Cruise Report: ASIRI Pilot, Leg 2
November 27 – December 13, 2013
Bay of Bengal
Emily Shroyer and Amala Mahadevan

A. Background

The South Asian summer monsoon winds travel over the Bay of Bengal (BoB) bringing rain to a vast part of the Indian subcontinent. Approximately 1.5 billion people depend on the monsoons for their livelihood. Yet, the predictability of weather and climate of this region is poor. The monsoons are a strongly coupled phenomenon invoking both ocean and atmosphere, and relatively little attention has been devoted to understanding the role of the ocean, from which the atmosphere derives all of its moisture fluxes.

In the summer, sea surface temperature (SST) is high and winds from the south travel over the Bay of Bengal picking up moisture and heat, and forming clouds that deliver intense rain windward of the Himalayas. The summer monsoon responds strongly to the SST and air-sea fluxes in the Bay. Intra-seasonal oscillations in monsoonal rainfall are related to surface ocean temperatures. The large terrestrial runoff carried by the Ganges, Brahmaputra, and Irrawaddy rivers freshen the northern Bay of Bengal maximally in October –November (as seen from the Aquarius and SMOS satellite missions and from moorings) making the Bay of Bengal one of the freshest ocean basins. The East Indian Coastal Current (EICC) transports freshwater south and around the eastern side of Sri Lanka. In the winter, winds are seaward from the north and are relatively dry and cold. The cold, dry air coming off the Tibetan plateau cools the northern BoB (as seen in satellite SST products and moorings), but overturning is suppressed by the surface freshwater contribution to the density.

The strong, but seasonally reversed winds, the large seasonal freshwater runoff, and its landlocked configuration in the north, are factors that make the Bay of Bengal highly anomalous in many ways. The circulation of the BoB is known to undergo a seasonal reversal. Surface temperatures respond quickly to solar insolation and are much higher than the Arabian Sea. It is an oxygen minimum zone, due to being poorly ventilated. It has a shallow mixed layer overlying a highly stratified pycnocline with strong horizontal buoyancy gradients in surface waters. The marine mammal population is also thought to be diverse and unusual due to the lack of a northward migratory route.

ASIRI is motivated by wanting to gain a better understanding of the Bay of Bengal upper layer processes, air-sea interaction, freshwater dispersal and mixing, particularly as these topics relate to monsoon prediction. Characterizing the upper ocean structure (salinity and temperature), mixing, and lateral dispersal of the freshwater, response to solar insolation, and the faunal diversity are some of the specific goals that motivate this study.

B. Broader Scientific Objectives

1. Understand processes governing the initiation and intra-seasonal variability in the South Asian monsoon leading to improvement in medium range forecasting of monsoons.

2. Quantitatively understand upper-ocean/mixed-layer dynamics and vertical mixing, their role in the upper ocean heat budget, air-sea fluxes, summer/winter monsoons and intra-seasonal monsoonal variability.

3. Measure air-sea fluxes of heat, moisture and momentum, relate fluxes to ocean and atmospheric parameters, test and refine bulk parameterizations of fluxes, study feedbacks on surface temperature and mixed layer structure.

4. Examine the effect of submesoscale processes and mesoscale eddies on the lateral dispersal of freshwater within the BoB.

5. Measure mixing rates and relate these to stratification and surface fluxes. Test parameterizations currently used in large-scale models and make recommendations. Observe and identify the role of near-inertial waves mixing of thermocline, pycnocline and barrier layer.

6. Examine and quantify biophysical variability and bio-optical signatures, and the feedbacks on physics.

7. Observe the marine mammal populations.

C. ASIRI 2013 Leg 2 Cruise Objectives

1. *Complete a large-scale hydrographic survey of the BoB at high spatial resolution.*

The large-scale survey is motivated by our need 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). As part of the large-scale survey, we measured NS variability in atmospheric conditions, upper layer properties (T, S), bio-optical properties (including depth-dependent solar insolation and inherent optical properties), and vertical mixing,

2. *Conduct a short process study in the southern BoB for comparison with Leg 1 work.*

The overall goal of the process study was to characterize the processes occurring at small vertical and lateral scales that are ultimately responsible for mixing in a region of strong salinity gradients in a geographical and physical region distinct from those sampled in Leg 1.

3. *Provide a venue for training and exchange with Sri Lankan/Indian colleagues.*

4. *Conduct the first large-scale marine mammal survey in the BoB.*

D. Cruise Description

This cruise was the second in a series of three ASIRI-related cruises taking place onboard the R/V *Roger Revelle* in 2014. It followed the first leg of the pilot led by Andrew Lucas and Jennifer Mackinnon, and preceded the final leg led by Hemantha Wijesekera. We boarded the vessel in Colombo and disembarked the evening of November 27, 2013 (roughly 1800). All port arrangements were made by Maritime Agencies. A debriefing with Leg 1 scientists was conducted onboard the *Revelle* on the morning of the 27th. The first 36 hours were spent transiting the Sri Lankan EEZ, during which all data acquisition was suspended with the exception of the marine mammal surveying and the underway thermosalinograph (TSG).

Physical oceanographers were organized into three, eight-hour watches. Chief scientists, E. Shroyer and A. Mahadevan, stood 12-hour watches. Marine mammal observers organized their own shift, which spanned daylight hours (roughly 600-1800). Sean Whelen, Ben Hodges, and Sebastian Bigore, all from Woods Hole Oceanographic Institution, led the three UCTD/CTD shifts. Shawn Shellito (UNH) and Melissa Omand (WHOI) handled the bioptical /optical/nitrate profiling, the flow through system and some water sampling, in collaboration with Durga Rao and Rongali Viswanadham (CSIR-NIO) who carried out water sampling and analysis over an extended depth range. The CTD rosette was equipped with additional mixing and bio-optical sensors. A more complete description of data sampling follows below in Section E. A full list of cruise participants is given in Section F.

The large-scale survey commenced on 29 November 2013 0200 UTC with a CTD profile to 750 m, followed by UCTD profiling to 200 m at 11 knots. CTD stations were spaced at 20 nm (Figure D-1) with approximately 2 hours between stations and half an hour on station. Typically, water sampling occurred at every other CTD station. Initially UCTD profiling was sporadic (averaged between 4-8 profiles between CTD stations); however, as science crew became proficient in the technique, the second winch was used to increase the sampling rate by roughly a factor of 1.5 to 2. UCTD profiles were procured at a rate of approximately10 times per hour by the end of the cruise. Our cruising speed between stations remained between 10-12 knots, and we covered about 320-350 km per day for most of the large-scale survey. Our survey covered a total of roughly 3500 km. It included 81 CTD stations (86 profiles) and almost 1500 UCTD profiles (including the process study).

On our way north, we stopped to deploy the Slocum Glider equipped with a Rockland Scientific Microrider (T-glider) on 30 November 2013 0515 at 9 59.350' N, 86 29.803' E. The glider was recovered on 6 December 2013 at 11 04.479' N, 86 22.478' E. The recovery was earlier than originally planned due to the development of a tropical cyclone in the region.

We reached the northern extent of the large-scale survey on 2 December 2013 1900. Here, we performed the first process study. Underway TSG salinity and temperature were used to identify the front (Figure D-2). This first effort tested our ability to track a persistent feature over several hours. We primarily used the UCTD in underway mode, although we switched to a tow-yow mode for a short period of time. We identified and repeatedly surveyed a fresh anomaly in the vicinity of 17 25’ N, 89 15’ E. The feature was tracked for roughly 24 hours. Afterwards, we headed south-southwest along the border of the Indian EEZ continuing our large-scale survey. During this time a low-pressure center continued to develop into a tropical cyclone in the central-west BoB. Once reaching 13 N, we decided to quickly head to the Slocum T-Glider and attempt a recovery before weather conditions worsened. UCTD sampling was maintained in transit to the glider; however, due to poor weather conditions the sampling rate was decreased to once every 30 minutes.

After the recovery of the T-glider, we continued in a southeast direction to the eastern side of international waters. A second feature for a process study was identified on 7 December 2013 0900 in the vicinity of 9 20’ N, 88 50’ E. In contrast to earlier work, this feature was a salty filament in a relatively fresh area. This feature was tracked for roughly 48 hours before its signature was lost. We completed the large-scale survey by heading west-southwest back towards the Sri Lankan EEZ. Once in the vicinity of Sri Lanka we continued with deep CTD casts (750 m), until needing to cut off sampling to return to port on 11 December 1200. We returned to Colombo at 0800 on the morning of December 13. Offload was completed by 2000 that same day.

In the coarse of the large-scale survey, five drifters were released. Release positions and times are given in Table D-1.

Table D-1: Time and position of drifter deployments.

Day-Time	Latitude	Longitude	Number
20131203 1009	17 19.679N	89 20.407E	Drifter 116180
20131203 1339	17 32.345N	89 05.407E	Drifter 116178
20131203 2358	16 54.034N	88 22.681E	Drifter 116173
20131204 1145	15 47.224N	87 04.104E	Drifter 116183
20131204 1613	15 22.670N	86 35.210E	Drifter 116179

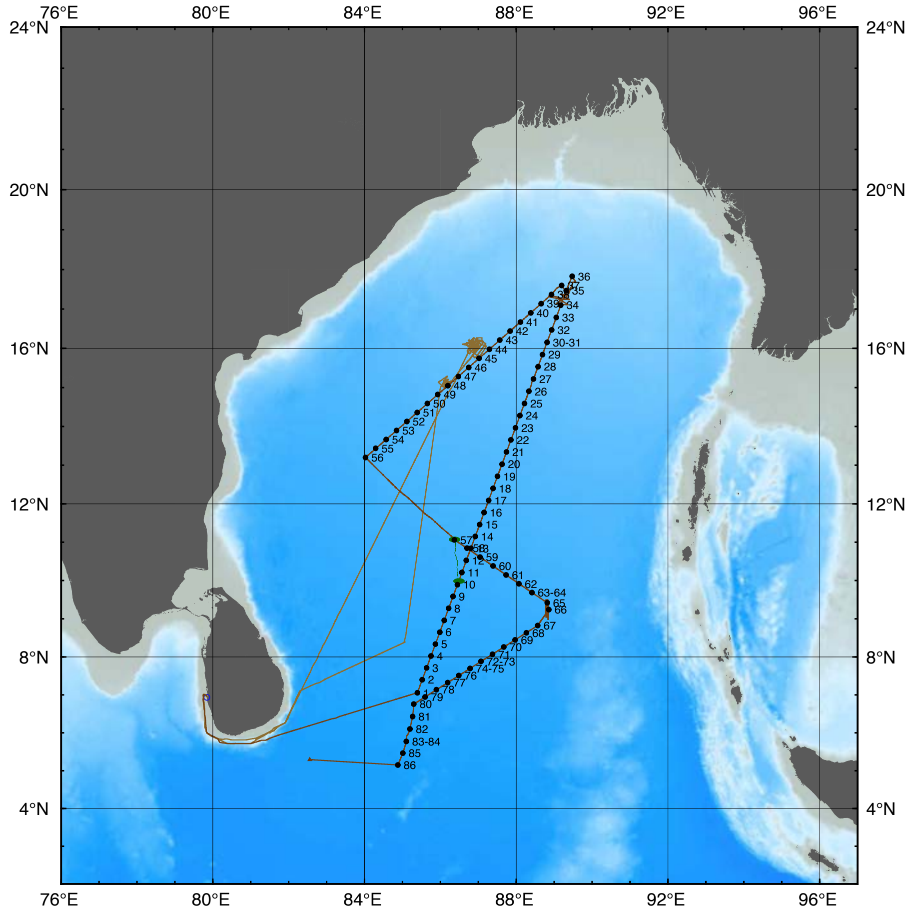

Figure D-1: Map showing cruise track for Leg 2 (black) with CTD stations. Cruise path for Leg 1 is shown in red. Figure courtesy Phil Mele.

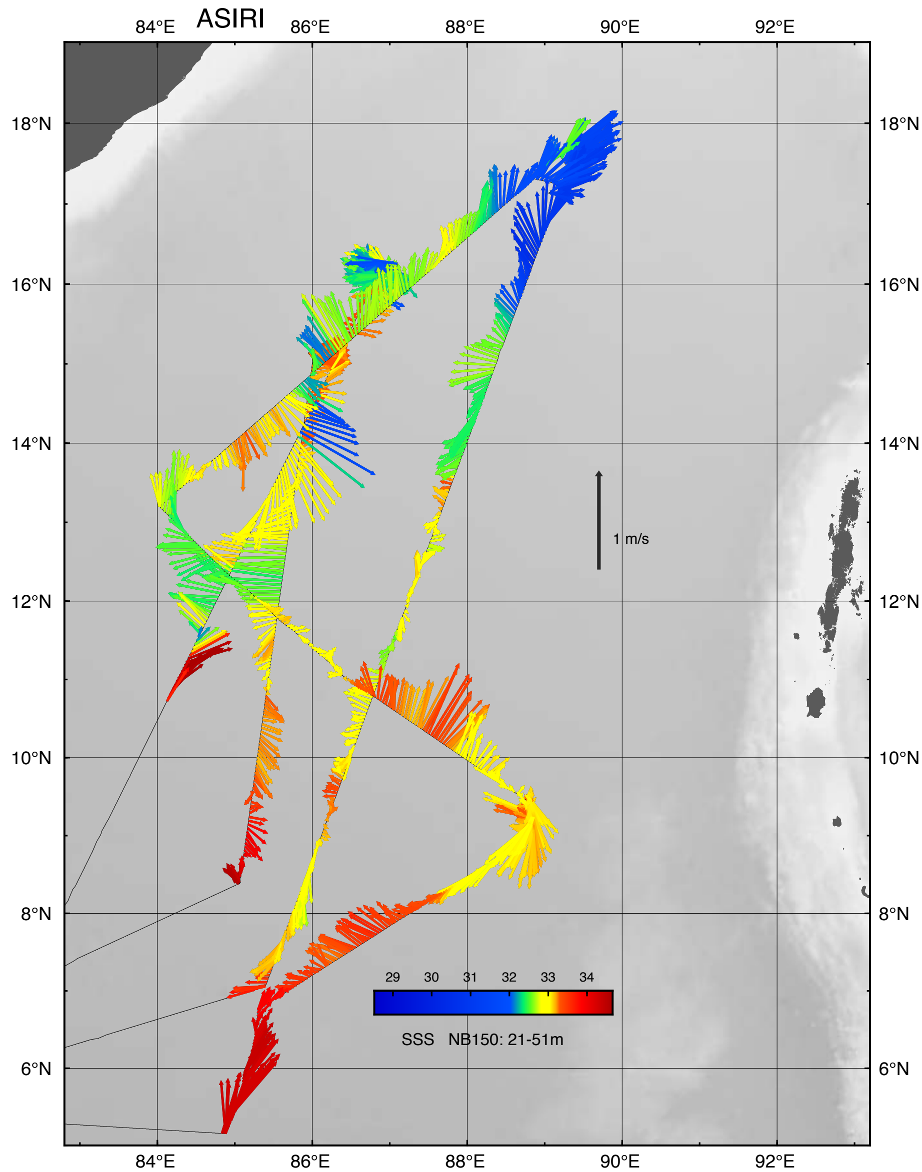

Figure D-2: Cruise paths for Leg 1 and 2 with vectors showing the depth-average velocity (between 21 to 51 m) and colors indicating SSS from the TSG. Figure courtesy Phil Mele.

E. Sampling Resources

We used the following scientific equipment: Revelle underway systems, including met sensors, Doppler sonar, HDSS, and TSG, underway CTD (UCTD), Revelle CTD equipped with Chipod (temperature variance measurement) and inherent/apparent optical sensors, expendable surface drifters, additional hull- and side-mounted acoustic Doppler profilers, and a Slocum glider equipped with turbulence sensors (T-glider). In addition to these resources, visual sightings formed the basis for a marine mammal survey of the region.

(E1) Underway CTD (UCTD) and CTD

Underway and CTD systems were used throughout the cruise. A summary plot detailing the full observation period is shown in Figure E-1. UCTD modes of profiling switched between underway (ship steaming at 10-12 knots), in which probes were pre-wound prior to each profile, and tow-yow (ship moving at ~4-5 knots), in which the profiler was deployed and remained in the water over roughly a four hour period before recovery and download of data. The probe quality was continually checked against TSG data and with CTD profiles. When probe sensors began to drift or show non-constant offsets (typically in the conductivity measurement), probes were retired. The termination on the UCTD line was continually checked, and the line was re-terminated upon signs of wear. During Leg 2, we lost one UCTD probe when the line broke.

UCTD probes were timed to fall to depths slightly exceeding 200 m before recovery of the profile when in underway mode. To increase horizontal resolution and prevent excessive straining of winches, profiles were limited to 150 m when in tow-yow mode. We primarily used an RBR CTD for the tow-yow mode rather than the traditional UCTD probes. The RBR had a few advantages: 1) allowed for addition of fast thermistor and small radiometer and 2) data downloaded in a matter of seconds rather than 10s of minutes.

CTD stations were occupied for roughly 30 minutes to one hour depending on depth and water sampling. Shallow profiles, which occupied the bulk of stations, were terminated at ~200 m, which we deemed appropriate for resolving surface waters. Deep profiles (to ~750 m) were made at the southern and northern extents of the survey line, as well as near the end of the cruise as we sampled along the border of the Sri Lankan EEZ. Optical sensors were depth rated to 250 m, so these sensors were removed for deep profiles. Turbulence sensors (rated to 6000 m) remained on the CTD cage throughout. Water sampling occurred on every other profile (see details below).

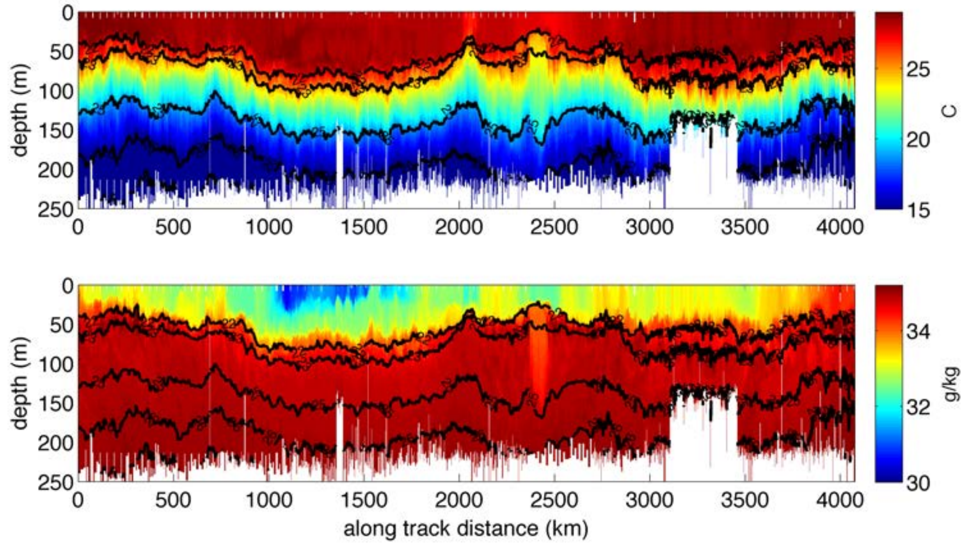

Figure E-1: Profiles of temperature and salinity from combined UCTD and CTD data. Isopycnals contoured on top of temperature and salinity. Figure courtesy of Amy Waterhouse.

(E2) TSG and Met Sensors

TSG (Figure E-2) and met sensors (Figure E-3) were operated throughout the cruise. The precipitation sensor was replaced prior to Leg 2 and seemingly worked throughout our leg. The fluorometer appeared to be returning faulty values for the first half of the cruise; it was cleaned and replaced on 6 December 2013 at 1130 (Figure E-2). Data acquired after this time may be useful; an independent measurement of fluorescence was maintained by UNH on the intake (see details below in Optical Sensors).

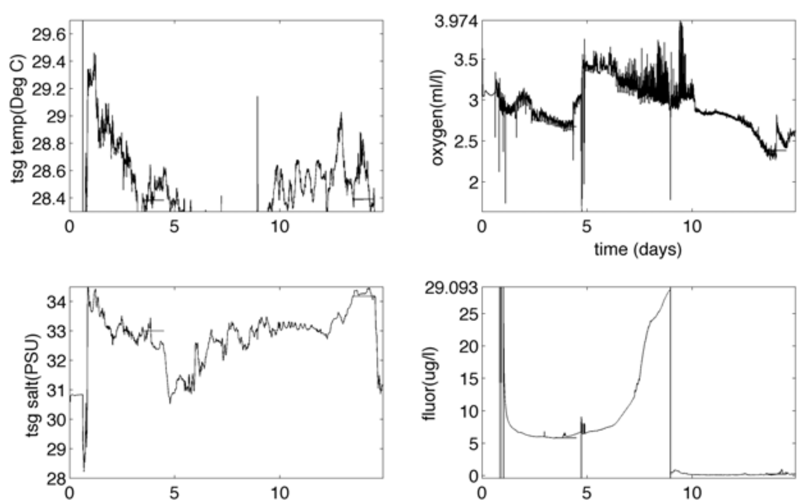

Figure E-2: TSG temperature, salinity, oxygen, and fluorescence.

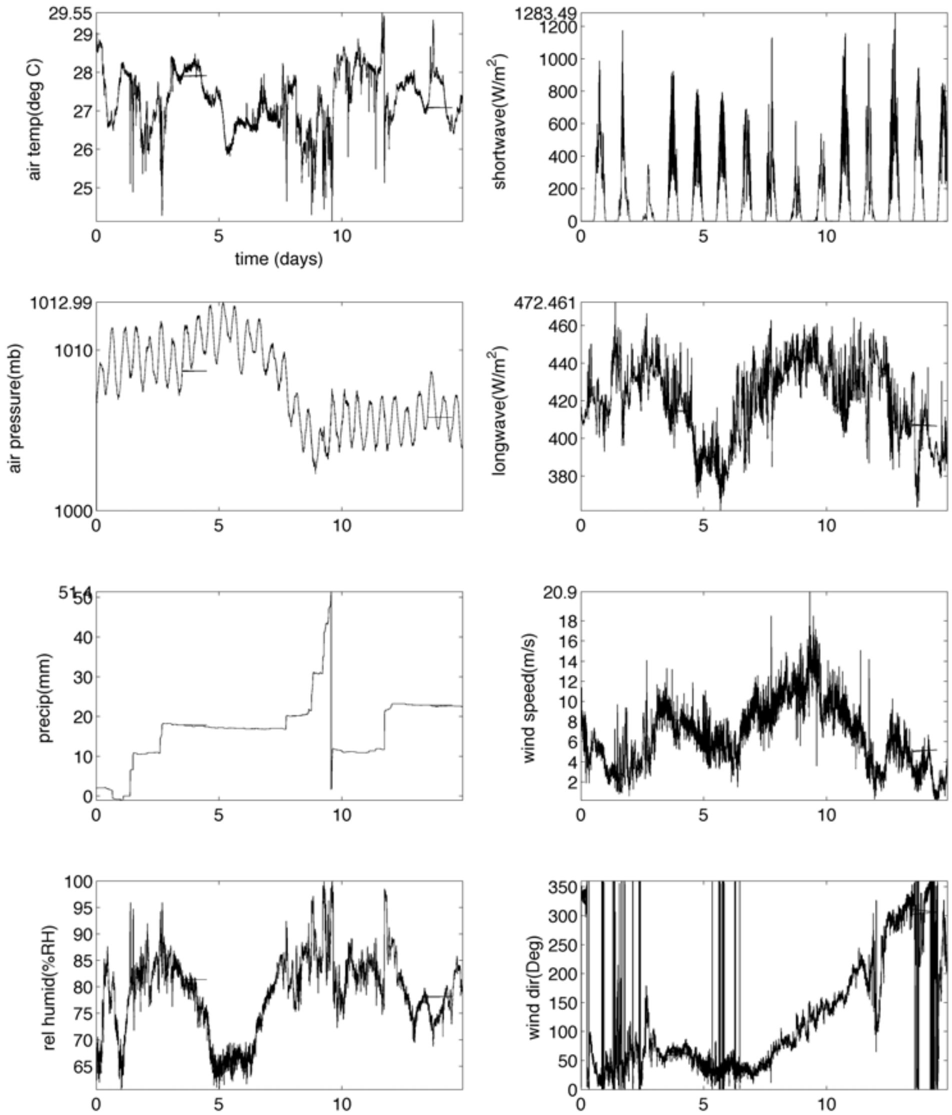

Figure E-3: Fields from meteorological sensors maintained by the *Revelle*.

(E3) Doppler Sonars

Five Doppler sonars were used during the pilot. The *Revelle* maintains three of these units: the HDSS (140 and 50 kHz; Figure E-4 shows data from the140 kHz.), a 75 kHz ADCP, and a 150-kHz ADCP (Figure E-5). In addition, a hull-mounted 300 kHz ADCP was operated throughout, allowing for closer resolution to the surface. The hull-mounted system was configured to sample as rapidly as possible (~1 Hz) in 2 m bins. Its vertical range extended to roughly 100 m. During the second process study, a side-mounted, five beam Sentinel V from RDI Teledyne (500 kHz) was deployed via a boom off the port side of the ship. This side-mounted system could only be maintained at slow (4-5 knot) transit speeds, and was configured to sample in 1 m bins at 2 Hz. The instrument was mounted at a 15-degree angle pointed away from the hull of the ship.

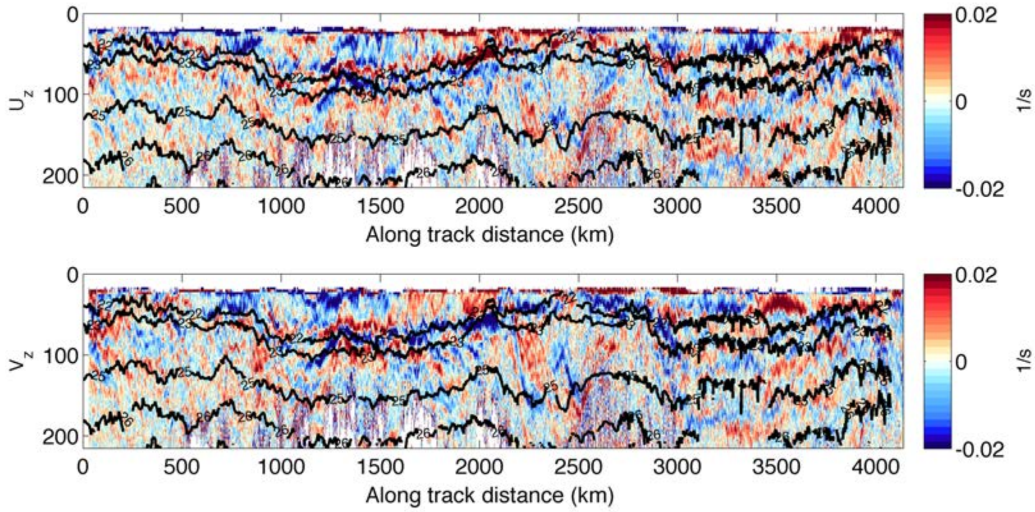

Figure E-4: Summary plot showing shear, calculated from HDSS data, as a function of depth and distance (km). Figure courtesy Amy Waterhouse.

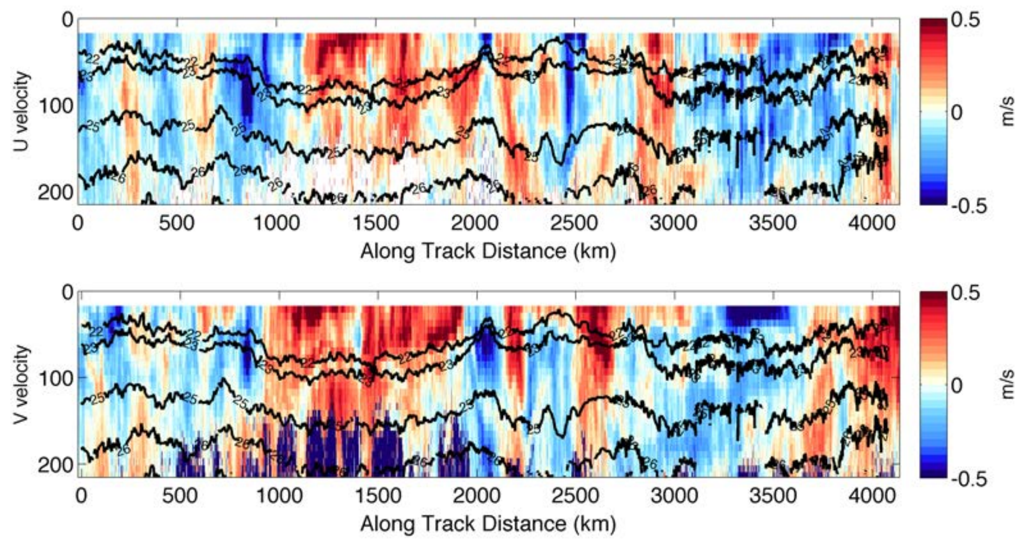

Figure E-5: Summary plot showing ADCP velocity (E-W upper panel and N-S lower panel) from the 150 kHz unit. Figure courtesy Amy Waterhouse.

(E4) Optical Sensors

Contributed by Melissa Omand (WHOI)

Apparent Optical Properties (AOPs): AOPs are properties of the ambient light and will be used to evaluate the depth- and time- dependence of the radiant heating rate. They complement the inherent optical properties (IOPs) measured. Hyperspectral radiometer (TriOS) and photosynthetically active radiation (PAR) quantum sensors (JFE Advantech) were mounted to the CTD-rosette and to minimally shaded sections of the deck. These measured the downwelling (cosine) solar irradiance over 256 visible, UV and infrared wavelengths spanning from 320 to 950 nm (Figure E-6). This data will allow us to estimate the attenuation of solar energy with depth and above water, since the energy depends on the light intensity and wavelength. The PAR sensors integrated photons between 400 and 700 nm; roughly the range over which light is available for photosynthesis. These sensors are smaller, cheaper and less power demanding than the radiometers, and comparison between the results from the two sensors will be useful to evaluate PAR's usefulness as a proxy for the radiometric observations.

Overall, we obtained 20 days of continuous above-water hyperspectral irradiance, and 17 days of above water PAR. With the CTD-rosette we gathered 67 hyperspectral irradiance, and 69 PAR water column profiles (to 210 m). For one day during the second process study, the PAR sensor was mounted to the tow-yo-ed uCTD. On this day, we obtained an additional 50 rapid profiles of PAR.

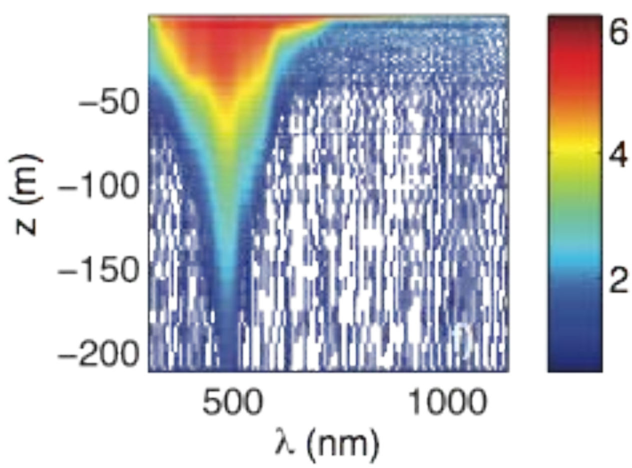

Figure E-6: An example from cast #2 of downwelling irradiance as a function of depth and wavelength.

Inherent Optical Properties (IOPs): A bioptical package provided by UNH (Joe Salisbury) was deployed and maintained on the CTD-rosette by Shawn Shellito. This package was equipped with an ac-spectrophotometer (measuring hyperspectral absorption and attenuation, WET Labs), and a BB-9 (measuring backscatter at 9 wavelengths, WET Labs). The package was also equipped with a pumped CTD (Seabird), O2 sensor (Seabird), chlorophyll and CDOM fluorometers (WET Labs). On three occasions spaced throughout the cruise, profiles were repeated with a nominal 60 um filter that will allow us to separate the absorption by particulates and dissolved material.

Submersible Ultraviolet Nitrate Analyzer (SUNA): An optical nitrate analyzer was mounted to the CTD-rosette, and 69 profiles of pre-QCed nitrate concentration were obtained. The SUNA estimates the nitrate concentration empirically from the attenuation spectral of UV light. The sensor is sensitive to colored dissolved organic matter (CDOM) and was tested extensively by WHOI undergraduate intern Lenna Quackenbush prior to the cruise. Bottle-sampled nitrate collected by NIO scientists indicate a reasonable performance by the SUNA in estimating the nitrate profile (Figure E-7).

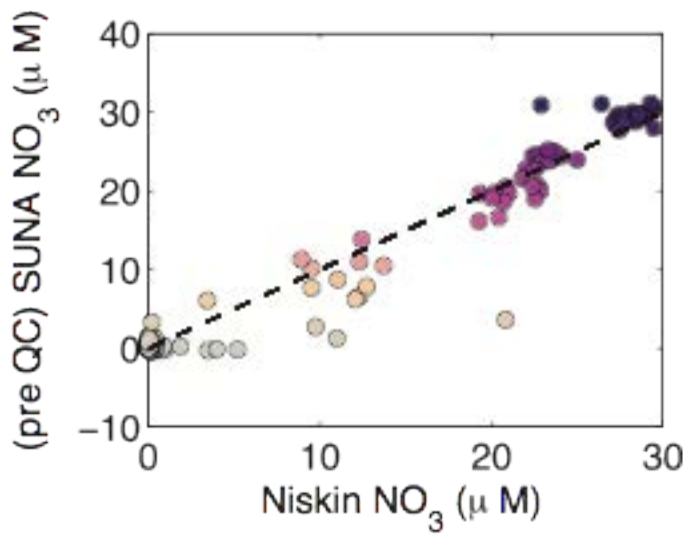

Figure E-7: Comparison of the SUNA-measured nitrate over all casts and depths, where the sensor was co-located with Niskin bottle sampled nitrate. The dashed line shows the one-to-one line.

Flow-through system: A flow-through system (LiCOR), provided by UNH (Joe Salisbury) and operated by Shawn Shellito, continuously measured near-surface pCO2, chlorophyll fluorescence, and O2.

(E5) Turbulence Sensors

Two chipods with microstructure temperature sensors were maintained on the CTD throughout the experiment. Chipods sample temperature at 10 Hz and temperature gradient at 100 Hz. The first system has a full-depth rated pressure case containing the electronics and batteries for the system and support two FP07 sensors. The second system was rated to 750-m and supported one thermistor; it was added to the CTD cage for redundancy. FP07 thermistors are attached to pressure cases via umbilical cables, so that thermistors can be mounted to the extremities of the CTD cage. Sensors were attached to poles secured to the CTD cage. In total, three thermistors were mounted (Figure E-8), two upward looking and one downward looking. Sensors were checked periodically for damage and replaced when needed (only once). A fast thermistor was also mounted to the RBR CTD, which was used for sampling during the second process study (see description below).

In addition to shipboard profiles, a Slocum glider equipped with a full turbulence suite (Rockland Scientific Microrider) was operated by Lou St. Laurent, WHOI. The glider was deployed on 30 November 2013 and recovered on 6 December 2013. The glider ran a northeastward transect between 9 59.350' N, 86 29.803' E and 11 04.479' N, 86 22.478' E. A second glider was kept in reserve, but not deployed due to the cyclone activity in the BoB. Sean Whelan led the small boat operation to deploy and recover the T-glider. These turbulence data should provide an uncontaminated view of near surface waters.

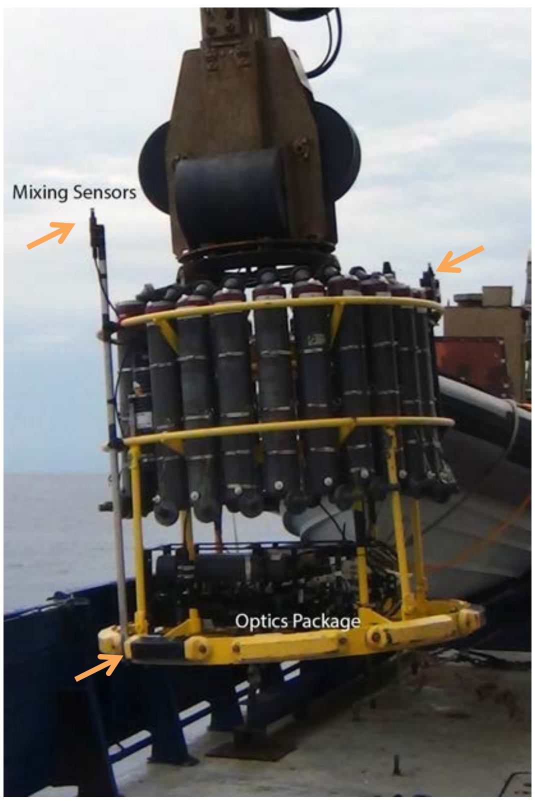

Figure E-8: CTD cage with optic (lower package) and mixing sensors (probes attached to pipes at upper left under label, lower left, and upper right)

(E6) Water Sampling

Contributed by Viswanathan and G. Durgarao (NIO, Visakapatnam)

Water was collected by scientists M. Omand (WHOI), S. Shellito (UNH), R.

Viswanathan and G. Durgarao (NIO, Visakapatnam) with Niskin bottles fired during the upcast of the CTD-rosette profiles. The two groups (NIO and WHOI/UNH) cooperated in their efforts, with slightly differing collection schemes and objectives.

NIO Vizag scientists: Water samples were collected from ~ 7 predetermined depths (near surface, 5m, 10 m, 25 m, 50 m, 100 m, 200 m depth) for analysis from 33 stations (roughly every other station) along the survey cruise track. Parameters analyzed included pH, Alkalinity, Nutrients, N2O, CH4, DIC, DMS, DOC, Particulate Organic Carbon (POC), Total Chlorophyll, HPLC pigments, and Primary Productivity (Figure E-9).

WHOI/UNH: Water samples were collected from 3 or 4 depths adaptively based on the downcast profiles. The target depths were generally: near-surface, at the base of the mixed layer (ML), within the thermocline (roughly 10 m below the ML) and at the deep Chl fluorescence maximum. Parameters for analysis included HPLC pigments, particulate organic carbon (POC), dissolved organic carbon (DOC), CDOM, dissolved inorganic carbon (DIC), pH, Alkalinity and phytoplankton taxa.

Figure E-9: Nutrients being analyzed by Viswa from water samples (left). Durgarao performing filtration for analysis of chlorophyll, POC, and HPLC pigments (right).

(E7)   Marine Mammal Survey

Contributed Mark Baumgartner (WHOI) and Kate Stafford (UW APL)

Objectives: Our primary objective for the cruise was to conduct a sighting survey for cetaceans in the oceanic waters of the Bay of Bengal while our ASIRI project partners simultaneously collected observations of physical and biological oceanographic conditions. Our secondary objective was to train Sri Lankan and Indian scientists in visual survey methodology and the accurate identification of oceanic cetaceans.

Methods:
Visual survey: Eight observers collected visual observations by rotating through 4 positions every half hour. Observers stationed at the port and starboard positions used

25×150 mounted “big-eye” binoculars, while an observer at the center station viewed the area near the ship with naked eyes and 7×50 handheld binoculars. An independent observer (the fourth position) also viewed the area near the ship with naked eyes and 7×50 handheld binoculars to verify all species identifications and to report any sightings missed by the three primary observers. The sighting team consisted of 2 expert observers (Suzanne Yin and Ernesto Vázquez), 2 very experienced observers (Kate Stafford and Mark Baumgartner), and 4 novices (Indian observers Ajith Kumar and Divya Panicker, and Sri Lankan observers Upul Liyange and Ishara Rathnasuriya). The center observer recorded weather conditions, visibility, and sighting data using the computer software *Wincruz* (http://swfsc.noaa.gov/uploadedFiles/Divisions/PRD/WinCruz.pdf). Standard survey effort consisted of active searching in sea conditions of Beaufort 5 or less while the ship was steaming at speeds of 8 knots or greater. Non-standard effort was conducted during small-scale surveys and process studies conducted by the physical oceanography team. No sighting effort was conducted while the ship was stopped at an oceanographic station. All survey effort was conducted in passing mode, so the ship was never diverted to identify species or estimate group sizes.

Training: The experienced observers (Yin, Vázquez, Stafford, and Baumgartner) provided extensive training to the novice observers (Kumar, Panicker, Liyange, and Rathnasuriya) in survey methodology, the use of both the big-eye binoculars and *Wincruz* software, and species identification while actively surveying and during regular evening meetings throughout the cruise.

F. Sampling Strategies

The cruise consisted of multiple operational modes: a large-scale rapid surveying component and two small-scale high-resolution surveys of frontal features.

(F1) Large-scale Survey

The large-scale survey was divided into four legs with the following waypoints: 7^o 2.966′ N, 85^o 23.52′ E; 17^o 49.42′ N, 89^o 28.28′ E; 13^o 12.82′ N, 84^o 1.494′ E; 9^o 24.01′ N, 88^o 51.42′ E; 6^o 45.73′ N, 85^o 17.88′ E. Summary plots showing temperature, salinity, and velocity for these four legs are shown in Figures F-1 through F-3. The standard sampling configuration consisted of CTD stations spaced every 20 nautical miles with UCTD operations being carried out continuously between stations. We ceased CTD operations from 1100 December 5, 2013 to 1600 December 6, 2013 due to inclement weather. During this time period, the frequency of UCTD profiles was reduced to roughly once per 0.5 hours.

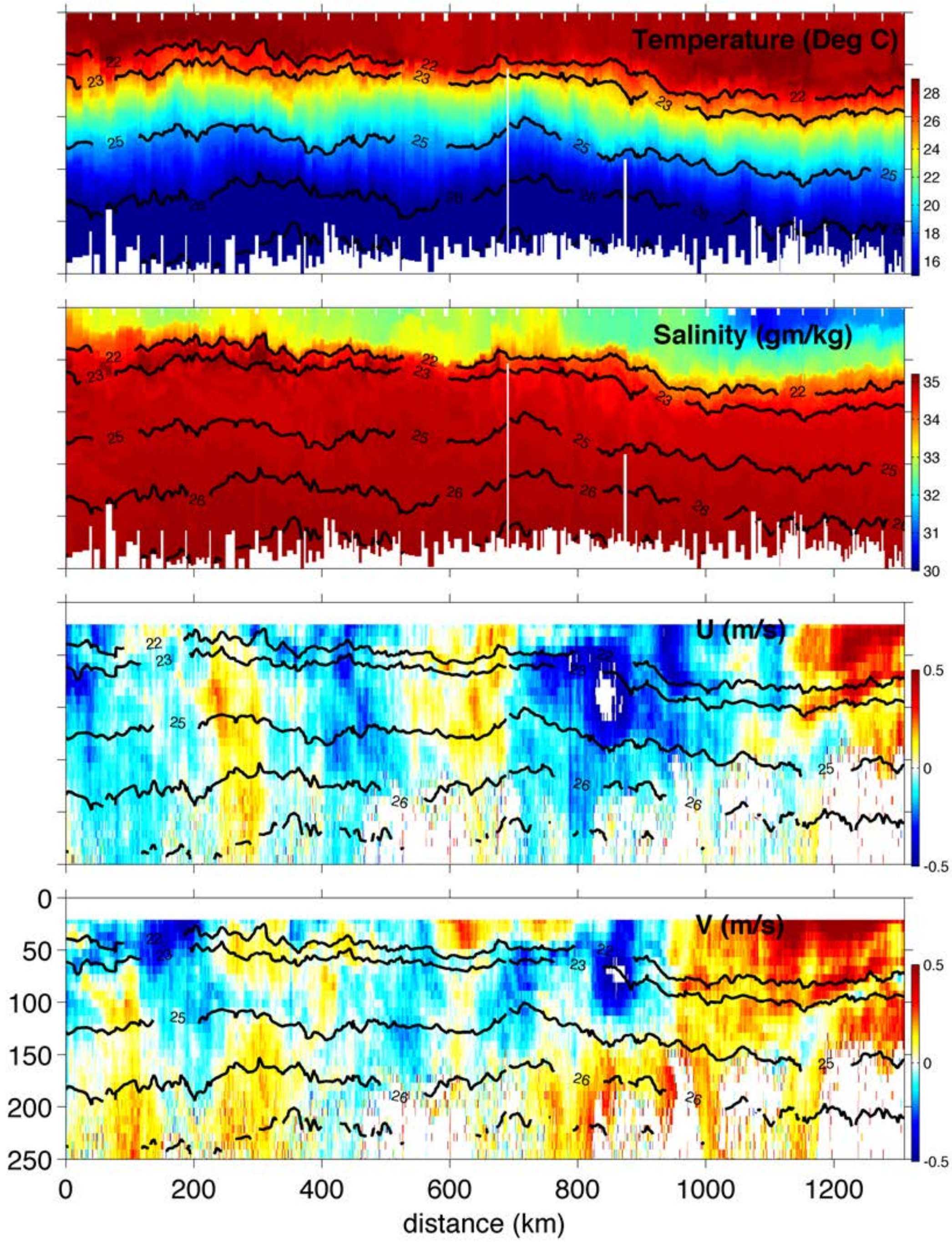

Figure F-1: Temperature, salinity, E-W, and N-S velocity along the northbound transect.

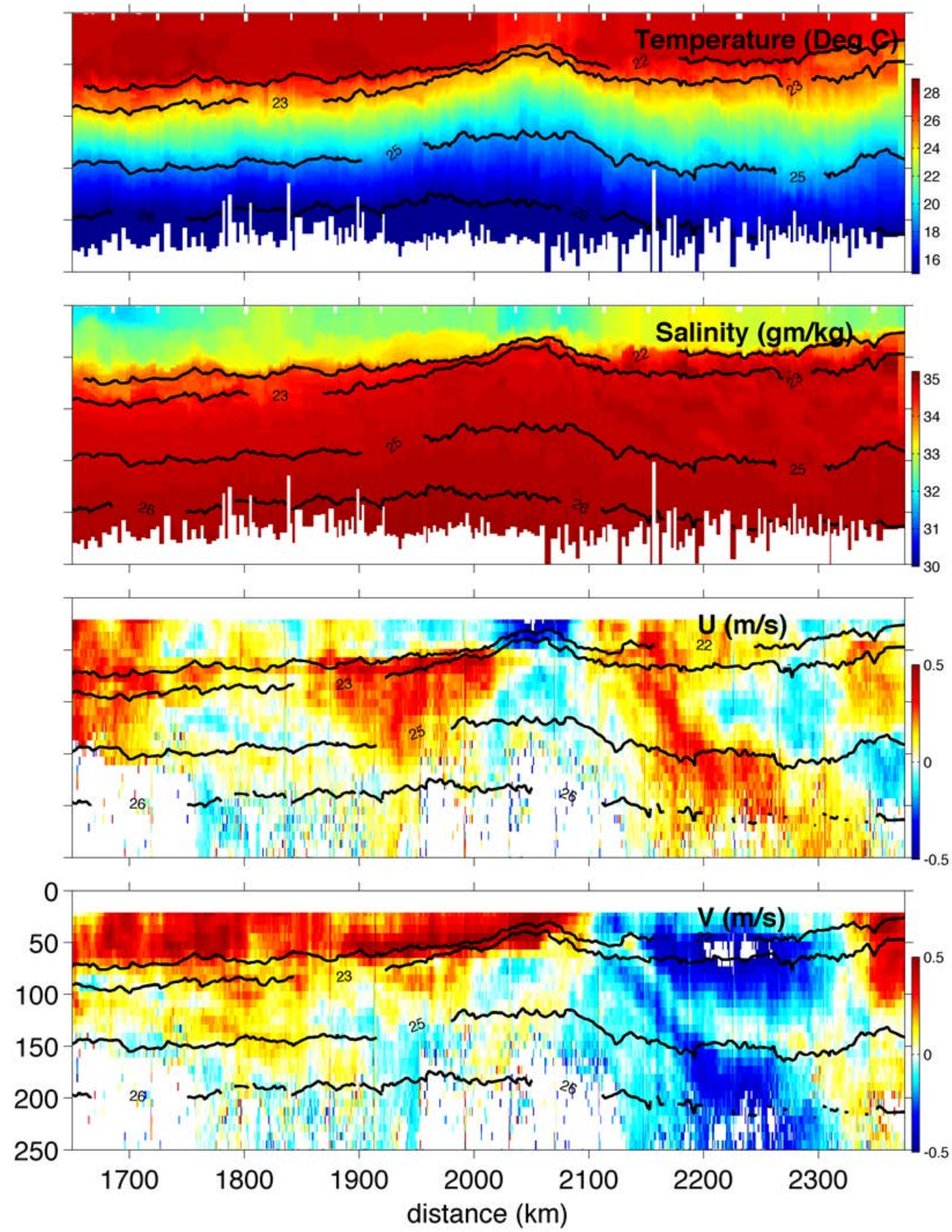

Figure F-2: Same as F-2 except plotted for southwest transect.

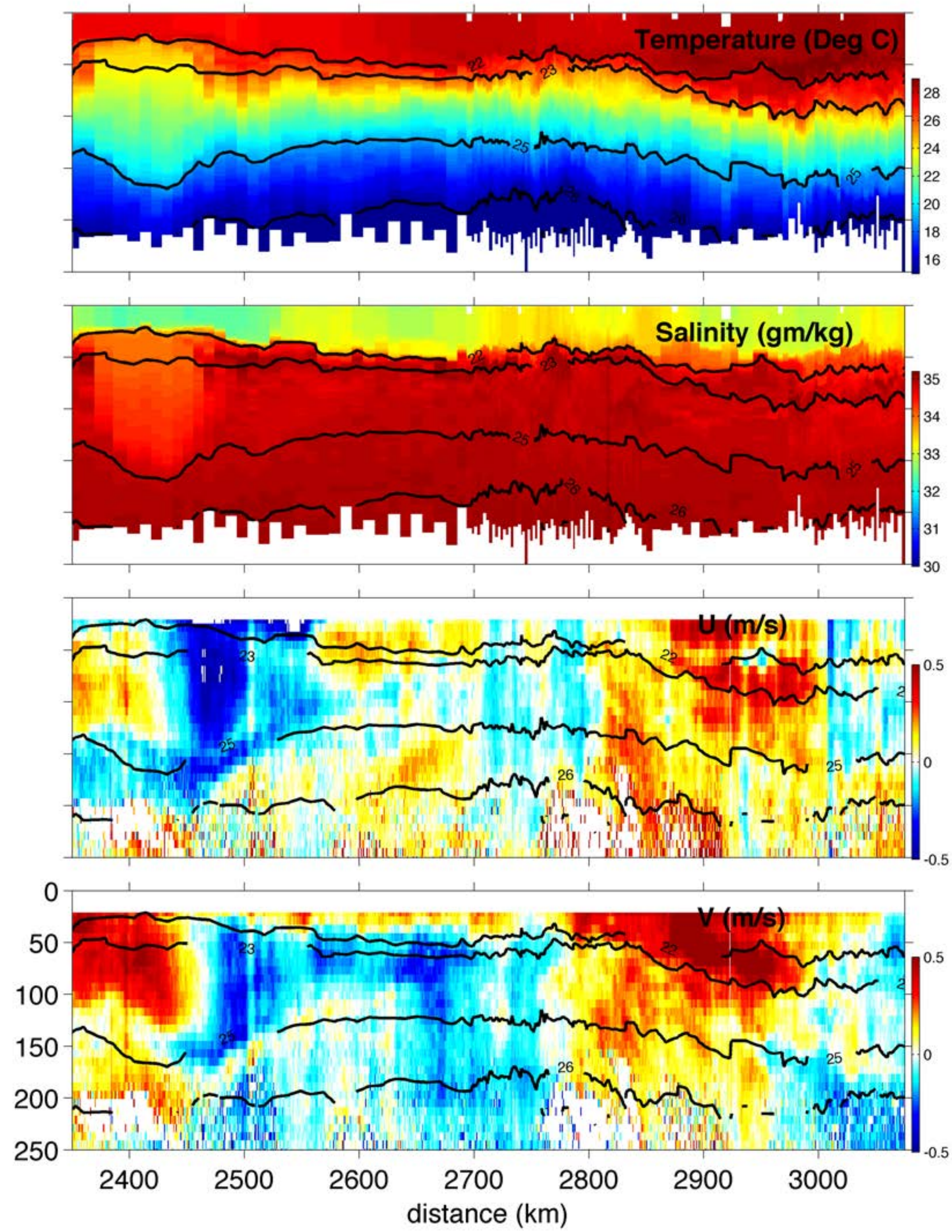

Figure F-3: Same as F-1 except plotted for southeast transect.

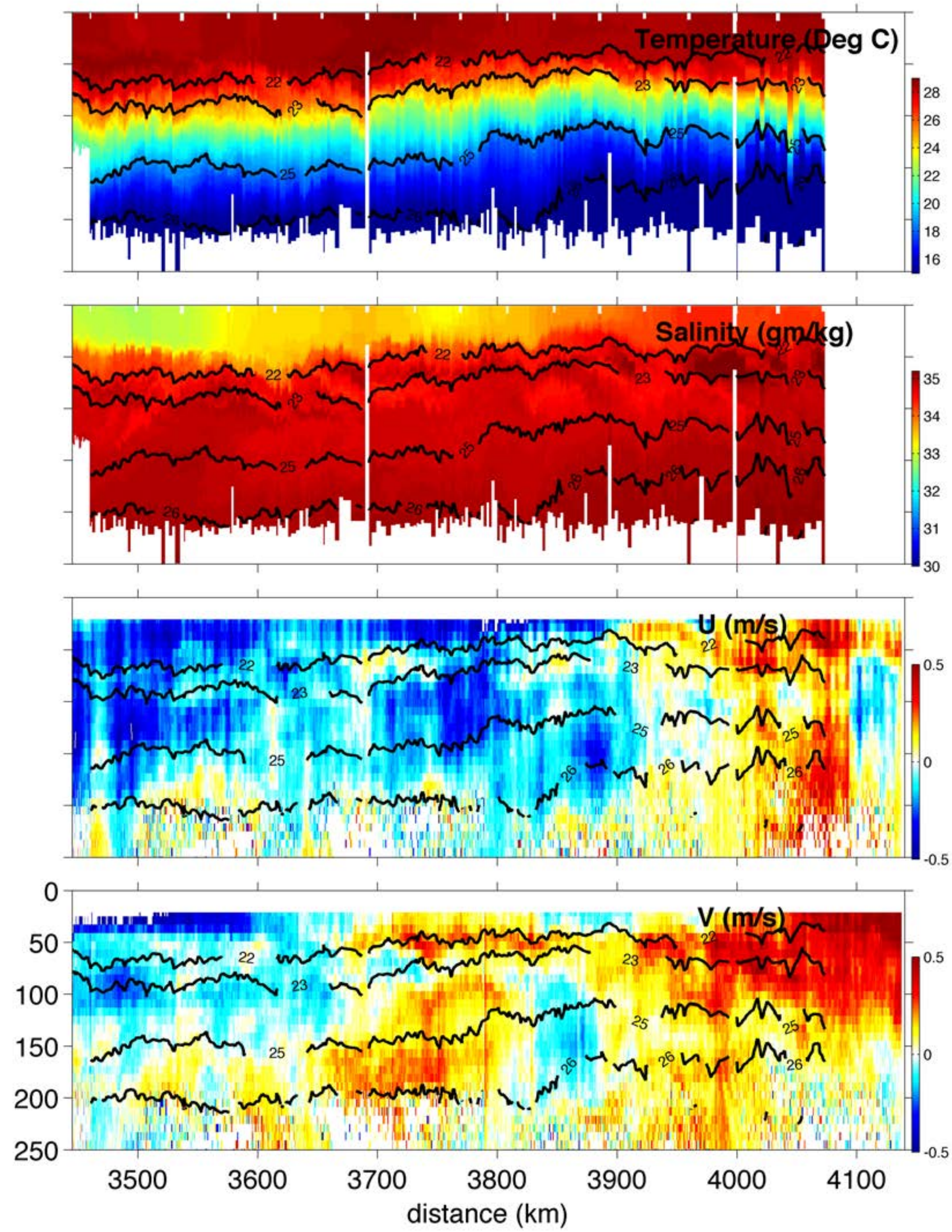

Figure F-4: Same as Figure F-1 except plotted for westward return transect.

(F2) Process Studies

We conducted two higher resolution surveys.

a) *Freshwater Front*- The first survey delineated a front between warm, fresh water and cool, salty water (Figure F-5), toward the northern end of our large-scale north-south transect (between 17.1 and 17.4 N). We conducted this survey rapidly, without slowing the ship, and traced out a frontal feature with a zigzag pattern conducted in about 12-15 hours.

b) *Warm Filament* -The second process study was conducted in the southeast portion of the large-scale survey (after we took refuge from the developing cyclone) and detailed a salty feature in relatively fresh surroundings (Figure F-6). For this survey, we slowed the ship to about 4-5 knots, and profiled in tow-yow mode to obtain profiles at a horizontal resolution of approximately 1 km. On each north-south transect we were able to pass completely through the feature – a salty and slightly cool, filament within the mixed layer of approximately 40 m depth. Interestingly opposing sides of the filament showed variable temperature structure (Figure F-7). Warmer water was seen beneath the mixed layer. The filament was likely to have been advected northward with time, as later transects found it in a more northerly position. The salinity contrast within the filament weakened with time and was minimal in later transects. We terminated the survey when the density contrast within the filament became very faint, suggesting that the filament was dissipated during the time that we surveyed it. The side-mounted ADCP was deployed for this survey, and profiles were procured to a depth of approximately 150 m. There were no CTD stations during the survey.

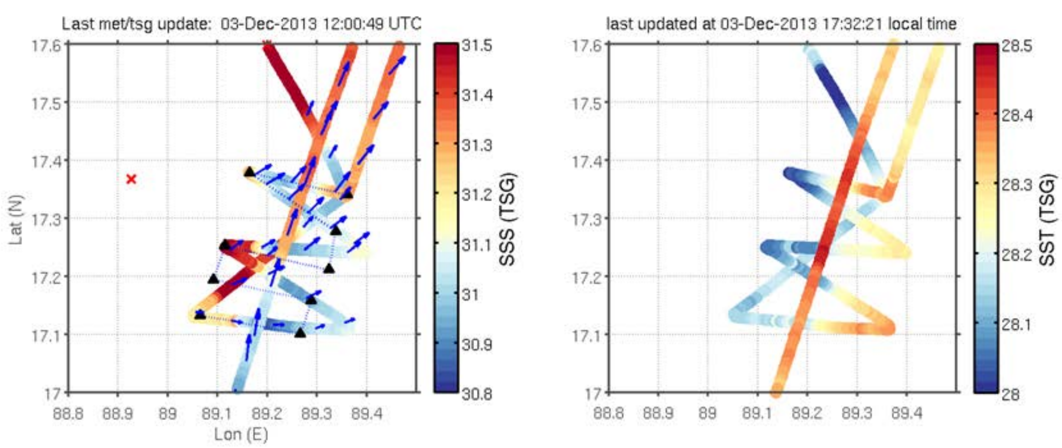

Figure F-5: TSG salinity and temperature while conducting the first high resolution survey.

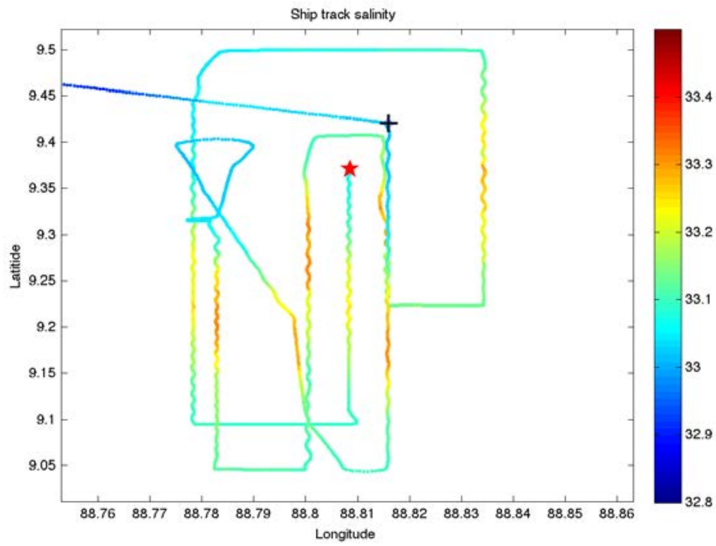

Figure F-6: TSG salinity while conducting the second process study.

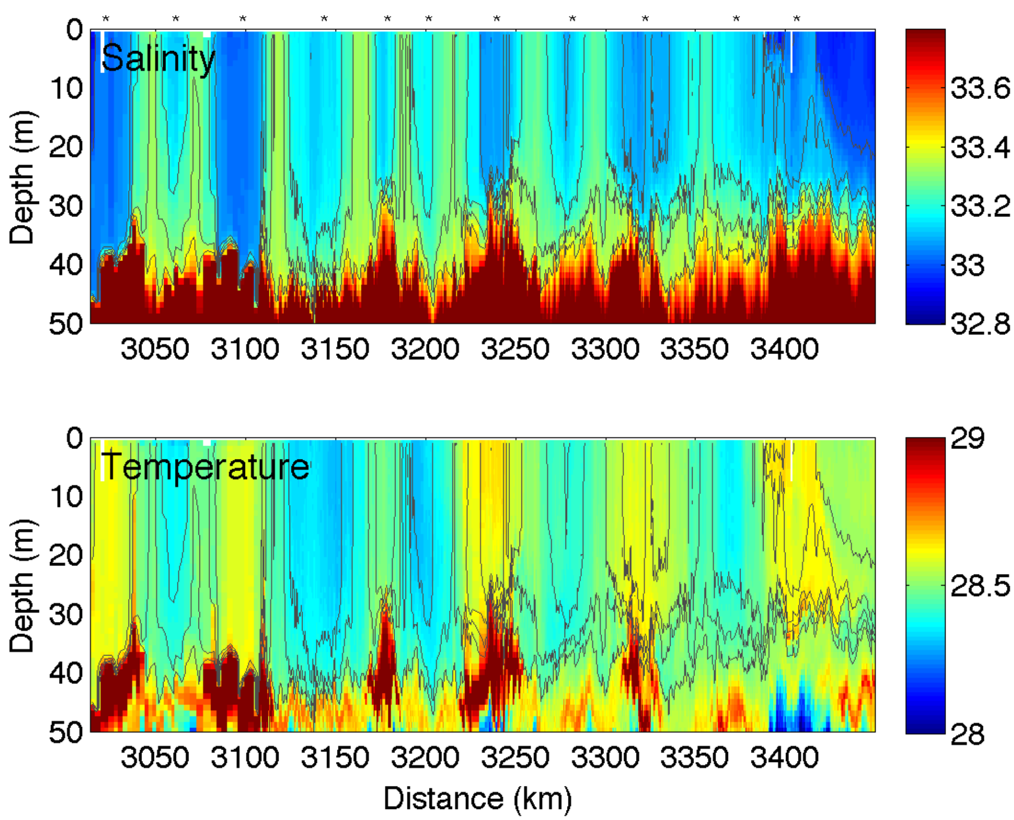

Figure F-7: Salinity and temperature during the second process study. Salinity is contoured in both panels. Profiles are along the ship track shown in Figure F-6. Turning locations are indicated on top of the upper panel (courtesy A Waterhouse).

(F3) Marine Mammal Survey

Visual survey: A total of 1669 km of trackline were surveyed in Beaufort 5 or less sea conditions, and 52 sightings of 12 different species were recorded (Table F-1, Figure F-8). Ten days of survey effort were conducted in standard survey mode during long transits. An additional 3 days of sighting effort were conducted in non-standard mode during small-scale oceanographic surveys, and 2 days were lost to poor weather (Beaufort sea states of 6 or higher). Diversity of encountered species was high (12 species; Table F-2), but there were also numerous unidentified sightings caused primarily by the survey methodology; because the ship could not be diverted from the trackline established by the physical oceanographic cruise objectives, distant sightings often went unidentified. Species sometimes were recorded as unidentified because of observer inexperience, but this was uncommon since experienced observers (including one of the two expert observers) were always on watch together with the novice observers. Sightings were mostly concentrated in the southern Bay of Bengal, with few cetaceans encountered in the central and northern Bay (Figure F-8). Sighting conditions tended to be better in the southern Bay when compared to the central and northern Bay (Figure F-8), but we suspect the observed difference in cetacean occurrence is likely real. Future cruises will help elucidate this north-south difference.

Training: Training activities for the Sri Lankan and Indian observers were as follows:

- Survey methodology
  - Review of standard visual survey methods, including role of port, center, starboard and independent observers
  - Review of weather, visibility, and sighting data reporting requirements
  - Evening homework assignment to write up a detailed survey methodology; homework graded by three experienced scientists
- Big eyes
  - Participation in set up and angular calibration of big-eye binoculars
  - Use of big-eye binoculars, including height adjustment, reticle-based distance measurements, estimation of object bearing, and scanning techniques
- *Wincruz* software
  - Continuous training on weather, visibility, and sighting data capture using *Wincruz* software during active surveying and during several evening meetings
  - Evening training meeting to do simulations of sighting events and subsequent data entry using role-playing and group discussions
  - Provided copies of *Wincruz* software to Sri Lankan and Indian scientists
- Species identification
  - Provided copies of marine mammal field guides and identification textbooks to Sri Lankan and Indian researchers several months prior to the cruise
  - Several evening homework assignments to sketch species and describe diagnostic features (e.g., Figure F-9); species sketched included common, spinner, spotted, bottlenose, and rough-toothed dolphins, melon-headed, pygmy killer, dwarf sperm, pygmy sperm, Blainville’s beaked, and Cuvier’s beaked whales

- Administered species quiz using photographs of species expected to be encountered in the Bay of Bengal; subsequently discussed quiz results, reviewed each of the species, and had participants identify and describe diagnostic features

Additional activities: Drs. Stafford and Baumgartner met with Sri Lankan scientists from the National Aquatic Resources Research and Development Agency in Colombo, Sri Lanka prior to the cruise on November 25, 2013. We presented a 1-hour talk on marine mammal biology, conservation, research methods, and the ASIRI project, and we discussed marine mammal research needs and priorities in Sri Lanka. We also met with scientists from the National Centre for Biological Sciences (NCBS) in Bangalore, India after the cruise on December 16, 2013. Both Baumgartner and Stafford presented 45-minute talks on marine mammal conservation, recent science projects, and the ASIRI project. We met with a group of both NCBS faculty and NGO and independent scientists to discuss research priorities and future plans to establish a marine mammal program at NCBS.

Table F-1: Results of sighting survey by date, including total trackline visually surveyed while on effort (Beaufort sea state ≤ 5), number of sightings, and species encountered.

Date	Trackline (km)	Sightings	Species
11/28	171	12	*Stenella coeruleoalba*, *Delphinus delphis*, *Tursiops* sp., *Grampus griseus*, *Pseudorca crassidens*, unidentified dolphin
11/29	110	12	*Stenella attenuata*, *S. longirostris*, *Grampus griseus*, *Feresa attenuata*, *Pseudorca crassidens*, *Kogia* sp, unidentified dolphin, unidentified small dolphin, unidentified medium dolphin
11/30	106	0	
12/01	168	1	unidentified small dolphin
12/02	142	0	
12/03[a]	173	0	
12/04	152	3	*Stenella longirostris*, *Physeter macrocephalus*
12/05	123	2	*Stenella longirostris*, unidentified large whale
12/06[b]	0	0	
12/07[b]	0	0	
12/08[a]	58	0	
12/09[a]	30	0	
12/10	140	1	unidentified small dolphin
12/11	111	7	*Stenella coeruleoalba*, unidentified small dolphin, unidentified large dolphin, unidentified Balaenoptera sp.
12/12	185	14	*Stenella attenuata*, *S. longirostris*, *S. coeruleoalba*, *Tursiops* sp., *Orcinus orca*, *Balaenoptera musculus*, unidentified cetacean, unidentified small dolphin
Total	**1,669**	**52**	

[a] Non-standard survey effort during small-scale surveys or process studies
[b] Weather conditions precluded visual effort

Table F-2: Number of sightings by species.

Sightings	Species
10	*Stenella longirostris*
7	unidentified small dolphin
6	unidentified dolphin
5	*Stenella coeruleoalba*
3	*Pseudorca crassidens*
3	*Stenella attenuata*
3	*Tursiops* sp.
2	*Grampus griseus*
2	*Delphinus delphis*
2	*Physeter macrocephalus*
1	*Feresa attenuata*
1	*Kogia* sp.
1	*Balaenoptera musculus*
1	*Orcinus orca*
1	unidentified Balaenoptera species
1	unidentified large whale
1	unidentified medium dolphin
1	unidentified large dolphin
1	unidentified cetacean

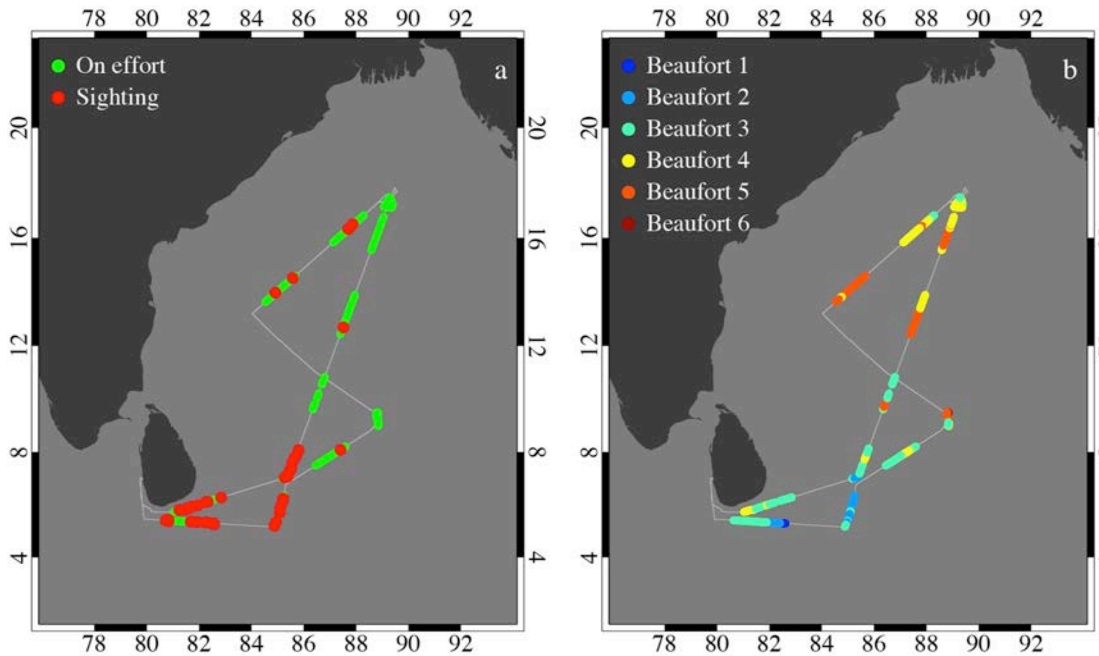

Figure F-8: (a) Locations of survey effort (green) and marine mammal sightings (red) along the cruise track (light gray). (b) Beaufort sea state along cruise track.

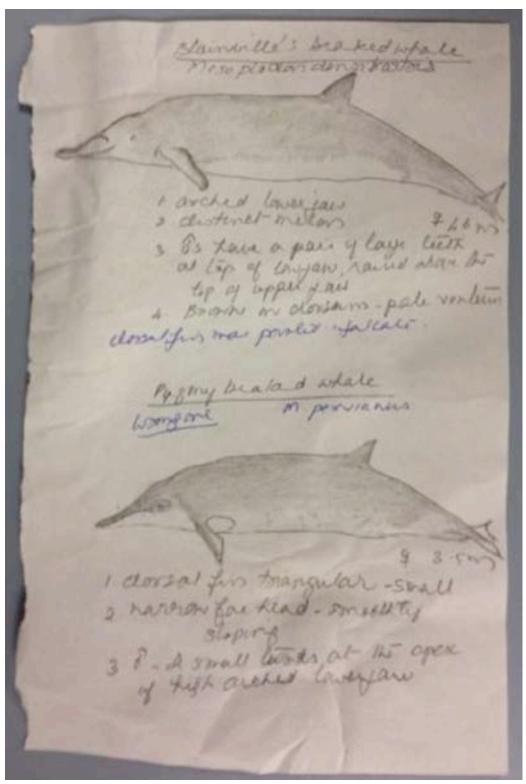

Figure F-9: Example of species identification homework assignment (sketch by Ajith Kumar).

G. Personnel

This ONR DRI builds international partnerships with India and Sri Lanka for studying the role of the Bay of Bengal on the South Asian Monsoons. A primary goal of the cruise was training and exchange with Indian and Sri Lankan colleagues. The cruise included participants from several institutions in the US, India and Sri Lanka (Table G-1). All members of the science team participated in watch standing; early days of the cruise were dedicated to training on instrumentation led by watch leads. The science crew met daily after dinner in the library for scientific discussion. Science talks were presented by a majority of the scientists during the course of the cruise. Participants took turns either talking about results from the ongoing observations, or their own scientific research. Talks were given by Sri Lankan, Indian, and US scientists.

Table G-1: Participant information.

Last Name	First Name	Institution	Nationality	Cruise role
SHROYER	EMILY	Oregon State University	United States	Chief Scientist
MAHADEVAN	AMALA	WHOI	United States	Chief Scientist
BAUMGARTNER	MARK	WHOI	United States	Marine Mammal Observer
BIGORRE	SEBASTIEN	WHOI	United States	CTD/UCTD Watch Lead
CHERIAN	DEEPAK	MIT	United States	PO Watch Stander
DURGA RAO	GIJJAPU	CSIR-NIO Regional Centre	India	Water Sampling
RATHEESH	SMITHA	SAC/ISRO	India	PO Watch Stander
HARICHANDRA	AKILA	NARA	Sri Lanka	PO Watch Stander
HODGES	BENJAMIN	WHOI	United States	CTD/UCTD Watch Lead
KADIYAM	JAGADEESH	NIOT	India	PO Watch Stander
KENNADY	SIMI	NIOT	India	PO Watch Stander
KUMAR	AJITH	NCBS	India	Marine Mammal Observer
KUMAR	PRAVEEN	INCOIS	India	PO Watch Stander
LIYANAGE	UPUL	NARA	Sri Lanka	Marine Mammal Observer
MELE	PHIL	LDEO	United States	PO Watch Stander
MISHRA	RAJANI	ESSO-NCAOR	India	PO Watch Stander
MORQUECHO	ERNESTO	WHOI	United States	Marine Mammal Observer
OMAND	MELISSA	SIO	United States	Optics/Water Sampling
PANICKER	DIVYA	NCBS	India	Marine Mammal Observer
PRAKASH	SATYA	ESSO-INCOIS	India	PO Watch Stander
RATHNASURIYA	ISHARA	NARA	Sri Lanka	Marine Mammal Observer
SHELLITO	SHAWN	UNH	United States	Optics/Water Sampling
SIVARAMAKRISHNAN	RAVICHANDRAN	TIFR	India	PO Watch Stander
STAFFORD	KATHLEEN	UW APL	United States	Marine Mammal Observer
SUHM	DIANE	Not Available	United States	PO Watch Stander

VISWANADHAM	RONGALI	CSIR-NIO Regional Centre	India	Water Sampling
WATERHOUSE	AMY	SIO	United States	PO Watch Stander
WHELAN	SEAN	WHOI	United States	CTD/UCTD Watch Lead
YIN	SUZANNE	WHOI	United States	Marine Mammal Observer

H. Other Contact Information

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