IndOOS-2: A roadmap to sustained observations of the Indian Ocean for 2020-2030

The Global Ocean Observing System

GLOBAL OCEAN OBSERVING SYSTEM FOR INDIAN OCEAN

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World Climate Research Programme

United Nations Educational, Scientific and Cultural Organization

Intergovernmental Oceanographic Commission

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

U.S. DEPARTMENT OF COMMERCE

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International Association for the Physical Sciences of the Oceans

IndOOS-2

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

Coordinating lead authors

Lisa M. Beal[1], Jerome Vialard[2], Mathew K. Roxy[3]

+ 60 authors

Dec 2019

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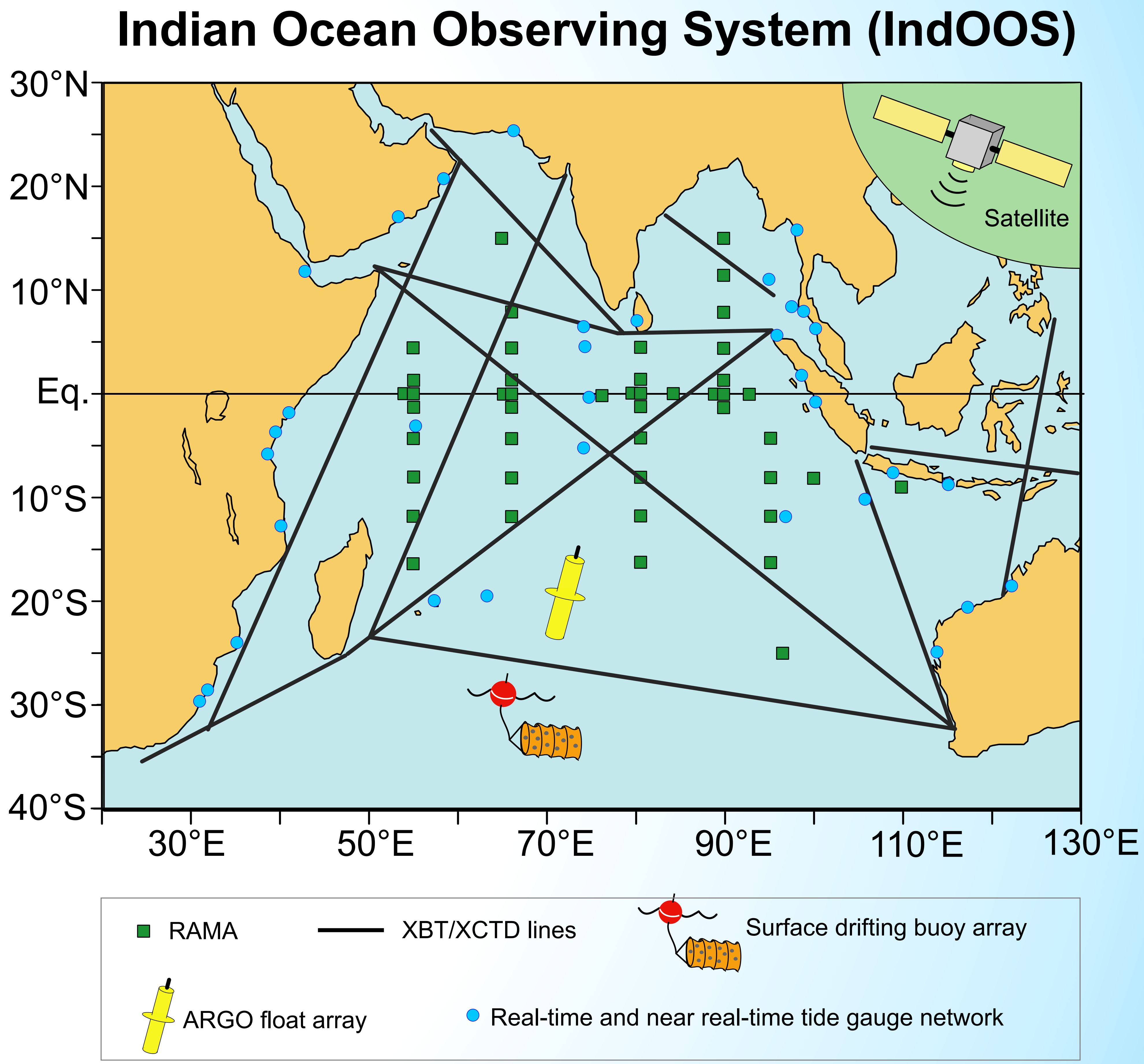
What is the Indian Ocean Observing System?

The mission of the IndOOS is to provide sustained, high-quality oceanographic and marine meteorological measurements that support knowledge-based decision-making through improved scientific understanding, and ultimately, through improved weather, ocean, and climate forecasts.

Why a review of IndOOS and roadmap to IndOOS-2?

- IndOOS design was established on the basis of an Implementation Plan drafted by the CLIVAR IORP in 2006.
- Since then, 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.
- The review findings provide a roadmap to address the clear and urgent need for expansion of the Indian Ocean observing system, designed to meet the requirements of a broad suite of users, as recognised in the GOOS 2030 Strategy.



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   b. Articulating the scientific and operational drivers of IndOOS and their societal impacts;
   c. Identifying the Essential Ocean Variables (EOVs) that address these drivers, their geographical coverage and spatio-temporal resolution.

Numbers of IndOOS-2

2000 +
EMAILS

60
AUTHORS

35
MONTHS

25
CHAPTERS

6
REVIEWERS

3
EDITORS

3
WORKSHOPS

= 136
ACTIONABLE
RECOMMENDATIONS

3-yr Timeline

Dates	Event
31 Jan – 2 Feb 2017	1st **IndOOS Review Workshop (Perth, Australia**): TORs, scope, outline
Feb – Mar 2017	Formulation of writing team, guidelines, and timeline
Jun 2017	Formulation of IndOOS Review Board
Apr – Sep 2017	First draft of 25 IndOOS Review chapters
Oct – Nov 2017	Cross-chapter review by lead authors, IORP, and SIBER
Dec 2017	First draft of Executive Summary
Jan – Mar 2018	Reviews of complete first draft from Review Board and broader community
22 – 23 Mar 2018	2nd **IndOOS Review Workshop (Jakarta, Indonesia**): Chapter presentations and discussion, reviews, formulation of rubric for prioritisation
Aug 2018	Comments and reviews collated and sent to lead authors with guidelines for final chapter revision
Aug – Nov 2018	Second draft of 25 IndOOS Review chapters
Nov 2018 – Feb 2019	Editing of all chapters, prioritisation of Actionable Recommendations, Second draft of Executive Summary, first draft of Introduction and Synthesis
Feb – Apr 2019	Final reviews and comments on complete second draft
14 – 15 Mar 2019	**Final IndOOS Review Workshop (Port Elizabeth, South Africa**): Final discussions focussing on possible omissions; Outcomes and implementation
June 2019	Final version ready for layout and proof reading
Sep 2019	Publication of Executive Summary ready for OceanObs'19
Dec 2019	Publication of full report and official launch during WCRP Climate Week at Fall AGU

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22 – 23 Mar 2018	**2nd IndOOS F** reviews, form
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Aug – Nov 2018	Second draft
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Feb – Apr 2019	Final reviews
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University of Hawaii

CLIVAR

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University of Cape Town

IMBeR

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WHOI, USA

CLIVAR

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CSIRO, Australia

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Peter Dexter, BOM, Australia

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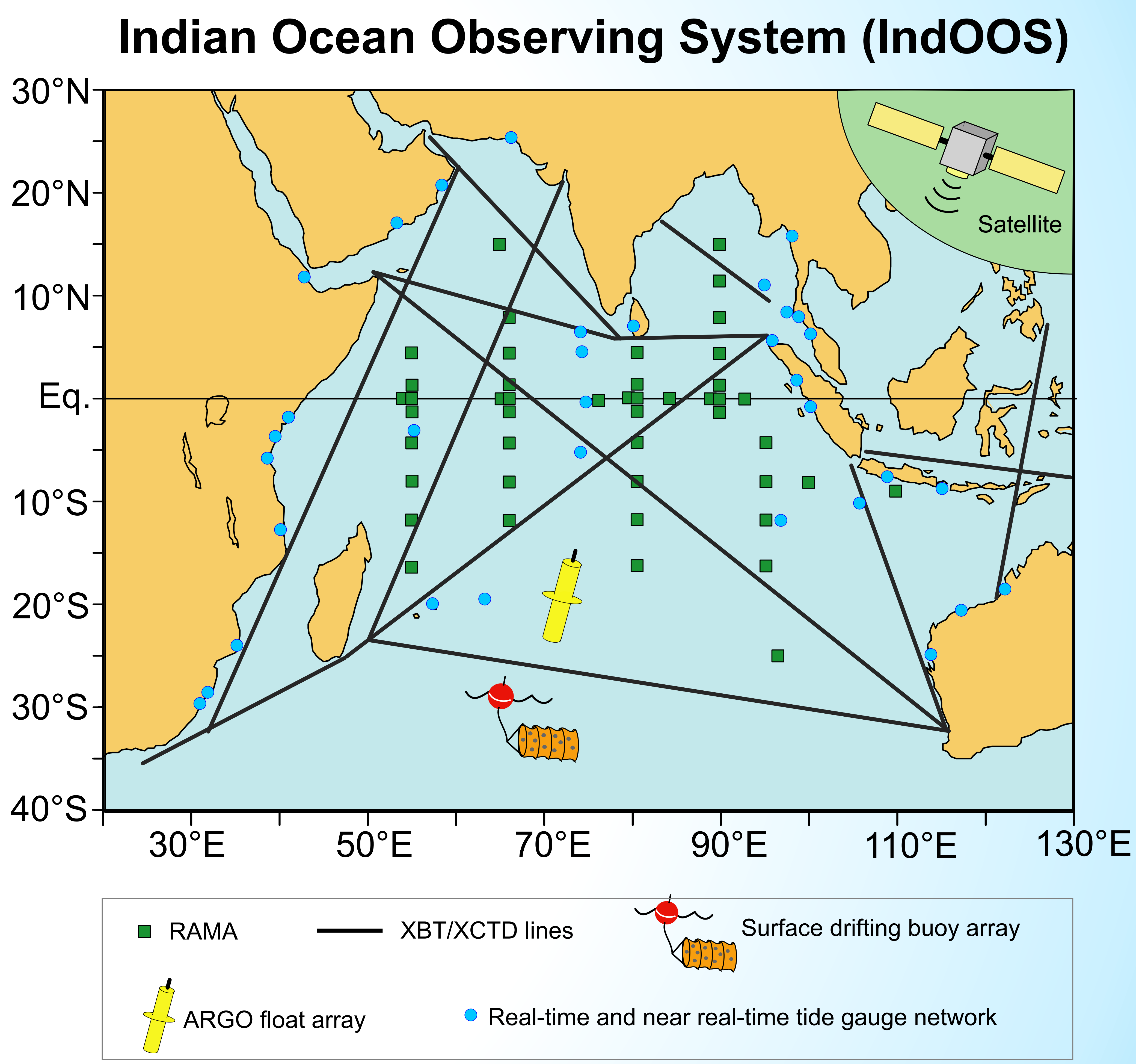
Review: Achievements of the IndOOS



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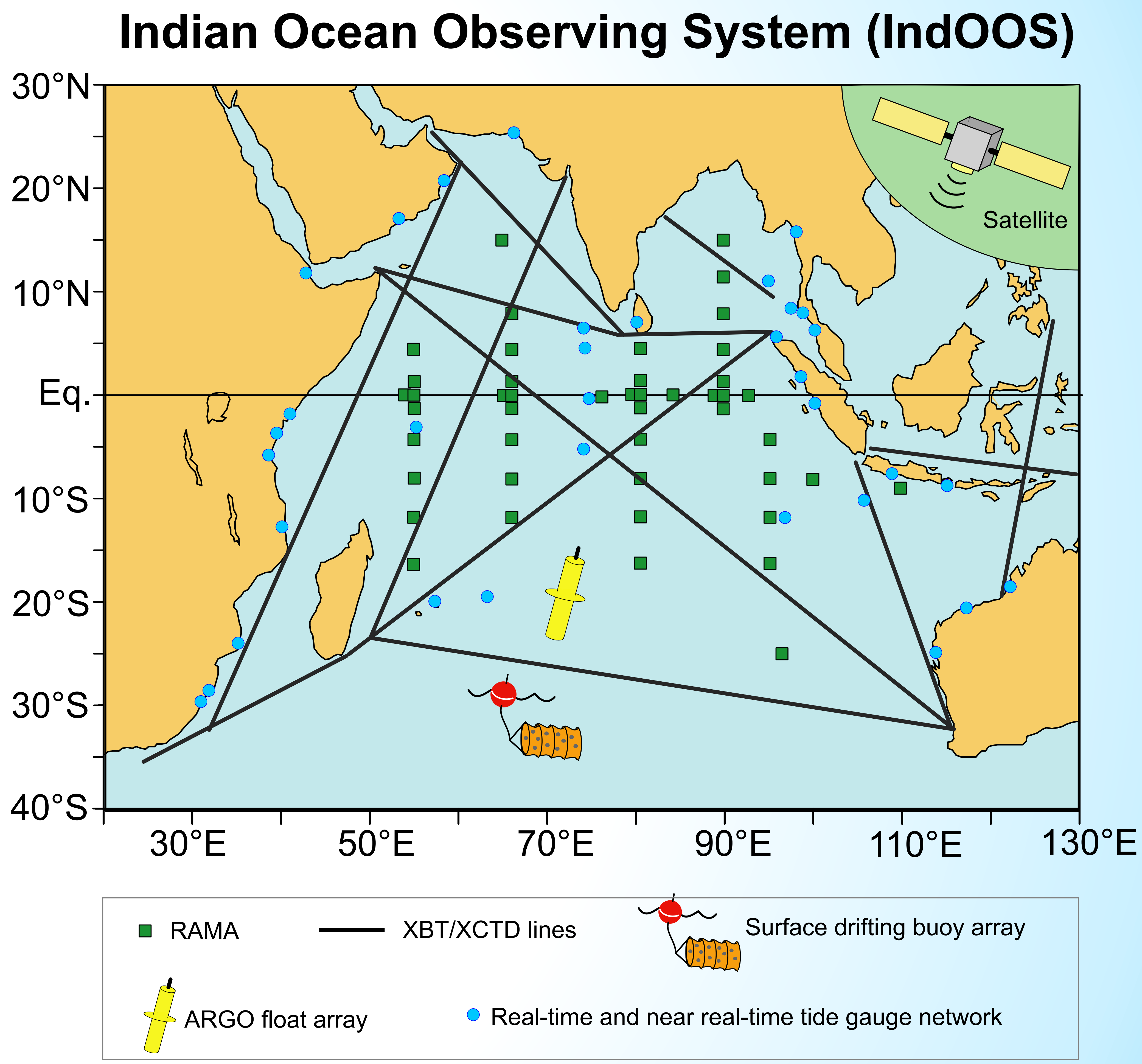
IndOOS has provided unprecedented knowledge of weather, ocean, and climate phenomena, among them:



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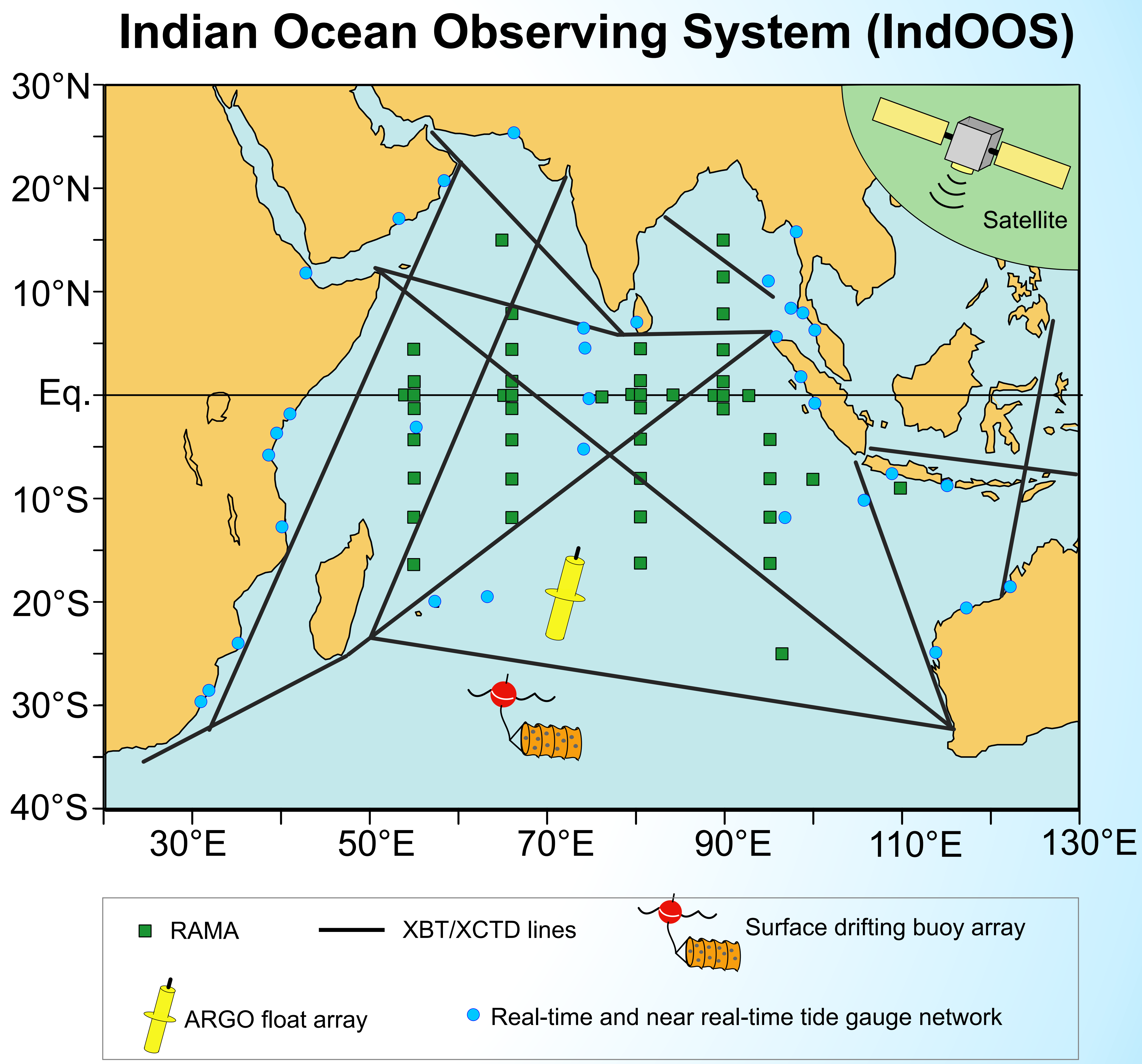

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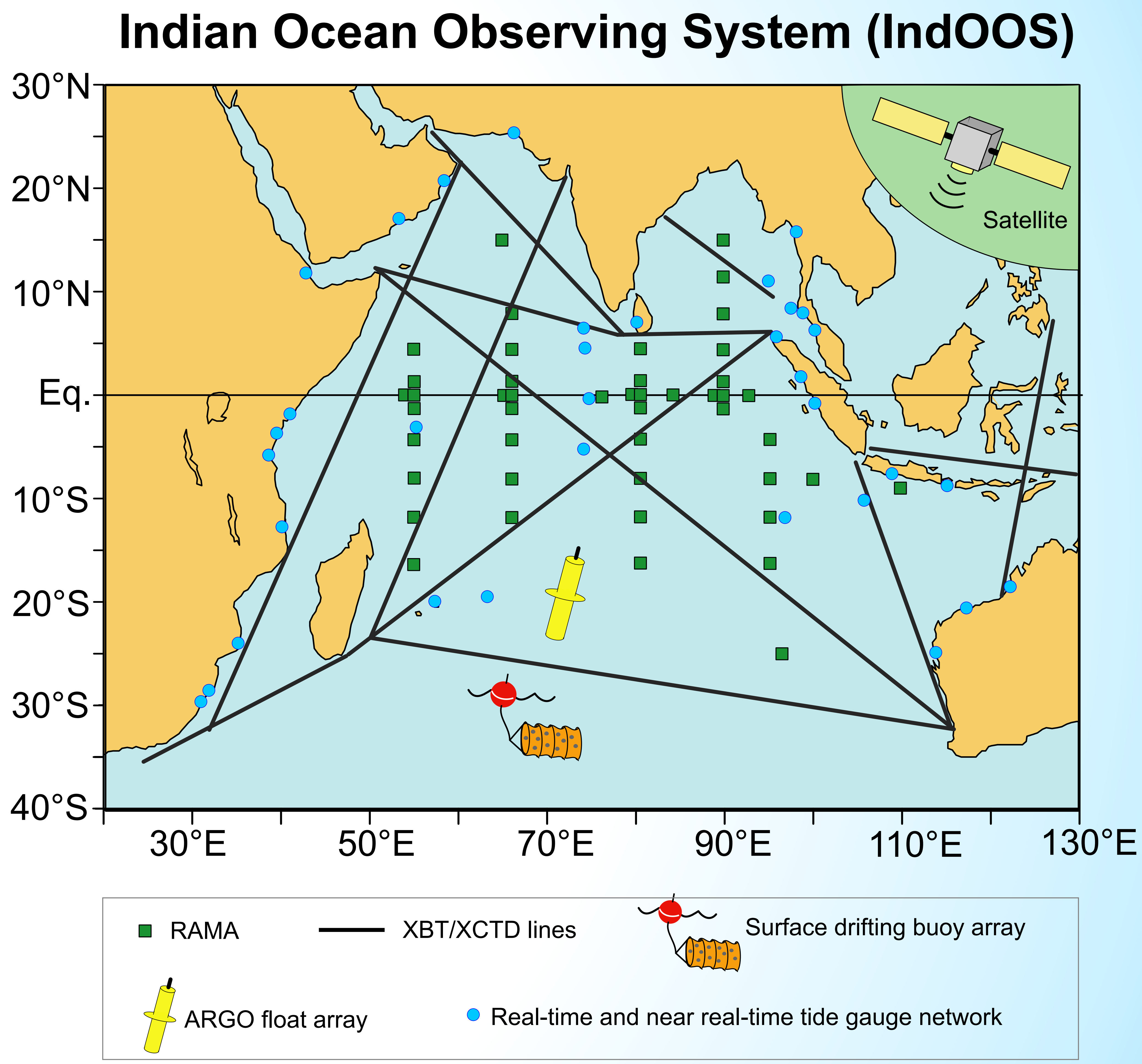

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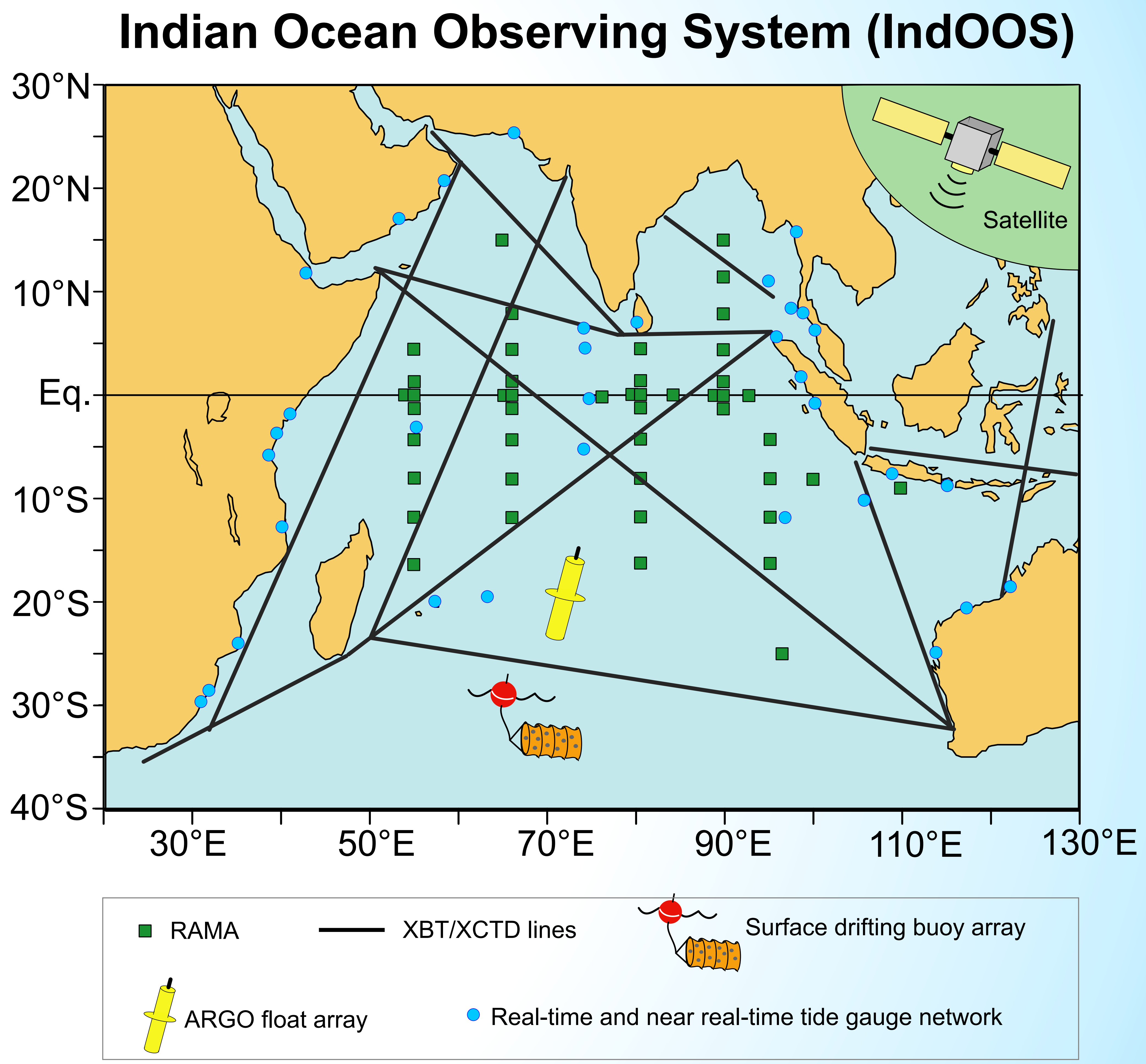

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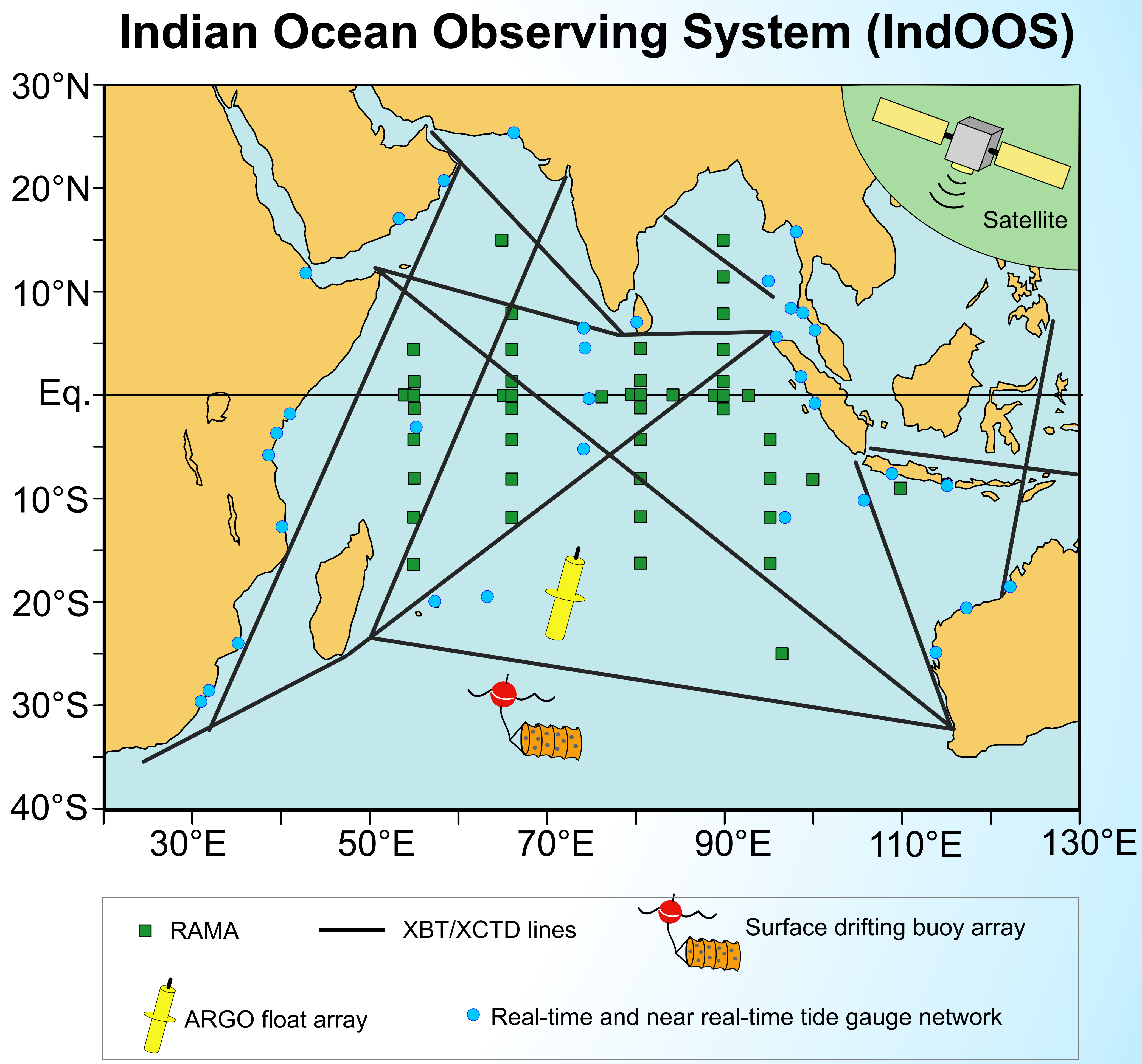
- Elucidated year-to-year climate variations in the tropical Indian Ocean (IOD) and their relationship to tropical Pacific climate variations (ENSO)



Review: Remaining gaps

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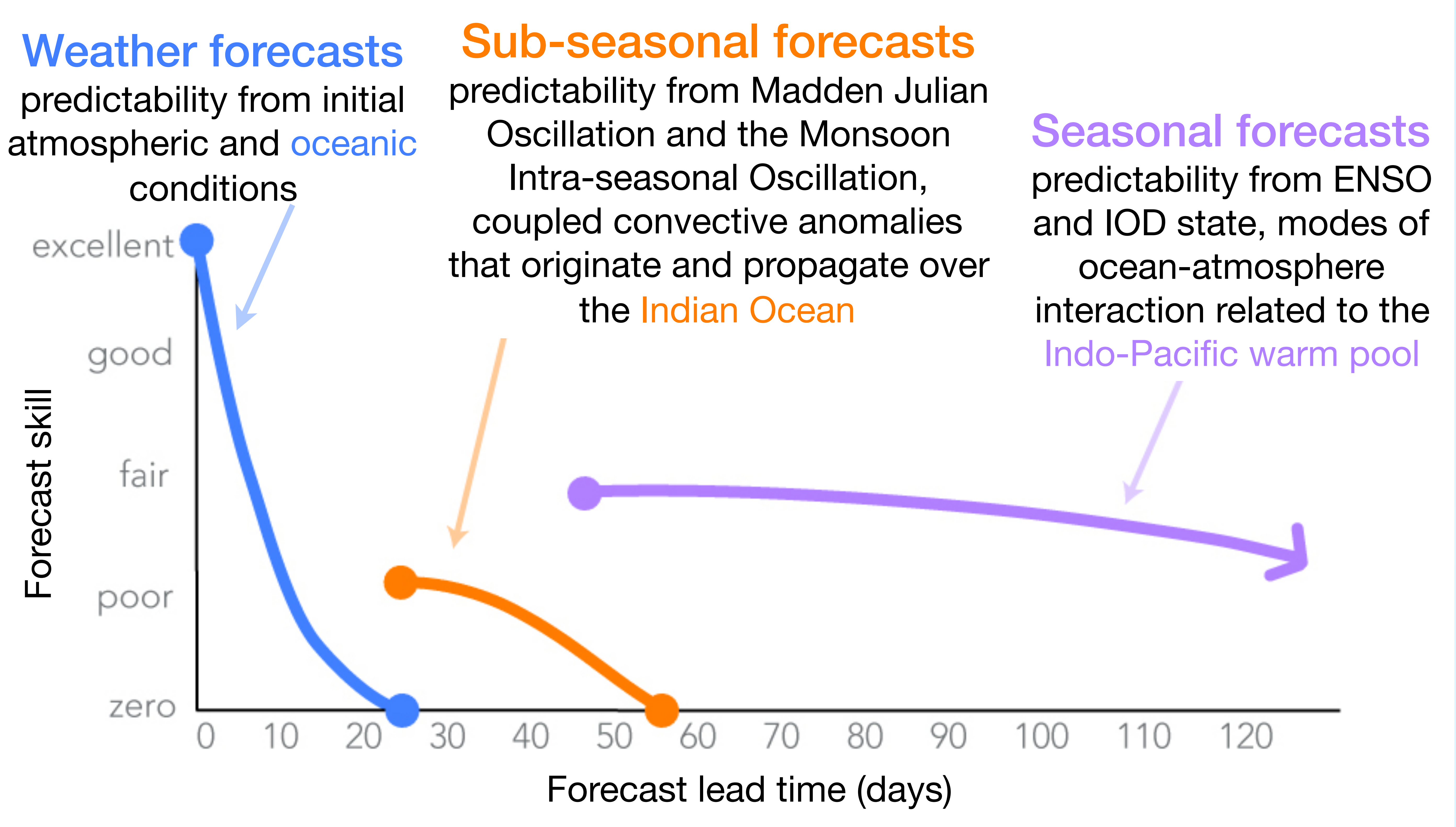

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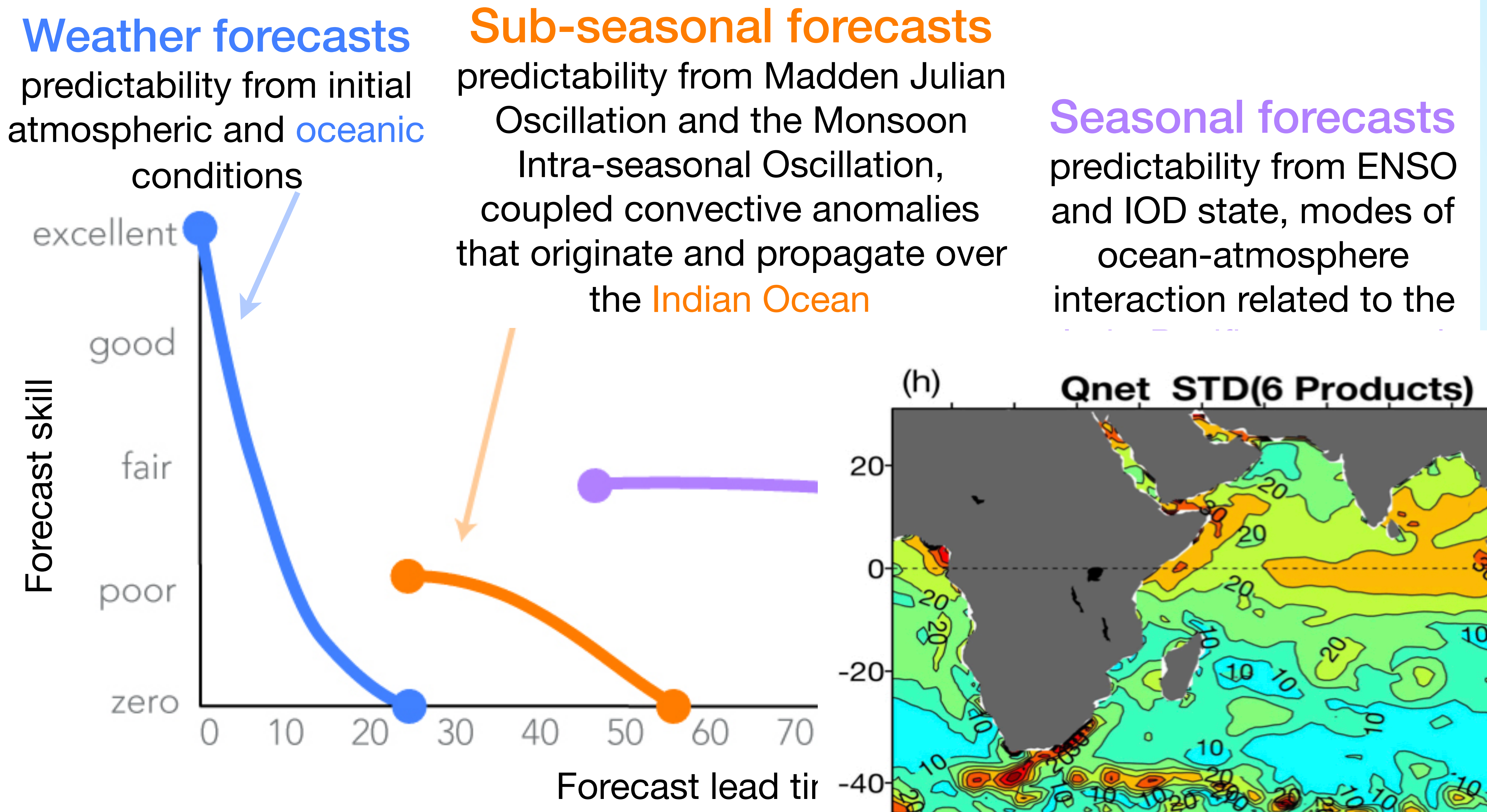

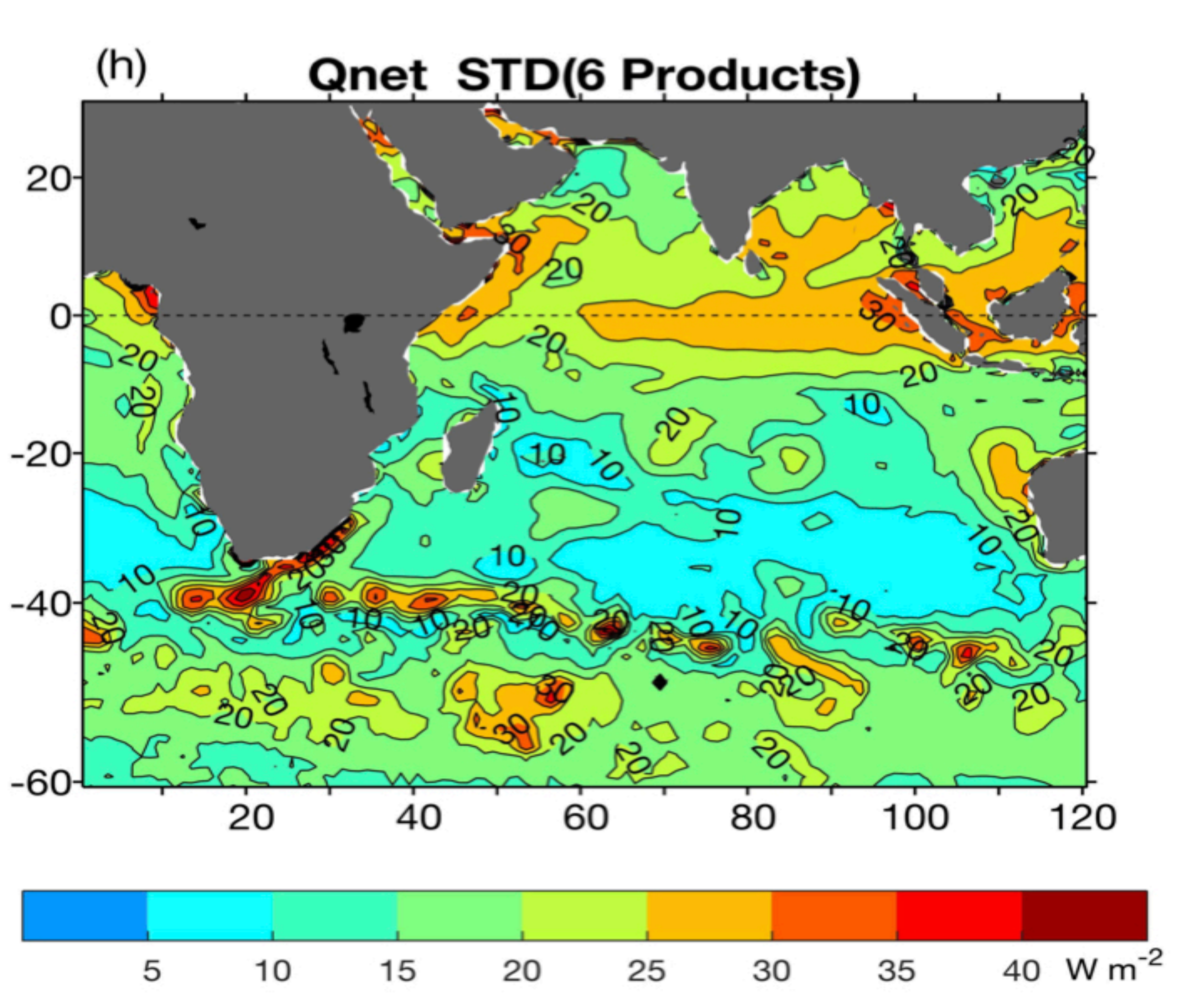

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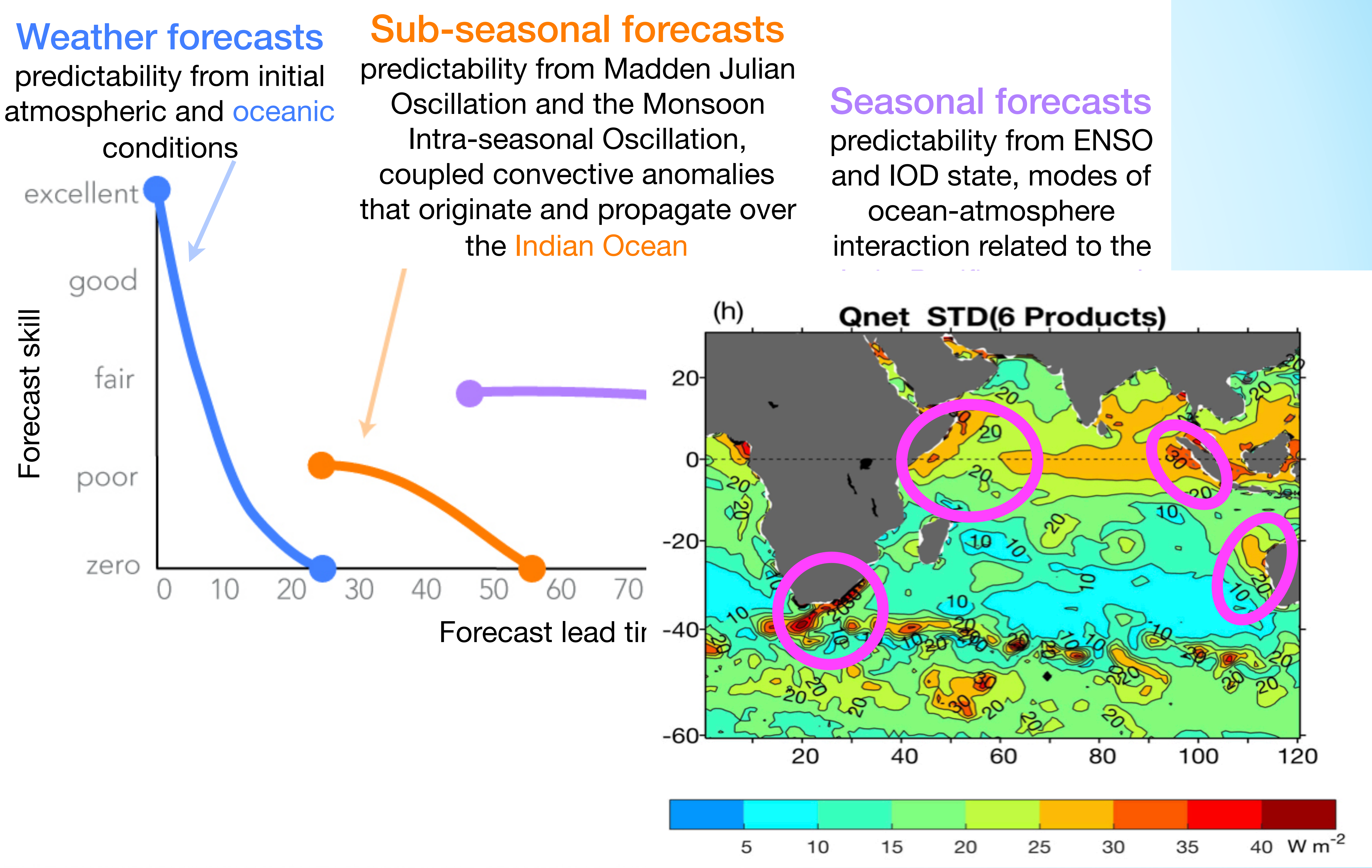

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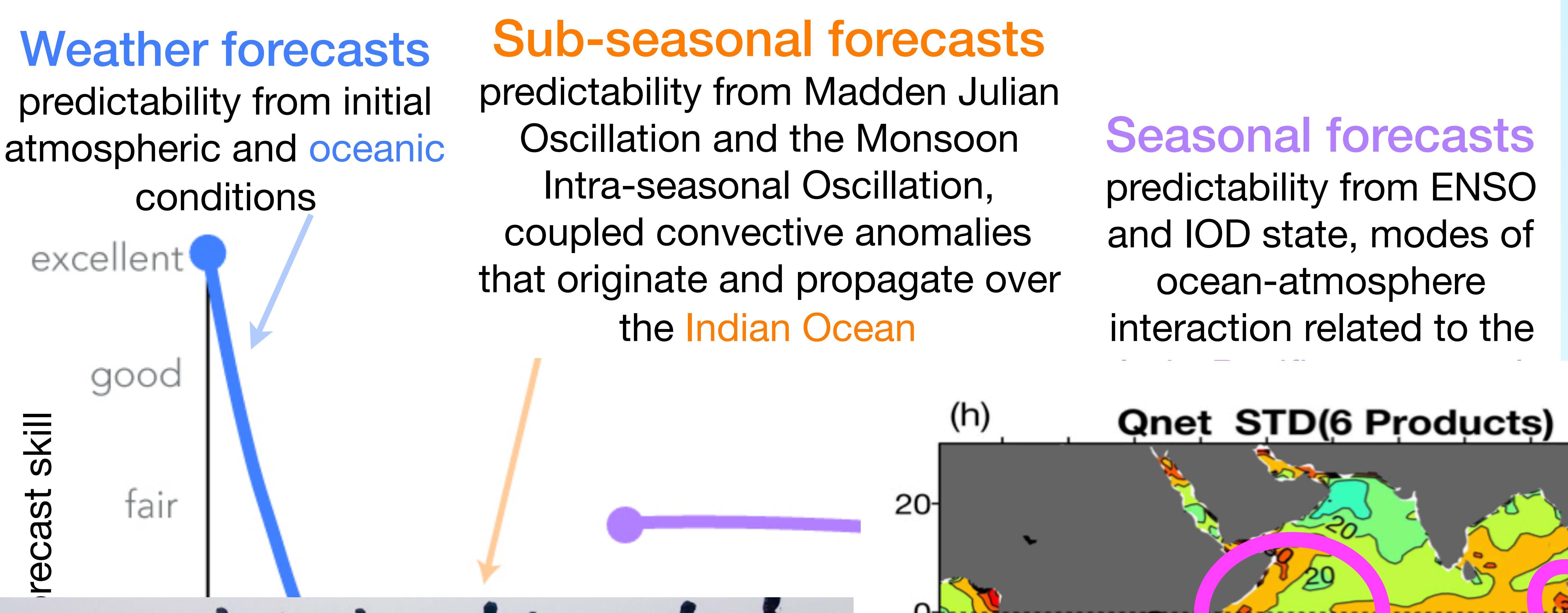
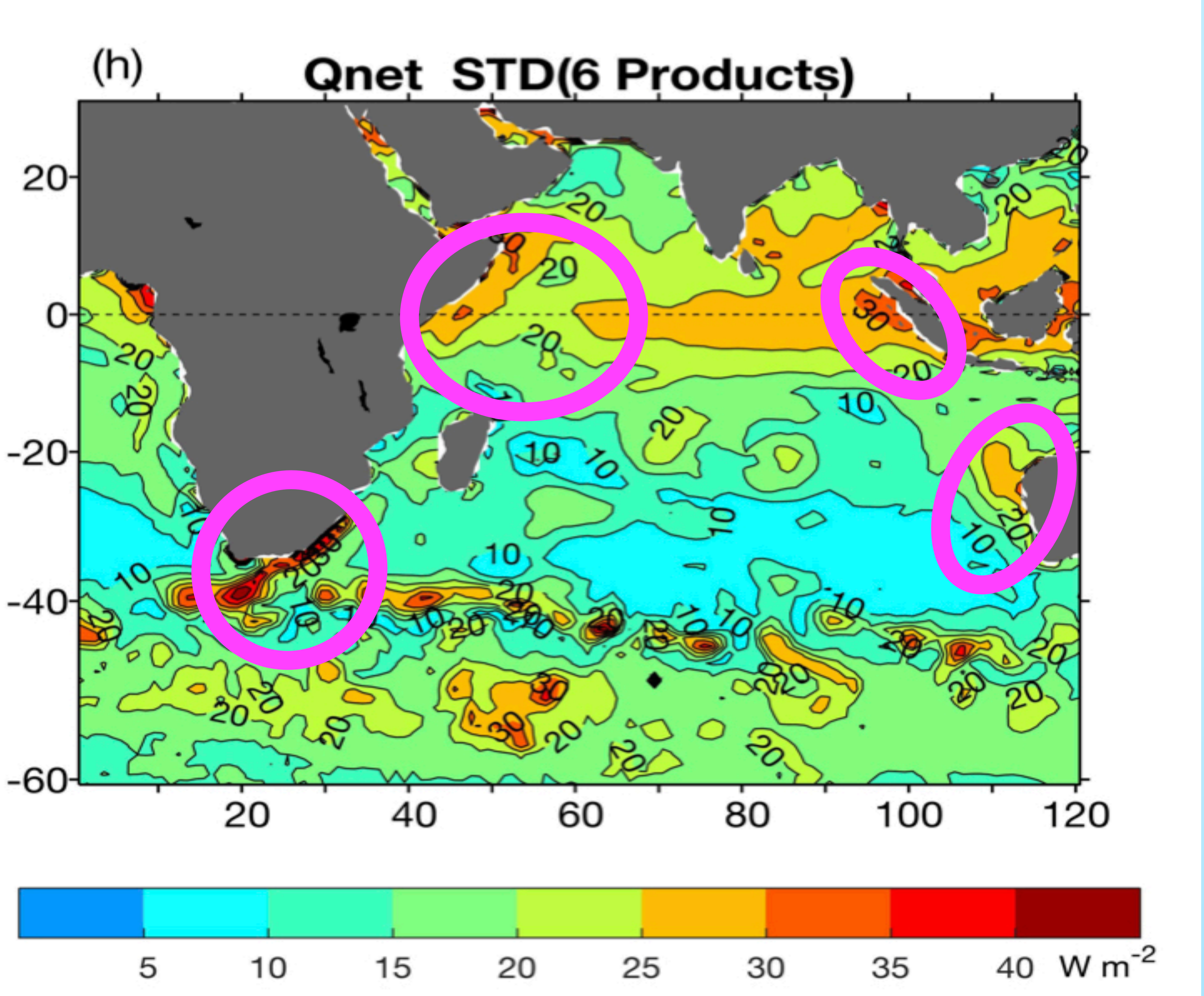
- Lack of observations in western equatorial Indian Ocean (piracy and vandalism) and of boundary currents
- No sustained ecosystem measures



Fish mortality event in Arabian Sea



Why do we need the IndOOS-2? Sea level rise

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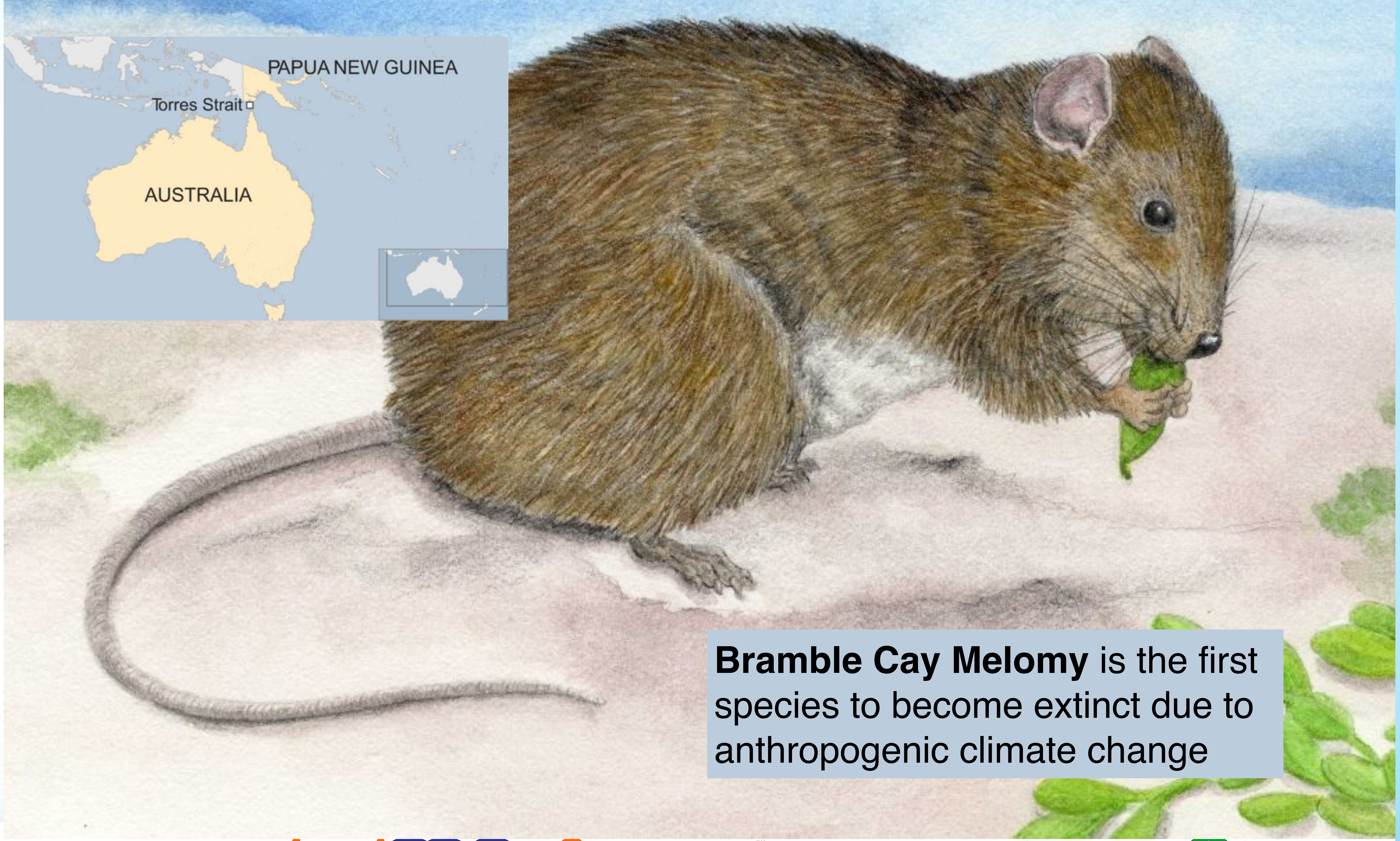

Bramble Cay Melomy is the first species to become extinct due to anthropogenic climate change

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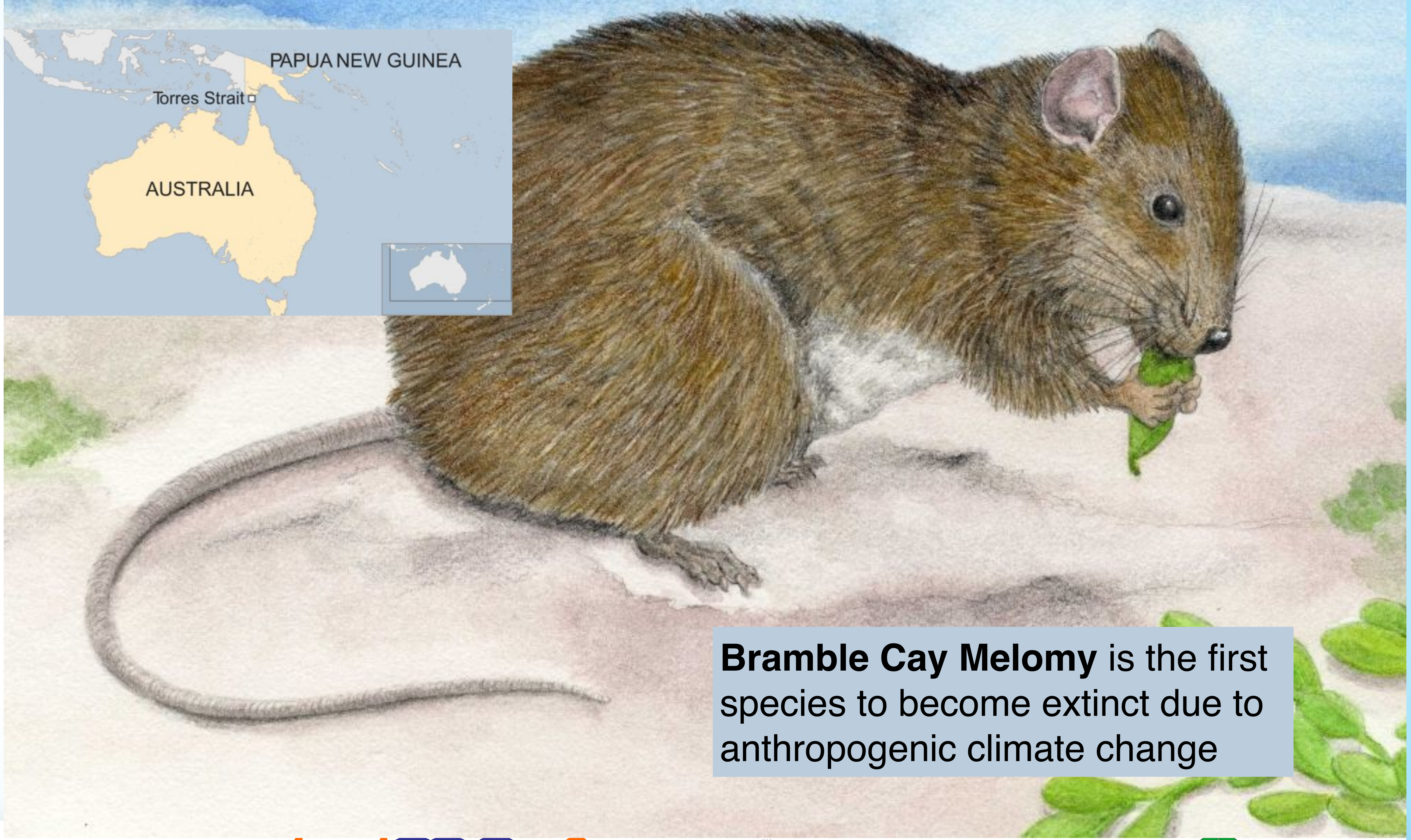

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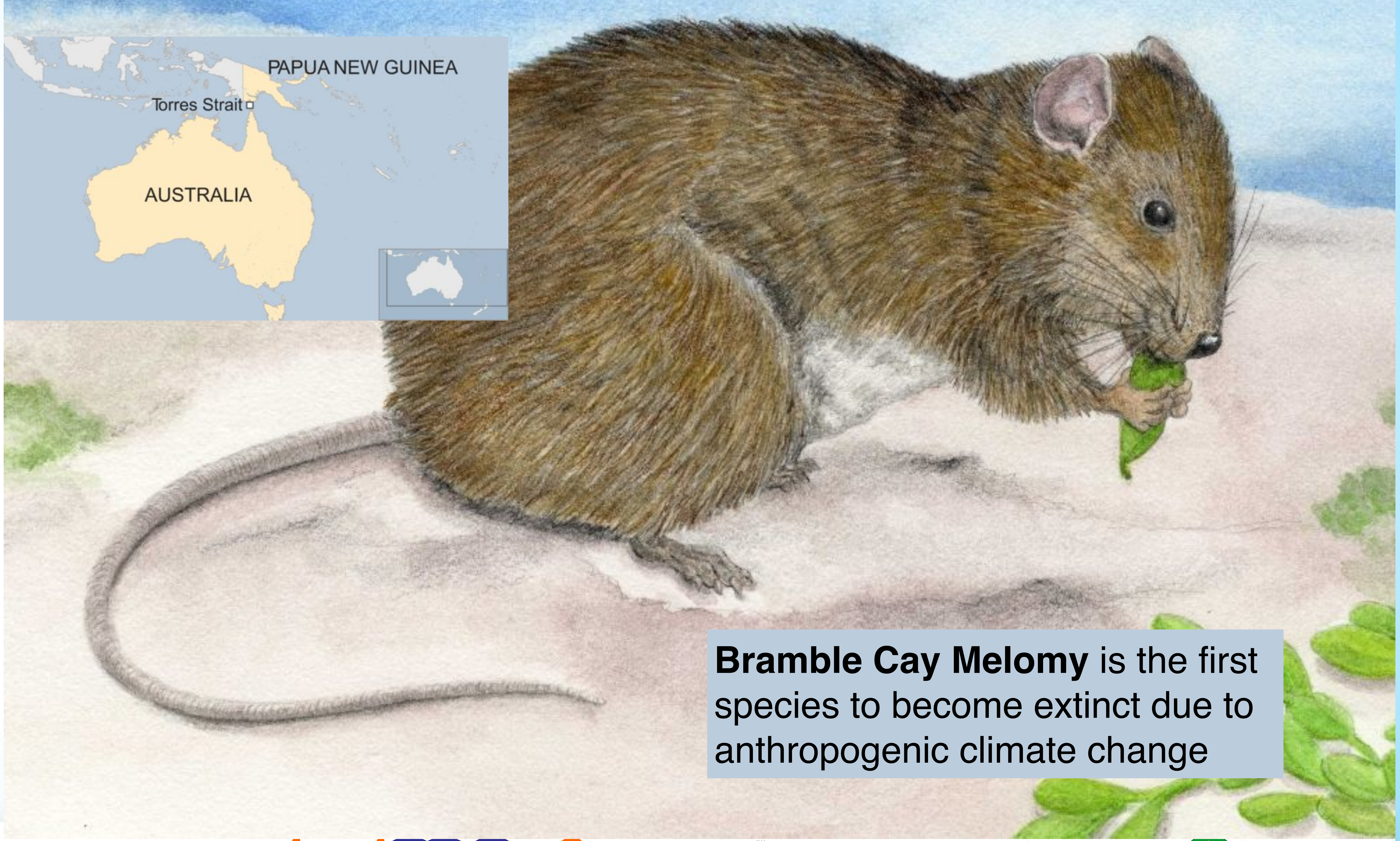

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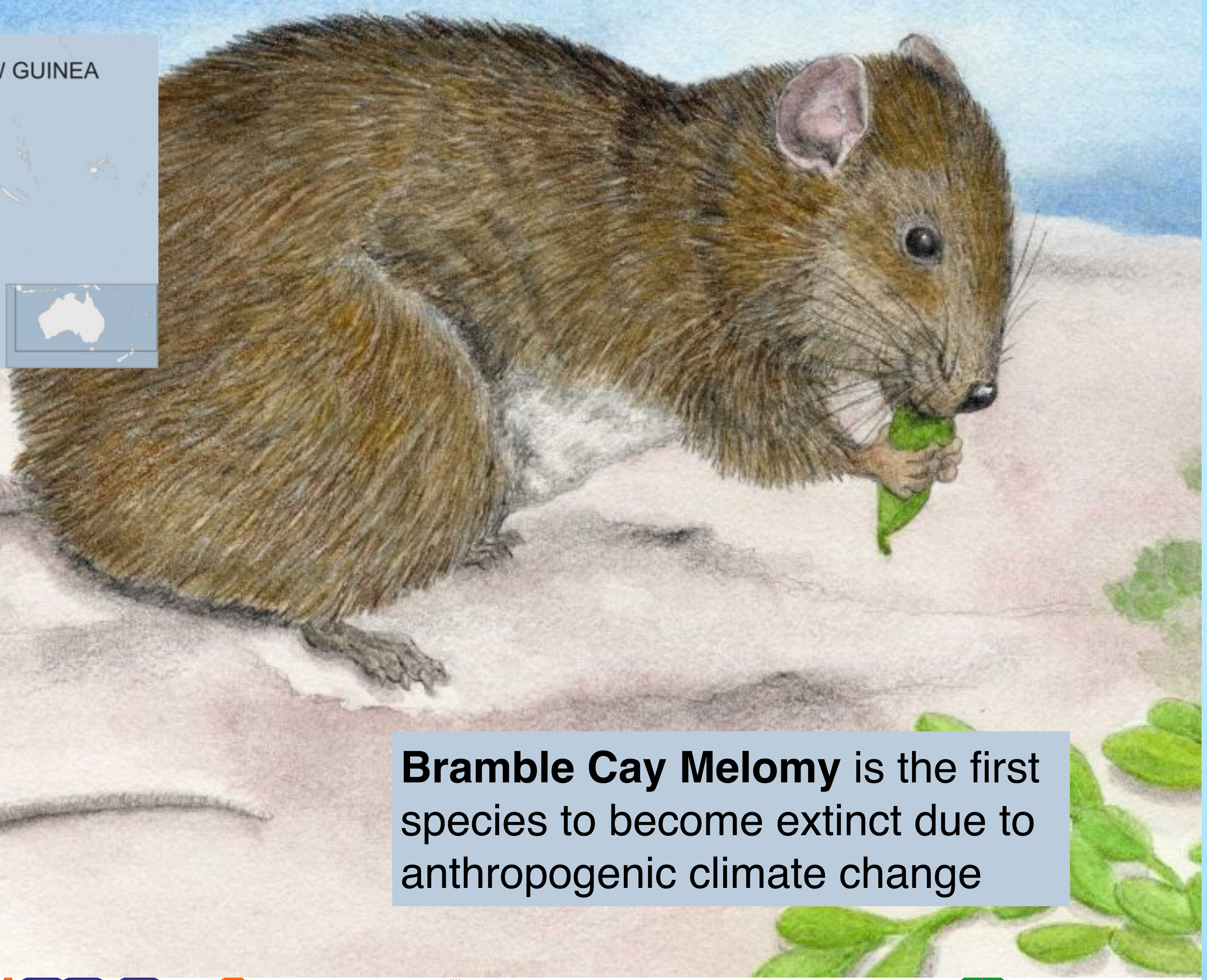
- Decadal IO variability unknown due to lack of long-term records



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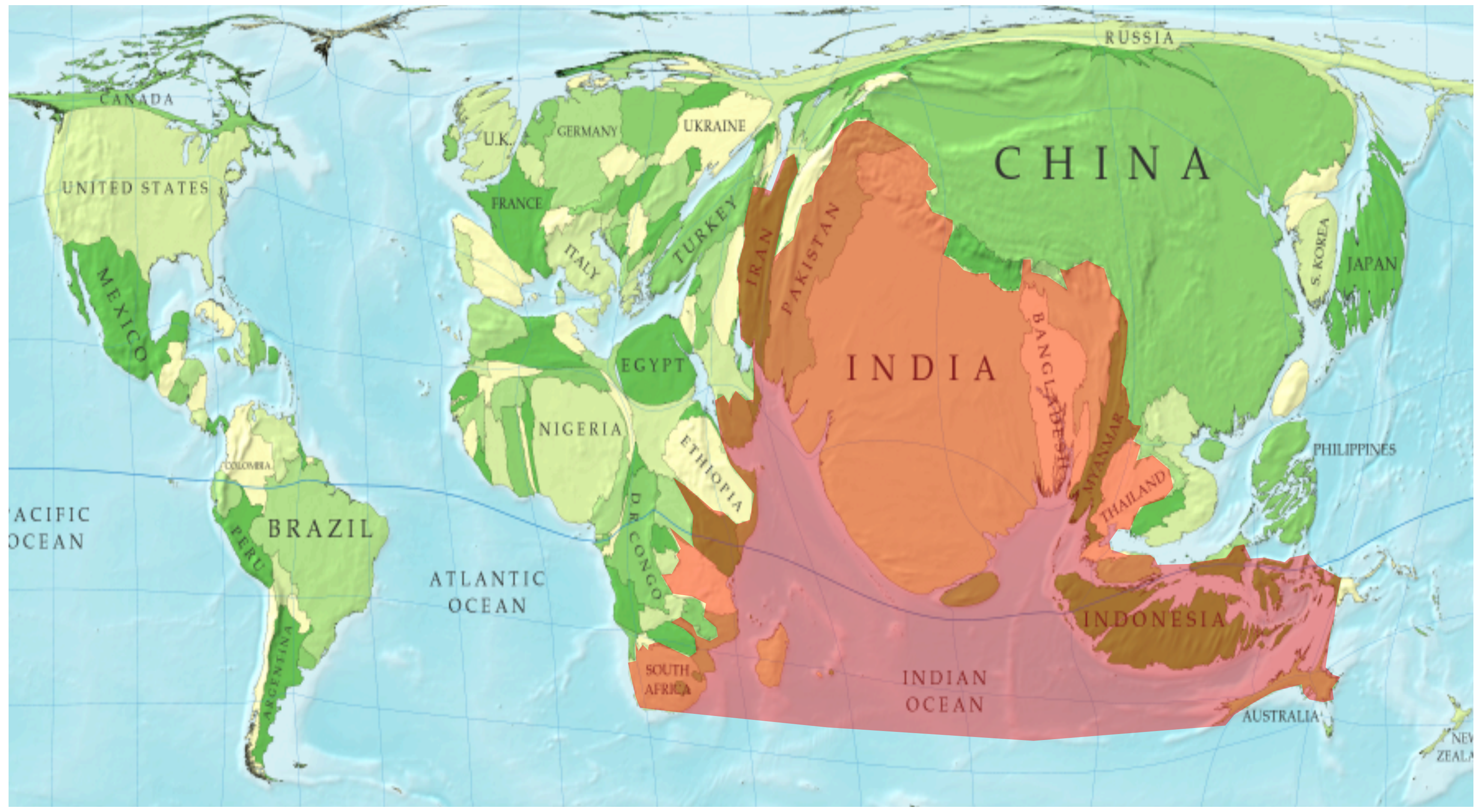
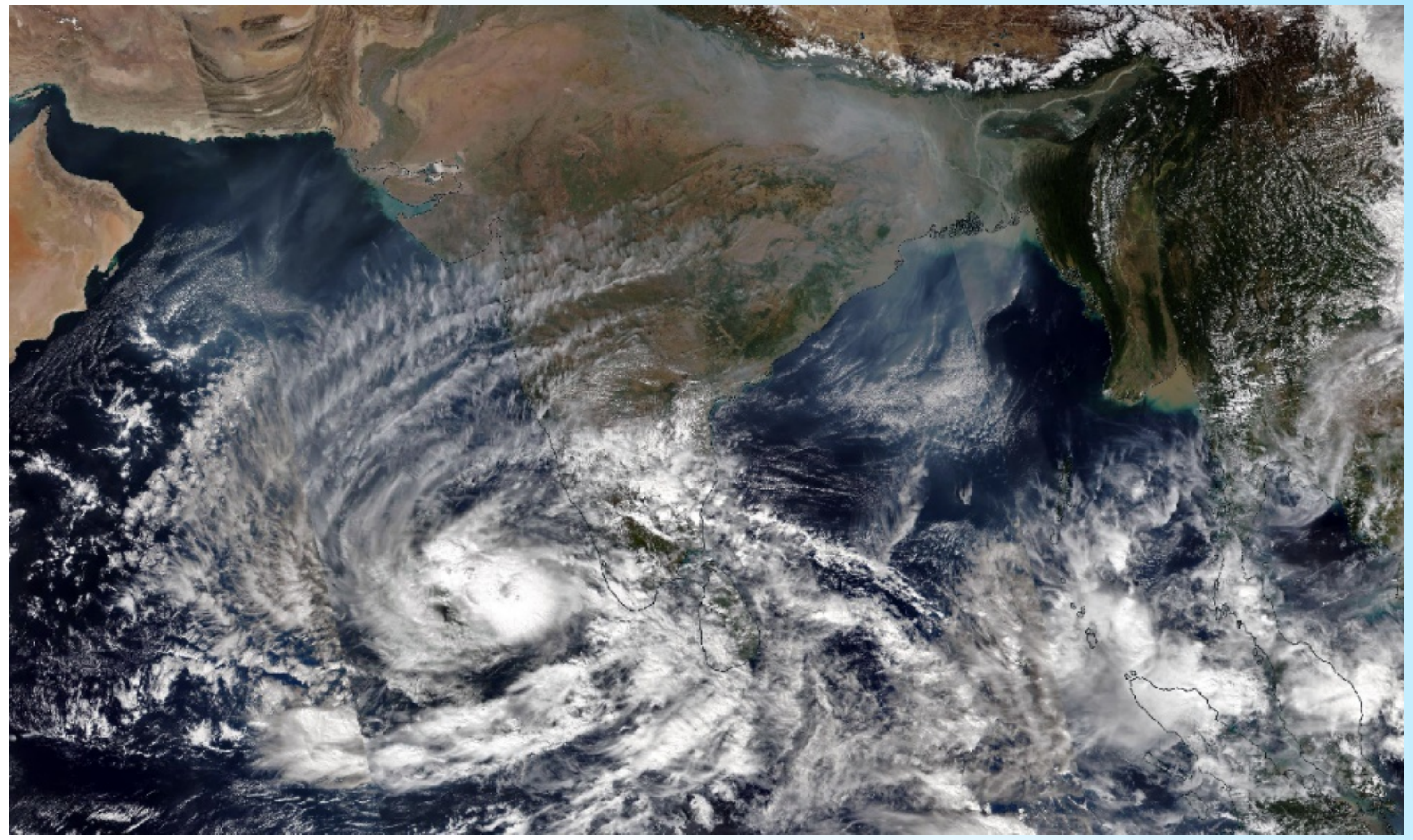
Why do we need the IndOOS-2? Increased vulnerability

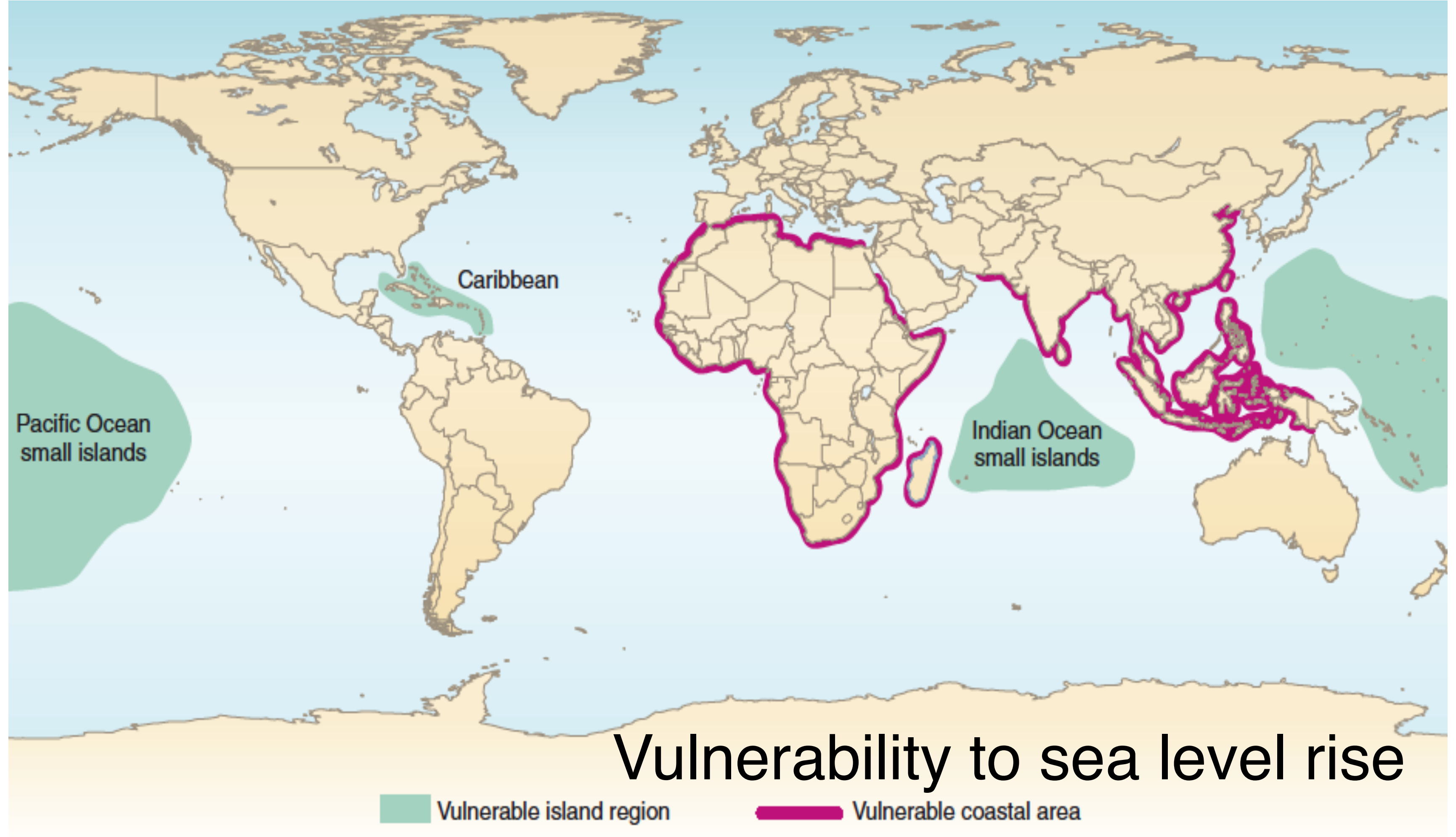
- Indian Ocean rim countries are increasingly vulnerable due to rises in population, sea level, and cyclone intensity.
- There are many small island developing states and least developed countries dependent on fisheries.
- The Bay of Bengal sees 5% of global cyclones, but 80% of global casualties. Cyclone Nargis in 2008: 140,000 dead, 1 million homeless, and $10 billion damages.



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)

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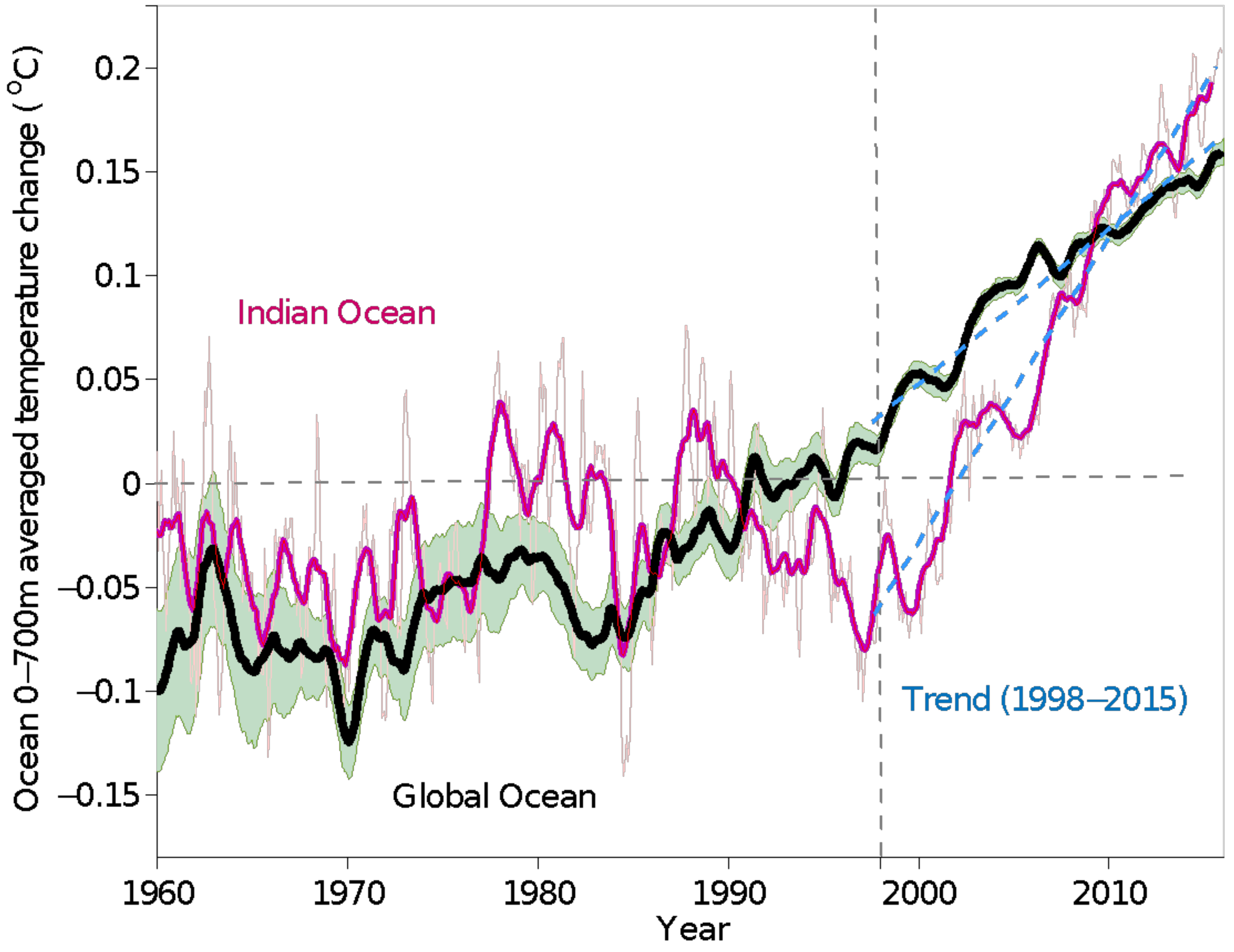

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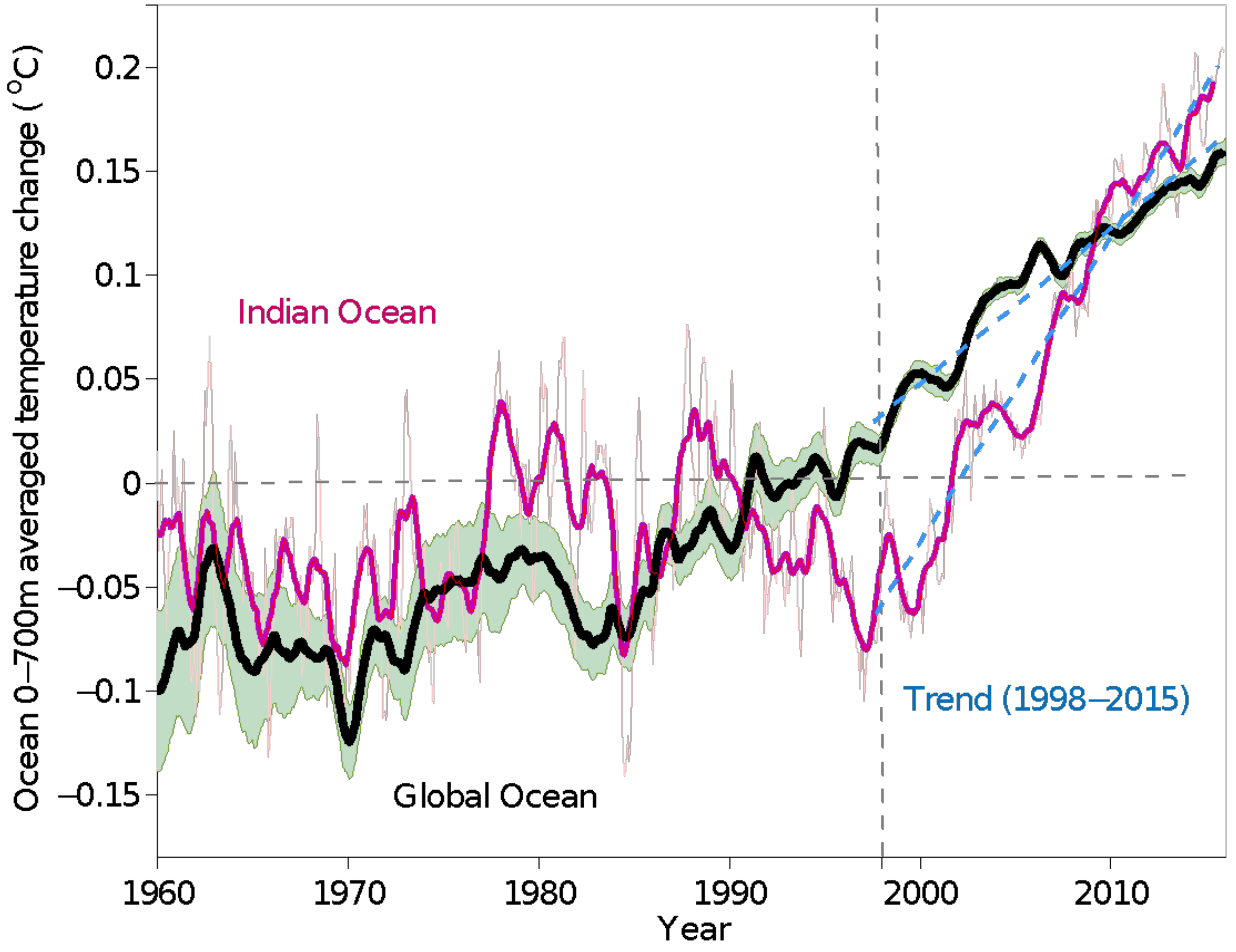
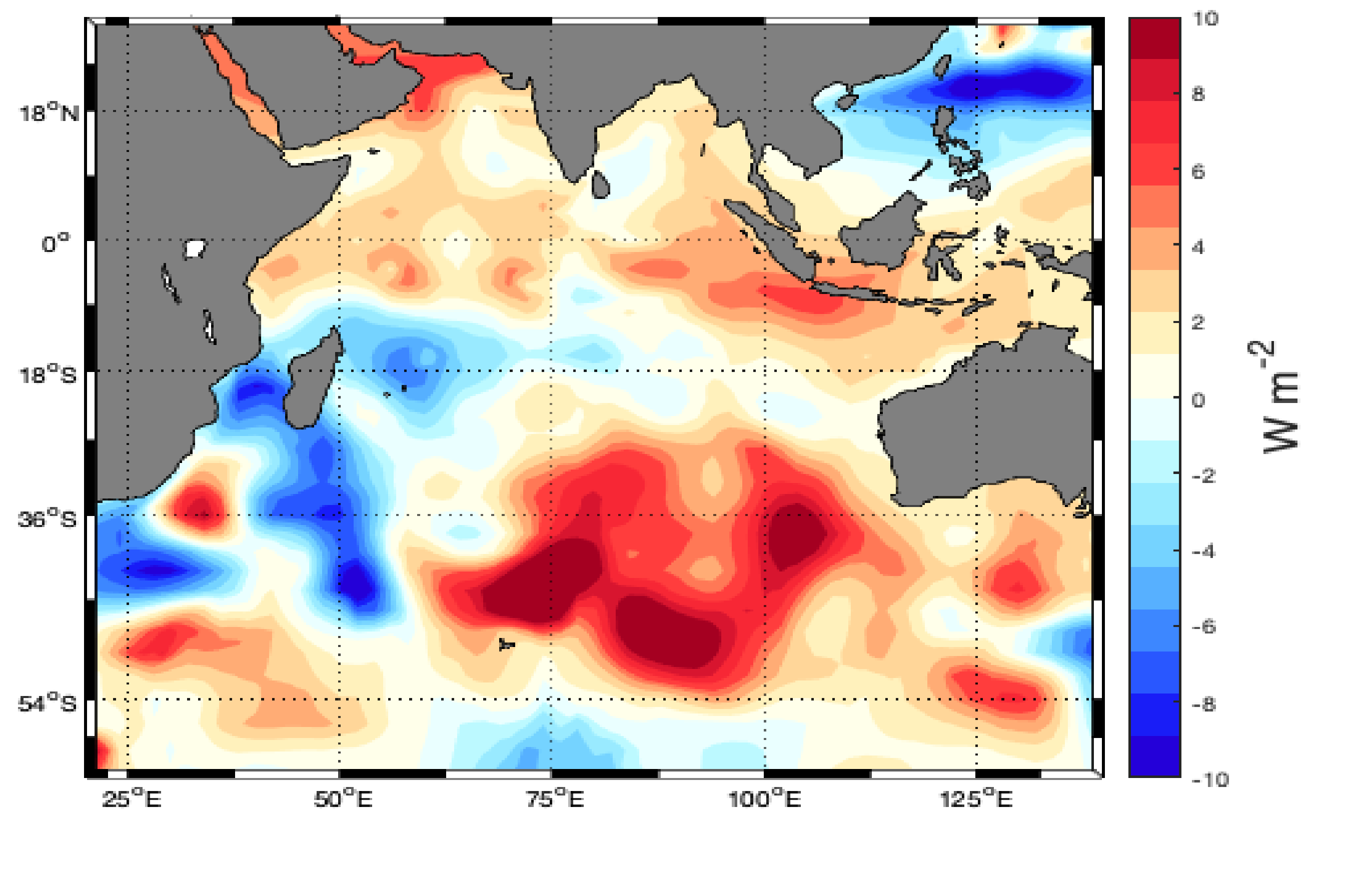


2006-2015, 0-2000 m heat content change



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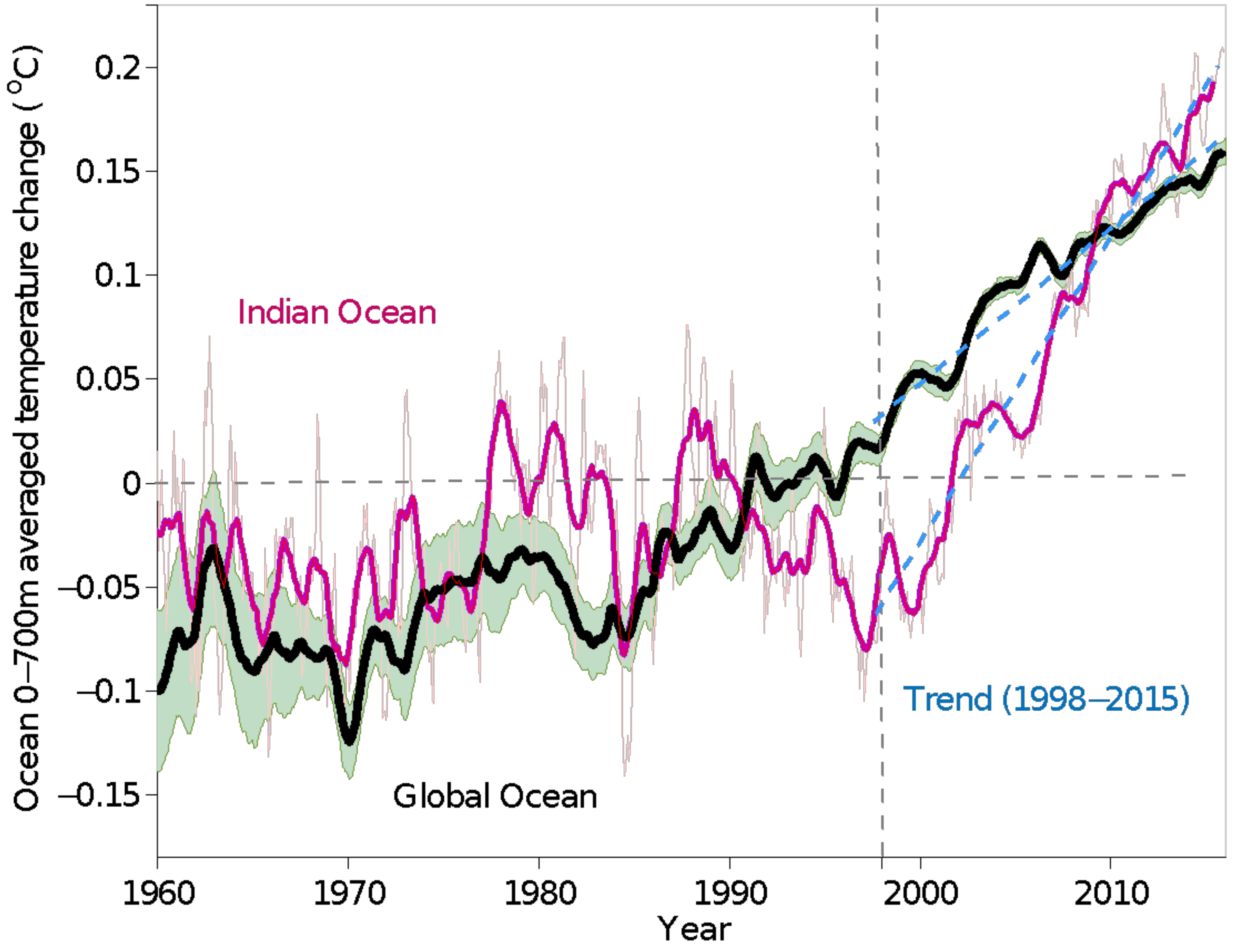

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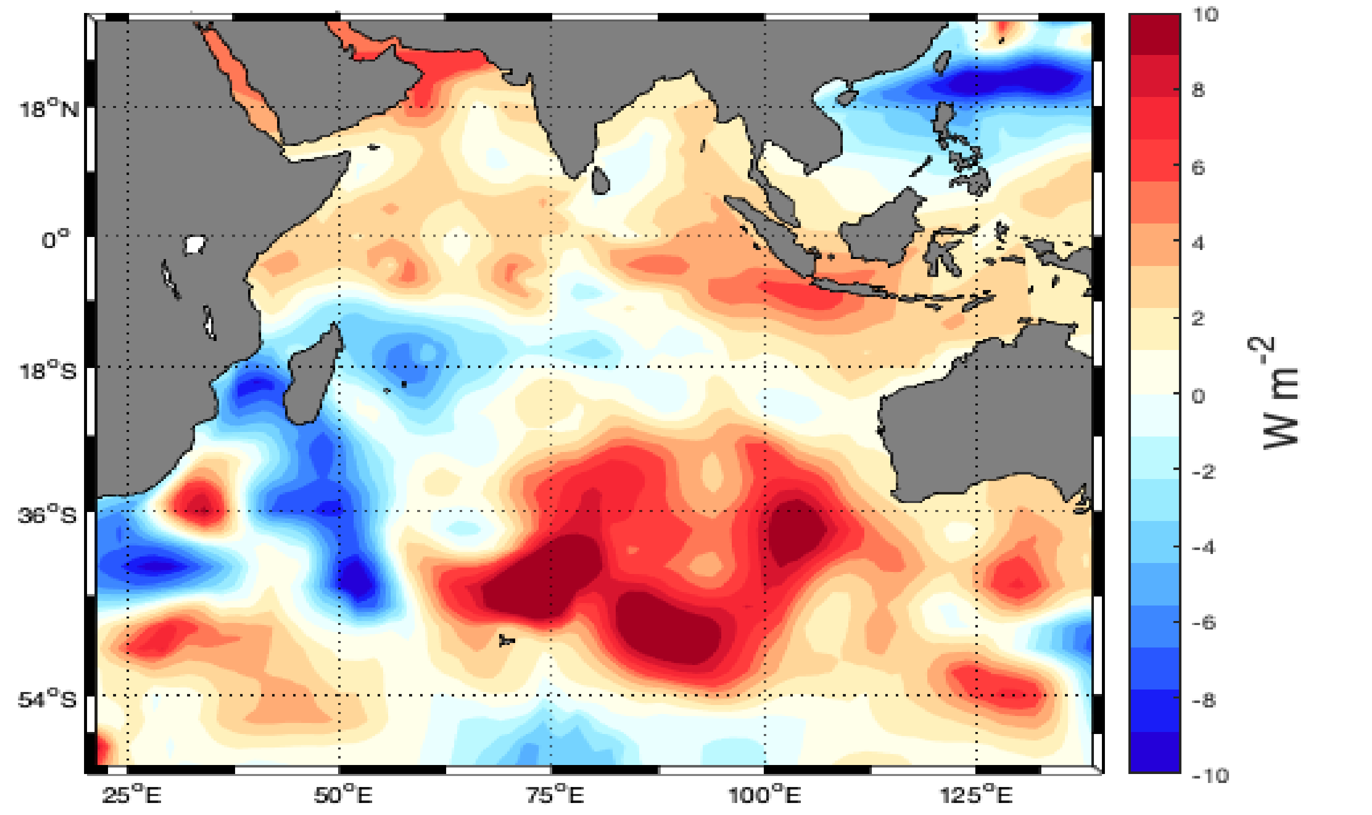
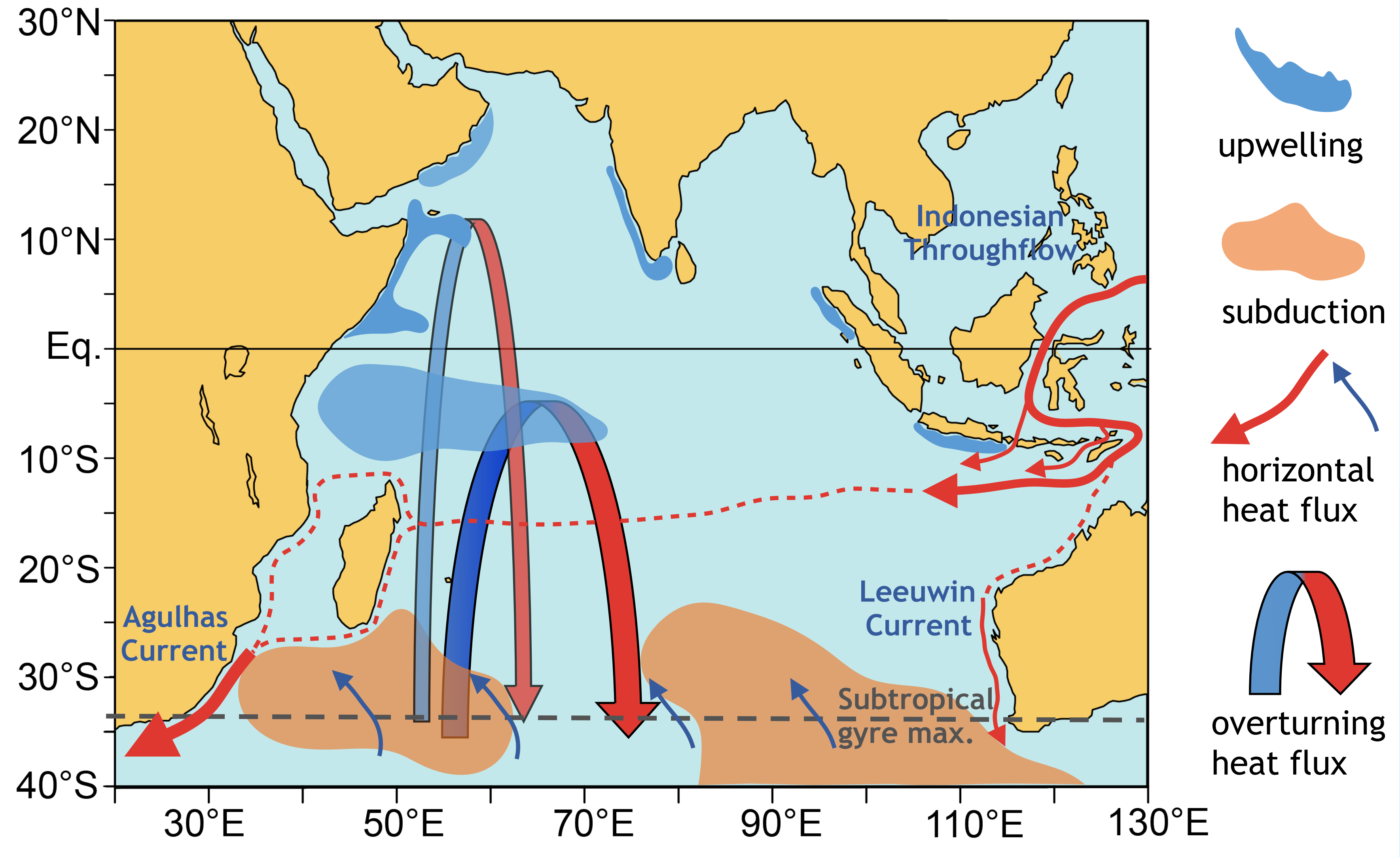


Main components of basin-wide heat budget



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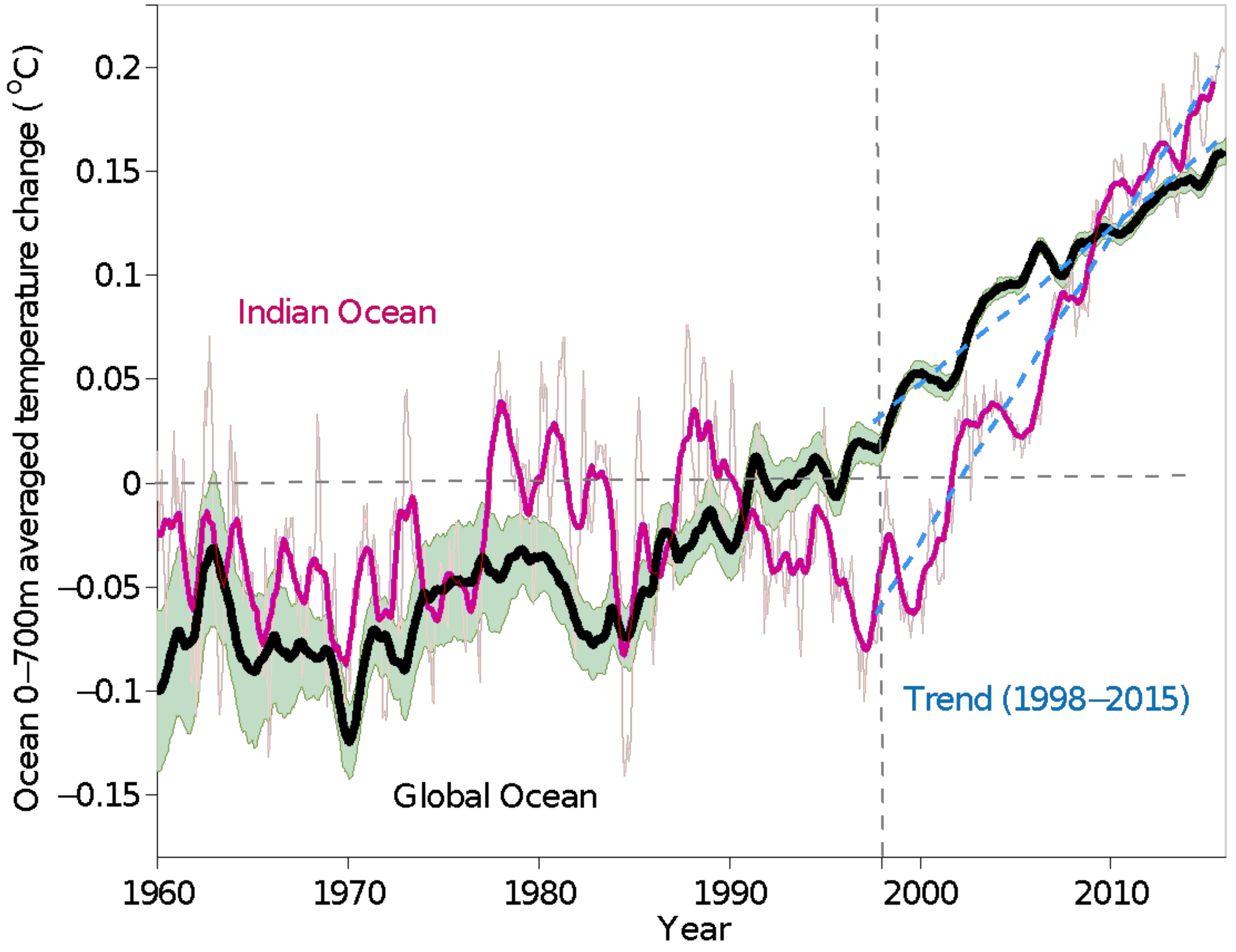
- Where will the heat go?



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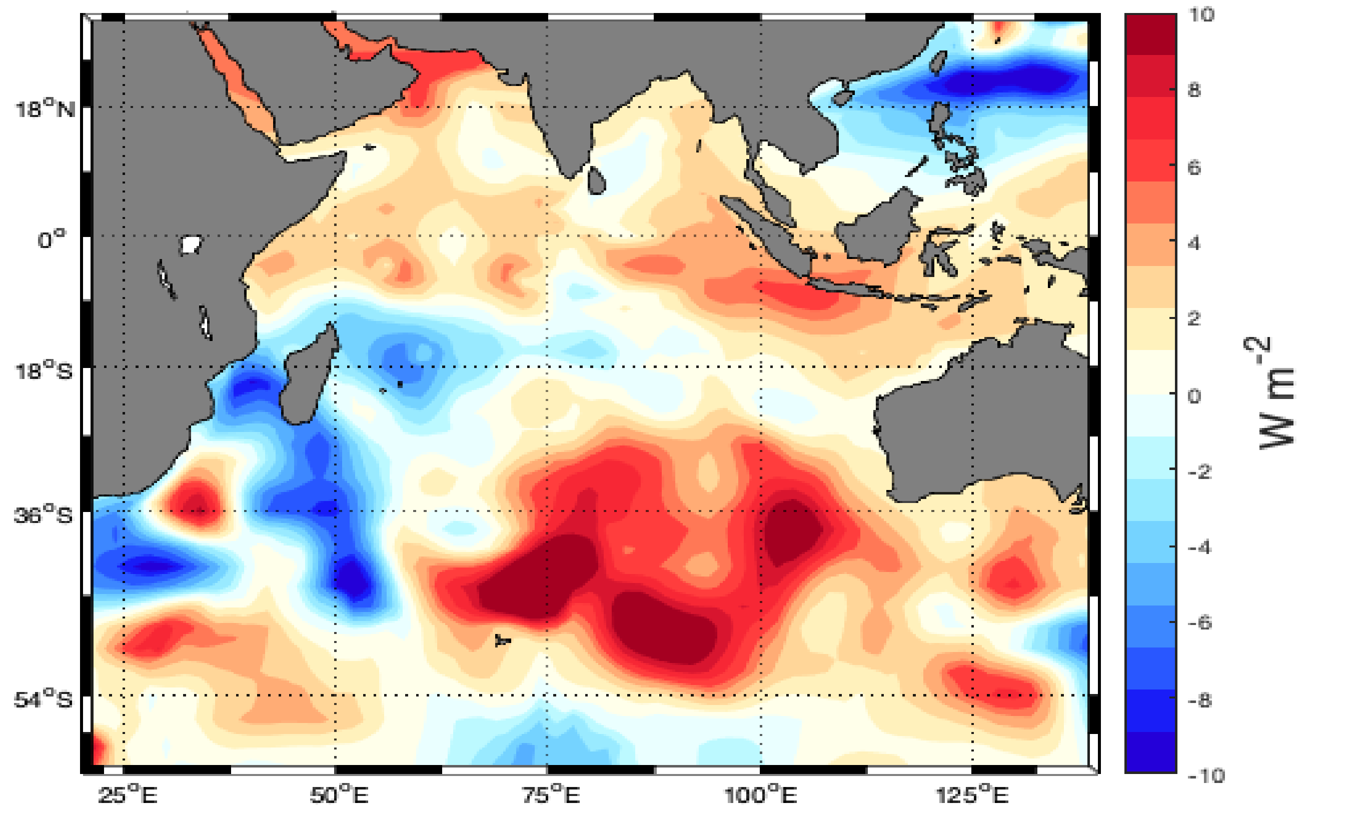

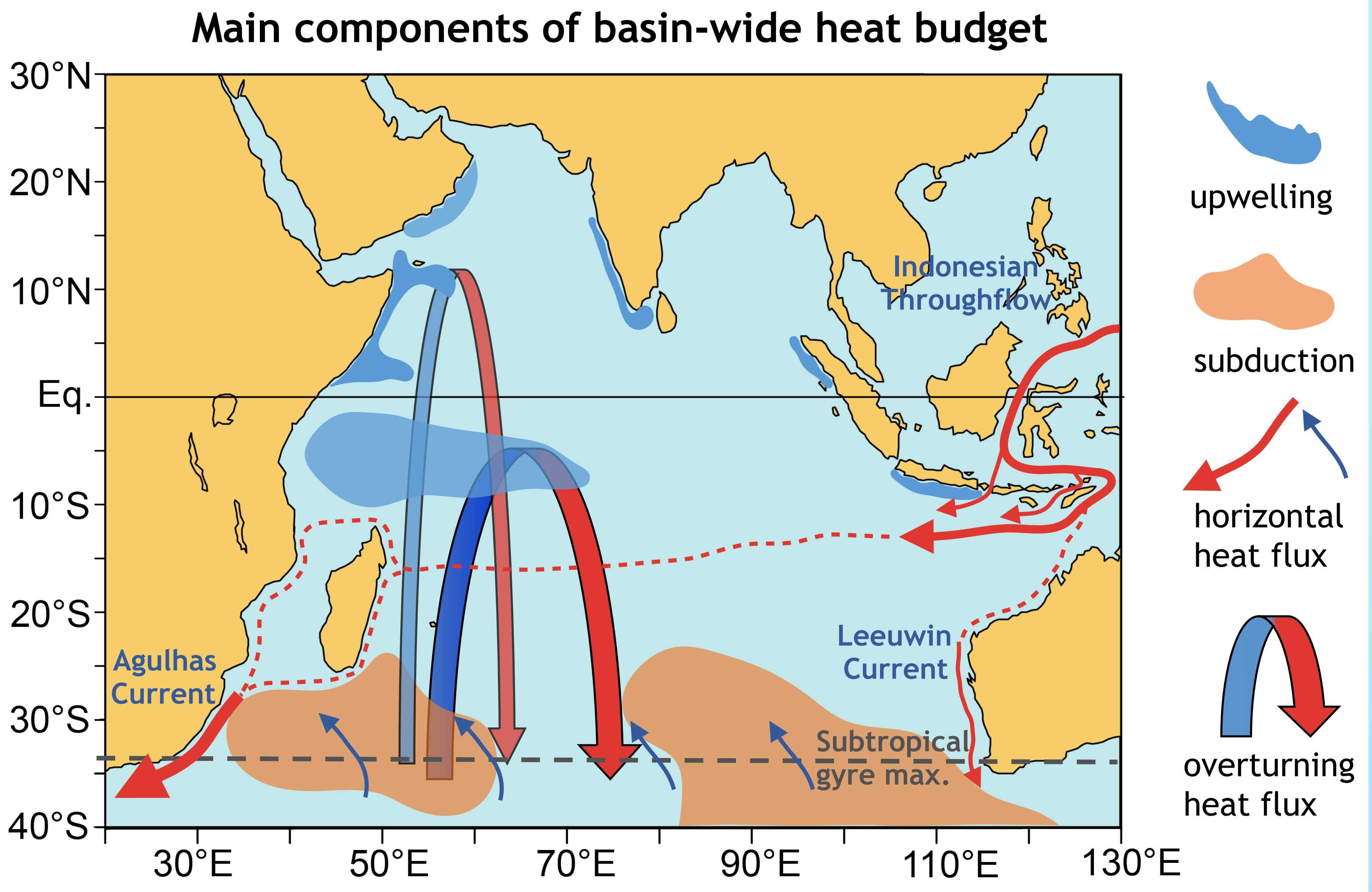

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Why do we need the IndOOS-2? Productivity in decline

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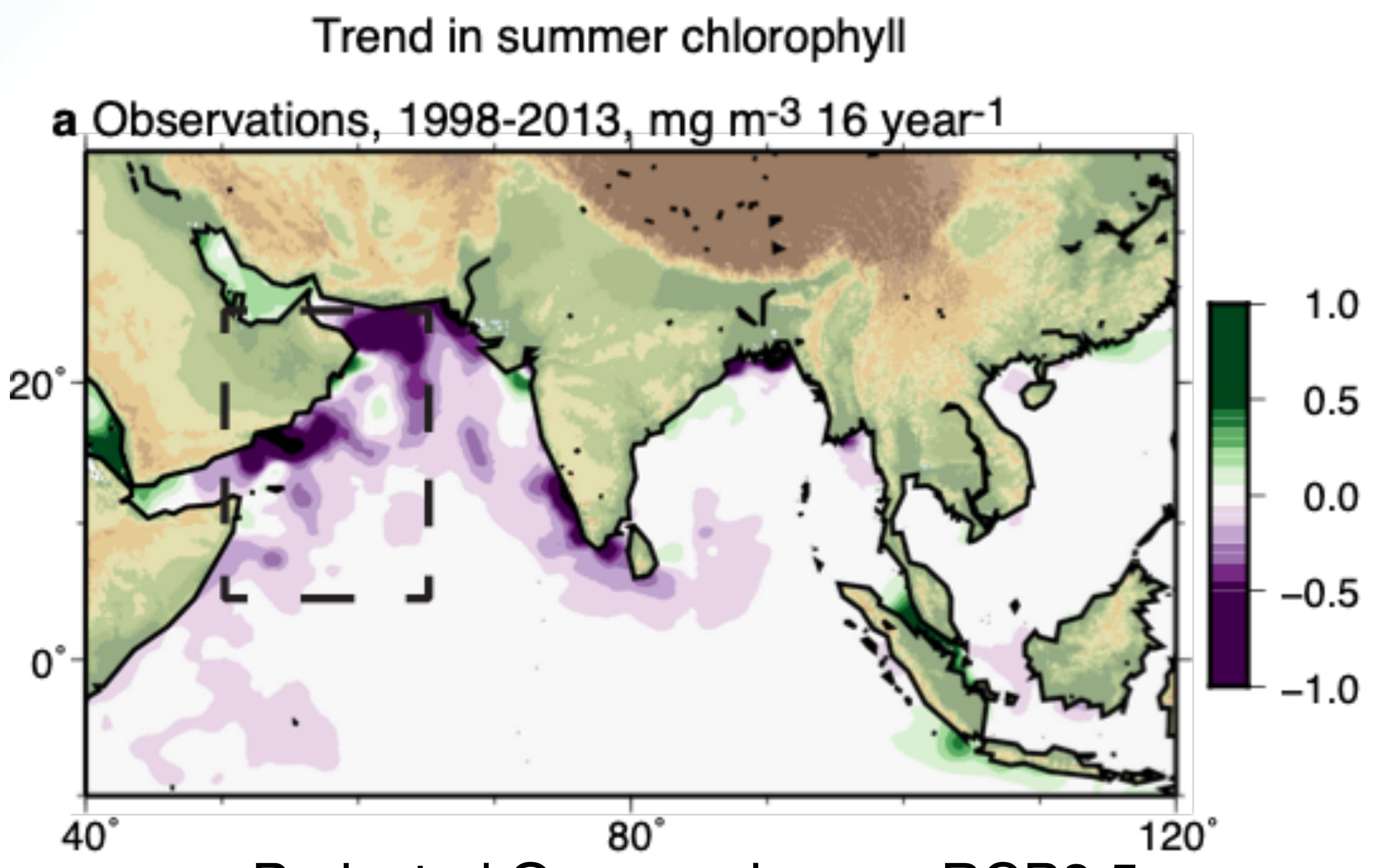

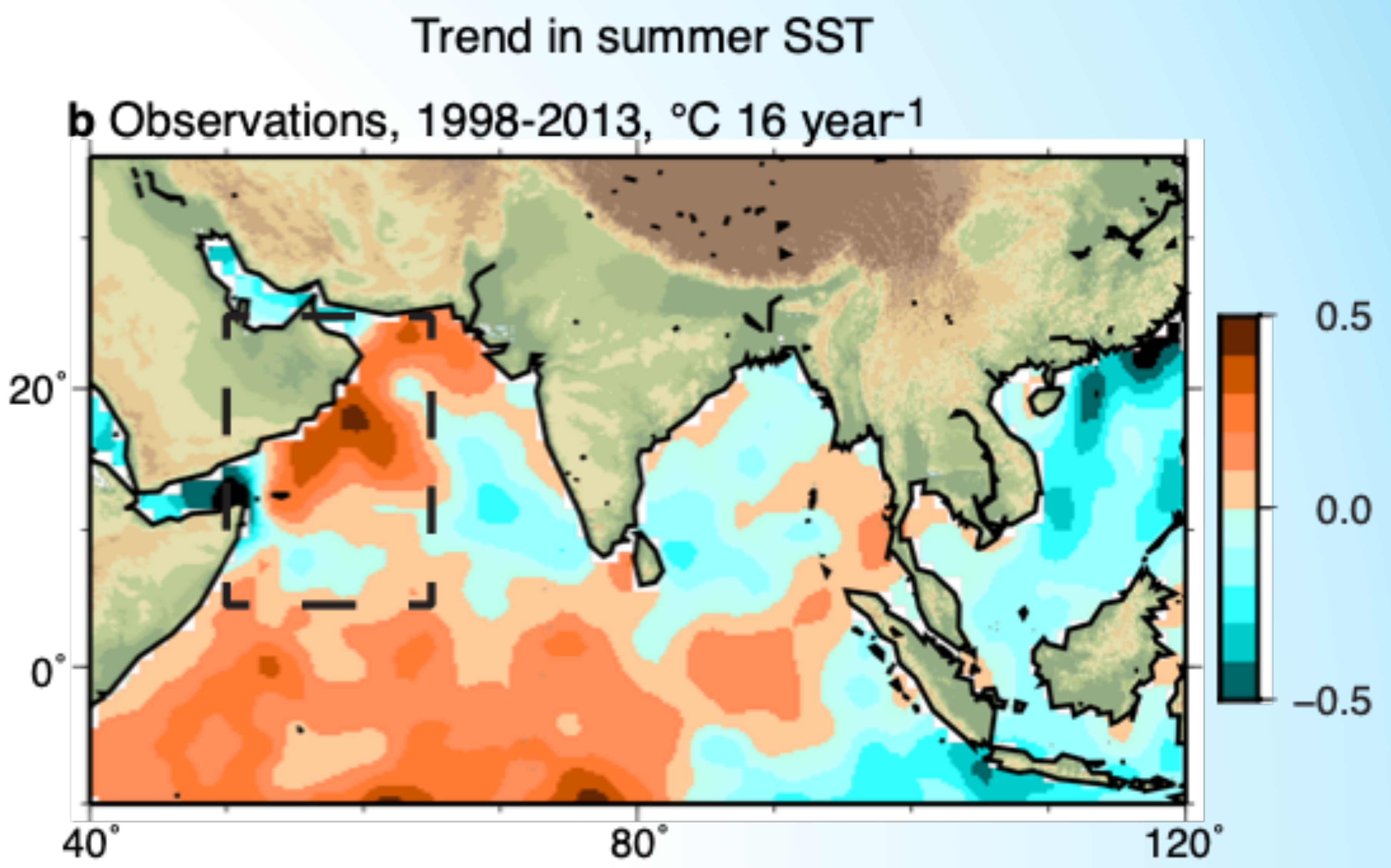

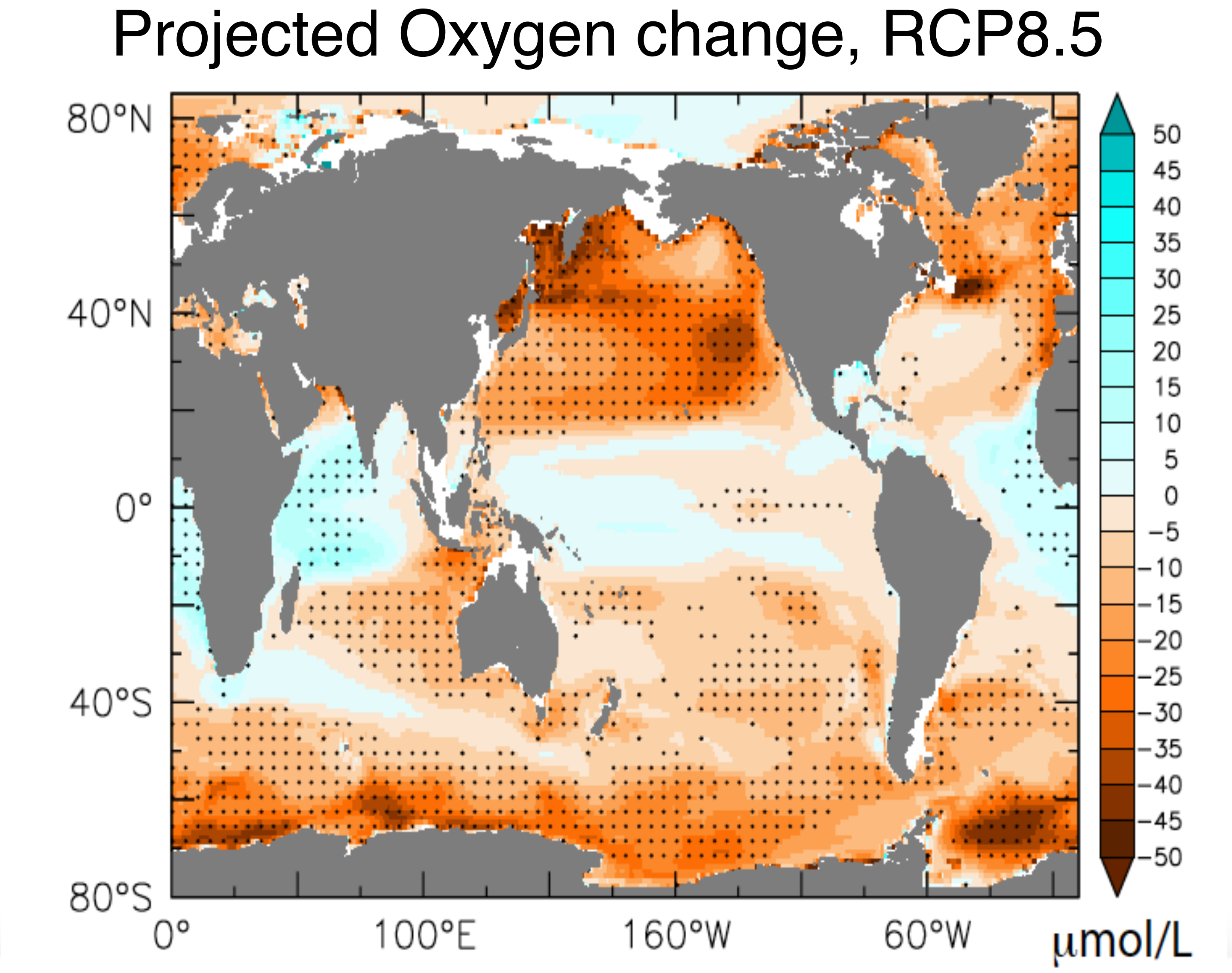

Bopp et al (2013), Naqvi et al (2009), Rashid et al (2013), Roxy et al (2016)

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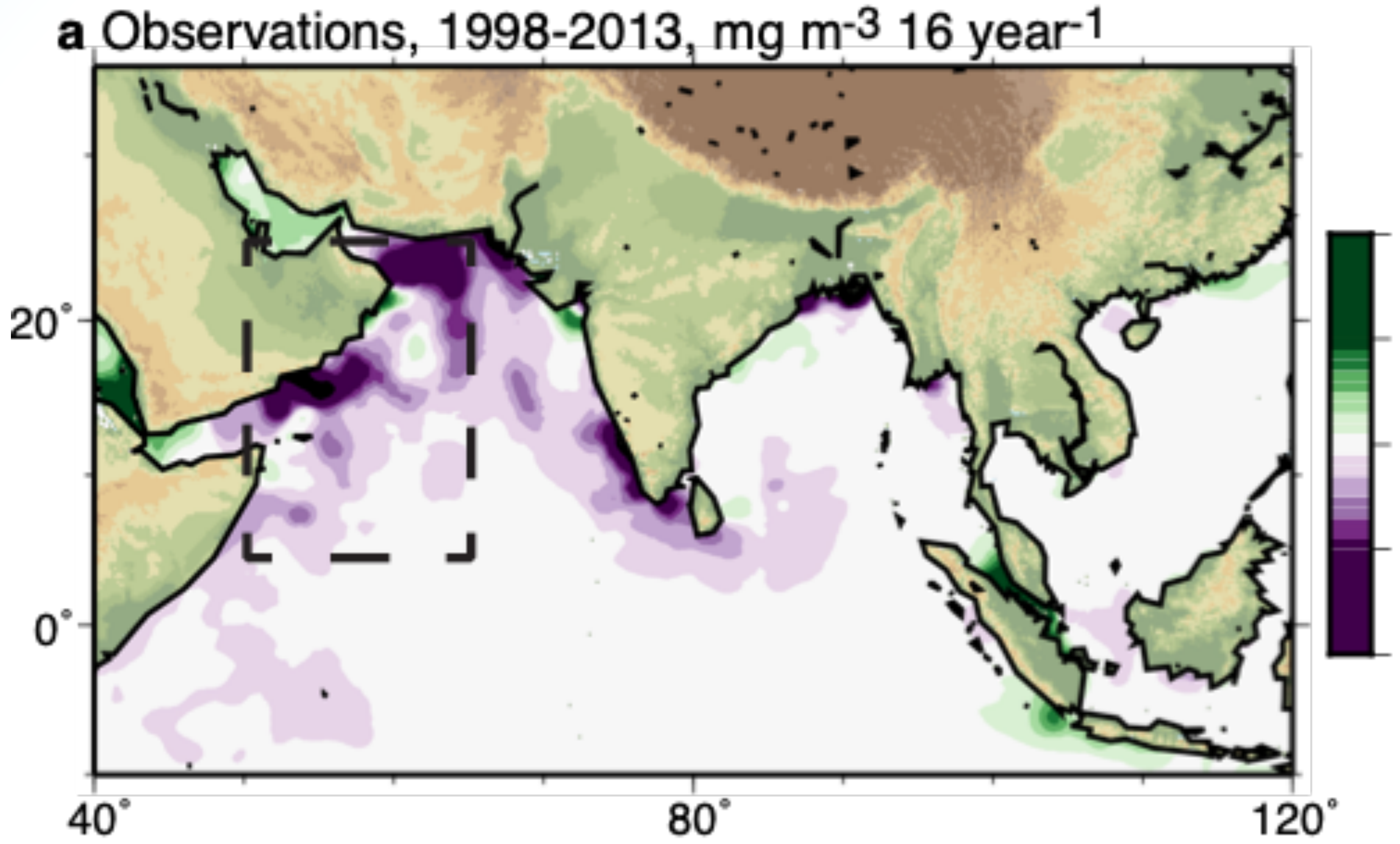
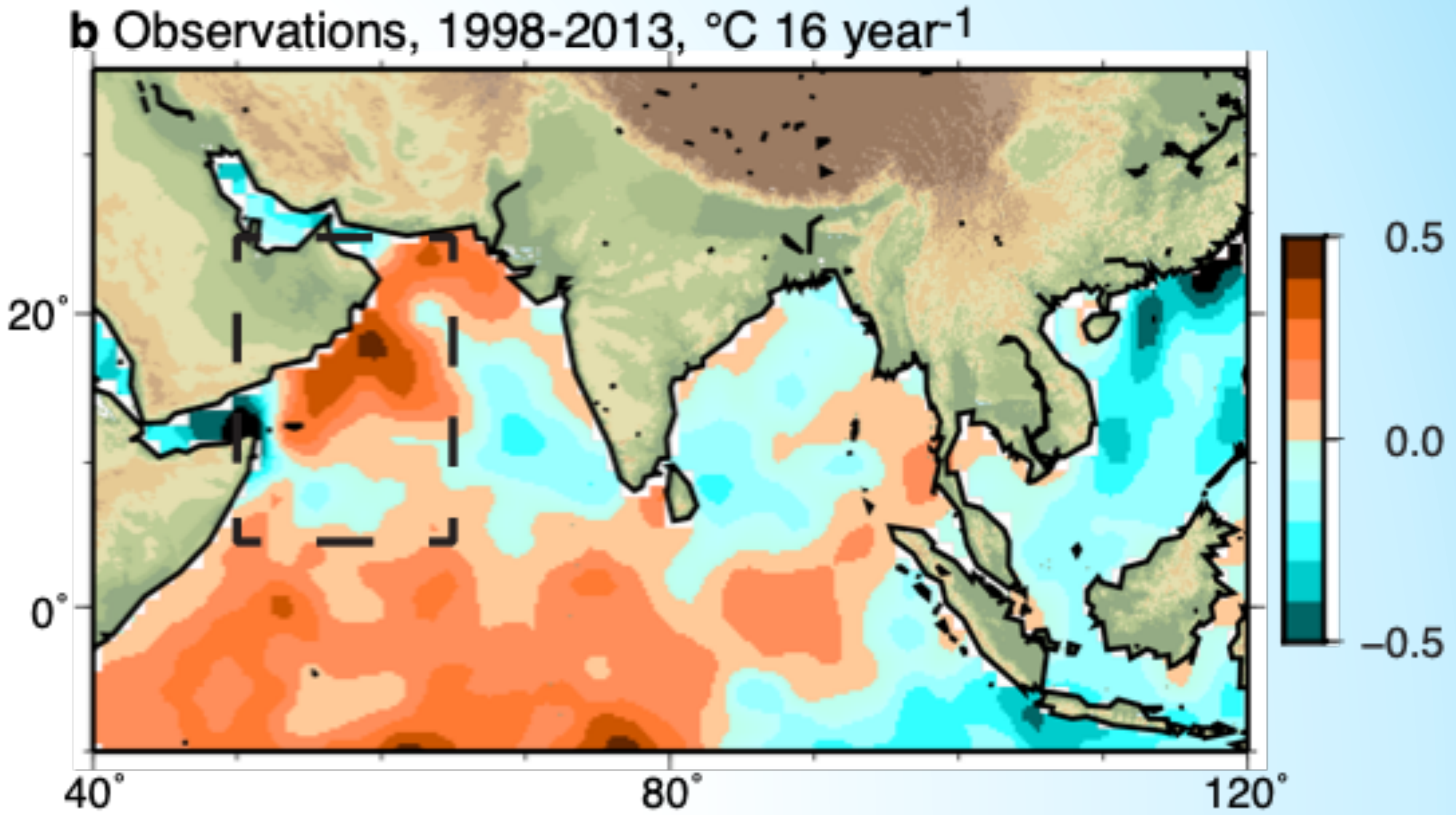
- Fish mortality events are predicted to increase due to enlarged oxygen minimum zone in Arabian Sea

Bopp et al (2013), Naqvi et al (2009), Rashid et al (2013), Roxy et al (2016)

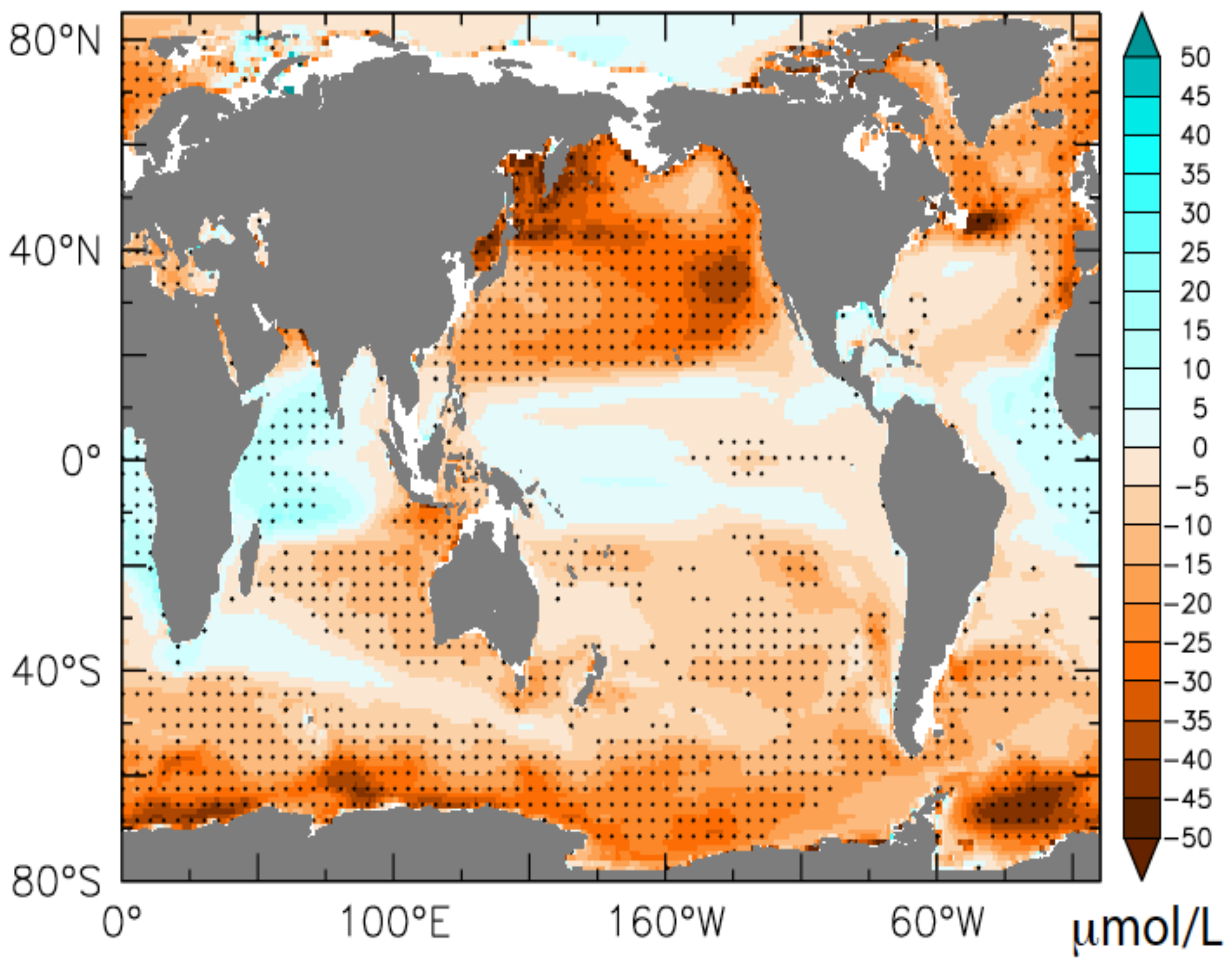
Trend in summer chlorophyll



Trend in summer SST



Projected Oxygen change, RCP8.5



Fish mortality event in Arabian Sea

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What are the scientific drivers of the IndOOS?

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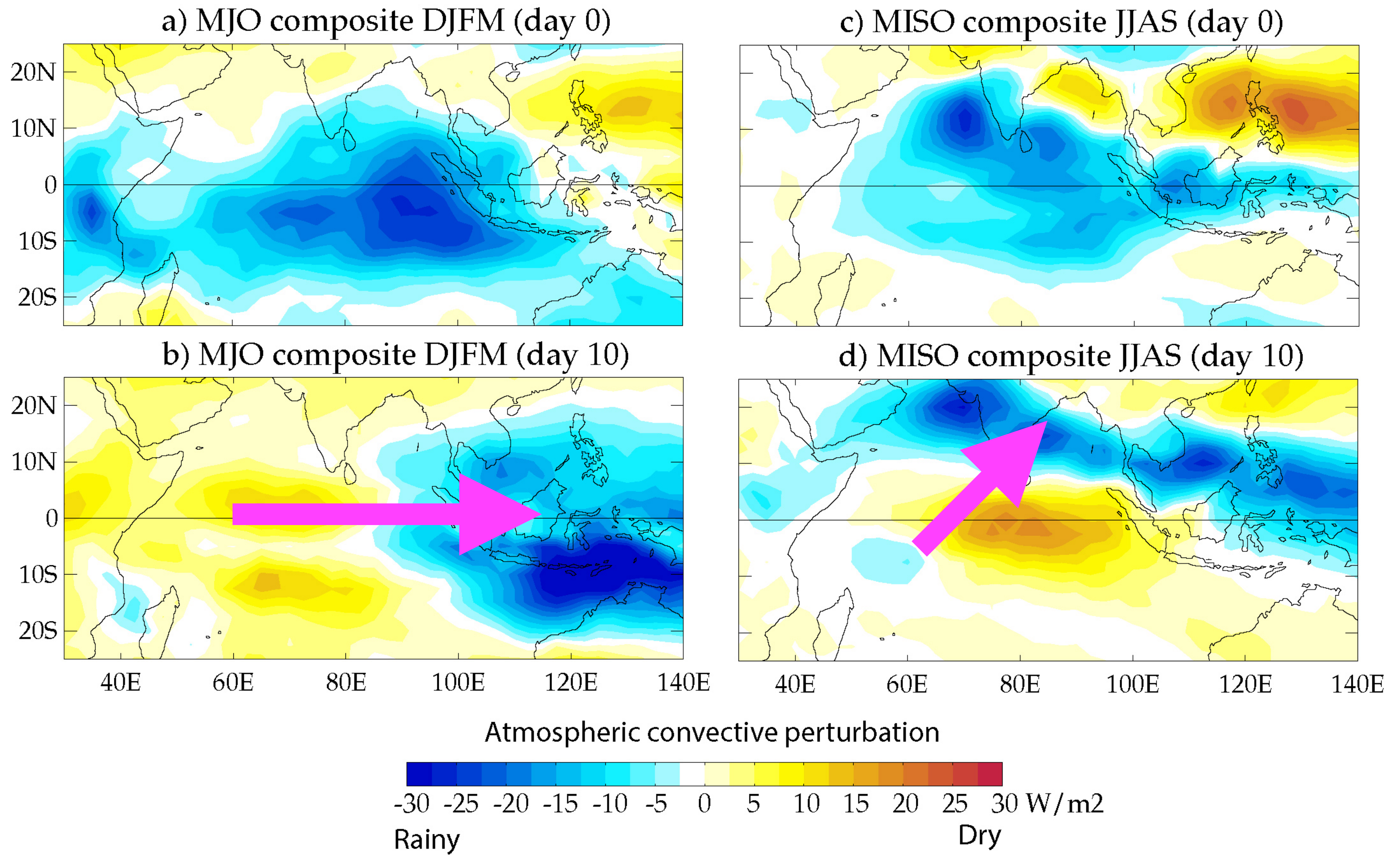
- The Madden Julian Oscillation (MJO) and Monsoon Intraseasonal Oscillation (MISO) are convective perturbations that originate in the Indian Ocean



The Global Ocean Observing System
World Climate Research Programme
International Association for the Physical Sciences of the Oceans

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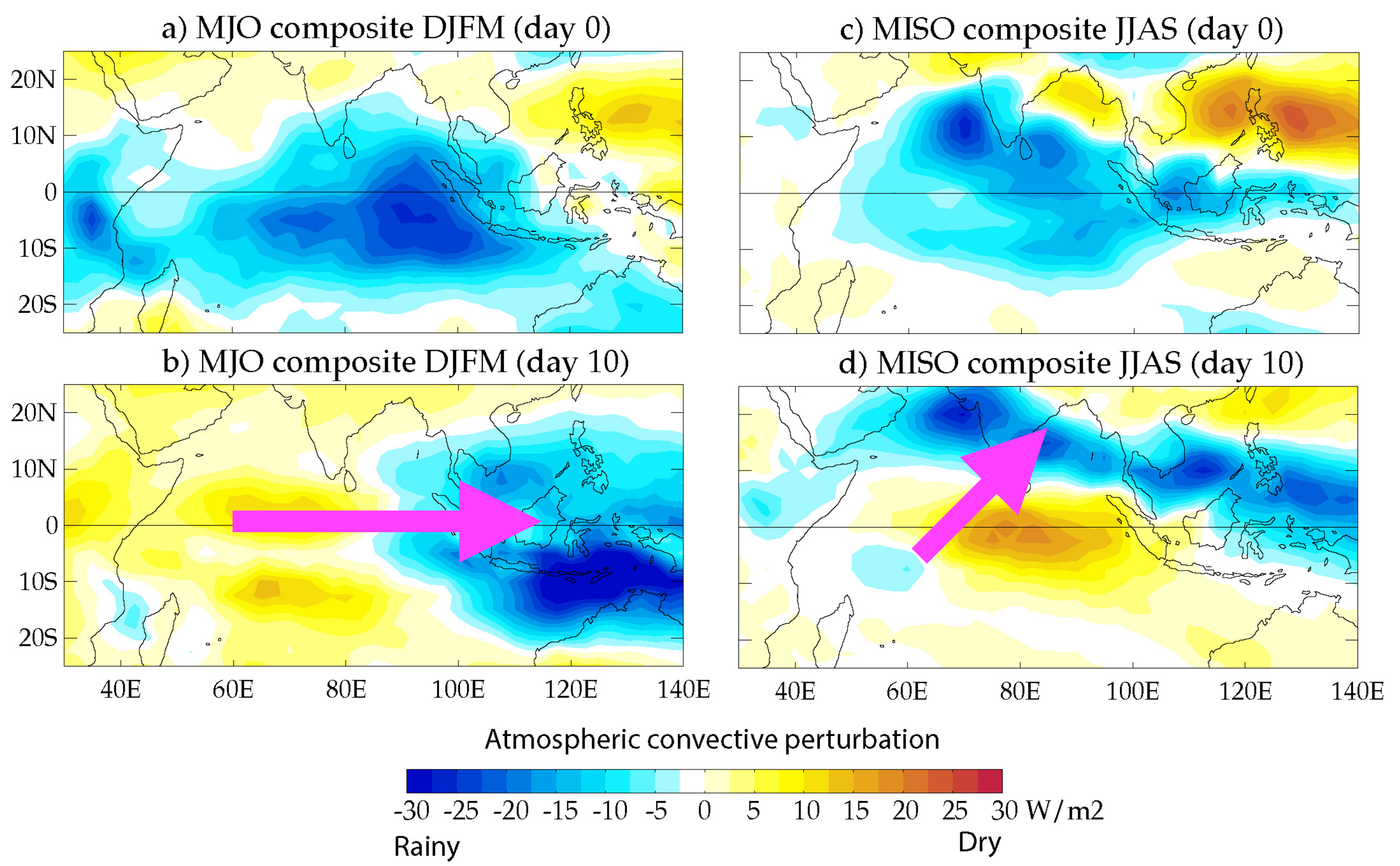

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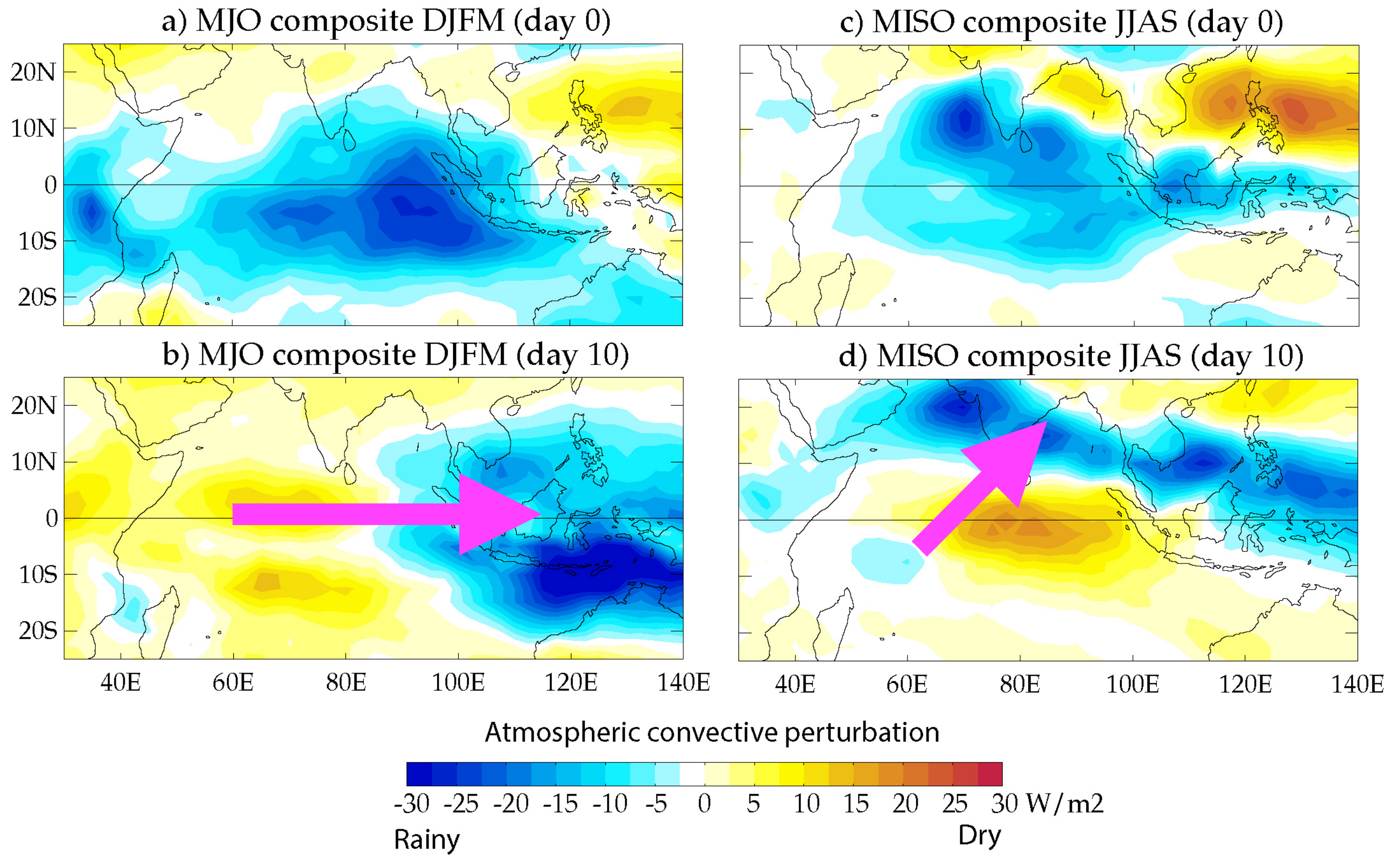

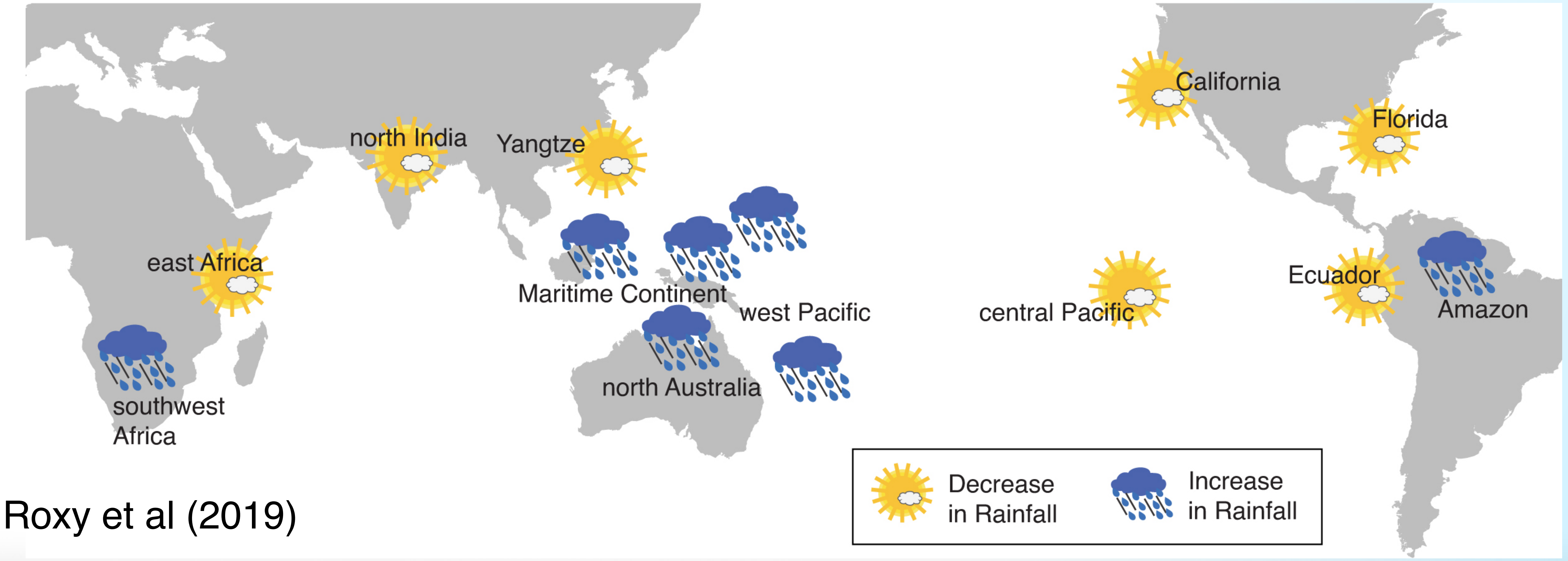

Roxy et al (2019)

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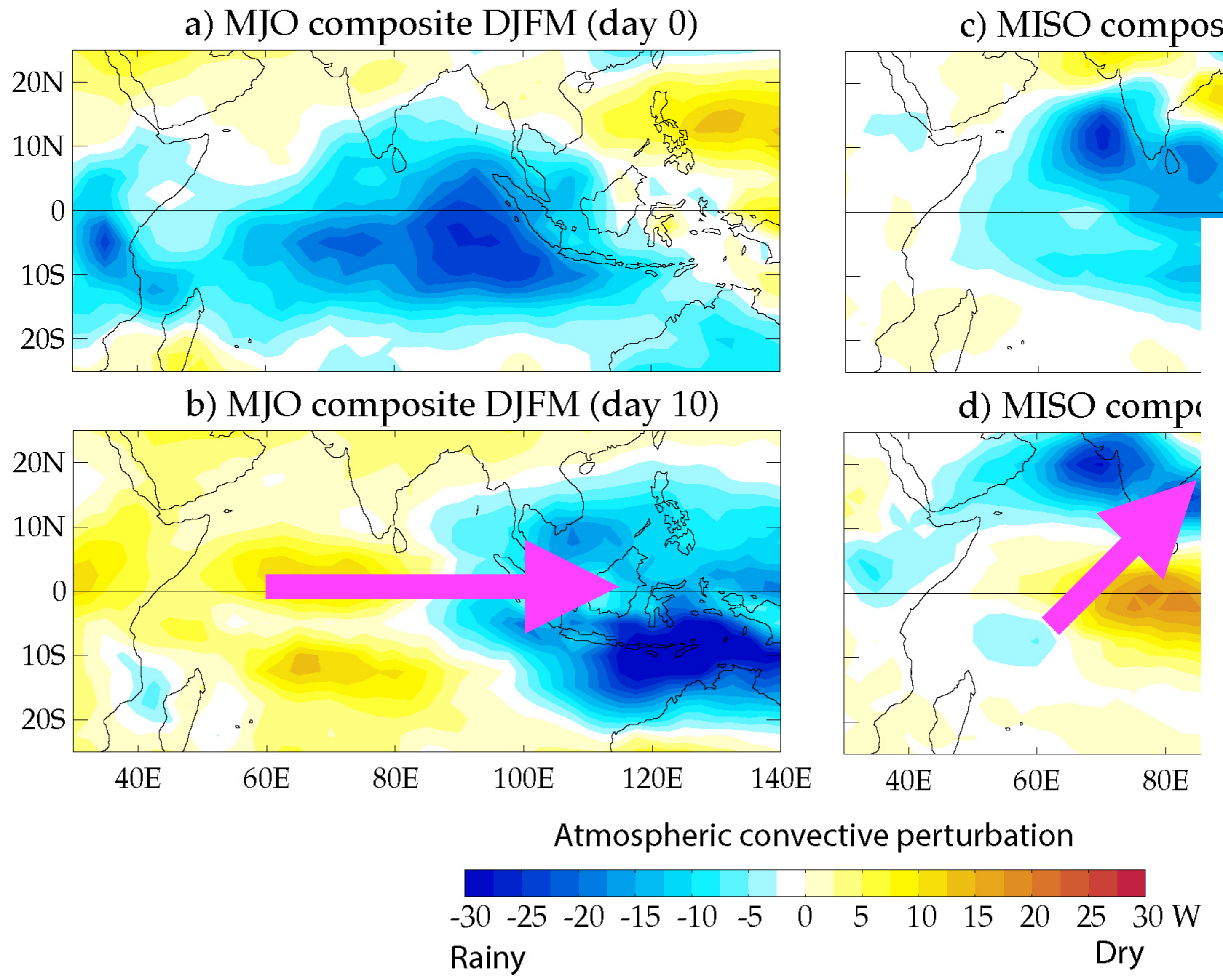
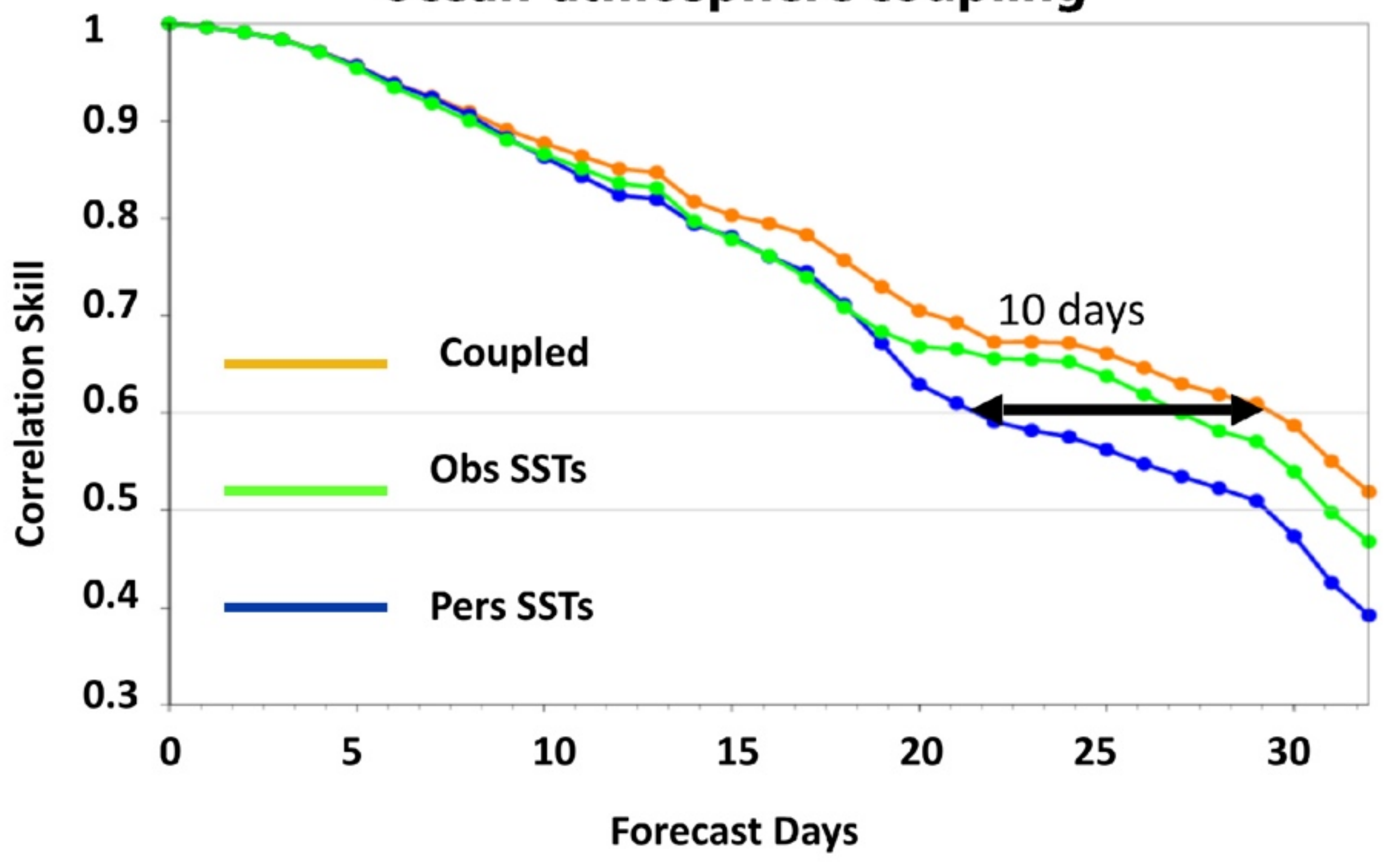
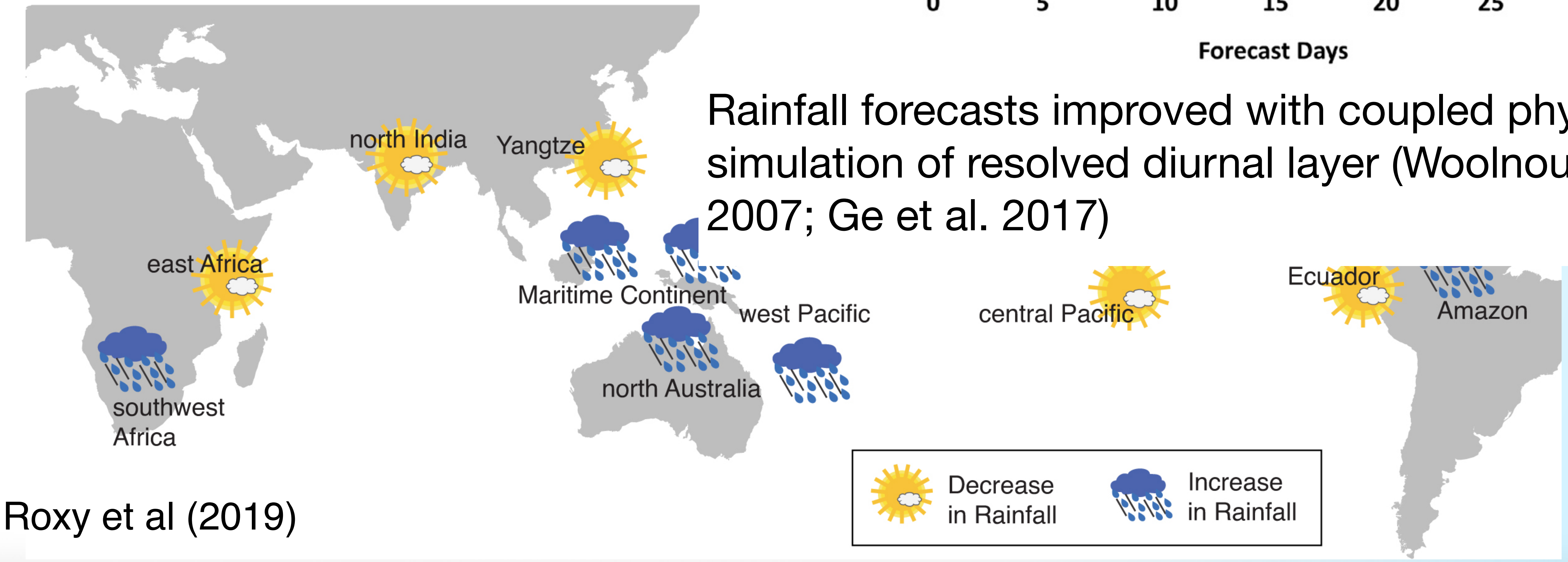
- Better observations of sub-surface stratification in the tropical Indian Ocean improves MJO/MISO predictability



Better MJO forecast skill when accounting for ocean-atmosphere coupling



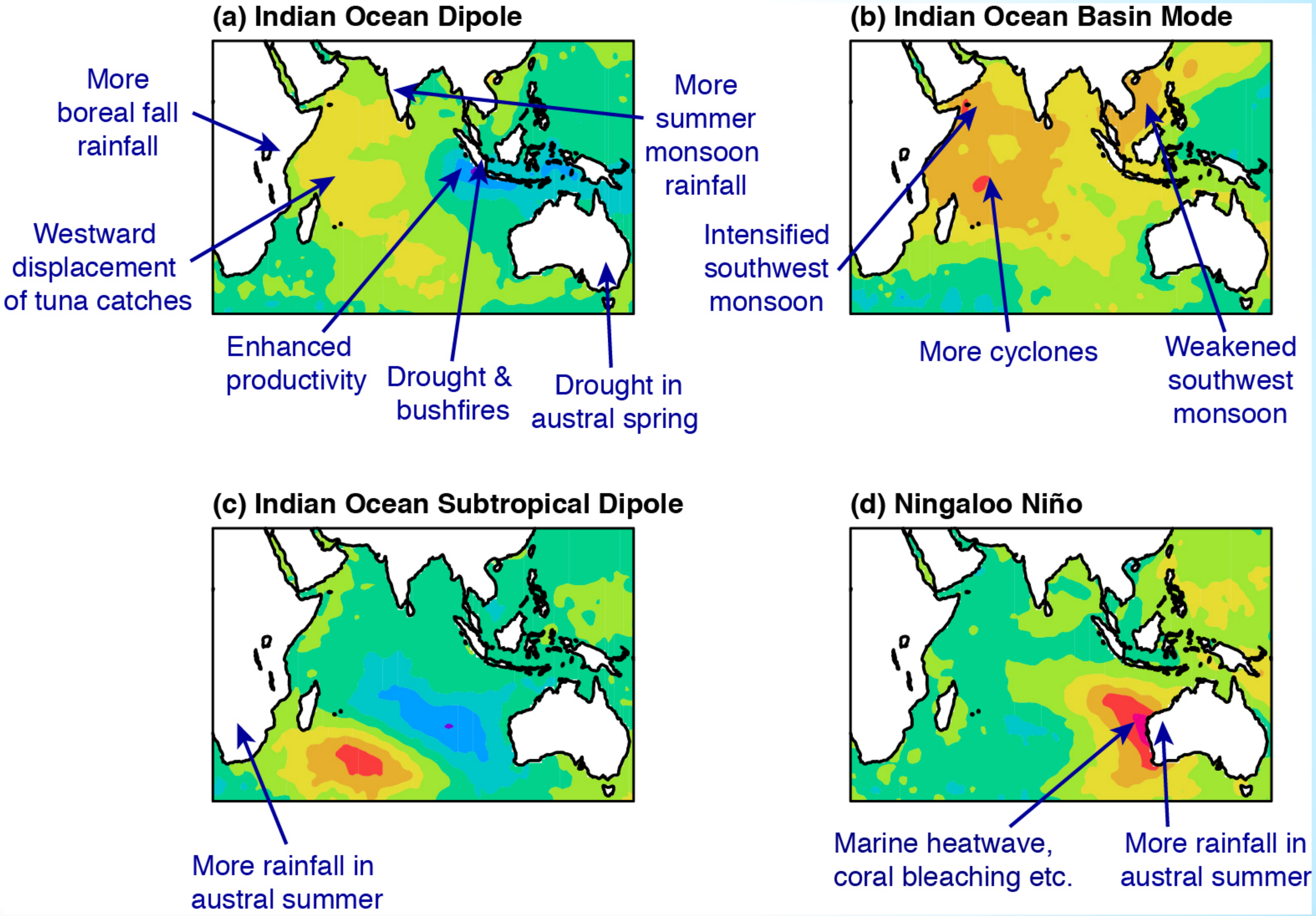
Rainfall forecasts improved with coupled physics and simulation of resolved diurnal layer (Woolnough et al. 2007; Ge et al. 2017)

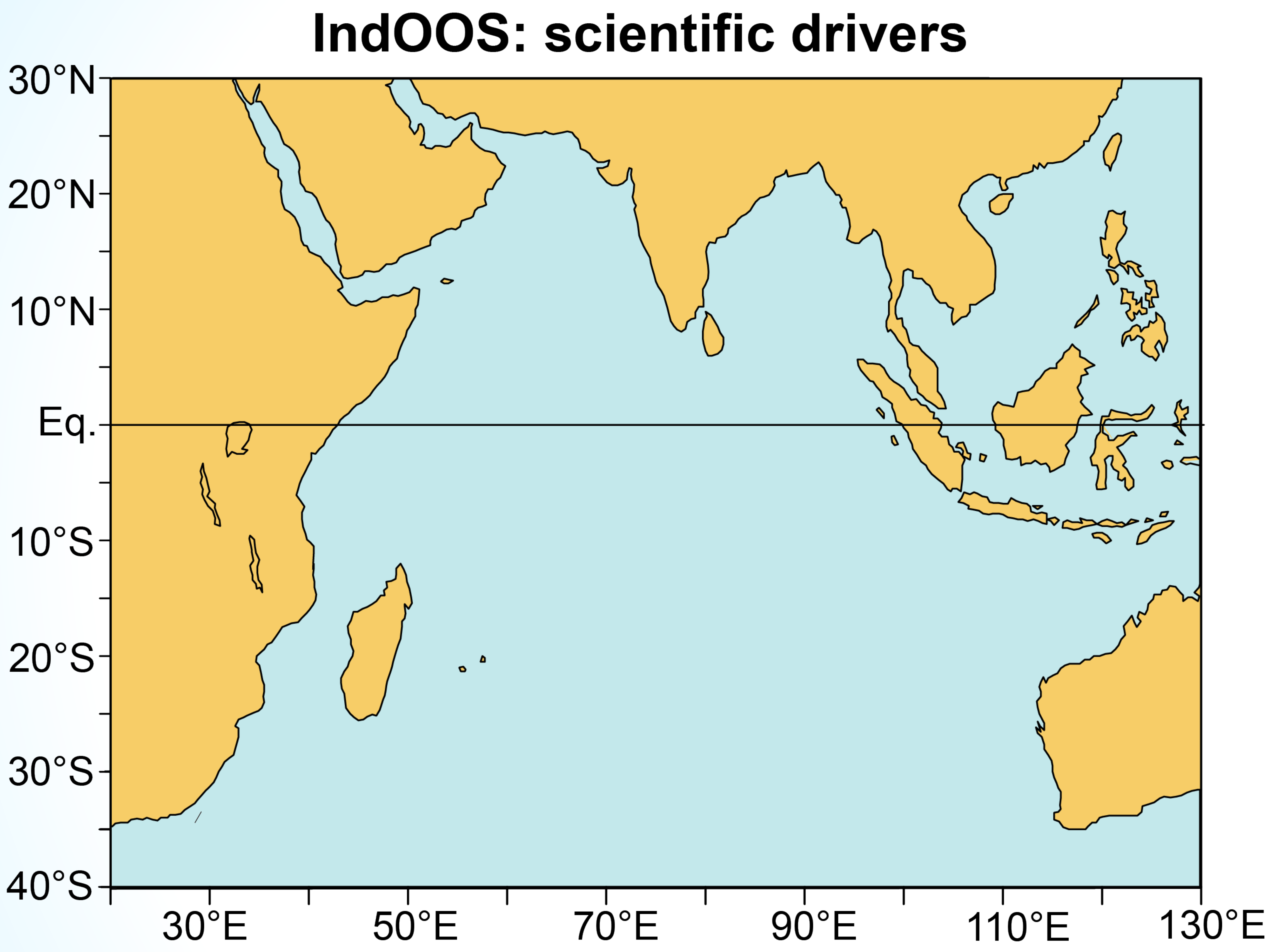


Roxy et al (2019)

What are the scientific drivers of the IndOOS?

- Interannual modes of SST variability within the Indian Ocean influence marine productivity, fish catch, rainfall, drought, and cyclogenesis.
- Paucity of long-term datasets mean that decadal variability remains to be characterised in the Indian Ocean




IndOOS: scientific drivers
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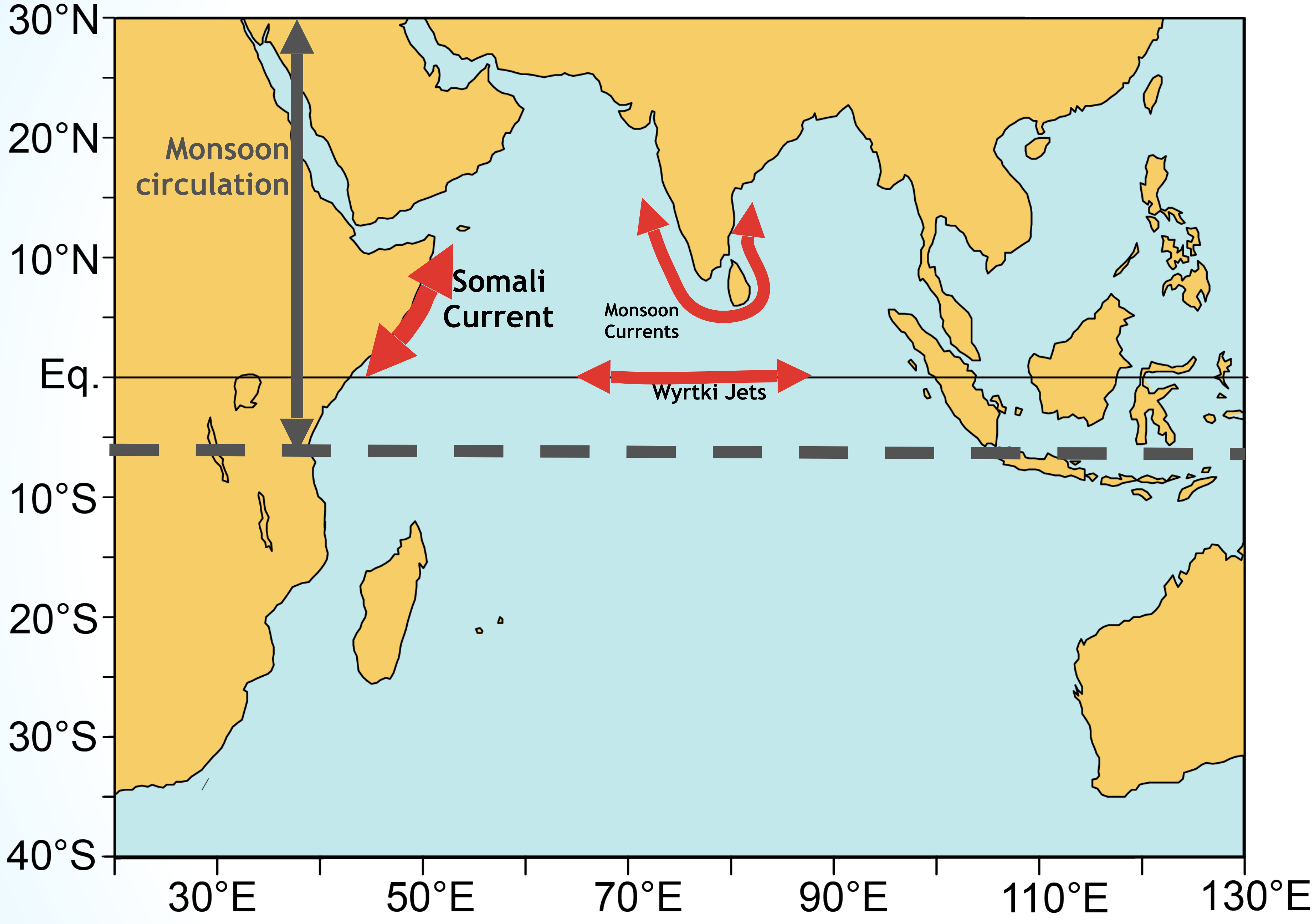

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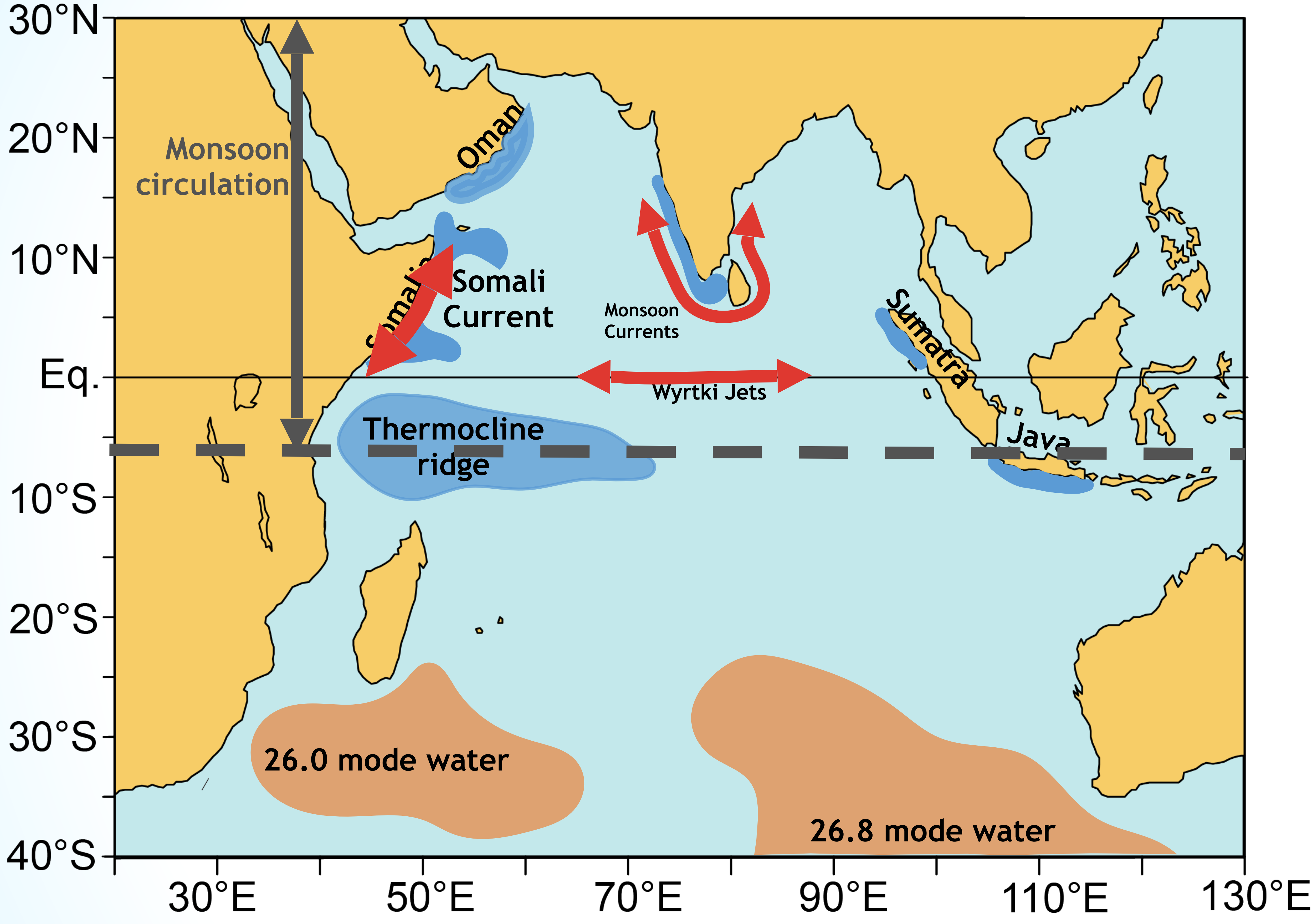

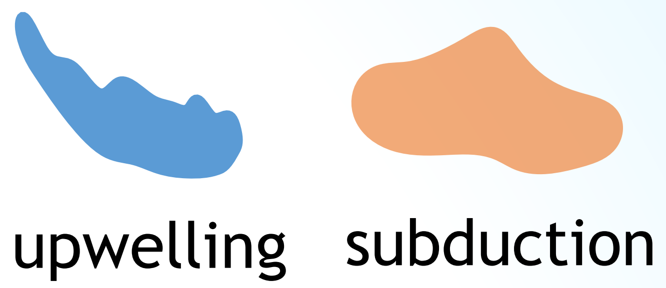

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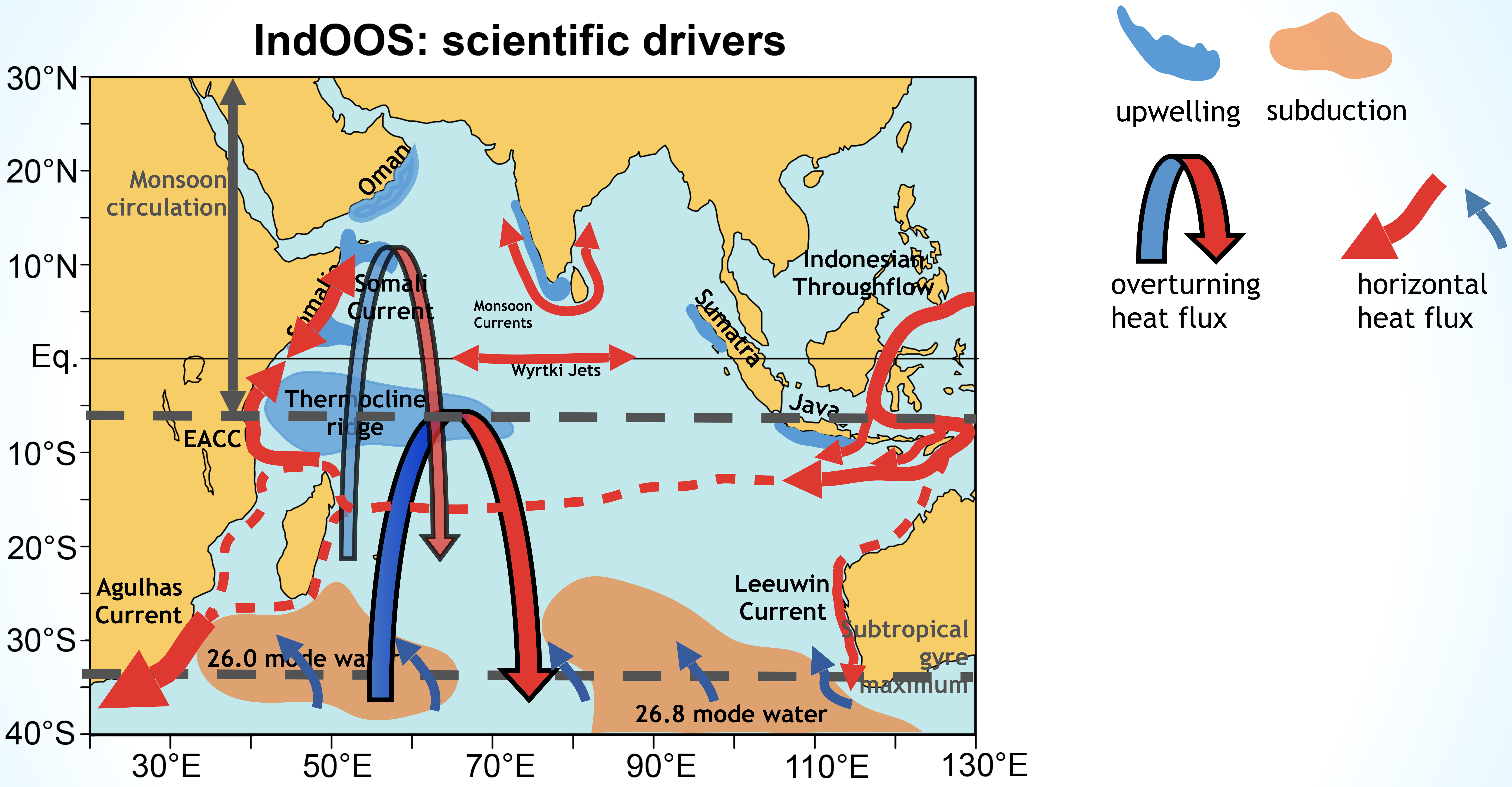

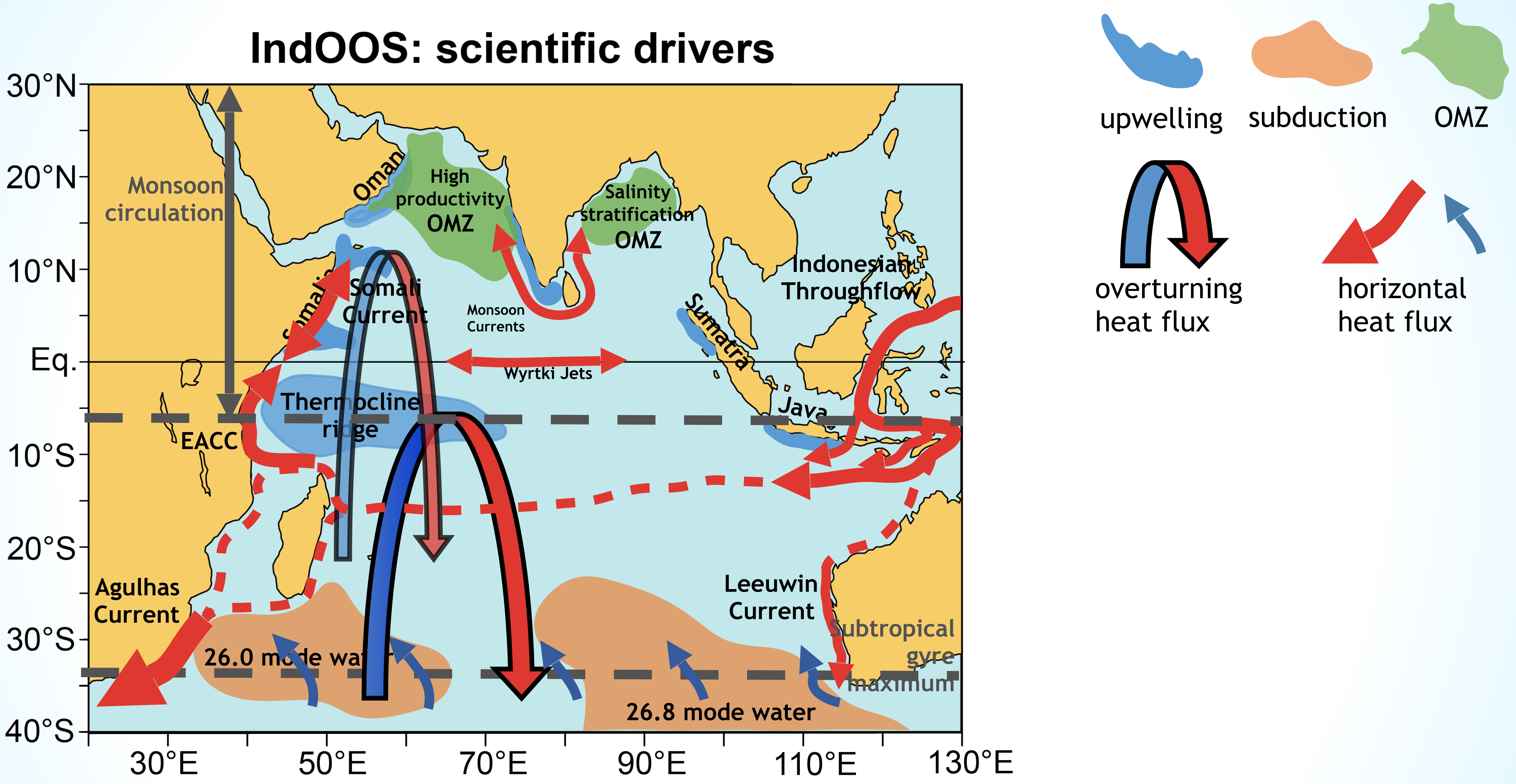
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26.8 mode water
upwelling
subduction
OMZ
overturning heat flux
horizontal heat flux

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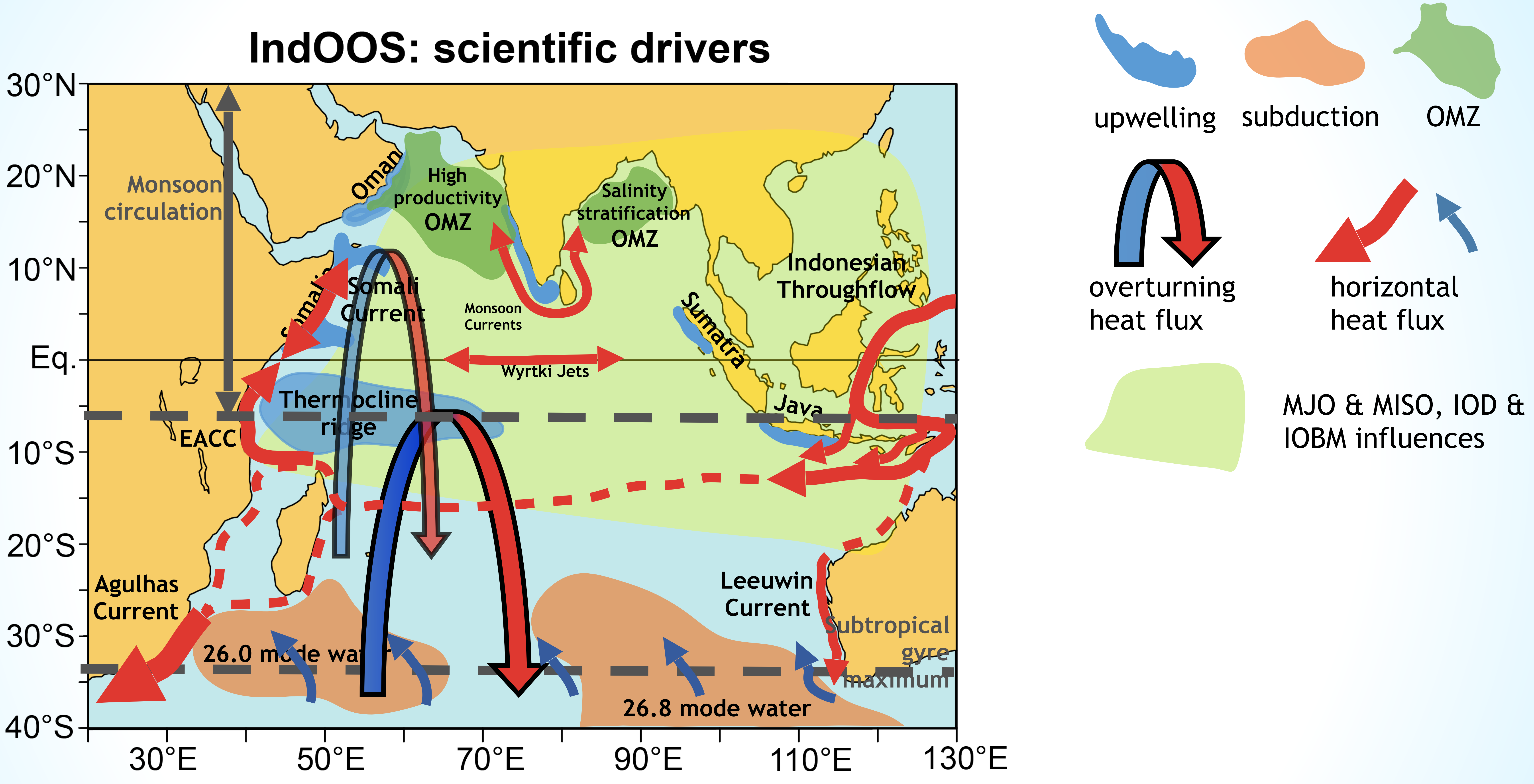

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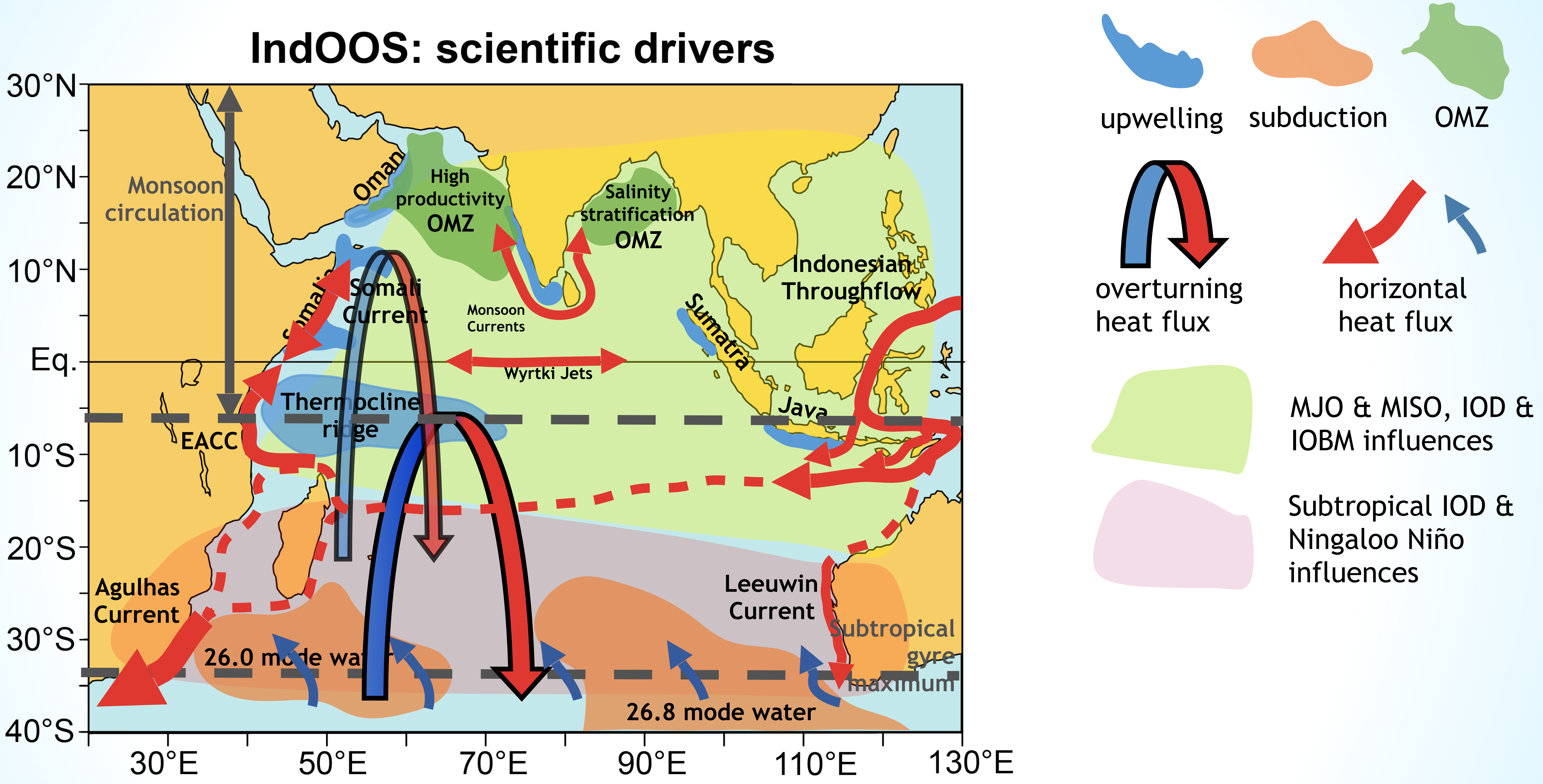
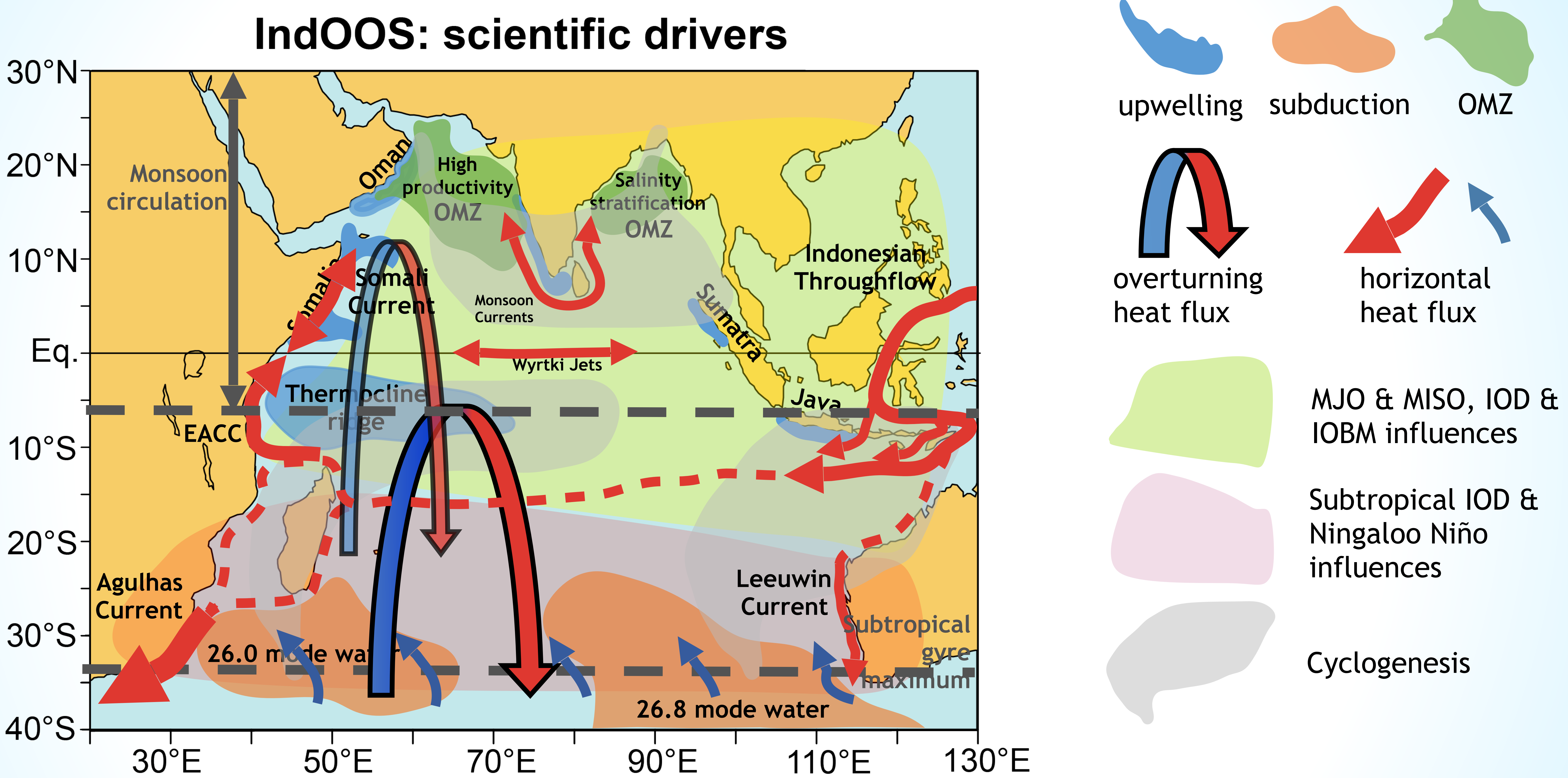
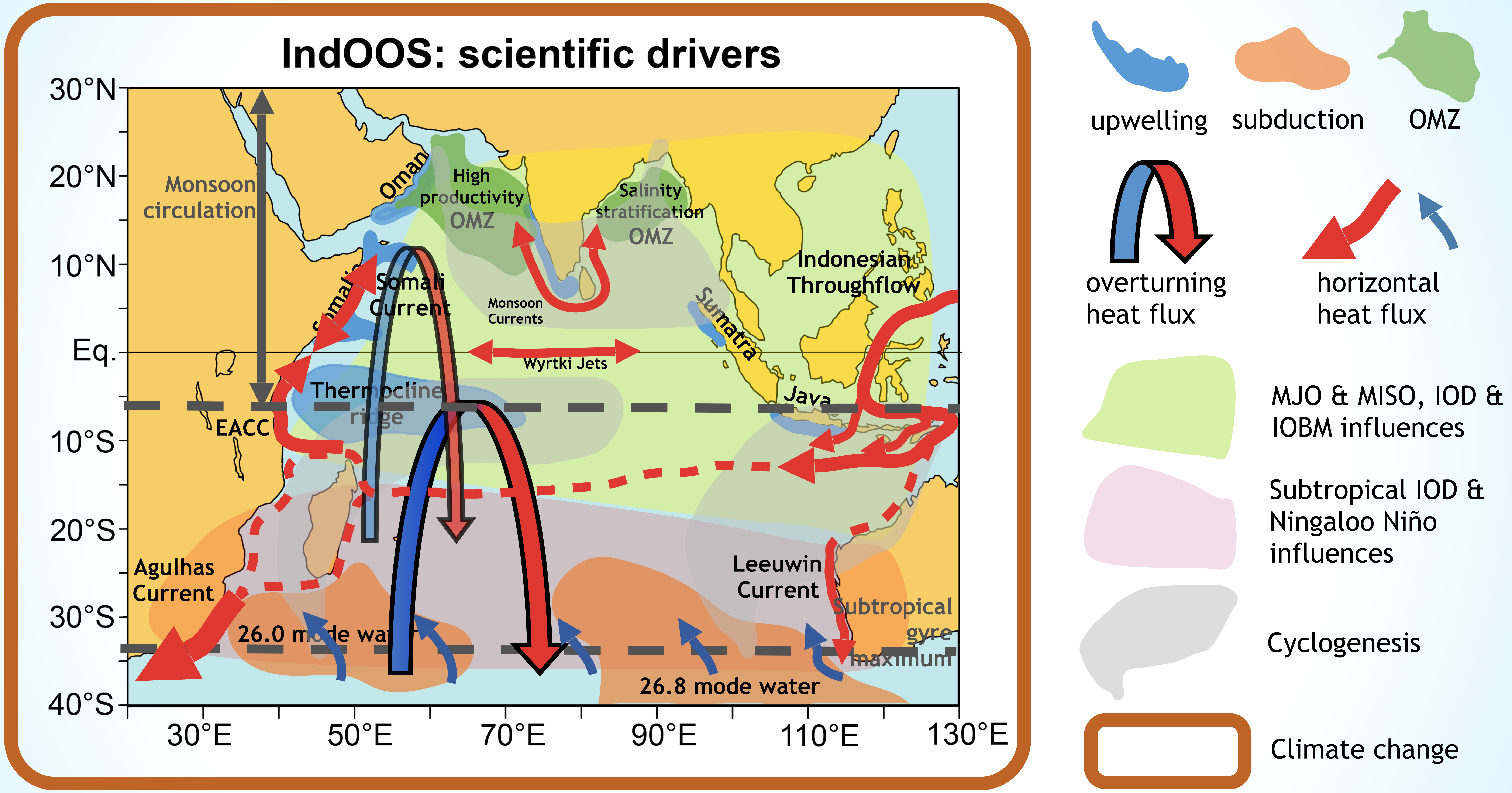




GCOS•GOOS•WCRP OOPC · IOGOOS Global Ocean Observing System for Indian Ocean · UNESCO United Nations Educational, Scientific and Cultural Organization · Intergovernmental Oceanographic Commission · GOOS The Global Ocean Observing System · IndOOS-2 · CLIVAR · NOAA · IMBeR · WCRP World Climate Research Programme · IUGG · IAPSO International Association for the Physical Sciences of the Oceans



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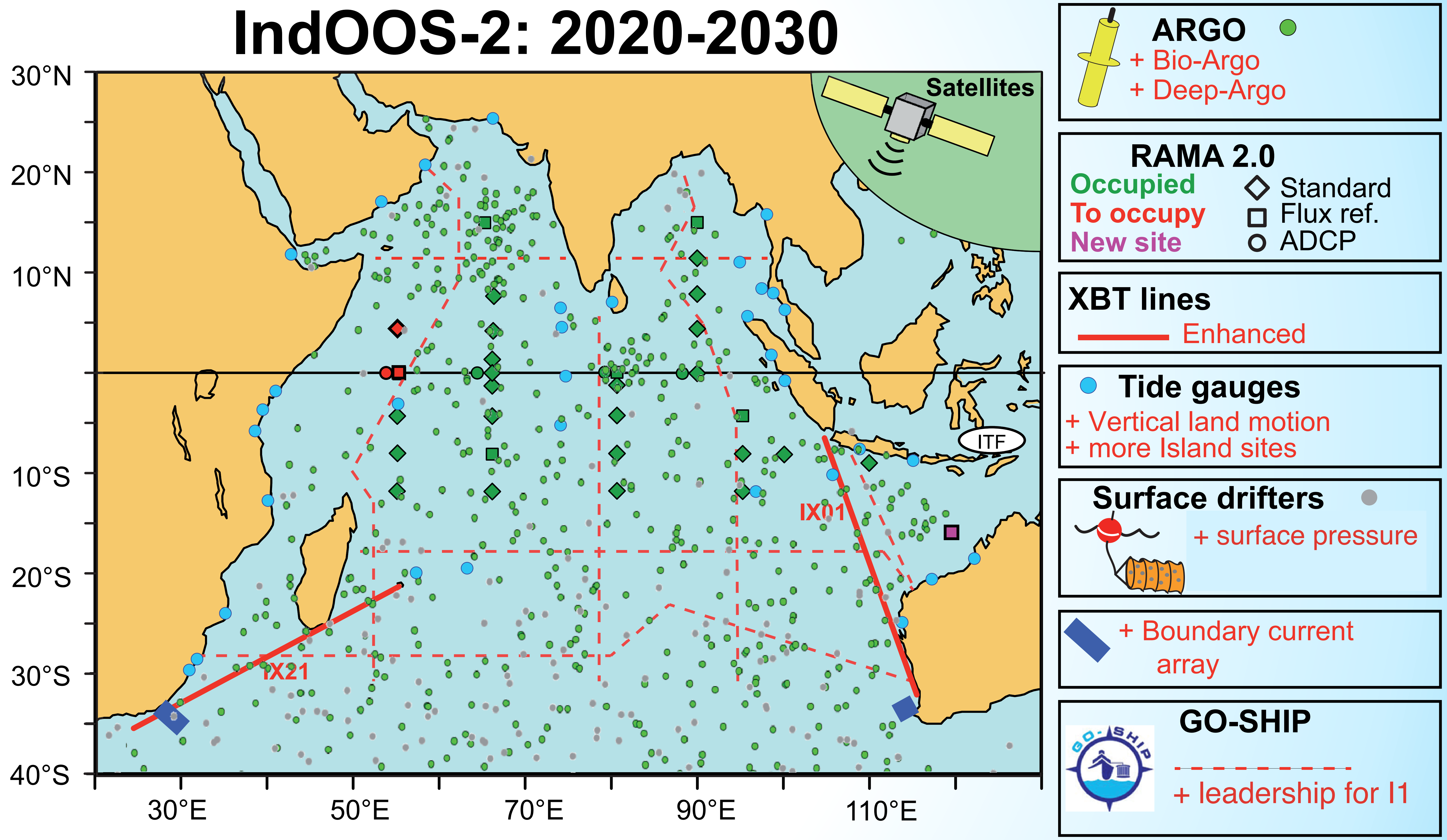
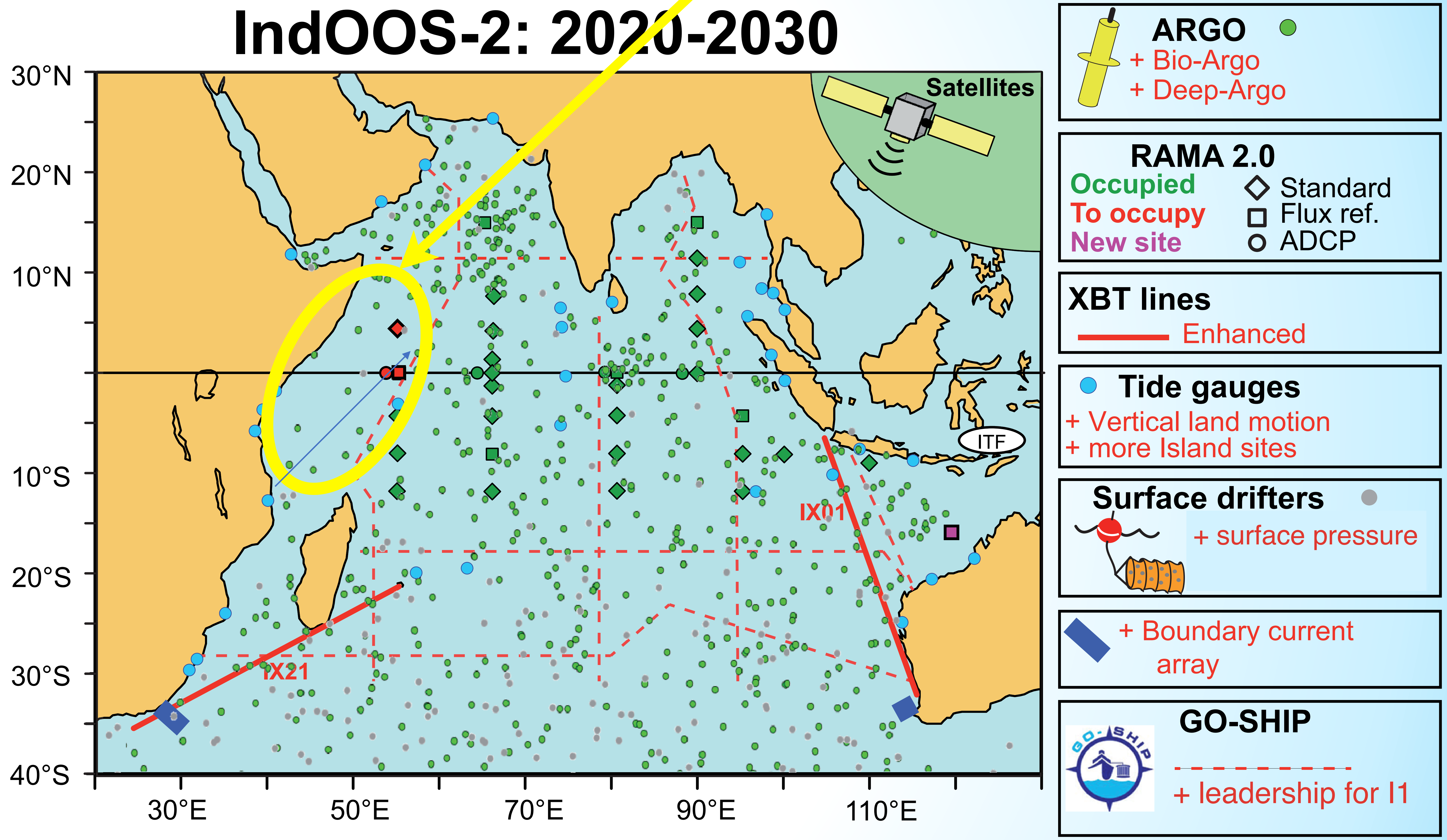
Roadmap for IndOOS-2: Core Findings



Roadmap for IndOOS-2: Core Findings

- Coverage of the **western equatorial Indian Ocean** needs to be completed.

EOVs: T, S, u(z), surface wind stress and heat flux



Roadmap for IndOOS-2: Core Findings

EOVs: oxygen, nutrients, carbon (DOC, DIC), phytoplankton biomass and diversity

- Coverage of the **western equatorial Indian Ocean** needs to be completed.
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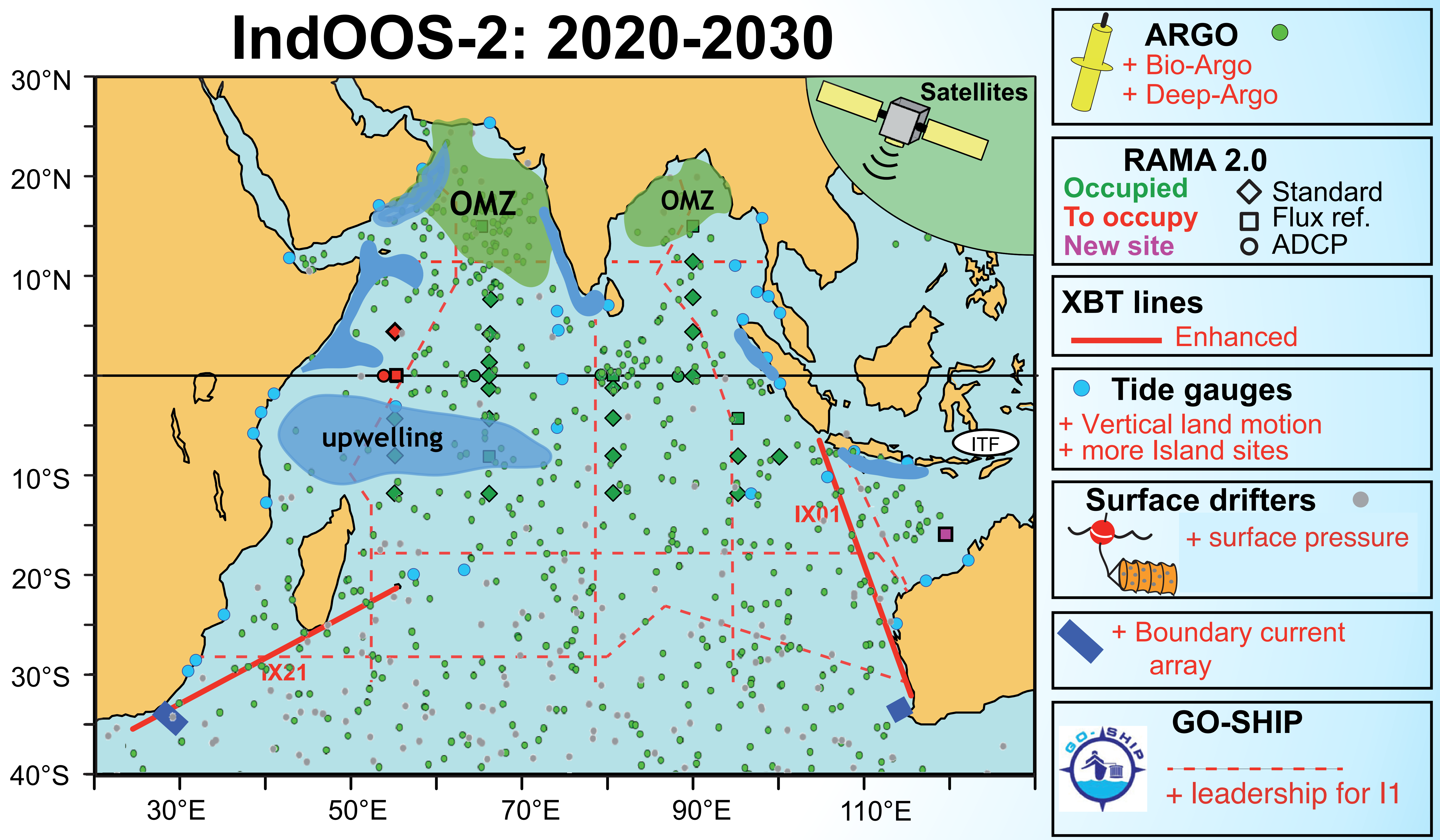

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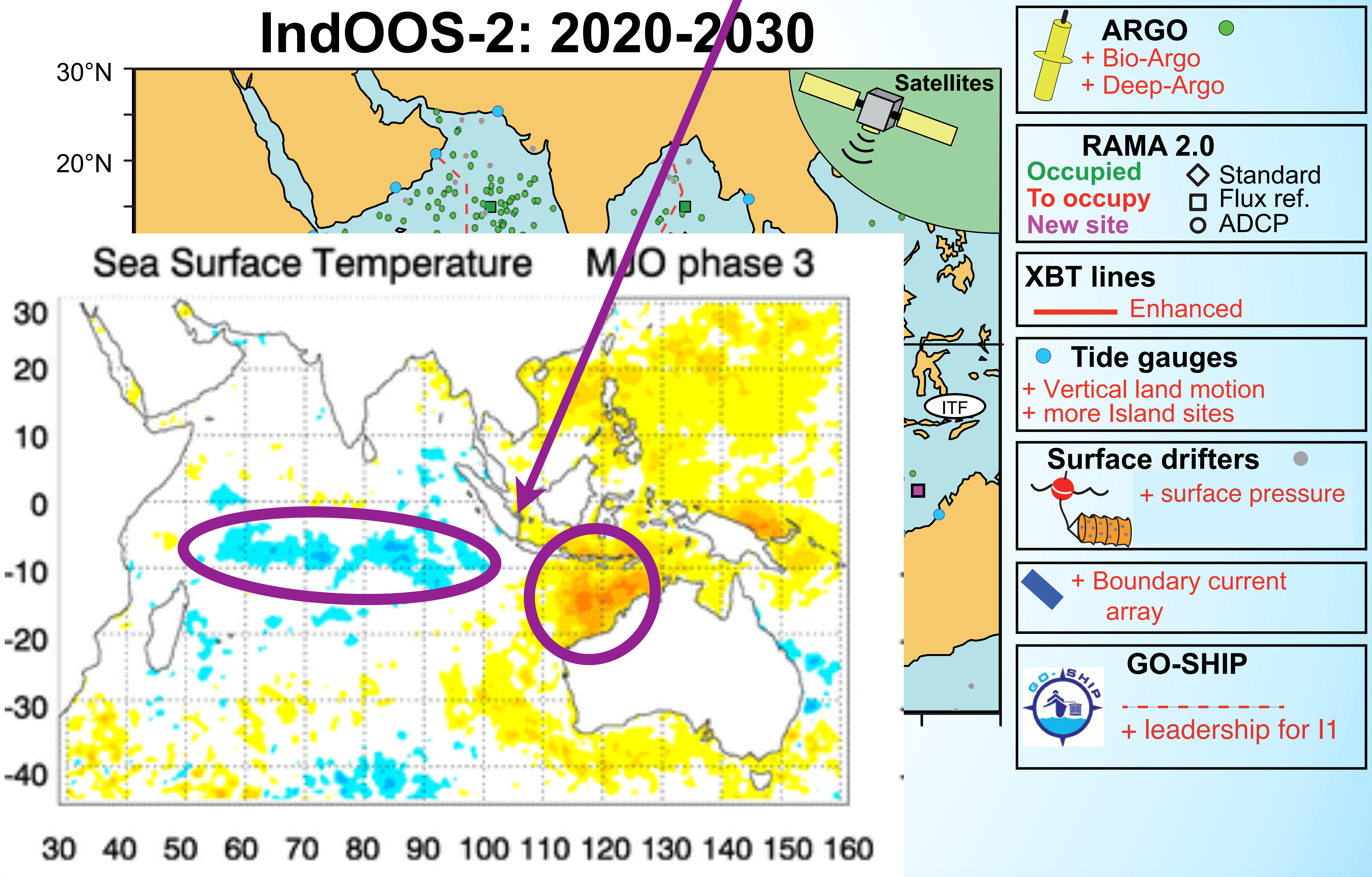
- Coverage of the **western equatorial Indian Ocean** needs to be completed.
- **Biogeochemical measurements must be collected alongside physical parameters**, initially targeted to regions of high variability and change, such as the OMZs and upwelling systems.
- **Enhanced vertical and temporal resolution of upper-ocean measurements** are needed in tropical regions strongly coupled to MJO and MISO development.

EOVs: T, S, u(z), surface stress, surface heat flux



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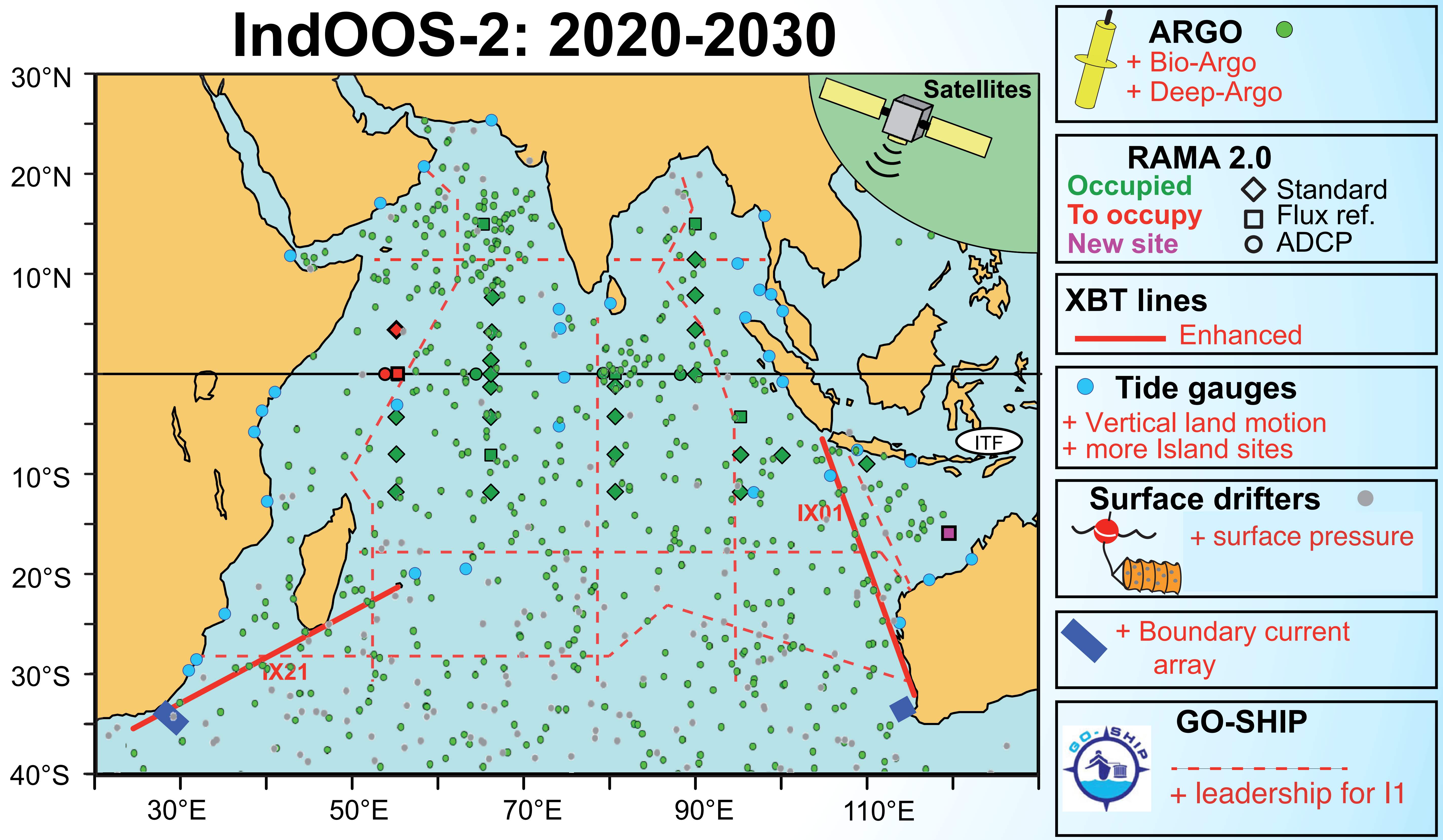

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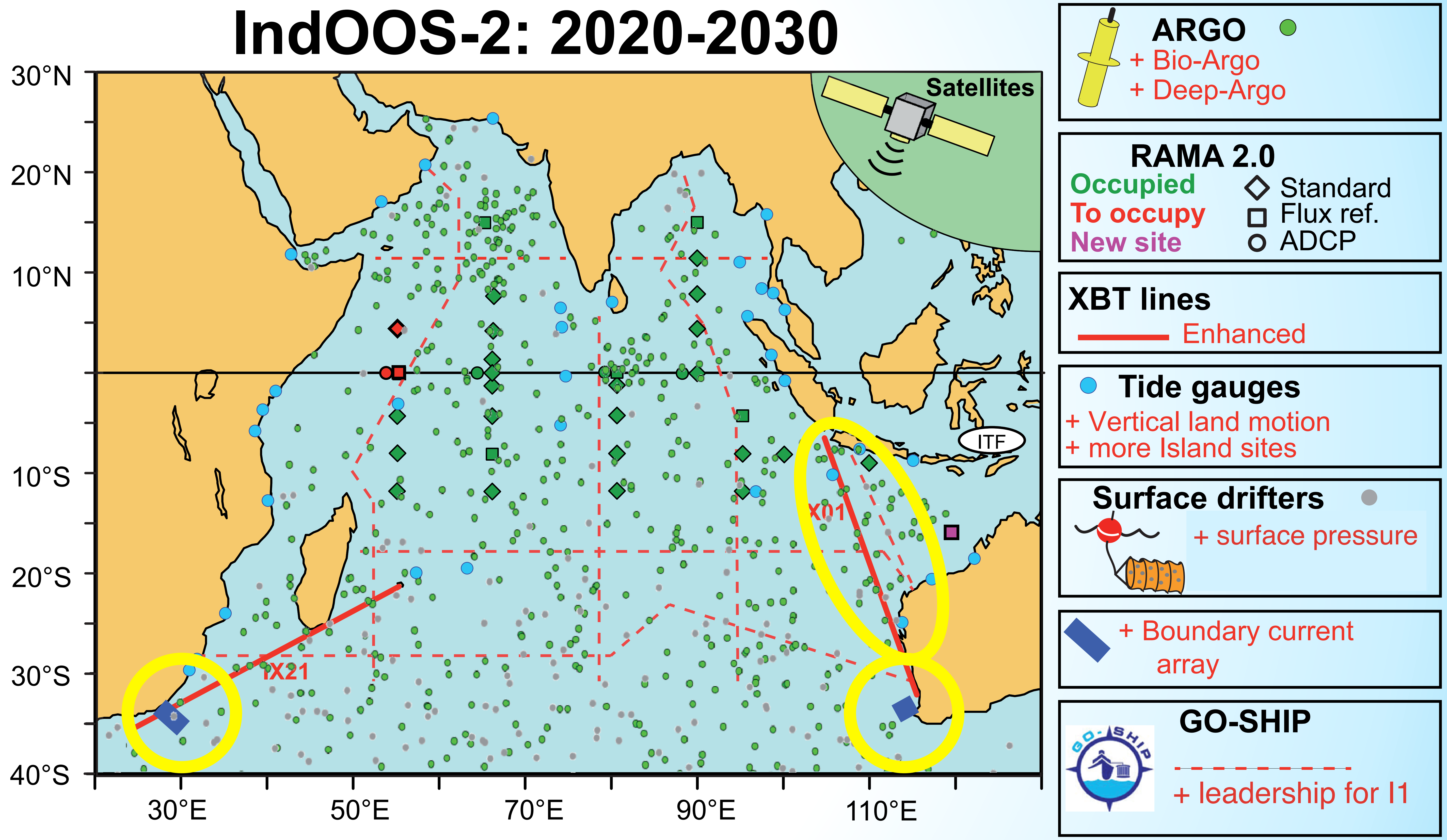
EOVs: T, S, u(z), O2

- **Boundary flux arrays** in the Agulhas and Leeuwin Currents are needed alongside an **enhancement of Indonesian Throughflow monitoring.**



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EOVs: T, S

- **Boundary flux arrays** in the Agulhas and Leeuwin Currents are needed alongside an **enhancement of Indonesian Throughflow monitoring.**
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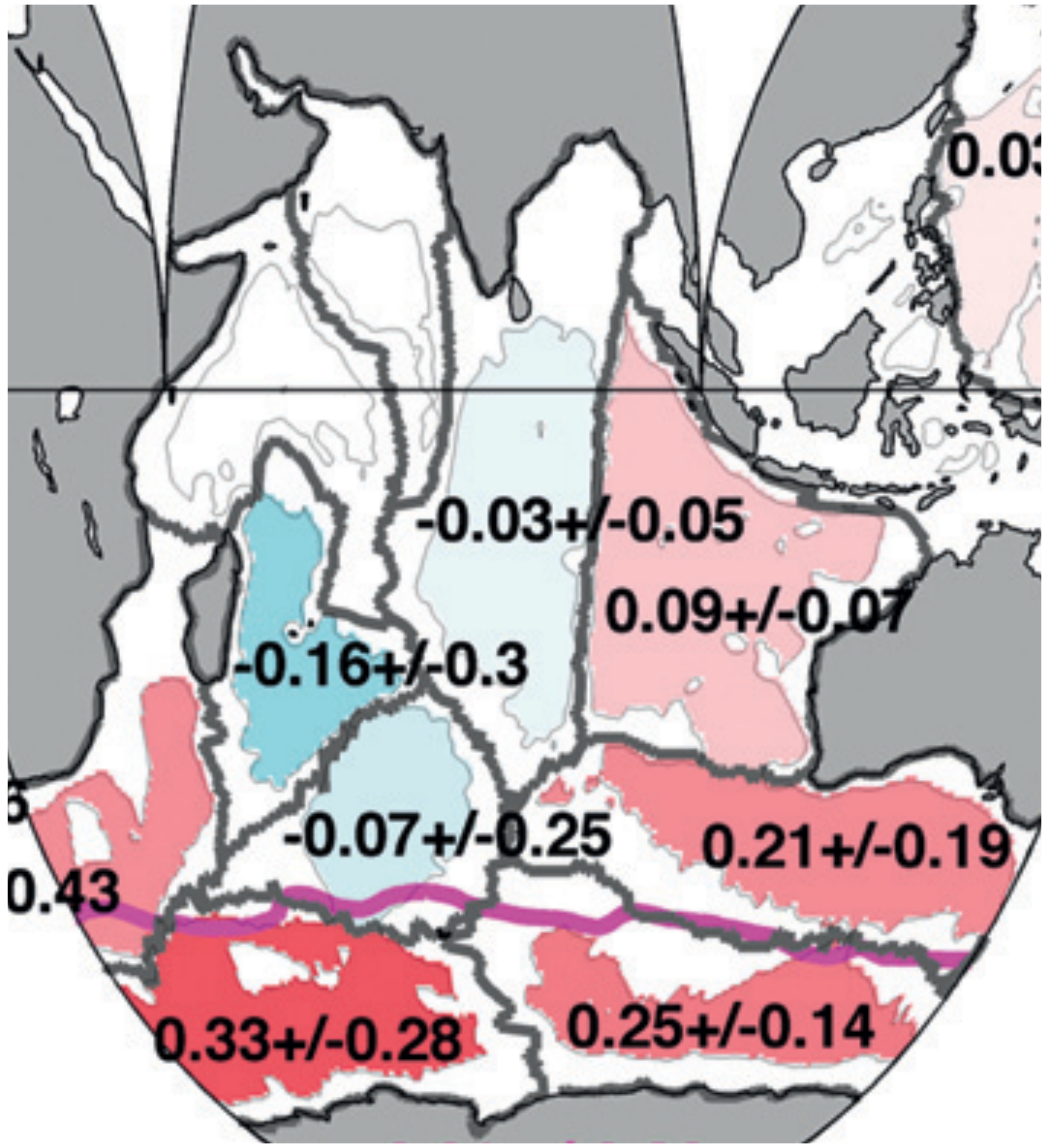
Warming below 4000 m, W/m2, Purkey & Johnson (2010).



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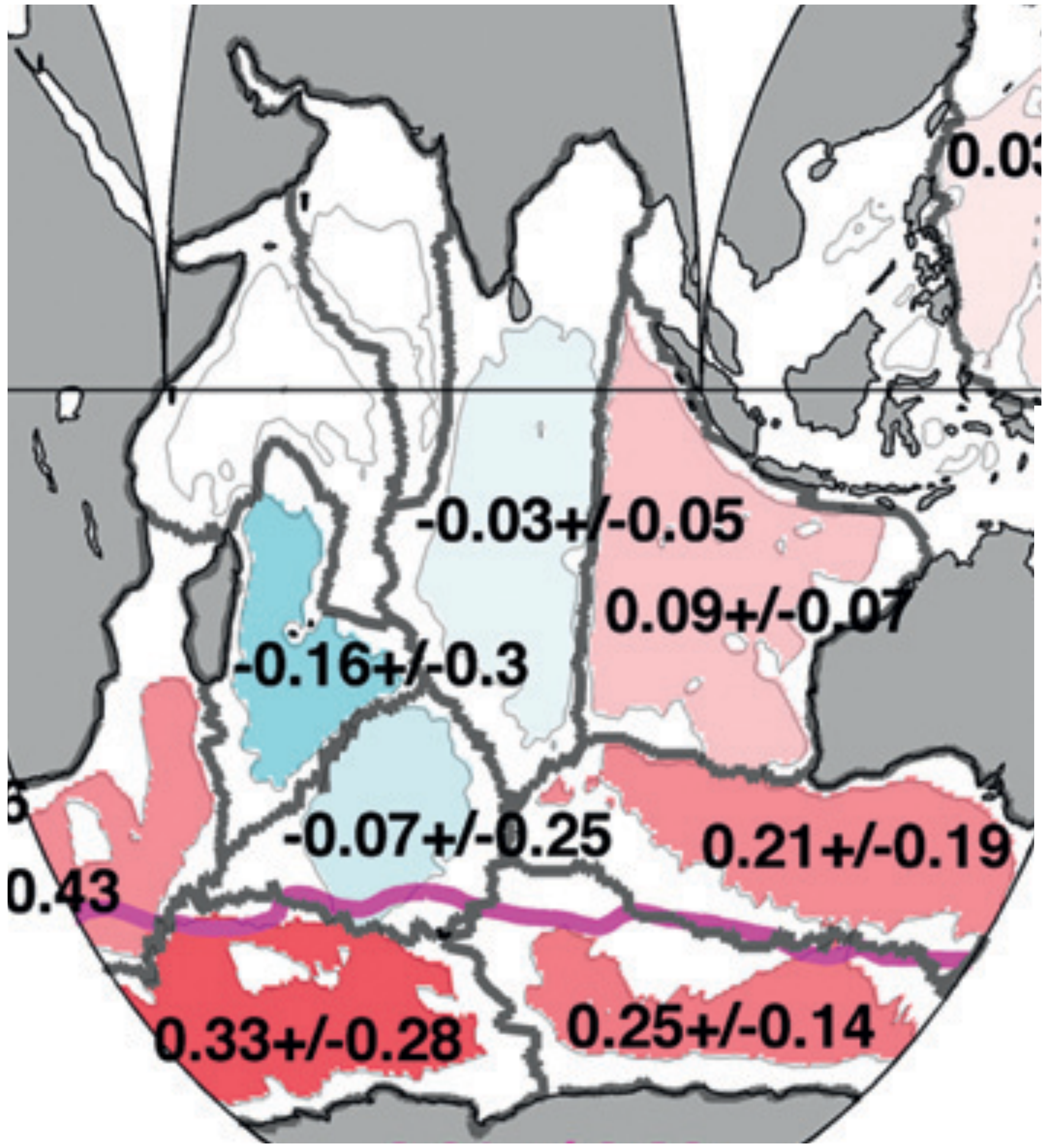

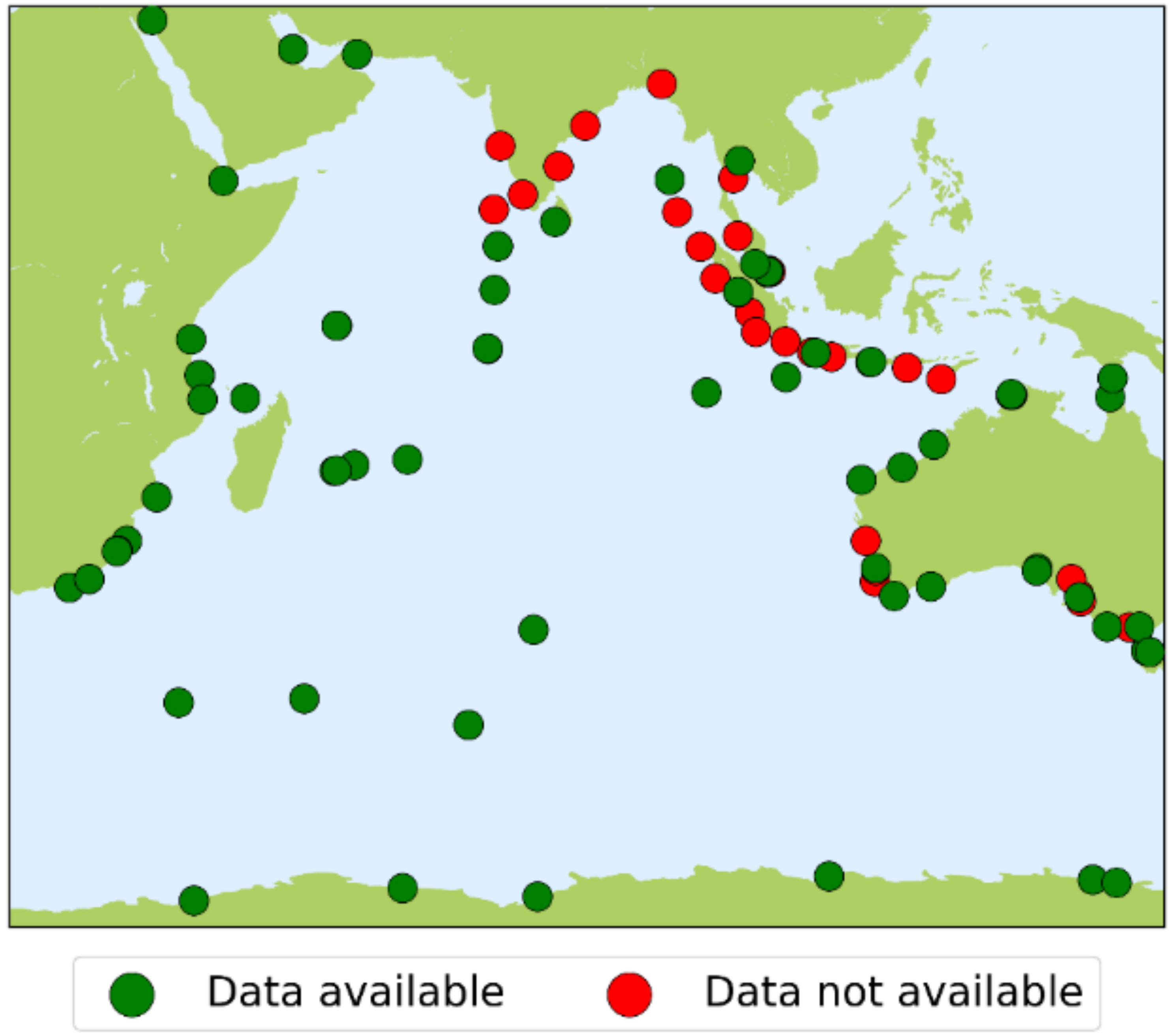

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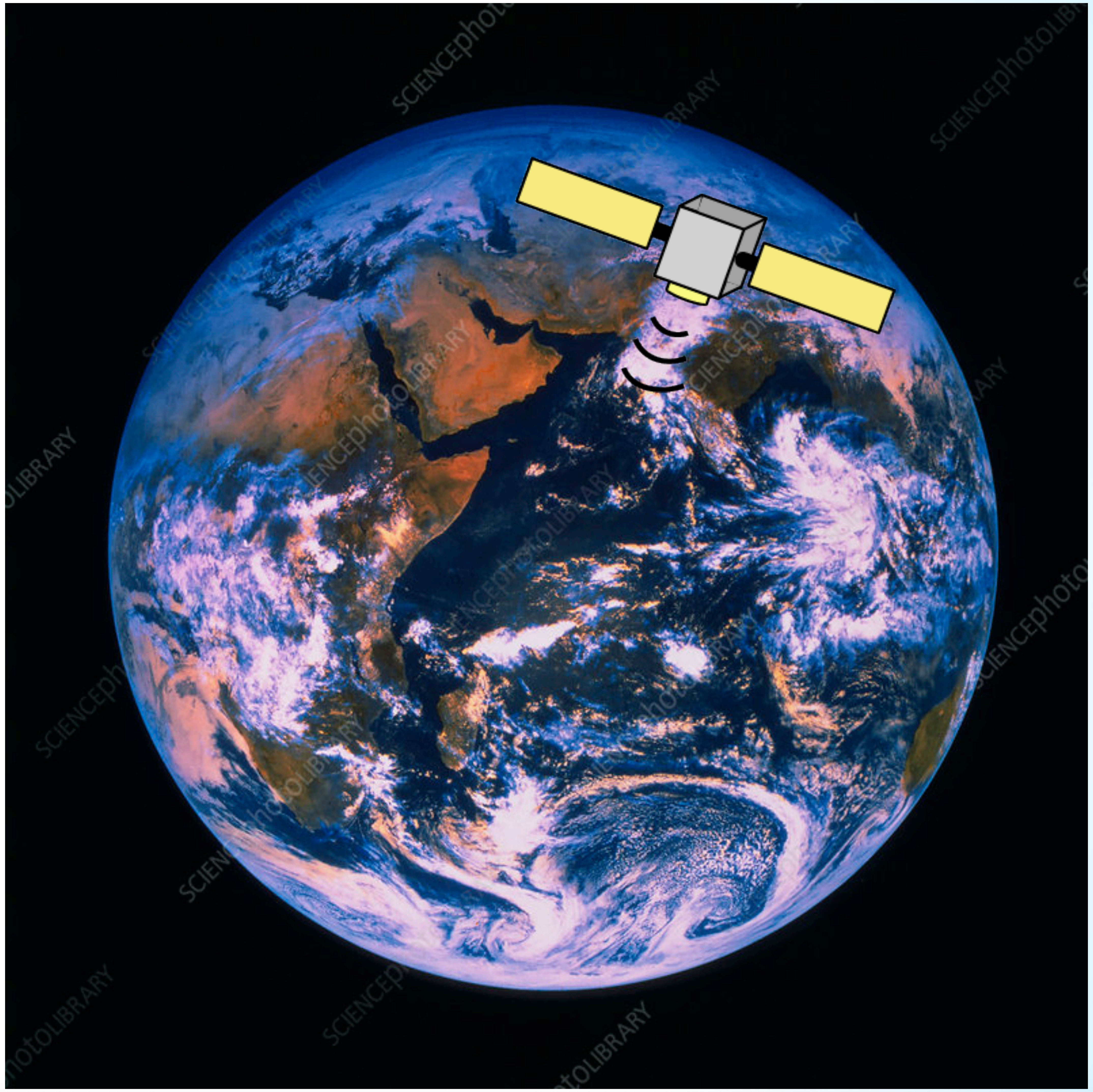
- Continuous, overlapping **satellite measurements are central** to the IndOOS.



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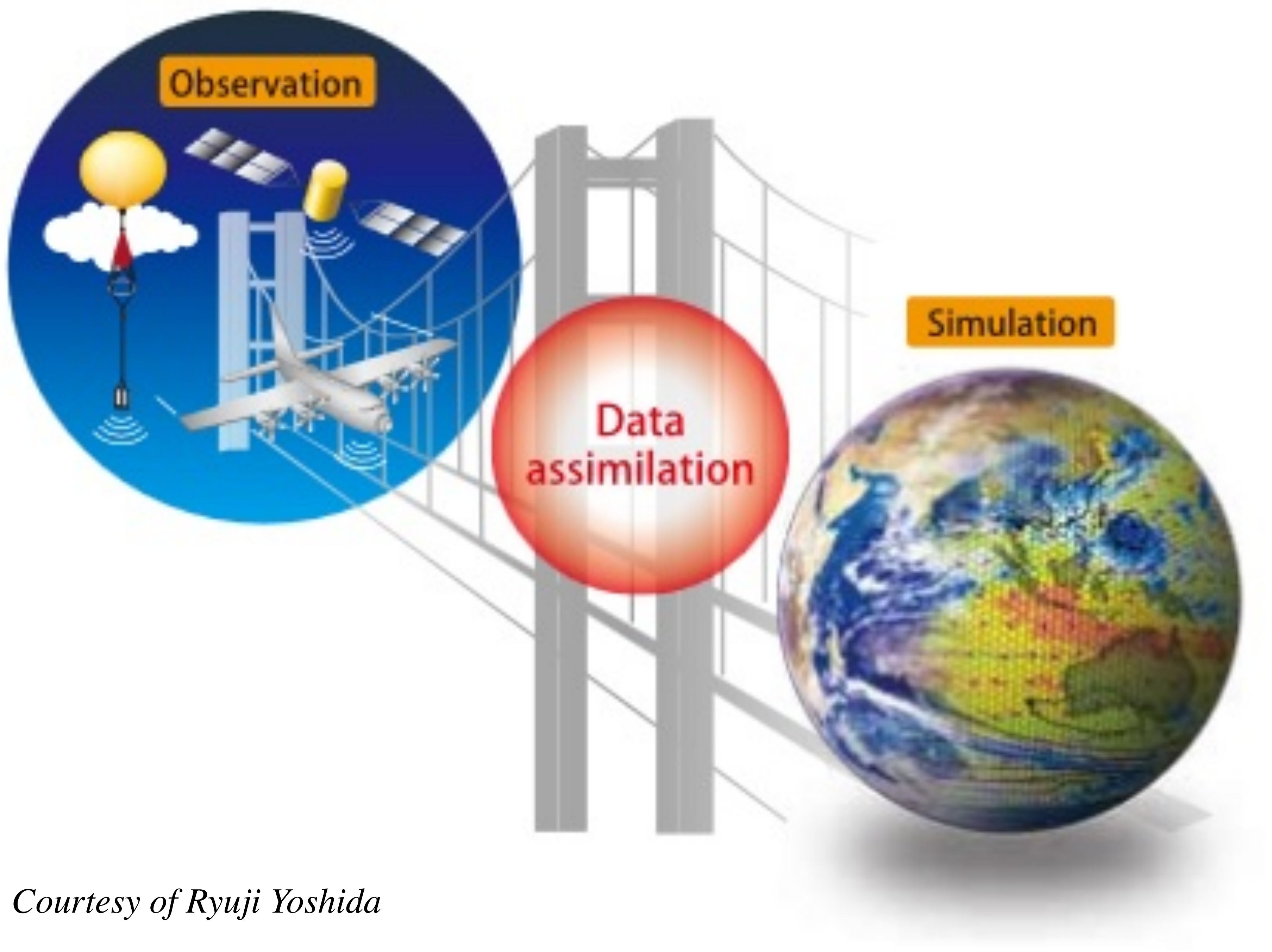

Courtesy of Ryuji Yoshida

Core Findings: Beyond *in situ* Observations

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Actionable Recommendations by Observing System Component
Tiers I and II: Maintain and Extend

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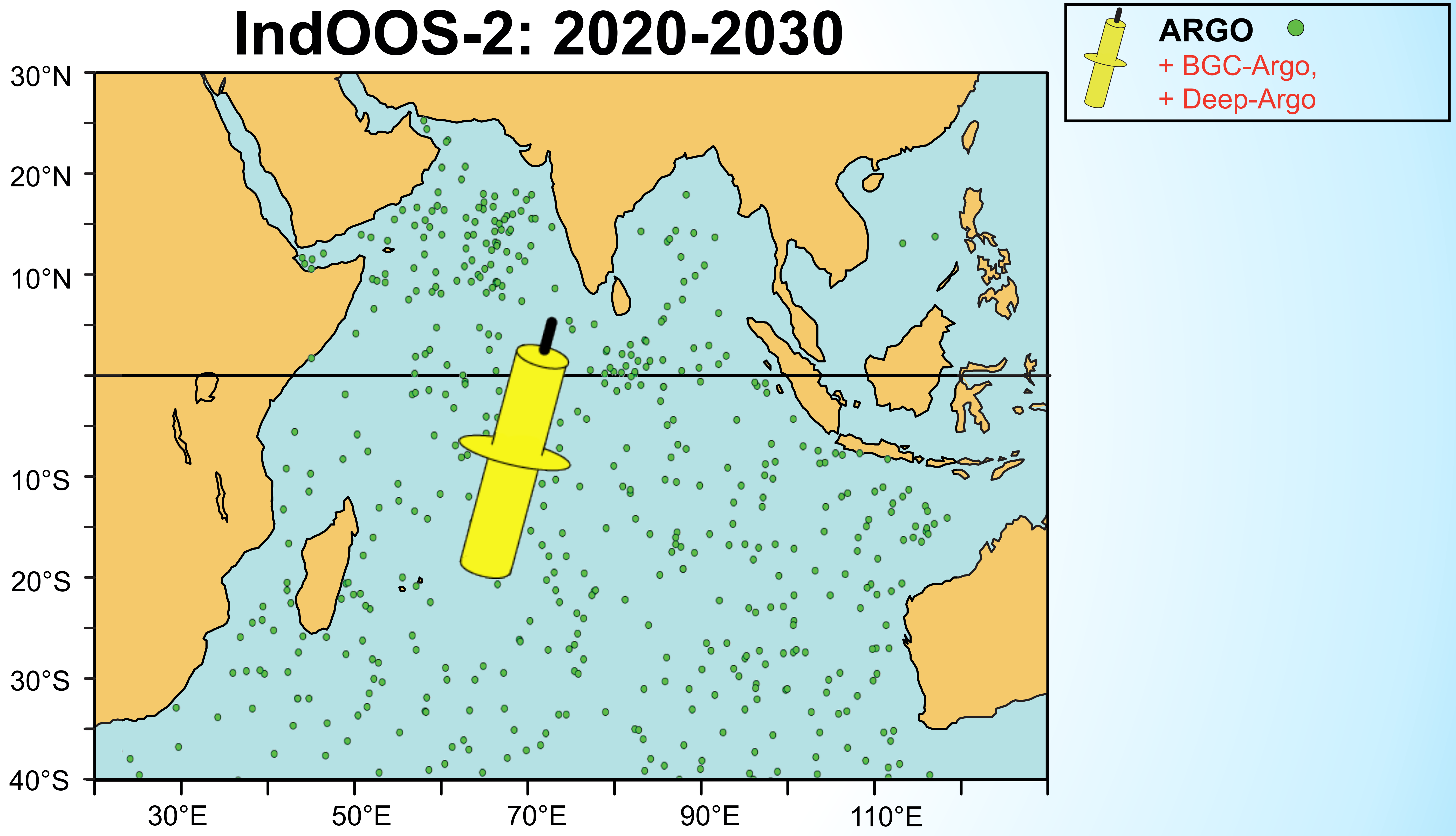

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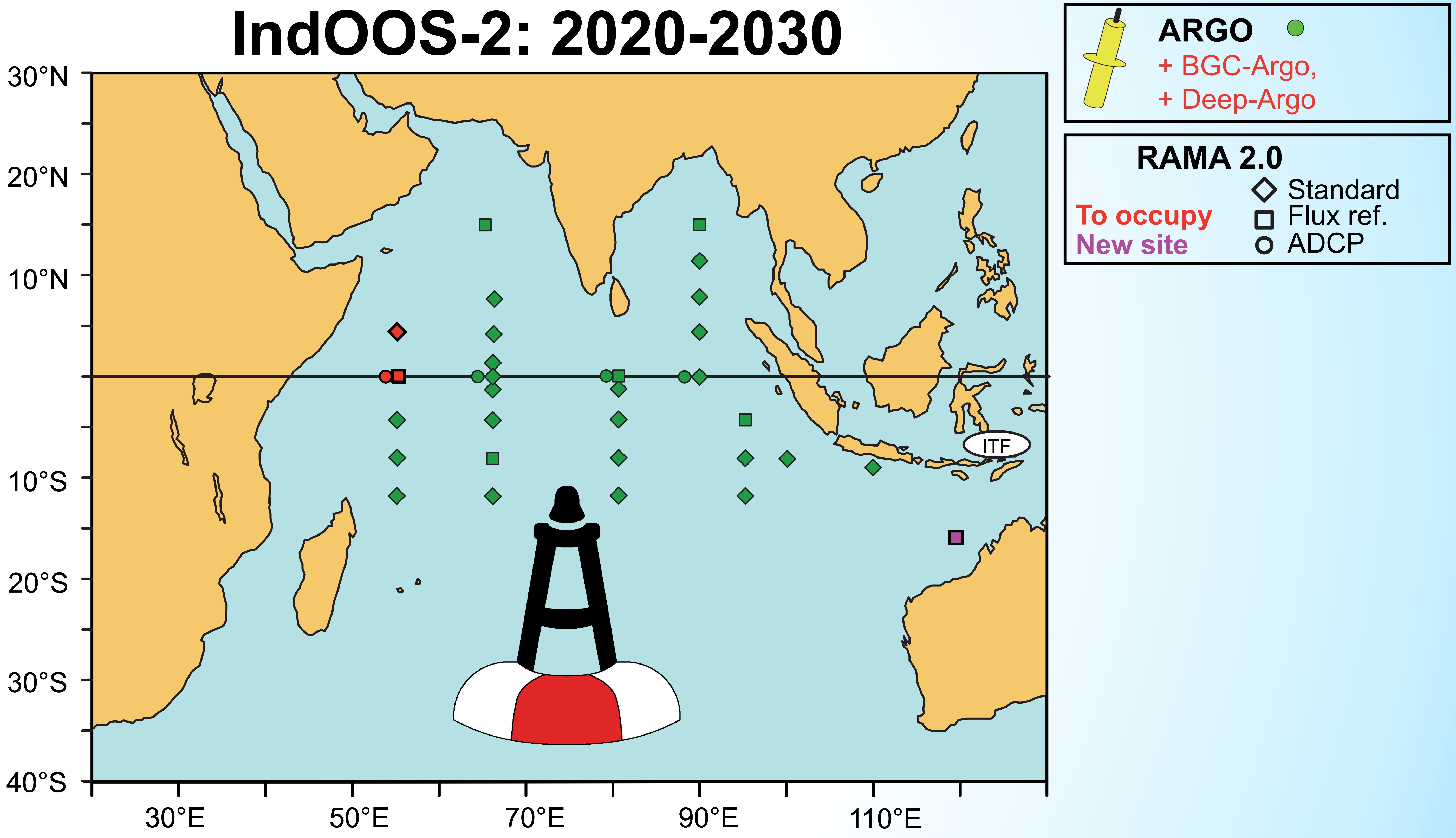

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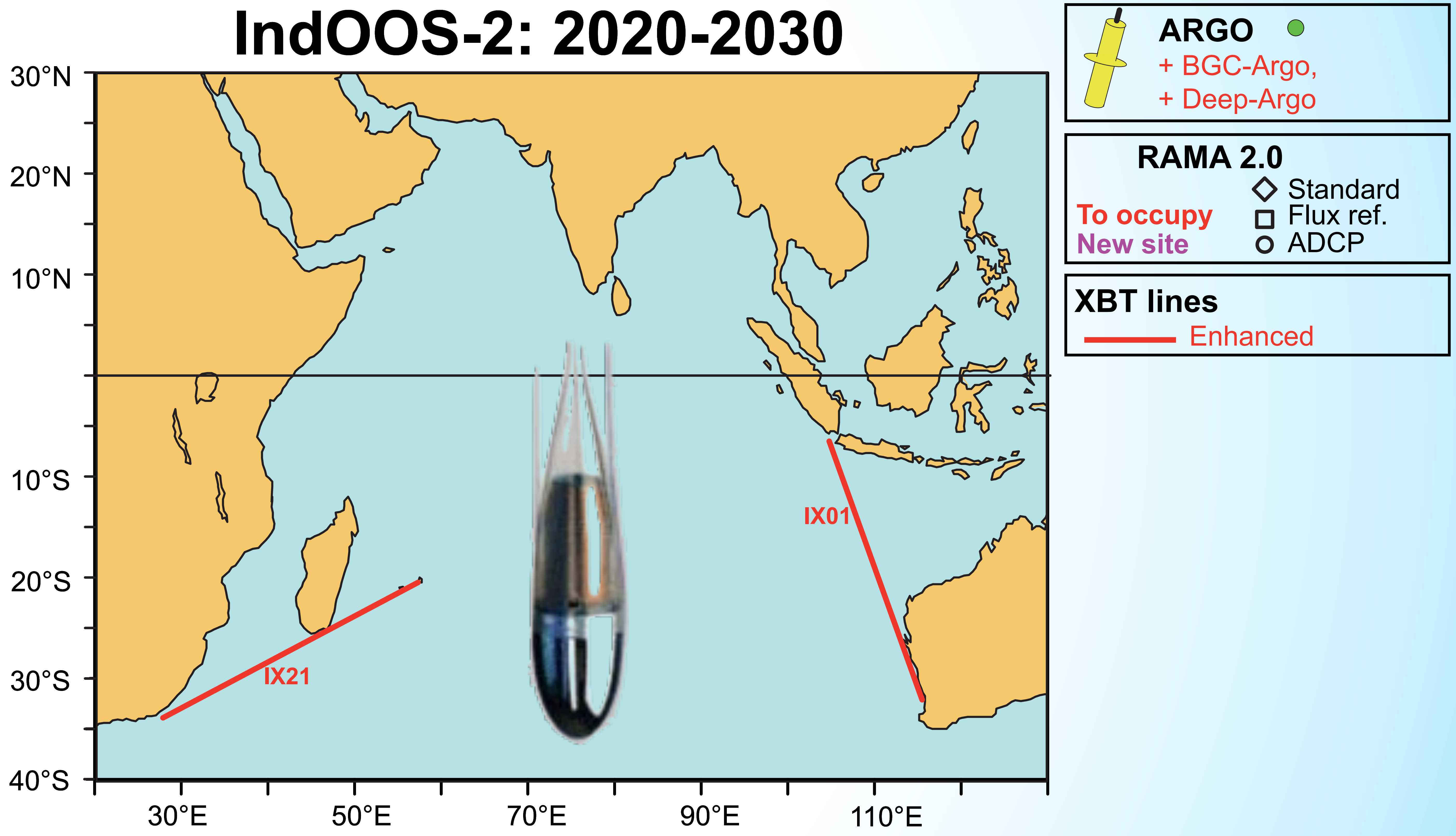

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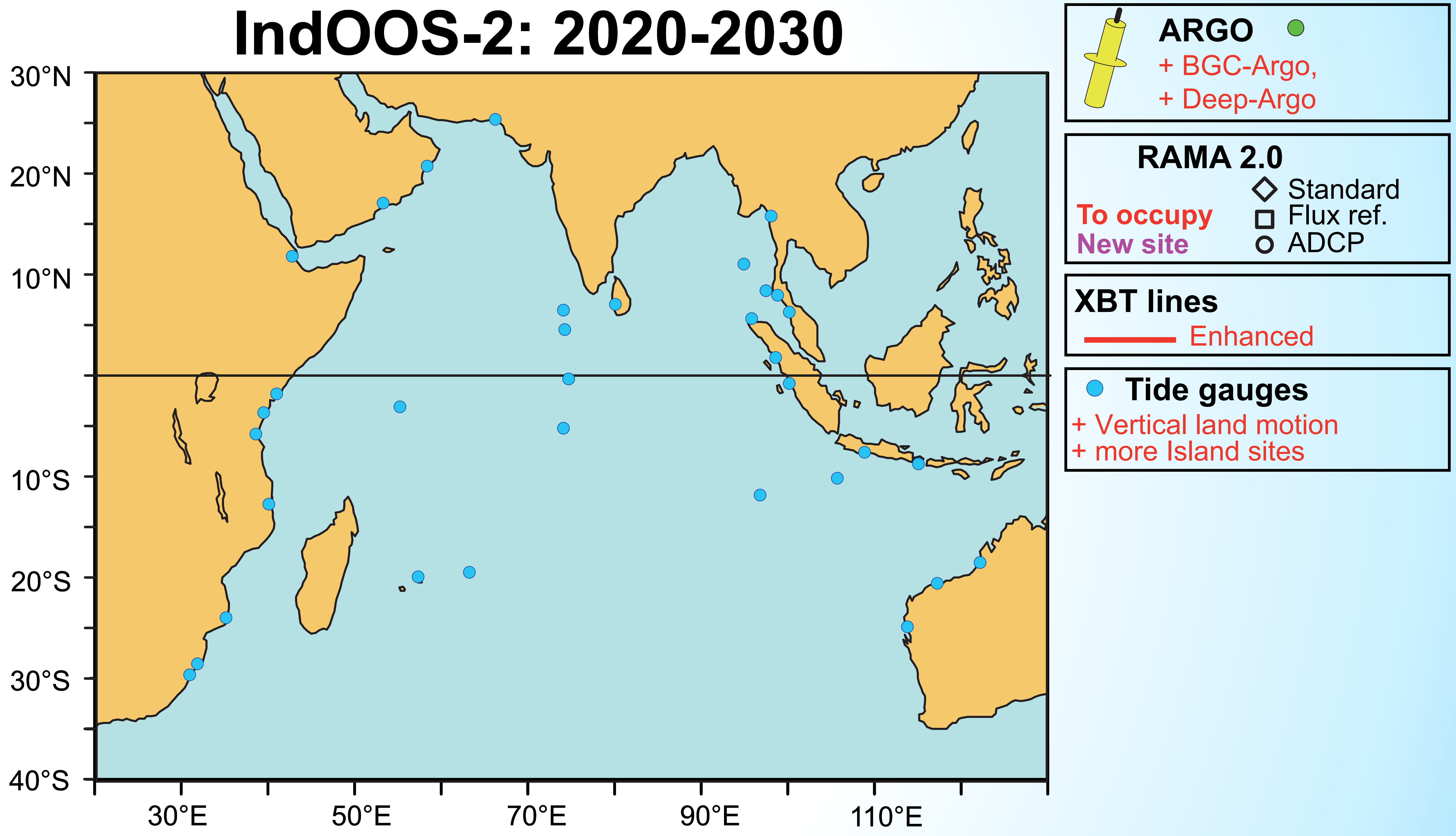

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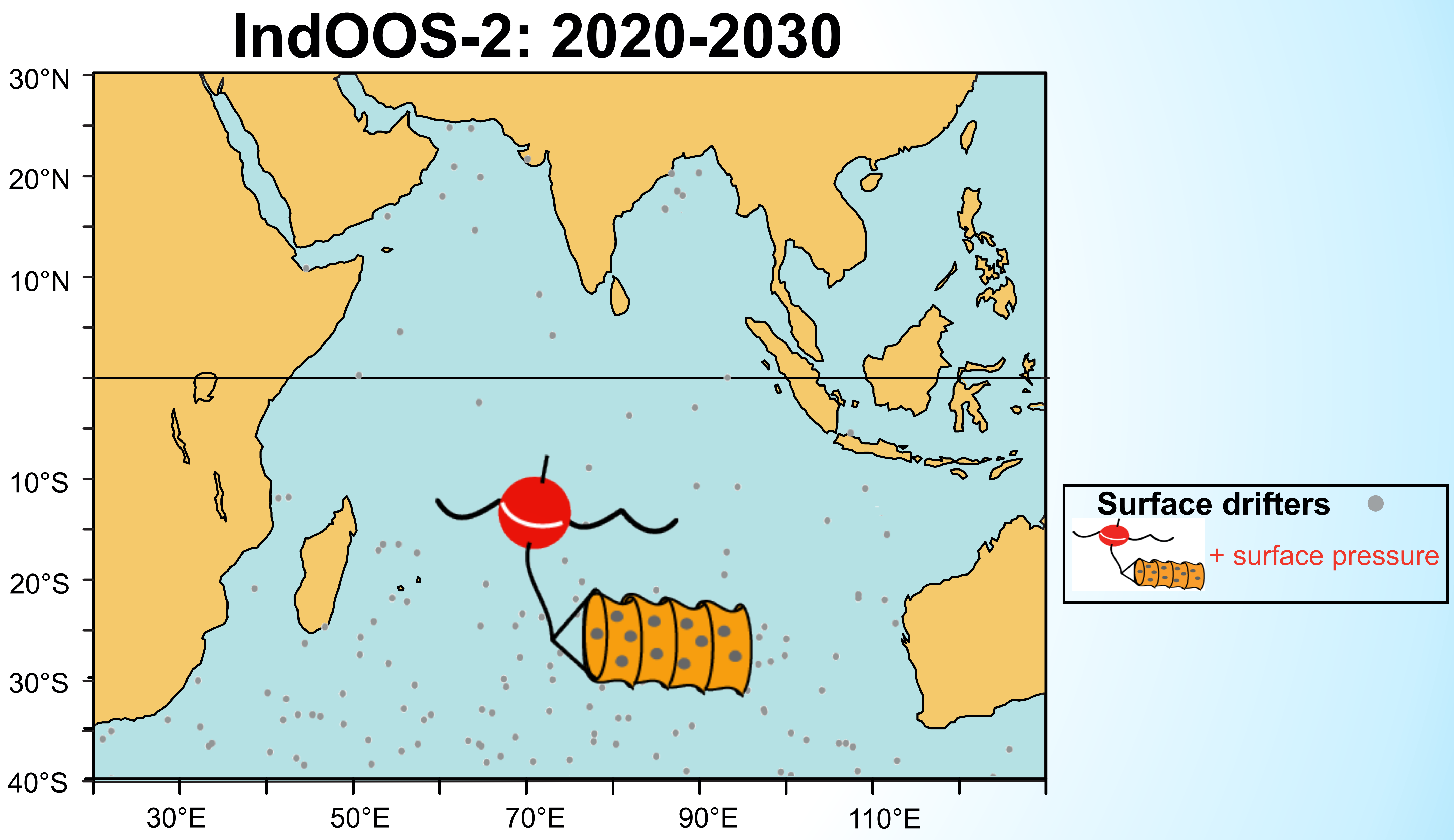

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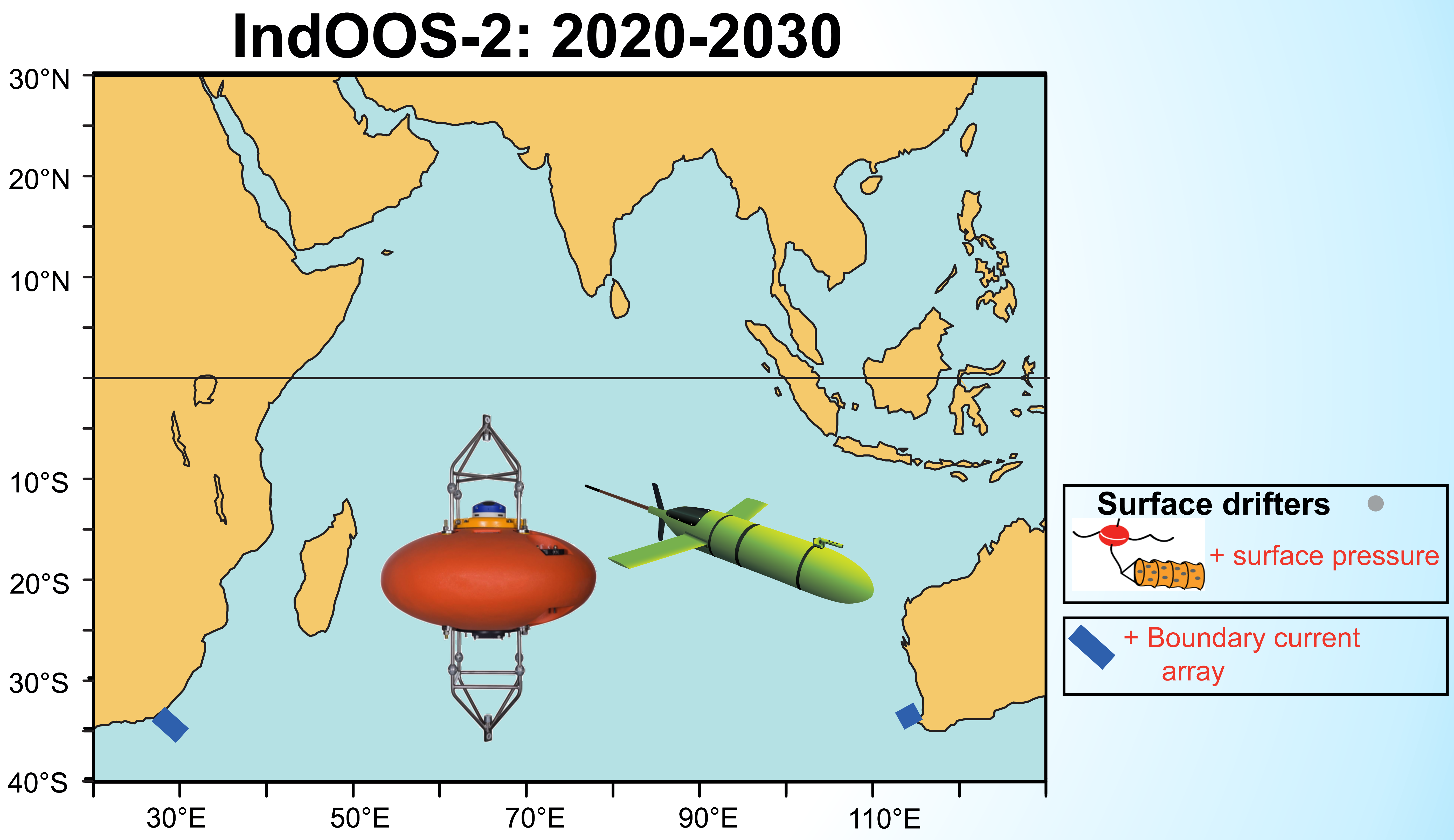

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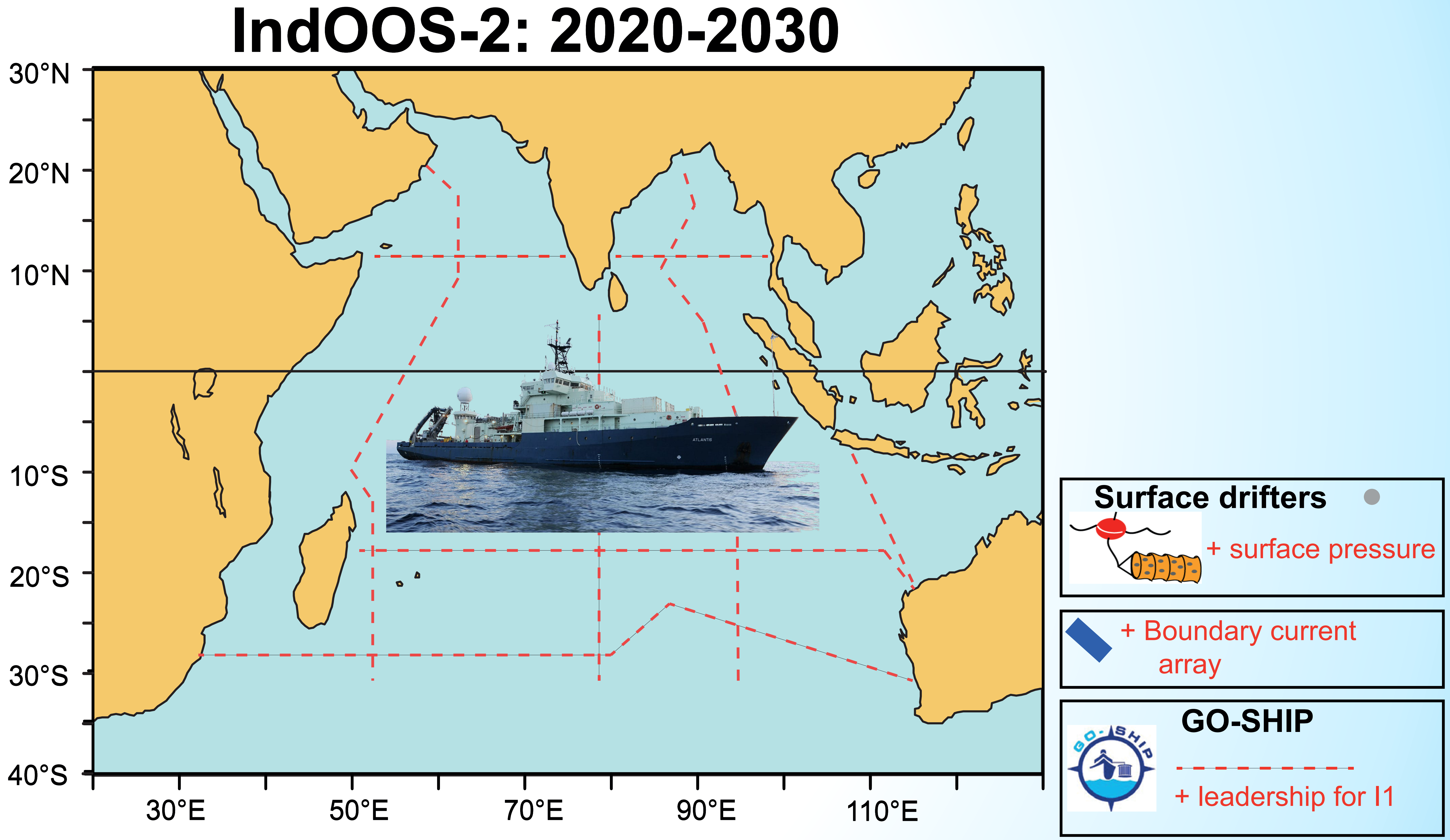

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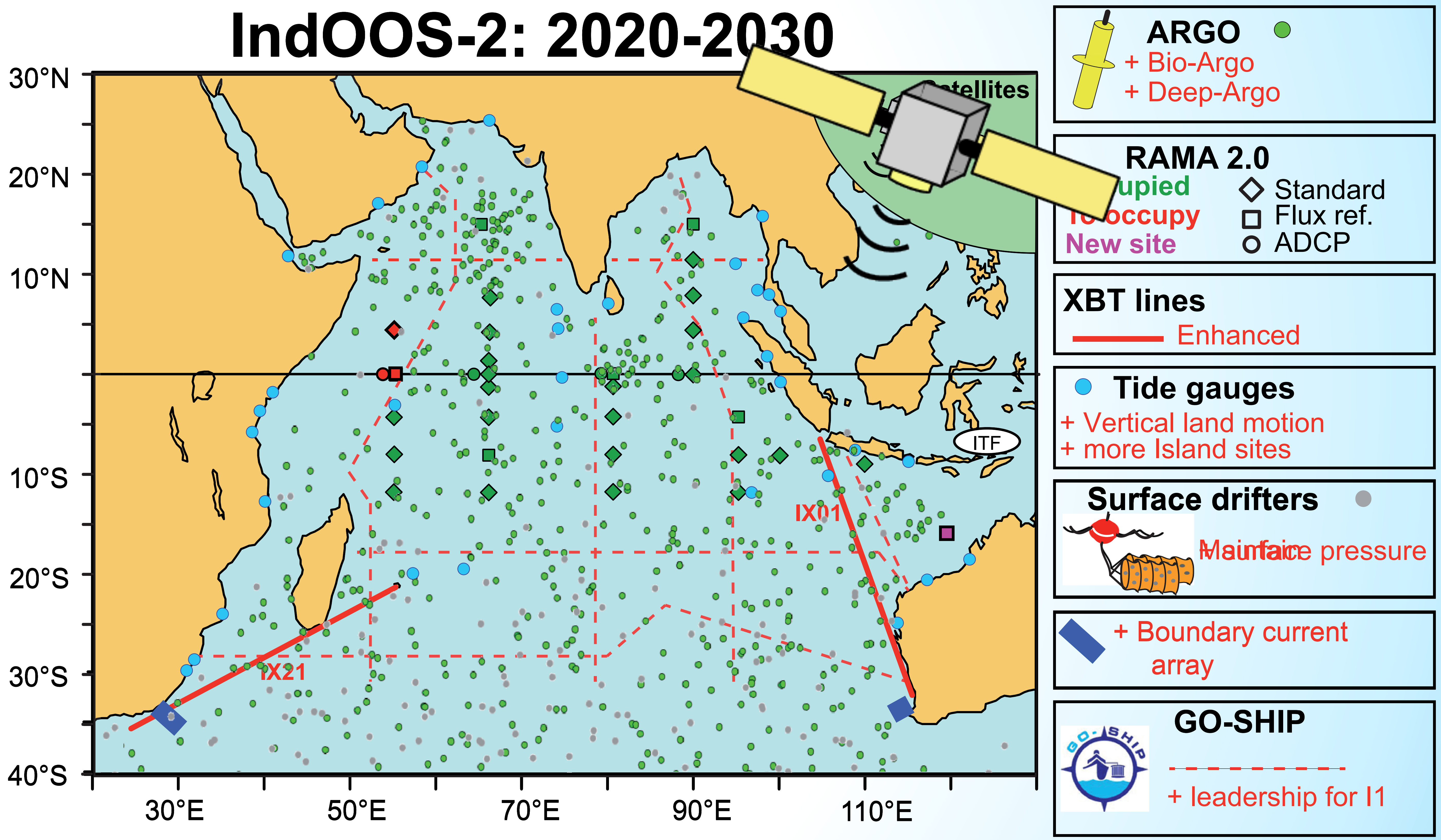
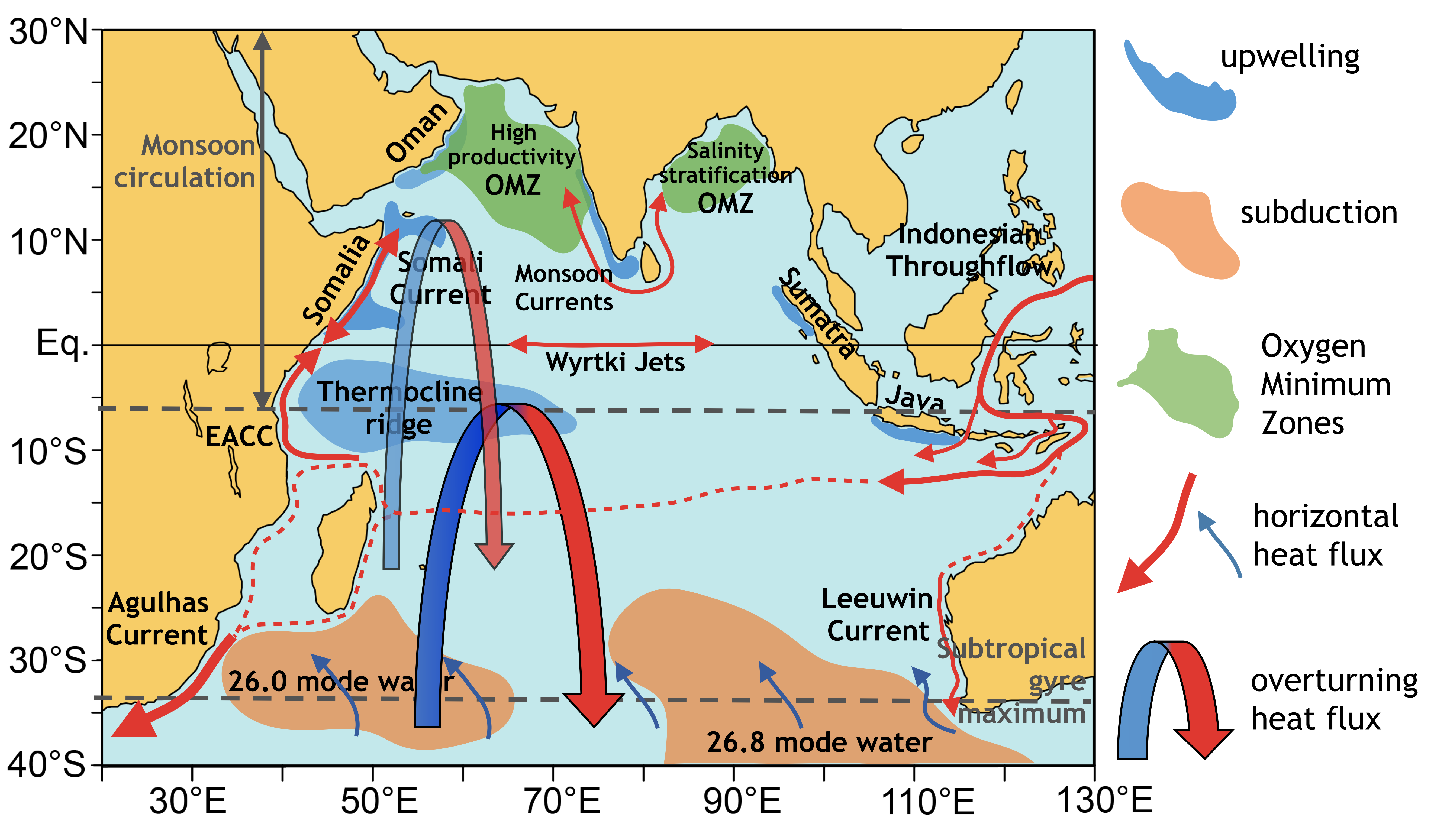


Tier III: Pilot projects to investigate efficacy, sustainability, and potential for integration into the IndOOS



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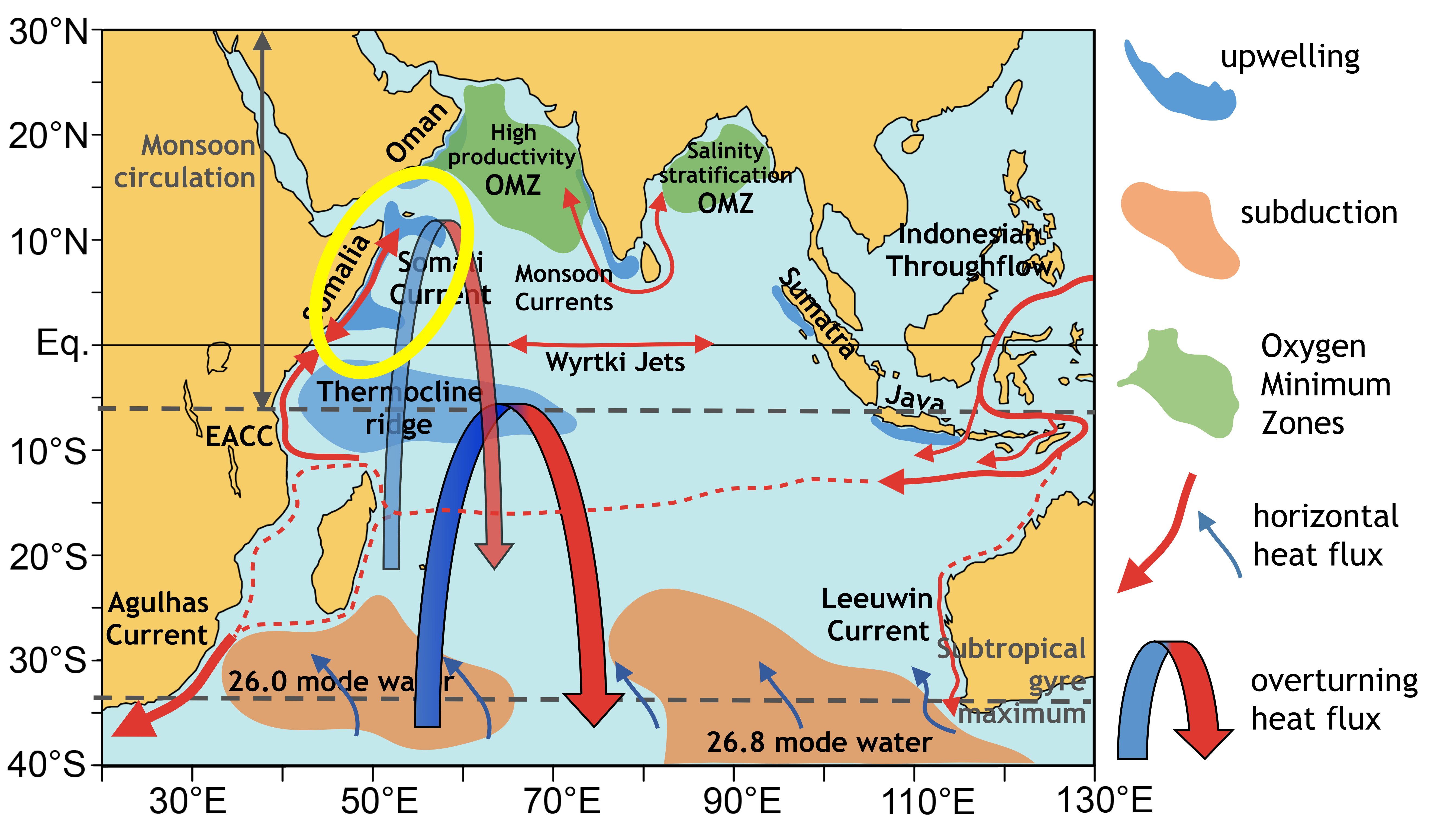

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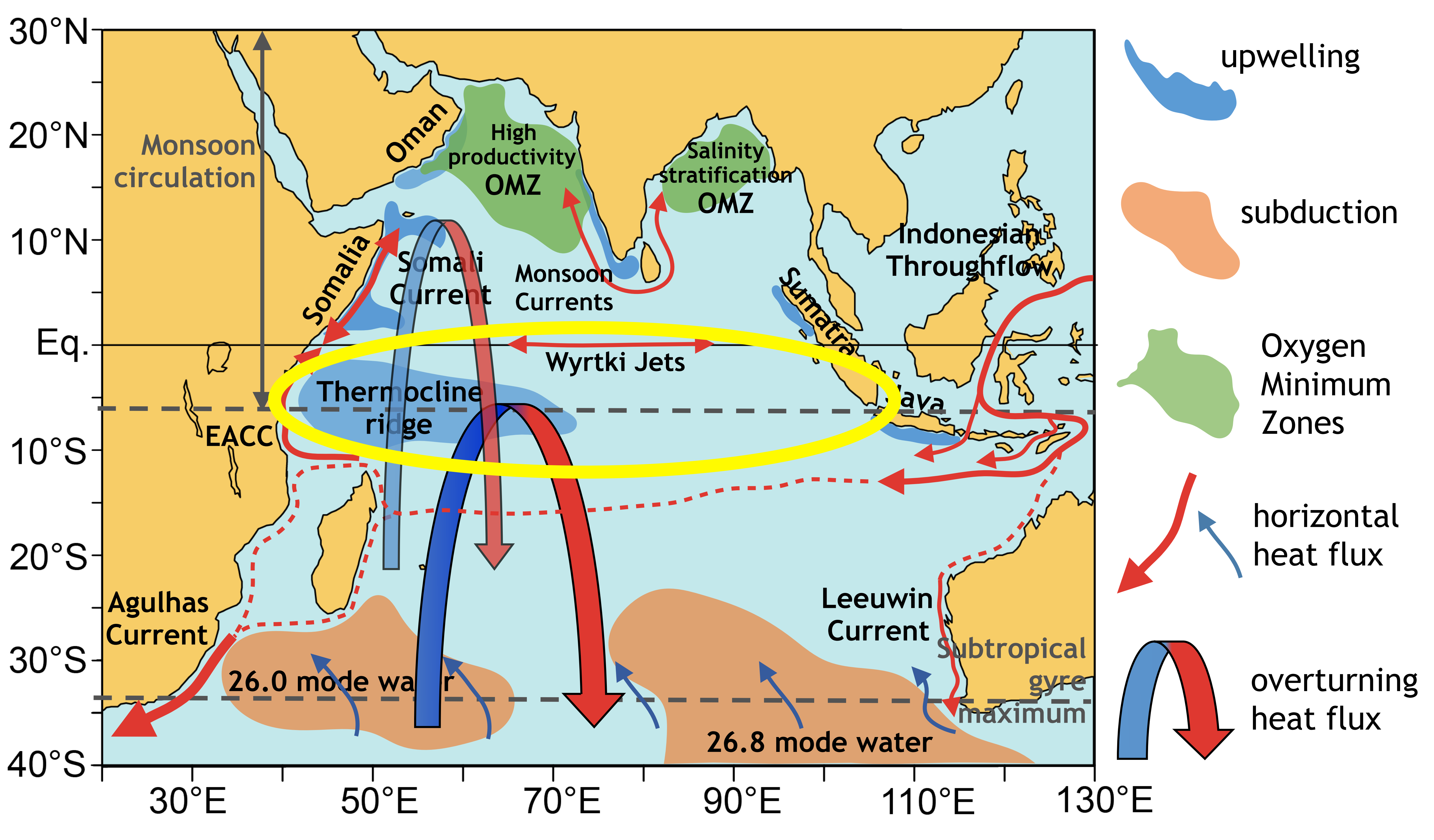

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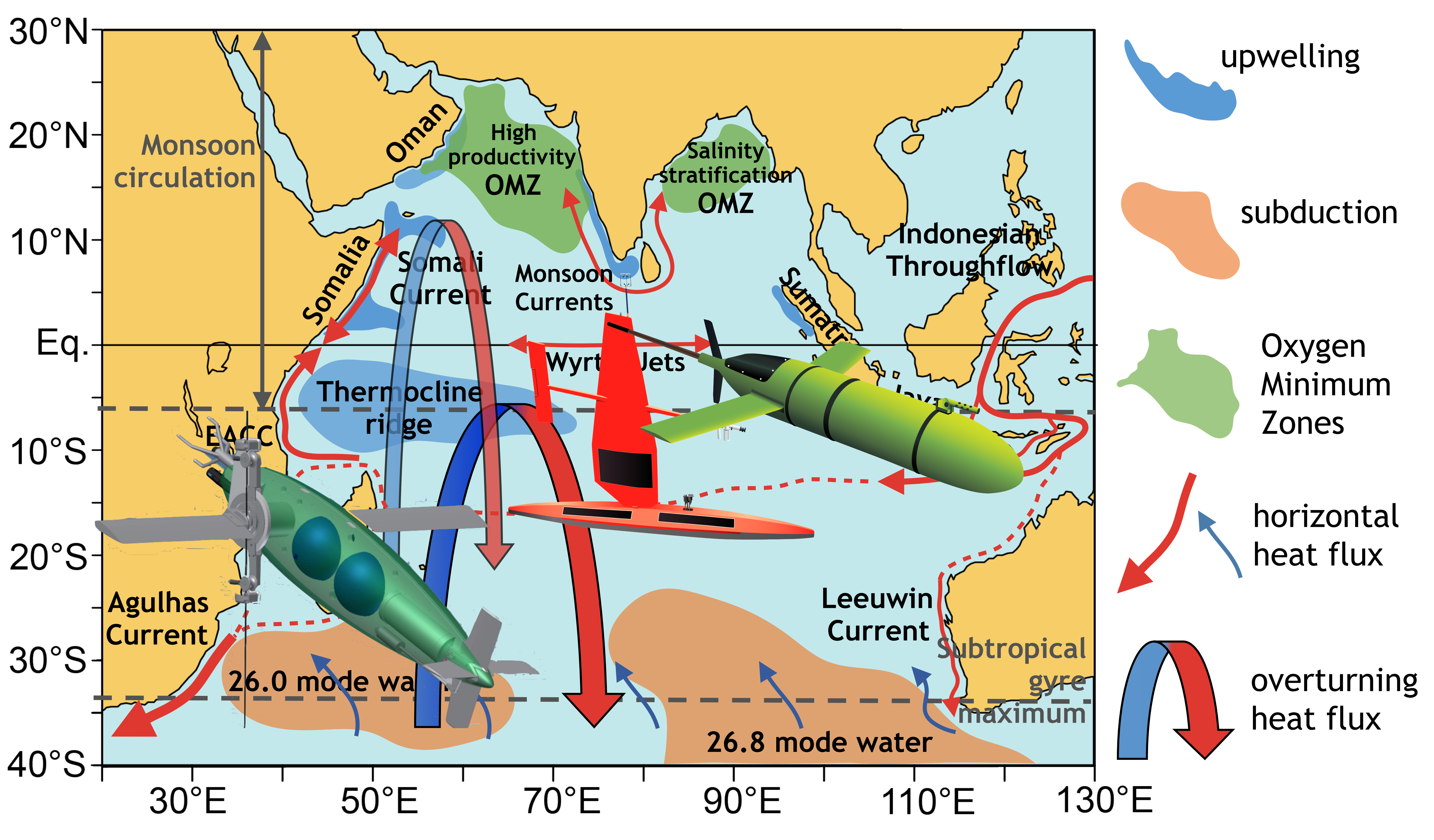

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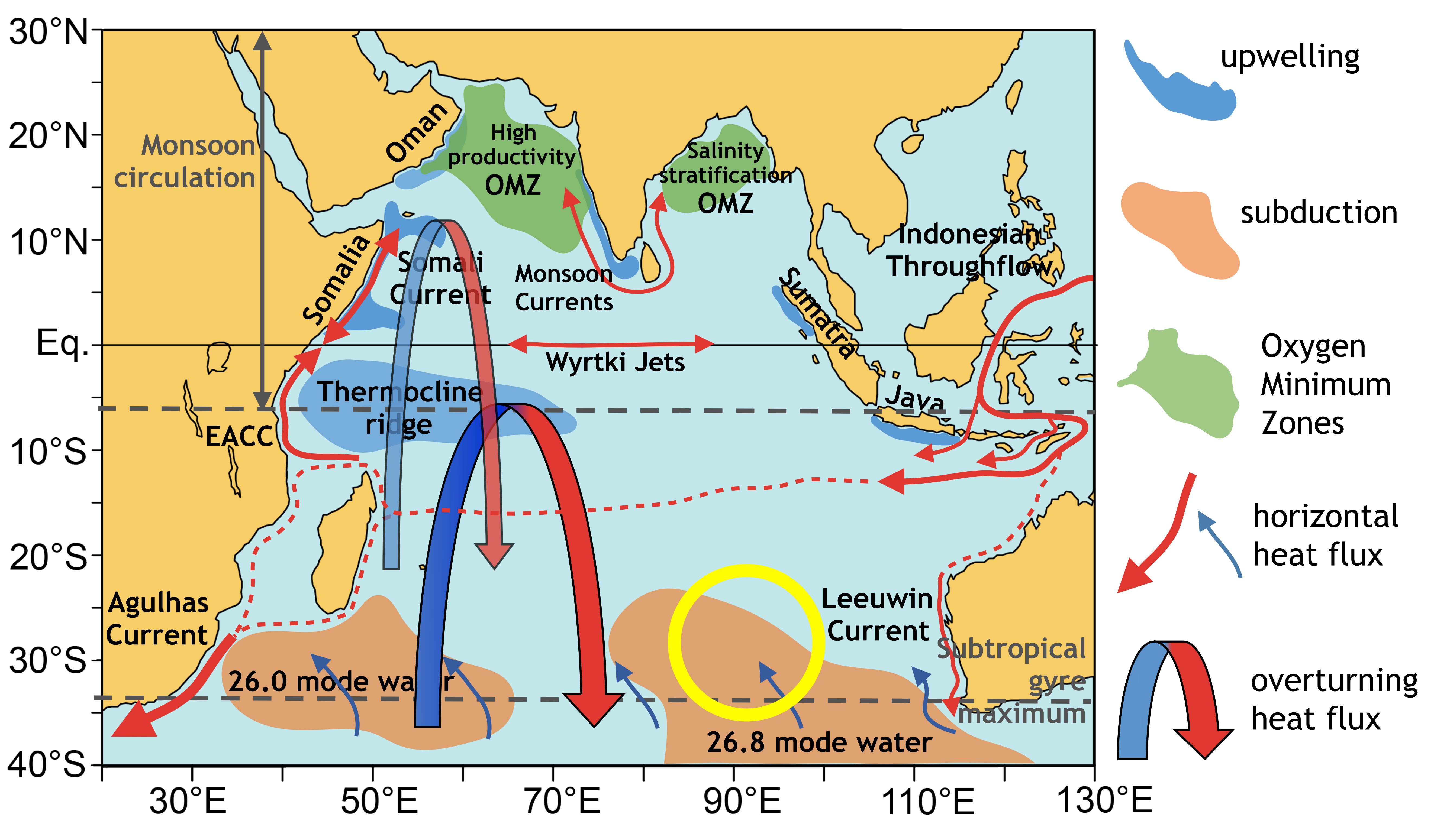
- Pilot study to measure **air-sea fluxes in subtropical mode water formation region**, possibly using saildrone.



Applications: Validation and Improvement of Data Products, Models, and Predictions

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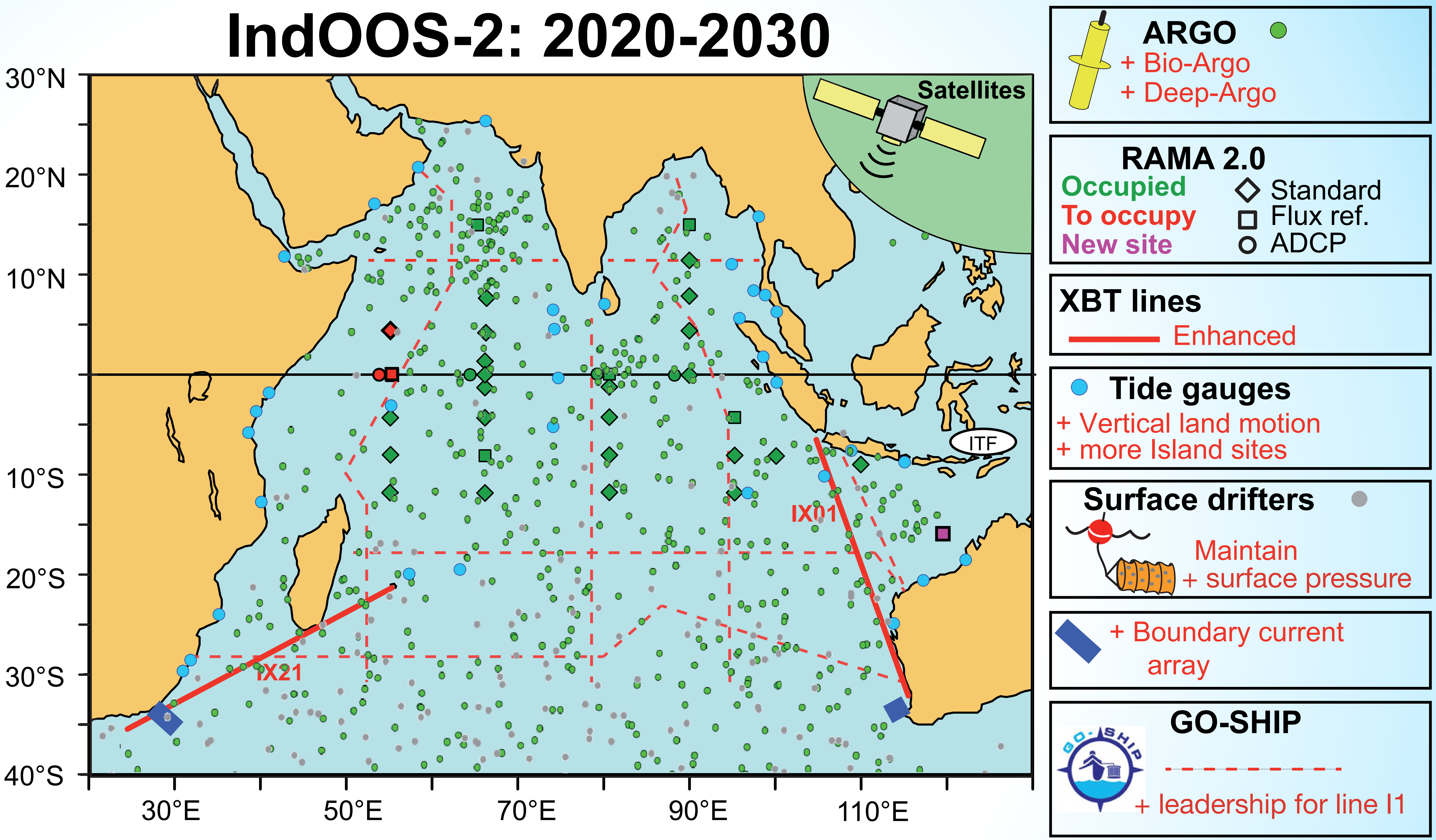
- Improve capabilities for reanalysis, prediction, and observing system evaluation through stronger collaborations among data assimilators, modelers, and observationalists.
- Develop collaborations with the paleo-proxy community to provide long records of surface temperature variability in the IOD eastern pole and of sea level variability near the west coast of Australia, in the Chagos archipelago, and Mascarene Islands.

To achieve these goals for IndOOS-2 we need…

- New partnerships among and with Indian Ocean rim countries, particularly as regards expansion into boundary systems (EEZs)
- Commitments to regional capacity building, best practices, and data sharing
- New investment from the global community
- Increased investment in governance and scientific leadership through WCRP and GOOS by the WMO, IOC-UNESCO, and ISC.

- Indian Ocean rim countries are becoming more vulnerable as climate change accelerates.

- IndOOS-2 can provide a fit-for-purpose observing system that leads to improved weather forecasts, climate predictions, and marine ecosystem understanding for the benefit of all



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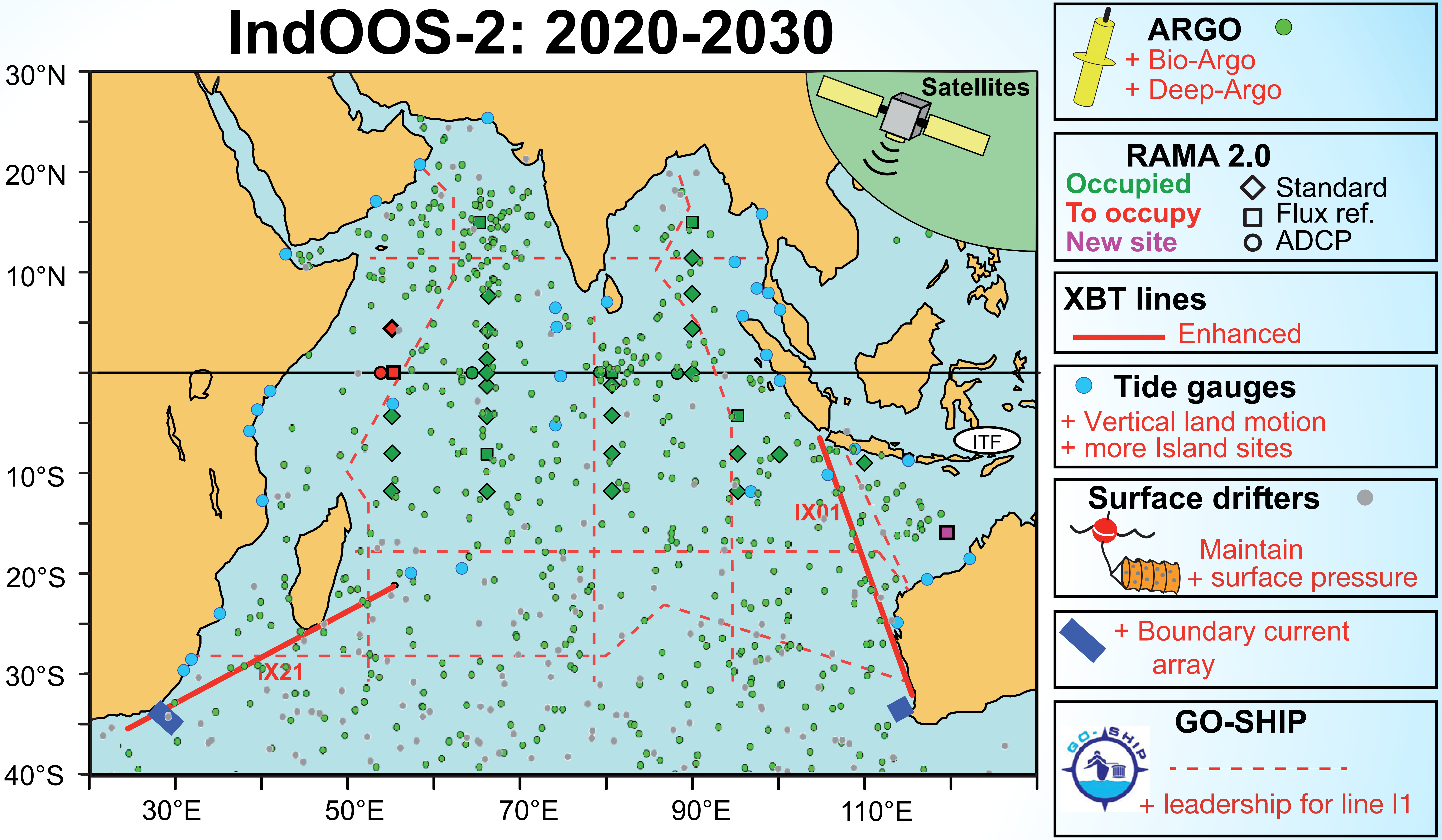
IndOOS-2: 2020-2030



IndOOS-2 roadmap: doi.org/10.36071/clivar.rp.4.2019

Questions and Comments

- The review process?
- The outcomes?
- How can I get involved?