14B.2 IMPROVED TROPICAL CYCLONE CIRCULATION CENTERS DERIVED FROM THE GBVTD-SIMPLEX ALGORITHM

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1. INTRODUCTION

The GBVTD technique (Ground-Based Velocity Track Display) (Lee et al. 1999) has been shown to accurately retrieve the circulation of a tropical cyclone (TC) from a single Doppler velocity field given a correct estimate of the circulation center (Lee and Marks 2000). With coastal NEXRAD data available every six minutes, GBVTD can provide high temporal and spatial resolution windfields for landfalling TCs. The GBVTD-simplex algorithm can objectively estimate the TC circulation center needed for subsequent wind retrieval by determining the location that maximizes the GBVTD-retrieved mean tangential wind (or vorticity) for a ring of specified radius. Depending on the characteristics of the TC and the quality of the radar data, however, center estimates may be subject to high uncertainty, and the resulting asymmetric windfield may be inaccurate.

Lee and Marks have demonstrated that a center estimate uncertainty of less than 2 km is desired in order to resolve the wavenumber one asymmetry of a TC with minimal error. Their analysis of Typhoon Alex (1987) suggested that the uncertainty in center estimates for this TC was less than 2 km, but without a way to verify the centers to this accuracy it is difficult to confirm that this is the case.

Hurricane Danny, a slow-moving category one storm, provides a unique opportunity to test the effectiveness of the GBVTD-simplex algorithm since two radars were able to view the same TC from a near perpendicular angle. The GBVTD-simplex algorithm was performed on datasets from the NEXRAD radars in Slidell, LA (KLIX) and Mobile, Alabama (KMOB) during the period 16:00-21:00 UTC on 18 July 1997. The center finding algorithm should be able to determine proximate center estimates from both radars independently.

Figure 1 shows the GBVTD-simplex centers, RMWs, and mean tangential wind from the two analyses. A statistical analysis of the distance between the selected centers is shown in Table 1. While some periods of the storm evolution agree well, others have a high degree of uncertainty in the center estimates. The mean distance between the independently determined centers is higher than the 2 km uncertainty recommended by Lee and Marks, suggesting low confidence in retrieving the asymmetric wind components. The purpose of this paper is to illustrate that additional information such as the temporal and spatial continuity of retrieved TC properties can be utilized from the GBVTD-simplex output to improve the center estimates.

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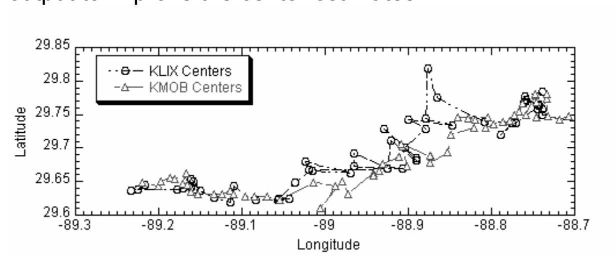

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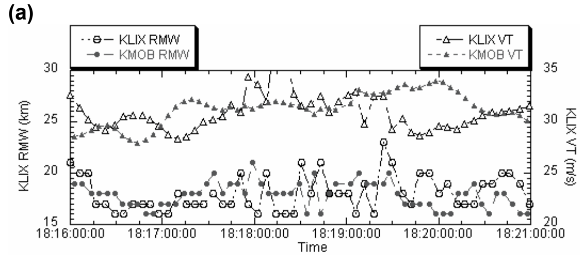

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Figure 1. **(a)** Mean circulation centers at 1km height selected by using the original simplex method. (**b**) RMW and mean tangential wind of selected centers over the five-hour analysis period.

Distance Between Center Estimates Using Original Simplex Selection Method	
Minimum	0 .114 km
Maximum	9.225 km
Mean	3.004 km
Median	2.499 km
Std. Dev.	1.960 km

Table 1. Statistical analysis of the distance between circulation center estimates from KLIX and KMOB radars using original simplex selection method at 1 km height. Calculations were made on linearly interpolated centers at one minute intervals to account for different radar scan times.

2. METHOD

The GBVTD-simplex algorithm conducts a simplex search for the vorticity center by starting from different initial guesses near the TC inner core. The mean center location is then calculated from all available solutions, resulting in a consensus estimate of the vorticity center. Individual centers beyond one standard deviation of the mean are regarded as outliers and are removed, and the mean is recalculated. The mean and standard deviation of the center location, number of converging solutions used in the calculation, and mean tangential wind for that ring are output. The simplex search is repeated for multiple rings, and the TC circulation center can then be selected by determining the radius of maximum wind (RMW) and the corresponding vorticity center.

Even though outliers are removed, the mean center location may be skewed by errant solutions or calculated from broadly located simplex results. In order to determine the confidence in a particular center estimate, one can examine the statistical information output from the simplex search. A higher number of converging solutions and lower standard deviation from the mean both suggest a strong consensus that the mean center calculation is representative of the true vorticity center of the ring.

Though one may have high confidence in individual centers, an easy determination of the RMW is not always possible. Factors such as double eyewalls, weak velocity gradients, radar data gaps, and strong TC asymmetries may make the RMW ambiguous. As shown in Figure 1, automatic selection based on the maximum mean tangential wind can result in erratic centers. Subjective examination of the data and handpicking centers can alleviate some of these problems. Figure 2 shows subjectively selected centers over the same five hour period as in Figure 1. Table 2 shows the improvement in the mean distance between the centers. While handpicked centers can produce good results, the significant time and effort involved, as well as the potential bias of subjective selection on TCs with only one radar dataset, make this a difficult process. An objective method that can select consistent centers similar to those picked subjectively would therefore be ideal.

The objective method improves upon the original GBVTD-simplex algorithm in two ways-- by utilizing the statistical information from the simplex search to improve confidence in individual centers at each radius within a radar volume, and by using spatial and temporal continuity to better determine the RMW and center location. It is also significantly quicker and easier than selecting centers by hand. All steps in this method are performed independently at different altitudes, to account for vertical variation in center location.

The first step in this method is to examine the radial profile of mean tangential wind and threshold values that are not near maximum inflection points. Weak tangential winds away from the inner core are therefore not considered when determining the RMW. The second step is to normalize the GBVTD-simplex output parameters: mean tangential wind, number of converging centers, and standard deviation of those centers. A score of 1 is applied to the best value for that parameter at a given time, with remaining values scaled linearly. This is done in order to combine the parameters, with different units and magnitude, into a single value to be used for comparison. The normalized values are weighted to get a combined score for each radius, and the radius with the highest score is selected as the best estimate of the RMW. We can therefore have some confidence in our initial center estimates even when the velocity gradient is weak. The optimal weights used to combine the parameters were determined empirically in a sensitivity test, and suggest that the standard deviation of the mean center calculation is a critical component in this score and is weighted heavier than the other two parameters.

The third step is to apply least squares polynomial curve fits to the RMW, center coordinates, and mean tangential wind over an arbitrary period of time, yielding four independent curves. X and y are fitted independently so that nonlinear storm motion can still be determined. A statistical f-test is used to determine the polynomial degree that best fits the data.

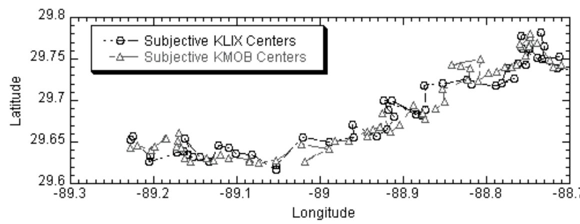


Figure 2. Mean circulation centers at 1km height selected from GBVTD-simplex output by hand.

Distance Between Center Estimates Using Handpicked Centers	
Minimum	0.110 km
Maximum	8.104 km
Mean	2.276 km
Median	2.169 km
Std. Dev.	1.320 km

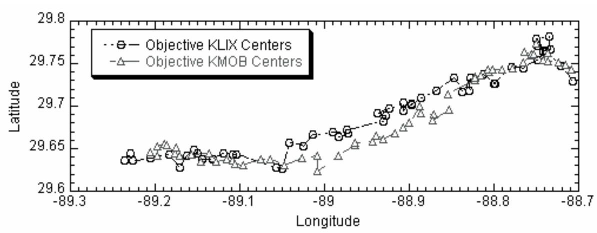
Table 2. Statistical analysis of the distance between circulation center estimates from KLIX and KMOB radars using handpicked centers at 1 km height.

A Gaussian membership function is then created for each of the curves, based on the variance of the least squares fit. A curve that fits the data well will have a narrow membership function, while a poor fit will be assigned a wider Gaussian function. The predicted value of each curve at each time is assigned a value of 1, and the individual simplex solutions from that time are mapped onto the functions. The simplex solutions that have the highest total membership score from the resulting functions are selected. The final center estimates therefore strike a balance between individual confidence, and spatial and meteorological consistency over time.

3. RESULTS

Figure 3 shows selected centers and the corresponding TC information using the objective method. The objective selection method tracks are more consistent and compare better between the two radars than the original simplex selection tracks. The RMW profiles are similar, but are less erratic than those in Figure 1, while the mean tangential wind profiles are nearly the same. The inverse oscillation between the two tangential wind profiles is likely due to an aliasing of the cross-beam mean wind component into the mean tangential wind. The centers are also qualitatively similar to the ones selected by hand.

The mean distance between the selected centers is shown in Table 3. The values are significantly better than the original simplex selections, and even slightly better than the handpicked centers. The GBVTD-simplex algorithm, coupled with the objective selection method, can determine TC circulation centers for Danny with a mean distance ~2 km, in agreement with the center uncertainty proposed by Lee and Marks for accurate wind retrieval. Table 4 shows a summary of the results for the lowest five kilometer heights for Danny. The mean distances are even better at heights above 1 km. This may be due to the strong wavenumber one asymmetry the lowest kilometer of the TC, resulting in different Doppler signatures from the two radars. Future improvements to the method will examine vertical continuity as an additional constraint for center selection.



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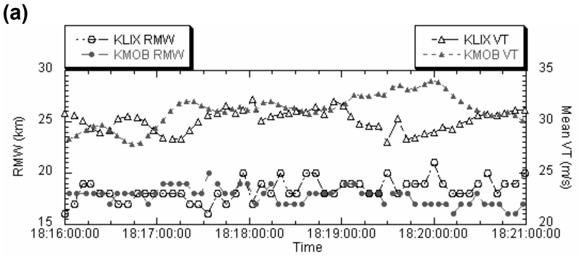

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Figure 3. (a) Individual simplex center solutions at 1 km height selected with the objective method, using .2 mean tangential wind, .2 number of converging centers, and .6 standard deviation of centers as weights. **(b)** RMW and mean tangential wind of selected centers over five-hour analysis period.

Distance Between Center Estimates Using Objective Selection Method	
Minimum	0.402 km
Maximum	4.930 km
Mean	2.203 km
Median	2.144 km
Std. Dev.	1.002 km

Table 3. Statistical analysis of distance between circulation center estimates from KLIX and KMOB radars using objective selection method at 1 km height.

	1 km	2 km	3 km	4 km	5 km
Minimum	0.40196	0.034882	0.060151	0.1481	0.084428
Maximum	4.93	4.041	5.4259	4.2956	4.0127
Mean	**2.2031**	**1.4412**	**1.7802**	**1.5679**	**1.7615**
Median	2.1443	1.5269	1.6452	1.5824	1.5359
Std Deviation	1.0022	0.67004	0.94474	0.71421	0.90274

Table 4. Summary of distance between circulation centers from KLIX and KMOB radars using the objective method for the lowest five kilometer CAPPI heights.

A sensitivity test was also performed to determine the optimal time interval for curve fitting. Figure 4 shows the results of this test from Hurricane Danny, and an additional test on Hurricane Bret. The test showed that longer intervals produced a lower average distance, with approximately three hours being the minimum time needed to achieve a 2 km uncertainty objectively. For all but the most rapidly moving TCs, this is not a severe constraint. Hurricane Danny, for example, was observed by the NEXRAD network for over 72 hours. With the WSR-88D in San Juan capturing many storms headed for the U.S. coastline, the GBVTD and GBVTD-simplex algorithms could provide valuable information to forecasters well in advance of landfall.

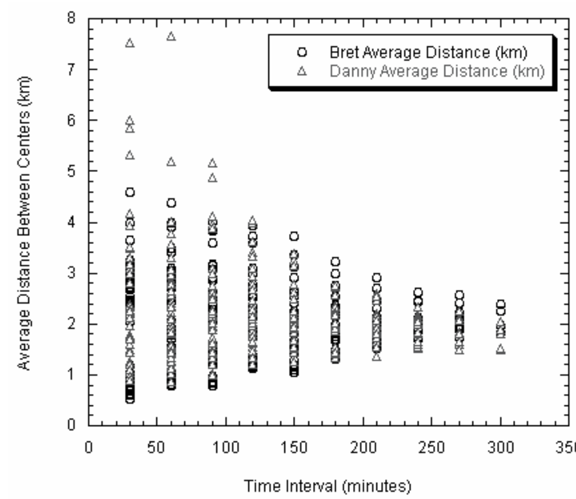

Figure 4. Sensitivity of the objective method to the curve fit time interval. Axes are average distance between centers versus time interval. Results are shown for Hurricanes Danny and Bret.

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