

Spatial Variations of the Wave, Stress, and Wind Fields in the Shoaling Zone

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LONG-TERM GOALS

Our long-term goals are to improve parameterization of surface fluxes in the coastal zone in the presence of wave growth, shoaling, and internal boundary layer development. These goals include improving the present form of similarity theory used by models to predict surface fluxes and stress over water surfaces, and documenting development of internal boundary layers in the coastal zone that are currently not modelled correctly, particularly in cases of flow of warm air over colder water.

OBJECTIVES

Our objectives for the last funding year of the SHOWEX project are to understand interactions between the atmosphere and surface waves in the coastal zone by analyzing simultaneous measurements of atmosphere and sea states, especially two-dimensional oceanic wave spectra measured from three laser altimeters on board the LongEZ aircraft.

APPROACH

In order to understand interactions between the atmosphere and surface waves in the coastal zone, the first step is to process the observed atmospheric and oceanic wave data. We are experienced in analyzing atmospheric turbulence data, therefore, we have focused on processing two-dimensional wave spectra data based on measurements from the laser altimeters. Using three laser altimeters on board a small aircraft to measure two-dimensional wave spectra is a new technique and has never been attempted. We selected a flight day, when two perpendicular flight tracks were flown with reverse flights along each flight track (Fig. 1). The detailed laser data preparation includes despiking data due to laser-drop-outs and removing aircraft motions. The Morlet wavelet directional wave analysis from Mark Donelan at the University of Miami (Donelan et al., 1996) is used to resolve two-dimensional wave spectra. In order to test sensitivity of the application of the wavelet method to the three laser measurements to natural data noise (random wave variations), flight direction relative to wave propagation direction, and Doppler effects due to different travel speeds between the aircraft and oceanic surface waves, several sub-projects based on simplified data sets are undertaken. Simplified data sets include monochromatic waves, more realistic waves with Gaussian distributions, and waves created in a lab environment by Mark Donelan's group. Sean Burns at NCAR, working with Jielun Sun, did all the data processing.

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WORK COMPLETED

We have tested detailed laser altimeter processing procedures. We have identified data spiking problems due to laser drop-out. By working with the NOAA LongEZ group and Mark Donelan, we also successfully modified Mark's program to fit our application since the original program was applied to ship and buoy measurements. Working with the LongEZ group, we also modified the program to remove the LongEZ aircraft motion. We implemented Mark Donelan's Morlet wavelet wave directional analysis method to the aircraft-measured laser altimeter data. We also compared the aircraft-retrieved two-dimensional wave spectra with those obtained from Tom Herbers' buoy measurements. In addition, by using simplified monochromatic waves, we have also tested the sensitivity of the application of the wavelet method to the laser measurement noise, flight direction relative to wave propagation direction, and Doppler effects due to different travel speeds between the aircraft and oceanic surface waves.

RESULTS

Using the simultaneous measurements from the three laser altimeters, both surface wave frequency and wavenumbers can be resolved with the wavelet analysis. However, the resolved wave frequency is Doppler shifted due to speed differences between the aircraft and surface waves. Because of non-linear wave interactions at the coastal zone, the resolved wavenumber reaches to a saturation value at low wavenumbers. The surface wave with the highest wave amplitude has its wavenumber below the saturation threshold, therefore, it cannot be resolved at least for our test case. The resolved, Doppler-shifted frequency compares reasonably well with the observed frequency from a nearby buoy. The resolved wave propagation direction is within the same quadrant as that resolved from the buoy (Fig.2).

In order to understand uncertainty of the resolved wave propagation direction, several monochromatic waves were constructed, and the wavelet method was applied to the simple waves. We found that the wavelet analysis method is very sensitive to the data noise, either due to measurement errors or due to natural random motions of surface waves.

In order to obtain two-dimensional wave spectra for all the flights during SHOWEX, the sensitivity of retrieved two-dimensional wave spectra, especially wave propagation direction, to flight direction relative to wave propagation direction, and to speed differences between aircraft and wave propagation needs to be further studied. The sensitivity test should be performed using simplified but more realistic wave spectra.

Simultaneous measurements of the atmospheric turbulence and sea states also proved to be useful for understanding synthetic aperture radar (SAR) images collected from the satellite, RADARSAT (Vandemark et al., 2001). Vandemark et al. found that short wave slope variance is responsive to large eddies associated with coherent secondary flow in atmospheric roll vortices. They also found that widespread streaking on scales of 1-2 km in SAR images is related to fluctuations of along-wind velocity associated with regions of near-surface convergence and divergence as part of roll vortices.

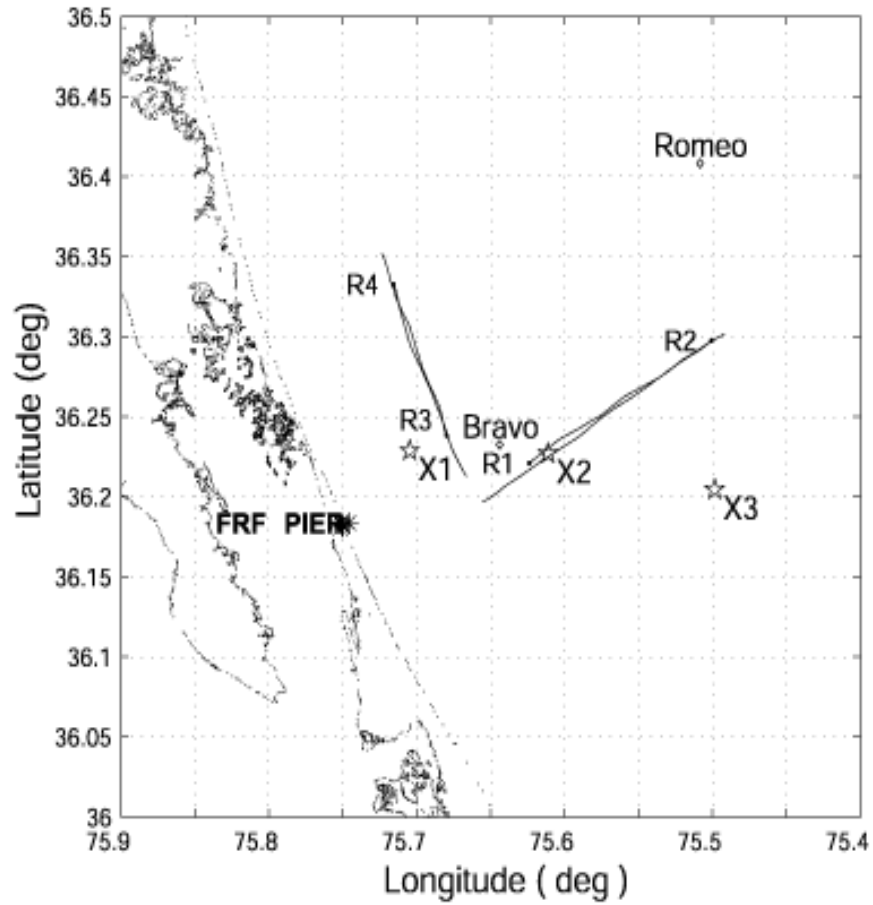


Figure 1: The four flight tracks off the coast of NC (R1, R2, R3, and R4) on November 15, 1999. Here x1, x2, and x3 are Datawell Directional Waveriders. Bravo and Romeo are SPARS buoys.

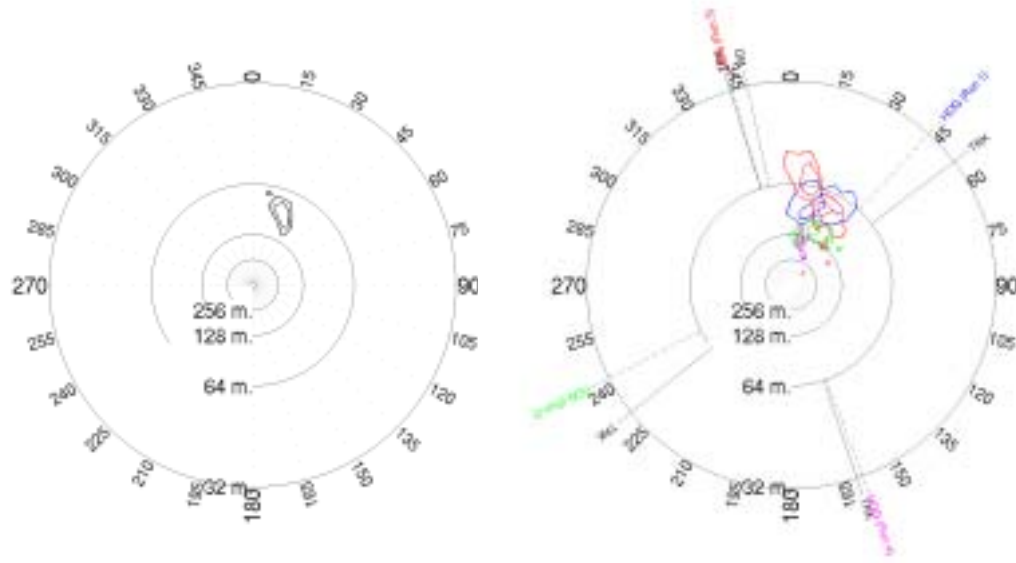


Figure 2: The resolved two-dimensional wave spectra from four aircraft runs (left), as in Fig.1, and from a nearby buoy in the polar spectral coordinates. The wavelength on the left panel is not Doppler corrected. The contour lines in the left and right plots are normalized wave amplitudes at 0.6 and 0.4, and normalized wave energy power at 0.6 and 0.4, respectively. The aircraft heading (HDG), which is color-coded with the resolved wave spectra, and flight track (TRK) for each run are marked as well as the wind direction (WD). The aircraft runs 1 and 2 are along the same flight track, with reverse headings, and runs 3 and 4 are along the same flight track, which is perpendicular to the track for runs 1 and 2. All four runs are within 30 km off the coast line of NC. [Each polar plot represents the resolved wave propagation direction with north on the top and east on the right, and the resolved wavelength marked by the circular rings.]

IMPACT/APPLICATIONS

Using remotely sensed surface waves from laser altimeters on board a small aircraft is a new observation technique. This technique allows the aircraft, which is equipped to measure atmospheric turbulence transport, to simultaneously measure oceanic surfaces. The moving observation platform will improve observations of spatial variations of air-sea interactions, especially over the region that is not easily accessible to buoys. Deployment of this technique during SHOWEX has demonstrated great potential for future air-sea interaction studies, for example, wave slopes and peak wave frequency as a function of off-shore distance (Sun et al., 2001). However, the derivation of the two-dimensional wave spectra needs to be further investigated and improved in order to carry out detailed analysis of momentum and energy transfer between the atmosphere and oceanic wave surfaces.

TRANSITIONS

Our work on the two-dimensional wave spectra was presented at the SHOWEX workshop at the University of Miami and the CBLAST LOW planning meeting at WHOI. We are currently working on several sensitivity tests before we finish the manuscript we are working on. The manuscript will be submitted to a journal for publication.

RELATED PROJECTS

Currently, we are also involved in the CBLAST LOW project. We participated in the LongEZ pilot experiment completed in July-August, 2001. We will analyze the LongEZ data to understand air-sea interactions under weak winds by applying similar data analysis techniques that we learned from the SHOWEX experiment, especially derivations of two-dimensional wave spectra.

SUMMARY

During the last funding year of the SHOWEX project, we have focused on deriving two-dimensional wave spectra from simultaneous measurements of surface wave heights through three laser altimeters on board the NOAA LongEZ aircraft. This remote sensing technique for two-dimensional wave spectra was first tested during the SHOWEX project, and we are the only group who has investigated this new methodology. We have found that the laser altimeter data are very useful to obtain wave slopes and frequencies and to understand interactions between the atmosphere and sea states. For example, based on the simultaneous measurement of the atmospheric turbulence transport and sea surface waves, we found that strong momentum transfer in the coastal zone is strongly influenced by upstream land surfaces when wind is off-shore (Sun et al., 2001). By comparing simultaneous measurements of meteorological components and sea states, Vandemark et al. (2001) found correlations between features observed from satellite SAR images and atmospheric roll vortices. The derived two-dimensional spectra approximately agree with those derived from buoy measurements. The derived wave propagation direction is sensitive to data noise, either due to measurement accuracy or natural random motions of ocean waves. Our participation in this ONR-sponsored work greatly enhanced NCAR's effort on air-sea interaction studies. Without this funding support, we could not carry out this research and improve our understanding of air-sea interactions. We have submitted a new proposal to ONR to continue our work on improving the technique to derive two-dimensional wave spectra and analyze the energy transfer between the atmosphere and oceans, especially over the coastal zone where spatial and temporal variations of air-sea interactions are significant.

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PATENTS

None