D3D: OVERVIEW, UPDATE, AND FUTURE PLANS

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1. INTRODUCTION

The NOAA Forecast Systems Laboratory (FSL) is tasked with evaluating and transferring potentially useful applications that may be present within the research community into operations. One such application that is currently being evaluated at FSL is a visualization tool from the University of Wisconsin known as Vis5D (Hibbard and Santek 1991). FSL has taken the Vis5D software package, with enthusiastic support from Bill Hibbard at the University of Wisconsin, and developed it into an application known as D3D (Display in three Dimensions), which could potentially add 3D visualization capabilities to National Weather Service (NWS) Weather Forecast Offices (WFOs). Vis5D and D3D can display 3-D grids of meteorological data using tools that include both 3-D displays and interactive 2-D displays.

This paper gives an overview of D3D, including a description of its components, history at FSL, present status in operations, and future plans. We are pleased that the interest in D3D has grown to the point that the Visualization Session at the Interactive Symposium on the Advanced Weather Interactive Processing System (AWIPS, Wakefield, 1998) will contain a number of papers discussing D3D. Most of the papers to follow in this session will discuss the use and initial impressions of D3D at some WFOs where it has been deployed. This paper serves as an introduction to the session.

2. OVERVIEW OF THE D3D TOOLS

The Vis5D software package is really a collection of tools, some of which are true 3-D displays, while others are just 2-D displays that can be used in a highly interactive manner. A summary of the tools in D3D is given in Table 1, and most are illustrated in Fig. 1a-d. It must be noted that tools can easily be combined, and one is not restricted to just displaying one field or one cross section at a time. 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/. Figure 1a shows an example of an isosurface of vorticity (a surface that encloses vorticity with values between 0 and 15 x 10^{-5}s^{-1}). The image is tilted to show the 3-D structure of the vorticity field as revealed by the isosurface. The data is from the Eta model's analysis field for the 1200 UTC run on 26 September 2001, when a deep upper-level closed low was positioned over the Great Lakes, with another in the Gulf of Alaska. The isosurface is the basic 3-D tool that is quite different from anything the forecaster currently has

Table 1: D3D tools

Tool	Description	Example
Isosurface	3D surface of a field	Fig. 1a
Plan view	Horizontal 2-D display	Fig. 1a
Cross-section	Vertical 2-D display	Fig. 1a
Sounding	SkewT, hodograph, vertical plot	Fig. 1b
Probe	Point display of data	none
Trajectory	Forward/backward trajectories	Fig. 1c
Volume Visualization	3D "fog" type display	Fig. 1d

available in D2D (AWIPS). Two of the D3D "2-D" type tools are also shown in Fig. 1a, the plan view and the cross section. The plan view is of 500 mb height contours at intervals of 30 dm, while the cross section shows both vorticity contours and an image of vorticity, linked together into one cross section that is aligned in a skewed direction to emphasize the flexibility in orientation.

Another 2-D tool that has been modified considerably by FSL is the Sounding tool, illustrated in Fig. 1b. The interactive part of this tool allows one to change the sounding location as desired with an instant update to the entire display. In addition, one can display any of the four components (SkewT, Vertical Plots, Hodograph, or Parameters) by themselves, or in any combination. The vertical plots option allows for display of any available field plotted against height, for up to three fields at once. The Probe tool (not shown) works like the sounding tool in that one can select any location for the probe, however, it simply displays the value of as many fields as desired for just
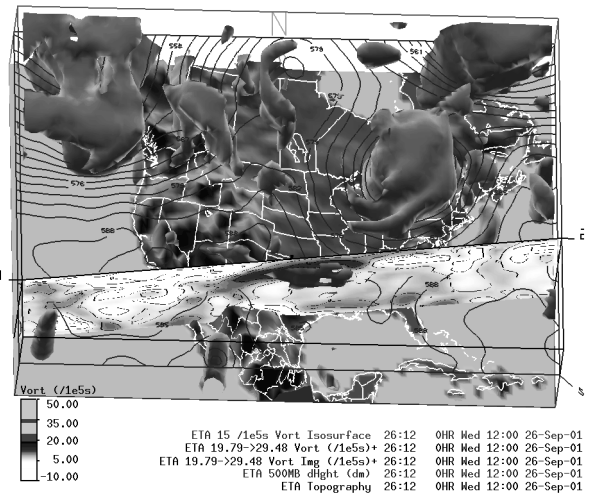

Fig. 1a. A combined D3D view showing an isosurface of vorticity, a plan view of 500 mb height, and a vertical cross section of vorticity displayed as both contours and as an image. The view is tilted to show structure in the isosurface and to view the cross section.

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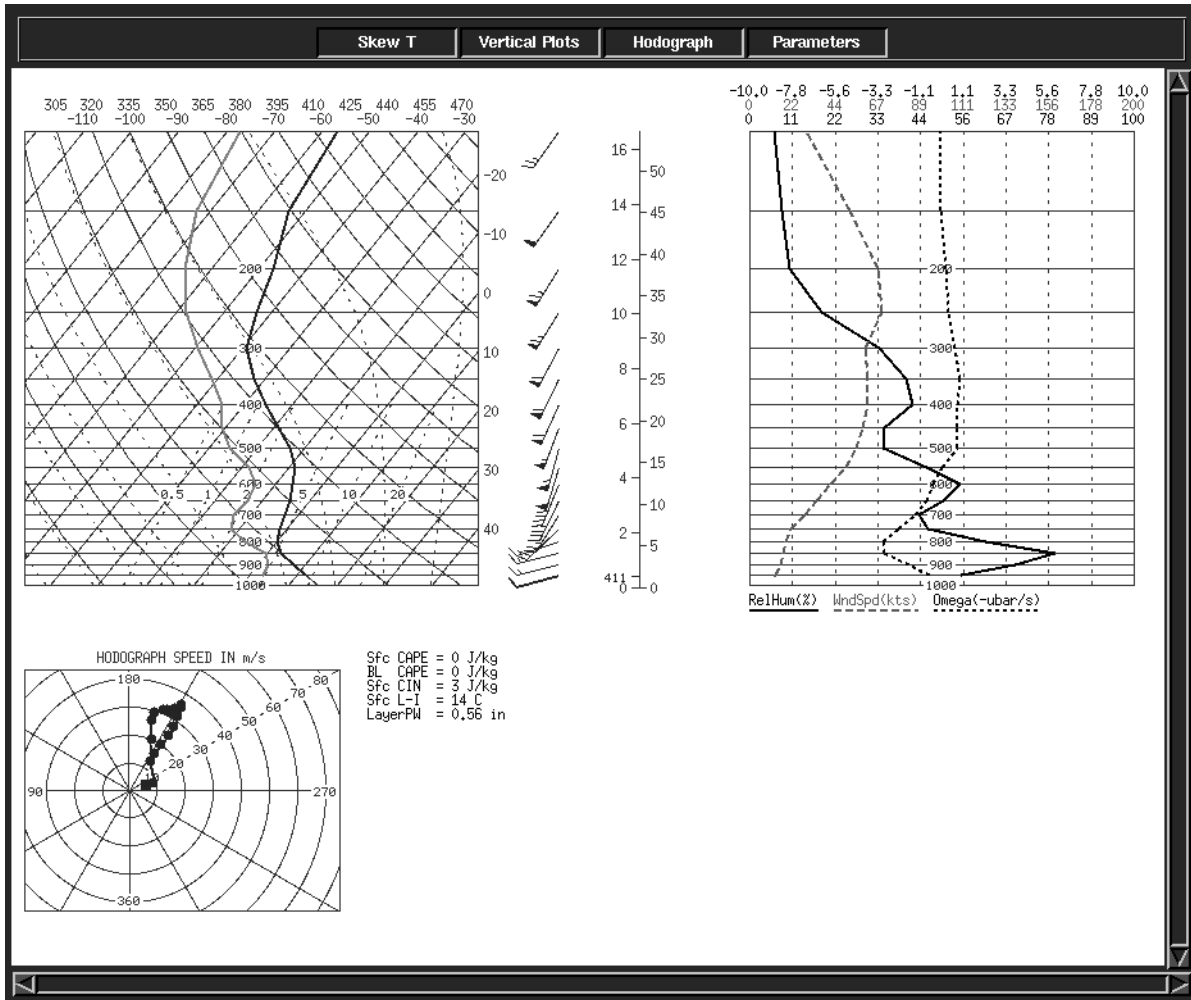
Fig. 1b. Example of the D3D sounding tool, with the cursor positioned over New England, for the 12 h Eta forecast.

a single point in space, rather than a vertical profile. While this limits the utility of the probe, there are some special applications where it may be of use, given the ability to impose certain restrictions on the probe location, such as fixing it to a specific height or pressure level in the vertical as its horizontal location is changed.

An additional feature of D3D and Vis5D is the ability to construct trajectories, with the option of tracing a trajectory from a given point forward in time, or examining the trajectory that traces air that reaches a given point. The trajectories can be displayed as lines or ribbons, and can be colored by another variable. This interesting tool is familiar to meteorologists, but they are unable to construct them in operations. Therefore, the D3D trajectory product will be somewhat like the isosurface in that it may take time for forecasters to determine what value trajectories have in operational forecasting and how best to utilize them. The paper by Barjenbruch et al. (2002, this session) discusses some potential operational uses of trajectories at the Boulder WFO. Examples of several different trajectory products available within D3D are shown in Fig. 1c. One of the most recent software changes was to create a new Graphical User Interface (GUI) for the tra-

jectory application, shown on the left side of Fig. 1c, that allows one to easily create five different types of trajectories: 1) "point," where one can launch a trajectory from a
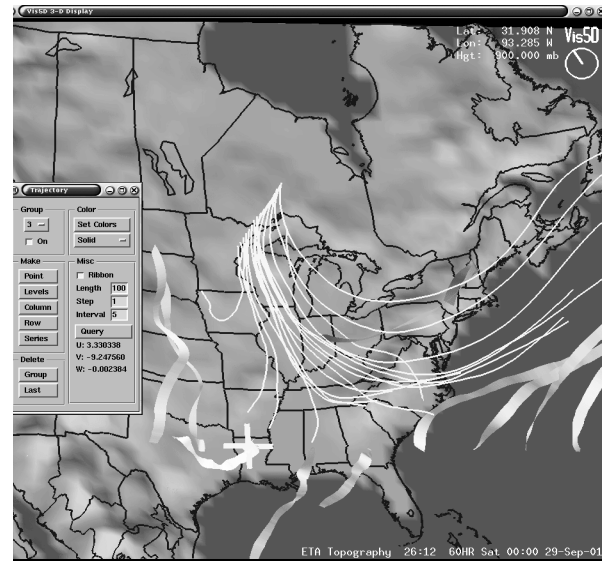

Fig. 1c. D3D trajectories showing three options.

selected level (the ribbon from Indiana to New England in Fig. 1c); 2) "levels," a predefined script that launches trajectories at one location at 50 mb intervals in the vertical (this is illustrated for the streamer of trajectories eminating from a point over northeastern Minnesota; 3) "column," another script that launches trajectories at a given level at intervals along a north-south line; 4) "row," which does the same for an east-west line, as illustrated for the trajectories along the row from Texas east into the Atlantic; and 5) "series," which automatically launches a point type trajectory at each available model time interval (6 h for the Eta, for example).

The last D3D tool is called Volume Visualization, which is a true 3-D type product, but unlike the isosurface that encloses a field at a prescribed level, it displays the entire range of data as a "fog" or "haze" type product. An example is shown in Fig. 1d for relative humidity, and al-
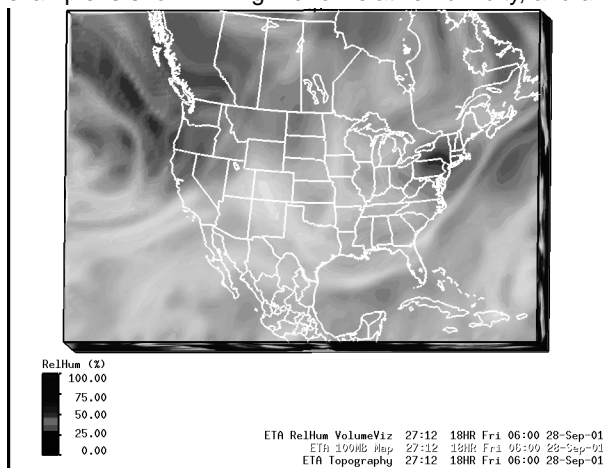

Fig. 1d. Volume Visualization of Eta relative humidity.

though much of the potential utility of the product is lost with a black and white figure, one gets a flavor for how the product works, in this case making the display of relative humidity appear much like a water vapor satellite image. One of the main difficulties with this application is that it uses a lot of computer resources, especially when the images are software rendered (as in the current setup). This makes it too slow to use operationally at this time under most machines in place, although with computer power increasing this limitation should diminish in the future.

3. HISTORY OF D3D AT FSL

3.1 *Early work with visualization*

In early planning for AWIPS the idea of having visualization as part of the overall AWIPS display package was discussed and planned for as a future component. Exploratory work with visualization at FSL began around 1990 using commercial software for some research applications. A commercial package called Application Visualization System (AVS5) was used extensively, including as a display tool for analyses from the Local Analysis and Prediction System (LAPS, McGinley et al. 1991) that are

displayed on the FSL web page (http://laps.fsl.noaa.gov). After several years of exploration we decided to use the University of Wisconsin's Vis5D package, with its superior animation capabilities, and long history in the meteorological research community. As a plus, Vis5D had already been exposed to the NWS through a COMET training module that used Vis5D to produce 3-D displays of pseudo-reflectivity for convective storms simulated by a research numerical model (Anticipating Convective Storm Structure and Evolution, released in 1996; see http://www.comet.ucar.edu).

3.2 *Preliminary evaluation of D3D*

After the decision in early 1997 to use Vis5D as the core software for D3D development, the next step was to decide what portions of the existing software should be modified. Since Vis5D was designed for use in meteorological research, the basic tools were already well thought out and were known to be useful for meteorological analysis. So the main focus was 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 tools that are in AWIPS D2D, which is the basic workstation used in every WFO. In order to minimize any learning curve associated with using D3D, it made sense to make it physically look like D2D, and to have similar methods of accessing and manipulating data that were already known to operational forecasters. So the first main software push was to replace the Vis5D product selection matrix (Fig. 2a) with a D2D-like Volume Browser (Fig. 2b)

Besides the changes necessary to make product selection using the Volume Browser, the redesign of the Volume Browser for D3D needed to incorporate the numerous editing functions for the D3D products. In Vis5D the editing functions are controlled by individual GUIs that become active with different mouse clicks on a product in the product selector matrix. As with the overall Vis5D product selector, these Vis5D tools were certainly effective enough, but their methods of editing fields (color, for example) were quite different than similar methods used in D2D, and so were also prime candidates for software changes as work began with D3D. Since certain parameters in D3D need specification that is not required in D2D, such as a value to prescribe for an isosurface, the D3D Volume Browser editing functions could not be exactly like their D2D counterparts. An example of how the D3D Volume Browser looks when editing an isosurface product (field) is shown in Fig. 3.

There were other important changes to Vis5D and how it interacted with the database that were required for an operational type 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 changes were made to
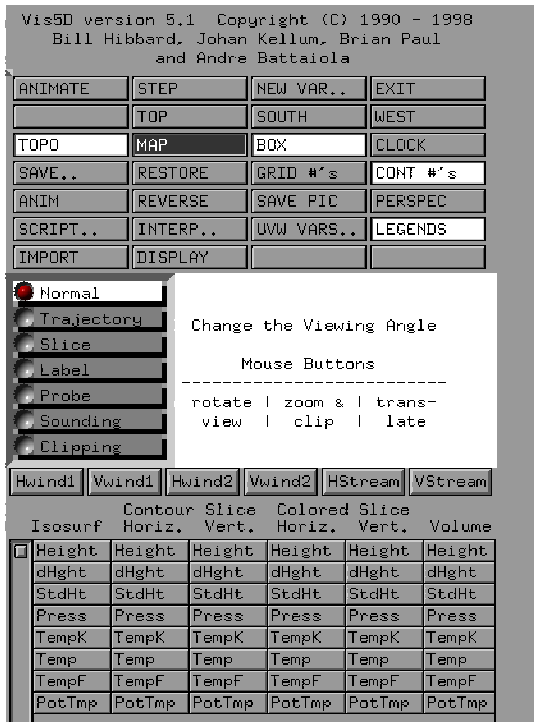
Fig. 2a. Vis5D product selector.

Fig. 2b. D3D Volume Browser, meant to replace what is shown in Fig. 2a.

Fig. 3. D3D Volume Browser in "edit mode" for editing an isosurface of vorticity. A value to display for the isosurface is controlled by the toolbar. Other editing functions like color selection and other features are invoked by other GUIs through the boxes on the right.

the application to allow it to reliably be used on an AWIPS platform (Hewlett Packard Unix workstation), we began to evaluate D3D at FSL, looking at both its performance as well as exploring the potential utility of the application for weather forecasting. A natural means to accomplish this initial more informal evaluation was available at FSL through our Daily Weather Briefing (DWB) program, a longstanding (since the early 1980s) program that involves a meteorologist giving a regularly-scheduled daily 30-min weather briefing to anyone interested in attending. The DWB allows for in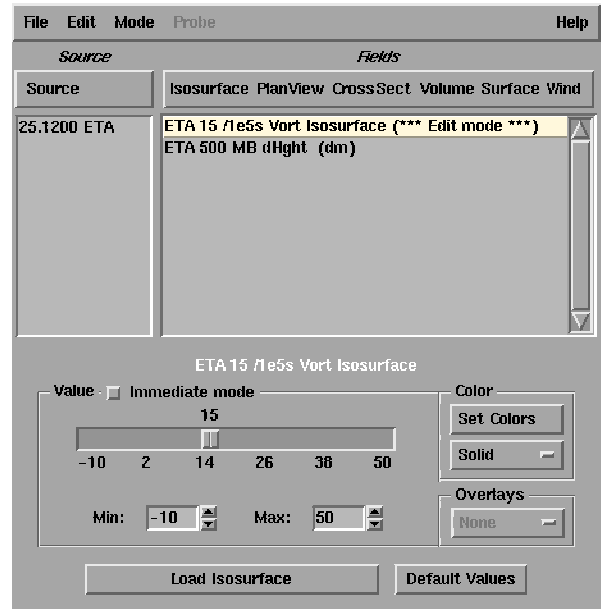formal evaluatuon of new technol-ogies such as D3D in a non-operational setting, and its use in the DWB began in the fall of 1997, from which we were able to receive a good deal of feedback that was useful in our initial development and refinement of D3D. After about a year of this effort, however, we felt even more could be accomplished with a more organized forecasting experiment, of the type that FSL employed frequently over the last 20 years in developing D2D. So in the summer of 1998 a real-time forecast exercise (RT98) was carried out using FSL meteorologists as well as a few forecasters from the nearby (now collocated) Denver WFO. RT98 did produce a higher level of useful evaluation, and again changes were made to encorporate some of the feedback we received.

3.3 *Real-time Exercise-1999*

After digesting much of the feedback from the RT98, which included a generally positive response to D3D, the next logical step in D3D development would be to expose the package to a wider variety of users via a more formal forecast exercise, again in the spirit of the early development days of D2D at FSL. The RT99 exercise was carried out from October to December 1999 at FSL. An invitation was sent to each of the six NWS regions and to all the National Centers to send one forecaster from each location to FSL for a period of two weeks. The response to the invitations to participate was excellent, as shown in Table 2. More information on RT99 can be found in Szoke et al. (2001).

The first two sessions were two weeks long to allow for a more relaxed but comprehensive exercise. The

Table 2: RT99 Attendees (NWS Region in parentheses)

Organization	Date
NCEP/Environmental Modeling Center	25 Oct-5 Nov
NCEP/Storm Prediction Center	
WFO/Missoula, Montana (Western)	
WFO/Amarillo, Texas (Southern)	
NWS Office of Meteorology	Nov 8-19
WFO/Gray, Maine (Eastern)	
WFO/Dodge City, Kansas (Central)	
WFO/Boulder, Colorado (Central)	Nov 8-12
WFO/Anchorage, Alaska (Alaska)	Nov 15-19
NCEP/Aviation Weather Center	Dec 13-17
NWS Headquarters	
NCEP/Tropical Prediction Center	

shorter final session was all that could be arranged to accommodate the last three participants who could not commit to a full two weeks. Week 1 focused on training users to become proficient with the system using specific exercises with real-time and case data, introducing each D3D tool separately to allow adequate time for individual evaluation, and for each tool comparing to what one could discern using similar (where applicable) features in D2D. Week 2 focused on evaluating D3D as part of an operational forecast system using three cases run in "delayed real-time" (DRT) mode. Extensive online evaluation was conducted daily using detailed questionnaires designed by the FSL evaluation team, with similar experience in evaluating D2D. Additionally, participants could enter freeform comments online at any time, a feature that turned out to be a very popular way to record their evaluation. For the shorter, final phase we tried to include most of the important features of the full exercise.

Although we compiled a large number of suggestions for improvement of D3D (FSL E-Team 2000), the overall feedback from RT99 was extremely positive, and many participants wanted to take the application back to their WFO or Regional Office in its current state. Because of some workstation limitations that did not allow for Volume Visualization to be adequately addressed during RT99, the main three dimensional tool not available in D2D was the isosurface. The forecasters in RT99 found that isosurfaces were certainly very illustrative in terms of visualizing the atmosphere as well as quickly finding features, but they also noted that it would take some time for forecasters to determine how best to use them. Clearly the atmosphere is three-dimensional, and the isosurface allows one to view it as such, but it was still difficult to overcome the tendency to want to view fields in the traditional 2-D manner, plus there were problems such as georeferencing in some situations that made them more difficult to quantiatively use.

While intrigued by the potential of isosurfaces, participants were also impressed with the other applications in the D3D package, including the movable cross sections and plan views, and the very popular sounding tool. While each of these have analogous D2D features, the manner by which one interacts with these tools in D3D enables the forecaster to quickly and effectively peruse a large volume of model output. 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" level or the most appropriate cross section.

In addition to various suggestions to improve D3D, some of the main criticisms included the desire to also display observed data, and the need to be able to examine more than one model at a time. Both of these issues could potentially be addressed with modifications in the future. Specific improvements were suggested to the Sounding tool, while a general consensus was to continue to make the D3D GUIs appear more like D2D, if possible. This was viewed as important in order to reduce the amount of forecaster training needed to use the system, allowing instead for the training to concentrate more on the meteorological use of features like isosurfaces.

3.4 *Post-RT99 D3D development at FSL*

We are limited at this time in the effort we are able to put towards D3D, so priorities have been chosen based on as much consensus as could be derived from RT99. The major changes were to complete the Sounding tool to where it is now (Fig. 1b), and to complete the replacement of all Vis5D interfaces with more D2D-like GUIs (both completed in an October 2001 release).

A very major development after RT99 was porting D3D from the AWIPS HP-Unix platform to a PC platform using Linux, which has also been developed at FSL for D2D as a potential replacement for the current AWIPS workstations. The significant advantage to this switch was to utilize the low cost but high performance of rapidly evolving PCs, which can easily be upgraded to take advantage of new computing power. Two important D3D issues were solved by porting to a Linux PC: 1) the potential problem of slow response to the highly interactive D3D, which can easily frustrate the user; and 2) an inexpensive way for a WFO to try D3D, since a WFO can now add an inexpensive PC to experiment with D3D without any impact on operations.

4.   CURRENT FIELD STATUS OF D3D

We noted that participants in RT99 often wished to take D3D back with them and install it at their WFO. This was not possible at the time because the AWIPS Unix workstations were only barely able to support D3D, and we believed that slow performance would be a significant detriment to D3D acceptability, based on RT99 results. Once the port to a Linux PC was complete, we announced the availability of the software to those who participated in RT99 (since they would be able to train their own staff), and many of the locations had an available Linux PC already, or were prepared to purchase one. The main stumbling block then was to hook the machine up to

the real-time AWIPS database, which involved the WFO making the necessary arrangements with Regional Headquarters and the AWIPS Program Office. We tried to assist by running tests to assure that D3D would not have a negative impact on operations in terms of slowing down AWIPS D2D performance. Our tests showed there was a minimum impact when using D3D, and no impact at all if the application is simply left idle. Additionally, D3D can be easily shut down and quickly restarted.

Initially two WFOs (Gray, Maine, and Dodge City, Kansas) pursued D3D in a lengthy but eventually (by early 2001) successful effort to incorporate it into their operations. The Gray WFO worked closely with Eastern Region Headquarters, which also has D3D. Their experiences with D3D thusfar are discussed in papers in this session (Hayes et al. 2002, and Johnson 2002). Other WFOs have also expressed interest in the application. FSL held a technology workshop for the NWS Southern Region late in 2000, and following this several of their WFOs sent representatives for a 3-day D3D training session in January 2001. This has resulted in the installation of D3D at WFOs in Talahassee, Florida (see Watson et al. 2002, two papers), Tulsa, Oklahoma, and Amarillo, Texas, and at Southern Region Headquarters. FSL closely works with the Boulder WFO, and they have had D3D since May 2001 (Barjenbruch et al., 2002). FSL also works with weather services around the world, and the Central Weather Bureau in Taiwan recently acquired a Linux-PC version of D3D for testing.

5. FUTURE PLANS

At this time D3D is not formally in the AWIPS development plans, though it may evolve into them in time if further evaluation finds the software to be useful for operational forecasting. Without this formal acceptance, funding for further development is limited, so we cannot make all the changes suggested by RT99 or the continuing feedback from the field. The next major software efforts will be towards making the application more flexible to different AWIPS databases, and eventually addressing issues like the incorporation of actual observations (point data or radar), as well as multiple model displays.

We are encouraged by the interest that has already occurred within the NWS in trying D3D at some WFOs. The availability of D3D on an inexpensive Linux PC platform, and the recent move toward installing at least one such platform to run AWIPS at many WFOs, should make it relatively easy for additional WFOs to try D3D. It is our strong belief that widespread experimental use of D3D by a variety of users, under a range of weather problems, is the best way to yield a broad range of input that should eventually lead to an application that can be of value to NWS forecast operations. The increasing use of local models among WFOs yields new parameters that forecasters are not accustomed to examining with forecast models, such as model-generated reflectivity and cloud forecasts, naturals for displaying in 3-D. We will need to devise new ways to make it easier for those who

have D3D in operations to evaluate the software and suggest changes to us, likely through changes to our evolving D3D homepage at http://d3d.fsl.noaa.gov. So far we have established a forum for exchange of email among users.

D3D is currently in use at two Regional Headquarters (Eastern and Southern), but not yet at any National Centers, even though they sent representatives to RT99. The Storm Prediction Center is a logical first choice, as their RT99 participant was quite enthusiastic about the Sounding tool, which has just been updated in the new release. Our future efforts will also involve continuing to spread the word about D3D, through appearances at conferences and workshops. We are interacting with COMET, where they have installed D3D in their training facility. The number of D3D papers at this session represents the most discussion that the application has had thus far, and is an encouraging sign that there is interest in pursuing this potential operational application.

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