D3D UPDATE: IS IT BEING USED?

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1. INTRODUCTION

The NOAA Forecast Systems Laboratory (FSL) has developed a 3D visualization tool called D3D (Display in three Dimensions), which could potentially add 3D visualization capabilities to National Weather Service (NWS) Weather Forecast Offices (WFOs). The advent of low-cost computers using Linux and their availability at many WFOs has made it possible to reliably run D3D, and over the past couple of years the software has been distributed to a significant number of WFOs that have expressed interest in trying it. A recent survey of those who have D3D revealed that there is a wide range of use and nonuse of the software at this time. There are many possible reasons for this, which are discussed here. We will also discuss the status of D3D, its current use, and future plans, as well as how the D3D package can provide a unique and potentially useful diagnosis of various meteorological phenomenon that can aid the operational forecast process.

2. AN OVERVIEW OF D3D

D3D is a collection of visualization tools based on the University of Wisconsin's Vis5D software (Hibbard and Santek 1991) and modified by FSL to be compatible with the standard NWS Advanced Weather Information Processing System (AWIPS, Wakefield 1998) located in every NWS WFO. The current D3D package uses the standard model grids found in AWIPS and can run adequately on a fairly basic low-cost Linux PC, independent of the D2D (Display 2 Dimensions) software that forms the main component of AWIPS.

The Vis5D software package is composed of five separate tools (Table 1), some of which are true 3D dis-

Table 1: D3D tools

Tool	Description
Isosurface	3D surface of a field
Plan view	Horizontal 2-D display
Cross-section	Vertical 2-D display
Sounding	SkewT, hodograph, vertical plot
Probe	Point display of data
Trajectory	Forward/backward trajectories
Volume Visualization	3D "fog" type display

plays, while others are just 2D displays that can be used in a highly interactive manner. The tools may be com-

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bined, as shown in Fig. 1, where cross sections, plan views and isosurfaces are displayed together . Full color illustrations of these tools, along with much more information on D3D, can be found on our homepage at http://d3d.fsl.noaa.gov/.
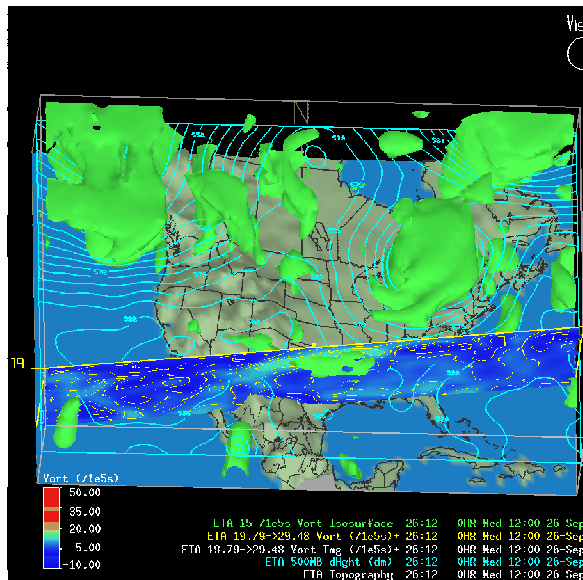

Fig. 1. A combined D3D view showing an isosurface of vorticity, a plan view of 500 mb height, and a vertical cross section of vorticity displayed as both contours and as an image. The view is tilted to show structure in the isosurface and to view the cross section.

3. HISTORY OF D3D DEVELOPMENT

FSL began exploratory work with 3D visualization around 1990 with a commercial visualization package, migrating to the freely available Vis5D in early 1997. Since then we have had a very close working relationship with Bill Hibbard, the key Vis5D developer at the University of Wisconsin. Vis5D was favored over other packages because it was designed for use in meteorological research, and the basic tools were already well thought out and used by researchers for meteorological analysis. FSL's development focused on the interfaces that Vis5D used to select fields, change colors, or otherwise interact with the data. While the methods employed by Vis5D were effective, they differed considerably from similar AWIPS D2D interfaces. Since AWIPS D2D is the basic workstation used in every WFO, our first main goal was to redesign these interfaces to look and behave as much as possible like the operational ones in D2D. Among other changes, a Volume Browser was developed for D3D to re-

place the Vis5D product selection matrix. This redesign also needed to incorporate the numerous editing functions for the D3D products, which extended beyond those that are used in D2D. Some of the Vis5D GUIs could be replaced by very familiar tools, such as a modified color selector that is virtually identical to the one used in D2D.

Other important changes were made to Vis5D as to how it interacted with the database in order to work in an operational setting. These are detailed in McCaslin et al. (1999, 2000), and basically involved how the application accessed the same files that D2D uses. Additionally, changes were made to enable one to switch to a different model in D3D without restarting the application. Other changes refined and enhanced Vis5D's display capabilities.

After sufficient development to the application to allow it to be used reliably on an AWIPS platform (then a Hewlett Packard Unix workstation), we began to evaluate D3D at FSL in the fall of 1997 by using it during FSL's Daily Weather Briefing program, a longstanding (since the early 1980s) program that involves a meteorologist giving a regularly scheduled daily 30-min weather briefing to an audience of researchers (OAR) and operational (NWS) personnel and the public. This provides a forum for informal evaluation and feedback on new technologies such as D3D in a nonoperational setting. We were able to receive a good deal of feedback that was useful in our initial development and refinement of D3D. A year later, we organized a forecasting experiment similar to most employed during development of D2D. A fairly low-key effort was organized during the summer of 1998 with a real-time forecast exercise (RT98) that used FSL meteorologists as well as a few forecasters from the nearby (now collocated) Denver WFO. RT98 produced a higher level of useful evaluation, and again changes were made to incorporate some of the feedback.

A far more formal forecast exercise was carried out from October to December 1999 (RT99) at FSL. The six NWS regions and all of the National Centers were invited to send one forecaster from each location to FSL for a two-week exercise. The response to the invitations to participate was excellent, and we ran two 2-week exercises and one abbreviated 1-week exercise to accommodate all the participants (see details in Szoke et al. 2001).

The overall feedback from RT99 was very positive, and many participants wanted to take the application back to their WFO or Regional Office in its current state. At that time, however, most offices were using HP Unix workstations that could run D3D, but only barely, and it was deemed unwise to distribute the software. A major breakthrough was the porting of Linux to the PC platform, which allowed for the Unix-based D3D (and D2D) applications to be run on very affordable and fast PC workstations. Many WFOs began to purchase individual Linux PCs for office applications, and when connected to the real-time AWIPS database, this provided an opportunity to try D3D with no real impact on operational processing. Performance testing demonstrated that D3D installed in such a manner should have virtually no computational impact on operational systems, and of course if there was any issue one could simply exit from the D3D application.

Once we had made some of the more important changes to D3D, arrived at from evaluation of RT99, and coupled with the availability of Linux PCs at WFOs, we began distributing the software, which was contained on a single CD along with a couple of case studies. The CD was designed so that one could run D3D with the case study data (a snowstorm case and the 3 May 99 Oklahoma tornado outbreak case) right from the CD, without installing the software or connecting it to the AWIPS database. Of course, more complete and desired testing would be for forecasters to try to use D3D in daily operations. We initially distributed D3D to a couple of RT99 participants, WFOs in Gray, Maine and Dodge City, Kansas, who had expressed the greatest interest, and had the required computer setup in place. After a relatively lengthy process of getting approval to attach their Linux PC to the AWIPS database, both offices began using D3D by early 2001.

Distribution of the D3D software became more widespread as we interacted with forecasters and other potential users at the AMS Annual Meetings in 2001 and 2002, and through presentations at those meetings (a complete list and online versions of these presentations and various papers can be found at our D3D Website). FSL also maintains an informational booth in association with other NOAA Laboratories and the NWS at the AMS Annual Meeting, and we used this opportunity to demonstrate D3D to interested parties and distribute CDs containing the software. A second D3D release with more improvements was completed in October 2001.

A map showing the state of D3D distribution and its current use is shown in Fig. 2 (an updated version of this appears on the D3D homepage). In addition to the distributions at the AMS Annual Meetings, some CDs were sent out by request from individual sites, and a few through visits by members of the D3D group. Eastern Region Headquarters held their annual meeting of Science Operations Officers (SOOs) in Boulder (at FSL) in April 2002, and we gave a short D3D presentation and distributed CDs to a number of SOOs at that time, hence the extensive coverage in the eastern U.S. COMET held a Mesoscale Analysis and Prediction Course (COMAP) in May and June 2002. We had helped COMET install D3D on their AWIPS workstations prior to this course, and D3D was used extensively during the 6-week session (Page and Niefield, 2003, this conference). Most of the participants (mainly SOOs from across the NWS) asked for a CD before they left.

4.   D3D IN OPERATIONS: USE AND NONUSE

It is clear from Fig. 2 that there is widespread distribution of D3D, but use of D3D is limited at this time. The different patterns of D3D usage can be explained in part by the relative newness of D3D at many of the WFOs, that is, a good number of the sites acquired D3D only a few

Fig. 2. Map showing the current (as of 30 Sept. 2002) distribution and use of D3D.

months ago. There are other reasons beyond just the newness, however, as disscussed below.

4. 1 Conflict with other initiatives

From correspondence with users from some of the sites in Fig. 2, a significant issue regarding WFOs not being able to get very much involved with D3D at this time is a major push across the NWS to implement the Integrated Forecast Preparation System (IFPS; see http://www.nws.noaa.gov/om/ifps/ifps.htm). IFPS involves an enormous shift in how forecasters prepare their forecasts, using a graphical editor to manipulate model grids, with the system then translating the grids into zone and other forecast text products. A number of the WFOs contacted indictated that this transition to IFPS and the training involved has made it virtually impossible to devote a serious effort to test D3D.

4. 2 Finding a suitable platform for D3D

Another issue that might inhibit immediate D3D use is finding a suitable platform for running the software. Although WFOs are moving toward a configuration that includes at least one complete Linux PC-based workstation in operations that would be ideally suited to run D3D, at this time the NWS wants to keep the system relatively free of outside applications during the test period, to reduce the risk of interruptions to operations with the new workstations. This means that the only option for running D3D with real-time data is to install it on a separate Linux

PC in the WFO, at least at this time. Further, although Linux PCs exist in many WFOs, they might not be connected to the AWIPS data stream, and making this connection is not always an easy task. In such cases some sites are finding that the easiest place to install D3D is on the Warning Events Simulator (WES) workstation, which is a new PC-Linux workstation whose primary function will be to examine archived cases in a delayed real-time mode, primarily for training purposes. The advantage to having D3D on an easily accessible workstation with real-time data would be the chance to take advantage of those slow weather days when a forecaster might have time to experiment with D3D. Also, having D3D available with real-time data also gives forecasters the chance to determine the potential of the D3D tools for aiding in the forecast problem(s) of the day. As an alternative, though, the WES seems like a plausible workstation that would at least allow for ready access to D3D.

4. 3 Philosophical and training issues

The paper by Johnson (2002) examined issues relative to this paper; that is, why D3D was not being used much at the Dodge City, Kansas WFO. Johnson hypothesized that visualizing the atmosphere in three dimensions was such a drastic change from the traditional 2-D approaches, in which most meteorologists were trained, that forecasters would tend to resist this change, even if they could benefit from it. He stated that if D3D were more easily available to forecasters to use with real-time data, they would find the most effective ways to use it and eventually become comfortable with 3-D visualization. He also noted that if college students were taught meteorology

with 3-D visualization, they would be more prone to want to use it, or even expect it, in operations.

The points raised by Johnson were discussed extensively at the 8th Workshop on Meteorological Operational Systems, sponsored by the European Centre for Medium-Range Weather Forecasts (ECMWF) in November 2001. We presented a talk on D3D (Szoke et al. 2002b), and there were other presentations on different systems that incorporated attempts at 3-D visualization. Comments during the conference and at some breakout discussion sections suggested that the reluctance of forecasters to readily accept 3-D visualization as an operational tool was not limited to the United States, and that the forecasters unfamiliarity with 3-D imagery as applied to meteorology resulted in a resistance to change from using traditional 2-D products.

Another issue noted by the experience of introducing 3-D in Germany was that forecasters were reluctant to use an "add-on" system to look at 3-D products, and because of this the German Weather Service decided not to proceed with introducing 3-D to forecasters until a workstation could be developed that seamlessly moves from 2-D to 3-D applications. While someday AWIPS might indeed be such a workstation, it would be an extensive development. In our view much could be learned from a comprehensive test of 3-D now, even if it is not a fully integrated system within AWIPS, that could make for a better workstation in the future.

4. 4 Toward improving the use of D3D

We should note that there are some sites where D3D has been used more extensively, and some of these took part in the AWIPS Symposium held at last year's AMS Annual Meeting (Barjenbruch et al. 2002; Hayes et al. 2002; Johnson 2002; Watson et al. 2002a, b). In fact it was somewhat of a milestone for D3D when we were able to have our own session at that conference. Most of the papers discussed applications of D3D at the different offices, specifically mentioning features such as trajectories (Barjenbruch et al. 2002) or applications appropriate for examining tropical cyclones (Watson et al. 2002a).

For those familiar enough with D3D to use it effectively it is difficult to deny that one can peruse far more model output more quickly using D3D than with D2D. Given that the atmosphere *is* three-dimensional, it is also hard to deny that examining the atmosphere using a 3-D tool is not more effective and complete than using 2-D displays. In fact, during RT99 the forecasters agreed that isosurfaces were certainly very illustrative in terms of visualizing the atmosphere as well as quickly finding features. A general consensus was that this 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" 2-D level (plan view) or the most appropriate cross section. But they also noted that it would take some time for forecasters to determine how best to use isosurfaces. Clearly the atmosphere is three-dimen-

sional, and the isosurface allows one to view it as such, but it was still difficult for the forecasters to overcome the tendency to want to view fields in the traditional 2-D manner.

There were other issues that compounded the difficulties forecasters had using 3-D products, and some of these were addressed with changes made to D3D. For example, there are problems with georeferencing in some situations that make the isosurface more difficult to use quantitatively. An addition was made to D3D to allow for easy switching back and forth from an overhead view, where one could then determine exactly where the isosurface was located, to an angled view for 3-D perspective viewing. We also added a feature to allow the background map to be moved in the vertical as another way to georeference an isosurface.

Despite these and other changes, in many cases forecasters have stated they are not sure how to use an isosurface effectively, and whether it adds value to their diagnosis. One of the more common issues mentioned is that there needs to be some training in how best to meteorologically use an isosurface. This was discussed most recently at the Eastern Region meeting in Boulder in April 2002. While we have some examples of D3D displays on our Website, it is clear that we need to add more complete training cases. We hoped that these would be coming more from WFOs rather than from the developers at FSL. Operational forecasters using D3D might arrive at the best combinations of isosurfaces and other D3D features for examining model output under various situations. There have been some examples from operations; for instance some of the papers from the AWIPS Symposium in 2002, and the paper at this conference by Neitfeld (2003).

We have discussed in some detail isosurfaces, because they are the primary 3-D component of D3D, but as noted in Fig. 1 and Table 1, D3D has other components. The interactive nature of these other D3D tools makes them very powerful for quickly interrogating model output, more so than their counterparts in D2D. Indeed, during RT99 the Sounding Tool received much praise, and specific improvements were made to this tool. The Sounding Tool allows one to display either a SkewT plot, or a hodograph, or both combined, along with selected stability and shear parameters, which can also be done in D2D, but in D3D one is able to move a cursor around a model domain and get an instant update to the information displayed. Similar interaction with Plan Views (for example, a 500 mb surface) and Cross-Sections, either through "handles" at the edge of the domain or through a slider bar within a GUI, allows one to quickly peruse lots of information with these 2-D tools. Trajectories are familiar to meteorologists, but are seldom used operationally because there has been no way to generate them with operational model output. D3D enables one to do so, and some forecasters have been quite intrigued with the trajectory application (see, for example, Barjenbruch et al. 2002). Volume Visualization is a D3D tool that is also three-dimensional, like the isosurface, but requires some-

what higher end PCs (now easily attainable at low cost) and has not been tested much to this point. More detailed discussion of these tools can be found in Szoke et al. (2002 a,b).

Some users of D3D who have not necessarily found it to have enough added value in model diagnosis, nonetheless suggested that it may be very useful in operations if used to display other data such as Doppler radar data. Work is currently underway to refine an earlier version (Roberts and Longmore 1999) of a radar reflectivity display using D3D. Certainly display of a field of equivalent radar reflectivity from a local-scale model, as well as from LAPS (Local Analysis and Prediction System, Mcginley et al. 1991), has shown some interesting potential. Others have indicated that D3D might be an effective way to examine ensemble model output, and an intriguing way of doing this is discussed by Alpert (2003, this volume). Others have indicated that they might be more willing to use D3D if it also displayed actual data in addition to model and analysis grids. Along these lines work is currently underway, on a separate project, to use D3D to display high-resolution lightning data, which could set the stage for other real-data displays within D3D. Finally, some have indicated that D3D would be improved if it could display more then one model at a time. Such multi-model context viewing is possible within Vis5D, and will likely be the subject of future efforts.

5.   CLOSING COMMENTS

Unfortunately space limitations prohibit showing specific examples of how D3D might be used under various case situations. At the conference we will show some of these examples, and detailed examples can be found on our D3D Website. In addition, the paper by Nietfeld (2003, this volume) examines some examples of D3D for a case from the Omaha, Nebraska, WFO.

Although D3D is a very small pilot program at FSL, by working with a well-established 3-D software package designed for meteorology, Vis5D, we have been able to focus on making changes that allow for compatibility with standard AWIPS model and analysis grids, and have made the overall package look and feel like the familiar AWIPS D2D. With the advent of Linux and the low cost of high-powered PCs available to WFOs, it has been possible to widely distribute D3D for experimental testing by operational forecasters.

Although individual forecasters have been impressed with many of the D3D capabilities, despite the wide distribution of D3D, it does not yet enjoy widespread use. We have discussed the factors likely conspiring to make this so. It is our belief that as IFPS becomes more routine to forecasters, they will have more time to begin seriously examining D3D. It is possible that until 3-D visualization becomes a regular and widespread part of meteorological teaching at the university level, operational forecasters will not easily transition into utilizing 3-D visualization. However, most who have used D3D agree there is potential value to operational forecasting, in particular

as an excellent way to more quickly and thoroughly examine the three-dimensional atmosphere, which could aid in alleviating the problem of potential forecaster overload in dealing with more and more numerical model output. To tap this potential we urge the operational weather agencies to begin a program to integrate D3D into operations with formal tests and risk reduction activities.

6.   ACKNOWLEDGMENTS

7.   REFERENCES

Alpert, J.C., 2003: 3-dimensional animated displays for sifting out medium range weather events. *Preprints, 19th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology*, Long Beach, CA. Amer. Meteor. Soc., Paper 15.2.

Barjenbruch, D.B., E. R. Thaler and E. Szoke, 2002: Operational applications of three-dimensional air parcel trajectories using AWIPS D3D. *Preprints, Interactive Symposium on AWIPS*, Orlando, FL. Amer. Meteor. Soc. J136-J138.

Hayes, J.C., J. W. Cannon and J. Watson, 2002: Applying D3D in an operational environment. *Preprints, Interactive Symposium on AWIPS*, Orlando, FL. Amer. Meteor. Soc. J124-J125.

Hibbard, W. R. and D. Santek, 1991: The Vis5D system for easy interactive visualization. *Preprints, 7th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology*, New Orleans, LA. Amer. Meteor. Soc., 129-134.

Johnson, J.R., 2002: Numerical model visualization using the FSL D3D: A paradigm shift for operational forecasters. *Preprints, Interactive Symposium on AWIPS*, Orlando, FL. Amer. Met. Soc. J126-J130.

McCaslin, P.T., P. A. McDonald, and E. J. Szoke, 1999: Developing and Testing a 3D Visualization Workstation Application at FSL. *Preprints, 15th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology*, Dallas, TX. Amer. Meteor. Soc., 498-501.

McCaslin, P.T., P. A. McDonald, and E. J. Szoke, 2000: 3D Visualization Development at NOAA Forecast Systems Laboratory. *AMC SIGGRAPH Computer Graphics*, Feb 2000, Vol. 34 No. 1, 41-44.

McGinley, J.A., S.C. Albers, and P.A. Stamus, 1991: Validation of a composite convective index as defined

by a real-time local analysis system. *Weather and Forecasting.* **6**, 337-356.

Nietfeld, D., 2003: The synoptic environment of the 11 April 2001 Central Plains tornado outbreak viewed in three dimensions. *Preprints, 19th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology*, Long Beach, CA. Amer. Meteor. Soc., Paper P1.1.

Page, M.P., and D. Nietfeld, 2003: Integrating D3D into National Weather Service science and training activities. *Preprints, 19th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology*, Long Beach, CA. Amer. Meteor. Soc., Paper 12.8.

Roberts, W.F., and S.P. Longmore, 1999: Real-time visualization techniques for a regional radar volume. *Preprints, 29th International Conference on Radar Meteorology,* Montreal, Canada. Amer. Meteor. Soc., 225-228.

Szoke, E.J., U.H. Grote, P.C. Kucera, P.T. McCaslin, P.A. McDonald, and W.F. Roberts, 2001: D3D: A potential 3D visualization tool for the National Weather Service. *Preprints, 17th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology*, Albuquerque, NM. Amer. Meteor. Soc., 10-14.

Szoke, E.J., U.H. Grote, P.T. McCaslin, and P.A. McDonald, 2002a: D3D: Overview, update, and future plans. *Preprints, Interactive Symposium on AWIPS*, Orlando, FL. Amer. Meteor. Soc., J118-J123.

Szoke, E.J., U.H. Grote, P.T. McCaslin, and P.A. McDonald, 2002b: D3D: using 3D visualization and other Vis5D tools in an operational forecast office. *Preprints, 8th fWorkshop on Meteorological Operational Systems*, Reading, England. European Center for Medium-Range Weather Forecasts, 164-171.

Wakefield, J.S., 1998: Operational Risk Reduction: Easing AWIPS into the Field. *Preprints, 14th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology*, Phoenix, AZ. Amer. Met.. Soc., 389-391.

Watson, A.I., J. D. Fournier, T. P. Lericos, and E. J. Szoke, 2002a: The use of D3D when examining tropical cyclones. *Preprints, Interactive Symposium on AWIPS*, Orlando, FL. Amer. Meteor. Soc. J131-J135.

Watson, A.I., T. P. Lericos, J. D. Fournier, and E. J. Szoke, 2002b: Better understanding of QG theory through the use of D3D. *Preprints, Interactive Symposium on AWIPS*, Orlando, FL. Amer. Meteor. Soc. J227-J232.