

## Ocean Battlespace Sensing (OBS) S&T Department Annual Report

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### LONG-TERM GOALS

To understand the role played by the submesoscale and the internal wave fields in modulating the physical properties of the upper ocean. These results have direct impact on parameterizations used by numerical models of both the process and forecast type in the Bay of Bengal and elsewhere.

### OBJECTIVES

Our work for the ASIRI project is designed to:

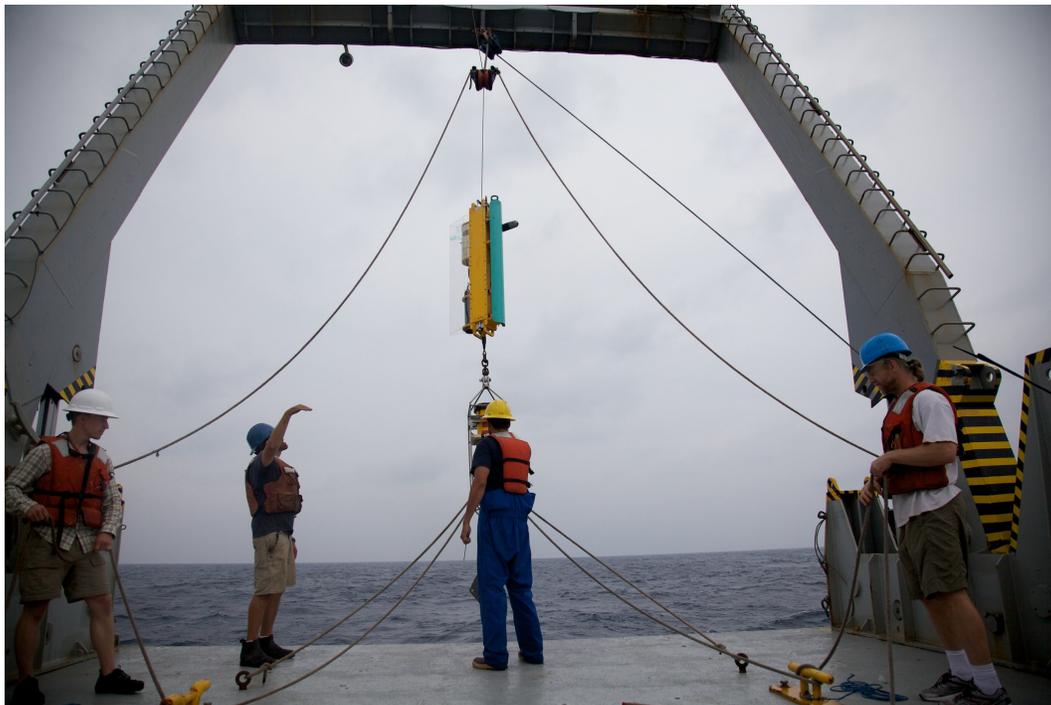
1. Provide *in situ* estimates of the evolution of the upper ocean dynamics from a set of free-drifting, rapid-profiling platforms.
2. Estimate *in situ* the vertical component of relative vorticity from a drifting array.
3. Examine the role of internal wave forcing and submesoscale dynamics on mixing and the heat budget of the Bay of Bengal mixed layer to improve numerical model parameterizations.
4. Foster scientific exchange and collaboration with Indian and Sri Lankan colleagues, including two-ship activities with the Indian vessel R/V Sagar Nidhi.

### APPROACH

We are contributing to a series of ship-based process experiments in the Bay of Bengal. In addition to participating in the leadership of the process cruises (Lucas was Chief Scientist on the Leg-1 Process Cruise in both 2013 and 2014) and the logistics of staging the Process legs in 2013 and 2014 (the

majority of gear in those studies was brought together and shipped to the Revelle through the Pinkel/Lucas lab at SIO), we have contributed the following assets:

- **Wirewalkers:** The Wirewalker wave-powered profiler (WW). WWs were deployed on leg-I of the fall 2013 and summer 2014 process cruises. WWs were equipped with CTD, current meters (courtesy of Emily Shroyer, OSU), optical and biological sensors (chlorophyll fluorescence, CDOM, optical back scatter, and in 2014 a hyper-spectral irradiance sensor), upward-looking 300 kHz ADCPs, and  $\chi$ -pods from Jonathan Nash (OSU) (Figure 1). The WWs were deployed in 3 unit clusters (on 150m wires, 2013 process cruise) or 4 unit clusters (on 100m wires, 2014 process cruise) for multi-day drifts.
- **Spar buoy:** To complement the WW array, we deployed a spar buoy on the 2013 process cruise with a densely instrumented vertical chain of temperature and conductivity temperature sensors, as well as two upward looking ADCPs (300 kHz and 1200 kHz). These observations complement the vertical resolution of the WW with temporal resolution in the high frequency internal wave band, which the WW does not fully resolve due to its 1 profile per 10-15 min repeat rate.



*Figure 1: Deployment of a WW outfitted with CTD, current meter,  $\chi$ -pod, optical instrumentation, and an upward looking ADCP from the A-frame of the R/V Roger Revelle during the June 2013 Process Cruise. Shown (left to right) are graduate student Ben Mater, Resident Technician Matt Durham, Chief Scientist Drew Lucas, and co-Chief Scientist Jonathan Nash.*

- **Near-surface ADCPs.** To supplement sonars permanently installed in the ship hull, two additional ADCPs were utilized during during process studies in 2013 and 2014. A 300-kHZ RDI ADCP was installed in an open well in the staging bay. This instrument was set to sample in 4-meter vertical bins with 1-second sampling. To acquire data even closer to the surface and additional ADCP was installed at the end of a pole mounted to the side of the ship. The instrument is a ‘Sentinel V’, a newly available instrument from RDI Teledyne

(<http://www.rdinstruments.com/followV.aspx>). The instrument pings at 500 kHz, and was configured to record data in 1-meter bins every 0.5 seconds. In order to avoid one of the beams hitting the ship hull, the instrument was mounted at a 15 degree angle to the vertical, pointing away from the ship.

## WORK COMPLETED

Our efforts have been part of the process cruises undertaken in the past year.

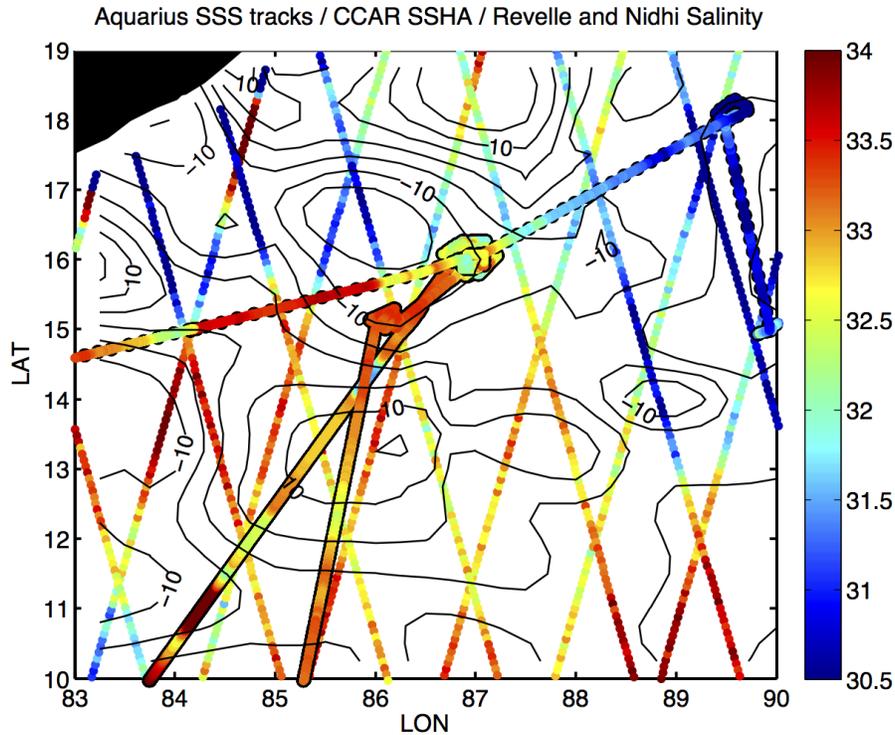
**November 2013** Leg-1 of the ASIRI Pilot cruise was primarily a small-scale (submesoscale) process study. Lucas was the Chief Scientist, with co-Chief Scientists Jen MacKinnon and Jonathan Nash rounding out the cruise leadership team. The general sampling strategy was to utilize the Revelle's extended shipboard sampling capabilities to sample small lateral scale features in the context of drifting profiling assets. This approach allowed for repeated horizontal surveys of evolving submesoscale features gathered concurrently with high resolution time series observations from the drifting instruments. These complementary approaches provide the detailed horizontal, vertical, and temporal resolution necessary to examine submesoscale dynamical variability *in situ*,

We utilized remote sensing products and real-time shipboard data, particularly from the flow-through system and the underway CTD (UCTD), to target general areas and then hone in on small-scale dynamics of interest. Based on the remote sensing information shared by our Indian colleagues, we conducted sampling activities centered around 2 locations: 15°N 86°E (14-16 November, 2013) and 16°N 87°E (17-23 November, 2013). Upon arrival at both locations, we conducted a preliminary survey utilizing the shipboard sampling and UCTD. We subsequently deployed 3 Wirewalker (WW) wave-powered profilers and a densely instrumented spar buoy. Once the drifting assets were deployed, we typically lowered our over-the-side 500 kHz ADCP and instrumented bow-chain, and resumed horizontal survey activities, utilizing the drifting array as an anchor for our drifting surveys. During deployments of the over-the-side pole and bow chain, our forward speed was limited to ~3 knots, leading to very fine spacing of UCTD casts during slow speed survey mode. We augmented these surveys with a series of sections and casts of a microstructure profiler (Rockland Scientific VMP-250) brought aboard and managed by Sri Lankan collaborators and Iossif Lozovatsky.

At the 16°N 87°E process study location, we were joined by R/V Sagar Nidhi for 3 days of two ship sampling effort. The Sagar Nidhi occupied a set of UCTD stations with a larger horizontal domain to enhance the spatial coverage of the dynamics of interest (Figure 2).

**June 2014** Leg 1 of the 2014 Air-Sea Interactions Research Initiative cruise in the Bay of Bengal left out of Chennai, India on 17 June 2014 (0730 UTC) and returned to the same port on 28 June 2014. Lucas and Shroyer were co-Chief Scientists. Sampling within India's exclusive economic zone was fully restricted, and a 20h commute to/from international water was required at the beginning and end of the cruise, yielding close to 9 days of dedicated science time. During that time we employed a variety of observational platforms to 1) map the large-scale (~ 100 km) physical context and 2) record the evolution of the upwind and downwind edges of a salty filament. Training of Indian and US students, which comprised a majority of the science crew, was one of the primary missions of the cruise (Figure 3).

The cruise was scheduled to sample during the early stages of the monsoon to contrast pilot work undertaken in winter 2013. Although precipitation during the cruise was minimal, oceanographic and forcing conditions differed significantly from those measured in the previous year providing a valuable point for comparison. The cruise consisted of two major components: 1) a large-scale rapid survey and 2) two smaller scale high-resolution surveys involving autonomous (Wirewalkers and Slocum-Turbulence glider) and shipboard assets. Specific objectives were based around the features apparent in Aquarius imagery, including the along-stream evolution of a salty filament advocated through a convergence zone between two mesoscale eddies. Analysis is ongoing.



**Figure 2: Underway salinity observations from the R/V Roger Revelle and R/V Sagar Nidhi two-ship activities during the November 2013 Process Cruise. Individual Aquarius tracks are shown for comparison.**

## RESULTS

Analysis is ongoing. Here we highlight two exciting results to date.

**Mixing and optical variability in submesoscale fronts from a quasi-Lagrangian perspective** WW profiling was very successful in both the 2013 and 2014 cruises. We gathered the *first concurrent, prolonged measurements of  $T$ ,  $S$ ,  $u$ ,  $v$ ,  $\chi$ , and optical characteristics from a quasi-Lagrangian perspective*. Although the Bay of Bengal is to first order Case-1 waters with very little optical variability related to biogeochemical processes, the results from this drift clearly indicated the important of small-scale fronts to the lateral and temporal variability of ocean color and potentially solar penetrative heating. As the WW drifted, rapid frontal slumping led to a rapidly deepening mixed



*Figure 3: Indian and US graduate students played a major role on both the 2013 and 2014 Process Cruises. SIO graduate student Caitlin Whalen (L) and Indian Institute of Technology, Bhubaneswar student Manita Chouksey (R) working on a Wirewalker wave-powered profiler.*

layer and elevated levels of heat diffusivity as calculated from the  $\chi$ -pod (J. Nash OSU). These observations are unique and will allow us to address important questions relating submesoscale variability and air-sea interactions.

**Assessing the variability of potential vorticity from shipboard surveys and concurrent drifting profiling vehicles.** A primary difficulty in the study of potential vorticity (PV) in the mixed layer is the spatial and temporal overlap between the internal wave field and the submesoscale. Unlike the internal wave field, which should not contribute to variability in PV, submesoscale variability induces rapid and small-scale changes in the PV field. Sampling the submesoscale is complicated by the non-synoptic nature of a shipboard survey relative to a propagating background internal wave field. In the case of the Bay of Bengal, an energetic internal tide, apparently generated at the Andaman Island arc, propagates through the basin and was apparent in all WW drifts. To this end, we have been collaborating with ASIRI PI Amit Tandon and ASIRI post-doc Sanjiv Ramachandran (UMass-Dartmouth). We have successfully implemented a plane-wave fit of M2 frequency and wavenumber to the WW data. The plane-wave can then be applied to the shipboard data, in effect "correcting" the observed density and velocity fields by removing the coherent M2 variability. Preliminary results (Figure 5) show that the strong lateral gradients observed by the shipboard survey **were not** driven by the internal tide.

## **IMPACT/APPLICATIONS**

The work completed in the past fiscal year will help to improve parameterizations of air-sea interactions in numerical models of the forecast and process type.

## **TRANSITIONS**

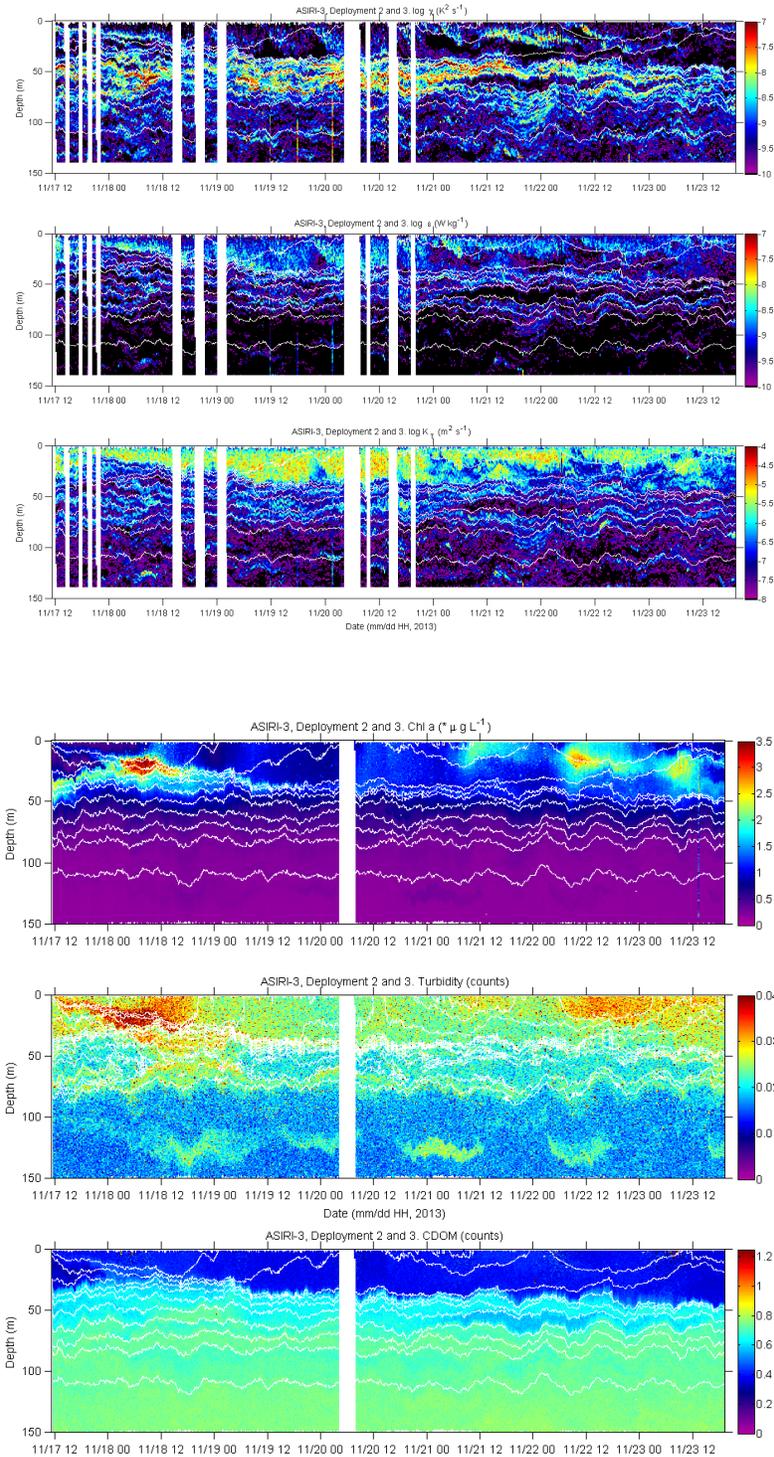
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## **RELATED PROJECTS**

In addition to the collaborations ongoing with other ASIRI PIs, the integration of the  $\chi$ -pod (Nash, OSU) and WW platform has broad applicability to the study of ocean mixing across a range of spatiotemporal scales. This integration work is directly applicable to future DRIs.

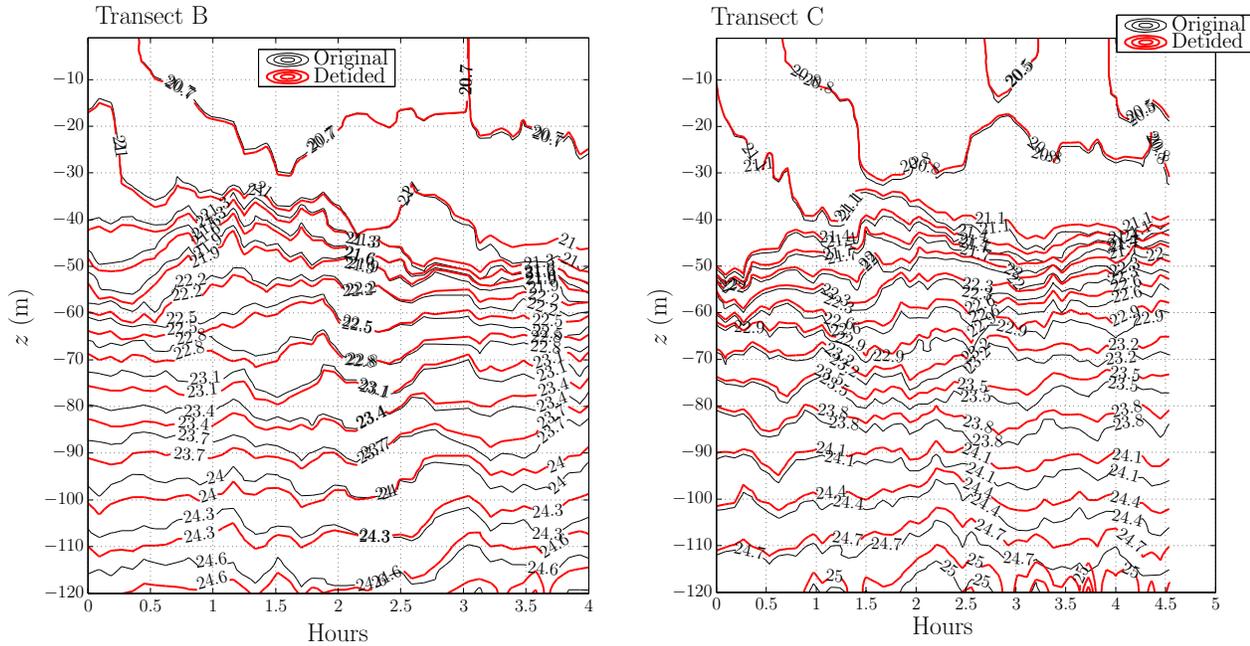
## **PUBLICATIONS**

Lucas, A. J., Shroyer, E. L., Wijesekera, H. W., Fernando, H. J. S., D'Asaro, E., Ravichandran, M., et al. (2014). Mixing to Monsoons: Air?Sea Interactions in the Bay of Bengal. *Eos, Transactions American Geophysical Union*, 95(30), 269270. doi:10.1002/2014EO300001



**Figure 4: Six days of along-drift variability in mixing and bio-optical quantities from the 2013 Process cruise WW-3, deployed at 16°N 87°E. Submesoscale lateral gradients evident in these data evolved rapidly, leading to small spatiotemporal scale variability in optical quantities and mixed layer characteristics. Both can be expected to influence air-sea interactions.**

## Removal of M2 signal using WW



The black lines show the unsmoothed density fields from the UCTD.

**Figure 5: The drifting WW array adds significant value to the shipboard sampling. In this case, a plane wave fit to the WW array data is used to remove the coherent M2 signal from the shipboard UCTD/hydrographic sonar survey. This procedure increases the confidence in the interpretation of the lateral gradients in the shipboard survey arising from submesoscale phenomena and not propagating mode-1 internal wave variability. This work is being carried out in collaboration with Amit Tandon and Sanjiv Ramachandran at UMass-Dartmouth.**