Measurement of Wave Coherence Using Spaceborne Synthetic Aperture Radar

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LONG-TERM GOALS

The Unites States Navy is evaluating the feasibility of constructing and deploying very large mobile offshore bases (MOBs). Such platforms may be 1.5 km long and 300 m wide. These structures fall far outside the scope of typical maritime design experience. Proper design depends upon the ability to characterize ocean waves fields, particular nonlinear features like wave "long crestedness" and wave "groupiness." The long term goal of this work is to quantitatively estimate these wave parameters**.**

OBJECTIVES

The specific objective of this work is to develop and apply techniques for the objective estimation of wave long crestedness and wave groupiness from spaceborne synthetic aperture radar (SAR) imagery of ocean surface waves. Spaceborne SAR imagery offers the unique combination of high resolution (25 m) and large swath (100 km) necessary to measure large scale wave coherence.

APPROACH

The authors listed above are the primary contributors to this work. The basic approach here is two fold. First, develop techniques to objectively measure two properties of wave coherence: ocean wave crest length and long crestedness. Second, apply these techniques to spaceborne SAR imagery. The difference between crest lengths and wave groupiness observed in SAR imagery and those predicted by linear theory is a measure of wave coherence caused by nonlinear wave-wave interaction.

WORK COMPLETED

SAR Wave Measurement

Ocean waves are typically measured at a single location as a function of time. However, assessment of the spatial coherence of waves requires measurement of the two-dimensional surface wave field. Spaceborne SARs offer important advantages in measuring spatial coherence: (1) They have sufficient resolution (typically 25 m) to capture ocean wave patterns. (2) Spaceborne SAR image swaths are typically 100 km wide or larger, providing a synoptic view of the wave field. (3) The global coverage of spaceborne SARs allows the acquisition of ocean imagery in the midst of storms.

The exact mechanisms that allow SARs to image waves have been discussed extensively in the literature [1-5]. The salient feature to note here is that the SAR image intensity is roughly proportional ocean wave slope.

Crest Length Measurement

Wave coherence can be manifested as wave "long crestedness", the lengths of typical wave crests. To economically assess wave long crestedness requires automated procedures that produce long-crestedness parameters from image archives with minimal human intervention.
The challenge of arriving at a statistical description of long wave crests is non-trivial. We have developed a rigorous and repeatable procedure for estimating cress lengths This procedure is dependent on the discretionary selection of only a few key parameters. The extraction of crest length statistics from SAR imagery involves two basic steps: (1) the filtering of a SAR image so that crests are conspicuously identified as separate "blobs," and (2) the measurement of crest length from these blobs. These techniques were developed as part of this work and are extensively documented in Monaldo [6,7]. Finally, we compare the observed crest lengths with those of an ocean having a similar simulated spectrum with no nonlinear interactions.

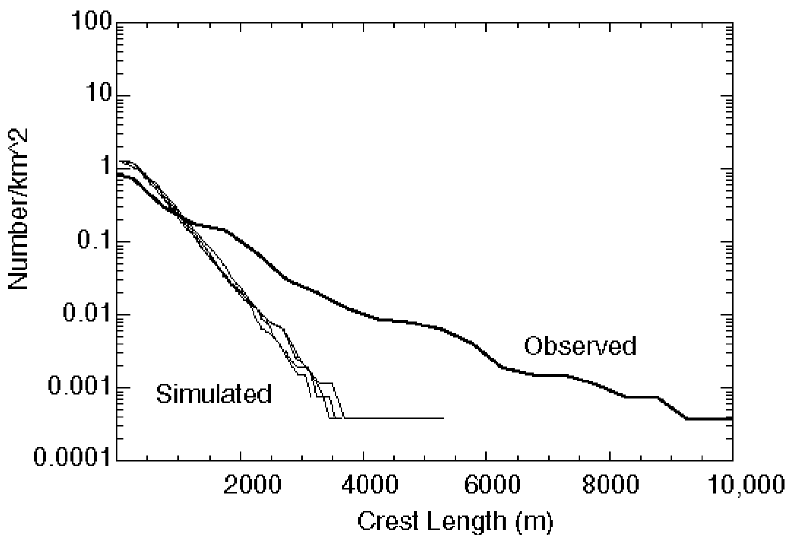

Figure: 1: The number of crests having a length greater than the abscissa near Hurricane Bonnie. The thicker curve is plotted from the imagery and the thinner curves are simulated.

Application of these techniques has been especially fruitful in examining imagery in vicinity of Hurricane Josephine (October 1984) and Hurricane Bonnie (August 1998). Results indicate that very long wave crests are more common on the ocean than would be expected from linear theory. Fig. 1 shows the number of wave crests longer than the abscissa that were found per square kilometer in Hurricane Bonnie SAR imagery. The higher curve was computed from the original image, while the lower curves were the result of simulations. The two curves represent the observed and simulated crest length statistics. From Fig. 1, we may infer that in the observed image one is likely to encounter two wave crests longer 1500 m in a 10 km^2 area. In the simulated images, it is not likely that a single such wave crest would be encountered. Similar results have been obtained with Hurricane Josephine data.

Wave Groupiness Measurement

The likelihood that large waves will group together in a series defines wave groupiness [6,7]. Any offshore platform will have more difficulty if especially large waves are grouped together possibly setting up a resonance. We suspected that wave groupiness might be apparent in the autocorrelation function.

Fig. 2 represents the one-dimensional autocorrelation function of an image near Hurricane Josephine along the path of wave propagation. At the center, or zero spatial lag, there are local correlations on scales of a few hundred meters. This corresponds to the existence of ocean waves in the image. Put more simply, a wave crest at any particular position is correlated with other wave crests one, two, or more wavelengths away. The correlation decreases as one moves farther away. The envelope of the oscillations is the signature of groupiness. For this case, groupiness has a spatial period of 2.5 km. Hence, for this particular wave field, one would expect especially large groups of waves separated by 2.5 km, about 10 wave periods.

Autocorrelations computed from simulated wave images based on linear theory did not exhibit this groupiness behavior. This is additional evidence that empirical data, rather than linear wave theory is needed to estimate wave groupiness. Similar conclusions were drawn from Hurricane Bonnie imagery

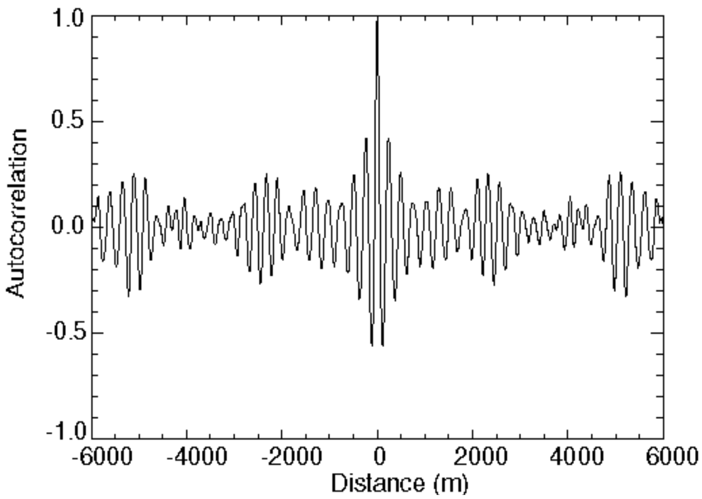

Figure 2: One-dimensional plot of the autocorrelation function versus lag distance for Hurricane Josephine data.

RESULTS

Spaceborne SAR images permits the measurement of ocean surface waves on scales and at resolutions necessary to make judgments about the effect of waves on very large offshore platforms. This past year we have developed and published the repertoire of image processing tools necessary to measure waves coherence properties from SAR images. Evaluation of imagery in the vicinity of Hurricane Josephine and Bonnie indicates that waves exhibit both longer crest lengths and more groupiness than would be expect on the basis of linear theory alone. It is clear that analysis SAR wave imagery is able to characterize properties of wave coherence.

IMPACT/APPLICATIONS

The procedures presented here allow SAR wave imagery to be used to gather statistics on wave coherence. These in turn can provide realistic wave coherence statistics to aid in the design of large offshore structures. The data we have examined indicate that real ocean surface waves are significantly more long-crested and "groupy" than would be predicted one the basis of linear theory alone.

RELATED PROJECTS

"Synthetic Aperture Radar Imagery of the Ocean Surface During the Coastal Mixing and Optics Experiment," Donald Thompson and David Porter

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RECENT PUBLICATIONS

- F. M. Monaldo. Measurement of ocean spatial coherence by spaceborne synthetic aperture radar. *1999 Very Large Floating Structures Conference*. Honolulu, Hawaii, September 22–24, 1999.

- F. M. Monaldo, "Measurement of wave coherence properties using spaceborne synthetic aperture radar," *JHU/APL Tech. Rep. SRO-00-01*, January 21,2000, 19 pages.

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