# Single Doppler Radar Tropical Cyclone Center Identification Using 'simplex-GBVTD' Algorithm

Wen-Chau Lee
National Center for Atmospheric Research[1]
Boulder CO, 80307
USA

Frank D. Marks
NOAA/AOML, Hurricane Research Division
Miami, FL 33149
USA

## 1. INTRODUCTION[1]

Since early 1980, the tropical cyclone circulation has been deduced from pseudo-dual-Doppler analyses of the NOAA WP-3D's airborne Doppler radar data (Marks and Houze 1984, 1987; Marks et al. 1992). In order to examine the dynamics of tropical cyclones, the derived flow fields need to be partitioned into tangential and radial components in cylindrical coordinates. The effect of a misplaced tropical cyclone center on an axisymmetric vortex introduces asymmetries into the wind field (Willoughby 1988). Hence, the accuracy of the partitioned wind components critically depends on the ability to define the tropical cyclone center at each altitude.

There are many ways to define the tropical cyclone center: reflectivity geometric center, zero velocity (Doppler and/or *in situ* wind), center of maximum vorticity, etc. These centers are not necessarily located at the same place. In addition, not all possible centers defined previously can be identified in a particular data set due to the characteristics of the observations. For example, it is sometimes easier to identify the vorticity center than the reflectivity center using airborne Doppler radar data because the velocities in the eyewall (i.e., vorticity) is usually well measured compared with the poorly measured weak reflectivity near the tropical cyclone center. The errors in estimating the tropical cyclone center position can be several kilometers and the uncertainties increase proportionally to the eye diameter and structure.

Using dual-Doppler radar derived winds in Hurricane Norbert, Marks et al. (1992) objectively identified vorticity centers at each altitude. The vorticity center is defined as the point that maximizes the tangential circulation within a 10-15 km-wide annulus centered on the radius of maximum wind. An iterative process involving the 'simplex' algorithm (Neldar and Mead 1965) was implemented to identify the vorticity center with great success. On the contrary, using single Doppler radar data (such as WSR-88D) to identify tropical cyclone center remains a challenging problem because obtaining tropical cyclone circulation from a single Doppler radar data is not straightforward and *in situ* observations by aircraft are normally not available on landfalling tropical cyclones. Recently, the development of the Velocity Track Display (Lee et al. 1994) and the Ground-Based VTD (GBVTD, Lee et al. 1998) techniques enabled us to extract primary tropical cyclone circulation from single Doppler radar data. It is feasible to identify the vorticity center from single Doppler radar observations of tropical cyclones using the GBVTD technique in conjunction with the 'simplex' algorithm.

The purpose of this paper is to present the 'simplex-GBVTD' algorithm, combining the 'simplex' algorithm and the 'GBVTD' technique, to identify tropical cyclone vorticity center from single Doppler radar data. Results of initial testing of this algorithm on axisymmetric tropical cyclones are presented in this paper.

## 2. METHODOLOGY

The VTD and GBVTD techniques use least-squares method to fit low order wavenumber tropical cyclone circulation to the Doppler velocities at each radius and altitude for a given tropical cyclone center. Both techniques are powerful in deducing the rotational component of the vortex circulation. The 'simplex' method maximizes/minimizes a function of N variables and compares function values at the vertices of a general simplex (triangle), followed by the replacement of a vertex with the highest (lowest) value of a new guess. The variables to be maximized/minimized by 'simplex' algorithm for a tropical cyclone can be a combination of mean tangential wind, wavenumber 1 tangential wind, and other resolvable quantities. In this study, the tropical cyclone center is defined as the vorticity center following Marks et al. (1992). Therefore, the 'simplex' algorithm is applied to identify

[1]Corresponding author address: Wen-Chau Lee, NCAR Remote Sensing Facility, Boulder, CO 80307. NCAR is sponsored by the National Science Foundation.

a point that maximizes the mean tangential circulation of a given Doppler velocity pattern.

The idealized tropical cyclones are constructed based on a Rankine combined vortex (e.g., Wood and Brown 1992). The key parameters in constructing the Rankine vortex are: radius of maximum wind (RMW), magnitude of the maximum axisymmetric tangential wind, and phase and amplitude of asymmetric tangential winds. The basic axisymmetric tropical cyclone has a maximum tangential wind of 50 m/s and the RMW at 20 km. The Doppler velocity pattern of each idealized tropical cyclone is sampled by a Doppler radar located 60 km south of the tropical cyclone center. The uncertainties due to beam expansion, range and velocity unfolding, and earth curvature effects are ignored. The only bias arises from the smoothing of peak Doppler velocities in the interpolation process from the constant altitude PPI into the tropical cyclone cylindrical coordinates.

The 'simplex-GBVTD' algorithm begins with an initial guess of the tropical cyclone center. This guess can come from reflectivity pattern or from the Doppler velocity pattern as described in Wood and Brown (1992). A simplex is formed surrounding the initial guess based on a pre-specified radius of influence that determines the distance to search for the next vertex. The GBVTD analyses are performed to compute the maximum mean tangential on the annulus for three vertices of the simplex derived from the initial guess. Then, the local gradients of the maximum mean tangential wind from all vertices are computed and a new simplex, either expanded or contracted from the initial simplex, is constructed. The iterations continue until (1) a maximum mean tangential wind of an annulus is identified, (2) the distances among all vertices are smaller than a threshold $\varepsilon$ (e.g., all vertices are close enough where the variations on their maximum mean tangential winds is small), or (3) maximum number of iterations is reached.

## 3. PRELIMINARY RESULTS

The 'simplex-GBVTD' algorithm was applied to identify the center of idealized tropical cyclones. In this study, the maximum number of iterations is set at 60 while $\varepsilon$=0.1 (e.g., distance among all vertices is less than 0.1 km). The radius of influence of the 'simplex' algorithm is set at 5 km. The maximum mean tangential wind is defined as the average of mean tangential winds on a 10 km-wide annulus centered at the radius of maximum wind. Table 1 illustrates the iteration process of 'simplex-GBVTD' algorithm applied to an axisymmetric tropical cyclone. In this example, the true tropical cyclone center is located at (0., 60.) and the initial guess of the center location is at (-2., 62.). It took 19 iterations to converge and the resulting center location is within 100 m of the true center. The computation time is less than 1 min CPU time on a SUN Ultra 1 workstation.

Table 2 summarizes the results of the 'simplex-GBVTD' algorithm on an axisymmetric tropical cyclone with several initial guesses. All runs converge in about 20 iterations. All runs resulted at points within 100 m of the true center.

Table 3 shows the results for an axisymmetric tropical cyclone with a 10 m/s NNE mean flow. In general, the 'simplex-GBVTD' algorithm is quite satisfactory. Adding a mean flow component degrades the results slightly. The mean error increases from ~100m in the no mean flow cases to ~300m with mean flow. There is one outlier not converging to the true center. Nonetheless, the algorithm is able to give reasonable center estimation.

| # Iteration | Xctr (km) | Yctr (km) | WS (m/s) |
|---|---|---|---|
| 0 | -2.000 | 62.000 | |
| 1 | 2.333 | 59.500 | 42.685 |
| 2 | 2.330 | 59.500 | 42.685 |
| 3 | 0.436 | 57.156 | 43.082 |
| 4 | -0.850 | 59.852 | 43.504 |
| 5 | -0.850 | 59.852 | 43.504 |
| 6 | -0.850 | 59.852 | 43.504 |
| 7 | 0.262 | 59.888 | 43.613 |
| 8 | 0.262 | 59.888 | 43.613 |
| 9 | 0.262 | 59.888 | 43.613 |
| 10 | 0.262 | 59.888 | 43.613 |
| 11 | 0.262 | 59.888 | 43.613 |
| 12 | 0.043 | 60.508 | 43.622 |
| 13 | 0.015 | 60.008 | 43.636 |
| 14 | 0.015 | 60.008 | 43.636 |
| 15 | 0.015 | 60.008 | 43.636 |
| 16 | 0.015 | 60.008 | 43.636 |
| 17 | 0.015 | 60.008 | 43.636 |
| 18 | 0.015 | 60.008 | 43.636 |
| 19 | 0.032 | 59.979 | 43.634 |

**Table 1: Example of the iteration process of the 'simplex' algorithm in identifying the center of an idealized tropical cyclone. The process began with an initial guess of the center at (-2., 62.) and the true center is located at (0., 60.).**

## 4. SUMMARY AND FUTURE WORK

This paper presents preliminary results of using the 'simplex-GBVTD' algorithm to identify tropical cyclone centers from single ground-based Doppler radar data. We demonstrated the potential of using this algorithm to identify tropical cyclone center by testing it on an axisymmetric tropical cyclone and axisymmetric tropical cyclones with a mean flow. The results are very promising and have great potential for real-time applications on the WSR-88Ds and other ground-based Doppler radars.

In the limited cases presented in this paper, certain initial guesses did not converge to the 'true' center. These outliers consistently converged to a point away from the true center. We found that by reducing the radius of the annulus (less averaging in tangential wind in radus) and/or reducing the radius of influence in the simplex algorithm, some of these outliers converged to the true tropical cyclone center. The effects of tuning these parameters such as ε and radius of influence are unknown. The choice of initial guess (how close it is to the true center) may influence the accuracy and speed of convergence in the algorithm. Nevertheless, systematic case studies on different flow structures and sensitivity studies on these tunable parameters are required to advance our understanding on the characteristics of the 'simplex-GBVTD' algorithm.

| Ini. Xctr | Ini. Yctr | Fin. Xctr | Fin. Yctr | # iter. |
|---|---|---|---|---|
| -2.0 | 62.0 | 0.032 | 59.979 | 19 |
| 5.0 | 64.0 | 0.004 | 59.922 | 20 |
| 3.0 | 57.0 | 0.017 | 59.807 | 18 |
| -4.0 | 56.0 | 0.003 | 59.956 | 19 |
| 1.0 | 53.0 | 0.029 | 59.984 | 19 |
| -1.0 | 67.0 | 0.023 | 59.887 | 20 |

**Table 2: Results of the 'simplex-GBVTD' algorithm from 6 different initial guesses for an axisymmetric tropical cyclone.**

| Ini. Xctr | Ini. Yctr | Fin. Xctr | Fin. Yctr | # iter. |
|---|---|---|---|---|
| -2.0 | 62.0 | 0.016 | 60.408 | 23 |
| 5.0 | 64.0 | 0.098 | 60.198 | 22 |
| 3.0 | 57.0 | 0.021 | 60.324 | 20 |
| -4.0 | 56.0 | 0.020 | 60.324 | 19 |
| 1.0 | 53.0 | 0.016 | 62.430 | 16 |
| -1.0 | 67.0 | 0.108 | 60.288 | 17 |

**Table 3: Same as Table 2 but for an axisymmetric tropical cyclone with a 10 m/s mean flow from 30 deg meteorological angle (NNE).**

## ACKNOWLEDGMENTS:

The Hurricane Research Division of NOAA/AOML hosted a 3-month sabbatical leave for the first author where most of the work was completed.

## REFERENCES:

Lee, W.-C., B. J.-D. Jou, B.-L. Chang, and S.-M. Deng, 1998: Tropical cyclone wind fields retrieved from single ground-based Doppler radar. Part I: The ground-based VTD technique. (Submitted to Monthly Weather Review).

Lee, W.-C., F. D. Marks, and R. E. Carbone, 1994: Velocity Track Display-A technique to extract real-time tropical cyclone circulations using a single airborne Doppler radar. *J. Atmos. Oceanic Technol.*, **11**, 337-356.

Marks, F. D, and R. A. Houze, 1984: Airborne Doppler radar observations in Hurricane Debby. *Bull. Amer. Meteor. Soc.*, **65**, 569-582.

Marks, F. D, and R. A. Houze, 1987: Inner core structure of Hurricane Alicia from Doppler radar observations. *J. Atmos. Sci.*, **44**, 1296-1317.

Marks, F. D., R. A. Houze, and J. F. Gamache, 1992: Dual-aircraft investigation of the inner core of hurricane Norbert. Part I: Kinematic structure. *J. Atmos. Sci.*, **49**, 919-942.

Neldar, J. A., and R. Mead, 1965: A simplex method for function minimization. *Comp. J.*, **7**, 308-313.

Willoughby, H. E., 1988: Linear motion of a shallow-water, barotropic vortex. *J. Atmos. Sci.*, **45**, 1909-1928.

Wood, V. T., and R. A. Brown, 1992: Effects of radar proximity on sing-Doppler velocity signatures of axisymmetric rotation and divergence. *Mon. Wea. Rev.*, **120**, 2798-2807.