TECHNIQUES FOR DEVELOPMENT OF GLOBAL I-KILOMETER DIGITAL ELEVATION MODELS

Dean B. Gesch
Senior Scientist
Hughes STX Corporation*
EROS Data Center
Sioux Falls, South Dakota 57198 USA

Kevin S. Larson**
Consultant
Berger & Co.
2828 Routh Street, Suite 350
Dallas, Texas 75201 USA

ABSTRACT

In response to well documented requirements for regional and continental scale digital elevation models (DEM's), the staff at the U.S. Geological Survey's EROS Data Center is developing global digital elevation data with a horizontal grid spacing of 30-arc seconds (approximately I kilometer). The DEM's are generated from several topographic data sources, each requiring specific processing methodologies and quality assurance procedures. The continent of Africa serves as a representative example for a description of the techniques used in development of the 1-kilometer elevation models. Digital Chart of the World (DCW), a vector cartographic data set based on the 1: 1,000,000 Operational Navigation Charts, was the source data for roughly one-half of the Africa DEM. The hypsography, drainage, and coastline data from the DCW were processed with a surface gridding program. The other half of the Africa DEM was generated from information derived from Digital Terrain Elevation Data (I)TED), a raster topographic data base with a horizontal grid spacing of 3-arc seconds (approximately 90 meters) produced by the Defense Mapping Agency. The DTED data were generalized to 30-arc seconds with a scheme that retains the topographic breaklines (streams and ridges) from the full resolution data in the reduced resolution representation. Because of differences in topographic detail and accuracy along the irregular boundary between the two data sources, the merging procedure included blending techniques to minimize the discrepancies. The resulting DEM has an absolute vertical accuracy of better than 100 meters (root mean square error).

INTRODUCTION

Digital elevation data are an important source of information in studies of land surface processes. Medium resolution topographic data, with a horizontal grid spacing up to I kilometer, have many applications such as continental-scale land characterization, climate modeling, large area hydrologic studies, and geometric and atmospheric correction of medium and coarse resolution satellite image data. Although the requirements for digital elevation data are well known and have been documented (Topographic Science Working Group, 1988; Guindon, 1993; Gesch, 1994), complete global coverage of digital elevation models (DEM's) with a resolution of I kilometer has been unavailable. In response to the stated needs of the geospatial data user community, staff members at the U.S. Geological Survey's EROS Data Center are developing global digital elevation data with a horizontal grid spacing of 30-arc seconds (approximately I kilometer). Previously, the best available global DEM was the ETOPO5 data set with a horizontal grid spacing of 5-arc minutes (approximately 10 kilometers).

Development of 1-kilometer DEM's has created unique challenges in the area of spatial data processing techniques. The DEM's are generated from several topographic data sources, each requiring specific processing methodologies and quality assurance procedures. The large volume of input data, and the significant computer resources required, demand that efficient production procedures be implemented. For this paper, the continent of Africa serves as a representative example for a description of the techniques used in development of the 1-kilometer elevation models.

---

* Work performed under U.S. Geological Survey contract 1434-92-C-40004.
** Work performed as an employee of the U.S. Geological Survey.

DATA SOURCES

The global 1 -kilometer DEM's are based primarily on data derived from two sources: Digital Chart of the World (DCW) and Digital Terrain Elevation Data (DTED). Additional sources have been used for areas where DCW and DTED are not available. More than 65 percent of the global land surface is covered by DTED, with coverage concentrated in the northern hemisphere. Consequently, the portions derived from DTED for the North America, Europe, and Asia I -kilometer DEM's are much more than for Africa. Approximately 56 percent of the Africa DEM is based on DTED, while the remaining 44 percent is based on DCW.

Digital Chart of the World

DCW is a vector cartographic data set based on the 1: 1,000,000-scale Operational Navigation Chart (ONC) series, which is the largest scale base map source with global coverage (Danko, 1992). The DCW and the ONC series are products of the Defense Mapping Agency (DMA).

The topographic information of interest for generating DEM's is contained in several DCW hypsography layers. The primary contour interval on the source ONC's is 1,000 feet (305 meters), and supplemental contours at an interval of 250 feet (76 meters) are shown in areas below 1,000 feet in elevation. The DCW drainage layers were also used as input to the DEM generation process; this information included stream networks, lake shorelines, lake elevations, and ocean coastlines.

Digital Terrain Elevation Data

DTED, also a DMA product, is a raster topographic data base with a horizontal grid spacing of 3-arc seconds (approximately 90 meters). Access to full resolution DTED for areas outside the United States is limited to agencies of the U.S. Government, but permission has been granted by DMA to the EROS Data Center to use and distribute a generalized 30-arc second version.

DATA PROCESSING

Data processing was accomplished using commercially available geographic information system software, vector-to-raster gridding software, and utilities developed specifically for this project. To more efficiently handle the numerous input data sets and to standardize the proper sequence of processing steps, the production procedures were automated to a great extent by employing preset parameter values, scripted command files, and consistent naming schemes for input and output data files.

DTED Generalization

The 3-arc second DTED were generalized to 30-arc seconds by selecting one elevation value to represent the area covered by 100 full resolution grid cells (a 10 by 10 matrix). There are several options for aggregating the 100 full resolution grid cells into I generalized, reduced resolution grid cell. A statistical approach uses a representative statistic such as mean or median of the 100 full resolution cells. Such an approach is ideal for low relief areas, but significant smoothing of features can occur in high relief areas. A resampling approach uses a geometric transformation to accomplish resolution reduction. Nearest neighbor and bilinear resampling are often used for raster elevation data. With the degree of generalization for the Africa DTED (100 cells to I cell), only 1, or a few, full resolution cells are sampled to calculate each generalized elevation, so there is a good chance that prominent topographic features may not be represented.

The Africa DTED were generalized with an approach that emphasizes the topographic breaklines (ridges and stream channels) as found in the full resolution data. The goal is to retain as much of the significant topographic information as possible in the generalized DEM. The breakline emphasis approach is similar to the concepts of the structure line model of generalization described by Weibel (1992).

Topographic breaklines were extracted directly from the full resolution DTED with the widely used methods described by Jenson and Domingue (1988). Based on the location of the breaklines, generalized grid cells were classified as either "ridge" or "stream" cells. Ridge cells retained the maximum value of the corresponding full resolution elevation values, while stream cells received the minimum elevation from the area of corresponding full resolution cells. In this manner, the significant topographic structure lines are preserved in the generalized data. Reduced resolution cells that do not contain breaklines were simply assigned a representative elevation value based on a nearest neighbor resampling of the full resolution DTED.

DCW Preparation and Gridding

The topographic information from the DCW was converted into an elevation grid through a vector-to-raster gridding approach. The hypsography, drainage, and coastline data were input to the ANUDEM surface gridding program developed at the

Australian National University (Hutchinson, 1989). ANUDEM, specifically designed for creating DEM's from digital contour, spot height, and stream line data, employs an approach known as drainage enforcement to produce raster elevation models that represent more closely the actual terrain surface and contain fewer artifacts than those produced with more general purpose surface interpolation routines. However, in order to prepare and format the DCW for input to ANUDEM a significant amount of preprocessing was required. This processing included editing and updating the vector stream lines so that the direction of each was oriented downstream (a requirement of ANUDEM). Further preprocessing involved detection and correction of erroneous contour and point elevations (Larson, 1996).

Ocean coastlines were assigned an elevation of zero for input as contours. Also, shorelines of lakes for which the DCW included elevations were tagged and used as contour input. Additional point control was input into the DCW gridding process in an effort to minimize the discrepancies along the border between the DCW and DTED. Points derived from generalized DTED within a I -degree buffer surrounding the DCW areas were input to ANUDEM so that the 30-arc second grids from the two sources would better match in the overlap area.

The output from ANUDEM was an elevation model grid referenced in the same horizontal coordinate system as the generalized DTED. The output grid spacing of 30-arc seconds has been shown to be appropriate for the information content present in the DCW hypsography layers (Hutchinson, 1996; Shih and Chiu, 1996).

DEM Merge

Prior to merging with the generalized DTED, several postprocessing steps were performed on the DCW grid. Lakes for which the DCW did not indicate an elevation were updated on the grid with the lowest grid cell elevation found along the shoreline. Also, an artifact of the surface interpolation process in areas just inland from the ocean coastline was detected and corrected. In these areas ANUDEM produced anomalous below sea level elevation values. Any grid cell that did not coincide with the DCW polygons that denote real below sea level areas was remapped to an elevation above sea level.

Merging of the generalized DTED and the DCW grid to produce the Africa DEM was accomplished by mosaicking the two data sets. The generalized DTED had the highest priority so that coverage of the source with the greater topographic detail and accuracy was maximized. The DCW grid filled in the areas of the African continent not covered by DTED. The merging procedure included blending of the two data sources along the irregular boundary to minimize the differences and smooth the transition. The blending was performed in an overlap area of I degree (120 grid cells) surrounding the DTED areas. The blending algorithm computes a weighted average with the weights for each data source determined on a cell-by-cell basis according to the cell's proximity to the edges of the overlap area (Franke, 1982.)

The final processing step performed on the mosaicked and blended product involved "clipping out" the land (as defined by the DCW coastline) and setting the ocean areas to a constant background value. The horizontal coordinate system of the final Africa DEM is decimal degrees of latitude and longitude referenced to WGS84, and the vertical units represent elevation in meters above mean sea level.

ACCURACY ASSESSMENT

The absolute vertical accuracy of the Africa DEM varies by location according to the source data. Generally, the areas derived from DTED have a higher accuracy than those derived from the DCW. The full resolution 3-arc second DTED have a vertical accuracy of ± 30 meters linear error at the 90 percent confidence level (Defense Mapping Agency, 1986). If the error distribution is assumed to be Gaussian with a mean of zero, the statistical standard deviation of the errors is equivalent to the root mean square error (RMSE). Under those assumptions, vertical accuracy expressed as ± 30 meters linear error at 90 percent can also be described as a RMSE of 18 meters. The areas of the Africa DEM derived from DTED retain that same level of accuracy because through generalization an actual elevation value from one full resolution DTED cell is chosen to represent the area of the reduced resolution cell (although the area on the ground represented by that one elevation value is now much larger than the area covered by the full resolution cell).

To characterize the accuracy of the areas of the Africa DEM derived from the DCW, the DCW grid was compared to 30-arc second DTED, which had been aggregated by averaging. By aggregating, the comparison could be done at the 30-arc second cell size of the DCW grid. Eliminated from the comparison were those areas of the DCW grid for which supplemental DTED point control had been included in the gridding process. If the averaged DTED are thought of as the reference data set, the RMSE of the DCW grid is 95 meters. To get an idea of the overall absolute accuracy of the DCW grid, the relative error between the DCW and DTED can be combined with the known error of the DTED itself in a sum of squares. The root of that sum of squares is 97 meters. Using the assumptions about the error distribution cited above, a RMSE of 97 meters can be expressed as ± 162 meters linear error at 90 percent confidence. This number compares favorably with an expected vertical accuracy (linear error at 90 percent) of one-half of the primary contour interval of 1,000 feet (305 meters) for the topographic maps on which the DCW is based.

SUMMARY

A digital elevation model of Africa at a 30-arc second horizontal grid spacing was produced by incorporating the elevation data derived from two sources, one was a vector source (DCW) and the other a raster source (DTED). The goal of the processing techniques that were implemented was to maximize the amount of topographic information that could be derived from each source. The resulting digital elevation grid, with an absolute vertical accuracy of better than 100 meters RMSE, provides new topographic data with a level of detail and accuracy suitable for many regional and continental applications, such as extraction of drainage features for hydrologic modeling (Danielson, 1996; Verdin and Jenson, 1996). The techniques developed and implemented for production of the Africa DEM have been extended to expedite completion of 1-kilometer DEM's for the other continents.

ACKNOWLEDGEMENTS

The authors express their thanks to the staff members of the Digital Data Production section at the EROS Data Center in recognition of their conscientious and successful efforts on the often tedious task of editing the DCW drainage data.

REFERENCES

Danielson, J.J., 1996. Delineation of drainage basins from I km African digital elevation data. In: Pecora 13 Symposium, Human Interactions with the Environment: Perspectives from Space, Sioux Falls, South Dakota, August 1996, Proceedings. American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland (in press).

Danko, D.M., 1992. The digital chart of the world. Geolnfo Systems, 2:29-36.

Defense Mapping Agency, 1986. Defense Mapping Agency product specifications for digital terrain elevation data (DTED) (2d ed.). Defense Mapping Agency Aerospace Center, St. Louis, Missouri, 26 p.

Franke, R., 1982. Smooth interpolation of scattered data by local thin plate splines. Computing & Mathematics with Applications, 8:273-281.

Gesch, D.B., 1994. Topographic data requirements for EOS global change research. U.S. Geological Survey Open-File Report 94-626, 60 p.

Guindon, B., 1993. Aspects of digital elevation data requirements for operational geocoding of RADARSAT imagery. Canadian Journal of Remote Sensing, 19:131-139.

Hutchinson, M.F., 1989. A new procedure for gridding elevation and stream line data with automatic removal of spurious pits. Journal of Hydrology, 106:211-232.

Hutchinson, M.F., 1996. A locally adaptive approach to the interpolation of digital elevation models. In: Proceedings, Third International Conference/Workshop on Integrating GIS and Environmental Modeling, Santa Fe, New Mexico, January 21-26, 1996. National Center for Geographic Information and Analysis, Santa Barbara, California. http://www.ncgia.ucsb.edu/conf /SANTA-FE-CD-ROM/main.html

Jenson, S.K., and Domingue, J.O., 1988. Extracting topographic structure from digital elevation data for geographic infon-nation system analysis. Photogrammetric Engineering and Remote Sensing, 54:1593-1600.

Larson, K.S., 1996. Error detection and correction of hypsography layers. In: Proceedings, Sixteenth Annual ESRI User Conference, May 20-24, 1996. Environmental Systems Research Institute, Inc., Redlands, California. http:Hwww.esri.com/ resources/userconf/proc96/WELCOME.HTM

Shih, T.Y., and Chiu, Y.C., 1996. On the quality of DCW hypsographic data, a study for Taiwan. In: Technical Papers, ASPRS/ACSM Annual Convention and Exhibition, April 22-25, 1996, Baltimore, Maryland. American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland, Volume III, p. 248-257.

Topographic Science Working Group, 1988. Topographic science working group report to the Land Processes Branch, Earth Science and Applications Division, NASA Headquarters. Lunar and Planetary Institute, Houston, Texas, 64 p.

Verdin, K.L., and Jenson, S.K., 1996. Development of continental scale digital elevation models and extraction of hydrographic features. In: Proceedings, Third International Conference/Workshop on Integrating GIS and Environmental Modeling, Santa Fe, New Mexico, January 21-26, 1996. National Center for Geographic Information and Analysis, Santa Barbara, California. http://www.ncgia.ucsb.edu/conf /SANTA_FE_CD_ROM/main.htmI

Weibel, R., 1992. Models and experiments for adaptive computer-assisted terrain generalization. Cartography and Geographic Information Systems, 19:133-153.