Bay of Bengal/Air-Sea Interaction Research Initiative (ASIRI)

- Air-Sea Interaction Research Initiatives - U.S. Office of Naval Research
- Integrated with Naval Research Laboratory program
- Coordinated with Sri Lanka
- Closely coordinated with India
Scientific Foci

- Understanding the processes that govern monsoon initiation
- Better understand the coupled physics involved in the monsoon so we might improve the predictive weather models
- Role of the ocean in determining monsoon strength
- Impact of the monsoon on the ocean
- Determine the important regions driving the ocean-atmosphere coupling (e.g. particular areas in the Bay of Bengal)
- Example Programs: Arabian Sea Study, JASMINE, DYNAMO, ITOP

Paluskiewicz
ASIRI-Bay of Bengal goals

• Exploring the conceptual, theoretical, dynamical constructs of air-sea interaction in the Bay of Bengal (BoB) // monsoonal regions

• Understanding the dynamics of the mixed layer

• Flux balances at different stages of the monsoon

• Role of the mesoscale in modifying monsoonal dynamics

• Improved process representation and coupling parameterizations in data assimilative models

Paluskiewicz
AS and BoB differences between the basins (Shenoi et al, 2002)

ARABIAN SEA

- weak convective activity
- cool SST
- weak near-surface stratification
- strong mixing and upwelling
- strong winds (Findlater Jet)

BAY OF BENGAL

- strong convective activity
- warm SST
- strong near-surface stratification
- weak mixing and upwelling
- weak winds

P-E < 0

P-E > 0

Paluskiewicz
The MLD and BLD in the Bay have distinct seasonal variations.
Surface Salinity from AQUARIUS

Large scale SSS features as revealed by Aquarius: Composite SSS since Aug. 25, 2011

Aquarius Yields NASA’s First Global Map of Ocean

Evaporation

River Runoff in

BOB ~ 50,000 m³/s

Mississippi River ~19,000 m³/s

India

Sri Lanka

Arabian Sea

Bay of Bengal

Salinity Climatology

15 Mar, 2010

15 Aug, 2010
Surface Currents in the Region
Field Program

Conduct a field experiment in the international waters of the Bay of Bengal; utilize model studies to determine critical areas of air-sea interaction.
- Structure these model-deployments as hypothesis tests
- Structure the process model – sensor choices as hypothesis tests
- Develop cooperative cruises to build a multi-stage sample set of the monsoon

(A) Autonomous platforms

<table>
<thead>
<tr>
<th>Size</th>
<th>Power</th>
<th>Easy Deployment</th>
</tr>
</thead>
</table>

Disposable Wave Buoys

Ppod

Wave Glider  Deployable met buoy  Air-Sea Interaction Profiler  Glider
Air-Sea Interaction Buoys

OMM/ASIRI Glider Lines

Add Chi pod sensors Flux reference site [15N, 90E]

Pilot Cruise: 8 Nov-15 Dec 13
Coupled Physical Processes in the Bay of Bengal and Monsoon Air-Sea Interaction

“Ocean Mixing and Monsoons (OMM)”
IISc. INCOIS NIOT IITM NIO Goa NIO Vizag SAC TIFR Hyderabad IIT Madras IIT Bhubaneswar IIT Bombay IIT Delhi

Debasis Sengupta
• River-dominated north BoB: Shallow, fresh layer over deep, warm layer; coupled monsoon subseasonal oscillations (ISO), tropical cyclones, *diurnal cycle, monsoon disturbances* ...

• Present ocean and coupled models deficient: *Incorrect fluxes, missing physics in ocean and atmosphere boundary layers*

**OMM:** A four-year (2013-2016) programme (A) Observations of ocean and atmospheric boundary layers; (B) Fine-scale models; (C) Regional ocean/coupled models, and (D) OGCM development.

**Pilot experiment:** November 2013 and May 2014

18-24 month IOP: October 2014-October 2016

**Goals:** (A) Legacy datasets (B) Model-based syntheses of multi-scale observations (C) Parameterise upper ocean physics, surface fluxes, atmospheric mixed-layer physics (D) Capacity development.

Debasis Sengupta
Hypotheses:

Surface fresh layer in the north Bay is shallow due to tilting, slumping of multi-scale salinity fronts, barrier layer warmed by solar penetration.

Air-sea gradients & fluxes depend on 3-d processes in atmos./ocean mixed layer; shallow ocean surface layer & atmos. stability determine transition from shallow to deep convection north of monsoon ITCZ.

Debasis Sengupta
• **Main Science Issues/Questions:**
  • Pathways, persistence, balance of freshwater
  • Physics of thin, fresh upper layer, salinity fronts
  • Key processes of upper ocean stratification/mixing and balances
  • *Consequences of shallow, fresh upper layer and deep, warm subsurface layer for air-sea coupling*
  • Causes of unique near-surface air-sea gradients
  • Surface flux algorithms/parameterisation
  • Local atmospheric mixed layer/ABL properties and stability, shallow-deep transition of monsoon convection
  • *Coupling of ABL to upper ocean on synoptic to intraseasonal scales*

**Approach:**
Synthesis of multi-scale 3-d observations with process models
Large-scale air-sea interaction with regional models
Parameterise fine-scale near-surface processes in GCM’s

Debasis Sengupta
OMM Observations 2013-2016

Ships, Moorings, UCTD, Upto-Surface Argo Floats, Drifters, Gliders, Lagrangian floats, Wirewalker, Turbulence probe, Possibly Aircraft & Radar

Debasis Sengupta
OMM: is now approved for funding!

18-month focus: Equipment acquisition, first deployments, Training of personnel in India (travel and local hospitality for US trainers will be covered by MoES) and US (150 man-months of training time in the US for the project). Pilot cruises 2013/2014 Laboratory for autonomous instruments

IOP (2015-16): Ship time 5-6 cruises 15-20 days each, smaller craft for coastal/EEZ work.

Instrumented aircraft time for atmospheric boundary layer

International collaboration outside EEZ: US Partners WHOI, Scripps, U. Washington, U. Massachusetts .... to train and work with young Indian scientists/PhD students

Co-ordination with other Bay of Bengal nations under IIOE (?)

Debasis Sengupta
Pilot: Things We Know

**Dates**

**Leg 1:**
- November 8: Mobilization
- November 12: Embark
- November 29: Disembark/Offload

**Leg 2:**
- December 1: Embark
- December 13: Disembark
- December 14: Demobilization

**Components**
- Survey
- Process
- Training-Exchange

**Resources**
- Turbulence Gliders
- Spray and Seagliders
- Shipboard Assets: uCTD, CTD, HDSS, ADCP
- Wire-walkers, Spar buoy
- Other: Argo, RAMA, etc.

Coordination with Sri Lankan and Indian Efforts
Pilot: Survey Leg 2

November 28   Embark
December 13   Disembark
December 14   Demobilization

How do we best use the available resources to differentiate small-scale mixing processes that contribute to the flux of heat and freshwater in the Bay of Bengal?

Motivation

We would like to understand the heat and freshwater distribution in the Bay of Bengal at small-spatial scales, given large-scale gradients associated with forcing (e.g., large source of freshwater input, heat fluxes, and wind forcing) and small-scale mixing processes (both lateral and vertical).

Specific Goals

• measure NS variability in atmospheric conditions, upper layer properties, and vertical mixing
• resolve sub-mesoscale and larger features using Doppler sonar, uCTD & chipod CTD
• training-exchange with Sri Lankan/Indian colleagues
• include a “southern” process study to compliment first leg
• marine mammal observations
Technique
- NS survey line using uCTD (4 km resolution)
- Underway systems (x-band, met sensors, flow through, Doppler, echosounder, etc.)
- CTD stations (to roughly 200 m), repeat with optics and chipod CTD
- Small Process Study (‘Southern’ Turbulence Glider Station, 12N)
  - Drifters (5, 15 m drogue) (small scale grid deployment)
  - Thermistor Chains (?)
  - Rapid small-scale survey with shipboard resources (tow-yo CTD or VMP)

What we can expect to get
- wavenumber content in the NS direction
- variability in mixed layer and barrier layer properties
- high resolution sampling over the large scale gradient
- variability in vertical mixing as a function of ML/BL properties
- comparison point to the northern process study
Survey Component (15 days at Sea)

This is not the actual transect line, but is representative of distance we can cover!!!!

3.25 day RT commute to Colombo
2.5 days for CTD (60-80 stations)
2.5 days for southern process leg
6 days of uCTD (1300 nm)
0.75 days Recovery of Glider
Process cruise planning
co-Chief Sci: D. Lucas and J. MacKinnon

Current UNOLS ship schedule dates, leg I:

Mobilization (Colombo): 8 November
Depart: 12 November
Demob. (Trincomalee, tentative): 27 November

Process cruise motivation:

Investigate small vertical and lateral scales, temporal evolution of salt, heat, buoyancy fluxes, vorticity from combination of drifting WW array and ship survey (Impact of submesoscale on lateral and vertical FW/buoyancy exchange).

Interaction with Sagar Nidhi in northern region (~17-18N) of strong FW lateral gradients. Inter-comparison of shipboard instrumentation (met/radiometers, uCTD, underway systems), LatMix style two ship operations

Training opportunities for students/colleagues.

Refine drifting array management/reseeding techniques.

Maximize science time given long transits to international waters/ water of interest.
Process cruise planning
co-Chief Sci: D. Lucas and J. MacKinnon

15d leg I: 7 days transit Colombo to 18N to Trinco = 8 science days

Approximate break-down: 2-3d for Seaglider, Spray, Slocum, ASIS deployment/recovery. 5-6d for “active-phase” process study
Nominal tasks: Process cruise

**Pre-cruise:** Utilize remote sensing (Aquarius, MODIS, Indian platform, SAR), models (NRL, Harper?), Sagar Nadhi schedule, identify likely region of strong small-scale lateral gradients (far north international waters).

**Transit** (4 d) to ~17-18N, deploy autonomous assets:

1) Long-range gliders (Spray, Sea Glider)
2) “Vertical time-series” Slocum turbulence glider (~12 N, to be recovered end of leg II, approx. 28d deployment, Lou: thoughts?)

**Process study location** (8 d): uCTD survey (Revelle X-band?) to identify gradient of interest.

- Deploy Slocum turbulence
- Deploy ~5 Luca drifters (15m drogue)
- Deploy WW/spar array
- Deploy ASIS
- Commence uCTD sampling around array (10km box, nominal)
- Tend array, re-seed as necessary (~1d^-1)
- VMP ()
- Nested survey with Sagar Nidhi
- Recover ASIS

**Steam to port** (3d)
## Process cruise: Toolkit

**co-Chief Sci: D. Lucas and J. MacKinnon**

<table>
<thead>
<tr>
<th>name</th>
<th>variables</th>
<th>cast freq.</th>
<th>nominal depth</th>
<th>vertical res.</th>
<th>horiz res.</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>uCTD</td>
<td>S, T, P</td>
<td>10 min</td>
<td>200m</td>
<td>1m (??)</td>
<td>1 km</td>
<td>(at 3.2 knots, nominal)</td>
</tr>
<tr>
<td>WW 1</td>
<td>S, T, P, Fl, χ, dO2, PAR, u, v, w, $\zeta^z$</td>
<td>15 min</td>
<td>150m</td>
<td>10cm</td>
<td>2km</td>
<td>Line of sight real time data transmission. Horizontal res. and $\zeta^z$ refer to the vort. array.</td>
</tr>
<tr>
<td>WW 2</td>
<td>S, T, P, Fl, χ, u, v, w, $\zeta^z$</td>
<td>15 min</td>
<td>150m</td>
<td>10cm</td>
<td>2km</td>
<td>Horizontal res. and $\zeta^z$ refer to the vort. array</td>
</tr>
<tr>
<td>Spar buoy</td>
<td>T, u, v, w, $\zeta^z$</td>
<td>N/A</td>
<td>100m</td>
<td>1m (300 kHz), 0.25m (1200 kHz)</td>
<td>2km</td>
<td>1200 kHz upward looking ADCP deployed at 20m, 300 kHz upward looking deployed at 100m. Horizontal res. and $\zeta^z$ refer to the vort. array</td>
</tr>
<tr>
<td>Slocum glider (2x)</td>
<td>S, T, P, microstructure, ?</td>
<td>?</td>
<td>150m</td>
<td>&lt;1m</td>
<td>?</td>
<td>Need Lou’s input</td>
</tr>
<tr>
<td>Shipboard CTD/rosette</td>
<td>S, T, P, Fl, χ, dO2, nitrate (?), optical</td>
<td>Irregular</td>
<td>200m</td>
<td>&lt;0.5m</td>
<td>N/A</td>
<td>Irregular casts as needed for water sampling (dO2 calibration, nutrients, etc.)</td>
</tr>
<tr>
<td>HDSS</td>
<td>u, v, w</td>
<td>1 min</td>
<td>0-250 m</td>
<td>6 m 20 m</td>
<td>300m-1000m</td>
<td>Training WW unit for collaborators, students.</td>
</tr>
<tr>
<td>WW 3</td>
<td>T, P</td>
<td>N/A</td>
<td>30m</td>
<td>10cm</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>