THREE-DIMENSIONAL VISUALISATIONS OF ATMOSPHERIC JET STREAMS

J. Tenenbaum
State University of New York
Purchase, New York, U.S.A

Summary: General circulation models exhibit systematic errors which have complex relationships in space and time. In this paper we describe a computer graphics technique which can aid in understanding one such problem: wind errors associated with the subtropical jet. Our approach consists of representing both the jet and the forecast errors as three-dimensional solids and presenting a time sequence in the form of a video or film loop.

1. INTRODUCTION

Forecast errors near the subtropical jet seem generic to all general circulation models (Tenenbaum, 1987; Arpe, 1988). One aspect of the problem is the growth of excessive winds above strong initial state jets during the first 5 days of Goddard Laboratory for Atmospheres (GLA) forecasts. The three-dimensional development of the error and its relation to the growth and undulation of individual jet streaks is difficult to follow in two-dimensional contour diagrams.

Other studies have used three-dimensional displays of meteorological phenomena (Grotjahn and Chervin, 1984; Klemp, 1984; Hasler et al., 1984; Hibbard, 1986). Our approach differs in dealing with a quasi-rigid object and in representing both the jet streak and the forecast error as three-dimensional solids. It is made possible in part by the increased power of graphics workstations and improved rendering and lighting algorithms.

2. METHODS

The results presented at this workshop make use of two separate workstations. The first is a Cubicomp PictureMaker system consisting of an IBM AT microcomputer, dedicated display list processor, 16-bit frame buffer, 19-inch color display, and proprietary software. This system, which has extensive interactive capabilities and a range of complex rendering and lighting algorithms, can render a typical frame in 3 min. The second is a Silicon Graphics IRIS 3120 workstation consisting of a Motorola 68020 CPU, 4 Mb of memory, 8 bit planes of display memory, and a series of proprietary graphics engines to transform and render polygon display lists. At present we use it with only the built-in software from Silicon Graphics. The specialized graphics hardware is capable of rendering our solids in real time.

Our results deal with the forecast of a jet streak above the Middle East using the GLA model initialized at 00 UTC on 1 February 1979. Contours of the analysis (40 m/s surface) and forecast error (20 m/s surface) were computed at 10° intervals in longitude from 20° E to 60° E, transmitted to SUNY Purchase, and digitized for the Cubicomp system at 16 points around the analysis or error contour. For the Silicon Graphics system each contour was approximated as an ellipse.

The resulting solids defined by 66 polygons (4 x 16 plus 2 ends) were rendered by the workstations to produce a color version of the black and white images in Fig. 1. In the color images the analyzed jet surface is rendered in white, the forecast errors in red or blue, and the approximate geography in green. Viewer locations include high above the Atlantic (Fig. 1) and low above Siberia (not shown).

Preliminary experimentation showed that 5 longitudinal slices were adequate for the analyzed jet but yielded forecast error polygons which were too non-planar to be accurately rendered. As a result, an additional 8 slices were interpolated at intermediate longitudes, yielding 194 polygons. Since the fine grid GLA model has 2 x 2.5° resolution, interpolation will not be required in subsequent work. The Cubicomp images used Goraud shading and a 12 bit map-mode of color presentation, which exploits only the most elementary capabilities of that system.

3. RESULTS

The video loops presented at the workshop display the subtropical jet at days 0, 2, 4, and 6 (Fig. 1a-d) of the forecast. The synoptic situation included a jet streak over North Africa dividing into a southwesterly and northwesterly branch. The latter pointed toward a downstream streak over Iran. By day 2 the split streak has disappeared, the downstream streak has grown westward toward 20° E, and a large volume of forecast error lies north of and above the jet. A check of that day's FGGE data set shows very few stations reporting upper air winds over Africa.

The major value of our technique is in providing a succinct presentation of the subsequent time development of the forecast error in three dimensions. The volume of forecast error moved eastward and upward directly above the jet streak at day 4 (Fig. 1c), and then expanded significantly while advecting downward and eastward to a position south of the streak at day 6 (Fig. 1d).

The flexibility of our approach is demonstrated by the second segment of the video loop, where the view has been changed from high above the Atlantic to low over Siberia. Errors above the jet are predominantly excess winds with wind directions ranging clockwise from southwesterly to north-westerly. When the image is viewed from the direction of Siberia a second type of error is visible. It involves deficits in the forecast jet streaks occurring below and to the north of the jet. The error volume includes wind directions from northerly clockwise through southerly. This error volume is illustrated in the color video in blue for days 2 and 4 and has disappeared (i.e., no error magnitudes exceeding 20 m/s) by day 6. An anticorrelation between the volumes of excess and deficit wind error is noticeable, an effect which would be much less obvious using traditional two-dimensional contour plots.

The subsequent segments of the video loops are devoted to decreasing the jumpiness of the presentation by rendering intermediate times ("in-betweening" in the nomenclature of computer animation). The next segment uses the "in-betweening" capability of the Cubicomp workstation by expanding the number of images from 3 to 15 for forecast day 2 through day 6. The revised sequence achieves the desired goal of producing a more clear cut definition of the intermediate stages of the error growth.

The final segment of the video loop presents an approximation of a continuous transformation from one synoptic time to the next. This segment was produced using elliptical approximations on the Silicon Graphics workstation. (The approximate approach was due to an incomplete data processing chain from NASA Goddard to the Silicon Graphics rendering routines.) For future work the overall performance of the Silicon Graphics workstation is relevant. It can easily render the 98 polygons (one intermediate interpolation) in the 1/30th of a second allocated to a single frame under the U.S. NTSC television standard.

4. ONGOING WORK

Our continuing meteorological (Tenenbaum, 1988) and graphical work on this project is in several areas. Improvements to the rendering process will include use of 16 bit plane full color images, more complex rendering algorithms (Phong), partial transparency, highlighting, multiple light sources, and approximations to continuous imagery.

A longer term investigation involves one of the possible explanations of systematic errors: the addition of shear-induced gravity waves to the orographic gravity waves already included in the ECMWF and GLA models. While the solids accurately delineate the analyzed jet and forecast error, it would be useful to display additional information indicating the vertical wind shear. Since color is already being utilized (and will be more critical when using more complex lighting and shading models), we must seek another visual cue. One possibility is the computer-graphics technique of texture mapping. This approach would make the analyzed jet appear bumpy in regions of strong shear and smooth in regions of weak shear.

5. CONCLUSIONS

Conclusions about the meteorological situation for the case illustrated are simple: serious problems appear in the combination of data and the GLA first guess forecast for the jet streak over Africa. The result is a large error volume at day 2, a vertical rise at day 4, and downstream growth and advection at day 6.

Conclusions about the utility of the computer graphics technique are more complex. The response of research and operational meteorologists ranged from "If I could push a button and get it, I'd love to use it" to skepticism whether the technique provides insights not obtainable from two-dimensional contour maps. The difficulty with the latter view is that some relationships, while visible after the fact with two-dimensional contour maps, would not initially be noticed.

What is clear is that these still and animated images are unusually effective in presenting one's results, however obtained. General circulation models are inherently four-dimensional (one wants to see the time development). "Fly-throughs" are not needed for the animated sequences though alternate locations for the "viewer" can bring out key aspects of the data. For research use the displayed images should not go beyond the essentials: simple geographical backdrops and other spatial cues. Finally, conference presentations aside, the workstation itself is probably the best output device. Current video technology loses a significant portion of the underlying image quality, and film lacks immediacy.

The still images demonstrate the value of fully rendered solids in presenting the three-dimensional relationship between the forecast errors and the actual jet streak. The video loops are even more powerful in showing the time development of the errors and the space and time correlations between the errors and the underlying flow.

5. ACKNOWLEDGEMENTS

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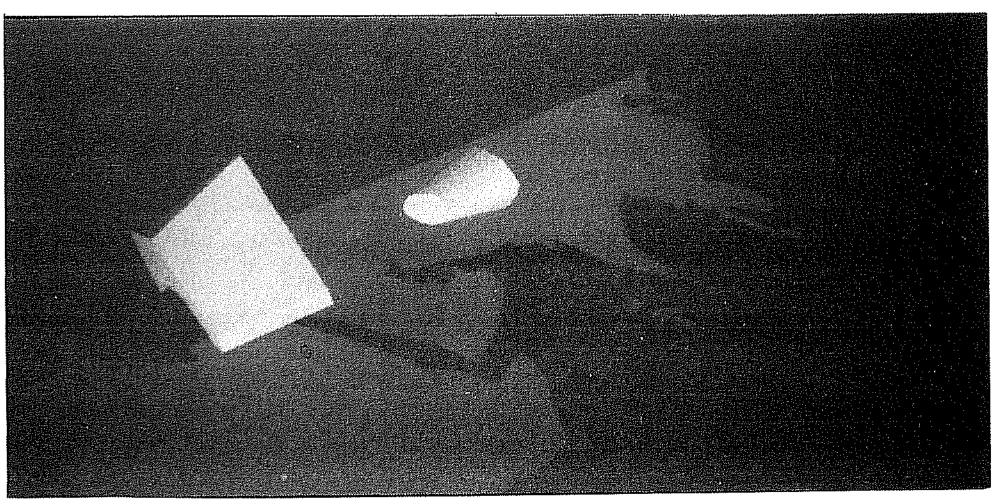
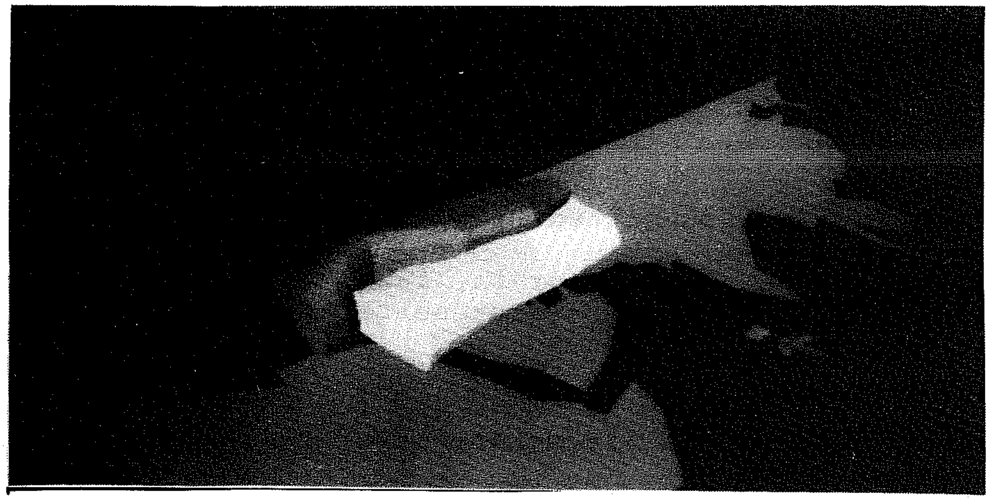
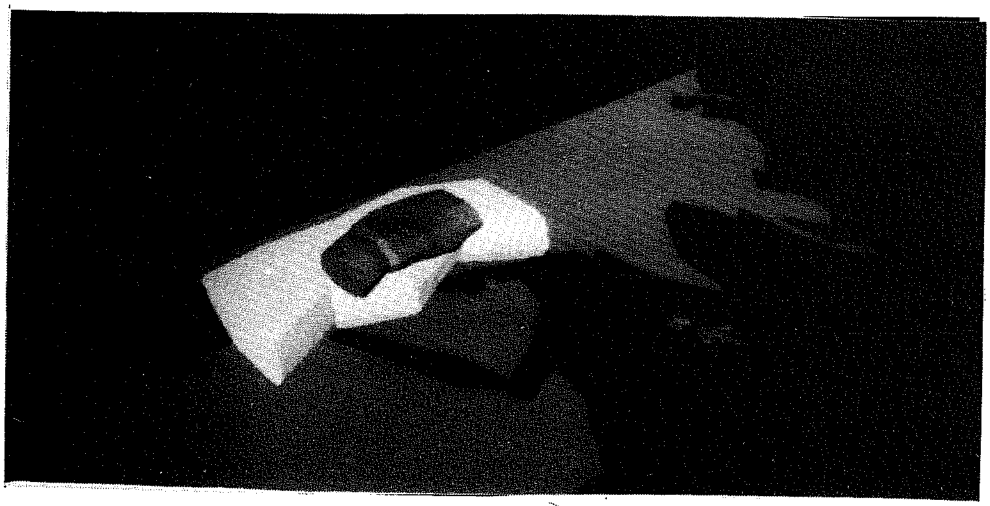
Fig. 1 View looking toward the northeast from high above the Atlantic for a GLA forecast initialized at 00 UTC 1 February 1979. The white solid encloses the volume where the analyzed jet exceeds 40 m/s. The medium gray solid encloses the volume where the westerly forecast error exceeds 20 m/s. The light gray shows the approximate geography.



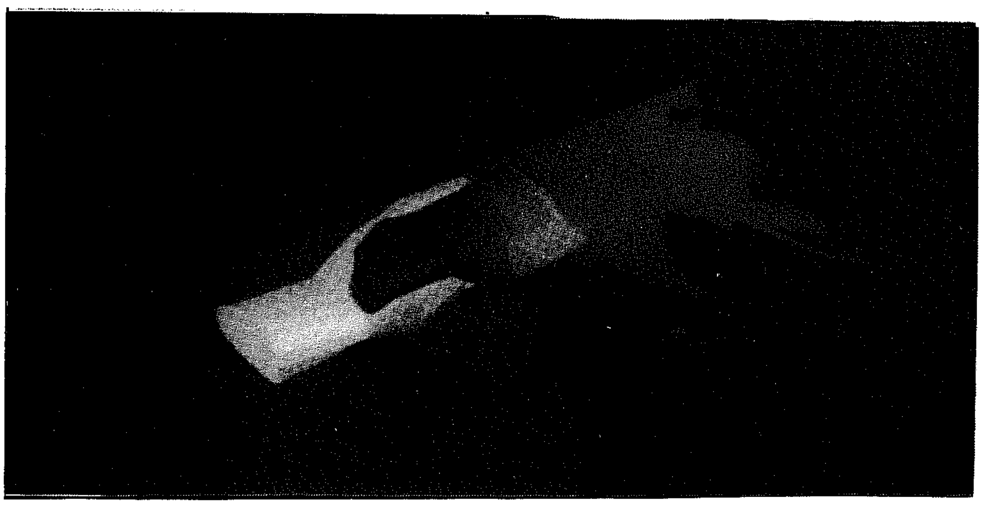
(a) Day 0, 00 UTC 1 February 1979



(b) Day 2, 00 UTC 3 February 1979



(c) Day 4, 00 UTC 5 February 1979



(d) Day 6, 00 UTC 7 February 1979