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In-Situ Wave Observations in the High Resolution Air-Sea Interaction DRI

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LONG-TERM GOALS

Ocean wave prediction models, based on a spectral energy balance, are widely used to obtain wind-wave forecasts and hindcasts on global and regional scales (e.g., Komen et al., 1994). However, these inherently stochastic models assume a Gaussian and homogeneous sea state and thus do not describe the nonlinear instability processes that can dramatically alter the structure of wave groups and produce anomalously large waves, also known as 'freak' or 'rogue' waves. Fully deterministic modeling capabilities are now becoming available that incorporate these nonlinear effects and provide the detailed phase-resolved sea surface predictions needed in many applications. Concurrent with the development of new models, advances in radar remote sensing techniques are enabling the detailed observation of the sea surface on the scales of wave groups and individual waves. The long-term goal of this research is to test these emerging new models and measurement technologies in realistic sea states and use them to better understand and predict the wave group structure and occurrence of extreme waves in the ocean.

OBJECTIVES

- Observe the nonlinear evolution of wave groups in realistic broad-band sea states.
- Provide ground-truth data for testing the capabilities of ship-board wave radar systems.
- Provide in-situ wave data for the verification of phase-resolving wave prediction models.

- Develop and test a prototype wave-resolving GPS drifter.
- Develop models for nonlinear wave evolution in a varying medium.
- Develop a statistical model for the evolution of inhomogeneous wave fields.

APPROACH

The primary goal of the High Resolution Air-Sea Interaction DRI is to advance observational and modeling techniques for monitoring the wave-resolved sea surface around a vessel. Field experiments were conducted off the California coast (Figure 1), using the deep water floating platform FLIP with a suite of meteorological and oceanographic instruments, airborne and ship-board radar systems, and an array of moored and free drifting buoys. Our contribution to these experiments consisted of an array of surface-following moored and drifting buoys that was embedded within the footprints of FLIP-based, airborne and ship-board remote sensing systems. The array covered a nominal area of about 15 by 15 km that spans the evolution scales of nonlinear wave groups.

The first set of field data were collected in a week-long pilot experiment in June 2009 offshore of San Clemente Island located on the seaward side of the Southern California Bight. This site provided a benign wave environment dominated by long-period swell from the Southern Hemisphere. The pilot experiment was followed by a month-long main experiment in June 2010 off the Northern California coast near Bodega Bay. The latter site was chosen to capture the energetic wind sea conditions driven by persistent strong alongshore winds.

In both experiments, drifting surface-following wave buoys were deployed on numerous occasions to provide in-situ wave measurements for air-sea interaction studies conducted with ship-board and air-borne sensors, and (in 2010) from the platform FLIP. The Datawell Directional Waverider (DWR) buoys used in the experiments, are small surface-following buoys that measure vertical and horizontal water particle motion at the sea surface directly, from which time series of surface height and slopes can be extracted. The accuracy of these buoys is well established (e.g., O'Reilly et al., 1996) and their reliability in high sea states makes them very suitable for deployments in the open ocean. The buoys include three different types of Datawell Directional Waverider buoys as well as a prototype lower-cost drifter equipped with an "off-the-shelf" GPS position receiver (Figure 1). Several different models of GPS position receivers were attached to the Datawell buoys to evaluate their potential use as low-cost sensors in wave-resolving drifters.

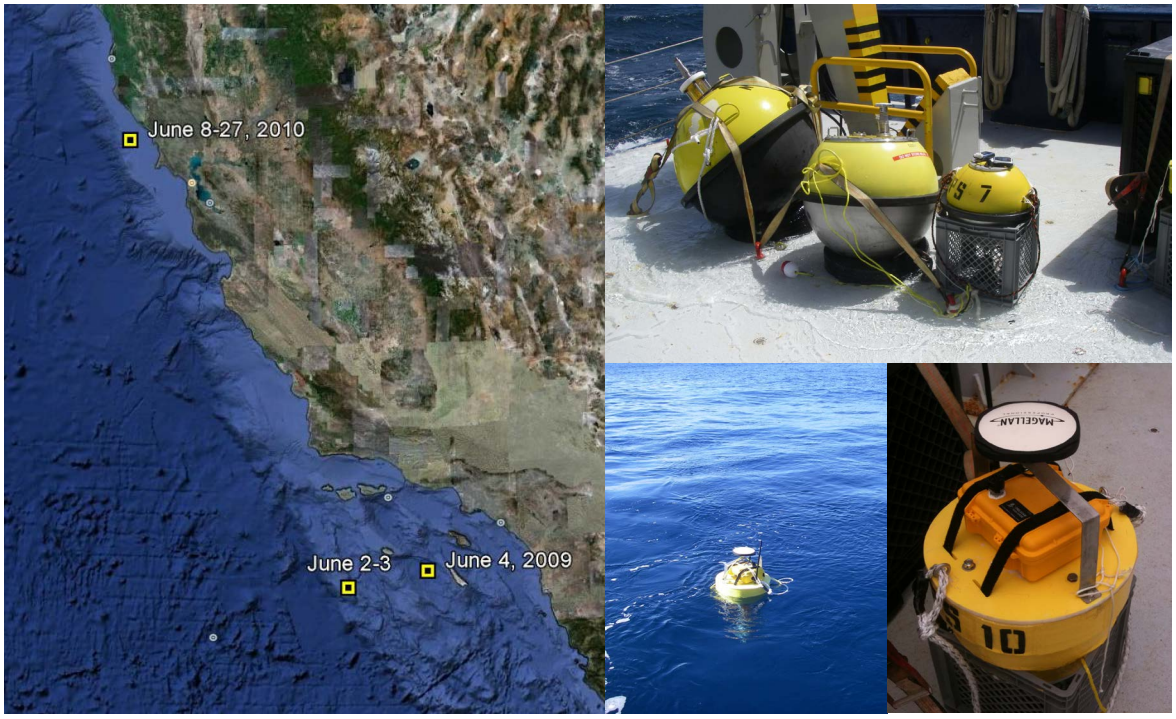

FIG. 1. Field site and instrumentation. Left panel shows the locations of the buoy deployments off the Southern California coast in 2009 and the Northern California coast in 2010. The upper right photo shows (from left to right) Datawell DWR-MkII, DWR-G7 and DWR-G4 buoys. The lower panels show a prototype GPS drifter in the ocean and up close. The Pelican case holds the Magellan Mobile Mapper CX GPS receiver and an RF transmitter. The Ashtech ProMark3 NAP100 antenna is mounted on the handlebar.

WORK COMPLETED

Three different types of sensor systems were used to measure waves in this study. The Datawell DWR-MkII buoys are equipped with accelerometers, tilt sensors and compass whereas the sensor package in the DWR-G7 and DWR-G4 buoys is based on the Doppler shift in GPS signals. The wave measurements from the Magellan, Locosys, and GlobalSat GPS receivers are all based on SBAS absolute position data. In the initial analysis phase, measurements obtained with these different types of sensor systems mounted on the same buoy were compared to validate the use of these in-situ wave measurements as a "ground-truth" for evaluating the capabilities of ship-board wave radar systems and verifying the accuracy of phase-resolving wave prediction models. Additionally, the sensor intercomparisons provided an opportunity to explore the potential use of relatively inexpensive GPS position receivers as wave sensors in surface drifters.

To summarize the sensor performance for all buoy deployments, comparisons of estimates of bulk wave parameters are shown in Fig. 2. Estimates of the significant wave height, the mean wave period, the mean direction and directional spread obtained from GPS position receivers are compared in scatter diagrams with estimates from the Datawell sensor on the same buoy. The estimates are based on horizontal buoy displacement data which are more robust than the vertical displacement data for the

Locosys and GlobalSat GPS receivers which have poor vertical accuracy. The agreement is generally good for all sensors with typical differences of only a few percent for the wave heights and periods, a few degrees for the mean wave direction, and less than ten percent for the directional spread. Overall, these comparisons show encouraging consistency between different types of wave sensors and demonstrate that reliable routine wave information can be extracted from inexpensive off-the-shelf GPS receivers.

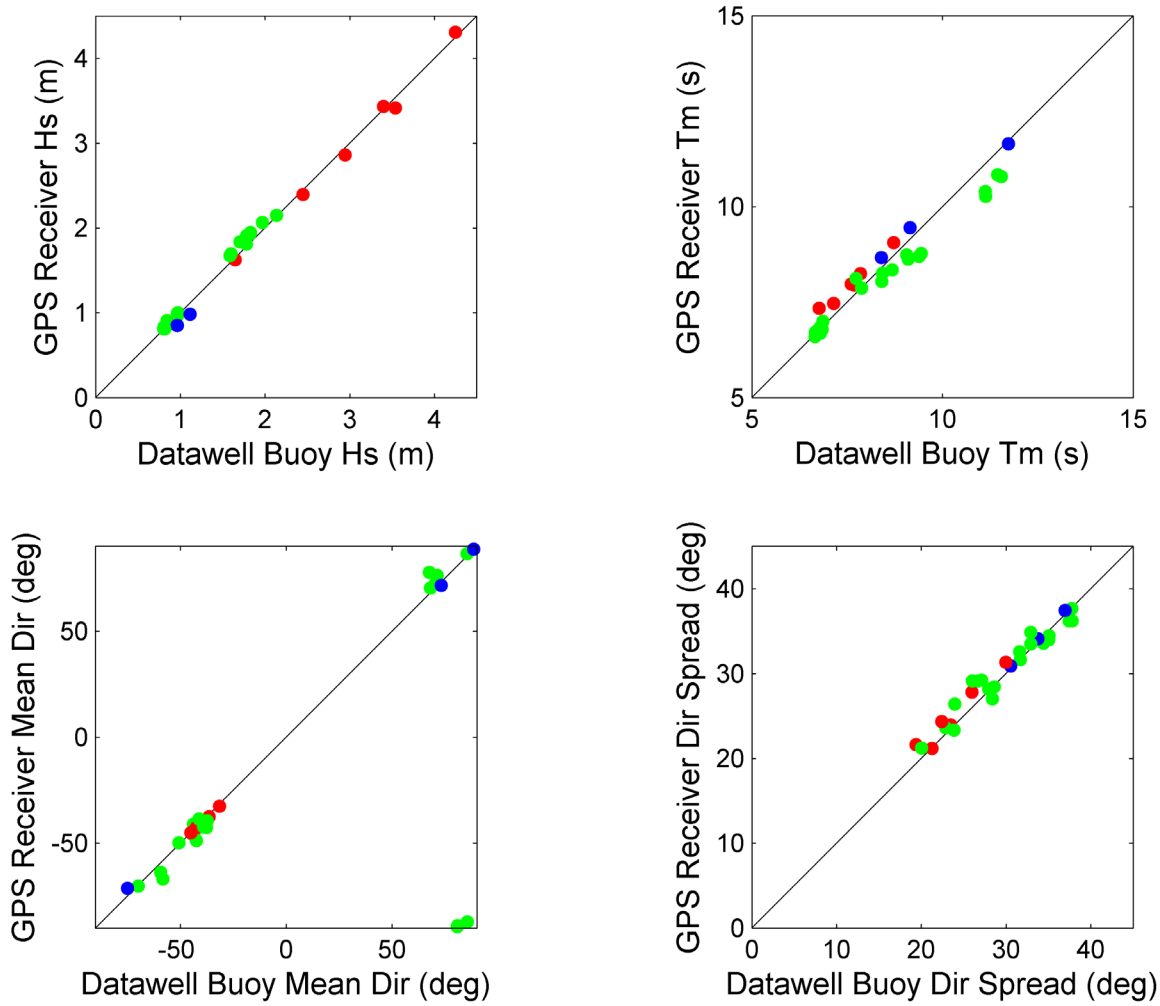

Fig. 2. Bulk wave parameter estimates obtained from GPS position receivers are shown in scatter diagrams versus estimates from the Datawell sensor on the same buoy. Blue circles: Magellan GPS receiver on drifting MkII buoy. Green circles: Locosys GPS receiver on drifting DWR-G4 or DWR-G7 buoy. Red circles: GlobalSat GPS receiver on moored DWR-G7 buoy.

RESULTS

Example observations of buoy deployments in benign swell conditions (significant wave height 0.9 m) on June 3, 2009 are shown in Fig. 3. In this deployment, five Datawell buoys were deployed including one DWR-MkII (0.9 m diameter, black curves), two DWR-G7 (0.7 m, green), and two DWR-G4 (0.4

m, blue). Deployed in a tight cluster, the buoys drifted north with a surface current of about 0.25 m/s. While the smaller (0.4 and 0.7 m diameter) buoys stayed close together, the larger (0.9 m) buoy drifted farther east suggesting possibly some windage effect from the packages mounted on the buoy. Estimates of the wave energy and direction spectra are all in good agreement, resolving a complex tri-modal wave field with a dominant narrow-band 0.06 Hz swell from the southern hemisphere, an intermediate wave system with a peak frequency of 0.14 Hz arriving from a westerly direction, and a weak high-frequency (about 0.25 Hz) wind sea from the north.

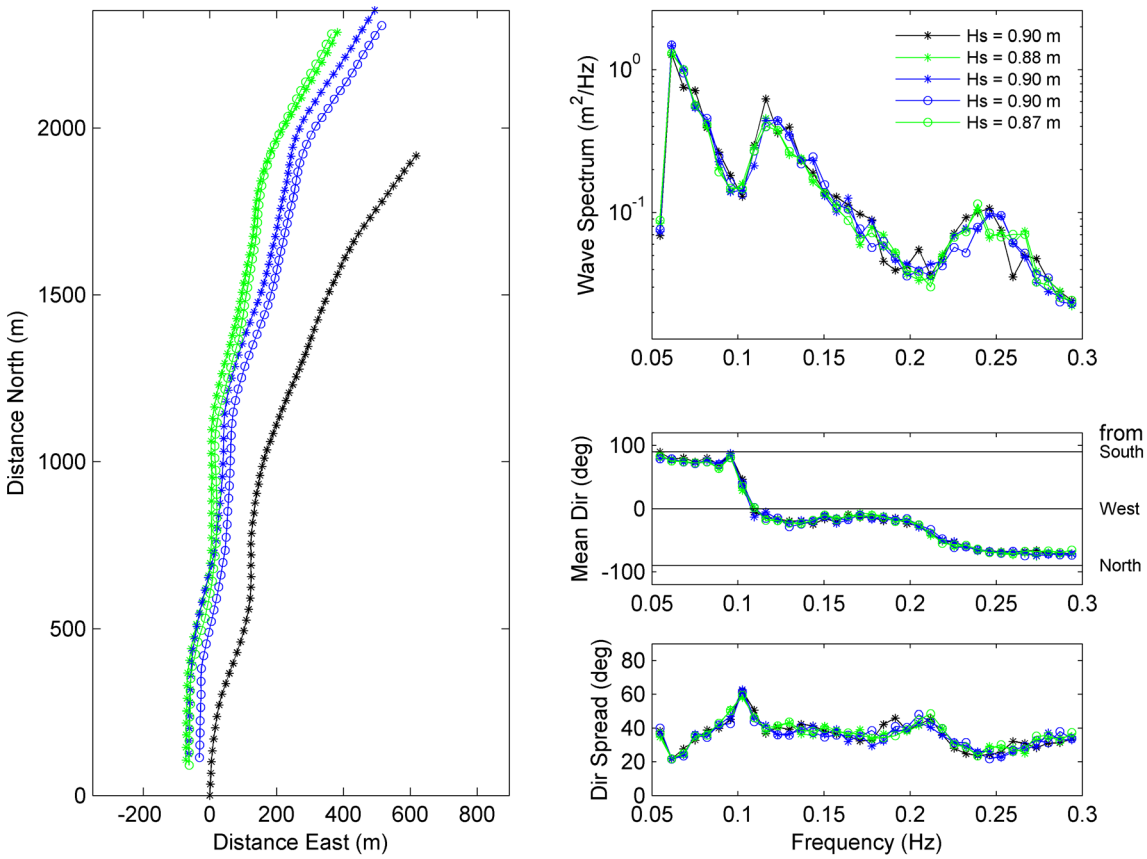

Fig. 3. Comparison of observations from five drifting Datawell buoys deployed on June 3, 2009. The buoys include one MkII (black curves), two DWR-G7 (green) and two DWR-G4 (blue) buoys. Left panel: drift tracks. The origin corresponds to the initial position of the MkII buoy. Right panels: from top to bottom: wave frequency spectra, frequency-dependent mean direction, and directional spread.

Comparisons of buoy observations in more energetic wave conditions in the 2010 experiment are detailed in Fig. 4. Results are shown for four occasions when the new prototype GPS drifters were deployed together with DWR-G7 and DWR-G4 buoys. The observations of moderately energetic sea states ($H_s = 1.7$-2.1 m) include narrow- and broad-band wave spectra with both uni- and bi-modal shapes. In all four cases, the dominant waves are driven by the prevailing strong northwesterly winds, with a variable lower-frequency southern hemisphere swell contribution. Estimates of the wave energy and direction spectra obtained with the prototype GPS drifters (red curves) are generally in

good agreement with the Datawell buoys (green and blue curves), with the exception of the high-frequency spectral tail where the higher spectral levels and directional spreading values suggest higher noise levels. Similarly, the higher spectral levels below the spectral peak recorded by the prototype drifter on June 12 (upper left panel) are indicative of measurement errors. Overall, the high level of agreement demonstrates that these relatively inexpensive drifters using off-the-shelf GPS receivers can consistently resolve the detailed spectral properties of ocean surface waves.

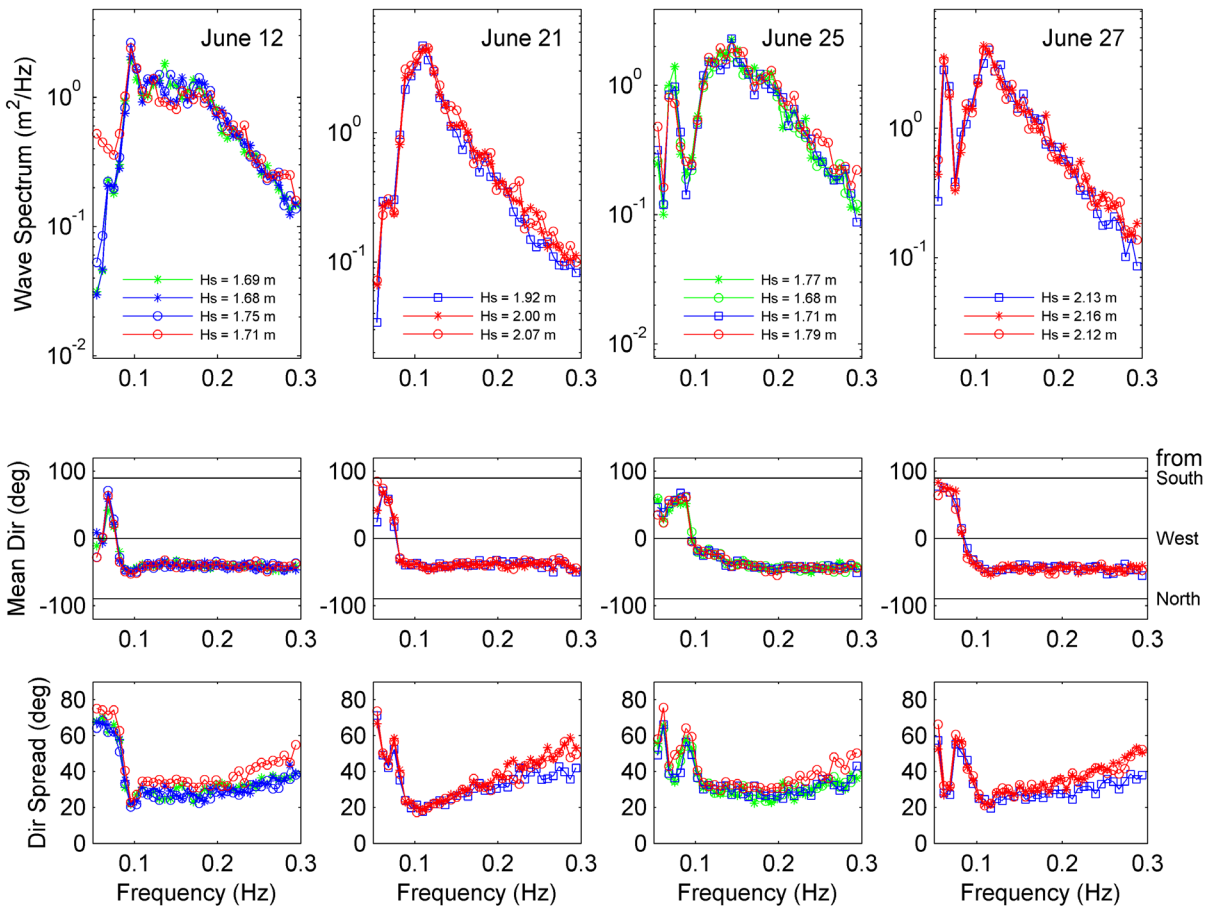

Fig. 4. Comparison of wave observations from Datawell DWR-G7 (green curves) and DWR-G4 (blue) buoys, and prototype GPS drifters (red), drifting within 1 km from each other. From left to right: results from four deployments in June, 2010. From top to bottom: wave frequency spectra, frequency-dependent mean direction, and directional spread.

IMPACT/APPLICATIONS

This project will yield an improved understanding of ocean surface wave dynamics in deep water and a comprehensive verification of numerical models and radar remote sensing techniques in natural broad-band sea states. These results are critical in the future development of a system for routine monitoring of the wave resolved sea surface around a vessel.

RELATED PROJECTS

The wave-resolving GPS drifters developed in this project are used in the ONR Inlets and River Mouths DRI.

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