AN ENHANCED GLOBAL ELEVATION MODEL GENERALIZED FROM MULTIPLE HIGHER RESOLUTION SOURCE DATASETS

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ABSTRACT:

Global digital elevation models are routinely used in a variety of earth science applications. GTOPO30, a widely used global elevation model produced by the U.S. Geological Survey, was produced in the mid-1990s from several regional sources of elevation information. Since the time GTOPO30 was developed, new and improved sources of elevation data have become available, and the U.S. Geological Survey and the National Geospatial-Intelligence Agency are collaborating on the development of a notably enhanced global elevation model that will replace GTOPO30 as the elevation dataset of choice for global and continental scale applications. The new model is being generated at three separate resolutions (horizontal post spacings) of 30 arc-seconds (about 1 kilometer), 15 arc-seconds (about 500 meters), and 7.5 arc-seconds (about 250 meters). An additional advantage of the new multi-resolution global model over GTOPO30 is that seven new raster elevation products will be available at each resolution. The new elevation products are being produced using the following aggregation methods: minimum elevation, maximum elevation, mean elevation, median elevation, standard deviation of elevation, systematic subsample, and breakline emphasis. The primary source dataset for the new global model is the Shuttle Radar Topography Mission 1-arc-second data. When complete, the new global model will undergo a thorough accuracy assessment against reference geodetic control and a relative comparison against the existing GTOPO30 at the 30-arc-second resolution. Full documentation describing the input datasets, the processing, the characteristics of the new global model product layers, and the accuracy assessment results will be available to users. The development of the new global elevation model is in progress, with completion scheduled for mid-2009.

1. INTRODUCTION

During the last two decades, digital elevation data have been used in a variety of hydrological, climatological, and geomorphological applications (Moore, Grayson, and Ladson, 1991). These applications have ranged from delineating drainage networks and watersheds to using digital elevation data for the extraction of topographic structure and three-dimensional (3-D) visualization exercises (Jenson and Domingue, 1988; Verdin and Greenlee, 1996; and Lehner, Verdin, and Jarvis, 2008). Watersheds have also been delineated at multiple scales using digital elevation data and assigned to a topological coding scheme that permits a logical aggregation approach to watershed boundaries (Verdin, 1997). Many of the fundamental geophysical processes active at the Earth's surface are controlled or strongly influenced by topography, thus the critical need for high quality terrain data (Gesch, 1994). Numerous regional, national, and near-global sources of elevation information exist, and many of these have been assembled into elevation models with full global coverage.

1.1 Existing GTOPO30 Elevation Model

GTOPO30, a widely used global elevation model, was produced by the U.S. Geological Survey (USGS) and became available in 1996 (Gesch, Verdin, and Greenlee, 1999). GTOPO30 provides elevations for the entire global land surface on a grid every 30 arc-seconds of latitude and longitude, which is about 1-kilometer spacing at the equator. The elevation data for the globe have been divided into 33 tile blocks (Figure 1) and are available at: http://eros.usgs.gov/products/elevation/gtopo30/ gtopo30.html.

At the time when GTOPO30 was developed, and even today, no one source of topographic information covered the entire land surface. GTOPO30 was derived from eight raster and vector sources of varying degrees of quality with processing techniques differing from continent to continent (Gesch and Larson, 1996; Gesch, Verdin, and Greenlee, 1999) (Figure 2). Since the time GTOPO30 was completed, the availability of high quality elevation data over large areas has improved markedly. These new data sources provide a significant improvement over the inputs to GTOPO30 with respect to consistent coverage, scale, quality, and vertical accuracy.

2. NEW GLOBAL ELEVATION PROJECT

The USGS and the National Geospatial-Intelligence Agency (NGA) are collaborating on the development of a notably enhanced global elevation model that will supersede GTOPO30 as the elevation dataset of choice for global and continental scale applications. The primary goal is to develop a fully global medium scale terrain elevation model from 90°N to 90°S to replace GTOPO30. The new model will be generated at three separate resolutions (horizontal post spacings) of 30 arc-seconds (about 1 kilometer), 15 arc-seconds (about 500 meters), and 7.5 arc-seconds (about 250 meters) from the best available higher-resolution data sources. Some areas, namely Greenland and Antarctica, will not have data generated at 7.5 arc-seconds because the source data do not support that level of detail. An

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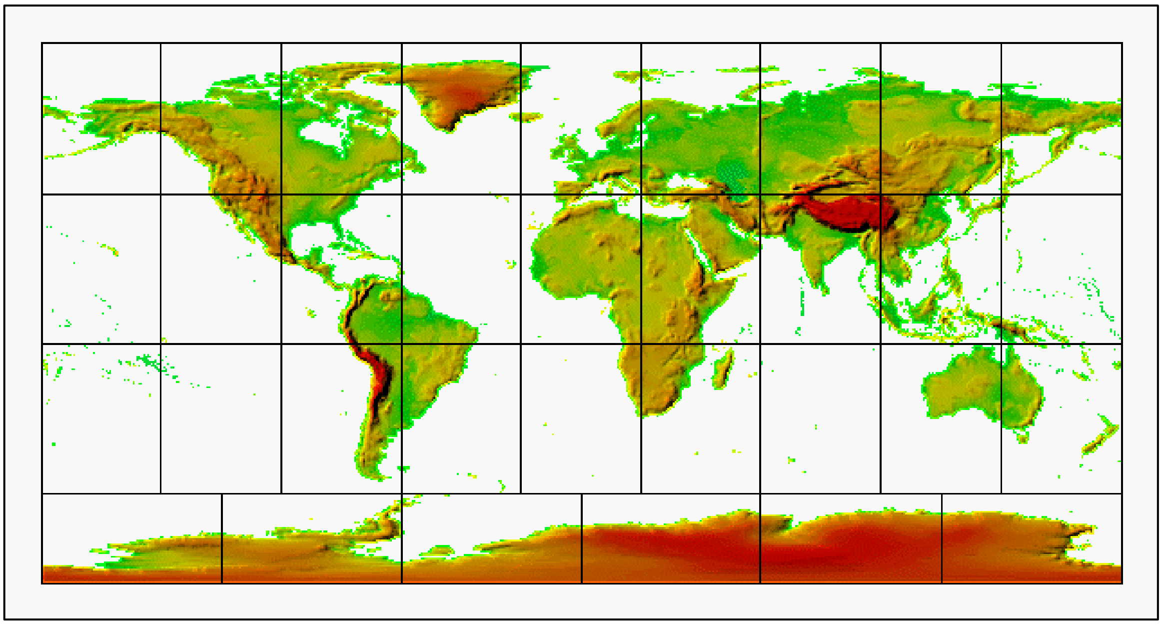

Figure 1. GTOPO30 Elevation Model

additional advantage of the new multi resolution global model over GTOPO30 is that seven new raster elevation products will be available at each resolution. The new elevation products will be produced using the following aggregation methods: minimum elevation, maximum elevation, mean elevation, median elevation, standard deviation of elevation, systematic subsample, and breakline emphasis. In addition to the elevation products, detailed spatially referenced metadata containing fields such as coordinates, projection information, and raw source elevation statistics will be generated on a tile-by-tile basis for all the datasets that constitute the global elevation model.

3. INPUT HIGHER RESOLUTION DATA SOURCES

The primary source dataset for the new global model is NGA's Shuttle Radar Topography Mission (SRTM) DTED®2 (void-filled) 1-arc-second data (Farr et al., 2007; Slater, et al., 2006). SRTM data cover 80 percent of the Earth's land surface (all latitudes between 60°N and 56°S) (Figure 3) and will provide a significant upgrade over the primary source datasets used for GTOPO30, the older 3-arc-second Digital Terrain Elevation Data (DTED®1), and Digital Chart of the World (DCW) 1:1,000,000-scale cartographic data produced by NGA. The void-filled SRTM data are a revised version of the dataset that is not currently publicly available. In addition to the voids being filled, the dataset contains further data editing not included in the original release (Slater, et al., 2006).

Additionally, the USGS 1-arc-second National Elevation Dataset (NED) (Gesch, 2007) will be used to cover a few areas in the conterminous United States that are not covered by SRTM data. To cover areas in Alaska beyond the northern limits of SRTM coverage, 2-arc-second NED data will be used. In northern Canada beyond 60°N latitude, 0.75-arc-second and 3-arc-second cartographically derived Canadian Digital Elevation Data (CDED) will be used as source data for the new global model. In northern Eurasia, 3-arc-second DTED® will be used as source data. If available during this project, the ASTER near-global 1-arc-second elevation model will also be considered as a source dataset for the northern latitudes beyond the coverage of SRTM (http://www.ersdac.or.jp/GDEM/E/).

The new global model will also include upgrades for Greenland and Antarctica. New elevation models derived from the Ice, Cloud, and land Elevation Satellite (ICESat), Geoscience Laser Altimeter System (GLAS) provide a considerable upgrade over source data used for those areas in the original GTOPO30 (Figure 4). Holes in the Antarctica ICESat dataset will be filled with version 2 of the Radarsat Antarctica Mapping Project (RAMP) 6-arc-second elevation dataset. SRTM holes in Australia will be filled with the GeoData 9-arc-second elevation data from Geoscience Australia (Figure 5). Data characteristics such as the projection system, horizontal and vertical units, and datum vary among the input data sources (Table 1). These input data characteristics need to be standardized to a consistent set of parameters in order to create a seamless global elevation dataset. Every input dataset is ingested on a tile-by-tile basis and converted to the geographic WGS 84 horizontal coordinate system with their respective horizontal units converted to decimal degrees and vertical units changed to integer meters. Vertical datum differences between the input data sources are not transformed but captured in the spatially referenced metadata.

4. GENERALIZATION PROCESSING

The global generalization of the input data sources is accomplished by developing workflows in Python 2.4.1 and accessing Environmental System Research Institute's (ESRI) ArcGIS 9.2[*] geoprocessing framework to perform raster and vector spatial analysis operations. The generalization, or

[*] Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

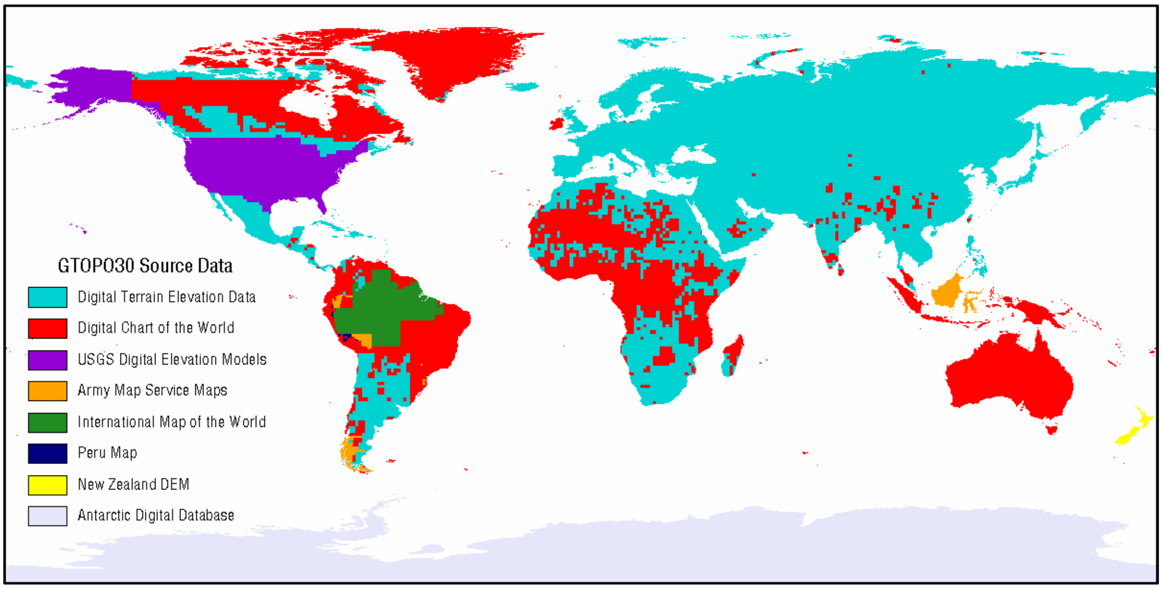

Figure 2. GTOPO30 Elevation Sources

aggregation, approach produces reduced resolution data that represent the minimum, maximum, mean, standard deviation, and median of the full resolution source elevations within the aggregated output cell. In addition, a systematic subsampling of the full resolution source data is used to produce a reduced resolution version at each of the output grid spacings. Also, an approach called "breakline emphasis" will be used to produce reduced resolution products that maintain stream (channel) and ridge (divide) geographic characteristics as delineated in the full resolution source data (Gesch, 1999).

Breakline emphasis maintains the critical topographic features within the landscape by maintaining any minimum elevation or maximum elevation value on a breakline that passes within the specified analysis window. Remaining pixel values are generalized using the median statistic (Gesch, 1999). The breakline emphasis methodology can be summarized into the following three major steps:

1. Topographic breaklines (ridges and streams) are extracted from the full resolution DEM, and then used to guide selection of generalized values.
2. Full resolution streams are automatically thresholded, which enables easy extraction of the level one through five Strahler stream orders.
3. Full resolution ridges are extracted by selecting the flow accumulation values that are equal to zero. Using focal and block image processing functions, ridges are thinned so that only critical divides are maintained.

4.1 Breakline Emphasis Product Case Studies

The breakline emphasis product will be especially useful for the generation of hydrologic derivatives or distributed hydrologic modeling applications conducted over large areas. One practical way to test the operational effectiveness of the breakline emphasis algorithm is to generate watersheds from the generalized breakline product and to compare the result against watersheds derived from a full resolution data source. The full resolution data source that is being employed to generate the ground truth watersheds is the bare earth Elevation Derivatives for National Applications (EDNA) (Verdin, 2000) database (http://edna.usgs.gov/). EDNA is a multi-layered database derived from a version of the 1-arc-second National Elevation Dataset (NED), which has been hydrologically conditioned for improved hydrologic flow representation. The two case study watersheds are the James River and Allegheny watersheds in the United States. These two areas were chosen because they represent very different areas in terms of topography with the James River watershed situated in a low relief / shallow sloped area and the Allegheny watershed positioned in a more moderate relief area.

4.1.1 Allegheny Watershed Case Study: The Allegheny watershed is situated in the northeastern United States on the Allegheny Plateau and bordered by the Allegheny Scarp on the eastern edge of the basin. The distinct ridge and valley formation is prevalent on the eastern edge with dissected streams located throughout the remaining basin area. Figure 6 displays the watershed boundary derived from the 7.5-arc-second breakline emphasis product in red and the boundary derived from the 1-arc-second EDNA elevation data in green. To quantify the change between the two boundaries, the Coefficient of Areal Correspondence (CAC) metric has been utilized. The CAC is a metric used to evaluate the corresponding overlap of two areal delineations (Taylor, 1977). The CAC is computed by dividing the intersecting area of two delineations by the union of the same two delineations. The result of the CAC metric in the Allegheny case study indicates a 98.6% spatial agreement between the EDNA 1-arc-second derived watershed and the breakline emphasis generalized 7.5-arc-second derived watershed.

4.1.2 James River Watershed Case Study: The James River watershed is situated in the flat lowland between the Coteau du Missouri and Coteau des Prairies plateau regions in central North Dakota and South Dakota in the United States. Figure 7 displays the watershed boundary derived from the 7.5-arc-second breakline emphasis product in red and the boundary derived from the 1-arc-second EDNA elevation dataset in green. The resulting CAC metric indicates a 97.3% spatial agreement between the EDNA 1-arc-second derived watershed and the

Figure 3. SRTM DTED®2 (void-filled) 1-Arc-Second Coverage Map

breakline emphasis generalized 7.5-arc-second derived watershed. This result is particularly encouraging because within the James River watershed the ridges (divides) are very subtle with very little change in the topographic relief structure. The outcome of the two case studies clearly indicates that the generalized 7.5-arc-second breakline emphasis product can delineate fairly accurate watershed boundaries, but it can accomplish this task with a much smaller volume of data.

5. OUTPUT DATA PRODUCTS

The new elevation products include the following: minimum, maximum, mean, median, standard deviation, systematic subsample, breakline emphasis. There are seven products generated at each resolution with a total of 21 products generated at all three output resolutions. Different products will be used in a variety of application situations. For example, the maximum elevation product could be used for the global calculation of airport runway surface heights or to determine the height of surface obstacles like mountains. The minimum elevation product is useful for determining below sea level areas and stream channel areas. The standard deviation product is not exclusive to but provides a good textural overview of the landscape surface. The breakline emphasis products will be useful for most hydrologic applications that involve watershed extraction and surface streamline routing. The remaining products, specifically the mean and systematic subsample products, will be useful for general visualization exercises and all-purpose morphological processing. The new generalized products provide more topographic detail than the existing GTOPO30 dataset due to the introduction of higher resolution data sources like SRTM. An area in northwestern Australia was compared using the 30-arc-second mean product and the 30-arc-second GTOPO30 product to contrast the changes in topographic detail (Figure 8). The difference map in the upper right corner of Figure 8 displays areas with increased elevations (red) and those with decreased elevations (blue) resulting from the improved digital elevation model. Results indicate a systematic average difference of 16 meters between the two products with the new mean product displaying more pronounced topographic detail in all areas, but especially in the regions with flats and ridges.

Because the input data come from varying source datasets, spatially referenced metadata will accompany the output elevation datasets. The spatially referenced metadata are contained within a geospatial polygonal dataset that contains footprints of each of the source dataset input tiles. The attributes of the source footprint polygons describe the characteristics of each input dataset used to generate the suite of new global elevation products.

5.1 Current Status and Future Plans

The status of the global SRTM generalization processing is displayed in Figure 9 with the green spatially referenced metadata footprints appearing in the upper left corner of the map. Australia was selected as the pilot continent because the landmass is almost entirely covered by SRTM and is an island with a defined shoreline boundary.

When complete, the new global model will undergo a thorough accuracy assessment against reference geodetic control and a relative comparison against the existing GTOPO30 at the 30-arc-second resolution. Full documentation describing the input datasets, the processing, the characteristics of the new global model product layers, and the accuracy assessment results will be available to users. The development of the new global elevation model is in progress, with completion scheduled for mid-2009.

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Dataset	Surface Type	Projection System	Horizontal Unit	Vertical Unit	Vertical Datum
SRTM (DTED® 2)	Reflective	Geographic	Arc-Second	Integer Meter	EGM96
DTED® 1	Bare Earth	Geographic	Arc-Second	Integer Meter	MSL
CDED	Reflective	Geographic	Arc-Second	Integer Meter	CVGD28
NED	Bare Earth	Geographic	Decimal Degree	Decimal Meter	NAVD88 & NGVD29
GeoData	Bare Earth	Geographic	Decimal Degree	Integer Meter	AHD
RAMP	Reflective	Polar Stereographic	Meter	Integer Meter	OSU91A
ICESat / GLAS	Reflective	Polar Stereographic	Meter	Centimeter	EGM96
GTOPO30	Bare Earth	Geographic	Decimal Degree	Integer Meter	MSL

Table 1. Major Input Source Data Characteristics

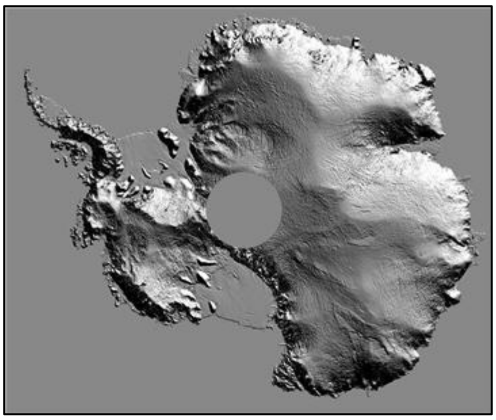

Figure 4. Antarctica: ICESat / GLAS: 15-Arc-Second Coverage Map

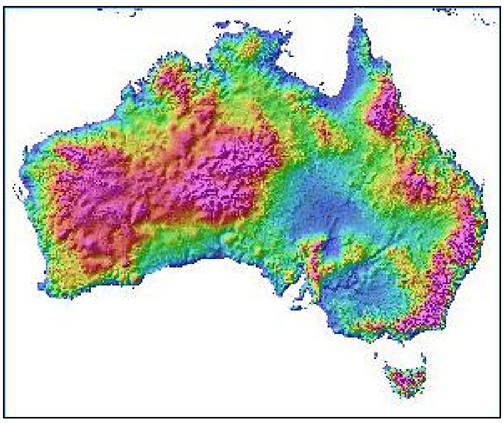

Figure 5. Australia: GeoData 9-Arc-Second Coverage Map (Source: Geoscience Australia)

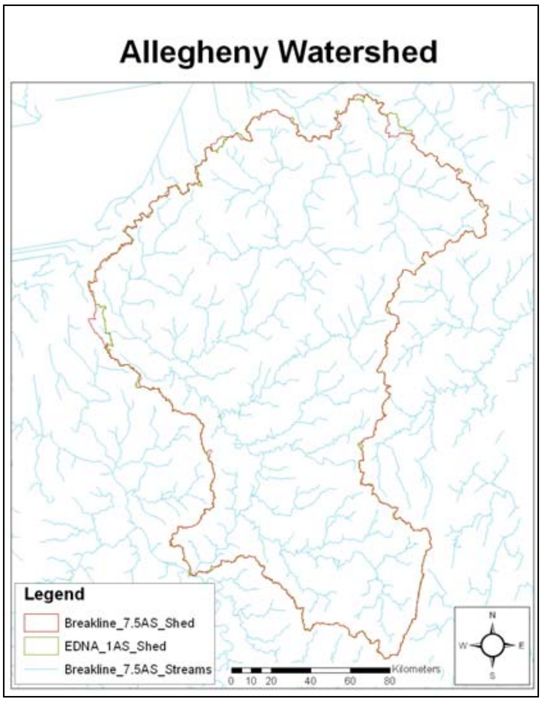

Figure 6. Allegheny Watershed Comparison

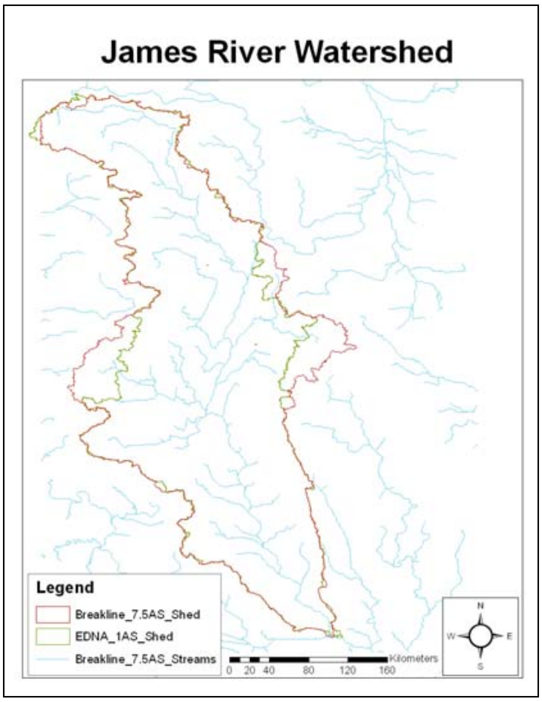

Figure 7. James River Watershed Comparison

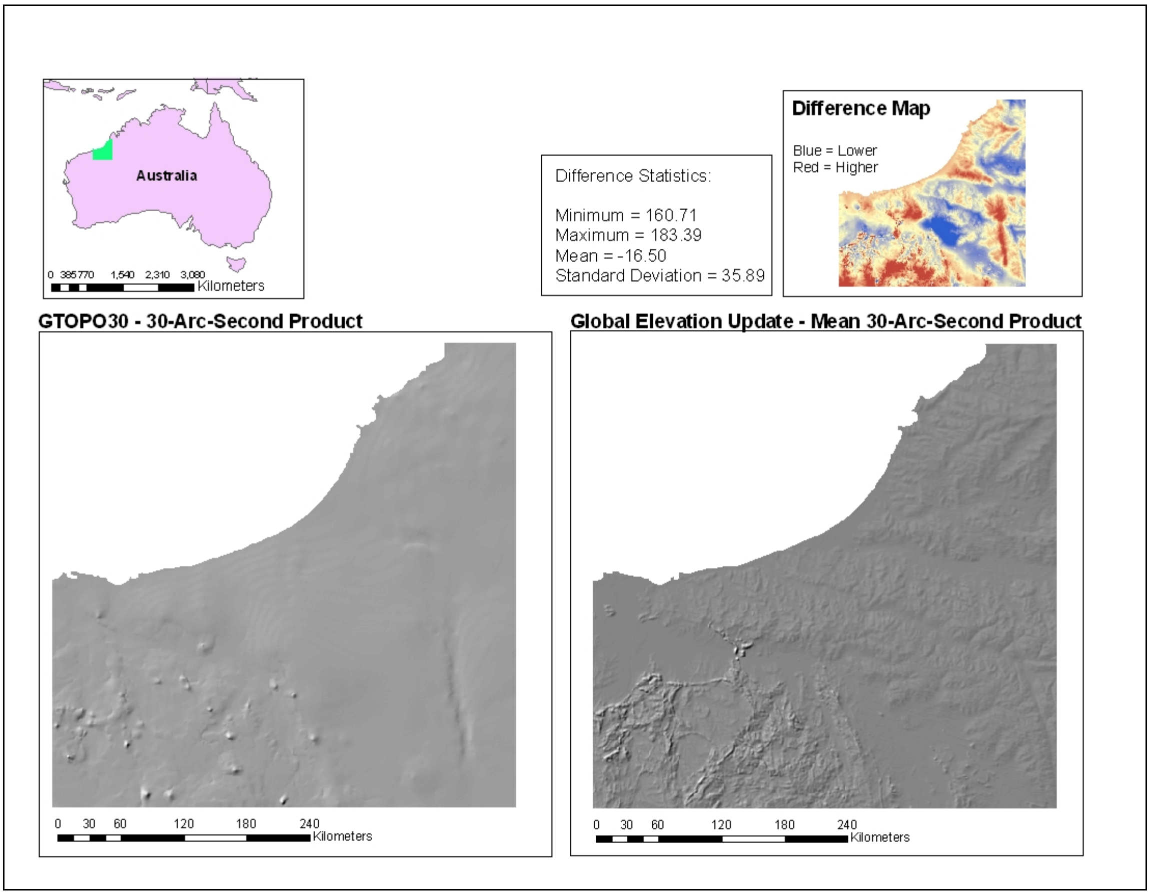

Figure 8. Comparison of the New Mean and Existing GTOPO30 30-Arc-Second Products

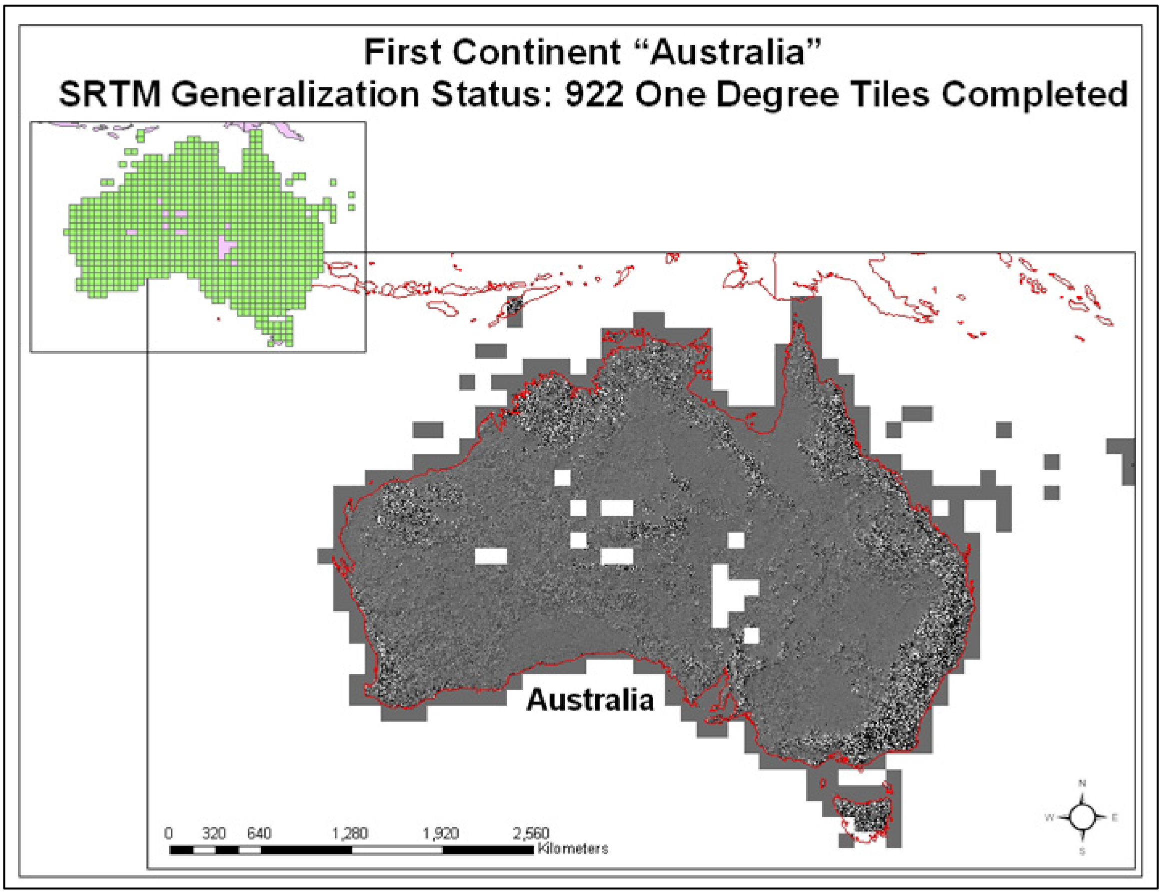

Figure 9. Global SRTM Generalization Status