Paper No. 14

MEASUREMENT OF HURRICANE WINDS AND WAVES WITH A SYNTHETIC APERTURE RADAR

O. H. Shemdin and D. B. King, *Jet Propulsion Laboratory, Pasadena, CA*

ABSTRACT

This paper presents an analysis of data collected in a hurricane research program. The data were collected with a Synthetic Aperture Radar (SAR) during five aircraft flights in the Atlantic in August and September, 1976.

Work has been conducted in two areas. The first is an analysis of the L-Band SAR data in a scatterometer mode to determine the surface windspeeds in hurricanes, in a similar manner to that done by an X-Band scatterometer. The data available is limited but sufficient for demonstrating that this technique is feasible and has certain advantages over X-Band scatterometers. However, further refinement and experimentation is necessary.

The second area of our work has been to use the SAR to examine the wave patterns in hurricanes. The wave patterns in all of the five storms are similar and show a marked radial asymmetry. The dominant waves propagate ahead of the storm in a broad arc that has an apparent center in a region of confused sea to the right and rear of the hurricane eye. The asymmetry in the wave patterns is attributed to the forward motions of the storms. The wave directions throughout the storms do not show a sensitive dependence on the forward speed of the storms or on their maximum wavespeeds. However, there is an increase in peak wavelength with increasing windspeed and forward velocity.

INTRODUCTION

Hurricane waves play a controlling factor in the design of permanent structures along the Gulf and East Coasts of the United States and in other parts of the world. In spite of their importance, they are poorly understood and often not adequately predicted. This lack of understanding is due in a large part to the difficulties involved in accurate data collection under the extreme conditions. It is shown that remote sensing techniques provide extremely valuable data sources in such situations.

Data Collection

In August and September 1976, the Jet Propulsion Laboratory (JPL) participated in a hurricane research program with a number of other NASA research centers and with the NOAA-National Hurricane and Environmental Meterological Laboratory. JPL collected information on the directional properties of hurricane waves using Synthetic Aperture Radar (SAR) onboard a NASA CV-990 research aircraft. The five flights were made into Tropical Storm Emmy on August 24 (designated as Emmy 1 in this paper), Hurricane Emmy on August 25 (Emmy 2), Hurricane Frances on August 31 (Frances), Tropical Storm Gloria on September 28 (Gloria 1), and Hurricane Gloria on September 30 (Gloria 2). These storms were all in the western Atlantic. Approximately 700 minutes of data were collected in these five storms.

Hurricane Wind Measurements

The technique of using airborne and spacecraft radar-scatterometers to measure ocean surface wind magnitudes and directions has been demonstrated and documented primarily with frequencies near 14 GHz. This report discusses the use of microwaves at L-band frequency of 1.215 GHz. The L-Band instrumentation was an adaption of a SAR whose primary function was to obtain high resolution images of the large gravity waves generated in the hurricane (Elachi, Thompson and King,1977). The usual form for the data is a two dimensional high resolution image of the surface reflectivity with resolution cell sizes of approximately 25 by 25 meters. We employed a different method of signal processing to yield a measure of the average reflectivity (backscattered radar cross section/unit area) over a much larger area. This technique is called the "scatterometer" mode of the instrument since it receives and continuously monitors the averaged power backscattered by an area on the surface (about 4.0 by 0.5 km) that is viewed at an angle of 20° off nadir. Thus the variations of the surface reflectivity (proportional to the surface roughness caused by the wind stress) can be measured along a straight line segment (at constant altitude) parallel to the aircraft flight path.

Three SAR passes across the eye and eyewall of Hurricane Gloria were analysed. These corresponded to times when there were reasonably simultaneous passes of the same regions by low level aircraft to obtain low level wind speeds. The data showed that the relative changes in radar cross sections followed closely the large variations in wind speed that were measured in the storm. The size of the observed area on the surface (footprint) was sufficiently small so that the velocity structure in the eye walls was resolveable to a smaller scale than for that of the presently designed scatterometers. All three passes had the largest backscatter from the eye wall regions, with a well defined minimum in the eye. As expected, the radar cross section then diminshed with increasing radial distance from the eye, corresponding to the lower wind speeds at the larger distances from the center.

Based on work done at X-Band, we then examined modifications of the SAR signal to account for wind direction. The wind speeds were modified by multiplying them by a factor of $\left[1+0.5\cos(2\phi)\right]$, ϕ being the angle between the radar beam axis and the wind. These results showed an improved correlation when the direction factor is included. The effect of rainfall was also examined and was shown to depress the signal intensity.

Other effects were also examined. The signal does not appear to saturate up to sustained wind speeds of ninety knots. Also, there does not appear to be any correlation between the scatterometer signal and the presence of large gravity waves.

The analysis conducted here was preliminary in nature due to the limited amount of ground truth available but does show that the technique of using L-Band to measure surface windspeeds is potentially useful. It has advantages over X-Band scatterometer of having significantly finer resolution and of being able to penetrate rainfall (abet with a modified signal). Its major disadvantage is a decrease in the sensitivity of widespeed fluctuations compared with X-Band.

Hurricane Wave Measurements

Figure 1 shows processed SAR wave imagery at selected locations throughout Gloria 2. Each wave image is enlarged ten times relative to the hurricane scale. The direction of hurricane forward motion is to the top of the figure. For comparison, all the hurricane flights were oriented in this manner, regardless of the direction of true north. These images are placed in their proper location relative to the moving eye of the hurricane.

The striking feature of Figure 1 is the pronounced asymmetry in the wave field. There is an arc of waves which extends from the right front quadrant through the left front and into the left rear storm center. The hurricane winds are blowing in a counterclockwise spiral and thus the dominant waves in much of the storm are traveling at 90° or more with respect to the local wind direction. The arc appears to have its center in right rear quadrant but there is no distinct origin. Instead, the wave patterns in this area suggest a confused sea. The Fourier transforms show multiple dominant peaks which are traveling in different directions.

The pronounced asymmetry in the wave field is caused primarily by the forward motion of the hurricane. The counterclockwise winds (for northern hemisphere storms) blow faster on the right hand side of a moving hurricane than on the left due to the added speed of the storm. This causes larger waves to be generated in this area. However, more importantly, these waves tend to travel with the storm and so stay in the generation region much longer. These dominant waves then propagate throughout most of the storm depending on the group velocities and directions of propagation.

The other hurricanes were then compared with Gloria II and found to have similar overall wave patterns. The variations in these patterns corresponded with variations in the storms forward velocity and maximum wind speeds. The faster moving storms and those with higher wind speeds had longer wave lengths in front of the storms but there was little change in wave propagation direction, except in the confused right rear quadrant.

Summary and Conclusions

This paper presents work done on the analysis of hurricane wind and wave data collection with a SAR. We have shown that a SAR has useful potential as an instrument to measure wind but that more analysis needs to be done before the procedure becomes operational. We have also analysed directional wave data in hurricanes and found them to be very different from predicted results and have attempted to explain the dominant mechanics involved.

REFERENCES

Elachi, C., T. Thompson and D. King (1977), "Observation of the Wave Pattern Under Hurricane Gloria with Airborne Synthetic Apperture Radar", Science, Vol. 198, pp. 609-610.

King, D., and Shemdin, O.H. (1978), "Radar Observations of Hurricane Wave Directions", Proc. 16th Int'l Conf. Coastal Eng., Hamburg.

Weissman, D. and King, D., (1978), "Relationship Between Hurricane Surface Winds and L-Band Radar Backscatter from the Sea Surface." Submitted to J. Atmos. Sciences.

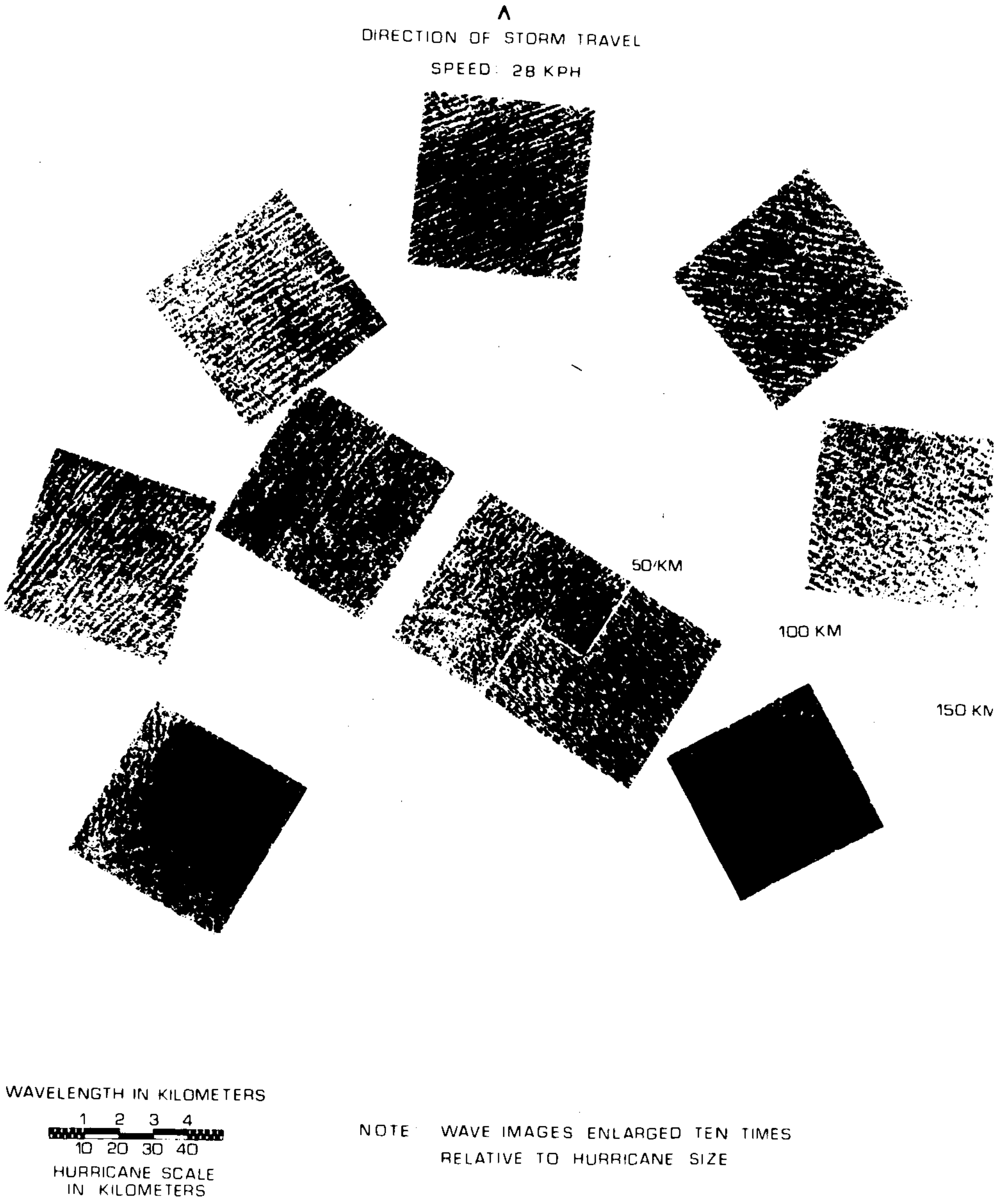

FIGURE I. SAR Wave Patterns in Hurricane Gloria II.