NON-UNIFORM CYCLONIC WIND FIELD VOLUME PROCESSING OF THE DOPPLER VELOCITIES FROM A SINGLE RADAR

Sergey Panov, Joseph Holms, Douglas Paris, Jason Selzler

Vaisala Inc. 7A Lyberty Way Westford MA 01886, USA
Fax: +1 978 692 9575, sergey.panov@vaisala.com

ABSTRACT

Traditional Velocity Volume Processing (VVP) is an effective and widely used method to characterize wind fields from one-dimensional Doppler radial velocities. Unfortunately, the VVP technique assumes fixed horizontal wind speed and direction within the field of view.

A new technique was implemented in the Vaisala IRIS system to analyze wind fields with significant vorticity. This new volume processing technique on the radial wind-field is similar to the VVP technique but fits a more complex wind model to the observed radial velocities. The model assumes a wind field typical for tropical cyclone environments. The technique is not sensitive to radial velocity folding. The resultant methodology estimates the maximum wind velocity within the storm and the maximum distance from the center of rotation.

The Vaisala's IRIS weather radar application allows users to estimate the center of tropical storms using spiral overlay. This volume processing technique uses a fixed center point to constrain the model. The resulting model gives users valuable information about the storm characteristics from a single radar site.

1. Introduction

The Doppler radar can be used to almost instantly assess the severity of the typhoon or tropical cyclone. However, the sparsity of the aerial coverage and the Doppler velocity folding make such an assessment difficult at best.

A number of techniques have been developed in the past to retrieve the velocity field. The velocity track display (VTD) (Lee et al. 1994) utilizes single-Doppler data collected by the airborne radar. The data from two successive flight legs can be processed simultaneously in the extended VTD (EVTD) (Roux and Marks 1996) technique. The ground-based VTD (GVTD) (Lee et al. 1999) was also used to study the wind field distribution of tropical cyclones and tornadoes (Lee and Wurman 2005). In the VTD based techniques, Doppler winds are analyzed within the rings concentric with the cyclone at a constant altitude.

A new technique was implemented in the Vaisala IRIS system to analyze wind fields with noticeable vorticity. This new volume processing technique of the radial wind field is similar to the VVP technique but fits a more complex wind model to the observed radial velocities. The model assumes a wind field typical for tropical cyclone environments. The technique is not sensitive to radial velocity folding.

2. The traditional Volume Velocity Processing (VVP) model and the extended VVP.

The Volume Velocity Processing (VVP) (Waldteufel and Corbin 1979) fits a simple model of the constant, or linearly changing, wind to the observed radial velocities at successive heights. The VVP was combined with unfolding (Siggia and Holmes 1991) of the observed Doppler velocities.

The extended model combines simple non-divergent constant horizontal velocity with a simplified vortex defined in a cylindrical coordinate system centered at the center of the cyclone. The model is in many aspects similar to one used to model tornado vortexes (Potvin et al. 2008) in processing multiple-Doppler radar data. The differences are that the Cartesian components of the linear flow field do not contain horizontal shear and divergence terms and the Rankine vortex distribution of rotational velocities is replaced with the Gaussian distribution.

The model parameters are two components of the translational velocity (V_x and V_y), the vortex azimuth and its distance from the radar (θ_v and D), scale of the Gaussian σ, maximum rotational velocity ω, and location of the Gaussian maximum relative to the vortex center Δ_0. The modeled radial velocity V_i^{mod} is described by a single equation:

$$V_i^{\mathrm{mod}} = \cos(\varphi_i)\left(\cos(\theta_i)V_x + \sin(\theta_i)V_y + D\omega e^{-(\Delta_i-\Delta_0)^2/2\sigma^2} \sin(\theta_v - \theta_i) \right) \tag{1}$$

, where θ_i and φ_i are the azimuth and elevation angles of the modeled data bin i, and Δ_i is the distance from the center of the vortex to the modeled data bin i. The Δ_i is expressed in terms of the distance from the bin i to the radar r_i projected on to the horizontal plane, $l_i = r_i \cos(\varphi)$, and previously defined parameters and variables:

$$\Delta_i = \sqrt{(l_i^2 - 2l_i D\cos(\theta_v - \theta_i) + D^2)} \tag{2}$$

One of the benefits of using Gaussian distribution instead of Rankine vortex (constant core ω at $\Delta_i \le R$ and $\omega \sim 1/\Delta_i^{\alpha+1}$ for $\Delta_i > R$) is that for each of the adjustable parameters a_j there is a relatively simple analytical expression for $\partial V_i^{\mathrm{mod}} / \partial a_j$ and that all those derivatives are continues functions.

If measured radial velocity V_i^{obs} is unambiguous, the nonlinear recursion can be used to minimize the cost function $J = \sum_{i=1}^{N} \left[V_i^{obs} - V_i^{\mathrm{mod}} \right]^2$ and to estimate all or a subset of the adjustable parameters.

3. The NLSQ fit in the angular representation of the observed radial velocities

It is likely that parts of the strong tropical cyclone will have wind velocity well outside of the Nyquist interval.

There are a few ways to address the velocity ambiguity problem. One option is to use the same model to fit azimuthal and radial shear, which can be measured unambiguously. Another option is to replace $V_i^{obs} - V_i^{\mathrm{mod}}$ differences with the shortest distance on the Nyquist interval. Both approaches were tried and worked, but suffered from the slow convergence and the low accuracy.

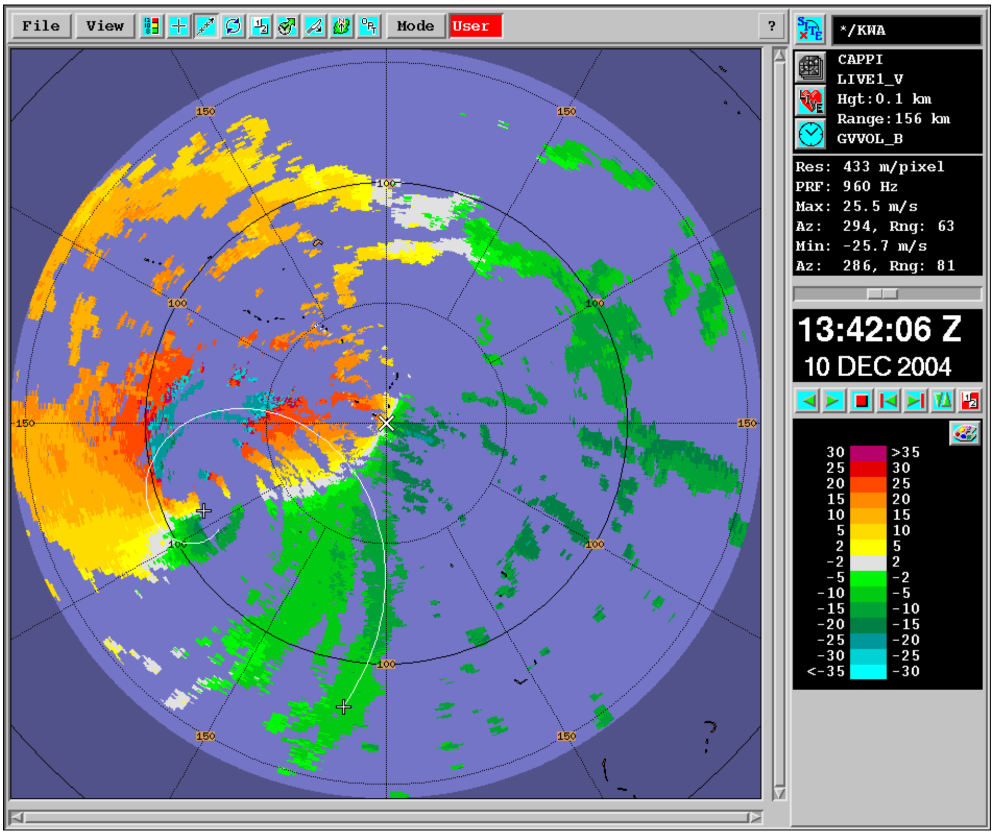
The approach which works well was inspired by the treatment of the differential phase Φ_{DP} in (Wang Y. and V. Chandrasekar, 2009). Analogous to angular Φ_{DP} represented by the complex unit vector $e^{j\Phi_{DP}}$, the Doppler velocity can be represented as $e^{j\Pi V_r / V_N}$, where V_N is the Nyquist velocity and V_r is the measured Doppler velocity.

4. Operational Use

The Vaisala's IRIS weather radar application allows users to estimate the center of tropical storms using spiral overlay. This volume processing technique uses the fixed center point to constrain the model. The results of the fit give users valuable information about the storm characteristics from a single radar site data. The reported parameters are the radius R at which the rotational component of the wind velocity reaches its maximum value V_{rot}

$$R = \frac{\left(\Delta_0 + \sqrt{\Delta_0^2 + 4\sigma^2}\right)}{2}$$
$$V_{rot} = R\omega e^{-(R-\Delta_0)^2/2\sigma^2} \tag{3}$$

as well as direction and the absolute value of the translational component of the wide wind field.



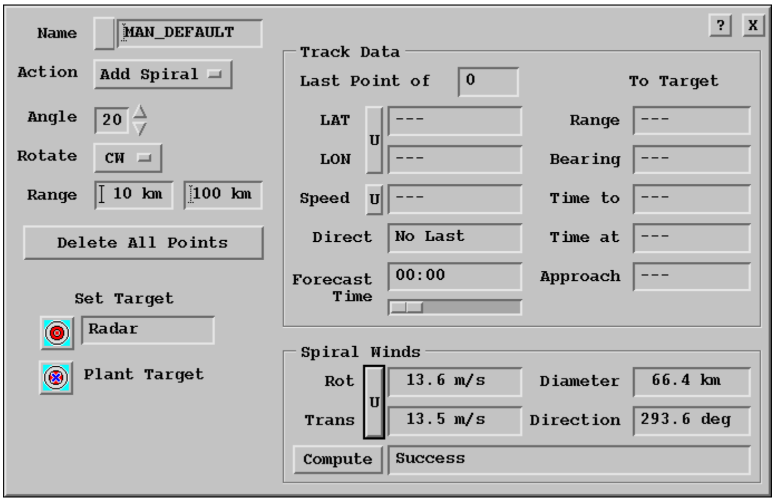
*/KWA

CAPPI
LIVE1_V
Hgt:0.1 km
Range:156 km
GVVOL_B

Res: 433 m/pixel
PRF: 960 Hz
Max: 25.5 m/s
Az: 294, Rng: 63
Min: -25.7 m/s
Az: 286, Rng: 81

13:42:06 Z
10 DEC 2004

Fig. 1 Spiral Tool.



Name: MAN_DEFAULT
Action: Add Spiral
Angle: 20
Rotate: CW
Range: 10 km 100 km
Radar

Last Point of: 0
LAT: ---
LON: ---
Speed: ---
Direct: No Last
Forecast Time: 00:00
Range: ---
Bearing: ---
Time to: ---
Time at: ---
Approach: ---

Rot: 13.6 m/s
Trans: 13.5 m/s
Diameter: 66.4 km
Direction: 293.6 deg
Success

Fig. 2 Spiral Tool Dialog.

Producing four parameters that characterize spiral winds (Fig.2) is not the only possible application. The extended VVP can be used to unfold Doppler radial velocities in cases when the conventional VVP unfolding fails or to generate the wind field product from the fitted model. The model might have to be improved by switching to a different, more realistic, rotational velocity distribution.

References

Lee, W. C., Marks F. D. Jr., and Carbone R. E., 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.

——,Jou J.-D., Chang P.-L., and Deng S.-M., 1999: Tropical cyclone kinematic structure retrieved from single Doppler radar observations. Part I: Interpretation of Doppler velocity patterns and the GBVTD technique. *Mon. Wea. Rev.*, **127**, 2419-2439.

Potvin, C. K., Shapiro A., Yu T.-Y., Gao J., Xue M., 2008: Using a Low-Order Model to Detect and Characterize Tornadoes in Multiple-Doppler Radar Data. *Mon. Wea. Rev.*, **137**, 1230-1249

Roux F., and Marks F. D., 1996: Extended velocity track display (EVTD): An improved processing method for Doppler radar observation of tropical cyclones. *J. Atmos. Oceanic Technol.*, **13**, 875–899.

Siggia, A. D. and Holmes J. M., 1991: One pass velocity unfolding for VVP analysis. *Preprints, 25th Conf. on Radar Meteorology, AMS*, 882-884.

Waldteufel, P., and Corbin H., 1979: On the analysis of single Doppler radar data, *J. Appl. Meteor.*, **18**, 532–542.

Wang Y. and Chandrasekar V., 2009: Algorithm for Estimation of the Specific Differential Phase. *J. Atmos. Oceanic Technol.*, **26**, 2565-2578