Atmospheric Forcing and the Structure and Evolution of the Upper Ocean in the Bay of Bengal

J. Thomas Farrar and Robert A. Weller
Woods Hole Oceanographic Institution
266 Woods Hole Rd
Clark 212A (MS29)
Woods Hole, MA 02543-1050
phone: (508) 289-2691 fax: (508) 457-2163 email: jfarrar@whoi.edu

Award Number: N0001413-100453
http://uop.whoi.edu/projects/Bengal/

LONG-TERM GOALS

Our long-term goals are to improve understanding and simulation of physical processes in the upper ocean that influence air-sea interaction and the upper-ocean environment. The focus of this project is an investigation of the processes that determine the vertical structure and evolution of the upper ocean in the southern Bay of Bengal. The Bay of Bengal is an interesting region from the perspective of air-sea interaction: the presence of a salinity-stratified barrier layer is believed to have important effects on the sea surface temperature field and the regional atmosphere because the shallow stratification favors a relatively rapid response of the upper ocean to surface forcing. The strong, shallow stratification in the region and the dynamical processes governing the upper-ocean structure and air-sea interaction have not yet been adequately characterized and understood, posing a challenge to the ability of numerical models to simulate and predict changes in the ocean and atmosphere there. With this project, we seek to use new and existing measurements to test, scrutinize, and improve the conceptual, theoretical, and dynamical constructs of air-sea interaction in the Bay of Bengal.

OBJECTIVES

The present effort involves inter-related observational components:

(1) Analysis of new and historical field observations and satellite data to improve understanding of air-sea interaction and upper-ocean dynamics in the presence of the barrier layer.

(2) Participation in research cruises to perform high-resolution (2-km horizontal, 1-m vertical) sampling of upper-ocean structure using an Underway CTD (UCTD).

(3) Deployment of an oceanographic surface mooring at 18°N, 89°E to provide a detailed view of the forcing and evolution of the complex upper-ocean stratification in the region. The mooring was deployed in December 2014 and carries instrumentation for high-quality estimates of surface fluxes and high-resolution vertical profiles of temperature, salinity, and velocity over the upper 200 m. The mooring has four deeper current meters to examine vertical structure over the water column and carries instruments for other investigators.

(4) Use the time series of surface meteorology and derived air-sea fluxes of heat, freshwater, and momentum to examine the realism of model-based surface meteorological and air-sea flux products in the northern Bay of Bengal.

(5) In partnership with Indian colleagues, work toward sustained observations at 18°N, 89°W.

APPROACH

During cruises in the Bay of Bengal in November and December 2013, we deployed an "Underway CTD" instrument (manufactured by Oceanscience of Carlsbad, CA) to measure vertical profiles of temperature and conductivity (salinity) from a moving vessel. The UCTD system (Figure 1) consists of a 2-kg instrument and a small electric winch; spectra line is wound on the instruments tailspool, and the winch is allowed to freespool, so that the instrument can be dropped from the stern of the ship and fall directly downward at a constant speed while the ship is underway. For temperature/salinity profiles of the upper 400 m of the ocean, casts can be repeated about every 15 minutes, giving a horizontal resolution of about 3.7 km at a ship speed of 8 knots. The horizontal resolution can be increased or decreased by varying the ship speed.

Our research group participated in two cruise legs in the Bay of Bengal during November/December 2013, with three people on each leg to lead 24-hour UCTD operations. We prepared and sent two complete UCTD systems to ensure against mechanical failures. Cruise participants from India and Sri Lanka were trained to stand watch and assist in UCTD operations.

In December 2014 we deployed from the Indian Oceanographic Research Vessel (ORV) *Sagar Nidhi* a heavily instrumented air-sea interaction mooring to collect measurements of the air-sea exchange of heat, momentum, and freshwater and the coincident evolution of the upper ocean. Because of the needs of the larger DRI and the measurements planned by Indian colleagues, we modified our original plan for a short-term deployment (~50 days) to instead perform a longer, one-year deployment near 18°N, 90°E spanning an entire year, including both the winter and summer monsoons.

Closely-spaced velocity, temperature, and conductivity instrumentation on the mooring line will return good vertical resolution of the structure and variability in the upper 200 m. Four additional current meters at 250, 500, 750, and 1000m will provide information about the vertical structure over the roughly 2000m deep water column. The mooring also carries Chipods for Moum and Shroyer (OSU) and optical and nutrient sensors for Mahadaven and Omand (WHOI). During the year, hourly surface meteorological data was telemetred. We have quality-controlled that data and computed air-sea fluxes of heat, freshwater, and momentum. The meteorological and air-sea flux data have been provided to other investigators who are colleagues in the Bay of Bengal work. We are gearing up now for the recovery cruise, planned for December 2015 on the Indian Oceanographic Research Vessel *Sagar Kanya.* We have collected atmospheric model data (National Centers for Environmental Prediction and European Centre for Medium Range Weather Forecasts) and have been comparing model and observed surface meteorology and air-sea fluxes.

Part of our approach for getting the most "bang for the buck" from this effort has been to partner with Indian colleagues (especially D. Sengupta of the Indian Institute of Science, M. Ravichandran of the Indian National Centre for Ocean Information Services, and R. Venkatesan of the National Institute of Ocean Technology) to conduct our fieldwork more efficiently in the region and to develop a plan to deploy an almost identical, India-funded surface mooring. As a result of this partnership, we were able to deploy our surface mooring from the ORV *Sagar Nidhi* this fall with only two WHOI mooring technicians and be able to do the recovery cruise in December 2015 with just three WHOI staff. We have continued a dialog with our Indian colleagues about sustaining time series observations and recently answered their request for a proposal to build a surface mooring.

WORK COMPLETED

In December 2014 we deployed the heavily instrumented air-sea interaction mooring to collect measurements of the air-sea exchange of heat, momentum, and freshwater and the coincident evolution of the upper ocean. This deployment was done from ORV *Sagar Nidhi* (Figure 1).

Figure 1: The surface buoy of the surface mooring deployed in December 2014 in the northern Bay of Bengal is shown with the ORV Sagar Nidhi in the background.

On our website, http://uop.whoi.edu/projects/Bengal/ we have served the hourly surface meteorological data to all users. We are collaborating with colleagues on contrasting the observed and model-based estimates of the air-sea fluxes and have an ongoing effort to collect model surface meteorology and air-sea fluxes at the mooring site.

We have just shipped the gear needed for the recovery cruise to Chennai, India in anticipation of sailing on ORV *Saga Kanya* in December.

RESULTS

Our surface mooring has been very successful at collecting surface meteorological data. Both of the ASIMET surface meteorological instruments have provided full records (Figure 2).

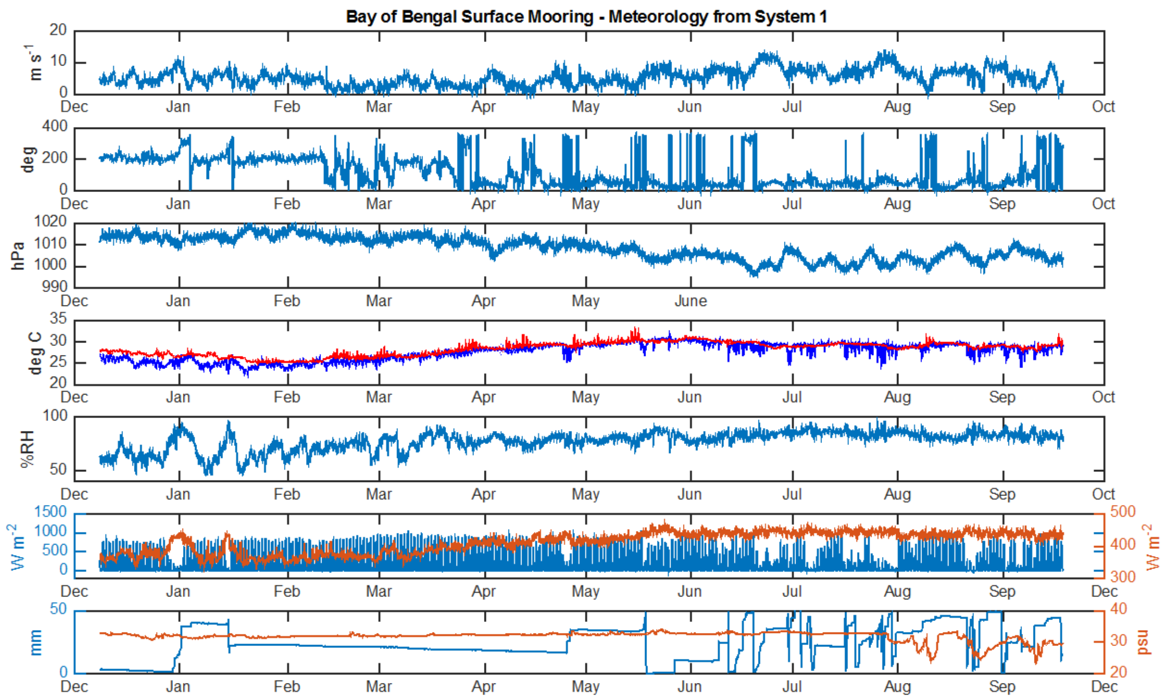

Figure 2: Time series of hourly surface meteorology as telemetered from ASIMET System 1 on the buoy at 18°N, 89°E. From the top, the panels are: wind speed, wind direction, air temperature (blue) and sea surface temperature (red) overplotted, relative humidity, incoming shortwave radiation (blue) and incoming longwave radiation (brown) overplotted, and rain gauge level (blue) and sea surface salinity (brown) overplotted.

The impact of the two monsoons on the surface forcing is evident in the wind rose (Figure 3) and in a plot of sea surface temperature, sea surface salinity, low-passed net heat, rain accumulation, and wind stress (Figure 4). The winter monsoon has moderate winds to the south-southwest, while the summer monsoon has strong wind events blowing to the northeast. Light winds (< 5 m s^{-1}) prevail during the intermonsoon, when the insolation contributes to a period of sustained oceanic heating. Moderate winds to the south-southeast, up to 10 m s^{-1}, moderate latent heat flux (as strong as -326 W m^{-2}), and a total of about 80 mm of rain were associated with the winter monsoon, which was a period of sustained oceanic heat loss. The strongest forcing occurred during the summer monsoon when the wind blew to the northeast, with the strongest winds (13.8 m s^{-1}) in late July. Heavy rain events, up to just over 15 mm hr^{-1}, and episodic, short intervals of net heat loss associated with very dark skies were seen during the summer monsoon. The alternation between periods of low-passed net heat flux approaching oceanic loss of -200 W m^{-2} to periods of ocean heat gain of up to 150 W m^{-2} corresponded to the active and break cycles of the summer monsoon.

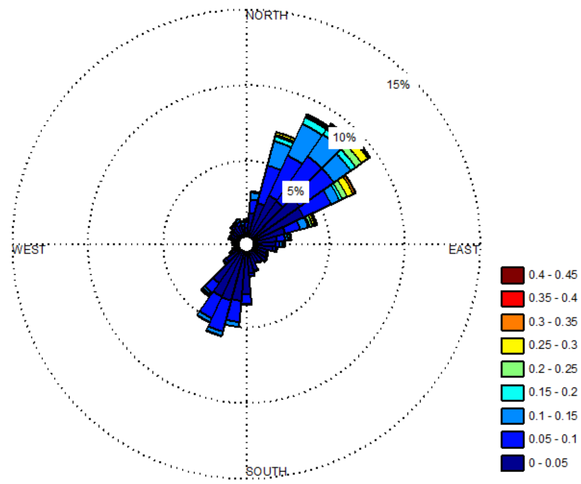

Figure 3. Rose plot or radial histogram of hourly wind stress vectors. The summer monsoon contributes the strongest stress values ($N\ m^{-2}$) , which are to the northeast. The winter monsoon contributes moderate wind events towards to south-southwest.

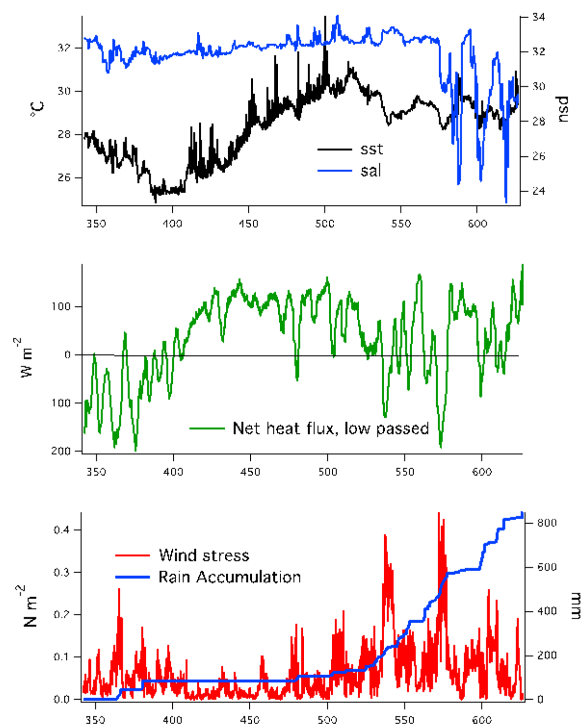

Figure 4: Time series plotted versus yearday 2014 for the surface mooring deployed in December 2014. Top panel shows sea surface temperature (black) and salinity (blue). Middle panel shows low passed (72-hour boxcar) net heat flux. Lower panel shows wind stress (red) and accumulated rainfall (blue).

IMPACT/APPLICATIONS

The surface mooring deployed in December 2014 and to be recovered in December 2015 will provide unique, accurate time series measurements of air-sea fluxes of heat, momentum, and freshwater and of upper-ocean (0-200 m) temperature, salinity, and velocity. These time series will serve as a benchmark for assessing atmospheric, oceanic, and coupled model performance in the northern Bay of Bengal. They will also serve as a key resource for improving the understanding of the processes that govern the evolution of the upper ocean in the northern Bay of Bengal and that couple the atmosphere and ocean together during the evolution of the monsoons.

TRANSITIONS

Our Indian colleagues have strong societal need for improved monsoon prediction. Model experiments indicate that the ocean plays a role in monsoon dynamics. Further improvements to prediction depend on accurate observations for both model initialization and model improvement. We are through this project transitioning to our Indian colleagues knowledge and experience on how to make accurate surface meteorological and air-sea flux observations. We are also transitioning to them our state of the art surface mooring technology.

RELATED PROJECTS

This project is closely related to the DURIP award, "An Air-Sea Interaction Buoy/Mooring System for Study of Air-Sea Interaction in the Open Ocean" (N00014-13-1-0685; PIs Robert A. Weller and J. Thomas Farrar). The buoy that was constructed under that award is being used for measurements of air-sea fluxes and upper-ocean evolution in the Bay of Bengal for this project.

This project is closely related to several other projects operating under the ASIRI DRI. There is close interaction on scientific goals, hypotheses, and measurements, as well as coordination on logistical matters, such as container shipments to Sri Lanka and India.

PUBLICATIONS

Wijesekera, H. and coauthors, 2015. Decrypting a Mystery Bay – The ASIRI Ocean-Atmsophere Initiatives in the Bay of Bengal. *Bull. Amer. Met. Soc., in press.*