11A.4 HURRICANE BONNIE LANDFALLING OBSERVED FROM ER-2 DOPPLER RADAR ON 26 AUGUST 1998 DURING CAMEX-3

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1. INTRODUCTION

The NASA ER-2 and DC-8 aircraft collected remote sensing and in situ data sets from Hurricane Bonnie (23, 24, and 26 August 1998) during the Convection And Moisture Experiment-3 (CAMEX-3). Bonnie was an exceptional case where NASA and NOAA had five aircraft sampling both upper levels and lower altitudes. The ER-2 was instrumented with the ER-2 Doppler X-Band radar (EDOP) and several radiometers ranging from visible to lower frequency microwaves. EDOP is a fixed dual-beam radar (nadir and forward-looking beams) which allows computation of both vertical and along-track horizontal winds.

The hurricane secondary circulation is typically difficult to measure at upper levels due to aircraft altitude limitations and sensitivity of the lower altitude airborne radars. EDOP is in principle, well suited to measure these components of the wind. When ER-2 flies across the approximate center of the hurricane circulation, the along-track winds derived from EDOP, are approximately equal to the hurricane radial flow comprising the secondary circulation. Assuming that the hydrometeor fallspeeds can be approximated, the radial and vertical wind components of the secondary circulation can be measured. Since the hydrometeor motions can be estimated with more confidence in the higher altitude ice regions (i.e., graupel and mixed phase are complicated at lower altitudes), the derived radial and vertical winds have higher accuracy at upper levels. On the other hand, the reflectivities are extremely low at higher altitudes, resulting in fewer Doppler velocity estimates.

A preliminary assessment of EDOP-derived radial wind is presented here with emphasis on mid to upper-levels. EDOP collected nadir and forward beam data on one of the Bonnie flight days (26 August), thus allowing for the first examination of hurricane radial winds from this approach.

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2. ER-2 FLIGHTS ON 26 AUGUST 1998

Flight lines on 26 August were designed to cross the center of the eye and outer rain bands of Bonnie at several orientations and in a coordinated fashion with the NASA DC-8 and the NOAA P3's. The ER-2 and DC-8 were closely stacked on top of each other, following within a kilometer of each other and separated by at most a few minutes. Bonnie was near landfall at the time of the overflights on 26 August, and eyewall replacement was occurring during and just subsequent to the ER-2 departure.

The flow structure from one of the east-west passes across the eye (1615-1643 UTC) is shown schematically in Fig. 1. This diagram depicts an outward sloping eyewall with height, divergence aloft, and mid-level subsiding inflow outside of the upward branches of the circulation. Other passes with the ER-2 at orientations approximately 325° -135° and 45°-225° were not as symmetric as shown in Fig. 1, and did not always have the descending branches.

Since the reflectivities are extremely low at higher altitudes in Bonnie, large portions of the secondary circulation are missed in the EDOP measurements. This is evident in Figure 2 which shows the EDOP reflectivity and along-track wind component at 1 km vertical intervals. The dashed upward sloping lines indicate the axis of peaks of inflowing and outflowing radial components suggested in Fig. 1. Note that the radial component is not symmetric about 0 ms^{-1} from one side of Bonnie to the other since the hurricane advection component to the northwest is not subtracted. The reflectivities are extremely low (0 dBZ) at 12 km altitude.

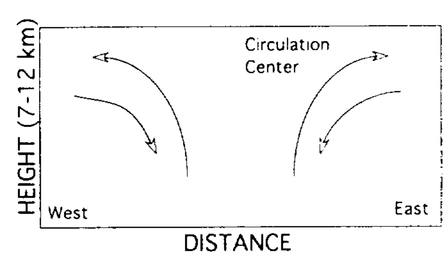

Figure 1. Schematic of Bonnie secondary circulation during 1615-1643 UTC pass.

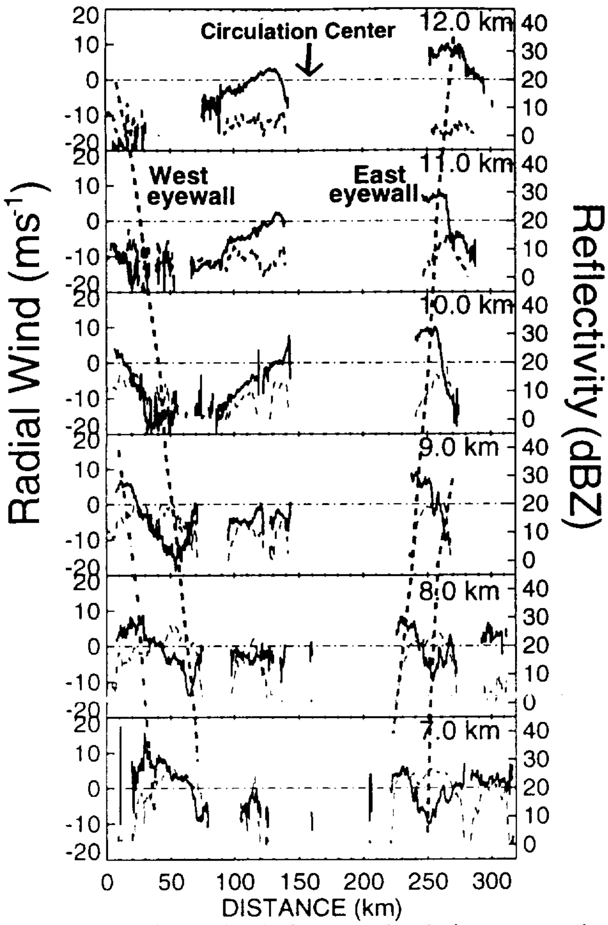

Figure 2. EDOP-derived along-track winds representing the hurricane radial winds (solid) and reflectivity (dashed) plotted at 1 km height intervals.

A simple estimate of divergence can be made by assuming a symmetric circulation using $2v_r/r$, where r is estimated from half the separation of the two outflow peaks (inner vertical dashed curves, Fig. 2), and v_r is the mean of the two peaks. Figure 3 shows that the eyewall diameter increases from about 150 km at 7 km altitude, to about 250 km at 12 km altitude (Fig. 3). On the other hand, the divergence does not vary widely with height with values ranging from 2.2-2.8 x $10^{-4}s^{-1}$, although there is a peak at about 10 km altitude. This divergence profile is somewhat different than typical model profiles which have a more erect eyewall and a divergence peak at the highest altitudes.

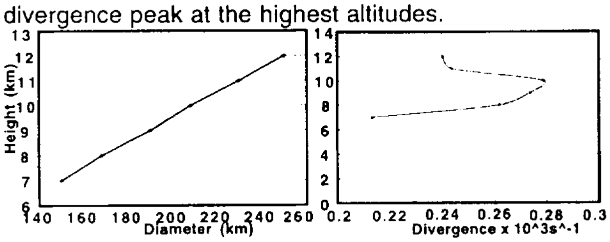

Figure 3. Divergence and outer eyewall diameter obtained from Fig. 2.

To obtain validation for these measurements, we have carefully mapped the EDOP reflectivity and along-track wind component to the locations of the DC-8 measurements. The DC-8 data shows a continuous wind profile across Bonnie, whereas EDOP sections are more spotty due to the absence of radar returns. Note that the peak reflectivities in the eyewall are about 20 dBZ at the 9.2 km. The along-track (radial) winds (lower panel Fig. 4) compare well in shape but with some differences in magnitude near 250 km distance. Nevertheless, the diameter and approximate magnitudes of radial velocity peaks are in remarkably good agreement. The DC-8 vertical velocity profile is rather turbulent, but there is coherent structure in the rightmost eyewall (250 km); the ER-2 also shows similar vertical velocity structure in this rightmost eyewall.

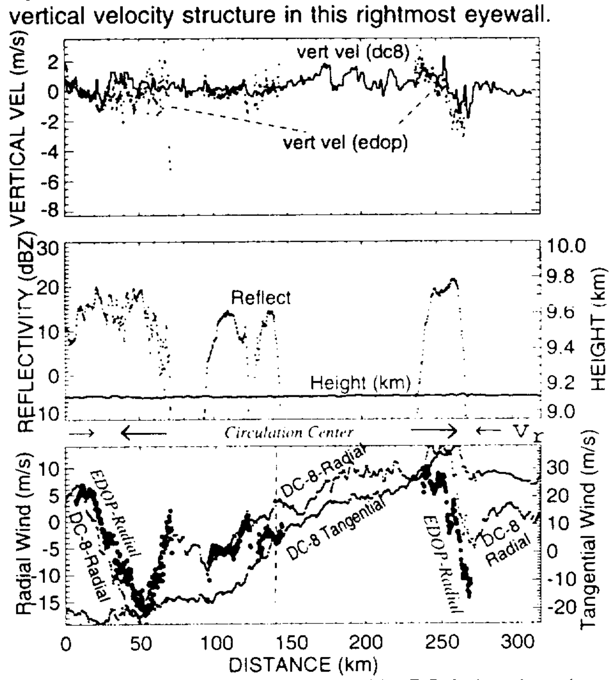

Figure 4. EDOP comparison with DC-8 in situ data. EDOP-derived vertical velocity and along-track winds are compared with DC-8 in situ vertical velocities and along-track winds. Also shown are DC-8 tangential winds, and EDOP reflectivities at the DC-8 altitude.

3. SUMMARY

The radial wind component in upper-levels of Hurricane Bonnie has been estimated using the EDOP along-track wind component derived from synthesis of the nadir and forward beam Doppler velocities. This approach has shown promise for estimating the hurricane outflow on the few-hundred kilometer scale. The analysis showed that the outflow divergence was distributed relatively uniformly above 7 km altitude. Future work will examine flight lines with other orientations, as well as to improve the approach through fitting.

ACKNOWLEDGEMENTS

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