Coastal Surface Current Variability

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LONG-TERM GOAL

The goal of the research effort is to study the effects of Gulf Stream and Florida Current intrusions and tides over the continental slope on coastal surface current variability detected from the Ocean Surface Current Radar (OSCR). A key aspect of the research is to understand the role of subsurface structure on surface current signatures in the internal wave band.

OBJECTIVES

Specific objectives of the research are to:

- Relate Interferometric Synthetic Aperture Radar (INSAR) images of internal waves to the high frequency band oscillations found in OSCR fields including the internal wave strain rates;
- Characterize time-space scales of the vertical structure current changes observed by OSCR, repeat track current profiles, and mooring data including comparisons of the vertical wavenumber spectra from ADCP profiles (with OSCR surface currents) to Garrett and Munk (1975) spectra;
- Examine the mean flow shear and vorticity to determine their role on forcing internal waves; and,
- Resolve the surface and subsurface tidal response, and relate differences in the semidiurnal tidal amplitudes to internal tides near or at the shelf break.

APPROACH

The OSCR system has been deployed in several venues including Cape Hatteras for the HIRES-2 experiment (Shay *et al*., 1995), OPRC Experiments along the Florida Keys (Shay *et al.*, 1998a), and in the DUCK94 Experiment (Shay *et al*., 1998b; Cook and Shay, 1998). The system consists of two HF radar transmit/receive stations operating at 25.4 MHz to acquire gridded surface current and Doppler spectra data over a 30 *km* x40 *km* region with a spatial resolution of 1.2 *km* at a sampling interval of 20 minutes. The radar approach is based upon the observation of the first-order Bragg return in the Doppler spectrum from gravity wavelengths of about 6 *m*. In the presence of a surface current, the frequency of the Bragg return is further shifted by an amount proportional to the radial current. Two

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transmitters and receivers perform as a phased array that utilize beam-forming techniques to isolate the ocean area where scattering occurs within the domain. Radial and vector surface current fields and the Doppler spectra are digitally recorded for subsequent processing and analyses.

Surface currents are treated as quasi-independent estimates at each of the 700 cells, which are then combined with subsurface mooring data and ship transect measurements to examine the relationships between surface and subsurface current structure, particularly in the internal wave band. Data quality is assessed using conventional statistical measures such as regression analysis and kinetic energy spectra. For example, measurements from the Duck94 experiment revealed differences of 7 cm s^{-1} between the surface and subsurface (4 *m*) currents from Vector Measuring Current Meters (VMCM) (Shay *et al*., 1998b). These observations are at the uncertainty limits of resolvable processes from the OSCR and VMCM instruments.

Rotary spectral energy peaks are used as a guide in isolating physical processes in the current signatures. A key element in identifying coastal current variability is the tidal influence. Tides are a source of current variability in the coastal ocean, and may in some instances contribute to the internal wave variability. Sea level records are used as a guide to select the tidal constituents used in the harmonic analysis of the current measurements from finite record lengths. These constituents are removed from the observed currents to form detided current records, which are then decomposed into the low-frequency (> 48 h), inertial, high-frequency and residual currents based upon digital filtering techniques.

TASKS COMPLETED

- Empirical orthogonal eigenfunction analysis have been performed on the spatially evolving time series to examine horizontal structure variations;
- Vorticity analyses have been completed from the data sets, including the assessment of the role of relative vorticity on near-inertial currents;
- Frontal analyses have been completed for the interaction between coastal and Gulf Stream water that exhibited characteristics similar to an occluded atmospheric frontal; and,
- Horizontal and vertical wavenumber analyses were performed on OSCR and ADCP data for the purpose of inferring the buoyancy frequency in the littoral ocean.

RESULTS

From the decomposed surface and subsurface current fields during HIRES, the EOF analysis using the real-vector approach on the surface current data resolved the tidal and Gulf Stream flows than those using the complex EOF. That is, the real-vector results indicated more realism in the results such as cross-shelf tidal propagation and closed-loop eddy structures on the shelf (Kaihatu *et al*., 1998).

Marmorino *et al.* (1998) demonstrated that the Y-feature found in the radar imagery was due to the an occlusion of a coastal ocean front with the Gulf Stream front as a third water mass was found in the hydrographic and surface current data. Using a 2-dimensional model, the fronts quickly sharpened and began to coalesce eventually occluding into a single front. This was shown to be analogous to the movement of a cold front as it overtakes a warm front, causing the warmer air to rise. In the ocean, the more dense water will sink. Shen *et al.* (1998) estimated the vorticity balance in this domain and found that the banded relative vorticity cells, which were elongated in the cross-shelf direction, were in quadrature with the divergence field.

From a ten-day period during the OPRC-2 experiment, submesoscale vortices located along the inshore side of the Florida Current were aligned with the 150 m isobath. Based on the observed surface current images, these submesoscale vortices translated from the western part of the domain towards the eastern part at a rate of 30 km day^{-1} (Shay *et al.*, 1998a). While low-frequency flows indicated little evidence of these features, these observed vortices were embedded in the near-inertial flows, which represents the low-frequency end of the internal wave spectrum. Based on a series of least-square fits, the horizontal wavelength of the motions was about 40 km with velocities of up to 30 cm s^{-1}. Their vertical structure at the ADCP mooring indicated vertical wavelengths of 45 to 50 m suggestive of a second baroclinic mode dependence (Shay, 1997). High-frequency motions were also observed with periods of 4 to 5 h where the vertical wavelengths were 20 to 25 m with horizontal wavelengths of 3 to 5 km. These energetic signals (20 cm s^{-1}) were associated with soliton-like wave packets forced by the tides at the shelf break.

During the DUCK94 experiment, the semidiurnal (M_2) tidal constituent dominated the tidal variability. Cook and Shay (1998) found a predominately cross-shelf tide propagation, with more of an along-shelf component close to shore. A similar situation existed for the S_2 tide, however it had enhanced amplitudes in the near-shore regime, a minimum in the mid-shelf area, and then increasing further offshore. The S_2 also exhibits more along-shelf variability compared to the M_2 constituent. Ellipses rotated clockwise, and maintained their ellipticity over most of the domain. The decreasing amplitude and phase with depth were consistent with theoretical models of frictional effects on the vertical structure of barotropic tidal currents. A large component of the tidal flow was barotropic at least at the two current meter moorings at 20 and 25 m moorings (Shay *et al*., 1998b). The K_1 and O_1 constituents were less important as compared to the M_2 constituent, but comparable in magnitude to each other. Both diurnal constituents varied in amplitude in the along-shelf direction where the ellipse orientations also indicated cross-shelf propagation on the inner shelf, and turn in the along-shelf direction further offshore.

IMPACT

The long-term impact here is: i) to improve our understanding of submesoscale to mesoscale surface processes that directly affect satellite based remote sensing; ii) to examine the effects of subsurface structure and internal wave oscillations on the ocean's surface and the subsequent detection by SAR; and iii) to understand the 3-dimensional circulation patterns in the coastal ocean using remotely sensed and in situ data.

TRANSITIONS

Surface current measurements from HIRES have been provided to ONR/NRL supported investigators for observational and numerical studies encompassing a broad spectrum of processes. The spatially-evolving fields will be provided to the research scientists for observationally-based model studies related to Coupled Oceanic and Atmospheric Mesoscale Prediction System and the Coastal Ocean Remote Sensing Programs at NRL. These types of measurements will also be made during periods when Autonomous Underwater Vehicles developed by Florida Atlantic University will acquire subsurface current and density profiles in a VHF OSCR domain in support of the ONR Ocean Modeling and Prediction program (Smith *et al.*, 1998). The radar approach may also be transitioned to NAVOCEANO operations for a JFTX this spring. This combined approach represents a new and unique technique to examine submesoscale variability in the littoral ocean.

RELATIONSHIP TO OTHER PROJECTS:

The OSCR deployment during HIRES was jointly supported by ONR Remote Sensing and MMS North Carolina Coastal Physical Oceanography Programs. This observationally-based oceanographic research project also has relevance to ONR Coastal Dynamics, Physical Oceanography, Underwater Acoustics and Oceanographic Modeling and Prediction for basic and applied research initiatives. Ongoing research programs such as COAMPS at the NRL, NSF CoOP, and ONR/NRL Chesapeake Bay Outfall Plume Study have benefited from this program.

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