# 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

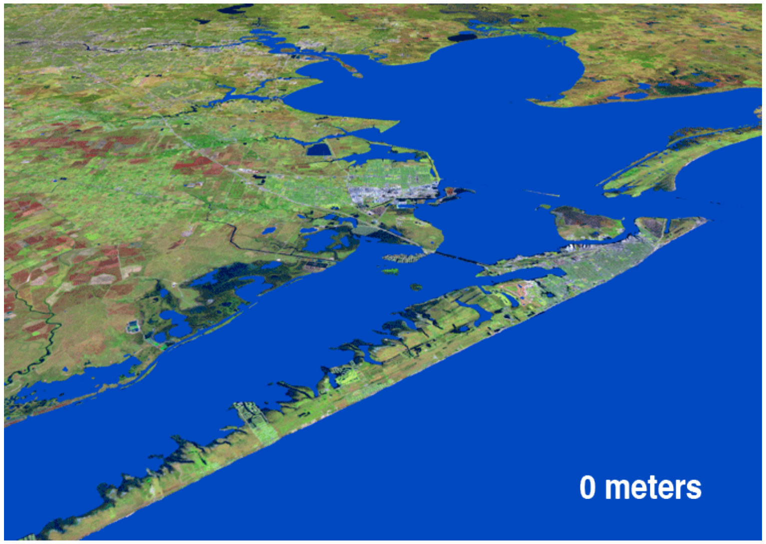
# The Need for Topographic Data

## Introduction

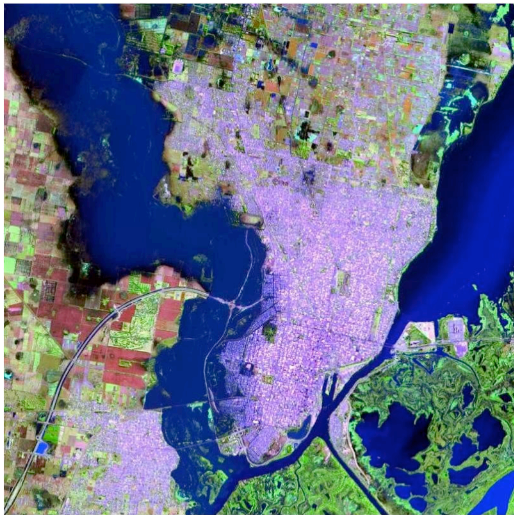
- Topography has a dominant influence on spatial and temporal patterns of water storage and transport
- Existing and potential applications of high-quality digital elevation (DEM) data are surprisingly diverse, even in low relief areas
- Hazards assessment, Natural disasters prevention and risk analysis. 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

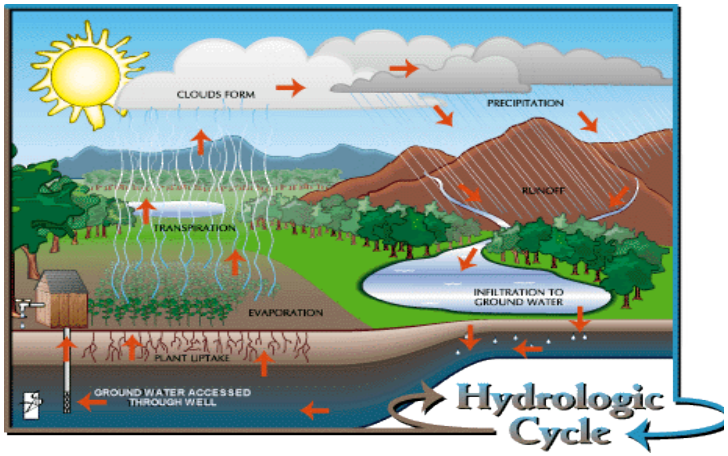
## Introduction



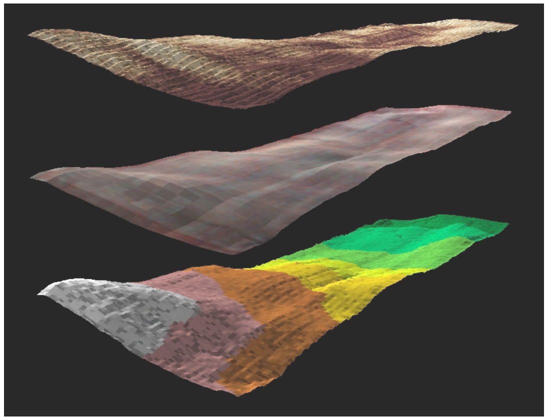
Hurricane Rita simulation
(*NASA - JPL, 2005*)



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



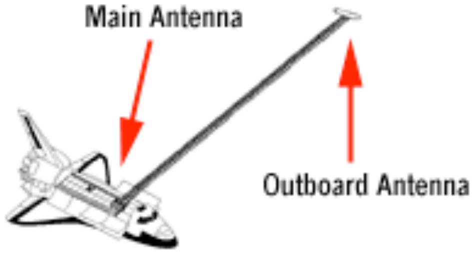
Hydrologic Modeling

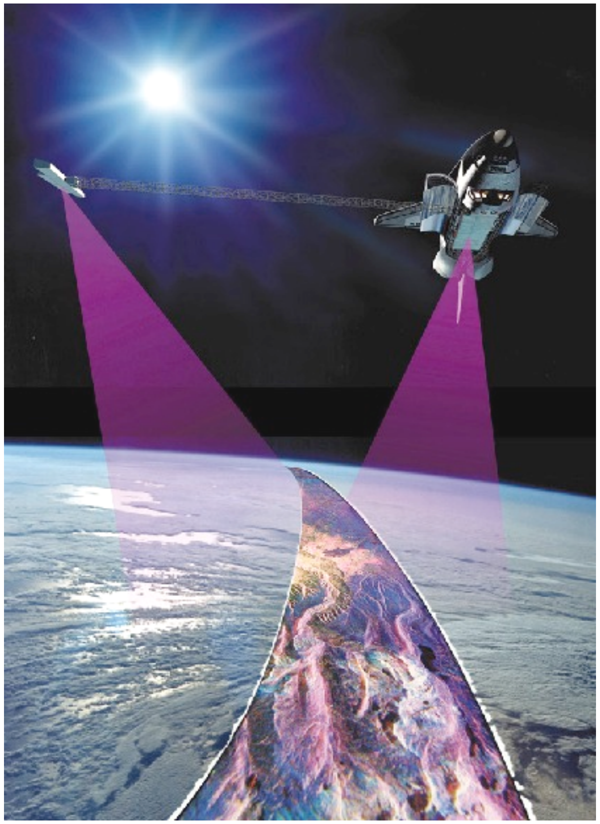


Agricultural applications
(*Johannsen, Beatty*)

# The Shuttle Radar Topography Mission

## Introduction





- 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

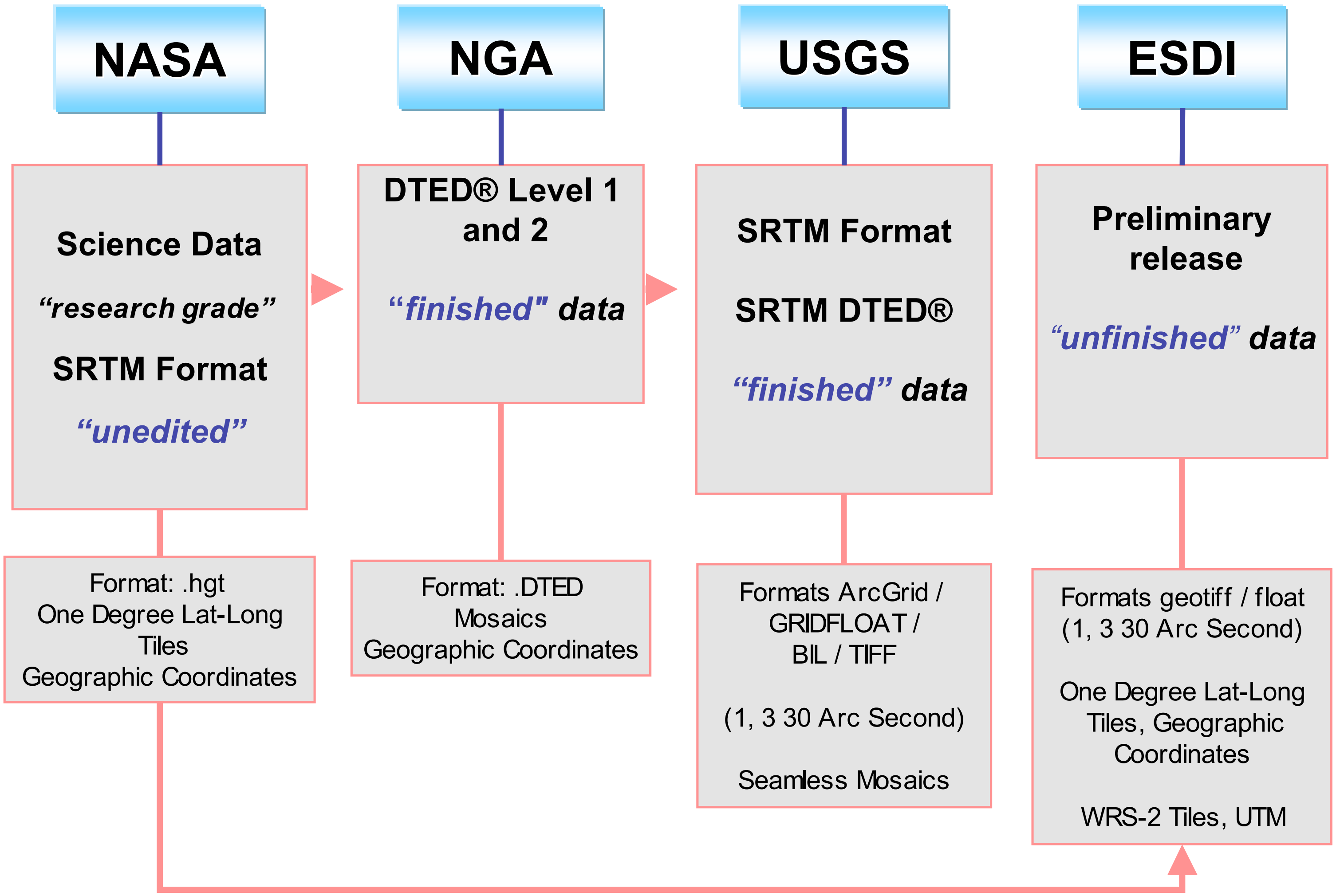
# Main Goals

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)

# Sources of SRTM Data

## Main Characteristics



**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

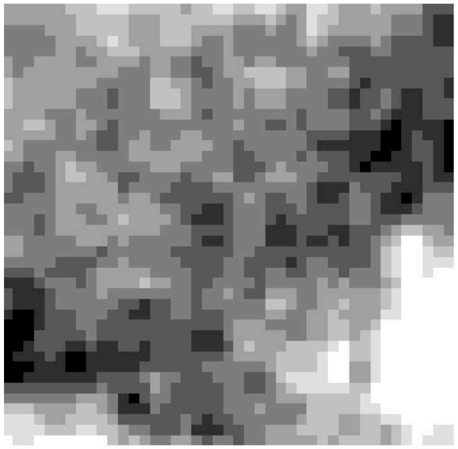
WRS-2 Tiles, UTM

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

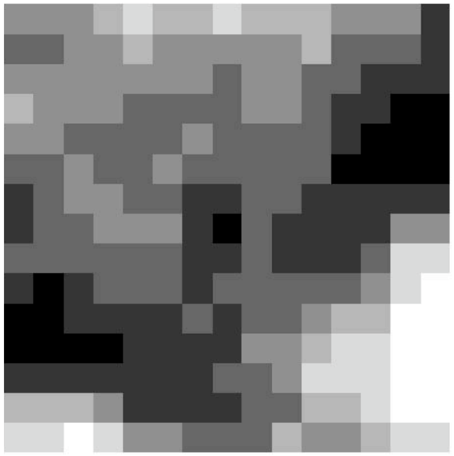
# SRTM-1 and SRTM-3

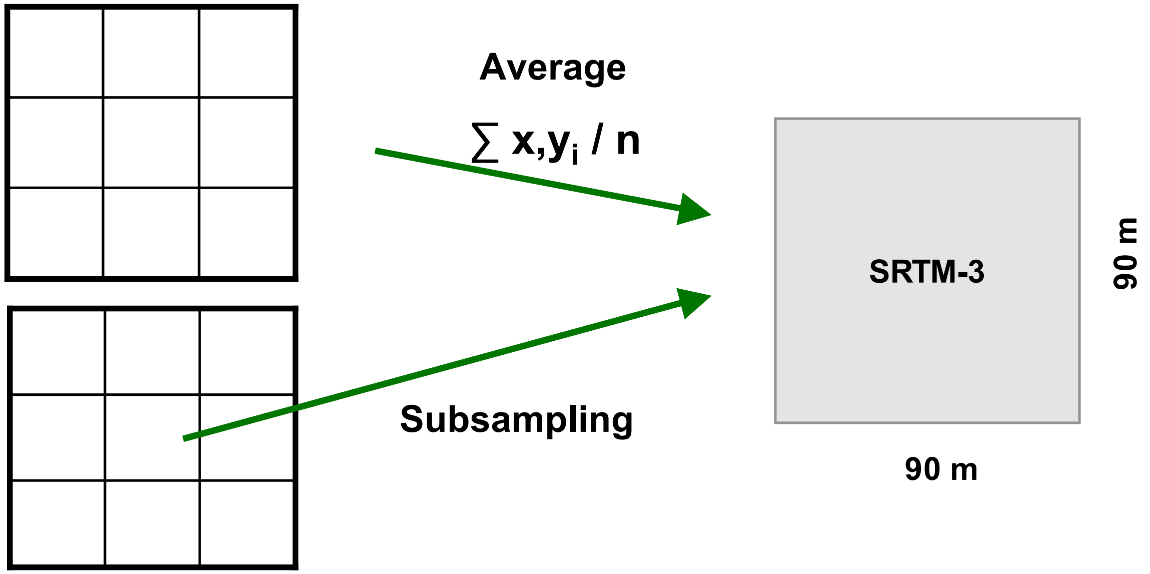
## Main Characteristics

### SRTM-1 (United States)



### SRTM-3 (Global Coverage)





**NASA**
Research grade
SRTM format

**NGA** (NIMA)
DTED format

**Average**

$\sum x,y_i / n$

**Subsampling**

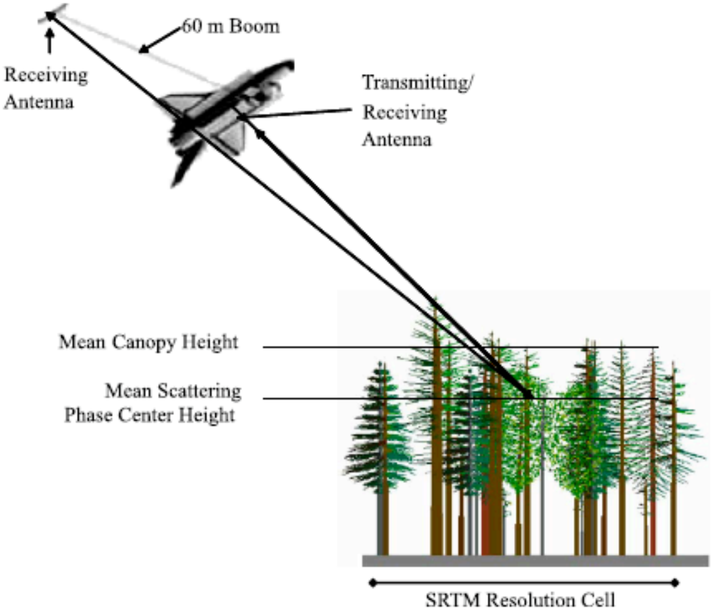
**SRTM-3**

**90 m**

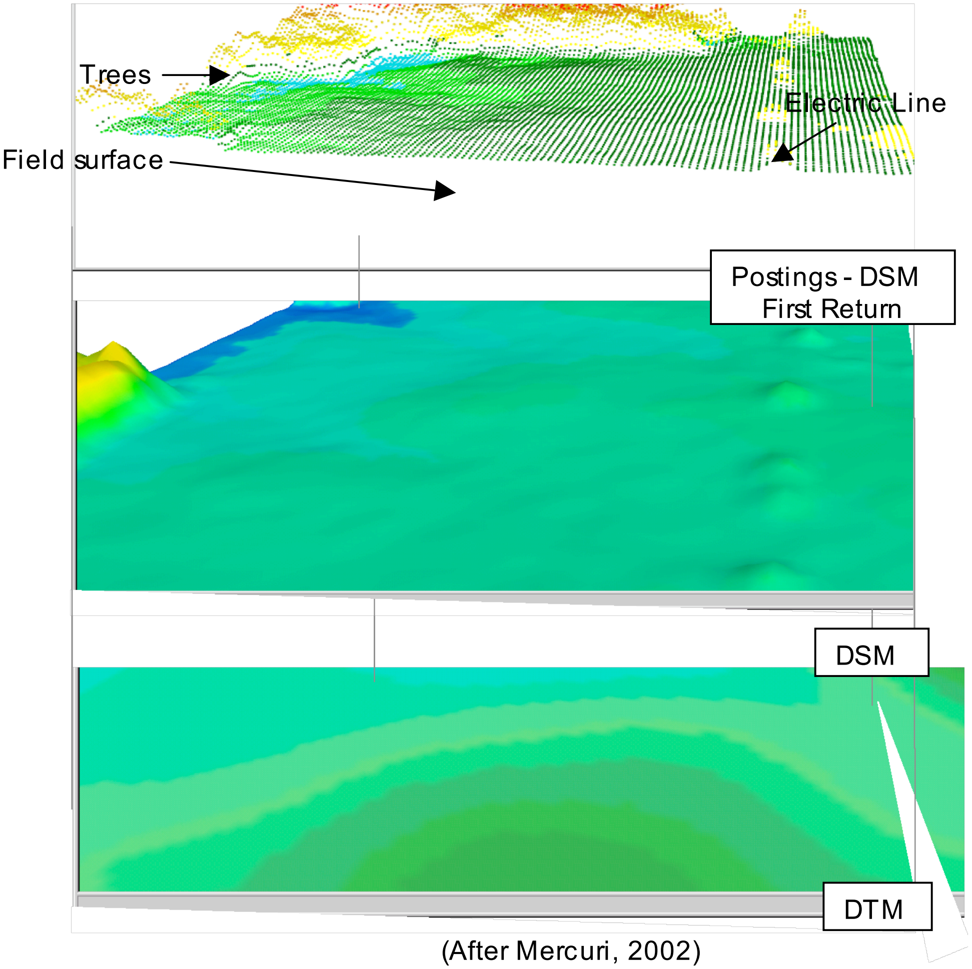
**90 m**

# SRTM: surface or "first return" DEM

## Main Characteristics



(After Kellndorfer, 2004)

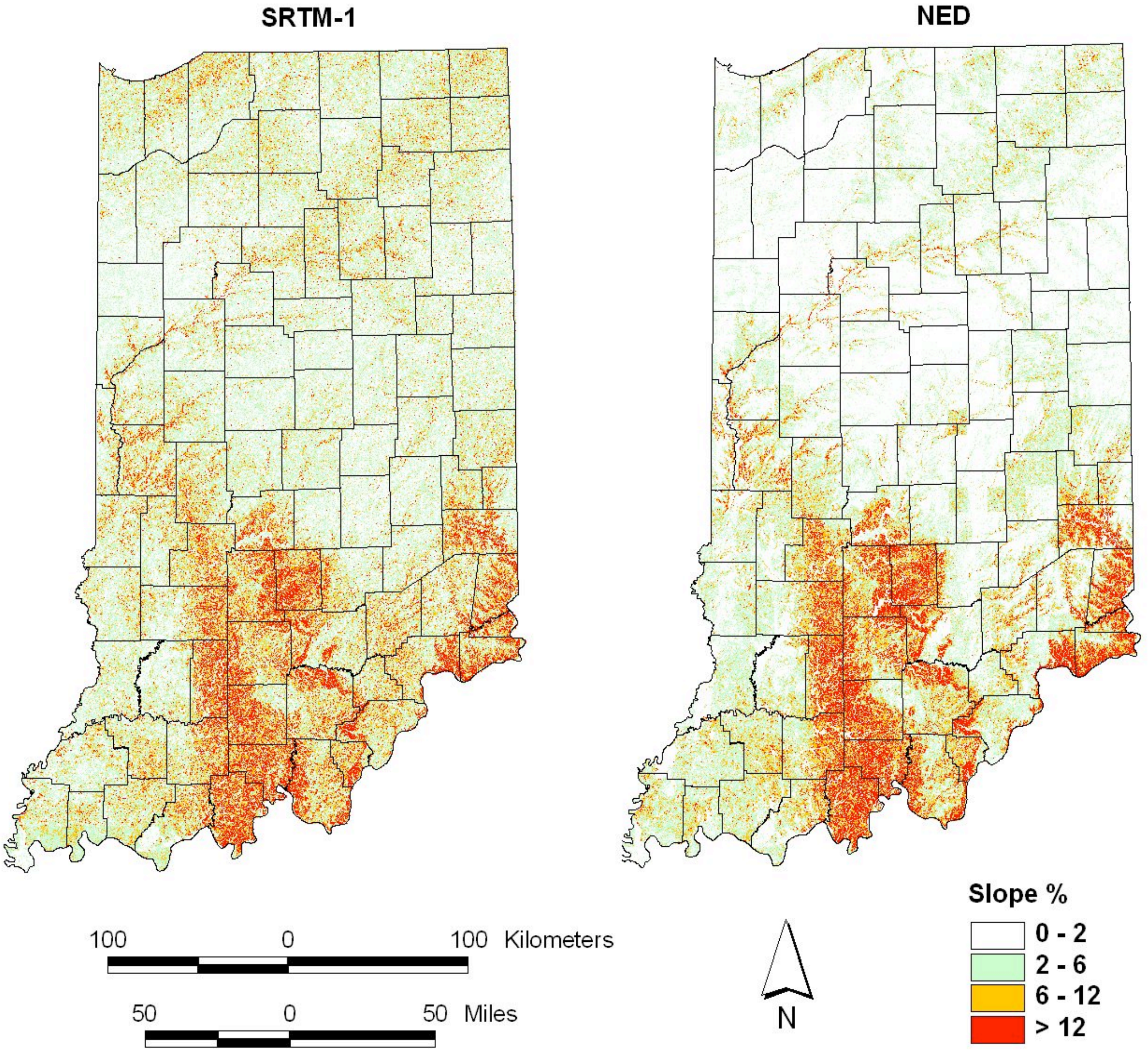


(After Mercuri, 2002)

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

# Topographic derivatives: slope

## Main Characteristics



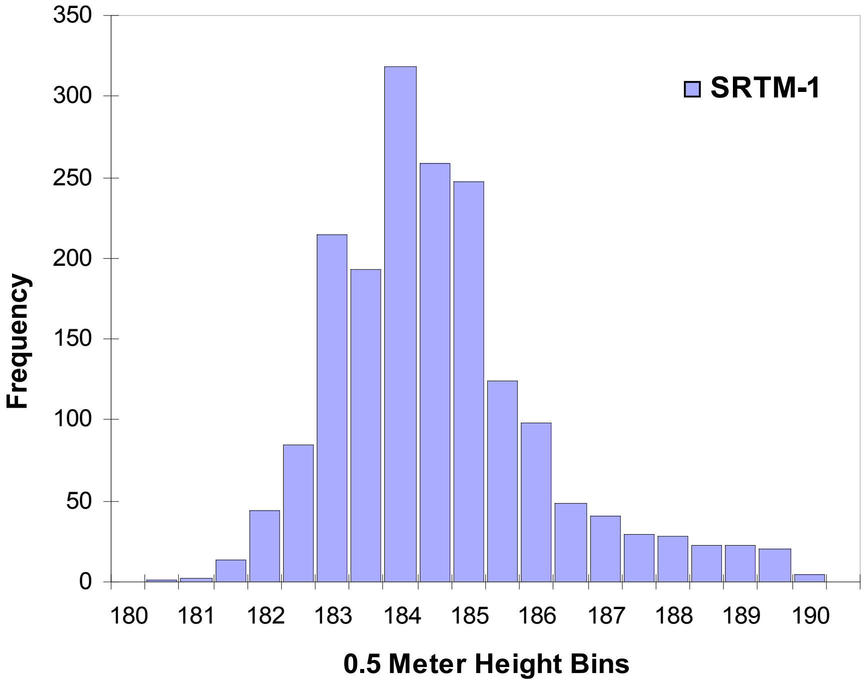
SRTM-1

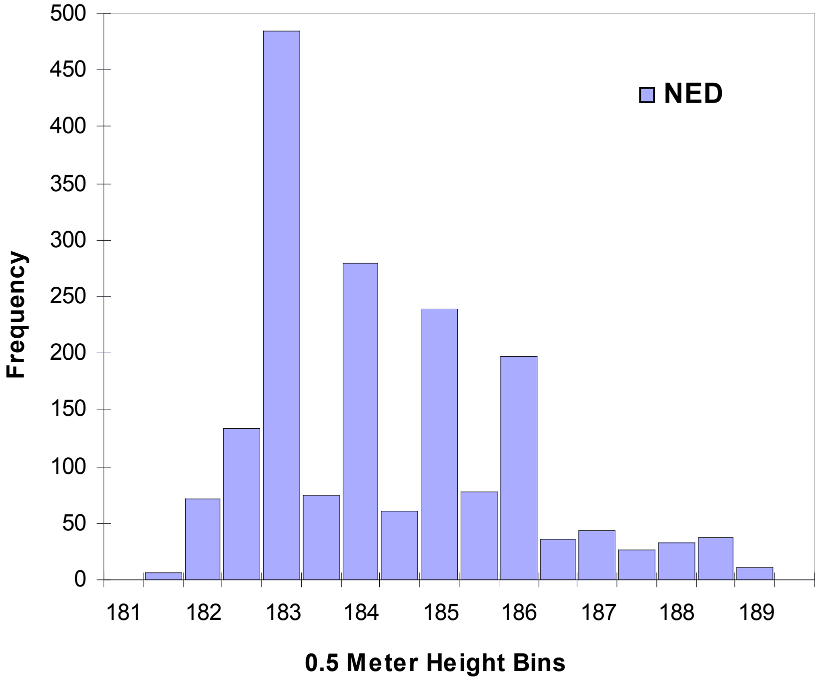
NED

D8 algorithm
ArcGIS

# Statistical Properties of SRTM Data in Low Relief

## Main Characteristics





- Gaussian distribution of values of remotely sensed SRTM-1DEM (30m)

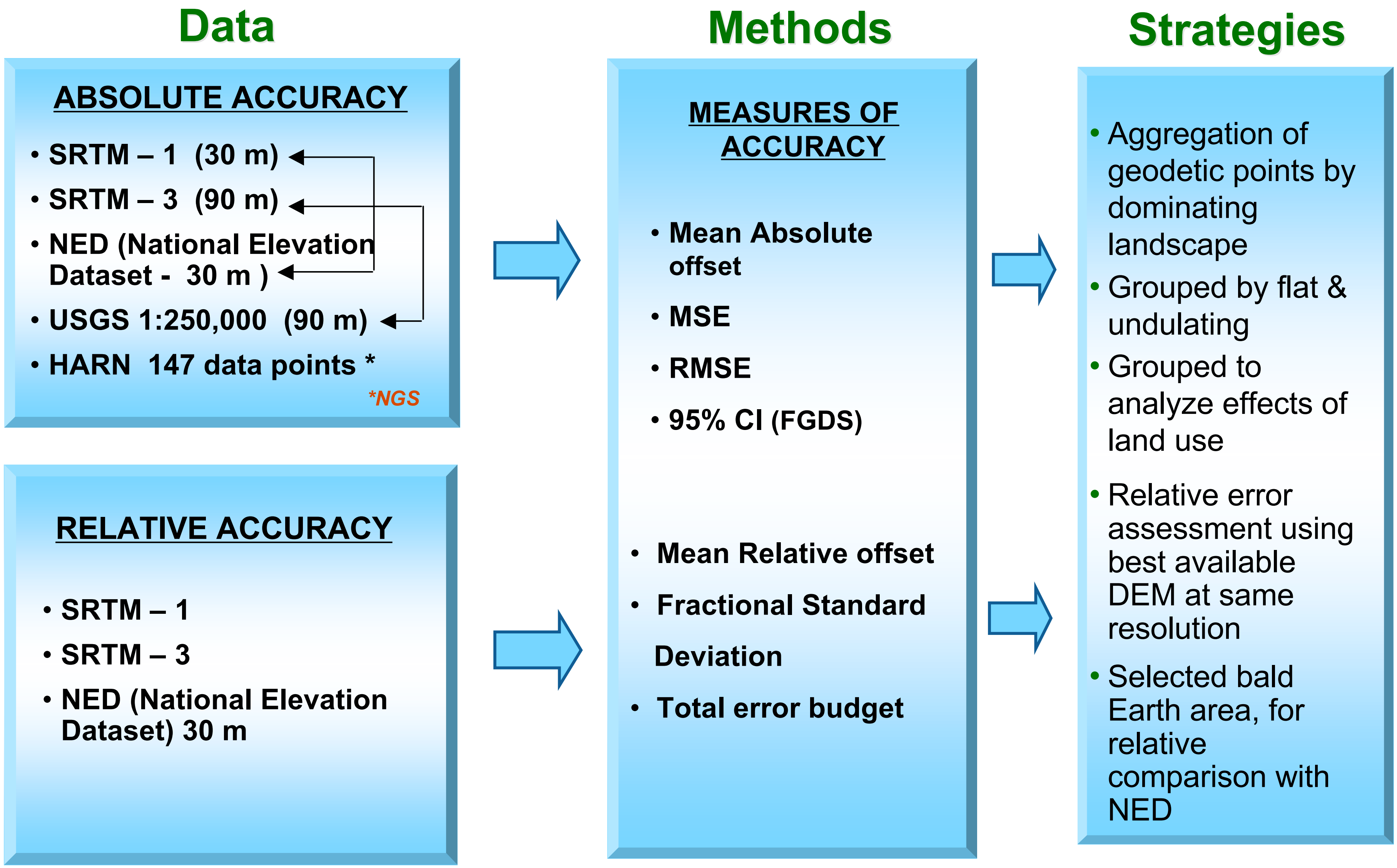
- Histogram extracted from low relief area illustrating distribution with sharp peaks of NED DEM (30 m)

# *Measures of Accuracy of SRTM 1 and 3 arc-second Data in Flat and Undulating Landscapes of Midwest United States*

- 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)

# Data, Methods and Strategies

## 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**

### Methods

**MEASURES OF ACCURACY**

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

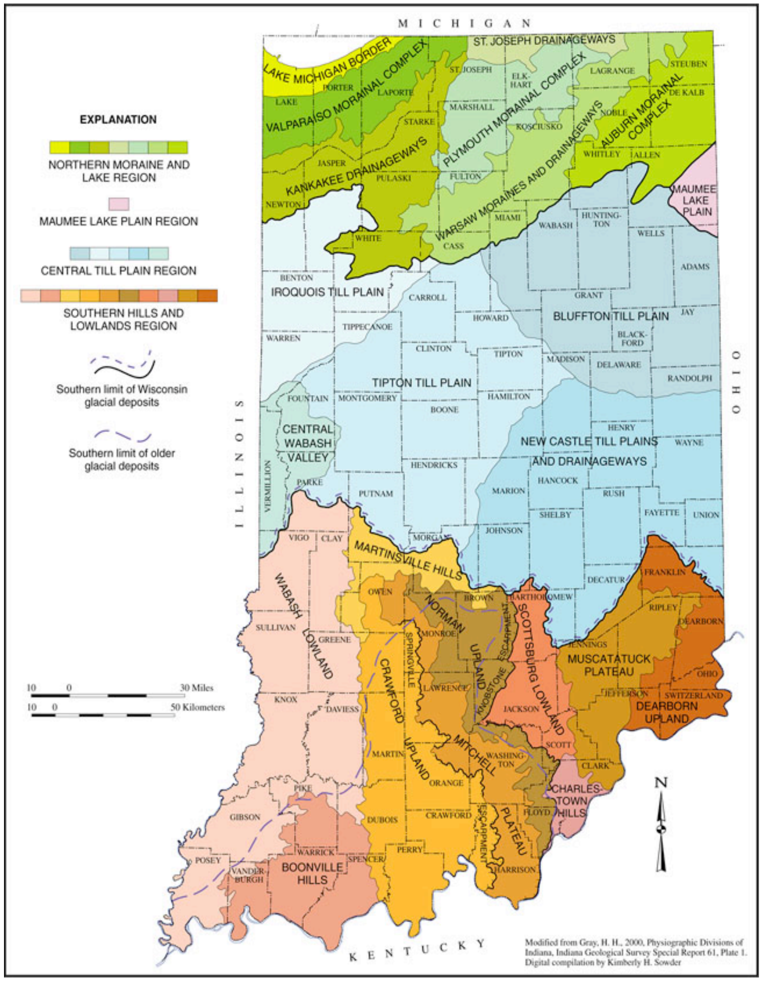
- **Mean Relative offset**
- **Fractional Standard Deviation**
- **Total error budget**

### Strategies

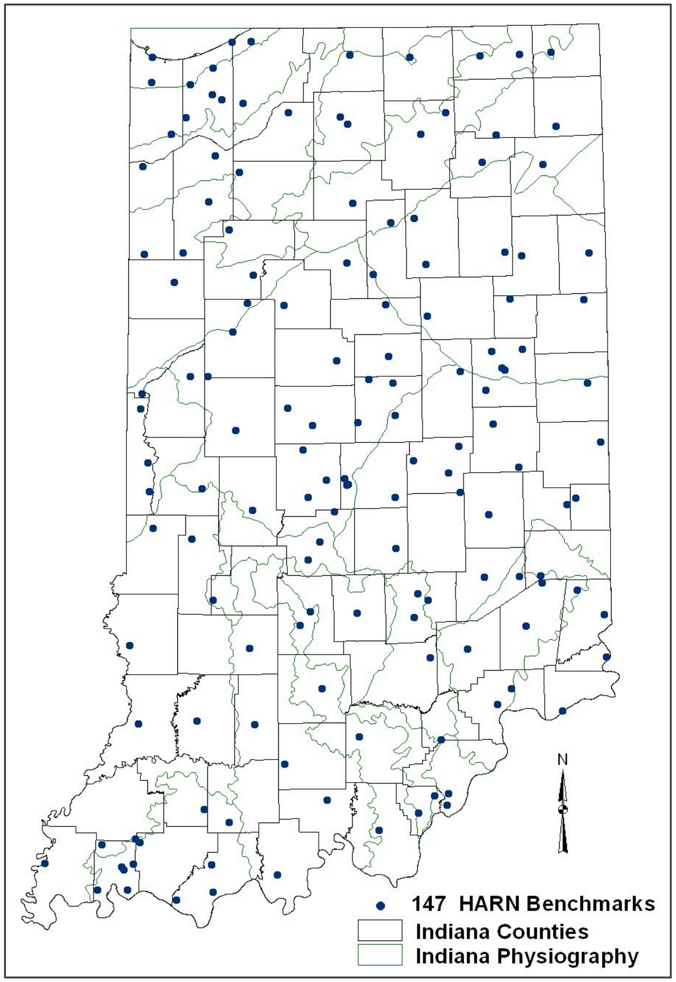
- Aggregation of geodetic points by dominating landscape
- Grouped by flat & undulating
- Grouped to analyze effects of land use
- Relative error assessment using best available DEM at same resolution
- Selected bald Earth area, for relative comparison with NED

# Aggregation of Test Points

## ACCURACY OF SRTM IN FLAT LANDSCAPES



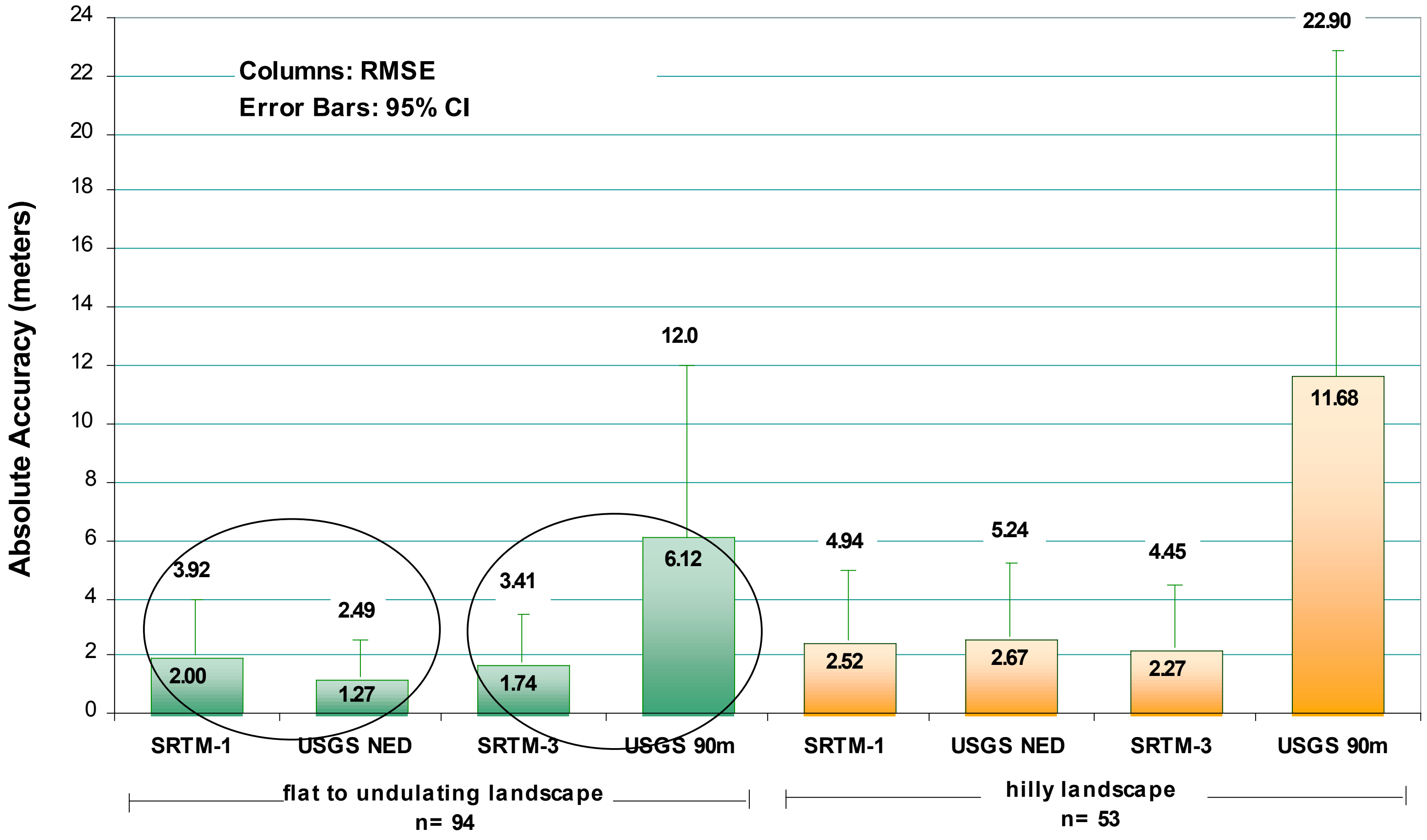
Modified from Gray, H. H., 2000, Physiographic Divisions of Indiana, Indiana Geological Survey Special Report 61, Plate 1. Digital compilation by Kimberly H. Sowder



- Physiographic Regions of Indiana
- 147 HARN geodetic points

# Absolute Accuracy Assessment: RMSE

## ACCURACY OF SRTM IN FLAT LANDSCAPES

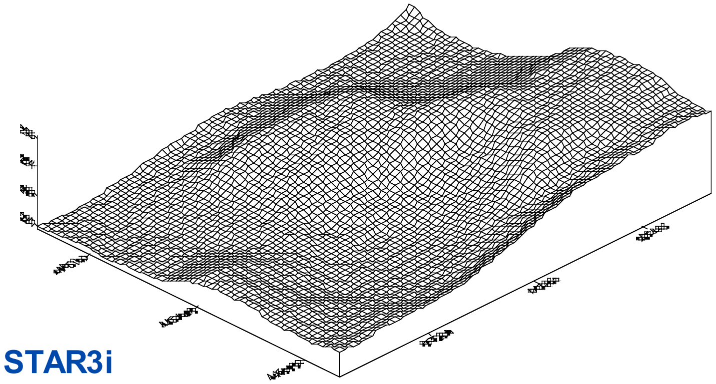


$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} \left( z_{independent} - z_{test} \right)^2}{N}}$$

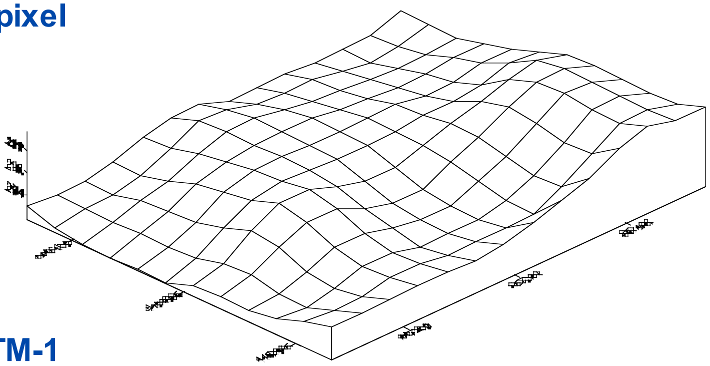
# Absolute Accuracy Assessment

## ACCURACY OF SRTM IN FLAT LANDSCAPES

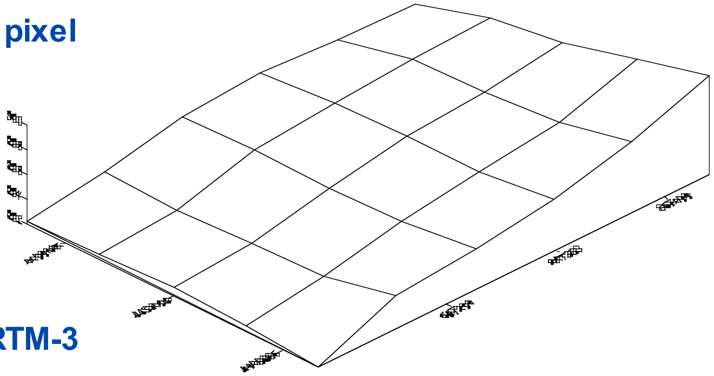
- However, better vertical accuracy at expense of poor representation of variability



- **IFSAR STAR3i**
  - **5 m pixel**



- **SRTM-1**
- **30 m pixel**

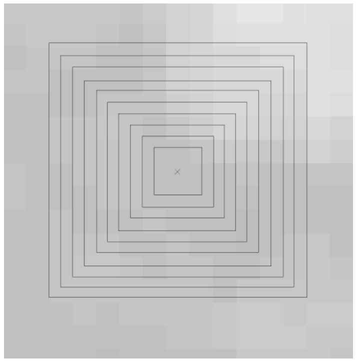


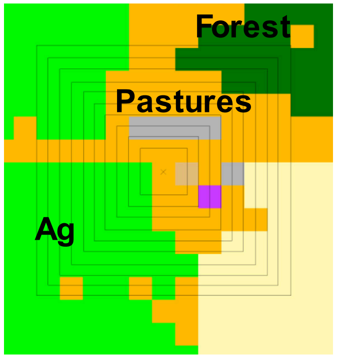
- **SRTM-3**
- **90 m pixel**

# Influence of Land Use / Adjacency Effects

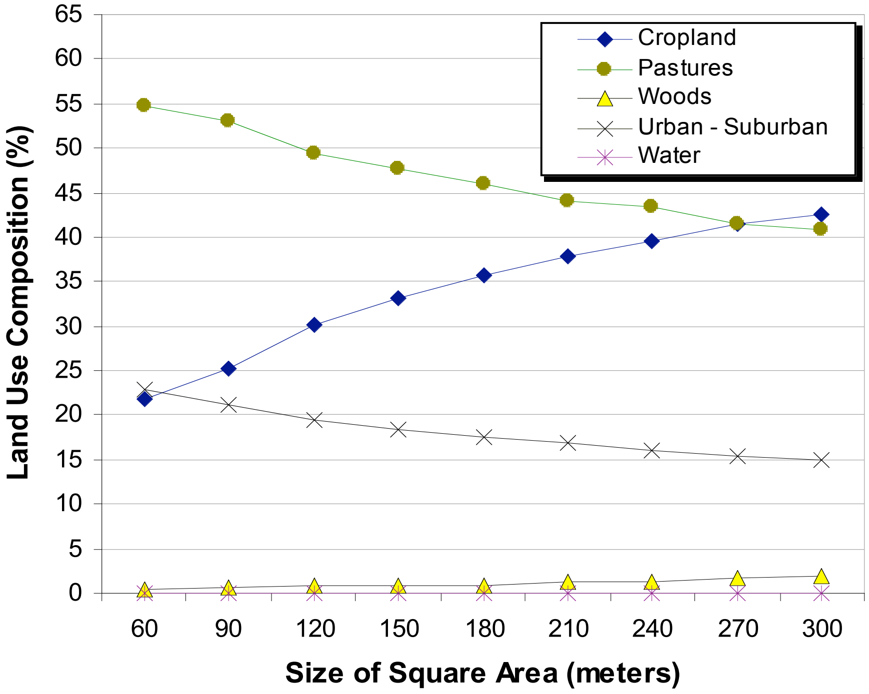
## ACCURACY OF SRTM IN FLAT LANDSCAPES

- Impact of changes of land use
- Adjacency effects of forested and build up land use

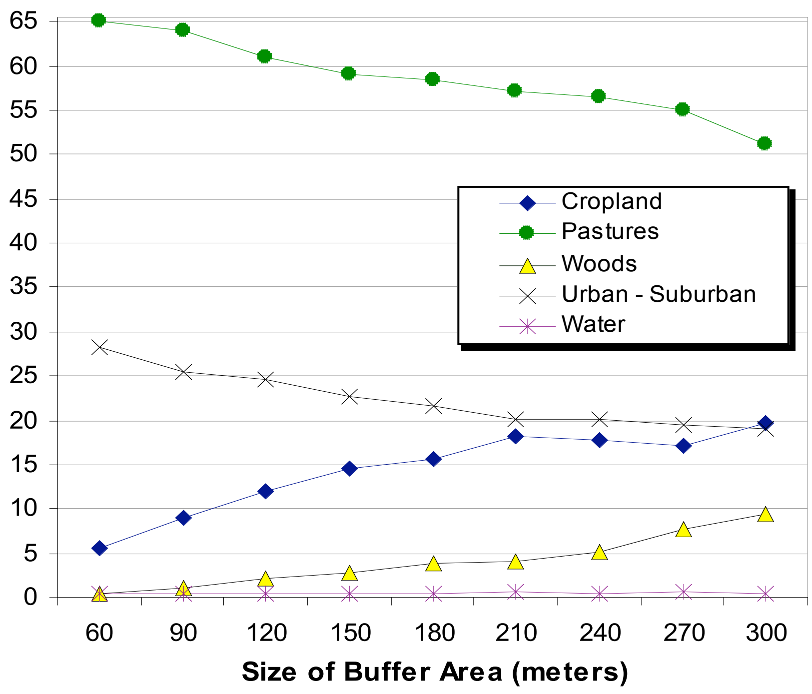




**Flat Landscape ( 94 test points )**

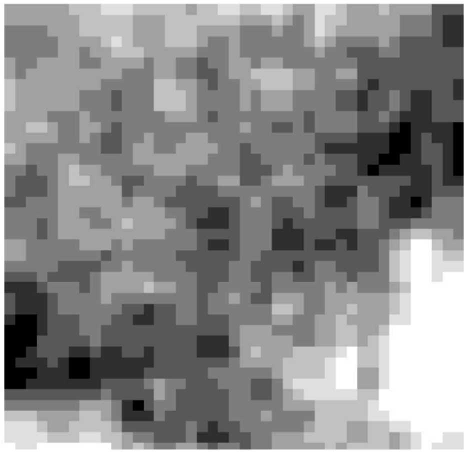


**Hilly Landscape ( 53 test points )**

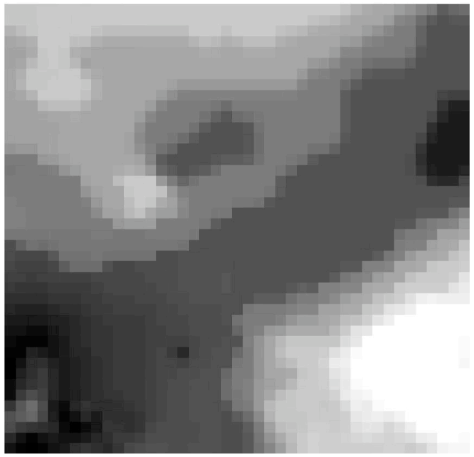


# Relative Accuracy Assessment

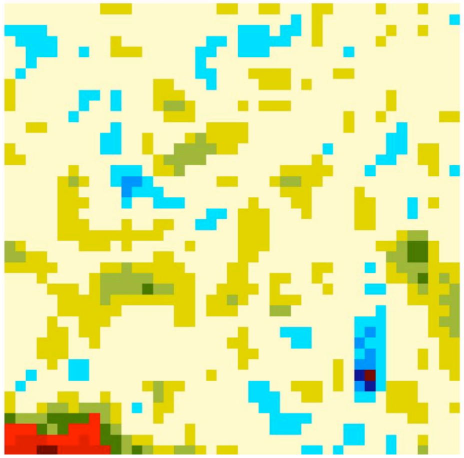
## ACCURACY OF SRTM IN FLAT LANDSCAPES



**SRTM-1**

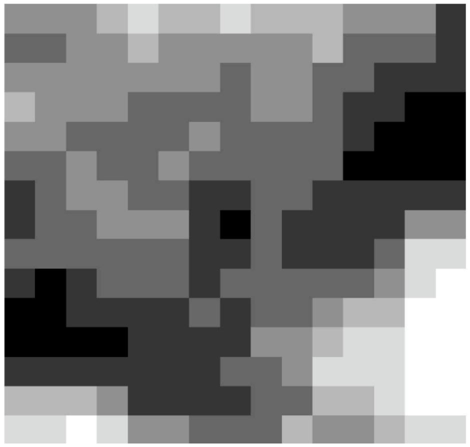


**NED**

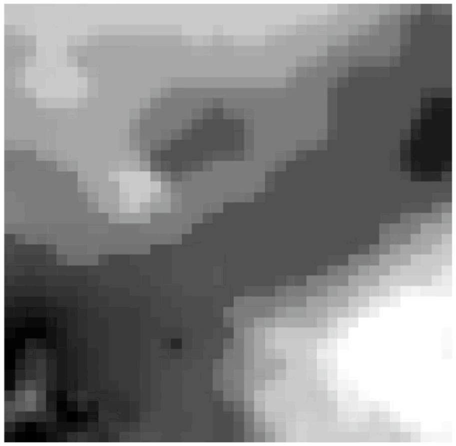


**Diff image: SRTM-1 - NED**

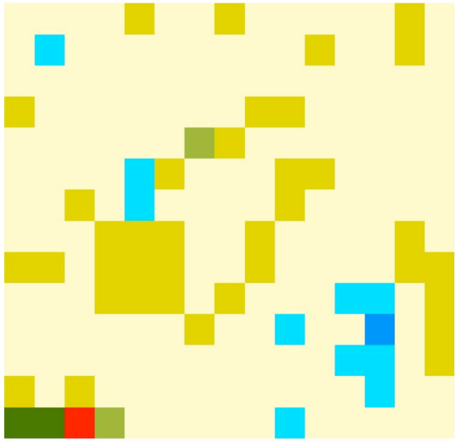
🟦 -3.7 - -3
🟦 -3 - -2
🟦 -2 - -1
⬜ -1 - 1
🟨 1 - 2
🟩 2 - 3
🟩 3 - 4
🟥 4 - 5
🟥 5 - 6.2



**SRTM-3**



**NED**



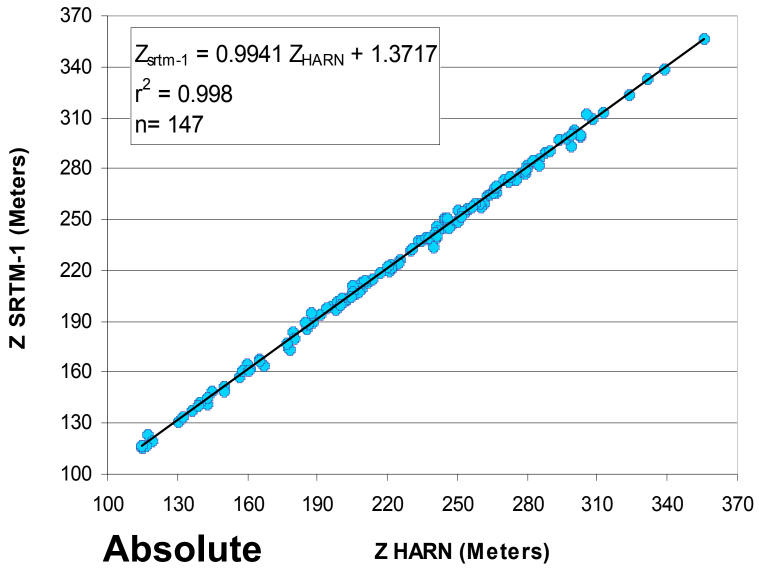
**Diff image: SRTM-3 - NED**

$$\text{Sources of Error} = \Delta_{rel} + e_{phase\,-\,noise} + e_{environment}$$

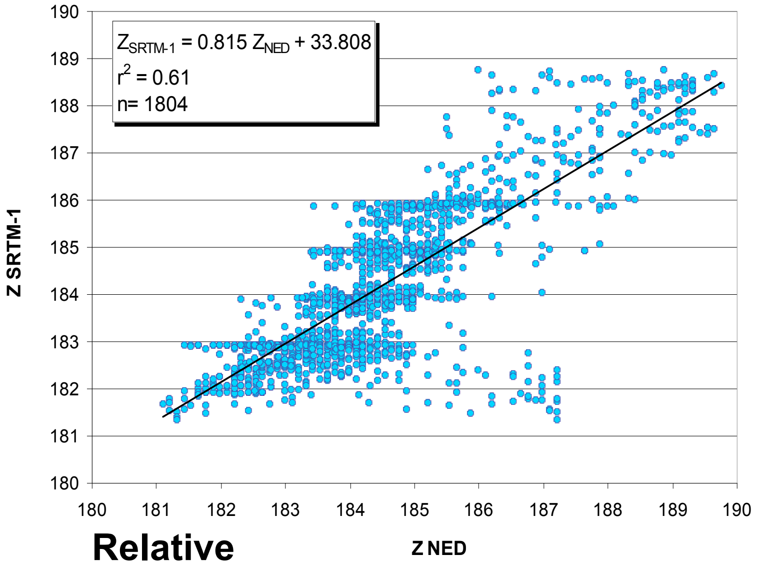
# Relative Accuracy Assessment

## ACCURACY OF SRTM IN FLAT LANDSCAPES

| | | |
|---|---|---|
| Mean Offset | $\Delta_{rel}\ (\text{mean offset}) = \frac{1}{N_{(x,y)}} \sum_{i=1}^{N_{(x,y)}} \left(Z_{SRTM} - Z_{NED}\right)$ | **X: 0.22 m**<br>**$\sigma_{diff}$ : 1.15 m** |
| Total Fractional Std Dev | $\sigma\ \text{Ä}Z_{SRTM\ -\ NED} = \sqrt{\sigma_{ZSRTM}{}^{2} + \sigma_{ZNED}{}^{2}}$ | **2.33 m** |
| Total Std Dev | Total σ SRTM = σ abs + σ rel | **4.53 m** |
| Total budget (abs, rel) | total error budget = $\Delta Z_{abs} + \Delta Z_{rel} + e_{\text{vegetation, land cover}}$ | **1.41 m** |



**Absolute**



**Relative**

# Conclusions

## ACCURACY OF SRTM IN FLAT LANDSCAPES

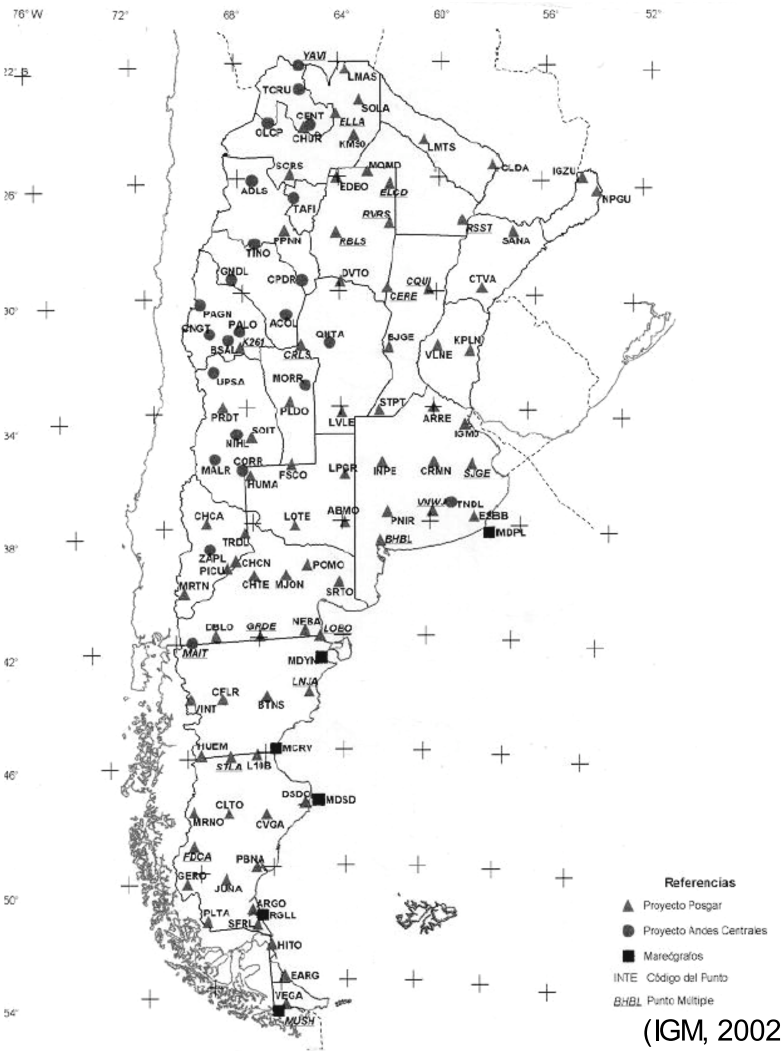
- Accuracy better than original mission specifications
- Accuracy within range of recent validation: ~ 5 – 6 m worldwide and ~ 4 m US (all landscapes and land uses)
- Measured vertical accuracy better than 5 m (IN all measures) at 95%
- Low relief, open terrain < 2 m (abs) , 1.41 m (rel), 4.53 m (SD)
- Relative positive bias for SRTM as compared with NED, (range -3 – 6m )
- Low vertical uncertainty values of SRTM-3 in flat areas

# *VERTICAL ACCURACY OF SRTM ELEVATION DATA IN ARGENTINA*

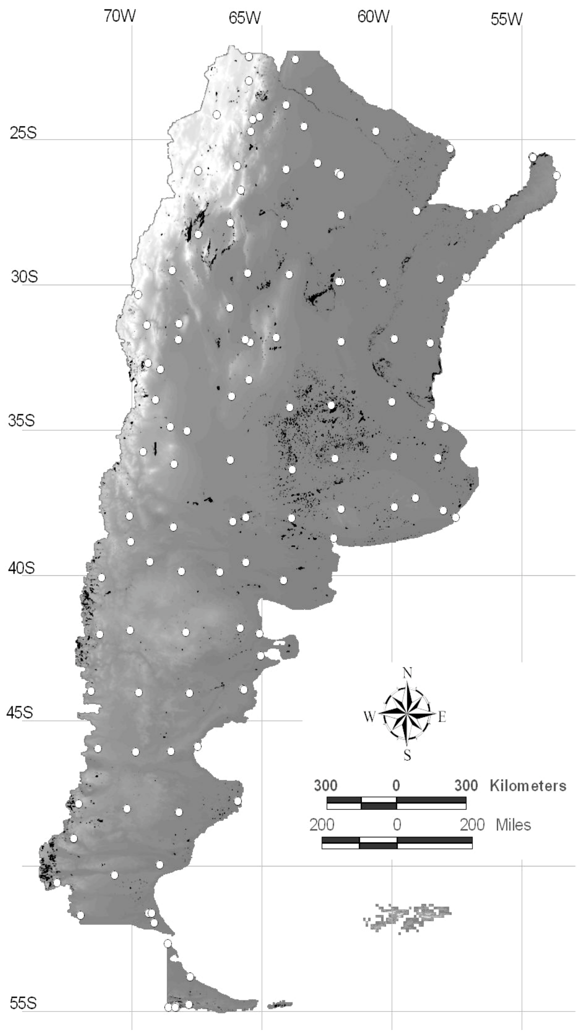
- Need accuracy assessment in order to know quality of SRTM-3 for multiple applications
- Need to generate geospatial framework maps
- No previous studies in area
- To collaborate in extensive program that is underway by NASA to verify SRTM data
- Numerous local studies need references regarding quality of SRTM DEM in order to justify its use in applications

# GEODETIC NETWORK & SRTM-3 in ARGENTINA

## Accuracy of SRTM-3 in Argentina



(IGM, 2002)



**Official POSGAR Geodetic Network (#127)**

SRTM-3 mosaic (>220 one degree tiles)

# Data, Methods and Strategies

## Accuracy of SRTM-3 in Argentina

### Data

**ABSOLUTE ACCURACY**

- **SRTM – 3**
- **POSGAR Network**

### Methods

**MEASURES OF ACCURACY**

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

**GEODETIC TRANSFORMATIONS**

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

### Strategies

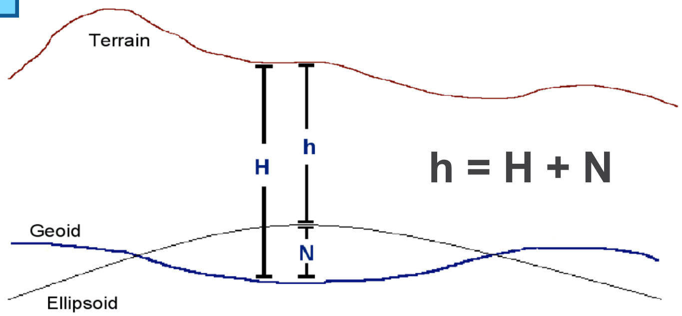
- Aggregation of geodetic points by dominating landscape
- Grouped to analyze effects of land use
- Grouped by flat landscape

***x, y*** SRTM and POSGAR : horizontal datum WGS84

***z*** SRTM = geoidal heights (H)

Posgar = Ellipsoidal heights (h)

Geoid: EGM96 (N)

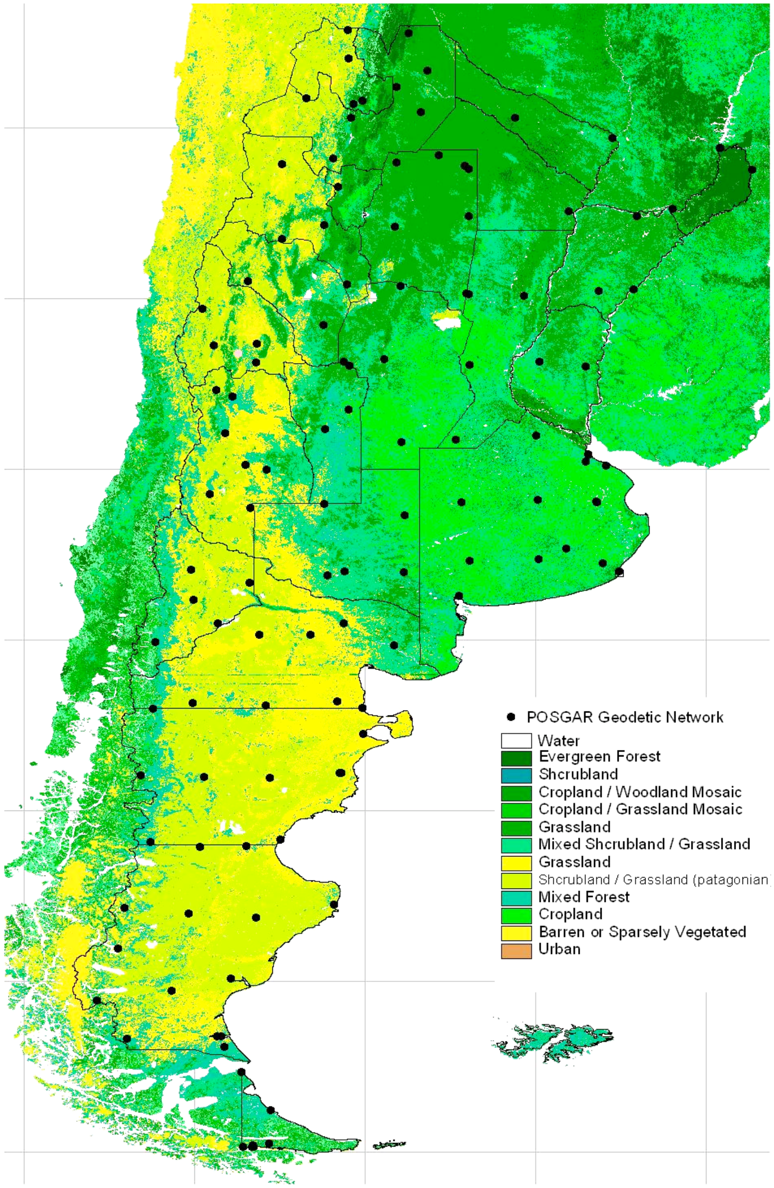


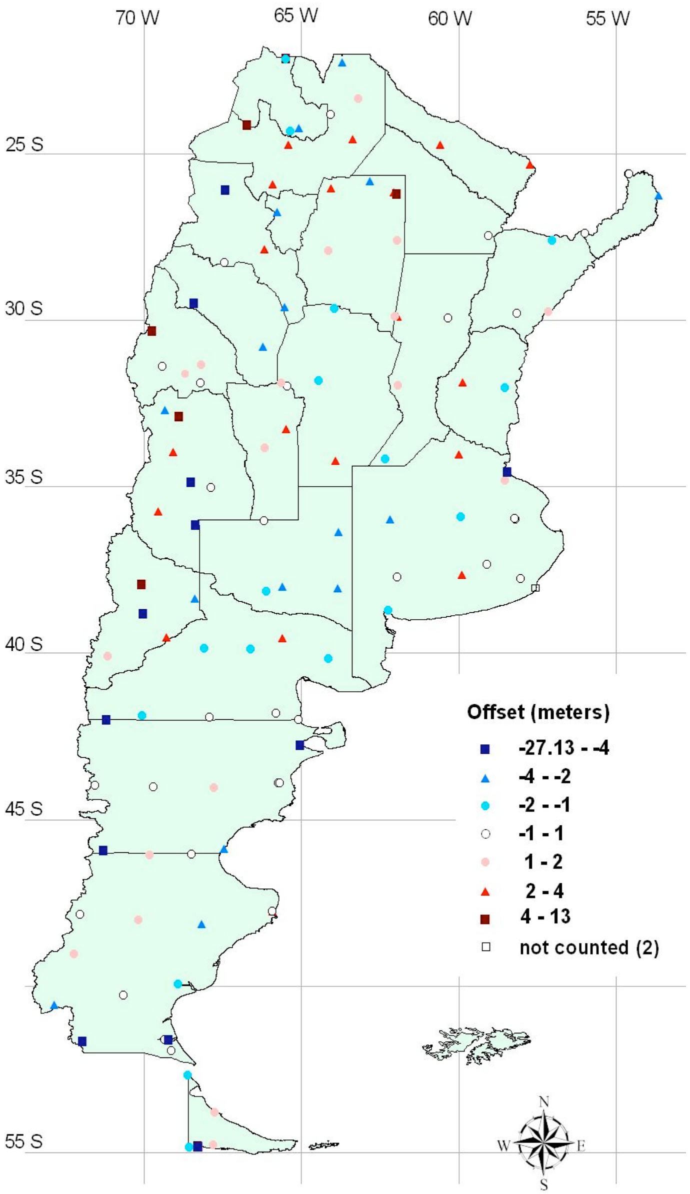
$h = H + N$

**(Mercuri, 2002)**

# Distribution of POSGAR / Land Cover / Offset

## Accuracy of SRTM-3 in Argentina





# Accuracy Results

## Accuracy of SRTM-3 in Argentina

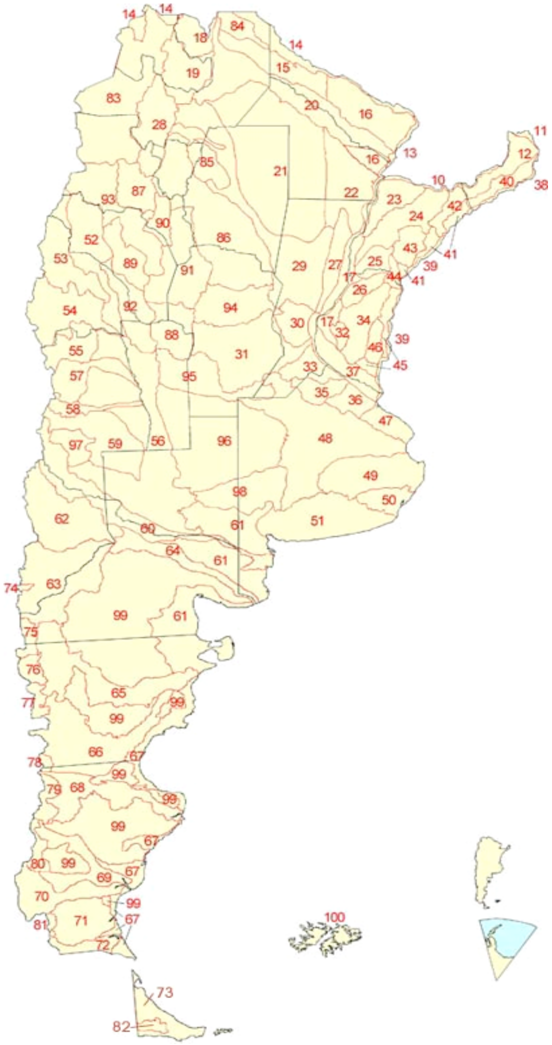
| **Land Use /Land Cover Category** | **Terrain Characteristics** | **n** | **Min - max (m)** | **Mean Offset (m)** | **RMSE (m)** |
|---|---|---|---|---|---|
| Cropland/Grassland mosaic | Flat *pampas* | 25 | -3.32 – 3.28 | 0.15 | 1.89 |
| Cropland/Woodland Mosaic | Flat to undulated forest (*Chaco*)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

# 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*



- Basins of Argentina

- 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

# Data, Methods and Strategies

## Characterization of Agricultural Watersheds

### Data

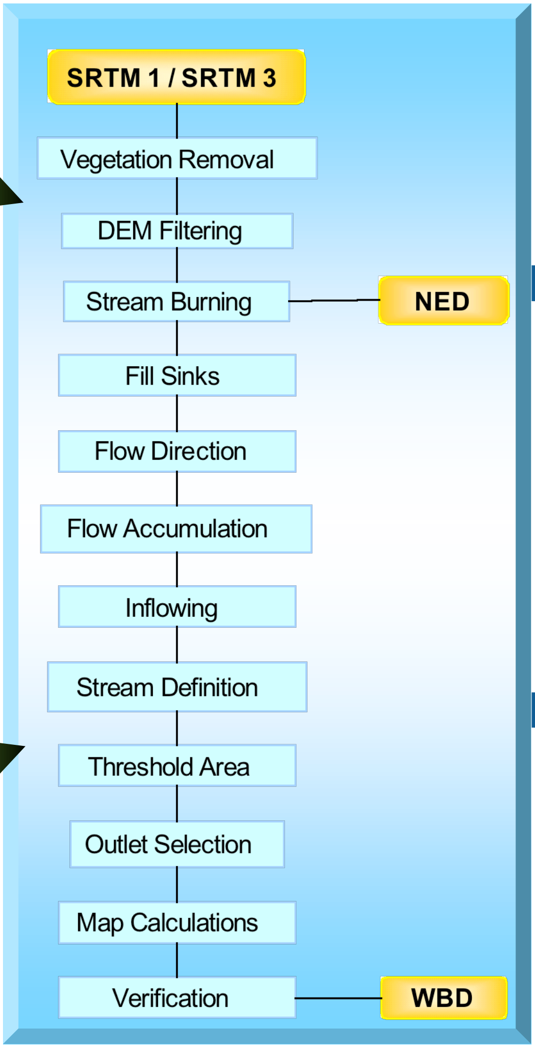
**Argentina: *Arrecifes* Basin**

- **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 — **NED**

Fill Sinks

Flow Direction

Flow Accumulation

Inflowing

Stream Definition

Threshold Area

Outlet Selection

Map Calculations

Verification — **WBD**

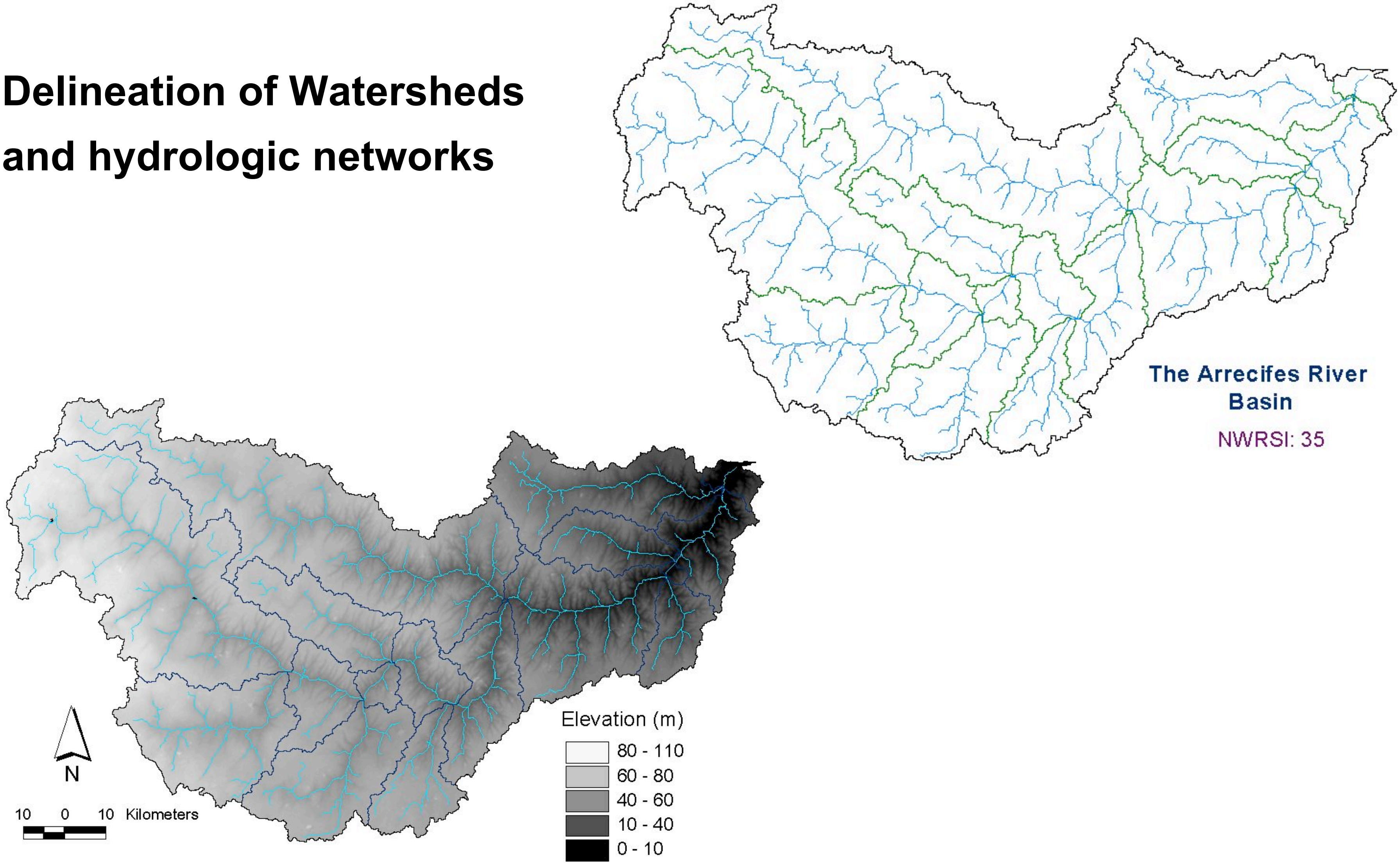
### Strategies

- 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 proyect and Indiana verification site using the same
- Development of water and land resources database using

# The *Arrecifes* River Basin

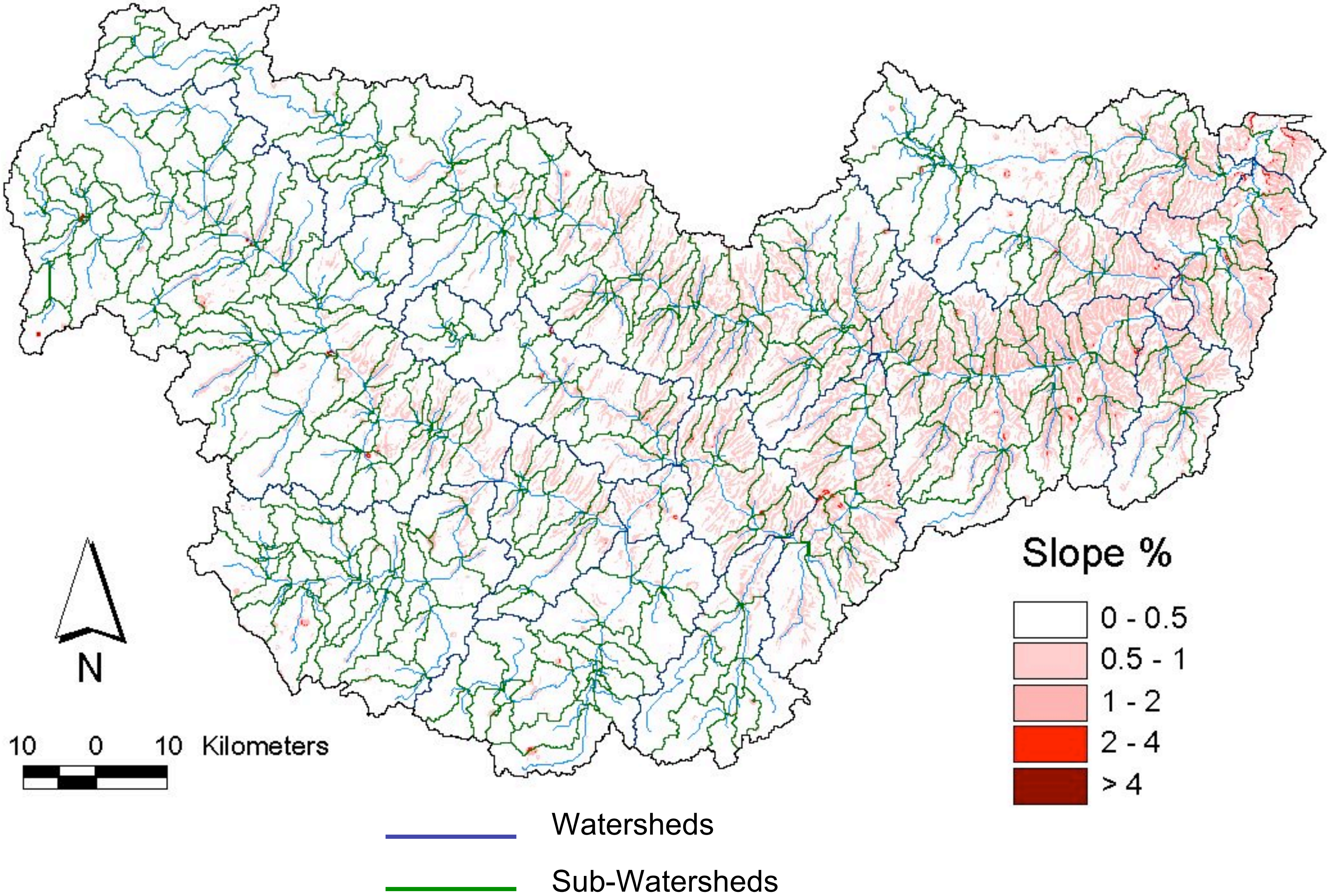
Characterization of Agricultural Watersheds

## Delineation of Watersheds and hydrologic networks



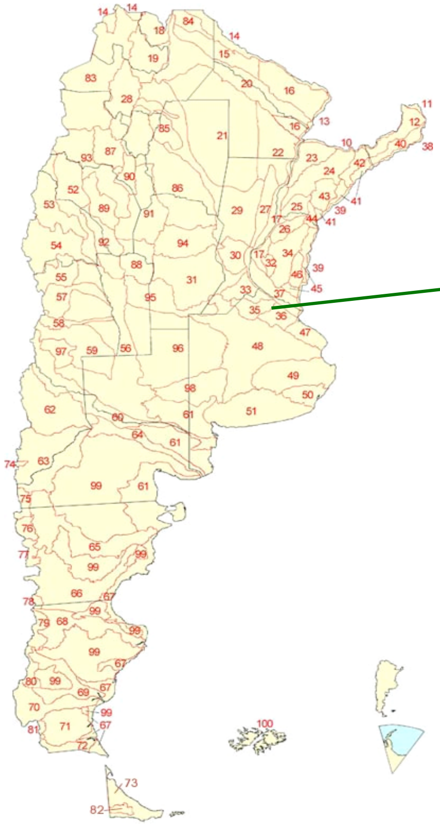
# The Arrecifes River Basin

## Characterization of Agricultural Watersheds



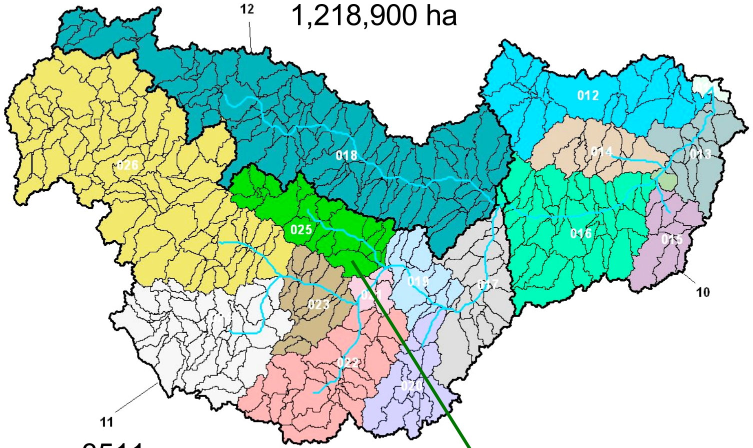
# Development of Hydrologic Units Database

## Characterization of Agricultural Watersheds

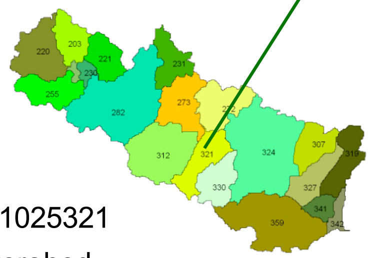


NWRIS

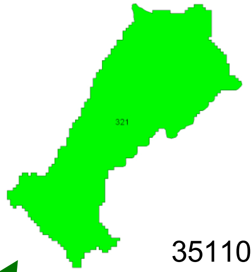
35
Basin
*Arrecifes River*
1,218,900 ha



3511
Sub basin
*Arrecifes* Middle
or Central



3511025321
Watershed
*Arroyo Dulce*
51,520 ha

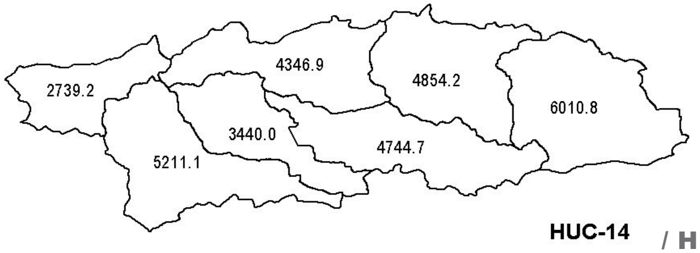


3511025321
Subw atershed
*La Magdalena*
2,212 ha

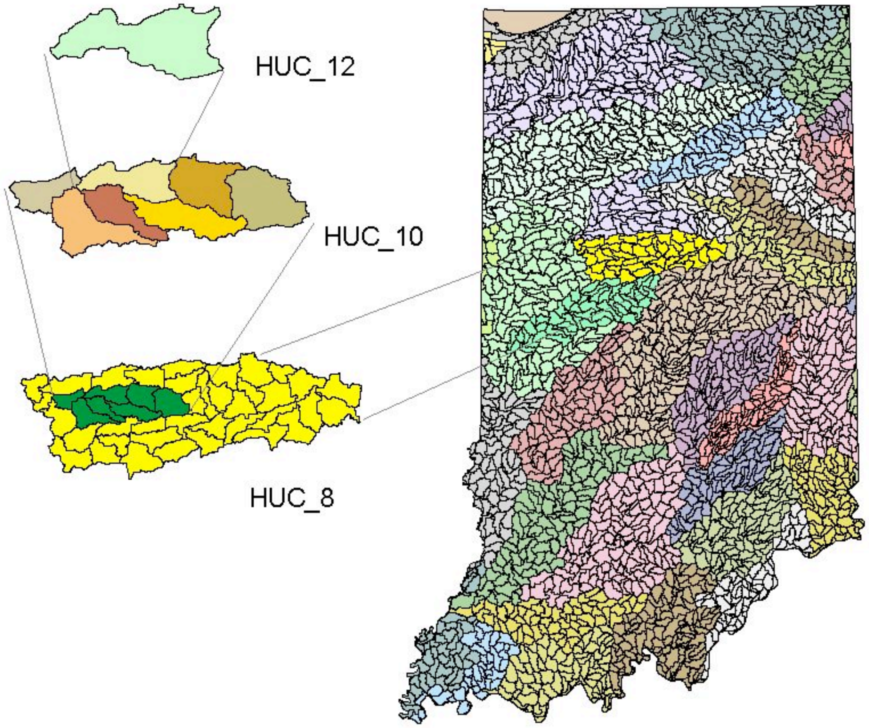
# Verification in Indiana: The Middle Fork Wildcat Creek

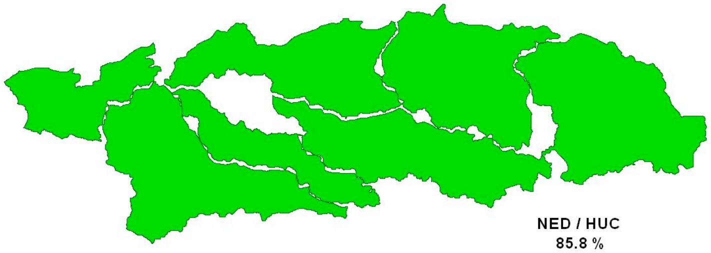
## Characterization of Agricultural Watersheds

- **Verification of delineation at watershed and sub watershed level Indiana**
- **Similar landscape and land use**

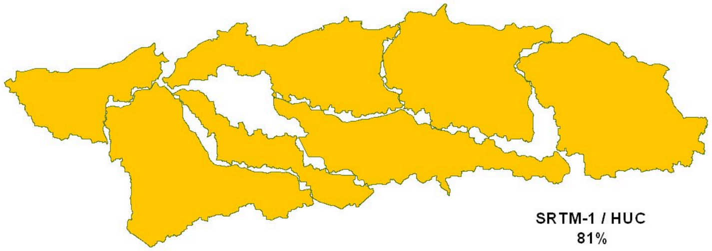


**HUC-14** / **HUC 12**

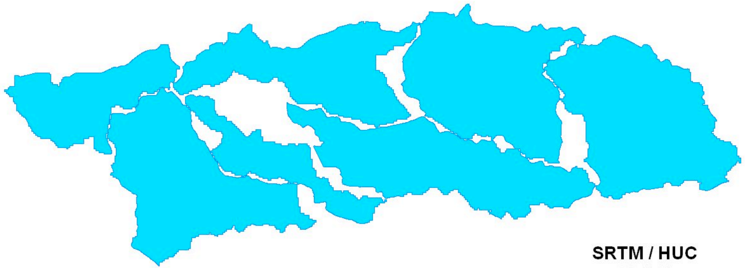




**NED / HUC**
**85.8 %**



**SRTM-1 / HUC**
**81%**

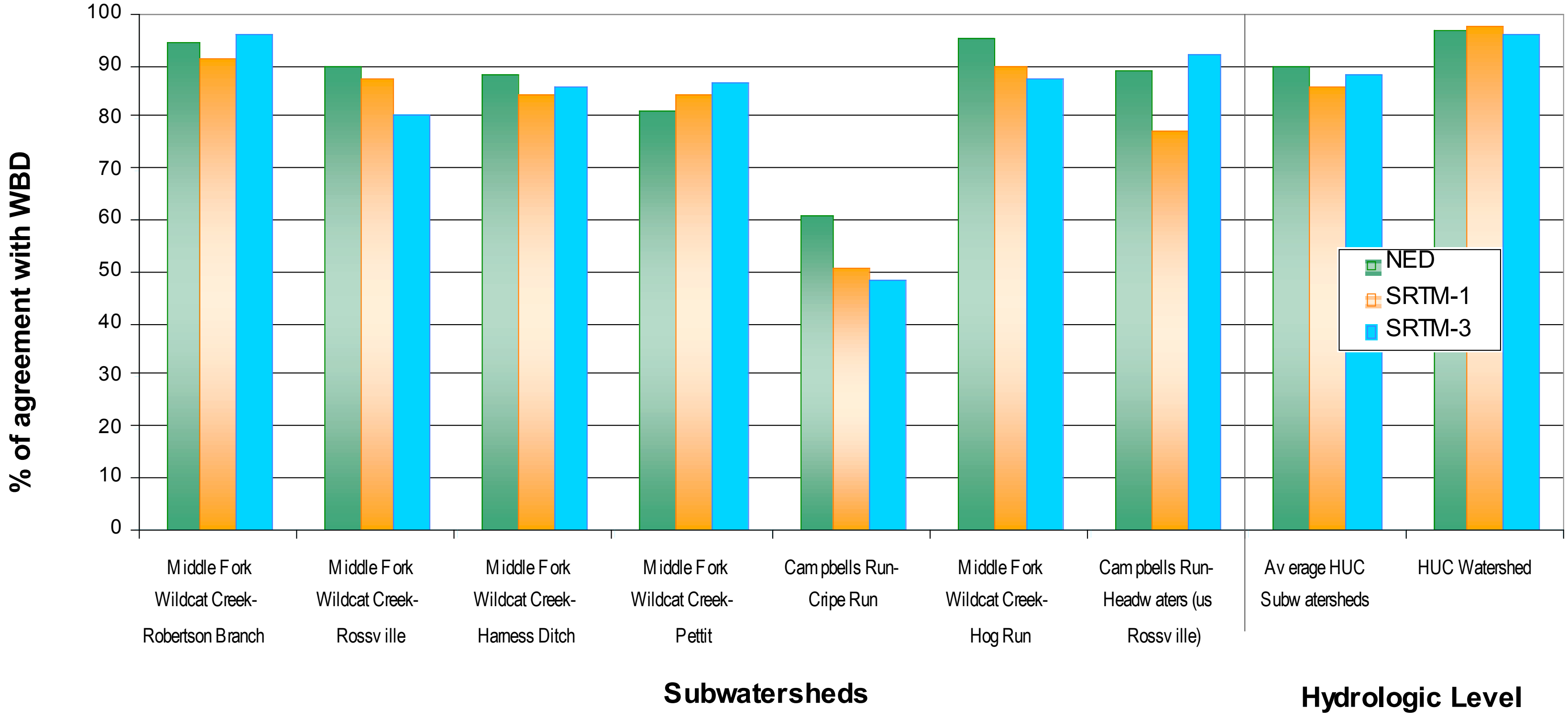


**SRTM / HUC**
**82.5 %**

# Verification in Indiana: The Middle Fork Wildcat Creek

## Characterization of Agricultural Watersheds

| Middle Fork Wildcat Creek | WBD10 Digits | NED | SRTM-1 | SRTM-3 |
|---|---|---|---|---|
| Area (ha) | 31,347 | 31,290 | 30,574 | 31,281 |
| Perimeter (m) | 109,645 | 165,900 | 164,400 | 143,280 |



# 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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