

## **Continued Analysis of SHOWEX Data**

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### **LONG-TERM GOAL**

Our long-term goal in this project is to understand, using data collected by our airborne microwave radar, CORAR, the propagation of surface waves longer than about 30 m from the deep ocean into the coastal zone.

### **SCIENTIFIC OBJECTIVES**

Our scientific objectives are to investigate the generation of forced waves produced by quadratic nonlinearities, the refraction of swell in shallow water, the possibility of determining bottom topography from refraction, and the effects of bottom topography and composition on the reflection and attenuation of swell propagating shoreward.

### **APPROACH**

Our approach has been to fly a coherent real aperture radar (CORAR) on the CIRPAS Twin Otter aircraft in order to make images in a sidelooking mode of the waves propagating toward and away from shore. From these images and data collected in a simultaneous rotating mode we attempt to compute directional wave spectra. The accompanying wind speed can also be determined from the rotating mode. We flew along with two NOAA radiometers that measured air/water temperature difference as well as wind speed and direction. Finally, we flew in formation with a NOAA LongEZ airplane that measured atmospheric winds and attempted to measure directional wave spectra at low altitude. We will compare our measurements with theirs.

### **WORK COMPLETED**

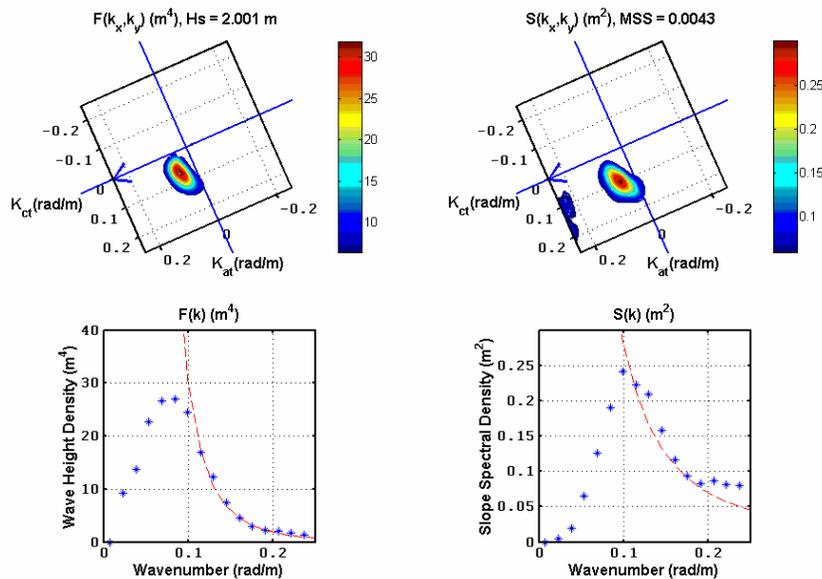
Data were collected simultaneously in the sidelooking and rotating modes during the main SHOWEX experiment in October and November, 1999. Subsequent analysis revealed that the incorrect antenna pointing direction had been used in the real-time corrections of the motion-induced Doppler shift in the rotating antenna. Thus the frequency modulated part of that data was not able to be utilized. All other data collected by CORAR seemed to be of very high quality. We have now submitted a paper to the Journal of Oceanic and Atmospheric Technology detailing our techniques and reporting the results discussed below (Plant et al., 2002).

## RESULTS

Initial results showed that directional spectra could be extracted from both the AM and FM parts of the sidelooking imagery and from the AM part of the rotating mode data. However, subsequent attempts to convert these spectra to calibrated wave spectra indicated that many times wave spectra derived from the AM products did not agree with those obtained from the FM part of the imagery.

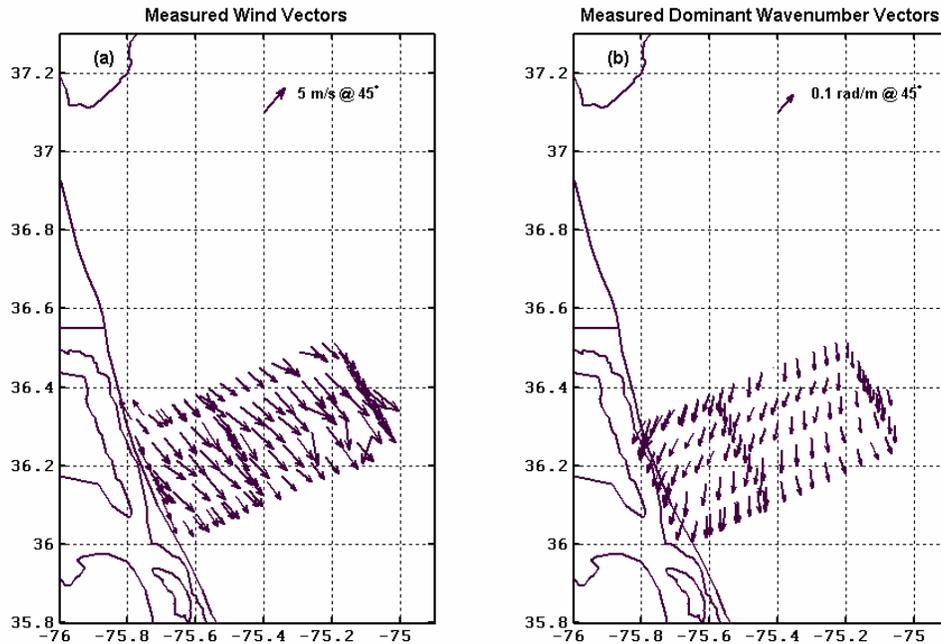
Furthermore, as we will demonstrate below, directional wave spectra obtained from the FM part of the imagery showed very well defined features that could be related to wind direction and bottom features. Furthermore, many features of these spectra could be modeled well using relationships obtained during the three-decade old JONSWAP. We have therefore concluded that spectra of received power cannot be easily related to directional wave spectra due to an insufficient knowledge of power modulations induced by waves and wind. For now we have set aside our attempts to better understand these modulation processes.

Directional wave spectra obtained from the FM part of the CORAR imagery, however, have yielded some very valuable insights into wave propagation in a coastal region. In particular they support the proposal of Donelan et al., 1985 (hereafter DHH) that winds blowing obliquely offshore generate dominant waves that do not propagate in the wind direction. On one particularly perspicuous day during SHOWEX, this feature of wind waves caused an offshore wind on the Maryland/Virginia coastline to generate shoaling waves in North Carolina.



**Figure 1. Wave height (left) and wave slope (right) variance directional spectra measured by our Coherent Real Aperture Radar (CORAR) during SHOWEX. Bottom spectra have been averaged over azimuth angle. Arrowheads show flight direction and the red dashed lines show  $k^{-4}$  for the wave height spectrum and  $k^{-2}$  for the wave slope spectrum.**

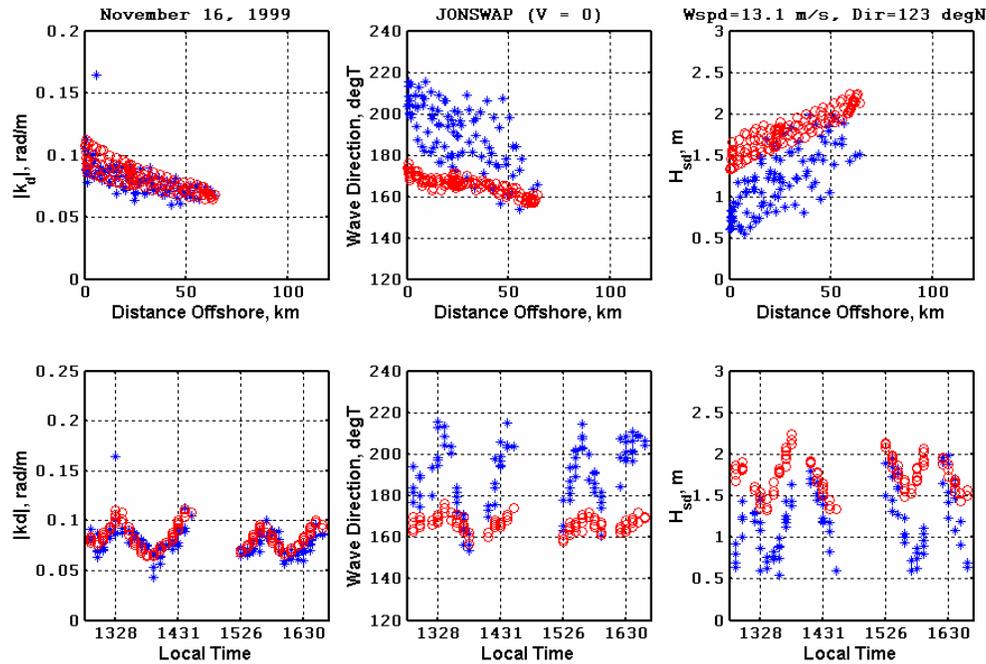
Figure 1 illustrates the directional wave spectra obtained from CORAR's FM imagery and shows the agreement of the azimuthally averaged spectra with expected forms. Extracting dominant wave directions and lengths from these spectra and wind vectors from scatterometry using the rotating mode yielded wind and wave fields as shown in Figure 2 on November 16, 1999.



**Figure 2.** *Wind vectors (left) and dominant wave number vectors (right) measured by CORAR on November 16, 1999 in the SHOWEX area near North Carolina.*

Clearly the directions of these dominant waves are not the same as the local wind direction; after refraction near the shoreline, they are, in fact, propagating nearly normal to the wind.

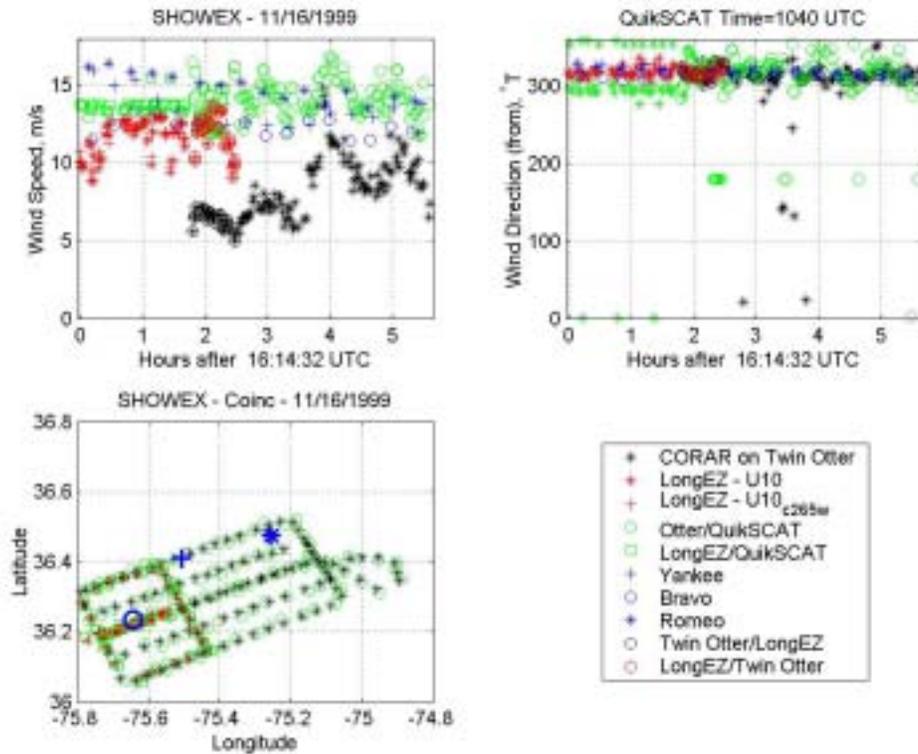
Using buoy winds to determine the wind speed and direction near the Maryland/Virginia coast, we applied the ideas of DHH to model the expected wave patterns near the North Carolina coast. However, rather than using the wave parameterizations developed by DHH on Lake Ontario, we used the JONSWAP parameterizations. The resulting comparison between modeled and measured waves is shown in Figure 3. Measured dominant wave numbers are fit almost exactly by the model. While the fits of wave direction and significant wave heights are not as good, the same patterns are seen in both the modeled and measured values. In Plant et al. 2002, we argue that the disagreement between these modeled and measured parameters is probably due to wave refraction during propagation from the Maryland/Virginia coast to the North Carolina one.



**Figure 3. Dominant wave number, dominant wave direction, and significant wave height modeled using JONSWAP parameters (red) and measured by CORAR (blue).**

The fit between model and measurements shown in Figure 3 is much better using these JONSWAP parameters than using the parameters determined by DHH. This result contradicts that of Walsh et al. 1989 for reasons that are unclear at this point.

Finally, we have recently compared wind speeds and directions that were measured by various instruments during SHOWEX with each other. The winds compared to date include those from our CORAR measurements, winds from the Miami buoys, winds from the gust probe on the LongEZ, and high-resolution QuikSCAT winds. We are nearly ready to include high-resolution RadarSat winds in our analysis. Figure 4 shows results obtained to date on November 16, 1999. Except for some expected aliases in the scatterometer data (QuikSCAT and CORAR), wind directions agree very well among all sensors. Wind speeds, however, are not in good agreement. Of particular concern is the disagreement in levels between CORAR and QuikSCAT. Note, however, that the slow variations of speed seen in both time series agree almost perfectly in phase. Analysis of this data set is still underway.



*Figure 4. Comparisons of winds measured by various instruments during SHOWEX. Top left – wind speeds, top right – wind directions, bottom right – locations of measurements.*

## IMPACT/APPLICATION

This project will shed new light on the interactions among wind, waves, and bottom that occur when long ocean waves propagate onto continental shelves. In addition to this scientifically interesting impact, the results will also allow an assessment of the feasibility of determining ocean conditions near denied coastlines by means of coherent radars mounted on remotely piloted vehicles.

## TRANSITIONS

CORAR has not yet been transitioned.

## RELATED PROJECTS

Closely related projects are the other ONR projects dealing with SHOWEX data, an NSF funded project to obtain high-resolution winds near shorelines from the RADARSAT SAR, and a NASA project attempting to extract high-resolution wind fields from QuikSCAT data.

## REFERENCES

- Donelan, M.A., J. Hamilton, and W.H. Hui, Directional spectra of wind-generated waves, *Phil. Trans. R. Soc. Lond.*, A315, 509-562, 1985.
- Plant, W.J., W.C. Keller, and K. Hayes, Simultaneous measurements of ocean winds and waves with an airborne coherent real aperture radar, submitted to *J. Ocean. Atmos. Tech*, 2002.
- Walsh, E.J., D.W. Hancock III, D.E. Hines, R.N. Swift, and J.F. Scott, An observation of the directional wave spectrum evolution from shoreline to fully developed, *J. Phys. Oceanogr.*, 19, 670-690, 1989.