



GeoSur Geospatial Application Workshop

June 8, 2009

USGS Earth Resources Observation and Science (EROS) Center

A New Enhanced Global Digital Elevation Model (DEM): The Status of Generalization, Void-Filling, and Accuracy Assessment Activities

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Work performed with support from the National Geospatial-Intelligence Agency (NGA)

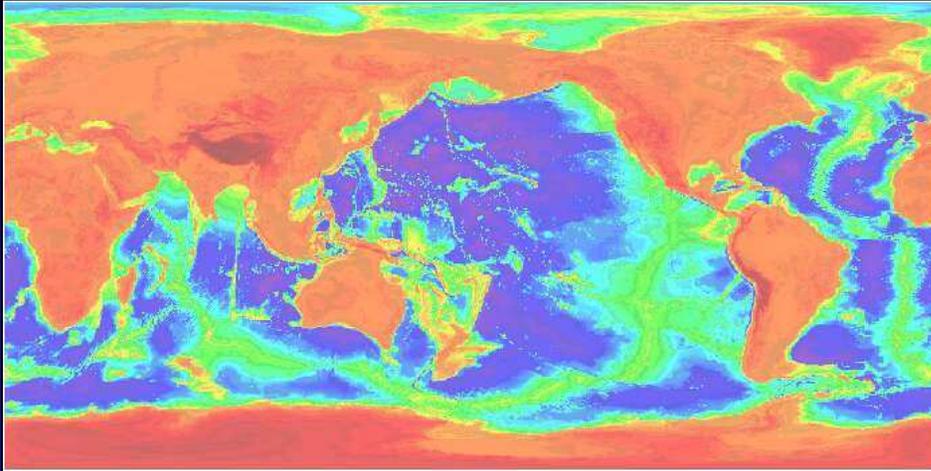
U.S. Department of the Interior
U.S. Geological Survey

Presentation Outline

- Existing Global Digital Elevation Sources
 - ETOPO5
 - GTOPO30
- Global Digital Elevation Replacement Project
 - Overview
 - Higher Resolution Data Sources
 - Generalization Techniques
 - Statistical Aggregation Methods
 - Breakline Emphasis
 - First Continent – Australia
 - Spatially Referenced Metadata
 - Product Comparisons
 - Validation and Evaluation
- Conclusions



ETOPO5 Global Elevation Model



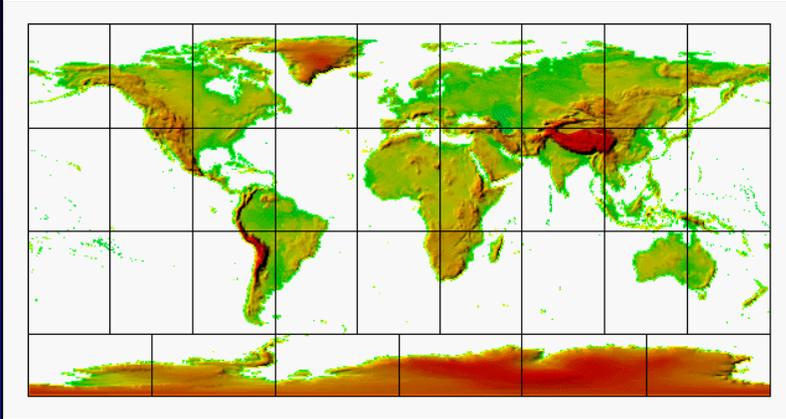
<http://www.ngdc.noaa.gov/mgg/global/relief/ETOPO5/>

■ Dataset Information:

- Stakeholder: NOAA, National Geophysical Data Center (NGDC)
- Surface Type: Land Surface and Sea Floor
- Horizontal Resolution: 5 arc-minutes (10 km)
- Vertical Unit: Integer Meter
- Projection System: Geographic Lat / Long
- Elevation Source: Digital Database of Land and Sea Floor Elevations
- Production Date: May 1988



GTOPO30 Global Elevation Model

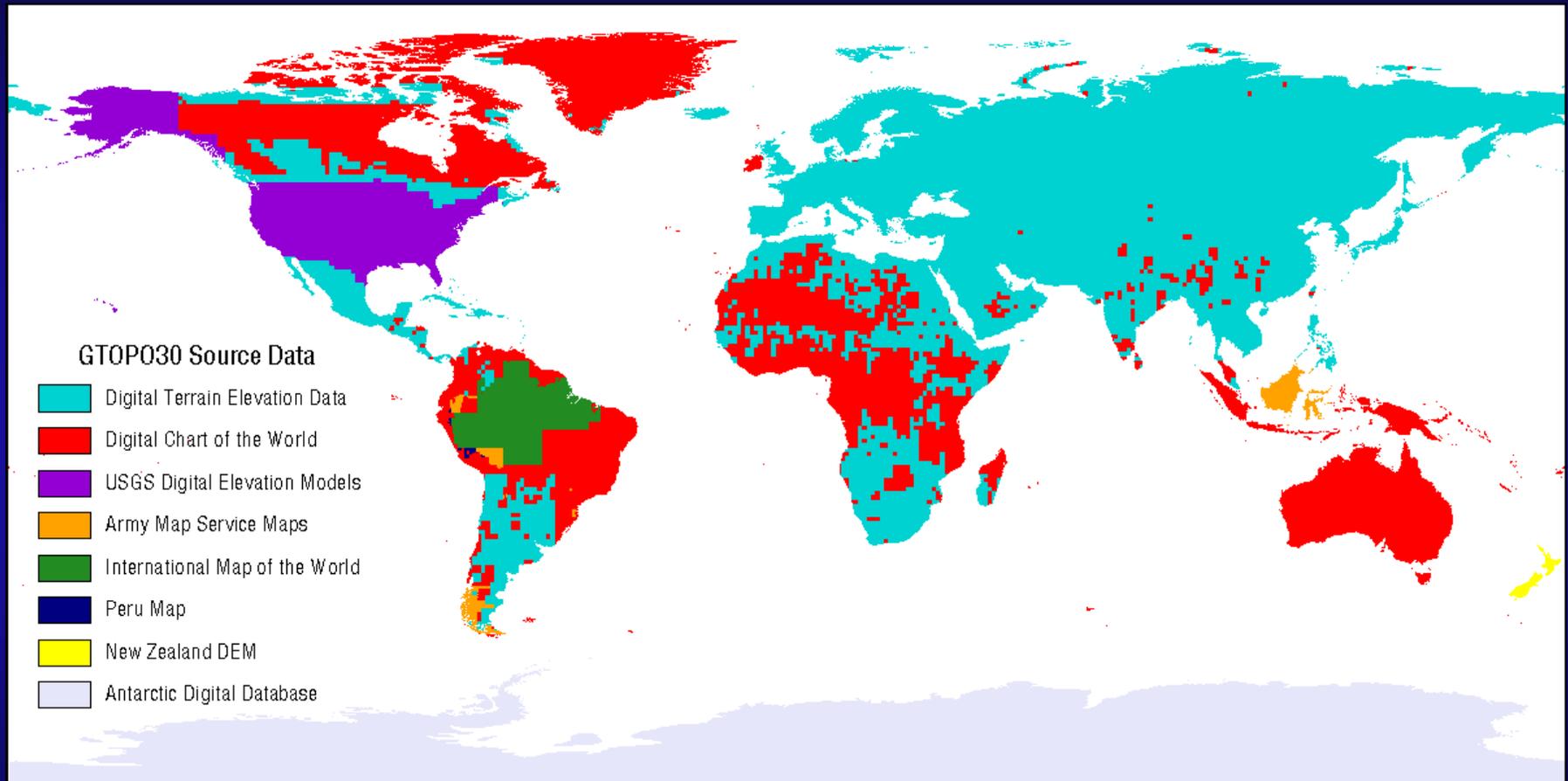


<http://edc.usgs.gov/products/elevation/gtopo30/gtopo30.html>

- Widely used for climate modeling, land cover characterization, hydrologic modeling, and EOS satellite image product generation
- GTOPO30 continues to be a very popular product, averaging over 12,000 files downloaded each month
- **Dataset Information:**
 - Stakeholder: U.S Geological Survey
 - Surface Type: Land Surface – Bare Earth
 - Horizontal Resolution: 30 arc-seconds (1 kilometer)
 - Vertical Unit: Integer Meter
 - Projection System: Geographic Lat / Long
 - Elevation Sources: 5 Vector and 3 Raster
 - Production Date: November 1996, Initial Release 1997



GTOPO30 Global Elevation Model – Source Data



Global Digital Elevation Replacement Project: Overview

■ Primary Goal

- To develop a fully global medium scale elevation model to replace and enhance GTOPO30. The new model will be generated at three separate resolutions (horizontal post spacings) of 30 arc-seconds (1 km), 15 arc-seconds (500 m), and 7.5 arc-seconds (250 m) from the best available higher resolution data sources.

■ Elevation Data Sources

■ New Source Data:

- Shuttle Radar Topography Mission (SRTM) DTED 2[®], 1 arc-second
- National Elevation Dataset (NED), 1 and 2 arc-seconds
- Canadian Digital Elevation Data (CDED), 0.75 and 3 arc-seconds
- SPOT5 Reference3D[®], 15 arc-second
- Geoscience Laser Altimeter System (GLAS) / ICESat, 15 and 30 arc-seconds
- Radarsat Antarctica Mapping Project (RAMP) Ver. 2, 6 arc-second
- Australian GEODATA 9 arc-second DEM
- Digital Terrain Elevation Data (DTED 1[®]), 3 arc-second

■ Metadata Compliant with FGDC Standards

- Detailed spatially referenced metadata will be produced for all the datasets that constitute the global elevation model.



Input Data Sources: Shuttle Radar Topography Mission (SRTM) DTED 2[®] (void-filled) - 1 Arc-Second

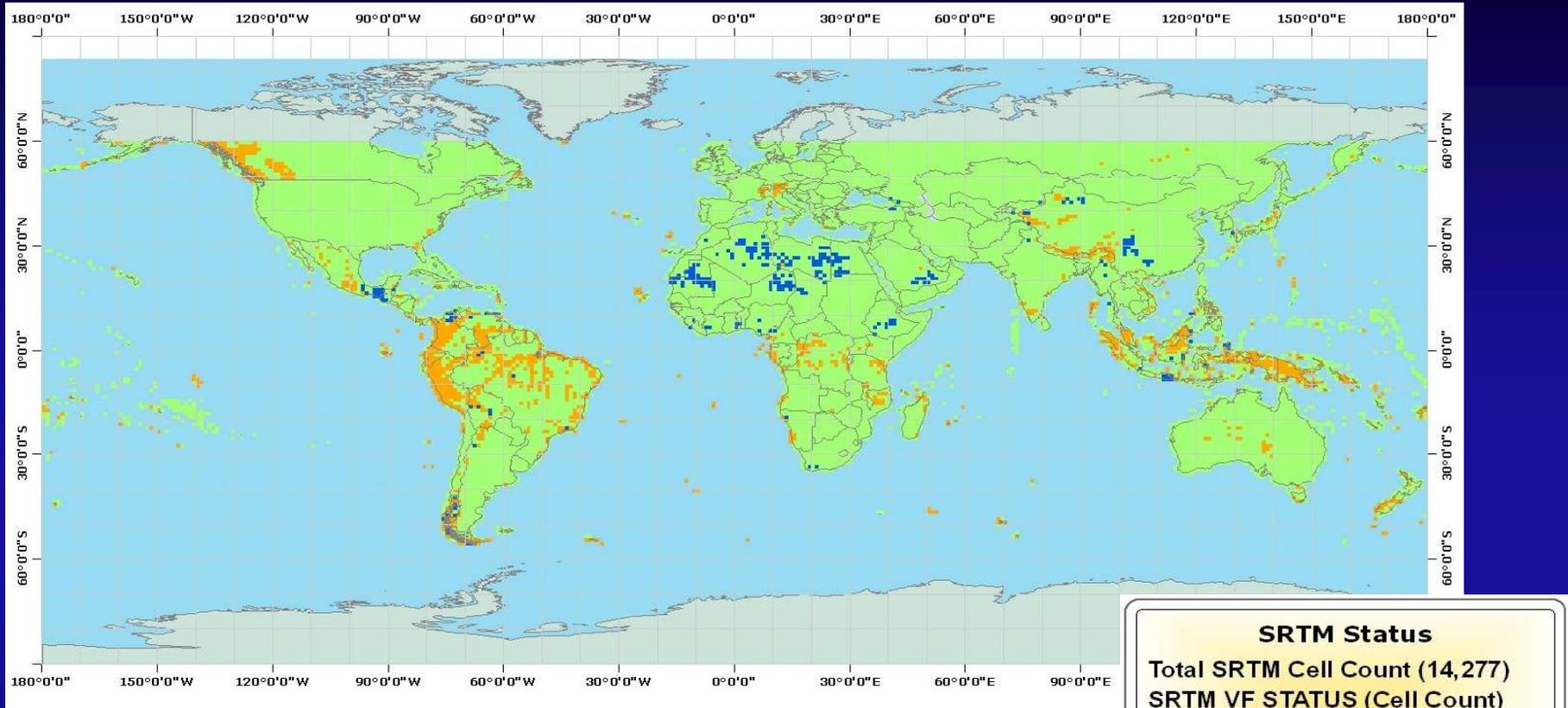


■ Dataset Information:

- Stakeholder: National Geospatial-Intelligence Agency (NGA); NASA
- Surface Type: Land Surface - Reflective
- Horizontal Resolution: 1 arc-second
- Vertical Unit: Integer Meter
- Projection System: Geographic Lat / Long
- Elevation Source: Shuttle Radar Topography Mission (SRTM) DTED 2[®] (void-filled), Limited Distribution (LIMDIS)
- Source Date: February 2000



SRTM Voids



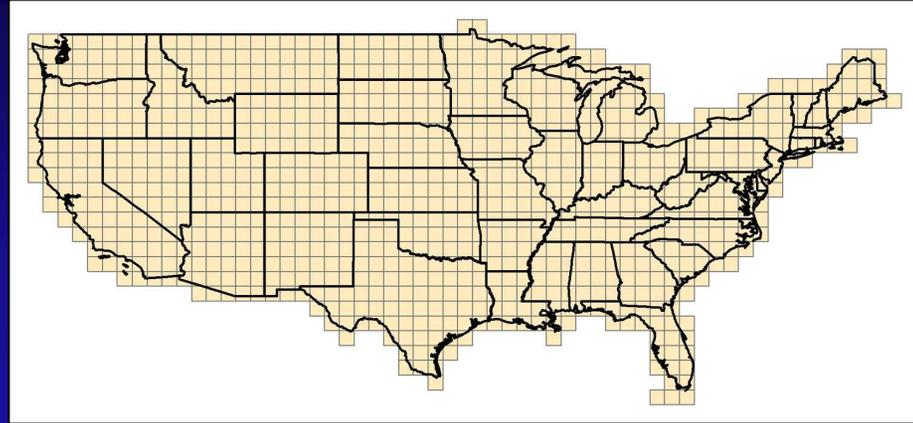
- Causes for SRTM Voids:
 - Limited Duty Cycle Aboard the Sensor (Large Area Blocks)
 - High Relief Areas (Shadow and Layover)
 - Poor Correlation of Radar Images in Desert Landscapes Due to the Sand Surface Texture



Input Data Sources: National Elevation Dataset (NED – 1 and 2 Arc-Second)



NED: 1 Arc-Second DEM

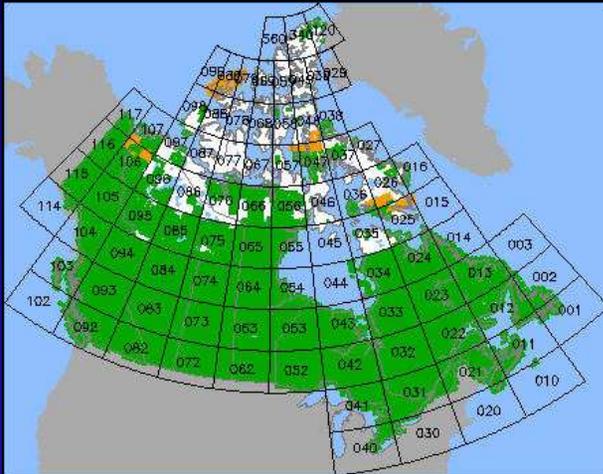


NED: 1 Degree Tile Coverage Map

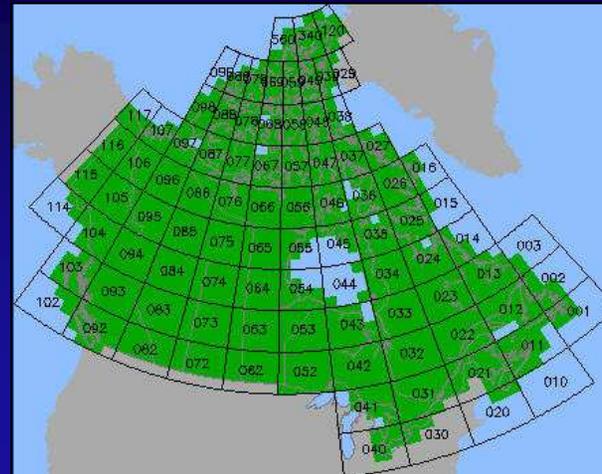
■ Dataset Information:

- Stakeholder: U.S Geological Survey (USGS)
- Surface Type: Land Surface – Bare Earth
- Horizontal Resolution: 1 arc-second (Conterminous U.S) and 2 arc-second (Alaska)
- Vertical Unit: Decimal Meter
- Projection System: Geographic Lat / Long
- Elevation Source: Database comprises the "best available" elevation data (primarily 10-m and 30-m DEMs). Data are in one seamless geodetic framework. Edges between contributed data and adjoining tiles are adjusted.
- Source Production Date: Depends on Input Data Sources

Input Data Sources: Canadian Digital Elevation Data (CDED – 0.75 and 3 Arc-Second)



CDED: 0.75 Arc-Second Coverage Map

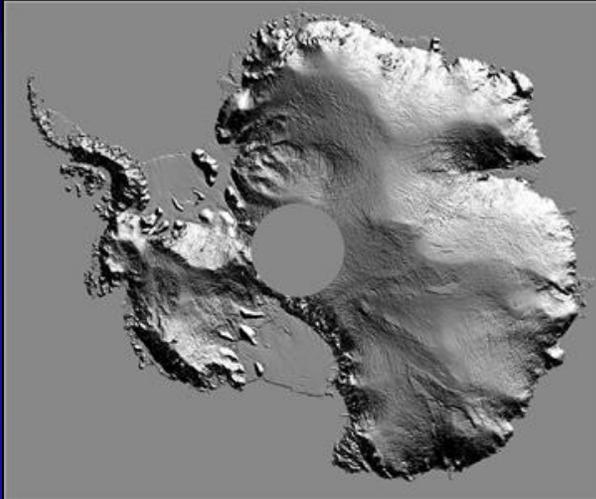


CDED: 3 Arc-Second Coverage Map

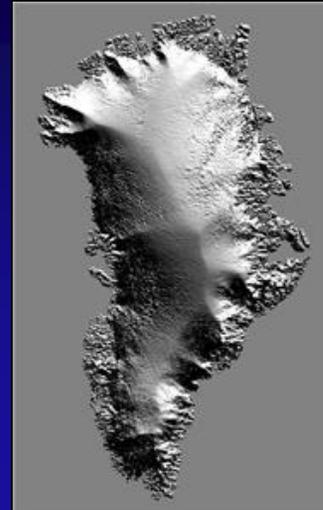
■ Dataset Information:

- Stakeholder: GeoBase (Natural Resources Canada)
- Surface Type: Land Surface – Reflective and Bare Earth
- Horizontal Resolution: 0.75 and 3 arc-second
- Vertical Unit: Integer Meter
- Projection System: Geographic Lat / Long
- Elevation Source: CDED is extracted from the hypsographic and hydrographic elements of the National Topographic Data Base (NTDB) at scales of 1:50,000 and 1:250,000, the Geospatial Database (GDB), and various scaled positional data acquired by the provinces and territories, or remotely sensed imagery.
- Source Production Date: Depends on Input Data Sources

Input Data Sources: GLAS / ICESAT DEM (15 and 30 Arc-Second)



Antarctica
GLAS / ICESAT: 15 Arc-Second (500-m) DEM



Greenland
GLAS / ICESAT: 30 Arc-Second (1000-m) DEM

■ Dataset Information:

- Stakeholder: National Snow and Ice Data Center (NSIDC); NASA
- Surface Type: Land Surface - Reflective
- Horizontal Resolution: 500 (Antarctica) and 1000 (Greenland) meters
- Vertical Unit: Centimeter
- Projection System: Polar Stereographic
- Elevation Source: GLAS / ICESat laser altimetry DEM of Antarctica (500 meter) and Greenland (1000 meter)
- Source Production Date: Depends on Sensor Collection Dates

Input Data Sources: Radarsat Antarctica Mapping Project (RAMP Version 2, 6 Arc-Second)

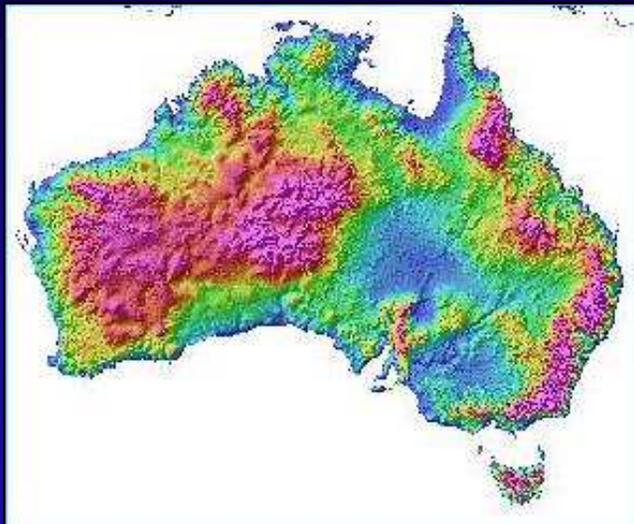


RAMP: 6 Arc-Second DEM

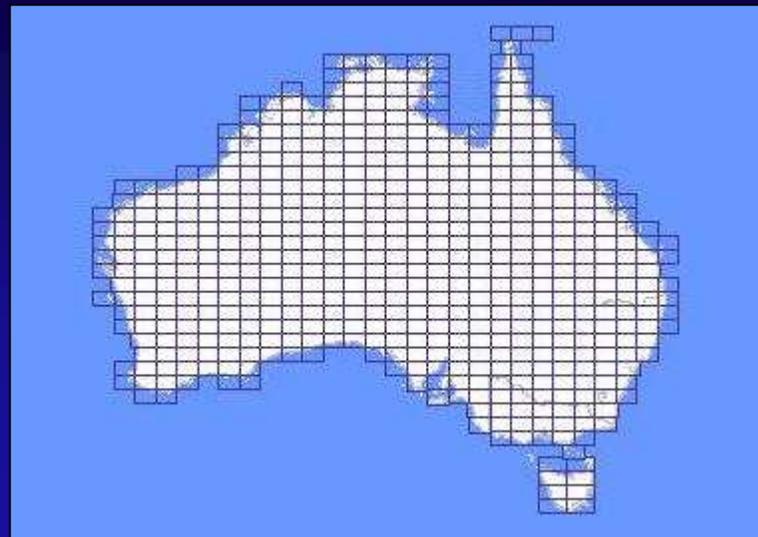
■ Dataset Information:

- Stakeholder: National Snow and Ice Data Center (NSIDC)
- Surface Type: Land Surface - Reflective
- Horizontal Resolution: 6 arc-seconds (200 Meters)
- Vertical Unit: Integer Meter
- Projection System: Polar Stereographic
- Elevation Source: Topographic source data were collected by various remote sensing instruments, ground survey teams, and projects between the 1940s and 1990s.
- Source Production Date: Depends on Input Data Sources

Input Data Sources: Australian GEODATA 9 Arc-Second DEM



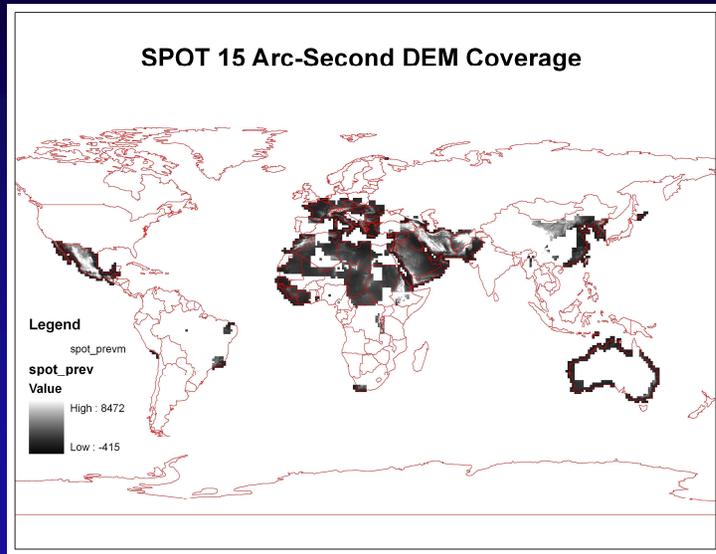
GEODATA: 9 Arc-Second DEM



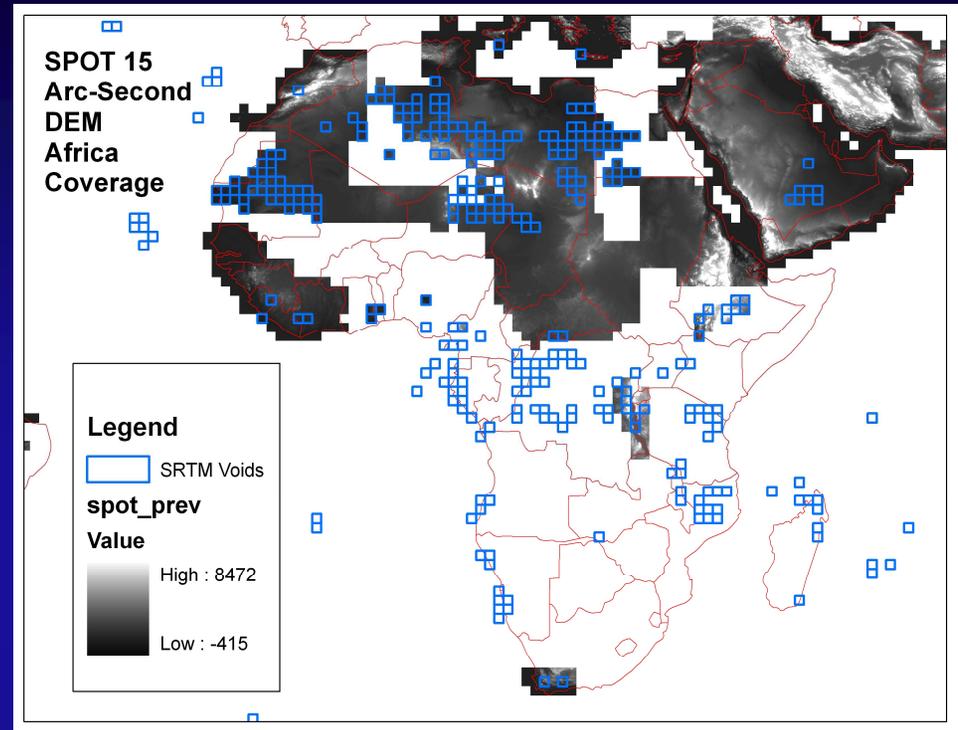
GEODATA: 250K Tile Structure

- Dataset Information:
 - Stakeholder: Geoscience Australia
 - Surface Type: Land Surface – Bare Earth
 - Horizontal Resolution: 9 arc-seconds
 - Vertical Unit: Integer Meter
 - Projection System: Geographic Lat / Long
 - Elevation Source: Surface elevation heights were generated from 1:100,000 scale topographic spot elevation heights and 1:250,000 scale streams and contours along with national trigonometric data points supplied from the National Geodetic Data Base (NGDB).
 - Source Production Date: Depends on Input Data Sources

Input Data Sources: 15 Arc-Second SPOT5 Reference3D



15" SPOT5 Reference3D Global Coverage



15" SPOT5 Reference3D Africa Coverage

Dataset Information:

- Stakeholder: SPOT Image / IGN
- Surface Type: Land Surface – Reflective
- Horizontal Resolution: 15 arc-second
- Vertical Unit: Integer Meter
- Projection System: Geographic Lat / Long
- Elevation Source: SPOT5 Reference3D
- Source Production Date: Depends on Input Data Sources



Global Digital Elevation Project: Products / Algorithms

■ Products / Algorithms

- Seven products generated at each resolution (7.5, 15, and 30 arc-seconds)
 - Breakline Emphasis (Hydrologic Applications)
 - Breakline emphasis maintains the critical topographic features within the landscape by retaining any stream (minimum elevation) or ridge (maximum elevation) value that passes within the specified analysis window.
 - Minimum Elevation Statistic (Stream Channel Identification)
 - Maximum Elevation Statistic (Air Traffic Navigation Application)
 - Mean Elevation Statistic (All-Purpose Visualization and Morphological Processing)
 - Median Elevation Statistic
 - Standard Deviation Statistic (Surface Texture / Roughness)
 - Systematic Subsample



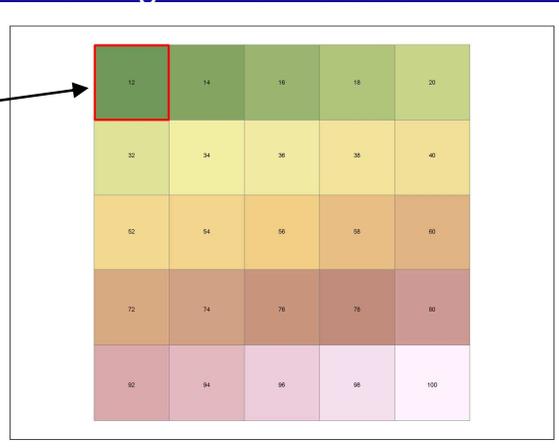
Generalization Algorithms – Statistical

- **Statistical Products (Minimum, Maximum, Mean, Median, Standard Deviation)**
 - ArcGIS Spatial Analyst Functions: Resample, Blockstd, and Aggregation
 - Summary: These products are resampled to a coarser resolution based on a specified aggregation strategy (Sum, Min, Max, Mean, Median, or Standard Deviation).
- **Systematic Subsample**

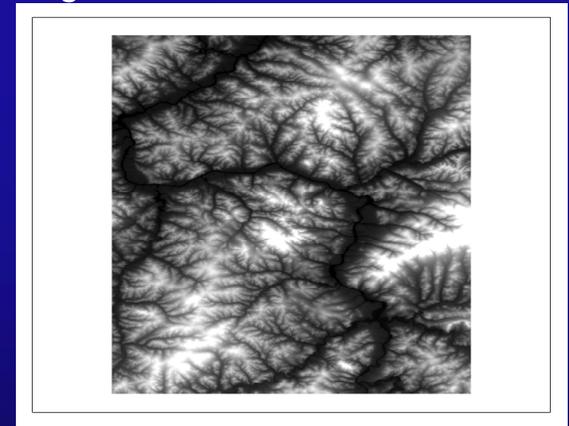
Sample 10 x 10 Grid, 100 Values



Sample 5 x 5 Grid, 25 Values,
Lower Right Pixel Value of 2 x 2



SRTM 7.5 arc-sec, One
Degree Tile, Maximum Statistic

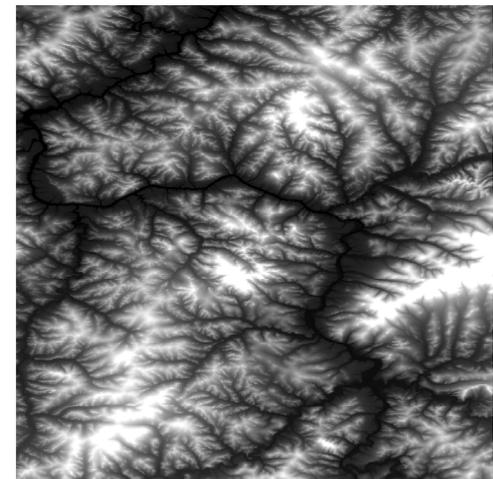


Generalization Algorithms – Breakline Emphasis

■ Breakline Emphasis

- **Summary:** Breakline emphasis maintains the critical topographic features within the landscape by emphasizing any stream (minimum elevation) or ridge (maximum elevation) that passes within the specified analysis window. Remaining pixel values are generalized using the median statistic.
- **Current Processing Flow**
 - Topographic breaklines (ridges and streams) are extracted from the full resolution DEM, and then used to guide selection of generalized values.
 - Full resolution streams are automatically thresholded, which enables easy extraction of the level one through five Strahler stream orders.
 - Full resolution ridges are extracted by selecting the flow accumulation values that are equal to zero. Using various image processing techniques, ridges are thinned so that only critical divides are maintained.

SRTM 7.5 arc-sec, One Degree Tile, Breakline Emphasis

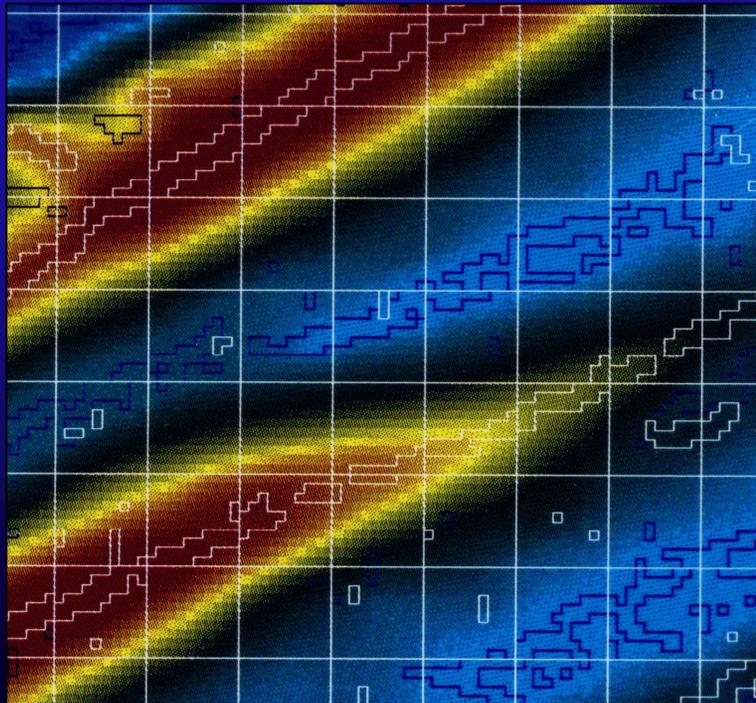


Generalization Algorithms – Breakline Emphasis

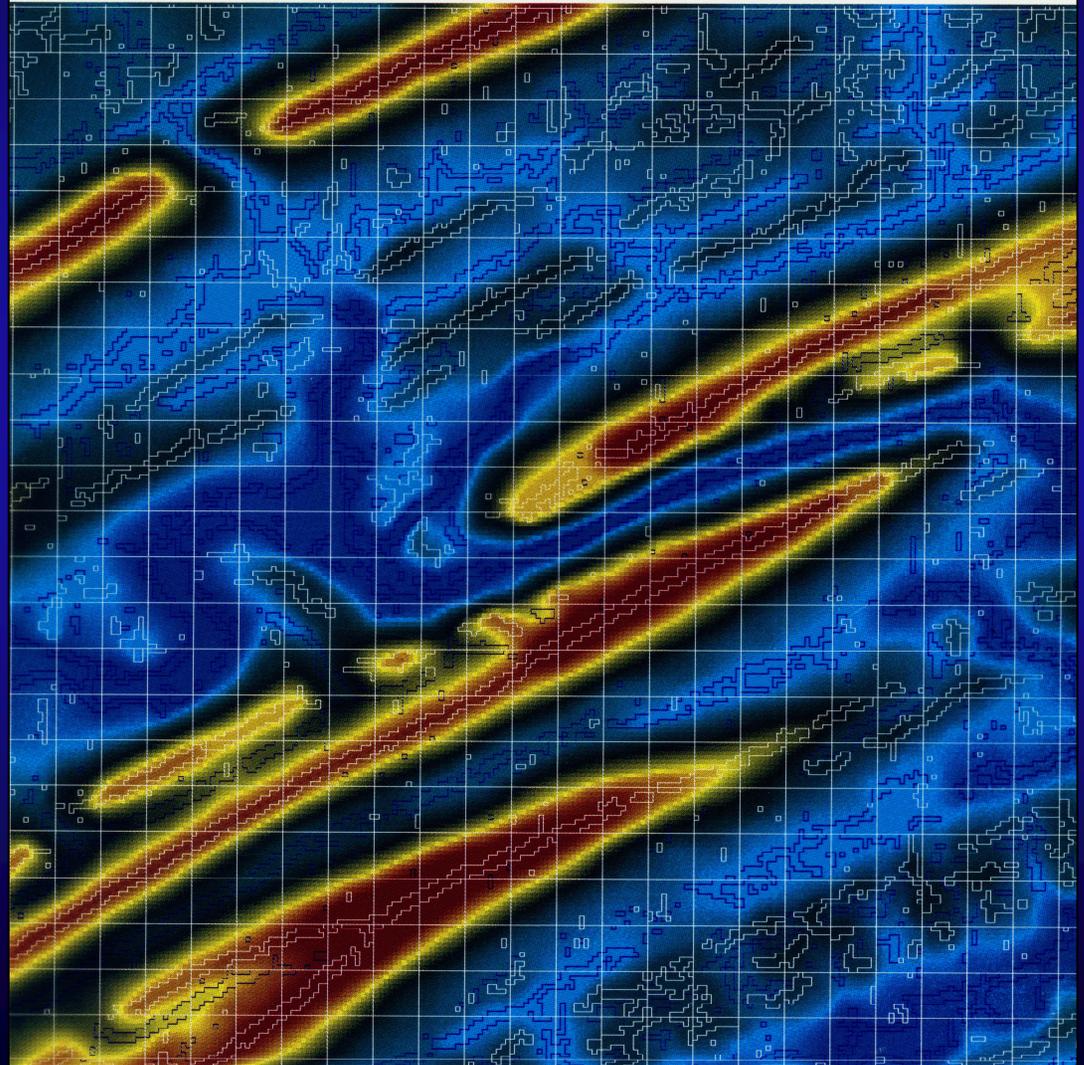
- Breakline Emphasis
 - Example: Ridge and Valley

Blue Lines = Streams

White Lines = Ridges

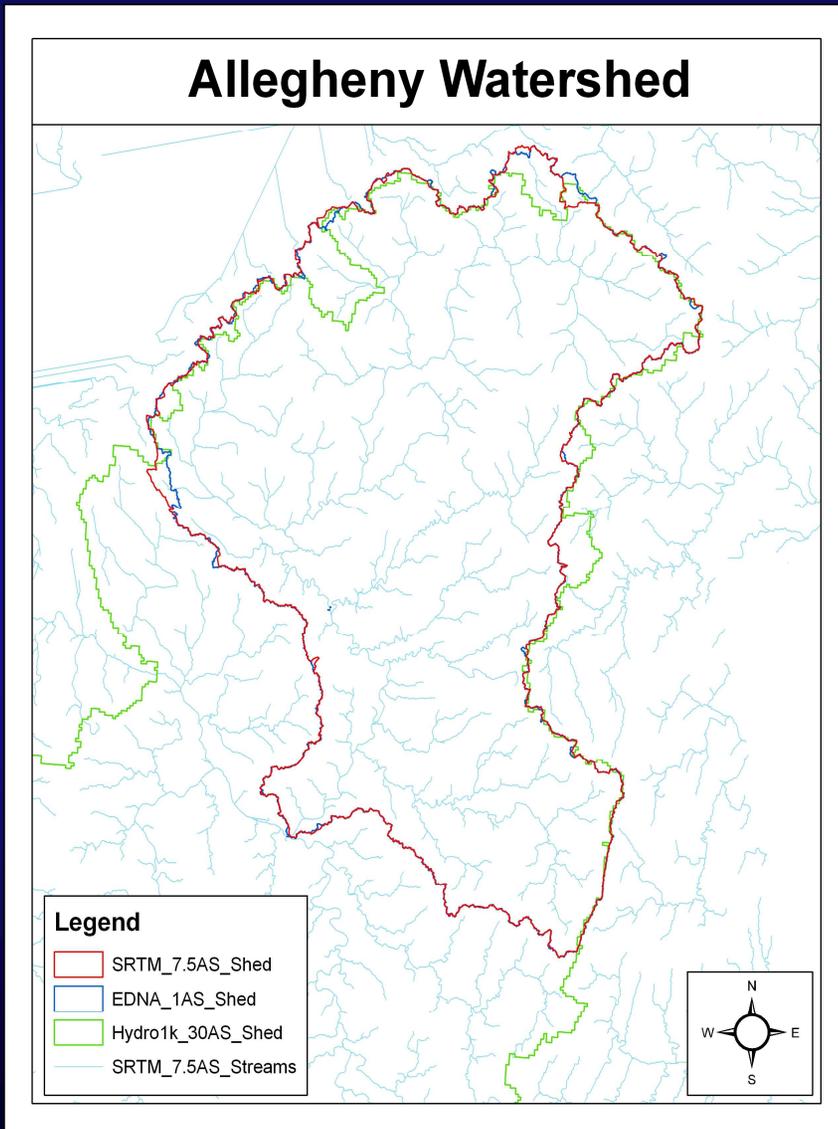


Full resolution with breakline cells outlined

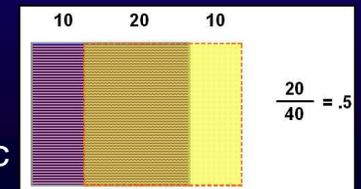


Allegheny Breakline Emphasis (Watershed Delineation)

- **Allegheny Physiography**
 - New York / Pennsylvania
 - Allegheny Plateau
 - Allegheny Front (Scarp)
 - Dissected Streams
 - Ridge and Valley
- **Coefficient of Areal Correspondence (CAC)**
 - The CAC is a metric used to quantify 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.
 - 98.6% Spatial Agreement Between the Elevation Derivatives for National Applications (EDNA) 30-Meter Derived Watershed and the Breakline Emphasis Generalized 7.5- Arc-Second Derived Watershed



Example: CAC Metric



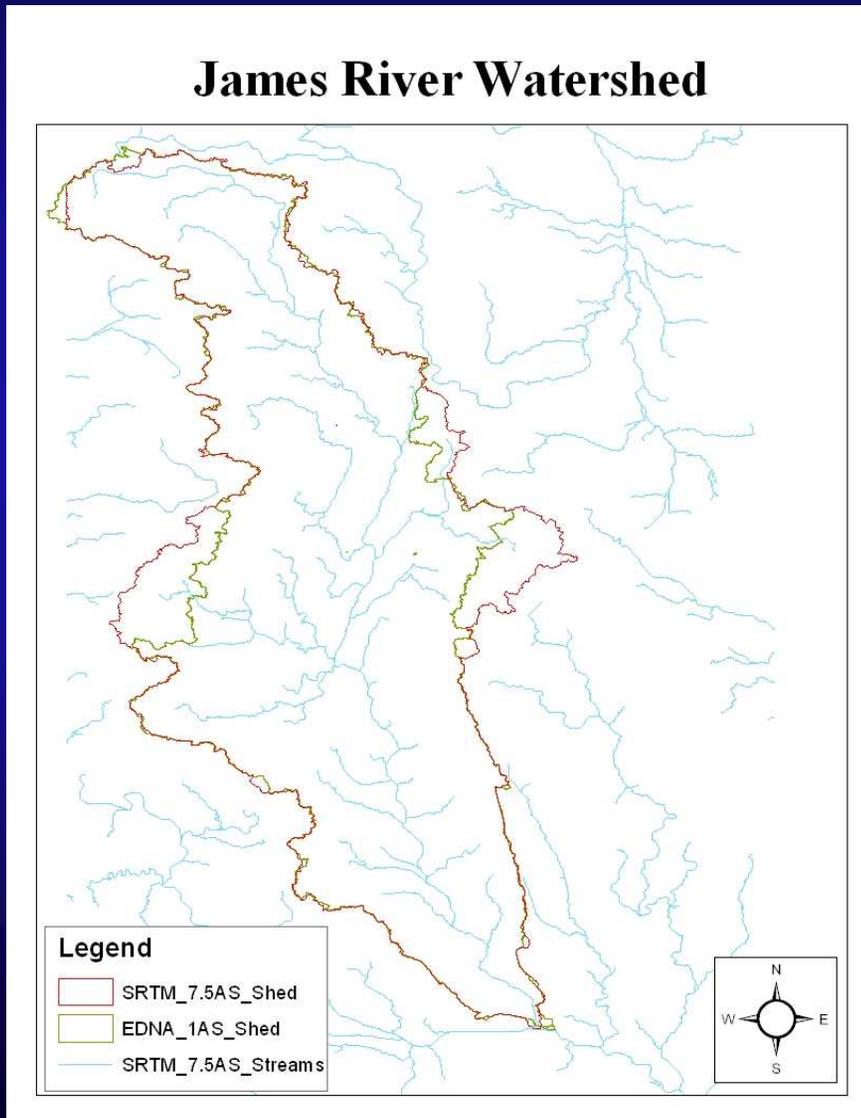
James River Breakline Emphasis (Watershed Delineation)

■ James River Physiography

- North Dakota / South Dakota
- Flat Lowland Situated Between the Coteau du Missouri and Coteau des Prairies Plateau Regions

■ Coefficient of Areal Correspondence (CAC)

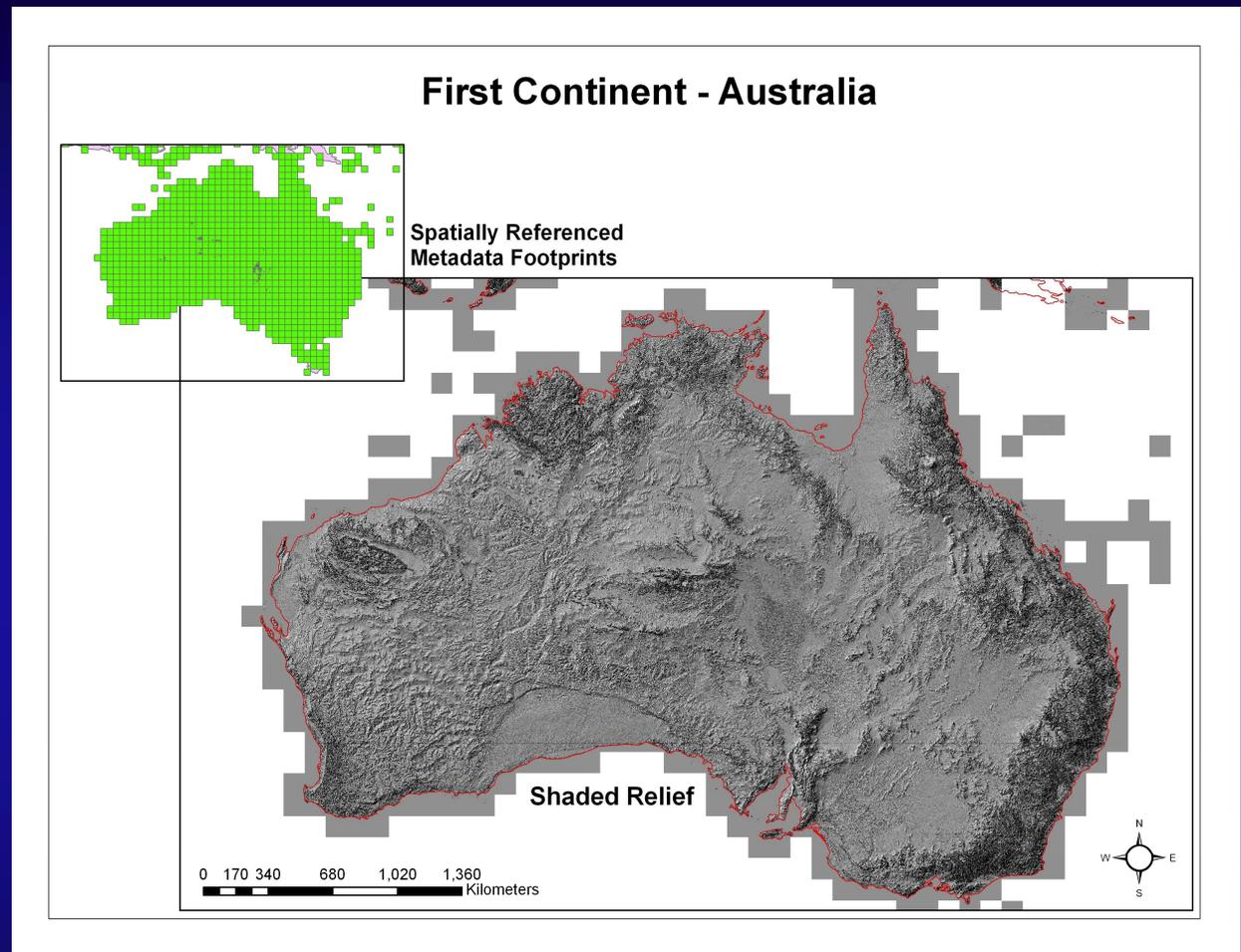
- 97.3% Spatial Agreement Between the Elevation Derivatives for National Applications (EDNA) 30-Meter Derived Watershed and the Breakline Emphasis Generalized 7.5-Arc-Second Derived Watershed



First Continent – Australia

Advantages

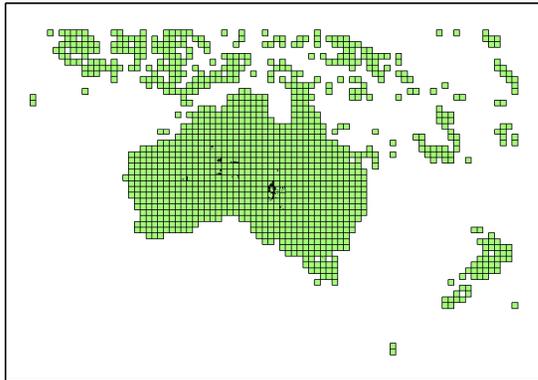
- Fast completion time due to the small continental area of Australia
- An island with a defined shoreline boundary, no external linkages with other land masses
- Continent almost entirely covered by SRTM
- Out of the 1198 one degree SRTM tiles that encompass the mainland only 19 were not completely void-filled



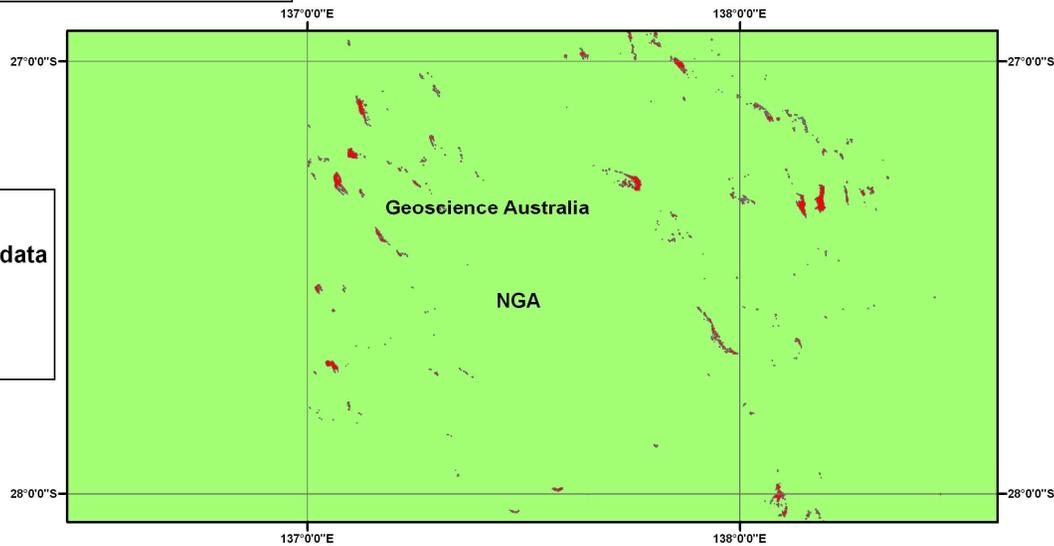
- Existing unfilled SRTM voids were filled using the NGA delta-fill algorithm with the GEOBASE 9-arc-second digital elevation dataset provided by Geoscience Australia

Australia Spatially Referenced Metadata

Australia Spatially Referenced Metadata



Zoom View - NGA SRTM One Degree Metadata and Geoscience Australia 9 Second GEODATA Void Metadata



Legend

Australia Spatial Metadata

Source Org

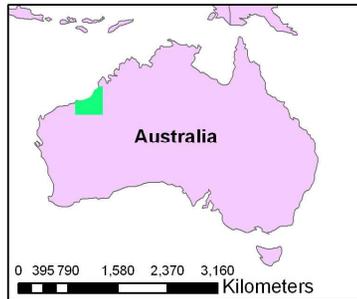
- Geoscience Australia
- NGA

Field	Value
FID	792
Shape	Polygon
ID	793
SOURCE_ORG	NGA
SOURCE	SRTM DTED2 Void Filled
EL_SURFACE	Reflective
NORTH	-27
SOUTH	-28
WEST	121
EAST	122
X_SRCE_RES	1
Y_SRCE_RES	1
HORZ_UNIT	Second
COORD_SYS	Geographic
HORZ_DATUM	WGS 84
VERT_DATUM	EGM96
VERT_UNIT	Meter
MIN_ELEV	307
MAX_ELEV	629
MEAN_ELEV	497.64
SDEV_ELEV	45.231
PROD_DATE	31May2008

Metadata fields and values captured at full resolution from the input source data



GTOPO30 and New Global Elevation Mean 30 Arc-Second Product Comparisons

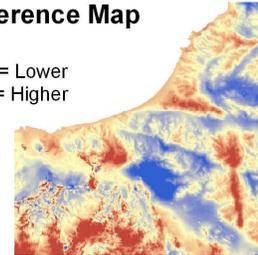


Difference Statistics:

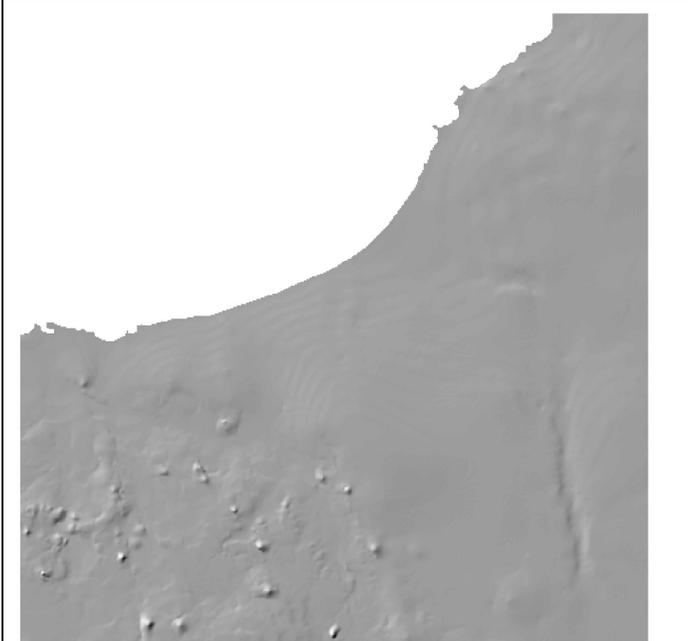
Minimum = -160.71
Maximum = 183.39
Mean = -16.50
Standard Deviation = 35.89

Difference Map

Blue = Lower
Red = Higher

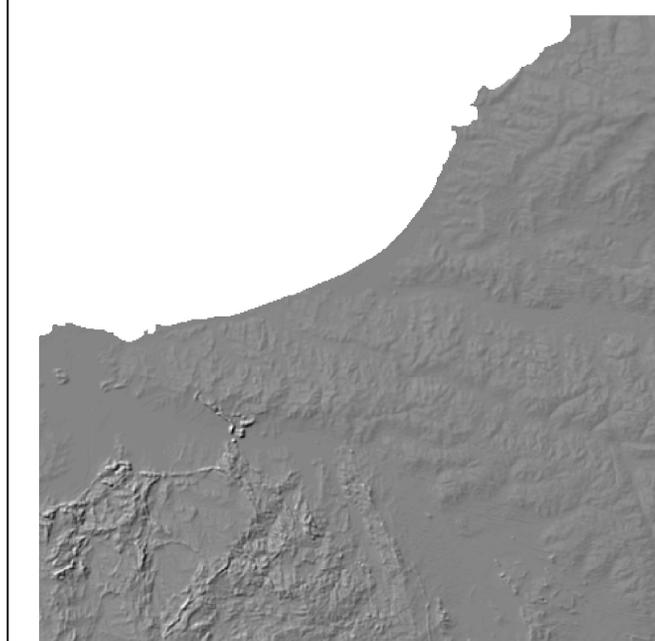


GTOPO30 - 30-Arc-Second Product



0 30 60 120 180 240 Kilometers

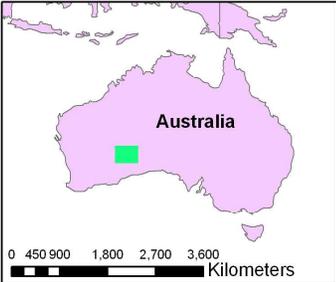
Global Elevation Update - Mean 30-Arc-Second Product



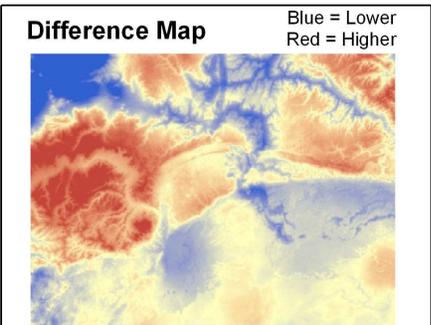
0 30 60 120 180 240 Kilometers



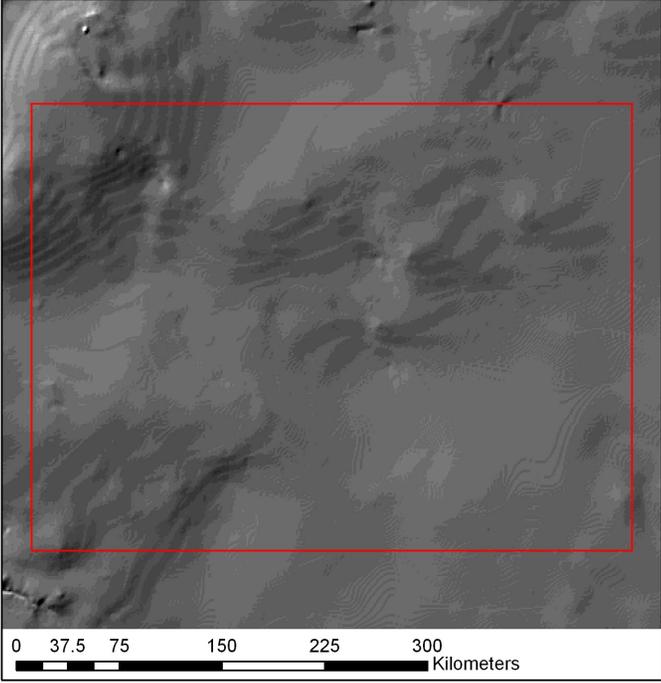
GTOPO30 and New Global Elevation Mean 30 Arc-Second Product Comparisons



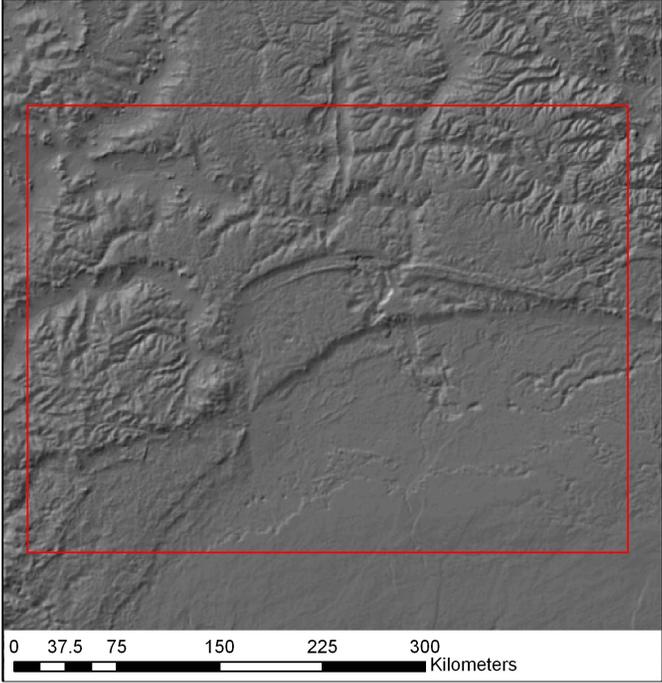
Difference Statistics:
Minimum = -230.00
Maximum = 150.00
Mean = -7.51
Standard Deviation = 51.30



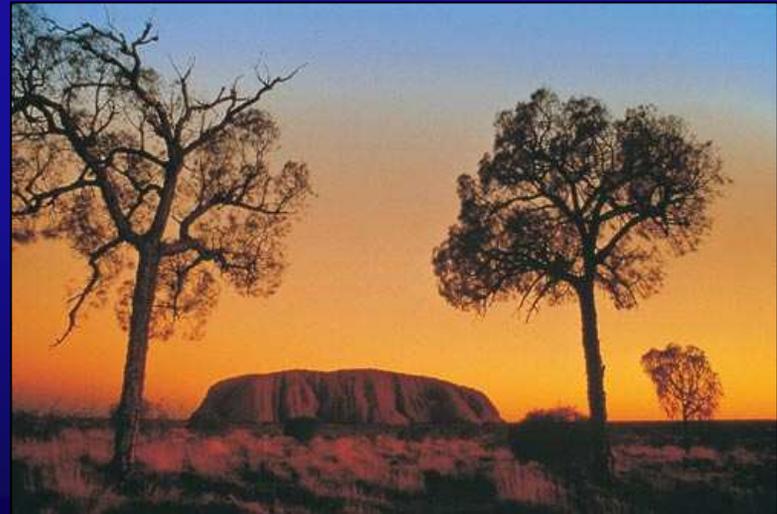
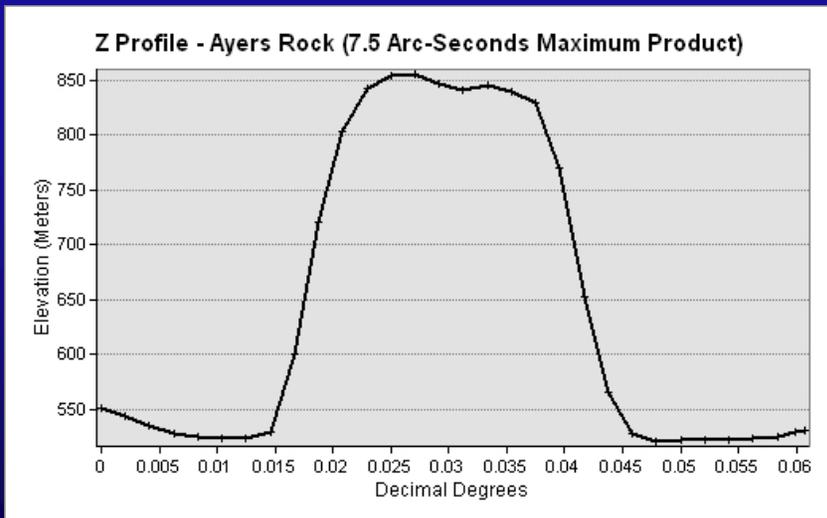
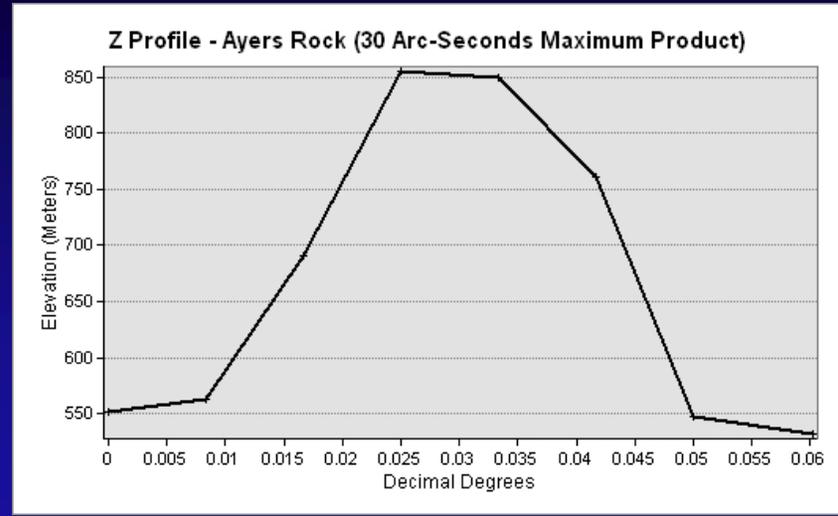
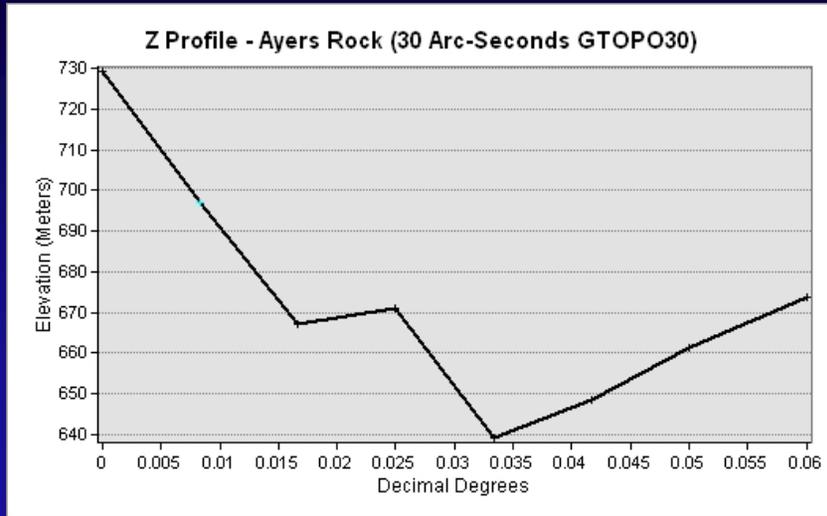
GTOPO30 - 30-Arc-Second Product



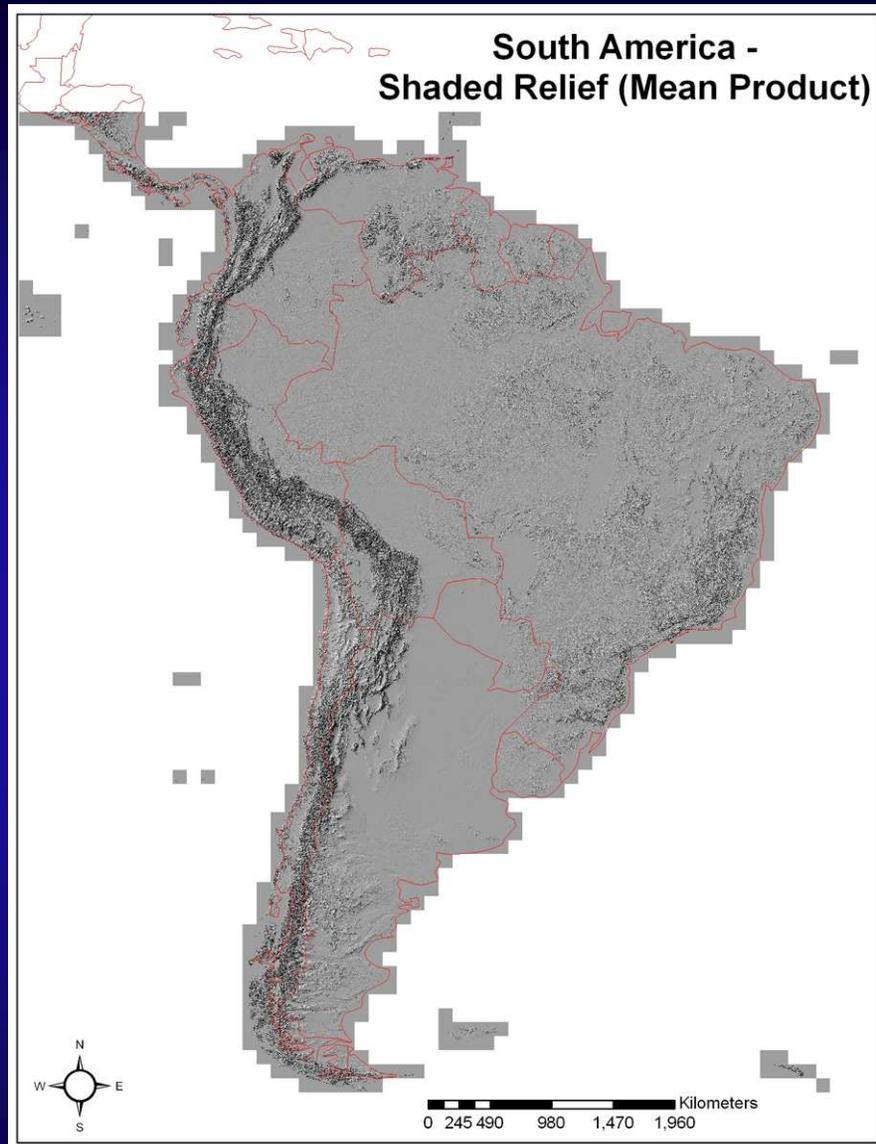
Global Elevation Update - Mean 30-Arc-Second Product



Ayers Rock – Z Profile Comparisons (GTOPO30 and New Global Elevation Maximum Products)



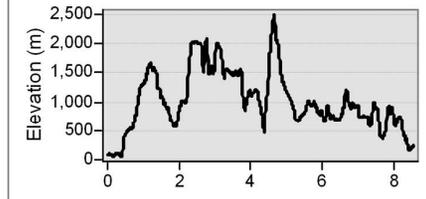
Second Continent - South America



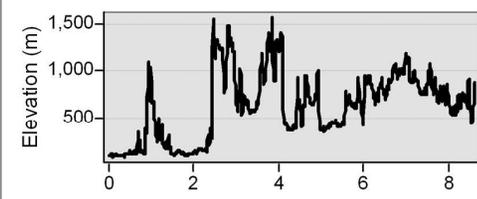
GTOPO30 and New Global Elevation Mean 30 Arc-Second Product Comparisons



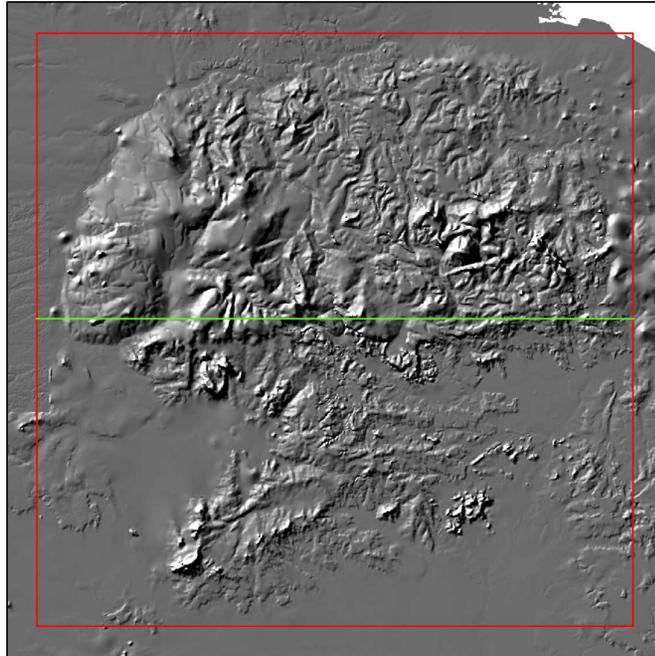
GTOPO30 Subset - Elevation Profile



Mean Subset - Elevation Profile

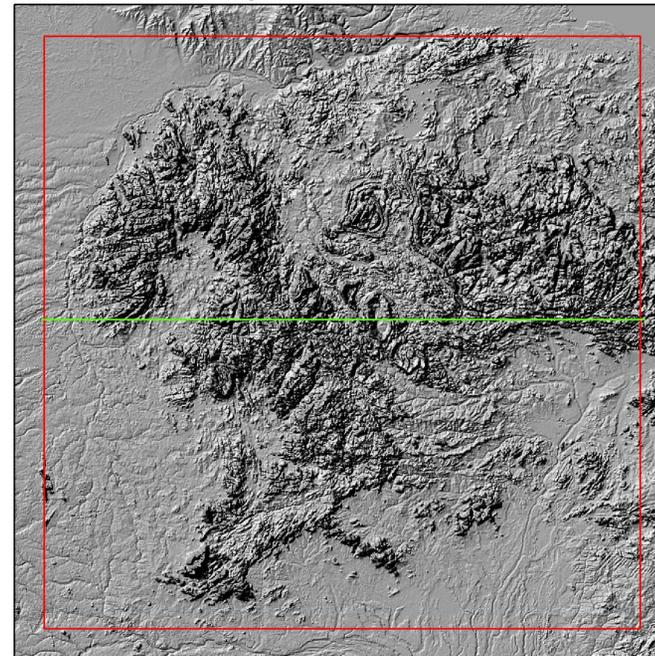


GTOPO30 - 30 Arc-Second Product



0 70 140 280 420 560 Kilometers

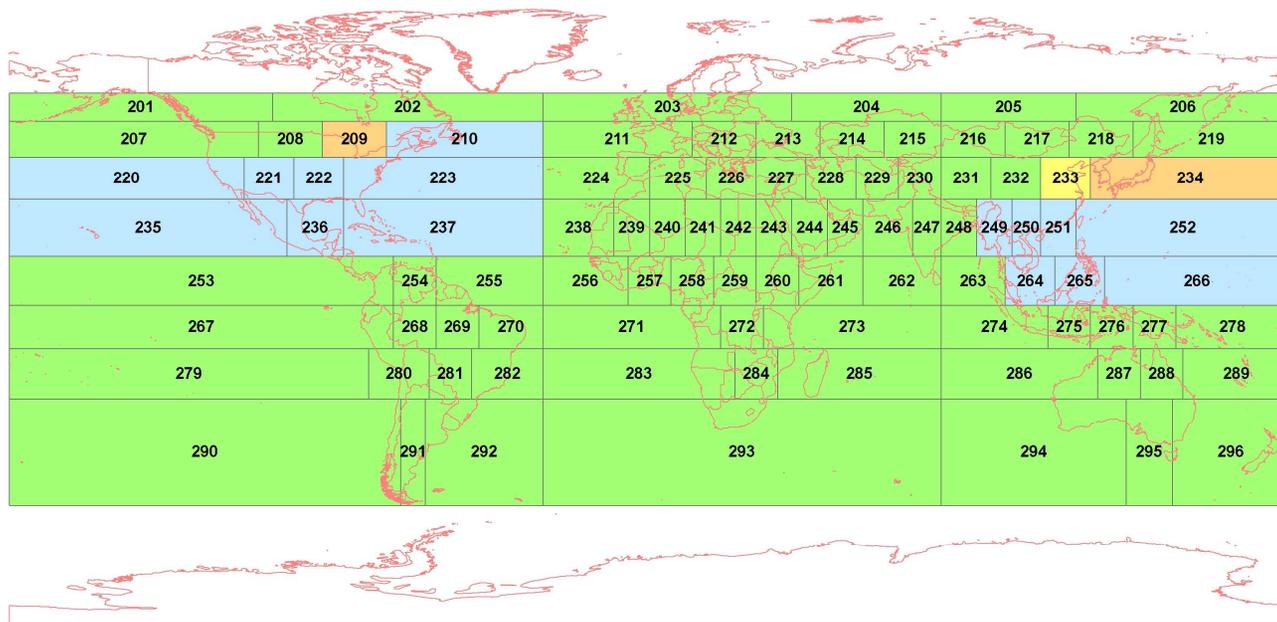
Global Elevation Project - Mean 30-Arc-Second Product



0 70 140 280 420 560 Kilometers



SRTM Generalization Status



Legend

SRTM_Index_SDV2

SRTMF2 Folders - Void Filled

- Processed - Generalized
- In Process - Generalizing
- Ingested
- Unprocessed



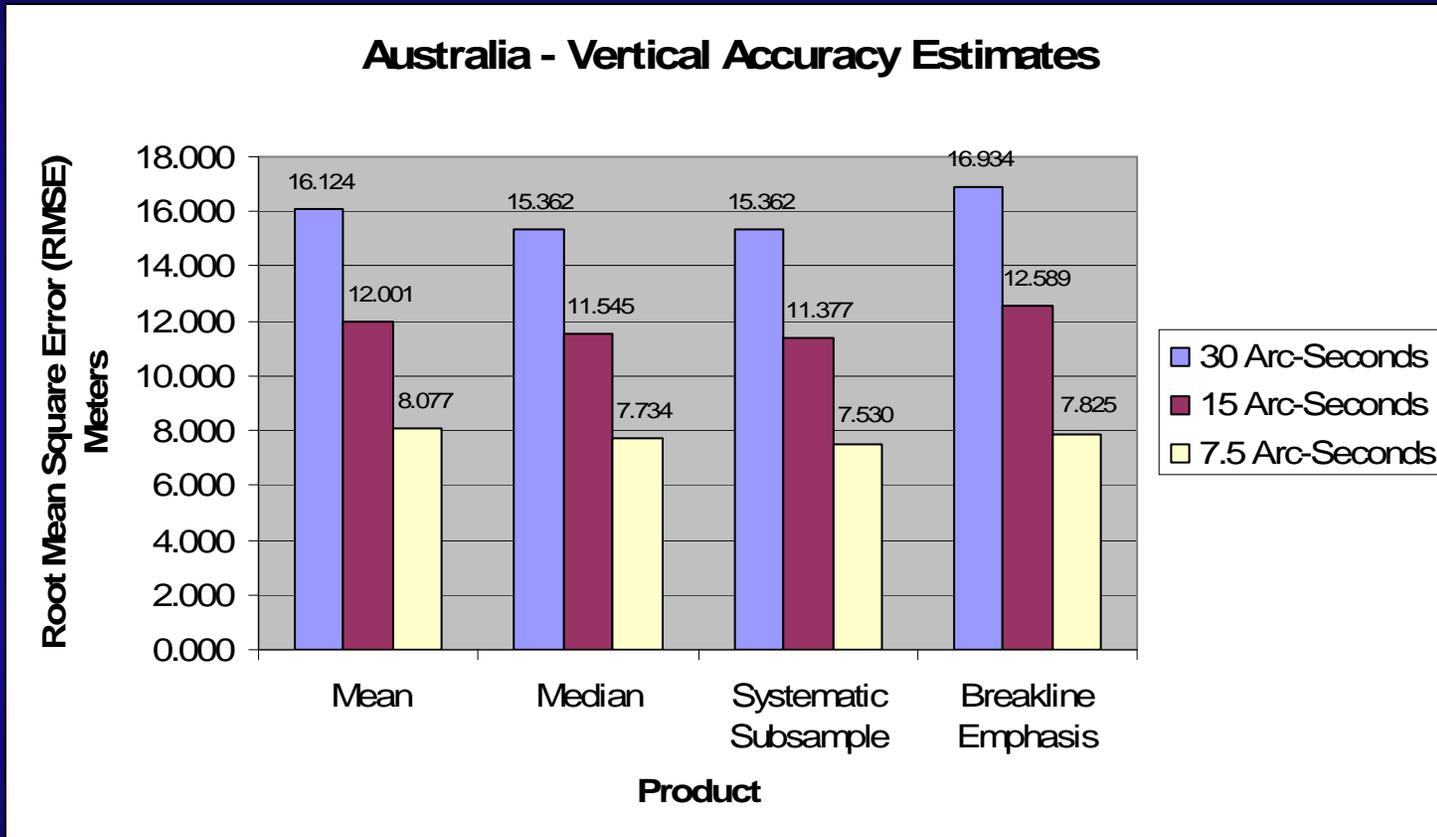
Validation and Evaluation

- **Comparison of the original GTOPO30 with the new 30 arc-second mean product**
 - Image Subtraction (Pixel-Based Surface Difference Map)
 - Elevation Profiles
 - Cross-Validation Prediction
 - Root Mean Square Error (RMSE)
- **Evaluation of the new model with NGA geodetic and photogrammetric control points, and kinematic GPS transects**
 - Elevation Profiles
 - Cross-Validation Prediction
 - RMSE
- **Assessment of the new model with ICESat laser altimeter data**
 - Elevation Profiles
 - RMSE
- **Full Dataset Documentation**



Australia Validation

- Comparison of the new global model with the photogrammetric control points

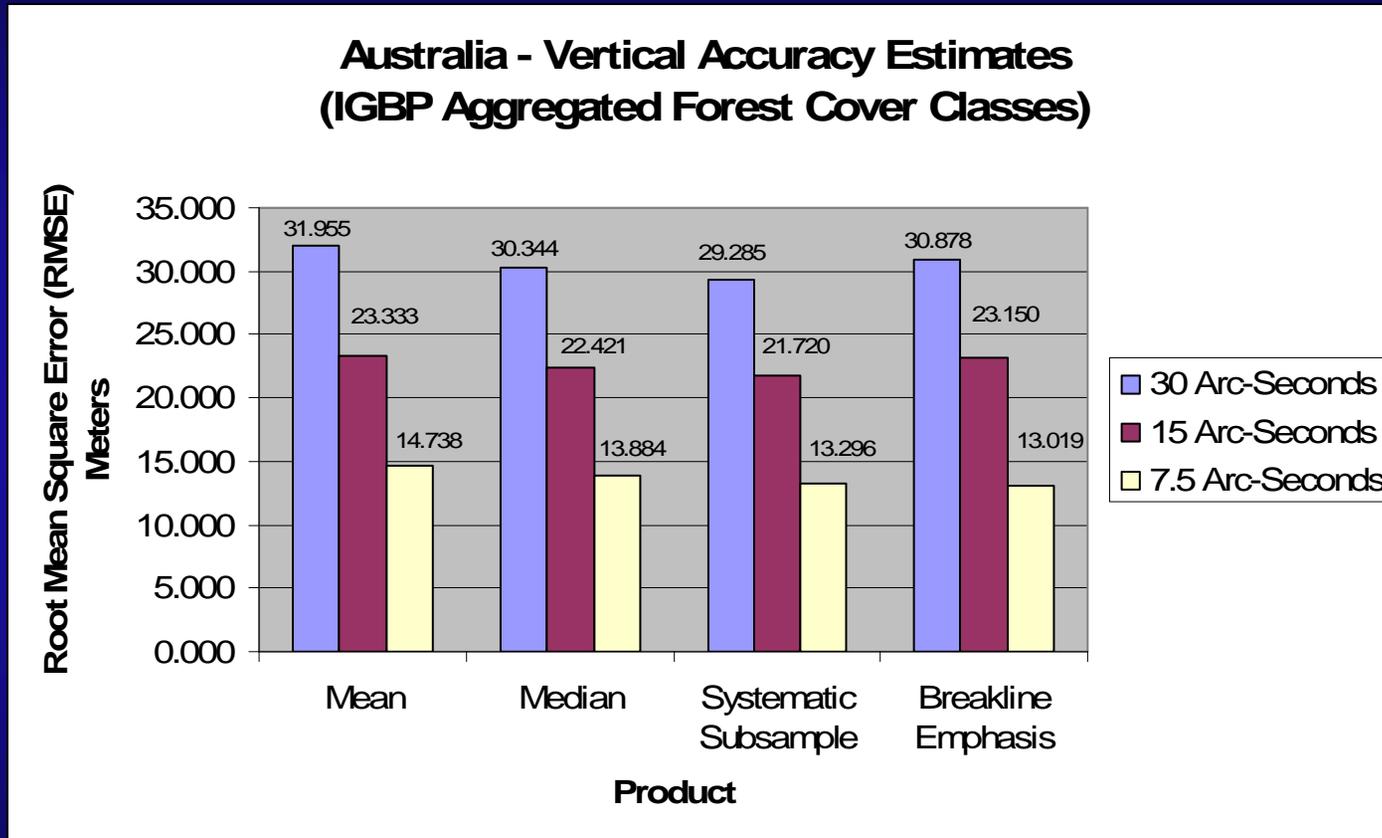


Australia – Vertical Accuracy Estimates



Australia Validation

- Comparison of the new global model with the photogrammetric control points stratified by IGBP forest cover

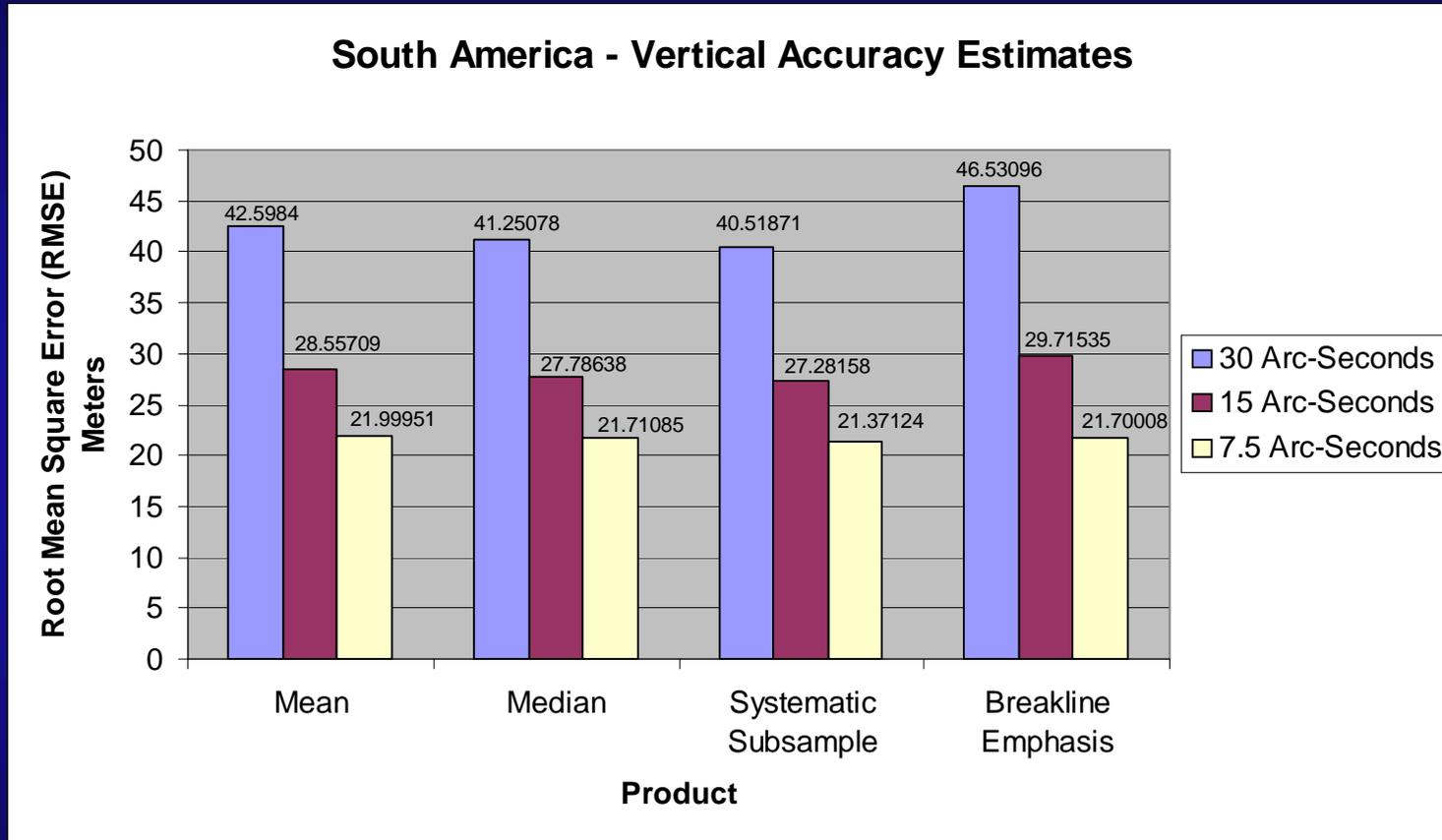


Australia – Vertical Accuracy Estimates (IGBP Aggregated Forest Cover Classes)



South America Validation

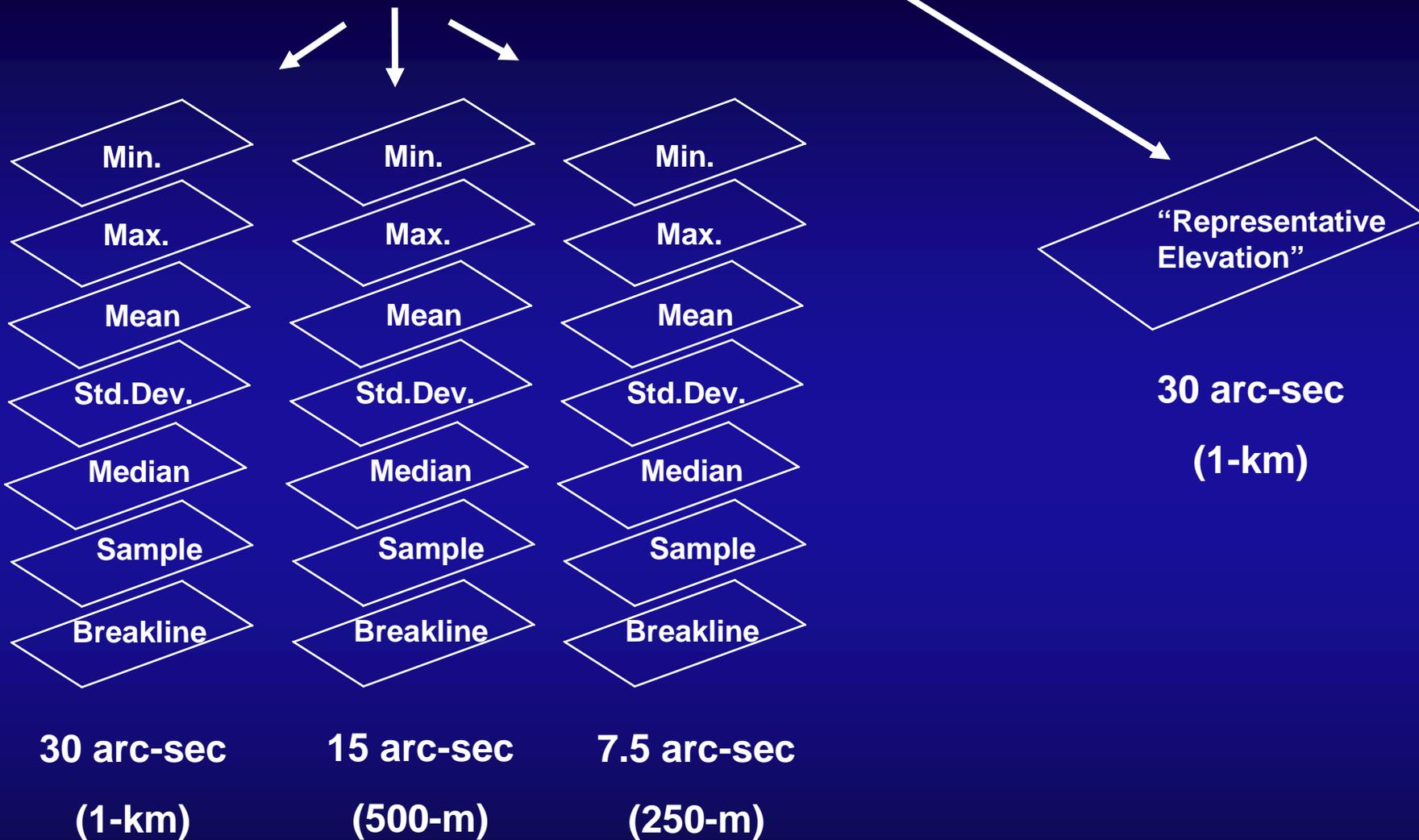
- Comparison of the new global model with the photogrammetric control points



South America– Vertical Accuracy Estimates



New Global DEM vs. GTOPO30



New Global Elevation Model Comparison with other DEMs

DEM	New Global Model	GTOPO30	SRTM	ASTER GDEM
Resolution	30 arc-sec 15 arc-sec 7.5 arc-sec	30 arc-sec	3 arc-sec 1 arc-sec	1 arc-sec
Coverage	Global	Global	60°N to 56°S	83°N to 83°S

- New Global Elevation Model:

- Global / Continental / Regional Applications (not requiring 1 or 3 arc-sec data)
- SRTM Voids Filled
- Will Use ASTER GDEM as Source Data for 60°N to 83°N, if available during project timeline
- Will Use ASTER GDEM as Source Data for Void Filling, if available during project timeline



Conclusions

■ Upcoming Schedule:

- Australia – Completed, June 2008
- South America – Completed, November 2008
- Africa – June, 2009
- North America – August 2009
- Eurasia – September 2009

■ Summary and Benefits

- Develop a fully global medium scale digital elevation model to replace and enhance GTOPO30.
- Generate products at three separate resolutions (horizontal post spacings) of 30 arc-seconds (1-km), 15 arc-seconds (500-m), and 7.5 arc-seconds (250-m) from the best available data sources
- Spatially referenced metadata will be produced for all datasets that constitute the global elevation model
- Products will be made available to the public with no redistribution restrictions



For More Information

USGS Topographic Sciences Home Page:

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