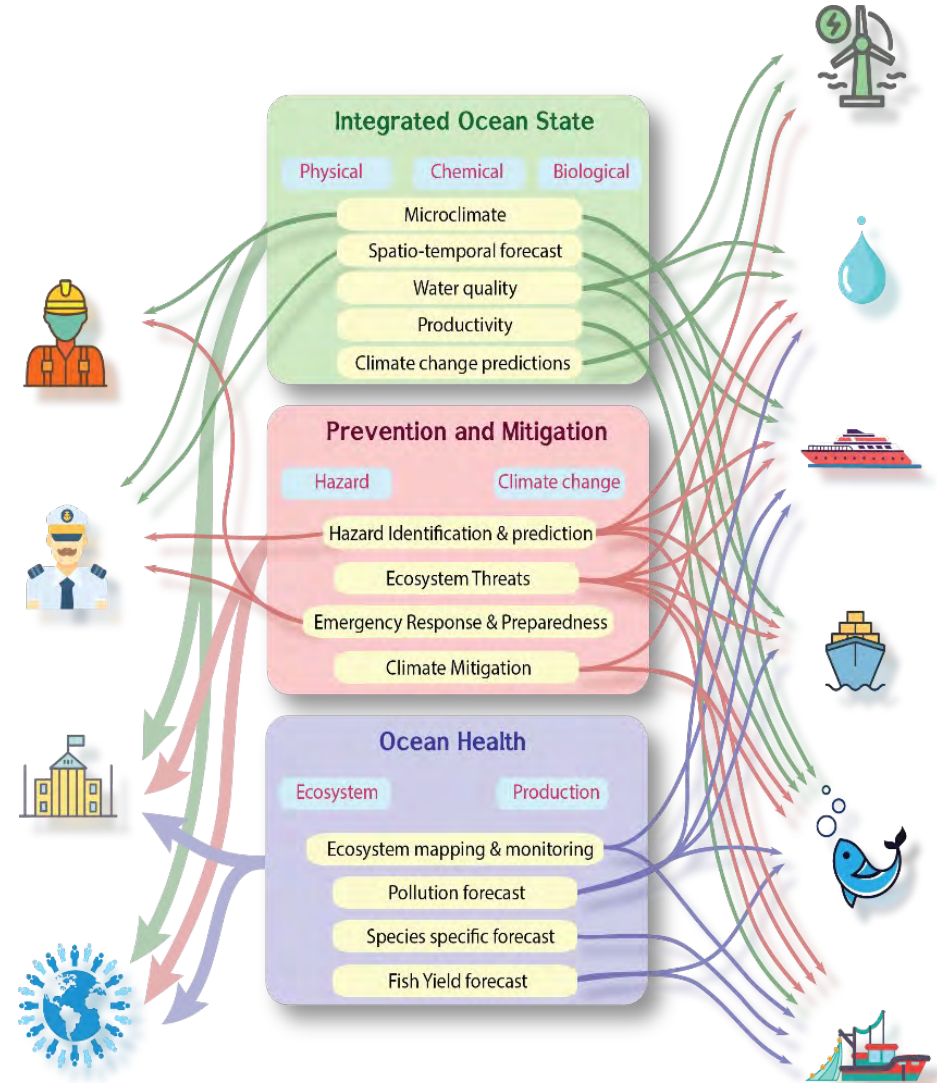
SEA
LEVEL
PROJECTIONS

CYCLONE
INTENSITY
AND
FREQUENCY

STORM
SURGE,
EXTREME
WAVE AND
EROSION

ECOLOGY,
HAB
AND
DEEP OCEAN
OBS

The Blue Economy Policy of the Govt. of India



Ocean Modelling Mission

Ocean Modelling Mission

Global & Regional
MOM6 & Wavewatch III

- Ocean Circulation & Wave Predictions
- Downscaled Ocean Climate Projections
- R&D in Ocean Sciences

Coastal
FVCOM & ADCIRC

- Integrated coastal inundation prediction system
- Coastal/shelf-sea prediction system
- R&D in coastal processes

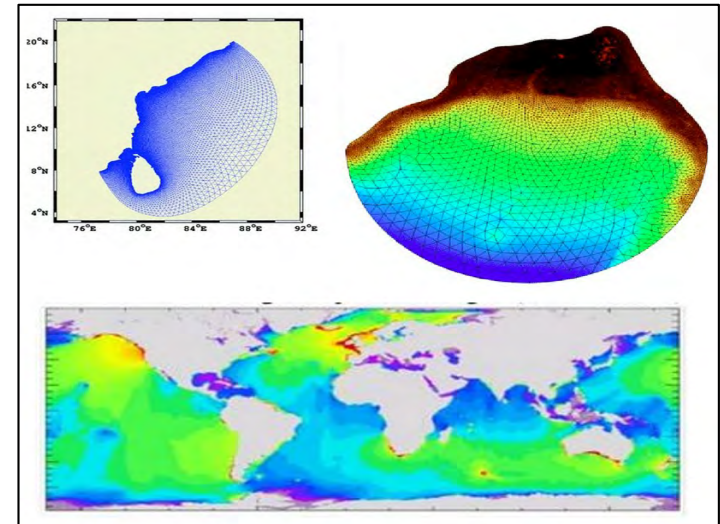
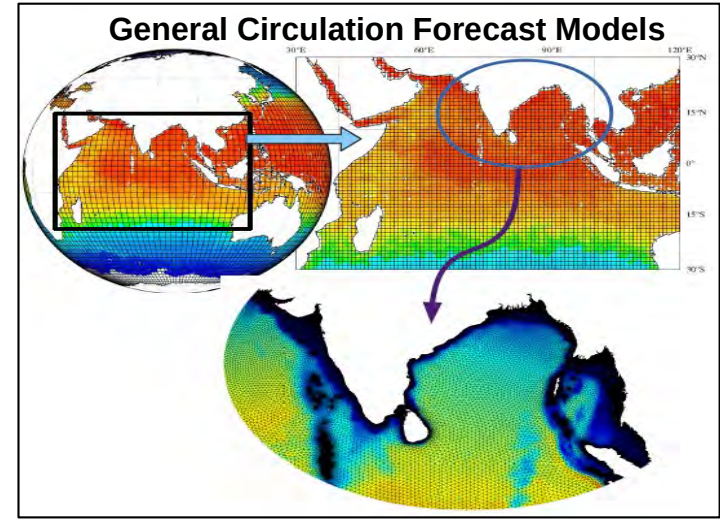
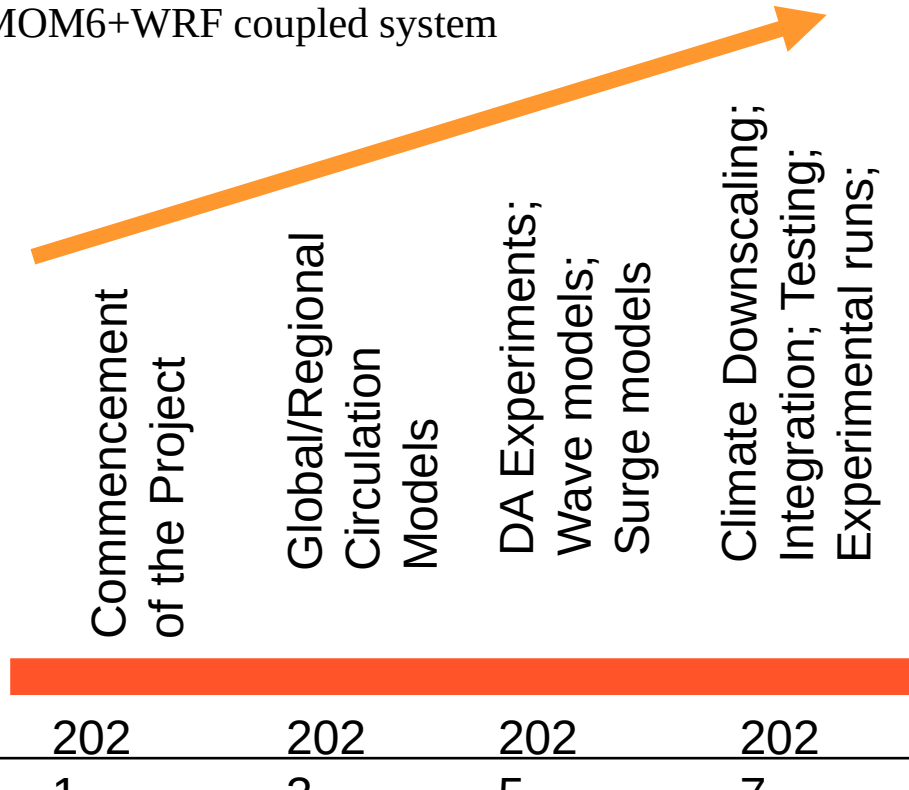
Data Assimilation
LETKF

- Ocean Analysis
- Ocean Reanalysis

Unified Ocean Modeling and Forecasting System

Proposed Ocean Modeling Framework

- MOM6 for global to regional level applications.
- LETKF based DA system in MOM6
- FVCOM for coastal/shelf sea/estuary applications.
- WAVEWATCH III for global to coastal wave forecast
- ADCIRC+SWAN for tsunami and storm surge prediction
- MOM6+WRF coupled system

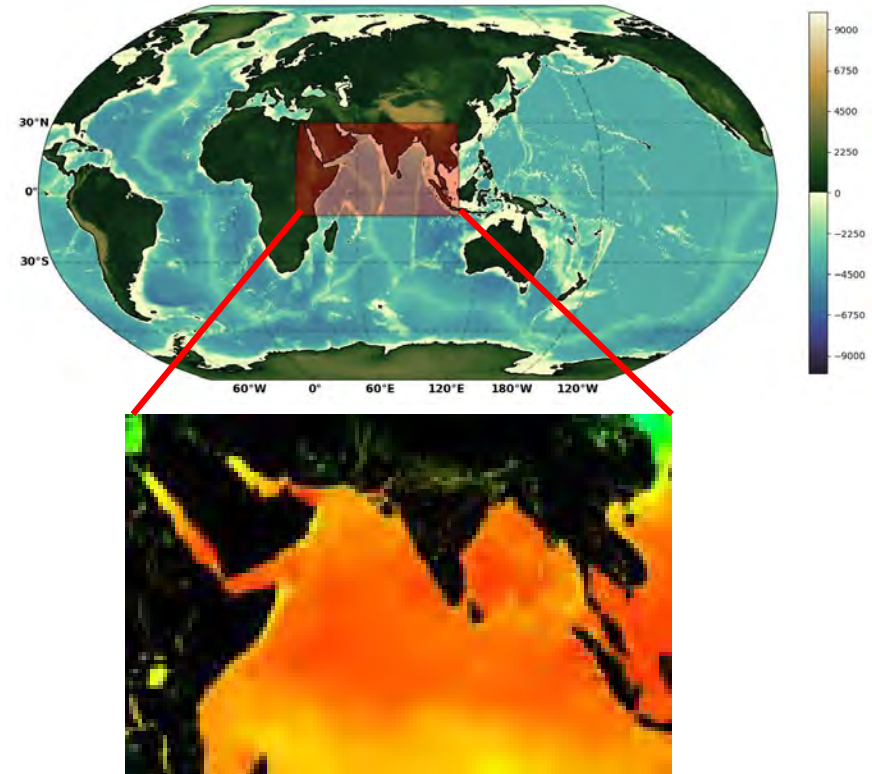


Coastal Prediction Models

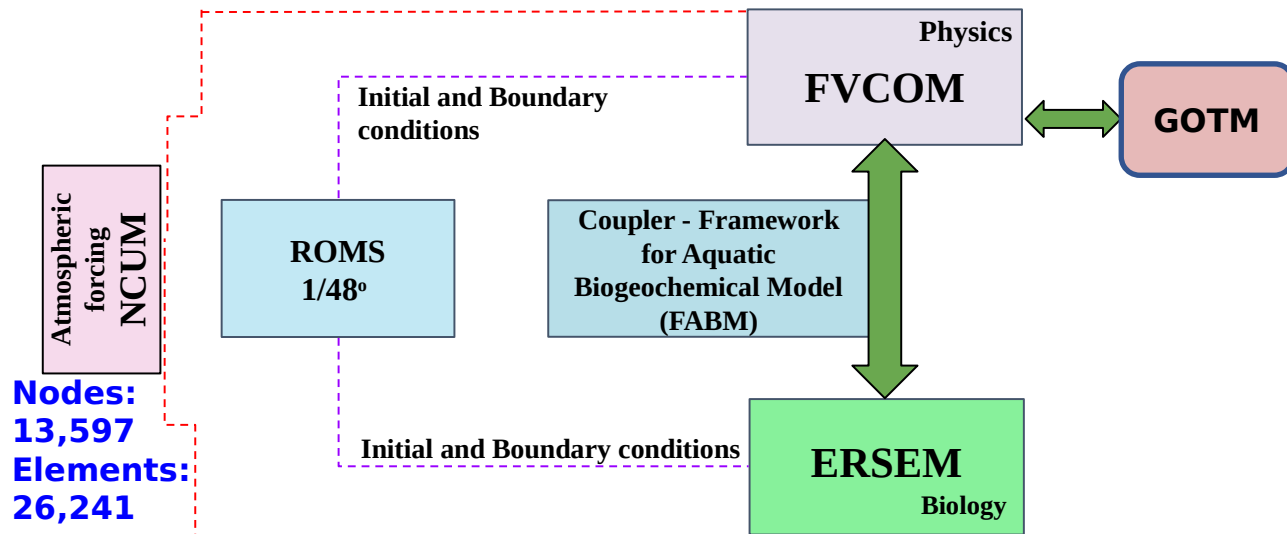
Modular Ocean Model 6 (MOM6)

As part of its unified modelling framework, INCOIS now plans to use MOM6 as its future workhorse for global and regional scale ocean modeling.

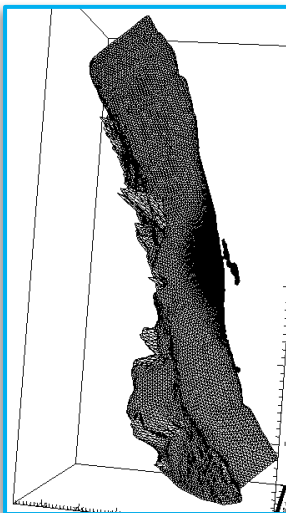
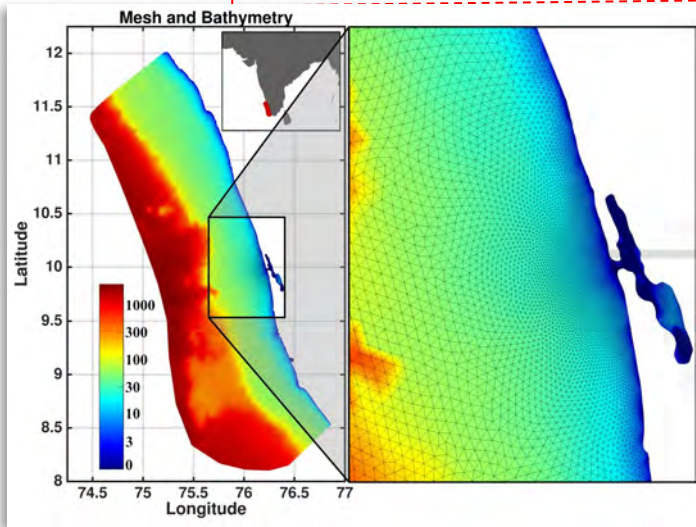
- INCOIS with the support of Prof. Eric Chessignat is setting up a global configuration of MOM6 under Monsoon Mission III.
- INCOIS is also setting up a regional configuration of MOM6 for the Indian Ocean.
- Experiments are progressing to incorporate realistic open boundary conditions and river discharge in the regional model configuration.



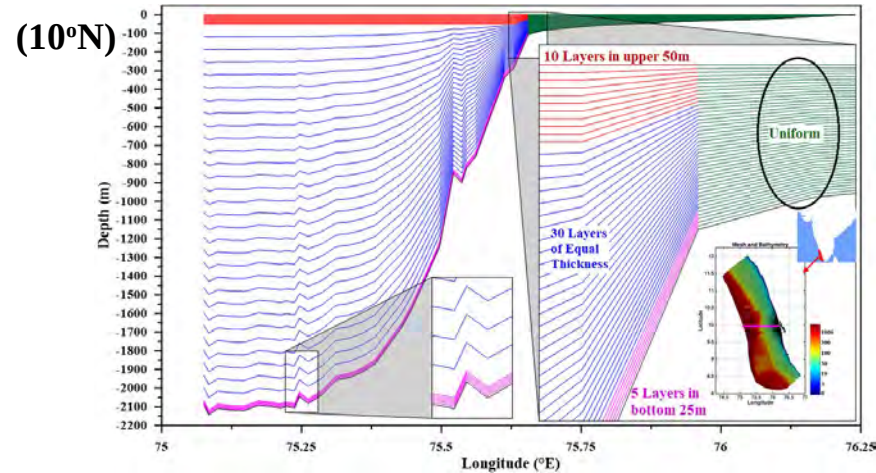
FVCOM



- Initial setup of FVCOM for the south-eastern Arabian Sea is now ready.
- Experiments are progressing to identify the most appropriate physics options for this configuration.

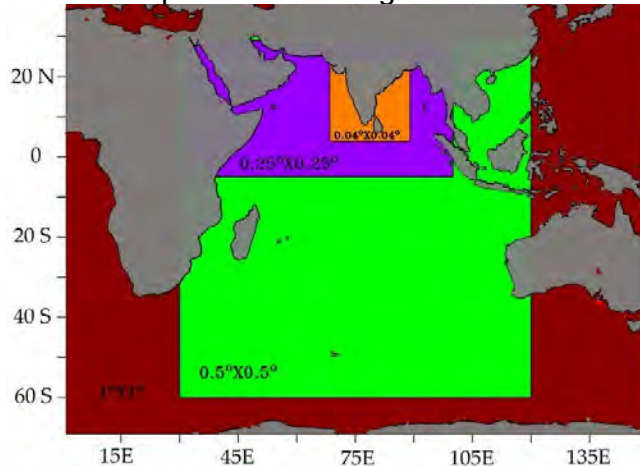


Vertical layers of FVCOM setup with hybrid coordinate (10°N)



Wavewatch-III

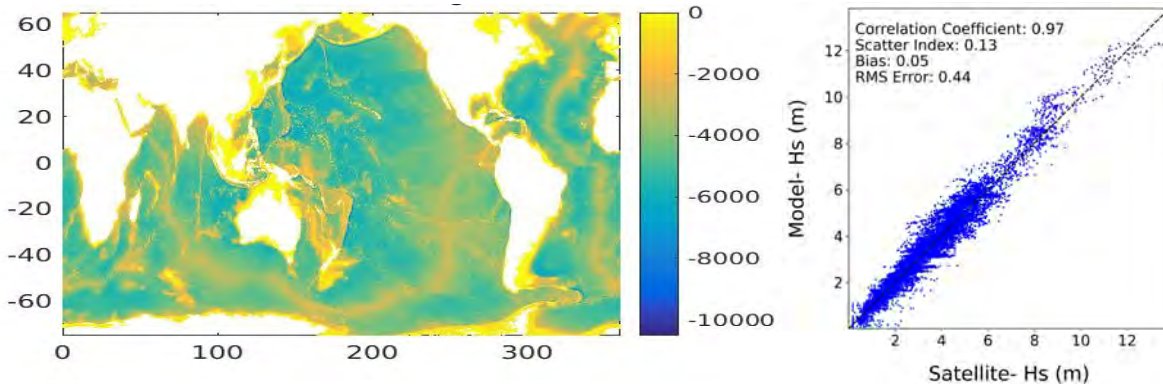
Operational Multigrid model



New Global Model

Buoy	Parameter	CC	Bias	RMSE
Deep sea buoys - AS and BoB	Hs	0.96	-8 cm	24 cm
	Ws	0.88	0.7 m/s	1.53 m/s
	Tm02	0.81	-0.72 s	1.29 s
Shallow water-Gopalpur	Hs	0.88	-0.19	0.32
	Tm02	0.56	0.78	1.78

- Ocean Modeling Mission envisages setting up a global high-resolution wavewatch-III model into which a regional unstructured grid wavewatch-III will be nested for very fine-resolution wave forecasts for the coastal waters.
- Global WWIII has been configured.
- Efforts are underway to configure regional unstructured WW-III.



Thank You

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