SHUTTLE RADAR TOPOGRAPHY MISSION:
ACCURACY ASSESSMENT AND EVALUATION
FOR HYDROLOGIC MODELING

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Outline

• Introduction and Main Goal
• Main Characteristics and Properties of SRTM

• Three main components of the thesis:
  
  • **Statistical Measures Accuracy of SRTM 1 and 3 arc-second Data in Flat and Undulating Landscapes of Midwest United States**
  
  • **Vertical Accuracy of SRTM Elevation Data in Argentina**
  
  • **Characterization of Agricultural Watersheds using Remotely Sensed Data**

• General Conclusions and Further Research
• Topography has a dominant influence on spatial and temporal patterns of water storage and transport

• Existing and potential applications of high-quality digital elevation (DEM) data are surprisingly diverse, even in low relief areas

• Hazards assessment, Natural disasters prevention and risk analysis. The increase use of GIS lead to a heavier reliance on DEMs. The importance and responsibility makes it inevitable to provide DEMs with adequate quality measures

• A DEM is a primary layer in geospatial analysis: need to know the error in a geospatial database, because the error propagates trough operations and calculations
The Need for Topographic Data

Introduction

Hurricane Rita simulation
(NASA - JPL, 2005)

Santa Fe flash flood
(CONAE - INTA, 2003)
Argentina

Hydrologic Modeling

Agricultural applications
(Johannsen, Beatty)
The Shuttle Radar Topography Mission

• SRTM obtained elevation data on a near-global scale (80% of Earth’s land mass)

• Most complete high-resolution digital topographic database of Earth at 1 arc second (30 m)

• Specially modified radar system – Single-pass IFSAR (Interferometric SAR)

• Consistent acquisition, common processing

• Available to end users all over the world

• NASA, NGA (NIMA), USGS

• 11-day mission, February, 2000
Main Goals

Introduction

• Investigate quality issues of SRTM,
• Provide measures of vertical accuracy with emphasis on low relief areas,
• Analyze performance for generation of physical boundaries and streams for watershed modeling and characterization
• “To help document the SRTM data quality and characteristics, and to describe applications benefiting from the data” (NASA / USGS)
Main Characteristics

Sources of SRTM Data

- **NASA**
  - Science Data
    - "research grade"
    - SRTM Format
      - "unedited"
  - Format: .hgt
    - One Degree Lat-Long Tiles
    - Geographic Coordinates

- **NGA**
  - DTED® Level 1 and 2
    - "finished" data
  - Format: .DTED Mosaics
    - Geographic Coordinates

- **USGS**
  - SRTM Format
    - SRTM DTED®
      - "finished" data
  - Formats ArcGrid / GRIDFLOAT / BIL / TIFF
    - (1, 3 30 Arc Second)
    - Seamless Mosaics

- **ESDI**
  - Preliminary release
    - "unfinished" data
  - Formats geotiff / float
    - (1, 3 30 Arc Second)
  - One Degree Lat-Long Tiles, Geographic Coordinates
  - WRS-2 Tiles, UTM

- "Finishing": delineating and flattening water bodies, better defining coastlines, filling small voids and removing spikes
SRTM-1 and SRTM-3

Main Characteristics

**SRTM-1 (United States)**

- NASA
- Research grade
- SRTM format

**SRTM-3 (Global Coverage)**

- NGA (NIMA)
- DTED format

\[ \sum \frac{x_i y_i}{n} \]

Average

Subsampling

90 m
SRTM: surface or “first return” DEM

Main Characteristics

- SRTM: IFSAR, Band-C,
- Requires pre-processing using Vegetation removal techniques
Topographic derivatives: slope

Main Characteristics

SRTM-1

NED

Slope %

0 - 2
2 - 6
6 - 12
> 12

D8 algorithm
ArcGIS
• Gaussian distribution of values of remotely sensed SRTM-1DEM (30m)

• Histogram extracted from low relief area illustrating distribution with sharp peaks of NED DEM (30 m)
• Accuracy main attribute of the quality of a geodatabase

• What is the vertical accuracy of SRTM?

• How do the SRTM data compare with USGS DEMs? (NED)

• Measures of absolute accuracy for SRTM-1 and SRTM-3 using a dense geodetic network

• Analysis of factors that can affect the error assessment in remotely sensed DEMs and sources of error

• Relative error assessment using the best available DEM at same resolution (NED)
ACCURACY OF THE SRTM IN FLAT LANDSCAPES

**Data**

**Absolute Accuracy**
- SRTM – 1 (30 m)
- SRTM – 3 (90 m)
- NED (National Elevation Dataset - 30 m)
- USGS 1:250,000 (90 m)
- HARN 147 data points *NGS

**Relative Accuracy**
- SRTM – 1
- SRTM – 3
- NED (National Elevation Dataset) 30 m

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**Methods**

**Measures of Accuracy**
- Mean Absolute offset
- MSE
- RMSE
- 95% CI (FGDS)

- Mean Relative offset
- Fractional Standard Deviation
- Total error budget

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**Strategies**

- Aggregation of geodetic points by dominating landscape
- Grouped by flat & undulating
- Grouped to analyze effects of land use
- Relative error assessment using best available DEM at same resolution
- Selected bald Earth area, for relative comparison with NED
Aggregation of Test Points

ACCURACY OF SRTM IN FLAT LANDSCAPES

• Physiographic Regions of Indiana
• 147 HARN geodetic points
Absolute Accuracy Assessment: RMSE

ACCURACY OF SRTM IN FLAT LANDSCAPES

\[ \text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (Z_{\text{independent}} - Z_{\text{test}})^2}{N}} \]
• However, better vertical accuracy at expense of poor representation of variability
• Impact of changes of land use
• Adjacency effects of forested and build up land use
Relative Accuracy Assessment

ACCURACY OF SRTM IN FLAT LANDSCAPES

Sources of Error = Δ_{rel} + ε_{phase} – noise + ε_{environment}
## Relative Accuracy Assessment

### ACCURACY OF SRTM IN FLAT LANDSCAPES

<table>
<thead>
<tr>
<th>Mean Offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta_{rel}$ (mean offset) = $\frac{1}{N_{(x,y)}} \sum_{i=1}^{N_{(x,y)}} (Z_{SRTM} - Z_{NED})$</td>
</tr>
<tr>
<td>$X$: 0.22 m</td>
</tr>
<tr>
<td>$\sigma_{\text{diff}}$: 1.15 m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Fractional Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma \cdot \bar{Z}<em>{SRTM ,-, NED} = \sqrt{\sigma^{2}</em>{Z_{SRTM}} + \sigma^{2}<em>{Z</em>{NED}}}$</td>
</tr>
<tr>
<td>2.33 m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total $\sigma$ SRTM = $\sigma_{\text{abs}} + \sigma_{\text{rel}}$</td>
</tr>
<tr>
<td>4.53 m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total budget (abs, rel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>total error budget = $\Delta Z_{\text{abs}} + \Delta Z_{\text{rel}} + e$ vegetation, land cover</td>
</tr>
<tr>
<td>1.41 m</td>
</tr>
</tbody>
</table>

---

![Graph](image1.png)

Absolute: $Z_{\text{SRTM-1}} = 0.9941 Z_{\text{HARN}} + 1.3717$

$\hat{r} = 0.998$

$n = 147$

![Graph](image2.png)

Relative: $Z_{\text{SRTM-1}} = 0.815 Z_{\text{NED}} + 33.808$

$\hat{r} = 0.998$

$n = 1804$
Conclusions

ACCURACY OF SRTM IN FLAT LANDSCAPES

- Accuracy better than original mission specifications

- Accuracy within range of recent validation: ~ 5 – 6 m worldwide and ~ 4 m US (all landscapes and land uses)

- Measured vertical accuracy better than 5 m (IN all measures) at 95%

- Low relief, open terrain < 2 m (abs), 1.41 m (rel), 4.53 m (SD)

- Relative positive bias for SRTM as compared with NED, (range -3 – 6m)

- Low vertical uncertainty values of SRTM-3 in flat areas
• Need accuracy assessment in order to know quality of SRTM-3 for multiple applications
• Need to generate geospatial framework maps
• No previous studies in area
• To collaborate in extensive program that is underway by NASA to verify SRTM data
• Numerous local studies need references regarding quality of SRTM DEM in order to justify its use in applications
GEODETIC NETWORK & SRTM-3 in ARGENTINA

Official POSGAR Geodetic Network (#127)

SRTM-3 mosaic (>220 one degree tiles)
**Data**

**ABSOLUTE ACCURACY**
- SRTM – 3
- POSGAR Network

**Methods**

**MEASURES OF ACCURACY**
- Mean Abs offset
- MSE
- RMSE
- 95% CI (FGDS)

**GEOODETIC TRANSFORMATIONS**
- Vertical datum
- Ellipsoidal vs geoidal heights

**Strategies**

- Aggregation of geodetic points by dominating landscape
- Grouped to analyze effects of land use
- Grouped by flat landscape

\[
x, y \quad \text{SRTM and POSGAR: horizontal datum WGS84}
\]

\[
z \quad \text{SRTM = geoidal heights (H)}
\]

\[
\text{Posgar = Ellipsoidal heights (h)}
\]

\[
\text{Geoid: EGM96 (N)}
\]

\[
h = H + N
\]

(Mercuri, 2002)
Distribution of POSGAR / Land Cover / Offset

Accuracy of SRTM-3 in Argentina
# Accuracy of SRTM-3 in Argentina

## Accuracy Results

<table>
<thead>
<tr>
<th>Land Use /Land Cover Category</th>
<th>Terrain Characteristics</th>
<th>n</th>
<th>Min - max (m)</th>
<th>Mean Offset (m)</th>
<th>RMSE (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropland/Grassland mosaic</td>
<td>Flat <em>pampas</em></td>
<td>25</td>
<td>-3.32 – 3.28</td>
<td>0.15</td>
<td>1.89</td>
</tr>
<tr>
<td>Cropland/Woodland Mosaic</td>
<td>Flat to undulated forest (<em>Chaco</em>)</td>
<td>21</td>
<td>-3.83 – 5.09</td>
<td>0.69</td>
<td>2.71</td>
</tr>
<tr>
<td>Mixed Shrubland/Grassland</td>
<td>Semiarid steppe</td>
<td>20</td>
<td>-9.19 – 6.54</td>
<td>-0.24</td>
<td>3.32</td>
</tr>
<tr>
<td>Mixed Shrubland/Grassland</td>
<td>Patagonian steppe</td>
<td>32</td>
<td>-8.43 – 6.44</td>
<td>-0.44</td>
<td>2.95</td>
</tr>
<tr>
<td>Mixed Forest</td>
<td>Patagonian <em>Andes</em></td>
<td>11</td>
<td>-7.18 – 5.73</td>
<td>-0.77</td>
<td>3.63</td>
</tr>
<tr>
<td>Evergreen Broadleaf/Subtropical Forest</td>
<td>Northeastern Argentina, highly undulated</td>
<td>4</td>
<td>-3.42 – 3.47</td>
<td>0.02</td>
<td>2.46</td>
</tr>
<tr>
<td>Barren or Sparsely Vegetated</td>
<td>Arid valleys / Andes mountains</td>
<td>10</td>
<td>-27.13 – 10.63</td>
<td>-3.11</td>
<td>10.40</td>
</tr>
<tr>
<td>Urban and Built-Up Land</td>
<td>Urban areas</td>
<td>2</td>
<td>7.62 – 12.61</td>
<td>10.16</td>
<td>10.48</td>
</tr>
</tbody>
</table>
Conclusions

Accuracy of SRTM-3 in Argentina

• All country, all landscape RMSE: 4.24 m

• Aggregation to analyze effects of land cover and relief:
  - open terrain land cover uncertainty <3 m
  - forested, high relief, urban and build-up areas >10 m

• Comparable results of SRTM-3 in low relief with US site in Indiana (global geoid solution)

• Need improved geodetic dataset and larger number of checkpoints
CHARACTERIZATION OF AGRICULTURAL WATERSHEDS USING REMOTELY SENSED DATA

• To create a consistent, seamless and hierarchical watershed boundary framework

• Starting point for hydrologic modeling approaches

• Need to generate base geodatabases for water and land resources

• Need to develop flood risk maps using digital topography

• Basins of Argentina
Argentina: Arrecifes Basin
- SRTM – 3
- Rasterized / Georef Topographic Quads 1:50,000
- Landsat TM
- NRWIS database 1:2,500,000

Indiana: Middle Fork Watershed
- SRTM – 1
- SRTM – 3
- NED (National Elevation Dataset) 30 m
- WBD (HUC12 or HUC 14)

Methods
- SRTM 1 / SRTM 3
- Vegetation Removal
- DEM Filtering
- Stream Burning
- Fill Sinks
- Flow Direction
- Flow Accumulation
- Inflowing
- Stream Definition
- Threshold Area
- Outlet Selection
- Map Calculations
- Verification

Strategies
- Delineation interface of SWAT
- Interactive selection of threshold (1500 ha)
- Verification of SRTM performance in Indiana at watershed level in similar relief and land use watershed
- Arrecifes projet and Indiana verification site using the same
- Development of water and land resources database using
Delineation of Watersheds and hydrologic networks
The Arrecifes River Basin

Characterization of Agricultural Watersheds
Characterization of Agricultural Watersheds

Development of Hydrologic Units Database

- **Basin**
  - Arrecifes River
  - 1,218,900 ha

- **Subwatershed**
  - La Magdalena
  - 2,212 ha

- **Watershed**
  - Arroyo Dulce
  - 51,520 ha
Verification of delineation at watershed and sub watershed level Indiana

Similar landscape and land use
Verification in Indiana: The Middle Fork Wildcat Creek

Characterization of Agricultural Watersheds

<table>
<thead>
<tr>
<th>Middle Fork Wildcat Creek</th>
<th>WBD10 Digits</th>
<th>NED</th>
<th>SRTM-1</th>
<th>SRTM-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (ha)</td>
<td>31,347</td>
<td>31,290</td>
<td>30,574</td>
<td>31,281</td>
</tr>
<tr>
<td>Perimeter (m)</td>
<td>109,645</td>
<td>165,900</td>
<td>164,400</td>
<td>143,280</td>
</tr>
</tbody>
</table>

% of agreement with WBD

Subwatersheds: Middle Fork Wildcat Creek, Robertson Branch, Rossville, Harness Ditch, Pettit

Average HUC Subwatersheds

Subwatersheds: Campbells Run-Hog Run, Campbells Run-Headwaters (us Rossville)

Hydrologic Level

Bar chart showing % of agreement with WBD for various subwatersheds with different elevation models.
Conclusions

Characterization of Agricultural Watersheds

• Creation of watershed boundaries, stream vector files and topographic attributes is practical with aid of SRTM-3, as a starting point for characterization

• Applications for large basins, SWAT may be used

• Verification in Indiana showed differences / agreement:
  - 3% between WBD and both SRTMs at watershed level
  - and better than 15% at subwatershed level

• Careful analysis of outlets and stream networks use for preparation of SRTM DEMs is required.
General Conclusions

- Encouraging results in terms of SRTM accuracy
- Must consider the particular characteristics of remotely sensed DEMs
- *First return* nature of SRTM need for consistent analysis to be aggregated by land use
- Opportunities for developing meaningful databases from SRTM DEMs on a global basis
- Opportunities to extrapolate successful modeling approaches developed on best available US geo-databases
Recommendations for Future Research

• Application of concepts and tools of geostatistics to examine the spatial distribution of errors

• Development of standards for SRTM and IFSAR DEMs in terms of accepted uncertainties, and also for DEM preprocessing and DEM preparation for hydrologic modeling

• Error propagation and the analysis of the effect of the topographic derivatives algorithms when are applied on SRTM

• Interpolation of SRTM to higher spatial resolution to provide improved delineations of streams and watershed boundaries

• Incorporation of digital elevation or its derivatives to a spectral set of bands to improve classification approaches in certain applications related to soils, soil moisture, surface conditions. Suitability of SRTM and LANDSAT, 30 m resolution, free sources of data with global coverage
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