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INCOIS

Sustained Observing System for understanding Indian Ocean Carbon Dynamics

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CLIVAR-GOOS Workshop

From Global to Coastal: Cultivating New Solutions and Partnerships for an Enhanced Ocean Observing System in a Decade of Accelerating Change
August 15-17, 2022 , ICTP, Trieste, Italy

Outline of the Presentation

- ✓ About - Indian National Centre for Ocean Information Services (INCOIS), Ministry of Earth Sciences, Hyderabad
- ✓ India's Ocean Observation Network
  - INCOIS – Ocean Observation Network
  - NIOT – Ocean Observation Network
- ✓ Marine Biogeochemical Carbon Cycle
  - Global Ocean Carbon Cycle
  - Indian Ocean Carbon Cycle
- ✓ Surface Ocean Carbon Measurements
  - Observing System Simulation Experiment (OSSE)
- ✓ Modeling physical-biological interactions in the Indian Ocean
  - Biogeochemical State of the Indian Ocean (BIO)
- ✓ REgional Carbon Cycle Assessment and Processes (RECCAP)v2
- ✓ Indian Ocean Observations - Future Directions

The Mission

To provide the Ocean Information and Advisory Services to Society, Industry, Government Agencies and Scientific Community through Sustained Ocean Observations and Constant improvements through Systematic and Focussed Research.

Our motto: Scientific Knowledge for Societal Benefit

Major Activities

INCOIS

- Ecosystem Based Services
- Ocean State Forecasts & Advisory Services
- Early Warning for Tsunami and Storm Surges
- Contribution to Weather/Monsoon/Climate Forecast
- Value-added Services for Coastal Management
- Information Bank & Web-based Service
- Capacity Building (ITCOOcean)

Computational & Web Infrastructure

International Interface

Satellite Oceanography

Ocean science and Modeling

Remote Sensing Satellites

- Oceansat-1(1999)
  Ocean Colour Monitor
- Oceansat-2 (2008)
  Ocean Colour Monitor, Scatterometer
- SARAL – ALTIKA
- Foreign Satellites

In-situ Observations

- Argo Profiling Floats
- Data Buoys
- Current Meter Arrays
- XBTs, Tide gauges
- BPRs, Coastal radars
- AWS, Research Vessels
- Process Specific Observations

- Fishing Community
- Coastal States
- IMD, Navy, NHO, Coast Guards
- Ports and Harbors
- Off-shore and Shipping
- Research Institutions
- Academia

India's Ocean Observation Network (Present Status)

INCOIS

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

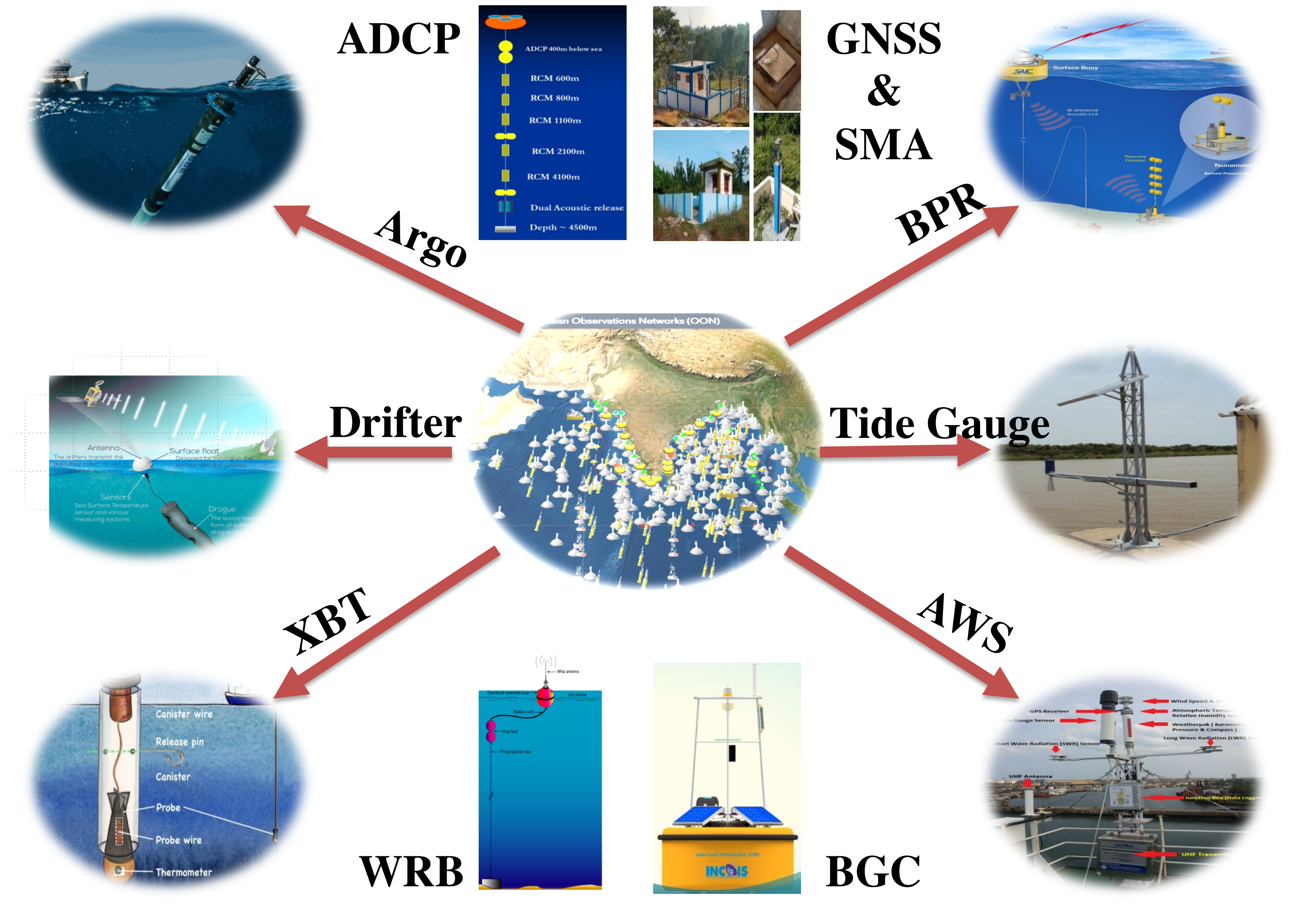
Coastal

- 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)

INCOIS – Ocean Observation Network



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

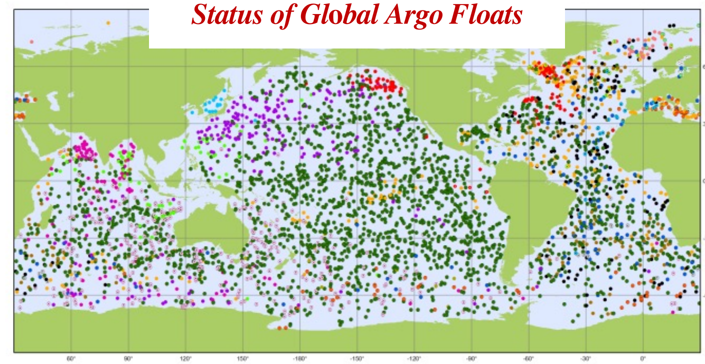
- GTS and INCOIS website in near real time
- Real-time data for operational purpose and Delayed-mode data for research purpose
- Derived Data products are available online

Current Status

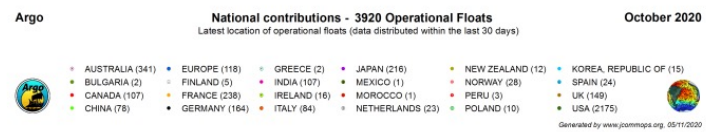
- 75 Floats (51 TS + 24 BGC) deployed during 2017-20

Future Plan

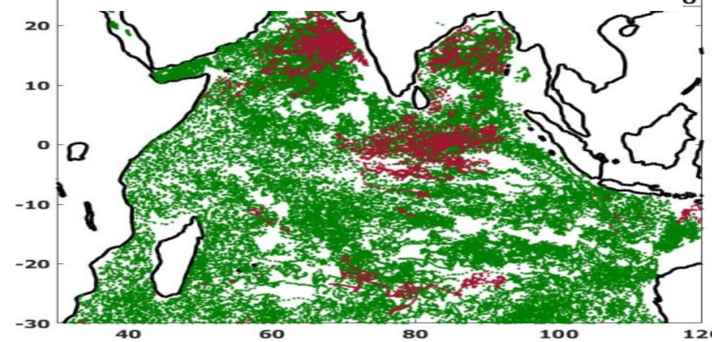
- 50 floats/year at least one float in 3x3 grid (33 floats with Temperature and salinity +17 Bio floats with CHL, DO and backscatter)



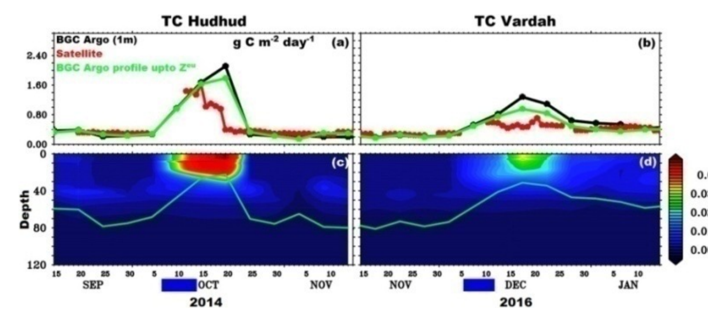
Status of Global Argo Floats

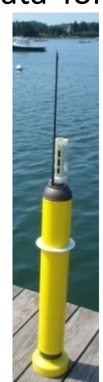


Distribution of Indian Argo floats since April 2017



Tropical Cyclone's Effect on the Biogeochemical Processes





Drifting Buoy Network

Drifting Buoy Network is a Global array of ocean surface drifters

Parameters

- Near-surface water temperature and atmospheric pressure.

Applications

- Accurate and globally dense set of in-situ observations of mixed layer currents, sea surface temperature, atmospheric pressure, winds, waves, and salinity.
- Near-real time data (SST, sea level pressure and surface winds on GTS) for operational weather analysis and prediction
- Development of monthly mean mixed-layer velocities in the Indian Ocean on 1° x 1° resolution.
- ‘Sea truths’ for validation of remotely sensed ocean surface parameters.

Data availability

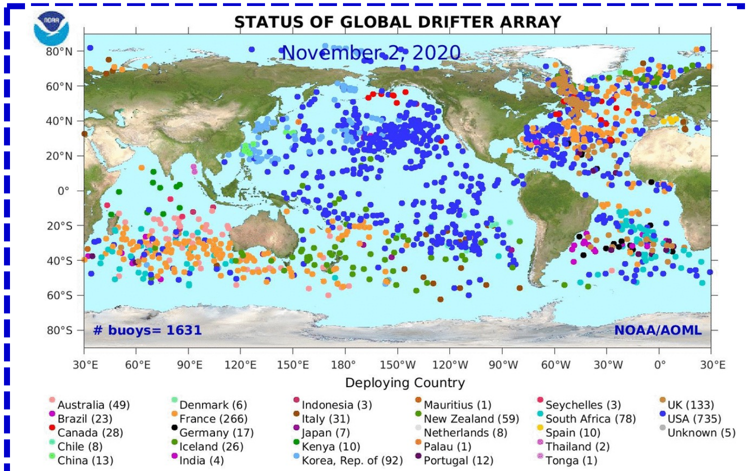
- GTS and INCOIS website in near real time.

Current status

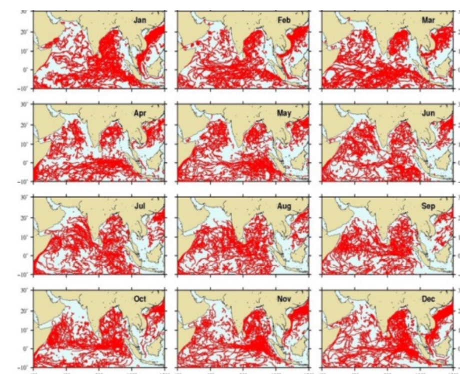
- 25 Drifters deployed during 2017-20 and 4 are active

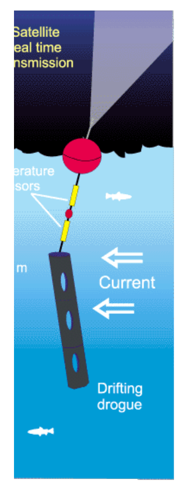
Future Plans

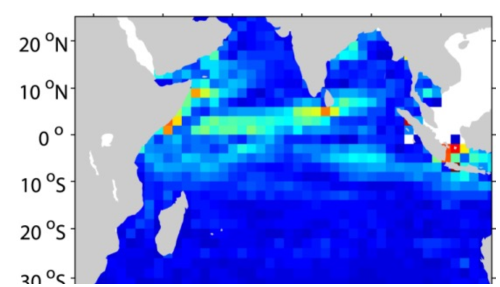
- 30 Drifters/year (at least one float in 5x5 grid)



Monthly Data Availability of Drifters

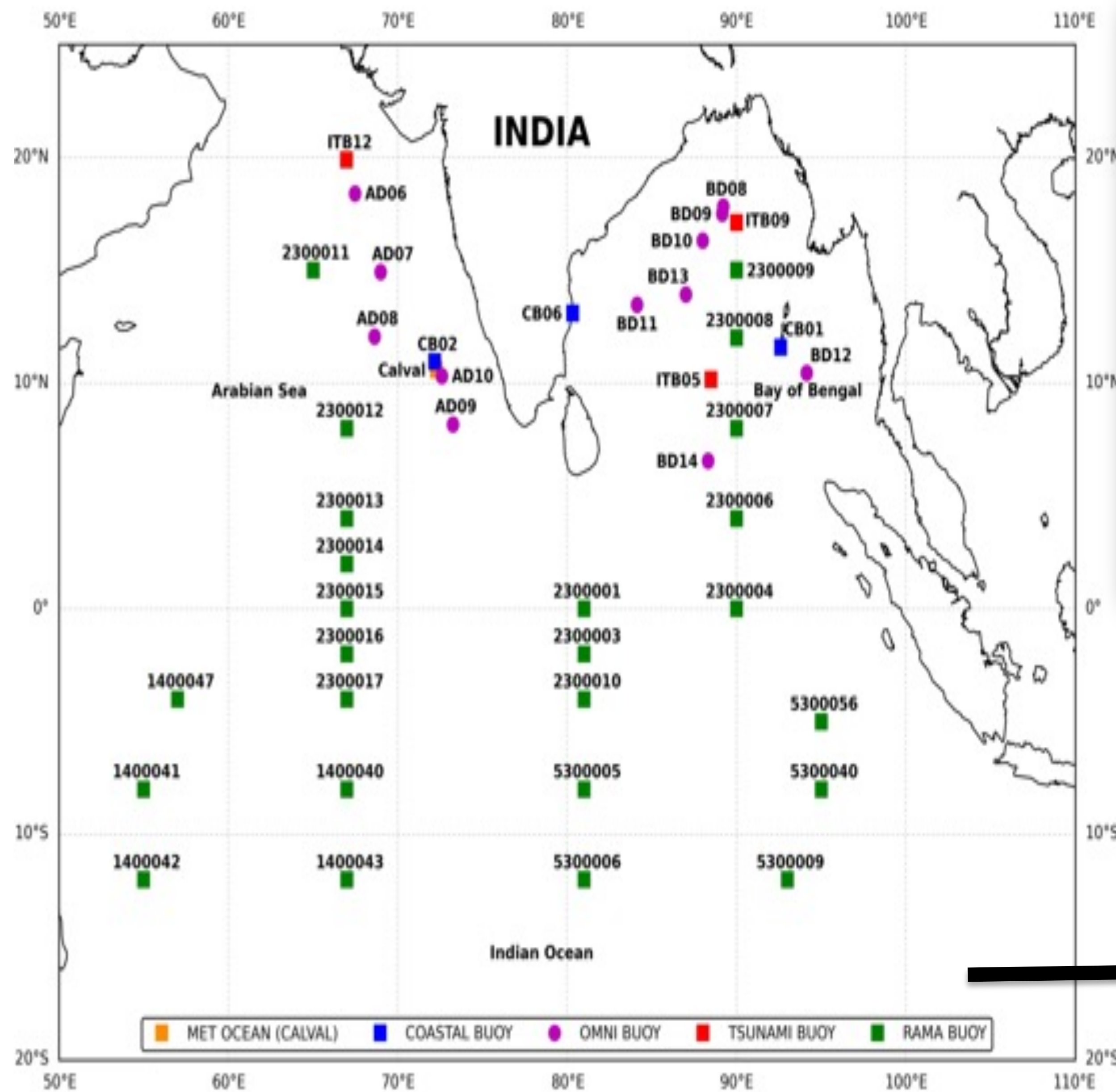




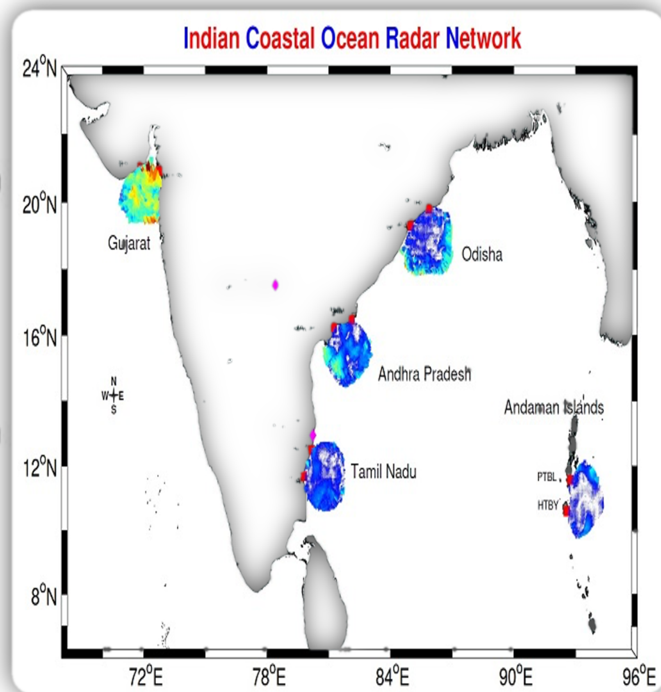


Annual harmonics of zonal current

NIOT – Ocean Observation Network



Moored buoy locations



High Frequency Radar (HFR) - A tool for synoptic online mapping of surface current fields and the spatial distribution of the wave directional spectrum.

- 12 OMNI buoys, 03 Coastal buoys , 03 Tsunami buoys
- 01 Cal-Val buoy
- 25 RAMA buoys,

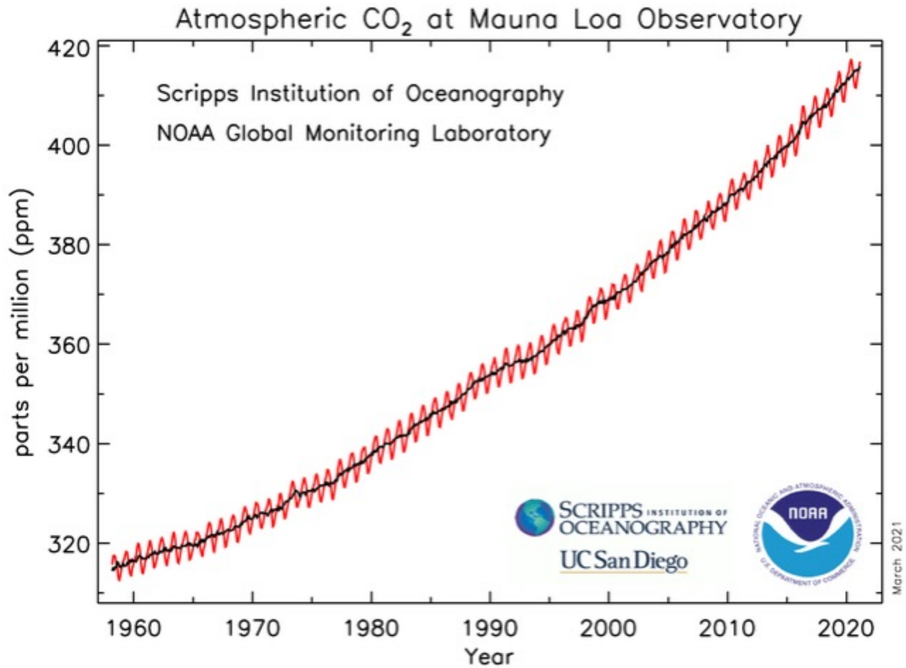
Global Ocean Carbon Cycle

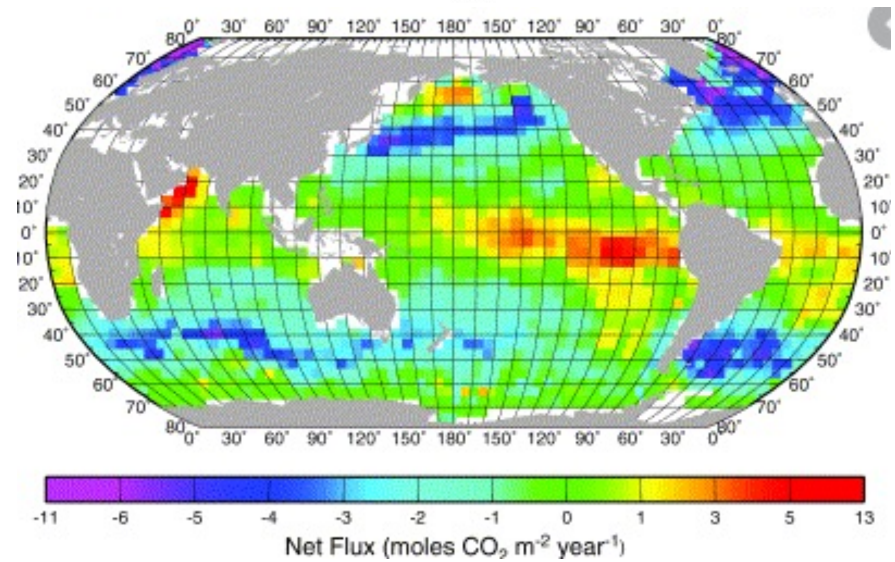
- The ocean plays a vital role in mitigating global climate change by sequestering ~30% of anthropogenically emitted carbondioxide (CO_2) per year (Le-Quéré et al., 2018).

- In the absence of this sink, the accumulation of human-made CO_2 in the atmosphere could have been amplified by a corresponding magnitude, and global warming would have been much more accelerated.

- The global ocean has taken up nearly 165 ± 20 Pg C emitted since the pre-industrial era (Le Quéré et al., 2018).

- The contemporary global ocean CO_2 sink is estimated to be 2.5 ± 0.6 Pg C yr^{-1} (Friedlingstein et al., 2019).





Mean annual net air-sea flux for CO_2 (moles CO_2 m-2 yr^{-1}) for the reference year 1995 (Takahashi et al., 2002).

Indian Ocean Carbon Cycle

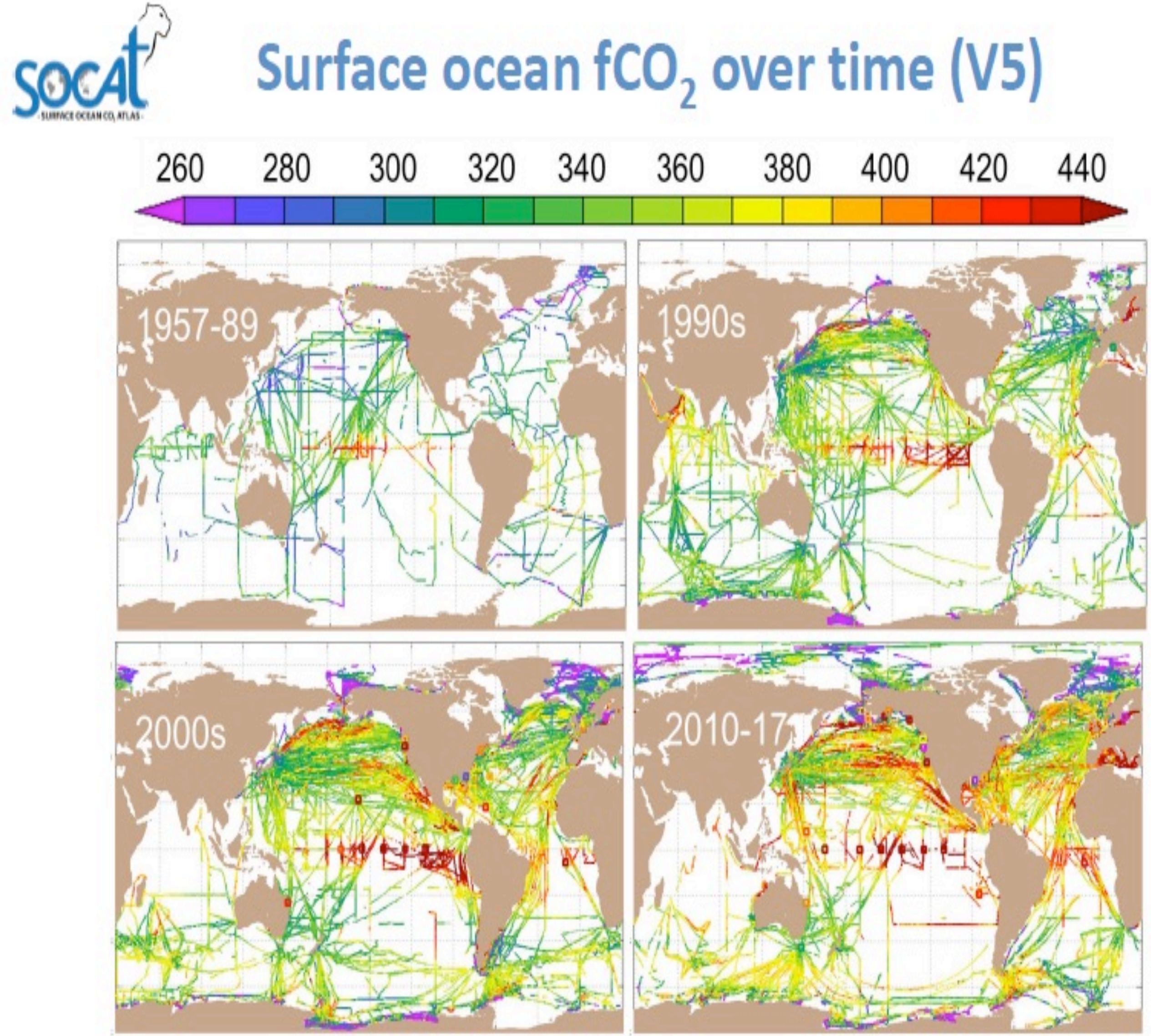
INCOIS

- **Tropical Indian Ocean (IO) alone contributed to storing 16.6 ± 5.1 petagrams anthropogenic carbon, amounting a 16% of the global total ocean sink (Sabine et al., 2004).**

Table-1: Estimates of sea-to-air CO_2 fluxes of Indian Ocean north of 40°S based on various estimates.

Methodology	Reference	Air-sea CO_2 fluxes (Pg C yr^{-1})
Synthesis of top-down and bottom-up approaches	Sarma et al. (2013)	-0.37 ± 0.06
Climatology of surface ocean pCO_2 based on direct measurements	Takahashi et al. (2014)	-0.24 ± 0.12
Neural Network-Self Organizing Map-based methods	Landschützer et al. (2016)	-0.17 ± 0.12
Variational assimilation of surface ocean pCO_2 in a biogeochemical model	Valsala and Maksyutov (2010)	-0.28 ± 0.18

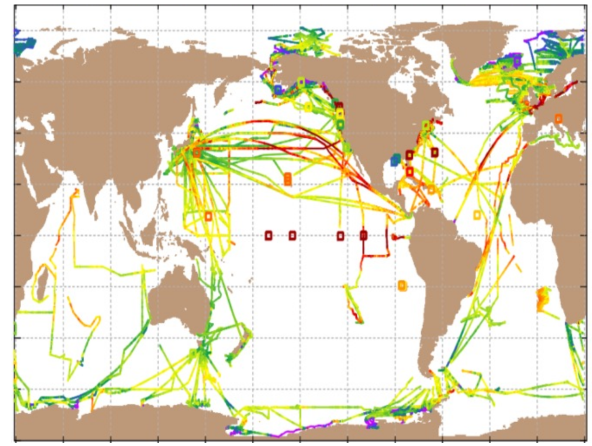
Global surface ocean pCO_2 measurements



- Equilibrium with atmospheric fCO_2 takes up to 1 year,
- Large open ocean and coastal regions not sampled.

Reference - Surface Ocean CO_2 Atlas (Bakker et al., 2016)

2020



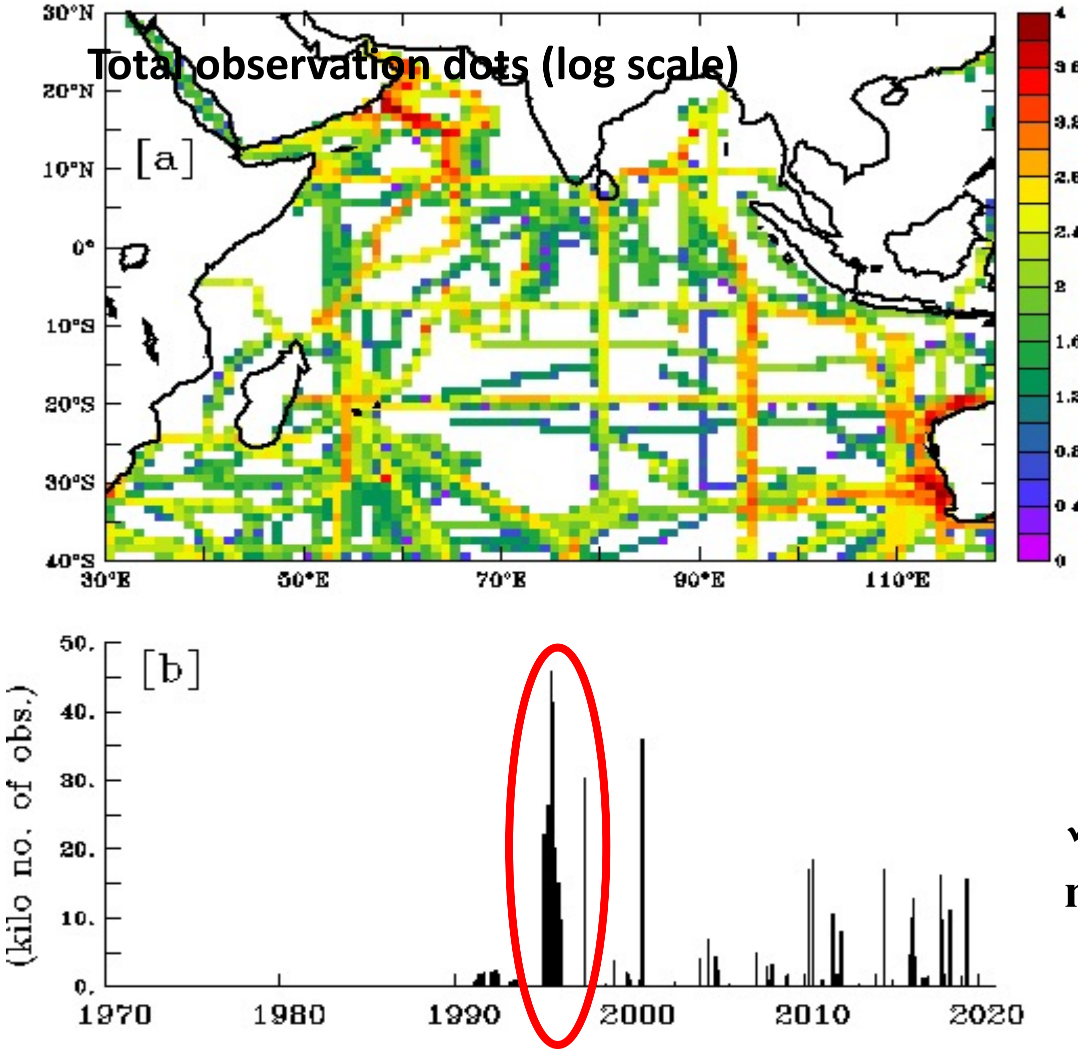
Not much new data added to the Indian Ocean

Major contributions:

World Ocean Circulation Experiment (WOCE) & Joint Global Ocean Flux Study (JGOFS) data in the southwest IO.

Indian Ocean surface pCO_2 measurements

INCOIS



SOCCATv2.1 2019 Database of Ocean pCO_2 from the Indian Ocean

- **Although the Surface Ocean CO2 Atlas (SOCATv3-2020) database consists of 95 million quality controlled surface ocean pCO2 measurements available from 1970 to 2019, the Indian Ocean (30ºE-130ºE, 40ºS-30ºN) shares only 0.8 million.**

- **It hardly represents 2.8% of the total quality-controlled global pCO2 data, especially for north of 30ºS (Pfeil et al., 2013; Rödenbeck et al., 2015; Bakker et al., 2016; Bakker et al., 2020).**

✓**The surface ocean pCO_2 can be measured by instruments**

-Mounted to moorings

-Attached to the hull of ships in case of underway sampling

-Bio-Argo floats (including pH sensors)

Observing System Simulation Experiment (OSSE)

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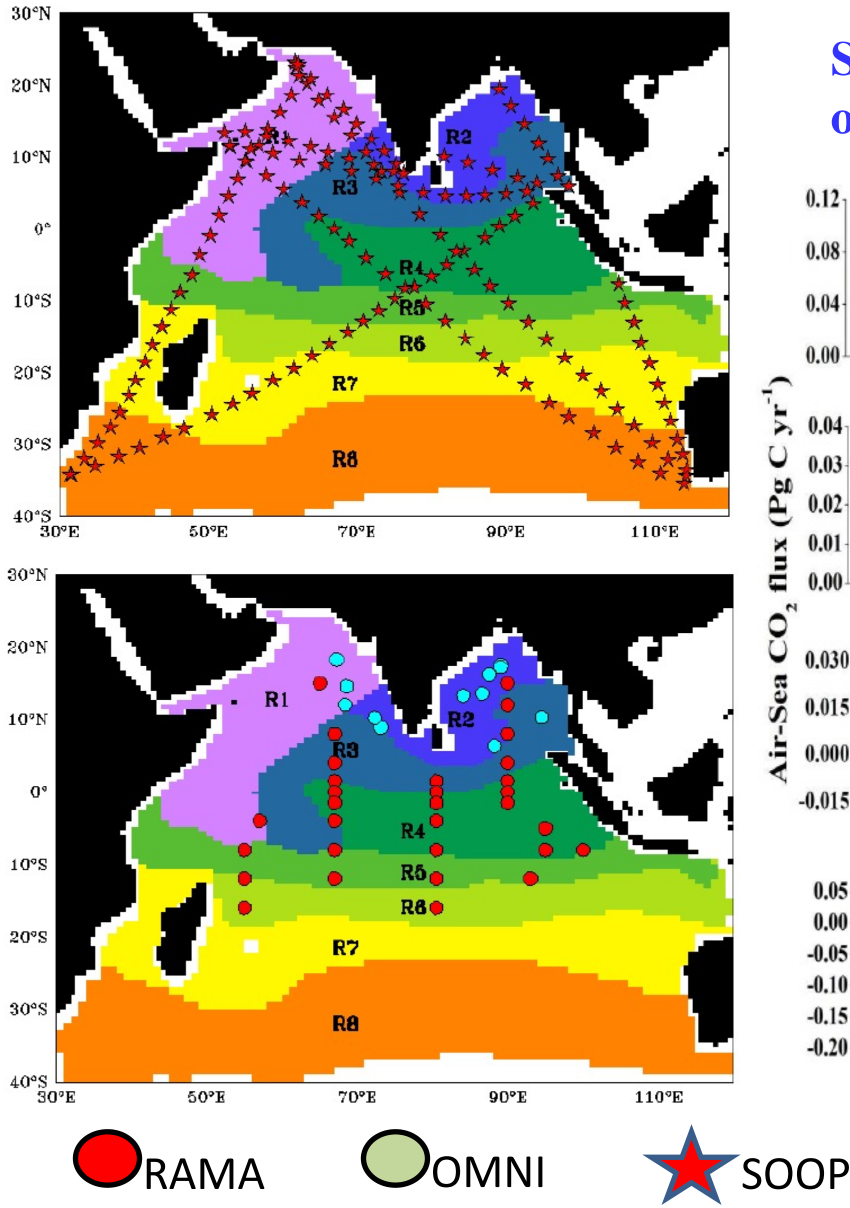
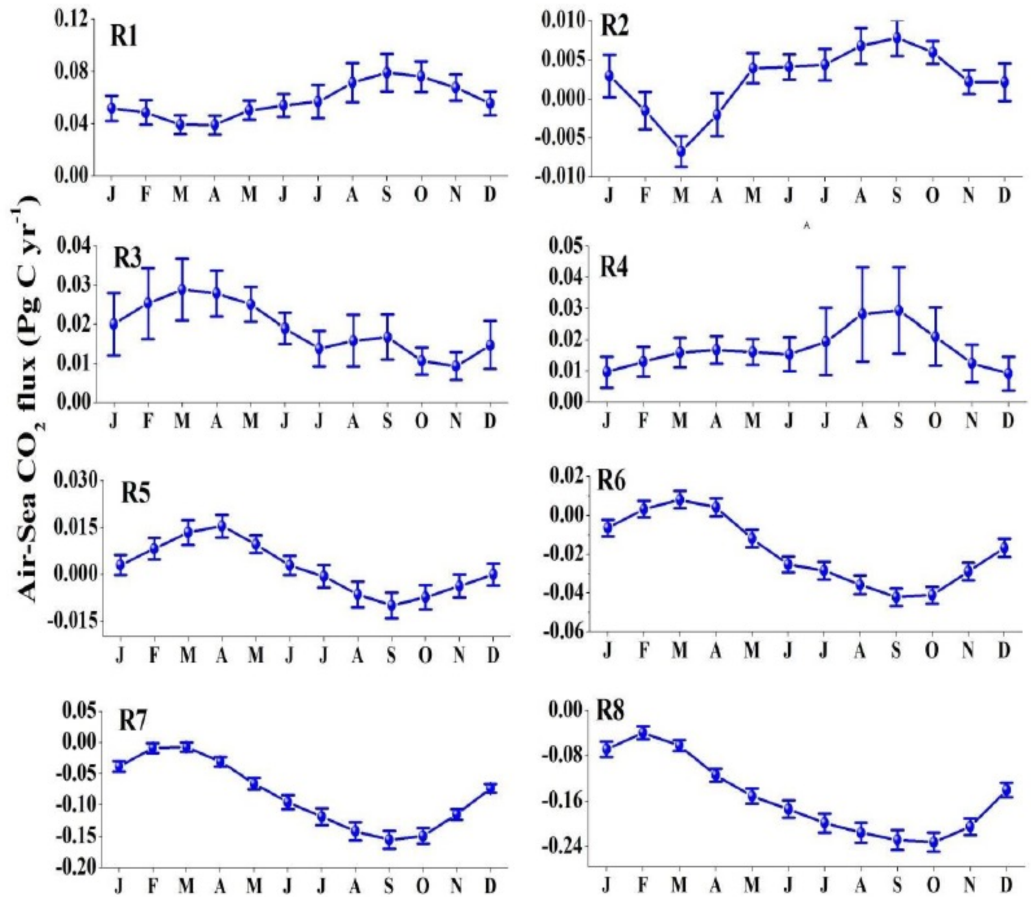
Oceanic Regions, Mooring and Ship-Tracks



Seasonality of sea-to-air CO_2 fluxes from 8-oceanic regions used in the inversion



Valsala et al. (2021)

Observing System Simulation Experiment (OSSE)

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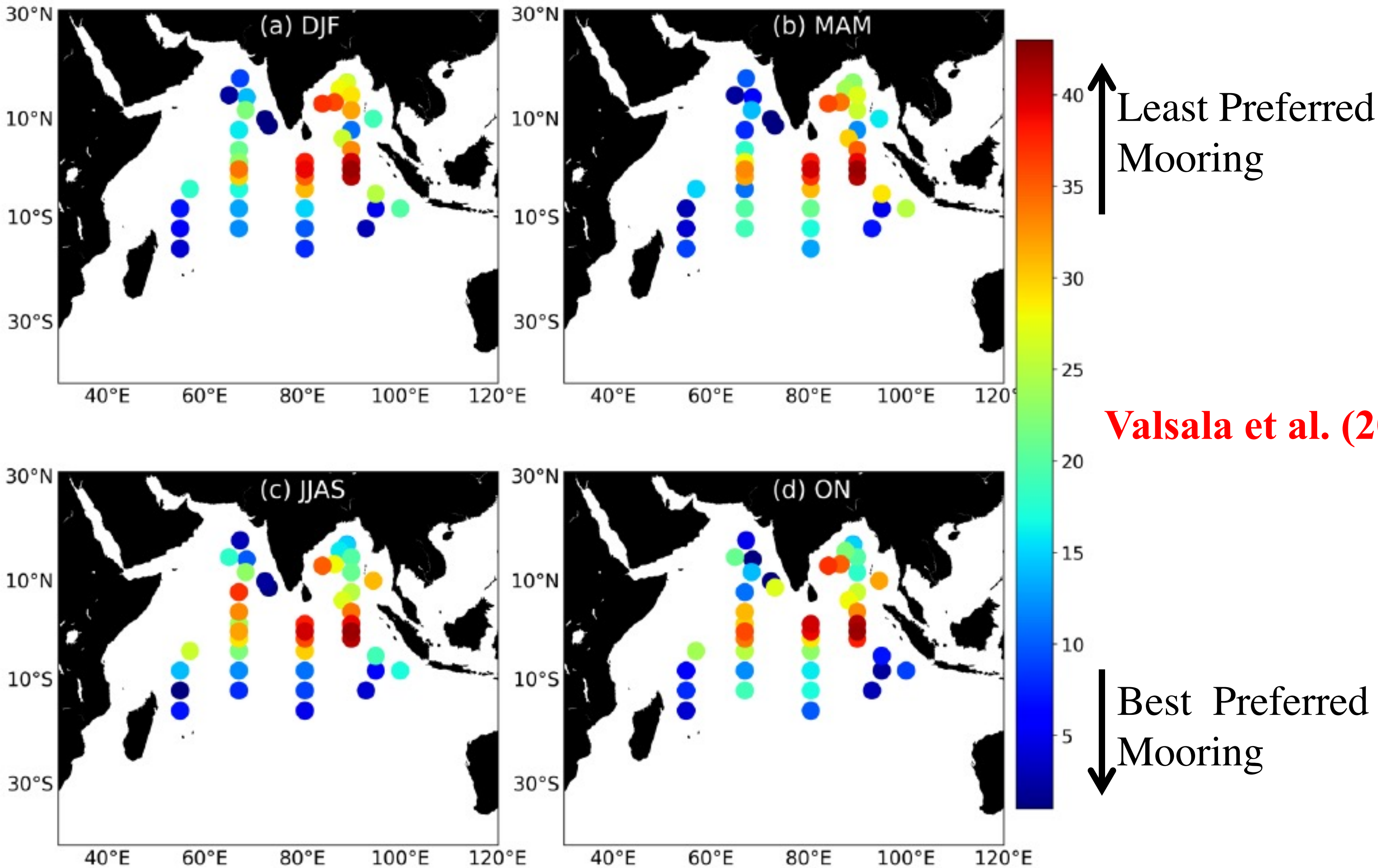
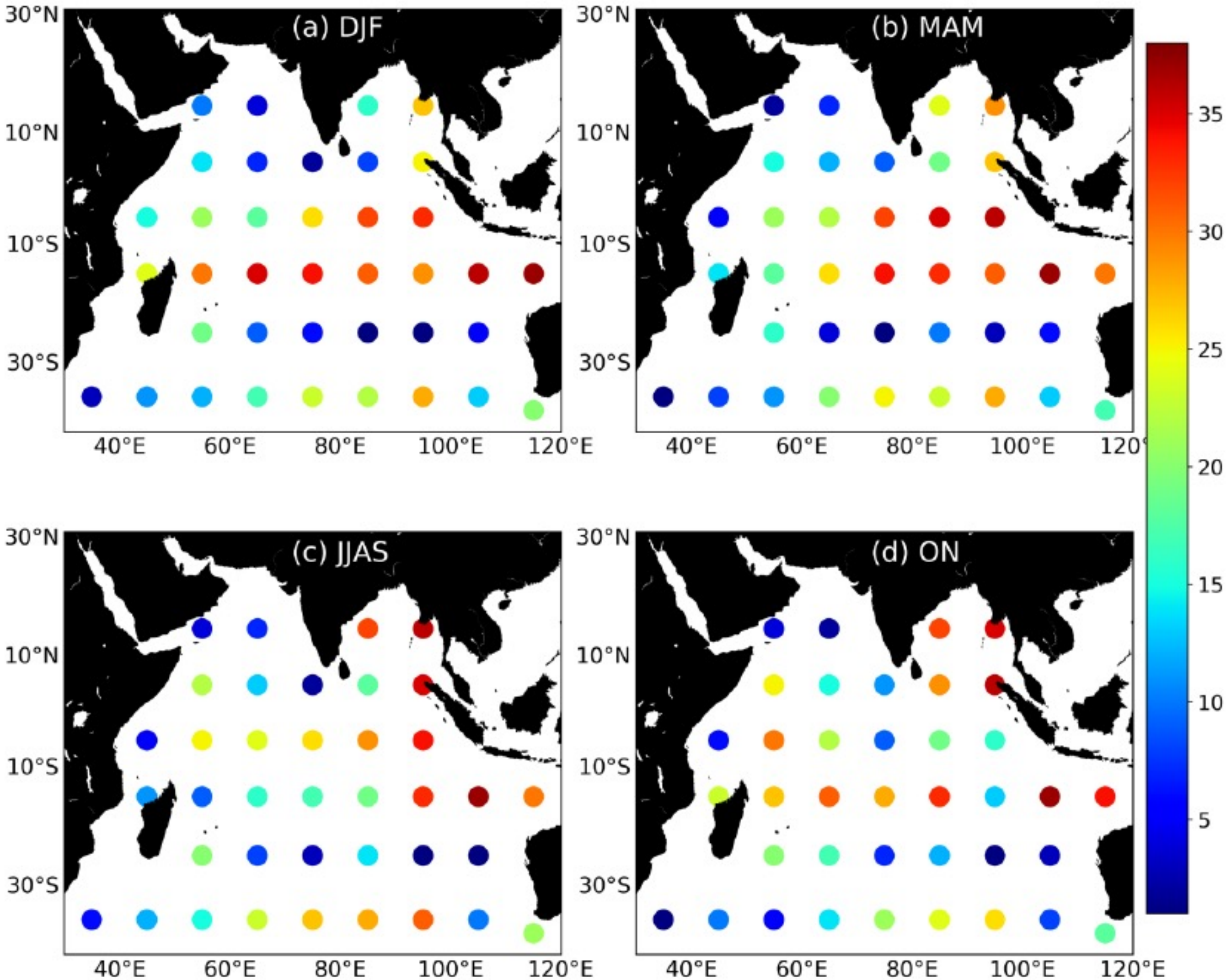


Valsala et al. (2021)

Rank of RAMA+OMNI moorings identified for each season for surface ocean pCO2 observation with deep blue (red) represents best (least) valued mooring for pCO2 observations from this OSSE experiment.

Observing System Simulation Experiment (OSSE)



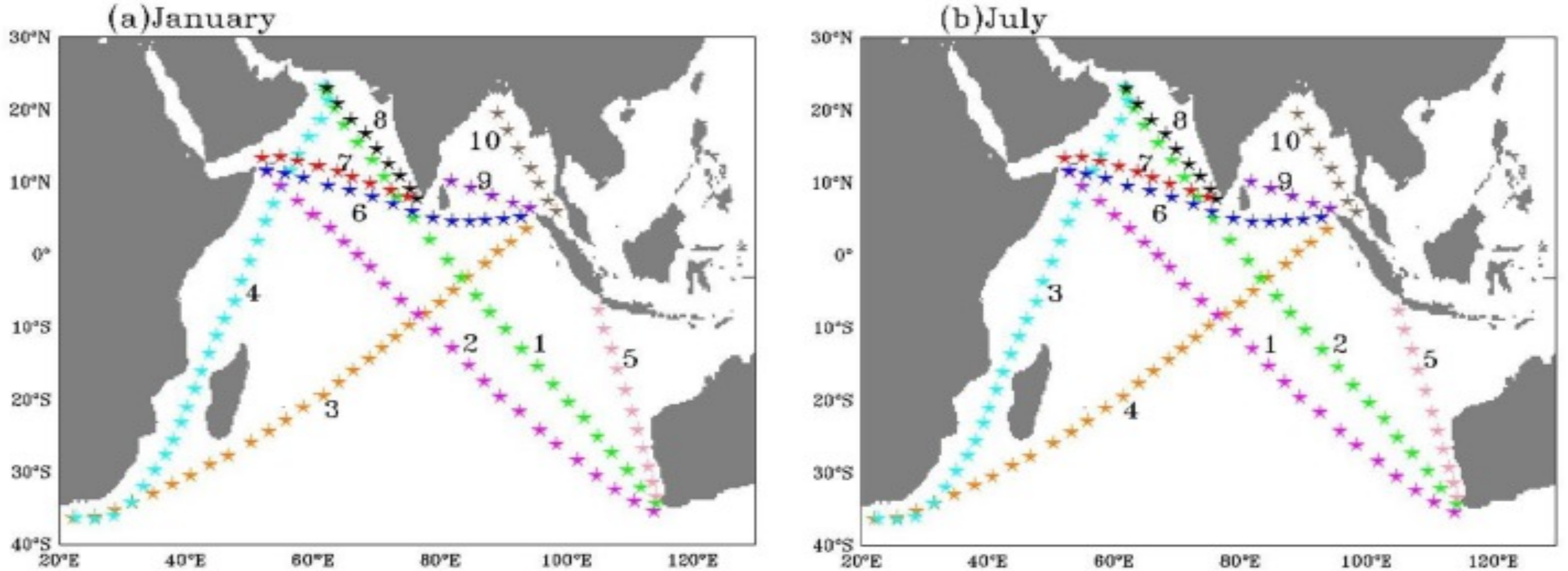
Least Preferred Mooring

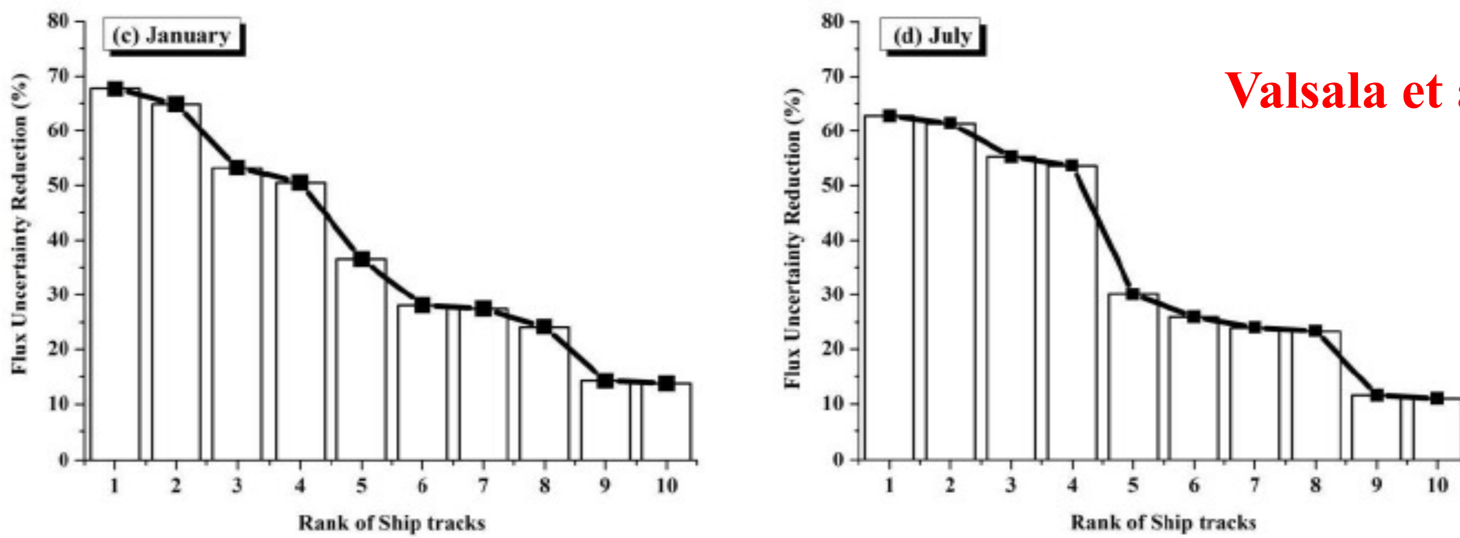
Valsala et al. (2021)

Best Preferred Mooring

Rank of Bio-Argo locations for each season for surface ocean pCO_2 observation with deep blue (red) represents best (least) valued mooring for pCO_2 observations from this OSSE experiment

Observing System Simulation Experiment (OSSE)

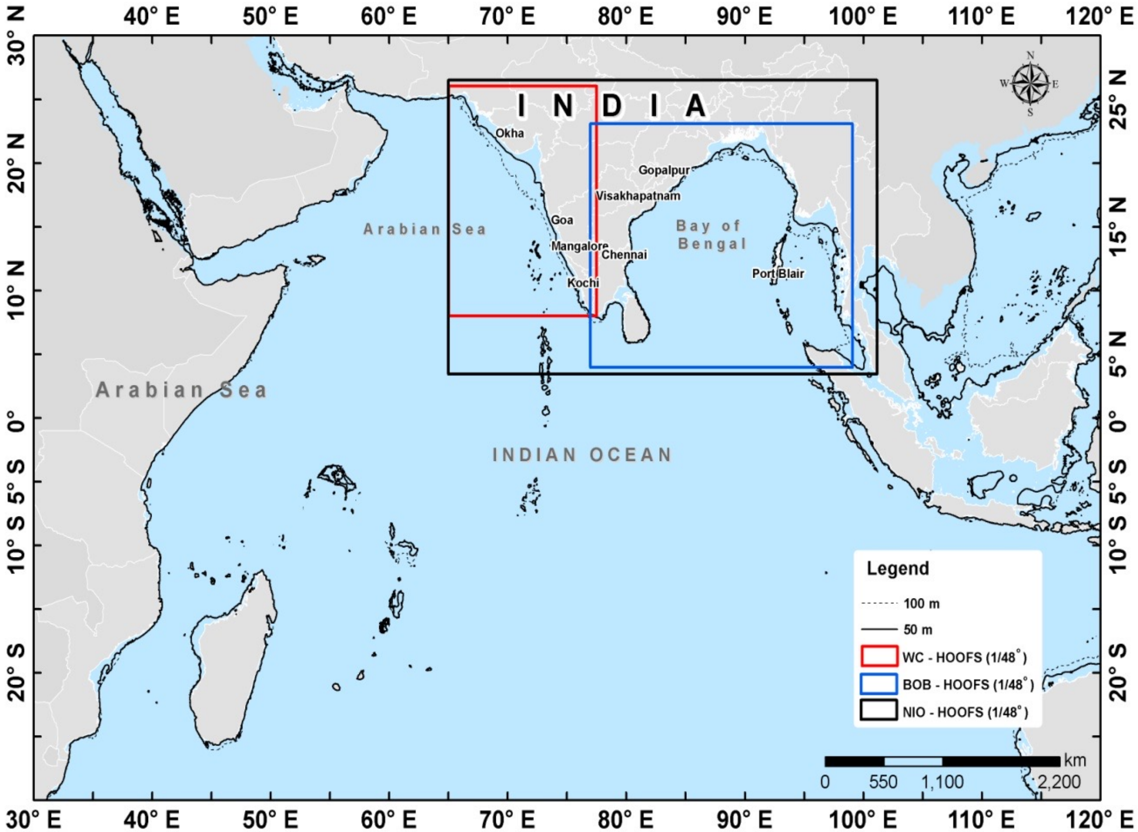




Valsala et al. (2021)

The colors are given for discerning various tracks. The rank of each track in total U.R. of sea-to-air CO_2 fluxes during January and July are written close to the tracks.

Biogeochemical State of the Indian Ocean (BIO)



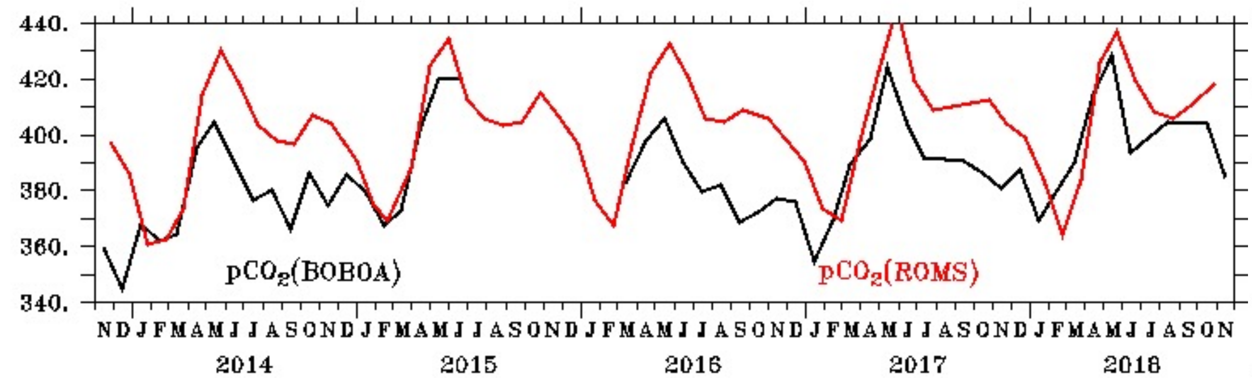
The biogeochemical state the ocean, which includes following major variables, is regularly updated by the BIO system:

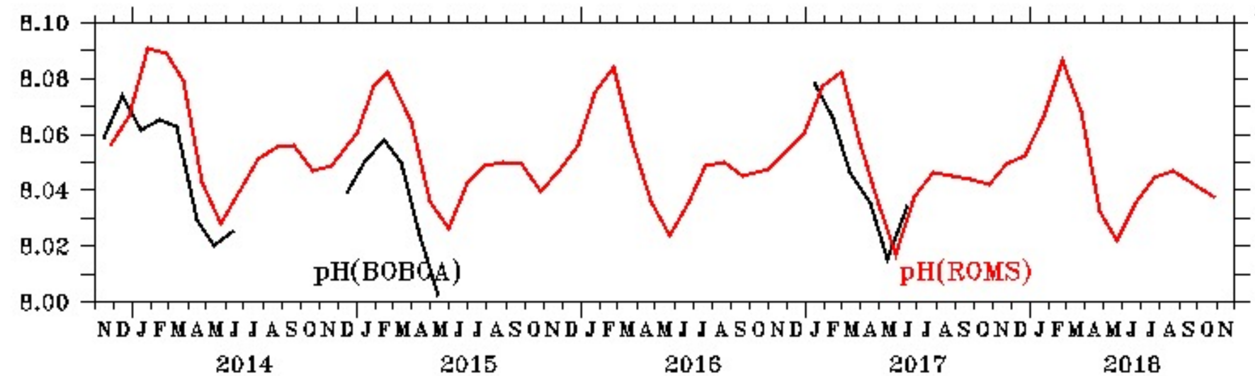
1. **Nutrients, Chlorophyll-a**
2. **Dissolved Oxygen etc.**
3. **Carbon Fluxes**

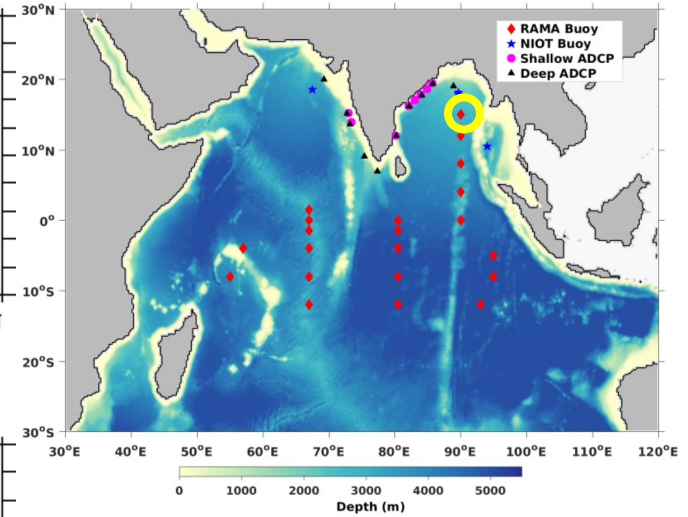
Chakraborty et al. (2018; 2019a,b; 2020; 2021)

- 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.**

Bay of Bengal Ocean Acidification Buoy





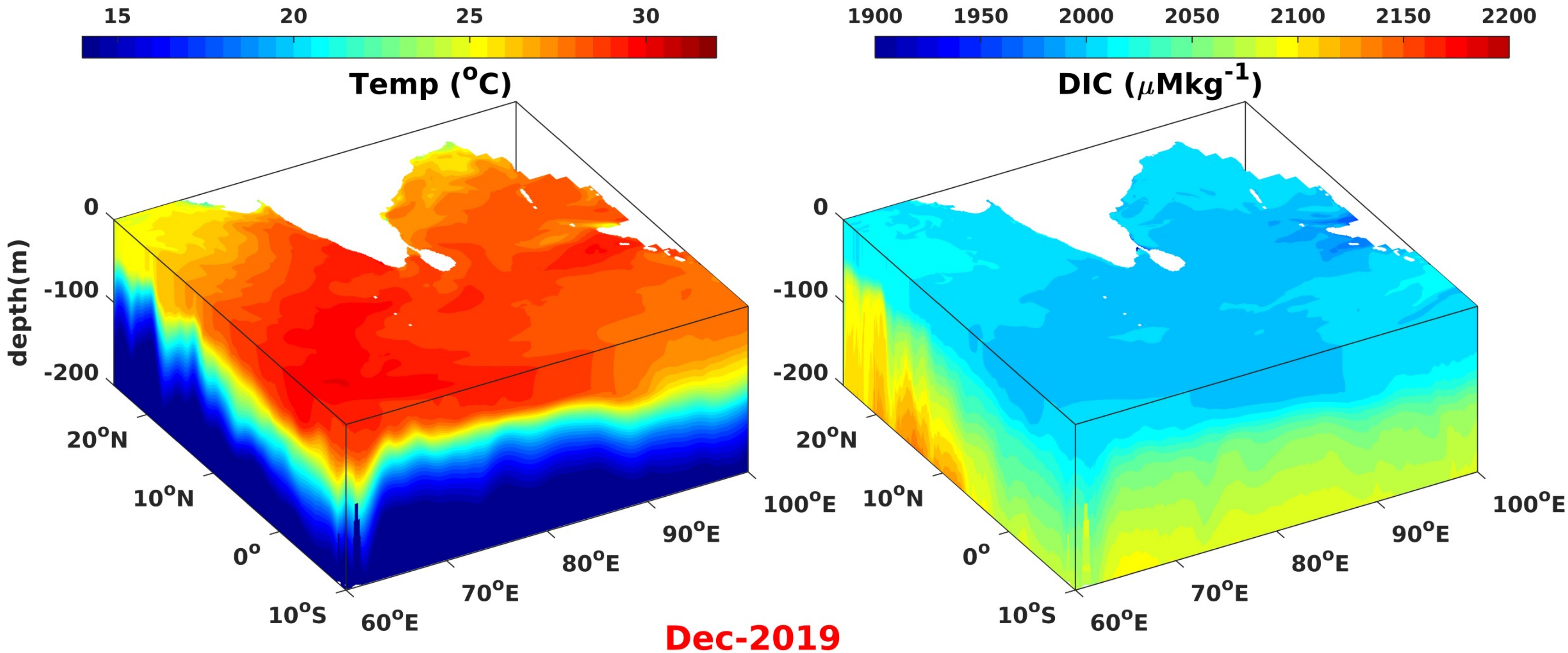


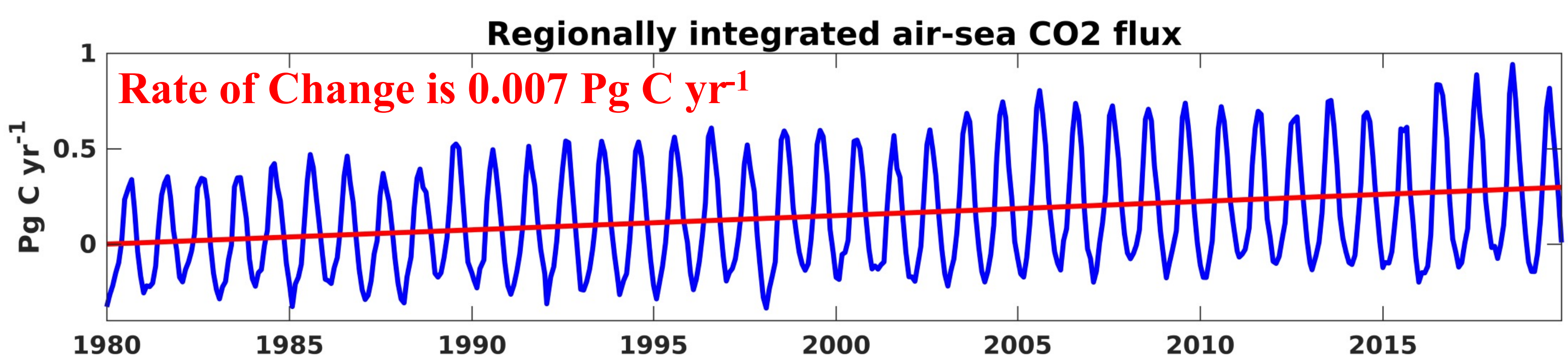
Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA) – Under MoES-NOAA OMNI-RAMA Joint Collaboration

- **The maxima of seasonal amplitudes of pCO_2 and pH occur during April-May and August-September for both basins.**
- **The maximum seasonal amplitude of pCO_2 contributed by Temperature and DIC complement each other.**
- **The maximum peak in pCO_2 is found to be concurrent with the peak in surface temperature during April-May. Salinity moderately controls the seasonal variability of pCO_2 at the BOBOA location.**

Chakraborty et al. (2021)

Model Simulations





INCOIS

RECCAPv2

REgional Carbon Cycle Assessment and Processes2

Gotemba, Japan 2019 – Launch of RECCAP2

Global Carbon Project

INCOIS

Scientific Objectives RECCAPv2

1. To establish mean decadal **GHG budgets** of large regions covering the globe at the scale of **continents (or large countries) and large ocean basins.**

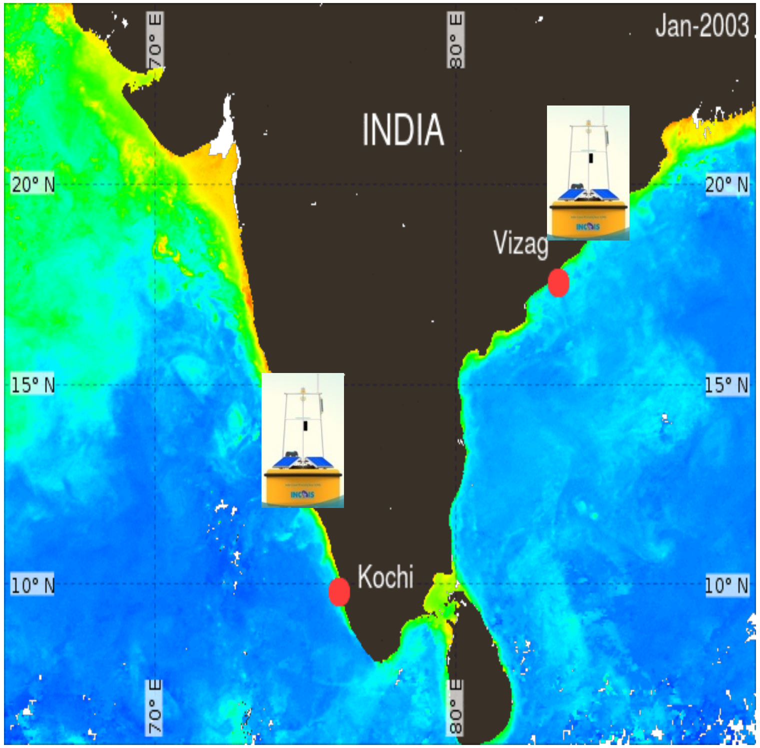
2. To evaluate the **regional contributions to the global budgets of GHGs and identify 'hot-spots'** of inter-annual variability and trends, and their underlying processes.

Regional Models in the Assessment Process

- **None of the global models capable of simulating Indian Ocean carbon cycle (Sarma et al., 2013). Those models which are doing good job in the north are not doing well in the south and vice versa.**

- **Regional models have been included along with global models to examine how best they are performing in the Indian Ocean, especially north, while dividing the Indian Ocean in to three zones**
  - **Arabian Sea (NW Indian Ocean)**
  - **Bay of Bengal (NE Indian Ocean)**
  - **South Indian Ocean**

Buoy Based Autonomous Water Quality Observatory



List of Variables –

Temperature, Salinity, Dissolved Oxygen, pH, Chlorophyll-*a*, Turbidity, Current Meter, Nutrients (Nitrite, Nitrate, Ammonium, Phosphate, Silicate), pCO_2 (water), pCO_2 (Air), Scattering at 700nm, CDOM, Geolocation, Depth, etc.

Objectives:

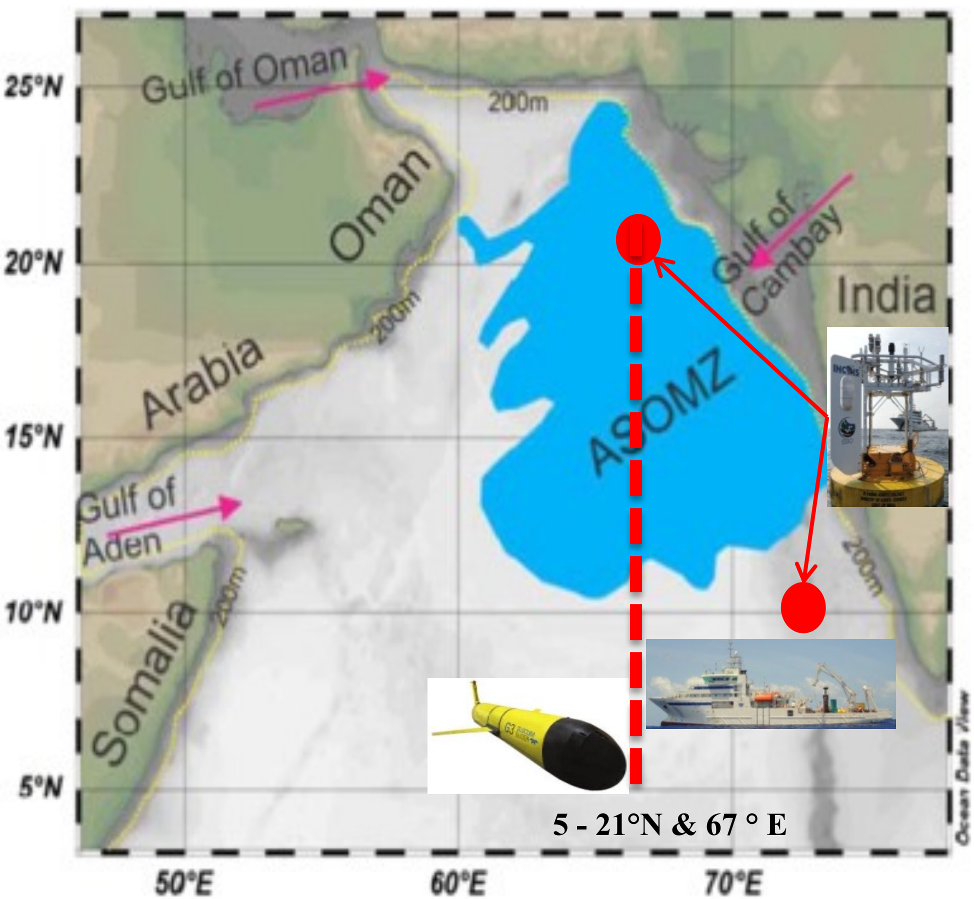
1. To establish sustained coastal observatories to monitor and understand coastal processes for now-casting and forecasting water quality

2. To develop water quality forecasts model for assessing the health of the coastal and estuarine waters by using the sustained coastal observatories for model validation and assimilation

EKAMSAT

EKAMSAT - Enhancing Knowledge of the Arabian Sea Marine environment through Science and Advanced Training

(An India-US joint programme)



SN	Parameter	SN	Parameter	SN	Parameter
01	Temperature	17	Silicate	33	Lead
02	Salinity	18	DIC	34	Mercury
03	Total Alkalinity	19	DOC	35	CDOM (Fluorescence)
04	pH	20	PIC	36	CDOM (Absorbance)
05	Dissolved Oxygen	21	POC	37	Pigment
06	BOD	22	TOC	38	Chlorophyll-a Total
07	COD	23	TIC	39	Chlorophyll-a-Pico
08	Nitrite	24	Total Carbon	40	Chlorophyll-a-Nano
09	Nitrate	25	Turbidity	41	Chlorophyll-a-Micro
10	Ammonium	26	TSM	42	Phytoplankton
11	Total Inorganic Nitrogen	27	Fecal Coliform	43	Zooplankton
12	Total Organic Nitrogen	28	*E. coli*	44	AOP
13	Total Nitrogen	29	Total Coliform	45	Dissolved Gases
14	Inorganic Phosphate	30	Iron	46	Dissolved N_2O Isotope
15	Organic Phosphate	31	Manganese	47	POC & PON Isotope
16	Total Phosphorous	32	Cadmium	48	DIC Isotope

Summary and Conclusions

- There is a big knowledge gap, mainly of poorly known air-sea CO_2 fluxes, which is critical to our understanding of the carbon cycle and the carbon budget in the Indian Ocean.

- There is a critical need to understand the status of Indian Ocean acidification in open-ocean and coastal environments and identify its key drivers and to examine its impacts on marine ecosystems.

- Ship-track measurements of underway pCO_2 in SOOP are far more efficient in constraining Indian Ocean CO_2 fluxes than time-series data from fixed moorings.

- The maximum flux uncertainty reduction achievable by installing pCO_2 sensors in the existing RAMA and OMNI mooring is limited to 30% in different seasons whereas a single track SOOP can reduce the current uncertainty by approximately 62%.

- Considering the relatively smooth operation and implementation of Bio-Argo floats, one may consider that around 20 Bio-Argos are still the right choice over installing mooring based pCO_2 sensors

- The rate of change of regionally integrated air-sea CO_2 flux is 0.00763 (Pg C/year).

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Your comments please …

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CLIMATE & OCEAN

Variability, Predictability and Change

GOOS

The Global Ocean Observing System

Co-sponsors

ICTP The Abdus Salam International Centre for Theoretical Physics

WCRP World Climate Research Programme

US CLIVAR