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## 1. INTRODUCTION

In an attempt to emphasize to National Weather Service (NWS) personnel issues regarding radar data quality, the NWS Warning Decision Training Branch (WDTB) and the National Severe Storms Laboratory (NSSL) have developed a new tool that explores some of the limitations associated with the Weather Surveillance Radar – 1988 Doppler (WSR-88D) (Crum and Alberty, 1993). This new tool, known as the Volume Coverage Pattern Explorer (or simply, VCP Explorer), provides the user with the ability to visualize several aspects associated with radar beam path propagation, with main emphasis on terrain interaction, and on VCP effects on vertical sampling errors.

The following sections will provide historical and technical background, the features of the VCP Explorer, applications for the tool, and future enhancements.

## 2. BACKGROUND

In 1994 a program was introduced to allow a user to visualize the height of the radar beam above the ground with an included topographic database for any WSR-88D site (Barker, 1994). Called RDRHGT, this program traced the beam path for either a standard atmospheric thermodynamic profile, or an observed profile provided that a RAOB sounding was available. This program was useful at the time, however a more functional program was needed to satisfy new training requirements for the NWS (e.g., new VCP impacts on vertical beam sampling, non WSR-88D data) and newer computer architecture.

With an increasing mix of computer operating systems (Linux and Windows) at NWS forecast offices, platform independence was a must for the new tool. Due to this requirement, the Sun Java programming language seemed to be a natural solution. Java not only provided the needed platform independence, but was a versatile language for creating graphics user interfaces (GUIs). But perhaps the greatest advantage to choosing Java was the ability to use the Visualization for Algorithm Development (VisAD) Java package developed by Bill Hibbard and others at the Space Science and Engineering Center at the University of

Wisconsin (Hibbard, et al., 1997). The VisAD package provides a unique data model for storing data and developing algorithms. Also, by building on the Java2D and Java3D technologies, VisAD offers state-of-the-art graphics capabilities.

The simple process of displaying the radar beam propagation path, based on equations described by Doviak and Zrnic (1993), was accomplished, including displaying two-dimensional beam widths. The capabilities of the Java/VisAD programming language quickly led to the expansion of the initial goals of the VCP Explorer.

## 3. FEATURES OF THE VCP EXPLORER

Figure 1 shows the layout of the VCP Explorer. There are four main areas of note in the display.

1. The current radar information is displayed across the top.
2. The left panel depicts the plan position indicator (PPI) with the selected radar being at the center of the PPI. The colored background of the PPI represents the terrain surrounding the selected WSR-88D with warmer(cooler) colors indicating higher(lower) terrain. The red radial in the PPI indicates the radar beam's azimuthal position.
3. The right panel shows the range height indicator (RHI). The smooth curved line is the radar beam, and the jagged line represents the terrain below the red radial in the PPI display. The coordinate system is translated such that the curvature of the earth is "flattened" to a constant altitude display.
4. The bottom right area is the "VCP Controls" section. This is where the user can select the desired elevation angle, azimuth, etc.

The VCP Explorer currently contains several features related to radar beam propagation and radar algorithm output. Most of these features simply illustrate basic concepts in a way that users of WSR-88D data may not have considered or fully understood. These features are also interactive, providing the user with multiple examples to compare different behavior of the same concept. The features are described below.

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### 3.1 Beam Propagation

The majority of the current version of the VCP Explorer is dedicated to radar beam propagation concepts. The following list provides a short description of these features.

- Azimuth Selection: The user can select any azimuth, either by dragging the end point of the "radar beam" on the PPI, or by entering an azimuth. In either case, the terrain under the beam path in the RHI will update instantaneously.
- VCP Selection: The user can choose and display one of several existing VCPs, or even create and choose a new VCP.
- Elevation Angle Selection: The user can choose any elevation angle in the selected VCP. The user can also enter any elevation angle (+90° to -90°) regardless of the VCP selected
- Beam Width Toggle: The 1° half-power beamwidth can be toggled on or off in the RHI
- All Beams Toggle: The user can display all the beams of a given VCP at the same time. (see Figure 2.) If the beam widths are also on, the user can see the possible vertical overlap between adjacent beam paths.
- Ground Clutter: The user can specify a minimum beam blockage threshold, and elevation angle, and the VCP Explorer will calculate and shade the blocked regions in the PPI. (Figure 2.)
- Non-standard Beam Propagation: If an atmospheric sounding is selected, the non-standard beam path is displayed along with the standard (1.21\*Earth's Radius) beam path.

### 3.2. Radar Algorithms

The VCP Explorer also has the ability to evaluate and display radar sampling issues as they relate to algorithms. Currently, the VCP Explorer will display algorithm output for several of the NSSL Nail Detection Algorithms (HDA), namely severe hail index (SHI), probability of severe hail (POSH), and maximum expected hail size (MEHS or "MESH"). Formulae used to calculate these parameters were taken from Witt, et al. (1998). The Java/VisAD code is already in place to display vertically integrated liquid (VIL) as well, however it currently is not being displayed.

The user is required to select a two-dimensional reflectivity profile (Figure 3a) from the VCP Explorer. The algorithm output for SHI, MESH, and POSH is calculated. Since the formulae for these parameters assumes perfect sampling, the reflectivity profile is first sampled 1000 times over its vertical extent to attempt to provide a theoretical value for each. Then the reflectivity profile is sampled at discrete heights based on the height of the centerpoint of each radar beam of a particular VCP as a function of range. The output is the

value of the respective algorithm as a function of range (Figures 3b-d).

Another algorithm-like feature built into the VCP Explorer illustrates errors in calculating height measurements with the WSR-88D. Based on the work by Howard, et al. (1997), the VCP Explorer provides two different ways to inform the user of the uncertainties in radar-based heights of storm features as a function of range from radar.

### 3.3 Miscellaneous Features

The VCP Explorer is designed to be a highly interactive application. There are several additional features that allow the user to further investigate the concepts that he or she is exploring.

The user can select from 143 WSR-88D radar sites. These sites include WSR-88D locations in Alaska, Hawaii, and Puerto Rico, as well as the continental United States. There are 47 terminal doppler weather radar (TDWR) sites to choose from as well. Many products can be overlaid by being toggled on or off. When a user is investigating a selected radar site, they have the ability to zoom in on both the PPI and RHI displays. A middle mouse click will provide a data readout for displayed data. When calculating the ground clutter, the user can determine what percentage of beam blockage should be considered. The terrain data come from a 30 meter resolution geographic information systems (GIS) file which is included for every available radar site.

## 4. APPLICATIONS

As stated previously, the VCP Explorer was designed for the training of NWS personnel. It is now available to each NWS forecast office. Forecasters now have the opportunity to explore data quality issues related to radar beam propagation, local terrain effects, and VCP selection.

Formal training on the features and functionality of the VCP Explorer was provided in the Data Quality section of the recent Advanced Warning Operations Course (AWOC) offered by WDTB (Ferree, et al. 2004). NWS training facilitators from forecast offices around the country attended AWOC in the fall of 2004, and, among a variety of topics, were introduced to the VCP Explorer. They were instructed in the basic operation of the tool, and were encouraged to train their staff to use it at their local office. For those interested in running the VCP Explorer, the self-contained, self-installing program can be downloaded at the following web address:

<http://www.cimms.ou.edu/~kmanross/VCP/PRPE/Installer/install.htm>

This address will also be the location of future upgrades.

Given the capability to explore TDWR locations, personnel in the Federal Aviation Administration may find the VCP Explorer useful as well.

## 5. FUTURE ENHANCEMENTS

The VCP Explorer has been a useful learning tool for both the users and the developers. There are many improvements that can be made to the current version, and the modularity of the Java programming and VisAD package allow for future enhancements to be added to the application.

Improvements to the current version include a more streamlined GUI, better error handling, radar radial manipulation when zoomed in (PPI), fully functional TDWR capabilities, and an improved online help. It is also desirable to be able to recall the last selected sounding and reflectivity profile if those windows are closed. As the program currently stands, the user must re-enter the profile if the external window is closed. Finally, for the case of non-standard beam propagation "ducting", the beam needs to be traced back to the Earth's surface.

There are many enhancements being considered for the VCP Explorer. Pending additions include the use of non-standard beam paths (and widths) in the calculation of ground clutter, displaying VIL, providing the ability to toggle individual radar algorithm output (SHI, MESH, POSH, and VIL) on or off in an attempt to make the display less cluttered.

Longer range additions to the VCP Explorer include displaying the Hybrid Scan Reflectivity Product (O'Bannon, 1997), adding an atmospheric sounding editor, and exploring the effect of different VCPs on other algorithms such as the Mesocyclone Detection algorithm (Stumpf, et al., 1998) to name a few. Certainly there are many more radar and algorithm concepts that could be incorporated into the VCP Explorer.

## 6. SUMMARY

A new tool for exploring radar data quality issues has been developed by the Warning Decision Training Branch and the National Severe Storms Laboratory for National Weather Service forecasters. The VCP Explorer is a platform-independent computer program that allows a user to examine the effects of radar beam propagation paths and how they interact with the terrain surrounding one of 143 WSR-88D, or 47 TDWR locations.

Users can manipulate radar beam azimuth and elevation angles and instantaneously witness interactions. The VCP Explorer can then calculate and display expected ground clutter patterns. As a result of the modularity of the Java programming language, and the display capabilities of the VisAD Java package, the VCP Explorer has been expanded to allow users to investigate how the choice of VCP affects certain radar-based algorithms.

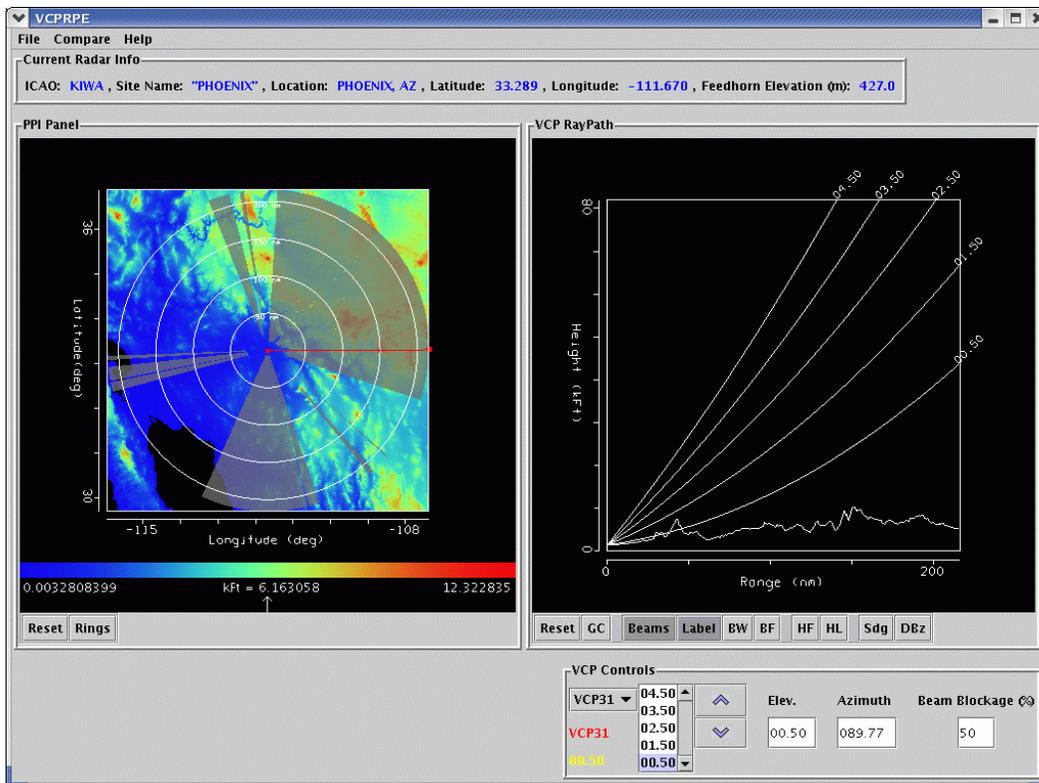
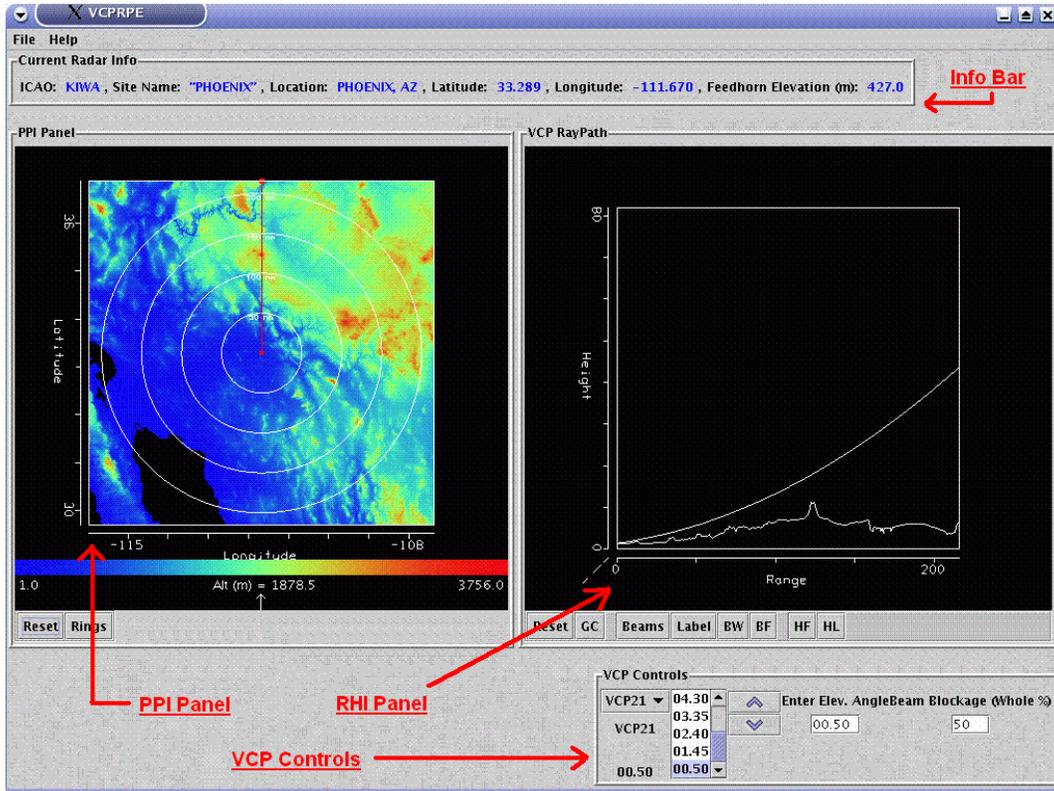
The VCP Explorer has already been used in formal training exercises. While program development is still ongoing and improvements are needed, the potential to add and display additional radar and algorithm concepts is great.

## 7. ACKNOWLEDGEMENTS

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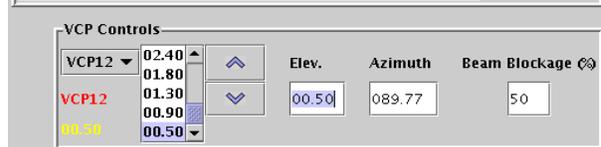
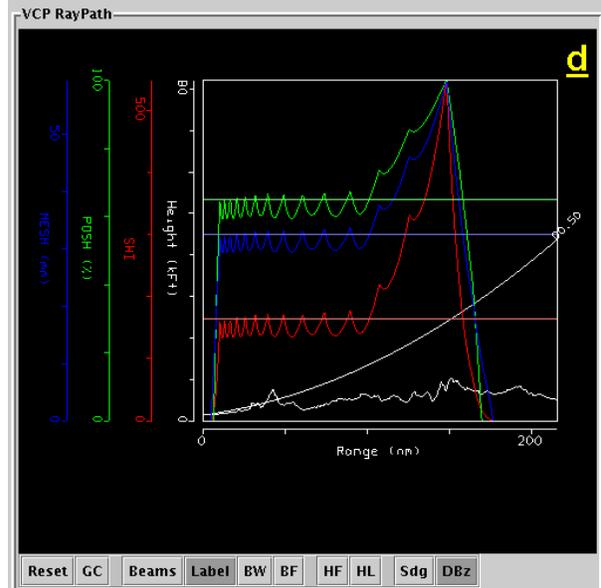
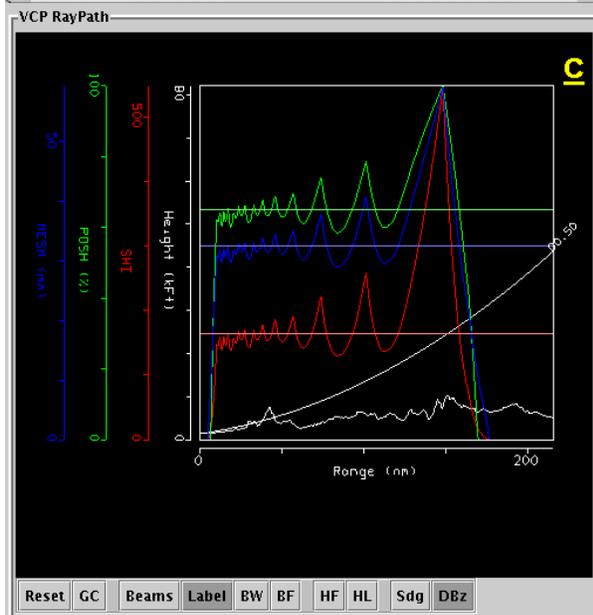
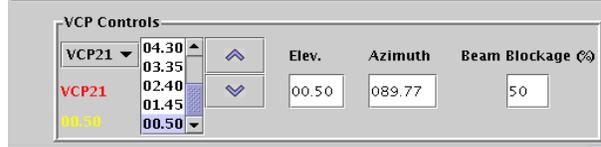
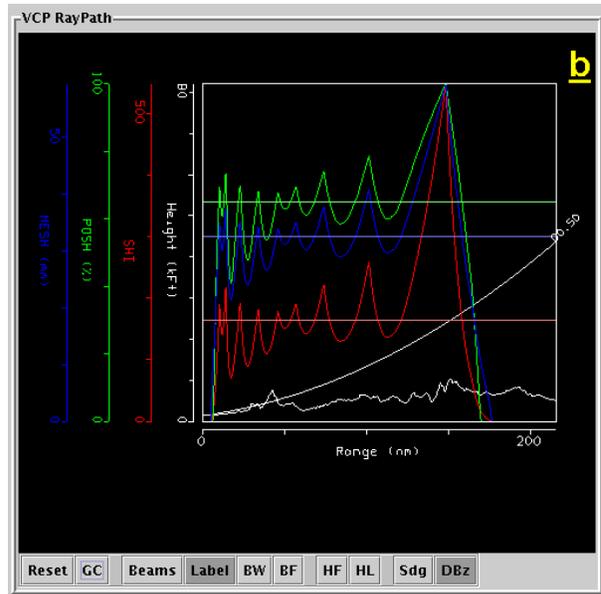
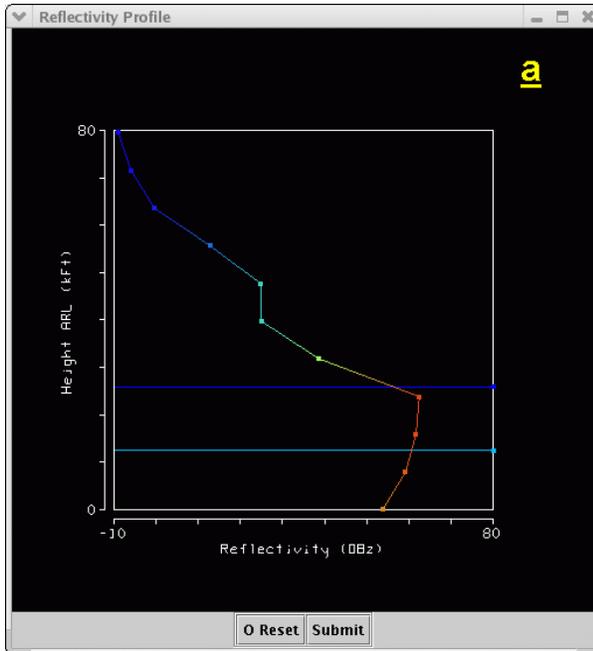


Figure 3a-d. Figure 3a is the reflectivity profile used in the calculations of severe hail index (SHI), probability of severe hail (POSH), and maximum expected hail size (MESH). Figures 3b-c show the output of the algorithms with the horizontal line being the theoretical value (see text), for SHI (red, in J/m/s), POSH (green, in %), and MESH (blue, in mm). Jagged lines of the same color are sampled values based on VCP 21 (3b), 11 (3c), and 12 (3d). The light(dark) blue horizontal line in 3a represents the height of the 0°C(-20°C) isotherm.