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OPERATIONAL APPLICATIONS OF THREE DIMENSIONAL AIR PARCEL TRAJECTORIES USING AWIPS D3D

David B. Barjenbruch* and Eric Thaler
National Weather Service Forecast Office
Boulder, Colorado

and

Edward J. Szoke
NOAA Forecast Systems Laboratory
Boulder, Colorado

1. INTRODUCTION

Perhaps one of the fundamental challenges facing the operational meteorologist is understanding the fully three-dimensional motion of the atmosphere, that is, visualizing air parcel trajectories. This is not a trivial task and there have been few explicit methods of accomplishing this visualization. Until recently, the main tool at the forecaster's disposal for trajectory analysis has been two-dimensional streamline analysis. However, these two-dimensional streamline patterns neglect the vertical component of the flow and duplicate horizontal trajectories only if they are stationary. As a consequence of these inadequacies, forecasters can be misled as the actual path that air parcels take to arrive in an area of concern. This can lead to errors in temperatures and moisture forecasts among other problems.

Because of its close proximity to the NOAA Forecast Systems Laboratory (FSL), the Boulder (formerly Denver) Weather Forecast Office (WFO) has always served as a test bed for new development that often becomes part of AWIPS. One recent development has been to test AWIPS on a PC platform using Linux, rather than the HP-Unix workstations currently in use. This workstation has been running Display Two-Dimensional (D2D), and with its sufficient computing power is also used as a platform to run Display Three-Dimensional (D3D), following the port of the D3D software to Linux. The D3D software that runs as part of the Linux PC AWIPS eliminates much of the aforementioned difficulties in visualizing air parcel trajectories in an operational mode. While D3D is a software package containing numerous data sets and a vast array of display capabilities, this presentation will concentrate on the utility of air parcel trajectories. Specifically, comparisons will be made between the old two-dimensional methods of estimating trajectories and the new D3D methods available in AWIPS.

* *Corresponding author address*: David Barjenbruch, National Weather Service, 325 Broadway,
Boulder, CO 80305-3328;
e-mail: David.Barjenbruch@noaa.gov

2. D3D TRAJECTORY COMPUTATION

D3D was derived from Vis5D software originally developed at the University of Wisconsin-Madison. The changes are explained by Szoke et. al (2001). Vis5D was created to examine and interact with large volumes of data and or model output from a research model. In research mode one can display model output at short time intervals, as desired, so computation of trajectories with Vis5D is relatively straight forward, as outlined in Hibbard (1986). In operations, bandwidth concerns limit the amount of model output that can be transmitted as full, three-dimensional grids. In the case of AWIPS, this interval for the Eta model is currently set at 6 hours, for the examples shown in this paper. Clearly a computation of trajectories at 6 hour intervals without any modification would lead to problems, and a trajectory that did not represent the forecast air motions very well. To overcome this, Vis5D (and therefore D3D) attempts to artificially shorten this lengthy time step by applying a factor to the data, depending on the size of the domain, that creates much small time steps. In the case of the Eta model and the AWIPS domain, the 6 hour interval is divided into approximately 130 such steps. While this cannot replace the use of 130 *actual* time steps, if they were available, in our experience the trajectories created by D3D have looked quite realistic and are usually fairly smooth.

3. FORECAST EXAMPLE

A case study from 8 September 2001 illustrates the utility of D3D and the advantages over the old two-dimensional analysis method. This case was characterized by an unseasonably strong upper level trough moving southeast from Alberta across the Rocky Mountains and Colorado. Initially, only light precipitation was associated with this system as it moved southeastward. However, increasing Quasi-Geostrophic forcing was forecast to react with a moist and slightly unstable airmass, along with north-northeasterly upslope flow over eastern Colorado. While the above dynamical factors would have alerted the operational forecaster to a potential significant weather event, the use of D3D trajectories helped the forecaster accurately assess where air parcels at separate levels in the atmosphere were originating. This aided the forecaster in quantifying the actual amount of vertical motion a parcel underwent as it moved to the area of interest.

Figures 1a through 1c show a top view of the air parcel trajectories for the 12, 18, and 24 hour forecast periods from the 1200 UTC 7 September 2001 Eta model run. Note these trajectories are for parcels that terminated near Denver at 1200 UTC 8 September 2001. It can be seen that the low level parcels

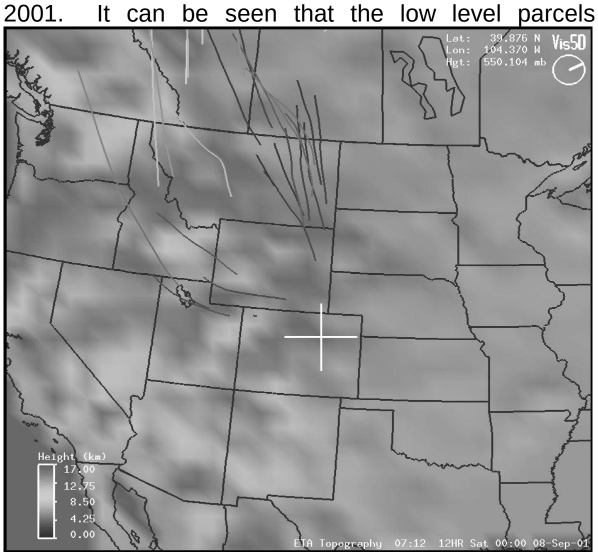

Fig. 1a. Eta 12 hour parcel trajectory forecast (top view) valid at 0000 UTC 8 September 2001.

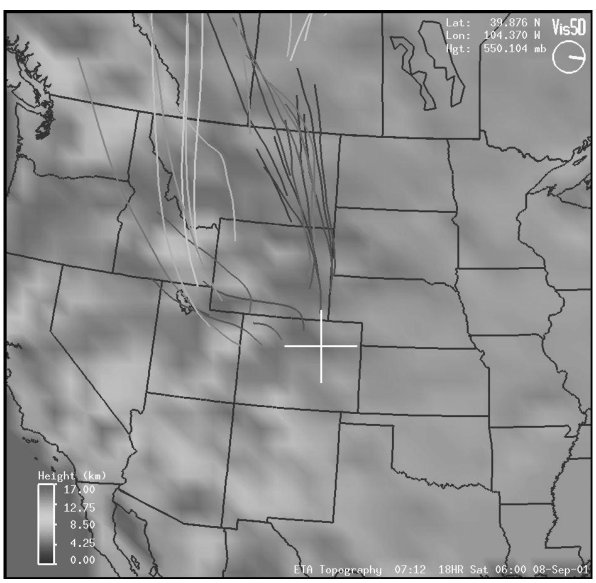

Fig. 1b. Same as Figure 1a except 18 hour forecast valid at 0600 UTC 8 September 2001.

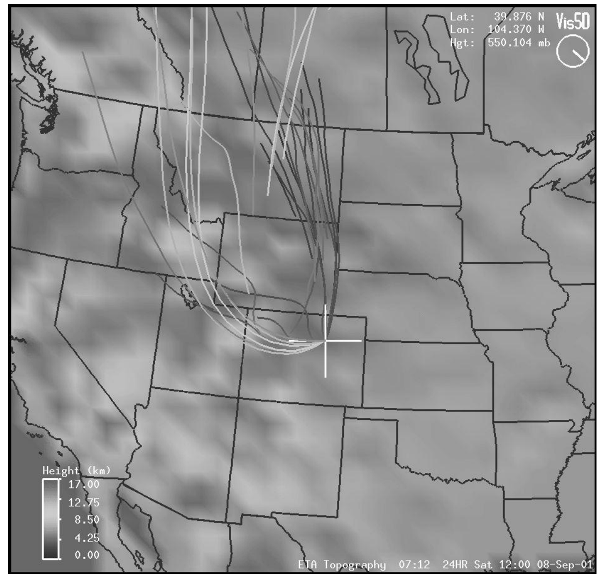

Fig. 1c. Same as Figure 1a except 24 hour forecast valid at 1200 UTC 8 September 2001.

originated in southern Saskatchewan and extreme northern Montana where surface temperatures were generally in the 45°F to 50°F range and dewpoints were near 40°F. If we rotate the view to the east for the 24 hour forecast (Figure 2), we can obtain additional

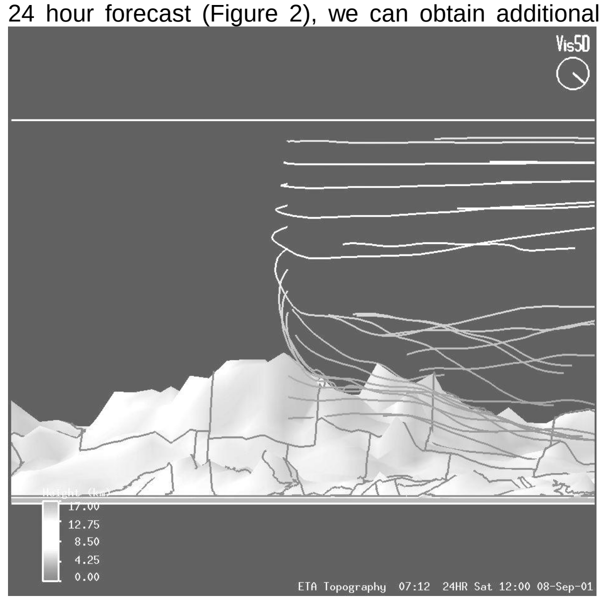

Fig. 2. ETA 24 hour trajectory forecast (east view) valid at 1200 UTC 8 September 2001.

information. For example, the parcels that originated near 850 mb over southern Saskatchewan rose sharply when they reached eastern Colorado, reaching near 500 mb by 1200 UTC 8 September. With that amount of upward vertical motion, it became evident that a widespread and significant precipitation event was likely to occur. In fact, over an inch of rain fell in most of the Boulder and Denver, Colorado metro areas, while heavy snow occurred in the Front Range mountains and foothills above 6500 feet where up to 13 inches of snow was recorded. This snow level was consistent with the upstream temperatures, dewpoints, and resultant wet bulb zero level observed at the point of origin.

In addition to the above figures showing column trajectories (trajectory parcels ending at various levels at a specific point at a single valid time) other means of trajectory display are also available in D3D. For example, trajectory time series generate a parcel trajectory for a specific point for every valid time in any numerical weather prediction model run. This would indicate where air parcels would have originated 6, 12, 18, 24, 48, etc. hours ago before reaching the specified point of interest. Trajectories may also be generated for numerous points along North-South or East-West oriented lines providing assistance in determining three-dimensional motions of the atmosphere.

Once D3D trajectories are calculated, forecasters are able to color code them according to numerous parameters such as pressure, height, temperature, lapse rate, theta-e, etc. Flexible color table can then be applied in order to highlight particular features or levels of interest. For instance, this capability was used to isolate an area of subsidence that substantially diminished convective development over the southern Front Range Foothills of Colorado on 6 August 2001.

While conventional Display Two Dimensions (D2D) has the functionality to display streamlines, it is not capable of showing trajectories, except for a limited trajectory data set based on the NGM. Even then, data is confined to a few parameters and only three levels: surface; 850 mb; and 700 mb (Reap, 1992). In addition, D2D streamlines (Figure 3) are only a "snapshot" of trajectories at a given point and given

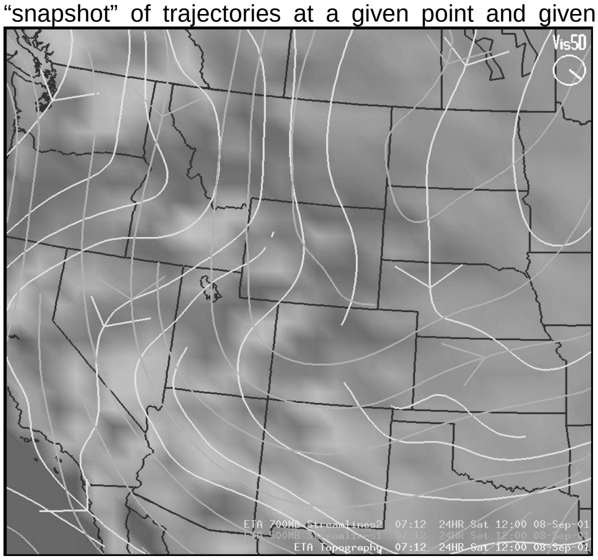

Fig. 3. ETA 500 mb (dark) and 700 mb (light) D2D streamlines valid at 1200 UTC 8 September 2001.

valid time and all vertical motion is excluded. The forecaster is left to interpret the exact path the parcel has taken, which may lead to forecast errors.

4. SUMMARY AND CONCLUSIONS

The AWIPS D3D software has been used operationally at the Boulder, Colorado National Weather Service Forecast Office since May 2001. D3D air parcel trajectories have been shown to be advantageous over D2D streamline analysis, largely attributable to the ability to show vertical motion and continuity of the parcel(s) of concern. This has allowed the operational forecaster to improve meteorological understanding and forecast techniques, including applications of conceptual models.

With increased use and familiarization with D3D, the operational forecaster will have a better understanding of air flow trajectories in a given weather pattern. This is expected to result in improved moisture, temperature, cloud, and precipitation forecasts. Some examples where D3D may aid operational forecasts include significant weather events associated with well-developed cyclones, the onset of summer monsoon and convection in the Desert Southwest, and the development of upslope clouds and precipitation in and near mountainous terrain. Additional case studies and air parcel trajectory visualization methods will be presented at the conference.

5. REFERENCES

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