PROJECTING GLOBAL RASTER DATABASES

E. Lynn Usery, Michael P. Finn, Douglas J. Scheidt

U.S. Geological Survey
Rolla, Missouri 65401

Phone: 573-308-3837; Fax: 573-308-3652
usery@usgs.gov; mfinn@usgs.gov; dscheidt@usgs.gov

KEY WORDS Global-Environmental-Databases, Decision Support, Transformation, Accuracy, Cartography, GIS

ABSTRACT

The need for regional and global models for spatially distributed phenomena and processes has driven the development of large raster databases of terrain elevation, population, land cover, vegetation, soils, temperature, and rainfall. The use of commercial geographic information system software to process these databases requires projection from spherical coordinates to plane coordinate systems and transformation from one plane system to another. Recent research has demonstrated that such projection and transformation of raster databases is error-prone and may generate data that corrupt the results from spatial models. This paper presents two approaches to handle the problems of raster database projection and transformation. The first is the development of a Web-based decision support system to aid users with the selection of appropriate projections based on data type, areal extent, location, and properties to be preserved. The second is a dynamic approach to projecting raster databases that adjusts the output pixel size according to the exact area of the corresponding pixel in the spherical coordinate system.

1. INTRODUCTION

Modeling regional and global activities of climatic and human-induced change requires accurate geographic data from which we can develop mathematical and statistical tabulations of attributes and properties of the environment. Many of these models depend on data formatted as raster cells or matrices of pixel values. Recently, it has been demonstrated that regional and global raster datasets are subject to significant error from mathematical projection and that these errors are of such magnitude that model results may be jeopardized (Steinwand *et al.*, 1995; Yang *et al.*, 1996; Usery and Seong, 2001; Seong and Usery, 2001). There is a need to develop methods of projection that maintain the accuracy of these datasets to support regional and global analyses and modeling.

Although recent research indicates that projection problems exist for raster databases at global and regional scales, there is little theoretical background for handling the relationships between the distortions that are due to projection methods. Also, there is little guidance for users of geographic information systems (GIS) and other software packages that offer the capability to project these regional and global raster datasets (Usery *et al*, 2001). In many cases, the software includes many projections, each projection with its own set of parameters and, according to projection theory, with its own particular strengths and appropriate areas of use. With this plethora of

projection choices and the ability to customize each projection, most GIS users do not have the knowledge to select a projection appropriate to the area of the world, data type, or particular problem being examined. Couple these selection problems with the inherent errors found in commercial software packages for projection transformation, many of which were designed for small datasets that span only a few hundred kilometers of the Earth's surface, and the scenario is ripe for error to occur and erroneous model results to be generated. Most users will not know that an error has occurred or that their model, while good, is generating erroneous results because of the inaccurate transformation of data.

2. APPROACH

Our research has been accomplished in three stages: 1) empirical investigation of errors resulting from the projection of regional and global raster datasets, 2) development of a decision support system (DSS) to guide users in the selection of an appropriate projection, including a tutorial, and 3) new projection methods that result in less error when used with large regional and global raster datasets (Usery *et al*., 2001). The empirical investigation has examined 10 different projections and 6 global raster datasets at various resolutions. The results indicate that variances in projection accuracy depend on the projection selected, the type of data (*i.e.*, categorical or continuous), the number and extent of the categories, the resolution of the output dataset, and latitude. Results of this empirical investigation are being used in the second and third stages of our research.

3. THE DSS

In the second stage of our research, we are developing a DSS for selecting an optimum projection considering various factors, such as pixel sizes, areal extent, number of categories, spatial pattern of categories, resampling methods, and error correction methods. The design and implementation is a Web-based

DSS for map projection selection. We designed the DSS for map projections of small-scale datasets. The initial prototype is currently in a test phase. The design includes an interactive interface to solicit information from a user and guide the user to the selection of an appropriate projection (or alternate projections) based on the input (Figure 1).
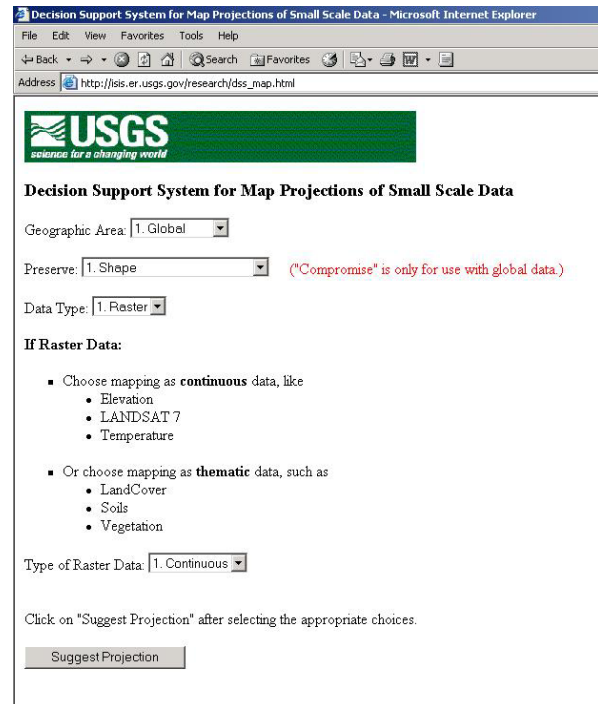

Figure 1. Interactive Interface for DSS.

The DSS poses questions interactively, in which the choice of the user determines the path in a decision tree to drive to a solution. The initial choice is among global, continental, or regional area of coverage. The second important choice is among the preservation of shape or area, or simply a compromise (such as the Robinson projection, which is neither conformal or equal-area, yet has nice visual appeal).

The system handles continents on the basis of their geographic location and directional extent. For example, the DSS handles continents with greater longitudinal range (Asia, Australia, and Europe) differently than those with greater
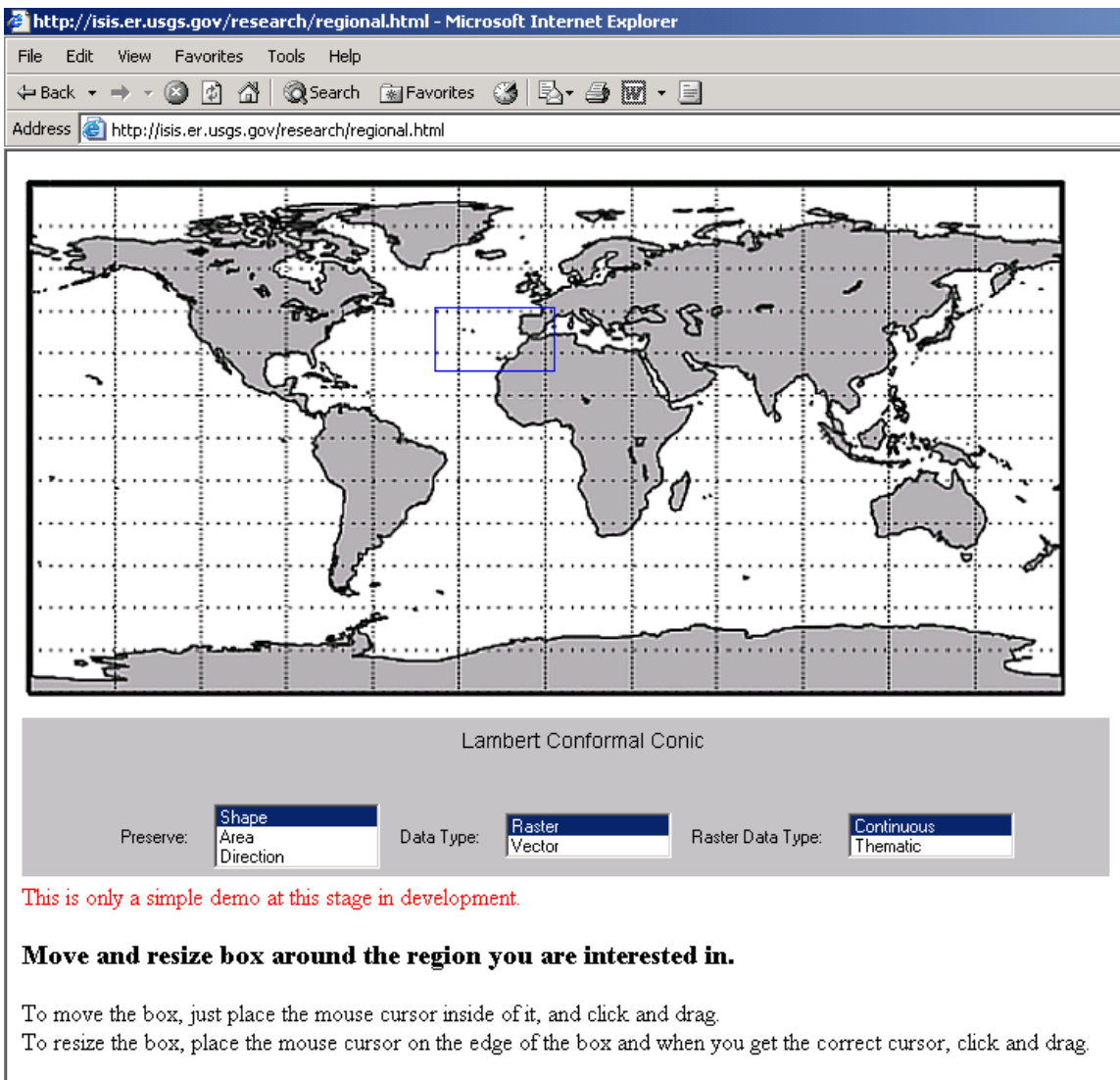
Figure 2. Regional Area Selection Interface.

latitudinal range (Africa, North America, South America) or polar location (Antarctica). For regional cases, the DSS allows the user to interactively define an area of interest. It also recommends a projection in real time. Figure 2 shows the interface for regional area selection.In recommending a map projection for small-scale regional data, the system factors in geographic location and directional extent in addition to the user's choice of conformal or equal-area projection.

Somewhat similar to the design described by Jankowski and Nyerges (1989), further implementation of the DSS will expand the user input to include data type, volume or resolution, and other appropriate options. Refinements planned for the current prototype DSS that will constitute "Version 0" include other choices based on the raster versus vector data model and thematic versus continuous data type. While the DSS relies on conventional theory for the selection of projections (Voxland, 1978; Snyder, 1987; Snyder and Voxland, 1989), the design includes a specific decision tree, which

handles regional and global raster projection. Decisions in this branch of the tree are based on results from our empirical research, which has examined many different projections with a variety of data types. The objective is to develop a "Version Beta 1" DSS that will include an integrated, Web-based map projections tutorial (Usery *et al.*, 2001).

The following describes the system flow of the DSS:

1. A user opens up the Web page in his or her browser.
2. The user selects among choices from the given fields on the Web page.
3. Upon submittal by the user, the DSS sends the responses in the fields to the server.
4. The Common Gateway Interface (CGI) program, written in Perl, processes the responses.
5. On the basis of the data, the CGI will then:
   a. Provide the appropriate projection for GLOBAL data.
   b. Create a new page displaying a clickable image of the world for CONTINENTAL data, then pass the user's choice of continent, along with the user's original responses, to another CGI (that acts much in the same way as the first CGI) and provide the appropriate projection.
   c. Send the user to a page that is running a Java applet that will interactively determine the appropriate projection using the geographic location and directional extent of the REGIONAL area that the user provides.[1]

4. PROJECTING EQUAL AREAS

The third stage of our work is to develop new projection methods for raster data that correct the transformation problems. Our approach includes dynamic projection, error theory models, and new resampling methods. This paper will discuss only the dynamic projection

---

[1]Java is a trademark of Sun Microsystems, Inc.

aspects, but an overview of our entire approach is available in Usery *et al.* (2001).

We are developing a dynamic projection method that adjusts projection methods for latitude on the basis of raster cell size to maintain cell sizes that match in area to the corresponding cells in geographic coordinates. We have computed the exact areas of raster pixels from geographic coordinates to establish a base from which to determine projection accuracies. Using raster cells in spherical coordinates of 1 degree by 1 degree, and also of 30 arc-sec by 30 arc-sec, we implemented a numerical integration procedure to compute exact areas on the Earth's surface at each latitude for these raster cell sizes. The resulting values, 90 for the 1-degree cells, *i.e.*, from 0 to 90 degrees, and 10,800 values for the 30-arc-sec cells, represent actual areas on the Earth's surface (Table 1).

Latitude (B)	1E Cell Size (m^2)	30O Cell Size (m^2)
0	12363671978	858631
15	11970315668	829390
30	10761202175	743627
45	8818730582	607188
60	6275277108	429370
75	3304173896	222291
90	107896706	63

Table 1. Areas of Cells from Sphere

These values have been applied to existing vegetation and land cover datasets to determine the exact areas of coverage of each of the vegetation types and land cover categories (Figure 3). Similar areas for datasets transformed in seven different projections are

being computed and compared with the actual spherical areas. This process provides the extent of error for these seven projections with respect to these two datasets.

The design of a projection procedure to maintain the areas determined in the numerical integration has taken the form of projecting each raster line independently. Using the sinusoidal projection equations as an example,

$$x = R(8 - 8_0) \cos N \qquad (1)$$
$$y = RN \qquad (2)$$

where, N is the latitude,
    8 is the longitude,
    8_0 is the initial longitude,
    R is the Earth's radius, and
    x and y are the plane coordinates,

the procedure involves applying the equations to each of N and 8 for the four corners of the spherical cell to determine corresponding plane coordinates (x,y) (Snyder, 1987; Seong *et al*, 2002). The usual approach for raster data is then to resample all pixels to the same pixel size, thus sacrificing the areas. In our approach, we resample each raster line to the appropriate area determined by the numerical integration procedure and shown for specific latitudes in Table 1. The difficulty of this approach is that it results in a dataset that cannot be seamlessly mosaicked into a single raster image for display because each raster line contains pixels with sizes different from all other lines. This difference in sizes means that the approach works in analytical engines but cannot be used directly to produce a typical raster display (since pixels on different raster lines are of different sizes).
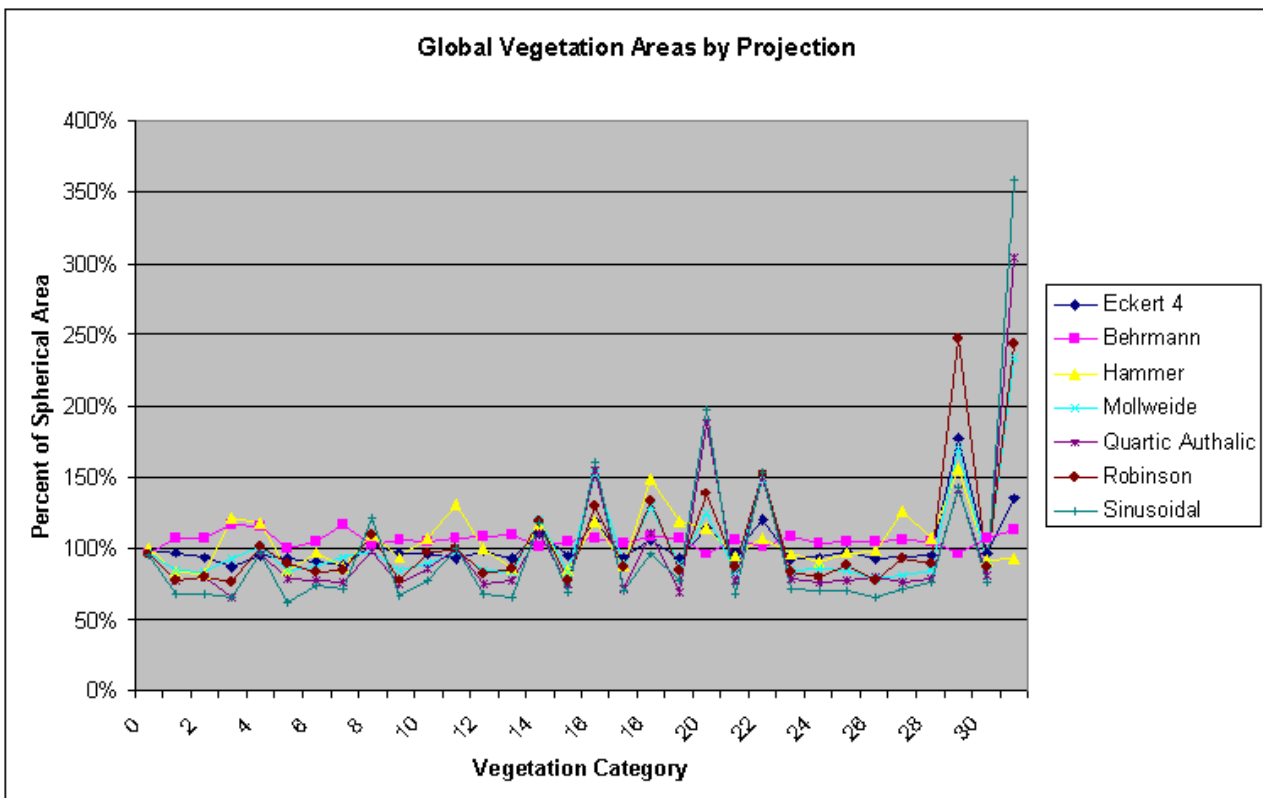

Figure 3. Projected areas compared with spherical surface areas from the global vegetation.

5. CONCLUSIONS

The projection of global raster datasets is a process that can result in considerable error for users unfamiliar with projection theory, implementation, and specific software problems. Our work has implemented a DSS to help users select an appropriate projection on the basis of factors commonly causing problems, including data type, location of regional area, extent direction, and characteristics to be preserved. We have also developed methods to improve accuracies for global raster projection for use with analytical engines. Future work will improve and expand the DSS to include a complete tutorial and examine the capabilities for displaying raster data of varying resolutions.

REFERENCES

Jankowski, P. and Nyerges, T., 1989. Design considerations for MaPKBS- Map Projection Knowledge-Based System. *The American Cartographer*, 16(2), pp. 85-95.

Seong, J.C. and E.L. Usery, 2001. Modeling raster representation accuracy using a scale factor model. *Photogrammetric Engineering and Remote Sensing*, 67(10), pp. 1185-1191.

Seong, J.C., K.A. Mulcahy, and E.L. Usery, 2002. The Sinusoidal Projection: A new meaning for global image data. *The Professional Geographer,* In press.

Snyder, John P., 1987. *Map Projections – A Working Manual*. U.S. Geological Survey Professional Paper 1395. Washington, DC.

Snyder, J.P. and P.M Voxland, 1989. *An Album of Map Projections*. U.S. Geological Survey Professional Paper 1453. Washington, DC.

Steinwand, D.R., J.A Hutchinson, and J.P. Snyder, 1995. Map projections for global and continental data sets and an analysis of pixel distortion caused by reprojection. *Photogrammetric Engineering and Remote Sensing*, 61(12), pp. 1487-1499.

Usery, E.L. and J.C. Seong, 2001. All Equal Area Map Projections are Created Equal, but Some are More Equal than Others. *Cartography and Geographic Information Science,* 28(3), pp. 183-193.

Usery, E.L., J.C. Seong, D. Steinwand, and M.P. Finn, 2001. Methods to achieve accurate projection of regional and global raster databases. *U.S. Geological Survey Open-File Report 01-383.*

Voxland, Philip M., 1978. *World Mapping and Projection Program: Reference Manual*. Regents of the University of Minnesota. Minneapolis, MN.

Yang, L., Z. Zhu, J. Izaurralde, and J. Merchant, 1996. Evaluation of North and South America AVHRR 1-Km data for global environmental modeling. *Third International Symposium on Integrating GIS and Environmental Modeling Proceedings*, Santa Fe, N.M.