Observing the Indian Ocean
In the time of COVID

Mike McPhaden, NOAA/PMEL

US CLIVAR Summit
Seattle, WA

1 August 2023
Scientific Drivers

- Indian Ocean Dipole
- Monsoons
- Ningaloo Niños
- Biogeochemistry & Ecosystems
- Ocean Circulation
- Tropical Storms
- Decadal Indian Ocean Basin Mode
- Trends
Indian Ocean rim countries are increasingly vulnerable due to increases in cyclone frequency and intensity, more extreme monsoon rainfall and drought, and rising sea levels.

The Bay of Bengal sees 5% of global cyclones, but 80% of global casualties. Cyclone Nargis in 2008: 140,000 dead, 1 million homeless, and $10 billion damages.

There are many small island developing states and least developed countries dependent on fisheries.

Increasing marine heat waves, ocean acidification and deoxygenation threaten sustainable fisheries.

Societal Need: Vulnerability to Natural Hazards

Dependency on fisheries

IndOOS Achievements

IndOOS has provided unprecedented data for improved understanding and forecasting weather, ocean, and climate phenomena:

- Real-time observations for weather and climate forecasts and warnings
- Coupled intraseasonal variations (MJO and MISO) and their influence on global hydro-climate
- Equatorial and monsoon circulations and variability of the Indonesian Throughflow
- Year-to-year climate variations associated with the Indian Ocean Dipole and its and their relationship to Pacific ENSO variations

~1000 publications
RAMA Data

Monthly data at 15°N, 90°E

Winds (m s⁻¹)

Monsoon wind variations

Ocean Current (10 meters depth, cm s⁻¹)

Ocean Eddies

Temperature (°C)

Very warm surface layer

Depth (m)

Salinity (PSU)

Fresh water from river runoff and rainall

High temporal resolution data

Daily Data

Global Tropical Moored Array Program (GTOAP), NOAA/PFZL

Mar 20 2018
Monsoon vs Trade Wind Regime

5-day Winds and Temperatures

16°S, 55°E Winds (m s⁻¹)

8°N, 90°E Winds (m s⁻¹)

Temperature (°C)

Depth (m)

2010 2011 2012 2013

2010 2011 2012 2013

Trade Wind Regime

Monsoon Regime
Argo in the Indian Ocean


2187 T/S profiles


221,614 T/S profiles (92% Argo)
Subtropical Cell

$\mathbf{W} \sim \text{Curl}(\boldsymbol{\tau})$

Schott et al, 2009
Since the inception of IndOOS, societal and scientific priorities and measurement technologies have evolved, many practicalities of implementation have been learned, and the pace of climatic and oceanic change has accelerated.
11 March 2020

After more than 118,000 cases in 114 countries and 4,291 deaths, the WHO declares COVID-19 a pandemic.

Source: CDC
COVID-19 Impacts on RAMA

Data return* in percent for December of 2019 (pre-pandemic) and 2022 (post pandemic)

87%

2%

Only one cruise between late 2019 and early 2023 (3+ years)

*Based on the number of days of data acquired divided by the number of days of data expected in a given time period
COVID-19 Impacts on Indian Ocean Argo

BGC Argo (pH, oxygen, nitrate, chlorophyll, suspended particles, and downwelling irradiance):
~20 deployments/yr pre-pandemic; 5 in 2020, 1 in 2021
75 in Dec 2019  71 in Dec 2022 (80% > 3yrs old).
COVID-19 Impacts on Indian Ocean Drifters

Dec 2019
287 deployed/ 261 active in Dec 2019

Dec 2022
76 deployed/ 116 active in Dec 2022

Green=good  Yellow=target
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Go Ship Lines
2018-20: 4
2020-22: 0

IX21 XBT Line
2018-20: 9 (HR)
2020-22: 6 (LR)

HR=high resolution (10-50 km)
LR=low resolutions (>50 km)
COVID Impacts Cause Critical Gaps in the Indian Ocean Observing System

Janet Sprintall, Motoki Nagura, Mathieu Belbeoch, Juliet Hermes, M. K. Roxy, Jing Li, Michael J. McPhaden, E. Pattabhi Rama Rao, Sidney Thurston, Srinivas Kumar Tummala

“...to document the gaps that have appeared over the past few years and...outline the expected slow road to recovery for the Indian Ocean observing system..”
Completed and Planned RAMA Cruises 2023-24

PMEL equipment, partner ship time
Partnerships are Strong

MoES/NOAA Partnership Renewed for 5 Years
12 August 2021

Joint OMNI/RAMA Data Portal hosted at INCOIS
https://incois.gov.in/geoportal/Buoys/index.html
Partnerships are Strong

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

MoES/NOAA/US Office of Naval Research Program 2022-2026

First cruise completed in June 2023
Partnerships are Strong

BMKG/NOAA Partnership Renewed for 5 Years
29 July 2022

“Representatives from NOAA and BMKG signed an updated Memorandum of Understanding that extends the partnership for five more years. This renewed MOU marks 17 years of successful long-term partnership....”

Baruna Jaya VIII
Partnerships are Strong

A Korea-US Indian Ocean Scientific Research Program (KUDOS)

Cruise completed in May-June 2023

Annual cruises planned 2024-26
Infrastructure Investment and Jobs Act of 2021 (aka Bilateral Infrastructure Law)

$2.5 M for RAMA/PIRATA mooring recapitalization

15 Nov 2021
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CLIVAR IORP Task Team

“to quantitatively evaluate COVID-19 impacts on IndOOS and their consequences” using OSSEs and other methodologies

Youmin Tang, Janet Sprintall, Juliet Hermes, Xiaojing Li, Tamaryn Morris, Shikha Singh, Michael J. McPhaden
Thank you!

Merci

Terima Kasih

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Actionable Recommendations Summary
Tiers I and II: Maintain and Extend

- **Argo**: Maintain the core 3° x 3° array, add 200 BGC-Argo floats, develop a Deep-Argo program.

- **RAMA**: Consolidate to RAMA-2.0 (13 less sites). Increase resolution of upper-ocean measurements, add mapCO2, BGC, and direct flux measurements to flux reference sites. Add new site off NW Australia.

- **XBT**: Maintain IX01 (ITF) and IX21 lines. IX01: Install auto-launchers and increase near-coastal resolution. IX21: add pCO2.

- **Tide gauges**: Add colocated measurements of land motion, add sites in SW Indian Ocean and on islands.
Surface drifters: Maintain core 5° x 5° array, evaluate addition of barometric pressure.

Boundary current arrays: Add observations of Agulhas and Leeuwin Currents, including hydrographic moorings to constrain basin-scale heat budget. (Monitor T,S,O2, and nutrients in Java-Sumatra and west coast India upwelling.)

GO-SHIP: Find national commitment for line I01. Add measurements of chlorophyll and phytoplankton community structure.

Satellites: Maintain overlapping, inter-calibrated missions, enhance spatial resolution of SSH.