Past and Current Process experiments in the Bay of Bengal: ASIRI-OMM-MISOBOB

Amit Tandon UMass Dartmouth

with

ASIRI, MISOBOB team (USA)

OMM team (INDIA)

RIO-MISO, EBOB (with Sri Lanka)

USA : UMass Dartmouth, WHOI, APL/UW, Scripps/UCSD, Oregon State Univ, University of Notre Dame, Columbia University, University of Alaska, University of Miami …
along with Naval Research Lab.(RIOMISO, EBOB)

Ministry of Earth Sciences
Government of India

India: Ocean Mixing and Monsoons (OMM) Indian Institute of Science Bangalore, Indian National Center for Ocean Information Services, National Institute of Ocean Technology, National Institute of Oceanography, Space Applications Centre, Indian Institute of Technology Madras, Indian Institute of Technology Delhi, Tata Institute for Fundamental Research, IMD

Sri Lanka: National Aquatic Resources and Research Agency (NARA)
Seychelles Meteorological Office
Maldives Hanimmadoo Climate Observatory
Singapore National University

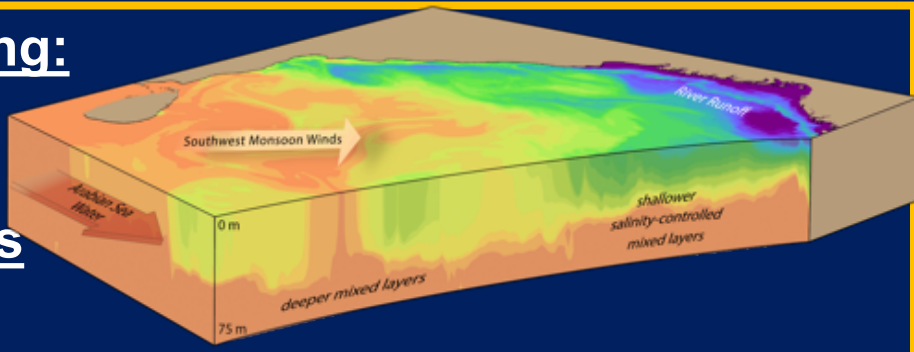
USA-India, USA-Sri Lanka Collaborative Research
Common Objectives and Interests

Develop strong collaboration between countries by identifying common science interest.
ASIRI-OMM-MISOBOB, ASIRI-EBOB-RioMISO


First Meeting in New Delhi, 2011

For Improved Monsoon Forecasting:
- Ocean Mixing
- Air-sea Fluxes

Extreme weather event predictions

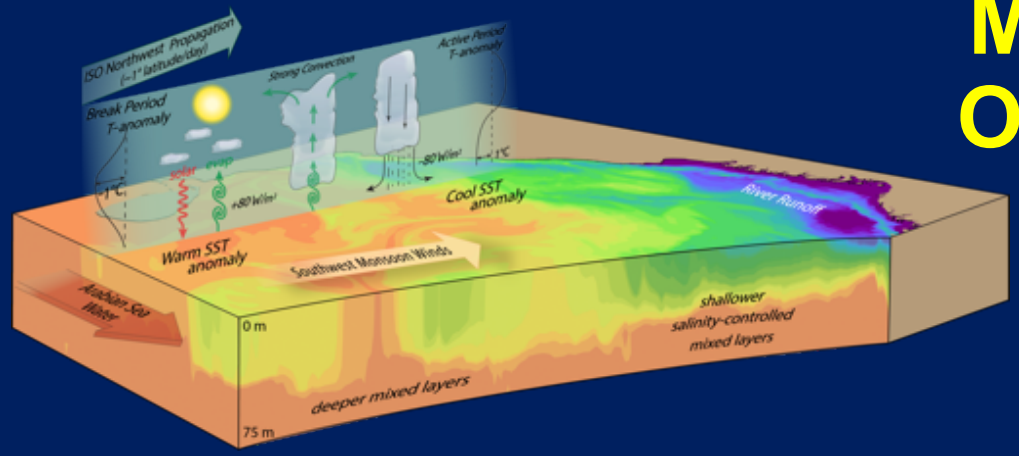


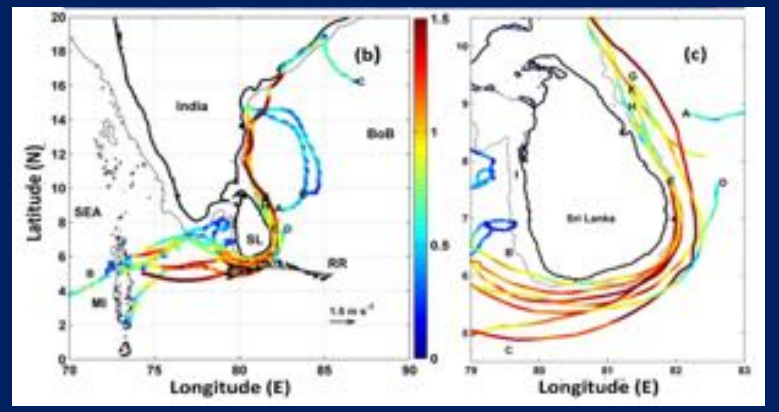
Indian interests:
- Science with Modern oceanographic instrumentation
- Capacity Building including glider training

Sri Lankan interests:
Fisheries; Capacity building for oceanographic research; Glider and buoy deployment training

USA interests:
- Improving model predictive capabilities
- Safety of ships at sea, navigation

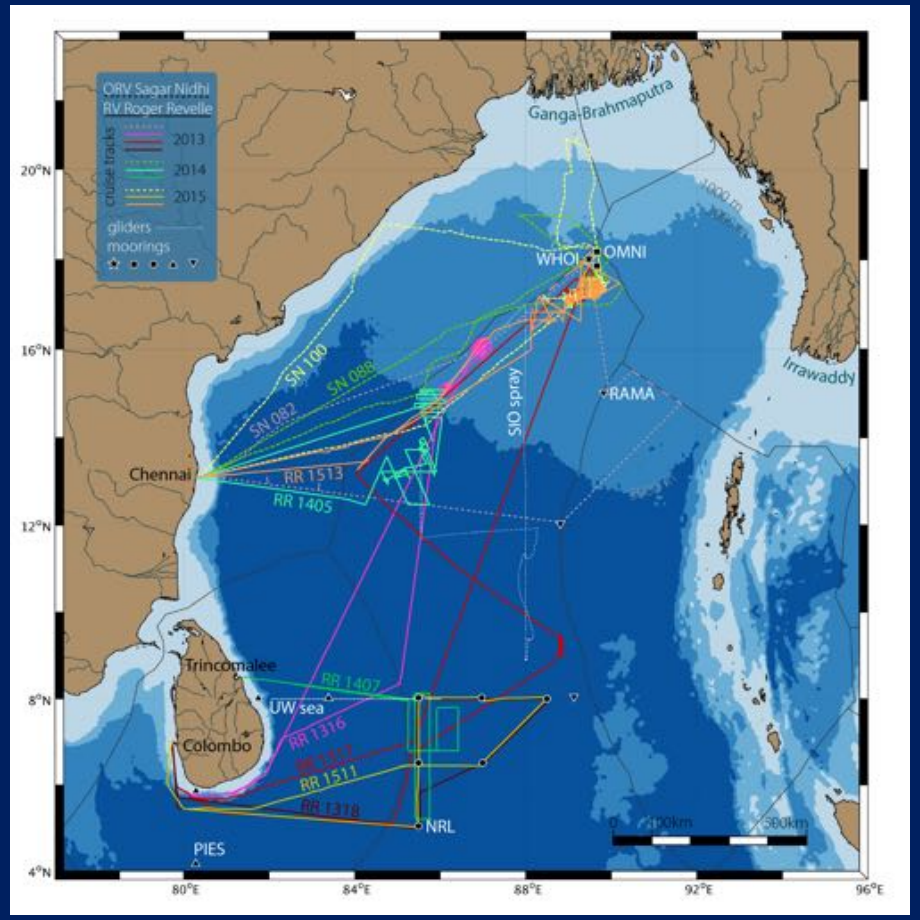
MISOBOB Objectives



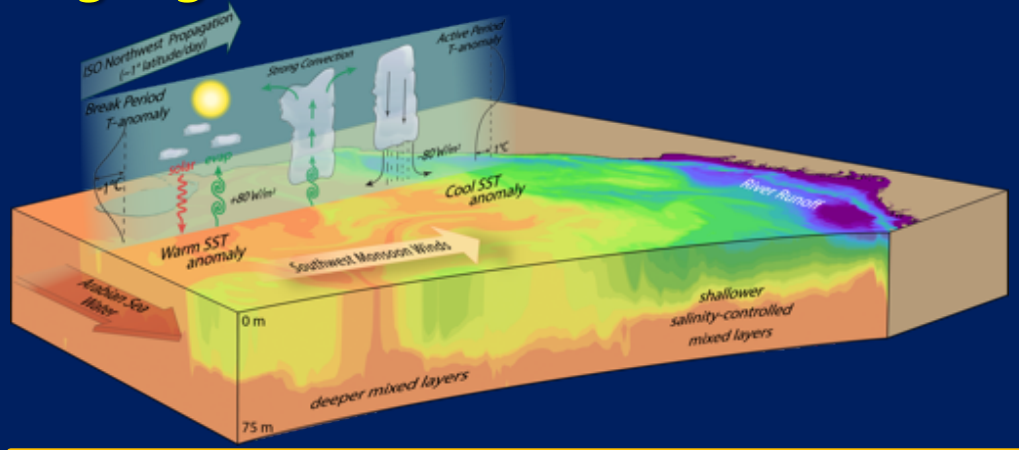


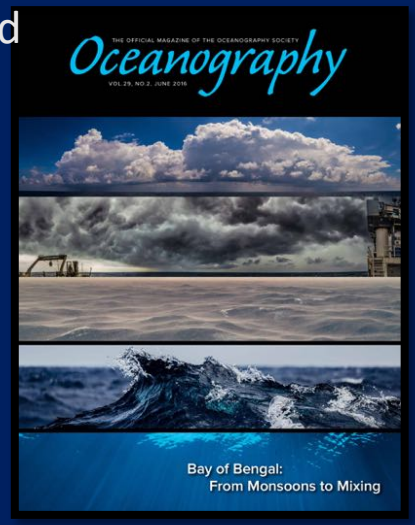
- Understanding the ocean influence on the intensity and propagation speed (roughly 1 degree north per day) of the coupled ocean-atmosphere MISO signal.
- Determining how the large-scale upper ocean variability in the Bay of Bengal, which includes shallow salinity-driven mixed layers in the north and deeper mixed layers in the south, influences the MISO signal.
- Evaluating how the submesoscale and mesoscale perturbations affect the upper-ocean background state.
- Integrate data and models to determine the spatial and temporal scales at which atmospheric and oceanic signatures need to be coupled to accurately capture the MISO propagation.

USA-India Joint Field Work 2013-2019: Highlights



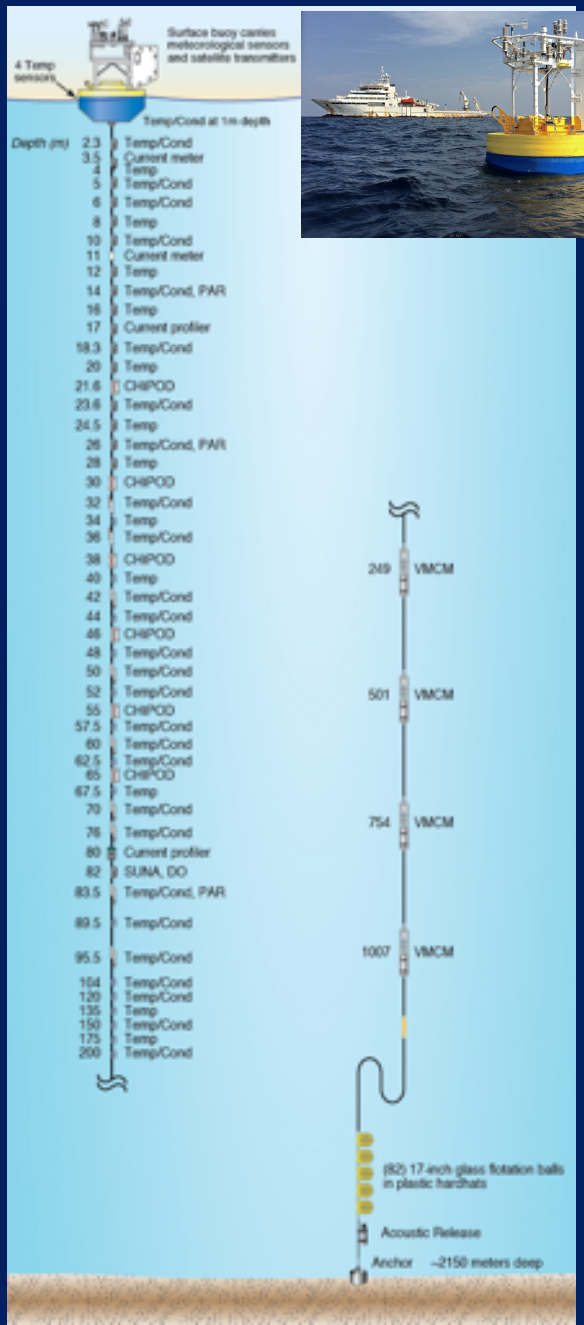
Mahadevan, Paluszkiewicz, Ravichandran, Sengupta and Tandon 2016

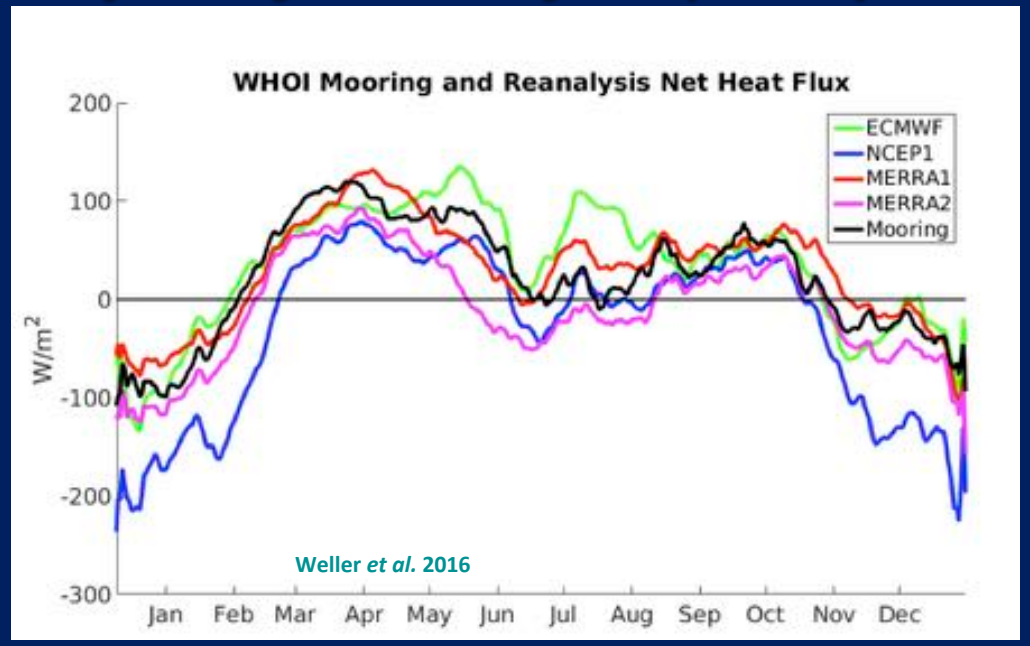


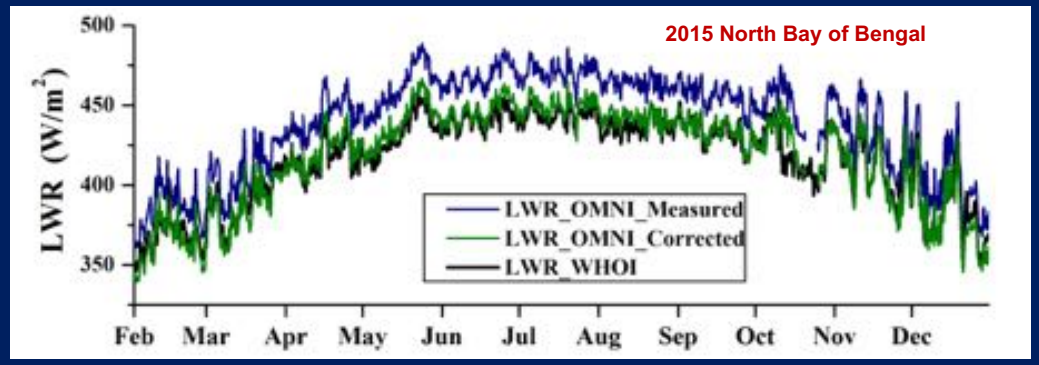


- Combined field efforts including multiple joint cruise operations (2013,2014,2015, 2018, 2019)
- R/V Revelle, Thompson...Sally Ride port calls to India
- Scientific exchange: meetings, workshops, ships
- Capacity building and training: summer schools, student exchange, targeted efforts
- Joint publications (Oceanography 2016, Deep Sea Research: Volume 1, 2019; Volume 2, 2020; Book..many other publications)

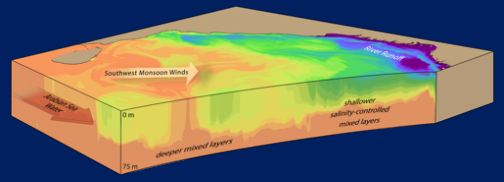
ASIRI –OMM: First Accurate annual cycle of air-sea flux (2015)





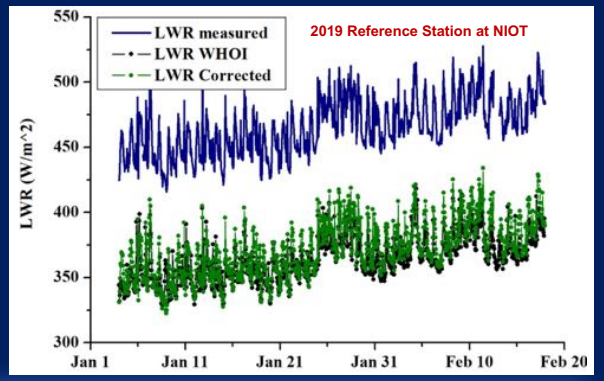


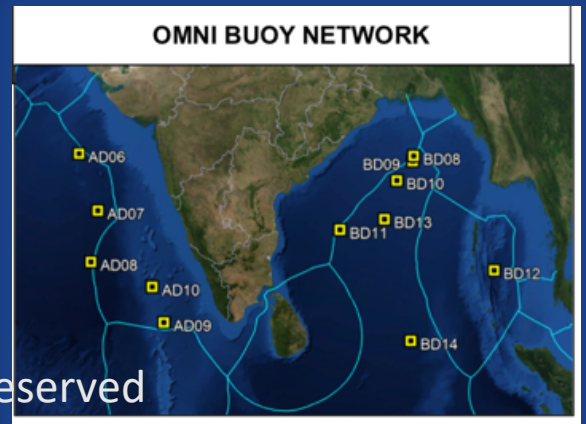
INCOIS Mooring deployed in 2019 to measure Direct Covariance Fluxes (planned recovery this year)



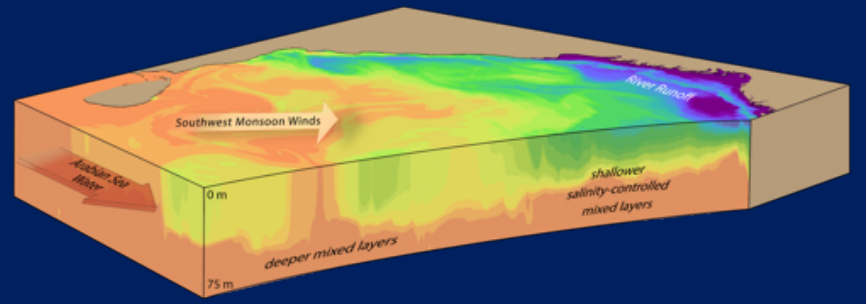
All products have large biases. Reduce biases from Indian NIOT buoy compared to WHOI.

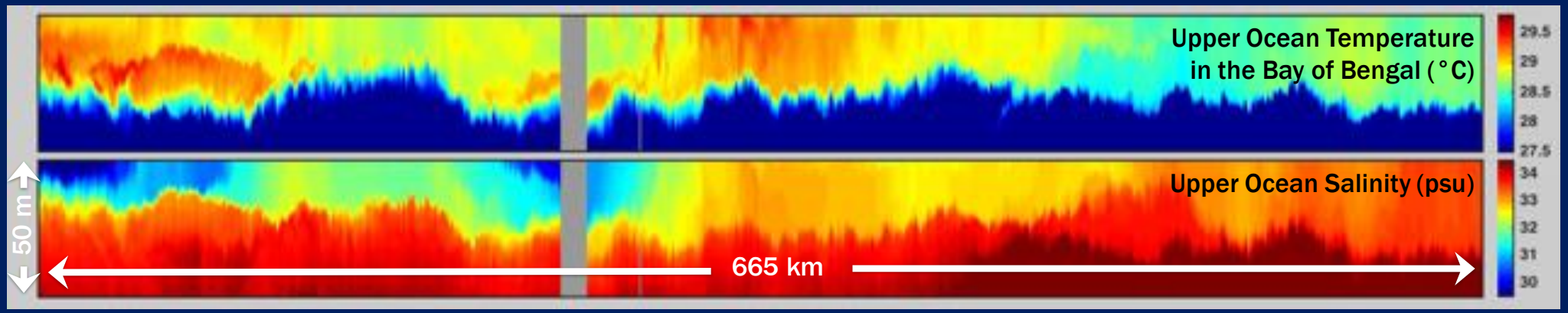
Led to improved flux measurements from Indian buoys (Joseph *et al.* 2020)





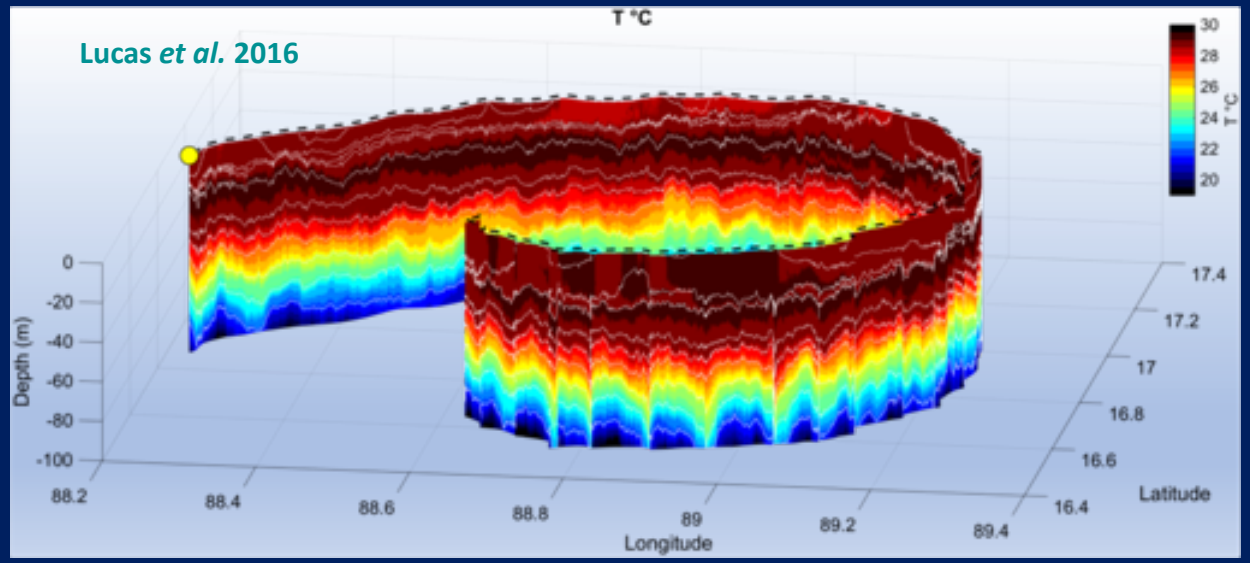
ASIRI –OMM-MISOBOB
Scales of intense stratification and sub-surface warm barrier layers





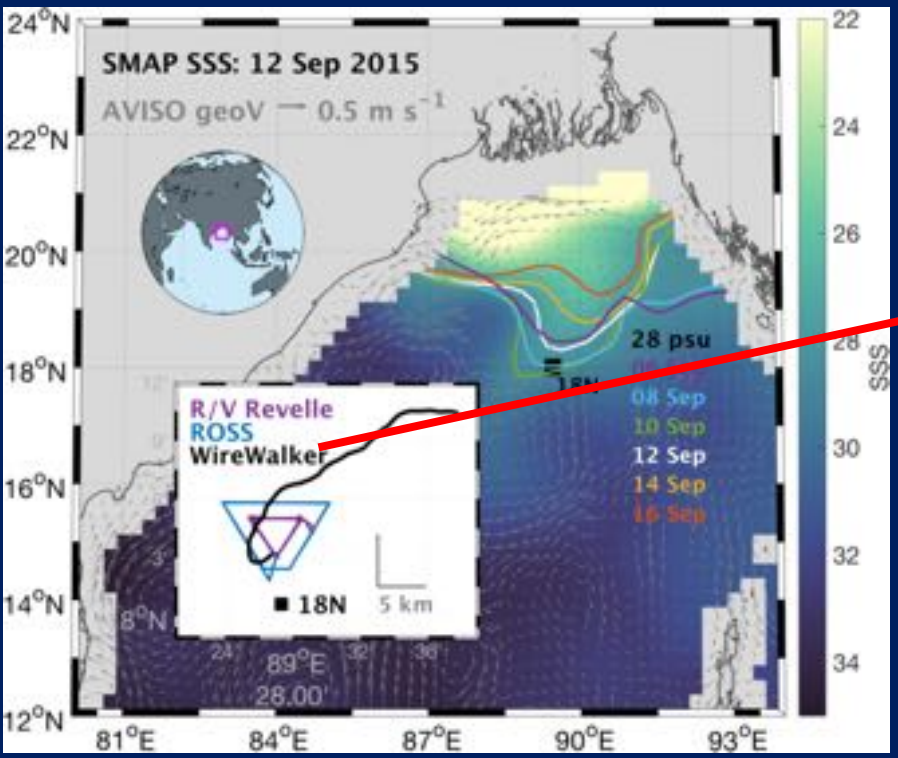
Shallow salinity stratification with very weak mixing below the halocline enhances air-sea interaction.

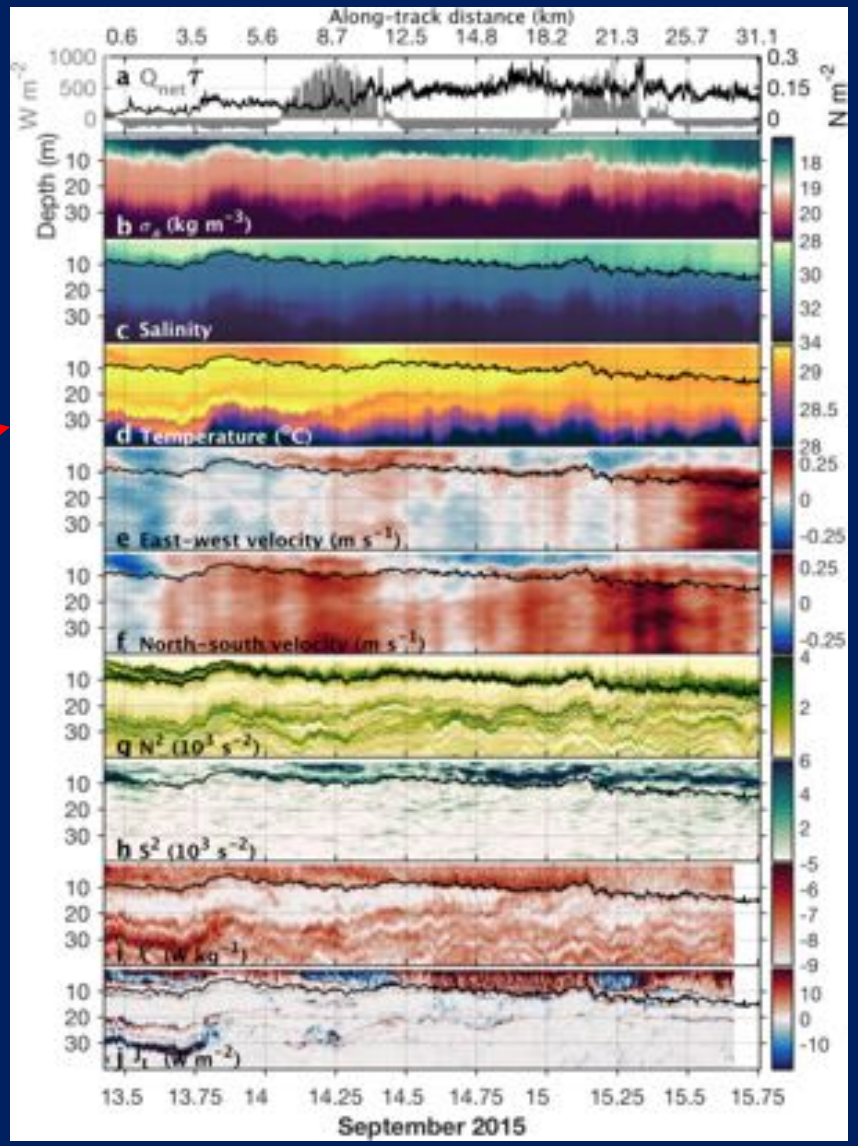
Trapped heat has important implications for cyclone development and Monsoon forecasts.



ASIRI-OMM-MISOBOB: Novel measurements of spatio-temporal patterns of turbulent heat fluxes

(Adams et al. 2018)



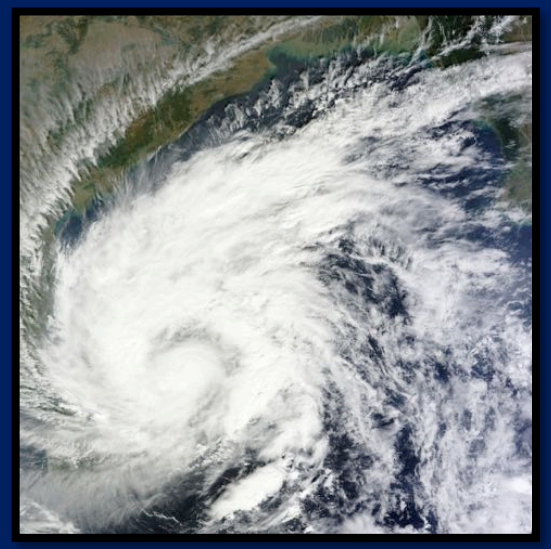


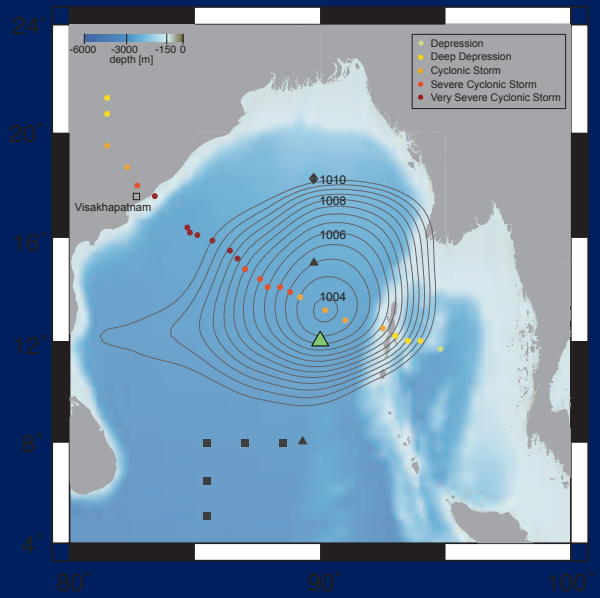
- Abrupt changes in turbulent heat flux to/from the ocean to atmosphere in sign and magnitude, **over small horizontal scales.**
- These heat flux gradients reflect gradients within the surface ocean not only of mixed-layer depth and stratification, but also of the three-dimensional processes (near-inertial shear, frontal instabilities) that drive turbulent mixing.

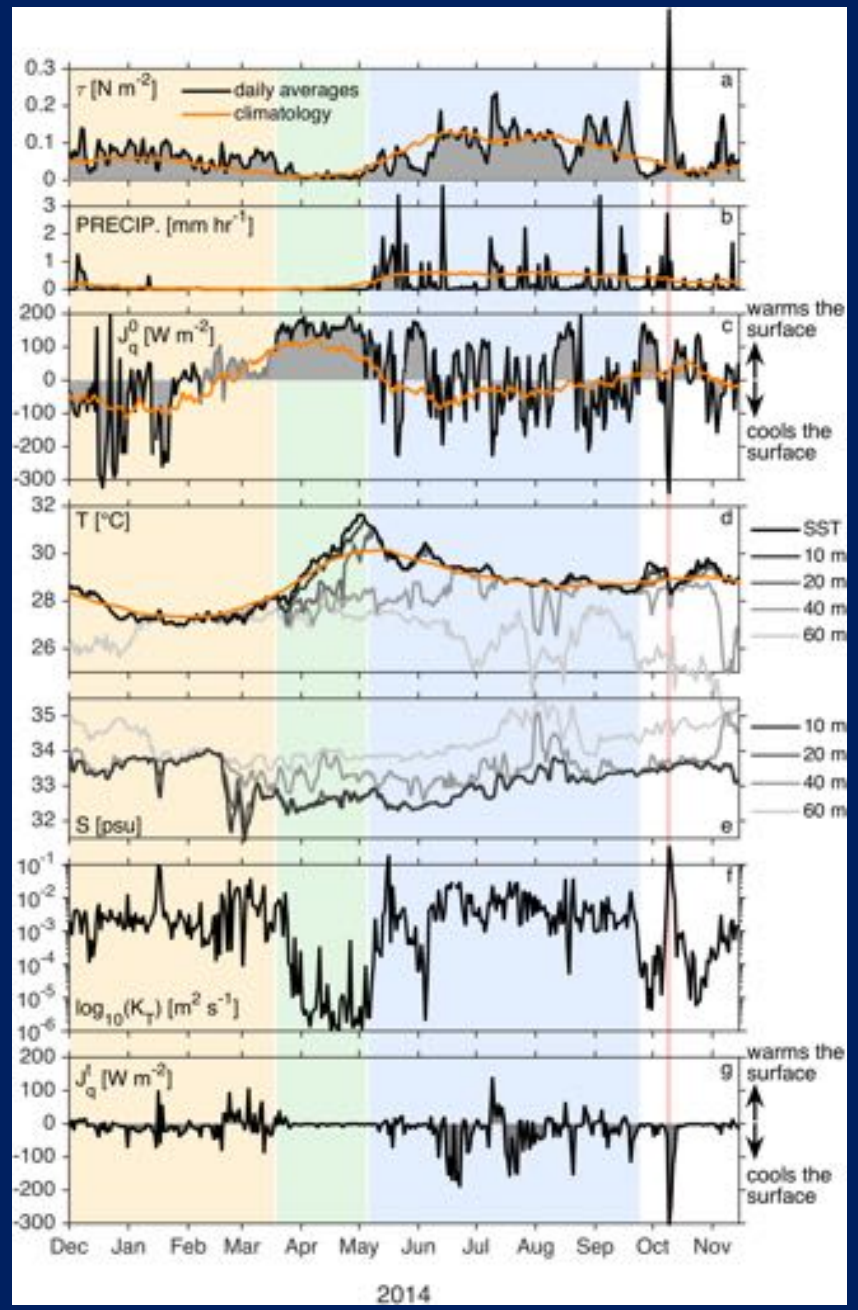
ASIRI -OMM-MISOBOB
Mixing in the Bay of Bengal from annual cycles to cyclones

Warner *et al*. 2016

- Anomalous Bay: High freshwater prevalence leads to minimal vertical mixing.
- Driver for Mixing required to be consistent with BoB circulation: Cyclones!
- As captured by ChiPods deployed during ASIRI during Hudhud







ASIRI –EBOB Boundary Currents

Transport of Important Water Masses

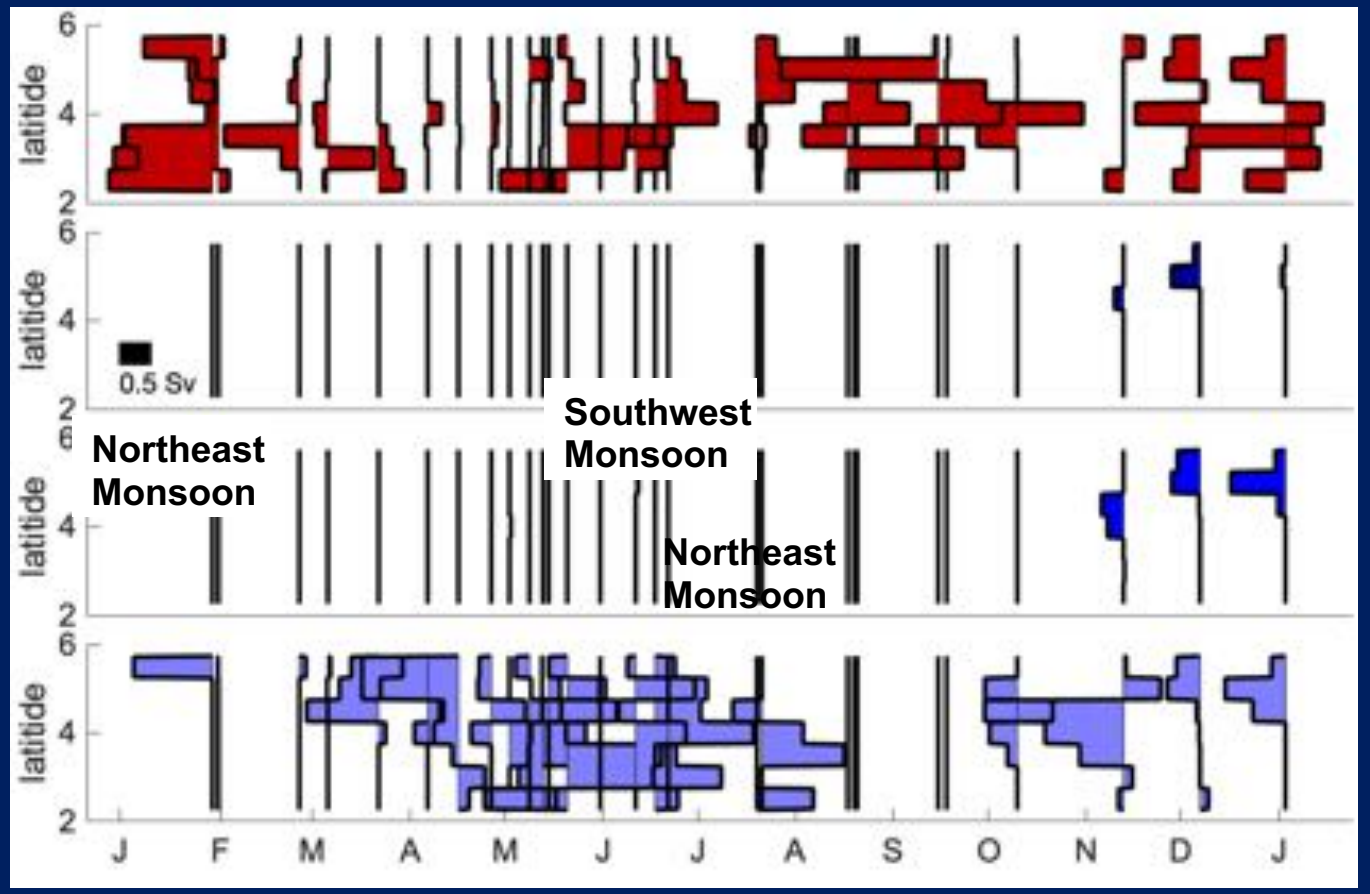
(Courtesy: Craig Lee UW; Priaynatha J. NARA Sri Lanka)

A

B

C

D

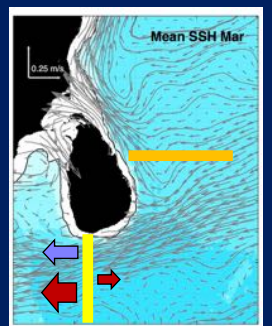


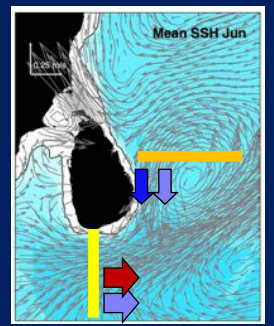
AS water comes in BoB during SW monsoon.

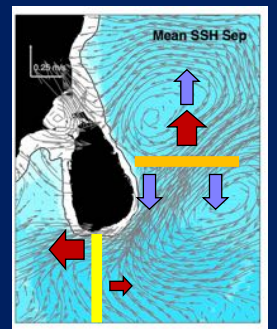
Modified **AS** water recirculates

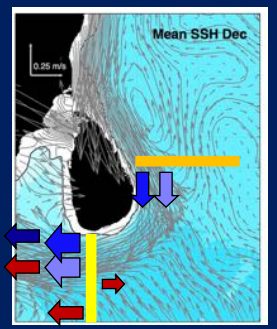
Very fresh water export during NE monsoon near the coast

Modified BoB water export during most seasons (transitions)





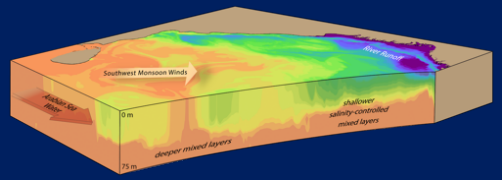




Strong recirculations

MISOBOB and RIO-MISO

Spanning the air & sea
USA / India / Sri Lanka



Ocean Observations

- Long-term Indian moorings collaborative with US
- Long-term Glider observations with Sri Lanka
- US and Indian Cruises supported by autonomous platforms e.g. slowly drifting flux+WWs, gliders

Atmospheric Observations

- Indian & Sri Lankan operational networks
- Additional Observations from Met stations
- C-130 flights from Sri Lanka
- Flux and boundary layer observations on cruises

Improved Process Understanding

- Process / Regional / Coupled models
- Indian and US oceanographers and atmospheric scientists
- Analysis of ASIRI and MISOBoB data

Operational Models

- NRL COAMPS
- Collaboration with Indian Operational and modelling centers

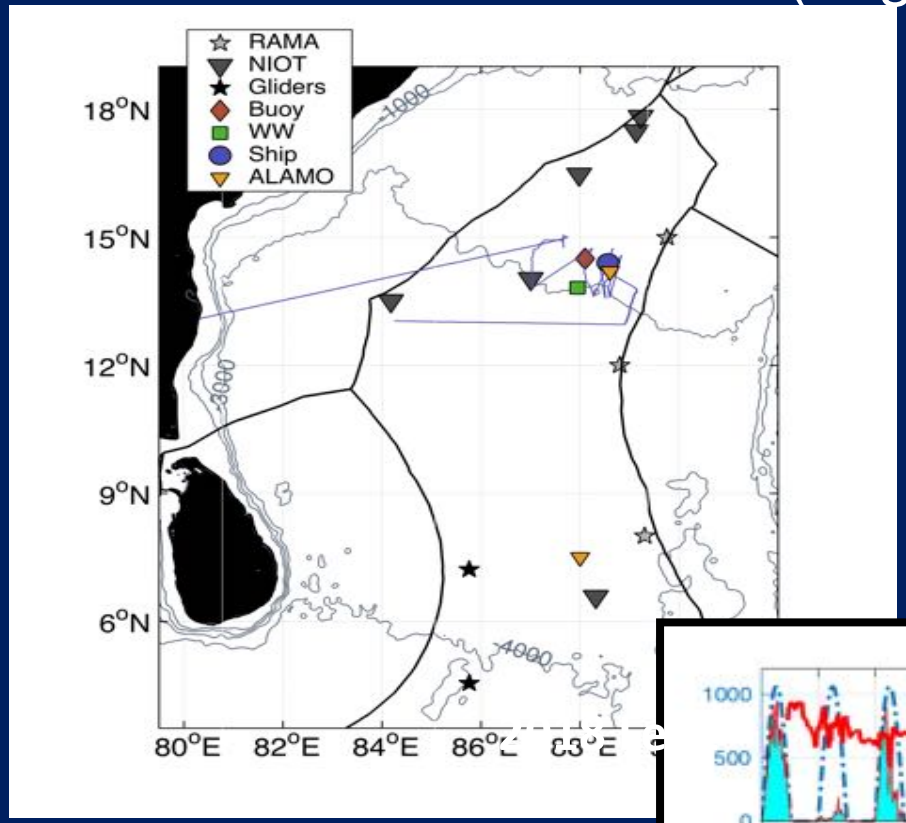
2018 FIELD PROGRAM

R/V Thompson photographed via drone; ship-based observational resources as shown. Activities during Leg 2 also included mooring deployments, VMP profiling, and towed surveying.

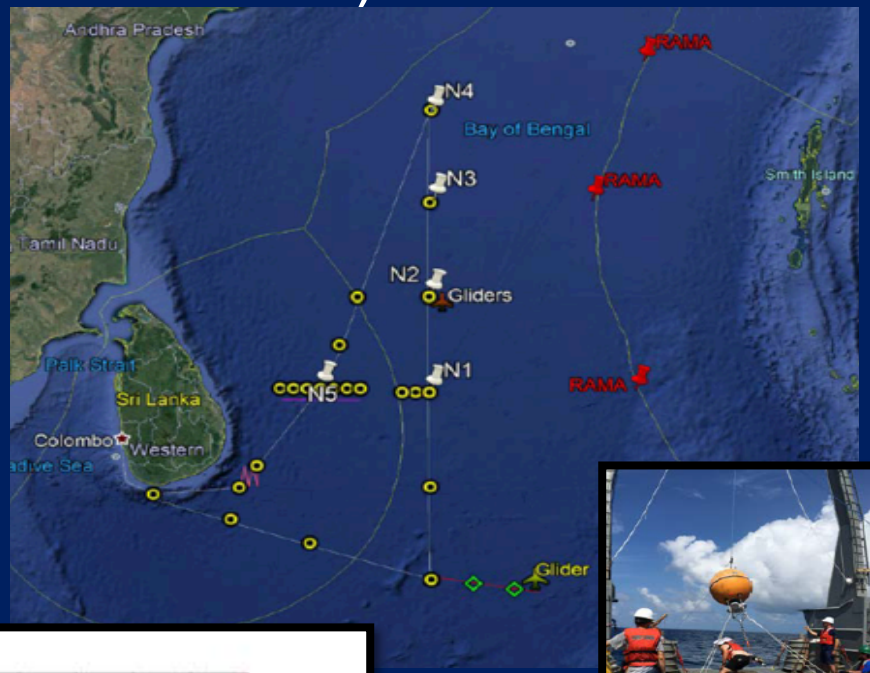
USAF C130 (53rd Weather Reconnaissance Squadron) forward of the bow mast. WRS53 at the cruise

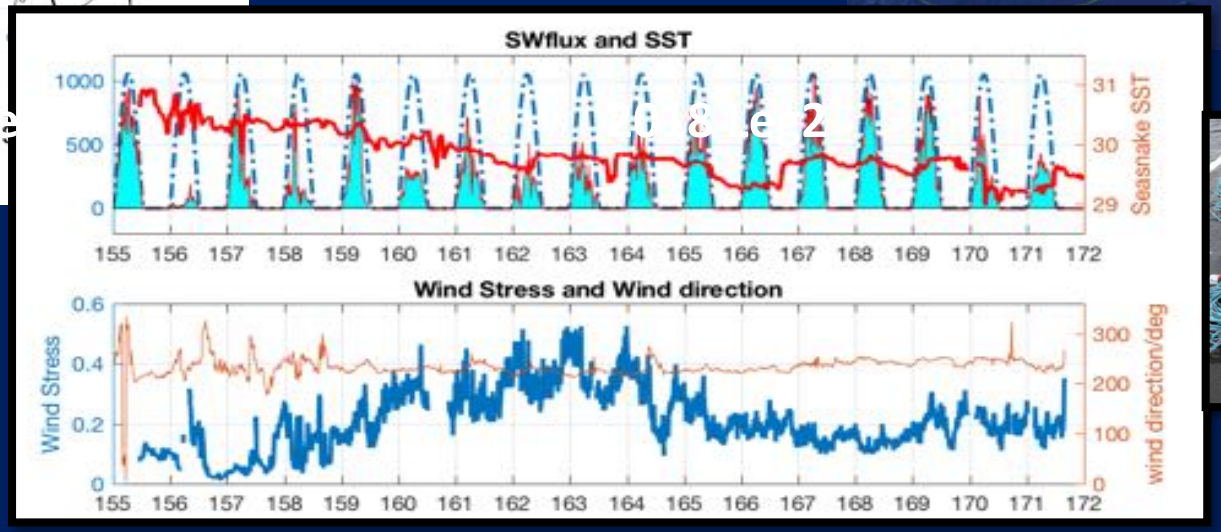
2018 FIELD PROGRAM

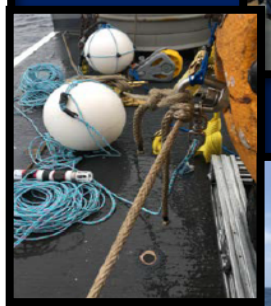
(Leg1 Chennai IN, Leg2 Colombo SL)



Leg1 captured the First MISO of the 2018 Monsoon







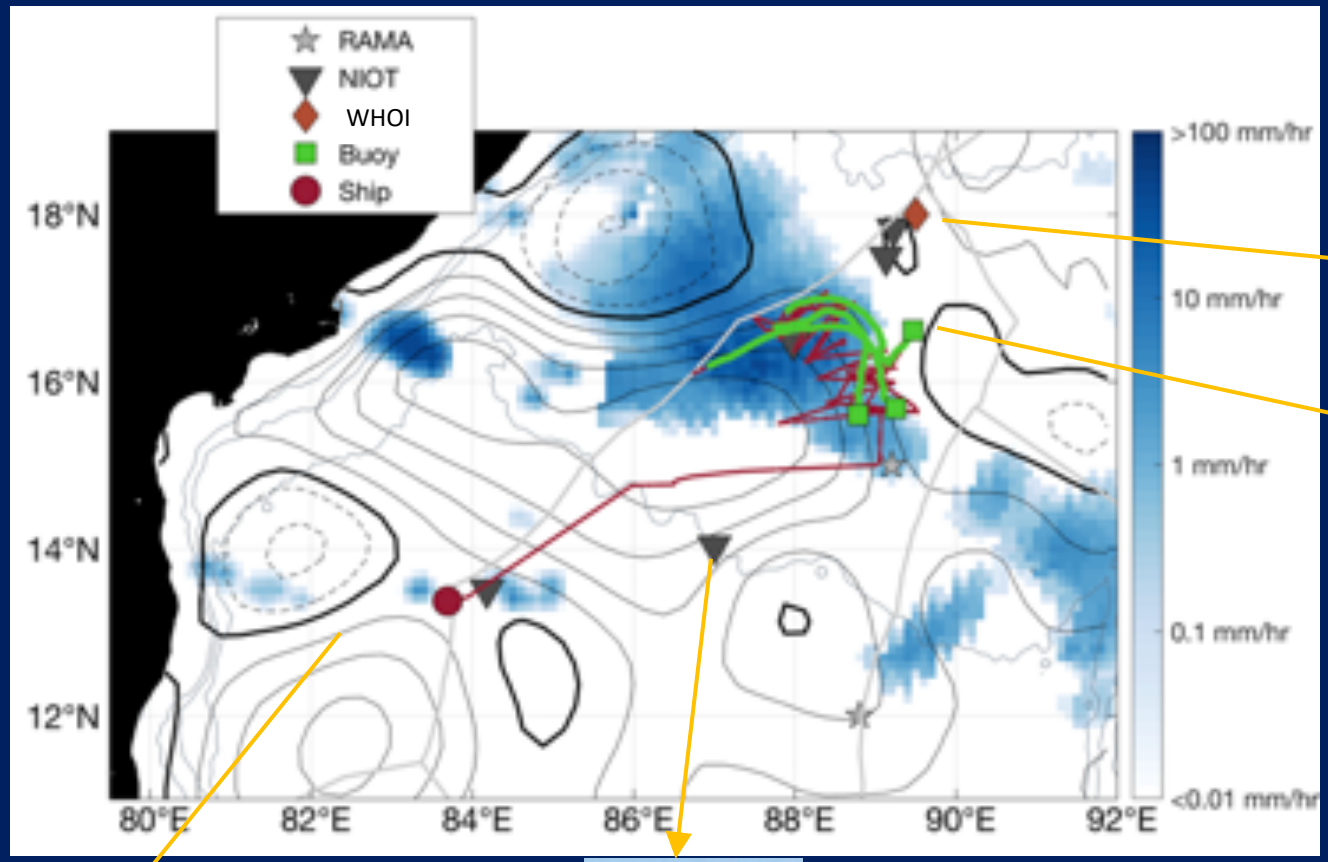
Atmospheric Conditions during Leg 1

Mooring Ops during Leg 2

June 4th –June 21, 2018

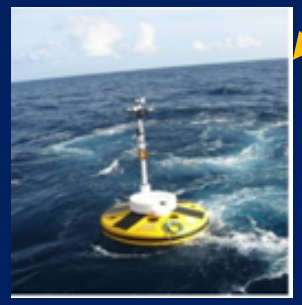
July 2019 Process Experiments

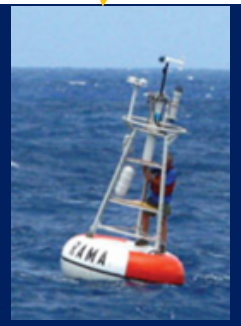
(Courtesy E. Shroyer): Fronts in the Atmosphere and Ocean Stirring from the Coastal Margins & Precipitation



INCOIS Air-Sea

~20-day WHOI+WW





- **Three drifting flux buoys deployed on periphery of an anticyclone**
- **Ship-tracked buoys around edge of eddy**
- **Maintained year-round OMNI/RAMA buoys**

Scientific Exchange (…ongoing)

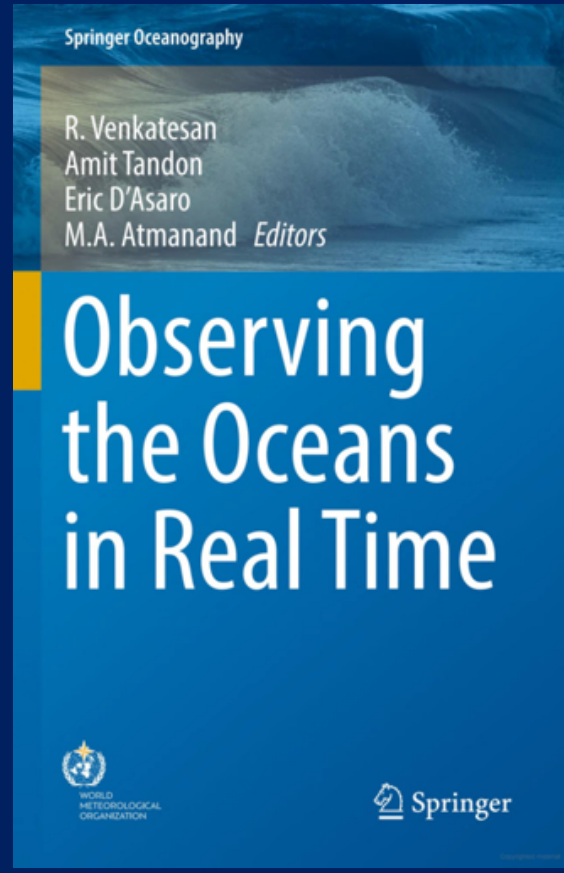
Four formal summer and winter training workshops in India with Indian and USA students

Workshops in the US (Oregon State, UMass Dartmouth, WHOI)

Many individual training activities, with trainees visiting US institutions

Multiple US PI visits to multiple Indian institutions

About 12 joint science meetings with US/India/SL PIs in India, Sri Lanka and in USA.



Technical Exchange (…ongoing)

- Collaborations onboard US and Indian vessels
- Indian scientists on US vessels (>50 overall)
- US scientists on Indian vessels
- Lagrangian float training and deployments.
- Glider training and deployments
- 18N INCOIS flux mooring and training
- Junior scientist visits to WHOI, APL/UW, UMass, Scripps, Oregon State etc.

Such activities have built new indigenous capability in India, and in Sri Lanka, training a new cadre of US scientists well versed in monsoon air-sea interaction, and forging strong links between US and Indian and US and SL oceanographic institutions.

Spanning the air & sea in the Bay of Bengal
International Collaboration

Long term Observatory

- Air-sea flux measurements + solar input
- Test bulk formulae for improved models
- Upper ocean vertical structure

Measurements of Mixing Rates

- Relate to air-sea fluxes and stratification
- Test and improve parametrizations
- Improve upper ocean structure in models

Process Observations and Modeling

- Understand freshwater dispersal mechanisms
- Understand mixing processes
- Estimate advection - test for seasonal variations