

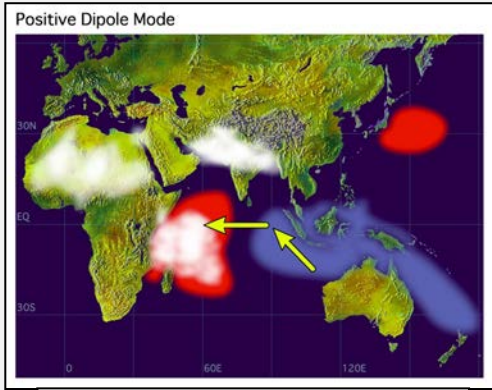
# Observing the Indian Ocean In the time of COVID

Mike McPhaden, NOAA/PMEL

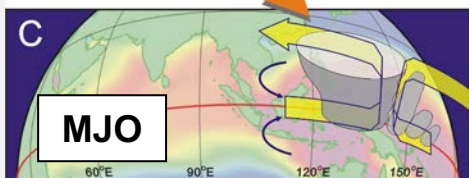
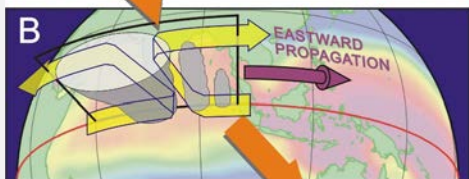
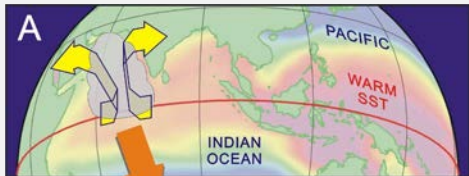
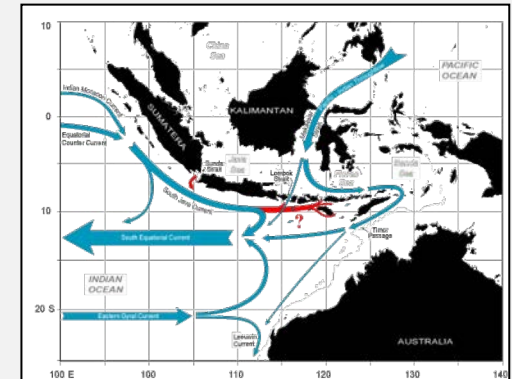
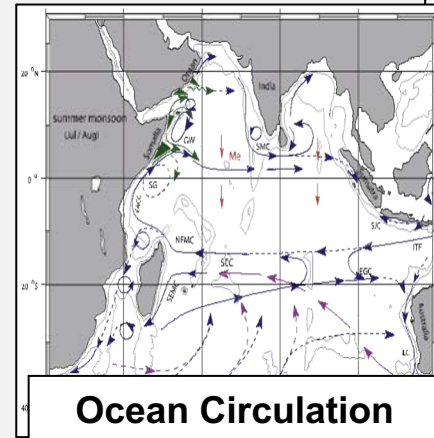
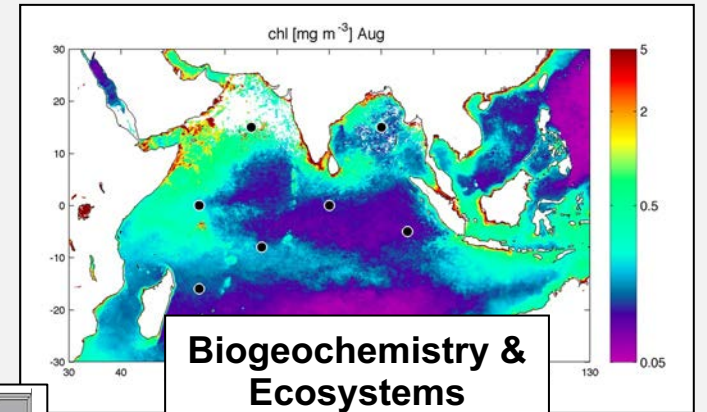
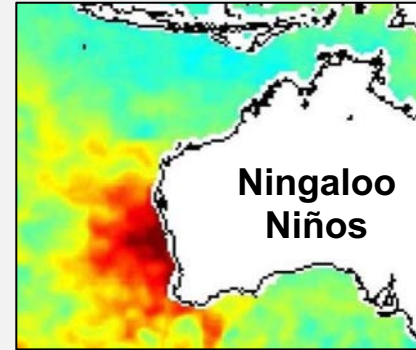
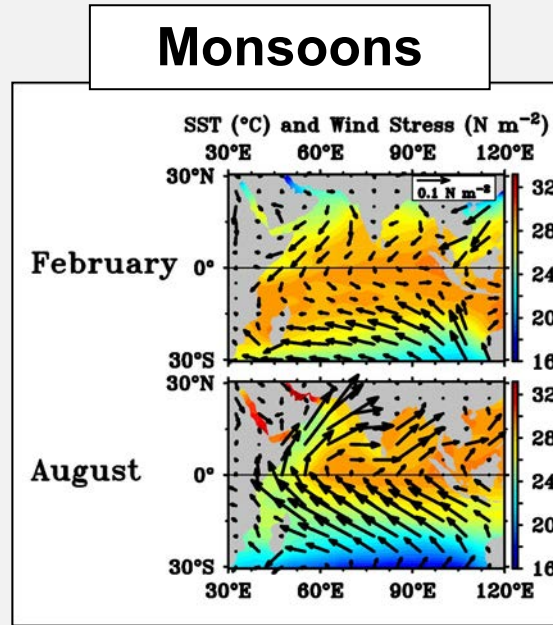
US CLIVAR Summit  
Seattle, WA

1 August 2023

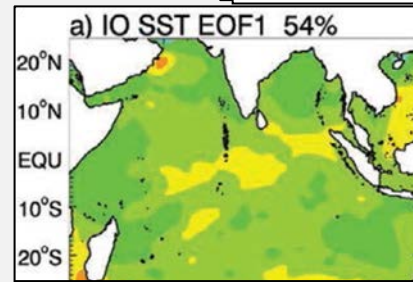
# Scientific Drivers



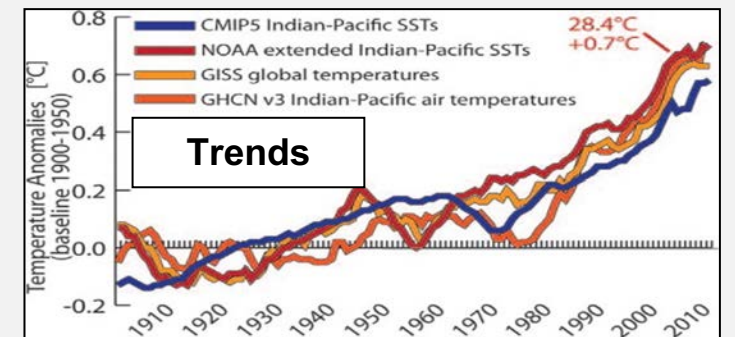
Indian Ocean Dipole



Tropical Storms

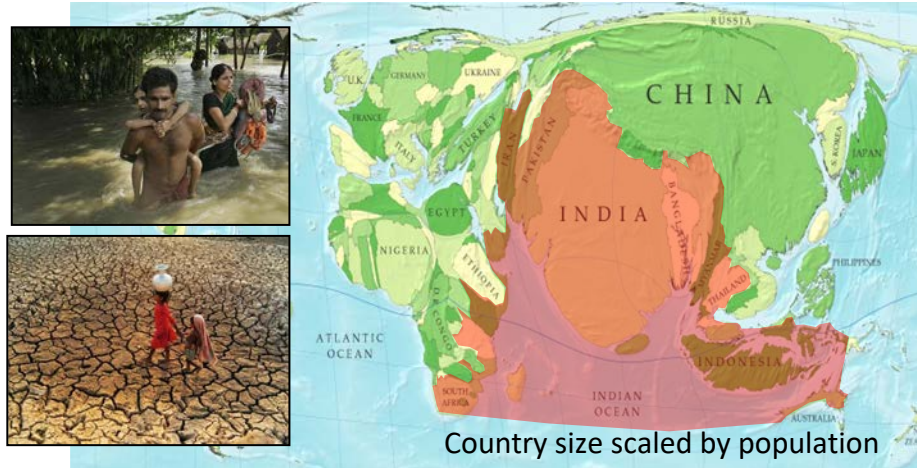


Decadal Indian Ocean Basin Mode



# Societal Need: Vulnerability to Natural Hazards

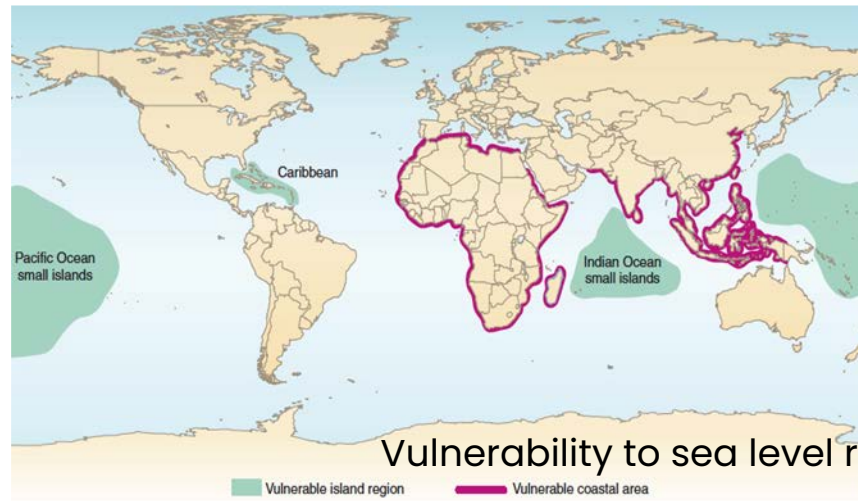
- Indian Ocean rim countries are increasingly vulnerable due to increases in cyclone frequency and intensity, more extreme monsoon rainfall and drought, and rising sea levels.
- The Bay of Bengal sees 5% of global cyclones, but 80% of global casualties. Cyclone Nargis in 2008: 140,000 dead, 1 million 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



One third global population

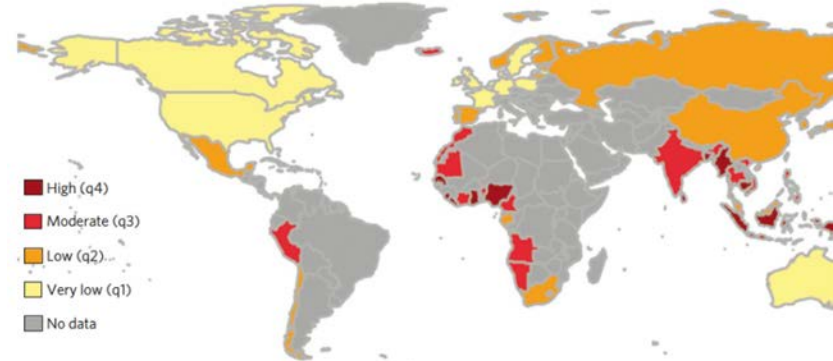


Arabian Sea cyclones are increasing



Vulnerability to sea level rise

Dependency on fisheries



Murakami et al (2017), Paul et al. (2009), Nicholls and Cazenave (2010), Barange et al (2014)

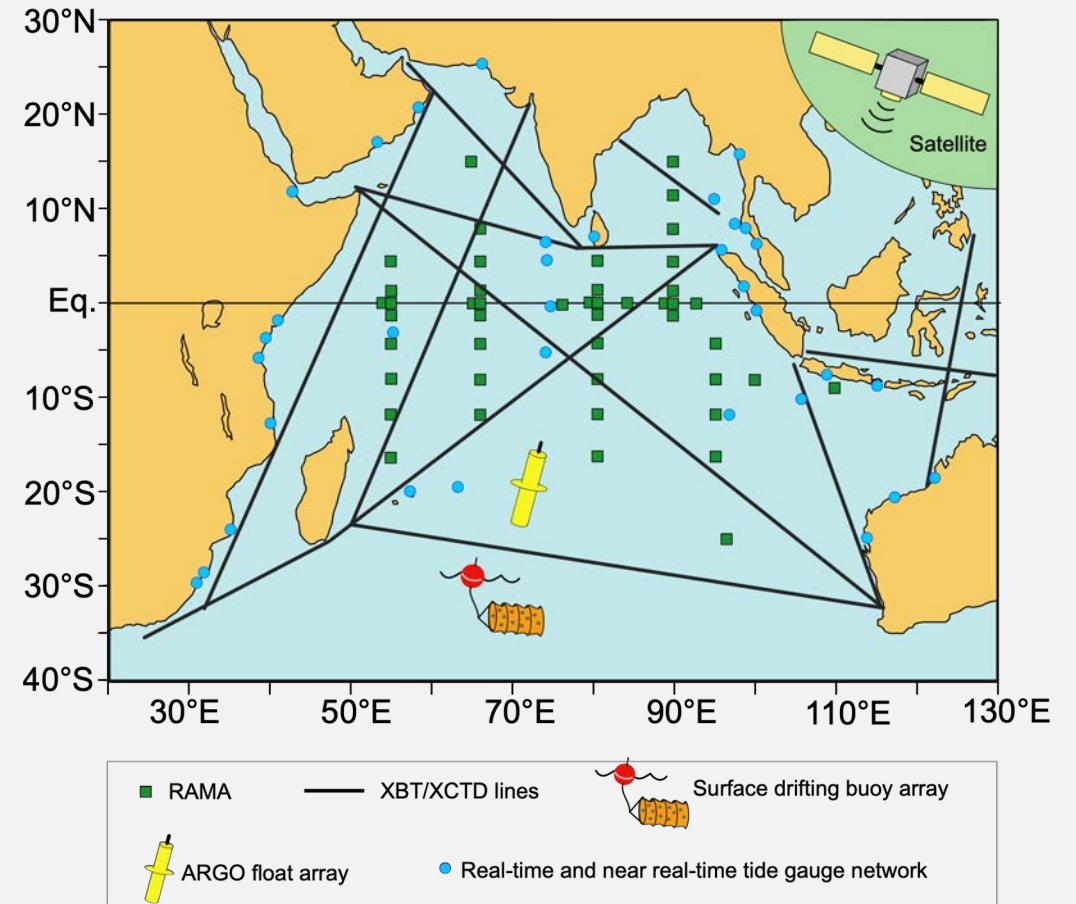
# IndOOS Achievements

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 relationship to Pacific ENSO variations

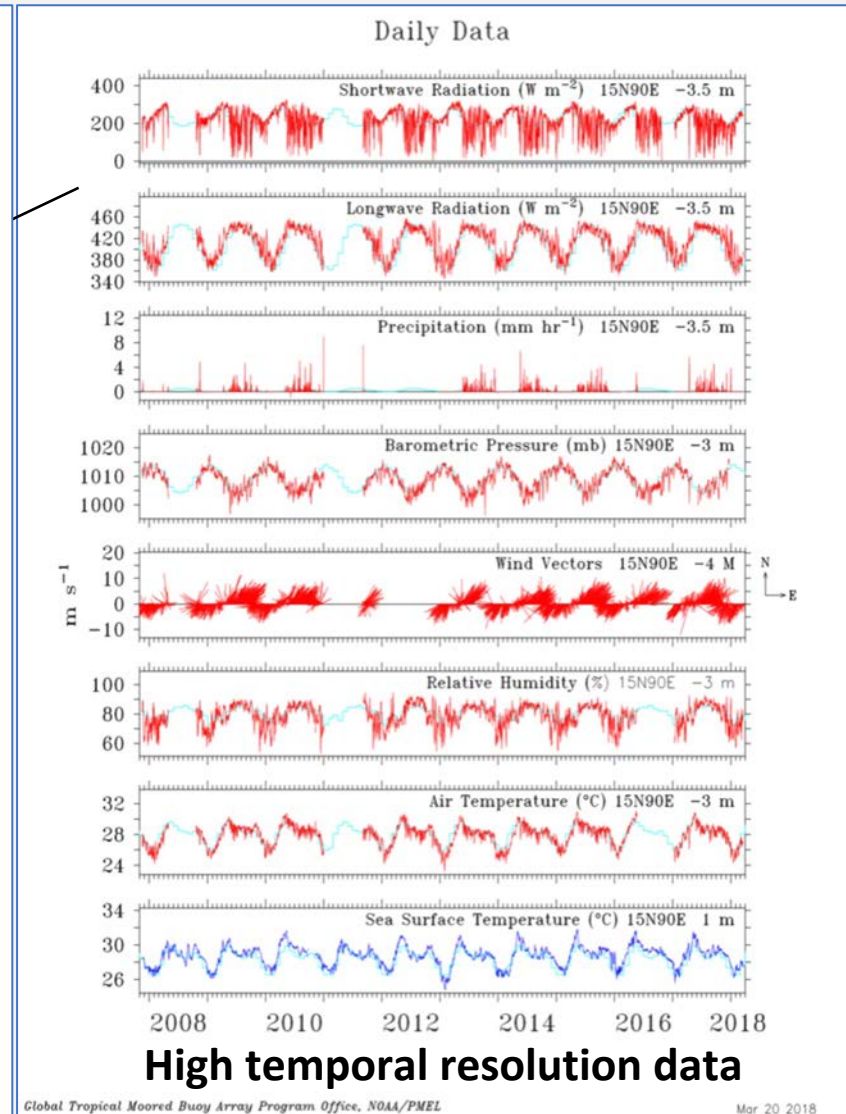
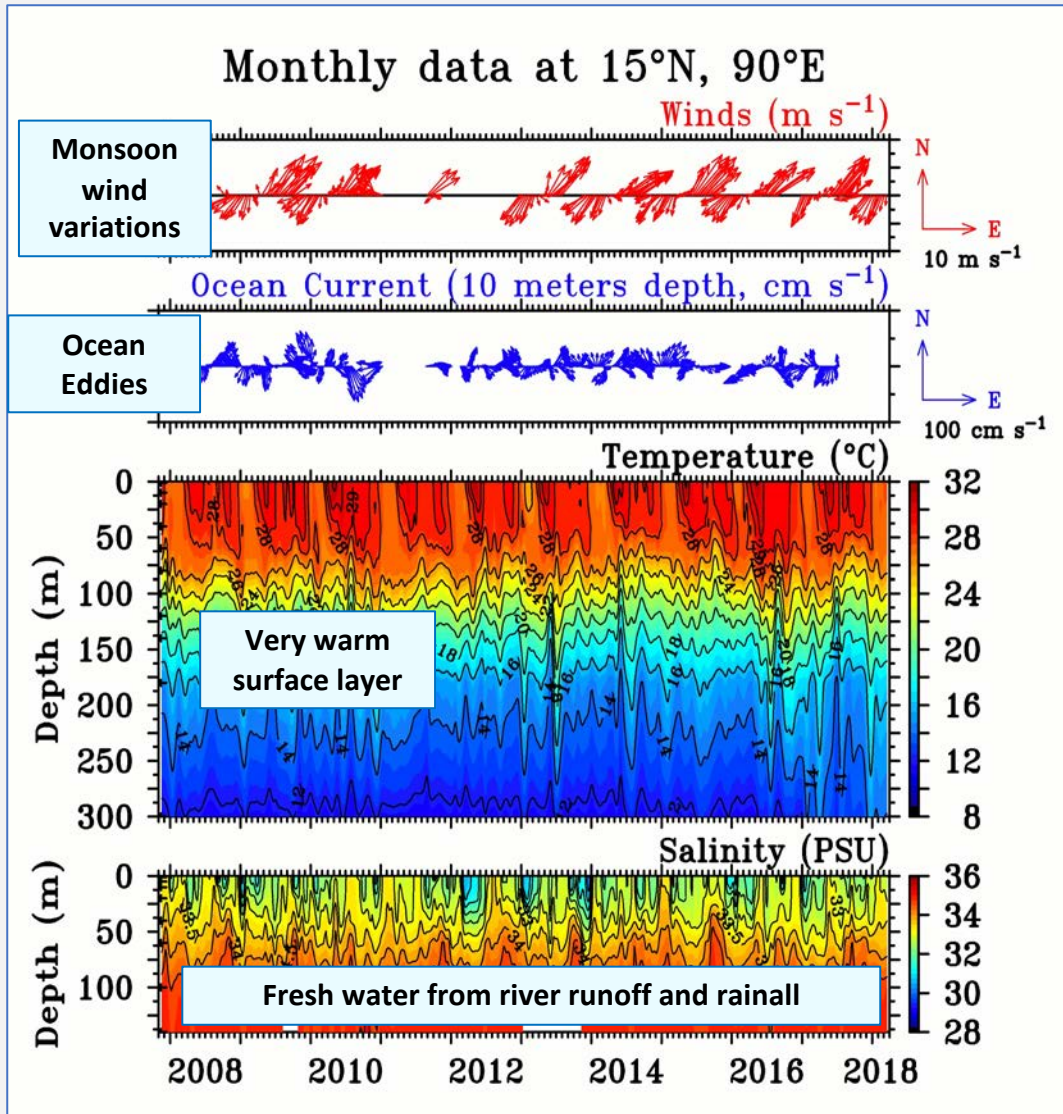
~1000 publications

## The Indian Ocean component of GOOS: Indian Ocean Observing System (IndOOS)

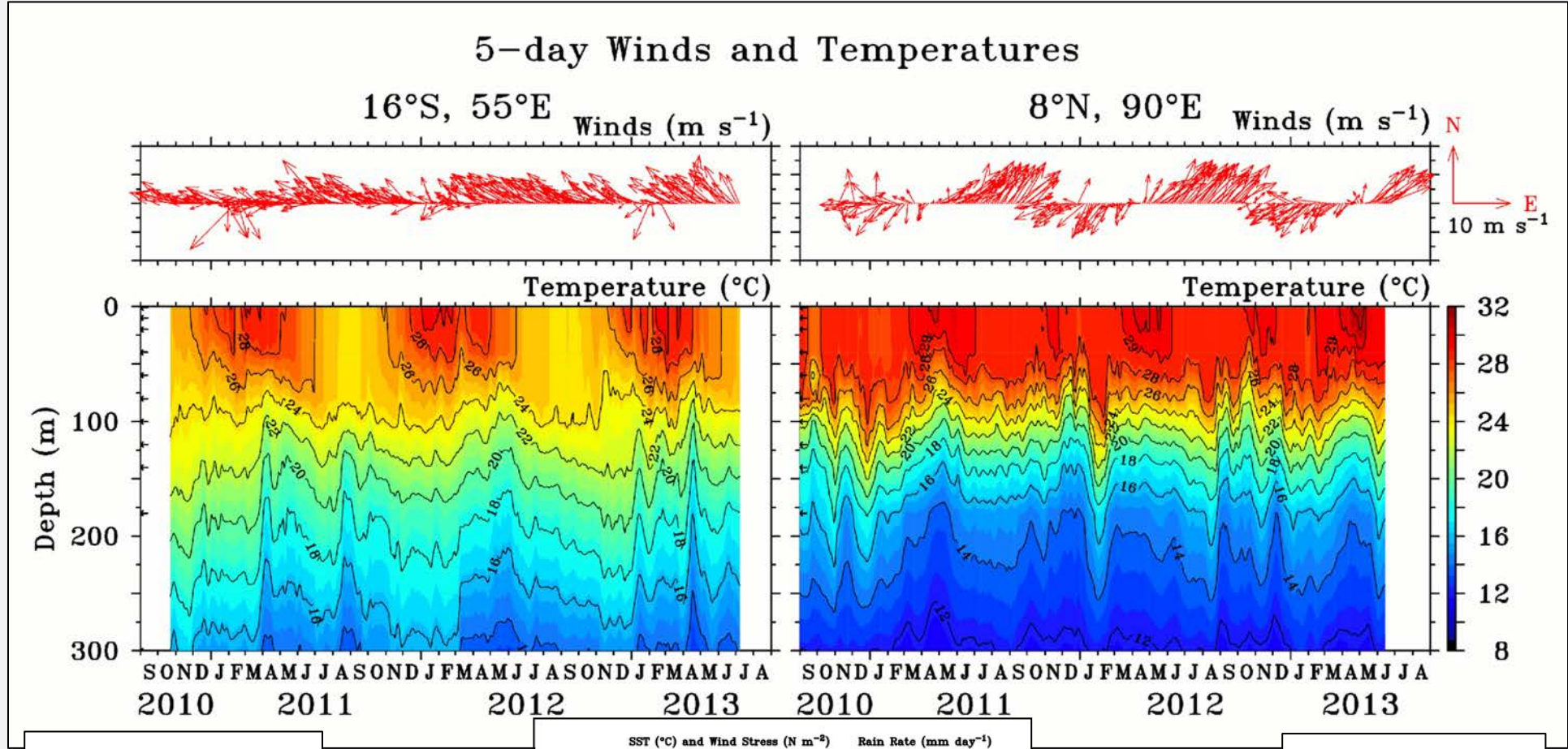


*Design and Implementation Plan published by the  
CLIVAR/GOOS IORP in 2006*

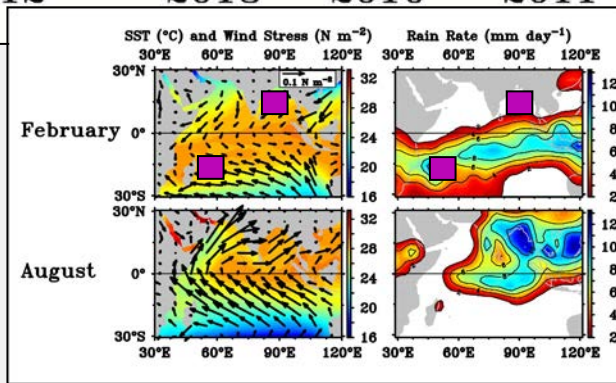
# RAMA Data



# Monsoon vs Trade Wind Regime

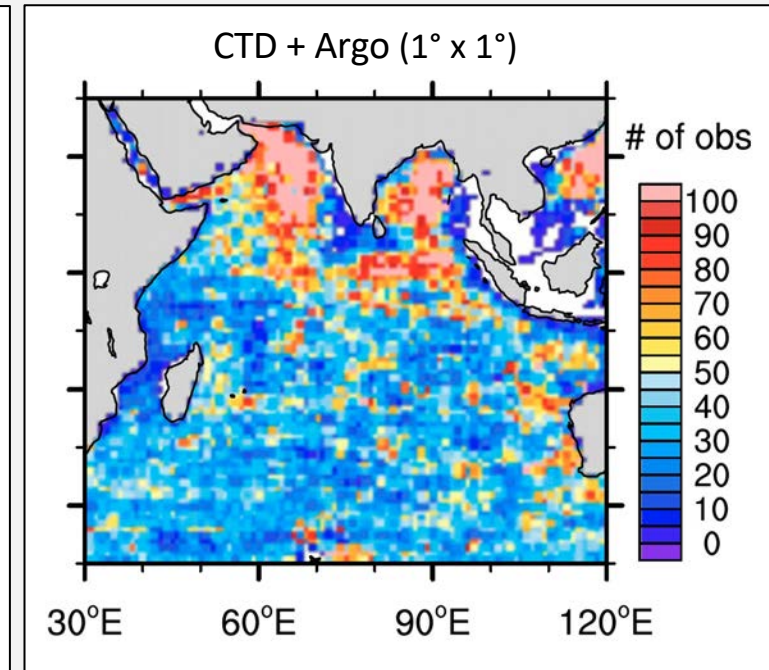
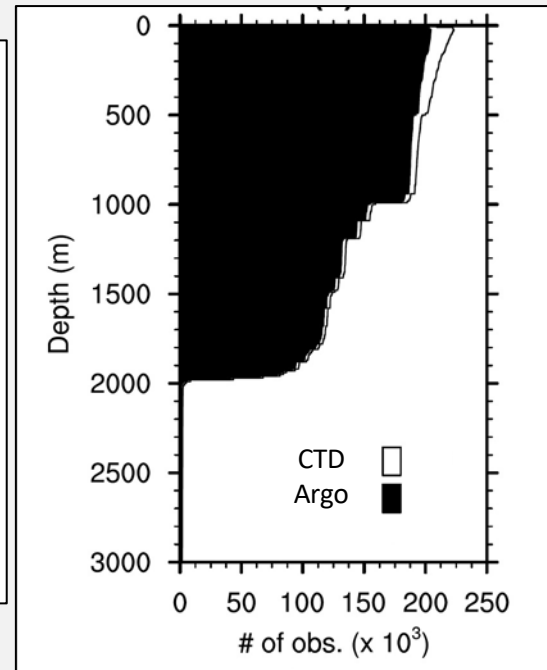
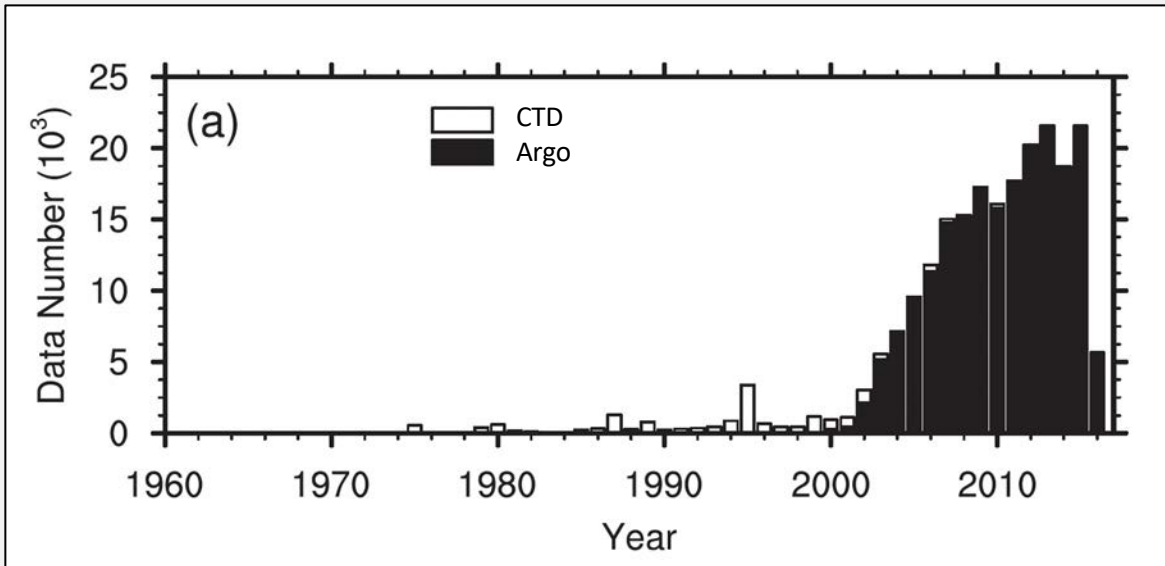


Trade Wind  
Regime



Monsoon  
Regime

# Argo in the Indian Ocean



Reid, J. L., 2003: On the total geostrophic circulation of the Indian Ocean: Flow patterns, tracers, and transports. *Prog. Oceanogr.*

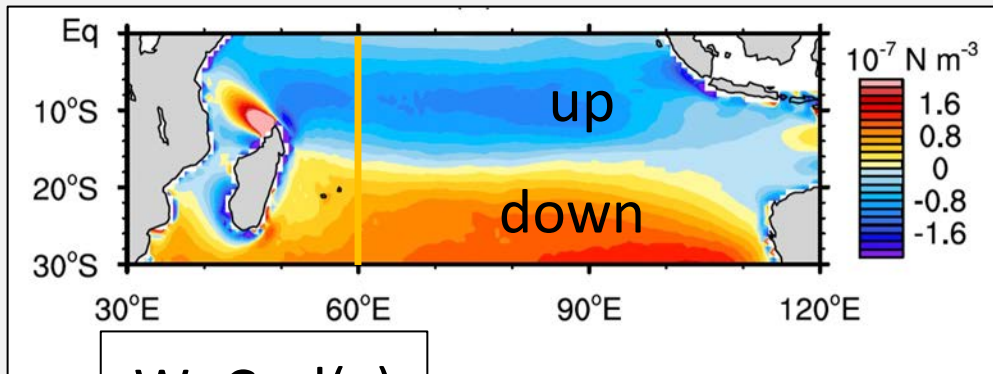
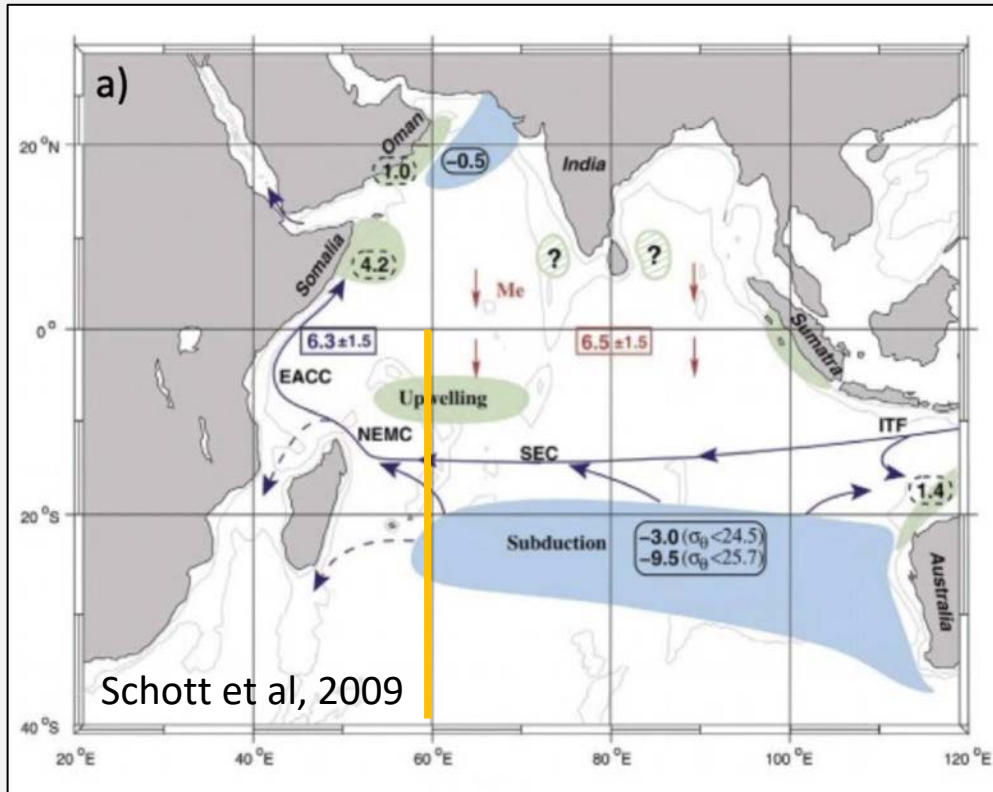
2187 T/S profiles

Nagura, M. and M.J. McPhaden, 2018: The Shallow Overturning Circulation in the Indian Ocean, *J. Phys. Oceanogr.*

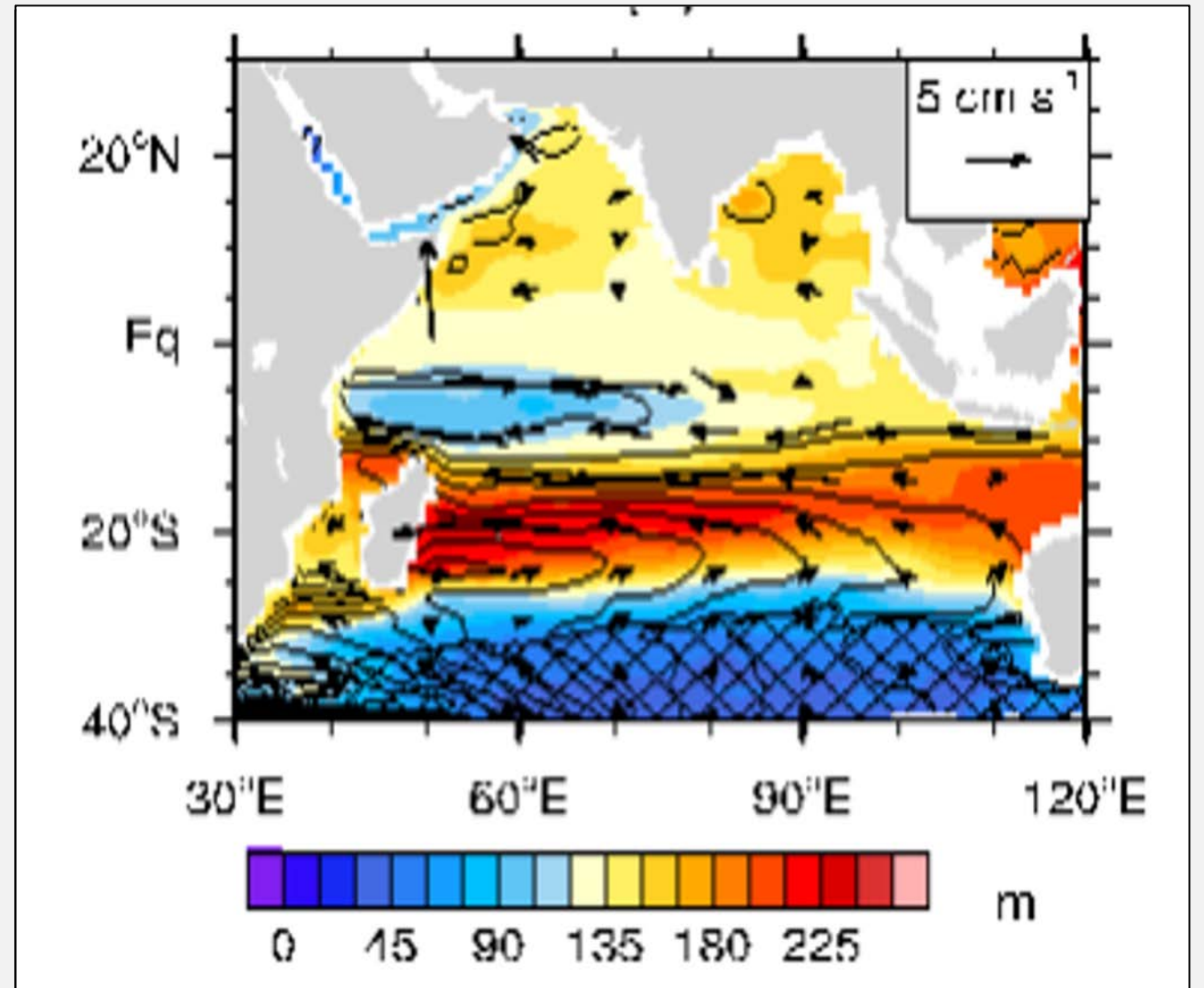
221,614 T/S profiles (92% Argo)



# Subtropical Cell



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







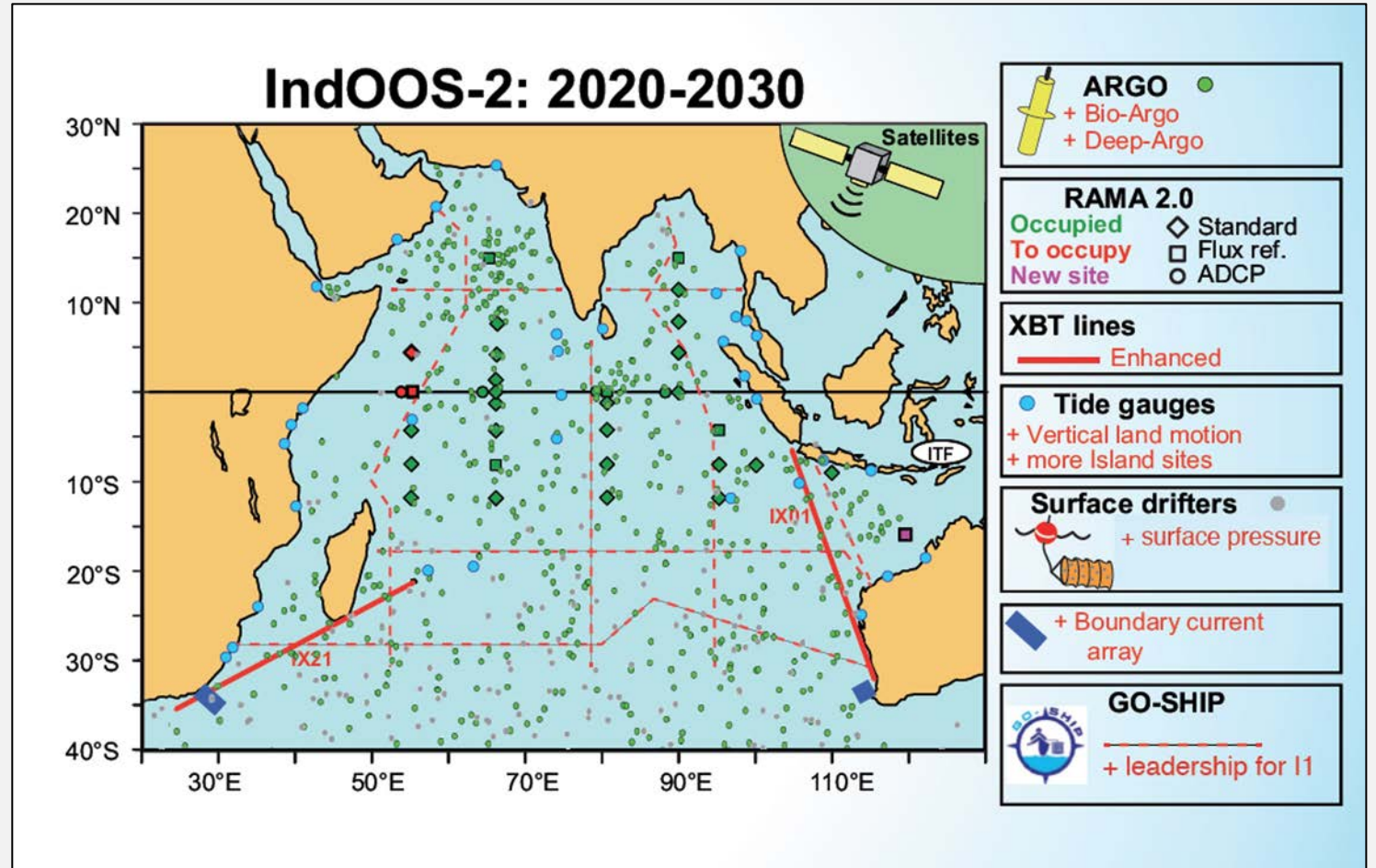
# A Roadmap to Sustained Observations of the Indian Ocean for 2020-2030

Coordinating lead authors

Lisa M. Beal<sup>1</sup>, Jerome Vialard<sup>2</sup>, Mathew K. Roxy<sup>3</sup>

July 2019

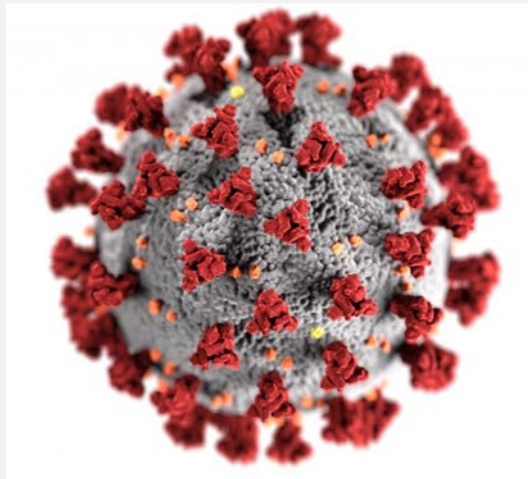
Sponsored by



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

SIDEBAR

Oct 2023

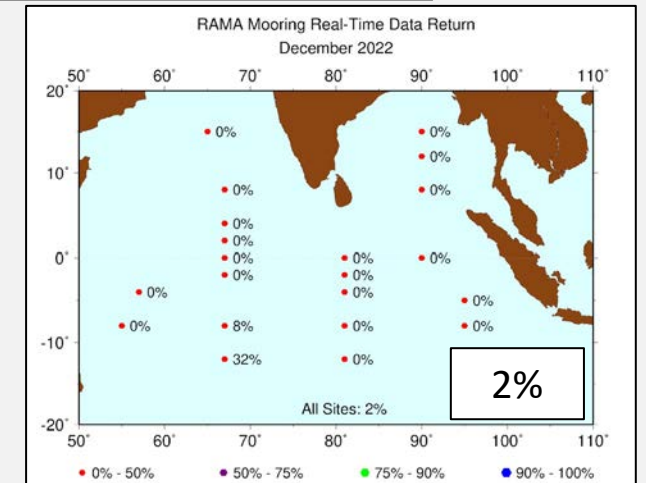
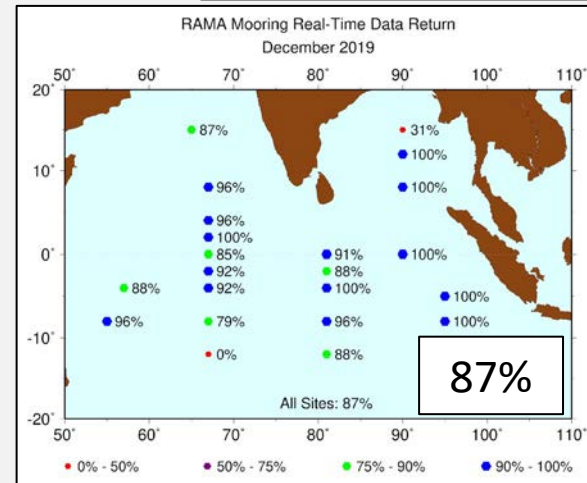
## SURVIVING PIRACY AND THE CORONAVIRUS PANDEMIC

By Kenneth J. Connell,  
Michael J. McPhaden,  
Gregory R. Foltz,  
Renellys C. Perez,  
and Karen Grissom



*Oceanography* THE OFFICIAL MAGAZINE OF THE OCEANOGRAPHY SOCIETY

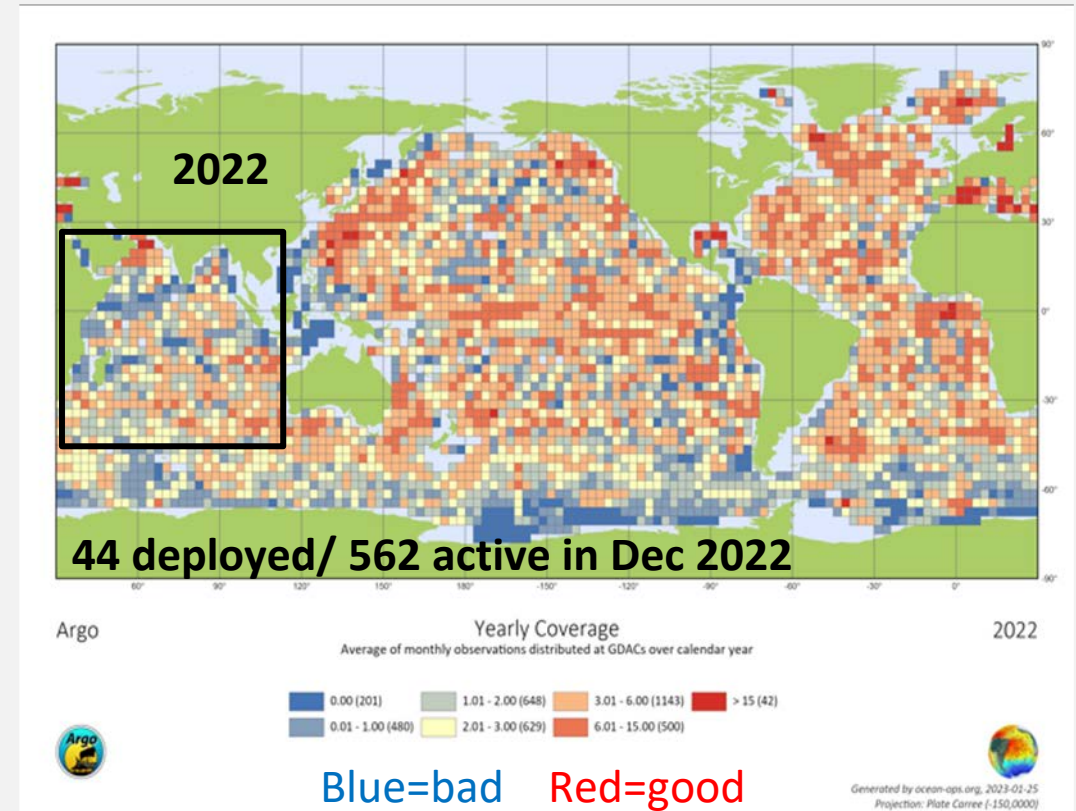
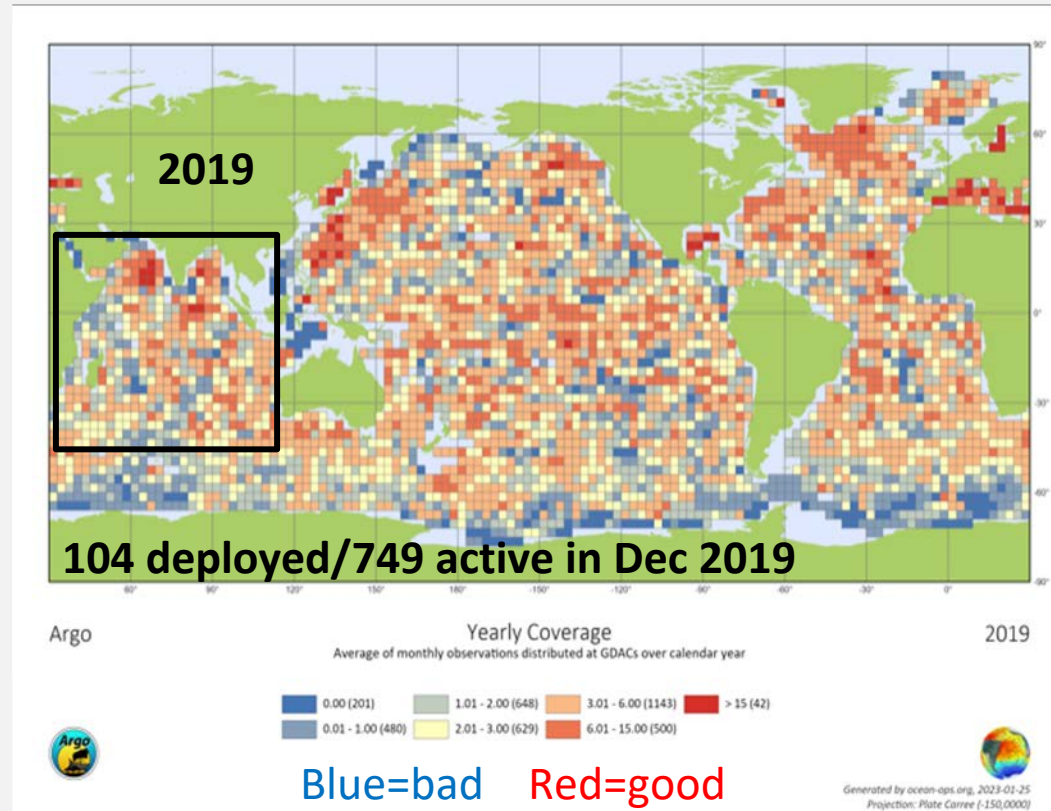
Data return\* in percent for Decembers of 2019 (prepandemic) and 2022 (post pandemic)



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

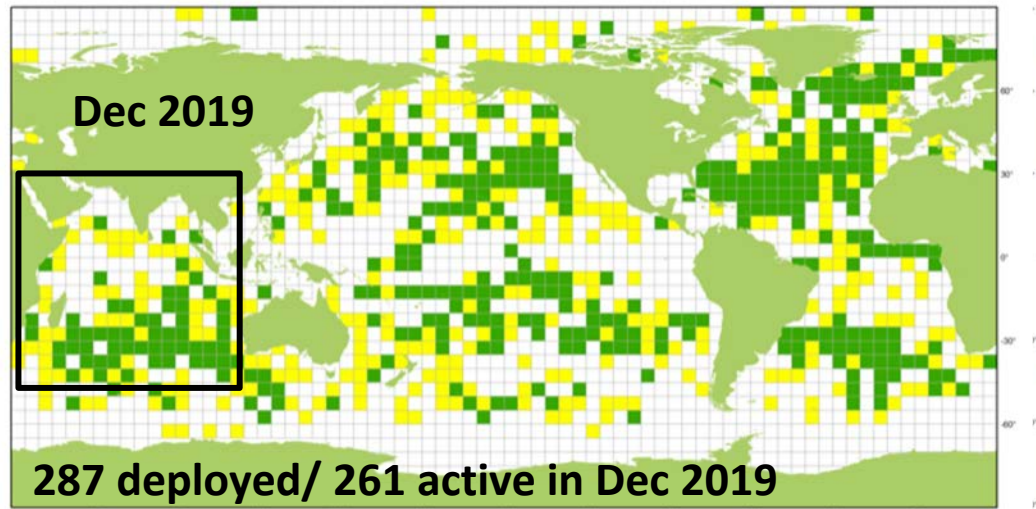
\*Based on the number of days of data acquired divided by the number of days of data expected in a given time period

# COVID-19 Impacts on Indian Ocean Argo



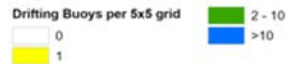
BGC Argo (pH, oxygen, nitrate, chlorophyll, suspended particles, and downwelling irradiance):  
 ~20 deployments/yr pre-pandemic; 5 in 2020, 1 in 2021  
 75 in Dec 2019 → 71 in Dec 2022 (80% > 3yrs old).

# COVID-19 Impacts on Indian Ocean Drifters



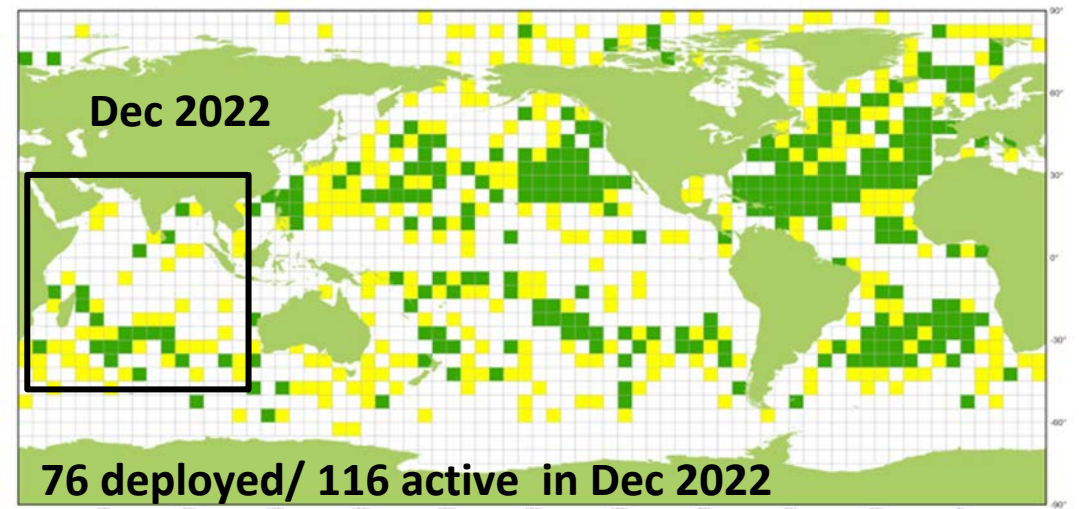
Data Buoy Cooperation Panel Density of Drifting Buoys December 2019

Density of drifting buoys based on the last location during the month. GTS data as received by Meteo France.



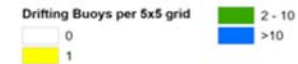
Generated by ocean-ops.org, 2023-01-01  
Projection: Plate Carree (-150,0000)

Green=good Yellow=target



Data Buoy Cooperation Panel Density of Drifting Buoys December 2022

Density of drifting buoys based on the last location during the month. GTS data as received by Meteo France.



Generated by ocean-ops.org, 2023-01-01  
Projection: Plate Carree (-150,0000)

Green=good Yellow=target

## Go Ship Lines

2018-20: 4

2020-22: 0

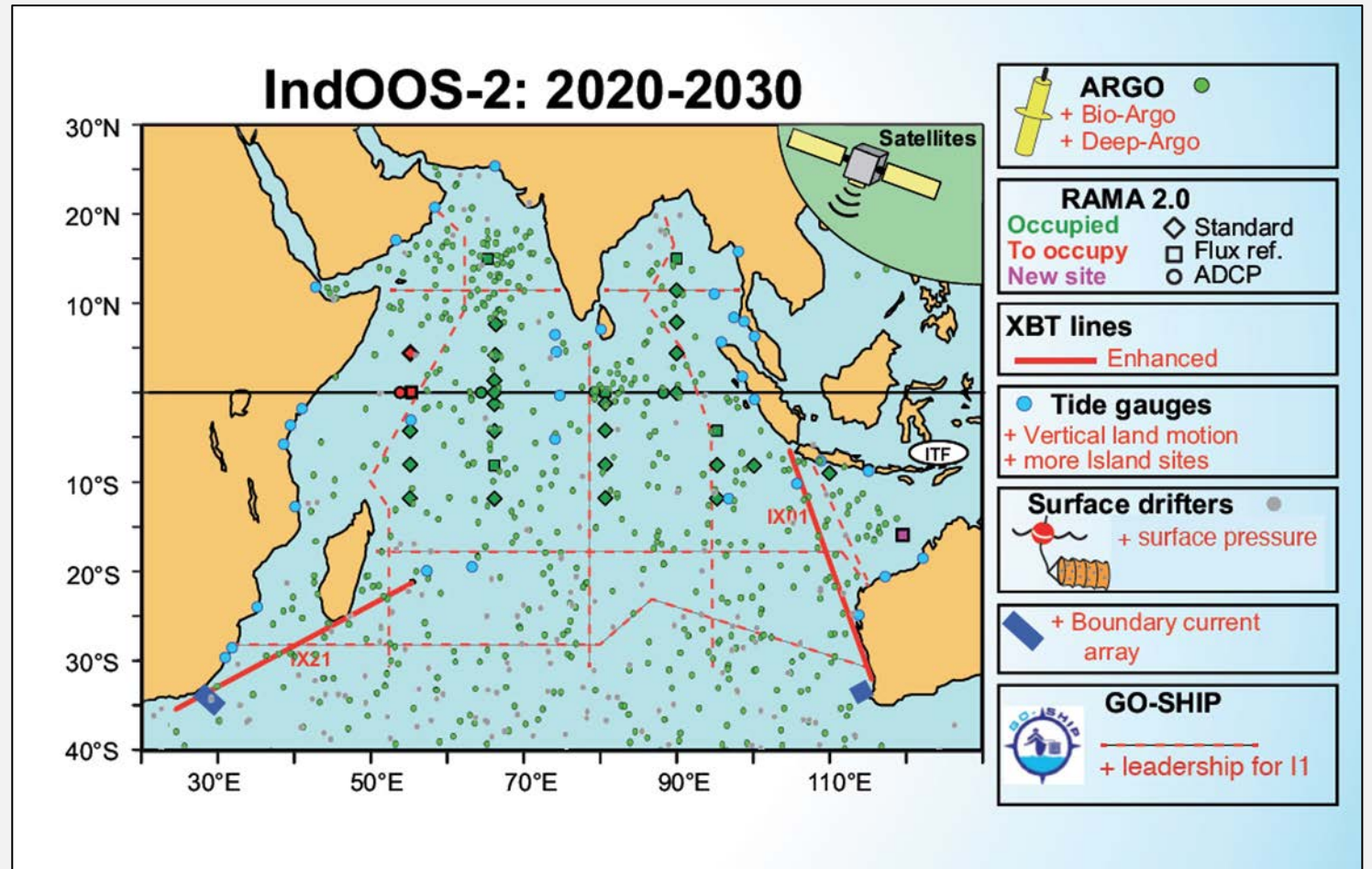
## IX21 XBT Line

2018-20: 9 (HR)

2020-22: 6 (LR)

HR=high resolution (10-50 km)

LR=low resolutions (>50 km)



# Publication in Preparation

*Bulletin of the American Meteorological Society*

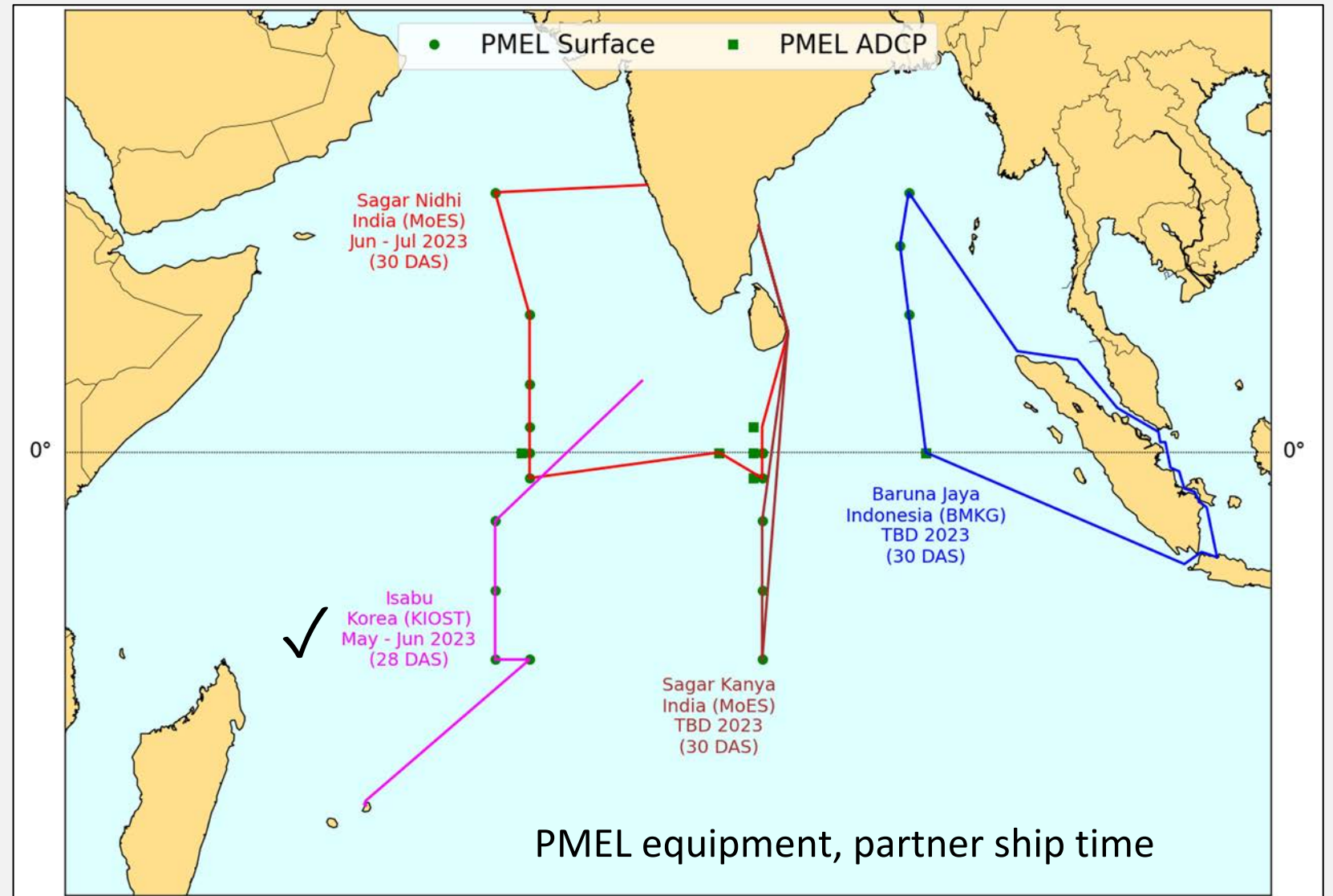
## **COVID Impacts Cause Critical Gaps in the Indian Ocean Observing System**

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..”

# Rebuilding RAMA

## Completed and Planned RAMA Cruises 2023-24







# Partnerships are Strong

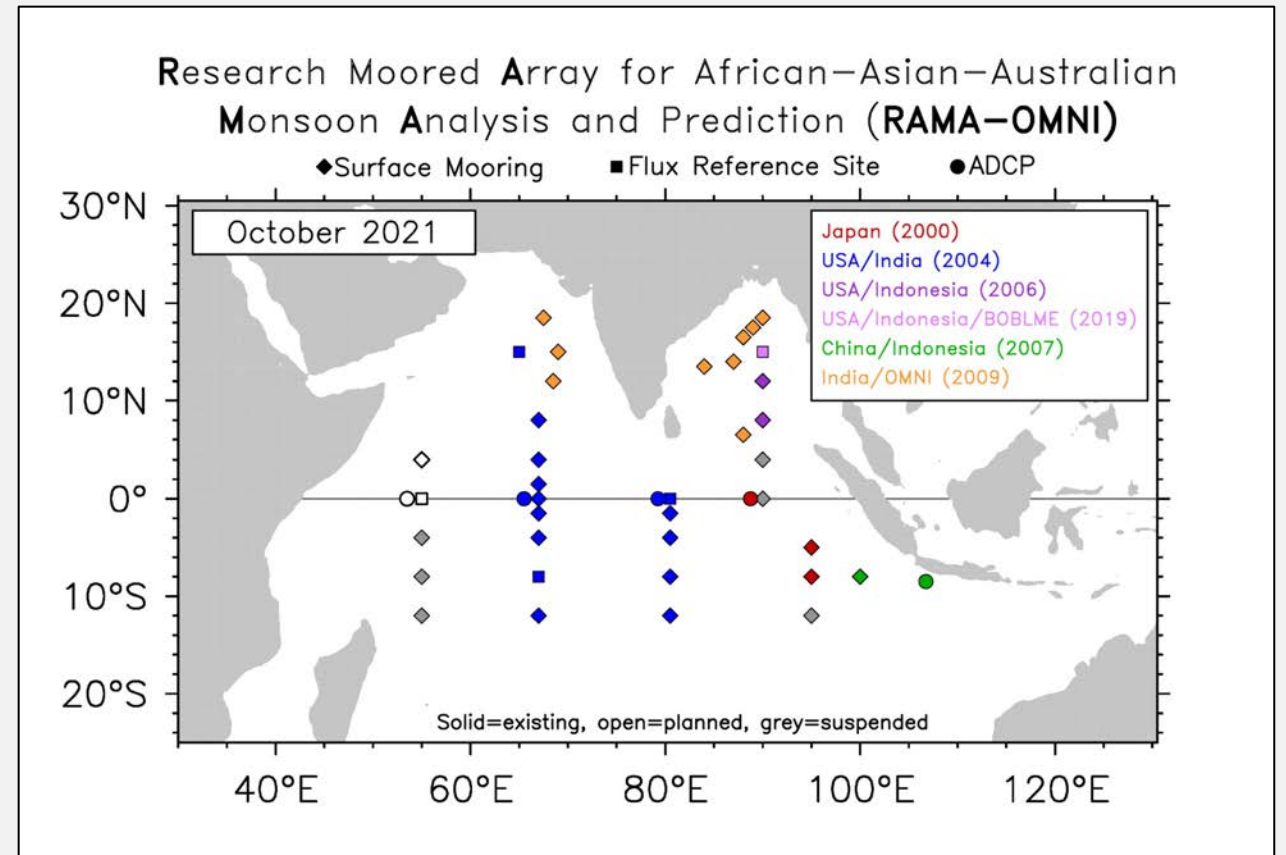
## MoES/NOAA Partnership Renewed for 5 Years

12 August 2021



Joint OMNI/RAMA Data Portal hosted at INCOIS

<https://incois.gov.in/geoportal/Buoys/index.html>





# Partnerships are Strong

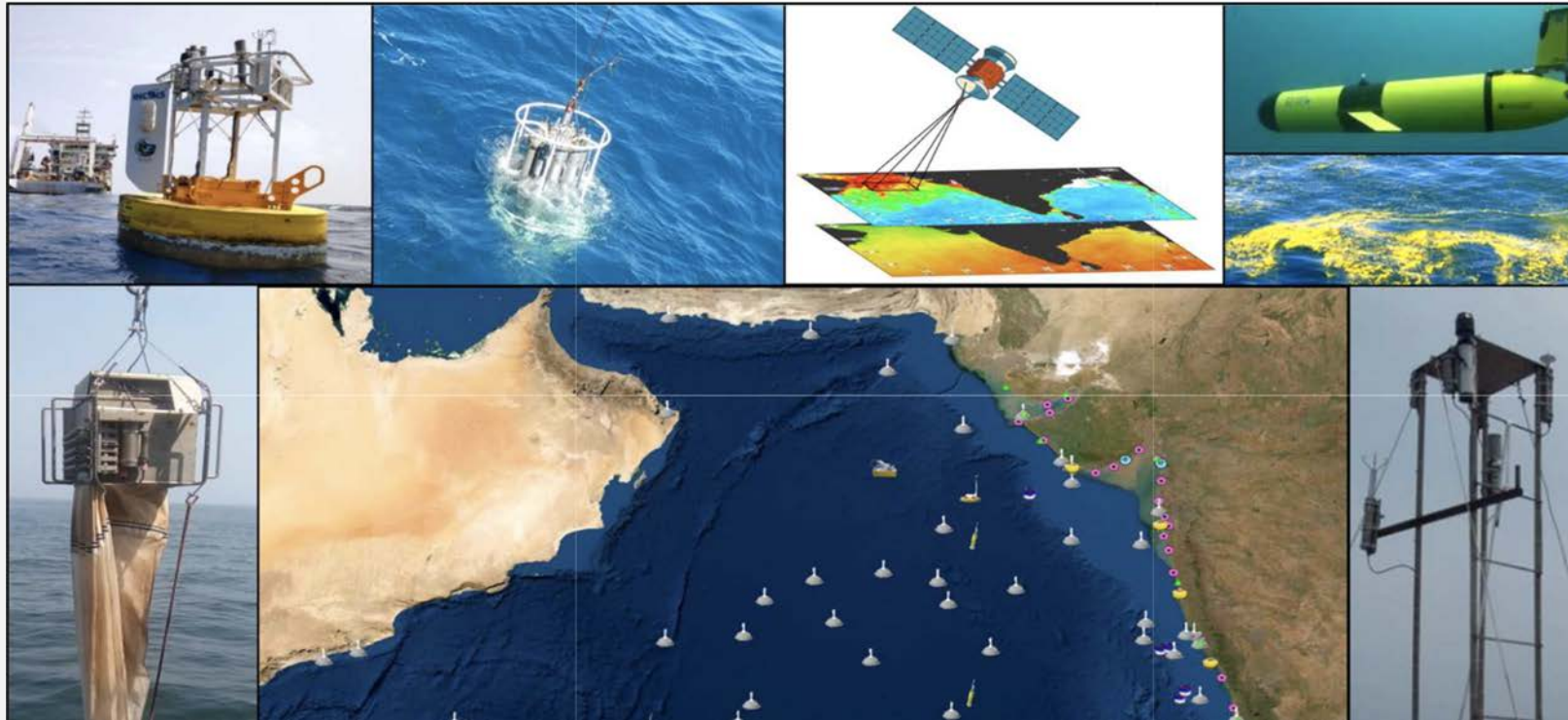


**EKAMSAT - Enhancing Knowledge of the Arabian Sea Marine environment  
through Science and Advanced Training**

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)



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

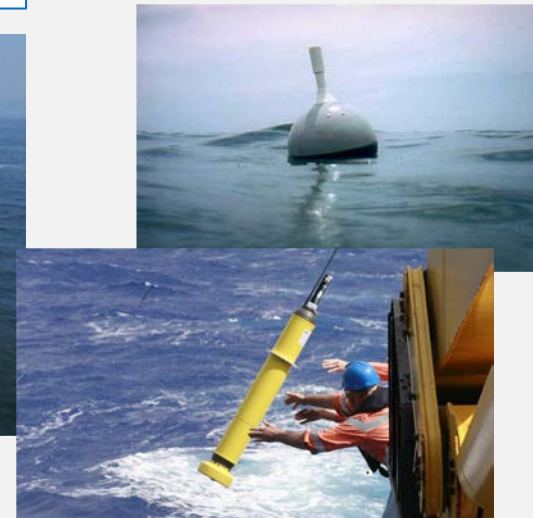
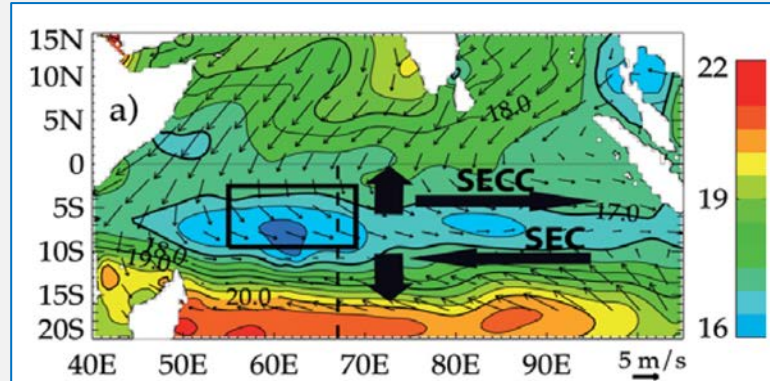
on the

Physical, Biogeochemical and Ecological Dynamics of the Seychelles-Chagos Thermocline Ridge

Michael J. McPhaden<sup>1</sup>, Hyoun-Woo Kang<sup>2</sup>, Robert Anderson<sup>3</sup>, Raleigh Hood<sup>4</sup>, Sang Hwa Choi<sup>2</sup>, Chan Joo Jang<sup>2</sup>, Dong-Jin Kang<sup>2</sup>, Youn-Ho Lee<sup>2</sup>, SungHyun Nam<sup>5</sup>, TaeKeun Rho<sup>2</sup>, Uwe Send<sup>6</sup>, Jerry Wiggert<sup>7</sup>, Dennis Hansell<sup>8</sup>, Ungyul Yi<sup>2</sup>

<sup>1</sup>NOAA/Pacific Marine Environmental Laboratory, Seattle WA, USA  
<sup>2</sup>Korea Institute of Ocean Science and Technology, Busan, Korea  
<sup>3</sup>Lamont-Doherty Earth Observatory, Columbia University, Palisades NY, USA  
<sup>4</sup>Horn Point Laboratory, University of Maryland, Cambridge MD, USA  
<sup>5</sup>Department of Earth and Environmental Sciences, Seoul National University, Seoul, Korea  
<sup>6</sup>Scripps Institution of Oceanography, La Jolla CA, USA  
<sup>7</sup>Division of Marine Science, University of Southern Mississippi, Hattiesburg Space Center MS, USA  
<sup>8</sup>Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL

8 November 2018



2019 KIOST 신규연구사업 기획과제

BSPP00794-10????-?

### 인도양SCTR 한미공동연구사업

(Korea-US inDian Ocean Scientific Research Program on the Physical, Biogeochemical and Ecological Dynamics of the Seychelles-Chagos Thermocline Ridge: 약칭 KUDOS)

### 기억결과보고서

2019. 4.

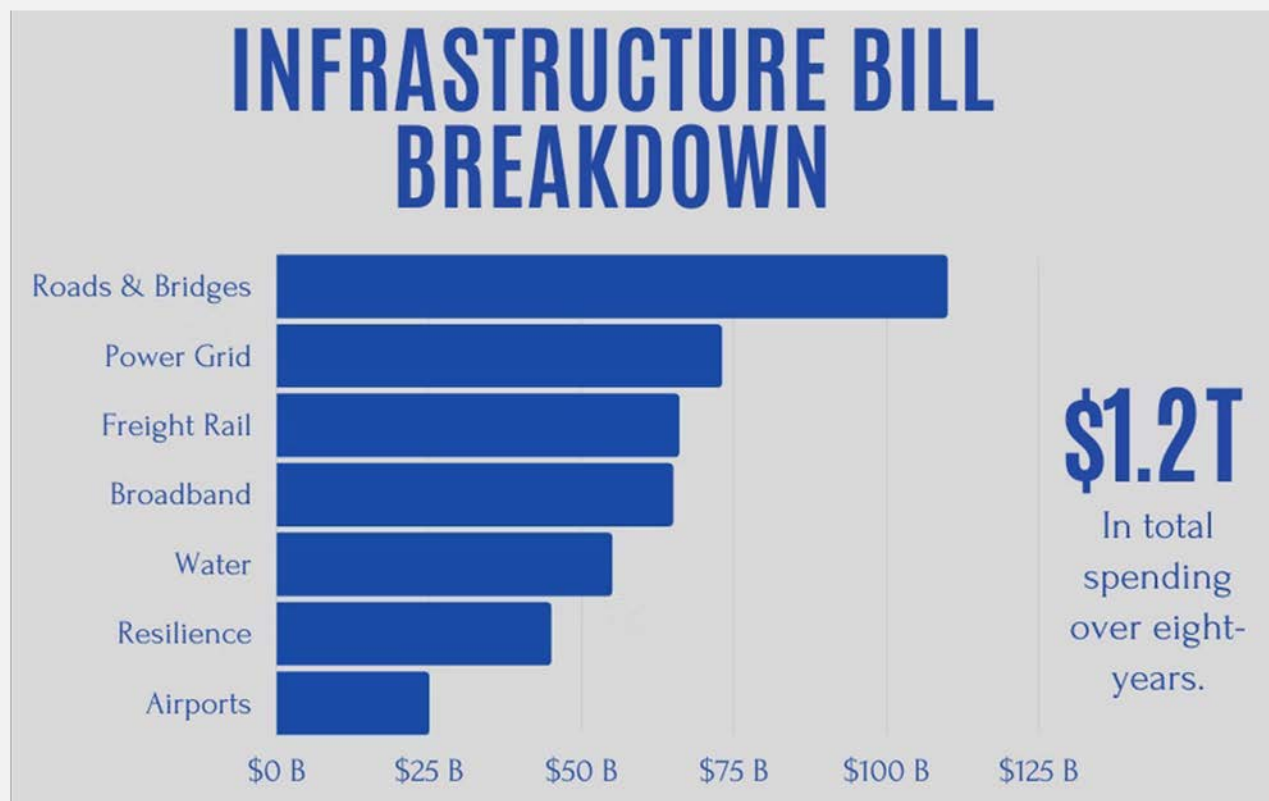


Cruise completed in May-June 2023

Annual cruises planned 2024-26



# Infrastructure Investment and Jobs Act of 2021 (aka Bilateral Infrastructure Law)



*\$2.5 M for RAMA/PIRATA mooring recapitalization*

# Publication in Preparation

*Bulletin of the American Meteorological Society*

## **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

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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

谢谢

Terima Kasih

धन्यवाद

**Thank you!**

고맙습니다

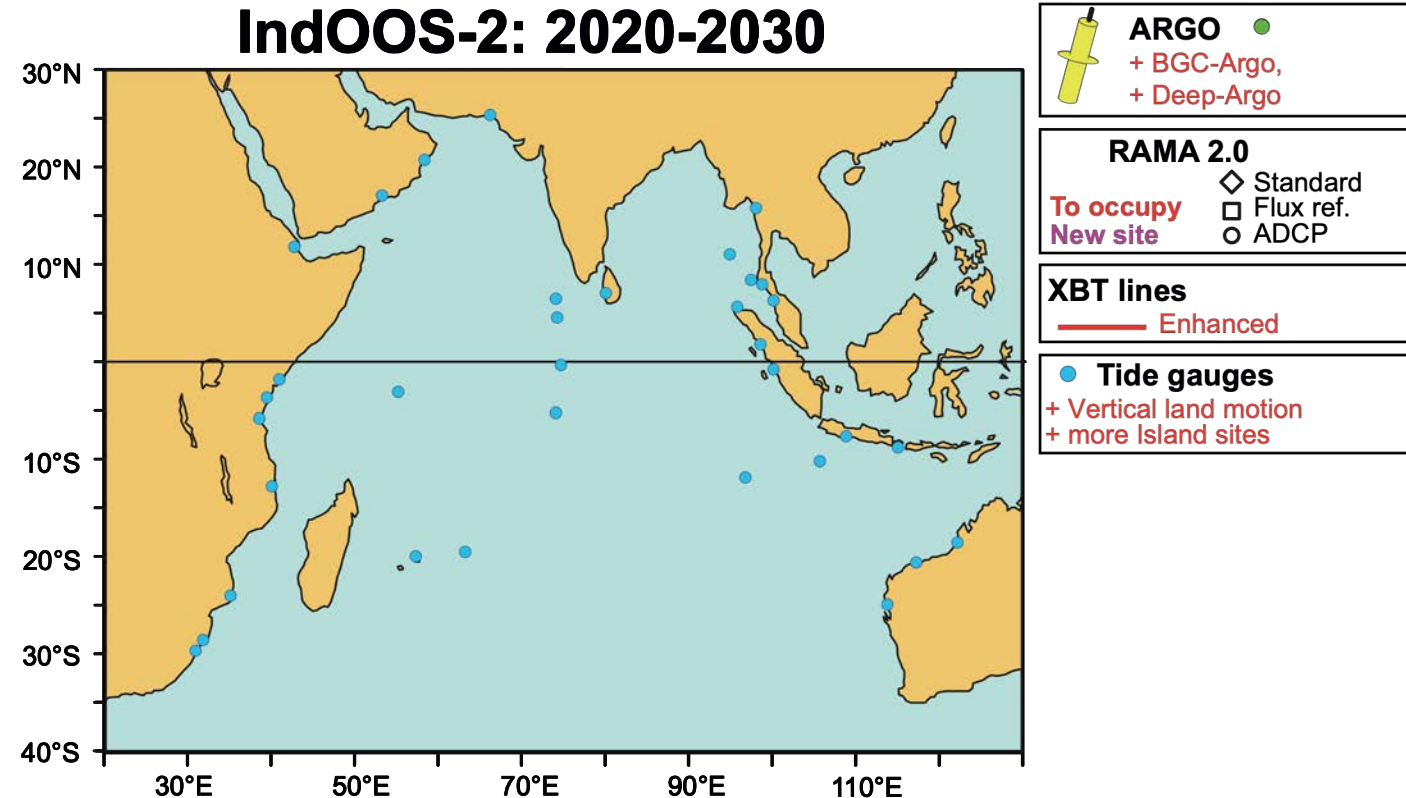
ありがとうございました

Merci

# 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 mapCO<sub>2</sub>, 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 pCO<sub>2</sub>.
- **Tide gauges**: Add colocated measurements of land motion, add sites in SW Indian Ocean and on islands.





# Actionable Recommendations Summary

## Tiers I and II: Maintain and Extend

- **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,O<sub>2</sub>, 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.

