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New Land Surface Digital Elevation Model Covers the Earth

Land surface elevation around the world is reaching new heights—as far as its description and measurement goes. A new global digital elevation model (DEM) is being cited as a significant improvement in the quality of to pographic data available for Earth science studies.

Land surface elevation is one of the Earth's most fundamental geophysical properties, but the accuracy and detail with which it has been measured and described globally have been insufficient for many large-area studies. The new model, developed at the U.S. Geological Survey's (USGS) EROS Data Center (EDC), has changed all that.

Elevations in the new model are spaced only 30 arc sec apart (about 1 km) compared to 5 arc min apart (about 10 km) in the best previous model, ETOPO5 [*National Geophysical Data Center*, 1988]. Scientists are now recognizing the advantages of the new model, GTOPO30 (Figure 1), and using it in numerous application areas.

The *Topographic Science Working Group* [1988] has thoroughly documented the general scientific requirements for topographic data, and scientific literature is rife with applications of such data in digital form. With increasing emphasis in global change research on studying the Earth as an integrated system and the corresponding implementation of global remote sensing and monitoring programs, such as NASA's Earth Observing System (EOS), the need for better data sets has been clearly evident. EDC first of all geared up to meet the requirements of the EOS program for topographic data used in radiometric and geometric correction of terrain effects on satellite sensor data. At the same time, the data set supplies researchers with regional and continental elevation data needed for investigations of the Earth's surface and atmospheric processes. These investigations include climate modeling, hydrologic modeling, and land cover mapping.

The developers wanted a data set that would be free of any use or redistribution restrictions and still provide the best available data with effective documentation for scientific use. The new model, developed over a 3-year period, does just that. A collaborative effort of several national and international organizations, the new DEM represents a vast improvement in the availability of basic Earth science information, yet is free of any licensing restrictions, royalties, or copyrights. To carry through on the goal of improved availability, EDC is distributing the data set by means of the World Wide Web, where users can easily download it free of charge.

Developing the New Model

Because no consistent source data set with global coverage exists, eight different sources of topographic information were processed to derive elevation values on a regularly spaced 30-arc-sec grid. The spacing was chosen to meet specific requirements for EOS image product generation [*Jet Propulsion Laboratory*, 1997]. Nearly 80% of the Earth's land area was covered by two sources, Digital Terrain Elevation Data (DTED) and the Digital Chart of the World (DCW), both products of the National Imagery and Mapping Agency (NIMA).

DTED has elevations spaced at 3-arc-sec intervals (approximately 100 m). The full-resolution DTED served as the primary source and was aggregated to the 30-arc-sec spacing of GTOPO30. The DCW served as the secondary data source to fill areas unavailable in DTED. The DCW is a cartographic data base that includes all the information present in a 1:1,000,000-scale topographic map series. Its topographic data—elevation contours, spot heights, drainage features, and ocean coastlines—were used in a contour-to-grid interpolation approach to generate elevation values.

Interpolation was performed using the Australian National University digital elevation model (ANUDEM) gridding package developed by *Hutchinson* [1989] and specifically designed for creating DEMs from digital contour, spot height, and streamline data. It uses an approach known as drainage enforcement to produce gridded elevation models that represent more closely the actual terrain surface and contain fewer artifacts than those produced with more general purpose surface generation routines.

Elevation values for land areas not covered by DTED or DCW were obtained by processing other small-scale digital cartographic data sets or medium-resolution national DEMs. Image mosaic techniques were used to merge data from the different sources. Blending (weighted averaging) was performed in transition areas between sources to minimize elevation differences.

Further details on the source data sets (including links to online product descriptions) and processing techniques used to generate GTOPO30 [*Gesch and Larson*, 1998] are in the data set documentation. A digital source map provided with the elevation data in GTOPO30 identifies the source used to derive the elevation for every grid cell in the DEM. The end result of all the processing is a global grid of elevation values (21,600 rows by 43,200 columns) in which locations are referenced horizontally in decimal degrees of latitude and longitude to the World Geodetic System 1984 datum. Elevation values are expressed in meters and are referenced vertically to mean sea level.

Data Quality

GTOPO30 is a significant improvement over previous models, but data quality does vary spatially within the model because of the different sources. The highest quality source data were given priority, but the topographic information content varies by location. This may have no effect on many applications, but it may be a limiting factor in others, especially those sensitive to very local topographic variation. The data set documentation will help a user decide if GTOPO30 data are suitable for a specific use.

The absolute vertical accuracy of elevations in GTOPO30 also varies according to the source data. Generally, elevations derived from the aggregation of higher resolution DEMs have the best vertical accuracy. The accuracy of elevations derived from the interpolation of digitized contour data is controlled by the contour interval of the original maps and the quality of the surface interpolation. Documentation with the model provides details about the stated accuracy of each source data set and tells how those numbers are used to estimate GTOPO30 accuracy.

A recent accuracy assessment of GTOPO30 used Shuttle Laser Altimeter (SLA) data as a highly accurate, independent reference [*Gesch*, 1998]. The SLA elevation measurements are excellent for this because they show a vertical root mean square error (RMSE) of less than 3 m when compared with precise sea surface height data (derived from radar altimetry), including adjustment for tides. A comparison with nearly 365,000 SLA point elevations showed an overall vertical accuracy of 70 m (RMSE) for GTOPO30. The relative vertical accuracy, or local point-to-point accuracy on the surface of the elevation model, determines the quality of slope, aspect, and other landform descriptors calculated by analyzing local elevation differences. Although it has not been specified for GTOPO30, the relative vertical accuracy of DEMs is often much better than the stated absolute vertical accuracy.

Geographic projection of GTOPO30 will be suitable for many uses, but for other applications the DEM should first be transformed to an equal-area map projection. This is especially true for any application that measures the area of, or distance across, a group of DEM grid cells. In the native geographic coordinate sys-

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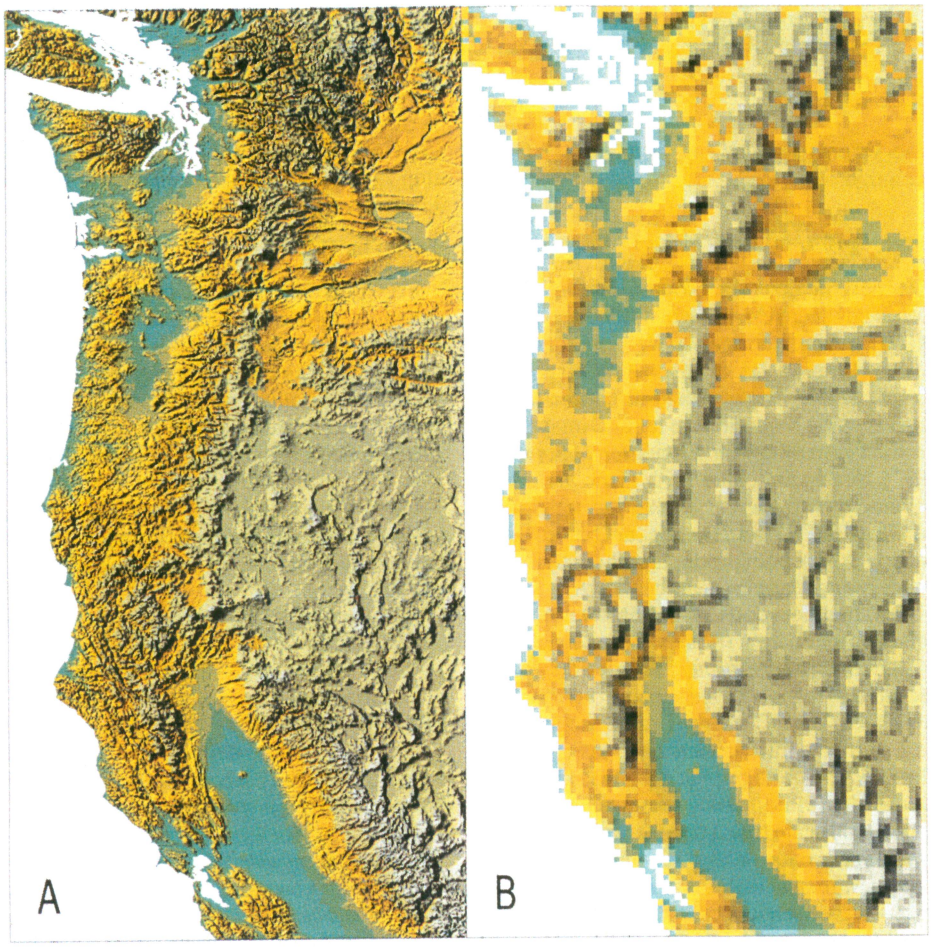

Fig. 1. Example of the increased topographic resolution of a) GTOPO30 over that of b) ETOPO5, previously the best available. The image covers the western U.S. region, from Puget Sound in the north to San Francisco Bay in the south.

tem of GTOPO30, the ground distance of 30 arc sec varies with latitude. Thus the north-south dimension of a grid cell stays almost constant at about 930 m as latitude increases, but because of the convergence of meridians toward the poles, the east-west cell dimension decreases from about 930 m at the equator to about 130 m at 82° latitude. Derivative products, such as slope gradients and lengths, drainage basin areas, and stream channel lengths, will be more reliable if they are calculated from GTOPO30 data first projected to an equal-area grid so that each grid cell, regardless of latitude, represents the same area as every other cell.

Distributing the Data

GTOPO30 is distributed through the EDC Distributed Active Archive Center, part of the EOS Data and Information System. The data set and accompanying documentation are at http://edcwww.cr.usgs.gov/landdaac/gtopo30/gtopo30.html. As a global grid, the entire GTOPO30 DEM has a size of about 1.8 Gb, too large for effective electronic transfer. To facilitate electronic distribution, GTOPO30 has been partitioned into 33 tiles and compressed, with the size of a compressed tile averaging about 8 Mb. The geographic extent of an individual tile was a compromise between file size and the number of files that would have to be handled for a continental or larger area. The files for each tile are in a simple binary image format that can be easily imported into many popular geographic information system and image processing packages.

At the GTOPO30 Web site, tiles can be selected from a global map, and preview images are provided for the data contained in each tile. Also at the site, a user can view a map of the source data coverage and examine the detailed data set documentation, which includes many links to information on sources, processing software, collaborators' sites, and reference literature. As an alternative to downloading GTOPO30 data, a user can place an order for CD-ROM copies using an electronic form on the Web site. The site also has links to sites that document the use of GTOPO30 in various applications, including visualization, hydrologic modeling [*Verdin*, 1997], land cover characterization, geoid modeling, and synthetic aperture radar data processing [*Seymour and Cumming*, 1998].

Future Directions

Several enhancements are planned for GTOPO30. Since the completion of the global data set, new source data have become available that may be useful for upgrading the quality of some areas, and they are being evaluated for possible inclusion. High-quality DEMs for Greenland and Antarctica have been derived from ERS-1 radar altimeter data [*Bamber et al.*, 1997]. Also, the Australian Surveying and Land Information Group has produced a DEM with 9-arc-sec grid spacing (approximately 250 m) based on large-scale topographic maps covering Australia. Inclusion of this DEM in GTOPO30 would provide a significant upgrade for that continent. Additionally, since GTOPO30 was completed, new DTED have been produced over South America, representing a 30% increase in DTED coverage there. Much of it falls within the low-relief Amazon basin, where use of the 3-arc-sec source would result in improved 30-arc-sec data.

Further accuracy assessment of GTOPO30 also will be done. A second flight with the SLA resulted in an enhanced reference data set of terrain elevations with much better spatial distribution of points than the first flight provided. The next stage of publicly available, high-quality topographic data will be realized when near-global coverage (±60° latitude) of 3-arc-sec DEMs becomes available within 2 years after the late-1999 flight of the Shuttle Radar Topography Mission (SRTM), a joint NASA-NIMA project (information on SRTM is available at http://www-radar.jpl.nasa.gov/srtm/).

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