Momentum, Vorticity, and Mass Fluxes at SandyDuck

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LONG-TERM GOALS

The goal is to characterize nearshore flows as a function of the forcing conditions; e.g., in terms of alongshore and cross-shore fluxes of mass, momentum, vorticity, sediment transport, etc.

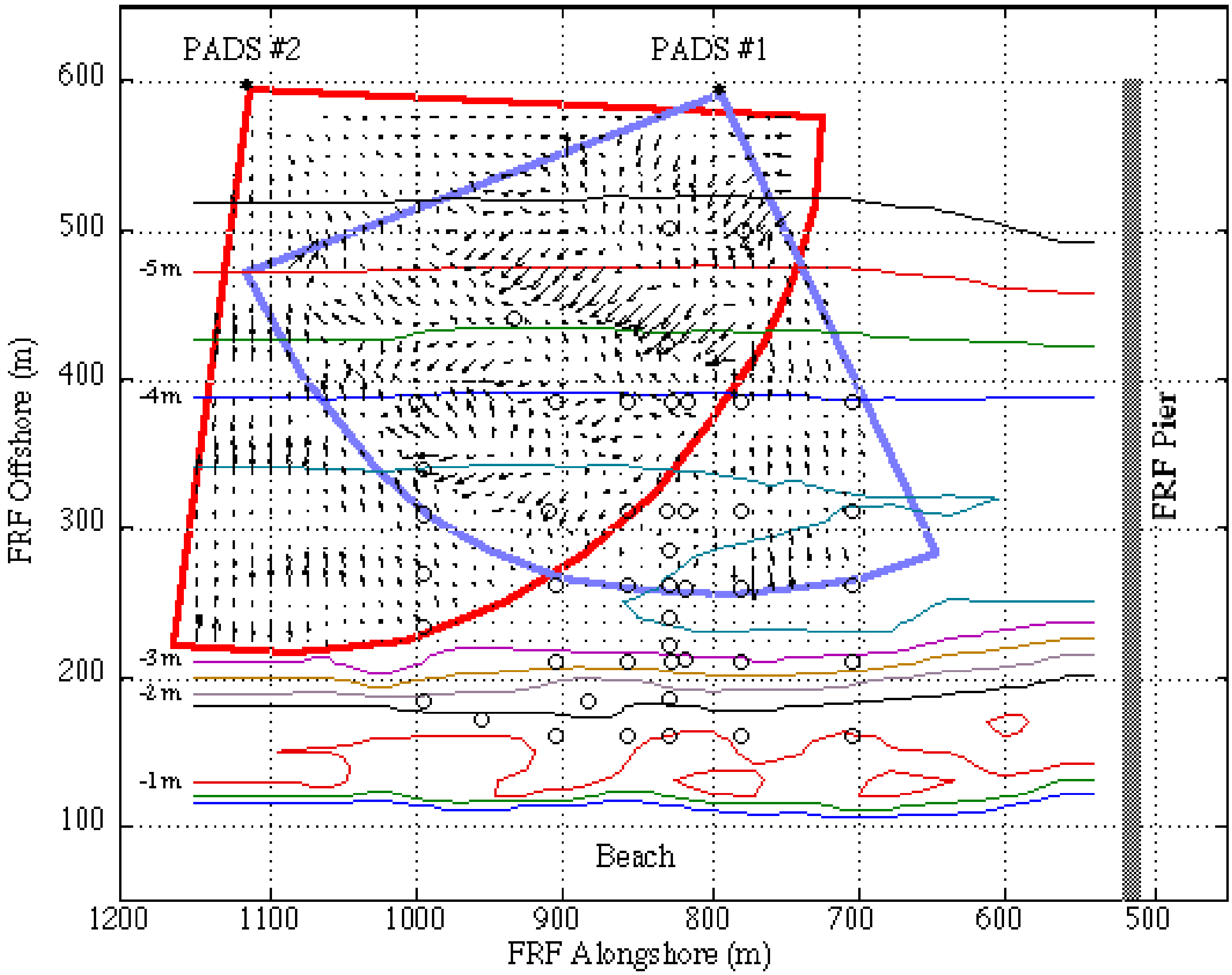
OBJECTIVES

The objectives of this project are (in order): (1) to understand and quantify the quality of data from "Phased-Array Doppler Sonar" (PADS) systems in the shallow water environment near shore. (2) To classify the observed circulation conditions in terms of wave height and direction, wind strength and direction, mean flow strength and direction, and (perhaps) variability. (3) To make the interesting segments of data available over the internet. (4) To begin integrating the data into models of the nearshore hydrodynamics.

APPROACH

Two "Phased Array Doppler Sonars" (PADS) were deployed as part of SandyDuck in 1997 (figure 1), and were operated for two months (September & October). The essential method is to project sound over a 90°-wide horizontal fan. The sound scatters off particles in the water and off the bottom. The backscattered signal is digitally beamformed into returns from discrete directions, and analyzed for the Doppler shift. The time-delay since transmission translates to radial distance. Thus, each PADS provides data over a wedge up to 400 m radius by 90°, with 8 m radial by 6° angular resolution. In the overlapping region, both horizontal components of flow are estimated. The data resolve both surface waves and lower frequency currents. This extensive coverage is compelling for the study of waves/current interactions, so there is incentive to investigate the approach thoroughly.

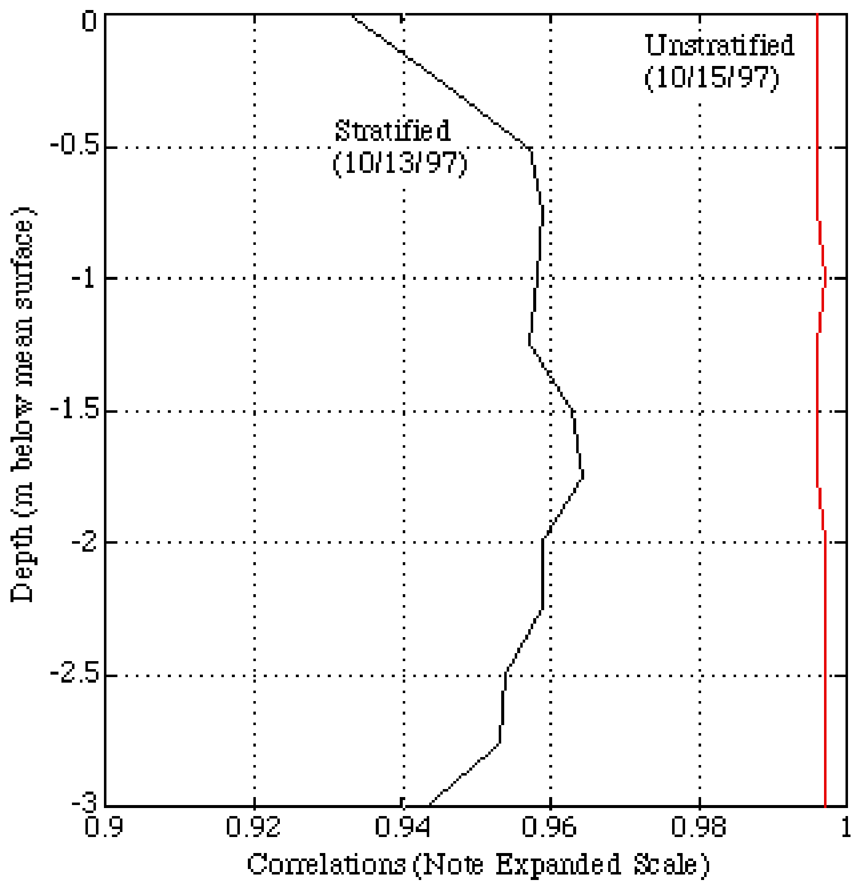
The first task is verification and calibration of these acoustic measurements. This is undertaken through comparison with independent measurements made at many locations in and near the area viewed by the PADS. Near-bottom currents were provided by S. Elgar et al. (WHOI and SIO) and A. J. Bowen et al. (Dalhousie), and, at one location, low-frequency current profiles in 25-cm vertical bins were provided by P. Howd (USF) for this purpose. The data provided by Elgar et al. resolve surface waves. Wave data provide more comprehensive and rigorous comparisons, since the waves have deterministic depth dependence, and propagate according to a well-defined dispersion relation. The former implies that detailed comparisons can be made regardless of the depth of measurement, while the latter implies that the surface wave field characteristics can be reliably interpolated and extrapolated over the entire domain surveyed by the PADS systems. The ability to carry out this comparison over the whole field of view, in turn, permits investigation into the time-space characteristics of the acoustic response. Rather than develop a complete wave propagation model, the approach taken here is to employ an approximate model, incorporating finite depth dispersion, action conservation, and dissipation due to breaking [*Thornton and Guza*, 1986], but neglecting focussing (i.e., assuming a beach that is uniform alongshore).



1. SandyDuck experimental site, showing the area covered by the two "Phased Array Doppler Sonars" (PADS). The arrows indicate velocity estimates from a single snapshot, dominated by swell from the upper right (SE); the longer arrows correspond to velocities approaching 1 m/s. Both horizontal components are estimated in the overlap region. The circles show locations of frames with other instrumentation. (At the USACE Field Research Facility, Duck, NC)

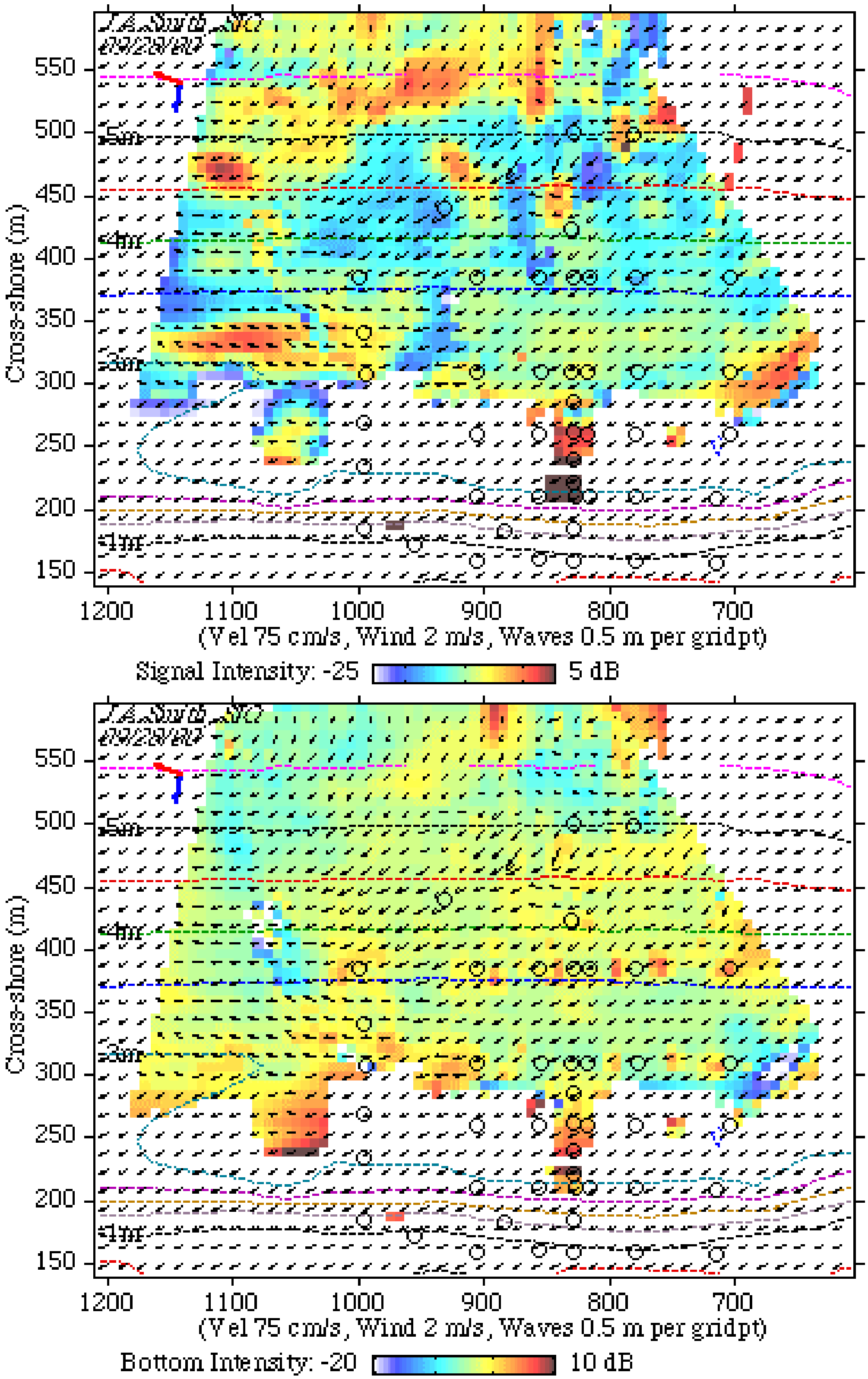
WORK COMPLETED

Comparisons were carried out between the low frequency "reference data" and similarly low-passed PADS data. In general, the correlations are quite high between the PADS data and fixed current meter measurements (figure 2). Slightly lower correlations are seen for stratified conditions, with maximum correlations occurring with fixed-level data at about 1.5 m below the mean surface (significant wave height at the time of comparison was about 0.5 m).



2. Correlations between PADS velocity estimates and point measurements at various depths. (Left) During stratified conditions correlations are slightly lower and exhibit a maximum near 1.5 m depth. (Right) For well-mixed conditions the correlations are uniformly high.

Next, comparisons were carried out at surface wave frequencies. The acoustic measurements degrade near the current meter frames, so the comparisons are actually made between measurements separated by at least 15 m. The correlations between PADS and current meter data are comparable to those for two current meters separated by 15 m. On the other hand, the PADS-derived velocities are always smaller in magnitude than the reference data. This is interpreted as due to "mixing" the desired (volume) signal with bottom backscatter having zero Doppler shift. A simple acoustic model is used to partition the received signal into bottom and volume contributions: the ratio of observed to "true" surface wave variance is used to estimate the fraction of the signal coming from volume versus bottom backscatter (figure 3). The surface wave properties are estimated using finite-depth dispersion, action conservation, and the Thornton-Guza model for wave dissipation rates [*Thornton and Guza*, 1986],



3. Color contours of acoustic intensity partitioned into a "signal" portion (upper) and a "bottom" fraction (lower plot), with velocity vectors overlaid. Note the "spots" in the signal fraction, while the bottom backscatter is more uniform. The spots advect with the flow, verifying that the scatterers are imbedded in the water; in contrast, the "bottom" varies only slowly. (12:24 UTC, 9/11/97)

together with the simplifying assumption of a quasi-one-dimensional beach. This “acoustic partitioning” is updated continually, based on velocity variance estimates formed over several minutes versus the inferred maps of the radial component of surface wave orbital velocities. Input wave parameters were taken either from the FRF 8 m array analyses or from Elgar et al.’s data.

RESULTS

For lower frequency motions such as shear-waves and eddies, the correspondence between near-surface and near-bottom measurements depends on stratification. When well-mixed, currents near the bottom correlate tightly with the near-surface currents. When stratified, the correlations between top and bottom become smaller, with veering in current direction as well. The depth of measurement most tightly correlated with the PADS data is near 1.5 m below the surface (mean with respect to waves, moving with the tide). At surface wave frequencies, cross-spectra show high correlations up to frequencies of about 0.2 Hz. Higher frequency waves have wavelengths comparable to the 20 m averaging scale of the measurements (i.e. less than 40 m). Again, the correlations are quite high, comparable to those between reference data separated by a comparable distance.

A simple surface wave model provides a means to deduce the division between volume (signal) and bottom backscatter levels. Due to the natural variability of bubble clouds (etc.), the volume backscatter can be highly variable in time and space, with anomalies generally advecting with the flow. In contrast, the bottom reflections are quasi-stationary (varying slowly with the tide, bottom roughness, etc.). The approach is successful in the sense that (1) the deduced bottom backscatter component does indeed vary on much longer timescales than the volume component, and (2) it provides “calibration factors” for the velocities that bring the sonar response in line with that of the independent current measurements for both the wave frequency and lower frequency flow fields.

IMPACT/APPLICATIONS

The means by which we have viewed the velocity and vorticity fields in this study is novel. The PADS measurements are a natural complement to the discrete arrays of high-precision current meters, pressure sensors, (etc.) deployed within and near the surf-zone. As observations of conditions and responses are built up, we can test models and improve our predictive ability.

REFERENCES

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RELATED PROJECTS

Future projects include possible participation in an experiment focusing on waves and currents over the head of a submarine canyon (NCEX), and open ocean measurements of waves and Langmuir circulation.

TRANSITIONS

Areas of interest include (for example) monitoring waves and currents at inlets and harbors.

PATENTS

Paperwork toward patenting PADS technology has been registered.