

## **ROSS: The Remotely-Operated Surface Sampler**

A medium-endurance, precision-navigated platform optimized for uncontaminated measurement of upper-ocean velocity, density and turbulence.

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### **OVERVIEW**

The Remotely Operated Surface Sampler (ROSS) is an open-ocean autonomous vehicle designed to carry out precision-navigated missions to sample upper-ocean physics. In its current configuration, ROSS cruises at 4 knots, is equipped with 300 kHz and 2 MHz ADCPs, and tows a 20-m lon thermistor/CTD chain. Its purpose is to complement traditional ship-board sampling by providing a comprehensive and uncontaminated 3D perspective of near-surface temperature, salinity and velocity at high vertical and horizontal resolution. The first set of extended open-ocean testing and data collection for ROSS occurred in Aug-Sept 2015 in the Bay of Bengal, where it participated in coordinated 3-ship operations with the R/Vs Revelle and Sagar Nidhi to study submesoscale dynamics associated with the summer Monsoon.



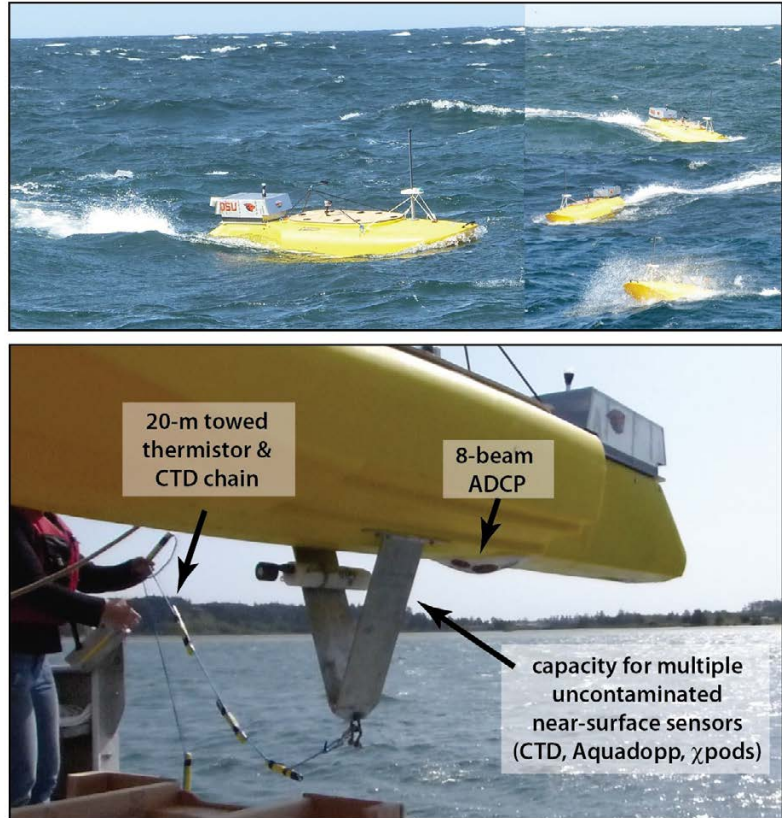
**Figure 1: ROSS in the Bay of Bengal, Sept 2015, performing coordinated sampling with the Indian R/V Sagar Nidhi and the US R/V Revelle.**

### **APPROACH**

Our first open-ocean design utilizes a commercially-available “Mokai” jet powered kayak, which is designed for personal transport on rivers/lakes, and has limited endurance. To make this into an ocean-capable research platform, we have added a

keel and waterproof covers/vents to improve seaworthiness, engineer control systems and long-range radio communications for navigation, and added ADCP wells and other sensor systems (Figure 2). The system was tested in April off the Oregon Coast in 30 knots of wind and seven-foot seas, and then shipped to India to participate in a joint experiment with two traditional research vessels.

**Figure 2: ROSS on the Oregon Coast in 30 knots and 7 ft seas.**



## RESULTS:

The first at-sea trials of ROSS are currently underway in the Bay of Bengal, and have been extremely promising. During a 10-day period in Sept 2015, the R/V Revelle was engaged in intensive coordinated sampling the Indian R/V Sagar Nidhi, performing parallel transects across a strong mesoscale convergence in which the ships sailed beam-to-beam. This type of sampling permits instantaneous spatial gradients in density and velocity to be computed, allowing quantities like vorticity and strain rates to be directly computed, which are dynamically important to the submesoscale evolution.

ROSS was deployed on 5 missions during this period, performing coordinated sampling with the 2 traditional research vessels on transects exceeding 100 km at a time. The separation between platforms was chosen to capture vorticity at multiple discrete scales. Deployments of ROSS immediately transitioned from engineering and feasibility tests to a fully integrated, operational mode. We anticipate the data we have recorded will play an important part to the goals/outcomes of the larger experimental project. We summarize the performance of ROSS below:

### 1. Seaworthiness/Endurance:

ROSS was deployed in 15-25 knot winds, intense squalls, and moderate sea states. The stability of ROSS has proven to be high; maintained both through the boat's design (it is wide), and enhanced by the addition of its short keel, from which we tow a thermistor chain and depressor weight. ROSS has been hit by numerous actively breaking waves, and survived without any significant damage or flooding. Range, towing a 20 m T-chain at 4 knots, is 125-200 km, depending on wind and sea-state.

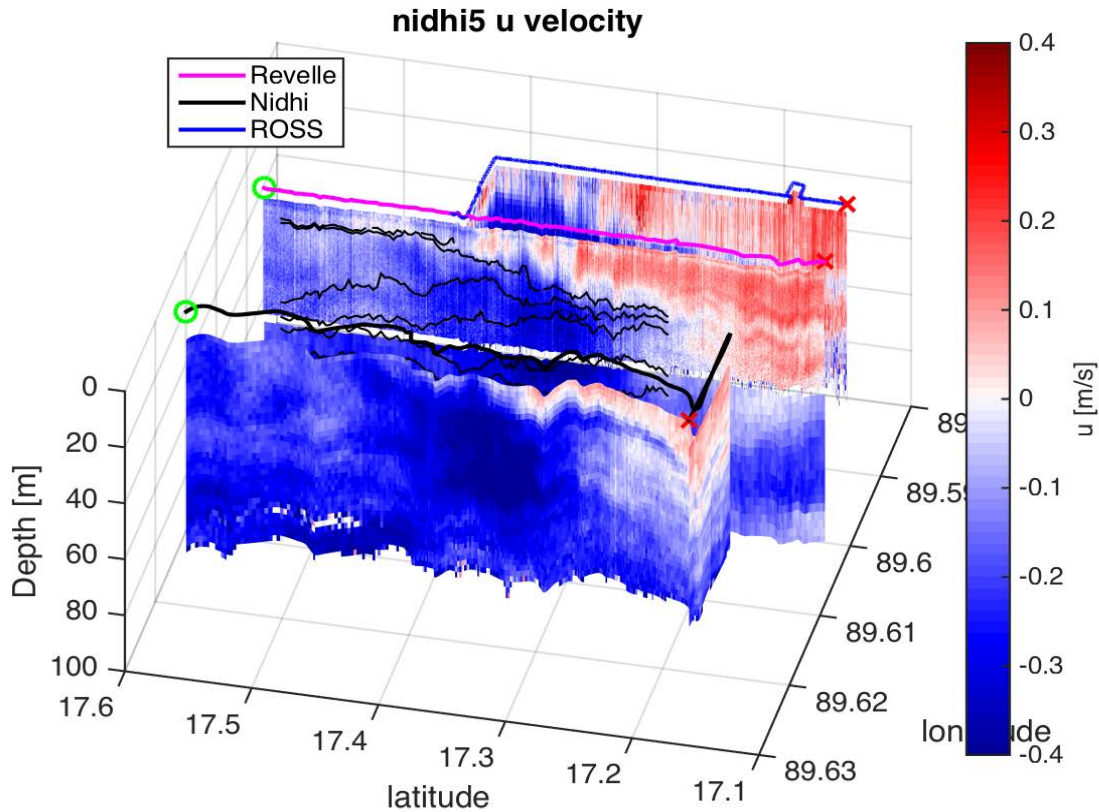


Figure 3: Track and upper-100 m velocity from ROSS and 2 traditional research vessels, each travelling in parallel, simultaneous lines in order to compute instantaneous vorticity.

2. **Navigation:**

ROSS is controlled with an off-the-shelf PixHawk autopilot (used on quad-copters), so can follow a programmed course to within a few meters RMS precision. For example, figure 3 shows the track of ROSS (blue line), compare to those of the traditional research vessels (magenta and black), which have many orders of magnitude more variance. We have recorded incidents where a breaking wave of squall front can push ROSS off course by up to 10 m; however the control system quickly gets it back onto its line.

We communicate with ROSS using a 900 MHz radio link which allows programming / reprogramming of waypoints over distances of 4-10 km. The system is robust to communications dropouts/failures, in that radio communications are not necessary for ROSS to execute full autonomous missions. Iridium is only used for tracking; in the next phase it will be used for control as well. For deployment and recovery, ROSS is steered using a traditional hand-held radio control transmitter

3. **Mechanical:**

Structurally, the Mokai platform has proved as an excellent prototype for this application, after we have added internal/external frames for lifting, acoustic



wells for ADCPs, cooling systems for electronics. Moreover, the jet powertrain presents no external moving parts to tangle with sensor arrays or to complicate handling on deck, making it relatively safe and robust. Our biggest problems so far have been associated with the engines themselves, which are air-cooled and not specifically designed for marine operations. We have experienced failures with fuel delivery, carburetors, and exhaust components, so we will transition to a marine engine in the next iteration.

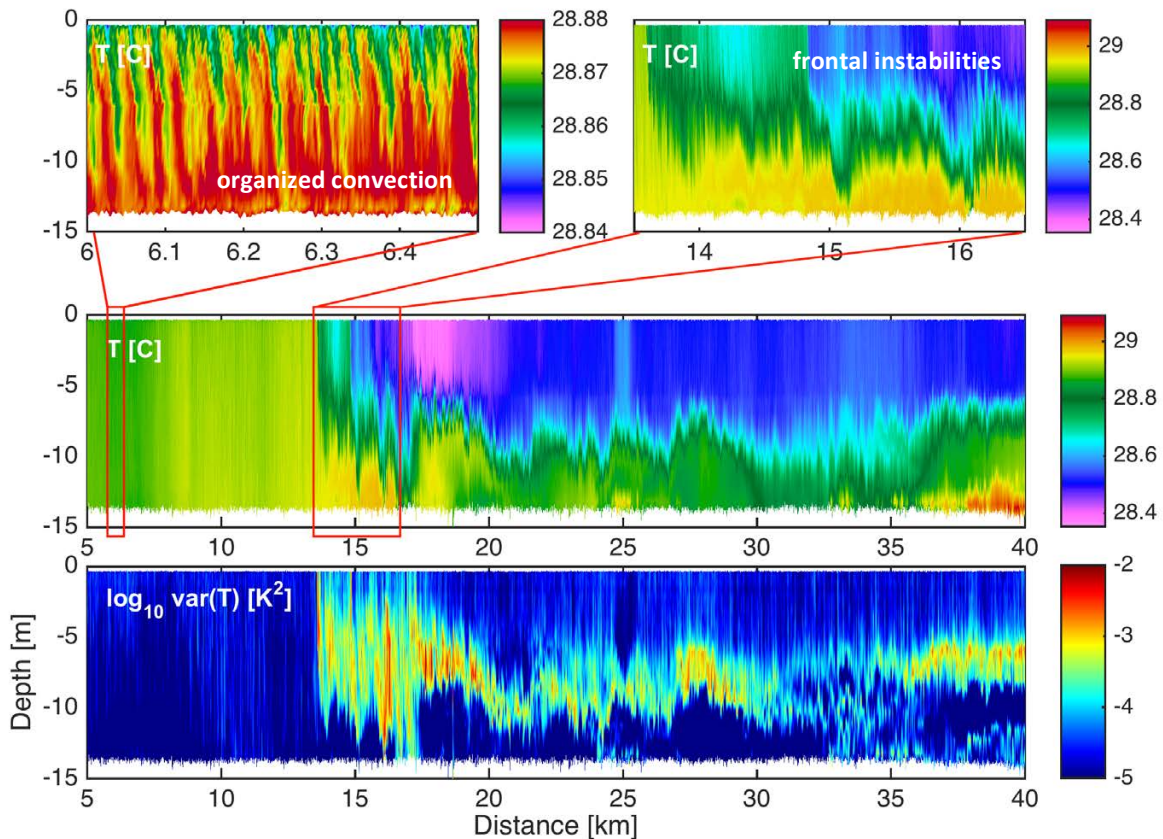


Figure 4: Upper 15-m temperature from ROSS' thermistor/CTD chain. Bottom panels show a 35-km long segment of T and T variance, which is a proxy for mixing. The upper panels show two close-ups; one 500-m wide segment illustrating the spatial structure of Langmuir-influenced nighttime convection with horizontal scales of 50 m (left) and the other showing the instabilities within a bore-like front over larger (3 km) horizontal scales (right)

#### 4. Data Quality:

Data return has been excellent.

- a. ADCP data from ROSS' 300 kHz broadband RDI is of similar quality to that which is recorded on the R/V Revelle, as shown in figure 3. The strength of ROSS is that it can help paint a more complete 3D picture of the flowfield, independent of the mother ship. Quantitatively, it permit calculations of instantaneous gradients without assumptions, allowing for quantities like vorticity to be accurately calculated. It is both the similarities and differences in the velocity data in figure 3 that are relevant to the submesoscale questions that we are addressing in ASIRI.

- b. The CTD/Thermistor data are quite spectacular, providing uncontaminated records with high horizontal and vertical resolution in close proximity to the sea surface. For example, the large-scale temperature structure (figure 4) shows a mesoscale convergence which drives nonlinear bores and submesoscale instability. Zoom-ins on the flow ahead of the front show the structure of nighttime convection influenced by Langmuir circulation cells. Since our first CTD sensor is at 15 cm depth, ROSS provides a unique opportunity to quantify the spatial structure of temperature / density inversions at the air-sea boundary (upper left panel), that drive convective cells (the green tendrils) with 50-m horizontal wavelength. These are imaged with >20 sensors over the top 15 m. At larger scales (upper right), the front is observed to have instabilities over a broad range of wavelengths, dynamics that set the rate at which fresh and salt water entrain and/or restratify. The bottom panel shows high frequency temperature variance, which we use as a proxy for turbulent heat flux.

Importantly, the fact that these data were collected in parallel with two other Research Vessels allows us to paint a more complete picture of complex 3D phenomena than has possible in the past.

#### **SUMMARY:**

##### ***Demonstration of success in ASIRI:***

Our first deployments of ROSS have demonstrated the viability of autonomous craft for coordinated sampling of near-surface ocean and atmospheric phenomena. In addition to proving its seaworthiness and navigational capabilities, the initial velocity, temperature and salinity data we have collected are likely to play an important role in untangling some of the finescale dynamics of the submesoscale in the Bay of Bengal.

##### ***Potential Applicability for other ONR projects:***

ROSS provides a unique perspective of small-scale physical phenomena in the upper ocean, offering flexible sampling of ocean properties right to the ocean surface. It is ideal for studying fronts, river plumes, near-surface phenomena like ice-melt or rain puddles, air-sea fluxes, and any other phenomena that is either thin, highly 3D, or trapped to the surface. It also has potential for sampling regions too dangerous for manned craft (like near glacier faces), and for interpreting the undersea structure of satellite inferred properties. Real time data sent back from ROSS could potentially be sent back to inform real-time decision making.