International
Oceanographic
Data and Information
Exchange

A regional ocean modeling system for short term prediction of marine ecosystem

Kunal Chakraborty

MDG, INCOIS

kunal.c@incois.gov.in

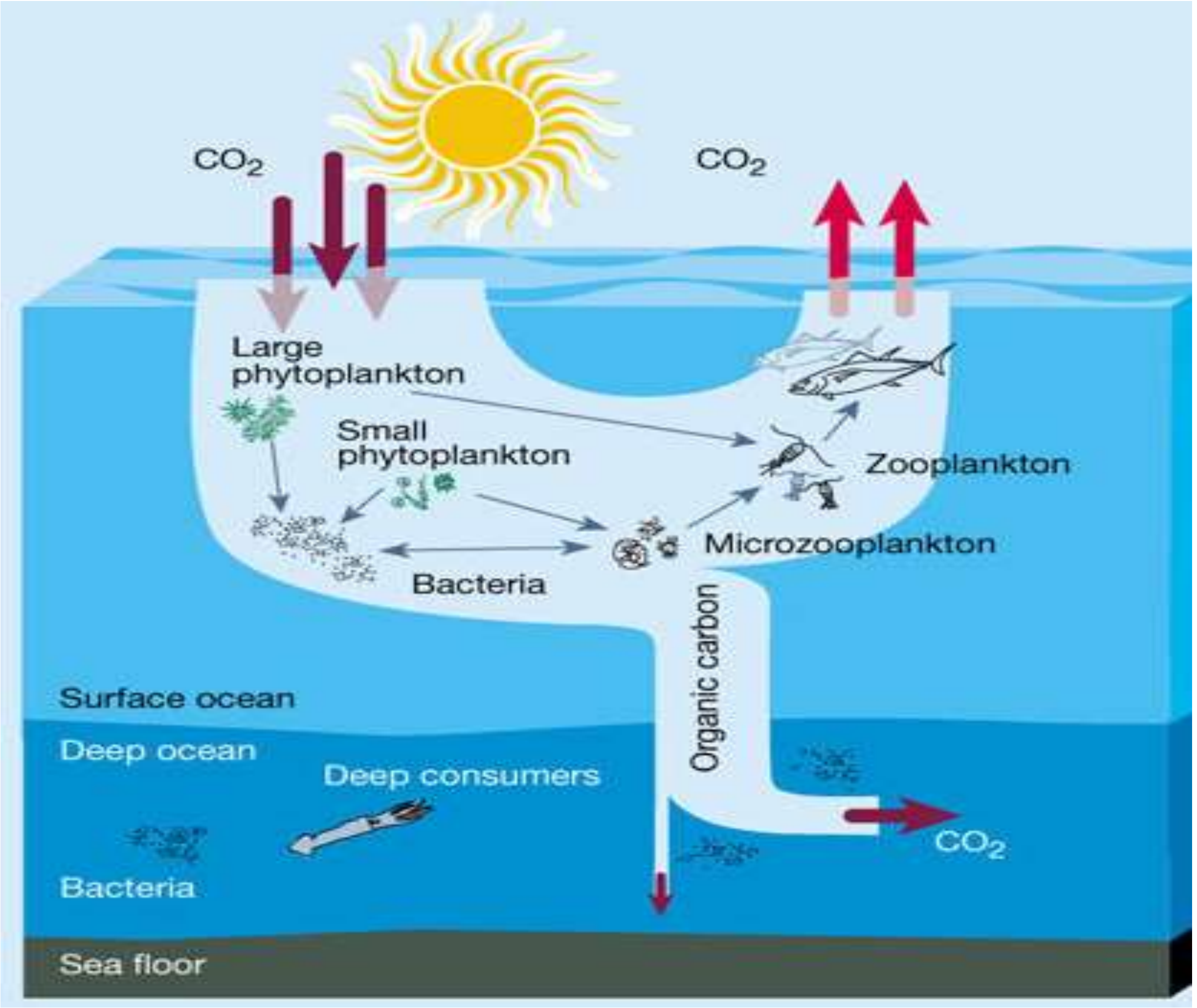
Discovery and Use of Operational Ocean Data Products and Services

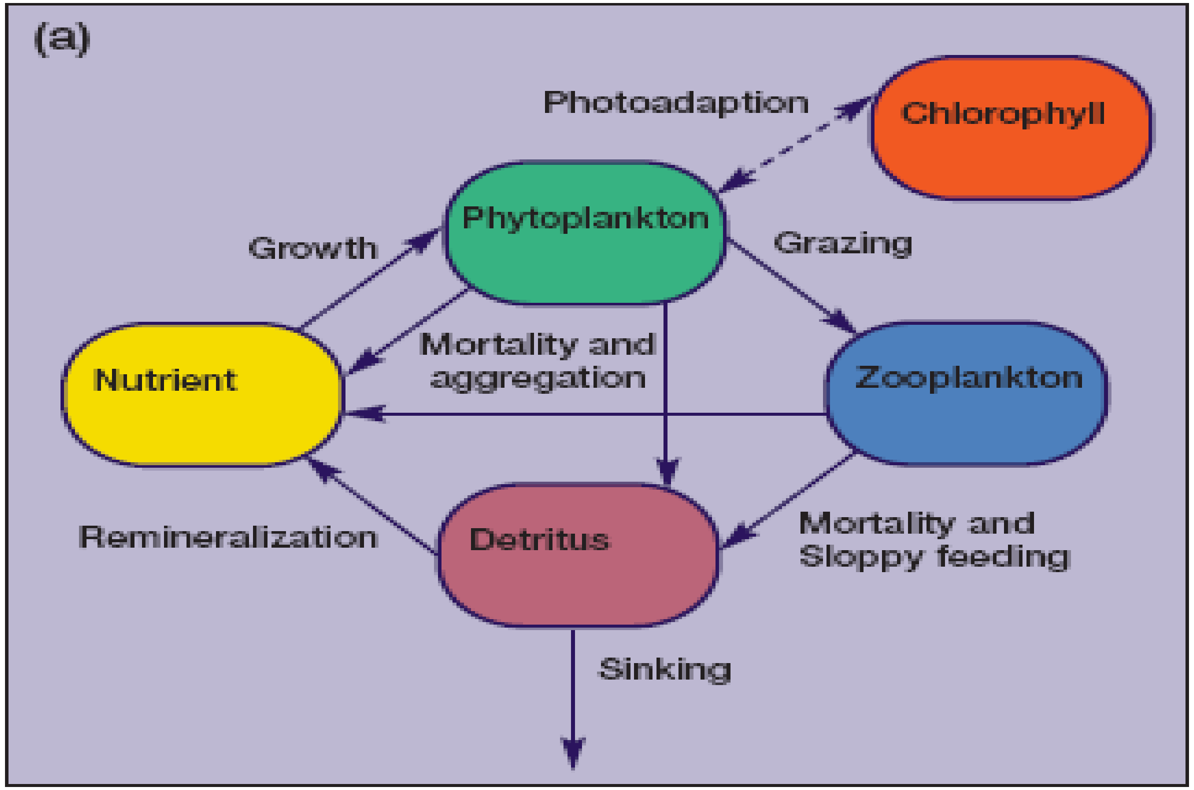
18-22 June 2018

ITCOocean, INCOIS, Hyderabad

With the support of the Government of Flanders, Belgium

Simple coupled physical-biogeochemical models of marine ecosystems





Formulating *quantitative* mathematical models of *conceptual* ecosystems

Courtesy: John Wilkin

Processes

- Biological:
  - Growth
  - Death
  - Photosynthesis
  - Grazing
  - Bacterial regeneration of nutrients

- Physical:
  - Mixing
  - Transport (by currents from tides, winds …)
  - Light
  - Air-sea interaction (winds, heat fluxes, precipitation)

Mathematical formulation

$$V \frac{d}{dt} C_n = sources_n - sinks_n + \sum_j transfer_{n,j}$$

e.g. inputs of nutrients from rivers or sediments

e.g. burial in sediments

e.g. nutrient uptake by phytoplankton

The key to model building is finding appropriate formulations for transfers, and not omitting important state variables

C is the concentration of any biological state variable

Rate of change of phytoplankton = uptake − grazing − mortality

$$\frac{dP}{dt} = \frac{V_m N}{k+N} f(I_o) P - GZ - \epsilon P$$

Rate of change of nutrients = − uptake + regeneration + input

$$\frac{dN}{dt} = -\frac{V_m N}{k+N} f(I_o) P + (1-\gamma)GZ + \epsilon P + aZ + \quad + m(N_o - N)$$

Rate of change of zooplankton = growth − mortality

$$\frac{dZ}{dt} = \gamma GZ - aZ$$

V_m	=	maximum nutrient uptake rate
k	=	half-saturation constant for nutrient uptake
$f(I_o)$	=	incoming solar radiation
G	=	grazing rate
ϵ	=	death rate of phytoplankton
γ	=	grazing efficiency
a	=	death rate of zooplankton
m	=	mixing rate
N_o	=	nutrient concentration beneath the mixed layer

Coupling to physical processes

Advection-diffusion-equation:

physics

$$\frac{\partial}{\partial t}C + \nabla \cdot \vec{v}\, C - D\Delta C = gain(C) - loss(C)$$

advection

turbulent mixing

Biological dynamics

C is the concentration of any biological state variable

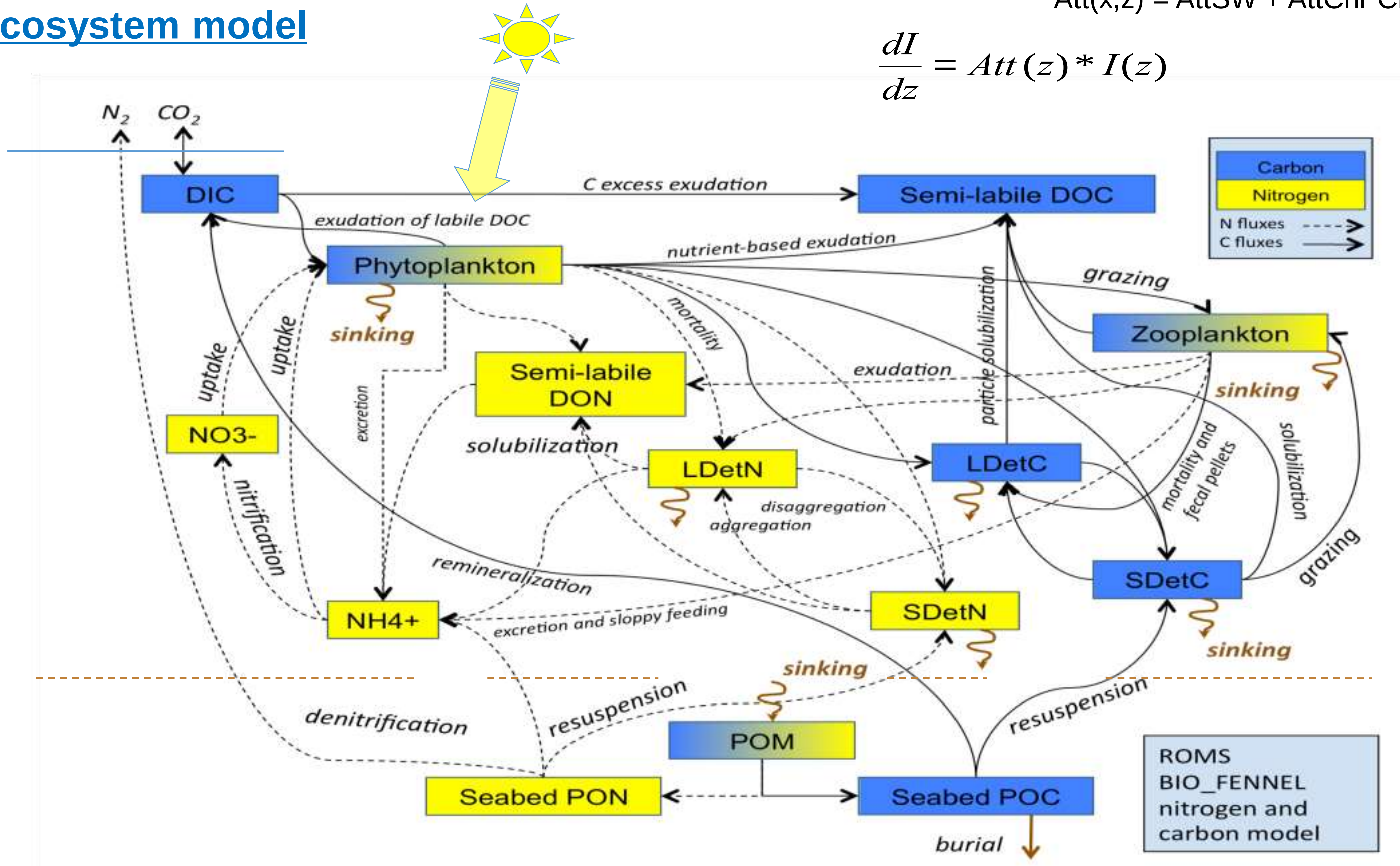
Examples of conceptual ecosystems that have been modeled

- A model of a food web might be relatively complex
  - Several nutrients
  - Different size/species classes of phytoplankton
  - Different size/species classes of zooplankton
  - Detritus (multiple size classes)
  - Predation (predators and their behavior)
    - Multiple trophic levels
  - Pigments and bio-optical properties
    - Photo-adaptation, self-shading
  - 3 spatial dimensions in the physical environment, diurnal cycle of atmospheric forcing, tides

Schematic of ROMS "Fennel" ecosystem model

Phytoplankton concentration absorbs light
Att(x,z) = AttSW + AttChl*Chlorophyll(x,z,t)

$$\frac{dI}{dz} = Att(z) * I(z)$$

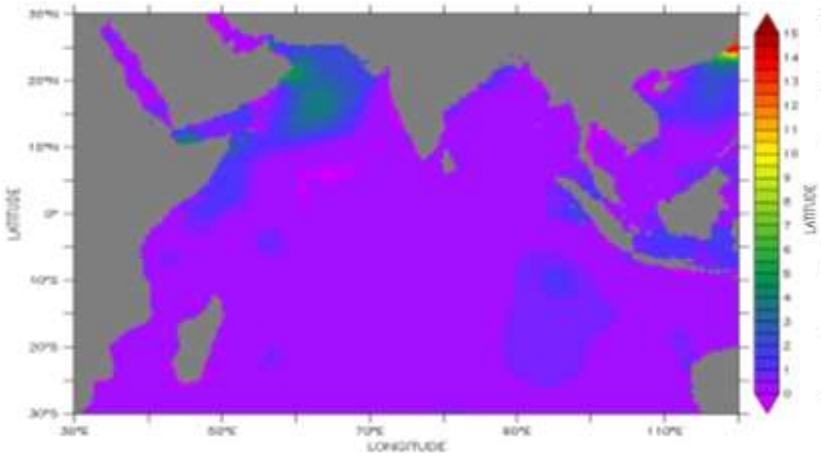


How to prescribe initial and boundary condition ?

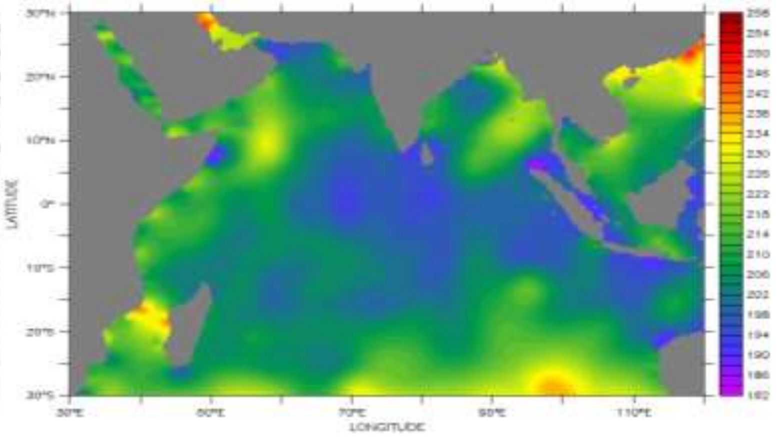
- The physical model (ROMS) is spun-up for 10 years using climatological forcing.

- Then the biological module is switched-on using the climatological state generated through physical simulation.

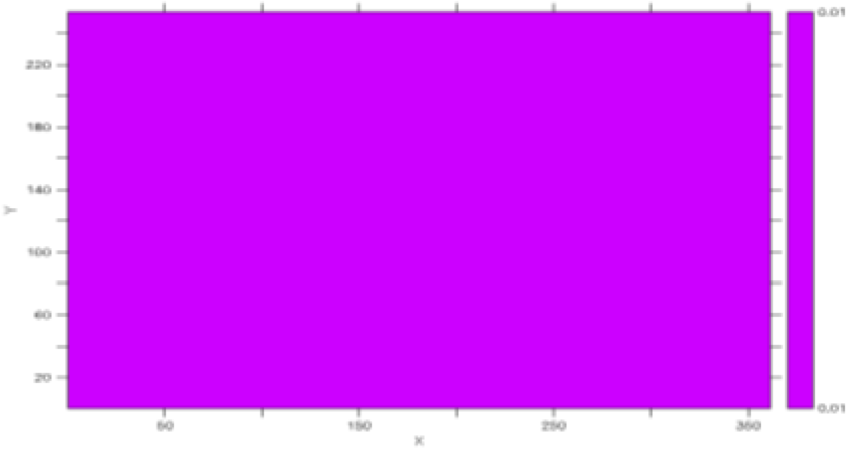
- Biological model initial state for phytoplankton, zooplankton, detritus etc. are set as uniform seed with 0.01 mg/m3 concentration. However, nitrogen and oxygen are initialized using WOA data.



Initial Sea Surface Nitrate Concentration



Initial Sea Surface dissolved oxygen Concentration



Initial concentration of sea surface chlorophyll.

Validation of the model simulated outputs with available observations in the Arabian Sea

- To intensively test the model capabilities towards simulating seasonality of physical (temperature and salinity) and biogeochemical (nitrate, chlorophyll and dissolved oxygen) state; we validate the model outputs with three independent observations viz.

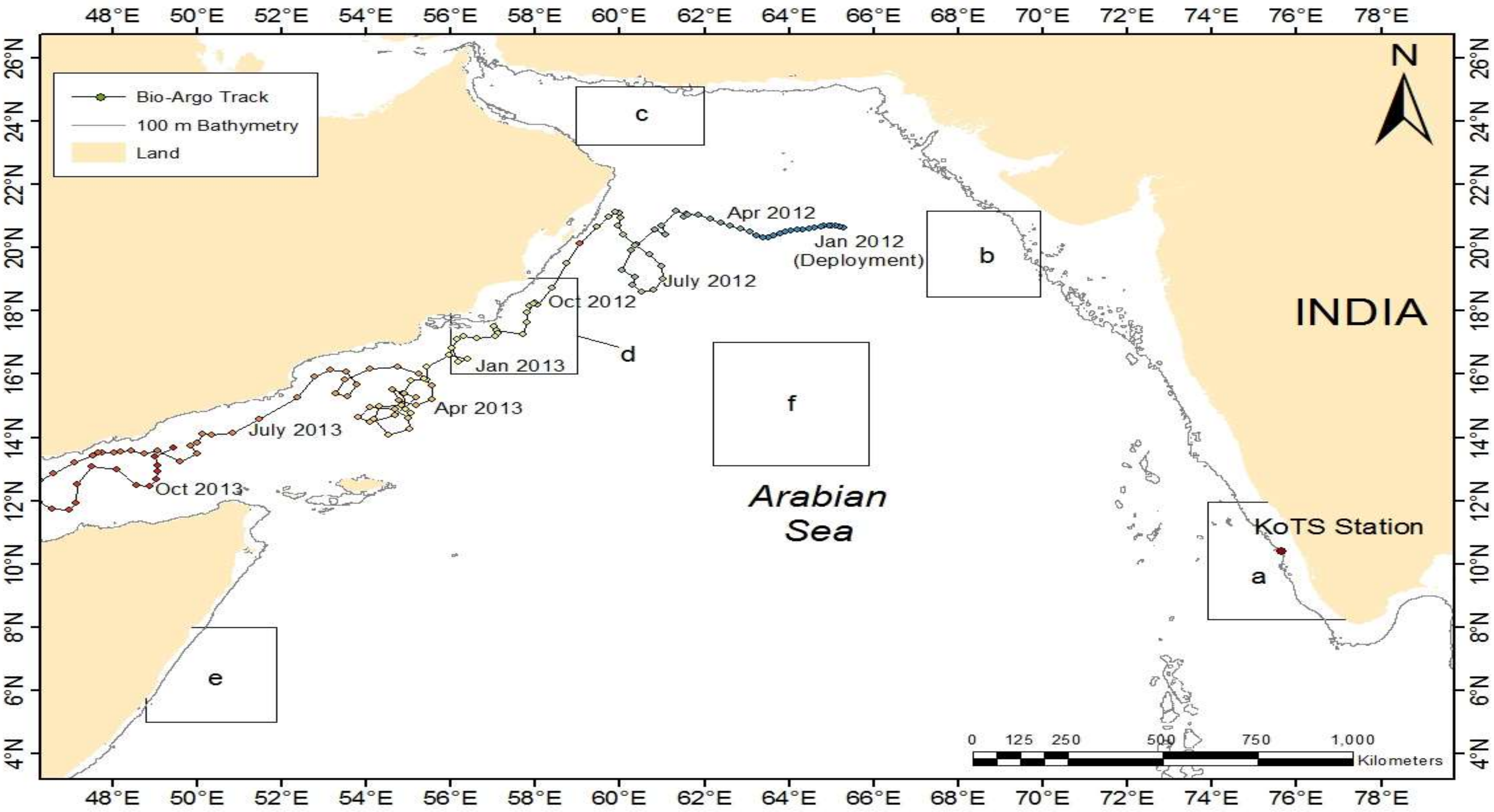
(1) satellite data,

(2) a bio-Argo float, and

(3) in-situ Kochi time-series station observations (KoTS).

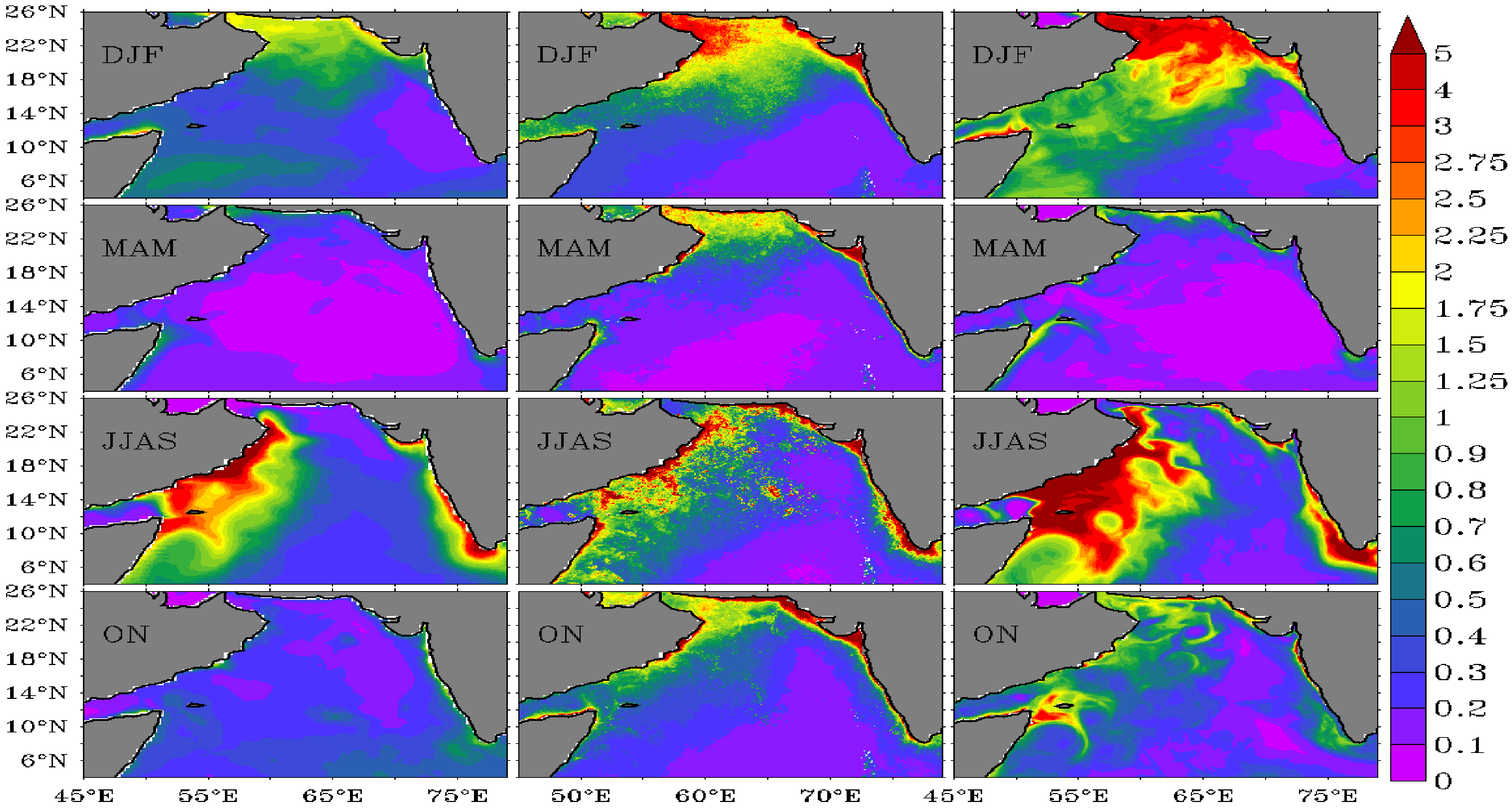
- The observations (such as in-situ sampling or Argo profiles) to validate model outputs are point observations while model output is in the form of a spatial average over 25 sq km and 9 sq km grid area, for ROMS-1/4 and ROMS-1/12 set-ups, respectively. Also, when daily model outputs are compared against in-situ data from observation made at monthly/fortnight frequency, they are expected to display differences for local anomalies and short-temporal signals.

Map of the study area



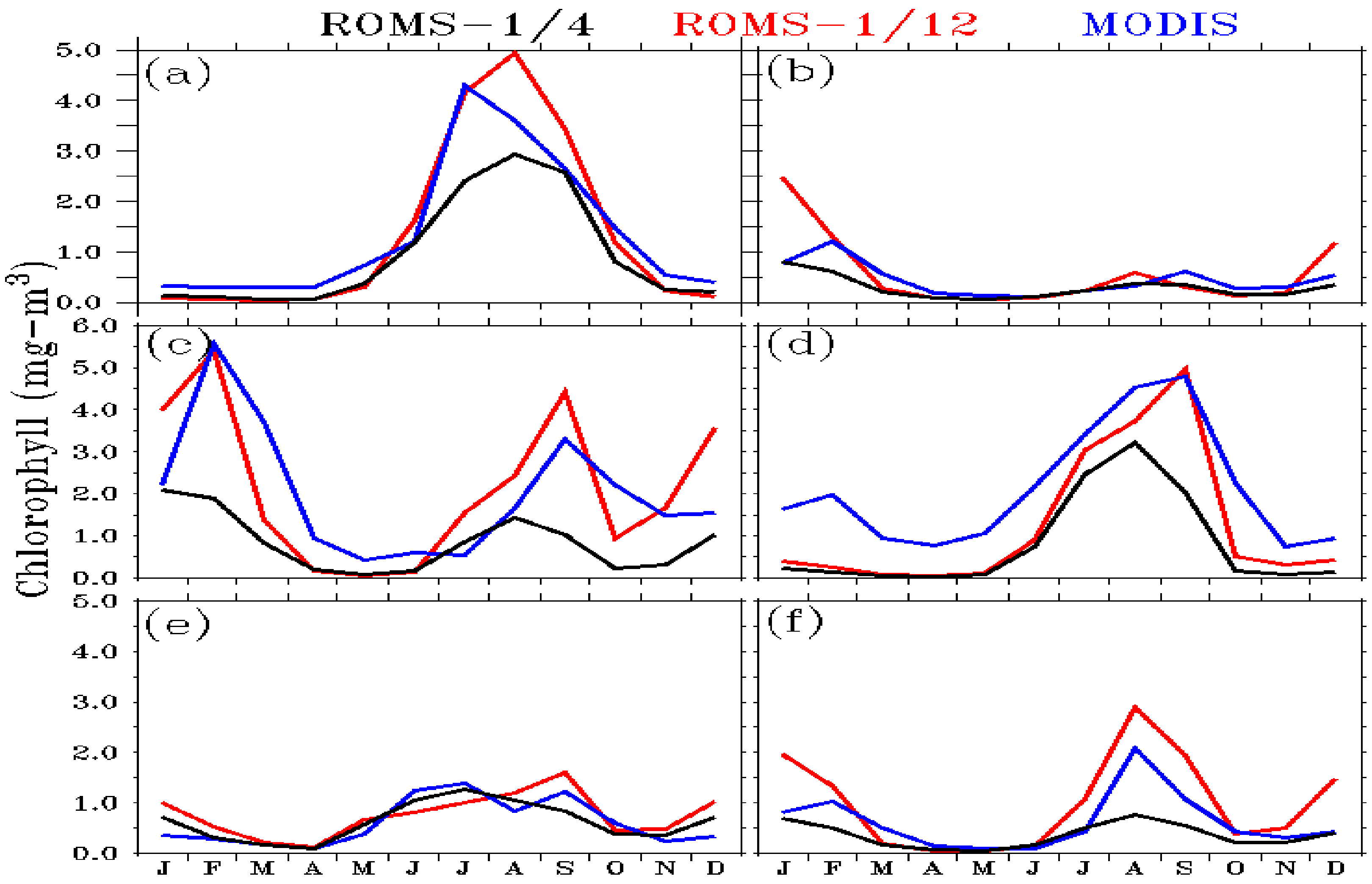
Kochi Time-Series station (KoTS) is marked in red circle. Argo-float (WMOID 5903586) trajectory marked in diamond symbol. The boxes ((a) southeast, (b) northeast, (c) north, (d) northwest, (e) southwest and (f) central Arabian Sea) are used for time series comparison of multiyear average of monthly chlorophyll concentration data from MODIS-Aqua satellite and INCOIS-ROMS model.

Spatio-temporal evolution of Chlorophyll-a variability in the seasonal scale in the Arabian Sea



Multiyear average of seasonal composite ((first raw) December-February (second raw) March-May, (third raw) (June-September) and fourth raw (October-November) of chlorophyll (mg m-3) obtained from ROMS-1/4 (left panel), MODIS-Aqua satellite (middle panel) and ROMS-1/12 (right panel).

Temporal evaluation of monthly averaged Chlorophyll-a between ROMS and MODIS



Temporal evaluation of monthly average of chlorophyll (mg m-3) obtained from MODIS (blue line), ROMS-1/12 (red line) and ROMS-1/4 (black line) at six different boxes in the Arabian Sea. ((a) southeast (74°E -78°E, 8°N -12°N), (b) northeast (67°E -70°E, 18°N -21°N), (c) north (59°E - 62°E, 23°N -25°N), (d) northwest (56°E -59°E, 16°N -19°N), (e) southwest (49°E -52°E, 5°N -8°N) and (f) central Arabian Sea (62°E -66°E, 13°N -17°N).

Time-depth section of nitrate (mg/m^3) along the trajectory of an Argo in the Arabian Sea

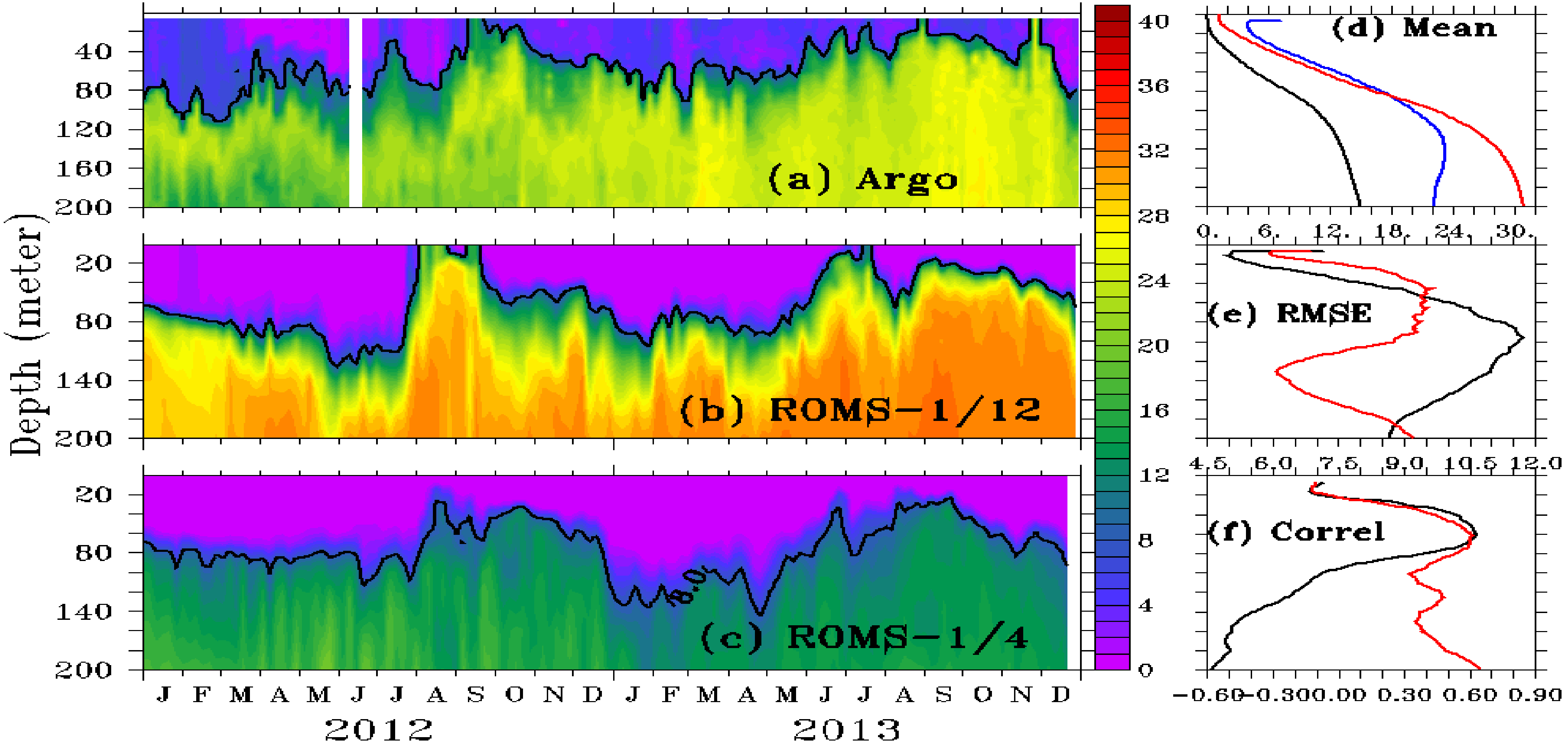
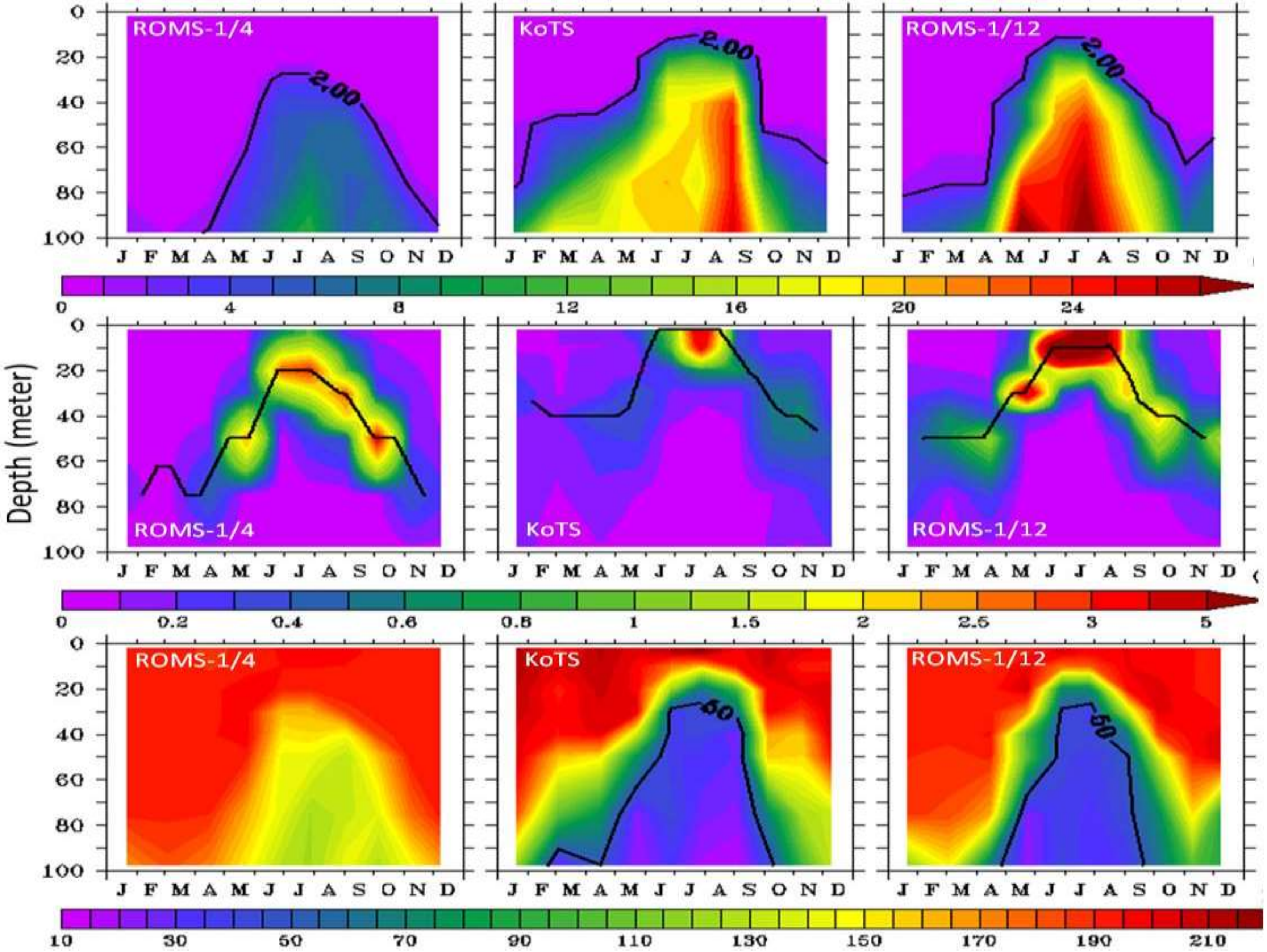


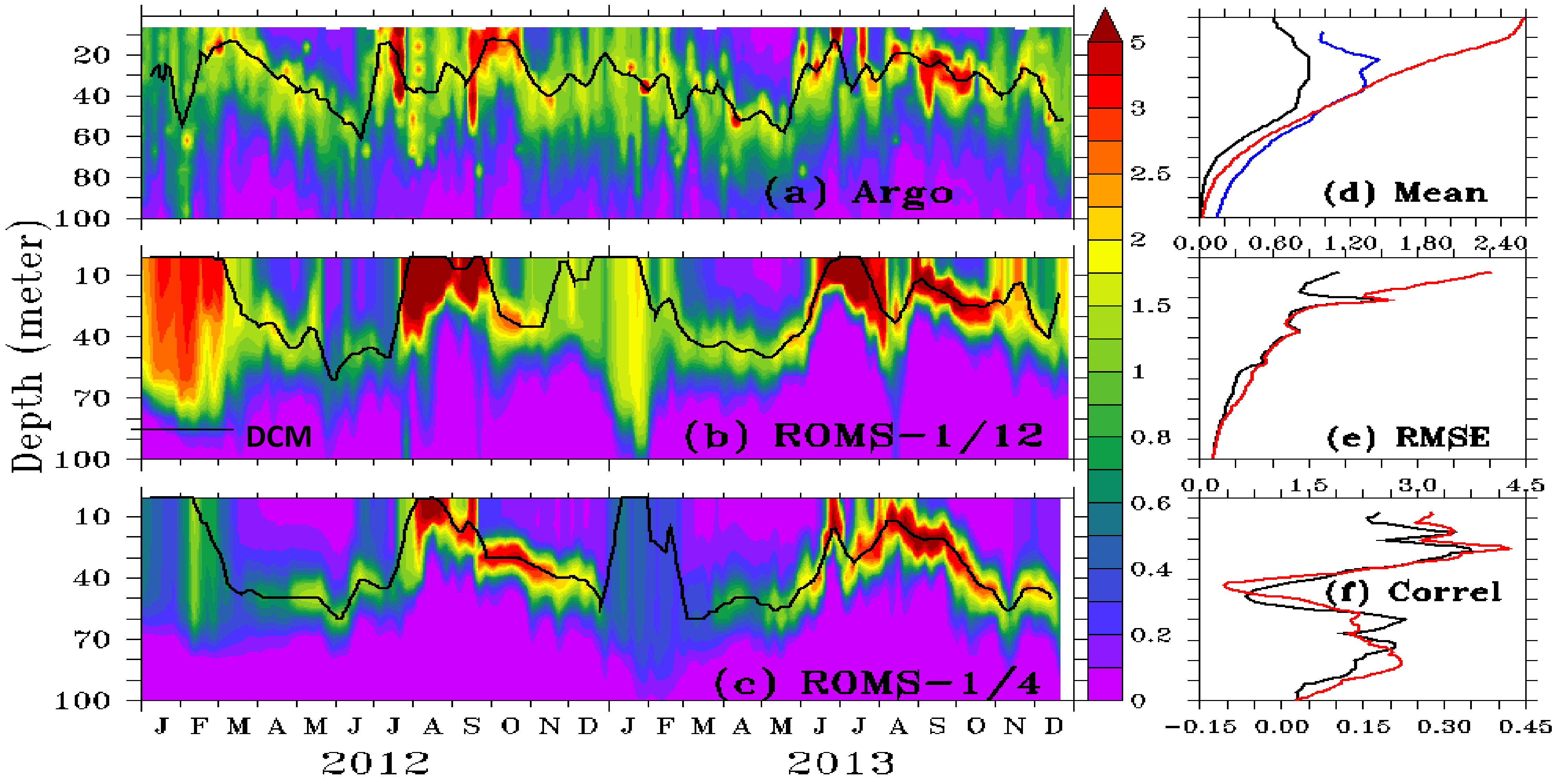
Figure . Time-series nitrate (mM) profiles obtained from (a) Argo (b) ROMS-1/12 and (c) ROMS-1/4 during 2012-2013. Depth-wise statistics of nitrate at Argo float location (d) Mean (mM; blue-Argo, red-ROMS-1/12 and black-ROMS-1/4), (e) RMSD (black-estimated between Argo and ROMS-1/4 and red-between Argo and ROMS-1/12) and (f) correlation (black-between Argo and ROMS-1/4 and red-between Argo and ROMS-1/12). RMSD and correlations are estimated between observation and model. To facilitate the analysis the model outputs are extracted at the time and at the location (nearest grid point) of Argo profiles. Black solid line is nitracline.

Evaluation of capability of the model to reproduce subsurface nitrate, chlorophyll -a and oxygen structure as observed in KoTS observation



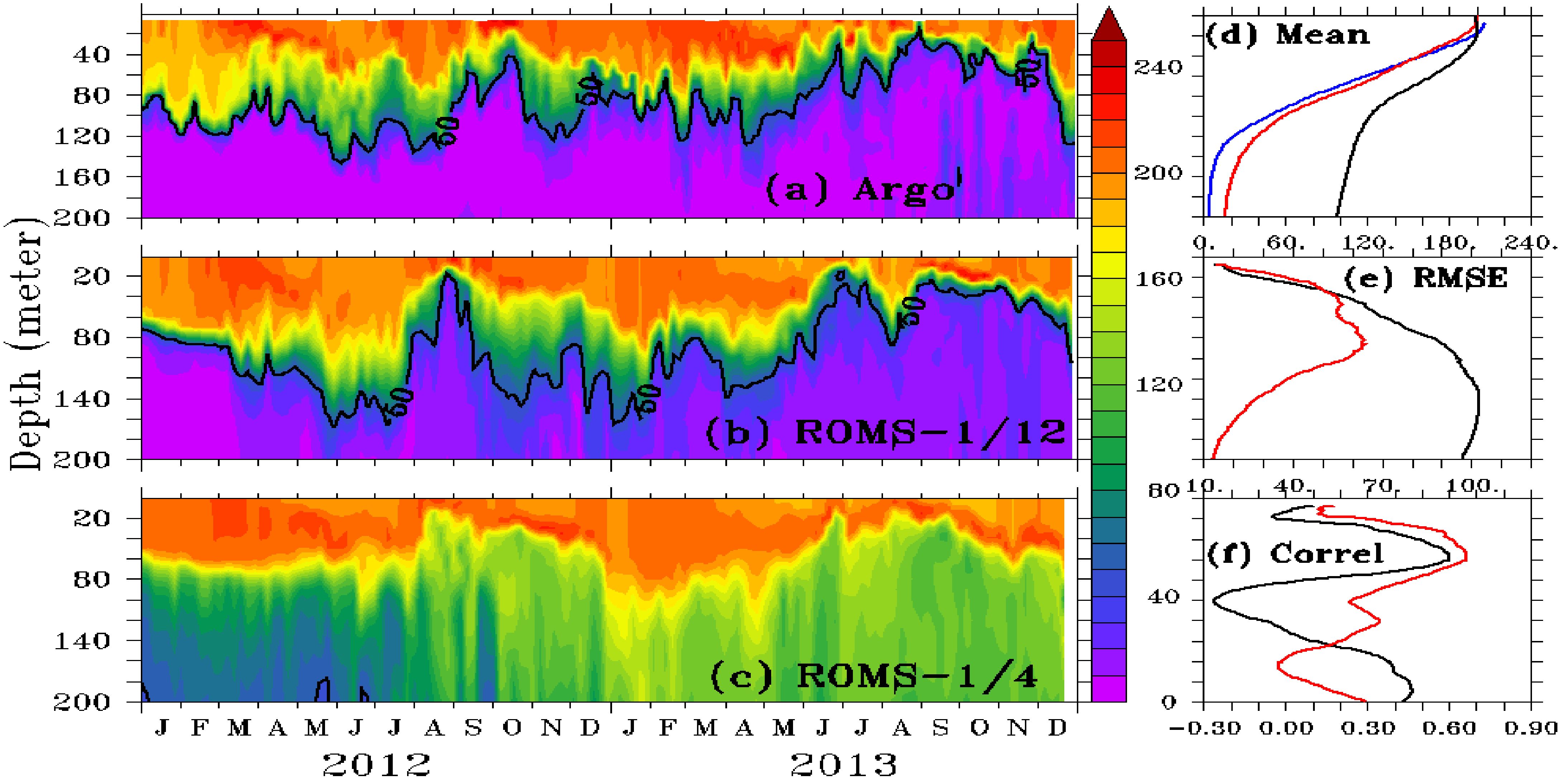
Temporal evolution of nitrate (mM) (upper panel), chlorophyll (mg m-3) (middle panel) and dissolved oxygen (µM) (lower panel), obtained from KoTS (middle pannel), ROMS-1/4 (left panel) and ROMS-1/12 (right panel) during 2012. Black line in upper panel is nitracline; Black line in middle panel is mean-depth of DCM (Deep Chlorophyll Maxima) and Black line in lower panel is oxycline.

Time-depth section of chlorophyll-a (mg/m³) along the trajectory of the Argo in the Arabian Sea



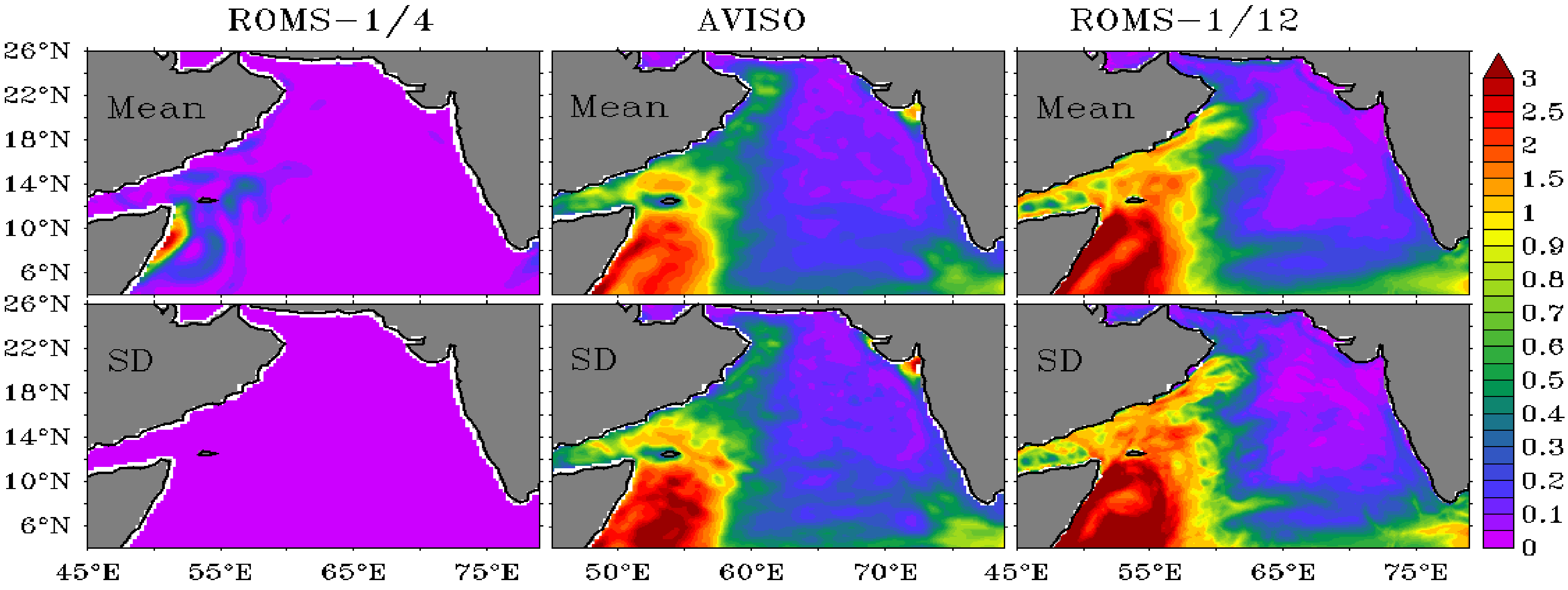
Time-series chlorophyll (mg m^{-3}) profiles obtained from (a) Argo (b) ROMS-1/12 and (c) ROMS-1/4 during 2012-2013. Depth-wise statistics of chlorophyll at Argo float location (d) Mean (mg m^{-3}; blue-Argo, red-ROMS-1/12 and black-ROMS-1/4), (e) RMSD (black-estimated between Argo and ROMS-1/4 and red-between Argo and ROMS-1/12) and (f) correlation (black-between Argo and ROMS-1/4 and red-between Argo and ROMS-1/12). RMSD and correlations are estimated between observation and model. To facilitate the analysis the model outputs are extracted at the time and at the location (nearest grid point) of Argo profiles.

Time-depth section of oxygen (µM /m^3) along the trajectory of the Argo in the Arabian Sea



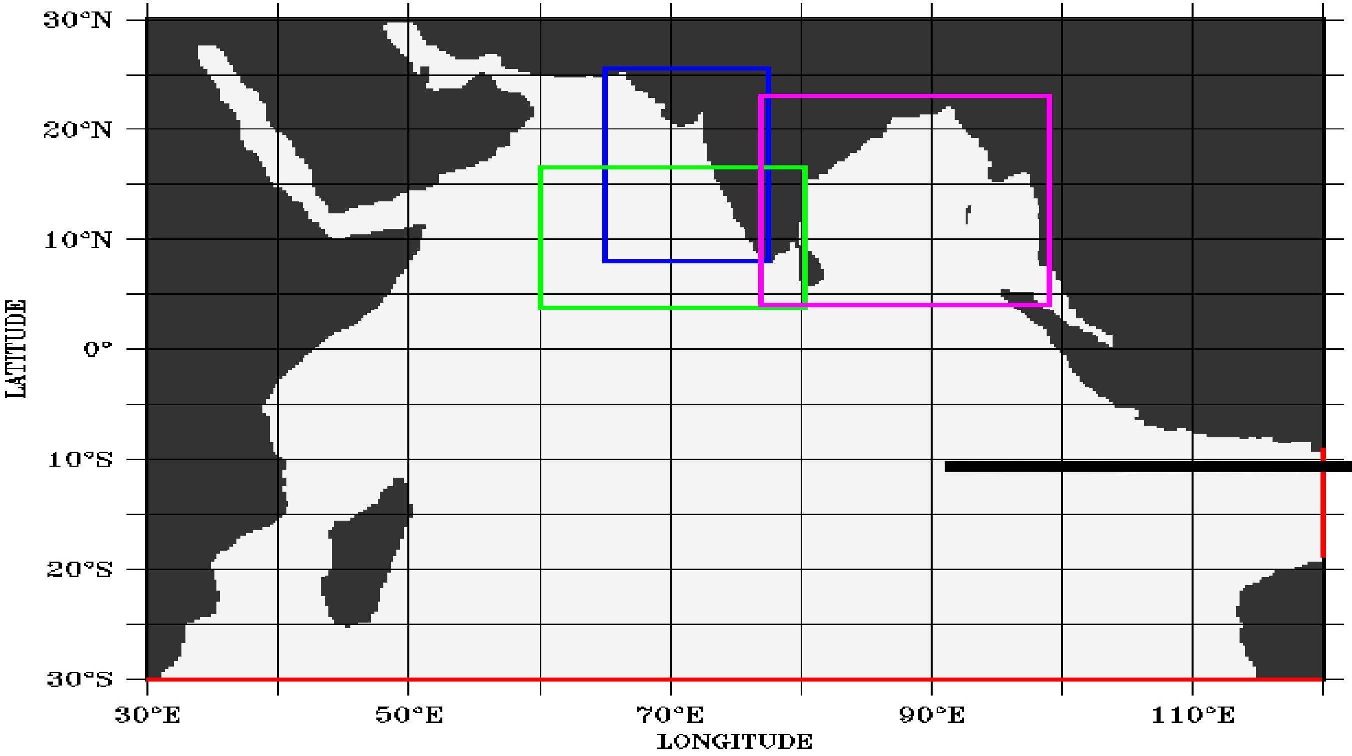
Time-series dissolved oxygen (µM) profiles obtained from (a) Argo (b) ROMS-1/12 and (c) ROMS-1/4 during 2012-2013. Depth-wise statistics of chlorophyll at Argo float location (d) Mean (µM; blue-Argo, red-ROMS-1/12 and black-ROMS-1/4), (e) RMSD (black-estimated between Argo and ROMS-1/4 and red-between Argo and ROMS-1/12) and (f) correlation (black-between Argo and ROMS-1/4 and red-between Argo and ROMS-1/12). RMSD and correlations are estimated between observation and model. 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.

Composite mean (top row) and standard deviation (bottom row) of multi-year (2011–2015) averaged Eddy Kinetic Energy (EKE, 10^−3 m^2 s^-2) in the Arabian Sea.



➢The better ability of ROMS-1/12 model in capturing the eddy field is clearly evident in the comparison between model and observation to produce eddy kinetic energy. In particular, mean and variability of eddy kinetic energy field is reasonably captured by higher resolution model setup in comparison with coarse resolution model. It is to be noted that mean eddy kinetic energy field in the ROMS-1/4 is one order less than satellite altimetry and ROMS-1/12.

Bio-physical Model(s) in ESSO-INCOIS (Configured using ROMS v3.7)



WC-HOOFS, SEAS-HOOFS & BoB-HOOFS

High Resolution Bio-Physical Model Configurations

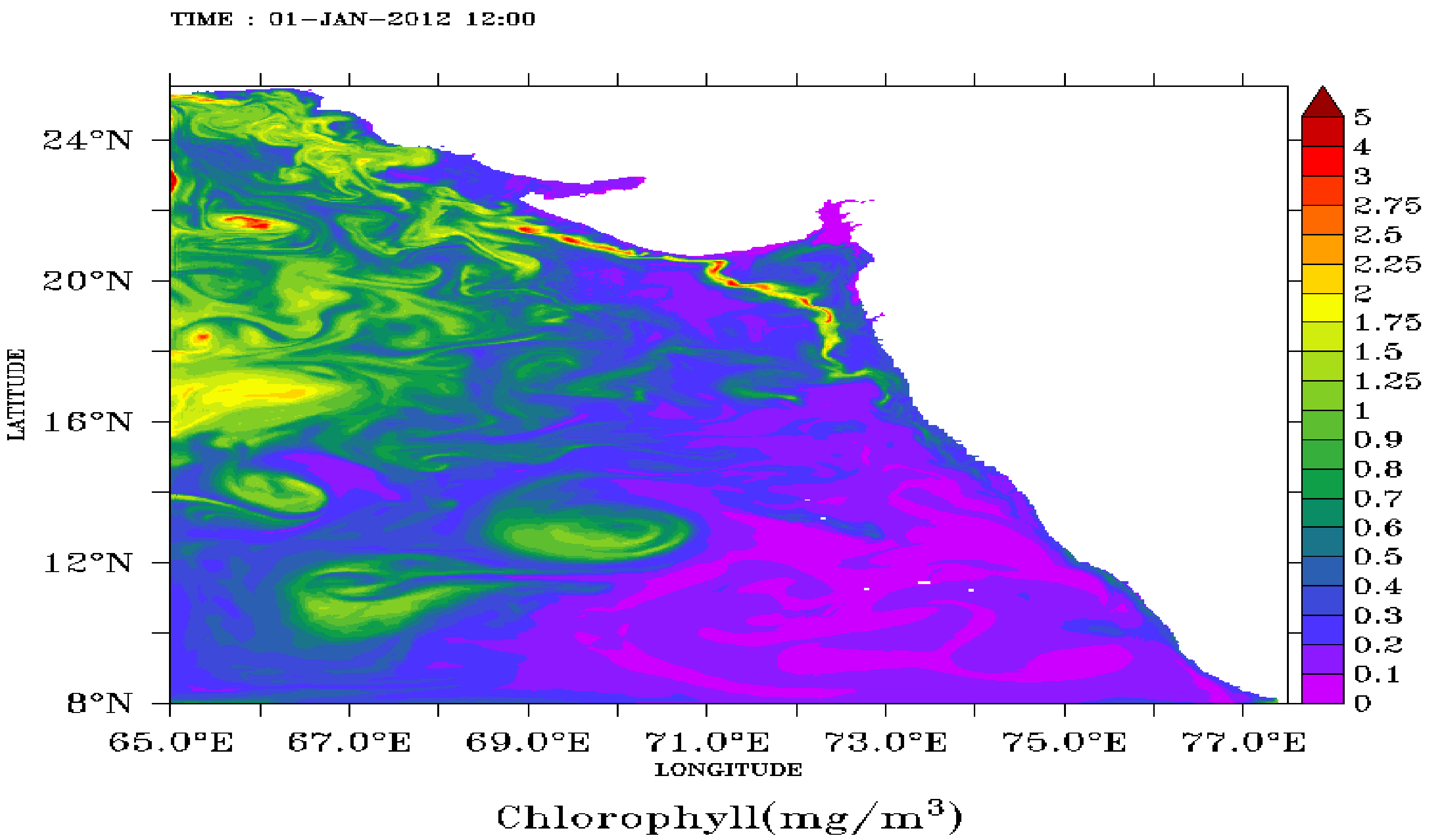
- **Domain**
  65^0E to 77.5^0E, 08^0N to 26^0N,
  60^0E to 80.25^0E, 3.75^0N to 16.5^0N
  77^0E to 99^0E, 04^0N to 23^0N
- **Resolution**
  Horizontal : $1/48^0$ (~ 2.25 km) & Vertical: 40 sigma levels.
- **OBC** ROMS_1x12 (for all the bio-physical variables)
- **Vertical Mixing Scheme**
  KPP (Large et al., 1994).
- **Forcing** Winds and Fluxes from NCMRWF
- **Model simulation period**: Since 01-JAN-2010 ….

Model Configuration (Indian Ocean)

- **Model**
  Physical Model ROMS v3.7 coupled to an ecosystem model (Fennel et al., 2006).
- **Domain 19**
  30^0E to 120^0E, 30^0S to 30^0N.
- **Resolution**
  Horizontal : $1/12^0$ (~ 9.5 km),
  Vertical: 40 sigma levels.
- **Open boundaries: East and South**
  OBC: INCOIS-GODAS (for the physical model) and WOA 2013 (climatological for biological model)
- **Vertical Mixing Scheme**
  KPP (Large et al., 1994).
- **Forcing**
  Winds from NCMRWF
  Flux from NCMRWF
- **Model simulation period**
  01-JAN-2003 onwards…

High Resolution ROMS (1/48^0) Simulated Sea Surface Chlorophyll during 2012

- Simulation capabilities of sea surface chlorophyll using high resolution ROMS is demonstrated here, intra-seasonal variability is adequately captured.
- Chlorophyll is the most important component in the food chain in the oceans.
- Sub-surface properties such as deep chlorophyll maxima and oxycline can help determine fishing depth.
- Potential applications of such simulation capabilities range from societal (e.g. fisheries) to science problems (e.g. climate change).
- Future scope of improvement includes higher trophic level interactions and carbon export calculations.



Model Configuration (WC-HOOFS)

- **Domain** 65^{0}E to 77.5^{0}E, 08^{0}N to 26^{0}N.
- **Resolution** Horizontal : 1/48^0 (~ 2.25 km), Vertical: 40 sigma levels.
- **Open boundaries: West and South**
  OBC: ROMS_1x12 (for all bio-physical variables)
- **Vertical Mixing Scheme** KPP (Large et al., 1994).
- **Forcing** Winds and Fluxes from NCMRWF
- **Model simulation period:** Running since 01-JAN-2010.

Marine Fishery Advisory Service (MFAS)

Inputs & Processing → **Products** → **Information Dissemination** →

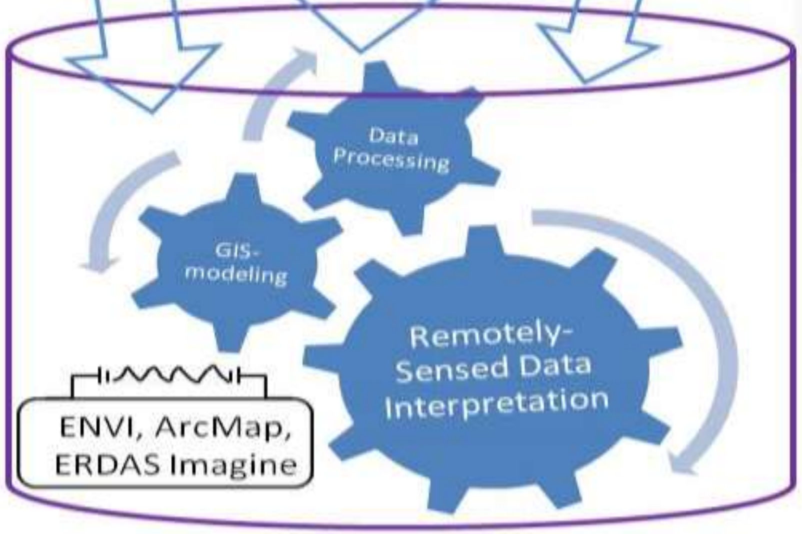
Inputs & Processing

INCOIS Ground Station
- Chlorophyll, TSM (Oceansat-2)
- SST (NOAA-18/19, MetOp-A/B)

INCOIS-ChloroGIN
Chlorophyll, Kd490 [Daily & 3d roll] (MODIS-Aqua)

For Tuna-PFZ Advisories

JPL -PO.DAAC
- SST (OSTIA GHRSST)



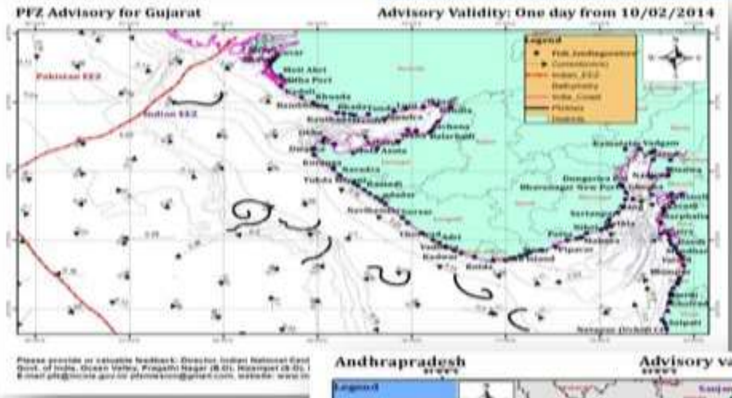
Products

PFZ Text
- Landing Center (LC)
- Direction (with angle)
- Distance from LC
- Bathymetry
- Position (Lat/Long)

PFZ Maps

INCOIS-PFZ Lab
- Potential Fishing Zones
- Bathymetry, Landing Centers
- Coastal Districts, EEZ boundary
- Fishing-Restriction Zones

INCOIS-OSF Lab
- Wind/Current Vectors
- MLD, D20, High Wind-wave



Tuna-PFZ Advisories

Information Dissemination

Direct
- ✓ Fax
- ✓ Phone
- ✓ Email
- ✓ Web-GIS

Mass-comm.
- ✓ Web-text
- ✓ EDBs
- ✓ DEAL
- ✓ University projects
- ✓ SMS/Mobile-Apps
- ✓ NGOs
- ✓ IVRS/Helpline
- ✓ Community Radio
- ✓ TV/Radio
- ✓ Newspapers

Courtesy: Dr. Nimit Kumar, ESSO-INCOIS

The Criterion for generation of PFZs

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

Parameter	Value
Window Size	32x32
Window Clarity (% of data have to present in the window)	75%
Overlap	50%
The ratio of variance between the two populations to the variance within the populations $\theta(\tau_{opt})$	0.76
Gradient Ratio	0.7
Cohesion Coefficients [C1, C2, C]	[0.9, 0.9, 0.92]
Mean temperature difference between the two populations (surface waters)	0.25

The **Chl-a fronts** are detected using **Canny (1986) algorithm**. Wall et al. (2008) showed that the regionally tuned Single Image Edge Detection (Cayula and Cornillon, 1992) is best suitable for identifying thermal fronts whereas the algorithm prescribed by Canny (1986) works better in delineating Chl-a fronts.

Arabian Sea		Bay of Bengal	
Canny Threshold	Canny Sigma	Canny Threshold	Canny Sigma
[0.75 0.78]	3	[0.65 0.70]	3

- **The frontal vectors thus delineated from satellite SST and Chl-a are superimposed to identify the common fronts.**
- **A tolerance limit of 10 km has been fixed to identify common fronts derived from both SST and Chl-a (Nammalwar et al., 2013).**
- **In the absence of Chl-a data, the strong persistent thermal fronts are identified as PFZ**.

Outstanding issues in generating PFZ advisories – Relevance of a bio-physical model

- **Presently, MFAS uses satellite data of SST and chlorophyll, which is hindered with cloud cover. The problem becomes acute during monsoon time. A bio-physical model simulated output is capable of resolving the hindrance.**

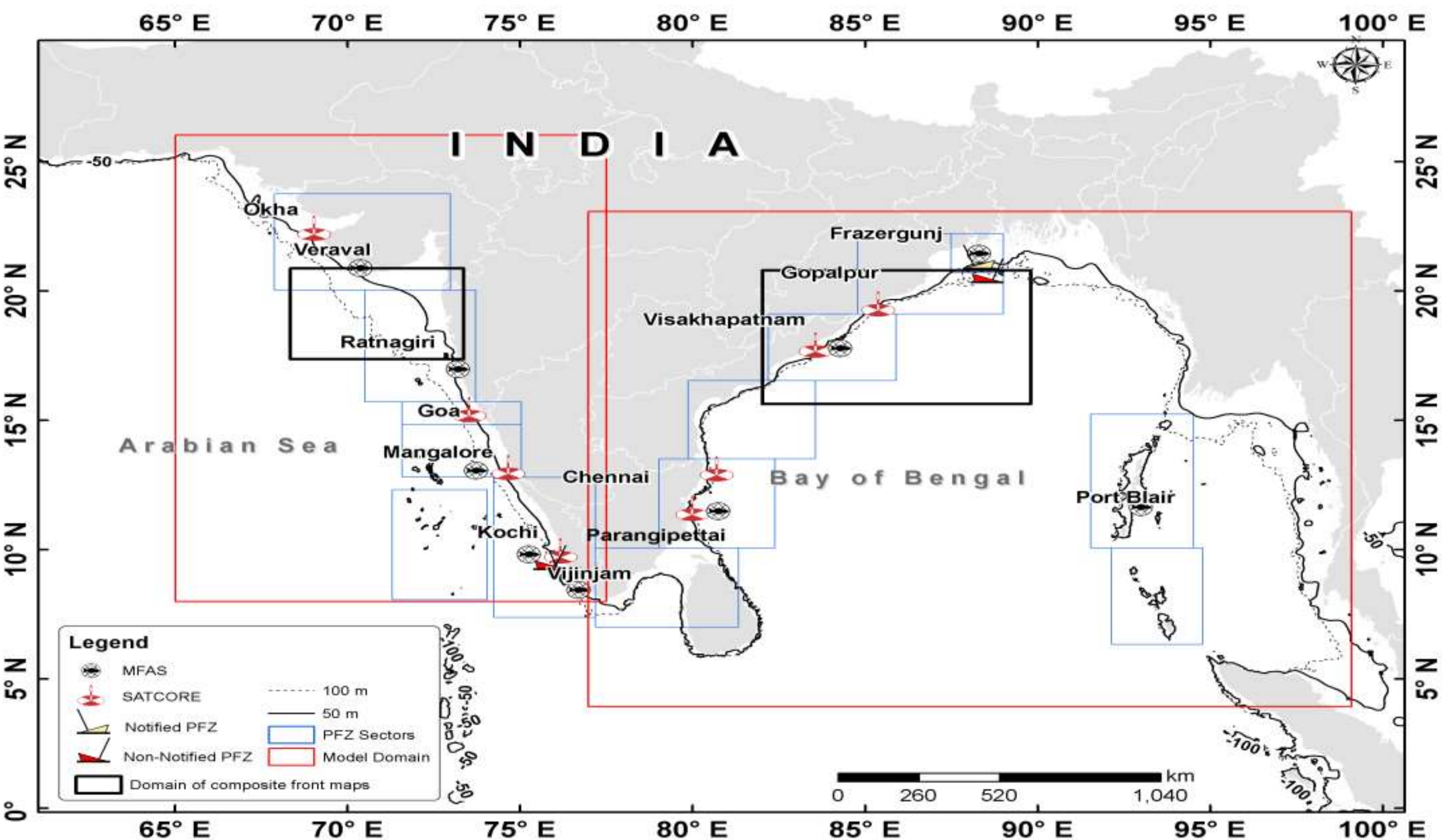
- **Other key parameters like dissolved oxygen is not available through remote sensing. A bio-physical model simulated oxygen can complement the service need.**

- **In addition to that, 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 bio-physical model certainly solve the same as fisher obtains data for next 2-3 days while beginning the fishing trip.**

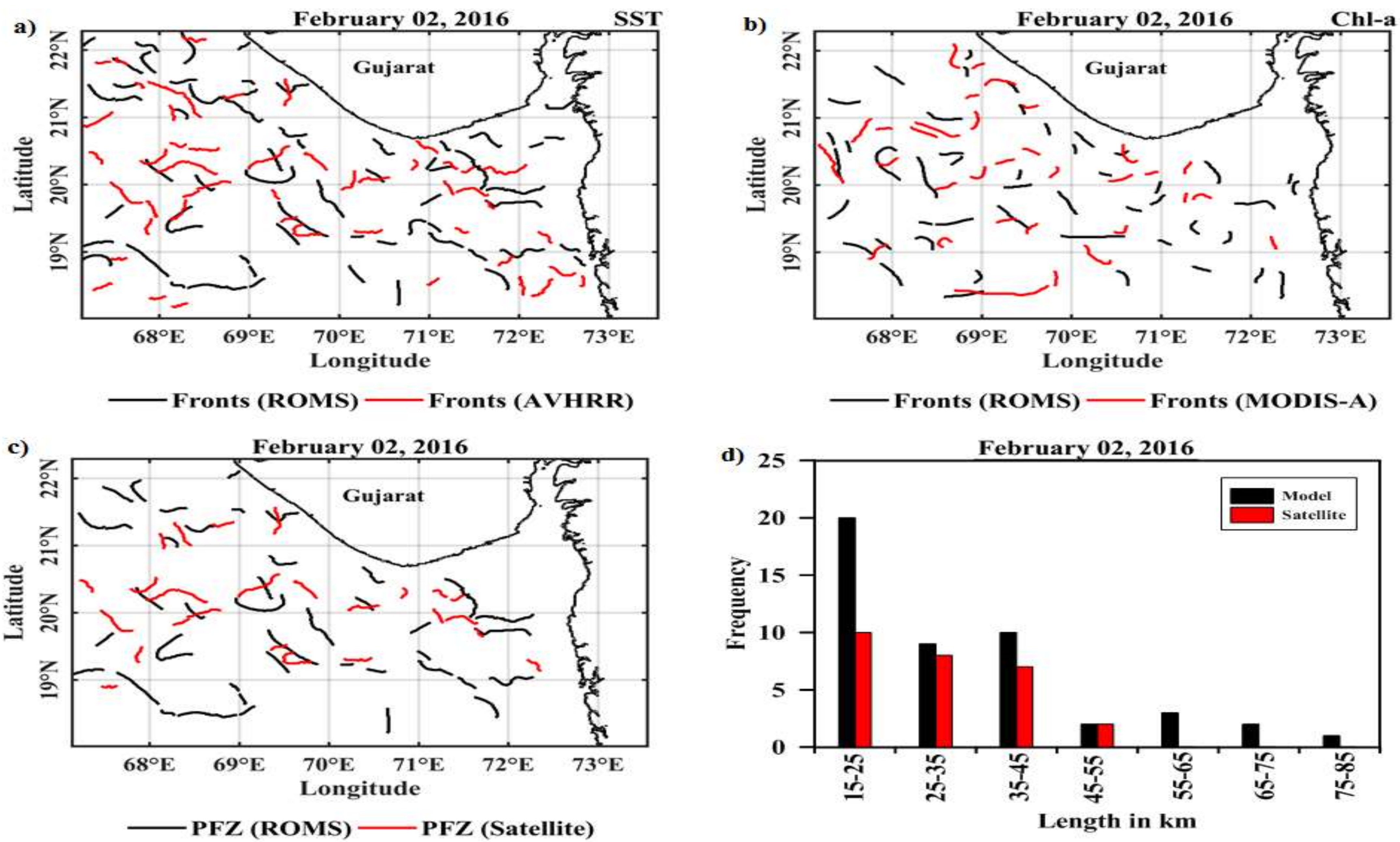
- **A bio-physical model simulation is useful towards developing strategies to manage coastal resources in a changing climate.**

High Resolution Bio-Physical Model(s) (Configured using ROMS v3.7)

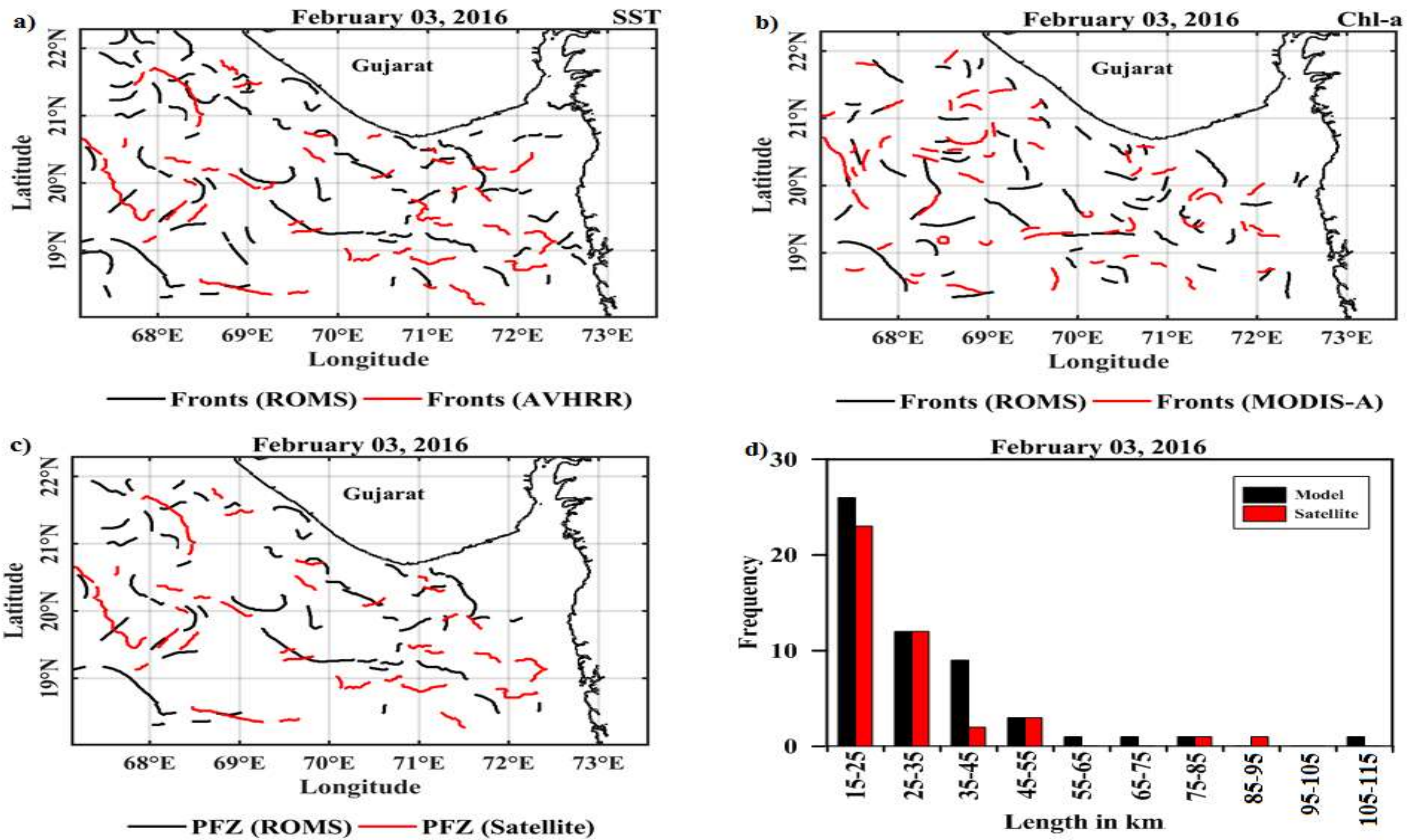


Courtesy: MDG Members & Ocean Colour Team, ESSO-INCOIS

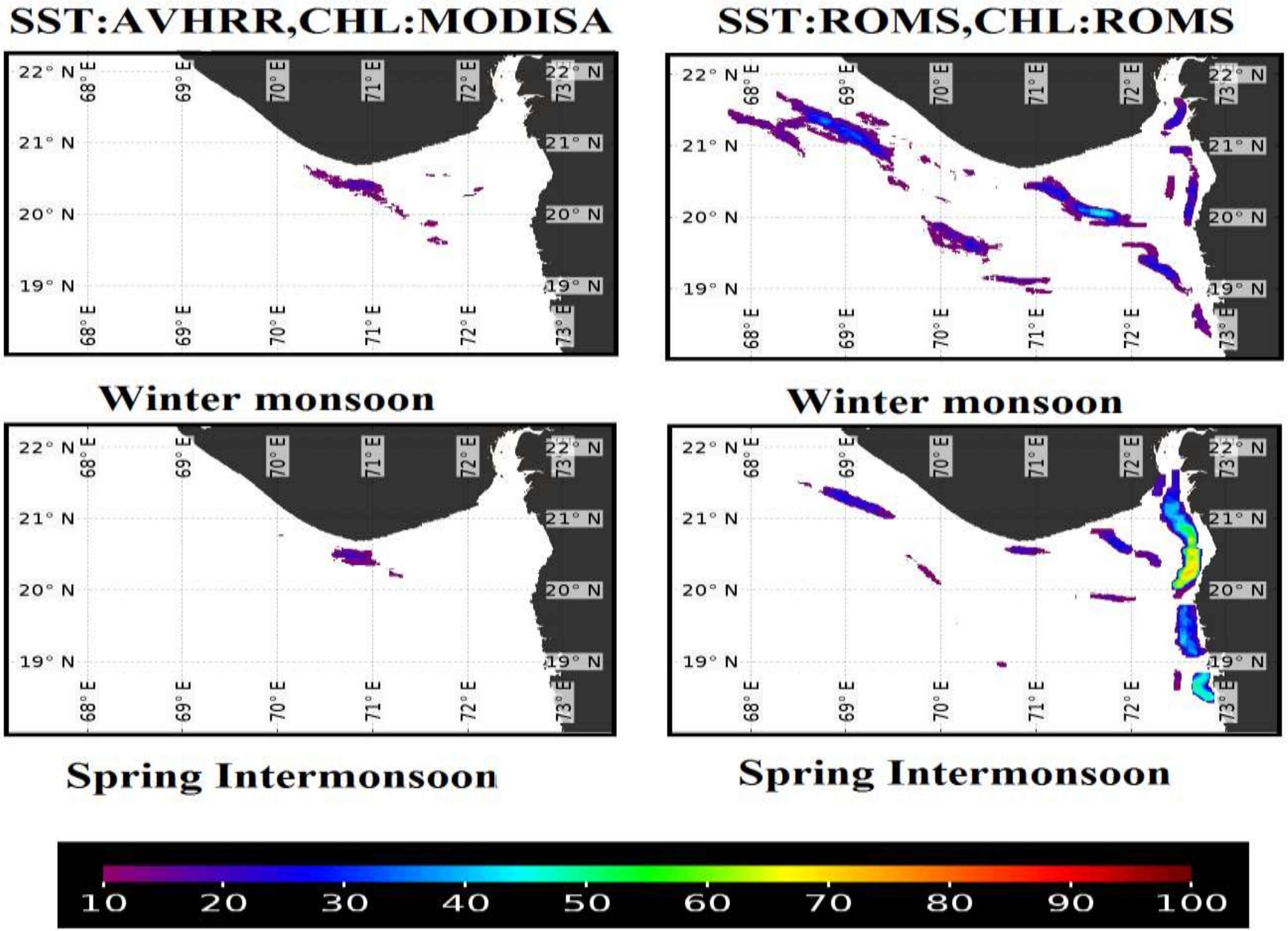
Comparative plots of thermal fronts, chl-a fronts and PFZs derived from satellite(s) and ROMS



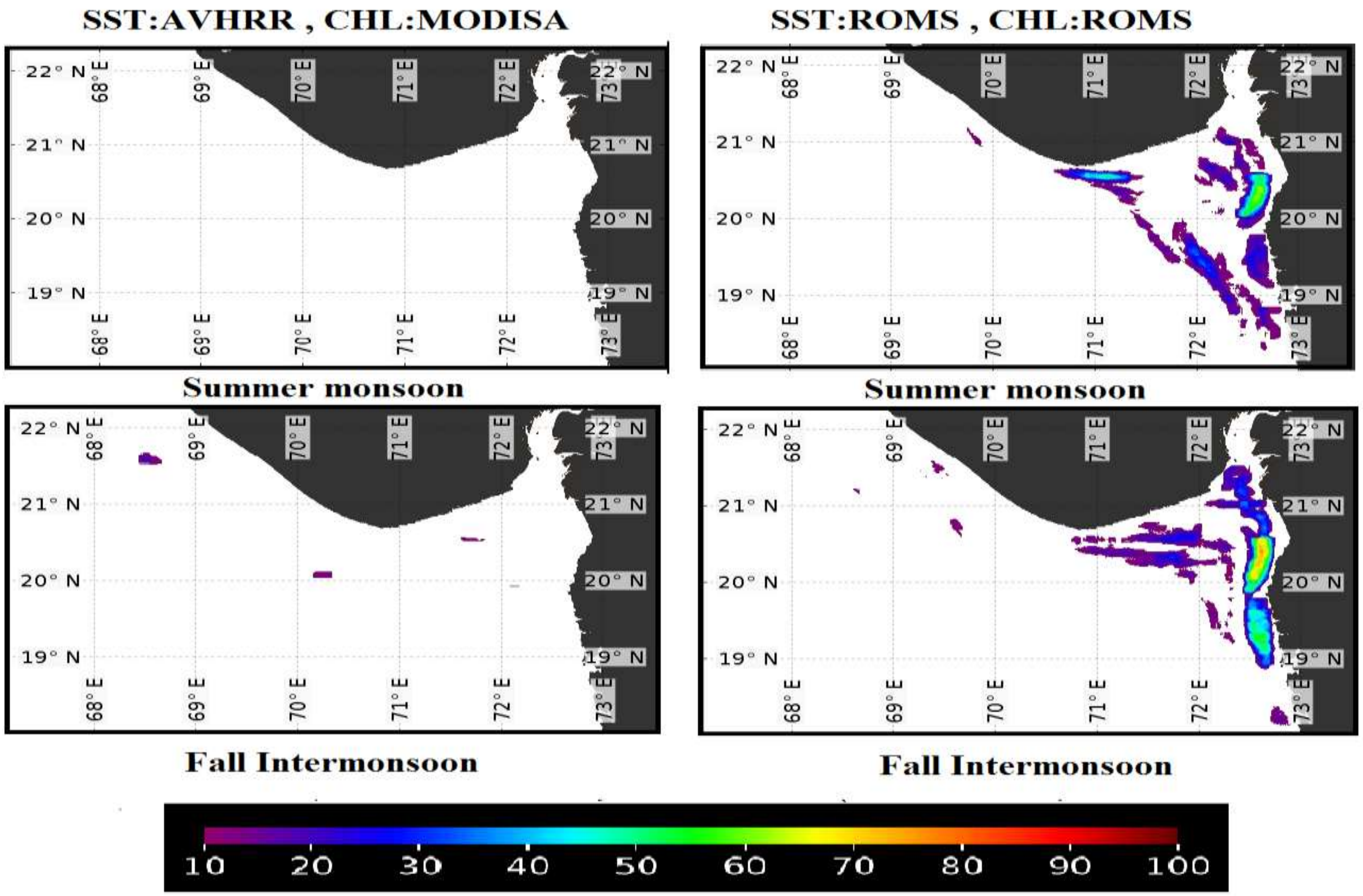
Comparative plots of thermal fronts, chl-a fronts and PFZs derived from satellite(s) and ROMS



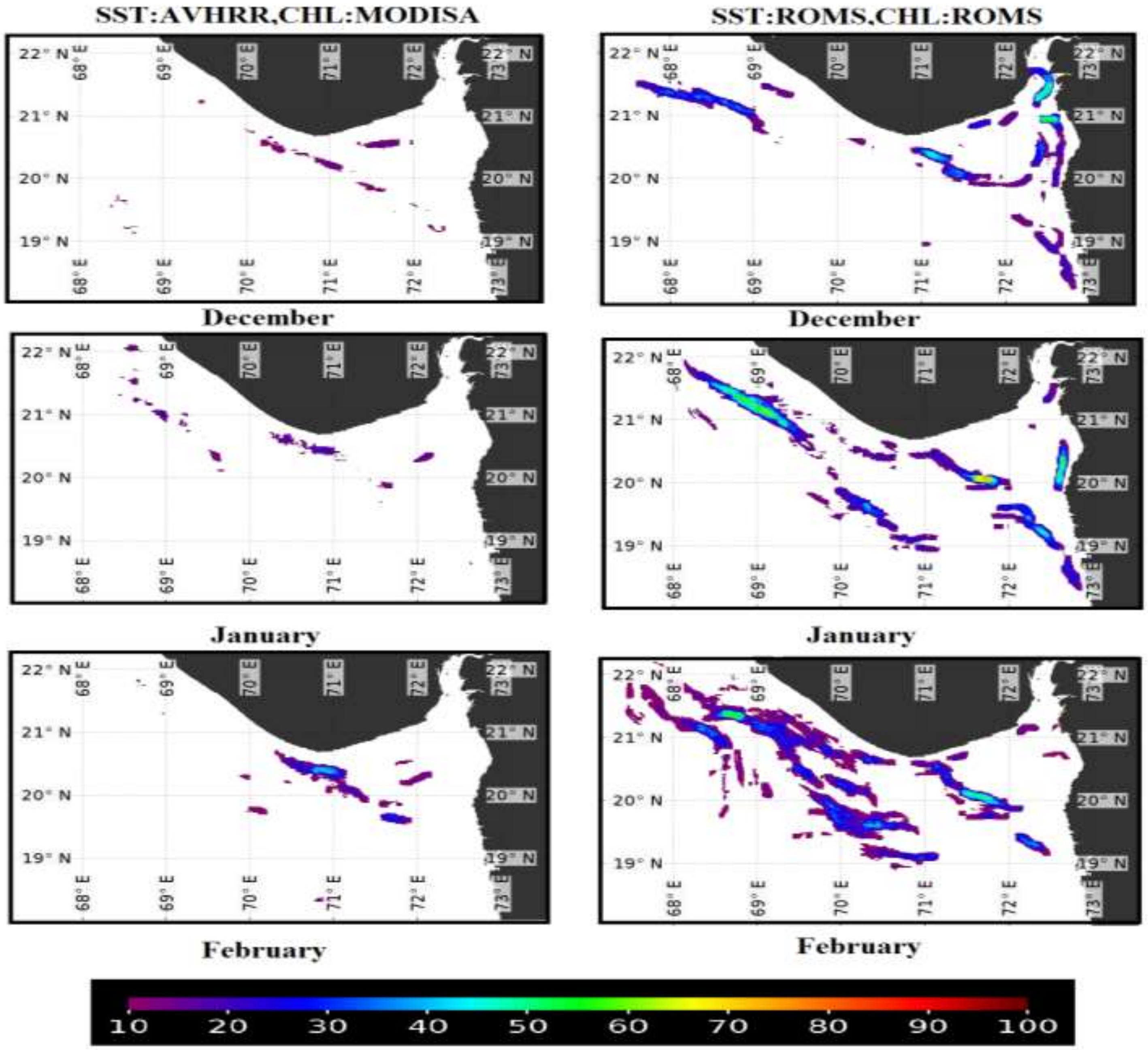
Seasonally persistent frontal zones off Gujarat



Seasonally persistent frontal zones off Gujarat



Persistent frontal zones for individual months off Gujarat



Thank you for your attention!

Acknowledgement:

1. Group Members, MDG, INCOIS
2. PFZ Team, INCOIS
3. Ocean Colour Team, INCOIS
4. DMG & CWG, INCOIS
5. Director, INCOIS