17B.3 DETERMINATION OF THE CIRCULATION CENTER AND INNER CORE EVOLUTION OF HURRICANE DANNY (1997) USING THE GBVTD-SIMPLEX ALGORITHM

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1. INTRODUCTION

It has been demonstrated that the primary circulation can be retrieved reasonably well by the ground-based velocity track display technique (GBVTD, Lee et al. 1999). The GBVTD technique uses single ground-based Doppler radar observations to deduce a TCs tangential wind circulation for a given storm center position. Plausible structures were retrieved by the GBVTD technique in landfalling Typhoon Alex (1987) in Taiwan, revealing many features that had not been documented in previous single Doppler radar observations (Lee et al. 2000). That study emphasized the significance of obtaining an accurate circulation center in order to accurately retrieve asymmetric circulation. Lee and Marks 2000, (hereafter, referred to LM) proposed a GBVTD-simplex TC center finding algorithm to objectively determine the TC circulation center (hereafter, referred to as TC center), the RMW and the maximum axisymmetric tangential wind, from a plan position indicator (PPI) or constant altitude PPI (CAPPI). As the GBVTD algorithm becomes a primary tool in TC operation and research using WSR-88D data, further quantifying the uncertainty in the GBVTD-simplex algorithm objectively is necessary. Hurricane Danny (1997) was observed by WSR-88Ds at Mobile, AL (KMOB) and Slidell, LA (KLIX) simultaneously while Danny was off the Gulf coast on 18-19 July 1997. This dataset provides the first opportunity to examine several key aspects of the GBVTD and GBVTD-simplex algorithms using solutions from two independent Doppler radar observations.

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Systematic comparisons between these two sets of GBVTD and GBVTD-simplex solutions provide objective evaluations of the limitations of these algorithms. The primary goals of the study are to: (1) quantify the accuracy of the circulation center and the primary circulations derived from the GBVTD-simplex algorithm proposed in LM, (2) propose an improved TC center finding procedure by taking into account the continuity of RMW, center location and the maximum mean tangential winds with time using multiple volumes of Doppler radar data, (3) evaluate the characteristics of the GBVTD-retrieved wind fields, and (4) examine Hurricane Danny's evolution and structures within the 5-h period. The GBVTD-simplex and the GBVTD technique are applied to 5-h of data gathered simultaneously by two WSR-88D radars, Mobile, AL (KMOB) and Slidell, LA (KLIX) at ~6 minute intervals in Hurricane Danny (1997). It is found that the GBVTD-simplex derived centers, which used only the maximum mean tangential wind as the sole criterion, were unsatisfactory and unstable. An improved algorithm is proposed to seek time continuity in RMW, maximum mean tangential wind, and the center position, in order to reduce the large fluctuations experienced in the LM approach. The TC structures derived from these improved centers will be used to make comparisons with the GBVTD analyses and quantify the accuracy of the derived circulation centers.

2. GROUND-BASED VELOCITY TRACK DISPLAY (GBVTD) AND SIMPLEX TECHNIQUE

The GBVTD technique developed by Lee et al. (1999) is used to deduce the primary circulation of the storm using only single Doppler radar observations. This technique is based on the principle that the TC circulation is near circular and can be decomposed using Fourier analysis at each radius, the circulation can be represented as a series of sine and cosine functions.

The GBVTD-simplex method searches for a point that maximizes the mean tangential wind of a hurricane. Hence, both the RMW and the maximum mean tangential wind can be estimated simultaneously.

3. RESULTS

It is found that the GBVTD-simplex derived centers, which used only the maximum mean tangential wind as the sole criterion, were unsatisfactory and unstable. These results were unsatisfactory because the differences were more than the 1.9 km (5% of a 18 km RMW) recommended in LM. An improved algorithm was proposed and applied that takes into account time continuity in RMW, maximum mean tangential wind, and the center position. This will reduce the large fluctuations experienced with the initial centers. These new centers were used to quantify the accuracy of the derived circulation centers. The quality of the GBVTD-derived circulation from these new centers was assessed.

3.1. Radar Reflectivity

Using the improved set of Danny's center, the kinematic structures of Hurricane Danny observed from both the KLIX and KMOB can be deduced from the GBVTD technique for the entire five-hour period. The Hovmoeller diagrams of the wave number zero (axisymmetric) reflectivity at 2 km altitude for KLIX (a) and KMOB (b) are shown in Fig. 1. Note that the reflectivity patterns from both radars are consistent. The axisymmetric reflectivity weakened between 1700 and 1900 UTC, then intensified after 1900 UTC. A secondary reflectivity maxima is located ~47 km from the circulation center and occurred around 1900 UTC. At 1800 UTC, there is a small area of 30 dBZ, ~20 km from the center shown by both radars. This feature is occurring at the same time that the secondary reflectivity maximum at 47 km starts to intensify (Fig. 1b). Weaker reflectivity (<15 dBZ) persists in the region from R = 0-7 km.

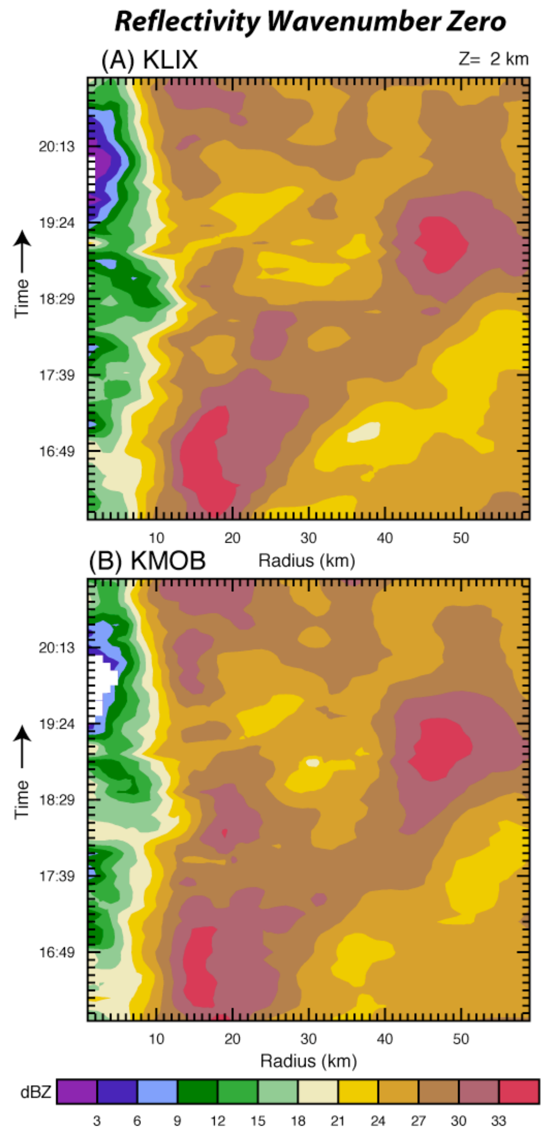

FIG. 1. Time-radius (Hovmoeller) plot of Hurricane Danny reflectivity wave number zero for (A) KLIX and (B) KMOB.

The wave number one reflectivity patterns (Fig. 2) for both radars also are in good agreement. The large area of 14-22 dBZ, located 10-40 km southeast of the center (R = 0) from 1700-2000 UTC coincides with the minimum in the reflectivity wave number zero (Fig. 1). The vector length in Fig. 2 is proportional to the magnitude of the wave number one reflectivity while the direction of the vector indicates the phase of the wave number one reflectivity maximum relative to the TC center. This sequence of events suggests that Danny evolved from a mostly axisymmetric TC into a wave number one asymmetric TC then returned to an axisymmetric TC during this five-hour period.

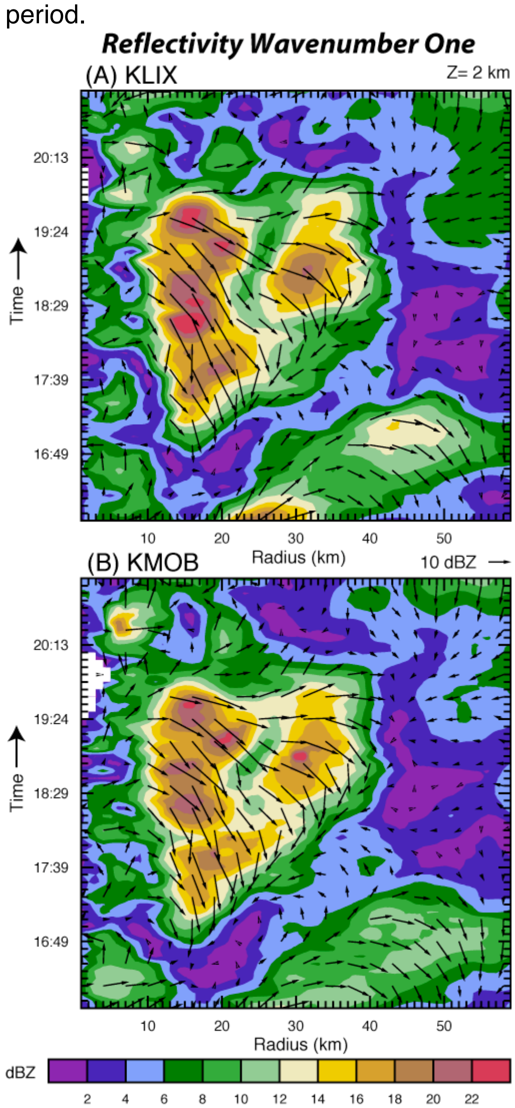

FIG. 2. Time-radius (Hovmoeller) plot of Hurricane Danny reflectivity wave number one for (A) KLIX and (B) KMOB at 2 km. The vectors represent the phase of wave number one of each radius and time where the vector length (direction) represents the wave number one amplitude (location relative to the center). The vectors point in the direction of the asymmetry and the magnitude is in dBZ. KMOB depicts weaker reflectivity dBZ values than KLIX.

3.2 Kinematic Structure

The Hovmoeller diagram for both KLIX (a) and KMOB (b) show the maximum tangential winds exceeding 30 m s^{-1}. The winds are weak inside the RMW, which is a characteristic of an eye. The agreement between the KLIX and KMOB wave number zero in Fig. 15 is definitely not as good as that in the reflectivity (Fig. 1). The maximum wave number zero V_T from KLIX (KMOB) is 31 m s^{-1} (35 ms^{-1}) (Fig 3). A steady increase of wave number zero V_T is observed from KMOB with periodic bursts (~1 hour) seen throughout the five-hour period (Fig. 3b). A similar trend was also resolved in the KLIX analyses (Fig. 3a) but was not as clear as those shown in the KMOB analyses. KMOB, in general, depicts greater axisymmetric V_T than those resolved in KLIX, especially around the later periods (i.e. 2000 UTC). The differences between the two estimated axisymmetric V_T are typically within 2 m s^{-1} except for a short period ~1710 UTC and a long period between 1910 and 2030 UTC where the magnitudes of the differences reaches 4 m s^{-1}. The “true” axisymmetric V_T is probably in between these two estimates. Hence, the uncertainties in the GBVTD-derived axisymmetric V_T is ~5%. Several possibilities that may contribute to these differences are examined below.

3.3 Evaluating the derived wind fields

Throughout this five-hour period, KLIX and KMOB sampled Danny nearly from perpendicular vantage points. Therefore, these two radars sampled completely independent components of Danny’s circulation. Because reflectivity is a scalar, it is not a surprise that the KLIX and KMOB reflectivity patterns agree much better than the GBVTD-derived velocity vectors that involve several assumptions. These two datasets and analyses provide a unique opportunity to evaluate the uncertainties embedded in the GBVTD analyses. By examining the GBVTD equations, the mean tangential wind [eq. (20) in Lee et al. (1999)] is affected by the unknown cross-beam mean wind and the unknown wave number two radial wind. In

Danny, wave number two components are small so it would be interesting to examine the effects of the unknown cross-beam mean wind (V_X) to the mean tangential wind. Since two independent Doppler radars sampled Hurricane Danny, this provides a unique opportunity to solve for the mean wind flow (V_M) and evaluate the effect of V_X.

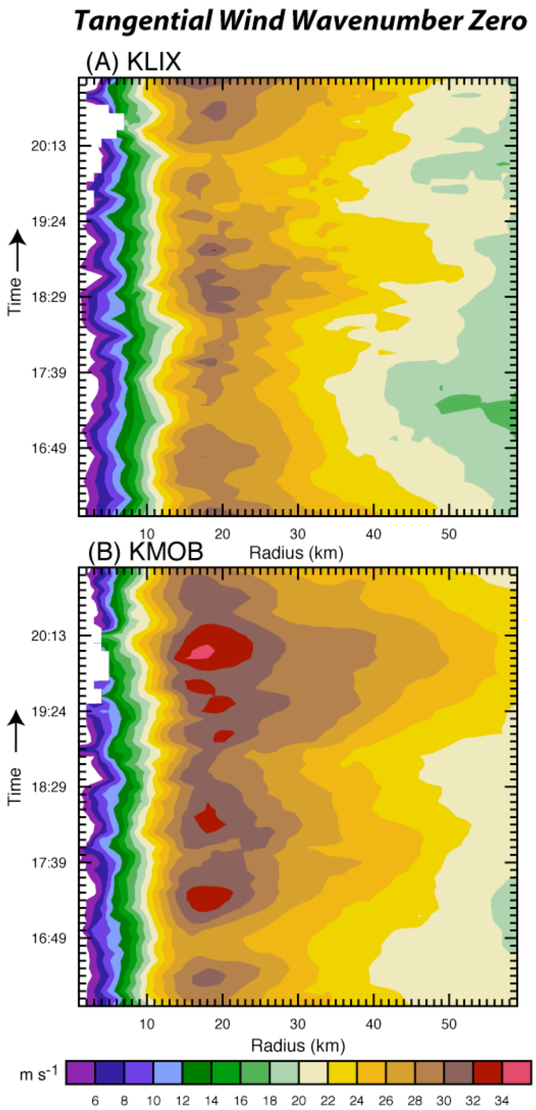

FIG. 3. Time-radius (Hovmoeller) plot of GBVTD derived mean tangential wind wave number zero for (A) KLIX and (B) KMOB.

Taking equation (19) from Lee et al. (1999)

$$V_M \cos\left(\theta_T - \theta_M\right) = A_0 + A_2 + A_4 - V_R C_1 - V_R C_3$$

where θ_T = the mathematical angle (i.e., 0 degrees east, 90 degrees north, etc.) for the tropical cyclone center viewed from the radar; θ_M = the direction of the mean wind flow, which is a function of altitude, A_N,C_N = Fourier coefficients of wave number N for the intersections of the radar beam and a ring of radius R, V_R = radial velocity of the TC, positive outward from the center.

Expressing this equation for both radars we are able to solve for cross-beam component (V_X). The cross-beam component (V_X) of V_M affects the V_T estimates (Lee et al. 1999) since it is aliased into V_T. The effect of V_X on the V_T estimates depends on the radius. Lee et al. (1999) demonstrates the bias in V_T due to V_M (their Fig. 11). Figure 4 displays V_X derived for both radars. Throughout the period, V_X fluctuates but remains below 0. The V_X differences are relatively small -less than one. Based on this result, the V_X component has minimal impact on V_T.

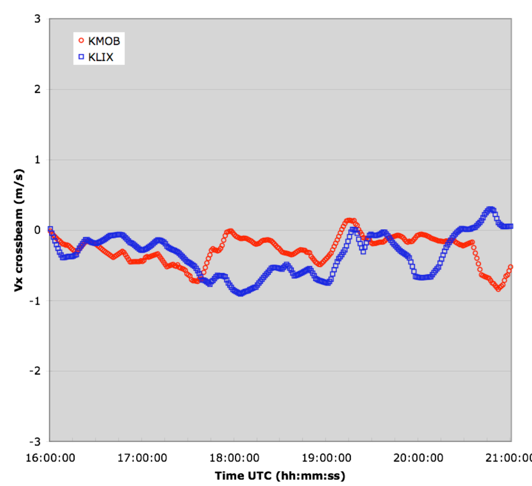

FIG. 4. V_X (cross-beam component) of V_M derived from KLIX and KMOB.

4. CONCLUSIONS

The kinematic structure of Hurricane Danny (1997) was examined using the GBVTD-simplex algorithm for two radars that sampled the hurricane simultaneously. Five hours of level-II Doppler data were utilized from ground-based radars located at Slidell, Mississippi (KLIX) and Mobile, Alabama (KMOB) viewing from nearly perpendicular vantage points to the circulation center every six minutes. This dataset provided a unique opportunity to quantitatively evaluate the GBVTD center-finding technique and the GBVTD-retrieved TC structures. Danny's centers were computed using the GBVTD-simplex method with both the KLIX and KMOB radar data. It is shown that the consistency of the two sets of centers can be dramatically improved by implementing new constraints so the TC characteristics are consistent in both space and time.

Danny's kinematic structures retrieved from KLIX and KMOB data using the improved sets of centers are consistent with the structures retrieved from the dual-Doppler analyses. Danny evolved from a mostly axisymmetric TC into a wave number one asymmetric TC then returned to an axisymmetric TC during this five-hour period. The mean tangential winds between these two analyses show an out of phase variation (~3 m s^{-1}) around a mean value of ~31 m s^{-1}. Attempts to isolate the possible causes of the variation were not successful. However, considering all the uncertainties discussed in this study, the uncertainty in the GBVTD-derived mean tangential wind is ~10%.

With two Doppler radars observing the same storm, the mean wind (V_M), the direction of the mean wind flow (θ_M) and the cross-beam component (V_X) were derived to evaluate the effects of the unknown cross-beam mean wind in determining the storm structures. In Danny, these variables played a small role in determining the differences in the derived centers. Danny was a slow moving minimal category 1 hurricane that can explain why these variables did not offer any clear indication as to why the derived centers differ.

5. REFERENCES

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