CARTOGRAPHIC VISUALIZATION IN THE ATMOSPHERIC SCIENCES

James R. Carter, Ph.D.
Geography/Geology Department
Illinois State University
Normal, IL 61790-4400, USA

Abstract

Cartographers are showing a specific interest in scientific visualization consistent with a direction defined as ViSC, Visualization in Scientific Computing. The thrust of this type of visualization for cartography is the map use environment where the user explores data in an interactive and private realm searching for unknowns. This paper examines how the atmospheric sciences employ such visualization tools to make maps consistent with this definition of visualization. Outputs from Global Climate Models and other forms of simulation are the basis for many such map products. The extensive system of weather forecasting requires exploration through visualization at many steps in the process of generating and disseminating forecast results. These examples are built on large masses of data.

There are other situations in the atmospheric sciences where the lack of computer-based data require seeking information from other forms of data. Three examples are cited, including the formulation in 1918 of the behavior of the extratropical cyclone. Consideration is also given to the ways sequences of maps are employed on television to explain unique weather events. Finally, the discussion focuses on some of the computer tools and sources of distribution of data that are unique to the atmospheric sciences.

1 Introduction

As we consider the use of maps in the processes of visualization, attention should be given to the many ways the atmospheric sciences use maps to discover meaningful patterns in the atmosphere and to communicate important spatial information to others. Many persons working in the atmospheric sciences are major users of maps and yet we in the cartographic community give little attention to these map makers and map users. Likewise, those map makers and map users seem to pay little attention to the work of the cartographic community. This paper is an attempt to look at many of the ways maps have been and are being used in the broad realm of the atmospheric sciences -- in meteorology and climatology.

work through the many datasets, in combination with local data, to interactively seek insights on which to base a revised forecast. In the later case, the weathercaster who explores the many datasets, map files, and images will be carrying out that private, interactive task of visualization. And, from that process the weathercaster will prepare graphics for publication in print or for presentation on television.

True visualization in MacEachren's cube [9] requires interactivity and the ability to 'play' with the data. The consistent presentation of satellite imagery and radar imagery on television weather programs should be considered as in an intermediate position in MacEachren's cube between true interactivity and the world of the public presentation of knowns. Often, the weather program presents a radar map or a satellite image map as a loop where 20 to 24 hours of motion are collapsed into a dynamic map showing change in space and intensity over time. Viewers may see this dynamic map iterated through the loop many times. While the weathercaster may reference certain features on these dynamic image maps, I find myself looking at the imagery and making my own analyses while paying no attention to the actions of the weathercaster. I suspect many other viewers do the same thing. Thus, we use the television images as our way to gain access to most current data and as our visualizing tool. Television does not provide an interactive environment where I can play with the data to manipulate images, but it does provide a ready and convenient environment where I can gain considerable insight about immediate trends in the atmospheric environment in which I am living. That immediacy is important.

4 Visualization Where Date Are Lacking

The discussions above concern those situations where data are most abundant and computer-based visualization tools are needed to work through the great quantities of data. However, in many areas in the earth and atmospheric sciences we call on visual representations as a way to gain insight out of very limited data. Before we can model and simulate, we need to gather empirical data to understand basic processes. While these processes may not use interactive computer technology at this stage, the processes are often private and interactive in the search for unknowns. Three examples illustrate cartographic visualization where data are lacking.

The Norwegian School of meteorology under Vilhelm Bjerknes used maps to develop the concept of the extratropical cyclone with its warm and cold fronts, long before the expression 'scientific visualization' became fashionable or possible with our new interactive tools. In a interesting narrative that includes reproductions of many maps and diagrams, Friedman [3] describes the iterative processes by which the meteorologists in 1918 were able to establish a relatively dense data collection network from which they could receive precise information on surface wind directions. Plotting the wind information on maps as streamlines, Jacob Bjerknes started to see zones of convergence and divergence. These sketch maps gave him the insights that led to an understanding to the processes operational in these complex natural systems.

One of the things prompting this paper was a most-interesting map accompanying an exhibit on the effects of Hurricane Iniki on the Island of Kauai, Hawaii. On 11 September 1995 Iniki passed directly over Kauai and severely damaged almost everything, including the forested areas. "Iniki was a very complicated storm accompanied by both mini-swirls and microbursts." [5, map]. The map shows where the dominant impact was from the First Wind or the Second Wind and the locations of the 26 microbursts and two mini-swirls. The basis for this map was interpretation from air photos, 35mm photos, and visitations to selected sites. Certainly, the process of examining these databases to visualize what happened during this exotic weather event deserves to be classified as a significant contribution to cartographic visualization. The work was done in private, interacting with photos of various kinds and scales, searching for insight on unknowns. The map I saw was the product of that effort.

Professor Fujita, whose team produced the Kauai map, is known for his study of tornadoes. In the 1970's he produced two maps of tornado activity in the U.S.A. and Canada. The map of Super Outbreak, [4] deserves mention here because the compilation of this map represents another exercise in visualization from limited data. The map shows the paths of 148 tornadoes that touched down in a 24-hour period on April 3-4, 1974. Segments along each tornado are classified as to their intensity on an ordinal scale. "Immediately after the outbreak, an aerial survey team was organized. Up to five aircraft were used to survey the entire damage area. Unexpectedly, continuous damage paths were found up and down steep slopes, across mountain tops, and through deep gorges." [4] Of course, this map was generated before the world of computer graphics, but the power of the creation of the map lies in the way the data were systematically collected and processed to get a picture of this period of intense tornado activity.

5 Cartographic Visualization for Communication

At the other end of continua articulated by MacEachren [9] is the realm of communication of knowns to the public in an environment where they have no ability to interact with the map data. These presentations take many forms, including the weather map printed in the daily newspaper or posted on a Web page on the Internet. On the other hand many of these maps appear on television mediated by a person interacting with the visual displays. Many of these mediators, or weathercasters, are part of the visualizing process and have spent years gaining insight by interacting with masses of data to put together presentations on screen.

Today, people in the Middle Latitudes expect to be able to turn on a television and see weather maps with their standard array of fronts and cloud patterns. The fact that the public now accepts these map symbols is testimony to those weathercasters who gave visual form to some fairly abstract concepts. Henson [7, p. 6] quotes one weather broadcaster as than any other community. This large production of maps is accounted for in part because of the dynamic nature of the atmosphere and because the behavior of the atmosphere has such immediate impact on so many people. Because these many maps are seen by such large audiences, we owe it to ourselves and to the audiences to contribute to the production, interpretation, and presentation of these maps.

8 References

[1] Carter, James R., 1993, "Weather Maps on Television in the USA," *Proceedings, International Cartographic Conference,* Cologne, Germany, pp. 244-254.

[2] DiBiase, David, 1990, "Visualization in the Earth Sciences," *Earth and Mineral Sciences,* Vol. 59, No. 2, pp. 13-18.

[3] Friedman, Robert Marc, 1989, *Appropriating the Weather: Vilhelm Bjerknes and the Construction of a Modern Meteorology.* Ithica, NY: Cornell University Press.

[4] Fujita, T. Theodore, 1975, *Superoutbreak Tornadoes of April 3-4, 1974.* Chicago, IL: University of Chicago, Departmental of Geophysical Sciences, map separate.

[5] Fujita, T. Theodore, 1992, "Damage Survey of Hurricane Iniki in Kauai," *NOAA: Storm Data,* Vol. 34, No 9, pp. 15-27 and map separate.

[6] Hearnshaw, Hilary M. and David J. Unwin, (eds.), 1994, *Visualization in Geographical Information Systems.* Chichester: John Wiley & Sons

[7] Henson, Robert, 1990, *Television Weathercasting: A History.* Jefferson, North Carolina: McFarland & Company, Inc., 193 pp.

[8] Hibbard, William and David Santek, 1989, "Visualizing Large Data Sets in the Earth Sciences," *Computer,* August, pp. 53-57.

[9] MacEachren, Alan M., 1994, "Visualization in Modern Cartography: Setting the Agenda," in MacEachren, Alan M. and D. R. Fraser Taylor, (eds.), 1994, *Visualization in Modern Cartography.* Oxford: Pergamon Press, pp. 1-12.

[10] MacEachren, Alan M., 1995, Proposed ICA Commission on Visualization. (manuscript)

[11] MacEachren, Alan M. and D. R. Fraser Taylor, (eds.), 1994, *Visualization in Modern Cartography.* Oxford: Pergamon Press, 248 pp.

[12] Max, Nelson, Roger Crawfis, and Dean Williams, 1993, "Visualization for Climate Modeling," *IEEE Computer Graphics and Applications,* July, pp. 34-40.

[13] McCormick, Bruce H., Thomas A. DeFanti, and Maxine D. Brown, (eds.), 1987, "Visualization in Scientific Computing," *Computer Graphics*, 21:6, ACM-SIGGRAPH: New York.

[14] Monmonier, Mark and Alan M. MacEachren, (eds.), 1992, Special Content: Geographic Visualization, *Cartography and Geographic Information Systems*, Vol. 19, No. 4, (Oct. 1992).

[15] NASA, 1992, Data diskette showing Ozone Intensity Levels over Antarctica for 12 Months and a copy of the program NIH Image. (distributed at a conference)

[16] NCAR, 1995, National Center for Atmospheric Research, NCAR Graphics Web Page, http://ngwww,ucar.edu:7777/

[17] Purdue University, 1995, WXP Web Page, http://thunder.atms.purdue.edu/

[18] Rhyne, Theresa, Mark Bolstad, Penny Rheingans, Lynne Petterson, and Walter Shackelford, 1993, "Visualizing Environmental Data at the EPA," *IEEE Computer Graphics and Applications*, March, pp. 34-38.

[19] Schiavone, James A., and Thomas V. Papathomas, 1990, "Visualizing Meteorological Data," *Bulletin, American Meteorological Society*, Vol. 71, No. 7, pp. 1012-1020.

[20] Schröder, Florian, 1993, "Visualizing Meteorological Data for a Lay Audience," *IEEE Computer Graphics and Applications*, September, pp. 12-14.

[21] Skilling, Thomas, 1994, telephone interview by James R. Carter, 12 July 1994.

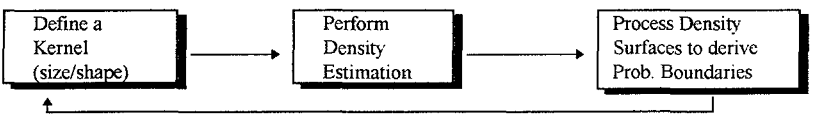
[22] Slocum, Terry A., in collaboration with Marc P. Armstrong, Ian Bishop, John Carron, Jennifer Dungan, Stephen L. Egbert, Loey Knapp, Donna Okazaki, Theresa Marie Rhyne, Demetrius-Kleanthis D. Rokos, Amy J. Ruggles and Chrisotopher R. Weber, 1994, "Visualization Software Tools," in MacEachren, Alan M. and D. R. Fraser Taylor, (eds.), 1994, *Visualization in Modern Cartography*. Oxford: Pergamon Press, pp. 91-122.

[23] SSEC, 1995, Space Science and Engineering Center, SSEC Web Page, http://www.ssec.wisc.edu/

[24] Treinish, Lloyd A., 1992, "Correlative Data Analysis in the Earth Sciences," *Computer Graphics and Applications*, May, pp. 10-12.

defining kernel sizes, we built an interactive environment so that various sizes of kernels can be dynamically defined and simulated at run time.

In our implementation, we first divide the entire study area into a grid. Each location where there is a demand point can be identified with a column number and a row number. Initially, all grid cells are given a value of 0. Kernels are defined and simulated into a smaller grid of frequencies which is overlaid and added to the overall grid at each location of demand points. By placing a kernel at each point location, the overall grid will have a composite frequency surface based on our estimation. For each service center, we construct an overall grid. For examples, two grids are generated for two service centers or four grids are generated for four centers.
Our implement of density estimation includes the following steps:

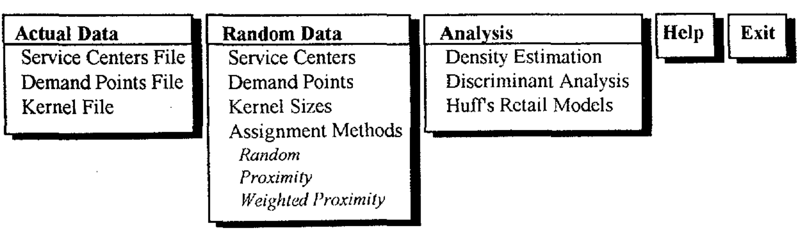


Subsequently, probability densities at each grid cell can be computed by first adding cell values from all constructed grids to obtain a sum. Densities on each surface can then be computed by dividing cell values with this sum. When all grids are processed in this manner, each grid should have probability densities from that location (as demand points) to any service centers.

Finally, boundaries that delineate territorial areas of service centers are identified by setting a threshold as cut-off level. For example in our two-center case, those grid cells whose densities are less than 0.50 are those cells that do not show significant preference towards any of the service centers. With this approach, probabilistic boundaries can be identified as zones, instead of controvertible boundaries of single lines.

THE SHOPPING CENTER EXAMPLE

This section describes an example of applying density estimation in raster GIS environment for detecting spatial patterns of point-based frequency data. We simulate a data set of 200 demand points as potential customers to 2 shopping malls. The implemented system is capable of processing actual data of up to 5,000 demand points and 10 shopping centers in a 300 by 400 grid. The implemented system has an interactive, menu-driven user interface:



Our implementation is able to process actual data if they are arranged in such a way that (1) demand points are listed in a file with three columns: x-coordinate, y-coordinate, service-center-assigned; (2) service centers are listed in a file with three columns: x-coordinate, y-coordinate,

size; and (3) kernels are listed in a file with the first record giving numbers of rows and columns and the actual densities listed in the records afterward.
To fully explore the relationship between kernel sizes and their effect on the identified probabilistic boundaries, we implemented our system to allow simulations of random data in all steps. Figure 3 shows the window that allows us to define number of service centers up to 4. Figure 4 shows an example of simulated kernel.

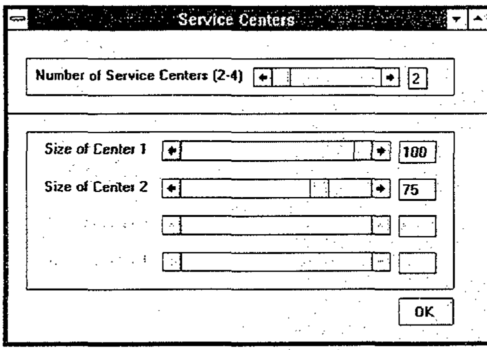


Figure 3: Service Centers window

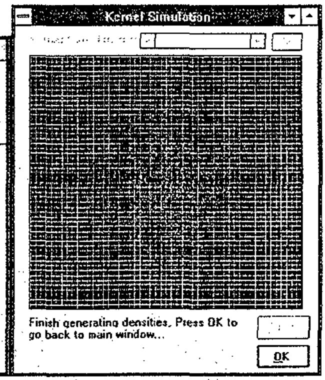


Figure 4: Kernel Simulation Window

Within the implemented system, there are three analyses available for us to analyze the spatial patterns of the input point data set. Discriminant analysis draws a linear boundary between two service centers and calculates mis-classification rate from point data to the constructed territorial areas of service centers. Huff's retail modeling applies sizes of the service centers to draw territorial areas and to compute mis-classification rate. The third procedure is the density estimation method that builds density surfaces, compute probabilistic boundaries, build territorial areas among service centers and compute mis-classification rate.

As a sample run, Figure 5 shows the probabilistic boundaries between the two simulated service centers. The two service centers are set to have sizes of 50 and 100 data units (i.e. number of stores). The demand points are set to be 100 random locations. For the kernel, we specify a kernel will spread over a grid of 50 rows by 50 columns. The entire study region is divided into a grid of 300 rows by 400 columns. The probabilistic boundaries are those cells whose densities toward any of the service centers are less than 50%.

As can be observed in Figure 5, the densities surrounding the service centers are the highest, indicated by the high intensities of black. As locations are distant from the service centers, the intensities of black become weaker and the intensities of the corresponding colors become stronger. The intensity of each service center's color is the strongest along the identified probabilistic boundaries.

CONCLUDING REMARKS

The implementation described in this paper is able to produce probabilistic boundaries among service centers. The method is feasible and the design of the implementation is dynamic in that every step of the analysis can be modified to allow simulation and more detailed exploration. The conversion from point-based data to surfaces is not new but the application of density estimation method provides a new alternative. Most importantly, our example suggests that boundaries delineating geographic phenomena of probabilistic nature can be effectively analyzed and represented cartographically.

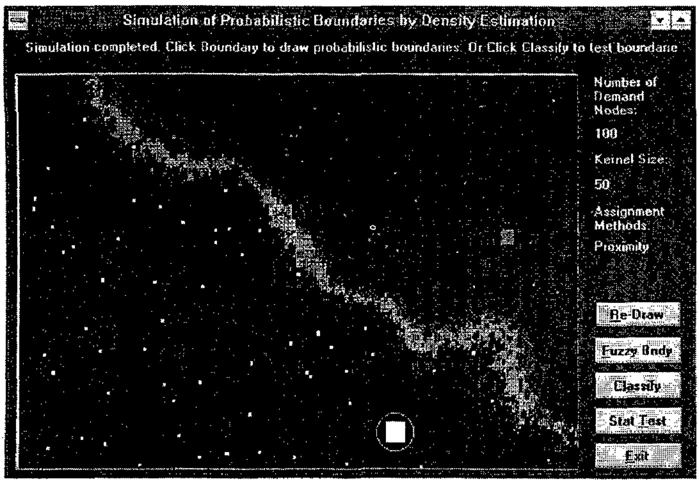


Figure 5: Probabilistic Boundaries Between 2 Service Centers and 100 Demand Points (Simulated)

References

[1] Bithell, J. F. , 1990. "An application of density estimation to geographical epidemiology," *Statistics in Medicine 9*: 691-701.

[2] Brunsdon, C., 1991. "Estimating probability surfaces in GIS: an adaptive technique." In J. Harts, H. F. L. Ottens, and H. J. Scholten (eds), *Proceedings, Second European Conference on Geographical Information Systems*, EGIS Foundation, Utrecht, Netherlands, pp. 155-64.

[3] Gatrell, A., 1994. "Density estimation and the visualization of point patterns." In H. M. Hearnshaw and D. J. Unwin (eds), *Visualization in Geographic Information Systems*. New York: Wiley and Sons, pp. 65-75.

[4] Silverman, B. W., 1986. *Density Estimation for Statistics and Data Analysis*. New York, Chapman and Hall. 175p.

[5] Scott, D. W., 1992. *Multivariate Density Estimation: Theory, Practice, and Visualization*. New York: Wiley & Sons. 317p.