Know the Earth…Show the Way

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

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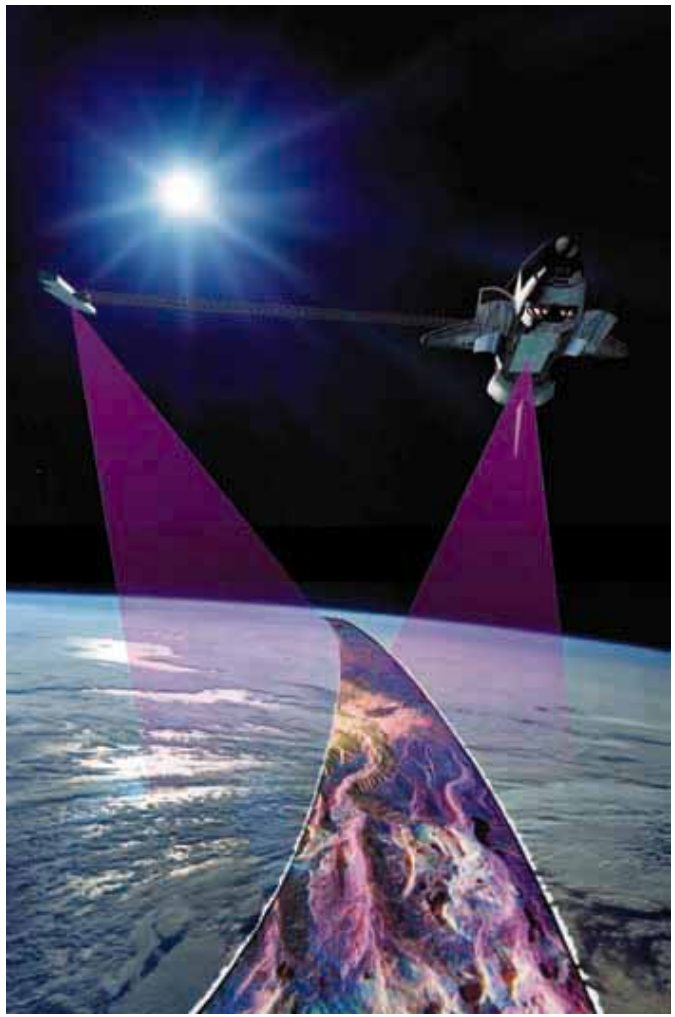
Presentation Outline

- Overview
- SRTM DTED-2® Accuracy Assessment
- THED Accuracy Assessment
- Estimating a Representative Global Assessment
- Summary and Conclusions

Overview

Overview of SRTM Mission

- Shuttle Radar Topography Mission (SRTM) was a joint mission between NASA and NGA (formerly NIMA)
- Utilized a C-band Interferometric Synthetic Aperture Radar (IFSAR) system
- Flown on the shuttle Endeavour over an 11 day period in February of 2000
- Purpose was to collect high resolution terrain data (reflective surface) covering 80% of the Earth's land mass



Artist Rendition of the SRTM Collection
(Courtesy of NASA/JPL-Caltech)

SRTM Accuracy Goals

- **SRTM Accuracy Design Goals at 90% Probability Level:**
  - Absolute Horizontal (AH) = 20 m
  - Absolute Vertical (AV) = 16 m
  - Random Vertical = 8m → Relative Vertical (RV) = 11 m

- **The accuracies associated with SRTM are defined as follows:**
  - **Absolute Horizontal (AH)** - 2-D horizontal error value such that if any point in the DTED cell or sub-cell is selected at random there is a 90% probability that its true horizontal position is within the AH value of a given position
  - **Absolute Vertical (AV)** – 1-D vertical error value such that if any point in the DTED cell or sub-cell is selected at random there is a 90% probability that the true elevation is within the AV value of the given elevation
  - **Relative Vertical (RV)** - 1-D vertical error such that if any two points in the DTED cell or sub-cell are selected at random there is a 90% probability that the true difference in elevation between them is within the RV value of the computed difference in elevation.
  - NOTE: Relative Horizontal (RH) error estimates are not provided for SRTM DTED® because it is difficult to measure with the coarse resolution data

Overview of SRTM Products

- **Digital Terrain Elevation Data - Level 2® (DTED-2®)**
  - Consists of cells covering a 1° x 1° geographical area
  - Post spacing: 1” x 1” between equator and 50° latitude, 1” x 2” above 50° latitude
  - Vertical Reference: Mean Sea Level (MSL)
  - Provides cell wide error predictions at the 90% confidence level for: AH, AV, RH

- **Terrain Height Error Data (THED)**
  - Attempt to provide error estimates at a finer resolution than those provided with the DTED®
  - Provides an estimate of the elevation random error per post
  - Includes metadata known as Vertical Systematic Error Model (VSEM)
    - VSEM divides a cell into 64 sub-cells (8 x 8)
      - Each sub-cell covers 7.5’ x 7.5’ and contains 450 x 450 posts
    - VSEM Provides (at the 90% confidence level):
      - A representative random error per sub-cell
      - An estimate of the distance over which the error is correlated
      - An estimate of the long-wavelength (systematic) error
    - Based on the estimated errors above, the VSEM also provides an estimate of the absolute vertical (AV) and relative vertical (RV) errors on both a cell and sub-cell basis.

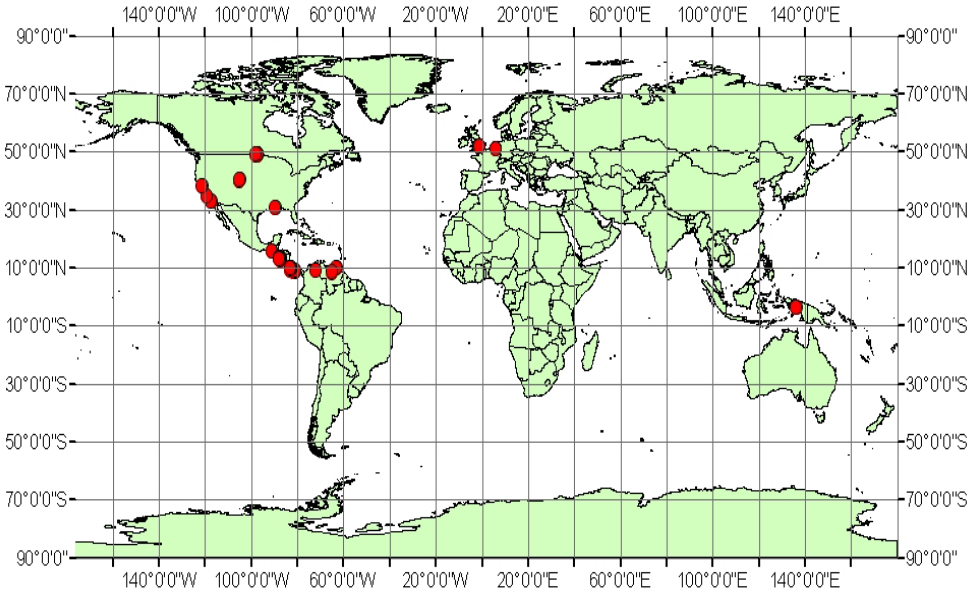
Goals of this Analysis

- Compare SRTM data to high quality reference DEMs considered to be "truth" data
  - Extension of a preliminary analysis presented at the 2003 ASPRS Annual Conference
  - Done primarily on a sub-cell basis

- The analysis performed based on the comparison can be divided into two parts, each with separate goals:
  - DTED Analysis:
    - Determine if the SRTM data meets the AV and RV specifications
    - Determine if any horizontal shifts exist in the datasets
  - THED Analysis:
    - Determine if measured RV values agree with predicted values
    - Examine how well the measured random errors compare to the random errors predicted in THED
    - If the THED does not accurately predict the errors, do indicators exist to determine when the THED is in error?

Ground Truth Data

- **Elevation Ground Truth**
  - Star-3i X-band IFSAR
    - 10 meter or 5 meter post spacing
    - Vertical Accuracy =1,2,3 m (1σ)
    - Horizontal Accuracy = 2.5 m (1σ)
  - 152 samples
  - Each sample covers approx. 1 sub-cell
  - Cover 21 unique geographic areas



Star-3i Data Samples

- **Land Classification Data**
  - The Global Land Cover 2000 (GLC2000)
    - The GLC 2000 was created as part of a project by the European Commission titled Global Environment Information System (GEIS)
    - Land cover classification was generated from SPOT-4 VEGETATION sensor
      - Contains Blue, Red, NIR, and SWIR channels
    - Worldwide data collected in 14 months from 1 November 1999 – 31 December 2000
    - The USGS/EROS Data Center participated in the classification of the data over North America.
    - More information on the dataset can be found at http://www.gvm.jrc.it/glc2000

Reference: "Global Land Cover 2000 database. European Commission, Joint Research Centre, 003. http://www.gvm.jrc.it/glc2000."

SRTM DTED-2® Accuracy Assessment

DTED-2® Analysis

- DTED Analysis
  - Determine if the SRTM data meets the AV and RV specification
  - Determine if any horizontal shifts exist in the elevation data

- The THED provides the following predicted values
  - Long Wavelength Error (L_k) for a sub-cell
  - Representative Random Error (σ_{RREK}): $[(\Sigma_j \sigma_{jk}^2)/n_k]^{1/2}$ for j=1,……,n_k
  - Absolute Vertical Accuracy per sub-cell ($AV_{sub\text{-}cell}$): $[L_k^2 + \sigma_{RREK}^2]^{1/2}$
  - Relative Vertical Accuracy per sub-cell ($RV_{sub\text{-}cell}$): $[2\ \sigma_{RREK}^2]^{1/2}$

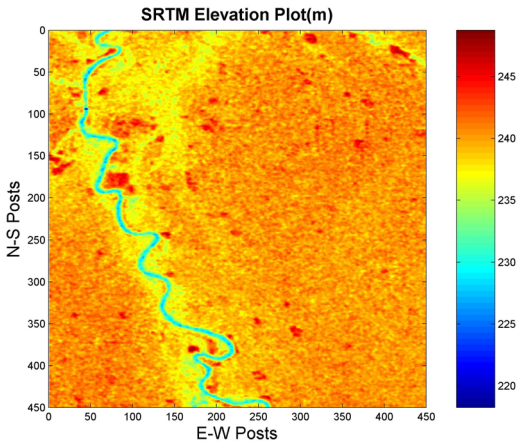
- Process: Compare the SRTM sub-cells to Star-3i and calculate:
  - Difference Matrix (D): D=Truth DEM – SRTM DEM
  - Bias (b): b=mean (D)
  - Random error matrix (E): E = D – b ; with elements e_{jk}
  - Measured RRE (σ_{RRE}): $[(\Sigma_j e_{jk}^2)/n_k]^{1/2}$ for j=1,……,n_k
  - Absolute Vertical Error (AV): $AV = [b^2 + \sigma_{RREK}^2]^{1/2}$
  - Relative Vertical Error (RV): $RV = [2\ \sigma_{RREK}^2]^{1/2}$
  - Detect any horizontal alignment errors (by finding minimum variance location), correct, and re-compute statistics

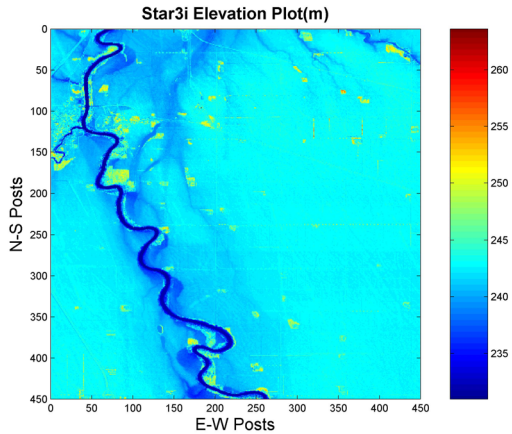
DTED-2® Analysis

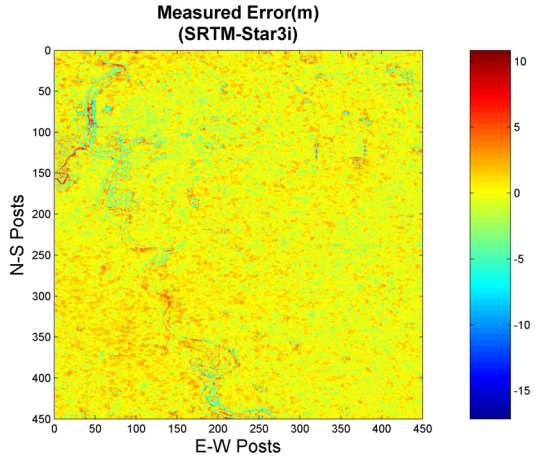
Sample of a Good Sub-Cell: Red River - GT1N48W097H2V1

Error estimates at 90% Probability Level

	Pre Horizontal Adjustment				Post Horizontal Adjustment Shift X:-1m Shift Y: 2.5m			
	LW /Bias (m)	RRE (m)	AV (m)	RV (m)	LW /Bias (m)	RRE (m)	AV (m)	RV (m)
Predicted	4.0	1.6	4.3	2.3	4.0	1.6	4.3	2.3
Measured	-2.5	2.1	3.9	2.8	-2.5	2.1	3.9	2.8





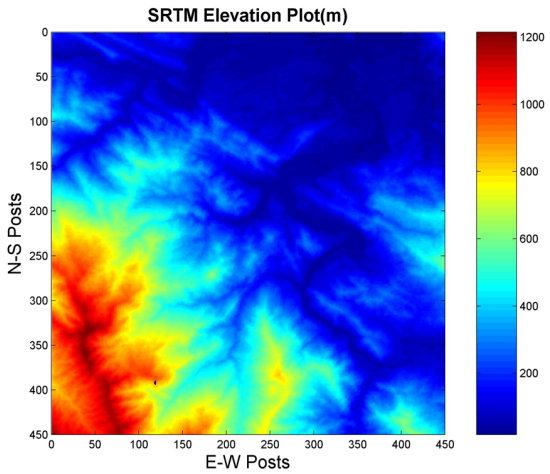


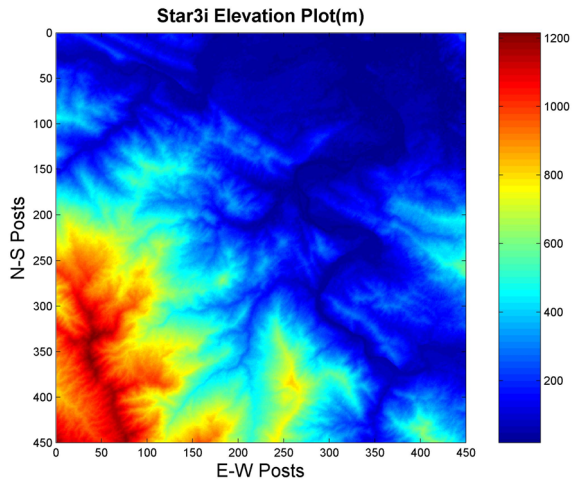
DTED-2® Analysis

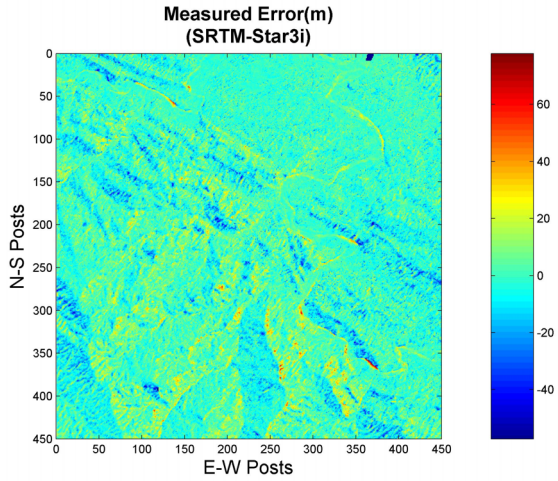
Sample of a Poor Sub-Cell: Panama – GT3N09W082C5V1

Error estimates at 90% Probability Level

	Pre Horizontal Adjustment				Post Horizontal Adjustment Shift X:-21m Shift Y: -6m			
	LW /Bias (m)	RRE (m)	AV (m)	RV (m)	LW /Bias (m)	RRE (m)	AV (m)	RV (m)
Predicted	4.9	6.9	8.5	9.7	4.9	6.9	8.5	9.7
Measured	3.0	15.1	15.6	21.1	2.1	12.2	12.2	16.9



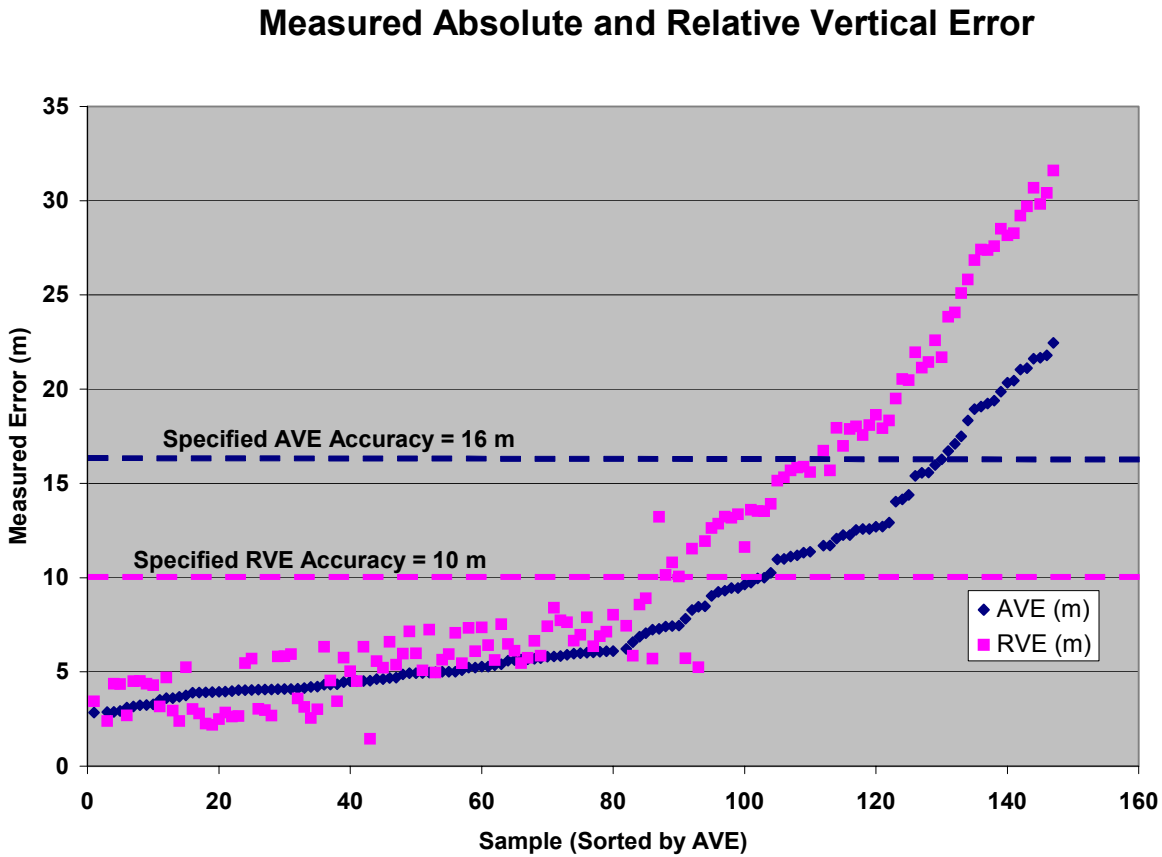




DTED-2® Vertical Accuracy Results

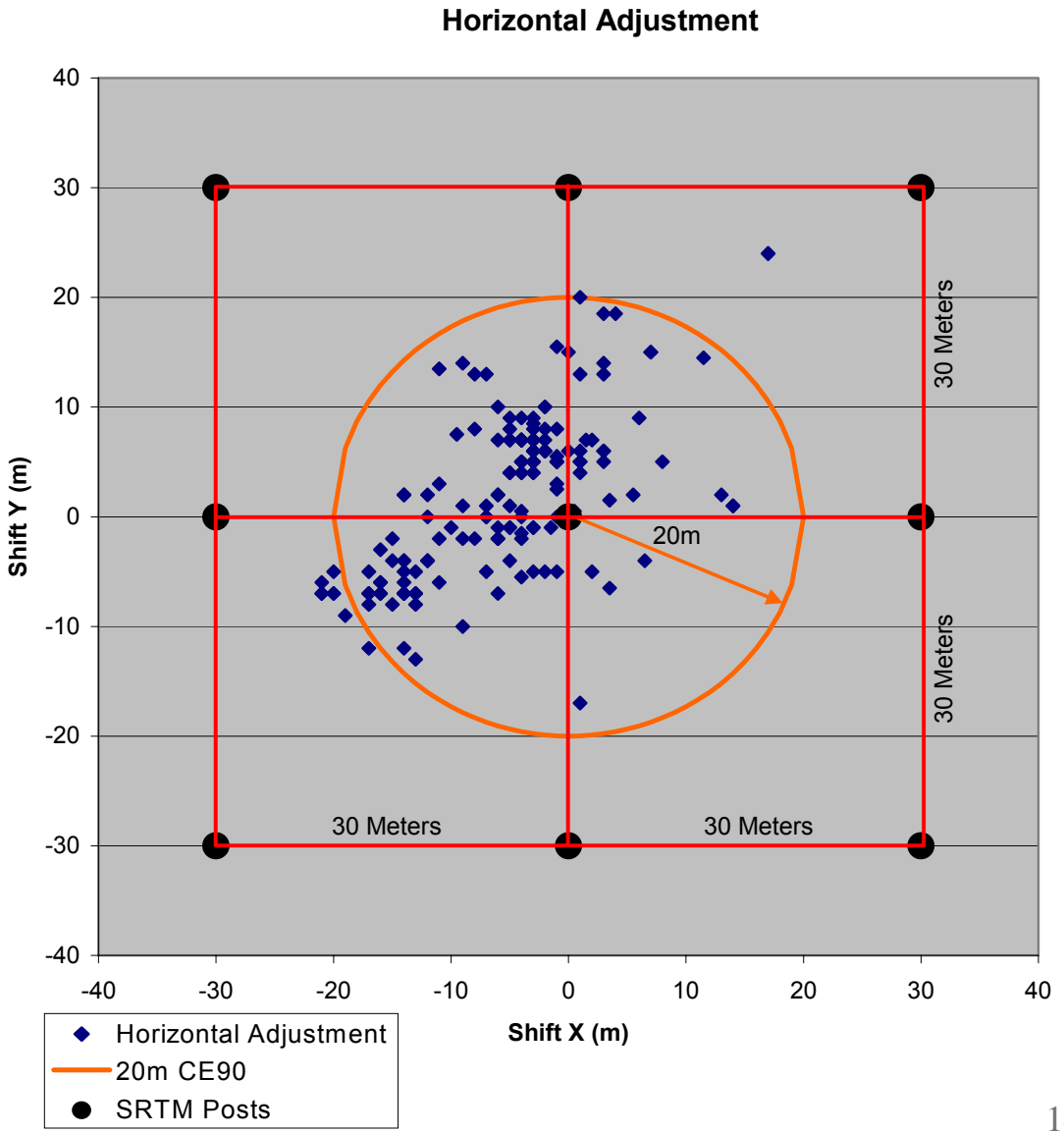
- The measured AV for the various samples show that most of them (88%) meet the SRTM specification
- Only 60% of the RV meet the specification

Note: Many of the samples used in this study are from regions that make IFSAR collection difficult



DTED-2® Horizontal Accuracy Results

- Quality of the horizontal positioning of the SRTM data is very good
- Design spec for absolute horizontal accuracy was 20 meters at the 90% confidence interval
- The measured horizontal shifts are well within this value



THED Accuracy Assessment

THED Analysis

- THED Analysis
  - Examine how well the measured random errors relate to the predicted random errors

- The accuracy of the THED was analyzed using several plots
  - Predicted long-wavelength error vs measured bias
  - Predicted random errors vs measured random errors
  - Predicted RV errors vs measured RV errors

- Using these same measures, the data was examined for trends related to
  - Land Cover Classification using GLC2000
  - Relief Properties based on the simple classification
    - Low Relief = Max. Elev. Diff. < 150m
    - Medium Relief = 150 m < Max. Elev. < 800 m
    - High Relief = Max. Elev. Diff. ≥ 800 m

THED Analysis

- Prior to starting the THED analysis, it was determined that the errors associated with the “truth” data should be considered

- To account for these errors, the values for the Star-3i error provided in the metadata were incorporated with the SRTM random errors:

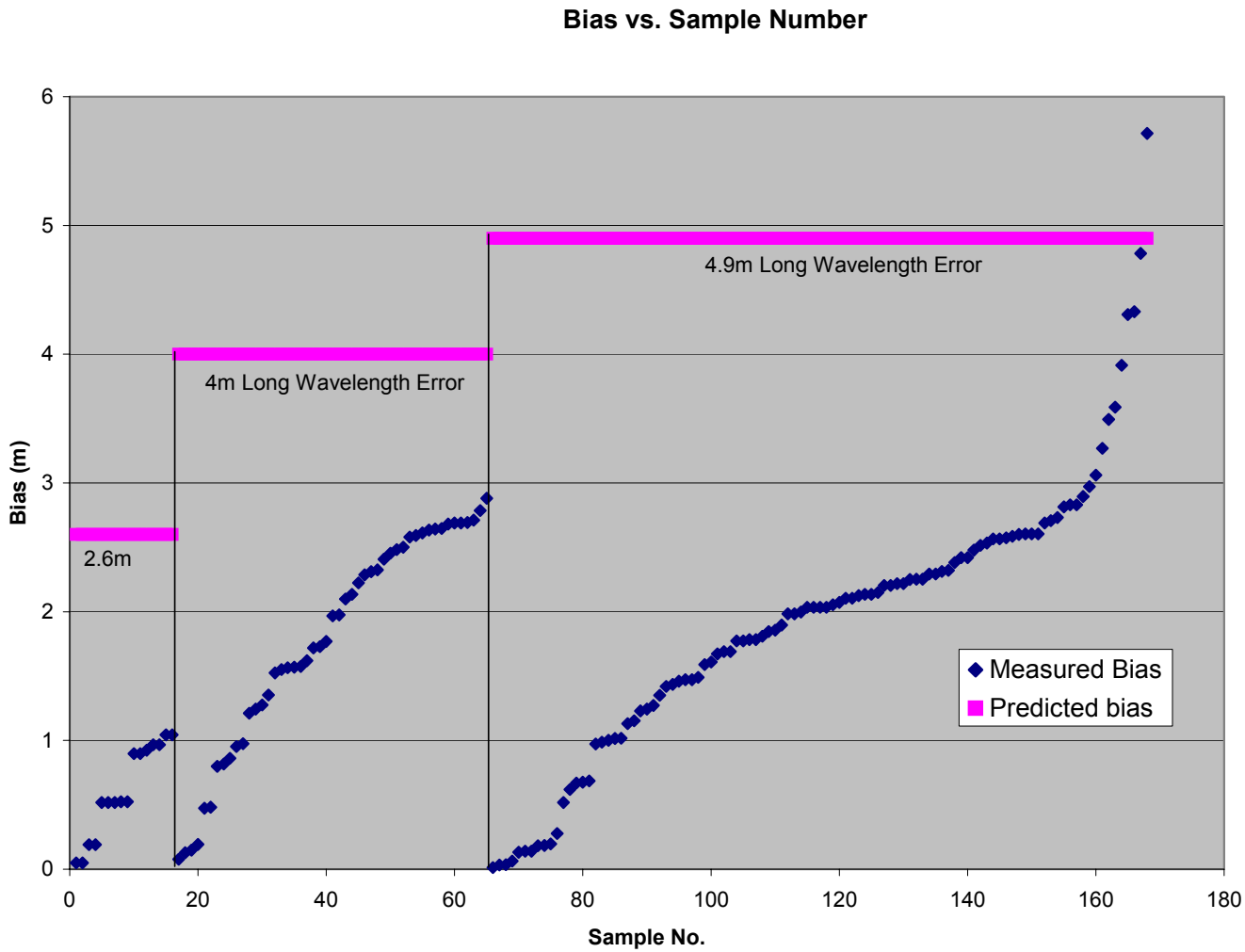
$$\sigma'_{RREK} = [\sigma_{RREK}^2 + \sigma_{90\text{-}Star3i}^2]^{1/2}$$

- After the revised estimates for the representative random error (σ'_{RREK}) were established, the values were used to re-compute the predicted AV and RV for each sub-cell

THED Analysis

- Measured bias is almost always less than the predicted error
- JPL predictions for this error provide a suitable bounding condition for the actual error

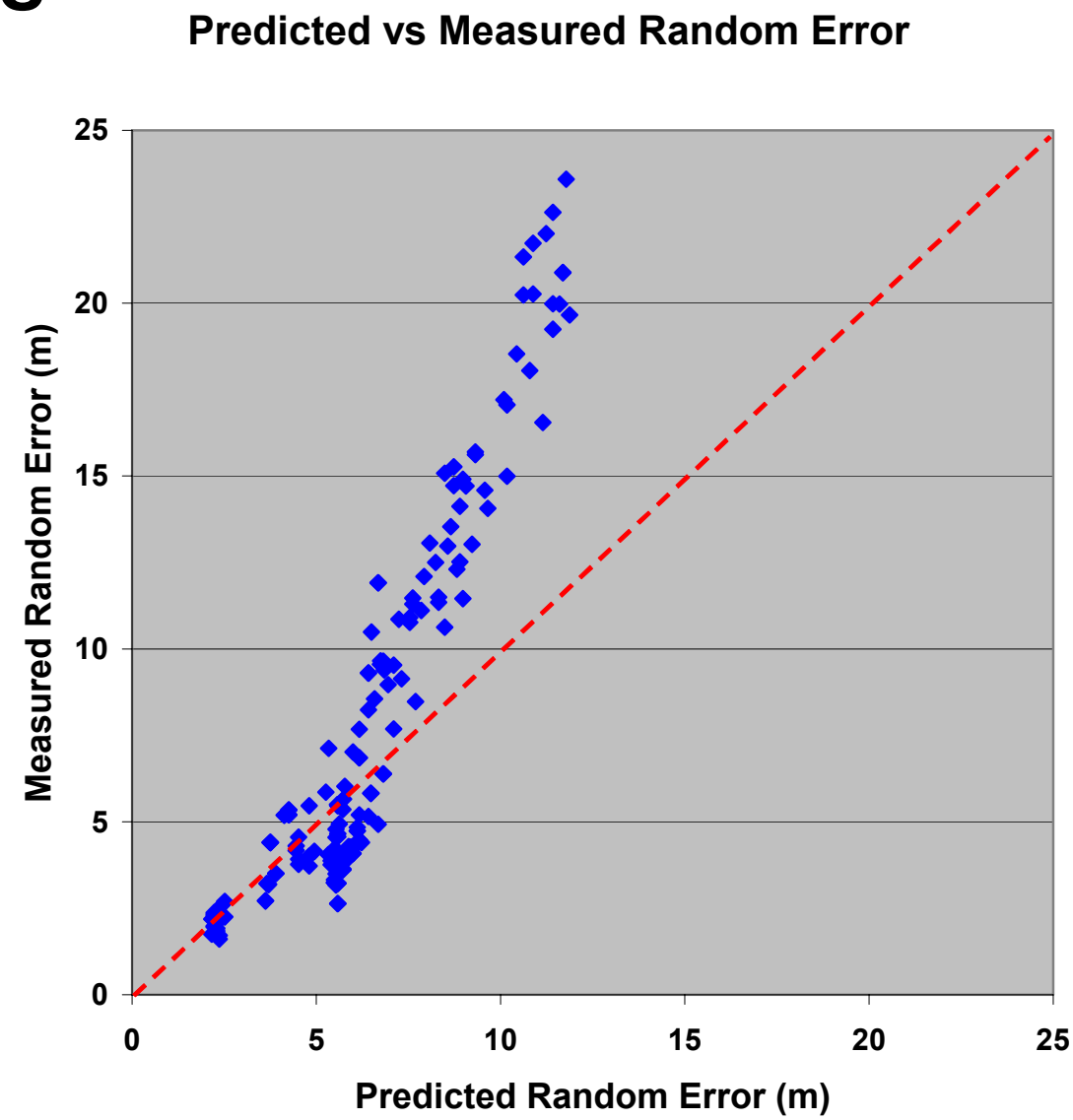
Note: The Long Wavelength Error estimate comes from the VSEM and is an estimate of residual unmodeled low frequency error



THED Analysis

- Plotting the predicted random error versus the measured random error indicates:
  - As measured random error increases, predicted values also increase
  - Measured random errors diverge from predicted values as errors increase
  - For random errors >7m, the THED under-predicts the measured values

Note: High relief data over represented in available ground truth samples

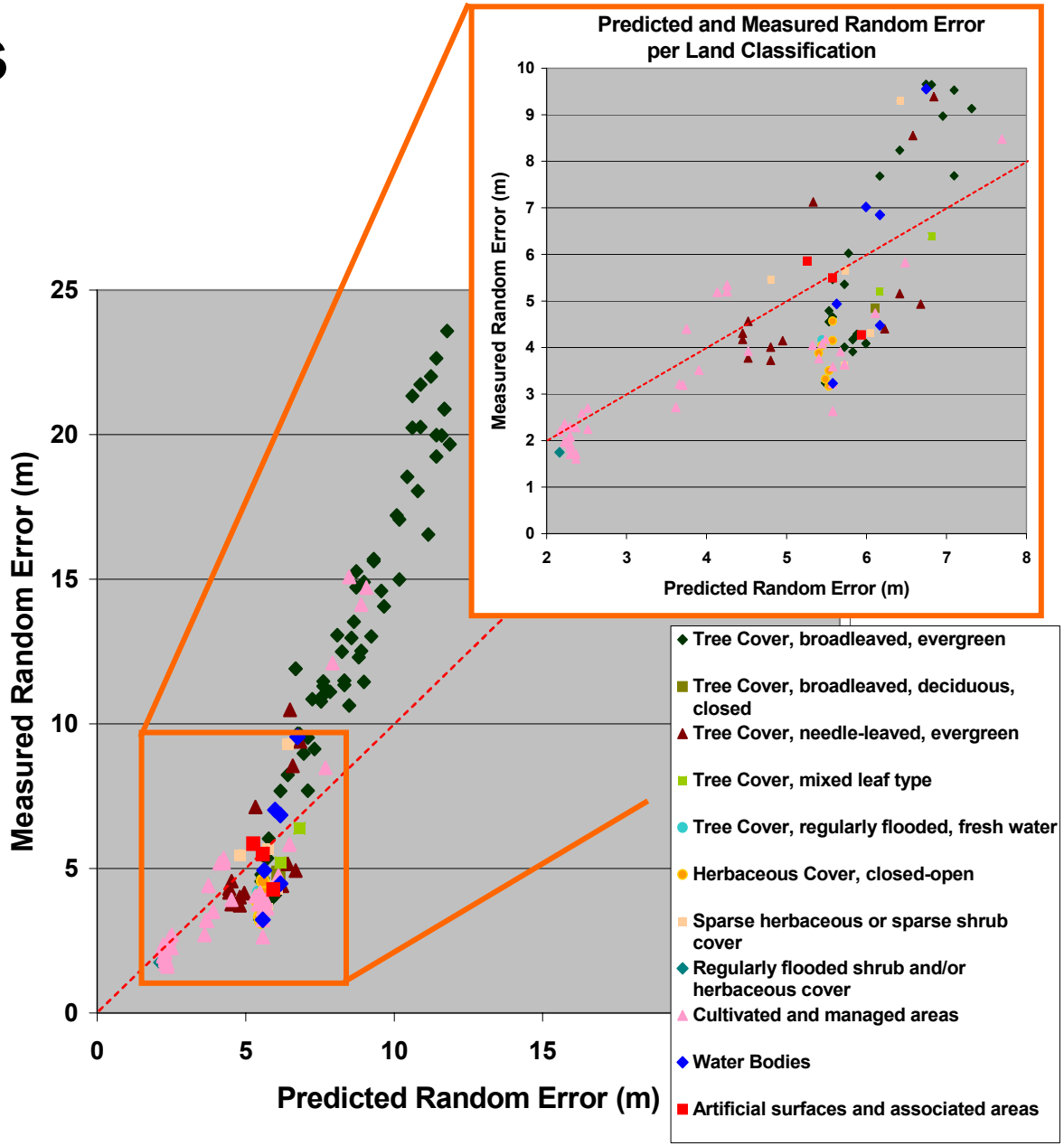


THED Analysis

- After the predicted and measured sub-cell statistics were calculated, the data was classified based on several characteristics:
  - Land Classification
    - GLC2000 Land-cover classification was examined for each sub-cell
    - Every sub-cell was classified based on the predominant land-classification within it.
    - Summary land-classification statistics were calculated for both the sample data and the global GLC2000 database.
  - Terrain Relief
    - Terrain Relief Characterized based on the maximum delta elevation in a sub-cell.
      - Low = Max. Elev. Diff. < 150m
      - Medium = 150 m < Max. Elev. < 800 m
      - High = Max. Elev. Diff. ≥ 800 m
    - Summary terrain relief statistics were calculated for both the study sample and the globe (global statistics based on GTOPO-30)

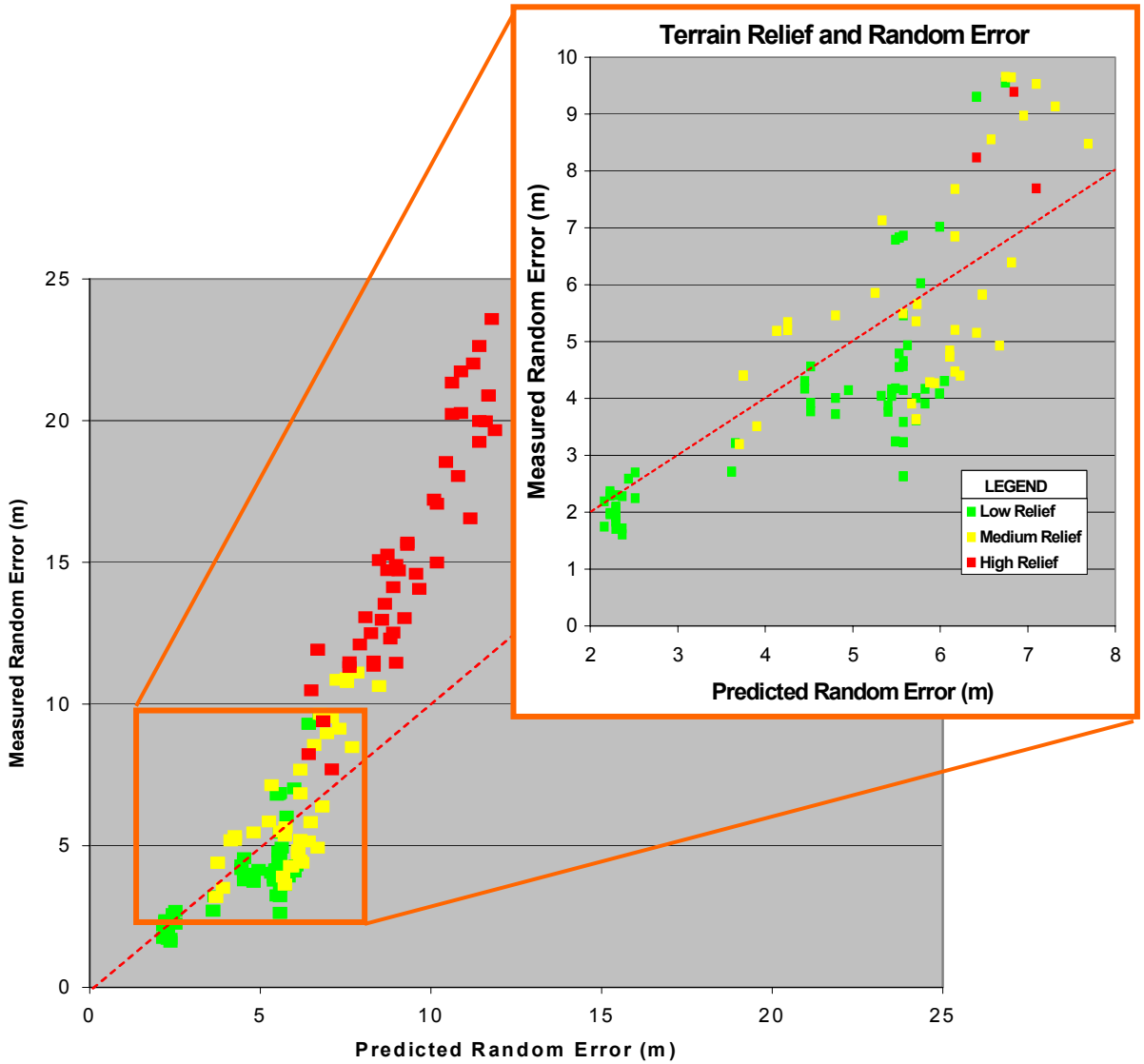
THED Analysis

- Data indicates a correlation between land cover and random error:
  - Many areas classified as cultivated have small random errors
  - Most areas with large random errors fall in the "Tree covered, broad leaved evergreen" class
- The detail area of the plot (random error < 10m) indicates that sub-cells from all land classes are grouped together around a measured random error of ~5 meters



THED Analysis

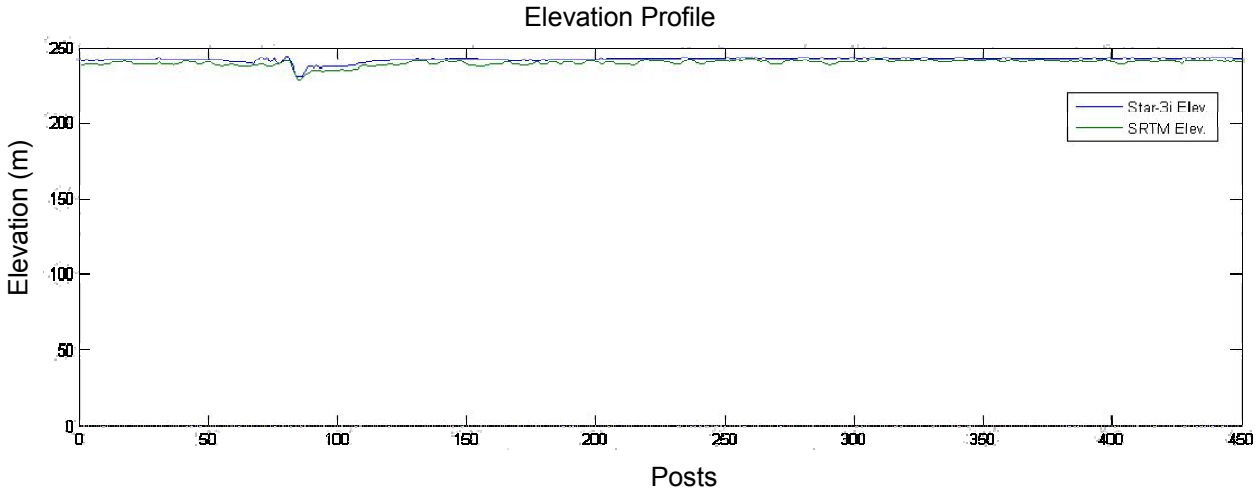
- Relief is a factor in both predicted and measured random errors
- Low relief areas have low predicted and measured random error
- In high relief areas, random errors are generally under-predicted
- In the region of 5 to 10 meters of random error, multiple relief categories overlap

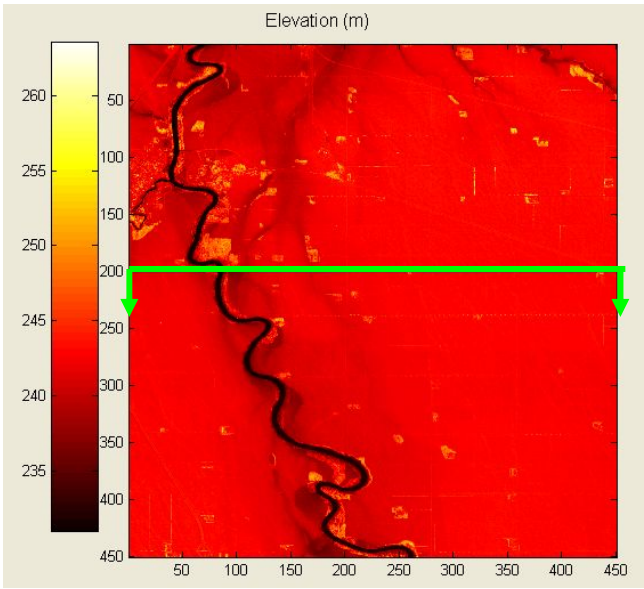


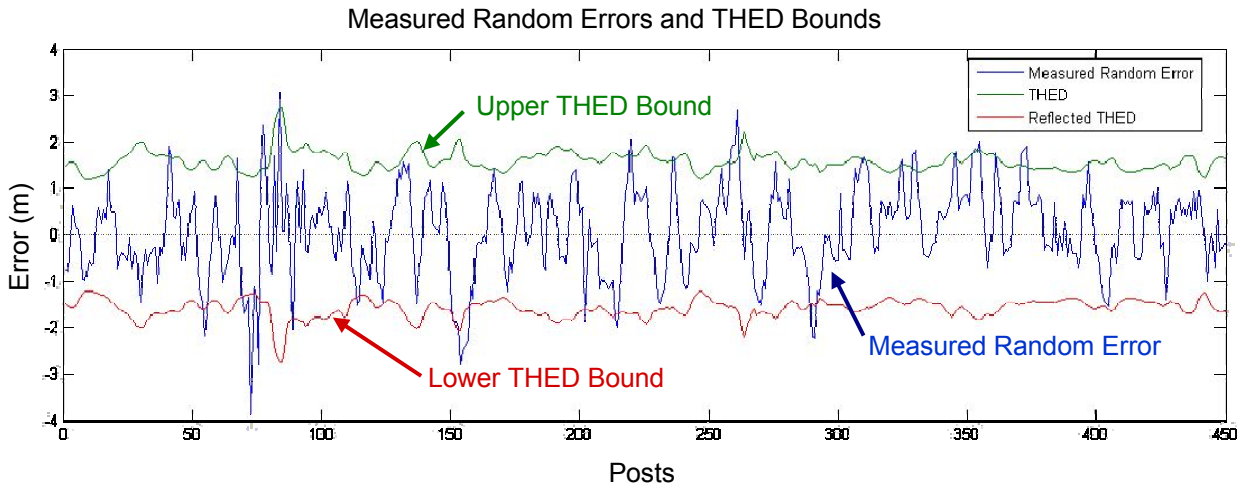
Sample Profiles: Low Relief / Cultivated

Sub-Cell:
GT1N48W097H2V1.BIL

Profile through an area of low relief that is cultivated

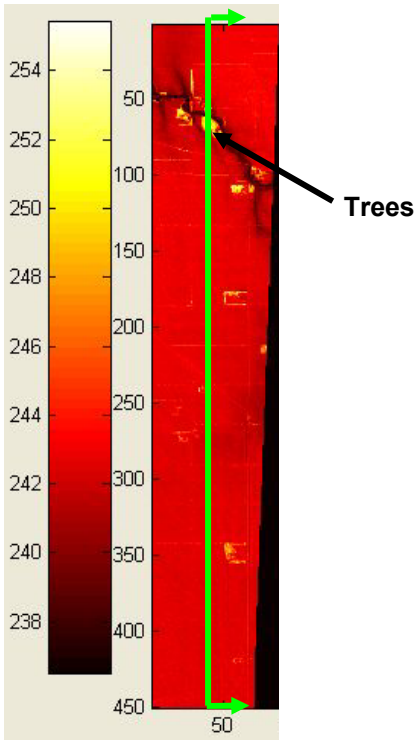


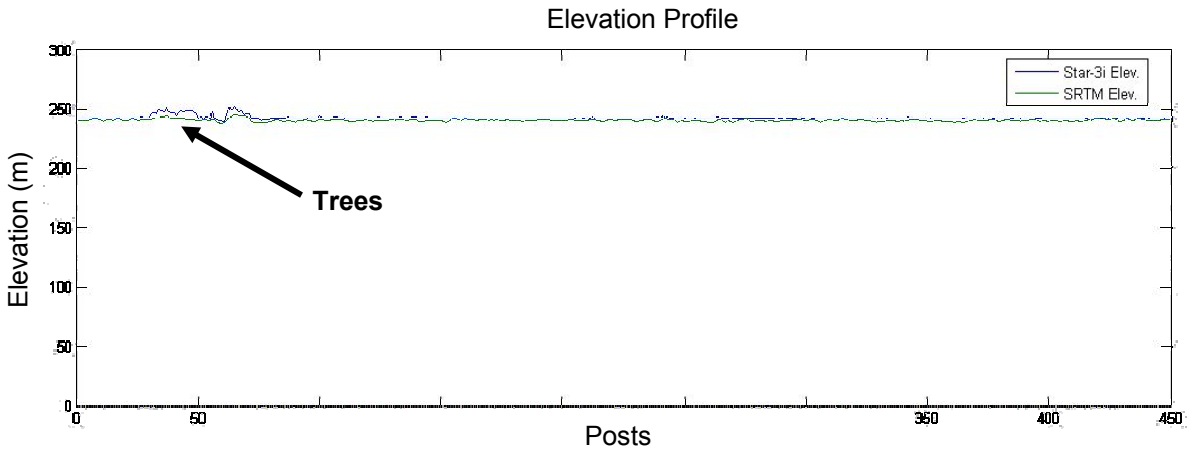


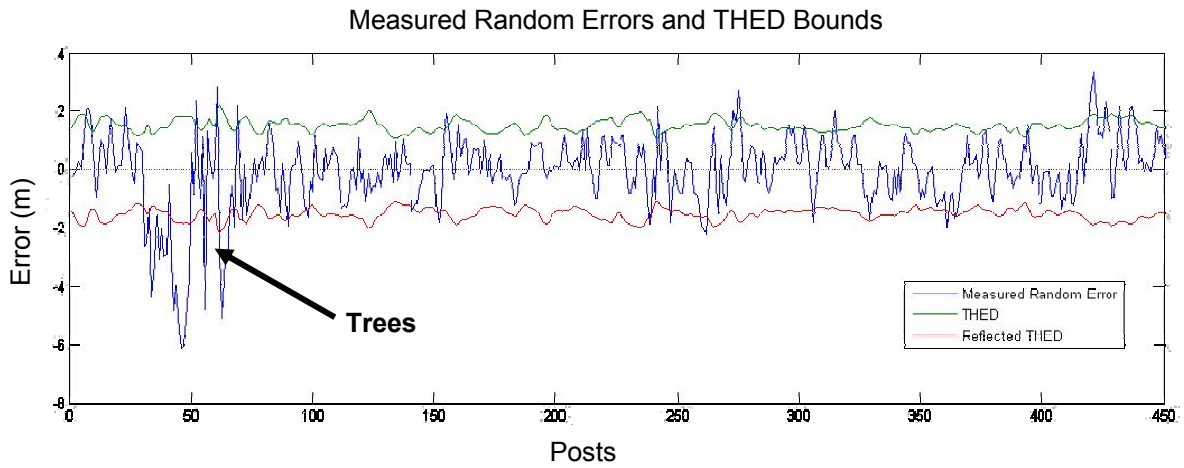


Sample Profiles: Low Relief with Vegetation

Profile through a cultivated area with a small area of trees beside a river

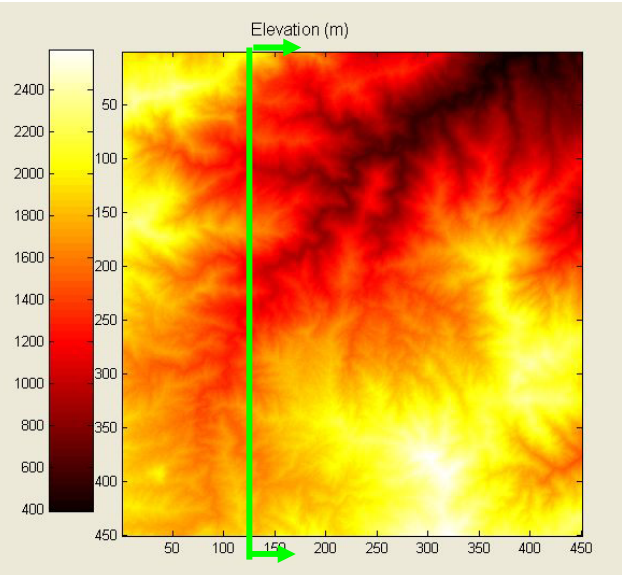


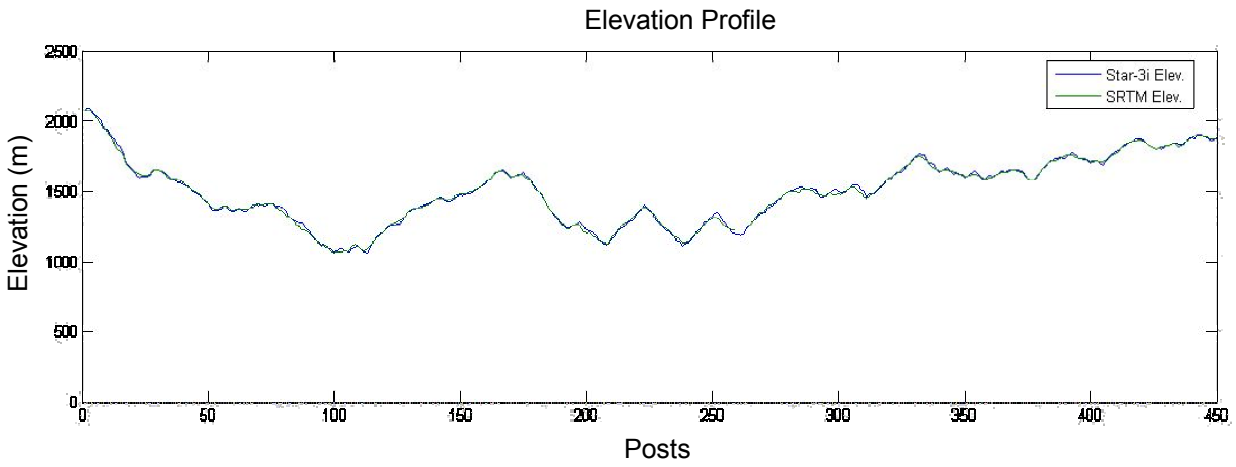


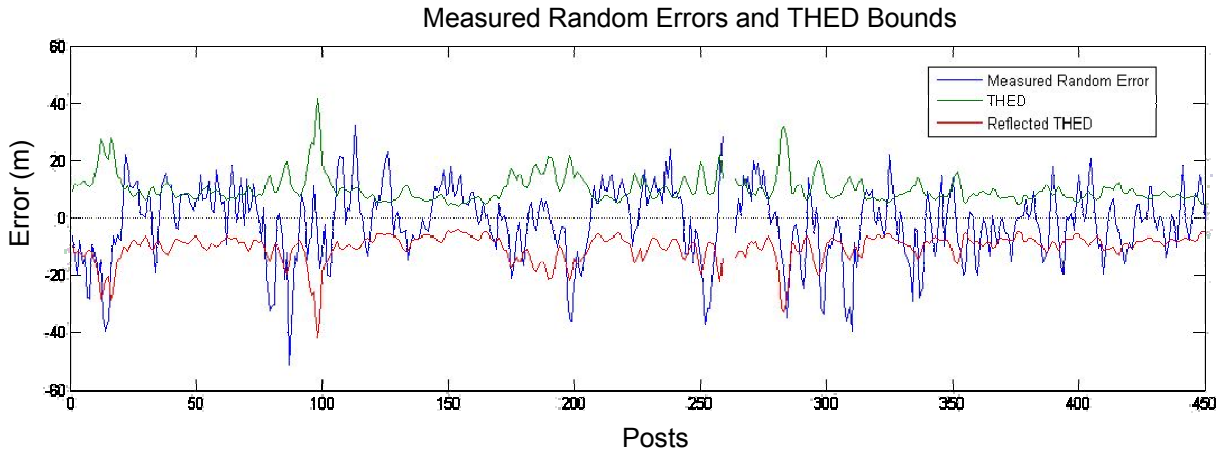


Sample Profiles: High Relief / High Vegetation

- Profile through an area of high relief with heavy vegetation.

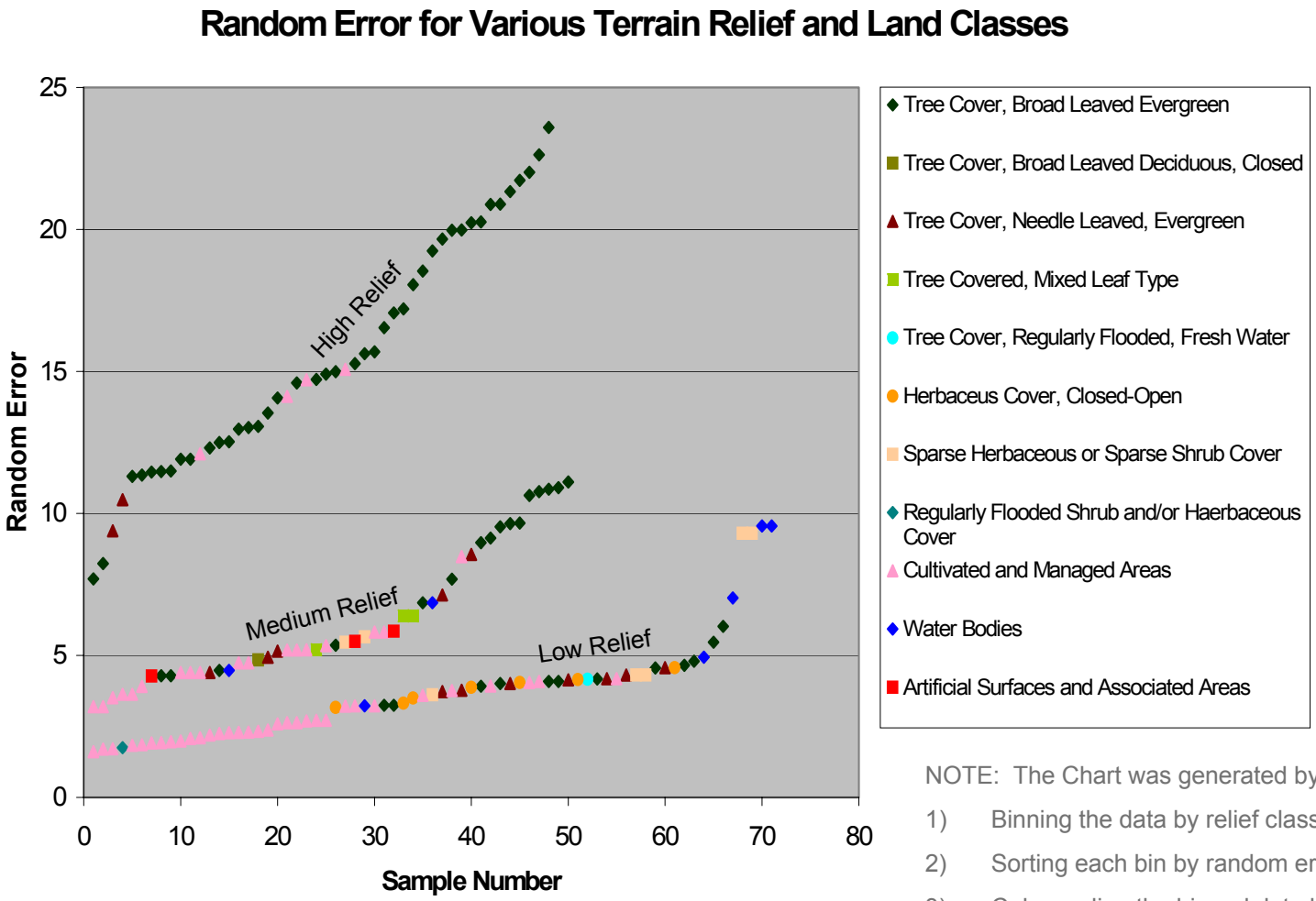






SRTM / THED Error Analysis

Combining the relief and land classification analysis shows relief is the dominant factor



NOTE: The Chart was generated by:

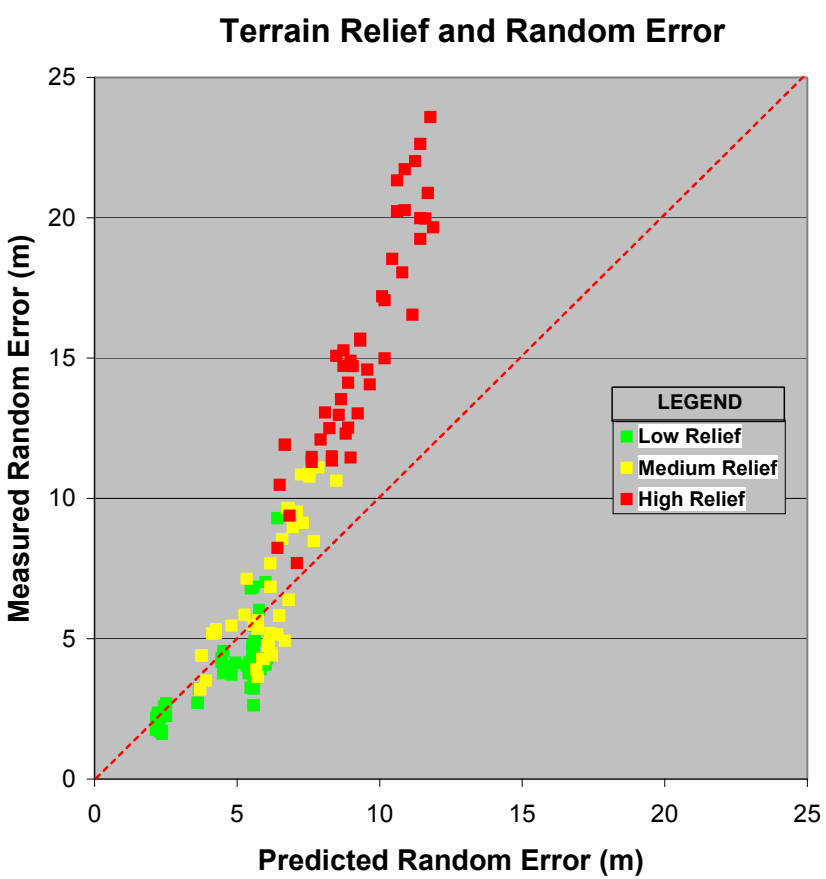
1) Binning the data by relief classification
2) Sorting each bin by random error
3) Color-coding the binned data by land classification

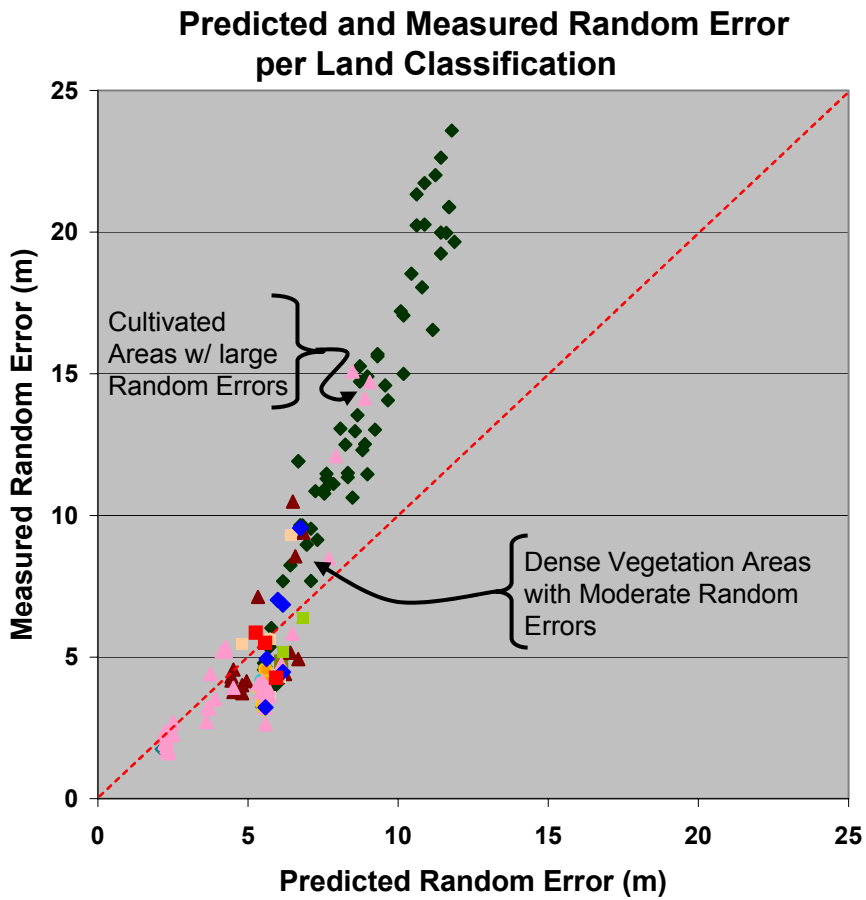
SRTM / THED Error Analysis

- Both land cover and topography of a sub-cell affect the predicted and measured errors of that sub-cell
- As expected, areas of high relief generally have larger random errors
- Similarly, areas of dense vegetation also seem to have larger random errors although there are datasets that conflict with this trend
  - Note that the majority of the sub-cells with dense vegetation in this study are also areas of high relief.
- If the plot of random errors color-coded by relief is examined beside the plot of random errors color-coded by land cover, it appears that relief is the dominant factor in random error because:
  - There are several sub-cells with dense vegetation that exhibit only moderate random errors
  - There are sub-cells in the “cultivated or managed areas” land class that are in high relief areas and they exhibit large random errors.

SRTM / THED Error Analysis

Comparison of the random error plot based on terrain and based on land classification





Estimating a Representative Global Assessment

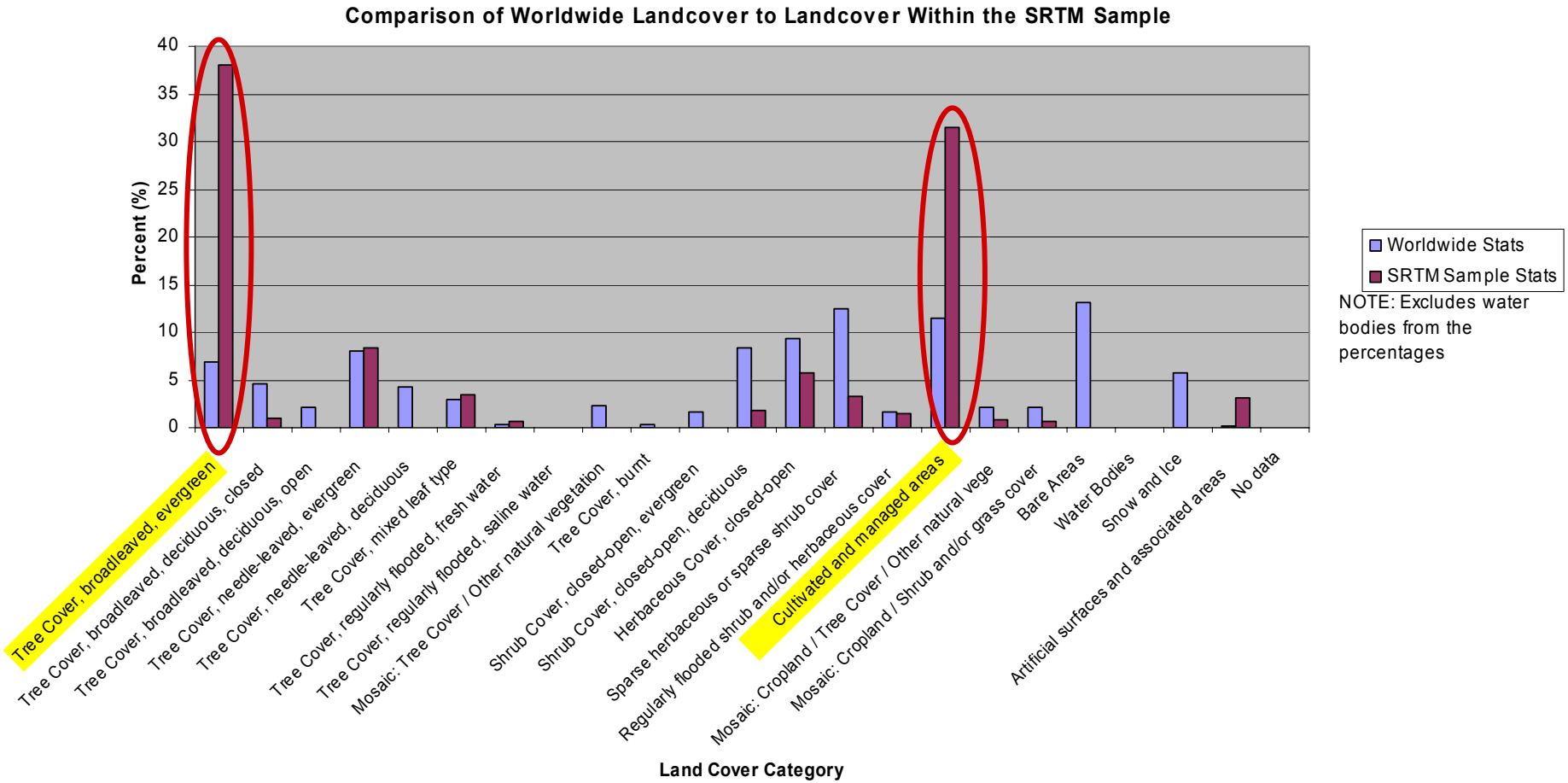
Representative Sample

- This analysis was performed using a large truth dataset distributed across 5 continents

- This dataset is not a representative sample
  - Land cover of ground truth samples does not match global distributions
  - High relief data over represented in available ground truth samples

- To illustrate this, percentages from our sample were compared to global percentages for:
  - Land Classification from GLC2000
  - Relief based on GTOPO-30

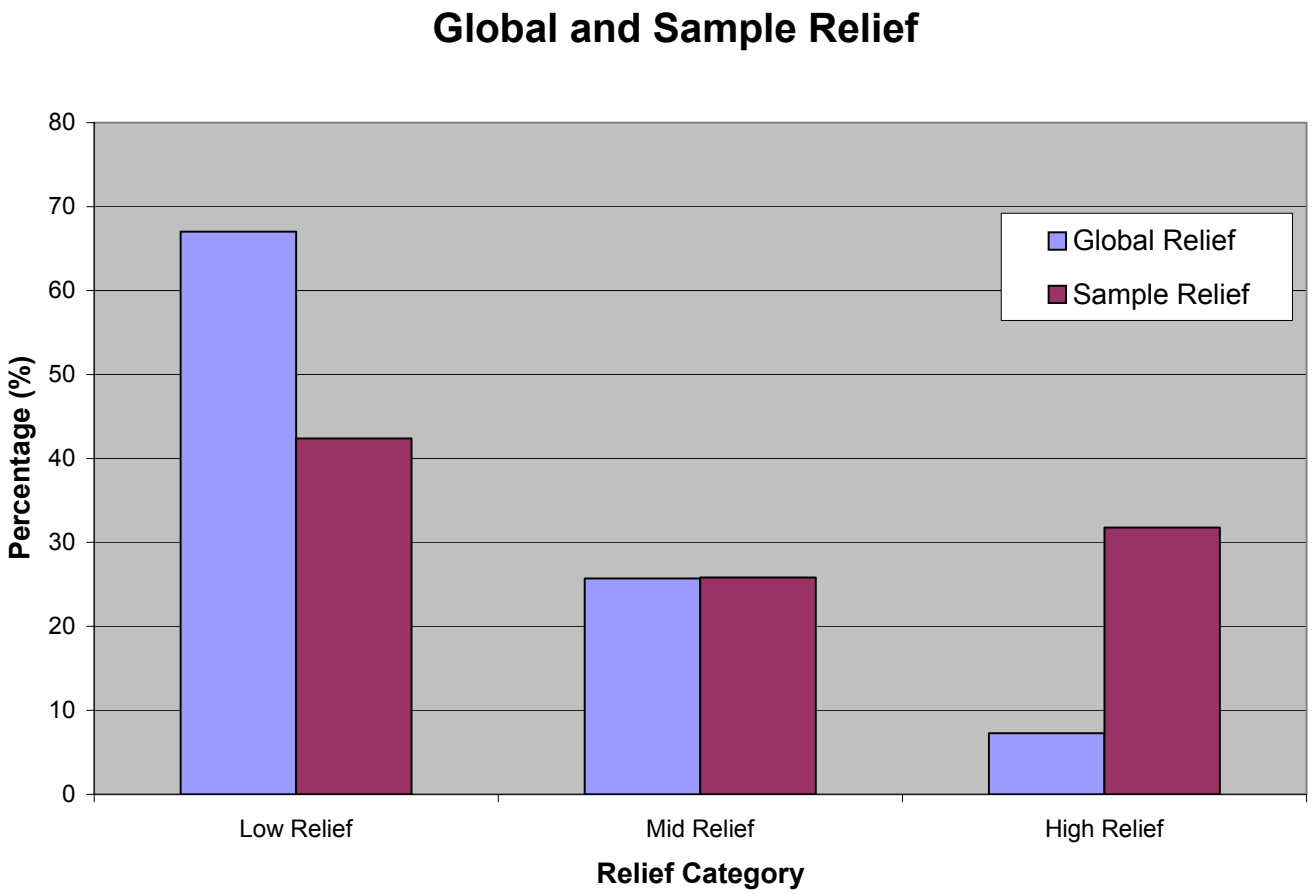
Representative Sample: Land Classification



•Examining the calculation based on land classification indicates that our study sample may be biased by too many samples in the “Tree covered, broadleaved, evergreen” and the “Cultivated and managed areas” categories.

Representative Sample: Relief

- It appears that the sample under-represents the low relief data and over represents the high relief data.



Representative Sample

Average accuracy results for our sample at the 90% probability level

	Random	AV (m)	RV (m)	Global Percentage
Overall	8.11	8.38	10.90	100.00
Low Relief	3.69	4.79	5.04	67.03
Mid Relief	6.36	6.64	8.76	25.69
High Relief	15.46	15.18	21.36	7.28

- Using global percentages for relief to normalize SRTM accuracies based on the results of this study yields the following global accuracy estimate:

  AV = 6.0 m RV = 7.2 m Random = 5.2 m

- These compare well to the JPL results averaged across continents:

  AV = 6.8 m RV = 6.9 m

Summary and Conclusions

Overall Assessment of SRTM Data

- Digital Terrain Elevation Data
  - Excellent results for absolute errors
  - RV results vary and are a function of relief
  - If a weighted average is generated based on relief, the overall accuracy results are well within specification

- Terrain Height Error Data
  - Provides a good indication of the quality of the SRTM data
  - As the predicted values in the THED increase, the measured random errors also increase
  - Although they show similar trends, the measured and predicted random errors diverge as the random errors increase with the THED under-predicting the random error
    - Divergence between measured and predicted errors is systematic, so it could me modeled and accounted for

Where precision is most important (lower values of THED), results are very good

Conclusions

- The SRTM mission provided excellent elevation data for many applications
- This analysis has verified previous results indicating that the SRTM data generally meets or exceeds its design specifications
- The THED provides a good general indication of the quality of the SRTM elevation data
- Relief appears to be a dominant contributor to the SRTM errors
- Based on these results, the SRTM user can:
  - Have high confidence in the SRTM elevation and error data in low and moderate terrain
  - Have high confidence in the elevation data in higher relief areas, realizing that the error estimates will often be optimistic
  - Use the THED (if available) to assess the general quality of a specific portion of SRTM data
- With minor modifications, the THED may be used to provide a very good prediction of the SRTM errors.

NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY

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