Hurricane Wave Topography and Directional Wave Spectra in Near Real-Time

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LONG-TERM GOALS

Develop a simple parameterization for the directional wave spectrum in the vicinity of a hurricane.

OBJECTIVES

Develop and/or modify the real-time operating system and analysis techniques and programs of the NASA Scanning Radar Altimeter (SRA) to process the SRA wave topography data into directional wave spectra during hurricane flights. Upload the spectra and the topography onto a web site immediately post-flight to make them available to ONR investigators.

APPROACH

The SRA has a long heritage in measuring the energetic portion of the sea surface directional wave spectrum (Walsh et al. 1985; 1989; 1996, 2002; Wright et al. 2001). There is an ambiguity of 180° in the direction of propagation of waves determined from topographic data. To obtain the directional wave spectrum, the energy of the FFT encounter spectrum must be doubled everywhere, the artifact lobes deleted, and the real lobes Doppler-corrected. Identifying the artifact lobes for deletion and partitioning the real spectral lobes into the various wave components has been a slow and labor-intensive process. Edward J. Walsh has overall responsibility for developing the techniques and corrections to enable this analysis to be performed during the aircraft flights. C. Wayne Wright will be responsible for the real-time operating system of the SRA and making whatever modifications may be required to enable near real-time processing of the data.

WORK COMPLETED

SRA operations during the 2003 hurricane season experienced a number of problems. When the final decision was made on 1 September to deploy for a flight into Hurricane Fabian the next day, Ed Walsh's routing was Denver-Chicago-San Juan-St. Croix. When the Denver-Chicago flight had a mechanical problem that would delay it past the connect time, Ed rerouted Denver-Philadelphia-San Juan-St. Croix. That later connection pushed him onto the last St. Croix of the day, which was canceled. He rebooked on the first St. Croix flight out of San Juan the next day, which was also

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canceled. The second flight departed almost 2 hours late and he missed the first flight into Hurricane Fabian on 2 September by about a half hour.

The SRA functioned well during the flights on 3 and 4 September, except that there was some intermittency in the sample of the transmit pulse during the transit to Fabian. This had been observed during the test flights and was corrected by tapping on the transmitter front panel where a video amplifier circuit board was mounted; suggesting a component or connection on the board was in an intermittent failure mode. A printed circuit board was designed to replace the old wired board and sent out for fabrication but it wasn't available before the Fabian deployment.

Ed Walsh went to Tampa on 9 September and installed the new board the next day with a great deal of help from the NOAA Aircraft Operation Center. The new board did not eliminate the intermittency problem, but tapping on the front panel where the board was mounted still brought back the transmit pulse sample. This suggested that the problem was in the cables going to or from the board and arrangements were made to make up new cables at Wallops and FedEx them to St. Croix. Ed Walsh deployed to St. Croix commercially on 11 September, but the only FedEx flight into St. Croix did not arrive until 4 hours after the 0800 takeoff for the first flight into Isabel. Although it was assumed that the SRA would work as well as it had during the Fabian flights, the transmit pulse sample was never present during the Isabel flight. The transmit pulse sample serves to zero-set the range measurements and its absence makes the SRA topography useless. A new problem had also arisen in that the returned signal strength was about 25 dB lower than it had been during the Fabian flights.

After the flight the transmitter was removed, the new cables installed, and placed back in the SRA but to no avail. Still no transmit pulse sample. The transmitter was removed again the next morning prior to the second flight into Isabel and worked on in the F.B.O.'s avionics shop with help from A.O.C. while the aircraft made the second flight into Isabel. The transmitter was reinstalled in the SRA after the flight but the transmit pulse sample was still missing.

Ed Walsh returned to Colorado on 14 September while N43RF made its third flight into Isabel. He was driving into Boulder when Pete Black told him the aircraft had blown an engine and would be returning to MacDill. He transited back to A.O.C. on 15 September and replaced the waveguide detector, the only remaining component in the transmit pulse sample path, with a new one FedExed in from California. Still no transmit pulse sample. He then removed the transmitter and FedExed it back to Wallops for further work. The problem was finally determined to be in the narrow pulse generator circuit, located at the back of the transmitter chassis, which should not have been affected by any amount of tapping on the front panel. The transmitter was shipped back to A.O.C. and reinstalled in the SRA. A ground check using a corner reflector indicated that the returned signal strength was still 25 dB low, leading to the discovery of a ruptured piece of flexible waveguide within the SRA antenna fairing under the aircraft. The flexguide was replaced and the SRA is now fully operational.

RESULTS

The Hurricane Fabian flights on 3-4 September 2003 were focused on the stepped descent flight patterns rather than the typical survey pattern. There purpose was to get flux measurements and spray droplet size distributions at six heights that could then be extrapolated to the surface at two different wind speeds and three quadrants defined by the SRA wave spectra. The flight patterns limited the

SRA ability to describe the general wave field distribution in the vicinity of the storm, but the data suggest

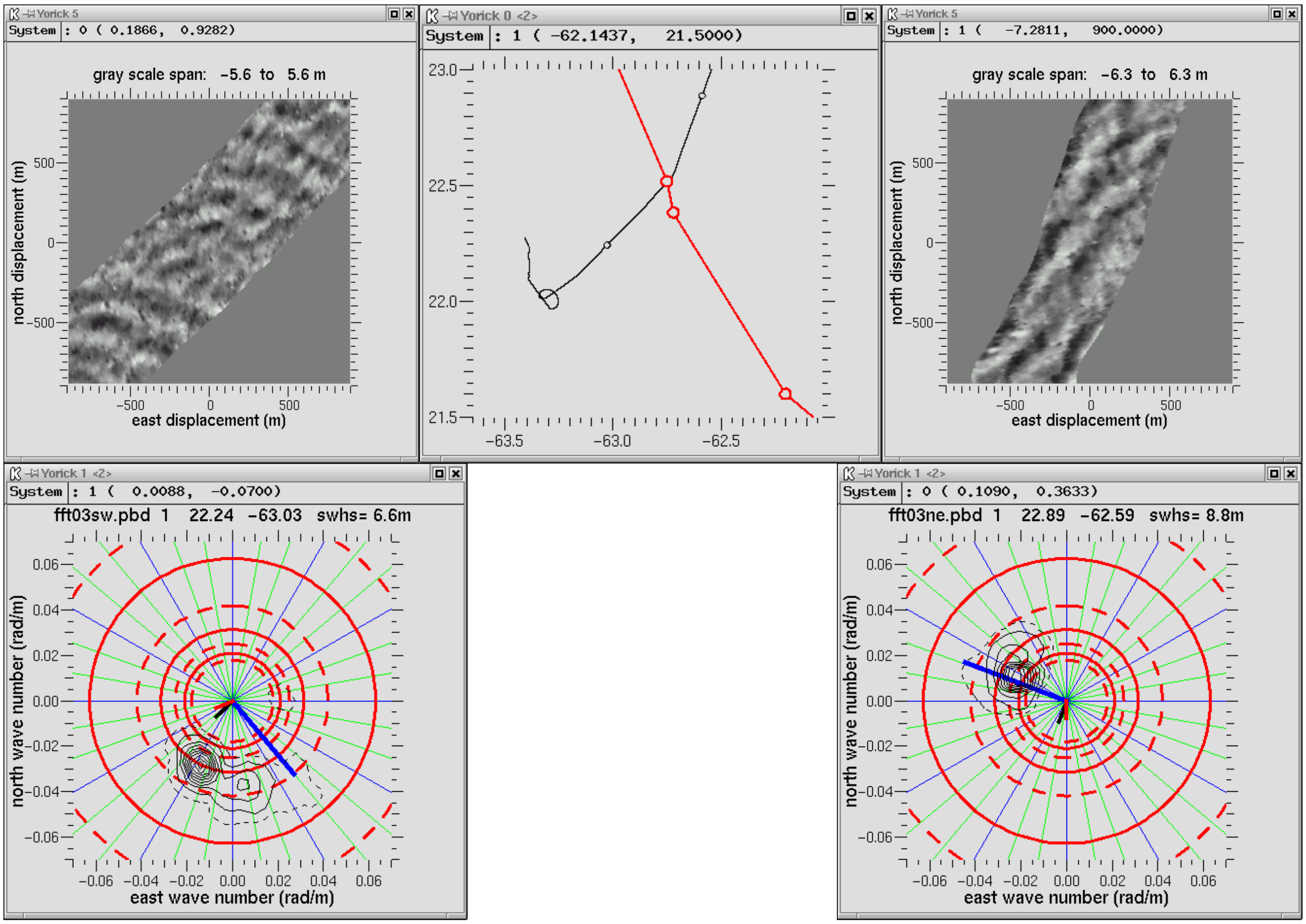

Figure 1. Wave topography and spectra SW and NE of Hurricane Fabian on 3 September 2003. [SW of eye, waves of 6.6 m height traveling south; NE of eye, 8.8 m waves traveling northwest]

some interesting preliminary insights. The aircraft had one flight line oriented approximately NE-SW on each day and the wave field was examined about 40 km from the eye in each direction along those lines at points where the rain attenuation of the SRA signal was not severe.

The center panels in Figures 1 and 2 show the Hurricane Fabian track in red with the eye fixes indicated by the large circles. The NE-SW aircraft track on the two days is indicated by the thin black line with the small circles identifying the positions of the gray-scale-coded wave topography data shown on the left (SW of eye) and right (NE of eye) sides of the figures. The directional wave spectra obtained by applying a 2-dimensional FFT to the wave topography data are shown below each topographic image.

The wave spectra have had the artifact lobes deleted and have been Doppler corrected. The solid red circles indicate wavelengths of 100, 200, and 300 m. The dashed red circles are wavelengths of 75, 150, 250, and 350 m. The latitude, longitude and wave height are indicated in each spectrum header. The thick blue radials indicate the downwind direction and their length is the wind speed (m/s) at the

1500 m aircraft altitude times 0.01. There is no wind vector on the NE spectrum of Figure 2 because the RS232 aircraft data stream to the SRA was disrupted. The short black radials indicate the aircraft ground track and the short red radials indicate the aircraft heading, which was approximated at 20 degrees to the right of the track on the NE spectrum of Figure 2.

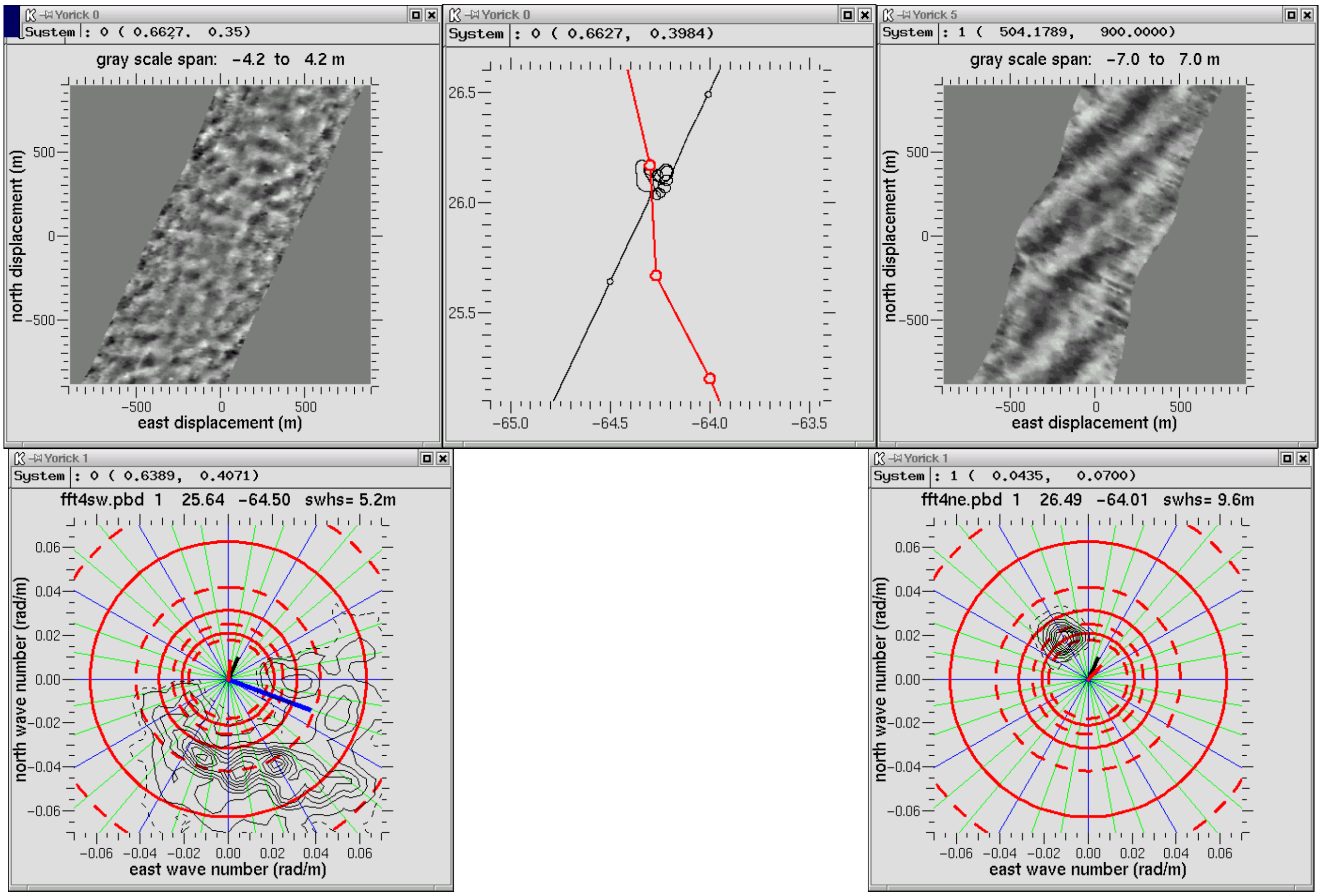

Figure 2. Wave topography and spectra SW and NE of Hurricane Fabian on 4 September 2003. [SW of eye, waves of 5.2 m height traveling south; NE of eye, 9.6 m waves traveling northwest]

For the 15 hour period prior to the data of Figure 1, NHC held the maximum wind speed of Hurricane Fabian fixed at 57 m/s. For the same interval prior to the data of Figure 2, NHC held the maximum wind speed fixed at 51 m/s. The average forward speed during the first interval was about 4 m/s. During the second interval it was about 6 m/s.

The waves and spectra look similar on the two days but have significant systematic differences on close inspection. The waves in the NE quadrant were higher (9.6 m vs 8.8 m) and longer (300 m vs 260 m) on the second day even though the nominal wind had dropped from 57 m/s to 51 m/s. The answer may lie in the increase in forward speed from 4 m/s to 6 m/s.

Stationary hurricanes with symmetric wind fields would have symmetric wave fields. The right forward quadrant of a hurricane is known to have the largest waves (Wright et al., 2001; Walsh et al., 2002). This is generally assigned to two considerations. First, the forward motion of the storm tends to increase the wind speed on the right side and decrease it on the left. Second, the waves on the right side have longer fetch and duration because the wind field is moving with them, although the dominant waves still outpace the storm. The waves in the left rear quadrant experience a wind field rapidly changing direction for a moving storm. The waves in the SW quadrant on the second day were lower (5.2 m vs 6.6 m) and shorter (170 m vs 200 m at 205 degrees; 150 m vs 170 m at 175 degrees) than on the first flight in Hurricane Fabian. The effect of a hurricane's forward speed on its wave field needs careful examination.

Because flights with the SRA are a relatively rare occurrence considering the number and duration of hurricanes in a typical season, an optimum solution would be to certify the output of a numerical wave model with the observations of the SRA for a wide variety of hurricane intensities, sizes and forward speeds. The wave model could then predict the wave properties throughout any hurricane with confidence. That process has begun (Moon et al., 2003) and the initial results are very promising.

IMPACT/APPLICATIONS

The SRA is providing the first quantified measurements of the directional wave spectrum spatial variation in the vicinity of hurricanes. The data will impact all the assessments of air/sea interaction in the hurricane environment and serve as a basis for validating wave models under those extreme conditions. The ability to be able to examine the three dimensional structure of individual waves and wave groups will also be very important for assessing the viability of various marine structures.

RELATED PROJECTS

All hurricane components of ONR CBLAST.

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