# Wind Input, Surface Dissipation and Directional Properties in Shoaling Waves


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## LONG -TERM GOAL

We wish to improve our understanding of the physics and interactions which govern the spatial and temporal evolution of surface waves in finite depth water.

## SCIENTIFIC OBJECTIVES

1) To measure the direct wind forcing of waves as they advance into shallow water.

2) To measure the evolution of the wavenumber spectrum as the waves shoal.

3) To estimate the kinetic energy dissipation in the surface waters.

# Report Documentation Page

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4) To determine the dependence of the energy and momentum input into shoaling waves on the wavenumber spectrum and the wind.

5) To determine the dependence of wave dissipation on the wavenumber spectrum and the rate of shoaling.

6) To determine the directional response of the wavenumber spectrum on surface current shears and variable bottom bathymetry.

## APPROACH

An extensive field program, SHOWEX (Shoaling Waves Experiment) was carried out to study the spectral balance of shoaling ocean waves in September – December 1999. Three air-sea interaction spar (ASIS) buoys were deployed at the inner and outer shelf off Duck, NC and acquired continuous time series of directional wave spectra using a nested wave wire gauge array, observations of meteorological variables (wind stress, atmospheric stability, pressure, and humidity), and near-surface oceanographic variables (near-surface currents, temperature, density and salinity). One of the ASIS buoy was deployed at the inshore edge of the inner shelf to provide meteorological measurements and to intercompare different directional wave measurements (directional waverider, bottom pressure array and HF radar). Direct measurements of the wind input to the waves were obtained from a small SWATH ship, the ‘‘*Fredrick G. Creed*‘‘, which was equipped with a special boom to measure pressure, flow and turbulence at four levels following the wavy ocean surface and the directional wave spectrum using a nested array of laser altimeters. These measurements will be used to estimate source terms for wind input and wave dissipation. The transects of the SWATH ship will provide the context of the measured spectral evolution of the wave field among the buoys and will be compared to calculations based on the action balance equation by incorporating the measured source terms. An HF Doppler radar measured surface vector currents maps over most of the domain including the ASIS buoys and directional waveriders from other investigators. Raw data was also collected to estimate directly: 1) the directional wave properties and 2) marine surface wind vectors over the domain at high spatial and temporal resolution. Combining the surface current measurements with the spectral wave data from the HF radar and the buoys will be used to study the intensity and variability of wave-current interactions. Combining the spectral wave data from the HF radar and the buoys and the high-resolution bathymetric data will allow us to study the variability of wave transformation due to small-scale variations in the bottom topography over the inner shelf. The estimates of the marine surface wind vectors from the radar data will provide high-resolution wind fields for local applications of numerical wave models and comparisons with airborne wind measurements.

## WORK COMPLETED

1. Three ASIS buoy systems (spar and tether buoy) were deployed during SHOWEX and collected continuous data: *BRAVO*: 29 Oct - 26 Nov; *ROMEO*: 22 Oct - 30 Nov; *YANKEE*: 29 Oct - 13 Dec, 1999.

2. Post-calibration of all sensors on the ASIS buoys has been completed and appropriate calibration constants have been determined from pre- and post-SHOWEX calibration data sets. Processing of all data is completed and means of meteorologic and oceanographic variables have been computed. Directional wave spectra are computed with the MLM and wavelet techniques. Preparation of data

sets for intercomparison with other buoys and instrumentation, for project studies and collaborative studies with other SHOWEX investigators are under way.

3. Deployment of two directional waveriders and a MiniMet buoy (Dobson) covering the experimental period of SHOWEX. All data has been processed.

4. The SWATH ship was operated during SHOWEX from 12 Nov - 07 Dec with a general 3 days on / 2 days off schedule. Final calibration of all sensors and instrumentation has been completed. Data from the laser altimeters has been processed to provide surface elevation measurements. Data processing of the profiles of pressure and Pitot tube sensors is on-going. Meteorological data from the bow mast (total of 190 20-min data runs were collected) has been processed in collaboration with F. Dobson. At the beginning and end of the experiment, a total of six days were devoted to collecting high-resolution bathymetry using a multibeam sonar for T. Stanton (NPS).

5. The Royal Military College, Kingston, ON (Dr. Joe Buckley) supplied an X-band marine radar equipped to acquire images of the wave field at grazing incidence angles twice/sec. These will be processed to show adherence to the expected dispersion relation, wave length, direction and height, and wind velocity and (if feasible) wind stress. The radar was run continuously whenever data acquisition with the U. Miami and BIO systems was in progress.

6. The HF radar system was deployed from 21 Oct - 13 Dec and collected data which generated surface vector currents maps. All surface vector currents have been post-processed and checked. Raw radar data have been transferred from tapes to CD-ROM and made available to Lucy Wyatt, Sheffield University for extraction of directional wave spectra.

7. First SHOWEX workshop, held at Oregon State University, to provide inventory of all data collected, establish common data formats and begin collaborations with other investigators.

8. The SHOWEX web site is continuously updated to reflect the current status of the pre- and post-experimental activities and new results. The web site will be used to exchange data and information among investigators. The web site is located at http://cheyenne.rsmas.miami.edu/showex.

**RESULTS**

Two of the innovative data systems on the SWATH ship, "Frederick G. Creed", during SHOWEX were the five laser-ranging gauge array for surface elevation and the vertical array of actual pressure probes to estimate the direct wind forcing of waves. Both of these systems were mounted off the starboard side at the end of the 7m boom. The lasers were infrared and so were reflected from the surface with virtually no penetration. They were pulsed at 2000 Hz and the resulting ranges averaged and recorded at 50 Hz. This reduced the range noise by a factor of six and enabled us to resolve the surface to ±0.003 m. Figure 1 is an example of frequency spectra and directional spectra obtained with this array.

The ship was heading at 6.5m/s into a strongly forced wind-sea with recent swell following. The vertical displacements of the end of the boom have been added to the relative range measurements of the lasers, but no correction has been made for the horizontal speed of the ship. The directional spectrum has been computed using the Wavelet Directional Method (Donelan *et al.,* 1996).

Figure 2 was obtained in pure wind-sea conditions with the ship heading directly into a strong wind. It shows the phase averaged downwind surface slope in a frequency band near the peak. The phase of the surface slope is selected by band passing the surface slope signal in the range 0.2 to 0.5 Hz and applying the Hilbert Transform to the band passed signal to determine the local phase. The pressure is simply the averaged of (full bandwidth) pressure at each phase of the surface slope. The pressure is shifted so that the maximum occurs at about 20 degrees down the maximum slope towards the trough. This may correspond to the average reattachment point for separated flow over these steep strongly forced waves. Note also the reduction in pressure amplitude with height above the surface. These data are being used to estimate the rate of wind input to the waves.

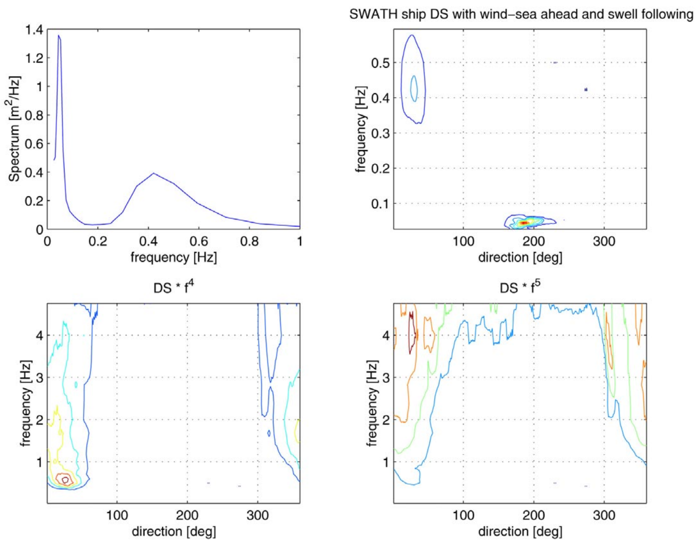


***Figure 1. Spectrum and directional spectrum obtained from the SWATH ship using the array of five laser-ranging gauges. The ship is heading into the wind with a swell following.***

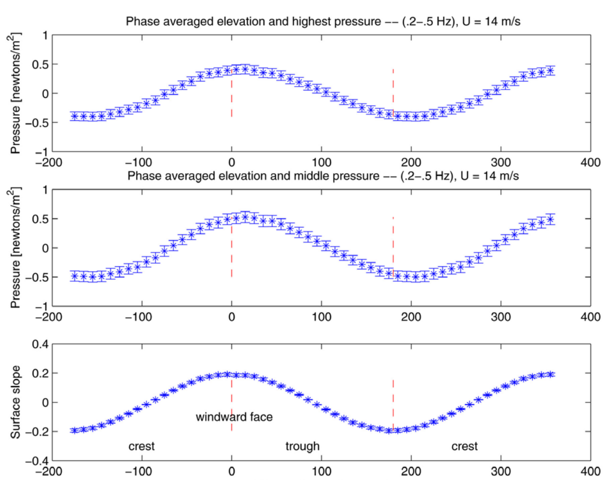


***Figure 2. Phase averaged surface slope and pressure measured at about 1.2m and 2m above the mean water level. The mean values are shown by asterisks with bars indicating ± one tenth of a standard deviation.***

The ASIS buoys were designed to provide high-resolution directional wave spectra for the experiment. In particular we are interested in studying the evolution and shoaling characteristics of the directional wave field over uneven bathymetry. Figure 3 shows an example of directional wave spectra measured at the three ASIS buoys around 3 November 2000, 2300 UTC when a moderately strong wind (~11 m/s) blew from west of north (345 deg at BRAVO) to northerly (350 deg at YANKEE) to east of north (5 deg at ROMEO). The inner shelf buoy (BRAVO) shows a developing windsea towards south-southeast and a shoaling swell field (Tp = 10 sec) propagating towards northwest. At the mid self buoy (YANKEE) the windsea is rapidly developing and shifting towards lower frequencies, while the swell, still heading towards the northwest has not yet felt strongly the effect of the bathymetry. At the outer shelf buoy (ROMEO), has shifted down further in frequency, but also split into two peaks. One peak is aligned with the prevailing direction of the north wind which now has the longer fetch, compared to the other peak which is still oriented more towards northwestnorth. The swell is not visible here. This is an excellent example and there are many more with which we hope to study the shoaling and refraction effects on the evolution of the directional wave spectrum.

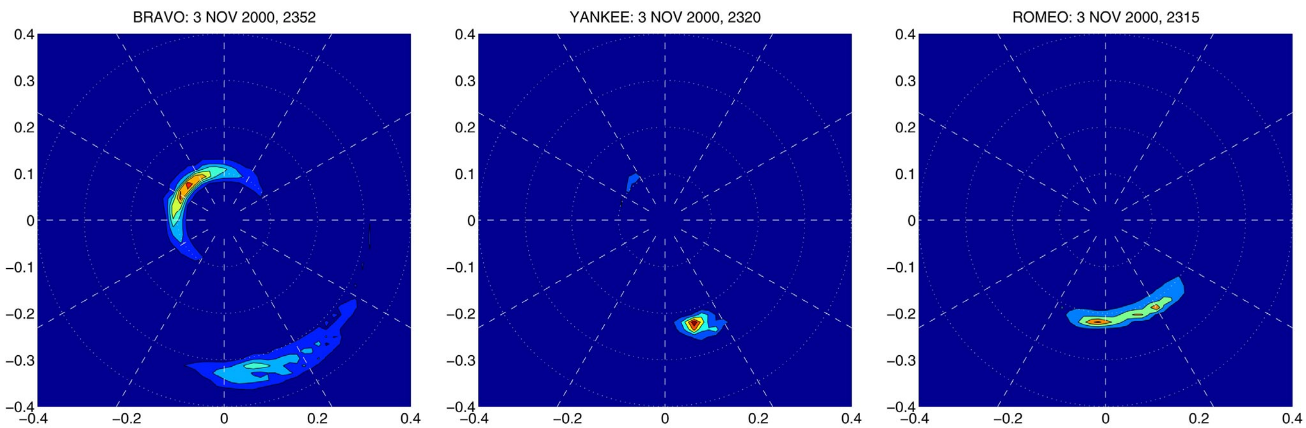


***Figure 3. Directional wave spectra measured with ASIS buoys BRAVO (left), YANKEE (middle), and ROMEO (right). The spectra were computed with the MLM technique. The spectra show the development of windsea with fetch for constant wind speed at 11 m/s with direction turning from 345 deg to 5 deg (left to right). The spectra also show the enhancement of shoaling of swell propagating towards northwest. Note that refraction has not yet turned the swell towards the coast.***

## IMPACT/APPLICATION

The ASIS buoy system has been tested under a variety of conditions in numerous experiments. Its superb stability characteristics (pitch and roll) makes it a suitable platform for high-resolution air-sea interaction, near-surface turbulence and directional wave measurements. In particular, The ASIS buoys could provide observations of wave breaking in strong wind forcing and the effects on coupling atmosphere and ocean via the wave boundary layer. Such measurements are critical to understand mixed-layer dynamics, transport of fluxes across the interface and backscatter issues in microwave and acoustic remote sensing over the entire range of wind speeds from low to high.

## TRANSITIONS

None yet.

## RELATED PROJECTS

1- The ASIS buoys were also used in a recent joint calibration/validation experiment for passive microwave radiometry for the upcoming Navy satellite WindSAT.

2- One ASIS buoy was deployed during the Adverse Weather Experiment conducted off the South Florida Ocean Testing Facility in support of calibrating AUV operations.

## REFERENCES

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Graber, H.C., E.A. Terray, M.A. Donelan, W.M. Drennan, J.C. Van Leer and D.B. Peters, 2000: ASIS - A new air-sea interaction spar buoy: design and performance at sea. *J. Atmos. Oceanic Tech.*, **17**(5), 708-720.