

Four-Dimensional (4D) Storm Cell Investigation in AWIPS

FY 2005 Proposal to the NOAA HPCC Program

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Four Dimensional Storm Cell Investigation in AWIPS

Proposal for FY 2005 HPCC Funding

Executive Summary:

Currently, there exists no way to visualize radar data in 3D at its native resolution during operations. Yet, base radar analysis of the 3D structure of thunderstorms as they change with time (4D) is the most promising approach to increasing severe weather warning lead-times. The National Severe Storms Laboratory (NSSL) has developed an interactive 3D display for radar data that uses OpenGL textures and hardware capabilities to enable interactive analysis of 4D radar data.

In this project, we will implement the OpenGL application developed at NSSL on the National Weather Service's AWIPS platform. This application will be tailored for National Weather Service use. The tailored application will be called the Four-dimensional storm cell investigator (FSI). The tailoring will involve these aspects: (1) We will enable FSI to ingest radar data from the AWIPS data stream. (2) We will create software hooks within D2D such that the FSI can be launched directly within AWIPS/D2D. (3) We will create a communication mechanism between D2D and the FSI so that changes in time and storm-cell of interest can be made from the D2D and reflected in the FSI.

Besides, the scientific challenges of developing a 4D native-resolution radar visualization system, there is also a high-performance technical challenge. Implementing a hardware-rendered OpenGL application for 4D within the AWIPS platform such that the application is responsive and not a performance-hog will require careful design.

Because the NSSL's OpenGL application is built for multiple-radar analysis, implementing this project will provide NWS forecast offices a way to visualize other radars in their vicinity. NSSL's display software was developed in part through previous HPCC-funded projects and the current project will make these visualization capabilities available to NWS operational forecasters. This project involves multiple line offices and the success of this project will have a national impact on severe weather operations within the National Weather Service. The FSI will take advantage of NSSL's existing 3D radar display application and develop additional features required for operational visualization of high resolution WSR-88D data in 3D, and deliver these concepts to the operational forecast environment for evaluation.

Problem Statement:

The Forecast Systems Laboratory (FSL) pioneered work to develop operational meteorological display systems that provide ways to analyze data in three-dimensions. The Display Three Dimensions (D3D) was adapted from the University of Wisconsin's Vis5D software (Hibbard and Santek, 1991) and built within the Advanced Weather Interactive Processing System (AWIPS) (Wakefield, 1998), 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).

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 development (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”.

Proposed Solution:

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). OpenGL, introduced in 1992, 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.

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 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.

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 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.

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 1). 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.

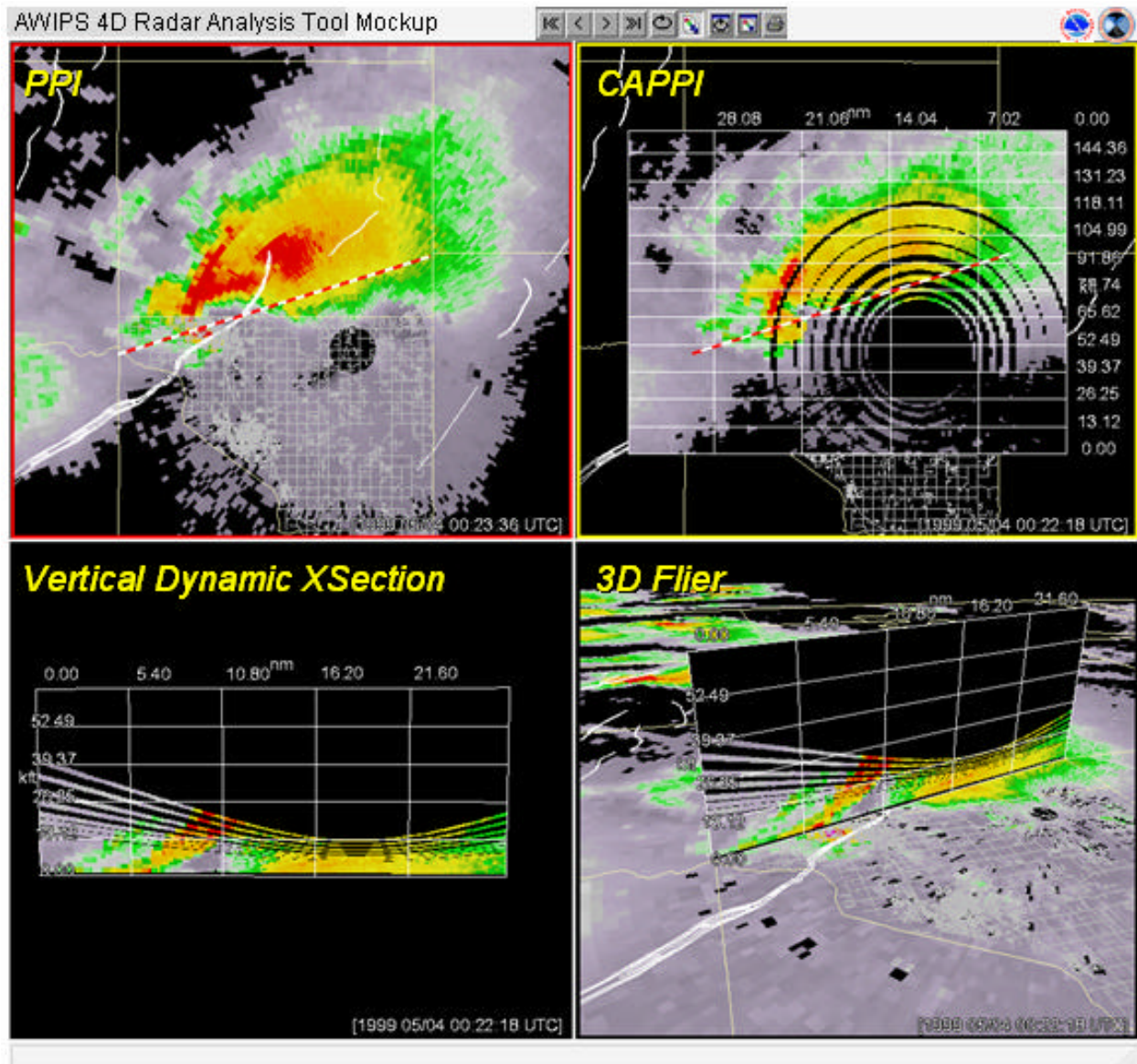


Figure 1: FSI 4-panel display mockup

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 slices¹. 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.

Implementation within AWIPS

A diagram of the proposed implementation of the FSI application within AWIPS is shown in Figure 2. 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

¹ Terminal Doppler Weather Radar (TDWR), with 0.5° beamwidth, can also be displayed.

- (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”.

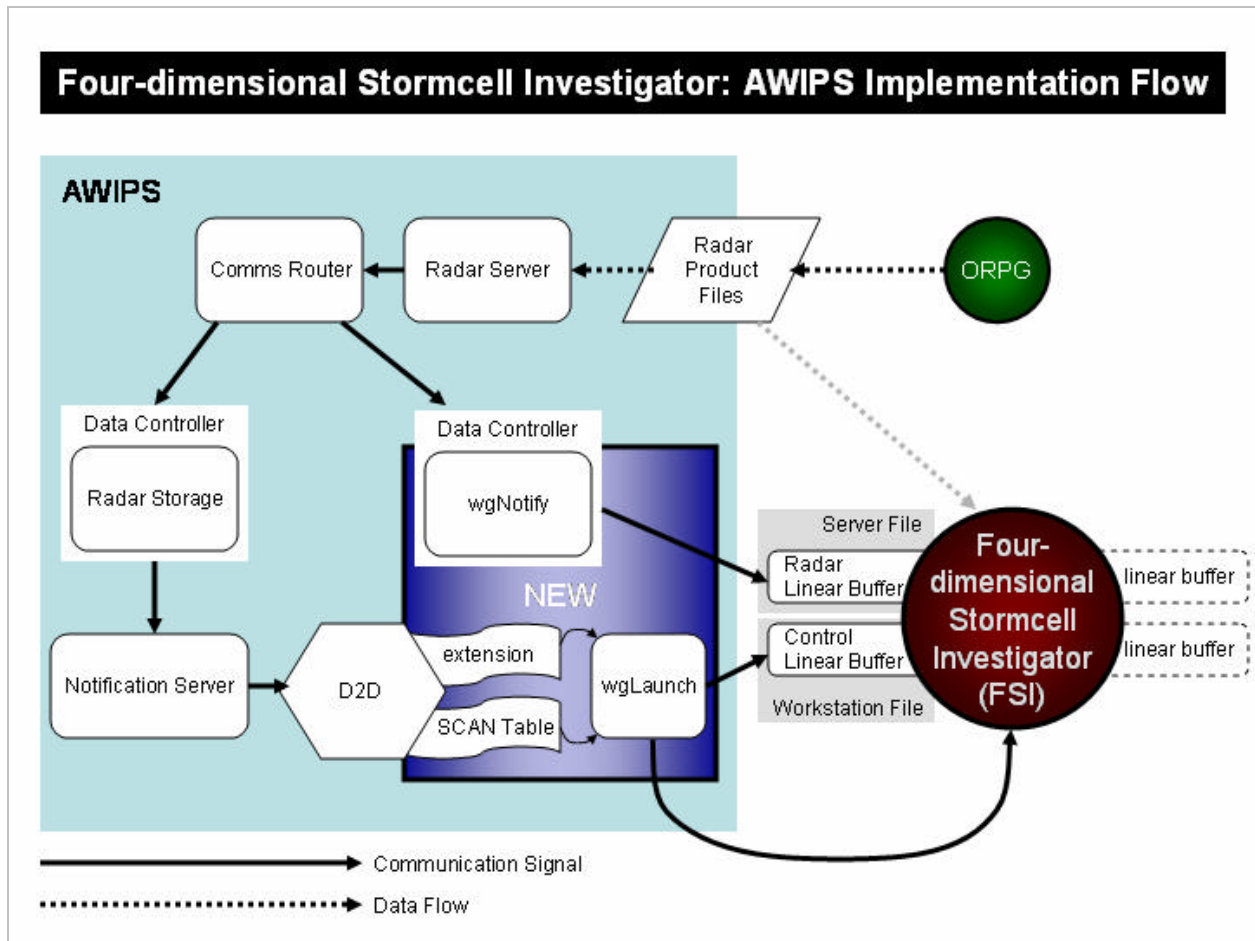


Figure 2: Flow of information and data between the Open Radar Products Generator (ORPG), the Advanced Weather Interactive Processing System (AWIPS), and the Four-Dimensional Stormcell Investigator (FSI).

Analysis:

The pre-eminent observational platform of the National Weather Service is the network of the WSR-88Ds. Yet, in the forecast offices, there exists no way to analyze how the 3D structure of thunderstorms changes with time. We believe that being able to analyze base radar data in 4D in an intuitive and interactive manner will lead to increased severe weather warning times. We will be implementing the 4D analysis software on the systems used in every forecast office around

the country. The scope of this project is broad, and it will contribute toward NOAA's mission of providing the public with timely, correct severe weather warnings.

Performance Measures

The software will be evaluated in the following technical metrics:

1. The time between the receipt of a new radar elevation scan and it showing up in the display.
2. The time to update a new radar volume for fly-throughs.
3. The time to create a new cross-section from an already loaded volume.
4. Number of frames per second achieved in interactive cross-sections.
5. Monitoring of system CPU and memory usage.

The development of a testbed for experimental warning decision applications such as the FSI (as well as new multiple-radar and multiple-sensor algorithms) is already underway at the MDL. 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.

Milestones

- Receive award notification (tentative) - March 15, 2005
- Develop FSI program functionality - November 15, 2005
- Integration test with AWIPS - December 15, 2005
- Deploy FSI on first test bed - March 1, 2006

Deliverables

A working FSI program on the AWIPS platform ingesting radar data in real-time and providing an interactive user experience in analyzing 4D radar data.