Spatial Coherence of Nonlinear, Nonstationary, Non-Gaussian Ocean Waves on a One-Mile Scale From Scanning Altimeter Radar

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LONG-TERM GOAL

The wave conditions in severe large storm waves are often critical to the survival design of marine structures. This project is directed toward the careful analysis of airplane-based scanning radar altimeter (SRA) data from NASA flights into hurricanes to extract the detailed geometry of large storm waves.

OBJECTIVES

Walsh has recorded SRA data in flights over the Hurricane Bonnie (1998) and Hurricane Floyd (1999) storm systems. The present project is directed toward developing new analysis and software for effectively analyzing such data, and then using the new methodology to extract the structure and related statistics of the individual large waves. Answers are sought to such significant questions as: How nonlinear are large storm waves, what are typical and extreme crest and trough lengths, and are the very large waves isolated or do they come in groups one after another

APPROACH

An airplane flying through maelstrom of hurricane winds is hardly an ideal platform from which to take measurements. As would be expected, SRA data contains substantial noise and error spikes attributable to violent airplane motion. Special analysis techniques have to be carefully designed to extract the correct scientific relationships from out of such messy data.

The large waves in confused seas are difficult to describe. Just what is a wave height or wave length in the chaotic storm condition? After considerable effort, the following “quartile-wave” definitions are proposed. All of the water surface elevations above and below mean water level from the grid of the SRA measurements over a specified region are ranked in order of increasing size. The 50 percentile elevation corresponds very nearly to the mean water level. A wave crest is defined as a “bump” of

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The wave conditions in severe large storm waves are often critical to the survival design of marine structures. This project is directed toward the careful analysis of airplane-based scanning radar altimeter (SRA) data from NASA flights into hurricanes to extract the detailed geometry of large storm waves.

15. SUBJECT TERMS

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water that exceeds the 75 percentile elevation. Similarly, a wave trough is taken as a water surface depression which drops below the 25 percentile elevation. The small sea surface irregularities which do not get outside of the [25 75]-percentile range are taken as being not significant.

It was a constant struggle to produce robust analysis methods which were not sensitive to the considerable amount of noise outliers that were often present. For example, the usual moment-based standard deviation formula was grossly affected by the severe outliers, and had to be replaced by estimates of the standard deviation based on ranks. Since the usual definition of significant wave height is based on the standard deviation of the sea surface, an accurate estimate of it is critical.

A variety of graphs and figures were developed to help one grasp and evaluate the SRA data. These included shift plots, outlier plots, and normal probability plots. However, the most useful graph turned out to be a special type of contour map which visually emphasized the crests and troughs and minimized the visual “clutter” as much as possible.

The ranked elevations were used to establish the [1, 3, 5, 10, 15, 20, 25, 75, 80, 85, 90, 95, 97, 99]-percentile elevations. The grid of SRA elevations were then contoured at these 20 levels. A colorbar coding was introduced which filled the contours outward from zero. All elevations between the 25- and the 75-percentile elevations were left white. Finally, a black contour was placed at mean water level. An example of the crest/trough map so produced is given in figure 1 for two 500 scan line segments in hurricane Floyd. The crests are colored orange to red, while the troughs are colored with shades of blue.

The code for the analysis was developed with Matlab scientific software. Since the Matlab contour package fills contours always upward from lower value to higher value, it was necessary to develop special routines using the “patch” command in Matlab to force the creation of the “outward” contour maps. A special colormap was also modified from the “jet” Matlab color map which started the red shading at the 75^{th} percentile introduced the blue shades below the 25^{th} percentile.

WORK COMPLETED

The SRA data from hurricanes Bonnie and Floyd were subdivided into flight segments of 500 scan lines each. For Bonnie, each segment was about 6 kilometers long and a little over one kilometer wide.

The flights in Floyd were at a higher elevation, so the 500 scan line segment were about 8 kilometers long and three kilometers wide. After carefully screening the data with shift plots, outlier plots, and normal probability plots, it was possible to prepare trough/crest contour maps for 205 segments in hurricane Bonnie and for 66 segments in hurricane Floyd.

Two scales of maps were produced. The first scale allows the study of overall wave-to-wave patterns and consists of two 500-line segments side-by-side on a page. An example of this is shown in figure 1. The second scale expands one-half of a 500-line segment up to fill a page, and shows the wave topography at a greater magnification. An examples of this scale map is given in figure 2.

All these contour maps and the supporting screening graphs will be made available to ocean scientists and engineers on the website http://faculty.gg.uwyo.edu/borgman. The users will have to be aware that the analysis algorithms used here are a constantly evolving body of techniques, and many of the graphs may be reworked as it becomes possible to do a better job of noise suppression and information extraction.

RESULTS

It was found that a good measure of nonlinearity in the very large waves could be based on ranks with the formula

$$non{-}sym\ \% \ = \ \frac{[99\ percentile\ elev]\ +\ [1\ percentile\ elev]}{[99\ percentile\ elev]\ -\ [1\ percentile\ elev]}$$

Since the one percentile elevation is a negative number and the percentiles roughly correspond to troughs and crests of the largest waves, the numerator approximates the difference between crest height and trough depth. The denominator is a rough measure of wave height of the larger waves. In the somewhat smaller waves of Bonnie, the non-sym % was one to two percent. This is not a very big value, and linear wave theory seemed to approximate the Bonnie wave systems fairly well. This was supported by the normal probability graphs which were very nearly straight lines.

The bigger waves in Floyd have much larger non-sym % values. This is illustrated in figure 1 which lists values of 7 and 8 percent. This is enough non-symmetry to indicate rather definitely nonlinear wave behavior in Floyd. Also, Figure 2 shows the occurrence in hurricane Floyd of "haystack" crests and deep "holes" for troughs. This may be a further type of nonlinear behavior, but further study is required.

A question early in the study was whether very large floating structures like the Mobile Offshore Base (MOB), which was about a mile long, was in danger of being hit by a large wave with crest length as long as it was. This could be a severe hazard to the structure if it could occur, and, indeed, was one of the reasons this contract had the phrase "Spatial Coherence" in its title. The data from Floyd answers the question decisively. Figure 1 has several long crests of length two kilometers or so.

IMPACT/APPLICATION

The ocean can be a very dangerous environment. The Atlas of Storm Wave Topography produced in this project presents in a clear way a mass of actual storm wave measurements for the two hurricanes, Bonnie and Floyd. This gives the marine engineer previously unavailable "ground truth" upon which to base the design of structures for safe operation in the ocean.

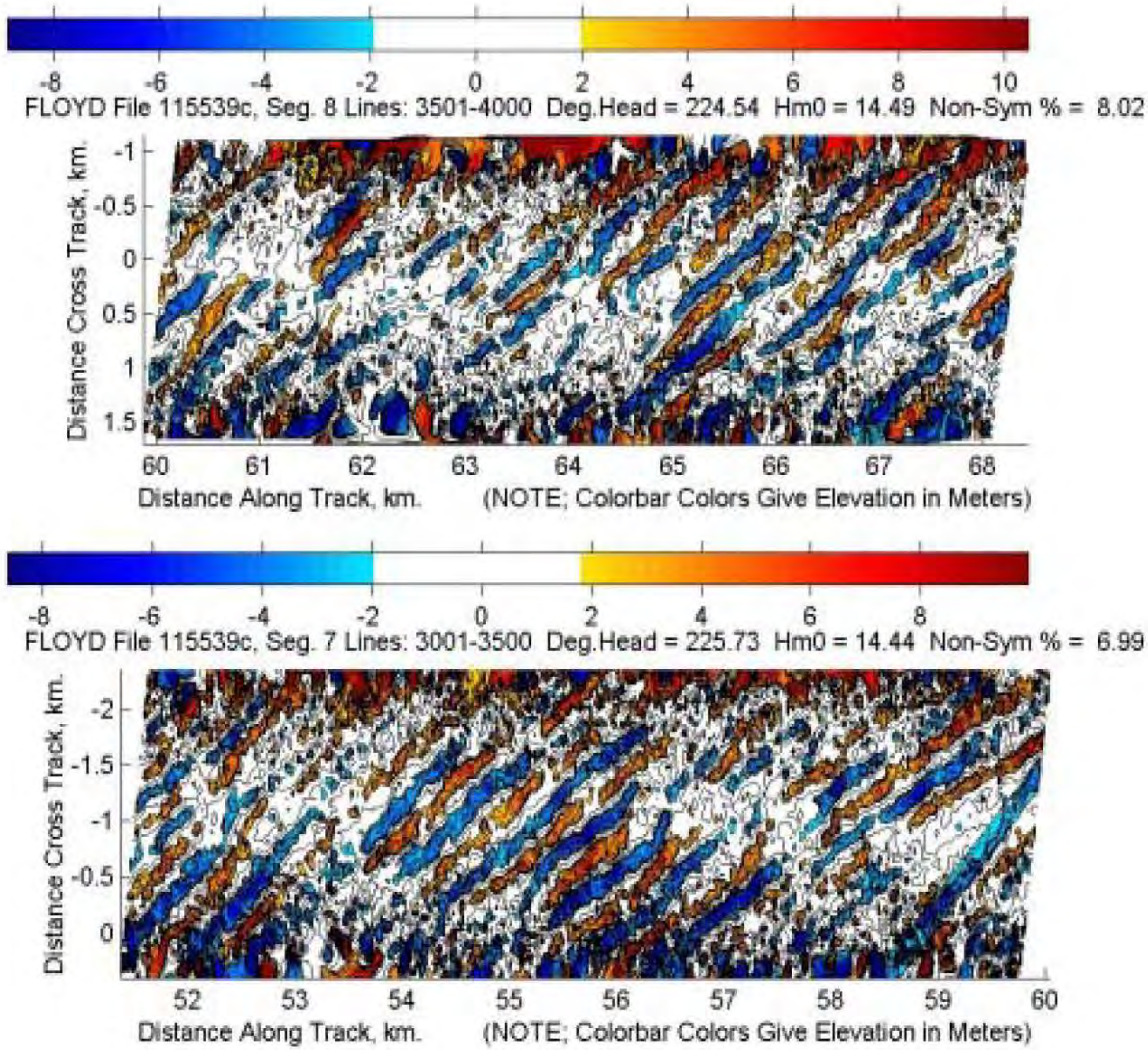

Figure 1:. Contour Maps of Wave Topography in Two 500 Line SRA Flight Segments in Hurricane Floyd [graph:colored contour map containing 18 m. waves with crests up to two km. In length]

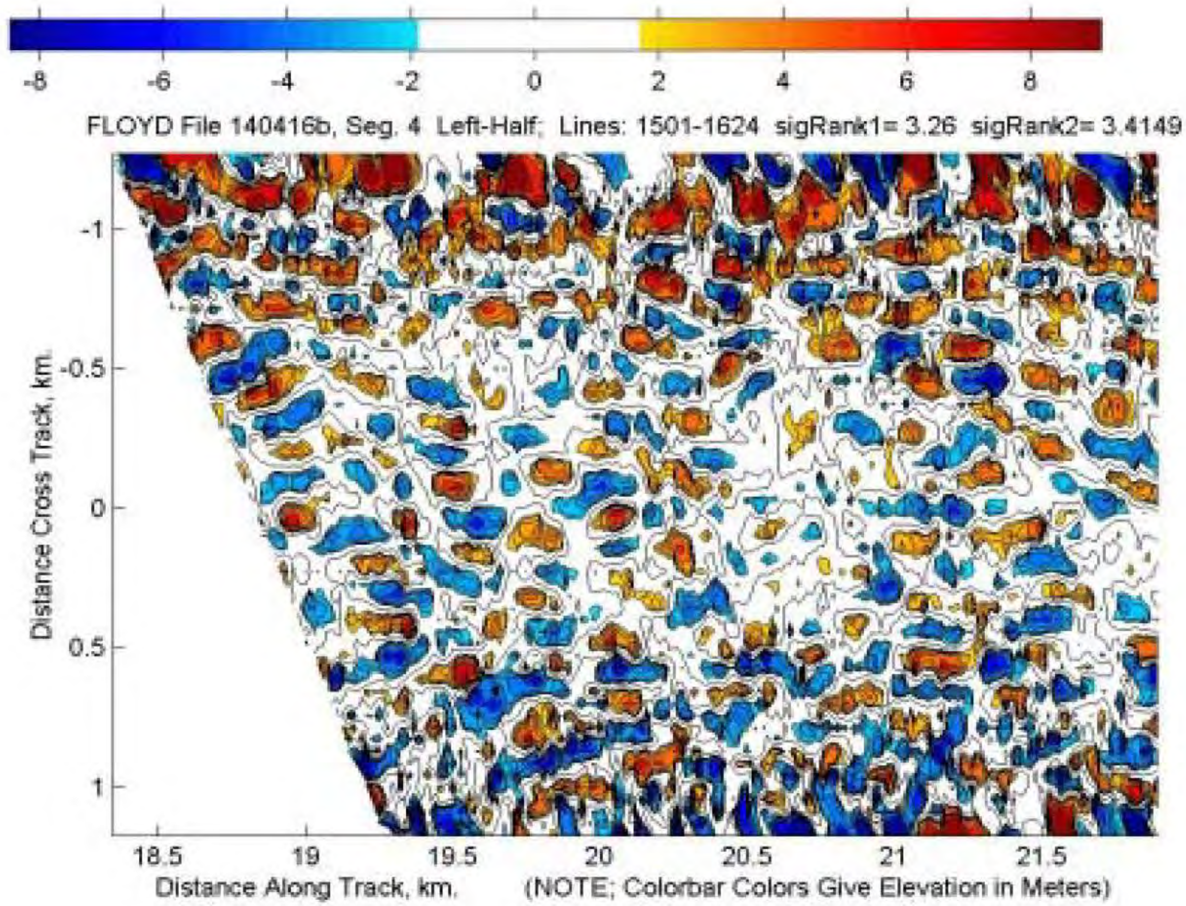

Figure 2: Contour Map of a Section the SRA Flight in Hurricane Floyd Showing Possibly Nonlinear "Mound" Waves. [graph: colored contour map containing 16 m. "mound" waves that may represent nonlinear wave structure.]