The Shuttle Radar Topography Mission

Data Validation and Applications

June 14-16, 2005

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The Shuttle Radar Topography Mission

Data Validation and Applications Workshop

June 14-16, 2005
Reston, Virginia, U.S.A.

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United States Geological Survey (USGS)

Program

Tuesday, June 14

7:30 am	Registration
8:30 am	Opening Remarks – Dean Gesch, U.S. Geological Survey
8:35 am	Welcome – Barbara Ryan, Associate Director for Geography, U.S. Geological Survey
8:45 am	NGA Perspective on SRTM – Irvin Buck, Deputy Military Executive, National Geospatial-Intelligence Agency
9:00 am	NASA Perspective on SRTM – James Garvin, Chief Scientist, National Aeronautics and Space Administration

The Production Process—Turning Measurements into Final Products

9:15 am	(1) From Raw Data to Digital Elevation Map – S. Hensley, Jet Propulsion Laboratory
9:45 am	(2) The Generation and Dissemination of "Finished" SRTM Data Products by NGA – J. Slater, National Geospatial-Intelligence Agency
10:15 am	(3) Overview of the X-SAR/SRTM Data Processing and Scientific Investigations – M. Werner, DLR-German Aerospace Center
10:45 am	Break

Accuracy Assessment and Comparison with Other Elevation Data

11:00 am	(4) A Global Assessment of the SRTM Accuracy – E. Rodriguez, Jet Propulsion Laboratory
11:25 am	(5) A Comprehensive Assessment of the Shuttle Radar Topography Mission Elevation Data Accuracy – P. Salamonowicz, National Geospatial-Intelligence Agency
11:50 am	(6) Vertical Accuracy of SRTM Data of the United States: Implications for Topographic Change Detection – D. Gesch, U.S. Geological Survey
12:15 pm	(7) An Evaluation of SRTM DTED® 2 Using "Standard" DTED® 2 – B. Heady, National Geospatial-Intelligence Agency

12:40 pm (8) Assessment of SRTM DTED® 2 Accuracy in the Coastal Zone – K. Slatton, University of Florida

1:05 pm Lunch

Accuracy Assessment and Comparison with Other Data *(continued)*

2:05 pm (9) Comparison of SPOT Reference3D Digital Elevation Model Data With SRTM-Derived DTED® Level 2 – V. Rudowski, Institut Géographique National

2:30 pm (10) Assessing the Accuracy of ASTER DEMs as Compared to SRTM DEMs – G. Bailey, U.S. Geological Survey

2:55 pm (11) An Evaluation of the SRTM 3-Arc-second Digital Elevation Data Set within the Upper Hunter Region of New South Wales, Australia – C. Martinez, The University of Newcastle

3:20 pm (12) Topographic Change and Topographic Data Evaluation: SRTM Compared to NED Across the Entire USA – R. Crippen, Jet Propulsion Laboratory

3:45 pm Break

Accuracy Assessment and Comparison with Other Data *(continued)*

4:00 pm (13) Geomorphometry from SRTM: Comparison to NED – P. Guth, United States Naval Academy

Comparison of X-band and C-band Data

4:25 pm (14) Comparison of DEMs Derived from SRTM / X- and C-band – M. Werner, DLR-German Aerospace Agency

4:50 pm (15) Assessment of SRTM X-band Data – J. Little, National Geospatial-Intelligence Agency

5:15 pm (16) How Complementary Are SRTM X- and C-band Data? – J. Hoffmann, DLR-German Aerospace Center

5:40 pm (17) Quantitative Assessment of C-band and X-band SRTM Datasets Over the CEOS-WGCV-TMSG Test Sites and Intercomparison of C-band DEM with the OS® PANORAMA DTM – J-P. Muller, University College London

6:05 pm Adjourn
Poster Setup

6:15-8:15 pm Reception / Poster session

Wednesday, June15

Comparison with ICESat

8:30 am	(18) ICESat Laser Altimetry and SRTM – B. Schutz, University of Texas at Austin
8:50 am	(19) ICESat Validation of SRTM C-band Digital Elevation Models – C. Carabajal, NVI Inc.
9:10 am	(20) Accuracy Assessment of SRTM, ICESat and Survey Control Monument Elevations of Multi-faceted Terrain in Alberta, Canada – A. Braun, University of Calgary
9:30 am	(21) Assessment of the Vertical Error in C-band SRTM DEM Using Data from Landsat-7 and ICESat – K. Bhang, The Ohio State University
9:50 am	Questions and Discussion on Comparisons with ICESat

Canopy Height and Vegetation Mapping

10:10 am	(22) Quality Assessment of Shuttle Radar Topography Mission C- and X-band Interferometric Data: Implications for the Retrieval of Vegetation Canopy Height – J. Kellndorfer, Woods Hole Research Center
10:35 am	Break

Canopy Height and Vegetation Mapping *(continued)*

10:55 am	(23) Comparison of Airborne LIDAR and SRTM C-band Elevations for a Vegetated Landscape – D. Harding, National Aeronautics and Space Administration
11:20 am	(24) The NLCD01-SRTM-NED Synergy in Kentucky: Possibilities and Limitations of Canopy Height Differential Analysis – D. Zourarakis, Kentucky Division of Geographic Information
11:45 am	(25) Forest Region Classification from SRTM Data Over the U.S. – C. Johnston, Vexcel Corporation

Methods

12:10 pm	(26) Multi-Resolution 3-D Wavelets and Splines for DEM Representation and Compression – L. Potts, The Ohio State University
12:35 pm	(27) Methods for Slope Configuration Analysis from SRTM Data – E. Reasor, Boeing
1:00 pm	Lunch

Void Filling

2:00 pm	(28) A Standardized Approach to Phase Unwrap Detection/ Removal and Void Fill of the Shuttle Radar Topography Mission (SRTM) Data – A. Ham, Boeing
2:20 pm	(29) Advanced SRTM DEM Void-Filling in a Production Environment – A. Zobrist, Jet Propulsion Laboratory
2:40 pm	(30) A New Approach for DEM Void Filling Used to Fill SRTM Voids – G. Grohman, National Geospatial-Intelligence Agency
3:00 pm	(31) Filling Voids in SRTM Data - Probabilistic Integration of Elevation Surfaces – E. Wright, Information Extraction and Transport, Inc.
3:20 pm	Questions and Discussion on Void Filling
3:40 pm	Break

Data Products and Distribution

3:55 pm	(32) The ICEDS OGC-Compliant Server for Interactive Global Mapping and Data Delivery Using SRTM and Landsat Data – J. Morley, University College London
4:20 pm	(33) Upgrade to the SRTM Dataset – M. Kobrick, Jet Propulsion Laboratory

Earth Science and Geospatial Applications

4:45 pm	(34) Global SRTM Derivatives for Hydrological Applications at Multiple Scales – B. Lehner, World Wildlife Fund
5:10 pm	(35) Analysis of Large Aeolian (Wind-blown) Bedforms Using the Shuttle Radar Topography Mission (SRTM) Data – D. Blumberg, Columbia University
5:35 pm	(36) Use of Shuttle Radar Topography Mission (SRTM) Digital Terrain Elevation Data to Facilitate Soils Mapping – W. McMahon, National Geospatial-Intelligence Agency
6:00 pm	Adjourn

Thursday, June 16

Earth Science and Geospatial Applications *(continued)*

8:30 am	(37) SRTM Models as Tools to Build a Spatial Data Infrastructure for Colombia – F. Salazar, Universidad de los Andes
8:55 am	(38) Assessment on the Use of SRTM DEM During Post Tsunami Operations – T. Rousselin, Géo212
9:20 am	(39) DEM Production with ERS Tandem and SRTM Data in Italy and Switzerland – F. Seifert, European Space Agency

9:45 am (40) The Geometric Accuracy of GeoCover's Landsat ETM+ Imagery: A Perspective from SRTM – K. Song, University of Maryland

10:10 am Break

Earth Science and Geospatial Applications *(continued)*

10:25 am (41) Impact of SRTM Data on Geospatial Support to US Army Operations – L. Fatale, U.S. Army Engineer Research Development Center – Topographic Engineering Center

10:50 am (42) Improvements in Aviation Safety Through the Use of SRTM Data Products – S. Young, National Aeronautics and Space Administration

Panel Discussion

11:15 am Accuracy Assessment, Reporting, and the Future of Topographic Mapping from Space

J-P. Muller, Chair, University College London and Committee on Earth Observation Satellites

M. Bernard, SPOT Image

J. Feuquay, U.S. Geological Survey

J. LaBrecque, National Aeronautics and Space Administration

P. Salamonowicz, National Geospatial-Intelligence Agency

M. Werner, DLR-German Aerospace Center

12:05 am Closing Remarks – D. Gesch, U.S. Geological Survey

12:15 pm Adjourn

1:30 pm Tour bus departs U.S. Geological Survey (Reston) for the Smithsonian National Air and Space Museum, Udvar-Hazy Center (at Dulles International Airport)

5:00 pm Tour bus departs museum for return to U.S. Geological Survey (Reston)

Poster Presentations

Accuracy Assessment and Comparison with Other Digital Data

(P1) SRTM Data Evaluation Over U.S. Urban Sites – W. Curtis, National Geospatial-Intelligence Agency

(P2) Statistical Measures of Accuracy of SRTM 1- and 3-Arc-second Data in Flat and Undulating Landscapes of the Midwest United States – P. Mercuri, Purdue University

(P3) Vertical Accuracy of SRTM Elevation Data in Argentina – P. Mercuri, Purdue University

(P4) Comparison of SRTM Elevation Data with Other Topographic Datasets for Italy – A. Taramelli, Perugia University

Comparison of X-band and C-band Data

(P5) Comparison of SRTM C-band and X-band DEMs Over Vegetated Areas in South Norway – D. Weydahl, Norwegian Defence Research Est.

Canopy Height and Vegetation Mapping

(P6) Regional Validation of SRTM Elevation Measurements: A Comparison with Medium-footprint Lidar Data Over Various Terrains – M. Hofton, University of Maryland

(P7) SRTM, NED and NLCD 2001 Data: Synergy of National Datasets for Biomass and Carbon Quantification in the U.S. – J. Kellndorfer, Woods Hole Research Center

Void Filling

(P8) Physically Based Interpolation of Data Voids in SRTM Data – O. Hall, Massachusetts Institute of Technology

Data Products and Distribution

(P9) The USGS Approach Toward Archiving and Distributing Shuttle Radar Topography Mission (SRTM) Data – R. Longhenry, U.S. Geological Survey

(P10) SRTM Data Management - A Provisioning Approach – K. Melero, SANZ, Inc.

Earth Science and Geospatial Applications

(P11) Water Slope and Discharge in the Amazon River Using the SRTM DEM – D. Alsdorf, The Ohio State University

(P12) Mapping Surface Processes and Tectonic Geomorphology Using SRTM Data – J. Barbour, Columbia University

(P13) SRTM Water Elevations and their Implications for Ground Water Flow Predictions – M. Becker, State University at Buffalo

(P14) The 2004 Sumatra Tsunami Event: Contribution of SRTM Data to the Analysis of Devastation – D. Blumberg, Columbia University

(P15) Detection of Internal Waves in SRTM Data of the Andaman Sea – T. Farr, Jet Propulsion Laboratory

(P16) SRTM-based Morphometric Analysis of the Poços de Caldas Alkaline Massif, Southeastern Brazil – C. Grohmann, University of São Paulo

(P17) Topographic Normalization of Landsat-class Imagery with SRTM Data – S. Hulina, GDA Corporation

(P18) Development of Aral Sea Basin River Network from SRTM Data – D. McKinney, University of Texas at Austin

(P19) Morphology and Migration of Large Sand Dunes Using SRTM and Altimetric Data – L. Potts, The Ohio State University

(P20) Surface Elevation Change Over Mountain Glaciers from ICESat and SRTM – J. Sauber, National Aeronautics and Space Administration

(P21) Holocene Deformation of a Shoreline in Mono Basin, CA: Comparison of SRTM to TOPSAR and GPS Data – W. Shaffer, State University at Buffalo

(P22) Study of Coseismic Deformation Due to the March 28, 1999 Mw6.5 Chamoli in the Garhwal Himalaya Region and the March 20, 1993 Mw6.2 South-East Tibet Earthquakes Using InSAR – S. Sripati, University of Colorado

(P23) Use of Shuttle Radar Topography Mission Data to Produce an Active Tectonics Map for South Asia – M. Starbuck, U.S. Geological Survey

(P24) Enabling Users to Understand the Impact of Terrain Data Quality on Derived Products - Probabilistic Line of Sight – E. Wright, Information Extraction and Transport, Inc.

ABSTRACTS
Oral Presentations

The Production Process — Turning Measurements into Final Products

(1) From Raw Data to Digital Elevation Map

Scott Hensley, Paul Rosen and Eric Gurrola
Jet Propulsion Laboratory, Pasadena, CA, U.S.A.

In February 2000 the Shuttle Radar Topography Mission (SRTM) carried out a mission to map the world's landmass between ±60° using radar interferometry. The radar mapping instrument consisted of modified versions of the SIR-C C-band and X-band radars flown on the shuttle in 1994. Modifications to the SIR-C radars included a 60 m retractable boom equipped with C-band and X-band receive-only antennas attached to the boom's end. Additional metrology systems designed to measure the shuttle position and attitude, as well as the position of the boom antennas, to high accuracy were also added. To map the world in the 10 days allotted for the mission required the C-band radar to operate in ScanSAR mode. The C-band interferometry data was collected in swaths that were comprised of four subswaths. ScanSAR mapping modes alternately switch between two (or more) beam positions in the cross track direction to increase the swath width at the expense of along track resolution. Exploiting the C-band polarization capability, the SRTM C-band radar operated in ScanSAR mode on vertical (V) and horizontal (H) polarizations to achieve an effective swath width of 225 km while maximizing the SNR over the swath. Operational processing of the C-band ScanSAR interferometric data into a seamless topographic map required several processor innovations. In this paper we present an overview of the SRTM processor and discuss how the raw data was converted into elevation data. Particular emphasis will be on the calibration and filtering of the data during the DEM generation process.

(2) The Generation and Dissemination of “Finished” SRTM Data Products by NGA

James A. Slater
National Geospatial-Intelligence Agency, Reston, VA, U.S.A.

“Finished” SRTM data products were produced in two stages. First, the Jet Propulsion Laboratory turned the raw radar measurements into terrain elevations, height error estimates and orthorectified images in the prescribed DTED® and NITF formats. These data files were forwarded to two NGA contractors, where additional editing was performed and additional products were generated to complete the second stage of the processing. The contractors carried out a series of operations on the JPL products that included (a) an initial quality check for missing files, data blunders and format errors, (b) detection and removal of large anomalous spikes or wells, filling small voids and matching edges of adjacent cells, and (c) generating additional final products such as DTED® Level 1 and an SRTM water body boundary file. The most significant effort involved the identification, delineation and height determination of water bodies (lakes, rivers, coastlines) as required by the DTED® specification. The orthorectified SRTM imagery was used as the primary reference for this task with additional support from Landcover water masks and medium scale maps. All water bodies are depicted as they appeared at the time of the shuttle flight (February 2000). The sheer size of the data set — over 14,000 one-degree by one-degree cells — required development of automated and standardized procedures for processing these data. To achieve a high level of consistency,

NGA developed a standard set of editing rules and production guidelines that were applied at the contractor production facilities. The final suite of related products for each one-degree by one-degree cell consists of two orthorectified image mosaics (one for ascending and one for descending passes), DTED® 2, DTED® 1, Terrain Height Error Data, a Seam Hole Composite Map (documenting strip image seams, missing data, and data alterations), and a vector file of water body shorelines. A subset of the finished SRTM data products has been delivered to the USGS EROS Data Center for public distribution. The rest of the finished products are restricted to the U.S. Department of Defense user community, but are available to other users on a case-by-case basis.

(3) Overview of the X-SAR/SRTM Data Processing and Scientific Investigations

Marian Werner, Achim Roth and Michael Eineder
DLR - German Aerospace Center, Oberpfaffenhofen, Germany

In February 2000, the Shuttle Radar Topography Mission (SRTM) successfully mapped the entire landmass between 60° N and 54° S using the NASA/JPL C-band and the DLR X-band Interferometric Synthetic Aperture Radar Systems. The data acquired were independently processed to Digital Elevation Models (DEM) by NASA-JPL (C-band) and DLR (X-band). A commonly used source was the Position and Attitude Determination Record (PADR) generated by the Attitude Orbit Determination Avionics (AODA) system. The PADR file provided the orbit and baseline information. All X-band data were systematically processed to 1 arc-second resolution DEMs according to DTED® 2 specification and cover a grid with 50 km swath width equal to about 60 million square kilometers on the earth. Processing was finished in summer 2004 and all the X-band DEMs are available via DLR's German Remote Sensing Data Center (DFD).

Principal investigators from all over the world have received more than 1000 image and DEM products from the X-SAR/SRTM data set to perform their proposed experiments and evaluations. Test areas in Europe, Africa, North and South America, Australia and Asia have been used. The major application was to validate the data set and to compare it with other DEM data sources and with the C-band data. There are also investigations about the use in geophysical applications like hydrology, oceanography, geology and forestry but also for archeology, disaster prevention, navigation and traffic monitoring.

This paper presents an overview of the X-Band data processing and results of the scientific use of X-band data elaborated by the PI team. Results reported so far, are indicating that the ambitious mission has performed as expected and the performance achieved fulfills the specifications. The major drawback for a broad use is the gaps in the X-SAR/SRTM data set.

Accuracy Assessment and Comparison with Other Elevation Data

(4) A Global Assessment of the SRTM Accuracy

Ernesto Rodriguez
Jet Propulsion Laboratory, Pasadena, CA, U.S.A.

The NASA/NIMA Shuttle Radar Topography Mission (SRTM) collected interferometric radar data, which has been used by JPL to generate a near-global topography data product for latitudes smaller than 60 degrees. As part of the SRTM mission, an extensive ground campaign was conducted by NGA and NASA to collect ground-truth that would allow for the global validation of this unique data set.

The table below summarizes the SRTM performance observed by comparing against the available ground-truth. All quantities represent 90% errors in meters.

	Continent					
Accuracy	**Africa**	**Australia**	**Eurasia**	**Islands**	**N. America**	**S. America**
Horizontal	11.9	7.2	8.8	9.0	12.6	9.0
Absolute Vertical	5.6	6.0	6.2	8.0	9.0	6.2
Relative Vertical	9.8	4.7	8.7	6.2	7.0	5.5
Long Wavelength	3.1	6.0	2.6	3.7	4.0	4.9

This talk presents a detailed description of how the results in this table were obtained. It also presents detailed characterization of the different components of the error, their magnitudes, and spatial structure.

(5) A Comprehensive Assessment of the Shuttle Radar Topography Mission Elevation Data Accuracy

Paul Salamonowicz
National Geospatial-Intelligence Agency, Reston, VA, U.S.A.

The Shuttle Radar Topography Mission (SRTM) was a joint project of the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). The SRTM not only resulted in an unprecedented near-global Level 2 Digital Terrain Elevation Data (DTED®) set, but also produced Terrain Height Error Data (THED), which quantifies elevation error information locally. This presentation provides results of a comprehensive accuracy analysis of both the SRTM DTED® and THED. The analysis quantifies the absolute and relative accuracy achieved as well as assesses the THED reliability in predicting DTED® error. The results show that the SRTM was very successful. It produced a highly accurate elevation product with predictable error that generally exceeded the absolute error requirements set forth for the mission.

(6) Vertical Accuracy of SRTM Data of the United States: Implications for Topographic Change Detection

Dean Gesch
U.S. Geological Survey, Sioux Falls, SD, U.S.A.

There has been much interest in the availability of SRTM data over the United States because the dataset represents a recent collection of topographic data acquired and processed in a consistent manner, resulting in nearly complete coverage of the nation. Two questions frequently have been asked: what is the vertical accuracy of the SRTM data, and how do the SRTM data compare with the USGS National Elevation Dataset (NED)? SRTM data and the NED have been assessed against a national set of geodetic control points from the National Geodetic Survey (NGS). This set of over 13,000 GPS benchmarks are used by NGS for their gravity and geoid modeling efforts, and the points serve as a useful high-accuracy reference dataset for assessment of SRTM and NED 1-arc-second data over the conterminous United States. In addition to calculation of absolute vertical accuracy, the relationship of specific terrain attributes, including slope, aspect, and local relief, to error in the SRTM and NED has been examined. Overall, the measured vertical accuracy of SRTM is better than 4 meters (RMSE), which far exceeds the mission specification, and the vertical accuracy of the corresponding NED is better than 3 meters (RMSE). The assessment also included analysis of the effects of land cover on vertical accuracy. The USGS National Land Cover Dataset (NLCD), which was derived from 30-meter Landsat data, was used to segment the accuracy assessment by land cover class. Generally, land cover that is more affected by the "first return" nature of SRTM (forested and built-up areas) contributes more uncertainty and a positive bias to the SRTM elevation data. A relative comparison of SRTM and NED also was conducted by differencing the datasets over their entire common extent. The standard deviation of the differences is 5 meters, and the mean difference is 1.75 meters (a positive bias for SRTM relative to NED). The measured absolute vertical accuracies for SRTM and NED are being used in an automated topographic change detection procedure. The change detection methodology makes use of the inherent vertical accuracies of SRTM and NED (segmented by land cover class) to set a threshold for labeling significant topographic surface changes in the SRTM-NED elevation difference dataset. The approach has been employed to complete a national inventory of vertical landscape changes, thus realizing the benefits of pairing the recent topographic "snapshot" provided by SRTM with the historical topographic baseline information in the NED.

(7) An Evaluation of SRTM DTED® 2 Using "Standard" DTED® 2

Barry Heady, William Curtis, Jeff Haase, George Kroenung, James Little and Kevin Tracy
National Geospatial-Intelligence Agency, Arnold, MO, U.S.A.

In order to independently validate the finished SRTM DTED® 2, the National Geospatial-Intelligence Agency (NGA) performed a number of different comparisons of the SRTM DTED® 2 with existing non-SRTM DTED® 2. Statistical comparisons, image and graphical representations, and DEM-to-DEM comparisons illustrate some of the unique characteristics of the SRTM data. "Standard" DTED® is derived from optical sources and references a bare earth surface in most circumstances, while SRTM DTED® is derived from radar measurements and represents the reflective surface. Understanding the differences between the two sources of DTED® is crucial to NGA and its customers so that the SRTM data are not misinterpreted or applied in inappropriate ways. Statistical analysis between non-SRTM DTED® 2 and SRTM DTED® 2 has confirmed that the SRTM data is of equivalent accuracy to non-SRTM DTED® 2. Results of the data comparisons are well within the error bounds of each product. In addition NGA has found that the SRTM DTED® 2 reflective surface solution does not differ greatly from the non-SRTM DTED® 2 solutions in the majority of cases. Additional analysis of specific examples relating to SRTM random vertical noise and phase unwrap error are presented and discussed, as are non-SRTM DTED® 2 artifacts discovered in the course of the analysis.

(8) Assessment of SRTM DTED® 2 Accuracy in the Coastal Zone

K. Clint Slatton, Sweungwon Cheung and Hojin Jhee
University of Florida, Gainesville, FL, U.S.A.

Oceanic phenomena, such as hurricanes, tsunamis, and sea-level rise, and terrestrial processes, such as fluvial erosion and subsidence, continuously modify the world's coastlines. Inland flooding caused by storm surge and extreme wave action is influenced by nearshore topography and bathymetry, which are the surface expressions of the underlying geology. As populations and development in coastal areas continue to increase, natural hazard risks must be accurately estimated. A mathematical framework for fusing data and estimating coastal zone surface elevations and shoreline position is therefore needed so that coastal flooding and erosion mechanisms can be more accurately predicted and mitigated.

The National Oceanic and Atmospheric Administration (NOAA) acquires and maintains many data sets for the U.S. coastal zone. NOAA's National Geophysical Data Center (NGDC) has assembled a single topographic and bathymetric database to provide surface elevations of the U.S. coastline. The primary acquisition modality for the bathymetric data is acoustic sonar deployed from boats. The standard grid spacing of the NGDC Digital Elevation Model (DEM) is 3 arc-seconds (roughly 90m × 90m). The topographic component of the NGDC data is taken from the National Elevation Dataset (NED) developed by the U.S. Geological Survey (USGS) from stereo aerial photography acquired over many years. The topographic data are also provided at a 3 arc-second spacing.

In this work, data from the Shuttle Radar Topography Mission (SRTM) are compared to and fused with the NGDC data. High resolution topographic lidar and bathymetric lidar observations over the shoreline are used to measure the error in the coarse-scale data sets. The study area covers a portion of the South Florida coastline near the city of Miami. Data fusion is carried out using the multiscale Kalman smoother (MKS). MKS is a globally optimal estimator for fusing remotely sensed data. In this work, we employ the MKS algorithm to assess the potential benefits of including SRTM data in the NGDC data set. In particular, we evaluate both vertical and horizontal accuracy of the SRTM DTED® 2 near the coastline. This is accomplished by statistical characterization of the Kalman innovations.

(9) Comparison of SPOT Reference3D Digital Elevation Model Data with SRTM-Derived DTED® Level 2

Veronique Rudowski and Philippe Campagne
Institut Géographique National, Toulouse, France

James Slater
National Geospatial-Intelligence Agency, Reston, VA, U.S.A.

Marc Bernard
SPOT Image, S.A., Toulouse, France

Nicolas Stussi and Steve Miller
SPOT Image Corporation, Chantilly, VA, U.S.A.

This paper presents the results of the comparison between SRTM DTED® level 2 and the SPOT Reference3D Digital Elevation Model product, the latter developed cooperatively by SPOT Image S.A. and the French Institut Géographique National (IGN). The U.S. National Geospatial-Intelligence Agency and SPOT have cooperated in an analysis of these two products to determine compatibility of the Reference3D product for SRTM void/gap filling, and its suitability for extending DTED® coverage to higher latitudes (above 60o North and below 56o South). This paper describes the results of the cross-validation of the two products, and presents the complementary nature of these products and their resulting synergies.

(10) Assessing the Accuracy of ASTER DEMs as Compared to SRTM DEMs

G. Bryan Bailey and Dean Gesch
U.S. Geological Survey, Sioux Falls, SD, U.S.A.

Gayla Evans, Zheng Zhang, Ken Duda, Marian Redlin and Bhaskar Ramachandran
SAIC, Sioux Falls, SD, U.S.A.

Hiroyuki Fujisada
Sensor Information Laboratory Corporation, Sioux Falls, SD, U.S.A.

The ASTER instrument onboard NASA's Terra spacecraft has an along-track stereoscopic capability using a near-infrared spectral band. To acquire the stereo data, ASTER has two telescopes, one for nadir and another for backward viewing, with a base-to-height ratio of 0.6. The spatial resolution is 15 m in the horizontal plane. Parameters such as the line-of-sight vectors and the pointing axis were adjusted during the initial operation period to generate Level-1 data products with the high-quality stereo system performance. The accuracy of the stereo data generated from the Level-1A data is better than 20 m without GCP correction for individual scenes, and as good as 10m with accurate GCPs. Geolocation accuracy that is important for the DEM data sets is better than 50 m. This seems to be limited by the spacecraft position accuracy.

Recent studies examined the accuracy of the Japanese version of the ASTER DEM data product, produced by the ASTER Ground Data System (ASTER GDS) at the Earth Remote Sensing Data Analysis Center (ERSDAC), and the U.S. version of the ASTER DEM data product produced by the Land Process DAAC at the USGS National Center for EROS. In addition, the accuracies of ASTER DEMs generated by two available commercial off-the-shelf software packages were examined. This paper presents the results of these detailed assessments, which examined DEMs from five test sites with different terrain characteristics, and it discusses the results in the context of the accuracy of SRTM-derived DEMs from the same test sites.

(11) An Evaluation of the SRTM 3-Arc-second Digital Elevation Data Set within the Upper Hunter Region of New South Wales, Australia

Cristina Martinez
The University of Newcastle, Newcastle, New South Wales, Australia

The recently released Shuttle Radar Topography Mission (SRTM) 3-arc-second digital elevation data set provides an almost complete coverage of the earth's surface. In this paper the SRTM data is evaluated for a small catchment within the Upper Hunter Valley region of New South Wales, Australia. The importance of scale and source data accuracy to digital elevation model (DEM) quality is investigated by comparing the SRTM data with a number of similar such data sets, including a high resolution 10m DEM created using a Differential Global Positioning System (DGPS) and a 25m DEM obtained from the Land and Property Information NSW (LPI). The 10m DGPS and 25m LPI DEMs were regridded using krigging to a grid spacing of 90m and compared with the SRTM data set both qualitatively (visual assessment) and quantitatively, using a number of well established geomorphic and hydrologic descriptors (area-slope relationship, cumulative area distribution, hypsometric analysis, Strahler statistics and width function). In addition the 10m DGPS DEM was extrapolated at 10m intervals up until a grid spacing of 90m to investigate the effect of increasing DEM grid size on these geomorphic and hydrologic descriptors, and to determine the most appropriate DEM scale for the study catchment. The results demonstrate that the SRTM data provides a very similar catchment representation to the 10m DGPS and 25m LPI DEMs regridded at 90m. The large grid size of the SRTM data however was shown to be too coarse to accurately capture the geomorphic and hydrologic properties of the study catchment, and a 10m DEM gird size determined to be the most appropriate resolution. Consequently, the requirement for qualitative and quantitative assessments of DEMs to ensure accurate representation of catchment geomorphology and hydrology is demonstrated.

(12) Topographic Change and Topographic Data Evaluation: SRTM Compared to NED Across the Entire USA

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This project uses SRTM data for topographic change detection, addresses key aspects of the utility of the data set, and provides a set of highly beneficial products. The results:

- Characterize, verify, and validate the SRTM elevation model.
- Lead to an improvement of the elevation database for the United States.
- Determine types, locations, and magnitudes of recent U.S. topographic changes, both natural and anthropogenic, as well as natural responses to human impacts.
- Demonstrate the use of SRTM data in conjunction with other global data sets for detecting topographic change related to dynamic geologic processes.
- Prepare for the future use of the SRTM data set as the year 2000 global reference against which future topographic change is measured.

The primary task is to conduct a full-resolution visual and numeric analysis of differences between SRTM data and the entire United States National Elevation Dataset (NED), so as to:

- Locate and characterize topographic changes that occurred between the source image dates of the NED and the time of the SRTM flight (February 2000).
- Locate and evaluate production errors in the NED that can be recognized only by comparison to an independently derived elevation model (SRTM).
- Locate and evaluate any problems in the SRTM data set that can be recognized only by comparison to an independently derived elevation model (NED).
- Characterize the relative advantages of the SRTM and NED elevation models.

Results to date show that subsidence, sedimentation, and other patterns of change are evident and measurable in SRTM-NED DEM differences, down to the quantization level of the data (one meter). They also demonstrate the value of SRTM-NED comparisons for the characterization, verification, and validation of both data sets.

(13) Geomorphometry from SRTM: Comparison to NED

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Digital elevation models (DEMs) provide powerful tools for understanding the earth's landforms. The SRTM mission produced 1" and 3" data covering the world, and the near global coverage of publicly available 3" data dramatically improves both the quantity and quality of DEM coverage for the world. For the US, however, the cartographically derived National Elevation Dataset (NED) provides a mechanism to assess the quality of the SRTM data.

We have compared the 1" and 3" SRTM over the continental US with the 1" NED, for a variety of geomorphometric parameters. For about 500,000 sample areas, we have computed the moment distributions (mean, standard deviation, skewness, and kurtosis) for elevation, slope, and curvature. For the basic elevation parameters like average elevation or relief, the two data sets correlate very highly. For the more derived measures like curvature and the higher moments like skewness and kurtosis, the correlations turn out to be much lower, and some (like the kurtosis of profile curvature) prove essentially uncorrelated.

The SRTM data set provides a spectacular new window on the earth's landforms, but users must understand its limitations. Compared to NED, SRTM has too much noise in the flat areas which increases computed average slope, while in high relief areas SRTM provides too much smoothing of topography and lower average slopes compared to NED.

Comparison of X-band and C-band Data

(14) Comparison of DEMs Derived from SRTM / X- and C-band

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The Shuttle Radar Topography Mission in February 2000 had two 'single pass' interferometric radar systems on board which are the C-band system of NASA/JPL and the X-band system from DLR. Both systems have been operated simultaneously during the mission. Independent processors have been developed to produce the digital terrain models. Both systems used the same Position and Attitude Determination Record (PADR) generated by the Attitude Orbit Determination Avionics (AODA) system. The PADR file provides the orbit and baseline information. Meanwhile the processing of all data has been finished and the digital height models and radar images are available to the public. Height error maps accompany the digital terrain models.

The proposed presentation shall compare the X- and C-band derived elevation models. Starting from the individual verification results the correspondence of the SRTM DEMs with respect to height and location accuracy shall be investigated. Potential global and local discrepancies shall be discussed. Where available both data sets will be compared to reference data like radar altimeter and local high resolution reference data sets. With SAR interferometry we measure the location or height of a representative phase centre of the backscattering resolution cell. C-band radar waves should have a higher penetration into the vegetation than the X-band waves. This should lead to differences in the interferometric height measured in the two systems over forested areas. In this paper the height differences observed in dependence of density and forest type is shown for some selected typical test sites. The resulting height differences are not very significant and well within the height error boundaries of both systems. Volume decorrelation had no significant impact due to the relative small baseline available for SRTM.

(15) Assessment of SRTM X-band Data

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The National Geospatial-Intelligence Agency (NGA) entered into a limited data exchange agreement with the German X-band data producers in late 2003/early 2004 for the purpose of comparing the elevations derived from the SRTM C-band data versus the elevations derived from the X-band system carried on the Space Shuttle. NGA received several one-degree by one-degree X-band cells at a resolution comparable to the C-band SRTM DTED® 2 for evaluation. The corresponding NGA C-band data sets were sent to Germany's Federal Ministry of Defense for their evaluation. NGA assessed the overall characteristics of the X-band data and was particularly interested in the X-band data as a potential source for filling voids in the C-band data. NGA concluded that the X-band data would not be useful as a potential source for C-band void fill based on an assessment of the X-band coverage and random noise associated with the X-band data in areas where X-band has coverage and C-band does not.

(16) How Complementary Are SRTM X- and C-band Data?

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Two separate digital elevation models (DEMs) were created from the C- and X-band data acquired during the SRTM mission. Although a joint analysis of the raw data from both frequencies would have facilitated the DEM creation and undoubtedly resulted in a superior final product, there were political reasons to process the X- and C-band data sets largely independently at the German Aerospace Center (DLR) and the Jet Propulsion Laboratory (JPL), respectively. The different choices made during the interferometric processing have resulted in two largely independent DEMs, despite their shared geometry.

Here, we compare the errors and characteristics of the two DEMs for four test sites with different terrain types. We find significant differences in the area and distribution of invalid regions and the error statistics. Based on these differences we then evaluate how merging the DEMs into a single, improved DEM using the error estimates accompanying the elevation data improves the completeness and accuracy of the DEM.

(17) Quantitative Assessment of C-band and X-band SRTM Datasets over the CEOS-WGCV-TMSG Test Sites and Intercomparison of C-band DEM with the OS® PANORAMA DTM

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The CEOS working Group on Calibration/Validation (WGCV) Sub-group on "Terrain mapping from satellites" (of which the author is Chair) have selected a number test sites in Europe and the US for a comparative assessment of different DEM extraction techniques. Two of these sites are in the UK and one in the US.

For "ground truth", the UK sites include kinematic GPS from the LANDMAP project (Muller et al., 1999), a 50m OS® PANORAMA DTM and 5 areas of 10 x 10km containing 5m airborne interferometric SAR derived DEM from Intermap Technologies (NextMap). The US site at

Puget Sound includes both National Elevation Dataset (NED) from USGS and 2m lidar (top and bottom of canopy) DEM commissioned by Federal and local organisations. In all cases, Landsat data is available for ease of interpretation and in the US the National Land Cover Dataset (NLCD) is also available.

For one of the UK sites, North Wales, 1-arc-second X-SRTM DEMs were available. For all 3 sites, 3-arc-second C-SRTM DEMs (both finished and unfinished) and for the US site, 1-arc-second DEMs were also available.

Results indicate that for all 3 test sites as for other CEOS test sites within Europe, after taking into account local datums, there is still a planimetric misregistration between the SRTM DEM products and all other products. We report here on whether this is an inherent problem with the GIS data analysis tools (ENVI, ARCgis) or a problem with the SRTM DEMs. Most height differences after correcting for this mis-coregistration appear to be due to forest cover with a small effect in very rugged areas due to SAR look angle in steep sided valleys. We show how the resultant difference maps can be used for the UK to estimate both woody biomass and material flow. The SRTM DEMs have an overall mean difference of around 1m and a standard deviation in the range 4-6m. The effect of the finishing process on C-SRTM DEMs will also be reported and how penetration depth at the different wavelengths is related to landscape object properties.

Muller, J.-P., J.G. Morley, A. Walker, J. Barnes, P.A. Cross, I.J. Dowman, K. Mitchell, A. Smith, K. Chugani, and K. Kitmitto (1999). The LANDMAP project for the creation of multi-sensor geocoded and topographic map products for the British Isles based on ERS-tandem interferometry, in Proc. Second International Workshop on ERS SAR Interferometry on "Advancing ERS SAR Interferometry from Applications towards Operations", ESA, 10–12 November 1999, Palais des Congrès, Liège, Belgium.

Comparison with ICESat

(18) ICESat Laser Altimetry and SRTM

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A new spaceborne geodetic tool was placed into a 600 km, near polar Earth orbit in January 2003. Although the laser altimeter carried on ICESat, known as the Geoscience Laser Altimeter System (GLAS), was designed to generate high accuracy profiles of the polar ice sheets to enable detection of surface change, many other applications of the instrument have been demonstrated, such as land topography, vegetation canopy height, hydrology and atmospheric characteristics. With a laser pulse repetition rate of 40 Hz and a 60-meter laser footprint on the surface, successive illuminated laser spots (footprints) are separated on the surface by 170 meters. The GLAS instrument has been shown to produce an altitude measurement of 2-3 cm precision, depending on the surface characteristics within the illuminated laser footprint. ICESat instrumentation enables determination of the direction of the laser pulse, which in turn supports the determination of the geodetic location of the laser footprint centroid (geodetic latitude, longitude and ellipsoidal height). The agile satellite allows pointing the laser at targets of opportunity as well. A variety of tests have been applied to validate the accuracy of the resulting laser altimeter surface profiles. Current accuracy estimates of the laser footprint location are decimeter level in geodetic height and 15 meters in horizontal position (latitude/longitude). Ongoing calibration/validation efforts are expected to improve these accuracies. With the current demonstrated performance of GLAS, it is evident that the laser profiles can serve as geodetic control points for other instrumentation, such as SRTM-derived topography. Examples of offsets between SRTM topography and the laser-derived elevation profiles are shown for a variety of land types such as salt flats, paleodunes, river deltas, marshes, and vegetated areas. For example, in the Okavango Delta area of Botswana, differences are typically 1 to 3 meters and occasionally 5 to 10 meters.

(19) ICESat Validation of SRTM C-band Digital Elevation Models

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Understanding the quality of the DEM data sets is crucial to their use in land process studies, as inputs to models, and in detection of change obtained from comparison of DEMs acquired at different times. Elevation data from the Geoscience Laser Altimeter System (GLAS) on board the Ice Cloud and Land Elevation Satellite (ICESat) provides a globally distributed data set that is well suited to evaluate the vertical accuracy of Digital Elevation Models (DEMs), such as those produced by the Shuttle Radar Topography Mission (SRTM). Here we document elevation differences between the SRTM C-band DEM and ICESat 1064 nm altimeter channel data. GLAS received echo waveforms enable estimation of SRTM radar phase center elevation biases with respect to the highest, centroid (distance-weighted average), and lowest elevations detected within the 80 m diameter ICESat laser footprints. Distributions of ICESat minus SRTM elevation differences are quantified as a function of SRTM local relief, percent tree cover (from the MODIS Vegetation Continuous Fields product), and waveform extent, a surrogate for total relief due to canopy height and ground topography. The results provide insights into C-band penetration into vegetation, and resulting biases with respect to the canopy top and underlying ground. The SRTM phase center is usually located between the ICESat highest and lowest elevations, and on average is closely correlated with the ICESat centroid. Regional comparisons have been completed for the northwestern United States, southern Alaska, the Amazon basin, east Africa, the Himalayas and Tibetan Plateau, and western Australia.

(20) Accuracy Assessment of SRTM, ICESat and Survey Control Monument Elevations of Multi-faceted Terrain in Alberta, Canada

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The Shuttle Radar Topography Mission (SRTM) has provided homogeneous and highly accurate data for Digital Elevation Models (DEM). The accuracy of the DEM depends on various factors including the roughness of the terrain, the slope of the terrain and the determination of the antenna positions onboard the shuttle. Both C-band and X-band DEMs show intrinsic errors of about 5-15 meters, limiting the accuracy of absolute height determination in numerous applications. A comparison and a potential calibration using more precise, but point-wise, height information is conducive to improve the SRTM derived DEMs. In Alberta, there are currently over 30,000 Alberta Survey Control Monuments (ASCM) that are primarily used for natural resources management and in particular as reference elevations for well-sites.

There are also approximately 200 GPS-on-benchmarks situated throughout the province. The values at these control monuments are typically established through conventional terrestrial leveling surveys. The NASA laser altimetry mission ICESat (launched in January 2003) provides height observations on land, ocean, vegetation and ice. Approximately 900,000 footprints are available along satellite tracks (with variable spatial resolution) in the province of Alberta. In this paper, the ASCM, GPS-on-benchmarks and ICESat elevations are used to quantify the differences with respect to SRTM derived DEMs in order to assess the accuracy over diverse terrain. A preliminary study in selected areas (North Dakota and Ibiza) indicated that the mean difference between SRTM 30-meter DEM and ICESat elevations is 0.59 m +/- 1.5 m, which demonstrates the potential of calibrating the SRTM elevations using ICESat values referring to a common vertical datum. The analysis focuses on data issues such as an inherent noise level in the SRTM data, datum transformations between the local vertical datum and the global vertical datum implied by SAR and altimetry data, calibration of elevations, and an assessment of the relation between surface type/roughness and height differences/uncertainties.

(21) Assessment of the Vertical Error in C-band SRTM DEM Using Data from Landsat-7 and ICESat

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The successful Shuttle Radar Topography Mission (SRTM) mission provided scientists with land-surface data necessary to study processes on a global scale with highly consistent accuracy. Experience with the SRTM DEM indicates that it does not exactly match the true surface elevation of the ground derived from other remote sensing datasets. SRTM DEMs include various types of errors in the vertical direction, due to motion of the 60 m antenna baseline and backscatter characteristics of radar phase from ground features. This study compares elevation values of the C-band SRTM 30-meter DEM with point wise elevations from ICESat laser altimetry to classify errors in the SRTM DEM. The accuracy measure is separately calculated as a function of the land use cover derived from the Landsat-7 image and geomorphological characteristics of the land surface. By separating the study into different geomorphology and land use cover, it is possible to identify SRTM DEM uncertainties over different surface types. This study addresses Otter Tail County, MN, and examines elevation differences between the SRTM DEM and ICESat elevations. Over different surface types, the SRTM 30-m DEM can be adjusted (bias removal) and improved using highly precise ICESat elevations as ground control points. The classified land use cover is categorized into water, wetlands, forest, urban areas, and bare rock/soil, while the geomorphological characteristics include outwash plain, collapsed outwash, hummocky moraine, and ground moraine. The errors in the C-band SRTM DEM are most commonly associated with the land use types rather than geomorphological categories. Also, the typical mean vertical difference between the SRTM DEM and ICESat was found in each classified land use type to be approximately 1.5 m, with the SRTM DEM measuring lower elevations. Forest typically shows much greater RMS errors than the bare rock/soil area of more than 5 m. Because the C-band SRTM DEM contains the vegetation/canopy height, the mean bias with respect to ICESat was maximized in forest and minimized in bare rock/soil. However, ICESat elevations do also deliver canopy heights, depending on the penetration of laser pulses through forests.

Canopy Height and Vegetation Mapping

(22) Quality Assessment of Shuttle Radar Topography Mission C- and X-band Interferometric Data: Implications for the Retrieval of Vegetation Canopy Height

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SRTM distinguished itself as the first seamless near-global spaceborne mission to demonstrate direct sensitivity to the vertical structure of vegetation (Treuhaft et al., 2004). This sensitivity has prompted recent efforts to investigate the feasibility of leveraging SRTM data as a source for regional- to continental-scale estimates of vegetation canopy height (Kellndorfer et al., 2004). Applications such as canopy height retrieval require an awareness of several key SRTM data characteristics and an understanding of their potential to impact data quality, i.e., vertical accuracy and horizontal spatial resolution. A study was, therefore, undertaken to assess the quality of SRTM C- and X-band digital elevation data in terms of vertical accuracy and horizontal resolution. In the case of SRTM, relative errors (local 200 km scale) due to uncompensated mast motion and high-frequency phase noise have perhaps the greatest influence on vertical accuracy. Spatial resolution is governed largely by imaging system parameters (e.g., pulse bandwidth, effective antenna length, etc.), but can be adversely affected by processing requirements (e.g., noise filtering). A detailed analysis is presented using co-located C- and X-band DEM data from four study sites located in North Dakota (2), Iowa (1), and southeast Michigan (1). Site selection was based on (1) the existence of X-band coverage, (2) the presence of level terrain, (3) the dominance of row-crop agriculture, and (4) the number of SRTM datatakes processed. Techniques are presented for quantifying and mitigating errors due to uncompensated mast motion and phase noise in SRTM DEMs. Errors due to uncompensated mast motion were found to be approximately 4 m for X-band and 1 m for C-band. Phase noise was observed to be more pronounced in X-band where fewer datatakes were processed than in C-band where a greater number of datatakes were acquired. Building on previous research, results of an effort to quantity the horizontal resolution of the C- and X-band DEMs are also presented. In both cases, horizontal resolution was found to be less than two SRTM pixels.

(23) Comparison of Airborne LIDAR and SRTM C-band Elevations for a Vegetated Landscape

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The C-band Digital Elevation Model (DEM) produced by the Shuttle Radar Topography Mission (SRTM) represents the elevation of the phase center produced by reflection of radar energy with a wavelength of 5.6 cm. C-band penetration into forest cover and the resulting phase center elevation depends on the distribution and density of the vegetation. High-resolution DEMs for the western flank of Mount Rainier, WA representing the highest detected surface (canopy top where vegetated) and underlying ground are used to assess SRTM C-band elevations for a landscape of variable relief with forested and cleared patches. The high-resolution DEMs were produced by airborne laser swath mapping with small-diameter (< 1 m) diameter footprints, an average density of 2 footprints per square meter, and detection of up to four discrete returns per laser pulse. SRTM elevation differences with respect to the highest surface and ground are evaluated as a function of vegetation height and density and topographic slope and azimuth. In mature forest stands, taller than 20 m, the phase center is nearly always located between the canopy top and ground. The depth of the phase center below the canopy top increases with increasing canopy height, perhaps because the ruggedness of the outer canopy surface increases as forests mature. In intermediate stature stands (5 to 20 m) the SRTM phase center varies from above the canopy top to below the ground. In un-vegetated areas, the SRTM phase center to ground elevation difference has a bimodal distribution; the peaks are ~ 3 m below the ground (probably due to an SRTM elevation bias) and ~ 20 m above the ground. The latter peak is due to clearings within forests where SRTM apparently senses the adjacent stands. The mean and variance of the SRTM phase center to ground elevation difference is correlated with local slope azimuth; the phase center is biased high from 30° to 300° and low from 300° to 30° and the variance is a maximum from 30° to 90° and 220° to 270°.

(24) The NLCD01-SRTM-NED Synergy in Kentucky: Possibilities and Limitations of Canopy Height Differential Analysis

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In a previous analysis (Zourarakis, 2003), polygonal and linear landscape features with contrasting elevations relative to their surroundings were noticed when examining SRTM data in areas of Central and Western Kentucky with uniform topographic relief. These features were ground-truthed and shown to correspond to peculiar patterns in the distribution of wooded areas, treed fence lines, municipal landfills and buildings. In addition, a reasonable spatial agreement between isolated forested areas – or forest blocks - as mapped in the Kentucky portion of the 2001 National Land Cover Dataset (NLCD01), and the SRTM-National Elevation Dataset (NED) differences were shown to occur in the Western regions of Kentucky. This paper analyzes the distribution of SRTM-NED canopy height differentials in relation to the NLCD01, and their potential utilization for feature extraction in regions of Kentucky with varying topography.

Zourarakis, D.P. (2003). “Kentucky’s Own “Faces on Mars”: NASA’s SRTM Data and Tree Canopy Height”, Kentucky State GIS Conference, Louisville, KY, August 18-21, 2003.

(25) Forest Region Classification from SRTM Data Over the U.S.

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The results of a preliminary study of the potential of using the SRTM Terrain Height Error Dataset (THED), ascending and descending orthoimage mosaics (OIMs), and DTED® to distinguish foliage from bare earth pixels will be presented. We extracted large sample sets of feature vectors from coregistered SRTM datasets over the U.S.; five sites were used. We determined their landcover classification using the National Land Cover Dataset as truth. We then used statistical image processing techniques to determine axes of separation for the two classes. Our preliminary conclusion is that this data has the potential to be used to derive estimators of forest vs. bare-earth/low vegetation coverage on the ground. The optimal estimators vary regionally; for example, the best estimators in Mississippi are not the same as those in Oregon. Feature separation appears to be better in regions with multiple coverage, i.e., in the north. Detailed results and directions for further research will be discussed. Note that the SRTM THED and OIMs are “Limited Distribution” data products.

Methods

(26) Multi-Resolution 3-D Wavelets and Splines for DEM Representation and Compression

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Satellite and airborne sensors that monitor the Earth routinely for various scientific and military applications produce large amounts of data, including the data produced to generate SRTM DEM data products. The utility of these huge amounts of accurate and high-resolution geospatial datasets places great demands on computation, storage, user-access and manipulation capabilities. An additional demand is associated with merging heterogeneous data types with distinct accuracy and resolutions (or data fusion), for example, to construct DEMs or geospatial data products for feature tracking and analysis. A crucial component is to develop mathematical algorithms for geospatial data processing, representation and analysis. Current approaches to reconstruct DEMs or DTED include gridding data and very high degree spherical harmonic expansions commensurate with the data resolution, which could potentially run into numerical problems. Multi-resolution 3-D wavelets and splines, on the other hand, include spherical wavelets and bivariate, trivariate and spherical spline functions that are capable of efficient multi-resolution decomposition and potential compression for efficient data representation, retrieval and analysis. This paper focuses on the utility of wavelets and splines developed for efficient representation of SRTM data (and other similar geospatial datasets) and their geophysical applications.

(27) Methods for Slope Configuration Analysis from SRTM Data

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The availability of near-global terrain information from the SRTM mission provides a new source to those interested in terrain analysis. A traditional terrain analysis product is slope configuration. Slope configuration analysis has been used in several terrain analysis products including Tactical Terrain Analysis Data Base (TTADB), Interim Terrain Data (ITD), and more recently Vector Product Format Interim Terrain Data (VITD). SRTM data has unique characteristics that can cause differences in slope configuration analysis when compared to traditionally collected terrain data sets. These differences are most apparent in the flatter categories of slope where a one-meter difference between adjacent elevations can cause a change in the slope category. A fully automated slope generation algorithm will be presented that attempts to mimic the traditional manual process in order to produce results that minimize the effects of SRTM data on the resulting analysis.

Void Filling

(28) A Standardized Approach to Phase Unwrap Detection/Removal and Void Fill of the Shuttle Radar Topography Mission (SRTM) Data

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The data collected during the Shuttle Radar Topography Mission contains a number of artifacts inherent to Interferometric Synthetic Aperture Radar (IFSAR) data, including phase unwrap errors and voids. Boeing, along with Intermap Technologies, is working with the National Geospatial-Intelligence Agency (NGA) to enhance the SRTM Digital Terrain Elevation Data (DTED®) by detecting and removing phase unwrap errors, and by filling voids in the data. This is done using Boeing's Continuous Surface Merge algorithm to feather elevation data from alternate sources into the SRTM DTED®.

Just as a standardized approach for finishing the DTED® was essential, it is also important for the enhanced, void-filled version of the data to be approached in this fashion. By applying uniform processes in a high-volume production environment Boeing and Intermap are updating not only the DTED®, but the entire SRTM product suite, including the Terrain Height Error Data (THED), Seam Hole Composite Map (SHCM), and SRTM Water Body Data (SWBD). This will ensure that users have a consistent elevation dataset, even after the original data has been enhanced.

An overview of the phase unwrap error detection and removal process, void filling techniques, and comparison to the results of other void fill methods will be presented. SRTM data users will see the benefit of approaching the void filling of SRTM data with this thorough, systematic, and streamlined process.

(29) Advanced SRTM DEM Void Filling in a Production Environment

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With completion of the joint NASA/DOD SRTM mission, several DOD agencies identified an immediate need for a preliminary version of the SRTM DEM product. To support the most important client needs, an advanced "void-filling" algorithm was developed to accurately fill the SRTM DEM holes with DTED® "Level 1" data (where available, and coarser GLOBE/NGDC data where unavailable). The developed algorithm optimally preserves the filler's terrain relief while adjusting the filler's elevation values to properly match/fit with the adjacent SRTM elevation values.

The void-filling algorithm begins when a group of pixels with the value –32767 (the void) are found. The void is viewed as a connected component in the SRTM, and has its edge pixels saved in a list. Based on accurate georeferencing, the area corresponding to the hole is cut from the filler DEM and bilinear-resampled to cover the void and overlap the SRTM edge pixels. The elevation differences of all the overlap pixels are calculated into the list and an average taken. The entire fill area is boosted by the average to get an approximate fit with residuals at each overlap pixel. Finally, each pixel in the fill area is boosted by a weighted average of the residuals, where the weight is set to 1/power (distance-squared), where 'distance' is the distance from the pixel being adjusted to the edge pixel. The power is user selectable from 0.5 to 3.0, but empirical analysis determined that a value of 2.0 produced the best results.

To support void filling and correct for other SRTM artifacts, the data processing was performed using the VICAR/IBIS image processing and geographic information system in a production-like environment due to the large number of DEM cells and variety of terrain involved. The processing scheme involved several steps, including the correction of land/water coastlines, the flattening of ocean "terrain," and the filling of holes in water and "sand seas" where the radar beams reflected away. After correction of the various artifacts, the resulting DEM product is believed to be a valid 'preliminary' product that can service many DOD requirements until the official NGA SRTM void-filled DEM product becomes available.

(30) A New Approach for DEM Void Filling Used to Fill SRTM Voids

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The current state of the Digital Elevation Model void filling art has remained relatively unchanged over the past several decades. To take a void area of an elevation model, fill in the next best available elevation source, perhaps remove a void perimeter bias, and then to feather around the interfaces of the void to make for a better cosmetic appearance has been the standard process. This process only works well when the two surfaces are very close together and perhaps only separated by a slight bias. This process is referred to as the fill & feather (FF) method of void filling. A new methodology is introduced here that changes this paradigm. We know we can't simply interpolate across the void with any kind of certainty. However we can interpolate the values in the void area within the difference (delta) surface between the two surfaces and add those values to the fill surface. This process moves the fill surface to the parent surface in such a way as to create a better fit. This will cause the fill source to more closely emulate the original parent surface, especially close to the void interfaces. Due to the continuous nature of terrain data, there will be no need for feathering. We call this new process the Delta Surface Fill (DSF).

We will focus on the case of SRTM data for our tests. We will create a new methodology where an analyst can simply, quickly and more appropriately repair voids in his DEM data.

(31) Filling Voids in SRTM Data - Probabilistic Integration of Elevation Surfaces

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A characteristic of SRTM data is the presence of data voids that result from radar shadow or other artifacts of the processing. This presentation describes an approach for filling voids by integrating SRTM2 data with lower quality elevation data. The algorithm is based on research that has developed, implemented and demonstrated a new capability to statistically merge different elevation files in a way that generates an updated estimate of the accuracy of the merged data. The theory includes consideration of spatial correlation, and is able to handle data whose data quality has not been completely specified (second order uncertainty). The theory can be extended to other spatial data representations (for example, vector or object representations). In addition to the application of filling voids in SRTM data, this data integration capability is one example of the kind of advanced data integration capabilities needed to support spatial data management especially in the current environment of heterogeneous data production.

Data Products and Distribution

(32) The ICEDS OGC-Compliant Server for Interactive Global Mapping and Data Delivery Using SRTM and Landsat Data

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The Department of Geomatic Engineering at University College London (UCL) and ESYS plc have been funded by the British National Space Centre (BNSC's) International Co-operation Programme 2 (ICP-2) to develop a web-based GIS service as a CEOS-WGISS prototype: ICEDS, the Integrated CEOS European Data Server. Particular aims of the completed first year of the project were to:

1. exploit Open Geospatial Consortium (OGC, recently renamed from the OpenGIS Consortium) technologies for map and data serving;
2. serve datasets for Europe and Africa, particularly Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) and Landsat TM data;
3. provide a website giving access to the served data along with global medium resolution datasets and cascaded services from other Web Map Servers;
4. provide software scripts and a document describing the data processing and software set-up methods developed during the project.

The SRTM data currently served from ICEDS is the unedited dataset downloaded in tiles in gzipped HGT files from the USGS FTP site. In order to be served on the ICEDS web portal and through an OGC Web Map Service (WMS), the SRTM data were colour hill-shaded with oceans and principal inland water bodies masked out. The decision was made not to attempt to fill the gaps in the unedited data but to highlight these regions as a form of qualitative validation. As a result of the hill-shading and masking process, unfilled pixels in the DEM appear as bright red in the final hill-shaded images. Two sub-sampled pyramid layers were created from the hill-shaded image for faster access. In addition to a WMS, ICEDS also provides a Web Coverage Service (WCS) allowing direct connection not to rendered views of the data but to the original data – in this case, the unedited SRTM elevations as a seamless layer. ICEDS is publicly accessible both through its Web portal (http://iceds.ge.ucl.ac.uk) and by WMS and WCS connections.

In using and testing the ICEDS site, the highlighting of unassigned pixels in the SRTM DEM has proved of great use in validating the dataset. Interesting regions of poor acquisition (e.g. areas in the Sahara) become immediately visible at the small (continental) scale and can be interactively zoomed to see more detail. They can then be compared against Landsat images to help to interpret the areas. NGA has kindly made available the inland water mask at 30m partially derived from the SRTM products. This can be overlaid over the hill-shaded SRTM DEMs as well as the Landsat TM mosaics of Europe and Africa kindly made available by Dr. Nevin Bryant at JPL. This is also very helpful in discovering artifacts as well as geocoding offsets between Landsat and SRTM. An interactive demonstration of the web site and its utility for data exploration and validation will be given.

(33) Upgrade to the SRTM Data Set

Mike Kobrick
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The National Geospatial-Intelligence Agency has completed editing the SRTM DEM data set. This editing consisted of flattening water bodies, i.e. adjusting the data such that lake and ocean surfaces are at constant elevations, defining shorelines such that they will be one meter higher than adjacent water elevations, assuring that mapped river surfaces decrease in elevation in the downslope direction, and filling small voids. This editing represents a significant improvement and upgrade to the SRTM data set.

As with the previous publicly released data this edited set is available at one arc-second sample spacing for the United States and its territories and possessions, and at three arc-seconds for the rest of the world. Consistent with DTED® standards the three arc-second data available through the USGS Seamless Server have been generated by sub-sampling the one arc-second data, taking for each three arc-second sample the center of a three by three array of one arc-second samples.

In response to requests from the scientific and research community NASA has generated a “research” edited data set, generated by 3x3 averaging of the one arc-second data instead of sampling. This effectively decreases the high frequency noise inherent in interferometric radar-derived DEMs, and is equivalent to taking “looks” in radar image data. Flattened water bodies and other editing were incorporated by comparing the NGA sampled data to data sampled directly from the one arc-second cells, and substituting any samples that differ (and were therefore edited) into the research data. This method is not perfect and may have introduced occasional artifacts in the vicinity of water bodies, but for research-oriented terrain analysis purposes this is overridden by the improvement in DEM characteristics provided by the averaging.

Finally, 44 cells have been regenerated from the raw radar echo data with minor modifications to the SRTM interferometric processor parameters such that numerous islands that previously appeared as voids because of phase unwrapping or other problems are correctly mapped. These new cells are included in the research data set.

The research data are available from the ftp server of NASA’s Land Processes Distributed Active Archive Center at the Eros Data Center.

Earth Science and Geospatial Applications

(34) Global SRTM Derivatives for Hydrological Applications at Multiple Scales

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Watershed analyses, hydrological modeling, and freshwater conservation planning typically require information on stream networks, watershed boundaries, or drainage routing schemes in digital format. Aiming to provide a new generation of these data at a global extent, World Wildlife Fund is currently developing a data set called HydroSHEDS (Hydrological data and maps based on Shuttle Elevation Derivatives at multiple Scales). HydroSHEDS is based on elevation data from the Shuttle Radar Topography Mission (SRTM). As its core data layer, it provides a seamless near-global drainage direction map at a resolution of 3 arc-seconds (90 meters). From this map, additional products are derived at multiple scales, including hierarchical watershed delineations and topological river networks. To generate HydroSHEDS, the original SRTM elevation data have been hydrologically conditioned in a sequence of automated procedures. Both standard methods of data improvement and newly developed algorithms have been applied, including customized gap filling, filtering, stream burning, and upscaling techniques. Manual corrections were added where necessary. Preliminary quality assessments indicate that the accuracy of HydroSHEDS significantly exceeds that of existing global watershed and river maps. For many regions the new data can support hydrological assessments at previously inaccessible resolutions and extents.

(35) Analysis of Large Aeolian (Wind-blown) Bedforms Using the Shuttle Radar Topography Mission (SRTM) Data

Dan Blumberg
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Dry land areas cover large parts of the landmasses of Earth. Of these a large portion is mantled by aeolian (wind-blown) deposits and subjected to aeolian process, i.e. the transport of sand or dust by wind. One of the most prominent morphologies created by wind driven deposits are dunes and in their larger form draas. The dunes and draas are often concentrated in vast areas forming sand seas and exist in many areas of the world. The Shuttle Radar Topography Mission (SRTM) successfully mapped the topographic features of the landmasses using radar interferometry. The objective of this paper is to demonstrate the potential for using the recently acquired data from the SRTM mission to map the height variability of the large sand seas and their respective dune forms. This is extended to an evaluation of the conclusions by White and Hyde that the various dune types cannot be distinguished based on their height variability. Several of the large ergs including the Rub al Khali, the Ramlat Wahiba, the Ramlat Sabatayn, Peski kara Kum, Takla Makan, and those in the Western Sahara and the Australian large dune fields were studied and will be shown in the presentation.

(36) Use of Shuttle Radar Topography Mission (SRTM) Digital Terrain Elevation Data to Facilitate Soils Mapping

William McMahon
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SRTM digital terrain elevation data and derivative values are used to identify and delineate major physiographic areas, landforms within physiographic areas, and landform elements. Soil landscape relationships described within the USDA World Soil Map soil mapping unit descriptions and other ancillary sources are used to develop soil landscape models and assign soil types to the different landforms and their landform elements. Spectral information from Landsat data is used to further differentiate soil types.

SRTM 90 meter and 30 meter elevation data are used to classify landscape components. A simplified procedure has been developed to organize the terrain into 15 classes to be used as input for further soils mapping and interpretation with satellite imagery, geologic information, climatic data, and other ancillary data. This simplified procedure divides the terrain into flat and non-flat surfaces. Flat surfaces are categorized into 6 classes, which are derived using two classes of relief (maximum elevation minus minimum elevation in a moving window) and three slope positions (derived from flow and inverse flow calculations from the SRTM data). Non-flat surfaces are categorized into nine classes using three relief classes and three slope positions, derived from the same procedures described above. The 6 classes from the flat terrain and the 9 classes from the non-flat terrain are then combined to create the 15 landscape components. Depending on the terrain, only subsets of the 15 classes may be relevant in an area.

These landscape components are used to establish soil association boundaries. Other digital terrain elevation data derivatives can be used to further differentiate soil landscape positions within these soil associations. The soil scientist then uses the soil landscape model to assign soil characteristics to the landscape components (soil texture, soil moisture, and soil depth) and convert the landscape component polygons to soil maps. When sufficient ancillary information is available, the soils can be classified using Soil Taxonomy.

In pre-selected test areas, these procedures approximate the USDA/NRCS State Soils Geographic (STATSGO) and Soil Survey Geographic (SSURGO) soil association boundaries.

(37) SRTM Models as Tools to Build a Spatial Data Infrastructure for Colombia

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Colombia lacks a structured and functional Spatial Data Infrastructure, which would require a complete and up-to-date coverage of semi-detailed topographical maps (1:25.000 – 1:100.000). Despite substantial efforts carried out since the middle of the last century by the Geographical Institute (IGAC) in conjunction with other national and international agencies, particularly the USGS, DMA and NIMA, still less than two-thirds of the country are covered by 1:25.000 maps, and a great part of them still belong to the 1950’s and 1960’s. A coherent 1:1’000.000 or 1:500.000 scale digital geodatabase is also not available. The task will hardly be achieved with photogrammetry techniques considering the existing technical, financial and human resources, as well as frequent cloud coverage and difficult access to major parts of the complex territory.

SRTM Project has provided a consistent almost worldwide set of data for low-cost, semi-automated, digital vector delineation of watershed boundaries, drainage and contour lines, apart from more complex hydrological flow modeling and terrain analysis, at scales of at least 1:200.000 (3 arc-second) and 1:50.000 (1 arc-second).

The presentation will provide examples of synergies of the above with LANDSAT data, also downloaded from University of Maryland's Global Land Cover Facility, existing cartography (IGAC and others), GPS points and tracks; and a simple methodological proposal to design and construct the basic Spatial Data Infrastructure urgently required in Colombia for research, environmental and development applications at different scales.

(38) Assessment on the Use of SRTM DEM During Post Tsunami Operations

Thierry Rousselin
Géo212, Paris, France

After the December 26th, 2004 tsunami, remote sensing data have been widely used in disaster and emergency management, mainly for basic cartography, damage assessment and recovery efforts planning and mitigation. SRTM 3”x3” DEMs, being the only available large scale DEM over the whole disaster area, were one of the key assets of those works. They were used as a foundation data for cartographic products, but they were also a direct source, during the first week, for initial damage assessment simulation (through the cartography of low altitude coastal areas). An in-depth analysis was conducted over more than 150 emergency products (produced within or outside of the International Charter “Space and Major Disasters”, by different teams of specialized professionals but also by outsiders). The results show a wide variety in product quality (the best not always coming from official dedicated producers). In a lot of cases, it shows a lack of understanding of data quality fundamentals, radar DEM quality specific aspects and metadata issues. Emphasized by the emergency, by the fact that DEM processing was especially important in the 0-20 meters range (where small errors have large consequences), and sometimes by bad choices in cartographic representation, it led sometimes to misleading products for recovery teams in the field. For future operations and use of those data in coastal low altitude areas, it is essential for the teams involved to be trained on data quality issues and at least to provide the necessary warnings with the data.

(39) DEM Production with ERS Tandem and SRTM Data in Italy and Switzerland

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The aim of the DUDES project is the production of a Digital Elevation Model over Italy and Switzerland using the X-SAR data from the Shuttle Radar Topography Mission (SRTM) and the SAR tandem data from the ESA ERS missions (ERS-1 and ERS-2). The project is funded under the Data User Programme of the European Space Agency.

The combination of ERS Tandem and SRTM X-band data allowed the production of a homogeneous DEM, filling the holes of SRTM X-SAR with multiple ERS Tandem pairs from ascending and descending passes. Test sites in Italy, Switzerland and Belgium have been chosen with a great variety of landscape and land cover. The validation of the DEM has been done with reference data from national geographic institutions. Horizontal and vertical accuracy has been evaluated and compared with DEMs derived from other space borne sensors.

The processing approach, the validation methodology and the results of the comparison will be presented at the workshop.

(40) The Geometric Accuracy of GeoCover's Landsat ETM+ Imagery: A Perspective from SRTM

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The accuracy of georegistration is an important factor for the use of remotely sensed data. The first step in Landsat processing is known as the level-0 to level-1G conversion, where the data is transformed geometrically from satellite orientation to north-up orientation and undergoes systematic geo-correction using ephemeris parameters. After this stage, Landsat imagery is distributed by USGS to users. The second stage is usually conducted by individual users to coregister the images with their other data sets. One significant issue is correction for relief achieved by use of available DEMs or warping the image to an existing ortho-photo.

The GeoCover project was funded by NASA and implemented by Earthsat. Global coverage of Landsat TM and ETM+ imagery were orthorectified using DTED® elevation data. This project provided an ortho-photo basis and enabled researchers to obtain their own orthorectified Landsat imagery. The GeoCover project has been completed and has a reported error of <50m RMS horizontally.

With the advent of SRTM data, we now can now assess GeoCover in a more thorough way. Since GeoCover is the actually the standard ortho-map for users globally, it is important to inform users globally how good GeoCover is and how to correct errors if there are any.

We have designed a method to use SRTM data to examine the horizontal accuracy of GeoCover. The basic knowledge is that, the shaded relief imagery of SRTM using the same sun height and azimuth as those when Landsat images were acquired, is very similar to the actual panchromatic band of Landsat imagery. By using phase-correlation over the whole image, we can estimate how geo-registration differences relative to longitude and latitude.

Our study selected one site in every continent except for Antarctica and our results show that in US home territory, the differences are <30m. But in other continents the differences vary from less than 90m to more than 200m. We believe this is a result of the varying accuracy of DTED® elevation data in the orthorectification process, since these data have much higher resolution in the US than elsewhere. All tested regions have moderate-to-high relief. The accuracy of georegistration does not appear to be significantly affected by either the presence of snow cover or the intensity of land use.

(41) Impact of SRTM Data on Geospatial Support to US Army Operations

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Danny C. Champion
U.S. Army TRADOC Analysis Center, White Sands Missile Range, NM, U.S.A.

The DoD Joint Staff and Intelligence Community have long recognized the need for a global high-resolution elevation model to better understand the operational environments in which the United States (US) military may be deployed. A major inhibitor to this improved understanding was the lack of availability of Digital Terrain Elevation Data (DTED®), especially at the Level 2 (DTED® 2) density and accuracy, which is vital to successful mission planning and mission execution. To address this shortfall, in February 2000, the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA) coordinated deployment of the Shuttle Radar Topography Mission (SRTM), a C-band radar, all-weather asset, capable of imaging day or night, and through cloud cover to collect near-global one-arc-second (approximately 30-meter resolution) data. The finished 30-meter resolution data (SRTM DTED® Level 2; referred to as SRTM2 in this study) became available to users in September 2004.

Previous studies have determined that digital elevation data produced from radar source exhibit different properties as compared to elevation data derived from traditional photogrammetric source materials and may not yield the same results when used in operational or training applications. The positional accuracy of SRTM2 is well documented and widely accepted, though the utility of the data, when applied to specific Army operational needs, is untested. Moreover, under certain conditions, the SRTM technology will fail to clearly represent the terrain surface resulting in output anomalies ranging from data degradation to complete loss of data (e.g., “data voids”). Inherent radar “noise” has also been identified as a concern especially for operations in very smooth terrain.

In order to address these issues, an examination of the SRTM2 was initiated under the Department of Army Study Program with sponsorship from the Deputy Chief of Staff (DCS), G2. The intent of these evaluations was twofold: 1) to determine the comparative utility of SRTM2 versus existing traditional products of a similar resolution (DTED® 2) and the 1:50,000 scale Topographic Line Map in an operational setting, and 2) to provide guidelines for Army’s use of SRTM2 data in applications requiring elevation data. Several applications were analyzed to examine the characteristics and performance of SRTM2:

- Line-of-Sight (LOS) prediction
- Contour generation
- Slope determination

In addition to these analyses, specially designed SRTM2 field validations such as “terrain profile” and “void fill” evaluations were conducted and the SRTM2 residual radar “noise” issue was also specifically addressed.

(42) Improvements in Aviation Safety Through the Use of SRTM Data Products

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Several user communities within the aviation sector require quality digital elevation models. Airborne applications include Terrain Awareness and Warning Systems (TAWS) and Synthetic Vision Systems (SVS). Both are intended to improve flight safety by improving pilot situational awareness - particularly in low visibility conditions. This improved awareness reduces the likelihood of the most common class of aviation accidents - Controlled Flight Into Terrain (CFIT).

This presentation will cover four topics: (1) a review the SVS concept and recent R&D accomplishments including pilot evaluations of various terrain portrayals; (2) a discussion of issues associated with the application of SRTM data products to proof-of-concept implementations; (3) a summary of recently published industry requirements for geo-spatial data content and quality and how SRTM data products align with these requirements; and (4) a detailed discussion of the stringent data integrity requirements implicit to the target level of safety for civil aviation.

Poster Presentations

Accuracy Assessment and Comparison with Other Elevation Data

(P1) SRTM Data Evaluation Over U.S. Urban Sites

William Curtis
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USGS-generated digital elevation models from the National Elevation Dataset (NED) were being used at the National Geospatial-Intelligence Agency (NGA) for urban area applications. An assessment was carried out to see if the SRTM elevations data could support similar applications. Three urban sites were chosen for the study - Chicago, New York and San Antonio. DEM images of both data sources are presented and differences (including site specific issues) are discussed. Optical imagery is used as an ancillary source for verification of the content of the various sites. NGA has concluded that SRTM DTED® 2 presents a consistent reflective surface solution over urban sites and that there are some inconsistencies between the SRTM DTED® 2 and the NED data. Most of the inconsistencies can be attributed to currency differences in the source of the data. In addition, there are void regions in the SRTM DTED® 2 data that would likely impact support of the urban area applications.

(P2) Statistical Measures of Accuracy of SRTM 1- and 3-Arc-second Data in Flat and Undulating Landscapes of the Midwest United States

Pablo Mercuri
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Digital Elevation Models (DEMs) are increasingly used even in low relief landscapes for multiple mapping applications and modeling approaches such as surface hydrology, flood risk mapping, agricultural suitability, and generation of topographic attributes. This paper describes quality issues of the SRTM through measures of absolute and relative accuracy of both resolution levels, 1 and 3 arc-seconds, to generate information that can be used as a reference in areas with similar characteristics in other regions of the world. The absolute accuracy is obtained from an accurate point estimation using the best available federal geodetic network in Indiana, which exhibits a mostly flat landscape with subtle undulations in north central areas of the state and predominantly open terrain land cover / use. The RMSE obtained for this area of the Midwest US surpassed data specifications. It was on the order of 2 meters for the 1-arc-second resolution level. A slightly lower value was estimated for the averaged 3-arc-second SRTM resolution with global coverage. Due to predominantly mixed land cover and land use related to the changes in topography to undulating landscape in southern Indiana, higher RMSE values were obtained. An increase in the error magnitude was found when surface features are in the vicinity or mixed land uses are nearby. A particular approach was developed to analyze not only the accuracy at the geodetic point, but also to identify adjacency effects due to the nature and behavior of the radar return signal that produce a general trend to increase the elevation values in this context. Measures of local variability were described by means of buffer zones with increasing diameter centered in each pixel where every geodetic control point is positioned, to identify the adjacency effects produced by forest patches and higher slope values as well as its correlation with the observed vertical errors. Spatial relationships among the bare Earth National Elevation Dataset (NED), higher resolution first return Star 3i IFSAR elevation data, and both SRTM resolution levels were also analyzed to evaluate the relative accuracy of the elevation model in selected flat areas of central Indiana.

(P3) Vertical Accuracy of SRTM Elevation Data in Argentina

Pablo Mercuri
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SRTM vertical accuracy was computed in Argentina, in the south of the American Continent. Elevations in Argentina range from 0 m to 6962 m (+22,841 ft.) on Aconcagua, the highest peak in the Western Hemisphere. The country has a geodetic reference frame, the POSGAR 94 (Posiciones Geodésicas Argentinas) network with 127 monumented stations separated by distances up to 200 km. Later it was enhanced into POSGAR 98, by a more precise computation of the observations and by its links to a continental system known as SIRGAS (Sistema de Referencia Geocéntrico para las Américas) and to the global International Terrestrial Reference Frame (ITRF). This network of ellipsoidal heights represents the embodiment of WGS 84. It became in 1997 the official reference frame in Argentina. It was used as higher accuracy elevations to compare to the unfinished release of the SRTM 3-arc-second DEM. Since the geodetic reference for SRTM data is the WGS 84 EGM96 geoid, geoidal undulations for all the points of the geodetic reference frame were calculated using the National Geospatial-Intelligence Agency (NGA/NIMA) EGM96 calculator and transformed to orthometric heights. A global RMSE of about 5 meters was obtained. Residuals ranged from 0.01 to 23 meters. The quantitative evaluation of performance involved the assessment of the magnitude of residuals segmented by land cover classes. While the difference in z between the geodetic network and SRTM 3-arc-second is lower than 3 meters in the flat Pampas areas, a substantial increase is observed in pixels nearby urban development and in some elevations in steeper terrain.

(P4) Comparison of SRTM Elevation Data with Other Topographic Datasets for Italy

Andrea Taramelli
Perugia University, Perugia, Italy

A common aspiration of many geomorphologists is to assess the geomorphologic variables of a landscape through some sort of calibrated analysis of a DEM. The United States National Aeronautics and Space Administration (NASA) has recently released a 90x90 meter DEM acquired by the Shuttle Radar Topography Mission (SRTM) in February of 2000. The DEM was produced by NASA's Jet Propulsion Laboratory, and is distributed through the U.S. Geological Survey EROS Data Center. Assemblage and local interpolation of the DEM for Italy was performed at Lamont-Doherty Earth Observatory of Columbia University. From the assembled DEM was obtained a set of morphometric variables that was used as an example of primary attribute and compound attribute. For the whole Italian Territory a 230-meter grid DEM is also available. This DEM was compiled by assembling and correcting the mean elevation values digitized on 1: 25.000 scale contour maps. Different morphometric parameters were used to compare the two low resolution DEMs. At regional scale the two national scale DTMs were compared with a medium resolution DEM available for the Umbria Region (Central Italy). The Umbria DTM was compiled by interpolating digital contour lines. This study presents the results of the comparison between the three Digital Elevation Models and some possible applications.

Comparison of X-band and C-band Data

(P5) Comparison of SRTM C-band and X-band DEMs Over Vegetated Areas in South Norway

Dan Johan Weydahl
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The SRTM mission gave a full coverage of the southern part of Norway for both the C-band and X-band SAR instruments. Large mountainous areas, fjords, forested regions and agricultural fields with urban areas and man-made structures govern the terrain in this part of Norway.

Unedited C-band DEM data (“90 m”) and X-band DEM data (“30 m”) are analysed in detail from a test site in south Norway. Digital topographic maps in scale 1:5000 are used as reference.

Investigations show that the horizontal accuracy of the SRTM DEMs is better than specifications.

The SRTM DEMs are corrected for a small vertical offset of -1.0 m and +3.3 m for X-band and C-band, respectively. The vertical accuracy is then evaluated with respect to the reference map over open, agricultural areas. The RMSE is estimated to 3.4 m and 4.6 m for the X-band and C-band data, respectively. This translates to an absolute vertical accuracy of 5.6 m and 7.6 m for the 90 % confidence level. This is much better than the 16 meters given in the SRTM specifications.

SRTM measures the height of the reflective surface rather than the bald Earth. Investigations show that dense forest stands in Norway will give an elevation that is 15-17 m above the ground. The absolute elevation difference between the two SAR systems over dense forest stands is in the order of 1-2 m. This tiny difference makes it difficult to extract other forest parameters.

The absolute relative height accuracy was estimated to be within specifications for all natural ground cover types.

We can conclude that the SRTM elevation data are better than the specifications. They can be used to update maps (e.g. gravel pits), and evaluate forest stand heights. Large errors in the SRTM DEMs are mostly due to extremely low SAR backscatter (lakes or concrete ground), or in terrain with steep slopes. With respect to the latter, SRTM imaged Norway from more or less one direction (the south). Errors introduced by the SAR viewing geometry can therefore not be corrected. However, a polar orbiting spaceborne system would compensate for this effect.

Canopy Height and Vegetation Mapping

(P6) Regional Validation of SRTM Elevation Measurements: A Comparison with Medium-footprint Lidar Data Over Various Terrains

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J. Bryan Blair and David Rabine
National Aeronautics and Space Administration, Greenbelt, MD, U.S.A.

NASA's Laser Vegetation Imaging Sensor (LVIS) is a medium-resolution (~25m), waveform-digitizing, airborne laser altimeter (lidar) system capable of mapping topography (including sub-canopy), canopy-top topography and canopy structure with sub-meter precision and accuracy in dense canopies. Since 2003 it has been used to collect data in support of various NASA programs including the North American Carbon Program, the Solid Earth and Natural Hazards program, and the Interdisciplinary Science Program. Biomes mapped include those in the northeast and mid-Atlantic regions of the US, California and Costa Rica. The LVIS data provided several unique datasets with which to validate elevation measurements made by the Shuttle Radar Topography Mission (SRTM), particularly in assessing data accuracy in forested regions. Comparisons between LVIS canopy-top topography, ground topography, and various canopy height metrics and coincident SRTM elevations will be presented. The full-waveform data product provided by LVIS represents a true 3-d volumetric assessment of canopy material, and can provide a unique insight into the interaction of SRTM with vegetation canopies.

(P7) SRTM, NED and NLCD 2001 Data: Synergy of National Datasets for Biomass and Carbon Quantification in the U.S.

Josef Kellndorfer
The Woods Hole Research Center, Woods Hole, MA, U.S.A.

A major goal of the North American Carbon Program (NACP) is to develop a quantitative scientific basis for regional- to continental-scale carbon accounting to reduce uncertainties about the carbon cycle component of the climate system. Given the highly complementary nature and quasi-synchronous data acquisition of the 2000 Shuttle Radar Topography Mission (SRTM) and the Landsat-based 2001 National Land Cover Database (NLCD), an exceptional opportunity exists for exploiting data synergies afforded by the fusion of these high-resolution data sources. Accurate area-based estimates of terrestrial biomass and carbon require biophysical measures that capture both horizontal and vertical vegetation structure. Whereas the thematic layers of the NLCD are suitable for characterizing horizontal structure (i.e., cover type, canopy density, etc.), SRTM provides information relating to the vertical structure, i.e., primarily height. Research from pilot study sites in Georgia, Michigan, and California has shown that SRTM height information, analyzed in conjunction with bald Earth elevation data from the National Elevation Dataset (NED), is highly correlated with vegetation canopy height. Currently, a project funded under the NASA "Carbon Cycle Science" program ("The National Biomass and Carbon Dataset 2000 – NBCD2000") is underway to generate a "millennium" high-resolution ecoregional database of circa-2000 vegetation canopy height, above-ground biomass, and carbon stocks for the conterminous U.S. which will provide an unprecedented baseline against which to compare data products from the next generation of advanced microwave and optical remote sensing platforms. Results from the pilot studies and an overview of the NBCD2000 project are presented.

Void Filling

(P8) Physically Based Interpolation of Data Voids in SRTM Data

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A characteristic feature of the unedited SRTM data is numerous data voids originating from a number of factors such as shadowing, layover, or other radar-specific causes. Previous work suggests that these voids can be subdivided into two equally likely groups: a group consisting of six or fewer contiguous missing values, and another with more than six contiguous missing elevation values. We present here a physically based interpolation algorithm which is comprised of two steps.

First, a smooth interpolant in the irregular domain A is obtained by solving the biharmonic equation with given boundary values for the solution u and its normal derivative u_n. This produces a smooth surface with the purpose of finding geomorphological macro structures. Second, micro structures are imposed on the smooth surface by adjusting elevation points according to a simple physical model. The structure of catchment topography depends largely on the interactions between hillslope and channel processes. The transition from convex hillslopes to concave valley forms is understood as a change in process dominance and can ideally be observed as a sharp break in the slope-area scaling. A plot of log-Slope versus log-Area for most landscapes reveals two distinct process regimes. The break in the slope-area scaling relationship typically marks the shift from convex to concave forms. Observed slope-area scaling is used in the proposed algorithm to adjust elevations points in such a manner that interpolated void regions are consistent with the local process dominance. We show that the algorithm can be generalized for all U.S. geomorphological regions.

Data Products and Distribution

(P9) The USGS Approach Toward Archiving and Distributing Shuttle Radar Topography Mission (SRTM) Data

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The Shuttle Radar Topography Mission (SRTM) successfully collected Interferometric Synthetic Aperture Radar (IFSAR) data over 80 percent of the landmass of the Earth between 60° N and 56° S latitudes in February 2000. The National Aeronautics and Space Administration (NASA) and National Geospatial-Intelligence Agency (NGA) sponsored the mission. NASA's Jet Propulsion Laboratory (JPL) performed preliminary processing of SRTM data and forwarded partially finished data directly to NGA for finishing by NGA contractors and subsequent monthly deliveries to the NGA Digital Products Data Warehouse (DPDW). All data products delivered by the contractors conform to the NGA SRTM and the NGA Digital Terrain Elevation Data (DTED®) product specifications. The DPDW ingests the SRTM data products, checks them for formatting errors, loads the SRTM DTED® into the NGA data distribution system, and ships the public domain SRTM DTED® to the U.S. Geological Survey (USGS) National Center for Earth Resources Observation and Science (EROS).

USGS EROS currently offers numerous formats and resolutions of SRTM elevation data. For 3-arc-second (90-meter) global coverage, data is available via a 13-grid Web ordering interface. For 1-arc-second (30-meter) coverage of the United States and its territories, data is available through a 7-grid Web ordering interface. The grid areas within each of these interfaces represent one piece of media (DVD). Users can get either NGA's DTED® format or the reformatted SRTM version of the data. This version is a simple binary raster format derived from the SRTM DTED® data.

SRTM data are also available through the USGS EROS Seamless Data Distribution System (SDDS). The SDDS distributes United States 1-arc-second and global 3-arc-second SRTM data. SDDS allows instantaneous downloads for areas up to 30 square degrees latitude/longitude in 100–megabyte files. The formats available include ArcGrid, bil, Gridfloat, and TIFF (32-bit floating point). Media is available for any selected area, regardless of size.

(P10) SRTM Data Management - A Provisioning Approach

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SANZ has encapsulated a process for provisioning geospatial data assets such as SRTM within a methodology for data management. This methodology was developed to optimize the value of spatial assets by reducing data-processing costs, reducing data-management costs and increasing data usage throughout the enterprise. The concept of provisioning data is to first have a stock of spatial data prepared before a need arises. Once the need occurs, an efficient provisioning process rapidly extracts and aggregates the SRTM data into a format specific to the end user. To support this process, all of the source data is pre-staged and catalogued for easy search, retrieval, and provisioning. The ability to access these large datasets in real time or near-real time requires a method for developing a virtual catalog of SRTM and other imagery regardless of where it physically resides within the organization. A process for aggregating individual datasets from various locations on multiple media formats is a necessary component of an enterprise data-cataloging system and forms the basis for the design of EarthWhere.

Earth Science and Geospatial Applications

(P11) Water Slope and Discharge in the Amazon River Using the SRTM DEM

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The terrestrial branch of the water cycle is an important component of weather, climate, and water resource management. In-channel stream discharge is a particularly appealing measurement because it represents a spatial and temporal integration of basin-wide hydrologic processes. Because of the paucity of discharge measurements in the non-industrialized regions of the world, remote sensing can provide the spatial and temporal coverage needed to monitor basins where in-situ measurements are lacking. We used the Shuttle Radar Topography Mission digital elevation model (SRTM DEM) to estimate slope on the central Amazon River. The standard deviation, hence error, of the water surface elevation data is +/-5.51 m for basin-wide, regional and local mainstem reaches. This error implies a minimum reach length of 733 km in order to calculate a reliable water surface slope. We find slopes of 1.92 cm/km for Manacapuru, 2.86 cm/km for Itapeua and 3.20 cm/km for Tupe. Using Manning's discharge equation with these slopes combined with channel width measurements from the Global Rain Forest Mapping synthetic aperture radar (SAR) mosaics, channel depths averaged from navigational charts, and reasonable estimates of Manning's n yields discharge values of 84,800 m3/s at Manacapuru, 79,800 m3/s at Itapeua, and 62,900 m3/s at Tupe. These values are within 6.2% at Manacapuru, 7.6% at Itapeua, and 0.3% at Tupe of the in-situ gauge based estimates for February.

(P12) Mapping Surface Processes and Tectonic Geomorphology Using SRTM Data

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The Shuttle Radar Topography Mission (SRTM) dataset provides an unprecedented opportunity to unify landscape analyses, and we are using it to delineate and characterize geomorphic parameters on a regional scale. When integrated with other regional data sources, our results allow us to make inferences about the roles of climate and tectonics in landscape evolution. Our analyses are based on the use of 3-arcsecond SRTM data to map landscape attributes such as drainage patterns, hillslope curvature, sinuosity, and relief. We will present two examples: (1) the use of hillslope morphology to identify specific mechanisms of hillslope failure in the Italian Apennines, and to assess landslide hazards; (2) the use river morphology and climatology to understand how typhoons affect patterns of erosion in the island mountains of the western North Pacific Ocean.

(P13) SRTM Water Elevations and Their Implications for Ground Water Flow Predictions

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SRTM elevation models include water surface elevations that may be used as head boundaries in numerical models of ground-water flow. Water elevations can be measured in open water surfaces, forested wetlands, or peatlands, resulting in different backscatter and error characteristics. We compared SRTM elevations to USGS DEMs and survey-grade GPS measurements in the Northern Highlands Lake District of Wisconsin. Differences in water elevations resulted in significant differences in numerical ground-water flow predictions. Error characteristics in radar-measured elevations are being considered with respect to how these errors may propagate through ground-water flow models.

(P14) The 2004 Sumatra Tsunami Event: Contribution of SRTM Data to the Analysis of Devastation

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A disastrous tsunami affecting coastal populations of the northern Indian Ocean occurred on December 26th 2004, following a mega-thrust earthquake (Ms>9.0) at the India-Burma plate interface of the Sumatra-Andaman Islands subduction zone. The Indonesian Island of Sumatra was the hardest hit by the tsunami. SRTM and other high quality radar data fill a critical data gap in evaluating regions at risk. SRTM data are currently being used to study how the populations are distributed with respect to elevation and distance from the shoreline in devastated areas. These data are being compared with optical remote sensing land surface change analyses derived from Landsat ETM+ imagery, which delineate the relationship between elevation, slope and aspect of inundated regions in northwest Sumatra. To evaluate the impact of the tsunami we have processed SRTM C-band and X-band DEMs. The C-band (λ=5.8cm) DEM with a 3-arc-sec (~90m) spatial resolution covered the entire land areas whereas the X-band (λ=3.1cm) coverage had a higher 1-arc-sec resolution (~30m) but had incomplete coverage. A correlation has been established between elevation contours and the extent of inundation within the region; however, the accuracy of the SRTM height data requires further local verifications. As part of the verification, the two SRTM datasets were compared for the region of interest and differences were found. While both datasets followed very similar topographic trends they differed significantly along the western coast of Sumatra. Transects from the mountainous area to the coast were extracted showing elevation differences of up to 32 m primarily in the coastal region and feathering to near zero inland. The reason for the difference between the datasets is currently being investigated and is potentially attributed to differences in the geodetic datum used for each.

(P15) Detection of Internal Waves in SRTM Data of the Andaman Sea

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By chance, a single pass of SRTM C-band data was acquired over the Andaman Sea, an area known for the existence of internal waves. Because no other SRTM passes were averaged with the single pass, the internal waves were detected in both the DEM and the image data. Surprisingly, the DEM showed an apparent amplitude of several meters for the waves, which seems too large for oceanic internal waves. This signal is most likely produced by the effects of strong ocean currents induced by the internal waves on the radar interferometry measurements. Although the amplitude of several meters is unrealistic for internal waves, the observations may demonstrate the detection of ocean currents with along-track radar interferometry, which has been done with X-SAR SRTM already. Internal waves occur in the ocean within a natural channel formed by two layers of different density caused by differences in temperature or salinity. They are commonly observed in radar images and optical photographs over regions of shallow bathymetry (e.g., the Straits of Gibraltar, the Gulf of California, and the Andaman Sea). The mechanism for imaging has been established as a change in surface roughness caused by currents induced by the orbital motion of the waves. However, the signatures of internal waves in radar interferometry measurements have never before been reported. The energetic internal waves in the Andaman Sea are well known for their strong horizontal currents of up to 1m/sec. These currents are apparently the cause of the wave showing up in the SRTM DEM. The Andaman Sea internal waves were observed in SRTM cell N08E092 and image N08E092_143_060_SS2_1_01; unfortunately, X-SAR SRTM did not cover this area, so no X-band data are available.

(P16) SRTM-based Morphometric Analysis of the Poços de Caldas Alkaline Massif, Southeastern Brazil.

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The Poços de Caldas Alkaline Massif (PCAM) is a Late Cretaceous collapsed volcanic caldera affected by syenite intrusions and alkaline dikes, located in the central-western portion of the Cabo Frio Magmatic Lineament (CFML), a 1000km-long alignment of Late Cretaceous and Paleogene alkaline bodies in southeastern Brazil. PCAM's main morphology is a semi-circular plateau with average altitude of 1300m, rising up to 400m above surrounding flatlands. The plateau is a remnant of the South American Planation Surface and resulted from differential erosion of basement rocks and volcanic ring dikes around the massif at the Late Cretaceous-Paleogene transition. Landforms within the massif have close relationship with Pleistocenic and Holocenic tectonic structures. The contrast between tectonic and lithologic influence on geomorphology favours morphotectonic analysis. Using SRTM 90m elevation data, morphometric analysis of PCAM was carried out with free software GRASS-GIS, as proposed by Grohmann (2004). DEM resolution was resampled to 50m in order to work at a scale of 1:50.000. The following parameters were evaluated: slope, aspect, surface roughness and isobase surface. Surface roughness was calculated as the ratio between real and planar area for cells of 1x1km. Isobase surfaces are interpolated from the intersections of 2nd and 3rd-order stream channels with contours. To derive drainage, the DEM was first smoothed with a 7x7-cell neighborhood operator (r.param.scale), and flow direction was obtained with the A\uT\d least-cost search algorithm (r.watershed); raster streams were then converted to vectors and manually classified. There is a high correlation between DEM-derived drainage and topographic maps showing that even at a relatively coarse resolution, SRTM can be used for semi-detailed geomorphological analysis. Availability of data assures that analysis can be carried out in a fast and inexpensive way.

Grohmann,C.H. (2004). Computers & Geosciences, 30:1055-1067.

(P17) Topographic Normalization of Landsat-class Imagery with SRTM Data

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The SRTM elevation dataset provides the user community with new abilities in application development. Here we present the use of SRTM data in a novel, automated topographic normalization routine for Landsat-class imagery collected over different regions of the world. The results of normalization with SRTM are compared to those performed with other DEM products. It is concluded that SRTM data allows for development of consistent, near-globally applicable topo-normalization algorithms for medium resolution imagery.

(P18) Development of Aral Sea Basin River Network from SRTM Data

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The Aral Sea Basin river network is being derived in ArcHydro format from the SRTM data. Issues and results will be discussed in this presentation.

(P19) Morphology and Migration of Large Sand Dunes Using SRTM and Altimetric Data

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The poorly understood complex and rapid variations of large sand dune morphologies of the world's deserts have significant importance on conservation and climate change and hence, are of interests to a wide variety of scientific and environmental applications including studies on aeolian processes, paleoclimate, civilian infrastructure management, and design of blown-sand control systems. Based on topographic mapping we know that the Namib desert hosts the worlds tallest sand dunes, however, we still don't know much about the driving forces controlling dune behaviour and migration.

The Shuttle Radar Topography Mission (SRTM, SIR-C and SIR-X) data can be used as a reference digital elevation model (DEM) to investigate and compare morphologic attributes of various sand dunes in parts of the Namib, Gobi, and Mojave deserts. Comparing SRTM DEMs with elevation data based on other geodetic and remote sensing sensors such as ICESat and ASTER, which have a better temporal coverage and operate until present, can substantially improve our understanding of sand dune migration compared to traditional approaches that use sequential topographical surveys over a limited region. To investigate the dynamics and morphology of sand dunes in deserts located globally we apply splines, wavelet analysis, and correlation filtering to construct and compare seasonal DEMs from available satellite altimetric data with regional SRTM DEMs. Another objective is to assess the potential of using space geodetic techniques to quantify topographic changes also using measurements from current InSAR missions (ENVISAT ASAR) and upcoming missions such as ALOS PSAR and RADARSAT-2.

(P20) Surface Elevation Change over Mountain Glaciers from ICESat and SRTM

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While the primary goal of ICESat is to measure elevation changes of the vast polar ice sheets, large temperate mountain glaciers (e.g. Alaska, Patagonia), which are sensitive indicators of climate change, can also be studied. These mountain glaciers, however, generally have rougher surfaces and steeper regional slopes than the ice sheets for which the ICESat design was optimized. Rather than averaging over large regions or relying on crossovers, we worked with individual ICESat footprint returns to estimate glacier elevations and surface characteristics. In the northern hemisphere at latitudes less than 59N, in the southern hemisphere outside of Antarctica, and during Laser 1 operations, the ICESat tracks do not generally repeat within 100 meters unless the ground track was specifically targeted. This makes it difficult to use ICESat to ICESat measurements to estimate elevation change. However, for the region between 60N and 60S, SRTM derived 90 meter DEMs from Feb. 2000 are available (C-band SRTM, JPL, Farr and Kobrick, 2001). As we show in this paper, a regional SRTM-derived DEM can be used along with ICESat to detect general patterns in elevation change for surfaces with variable slope and roughness with near-repeat ICESat tracks. We report results from the Malaspina Glacier of southern Alaska to illustrate the applicability of using ICESat and SRTM to discern elevation change.

(P21) Holocene Deformation of a Shoreline in Mono Basin, CA: Comparison of SRTM to TOPSAR and GPS Data

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Testing the use of the Shuttle Radar Topography Mission (SRTM) as a geological instrument was undertaken by comparing SRTM data with those from TOPSAR and GPS measurements made on a prominent late-Holocene lake terrace that encircles Mono Lake, California. Topographic profiles across the late-Holocene terrace were constructed using the SRTM, TOPSAR, and GPS measurements. It was noted in reconciling the SRTM DEM to the TOPSAR DEM that there was some discrepancy. In the northern part of Mono Basin, the SRTM profiles were above the TOPSAR profiles in regions of slope concavity. This difference is due to the phase-center offsets of antennae. However, the SRTM data for the southern rim of the lake terrace matched the TOPSAR data more closely. The SRTM profiles were more consistent with GPS profiles, having an average difference in elevation of 4 m. The break-in-slope of the profiles at the beach berm - shoreline bluff were used as a vertical datum. These displayed remarkable deformation when plotted against the polygonal distance around the lake. Near the vents of the latest eruption of Mono Craters, there is a vertical offset of 29 m in the break-in-slope, which may be produced by a NW trending dike underlying the Mono Craters.

(P22) Study of Coseismic Deformation Due to the March 28, 1999 Mw6.5 Chamoli in the Garhwal Himalaya Region and the March 20, 1993 Mw6.2 South-East Tibet Earthquakes Using InSAR

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The March 28, 1999 Mw6.5 Chamoli, India earthquake occurred at the border of India and Xizang in the Garhwal Himalaya region. The coseismic deformation due to this earthquake has been studied using SAR data from ERS-1 and ERS-2 satellites. Analysis of the two interferograms from an ascending and descending track show deformation extending over an area of approximately 30x30 square kilometers that is consistent with a nearly NE-SW trending north 15-degree-dipping thrust fault at a depth of 13.2 km. The difficulties of this area include the vegetation cover, the rugged terrain and frequent thick cloud cover. This is the first earthquake of the Himalayan region to be studied by this technique.

Analysis of ERS-1 and ERS-2 data for the March 20, 1993 Mw6.2 South-East Tibet shows deformation consistent with normal faulting on a nearly N-S trending east 55-degree-dipping fault at a depth of 7.8 km. The deformation pattern also shows an Mw5.1 aftershock that occurred on the same day with normal fault motion on a 25-degree-dipping fault at a depth of 8.1 km. This region is relatively arid which made it easier to produce the interferogram.

SRTM data was used for eliminating topography for both earthquakes.

(P23) Use of Shuttle Radar Topography Mission Data to Produce an Active Tectonics Map for South Asia

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A seismic hazards mapping project has been proposed by international seismologists and geologists working together in South Asia as part of a UNESCO/USDOE coordinated group. Representatives from science agencies in Pakistan, India, China, Nepal, Sri Lanka, Iran, and Bangladesh have agreed to provide structural and seismic data, which will be integrated into an active tectonics map of South Asia with assistance from the U.S. Geological Survey. The most suitable base layer for such a map is a moderate resolution topographic shaded relief image. Shuttle Radar Topography Mission (SRTM) data were selected as the best available data source for this project because of its spatial resolution, uniformity, and availability throughout the South Asia region. In addition to being the base map layer for the final map product, the shaded relief imagery will be used by various country participants to digitize, register, and modify their existing seismic information. Finished SRTM data have been obtained from the National Center for Earth Resources Observations and Science and processed to create the shaded relief digital image needed by the participating countries. Void areas were filled with GTOPO30 30-arc-second elevation data. A 3 by 3 low pass filter was used to decrease the visual effect of the GTOPO30 patches. Both elevation data and shaded relief images will be subdivided into sub-regions and distributed on CD-ROM to each participant for their use in data preparation.

(P24) Enabling Users to Understand the Impact of Terrain Data Quality on Derived Products - Probabilistic Line of Sight

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A Department of Army Study Program with sponsorship from the Deputy Chief of Staff (DCS), G2, evaluated the utility of SRTM2 data for applications requiring elevation data. That study determined that the SRTM2 data is significantly better then existing DTED® level 1 or level 2 Data. The positional accuracy of SRTM2 is well documented and widely accepted, though the utility of the data, when applied to specific Army operational needs, is untested. However, the study also identified a pattern of elevation errors that could cause users to draw incorrect conclusions from applications, like Line of Sight, that use SRTM2 data. Inherent radar “noise” has also been identified as a concern especially for operations in very smooth terrain.

This presentation describes a Probabilistic Line of Sight algorithm that predicts the probability of line of sight based on the geometry of the line of sight and the quality of the elevation data. The algorithm uses an error model for the elevation data that includes spatial correlation of the errors. Use of the algorithm allows users to immediately appreciate the improvement in the accuracy of line of sight predictions that result from using SRTM2 data, while also understanding the remaining uncertainty that results from the elevation errors that remain in SRTM2 data.

The presentation will include a discussion of error models developed for SRTM2 data, and a demonstration of an implementation of the Probabilistic Line of Sight algorithm.

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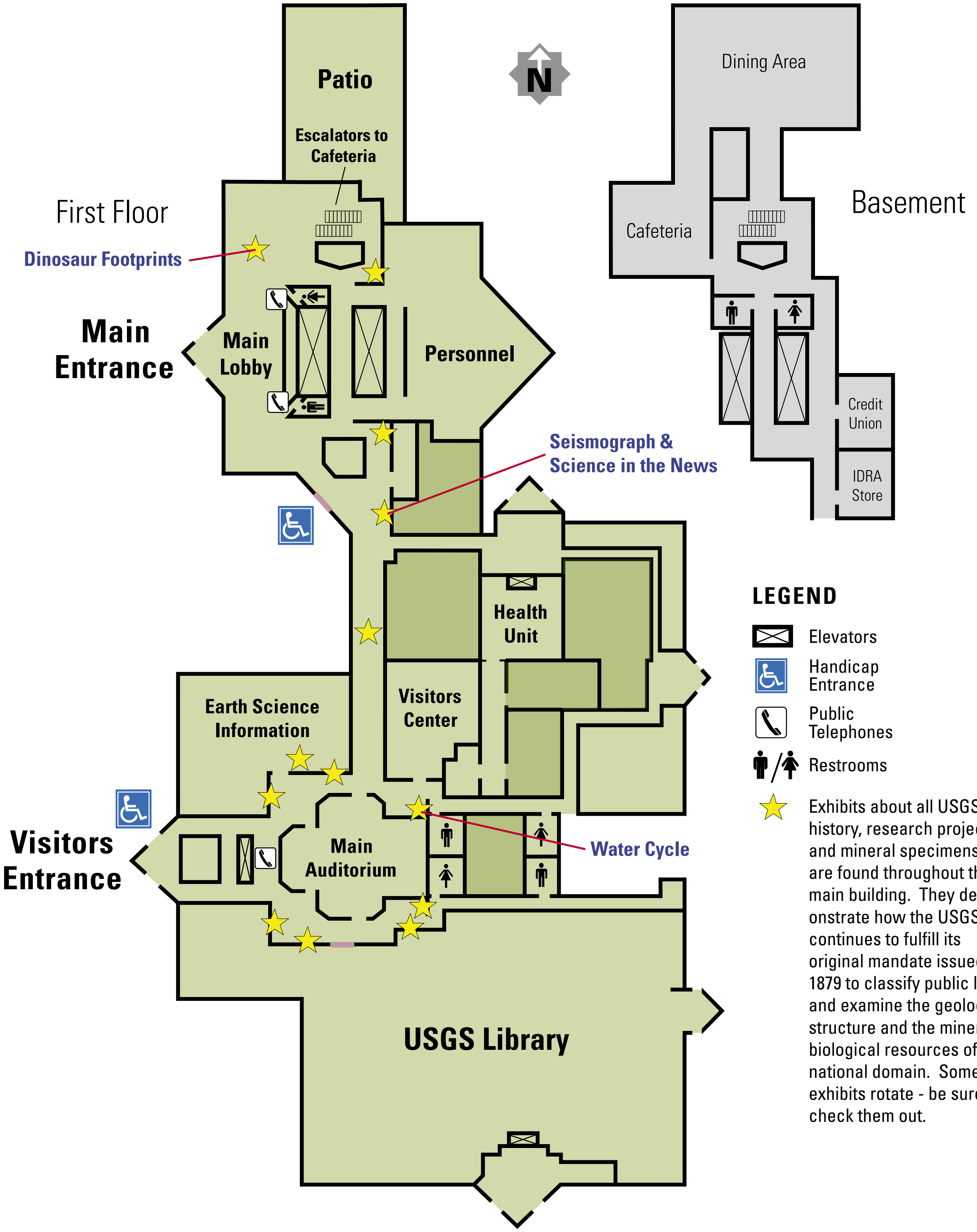

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★ Exhibits about all USGS history, research projects, and mineral specimens are found throughout the main building. They demonstrate how the USGS continues to fulfill its original mandate issued in 1879 to classify public lands and examine the geological structure and the mineral and biological resources of the national domain. Some of the exhibits rotate - be sure to check them out.