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RAIN RATE MEASUREMENTS IN HURRICANE HUMBERTO USING THE AIRBORNE NASA SCANNING RADAR ALTIMETER

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1. INTRODUCTION

The NASA Scanning Radar Altimeter (SRA) sweeps a radar beam of 1° half-power width (two-way) across the aircraft ground track within ±22° of nadir, simultaneously measuring the backscattered power at its 36 GHz (8.3 mm) operating frequency and the range to the sea surface at 64 points spaced across the swath at 0.7° incidence angle intervals. The measurement geometry is shown in Fig. 1 with the specific numbers referring to the flights made into Hurricane Humberto on 23 and 24 September 2001, aboard a WP-3D hurricane research aircraft of the NOAA Aircraft Operations Center. The ranges produce raster lines of sea surface topography at a 10 Hz rate. The SRA was primarily designed to produce sea surface directional wave spectra, but the backscattered power measurements can be used to determine path integrated rain rate below the aircraft.

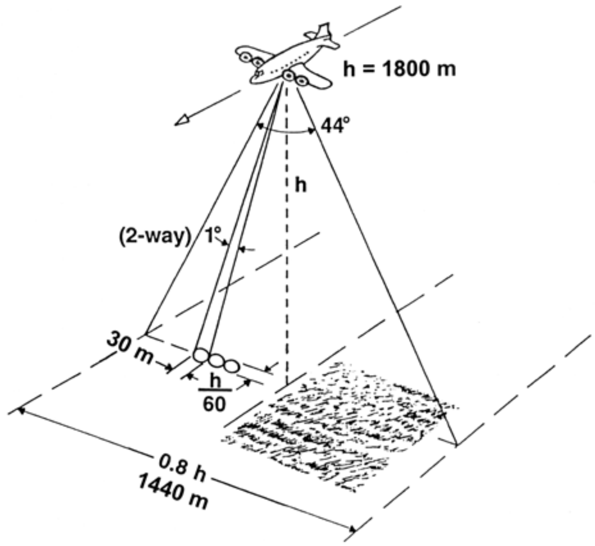

Fig. 1. Scanning Radar Altimeter measurement geometry.

2. HURRICANE HUMBERTO

Hurricane Humberto strengthened to Category 2 during the first flight, then diminished to Category 1 for the second flight. The SRA aircraft flight pattern, shown in Fig. 2 for 24 September 2001, was the same on both days. It featured three radial passes through the eye, connected by downwind legs, and was coordinated with three other aircraft in the Coordinated Observations of Vortex Evolution and Structure (COVES) experiment.

The surface wind speed measured by the NOAA AOML Hurricane Research Division (HRD) Stepped Frequency Microwave Radiometer (SFMR) along the flight track is shown in Fig. 3. The closest approach to the center of the eye on the three radial passes is indicated by the wind speed minimums at 2124 and 2254 UTC on 24 September and 0032 UTC on 25 September 2001. The rain rate measured by the SFMR along the aircraft ground track is shown in Fig. 4

3. SRA RAIN MEASUREMENT TECHNIQUE

Calculations based on the Marshall-Palmer distribution indicate that the attenuation (dB/km) of a 36 GHz radar signal is approximately linearly related to rain rate (Olson et al. 1978). At 1.8 km height, the SRA signal suffers a 1 dB attenuation for each mm/hr of rain rate. If the sea surface radar backscatter coefficient is constant as one transitions into a region of rain, the loss of signal will determine the rain rate to an accuracy of a fraction of a mm/hr. In general, changes in the backscatter coefficient at nadir are small compared to the rain absorption in the hurricane high wind environment and can be differentiated from changes in rain absorption by examining the variation of backscattered power with incidence angle.

Figure 5 shows the variation of the backscattered power at (a) 37.43°N, 66.69°W, near the beginning of the southeast pass through the eye, and at (b) 37.04°N, 65.71°W. The first observation was during a SFMR data gap, but the SRA data itself (Walsh et al. 1998) indicated

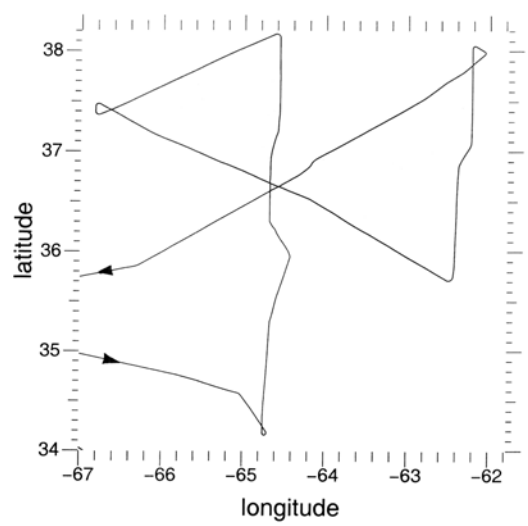

Fig. 2. NOAA aircraft flight track on 24 September 2001.

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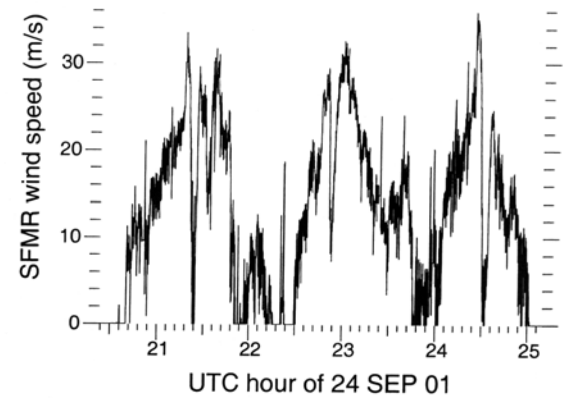

Fig. 3. SFMR surface wind speed.

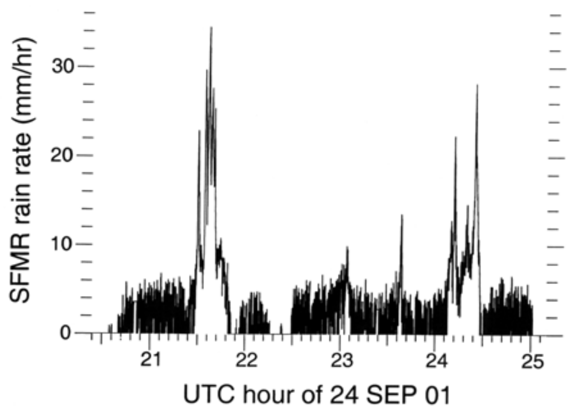

Fig. 4. SFMR rain rate.

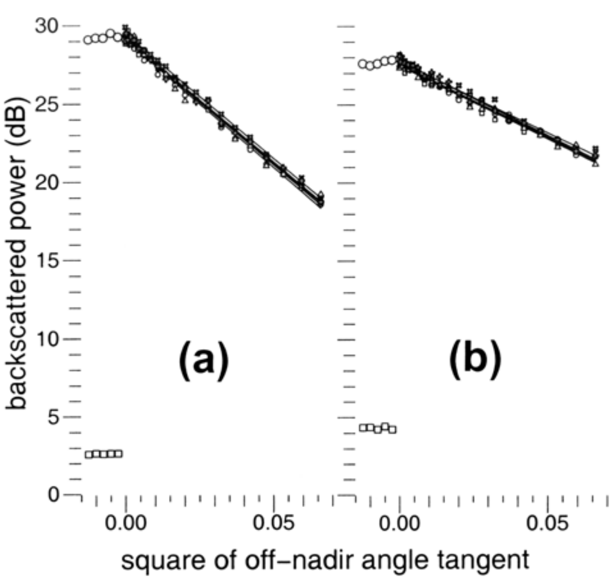

Fig. 5. Backscattered power falloff with incidence angle for surface wind speeds of about (a) 6 m/s at 2224 UTC, and (b) 12 m/s at 2236 UTC.

that the surface wind speed was about 6 m/s. The SFMR indicated a wind speed of about 12 m/s for the second observation. The SRA is not absolutely calibrated in power, but Fig. 5 and 6 show the relative signal levels.

Each panel shows averaged backscattered power from five contiguous groups of 100 SRA scan lines (10 s). Left and right sides were averaged to mitigate variations in surface roughness, wave tilts, and rain rate. With 200 points averaged for each incidence angle, the expected standard deviation of the data points would be 0.3 dB. The five straight lines fitted to the data between nadir and 14°off-nadir (middle 2/3 of swath) almost coalesce in Fig. 5. The peak value and slope of the fitted lines evolve slowly with wind speed in the absence of rain.

Figure 6 shows data taken in the vicinity of 36.29°N, 63.72°W. The rain increased from about 3 to 9 mm/hr over the first 50 s (a), and then decreased back to 3 mm/hr over the next 50 s (b). The circles to the left of the fitted lines show the time sequence of the peak values of the fitted lines. In the absence of rain the peak power varies inversely as the mean square slope, determined from the slope of the lines, and indicated (*100) by the squares in the vicinity of 5 on the ordinate.

At the 1.8 km height of the Humberto flights, the SRA signal margin was wiped out at a 15 mm/hr rain rate. At 1 km the shorter path length would make the technique viable up to 30 mm/hr, covering almost all of Humberto.

4. REFERENCES

Olsen, R. L., D. V. Rogers, D. B. Hodge, 1978: The aR^b relation in the calculation of rain attenuation. *IEEE Trans. Ant. Propagation*, **AP-26**, 318-329.

Walsh, E.J., D. Vandemark, C. Friehe, S. Burns, D. Khelif, R. N. Swift, and J. Scott, 1998: Measuring sea surface mean square slope with a 36 GHz scanning radar altimeter, *J. Geophys. Res.*, **103**, 12,587-12,601.

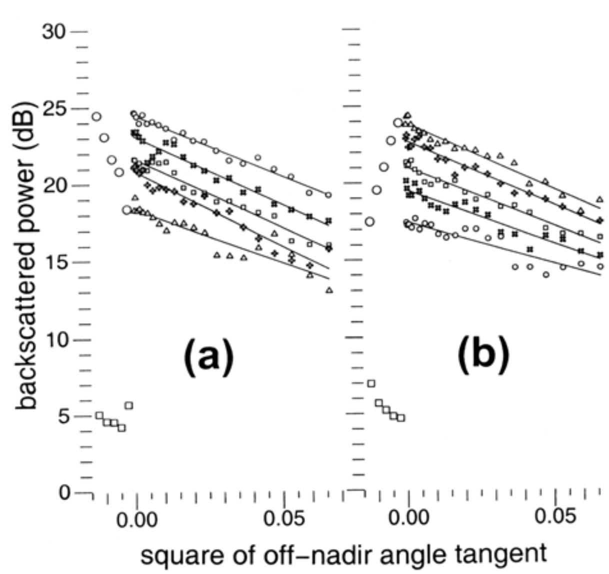

Fig. 6. Backscattered power falloff with incidence angle at 2305 UTC for surface wind speed of about (a) 26 m/s with rain rate increasing from 3 to 9 mm/hr, and (b) 27.5 m/s with rain rate decreasing from 9 to 3 mm/hr.