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STATUS ON THE FOUR-DIMENSIONAL RADAR ANALYSIS TOOL FOR AWIPS

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1. INTRODUCTION

Stumpf et al. (2004) reported on a project being coordinated to integrate a 3D base radar data display tool developed at the National Severe Storms Laboratory (NSSL) into the Advanced Weather Interactive Processing System (AWIPS) (Wakefield, 1998). This prototype AWIPS radar display tool is currently known as the *Four-Dimensional Stormcell Investigator (FSI)*.

Since that publication, some progress has been made to improve the NSSL 3D radar display. However, the work to integrate the NSSL tool into AWIPS has unfortunately been put on hold due to lack of resources. The following manuscript will detail the status of this work done to adapt the WDSSII display system as a 3D, and four-dimensional (animate in three dimensions), base radar data analysis tool for NWS severe weather warning decision operations. We will provide some of the same background information from the previous manuscript, but we will also report on the progress made, and provide more up-to-date information and figures describing the new application. Finally, we will discuss the use of the new application in light of some recent activity to develop a Hazardous Weather Testbed for National Weather Service (NWS) Weather Forecast Office (WFO), to prototype new and experimental severe convective weather warning applications, displays, and concepts.

2. BACKGROUND

Historically , the tools to analyze base Weather Surveillance Radar – 1988 Doppler (WSR-88D) radar data within the National Weather Service (NWS) Weather Forecast Office (WFO) severe weather warning decision-making environment have limited users to two-dimensional (2D) representations of the data. This is primarily because most meteorologists have been trained in the paradigm of 2D weather analysis, including radar data. Conceptual models of severe storms (e.g., supercell thunderstorms) are frequently portrayed with 2D dimensional representations and with 2D cross-sections.

For example, the seminal NWS training document to identify features associated with supercell thunderstorms using radar, known as the "Lemon Technique", was based on radar display technology of the time (Lemon, 1977). The old Weather Surveillance Radar – 1957 (WSR-57) radar control and display consoles allowed meteorologists to manually control the radar beam azimuth and elevation. This allowed radar operators to cut both quasi-horizontal cross-sections in the form of the Plan Position Indicator (PPI) display, as well as quasi-vertical cross-sections in the form of the Range Height Indicator (RHI) display. Figure 1 illustrates some of the features associated with a classic supercell as they would be depicted on both a PPI and an RHI display. Traditional severe convective storm analysis was based on the ability of a meteorologist having the ability to slice and dice storms in both horizontal and vertical cross-sections.

In the present-day NWS, meteorologists continue to infer storm structure using 2D representations of the WSR-88D data. However, the WSR-88D does not allow for manual control of the radar, and RHIs are impossible. Therefore, NWS meteorologists are trained on AWIPS to use elevation scan PPIs, either as single images, via a 4-panel display, or using the "all tilts" feature to mentally assemble a series of PPIs at various elevation angles to develop a 3D depiction of the storm. While this is adequate in some sense to gain a 3D understanding of the storm, this process has its limitations. First, the data on a PPI is from a constant elevation angle, and not a true horizontal cross-section. When storms are close to a radar, higher elevation angle PPIs are used to analyze storms within their higher altitudes, and these cross-sections can be quite tilted from the horizontal. Furthermore, an additional step of using the data sampling feature is needed to determine the altitude of the radar feature (which can vary across the PPI especially at higher elevation angles).

AWIPS does have a vertical cross-section capability, but it is limited in that it is not user-friendly, is only complete (filled with data from bottom to top) during a short interval at the end of a volume scan, and is not dynamic, meaning it must be re-drawn to change the location of the cross-section. All of these limitations add to the

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length of time it takes to analyze a storm. Warning decision making demands rapid assessment of the 3D structure of storms, and these limitations can shave off valuable lead time for warnings.

In reality, the atmosphere exists in three dimensions. To quote Szoke et al. (2003), "…it is (therefore) also hard to deny that examining the atmosphere using a [three dimensional (3D)] tool is not more effective and complete than using 2D displays…" This includes the analysis of radar data for severe storm warning decision making.

The Forecast Systems Laboratory (FSL) pioneered work to develop operational meteorological display systems that provide ways to analyze data in three-dimensions (McCaslin et al. 1999; Szoke et al. 2001; Szoke et al. 2002). The Display Three Dimensions (D3D) was adapted from the University of Wisconsin's Vis5D software (Hibbard and Santek, 1991) and built within the AWIPS, which is currently a part of every WFO.

Radar data provide unique display challenges in three-dimensions, particularly because the native data coordinates are on a spherical grid coordinate system. However, Viz5D was designed for Cartesian gridded data (e.g., numerical model data), and not spherical data coordinates. Spherical radar data can be resampled to a Cartesian grid (Roberts and Longmore, 1999), but some information is lost, particularly at close ranges to the radar where Cartesian grid pixels oversample the spherical grid data. Furthermore, radial velocity is a vector defined in a spherical coordinate system (flow is measured perpendicular to a constant azimuth angle). A resampling of the scalar magnitude of the radial velocity to another coordinate system renders the vector information invalid. In fact, the D2D displays WSR-88D data in its native resolution (otherwise known as "8-bit" data) to satisfy NWS severe weather warning decision requirements.

Severe storm researchers and application developers at the National Severe Storms Laboratory (NSSL) and FSL already extensively use 3D imagery to facilitate their understanding of atmospheric processes. For example, during the development of the NSSL Warning Decision Support System – Integrated Information (WDSSII; Hondl 2002), a 3D display tool was developed. This tool aided the research and development of multiple-sensor severe weather applications that required the analysis of intermediate and final output in 3D earth-centric and time-centric coordinates.

Since much of the application development work at NSSL is focused on radar data, the WDSS-II display tool was designed to accurately and precisely represent radar data on spherical coordinates in three dimensions. Although the primary emphasis for this development was for research and development, the operational use of such 3D displays became immediately apparent. Since many of the developers are also research scientists trying to diagnose storm structure in 3D, it made sense to impart that capability to operational meteorologists who are also diagnosing storms for warning decisions. Thus, a prototype 3D display system was tested at several NWS WFOs (Stumpf et al. 2003, Scharfenberg et al. 2004). Display concepts and algorithms of the original WDSS system were incorporated into the System for Convection Analysis and Nowcasting (SCAN; Smith et al. 1999) which is part of the operational baseline of AWIPS.

2. PROTOTYPE REQUIREMENTS

The development of a 4D data analysis tool used for short-fused warning decision making entails special challenges. The FSI would have to provide quick and easy access to the data, such that the decision maker can move quickly from storm to storm and extract information as the radar data volumes rapidly update (e.g., be able to choose a cross-section, and dynamically interact with one storm on the order of 15 to 30 seconds). Foremost, the software has to be bug free and cause minimal impact to AWIPS systems resources.

The results of testing D3D in various real-time exercises are being considered as requirements for the FSI are developed (McCaslin et al. 1999; Szoke et al. 2001; Szoke et al. 2002). As with the D3D, the FSI interface should have a look and feel similar to the AWIPS Display Two Dimensions (D2D), with comparable features for animation control, product labels, keyboard shortcuts for product selection and "all-tilt" control, and colormap configuration. The radar data should be represented in its native spherical coordinate system, with no resampling to other coordinate systems or to lower resolutions. In other words, the native "8-bit" spatial resolution and data precision must be retained. And the data should be accurately representable in 3D space, plotted on a spherical globe (so that no coordinate transformation is needed) with the horizontal to vertical aspect ratio in natural ratios (1:1). This provides the user a true-to-life image of the storm, as if the user was looking outside at a storm with "x-ray glasses".

Results of the D3D testing also concluded that, although the atmosphere is three-dimensional, it was still difficult for many forecasters to overcome the tendency to want to view fields in the traditional 2D manner. Thus, the FSI should provide a good linkage between 2D and 3D representations of the radar data. The FSI should provide flexibility for users to choose and manipulate 2D representations of the 3D data. Szoke et al. (2003) concluded that such flexibility should allow operational forecasters to better focus on the important aspects of a forecast more quickly and with less chance of missing some critical feature because they failed to examine the "correct" 2D plan view or the most appropriate cross section. This also allows forecasters to compare the 2D representations with the original conceptual models of severe storms developed several decades ago (e.g., Lemon 1977), and tie those to 3D depictions of the data. Another initial requirement is the ability to view all three radar data moments (reflectivity, velocity, and spectrum width[1]) as well as storm-relative velocity (with manual override of the storm motion vector) with the ease of toggled keyboard shortcuts. All 3D manipulation controls (keyboard and mouse) should be easy to use, and alternative control configurations should be provided to allow the control of the display by persons with disabilities.

3. PROTOTYPE DESIGN

3.1 The WDSSII GUI ('wg')

The WDSSII Graphical User Interface ('wg') is a powerful 4D data analysis tool that is used extensively by NSSL and other researchers in academia for multi-sensor severe weather application development and applied research activities. The 'wg' display functionality is built using OpenGL (www.opengl.org). Introduced in 1992, OpenGL provides an environment and application programming interface (API) for developing interactive 3D graphics applications. It incorporates functions for rendering, texture mapping and other powerful visualization functions. Many of these functions are supported natively in hardware on a variety of graphics cards, making OpenGL a fast and interactive solution to 3D visualization. The display application was originally developed for the Linux operating system (same used for AWIPS), but more recently has been ported to operate in the MS Windows operating system as well. The dependency on the WxWindows libraries has also been replaced with GTK libraries to facilitate this port. GTK also enables the use of keyboard shortcuts that AWIPS users are familiar with.

OpenGL requires a rectilinear coordinate system, so that matrix operations such as translation and rotation can be implemented in hardware. Programmers build a model of the OpenGL universe by specifying object locations in the coordinate system. Programmers also specify the matrix transformations that need to be performed in response to user inputs such as panning, zooming, yaw and roll.

The coordinate system that is used in 'wg' is an earth-centered Cartesian coordinate system. The origin of the coordinate system is at the center of the earth. The x and y axes are at the plane of the equator, while the z axis coincides with the earth's polar axis.

Whenever 2D or 3D data are ingested by the display, they are converted into corresponding 2D or 3D drawable structures that operate in the earth-relative coordinate system. For the native radar data from a spherical grid, each elevation scan (or "PPI display") is converted such that the radar sample volumes (gates) represent an illumination of the 2D surface of a 3D conical section. The apex of the cone is at the radar location, and the axis of the cone is perpendicular to the earth at the radar location. The radar data are mapped to the 2D cone surface gate by gate using the beam center angle, elevation, and gate spacing, with the appropriate color for the data value. The surface of the cone is mapped onto an OpenGL "texture" situated in earth-centered coordinates. Since the earth location of every gate is computed independently, the height of each gate can be computed using a 1.21 $\times$ earth radius formula, the standard atmospheric refraction formula used within the Open Radar Product Generator (ORPG).

For radar cross-sections, the spherical radar data is remapped to a 2D plane surface. The 2D plane and 2D conical surfaces are then represented in 3D space, such that on-the-fly 3D navigation about the surfaces from any viewing angle can be performed. Cross-sections can be preformed in the vertical ("VSlice") and in the horizontal (CAPPI). Each of these cross-sections is dynamic, meaning that after the cross-section is drawn, the location, orientation, length, and/or area of the cross-section can be manipulated, and the resulting cross-sectional data updates on the fly.

Examples of a constant elevation angle texture (or "PPI display"), and a vertical cross-section from a classic supercell near Mulvane Kansas on 12 June 2004 are shown in Figure 2. Note the similarity of the features as shown in Figure 1, the conceptual diagrams illustrating the "Lemon technique" for identifying supercell storms (Lemon 1977). Since the cross-section capability is dynamic, a user can quickly select and analyze a series of cross-sections in rapid and animated succession. Examples of both vertical and horizontal (CAPPI) cross-section series of the same storm are shown in Figure 3 and Figure 4, respectively.

Several new features have been added to the cross-section applications since Stumpf et al. (2004). An interpolation function has been added (see next subsection). In addition, the vertical cross-section has been modified such that the vertical plane wraps the Earth's surface in an arced fashion, so that data at constant display height are at constant real altitude (Fig 5). Similarly, horizontal cross-sections (CAPPIs) are displayed on a curved surface, such that the data on the surface is at a constant altitude above sea-level at all points on the CAPPI surface (Fig 6).

Zooming is implemented by simply decreasing the height of the user's viewpoint. Panning is implemented by translating the viewpoint of the user along the earth's surface at constant height. Roll and yaw are implemented by allowing changes in all three dimensions at the same time, and taking into account the view direction. All of these 3D view controls can be executed in a continuous fashion, allowing a user to

[1] Presently, spectrum width is only available to AWIPS as a 4-bit product.

smoothly and quickly analyze and scan threat areas faster than with point-and-click and stepwise zoom and re-center functions.

The 'wg' also has the capability to display 3D isosurfaces (similar to the D3D). However, the initial version of the FSI will only include the simpler 2D cones and planes represented in 3D space. Isosurfacing can be particularly challenging when applied to radar. For example, a user might want to peek "inside" an isosurface and also be able to display all the values for every radar grid point. Isosurfacing techniques also tend to smooth the native data, which could be disadvantageous since effective warning making requires that radar data be in its highest and native resolution.

3.2 The FSI configuration

The 'wg' allows for multiple-windowed environment, with spatial, temporal, and data linking between windows. Therefore, based on some feedback from early prototype testing at WFOs [at Jackson, MS (Stumpf et al. 2003), Wichita KS, and Norman OK (Scharfenberg et al. 2004)], and also following some concepts developed for an Australian 3D radar viewer (3Drapic; Joe et al. 2004), the initial layout configuration of the FSI will include four linked panels of base radar data. These linked panels will include both 2D and 3D representations of the same data, to facilitate the migration to 3D data analysis for users who are not yet comfortable with it.

A default data display with four linked panels will contain different base radar data views (see display mockup in Figure 7). For each panel, the user can choose the data type (linked to all panels) and the elevation scan and volume scan ("all-tilts" functionality). Users can also interact with the data (including the cross sections) while it is animating (4D). The panels will include:

a. *Plan Position Indicator (PPI).* The user can choose the elevation angle as well as draw and interact with a vertical cross-section reference line (more below). The view will be locked to a zenith viewing angle, and continuous zoom and pan controls will be available. The data will be projected to a zero-altitude (above radar level) spherical surface to avoid parallax issues.

b. *Constant Altitude PPI (CAPPI).* The user can choose the constant altitude using dynamic controls. As with the PPI, the user can also draw and interact with a vertical cross-section reference line (more below). The view will be locked to a zenith viewing angle, and continuous zoom and pan controls will be available. The data will be projected to a zero-altitude (above radar level) spherical surface to avoid parallax issues.

c. *Vertical Dynamic XSection (VDX).* From either the PPI or CAPPI panel, the user can initiate a cross section reference line by clicking one end point and stretching a line to the other end point. The user can then manipulate the cross-section reference line in the PPI or CAPPI panel, and the VDX data display will dynamically update on-the-fly. The view will be locked perpendicular to the plane of the cross-section, and continuous zoom and pan controls will be available.

d. *The 3D Flier (3DF).* The radar data in this panel will be plotted in true 3D earth coordinates. Shown will be the selected elevation angle of data in the PPI panel plotted on a conical surface, as well as any vertical or horizontal cross-section planes that are being displayed in the VDX and CAPPI panels respectively. These three data surfaces can be independently toggled off or on, and all the surfaces will be represented in 3D space. The user will have continuous zoom and pan controls, as well as continuous pitch and yaw controls. The user can also fly about the data in an "airplane mode" (constant altitude but with choice of viewing angles). The view can be quickly reset to a zenith viewing angle at any time

The FSI will have the capability for dynamic cross-sections. After launching a cross section of any length or angle on the PPI or CAPPI, the user can then interact with the placement of the drawn cross section on the fly while the cross-section data displays dynamically change. Users can manipulate either end point of the cross-section reference line (on the PPI or CAPPI panel), or drag the entire reference line through the radar data while the cross-section views in the VDX and 3DF will update dynamically. And the data in the cross-section views will also update while the data are updating or animating.

There will be a simple control panel at the top of the FSI display with D2D-like buttons for all-tilts, animation, and colormap controls, and a choice of map overlays. A linked cursor with data sampling readout capability will also be available for all panels.

The FSI will have the capability to provide an "enhanced all-tilt", or *virtual volume* scan capability (Lynn and Lakshmanan 2002). Elevation scans from individual radars will update and replace the previous elevation scan in the virtual volume such that there is always a complete volume scan of tilts at all times. This also means that the cross sections will always contain the latest elevation scans of data and always be complete.

The half-power beam width of typical WSR-88D radar data is about 1°. This 1° actually represents a 3D cone of power return, which means the 1° "azimuthal" beamwidth also applies in the vertical (an "elevation" beamwidth). So where adjacent elevation angles are more than 1° apart, there will be data gaps between the elevation slices[2]. The FSI will allow the user to toggle between cross-sections showing the data gaps, or with the data gaps filled in via an intelligent interpolation scheme by using a keyboard shortcut. Allowing for the display of the vertical gaps will educate users of the limitations of radar sampling the vertical (Howard et al. 1997) and is actually the preferred method of cross-section display used by NSSL researchers. Figure 8 shows an example of a vertical cross-section with and without interpolation.

3.3 Implementation within AWIPS

A diagram of the proposed implementation of the FSI application within AWIPS is shown in Figure 9. The initial interface requirements will include two notification processes.

a. *wgNotify*: A persistent server process that will update a Radar Linear Buffer for the FSI. This will run on one of the AWIPS Linux servers, and the Radar Linear Buffer will exist as a file on the server. This will extend the AWIPS notification to include the FSI as a "client" without integrating the FSI into the AWIPS Inter Process Communication (IPC). The Radar Linear Buffer will include locations of ORPG product files for all three radar moments (Z, V, and SW) as well as a Storm-Relative Velocity (SRM) product.

b. *wgLaunch*. A script that will launch the FSI display. Will use an interactive D2D extension to point-and-click on a storm of interest, or launch from the SCAN Storm Cell Table, to define sub-domain for the FSI. This script will also create a Control Linear Buffer index exclusive to each D2D, which will interface with the FSI. The Control Linear Buffer index will include:

    1. Point location coordinates (lat/lon)
    2. Time coordinates
    3. Source information (the initial single-radar source, which can be changed later in FSI)
    4. Map shapefile information
    5. (optional) Motion information (for a Lagrangian 3D tool in storm reference space) – from SRM product, SCAN Storm Cell Table storm motion, or manual input. This is so that the FSI will remain centered on the storm while the products update and for optional storm-relative animation purposes.

Only one FSI will be available per workstation due to currently unknown impact to system resources. However, no system resources will be used for FSI unless "user-triggered".

[2] In a future version, Terminal Doppler Weather Radar (TDWR), with 0.5° beamwidth, may also be displayed.

4. TRAINING, AND PROOF-OF-CONCEPT TESTING

In order to make quick and effective decisions, the meteorologist will also have to be well versed in the understanding of the meteorological signatures associated with severe weather from a non-traditional 3D perspective. It must be determined exactly how these tools will add value to the warning decision making process without getting "seduced by pretty pictures". *The development and prototype testing of the FSI should be introduced concurrently with an effective training program.* Although proper training on the knobology of the FSI is required, training should also strongly focus on the science and decision-making aspects of understanding and viewing storms in 3D, a new paradigm that can be challenging for many operational meteorologists. This training should include innovative ways to compare storm features using only traditional 2D methods (e.g., via "all-tilts"), alongside the FSI methods that link 2D and 3D representations together. The FSI also needs to be tied to the Weather Event Simulator (WES; Ferree et al. 2002) to facilitate displaced real-time warning scenarios.

After the D3D was installed for testing at the Dodge City, KS, WFO, Johnson (2002) noted that the use of the system was limited. He commented that if college students were taught meteorology with 3D visualization, they would be more prone to want to use it, or even expect it, in operations. Unfortunately, we don't have the luxury of immediately educating the NWS's professional meteorologists overnight, so the process is expected to require some patience.

A new testbed for experimental warning decision applications such as the FSI (as well as new multiple-radar and multiple-sensor algorithms and very short-term numerical models) is being planned by the MDL, NSSL, and the NWS Warning Decision Training Branch (WDTB). There is currently a proposal to expand the Storm Prediction Center (SPC) Hazardous Weather Testbed (HWT), or "spring program" to include a WFO component focusing on the shorter-term convective weather warning needs. This is important in light of some possible changes in the way the NWS will provide hazardous weather services and products in the future.

The initial testbed is proposed to be part of the Norman National Weather Center (NWC). The testbed will include an application development laboratory in which simulated WFO operations using experimental applications, displays, and operations concepts will be conducted using live data from any part of the Continental U.S., emulating the operations at any WFO. Visiting meteorologists from other WFOs, NWS regions, and universities will participate in the exercises, issuing experimental, but non-operational warning products. The testbed will also include a second experimental facility directly co-located with the Norman WFO, in which certain more-mature experimental applications will be used to issue official operational warnings. Eventually, the experimental warning decision application testbed locations should include at least one WFO site per region.

5. SUMMARY

Assuming resources will be made available soon, the remaining work to integrate the WDSSII GUI with AWIPS will be completed such that the first version of the FSI is expected to be ready by AWIPS Operational Build 8 (OB8; fielded fall 2007) or beyond. Alpha testing of the FSI will precede nationwide deployment, and will occur at WFO testbed location(s). Feedback will be acquired in similar fashion to the FSL real-time D3D exercises (McCaslin et al. 1999; Szoke et al. 2001; Szoke et al. 2002), utilizing usage logs and user surveys.

The first prototype of the FSI will be limited to base radar data alone. Derived radar data fields, and algorithm output will not be considered for the initial version. However various additional advanced data analysis methods currently available in WDSSII may eventually be integrated into SCAN to provide new and innovative multiple-sensor severe weather warning products to AWIPS.

The 3D displays are not designed to replace 2D displays, but augment them. They will reduce the amount of 2D data needed for analysis and to relieve meteorologists from having to do mental two-dimensional to three-dimensional calculations. It is hoped that operational 3D visualization of radar data will allow meteorologists to discover new clues and new 3D signatures useful in the diagnosis of severe storms, including wind, hail, and tornado signatures from supercell and non-supercell storms. 3D (and 4D) visualization in meteorology is expected to be revolutionary public benefits through increased warning skill and warning service.

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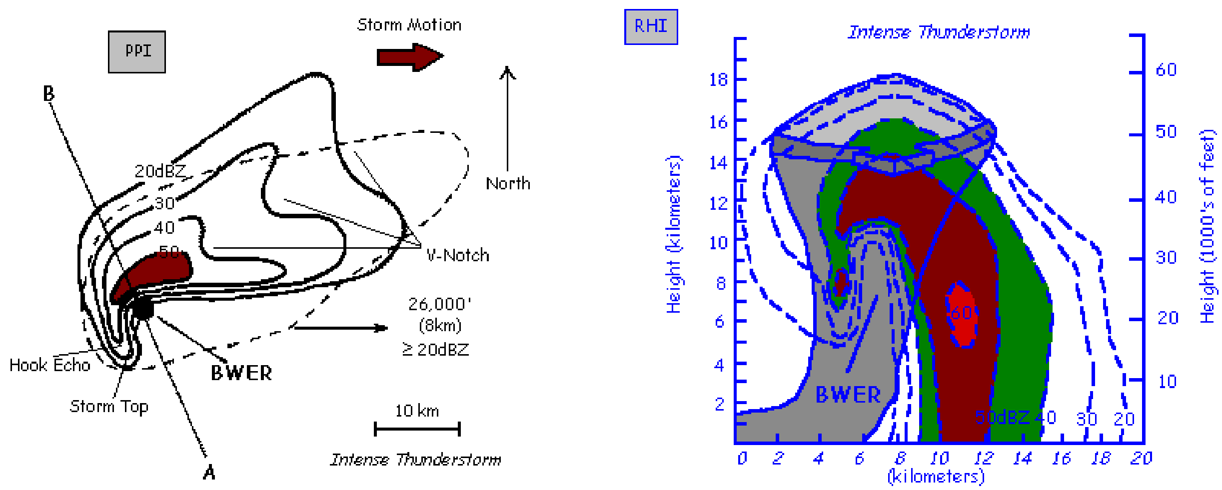

Figure 1: Illustrations of the "Lemon Technique" for operationally identifying supercell thunderstorms using conventional radar (Lemon 1977). On the left is the depiction of a supercell storm using a "Plan Position Indicator" (PPI) display, which is a quasi-horizontal cross-section through the storm (at constant elevation angle). On the right is the depiction of the storm using a "Range Height Indicator" (RHI) display, which is a vertical cross-section, defined by the line A – B on the left image. Various supercell storm features are labeled, including the Bounded Weak Echo Region (BWER).

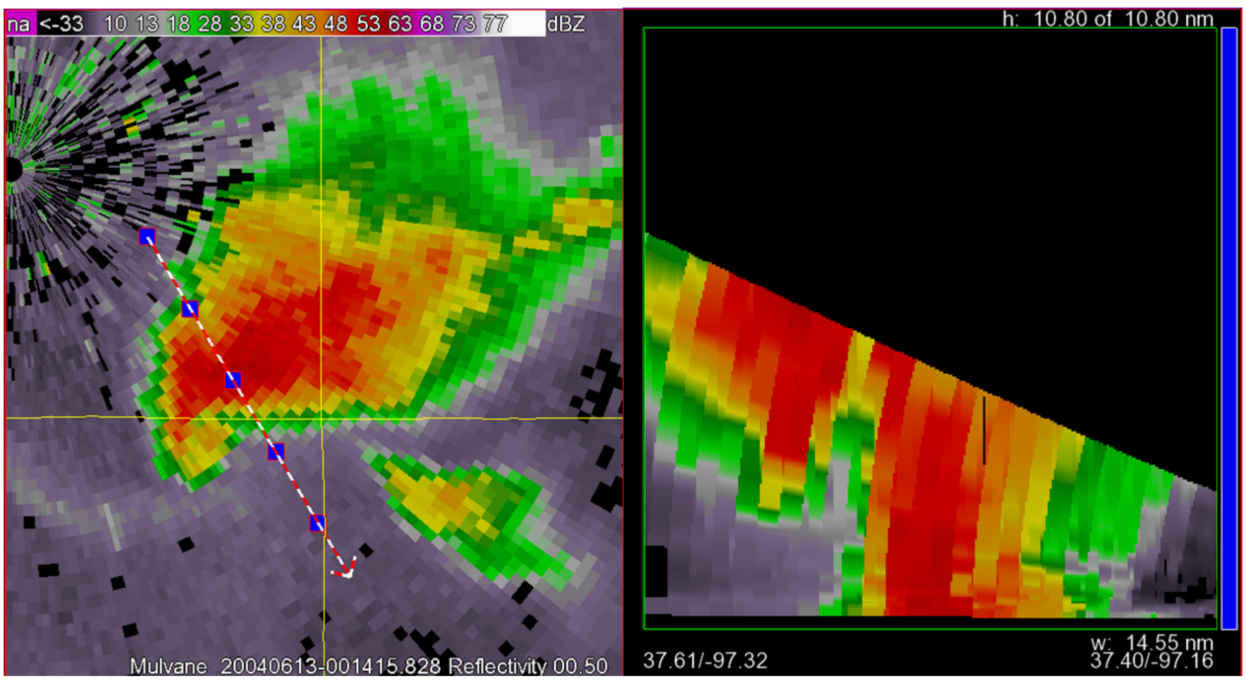

Figure 2: On the left, a constant elevation angle texture (or "PPI display"), and on the right, a vertical cross-section from a classic supercell near Mulvane Kansas on 12 June 2004. Data above the diagonal line on the vertical cross-section are missing due to the radar "cone-of-silence". Data are from the KICT WSR-88D.

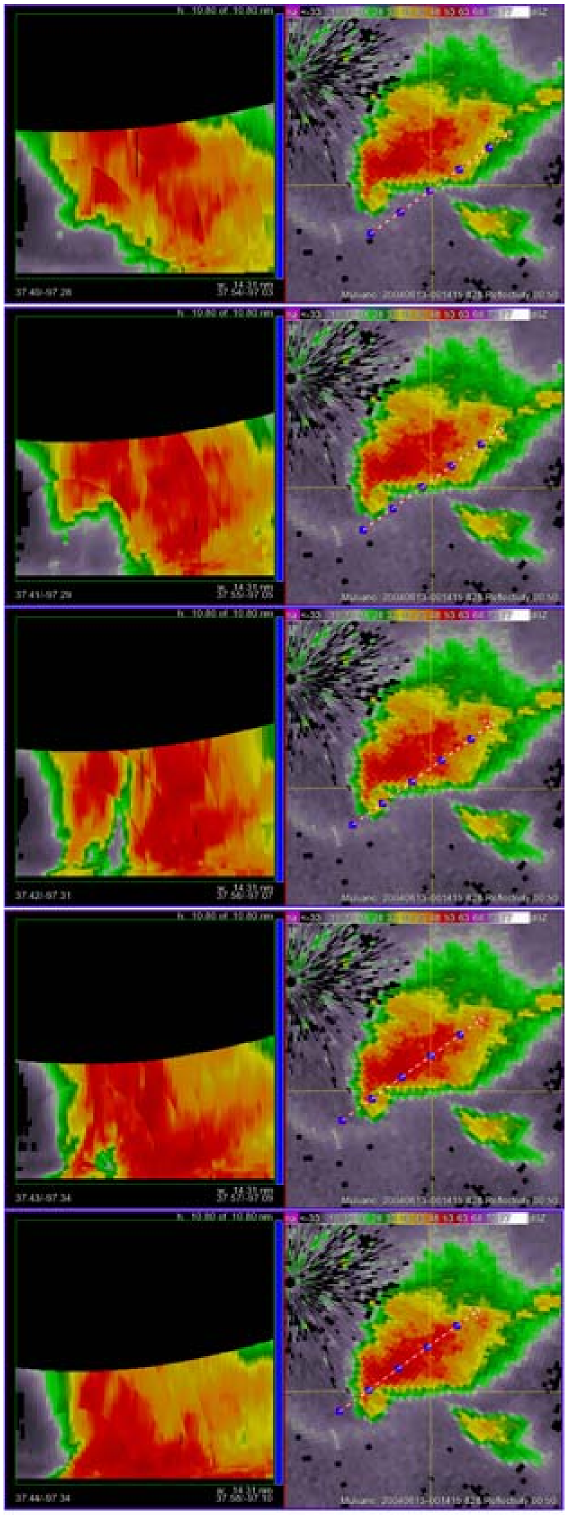

Figure 3: Vertical cross-section series of the supercell storm near Mulvane Kansas, on 12 June 2004. On the left is the vertical cross-section data. On the right is the PPI data, with the location of the vertical cross-section shown as a dashed line with 5 blue square icons overlaid. Data are from the KICT WSR-88D.

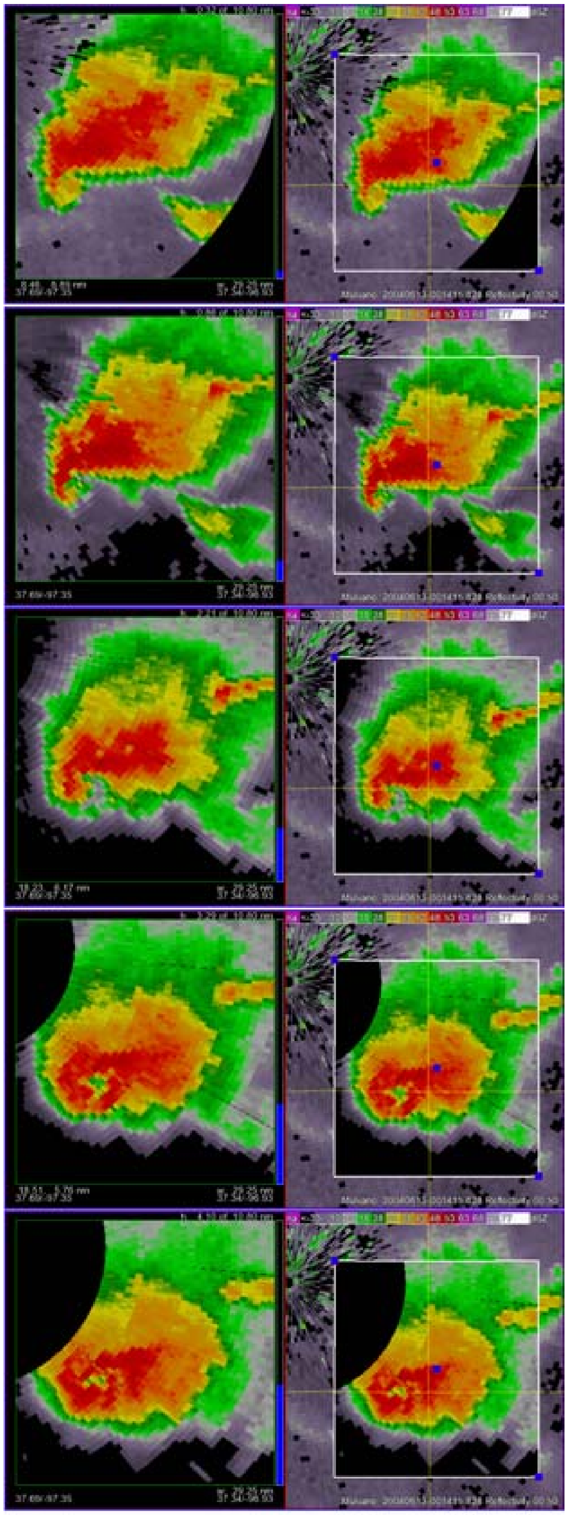

Figure 4: Horizontal cross-section (CAPPI) series of the supercell storm near Mulvane Kansas, on 12 June 2004. On the left is the CAPPI data. On the right is the PPI data, with the location of the horizontal cross-section shown as an open white square with 3 blue square icons overlaid. Data are from the KICT WSR-88D.

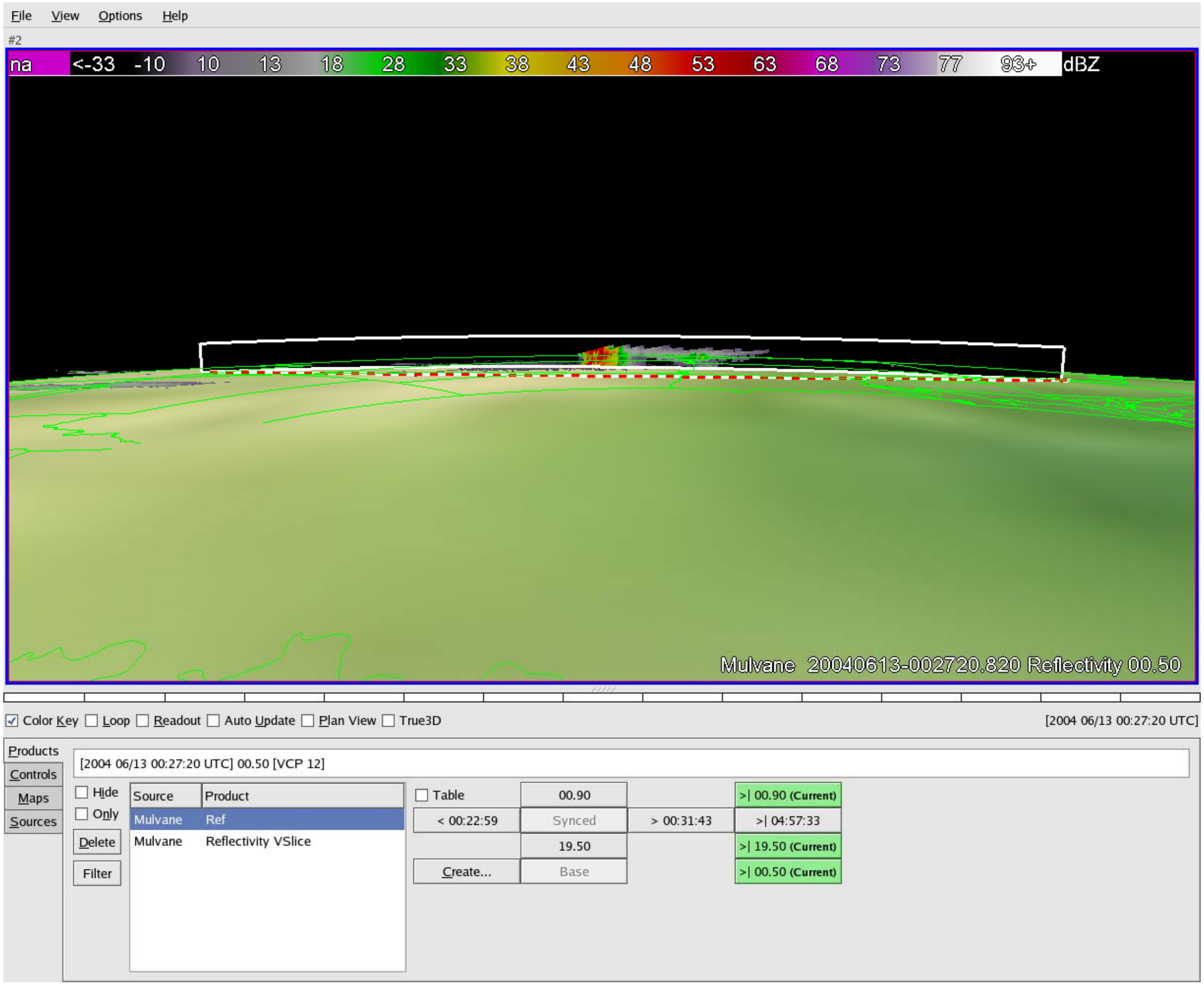

Figure 5: Three-dimensional representation of a vertical cross-section, drawn long enough to depict a vertical plane that wraps the Earth's surface in an arced fashion, so that data at constant display height are at constant real altitude. Data are from the KICT WSR-88D on 12 June 2004.

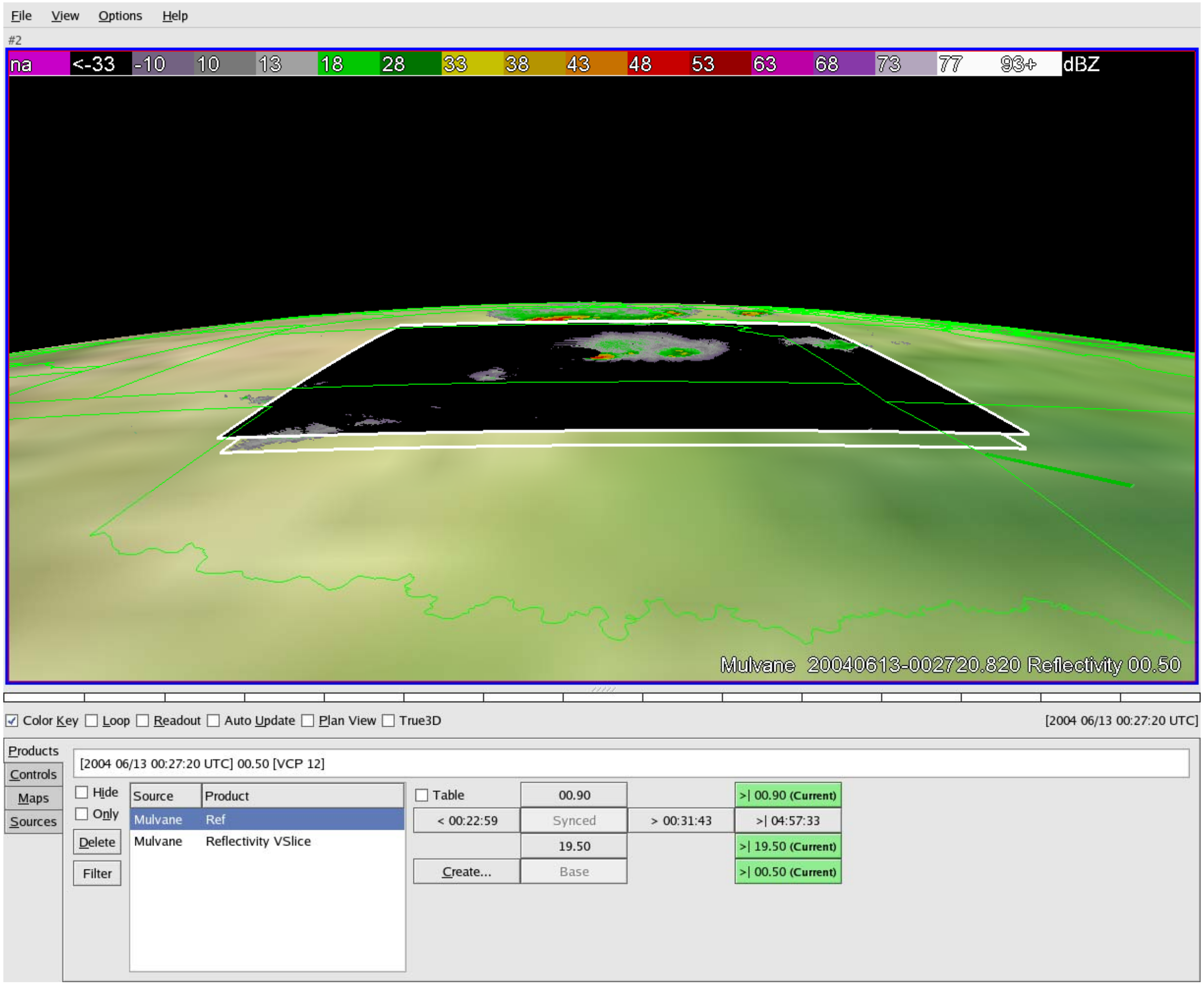

Figure 6: Three-dimensional representation of a horizontal cross-section (CAPPI), drawn large enough to depict a horizontal plane that wraps the Earth's surface in an arced fashion, such that the data on the surface is at a constant altitude above sea-level at all points on the CAPPI surface. Data are from the KICT WSR-88D on 12 June 2004.

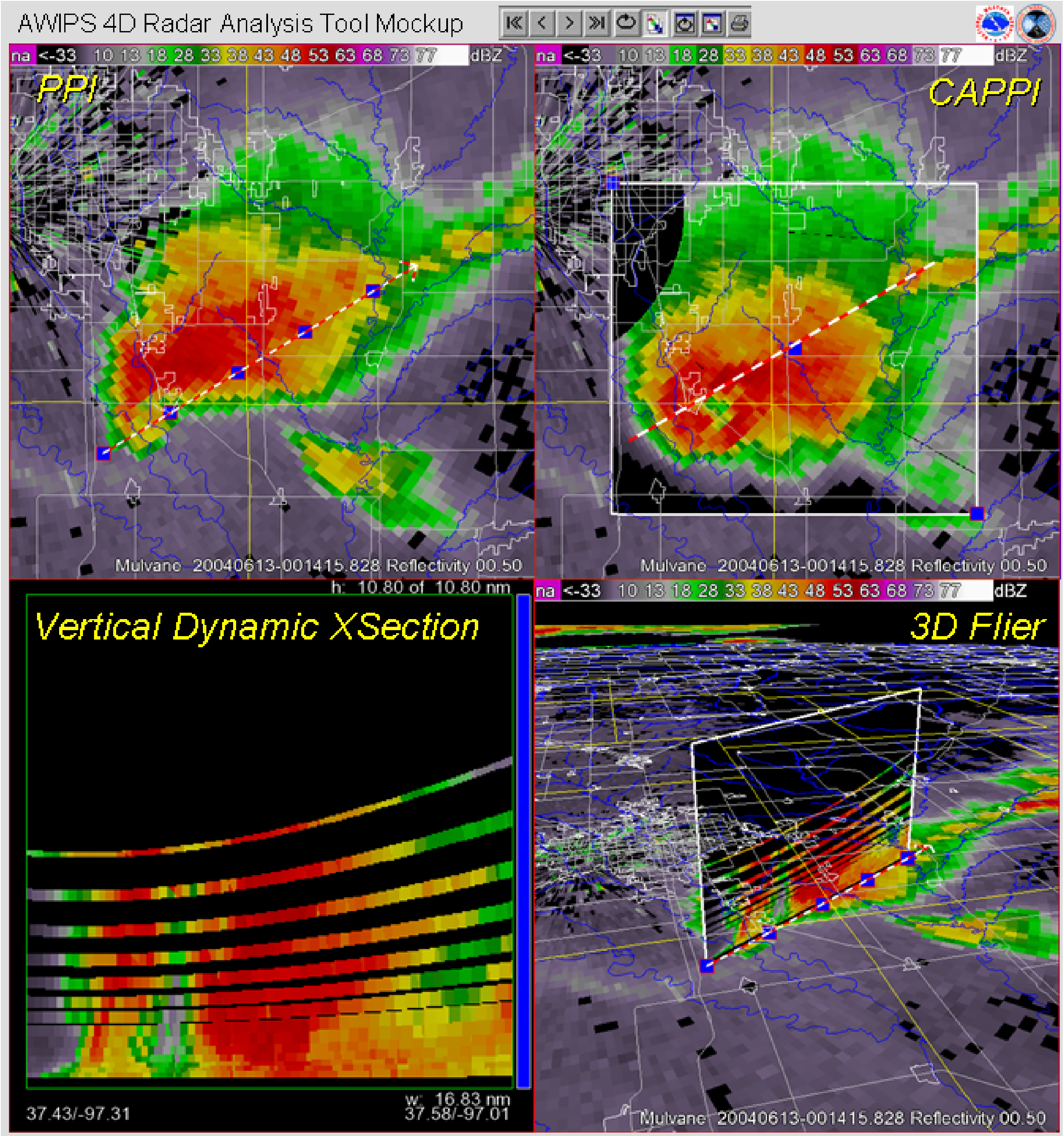

Figure 7: FSI 4-panel Display Mockup. Radar data are from the KICT WSR-88D on 12 June 2004.

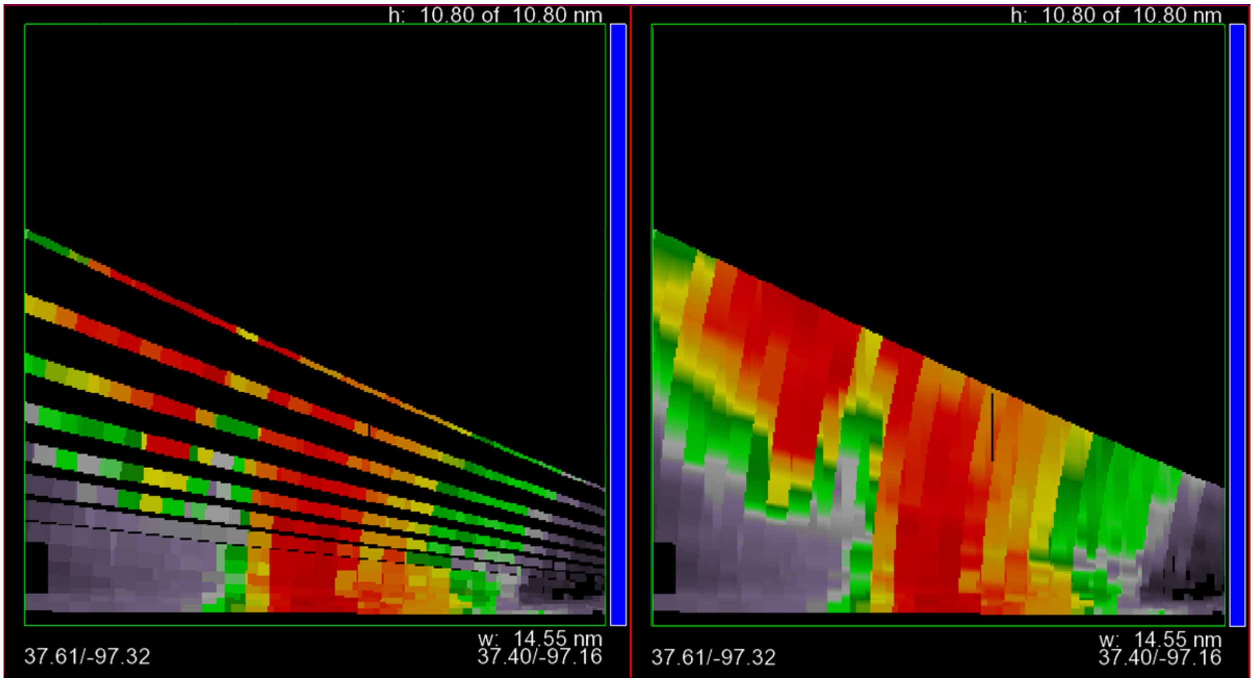

Figure 8: The vertical cross-section in Figure 2, from a classic supercell near Mulvane Kansas on 12 June 2004. On the left is the cross-section with vertical interpolation between elevation scans disabled. On the right, the vertical interpolation is enabled. Data above the diagonal line on the vertical cross-section are missing due to the radar "cone-of-silence". Data are from the KICT WSR-88D

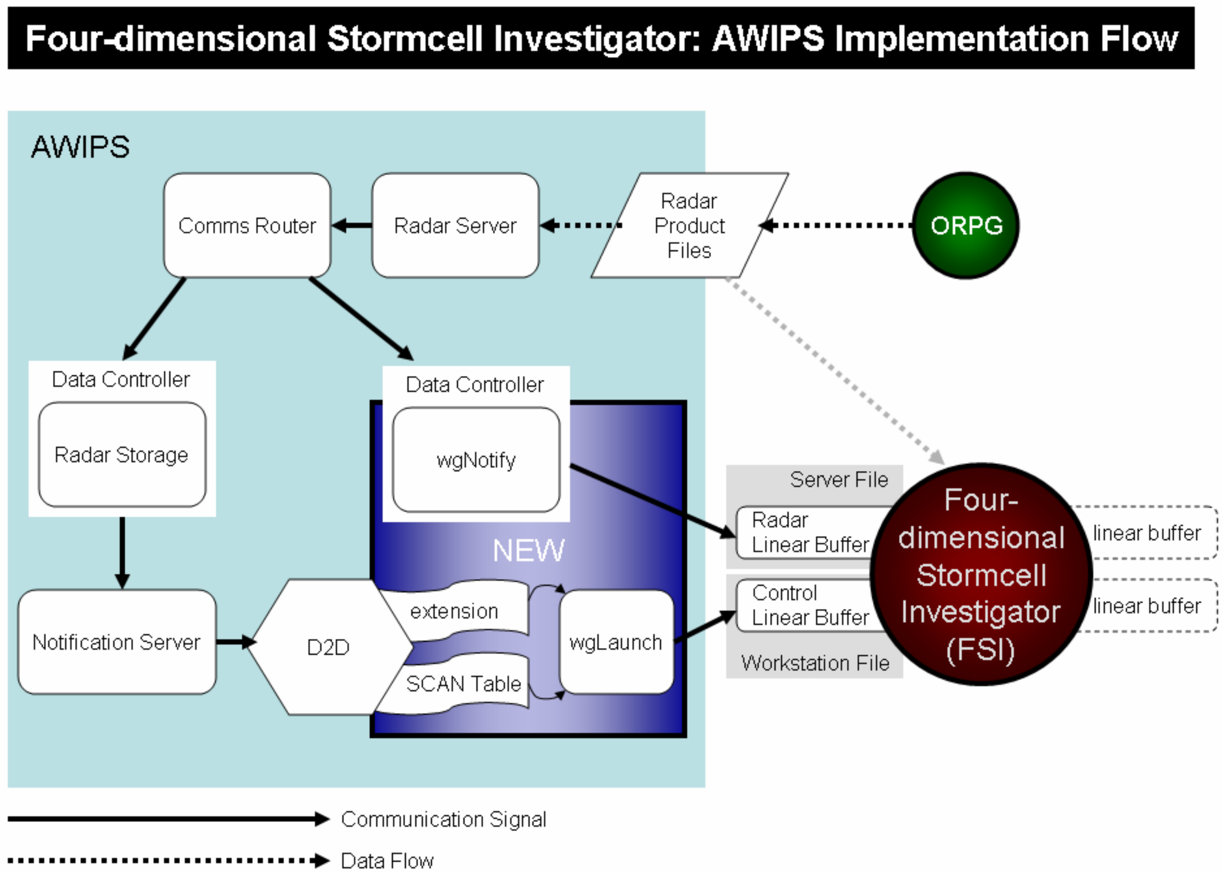

Figure 9: Flow of information and data between the Open Radar Products Generator (ORPG), the Advanced Weather Interactive Processing System (AWIPS), and the Four-Dimensional Stormcell Investigator (FSI).