P5.3 THE UTILITY OF THREE-DIMENSIONAL RADAR DISPLAYS IN SEVERE WEATHER WARNING OPERATIONS

Daniel D. Nietfeld
NOAA/National Weather Service Valley, NE

1. INTRODUCTION

Traditional methods of interrogating severe thunderstorms using radar data have primarily utilized two-dimensional displays (2-D). The 2-D displays were either a quasi-horizontal plane of x-y coordinates (north vs. south), or a vertical plane of x-z coordinates (horizontal distance from the radar vs. height above ground). Using these displays, meteorologists have been able to assess the vertical and horizontal structure of thunderstorms by viewing multiple images of either: each elevation angle of the radar, or multiple vertical cross sections through the storms.

Recently, software and hardware advances have allowed for the display of radar data in three-dimensions (3-D), using an earth-centered coordinate system. This enables the software to display the complete vertical and horizontal distribution of radar data within one image, of which the viewing perspective can be altered by the user.

This paper examines the utility of 3-D radar displays for the purpose of interrogating the severity of thunderstorms and making associated warning decisions. The background for the conclusions in the paper come from experiments with three-dimensional displays in an operational NOAA/National Weather Service Weather Forecast Office (WFO) at Omaha-Valley, Nebraska (OAX) during the 2006 convective season.

This work is an extension of an earlier project to determine the utility of using 3-D displays of synoptic and mesoscale model data in an operational setting. Parallels from that study will be drawn, and extended to the storm scale.

2. METHODOLOGY

The warning meteorologists at WFO OAX used the Gibson Ridge software package GR2Analyst Edition (GR2AE) (http://www.grlevelx.com/) to interrogate severe storms during 16 separate episodes spanning from 30 March, 2006 through 3 September, 2006. This software was used only as an additional tool to the AWIPS Display 2 Dimension (D2D) software (MacDonald, 1996), which is the traditional software used for warning operations. The D2D software only allows the user to view 2-D perspectives, and most commonly the quasi-horizontal tilts of each elevation scan. These views were used either in a 4-panel method which displayed 4 different elevation angles (See Fig. 1), or in an "all-tilts" method in which each new elevation angle was displayed as it arrived in the AWIPS workstation.

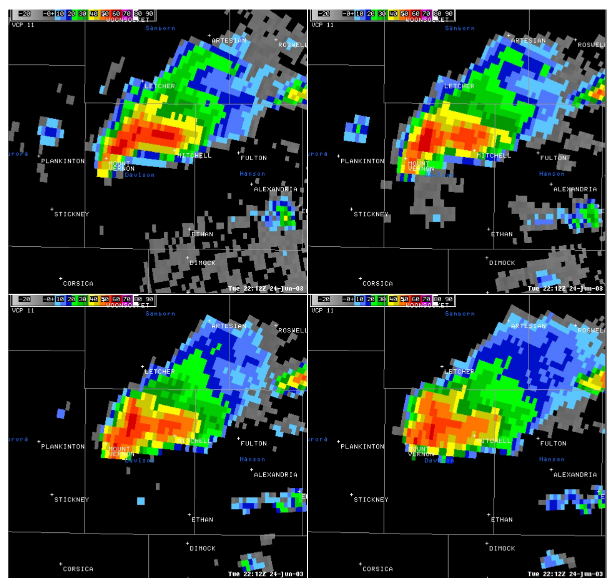


Fig. 1) A 4-panel display of reflectivity on June 24, 2003 from the NWS Sioux Falls radar. Upper left is the 0.5 degree elevation angle, upper right is the 1.5 degree elevation angle, lower left is the 3.4 degree elevation angle, and the bottom right is the 4.3 degree elevation angle.

These traditional methods have been proven to be an efficient means to fully examine data throughout the depth of the storm, and assess storm structure quickly. To ensure no degradation in warning operations, the traditional D2D methods continued to be utilized by the primary warning

* *Corresponding author address:* Daniel D. Nietfeld, NOAA/National Weather Service Forecast Office 6707 North 288th Street Valley, Nebraska 68064; e-mail: dan.nietfeld@noaa.gov

meteorologists, however the 3-D methods were utilized by staff who were not the primary warning meteorologists, in an evaluation mode. The various functions and aspects of the displays were assessed for their usefulness and notes were taken regarding the operational benefit of the 3-D perspectives.

This study was limited in that there was not a formal survey conducted, but rather informal queries to the users who had an opportunity to evaluate the 3-D methods alongside the traditional 2-D methods.

3. ASPECTS OF VIEWING 3-D DATA

3.1 *Cross Sections*

3.1a *Reflectivity Cross Sections*

The warning meteorologists at WFO OAX found the cross sections of reflectivity to be one of the more useful aspects of the new displays. Although this can traditionally be thought of as a 2-D view, the ability to modify the position and swing of the cross section with slider bars allows the user to quickly assess the height of strong reflectivity cores which often represent the updraft of a storm. Especially when interrogating a storm for the potential for hail, knowing the height of the 50-55 dbZ core has proven to be a successful method to identify large hail (Donavan, 2006). On July 13, 2006, hail 2.5 inches in diameter (tennis ball size) fell in the city of Beatrice, Nebraska. In that event, the 60 dbZ core height reached 41,000 feet just before the large hail was reported (See Figures. 2 and 3).

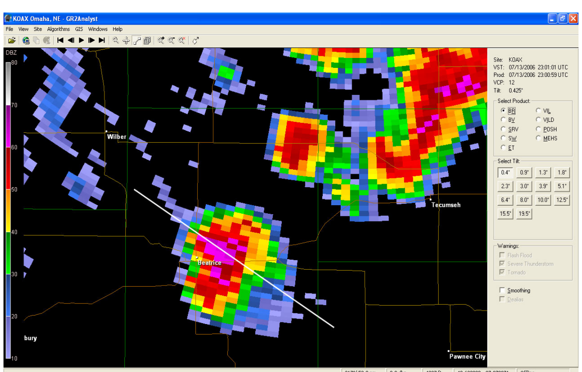


Fig. 2) The 0.5 degree elevation angle plan view display of reflectivity from the KOAX radar on July 13, 2006. The white line represents the vertical plane that the cross section was created along. Hail the size of tennis balls was falling in the town of Beatrice, Nebraska at the time of this radar image.

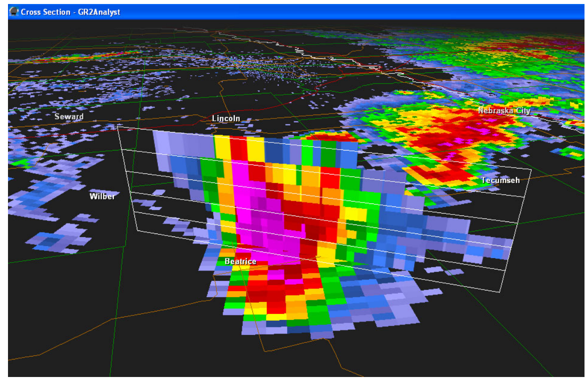


Fig. 3) The reflectivity cross section, created along the white line seen in Fig. 2, from the KOAX radar on July 13, 2006. Note the height of the 60 dbZ echo has reached 41,000 feet. Hail the size of tennis balls was falling in the town of Beatrice, Nebraska at the time of this radar image.

Some utility was noted by the warning meteorologists in using the reflectivity cross section to determine the geometry of weak echo regions (WERs) and bounded weak echo regions (BWERs). Certainly the “overhang” of the updraft above the surface inflow could be identified well.

3.1b *Velocity Cross Sections*

Viewing cross sections of either base velocity or storm-relative velocity (SRV) was another marginally useful aspect of 3-D displays. As with the cross sections of reflectivity, the chief benefit was the quickness of which the user could display the vertical profile of velocity throughout the storm using the position and swing slider bars. However, the user did need to be conscientious of the orientation of the cross section to the radar beam. Often the more useful information was displayed when the cross section was parallel to the radar beam as opposed to perpendicular. In the parallel fashion, it was occasionally feasible to identify features such as a mid-altitude radial convergence (MARC) signature (Schmocker et. al, 1996).

Storm top divergence was relatively easy to asses using the cross section of SRV. Figure 4 shows the same storm as in Figs. 2 and 3, except SRV is displayed in the cross section. The maximum values inbound were 80 knots and the maximum outbound was 81 knots at 44,000 feet. This yields a storm-top divergence of 161 knots, which is consistent with values found by Boustead, 2006 for tennis ball size hail.

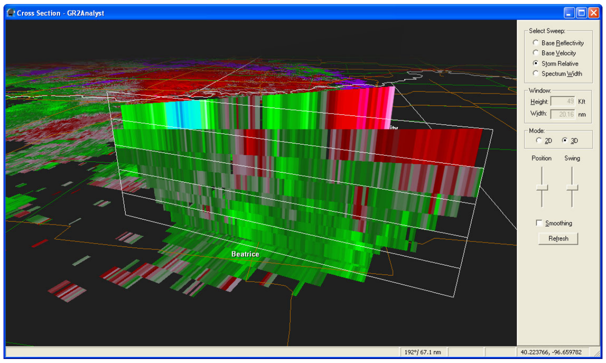


Fig. 4) A cross section of SRV data on July 13, 2006 near the town of Beatrice, Nebraska where tennis ball size hail was falling. Maximum values inbound were 80 knots, with maximum values outbound of 81 knots, from the KOAX radar. The plane of the cross section is parallel to the orientation of the radar beam.

3.2 *Isosurfaces*

The GR2AE software also allows for the display of truly 3-D, opaque isosurfaces of a specific value of reflectivity, velocity, or spectrum width. The user specifies a cube of space, or volume, and then a solid color is assigned to any point within that volume where the magnitude of the parameter chosen equals the value specified by the user. The value is set using a slider bar, which allows the user to quickly display the desired isosurface. Evaluations of reflectivity isosurfaces were performed on about 15 severe thunderstorm events in real time.

Warning meteorologists found the reflectivity isosurface to be a useful tool in assessing the structure of storms and identifying features indicative of severe weather. Low values of reflectivity, such as those associated with thick clouds (5-15 dbZ) were useful to display overall storm shape and extent, including the overshooting top, anvil dispersion, and updraft tilt (See Fig. 5). However, displaying the higher values of reflectivity that are often associated with updraft cores proved to be especially revealing when viewed as a 3-D isosurface. The 3-D isosurface was a quick and efficient method to display the height and shape of the updraft cores. This allowed the user to evaluate the existence of hail growth, as well as WERs and BWERs which are associated with the presence of a tilted updraft (See Fig. 6).

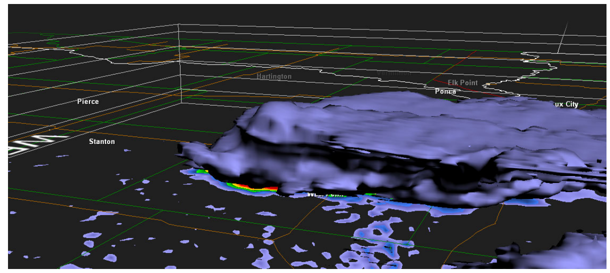


Fig. 5) The isosurface of 10 dbZ on May 3, 2006 over northeast Nebraska, from the KOAX radar. This storm produced hail to 1 inch.

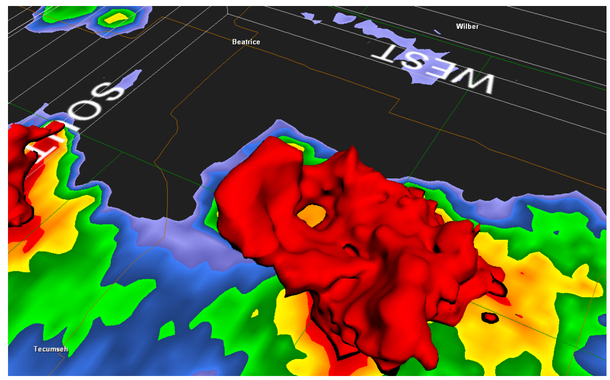
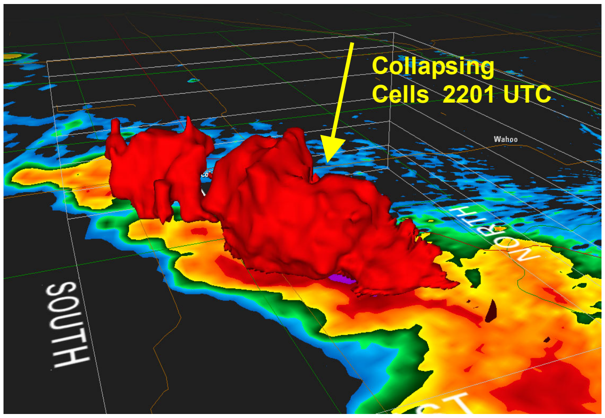
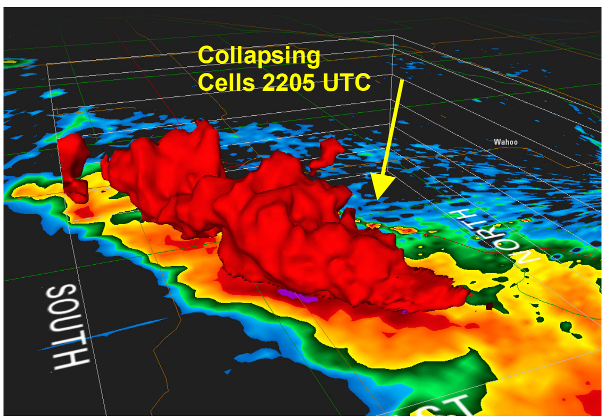


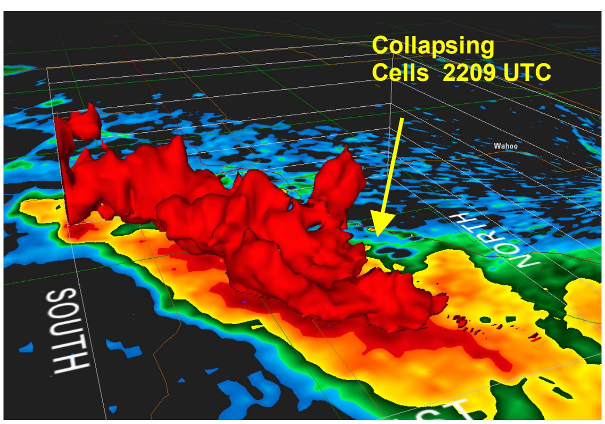
Fig. 6) The isosurface of 60 dbZ on April 15, 2006 while a tornado was moving through Gage County Nebraska…showing the tilted nature of the updraft and the BWER. From the KOAX radar.

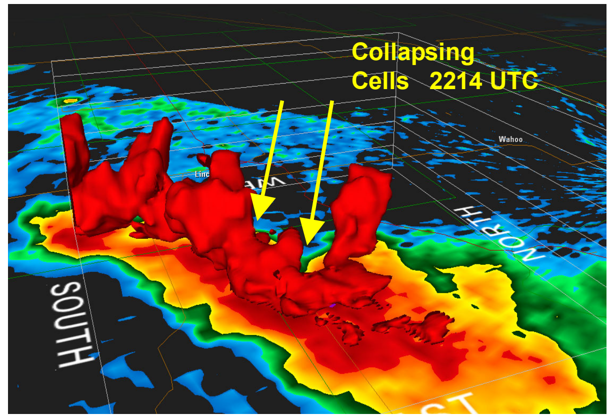
Viewing isosurfaces of reflectivity was quick and efficient, as was changing the desired value of the reflectivity isosurface. This allowed the feature to be utilized in a severe weather warning operation, where time is of the essence.

One of the more challenging tasks in severe weather warning operations has been the timely detection of convectively driven downburst winds. Warning meteorologists are taught to attempt to identify the "collapsing" core of the storm, and as this collapse occurs the storm is capable of producing a strong downburst (Wakimoto, 2001). However, in traditional 2-D plan view displays, identifying the collapsing cores has been quite difficult if not impossible in some circumstances. The warning meteorologist must interpolate between times and elevation angles to attempt to infer this collapse. The isosurfaces in a 3-D display greatly improved this task. Visualizing the collapsing cores was elementary and in many cases, quite obvious. This resulted in higher confidence in a severe thunderstorm warning for damaging winds, and perhaps more specific information regarding the timing and location of the downburst. Figures 7-10 illustrate the collapsing core during a downburst event that occurred near Elmwood, Nebraska in Cass County on July 13, 2006.









Figs. 7-10) The isosurface of 55 dbZ on July 13, 2006 around the time a downburst was occurring near Elmwood, Nebraska in Cass County that blew over power poles. From the KOAX radar, valid 2201, 2205, 2209, and 2214 UTC (top to bottom, respectively). Note the descending reflectivity core through time.

3.3 *Lit Volume*

Another volumetric method of displaying the radar data in 3-D is called lit volume, and the GR2AE software included this capability. With a lit volume display, the user chooses the degree of transparency that will be assigned to each value of reflectivity, velocity, or spectrum width. This allows for the ability to see “inside” the storm, and identify the structure of the higher reflectivity, velocity, or spectrum width values that are within the shell of the thunderstorm. Evaluations of lit volume reflectivity and velocity values were performed on about 5 severe thunderstorm events in real time.

3.3a *Reflectivity Lit Volume*

This display technique using reflectivity data was evaluated several times by the warning meteorologists, however it’s operational usefulness was determined to be rather limited. One of the concerns expressed was the time spent on manually adjusting the transparency values of various reflectivities. This was often needed due to the desire to view differing features of the storm (ie., the “shell” vs. the inner core), and the differing reflectivity values that occurred in various environments. For example, transparency settings for an updraft core in a supercell in April may be quite different than those for an updraft core in July. Furthermore, there seemed to be little if any additional useful information displayed in the lit volume than what could be displayed using an isosurface. Because the isosurface was a more efficient means to examine the data, it became favored over the lit volume. More evaluation, practice, and experimenting with the lit volume capability may indeed yield more useful application of this capability.

3.3b *Velocity Lit Volume*

The lit volume displays of SRV did reveal the 3-D structure of mesocyclones in a timely fashion, which is one of the primary goals of a radar operator during severe weather warning operations. Although these displays occasionally required brief manual adjustment, the benefit gained was determined to be worth the time spent on displaying the data. Within one image, the user could discover the presence of a mesocyclone, its depth, its diameter, and its magnitude (See Fig. 11). Unfortunately there were few rotating thunderstorms available within the KOAX radar range during the evaluation period. However those that were examined produced favorable opinions by the warning meteorologists working the severe weather events.

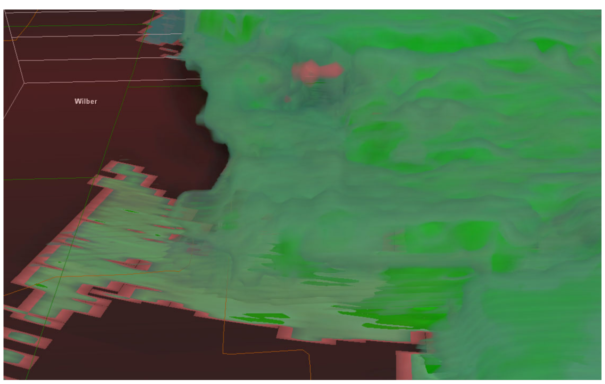


Fig. 11) The lit volume display of a mesocylone associated with a tornadic storm on April 15, 2006 in Gage County, Nebraska (near Beatrice, Nebraska). From the KOAX radar at 2150 UTC. Green colors represent winds blowing toward the radar, and pink colors represent winds blowing away from the radar.

4. FUNCTIONALITY IMPORTANT TO WARNING OPERATIONS

When using any tool to display radar information for the purpose of making timely and accurate severe weather warning decisions, the tool should contain certain functionality that supports the delivery of key information as fast as it is available. When the radar completes one revolution at various elevations angles, that information should be available to the user immediately. Having to wait for an entire volume scan of data is not timely and results in the user seeing the data possibly too late to incorporate into a warning with substantial lead time. Therefore it is essential that cross sections and volumetric displays dynamically update on-the-fly when new data is available.

Because the resolution of the data is very fine, it is essential that mouse sampling of all data is an available option. This sampling needs to contain the value of the field being sampled, in addition to its location in space (x, y, and z coordinates, or lat, lon, and height above ground).

Most severe weather events occur within the range of multiple radars, and using all of the available radars provides different perspectives on severe storms. Radar tools and applications should allow for the incorporation of multiple radars into the display.

Although radar data does provide some of the most useful information to assist in warning decision making, the user must also take into consideration the environment in which the storms are occurring. Tools that display radar data should also be able to overlay and display environmental data, and other data from remote sensing platforms.

The above mentioned functionality is part of the design of the new NOAA software known as the Four-Dimensional Storm Cell Investigator (FSI). This software will update the NWS WFOs with improved tools for warning decision making (Stumpf, 2006).

5. CONCLUSIONS

Three dimensional displays of radar data were evaluated in a real time, operational severe weather warning environment during the convective season of 2006 at WFO OAX. Although the severe weather activity was below average, there were sufficient storms and sufficient evaluations to draw the conclusion that 3-D radar displays did benefit the warning operations greatly. Warning meteorologists were able to assess an entire volume of base data (reflectivity, velocity, and spectrum width) within one display, then use the mouse to “fly around” the 3-D space and closely examine the structures and features of the storms. The majority of the time this 3-D depiction was more timely and more efficient than the traditional 2-D methods using the D2D program. Warning meteorologists have been trained to conceptualize the 3-D images while looking at 2-D plan-view data. There is no longer a need to mentally convert the 2-D images into a 3-D conceptual model because the software is able to illustrate the 3-D storm-scale environment. This would seem to be a breakthrough in severe weather warning operations using radar data to base warning decisions.

The most useful aspects of 3-D radar displays were the cross sections of reflectivity and velocity, as well as the isosurface of reflectivity. Although more cumbersome to use, the lit volume displays of SRV were beneficial to identify the structure of mesocyclones quickly. The lit volume of reflectivity required too much manual interaction with the software to be of substantial use in a warning operation.

The evaluation of spectrum width data displayed in 3-D needs to be explored to determine its usefulness. It is likely that new discoveries may found within the spectrum width signatures. This component of 3-D radar displays was not evaluated in this study, however plans are in place to thoroughly examine 3-D spectrum width data in the future.

6. AKNOWLEGEMENTS

The author thanks Josh Boustead from WFO OAX for reviewing the paper and providing helpful insight into the cases used, the staff at WFO OAX for participating in the 3-D radar evaluations, the staff at WFO Tulsa for providing ideas and insight, Mike Magsig and Jim LaDue from the NWS Warning Decision Training Branch for providing comments and ideas about 3-D radar displays, and Greg Stumpf from the NOAA NSSL/MDL for providing comments, insight, and leadership in advances in warning decision tools.

7. DISCLAIMER

The views expressed are those of the author and do not necessarily represent those of the National Weather Service.

8. REFERENCES

Boustead, J., 2006: Using maximum storm-top divergence and the vertical freezing level to forecast hail size. Tenth Annual Severe Storms and Radar Conference of the Central Iowa National Weather Association Chapter oral presentation.

Donavan, R., 2006: A Comprehensive Severe Hail Detection Technique Developed Across the Central Plains. Tenth Annual Severe Storms and Radar Conference of the Central Iowa National Weather Association Chapter oral presentation.

MacDonald, A. E., and J. S. Wakefield, 1996: WFO-Advanced: An AWIPS-like Prototype Forecaster Workstation. Preprints, 12th IIPS conference. Amer. Meteor. Soc.

Schmocker, G.K., R.W. Przybylinski and Y.J. Lin, 1996: Forecasting the initial onset of damaging downburst winds associated with a mesoscale convective system (MCS) using the mid altitude convergence (MARC) signature. Preprints, 15th Conference on Weather Analysis and Forecasting, Norfolk, Amer. Meteor. Soc., 306-311.

Stumpf, G. J., M. T. Filiaggi, M. A. Magsig, K.D Hondl, S.B. Smith, R. Toomey, and C. Kerr, 2006: Status on the Integration of the NSSL Four Dimensional Stormcell Investigator (FSI) into AWIPS. Preprints, 23rd Conf. on Severe Local Storms, St. Louis, MO, Amer. Meteor. Soc., 8.3.

Wakimoto, R. M. 2001: Convectively driven high wind events. *Severe Convective Storms, Meteor. Monogr.*, No. 50, Amer. Meteor. Soc., 255-298.