Development & Assessment of the Global Land One-km Base Elevation Digital Elevation Model (GLOBE)

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Abstract

The Global Land One-kilometer Base Elevation (GLOBE) digital elevation model is the most thoroughly designed, reviewed, and documented global digital elevation dataset to date. GLOBE was developed by an international group of specialists, cooperating with the Committee on Earth Observation Satellites (CEOS) Working Group on Information Systems and Services (WGISS), International Geosphere-Biosphere Programme's Data and Information System (IGBP-DIS), and IGBP Working Group IV/6. GLOBE comprises a global 30 arc-second latitude-longitude array, with land areas populated with integer elevation data. GLOBE is available on the World Wide Web, and on CD-ROM in a format convenient for image processing and raster geographic information systems (GIS). Full GLOBE documentation is available on the CD-ROM and Website. This paper summarizes some findings made during GLOBE's development.

1. Objectives and Design of GLOBE

When GLOBE was conceived almost a decade ago, the definitive global digital elevation model was ETOPO5, managed by the National Centers for Environmental Information (NCEI). ETOPO5 is a mosaic of the Digital Bathymetric Data Base 5 global bathymetric model (derived by interpolating elevation contours derived from several million point soundings), TERDAT (a 10-minute gridded global DEM) and selected regional 5-minute DEMs. TerrainBase (Row and Hastings, 1994, Row and others, 1995) was being designed with more 5-minute data output from a collection of co-registered grids of various resolutions corresponding to those of original data sources.

GLOBE's objective was to open an empty two-dimensional latitude-longitude 30 arc-second computer array, then populate it with the best available data that could be distributed with minimal restrictions. In addition, a completely unrestricted version of GLOBE was envisaged. It would do this by opening several two-dimensional arrays with gridding corresponding to available source materials, prioritizing source data by quality, developing blending methods where appropriate, then mosaicking and documenting the best possible grid as GLOBE Version 1.0. All actions in developing GLOBE were reviewed and approved by the GLOBE Task Team of CEOS-WGISS, with participation by IGBP-DIS and ISPRS Working Group IV/6.

2. Sources and Adaptation Methods

Originally, GLOBE sources were divided into two categories, in two different ways:

2.1 Raster vs. Vector Source Data

- **Raster Data Sources:** Though DEMs can include point elevations, digitized vector contours, and raster grids, most current DEMs are in raster format. With the exception of raster DEMs from the USA, the GLOBE project was not optimistic about receiving many raster DEMs, due to traditional copyright and security restrictions imposed by most traditional makers of such data.

- **Vector Data Sources:** The U. S. Defense Mapping Agency (DMA, now the National Imagery and Mapping Agency, NIMA) designed and released the Digital Chart of the World (DCW) in 1992. DCW included digitized contour lines and selected point elevations for much of its global coverage. The U. S. Geological Survey and University College London designed techniques for converting these data to 30" grids using techniques similar to those discussed by Hutchinson (1996). Originally, these were the main hope for improved data coverage in GLOBE.

2.2 Resolution Higher or Lower than GLOBE's

- **Source Resolution at 30" or Better:** Most raster DEMs fit this category. At GLOBE's inception, available data included USGS and NGDC data for the USA, and data for Italy contributed by the Servizio Geologico Nazionale of Italy to TerrainBase. Other DEMs were considered essential, but difficult to obtain for GLOBE.

- **Source Resolution Less Than 30":** DCW was considered slightly worse than 30", but close enough to serve well where better data were lacking. In the absence of better data, sources for ETOPO5 or TerrainBase could complete global coverage.

2.3 Creative Arrangements With Data Sources

Fortunately, several major producers of raster DEMs were willing to negotiate varying types of contributions to GLOBE:

- The Defense Mapping Agency and GLOBE jointly designed a prototype 30" extraction from its 3" Digital Terrain Elevation Data, which eventually became its publicly distributed DTED Level 0. This pioneering data set offers "maximum," "minimum," mean and spot elevation values for each included 30" grid cell. It covers over half of the Earth's land surface. Although GLOBE quality review found problems (see section 3.2 below) with DTED Level 0 "minimum" and mean values, the other two parameters are important for users of GLOBE.

- The Australian Surveying and Land Information Group offered to let NGDC produce a 30" grid from AUSLIG's large point elevation database. The resultant grid would still be copyright by AUSLIG, but licensed to NCEI for distribution with GLOBE.

- The Geographical Survey Institute of Japan designed a publicly releasable 30" synopsis of its higher-resolution copyright data, and contributed it to the scientific community, including GLOBE.

- Manaaki Whenua Landcare Research of New Zealand contributed a DEM to public access via the U. S. Geological Survey, which was also used in GLOBE.

- The Scientific Committee on Antarctic Research offered to let its Antarctic Digital Database be used for such purposes. USGS converted these digitized contours to grids.

Other areas received contributed elevation grids. Beyond this, there remained some areas without coverage. For these areas, the Geographical Survey Institute of Japan adapted selected maps to digital form. Then the U. S. Geological Survey converted those digital data to grid form for use in USGS' GTOPO30 model. GLOBE then used selected data (including some of the data noted just above) from GTOPO30.

NIMA released DTED Level 0 in 1996. USGS released its own GTOPO30 in 1997; GLOBE continued with its own enhancement of coverage, quality control, and documentation.

2.4 Future Enhancements: Contributions are Still Valuable

The GLOBE Secretariat is still working on enhancements to GLOBE data, documentation, and access. If you have DEM coverage for any area, we would like to discuss possible arrangements for access to 30" or better versions of these data for GLOBE.

3. Quality Assessment

Available for assembly into GLOBE Version 1.0 were data from 11 original sources, some of which had more than one form of post-source processing. A total of 18 combinations of source/lineage were used in GLOBE.

3.1 Types of Quality Review Techniques

Quality review included (1) viewing source imagery with various color palettes in NGDC's public domain GeoVu browse and visualization utility and the GRASS GIS. Among the most useful palettes is GRASS' "random" color palette, which assigns each elevation a color rather different than neighboring elevations. This allows one to view non-terrain-like "geometric" features in a DEM, such as ungraceful mosaicking sutures; (2) viewing slope, aspect, and shaded relief images of each source data set; (4) principal components analysis inputting all available sources for a given area; (5) histogram analysis of each source data set, and (6) statistical comparisons between sources, to see if any source had a particular elevation bias.

Two online examples of these reviews are for Japan and Italy.

3.2 Examples of findings

Statistical comparisons confirmed that DTED Level 0 "minima" were frequently higher than comparable "mean" values from the same data set. "Mean" values were lower than spot values more than should occur. Independent evaluations of DTED Level 0 data with full 3"-gridded DTED Level 1 data suggested that the spot values were the most representative DTED level 0 values, not the originally intended computed means.

Most DEMs derived from contour maps had histograms that favored contour values in the original maps. This well-known but less-than-ideal characteristic was, however, not evident in the Geographical Survey Institute's contributed DEM. GSI's techniques for DEM development may be worth wider circulation, as they may contain techniques worth adopting by other agencies.

Shaded relief analysis showed that the Servizio Geologico Nazionale's DEM of Italy was much more terrain-like for low elevations than alternative candidates.

Histogram analysis was used to estimate vertical accuracies for sources without documented statements of precision. Histogram peaks suggested that implied contour intervals in Japanese and Australian sources were about 20m, giving these countries nominal estimates of 10m (6m Root-Mean-Square-Error) vertical precision. At the other end of the scale, DCW and some other sources in frontier areas have RMSE of about 100m or greater. Although DTED's design criteria aim for 18m RMSE, considerable amounts of DTED were developed under conditions that could not meet its design criteria.

3.3 Summary of the Quality Assessment

Overall, perhaps half of GLOBE exceeds 20m RMSE, where data for Antarctica may be as much as 300m off.

Some may be disappointed by the worst-case vertical accuracies for some areas in GLOBE. However, discrepancies between different geodetic models can create elevation differences in this order of magnitude. Some maps and digital data sets lack full documentation details, and errors have been detected in the projection and datum information in some maps and digital data. With such mislabling of source materials in mind, GLOBE's overall accuracy appears to be a pleasant surprise.

Please remember that specific features may be missed or stylized in such a data set. Critical applications should be designed with caution. Treat all data sets such as GLOBE as you might treat hot coffee. Expect some pain in learning how to handle GLOBE or hot coffee, if you do not already know how to handle them. The pain, and the benefit from learning, are yours.

4. Assembly

All candidate data sets were placed in the GRASS GIS, and assembled using the r.patch program with appropriate masking at each stage to avoid having non-zero values in a lower-quality subsequent patch overwrite higher-quality zero elevations. From previous experience (Row and others, 1995) NGDC had learned that blending replaces abrupt discontinuities with "smeared out" discontinuity zones. It was able to avoid most such blending. When blends were needed to improve data continuity at sutures, these were done in advance of the patching process.

Testing of the final GLOBE mosaic found a surprisingly good fit in most cases. However, it found an apparent vertical misfit between DEMs derived from Digital Chart of the World and other adjacent DEMs from other sources in some areas. This may be caused by inadequate documentation of vertical datum in source materials for DCW. An example of such an apparent misfit was reported for Japan at a GLOBE Task Team meeting (Hiroshi Murakami, 1995, oral communication). These vertical discontinuities appear to be relatively small and rare. They are under consideration for adjustment in future enhancements of GLOBE.

5. Data Access

There are two versions of the GLOBE data set: (1) Best Available Data (BAD) GLOBE, which allows the inclusion of copyright data if those data may be distributed without restriction by the GLOBE Task Team. (2) Globally Only Open Access (GOOD) GLOBE, which contain data with any copyright or proprietary restrictions.

GOOD data are available from the GLOBE Website (noted above in the abstract), and on CD-ROM. Arrangements are being made for additional distributors, and for Web mirror sites. The CD-ROM version is accompanied by NCEI's GeoVu software, enabling one to browse, visualize, assess, and do limited processing (such as limited reformatting and subsetting) of the data. In addition, the CD-ROM contains a "plastic Website" that can be accessed with popular Web browsers. Extensive documentation is available in hardcopy, as well as in various print-file (.pdf, PostScript) and Web-based (.html) options.

BAD GLOBE data are currently available only via CD-ROM. Currently the only area with BAD GLOBE data coverage is Australia (there is overlapping GOOD coverage for the same area), though other possible copyright enhancements are being considered for future versions of GLOBE.

Web access to GLOBE data and documentation is free. CD-ROMs have a nominal charge.

6. Future Prospects for Global DEMs

GLOBE meetings were part of an improved climate of cooperation between several producers of copyright, security-restricted, and/or completely unrestricted DEMs. Three related hopeful developments are underway:

1. The National Imagery and Mapping Agency (NIMA) and the National Aeronautics and Space Administration (NASA) have agreed to launch the joint Shuttle Radar Topography Mapper (SRTM) mission in late 1999. Using the Shuttle Imaging Radar system, this dedicated mission hopes to record complete global coverage of interferometric synthetic aperture radar (SAR) data, from which DEMs will be derived. 3 arc-second global DEMs are anticipated for public release early in the next decade, covering areas covered by SRTM (about 60o North to South latitudes).

2. Radarsat was operated last winter to provide interferometric looks at Antarctica, for the development of a South Polar DEM to complement SRTM coverage in the southern hemisphere.

3. Several private satellite initiatives include stereo-optical coverage in their design. Hopes are high for local DEMs of high resolution, relatively quick production speed, and relatively user-selectable repeat cycles from such initiatives.

In short, in the best of all worlds, GLOBE will be unnecessary sometime in the next decade. However, before this happens, SRTM and other missions will have to combine to create complete global coverage, and that coverage will have to pass a quality assessment exercise. GLOBE will probably have an important role to play in that assessment.

7. Acknowledgements

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