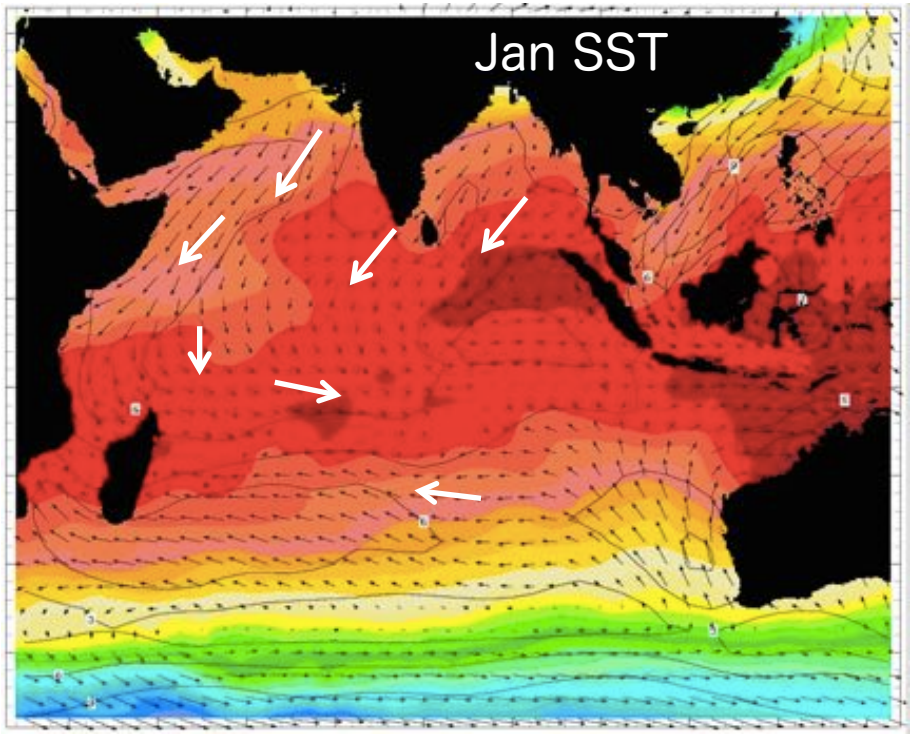
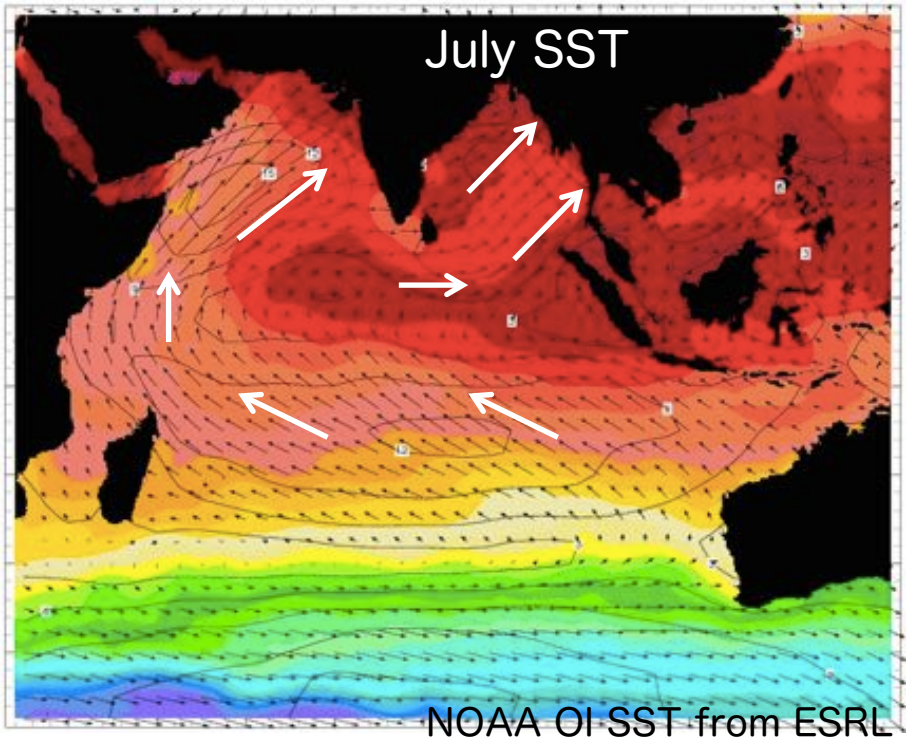
Tropical Indian Ocean science and program updates

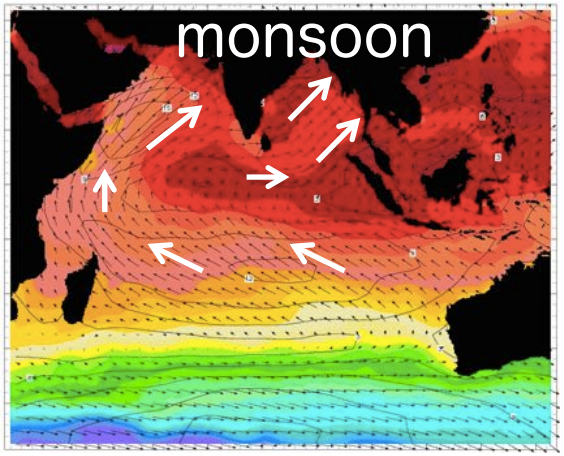
Kyla Drushka
with input from Nick D'Adamo, Luca Centurioni, Craig Lee, Amit Tandon, Chidong Zhang





Air-sea interaction on many time scales

Seasonal
(monsoon, reversing jets)

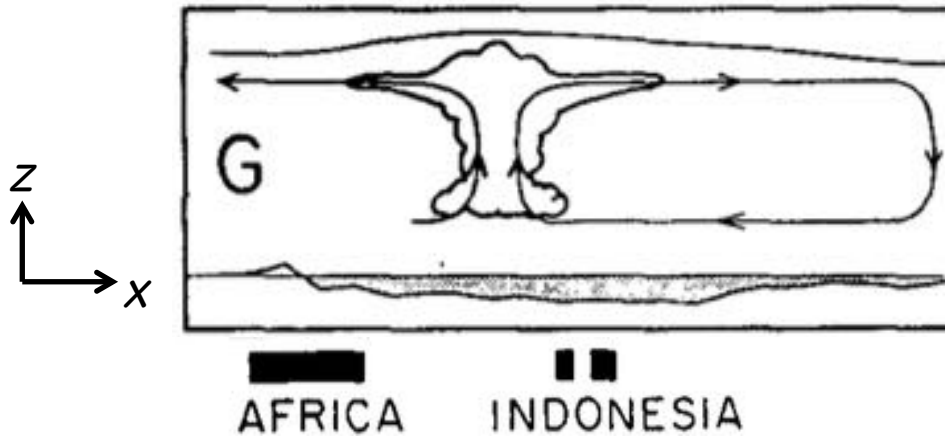


Air-sea interaction on many time scales

Seasonal
(monsoon, reversing jets)

Intraseasonal
(MJO, Kelvin waves, monsoon active-break phases)

Madden-Julian Oscillation



From Madden & Julian 1972

Air-sea interaction on many time scales

Seasonal
(monsoon, reversing jets)

Intraseasonal
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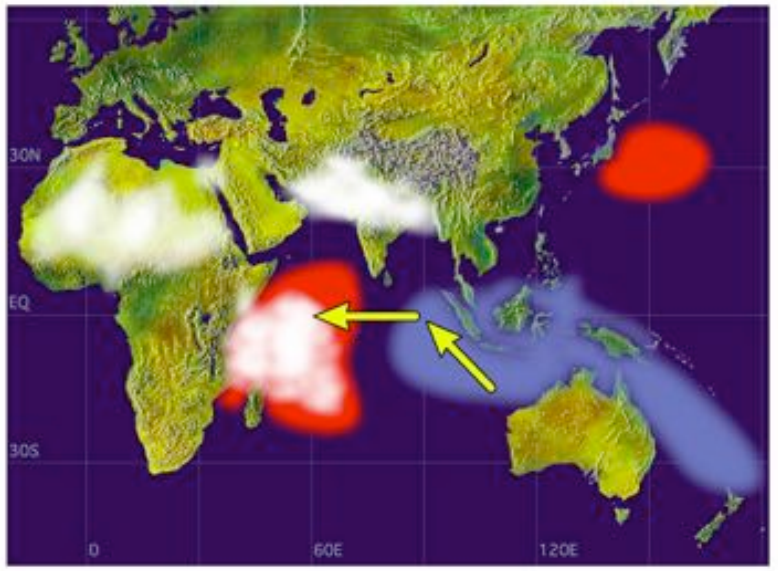
Interannual
(Indian Ocean Dipole,
ENSO-related basin-wide warming)

Indian Ocean Dipole



From JAMSTEC

Air-sea interaction on many time scales

Seasonal
(monsoon, reversing jets)

Intraseasonal
(MJO, Kelvin waves, monsoon
active-break phases)

Interannual
(Indian Ocean Dipole,
ENSO-related basin-wide warming)

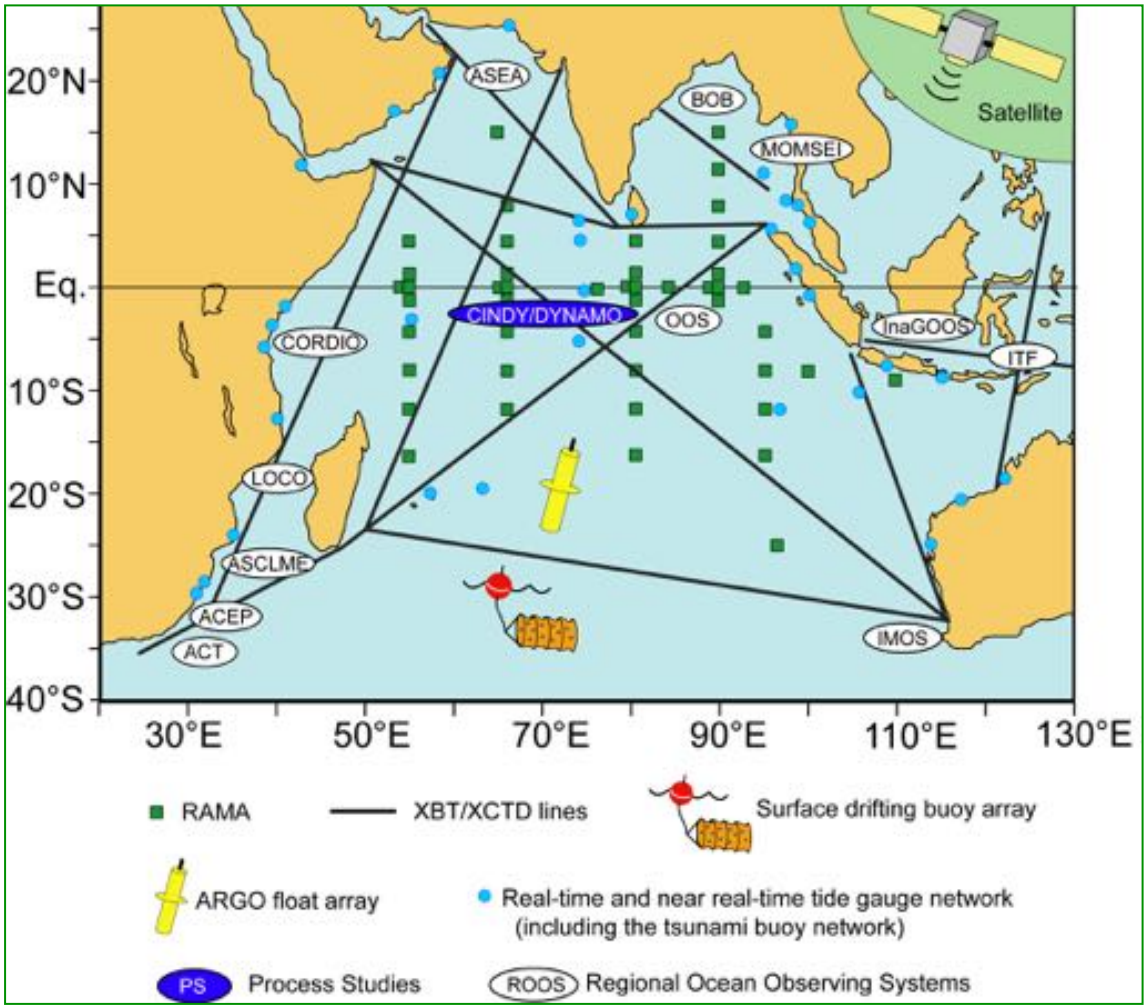
Decadal, multi-decadal

Short-scale
(tropical cyclones, eddies)

CLIVAR Indian Ocean panel (early 2000s)

Achievements:

1. Indian Ocean Observing System (IndOOS)



from *CLIVAR/IOC-GOOS Indian Ocean Region Panel: Achievements and Future plans (2014)*

CLIVAR Indian Ocean panel
Achievements in the past ~10 years

1. Indian Ocean Observing System (IndOOS)

2. Scientific achievements:
   - Meridional overturning circulation, thermocline ridge
   - Quantifying inputs (ITF, Tasman Leakage, Leeuwin undercurrent), outputs (Agulhas, Leeuwin Currents), and circulation features
   - Cyclones, MJO, eddies
   - Interannual variability (IOD and ENSO teleconnections)
   - Decadal/multi-decadal variability: review paper (Han et al. 2014)
   - Biogeochemistry

from *CLIVAR/IOC-GOOS Indian Ocean Region Panel: Achievements and Future plans (2014)*

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   - Cyclones, MJO, eddies
   - Interannual variability (IOD and ENSO teleconnections)
   - Decadal/multi-decadal variability: review paper (Han et al. 2014)
   - Biogeochemistry

3. Capacity building:
   - Conferences, meetings, training programs, technology sharing, research cruises

from *CLIVAR/IOC-GOOS Indian Ocean Region Panel: Achievements and Future plans (2014)*

CLIVAR Indian Ocean panel
Plans for the next 5 years

- Complete & sustain IndOOS.
- Develop studies / improve understanding of:
  - decadal and multidecadal variations in the IO
  - influence of SST on the atmosphere
  - meso- and submesoscale variability and its impacts
  - tropical cyclones
  - inter-basin exchanges, including nutrients and organic matter
  - coordinated modelling experiments, in particular seasonal to decadal forecast.
  - exploit new Aquarius and SMOS salinity data

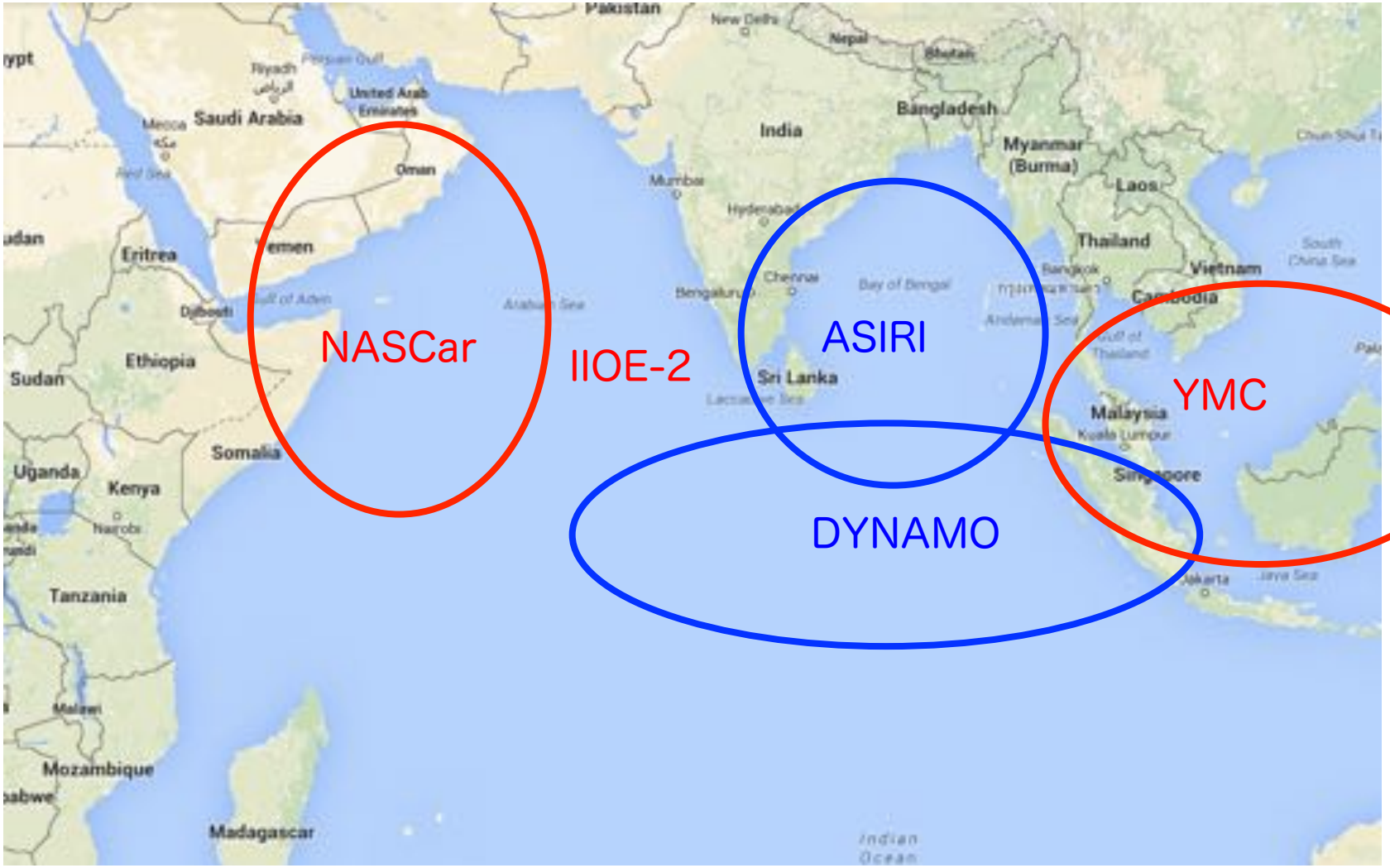
- Support YMC, IIOE-2

- Support two emerging regional programs (as part of IIOE-2):
  - Eastern IO upwelling system: its dynamics and ecosystem impacts.
  - Agulhas System Climate Array

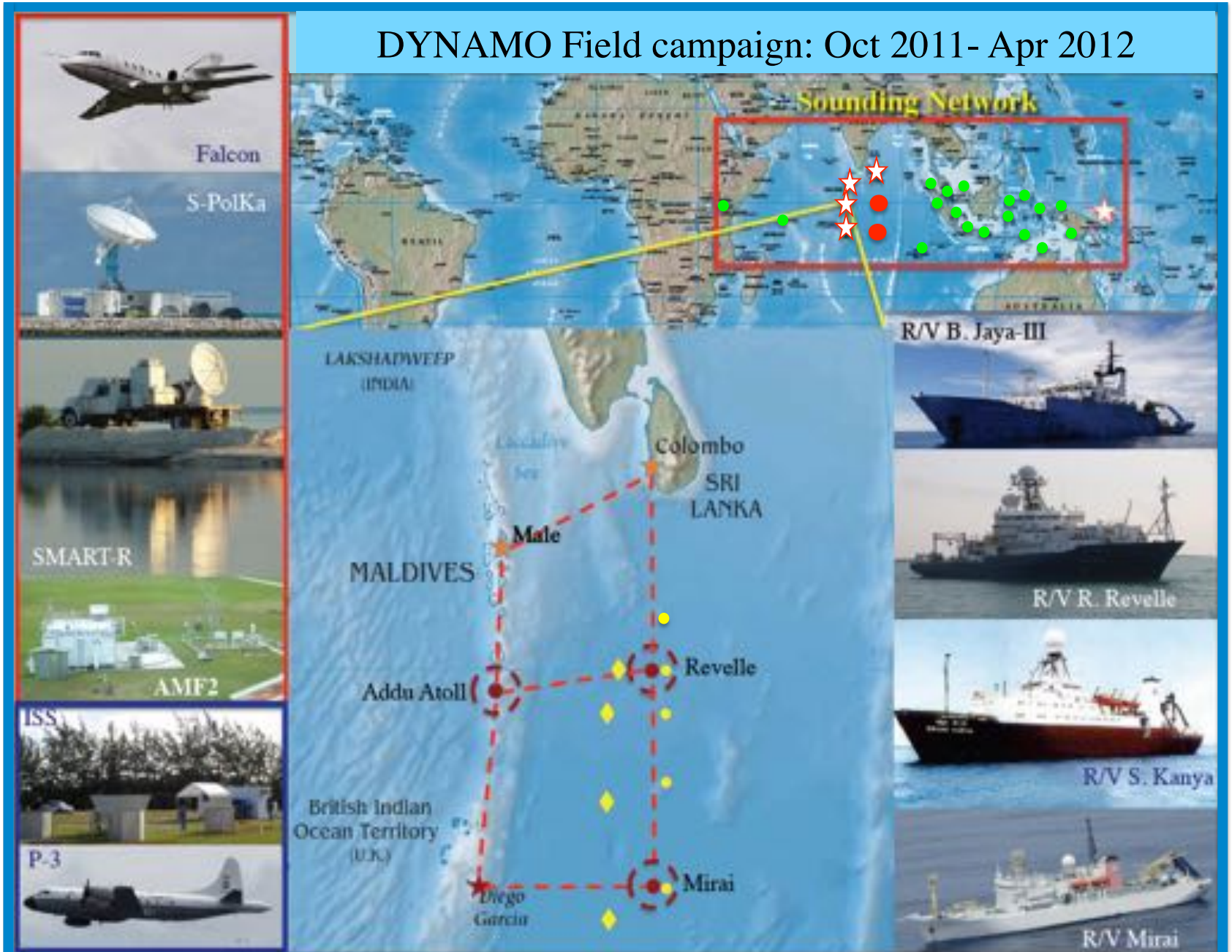
from *CLIVAR/IOC-GOOS Indian Ocean Region Panel: Achievements and Future plans (2014)*

Indian Ocean field programs

Past/ongoing and future



DYNAMO update (from Chidong Zhang)

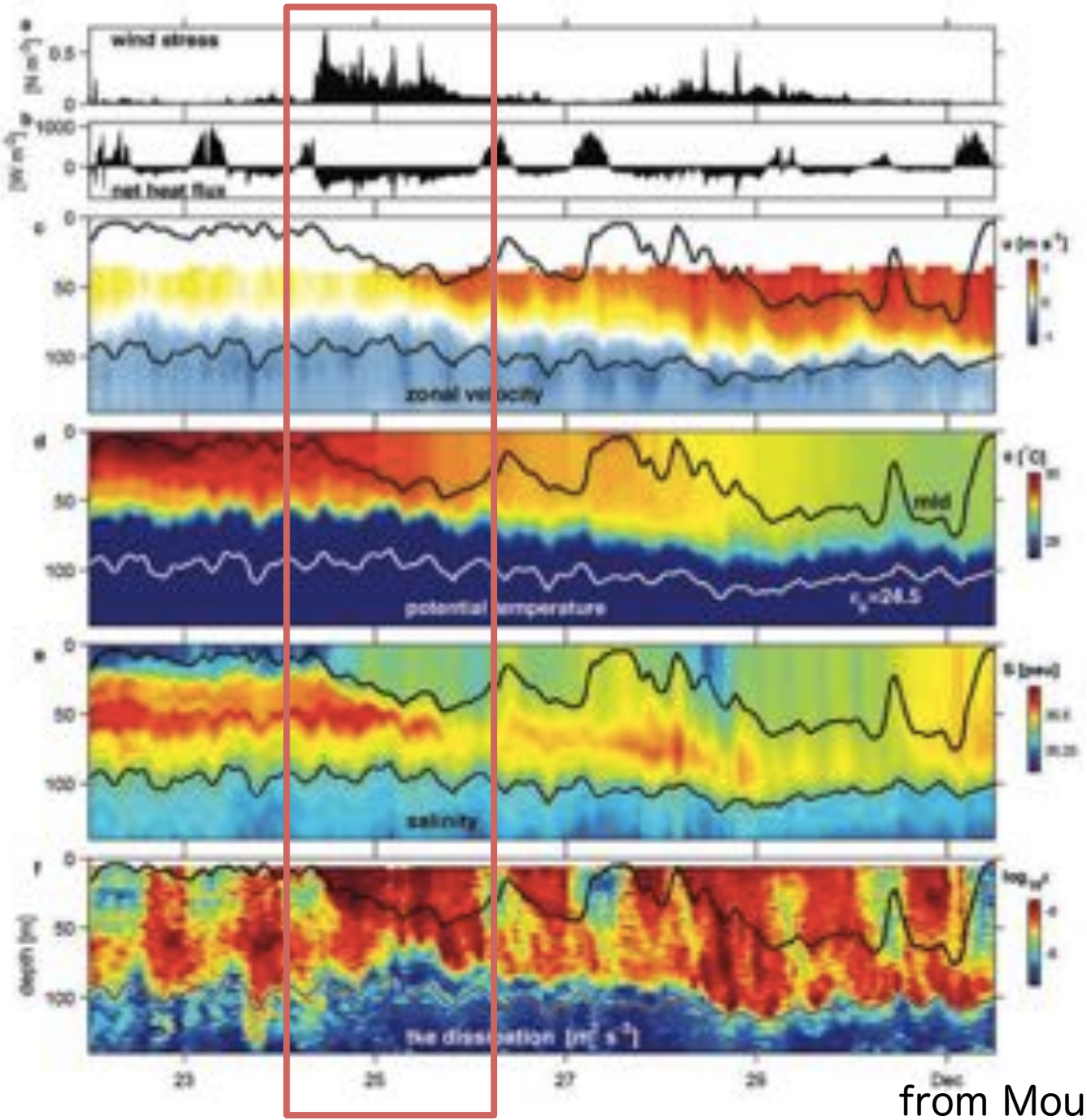


DYNAMO Data:

- Released for public use since March 2013
- Archived at
  - NCAR EOL (http://data.eol.ucar.edu/master_list/?project=DYNAMO)
  - ARM (http://www.arm.gov/campaigns/amf2011amie-gan)
  - JAMSTEC (http://www.jamstec.go.jp/iorgc/cindy/obs/obs.html)
- DYNAMO Legacy Data Products:
  - Combined air-sea time series
  - radar, aircraft, and sounding products
  - integrated products for case studies

- DYNAMO-related publications: 73 since 2013

DYNAMO results from one MJO event (from *R/V Revelle)*



Wind stress

Heat flux

Zonal velocity

Temperature

Salinity

TKE dissipation

from Moum et al. BAMS 2013

DYNAMO: US Effort

US funding from

NSF, DOE (ARM &ASR), ONR, NOAA, NASA

The role of US CLIVAR in DYNAMO:

- Critical in communication among the Inter-agency group (IAG) and between the IAG and PIs;
- Disconnection between expectations from the PSMI and peer reviewers.

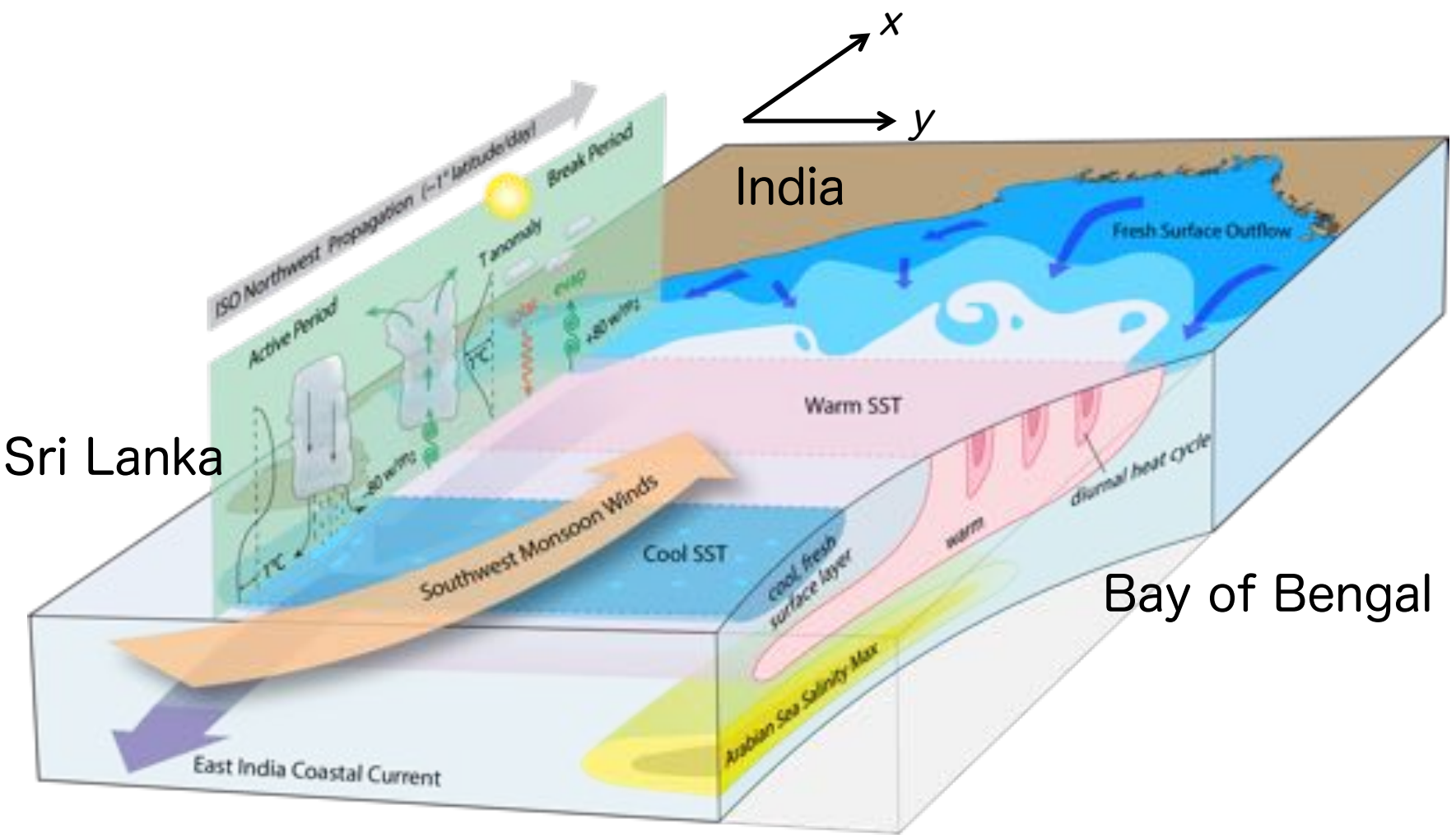
Air-Sea Interactions in the Northern Indian Ocean (ASIRI): 2013-present

Objective: *improved monsoon prediction* through a better understanding of the upper ocean structure, processes, and ocean-atmosphere exchange.

- Arabian Sea – Bay of Bengal exchange dynamics
- Atmospheric phenomena that modulate air-sea exchanges
- Ocean response to surface forcing through observations & high-res coupled models

+ partnership with Indian & Sri Lankan scientists: cruises, science meetings, summer school

ASIRI schematic



from Emily Shroyer

ASIRI multi-year observational program

R/V Revelle - 5 legs (2013,2014)

R/V Sagar Nidhi (India) - process study (2014)

R/V Samudrika (Sri Lanka) – coastal measurements

+ more cruises next month (*Revelle* and *Sagar Nidhi)*

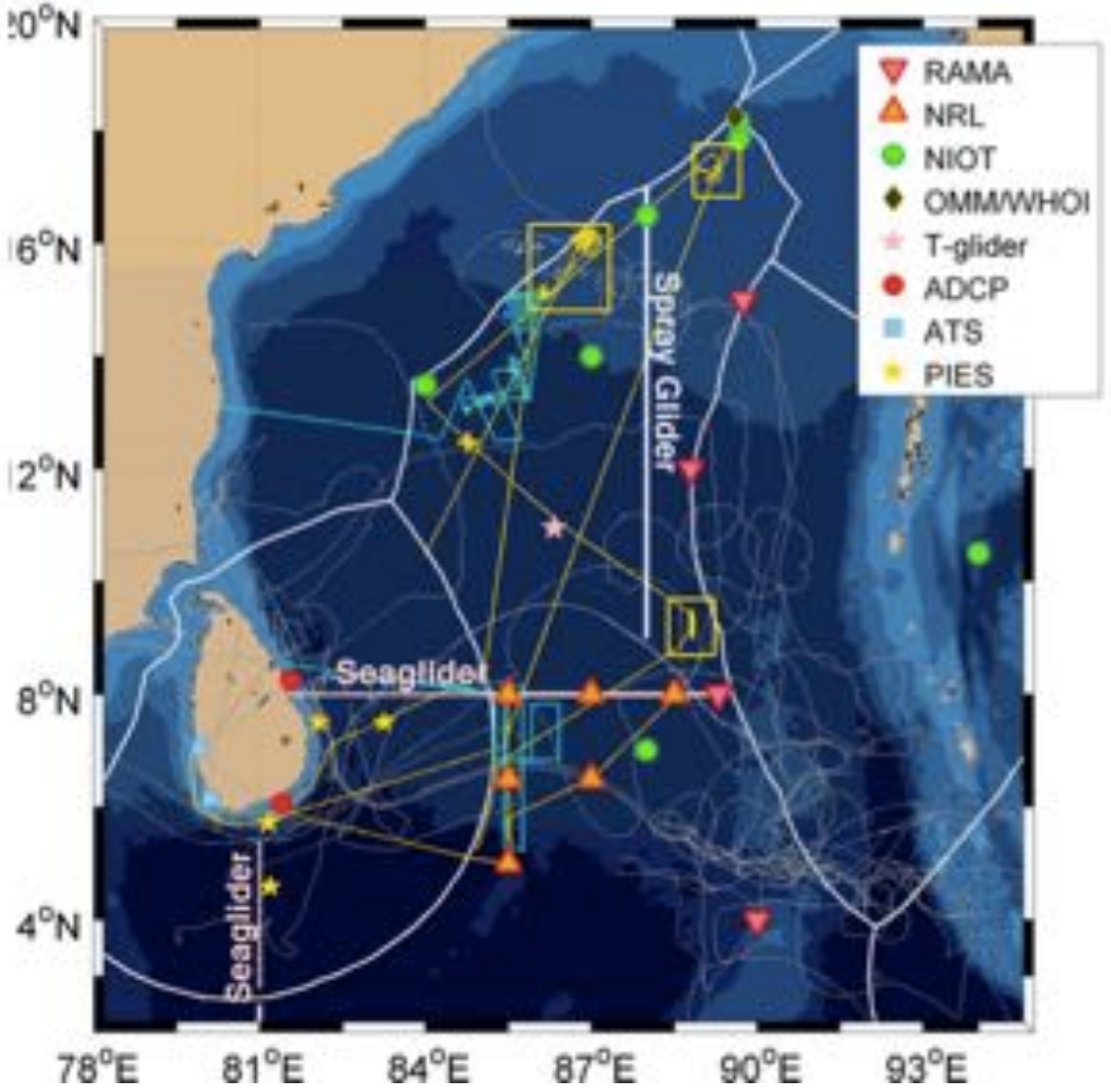
Seaglider, Spray gliders, turbulence gliders

Moorings

PIES

Atmospheric stations

Drifters

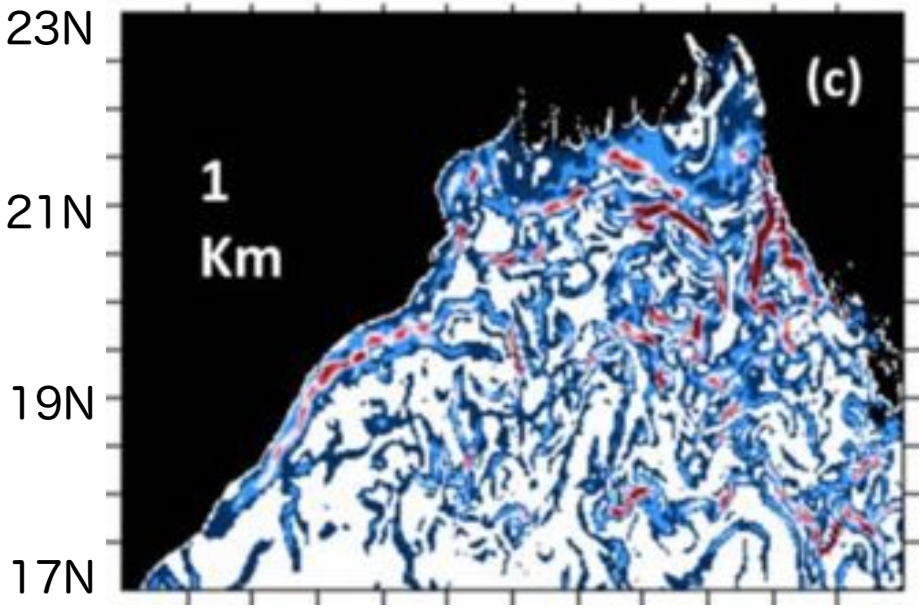


ASIRI – early results

WHOI air-sea flux mooring at 18N:

Biases in ECMWF (Bob Weller) and MERRA (Jared Buckley)

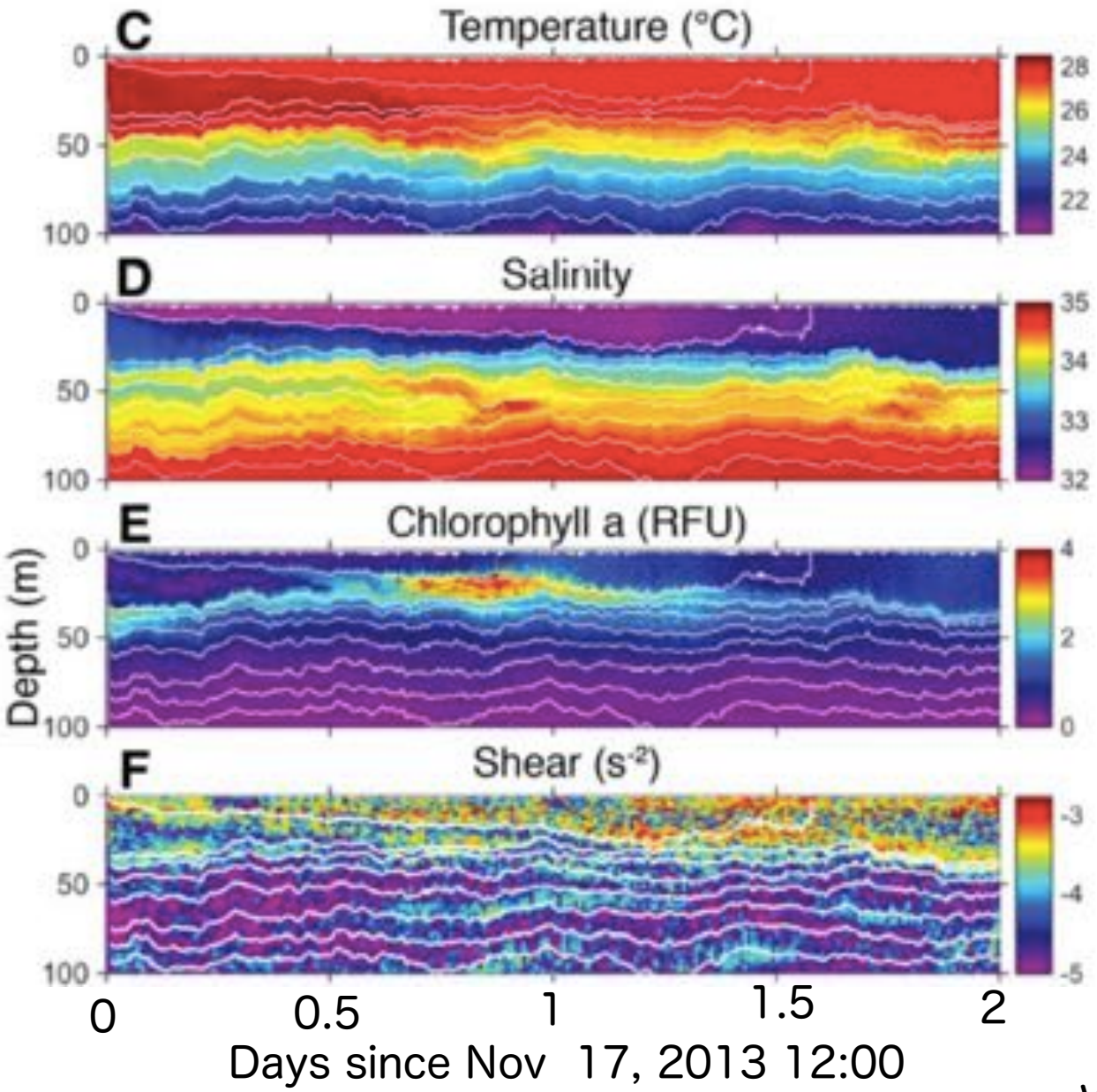
No current funding plan to sustain this mooring.



SST fronts from GHRSST 1-km satellite data:

Many strong sub-mesoscale and smaller-scale frontal features

Subsurface features from a Wirewalker array



Subsurface T max

Salinity stratification dominates vertical structure

Strong shear deepens with mixed layer

Drew Lucas data; from Wijesekera et al., submitted

ASIRI – early results

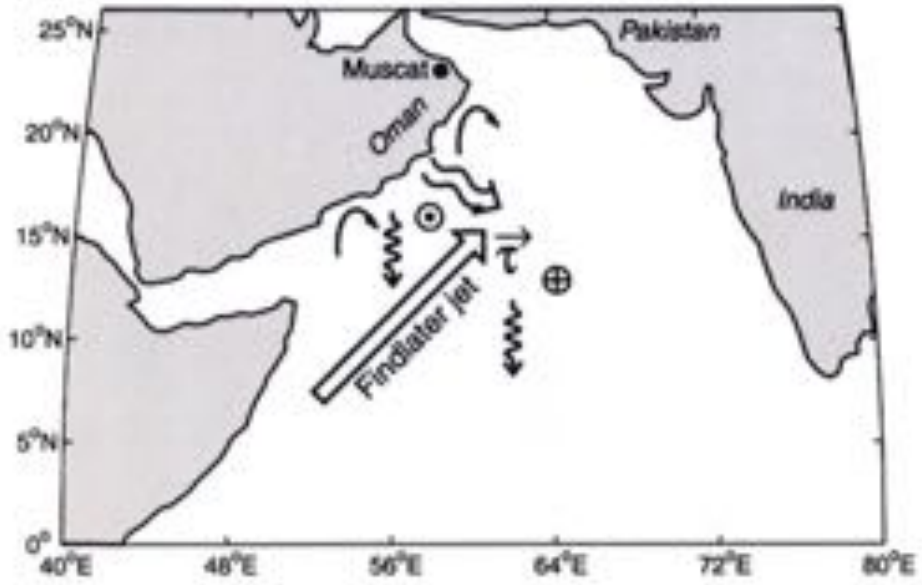
- Freshwater from Bay of Bengal river outflow persists during both winter and summer monsoons
  - → shallow strong haloclines
  - → implications for model SST errors
- Model biases due to missing physics
  - → erroneous atmospheric convection
  - → monsoon forecasting errors
  - * *New modeling efforts are still needed*
- Ocean variability at many scales that will feedback on the air-sea fluxes in the Bay.

NASCar overview (from Luca Centurioni, Craig Lee)

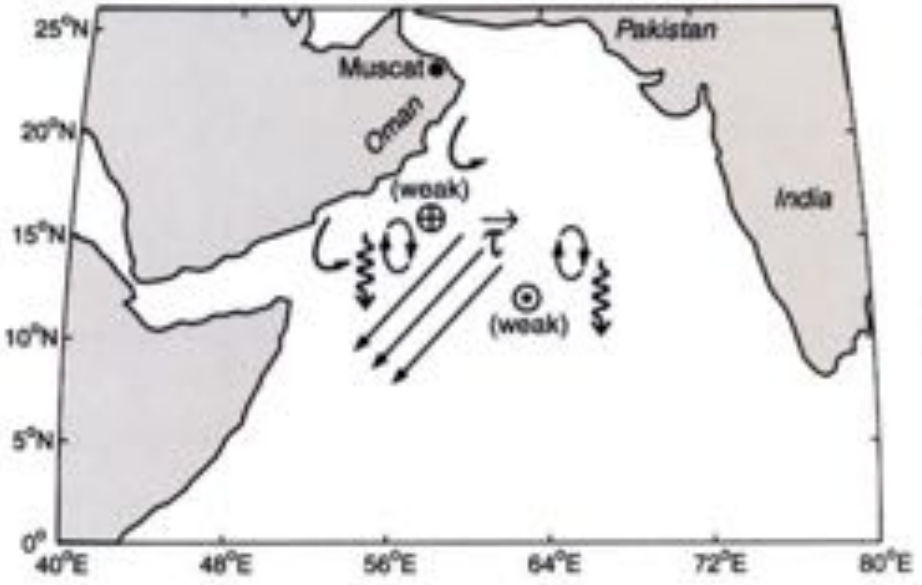
North Arabian Sea Circulation – autonomous research

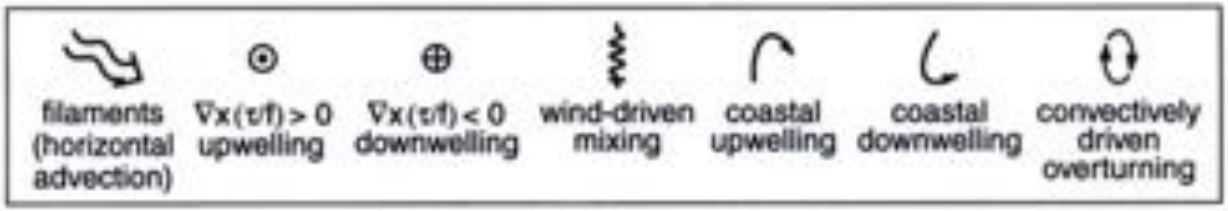
Local drivers of the Somali Current:

Southwest monsoon



Northeast monsoon





from Lee et al. 2000

NASCar overview

Objectives (ASIRI complement)

Physics

Characterize local & remote processes governing Arabian Sea circulation & the Somali Current system, and their seasonal and interannual variability

Predictability

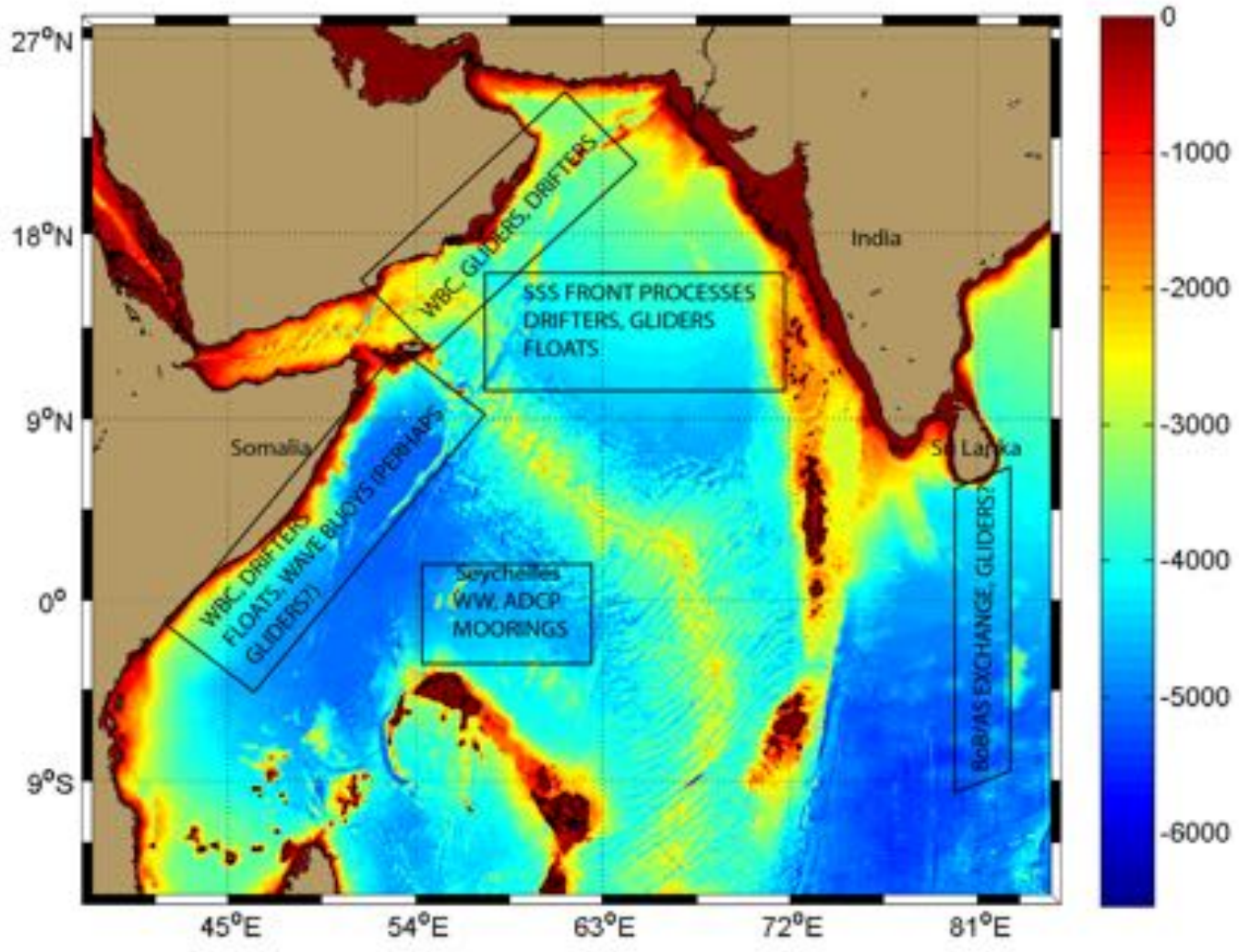
Improve/evaluate ocean models.

Strategy

Autonomous observing array for persistent, sustained measurements in a denied region:

Drifters, Seagliders, gliders, profiling floats, Wirewalkers, and wave buoys, plus existing observing system (e.g., Global Drifter Program, Argo, RAMA) and satellite products

NASCar plan



Ships of opportunity only (US, Aus Navy; Seychelles fishing/ charter fleet; cargo ship; Oman research vessel)

From the draft NASCar Science Plan (2015)

NASCar overview

Science Questions

Local Processes

- monsoon forcing
- mesoscale and sub-mesoscale processes, turbulence, internal and surface waves

Remote Processes

- Rossby waves
- SST-wind-currents coupling
- sub-seasonal & small-scale links
- African land mass, air-sea-land interaction processes

Seychelles Specifics

- Drivers of waves, currents, and water mass properties
- Drivers of mass and momentum transport
- Seychelles-Chagos thermocline ridge variability and Arabian Sea links

YMC Overview (from Chidong Zhang)

Years of the Maritime Continent July 2017- July 2019

Goal: Observing the weather-climate system of the Earth's largest archipelago to improve understanding and prediction of its local variability and global impact

a field campaign that connects Indian & Pacific, and ocean-atmosphere-land (CLIVAR-GEWEX-SPARC).

46 participating institutes from 15 countries, including US, Philippines, Indonesia, Australia, Singapore, Japan, France, China, Taiwan, Switzerland…

YMC Motivation

Local Variability:

- Monsoons, the MJO, equatorial waves, Borneo vortices, cold surges, tropical cyclones;
- severe rainfall, flood events, drought; severe storms; high wind events; air quality

Global Impact:

- Convective center (Walker circulation, ENSO, MJO, troposphere-stratosphere interaction, Rossby-wave source and teleconnection)
- Indonesian throughflow

Model biases:

Diurnal cycle, monsoon, MJO, mean precipitation

YMC Science Themes

Theme 1: *Atmospheric Convection*.

Theme 2: *Upper-Ocean Processes and Air-Sea Interaction*.

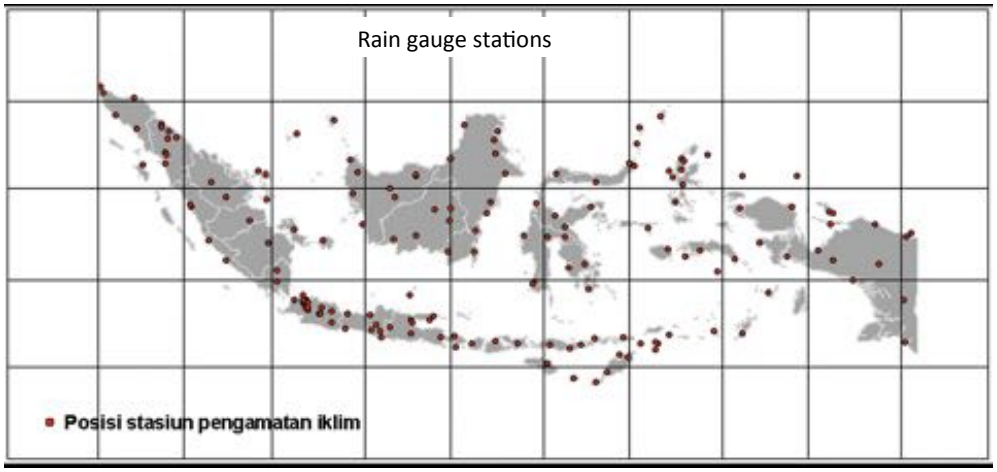
Theme 3: *Stratosphere-Troposphere Interaction*

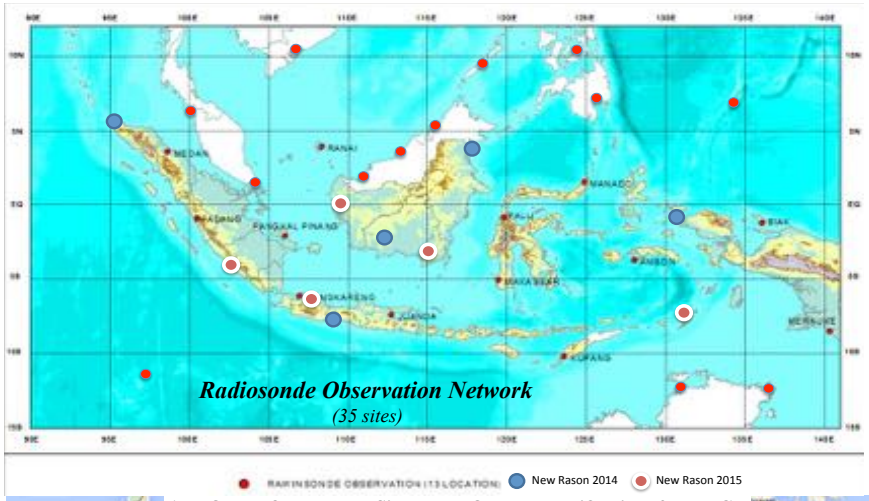
Theme 4: *Aerosols*.

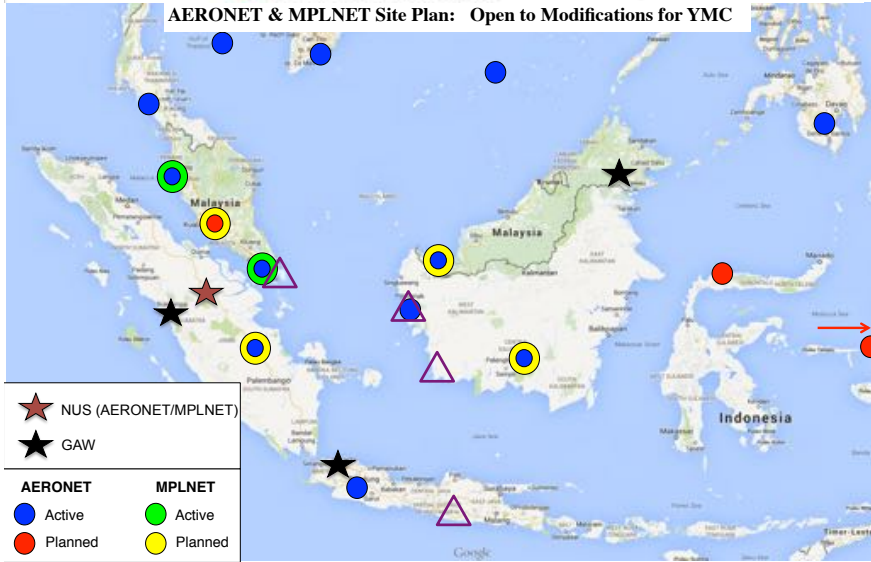
Theme 5: *Prediction improvement*.

YMC Main activities: Data sharing

Through collecting, archiving, and sharing data from observing networks in the MC region, satellites, and NWP products, build a two-year (July 2017 – July 2019) comprehensive database for detailed documentation of multi-scale variability and interaction of the MC weather-climate system.



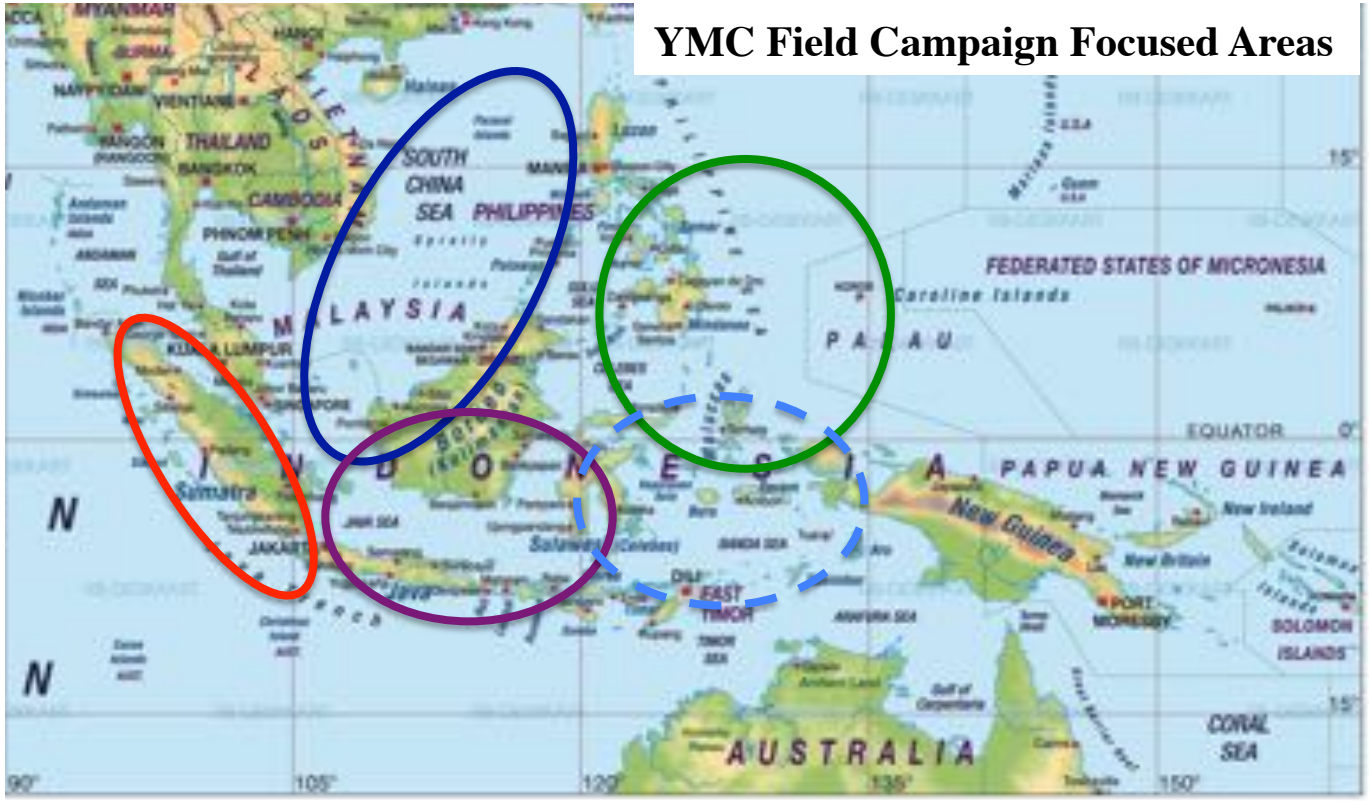




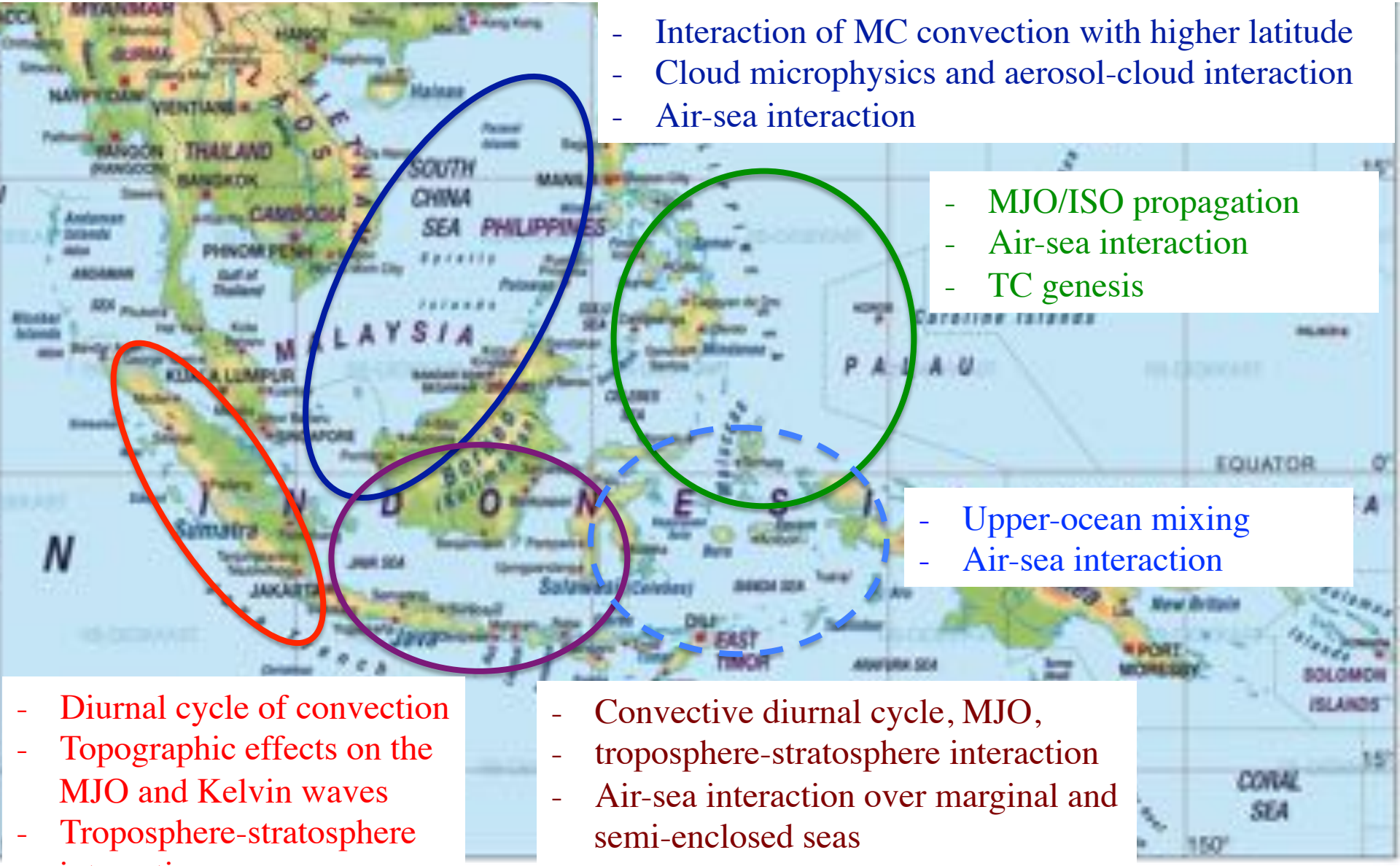
YMC Main activities: Field campaign

Data Sharing: Through collecting, archiving, and sharing data from observing networks in the MC region, satellites, and NWP products, build a two-year (July 2017 – July 2019) comprehensive database for detailed documentation of multi-scale variability and interaction of the MC weather-climate system.

Collect special observation through a two-year (July 2017 – July 2019) field campaign to advance our understanding of physical processes key to the multi-scale variability and interaction of the MC weather-climate system.



YMC Focused Observing Areas



- Interaction of MC convection with higher latitude
- Cloud microphysics and aerosol-cloud interaction
- Air-sea interaction

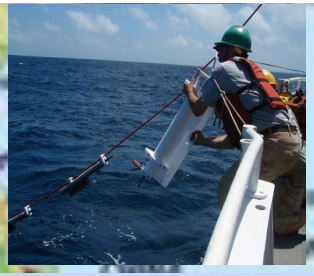
- MJO/ISO propagation
- Air-sea interaction
- TC genesis

- Upper-ocean mixing
- Air-sea interaction

- Diurnal cycle of convection
- Topographic effects on the MJO and Kelvin waves
- Troposphere-stratosphere interaction
- Coastal upwelling and air-sea interaction

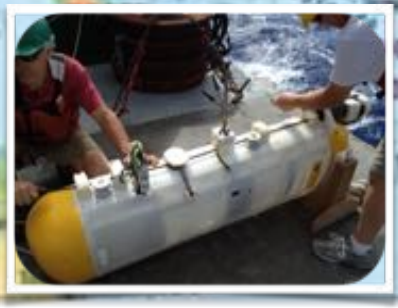
- Convective diurnal cycle, MJO,
- troposphere-stratosphere interaction
- Air-sea interaction over marginal and semi-enclosed seas

YMC Field Campaign Facilities: Seaborne



R/V XiangYangHong18

R/V Mirai



YMC Field Campaign Facilities: Airborne

NASA P-3B (CAMPEx)

Aeroclippers

NCAR C-130

UKMO FAAM BAe146-301

YMC Field Campaign Facilities: Surface radars

R/V Mirai

Equatorial Atmosphere Radar

C-band dual-pol

X-band Doppler radar

NCAR S-Polka

X-band mobile radars

R/V Investigator

YMC Main activities: Modeling

Data Sharing: Through collecting, archiving, and sharing data from observing networks in the MC region, satellites, and NWP products, build a two-year (July 2017 – July 2019) comprehensive database for detailed documentation of multi-scale variability and interaction of the MC weather-climate system.

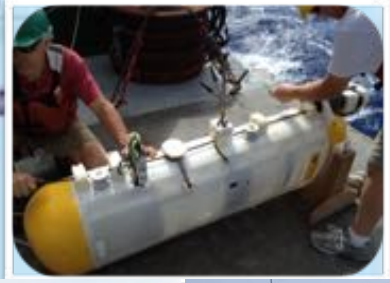
Field Campaign: Collect special observation through a two-year (July 2017 – July 2019) field campaign to advance our understanding of physical processes key to the multi-scale variability and interaction of the MC weather-climate system.

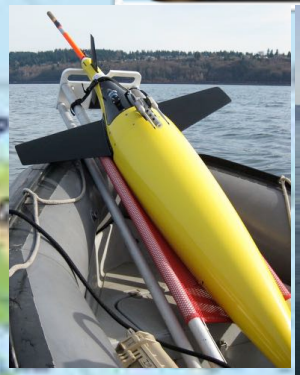
Modeling:

- Coordinated numerical experiments
- High-resolution (cloud-permitting) simulation and experimental forecast
- High-resolution (cloud-permitting) data assimilation

- WCRP-WWRP Subseasonal Prediction Project
- Subseasonal-to-Seasonal Prediction Project (S2S)/MJO Task Force (MJOTF) Joint Maritime Continent Initiative

YMC Field Campaign: US Participation (ONR, NASA, DOE, NSF, NOAA)

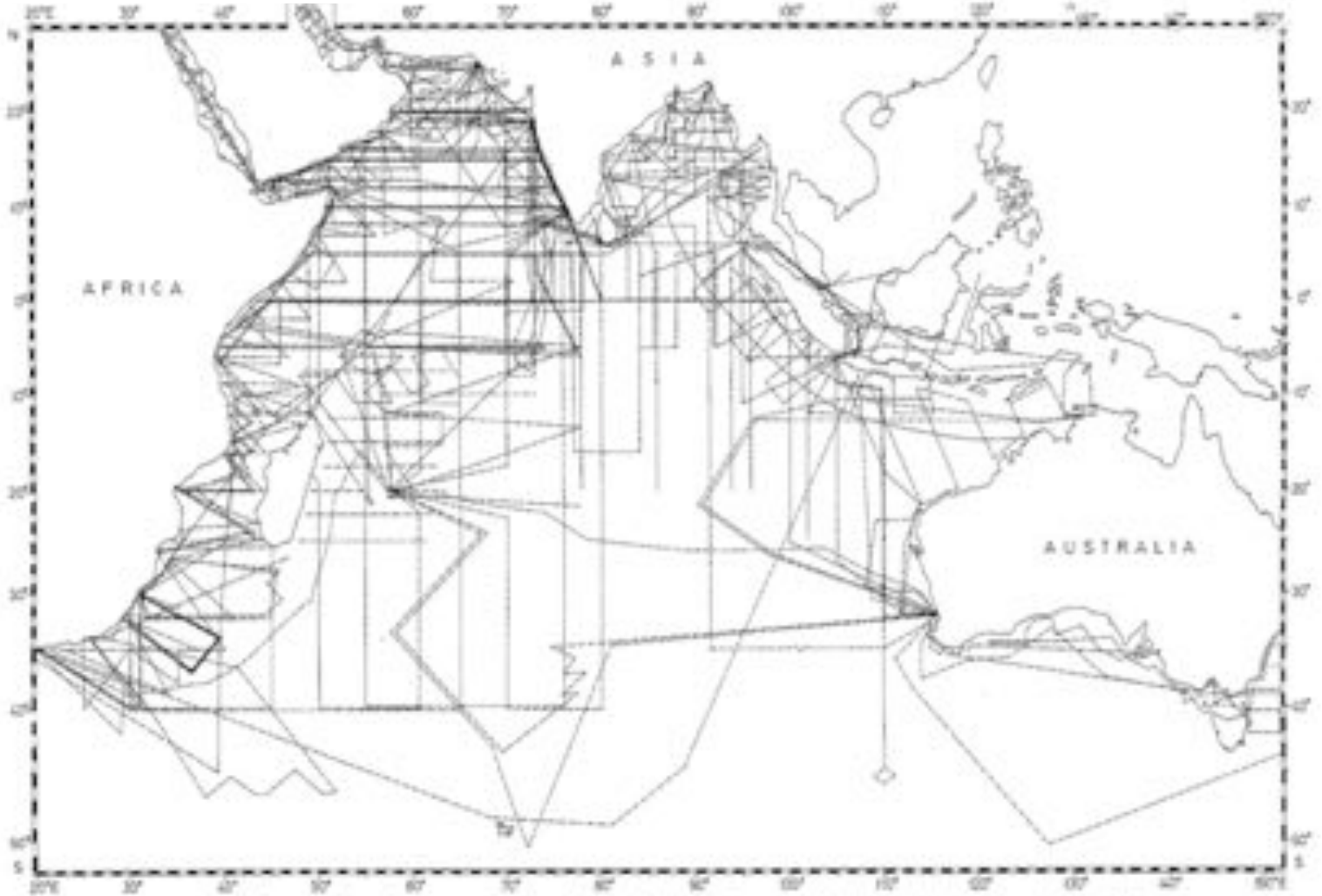




IIOE-2 overview (from Nick D'Adamo)

Second International Indian Ocean Expedition

Original IIOE: 1959-1965



Cruise tracks of research vessels during the International Indian Ocean Expedition. Based on information from the Office of Oceanography, UNESCO, Paris

from INCOIS

IIOE (1959-65)

products

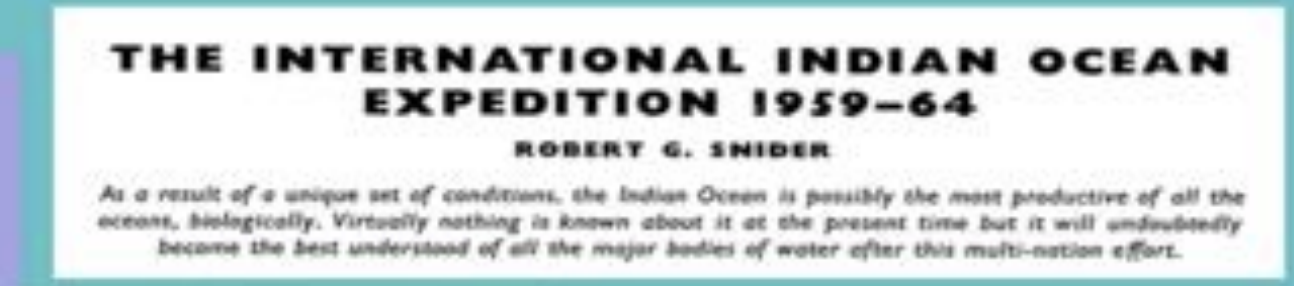
SCOR IIOE website

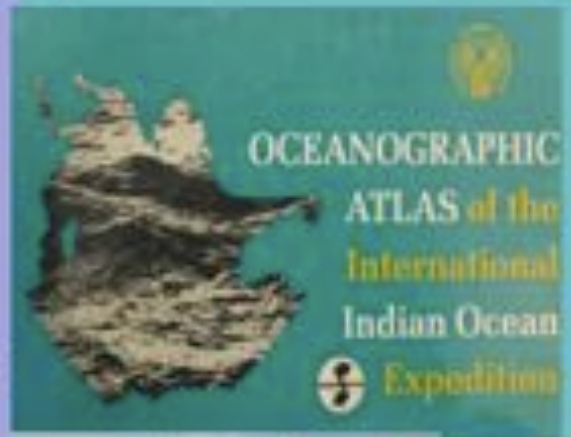
www.scor-int.org/IIOE_History.htm

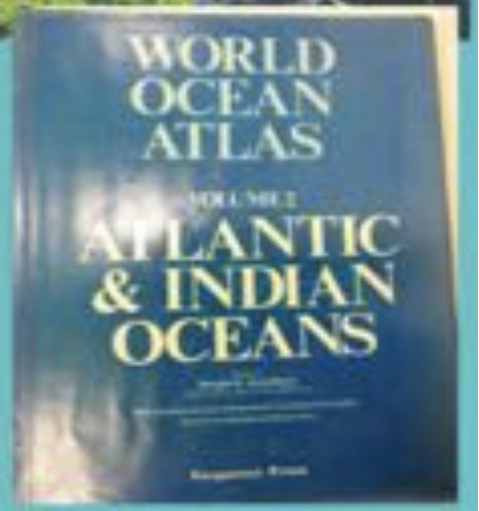
IOC Library / archives

IIOE papers

Berhman (UNESCO; 1981)







IIOE-2: why now?

- Indian Ocean still relatively poorly understood
  - Natural and human disasters (climatic, oceanographic, search + rescue)
  - Environmental problems, climate change
  - Food security – agriculture, fisheries
- New technology
- Indian Ocean is undersampled – especially for biogeochemistry
- Much larger total EEZ now. *For effective research, we need to collaborate under a collegial framework*

IIOE-2: an opportunity to...

- Link & synergize individual research programs
- Tackle truly basin-wide integrative issues that cannot be solved by singular national approaches
- Engage in capacity-building

IIOE-2 planning undertaken under leadership of:

- Indian Ocean Global Ocean Observing System (IOGOOS)
- Scientific Committee on Ocean Research (SCOR)
- UNESCO Intergovernmental Oceanographic Commission (IOC)

  * IOC recently endorsed IIOE-2 *

Science Plan for IIOE-2

Raleigh Hood (USA) & ~100 authors. Reviewed widely by international community. Edited by scientists from Australia, China, Germany, India, Japan, Netherlands, UK and USA.

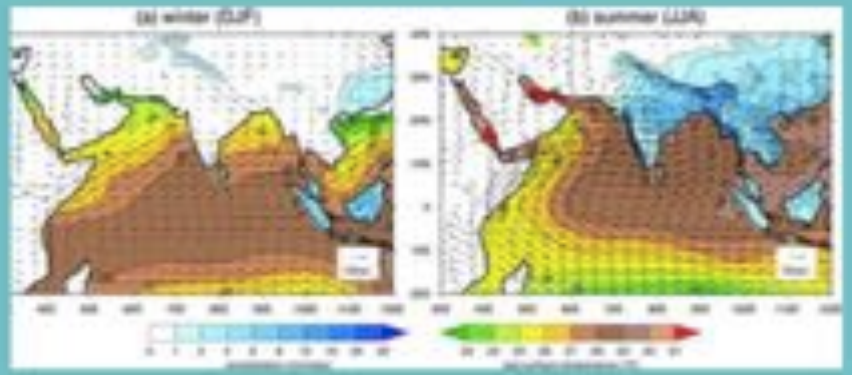
Purpose: to advance our understanding of interactions among geological, ocean and atmospheric processes that give rise to the complex physical dynamics of the Indian Ocean region, and to determine how those dynamics affect climate, extreme events, marine biogeochemical cycles, ecosystems and human populations.

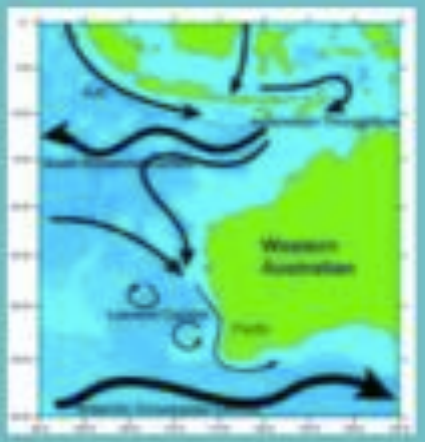
Scientific Themes

1: Human induced stressors & their impacts

2: Boundary current dynamics, upwelling variability and ecosystem impacts

3: Monsoon variability & ecosystem response

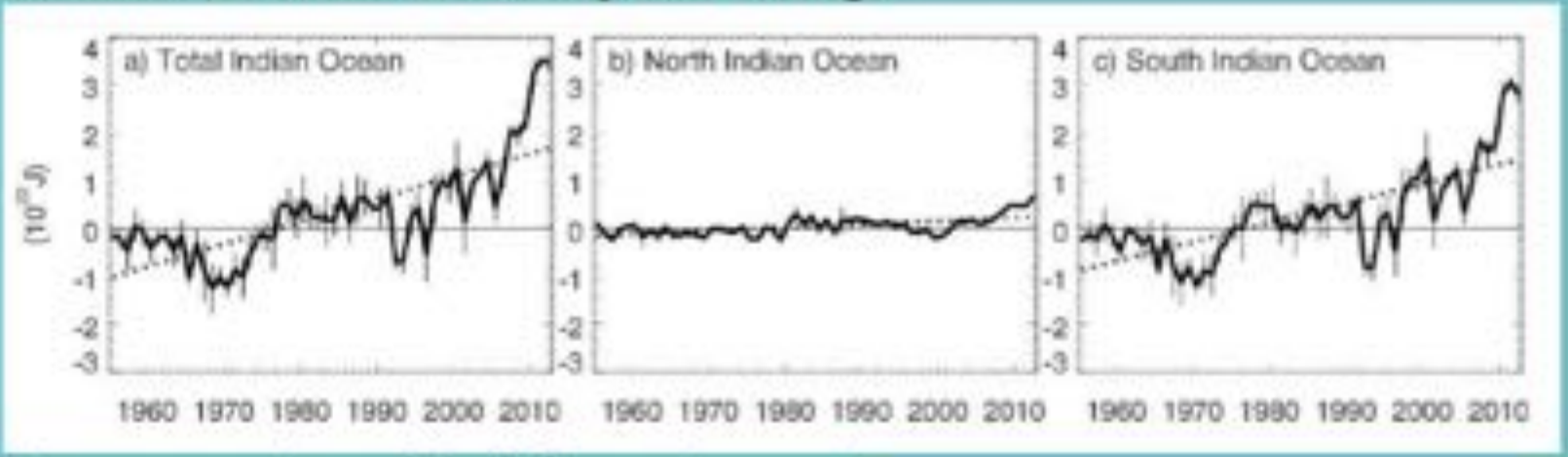




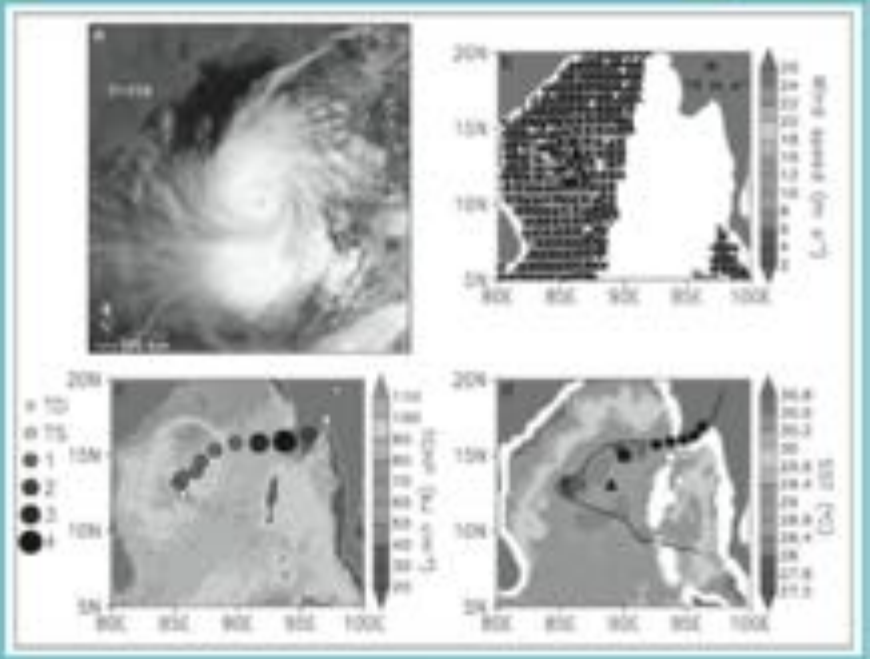
Science Plan for IIOE-2

Scientific Themes

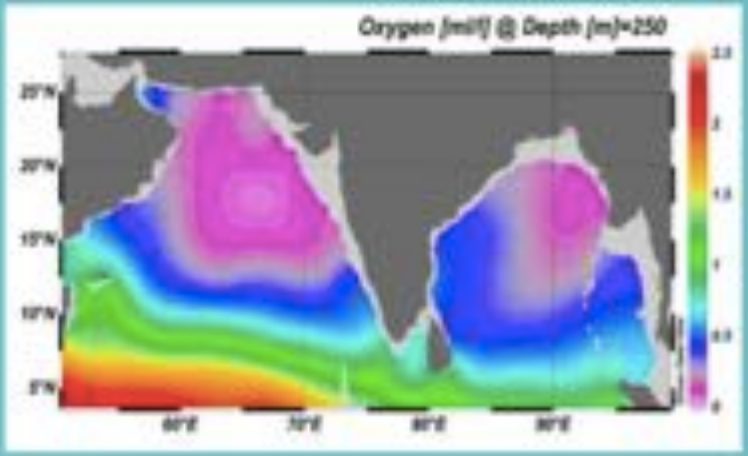
4: Circulation, climate variability and change



5: Extreme events and their impacts on ecosystems and human populations



6: Unique features of Indian Ocean



IIOE-2 is a larger envelope for existing programs (e.g. completing RAMA, YMC, eastern Indian Ocean Upwelling Initiative) and also an opportunity for new programs.

Meeting Nov 30-Dec 4, 2015 in Goa, India (http://io50.incois.gov.in/)

Discussion topics

What should our priorities be moving forward?

- Which elements of the sustained observing system are critical? (RAMA, Argo, XBT, etc)?
  - e.g. a flux mooring at 18N?
- What process studies are needed?
- Where are modeling efforts needed?
  - E.g. Bay of Bengal? Maritime continent?

How can US-CLIVAR interact with the CLIVAR Indian Ocean WG?

Are US agencies interested in funding proposals in the Indian Ocean to take advantage of the current programs?