LONG-TERM GOALS

The long-term goals are to develop techniques to measure inner shelf processes using airborne remote sensing instruments and to contribute to the understanding of inner shelf processes with our observations.

OBJECTIVES

The inner shelf region is characterized by subsurface processes that express observable signatures at the surface of the ocean. For example, internal waves generated at the shelf edge are associated with strong surface roughness and velocity signatures that can be measured with remote sensing instruments such as radars (e.g., Kropfli, 1999 and Plant et al., 2010) and infrared imagers (e.g. Marmorino et al., 2004; Zappa and Jessup, 2005). Fronts and eddies also generate increased surface roughness, and typically cause changes in surface temperature that detectable by remote sensing techniques. Remote sensing instruments also measure surface processes, such as waves and slicks, and while this sensitivity to both surface and subsurface processes provides a comprehensive view of the inner shelf, it complicates analysis of individual phenomenon. Our goal is to develop methods to extract geophysical parameters, such as wave amplitude, current magnitude and direction, and mixing, from remote sensing data.

Our specific objectives are to:

1. Measure geophysical parameters of internal waves and inner shelf currents over spatial scales of kilometers and temporal scales of hours using remote sensing techniques.
2. Improve estimation of internal wave parameters from SAR by using ATI-derived surface velocity.
3. Observe and measure surface velocity and mixing lengths associated with internal bore dissipation and eddies using surface temperature maps.

APPROACH

We use an integrated airborne instrument package (Figure 1) known as the Compact Airborne System for Imaging the Environment (CASIE) that includes a dual-beam along-track interferometric synthetic
aperture radar (ATI-SAR, Farquharson), and thermal infrared (IR, Chickadel) and visible wavelength cameras (Chickadel) to acquire remote sensing data. The ATI-SAR measures backscattered intensity (related to surface roughness and slope), and surface velocity (related wave orbital motion and surface currents). The thermal infrared camera measurement is a combination of thermal emission (related to SST) and reflection of infrared energy from the surface. All instruments use the precision inertial navigation to accurately georeference the remote sensing data.

**Figure 1:** The APL-UW airborne instrument attached to the belly of the Cessna 172. Visible are the ATI-SAR antennas and the fixed infrared and visible wavelength cameras.

**WORK COMPLETED**

**Satellite Imagery**
In preparation for the DRI pilot field experiment, we requested radar (TerraSAR-X and TanDEM-X) and infrared (ASTER) satellite images over the Point Sal area prior to the start of the experiment to learn about processes that occur in the area. Internal wave-like features and, at times, large areas of slicks that dampen surface roughness are visible in the SAR imagery (Figure 2). Unfortunately, our request for a TerraSAR-X/TanDEM-X acquisition with a good imaging geometry could not be met due to a scheduling conflict with a higher-priority acquisition, so the images were acquired with a low incidence angle (20 degrees), and as a result, the interferometric phase did not contain a strong signature of horizontal flow.

Historical collections of ASTER data were selected for examples of surface temperature signatures related to frontogenesis and internal waves along the Point Sal coastline. Examples of thermal and visible ASTER data from June 2010 (Figure 3) containing both internal wave and multiple fronts represent the type of imagery available. An ASTER data collection was also requested for the pilot experiment with two possible overpasses occurring during the pilot experiment. However, clouds obscured the ocean view on both instances resulting in unusable imagery.
Pilot Field Experiment
We participated in the DRI pilot experiment planning by coordinating aircraft operations with Vandenberg Air Force Base (AFB) and the Scripps Institute of Oceanography. We provided technical information about our sensors to spectrum control managers, and information about our sampling strategy and instrumentation for the environmental impact assessment.

During the pilot experiment, we conducted six research flights over five days (Table 1). An inversion layer was present on all days that caused low clouds (~1000 ft) over the Point for large parts of the
days. This inversion also caused unexpectedly high temperatures (between 26 and 30 degrees Celsius) at flight altitude (~3000 ft), which caused a computer to overheat and required us to reconfigure our system before Flight 03. Flight tracks were flown that focused our measurements in the 22 m resolution model domain and to cover the array of in situ sensors deployed around the point (Figure 4). We also sampled along the shore north of Point Sal (flight track not shown in Figure 4), and we tested our gimbaled camera system by flying circles around the Point to capture a time series of images.

Table 1. Flights conducted during the pilot experiment.

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Figure 4. Flight tracks (white lines) and area covered (yellow boxes) over the in situ sensors deployed around Point Sal. All of the 22 m resolution model area (red box) and most of the 66 m resolution model area (magenta box) are covered by the airborne measurements.
ATI-SAR data was collected during the six flights. The radar data was checked to verify correct system operation at the end of each day. We have processed data from Flight 01 (June 28) with the latest version of our SAR processor, and are in the process of upgrading our processing code based on the results. Once complete, we will process the data from all flights. The low-layer of clouds that persisted during much of the flights did not affect the measurements with the radar, but the low wind conditions on the fourth and fifth days are likely to have generated insufficient surface roughness for good radar data.

Imagery was recorded by the instruments in the CARIS platform. These include a pair of thermal infrared (IR) cameras that are fixed to a view coincident with the ATI-SAR swath, a motion compensated gimbal with mid-wave IR and visual cameras, and a fixed visual cameras. The camera gimbal (in its first field deployment) was operated briefly to observe the interaction between surfzone and shelf processes. However, the data collection computer for the main imaging system (fixed IR cameras) failed and was replaced by the gimbal computer, thus we have gimbal data only from the early part of the pilot experiment. This data is still in pre-processing.

**RESULTS**

**ATI-SAR**

Surface signatures of internal waves observed in the ATI-SAR data typically have a strong well-defined leading soliton, followed by several more ragged-looking solitons (Figure 5). Each soliton has a narrow band of increased backscattered power (Figure 5, left) at the leading edge and a broader region of suppressed surface roughness trailing the leading edge. The solitons also appear in the $x$- and $y$-components of surface velocity field (Figure 5, middle and right respectively). It is interesting to note that although the solitons are propagating largely in the $x$ direction and have a strong positive $x$-component of velocity, the $y$-component of velocity appears to be largely negative. We will explore the physical interpretation of these velocity signatures our analysis. We have also started looking at the surface velocity field around Point Sal measured by the radar (not shown in this report).

**Infrared imaging**

Examples of the fixed IR camera data are shown from 1 July 2015 in Figure 6. Surface temperature signatures reflect the large and small processes evident in the mosaicked imagery. Fronts from shoreward-propagating internal waves span several kilometers and display three-dimensionality, and some associated structures appear to be large turbulent surface plumes (Figure 6, right) in the wake of the internal waves. Mixing of warm surface water and cooler interior water at the shoreline appears to involve large rip current plumes extending up to a kilometer from shore (Figure 6, left). Apparently southward coastal flow at this time is driving turbulent mixing at the rocky shoals at the Point Sal headland. These observed features are in agreement with past satellite infrared data investigated during the planning for the pilot experiment. In future work we will focus on continued processing of gimbal and visual data, compare scales of features with satellite imagery and explore quantification of surface processes (circulation, waves) and scales from the infrared data.
Figure 5. ATI-SAR measurements approximately 5 km offshore of the western tip of Point Sal. Surface signatures of internal waves are clearly evident in both the backscattered power image (left) and the $x$-component (middle) and $y$-component (right) of surface velocity. These data were collected on June 29, 2015 between 00:42 and 01:14 UTC.
This work will improve methods for observing inner shelf processes with airborne, e.g., UAV, and satellite-borne remote sensing instruments.

RELATED PROJECTS

This work is being done in collaboration with other researchers funded by the Inner Shelf DRI and the Littoral Geosciences and Optics Program.

The instrumentation and methods used in this program were developed during the Data Assimilation and Remote Sensing for Littoral Applications (DARLA, N000141010932) project. These instrumentation and methods have also been used for the NSF-funded Science and Technology Center on Coastal Margin Observation and Prediction (CMOP). The ATI-SAR is also being used in a NASA/JPL-funded subcontract to provide surface currents validation measurements. The thermal imaging system is also being used in a NASA funded project to measure snow surface temperature.

REFERENCES

