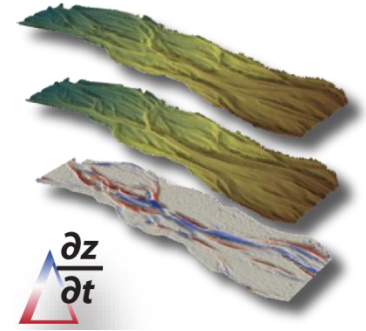


# GEOMORPHIC CHANGE DETECTION

---

## COMMON APPROACHES TO ESTIMATING DEM ERRORS



# TERMINOLOGY

---

The following are definitions of various terms used throughout the Geospatial Positioning Accuracy Standards.

**accuracy** - closeness of an estimated (e.g., measured or computed) value to a standard or accepted [true] value of a particular quantity. (National Geodetic Survey, 1986).

NOTE Because the true value is not known, but only estimated, the accuracy of the measured quantity is also unknown. Therefore, accuracy of coordinate information can only be estimated (Geodetic Survey Division, 1996).

**accuracy testing** - process by which the accuracy of a data set may be checked.

**check point** - one of the points in the sample used to estimate the positional accuracy of the data set against an independent source of higher accuracy.

**component accuracy** - positional accuracy in each x, y, and z component.

**confidence level** - the probability that the true (population) value is within a range of given values.

NOTE in the sense of this standard, the probability that errors are within a range of given values.

**dataset** - identifiable collection of related data.

**datum** - any quantity or set of such quantities that may serve as a basis for calculation of other quantities. (National Geodetic Survey, 1986)

**elevation** - height of a point with respect to a defined vertical datum.

**vertical accuracy** - measure of the positional accuracy of a data set with respect to a specified vertical datum. (adapted from Subcommittee for Base Cartographic Data, 1998).

**vertical error** - displacement of a feature's recorded elevation in a dataset from its true or more accurate elevation.

- Check out: <https://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part1/chapter1>

# WHAT ARE SOURCES OF POINT ERROR?

- From Sensor

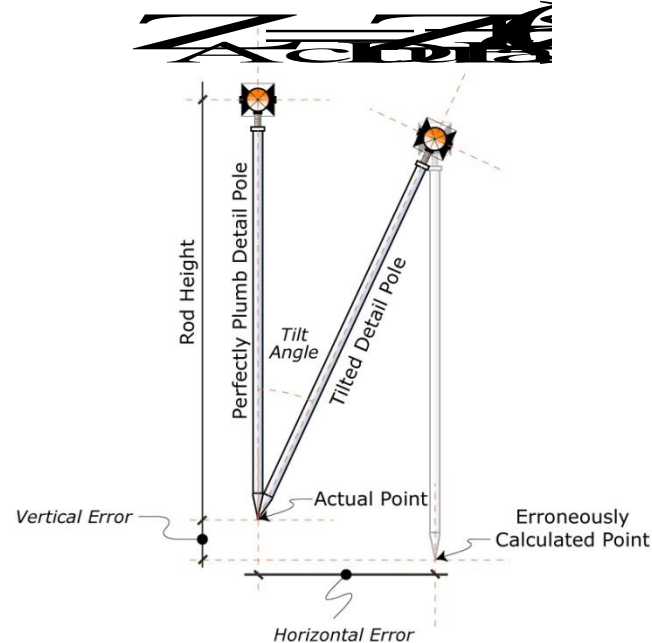
- Instrument precision
- Positional error of instrument/sensor
- Orientation errors
- Network occupation error
- Range errors

- At sample point

- Footprint
- Angle of incidence
- Range distance
- Swath angle
- What part of surface is being sampled

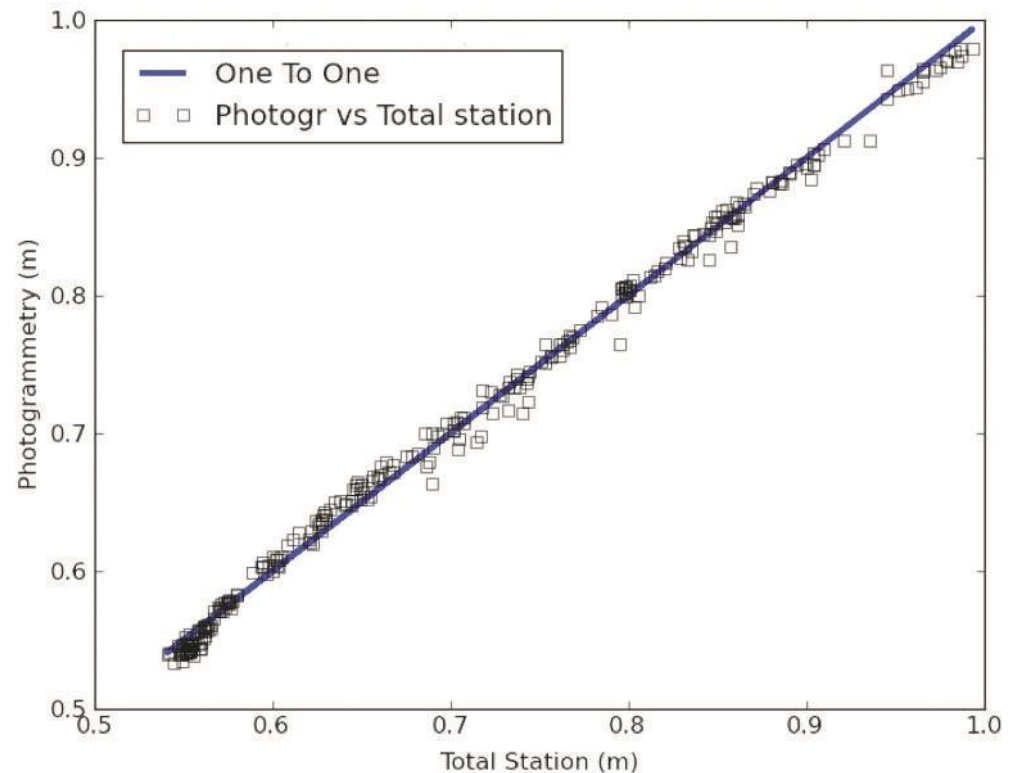
- User Errors

- Incorrect rod-heights, offsets, settings
- What part of surface is being sampled
- Tilt errors

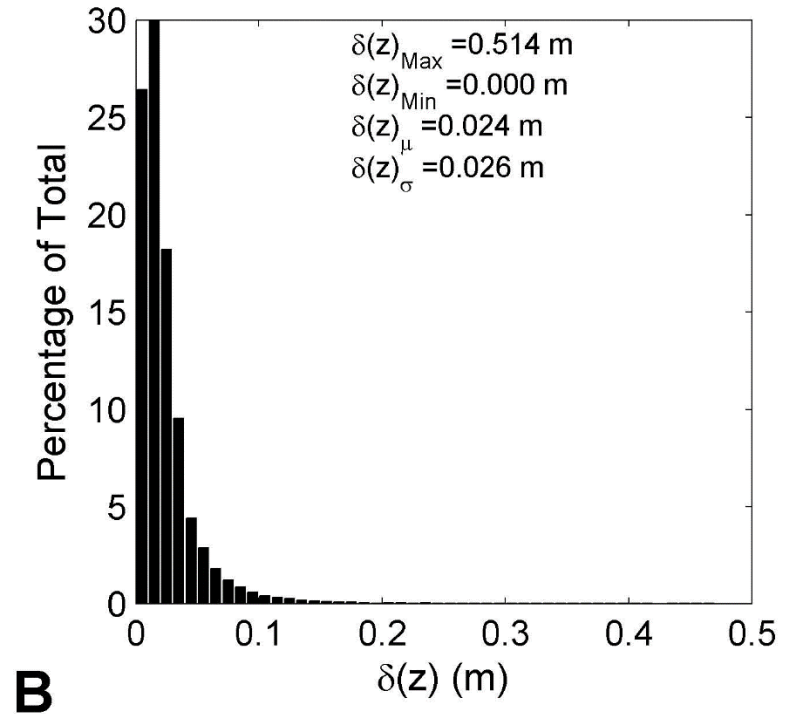
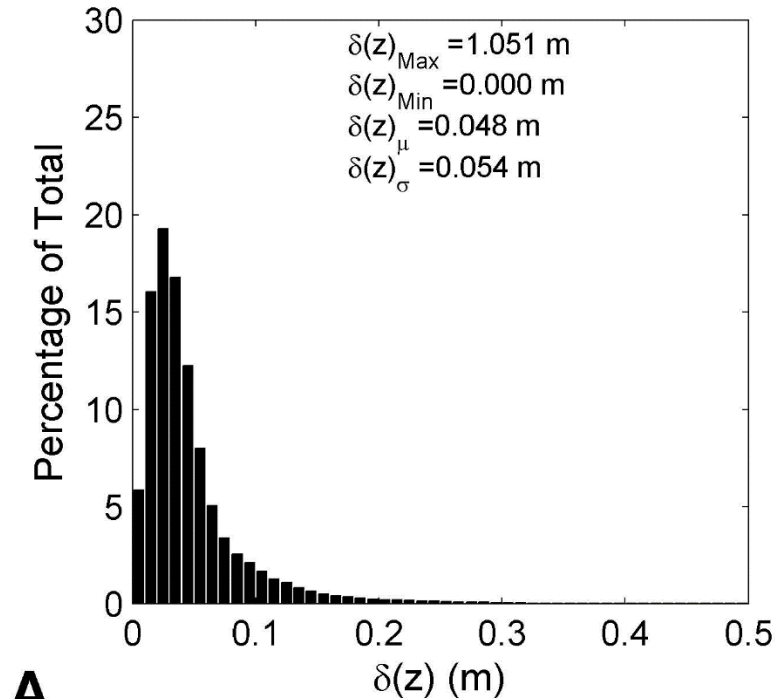


# WHEN WE SAY ERROR...

- In statistics, an error is defined as the difference between a *computed, estimated, or measured value* and the *accepted true, specified, or theoretically correct value*
- In practice, we often treat the more precise method as '*theoretically correct*'



# DISTRIBUTIONS OF ERROR



How do I get something like this?

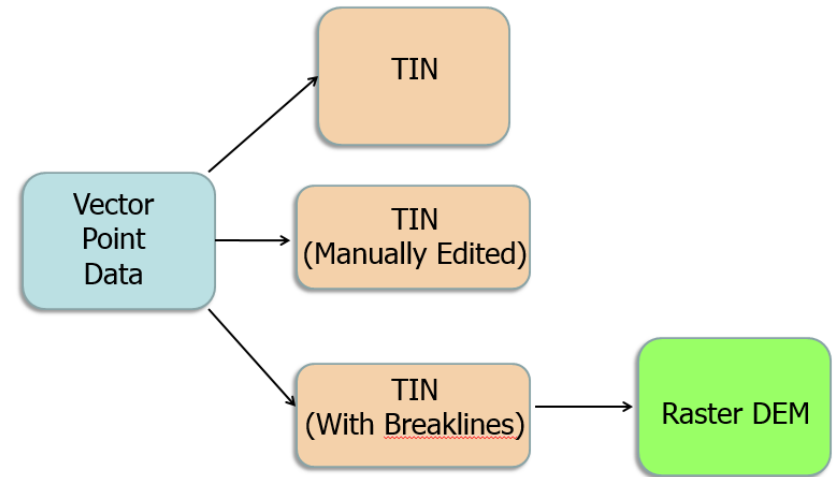




# WHAT DO WE DO WITH UNCERTAIN XYZ POINTS?

---

- We interpolate them to a TIN
- We then further interpolate them to a raster



# WHAT IS DEM ERROR?

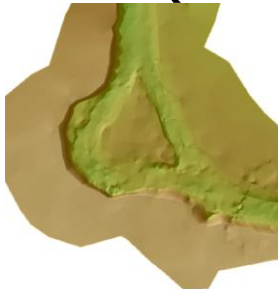
---

- A measure of how uncertain DEM is?
- The DEM is a raster model of elevation, so error is only considered in vertical (i.e. elevation)
- If horizontal accuracy  $\gg$  cell resolution, this is okay (if not... we're in trouble)



# FEDERAL STANDARDS – FGDC – Class 1

- Horizontal or Vertical (which ever is limiting)
- 1:200 (2.5 cm)



- 1:1000 (25 cm)



Federal Geographic Data Committee  
Geospatial Positioning Accuracy Standards  
Part 3: National Standard for Spatial Data Accuracy  
Appendix 3-D (informative): Other Accuracy Standards

FGDC-STD-007.3-1998

Table 4  
ASPRS Accuracy Standards for Large-Scale Maps  
Class 1 horizontal (x or y) limiting RMSE for various map scales  
at ground scale for *metric* units

Class 1 Planimetric Accuracy Limiting RMSE (meters)	Map Scale
0.0125	1:50
0.025	1:100
0.050	1:200
0.125	1:500
0.25	1:1,000
0.50	1:2,000
1.00	1:4,000
1.25	1:5,000
2.50	1:10,000
5.00	1:20,000

See:

<https://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3>

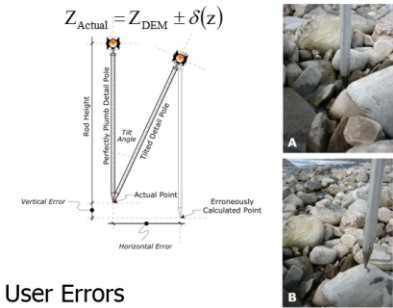


# WHAT ARE SOURCES OF DEM UNCERTAINTY?

- Point-Based
  - Total Propagated Uncertainty at each point?
  - Horizontal accuracy
  - Vertical accuracy
  - Busts & Blunders
- Interpolation-Based
  - Interpolation models used (e.g. TIN & TIN to Raster vs. IDW, Kriging)
  - Cell Resolution used
  - Resampling errors!

## WHAT ARE SOURCES OF POINT ERROR?

- From Sensor
  - Instrument precision
  - Positional error of instrument/sensor
  - Orientation errors
  - Network occupation error
  - Range errors
- At sample point
  - Footprint
  - Angle of incidence
  - Range distance
  - Swath angle
  - What part of surface is being sampled
- User Errors
  - Incorrect rod-heights, offsets, settings
  - What part of surface is being sampled
  - Tilt errors



- User Choices (Structural Uncertainty)
  - Projections...
  - Methods for interpolation
  - Methods for cleaning
  - Sampling



# DEM ERROR



DEM error

- Most common approach is to use one value everywhere! i.e.  $const. \approx \delta(z) \neq f(x, y)$
- WRONG thing to do is to use manufacture reported instrument precision (way too liberal)
- Probably too conservative to use full error budgeting or TPU (total propagated uncertainty)
- What to use for that one value?



# FGDC – SPATIAL ACCURACY STANDARD

---

Federal Geographic Data Committee  
Geospatial Positioning Accuracy Standards  
Part 3: National Standard for Spatial Data Accuracy

---

FGDC-STD-007.3-1998

## 3.2 Testing Methodology And Reporting Requirements

### 3.2.1 Spatial Accuracy

The NSSDA uses root-mean-square error (RMSE) to estimate positional accuracy. RMSE is the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points<sup>1</sup>.

Accuracy is reported in ground distances at the 95% confidence level. Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the product.

- From: <https://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3>



# FGDC – ACCURACY TEST

---

## 3.2.2 Accuracy Test Guidelines

According to the Spatial Data Transfer Standard (SDTS) (ANSI-NCITS, 1998), accuracy testing by an independent source of higher accuracy is the preferred test for positional accuracy. Consequently, the NSSDA presents guidelines for accuracy testing by an independent source of higher accuracy. The independent source of higher accuracy shall be the highest accuracy feasible and practicable to evaluate the accuracy of the dataset.<sup>2</sup>

The data producer shall determine the geographic extent of testing. Horizontal accuracy shall be tested by comparing the planimetric coordinates of well-defined points<sup>3</sup> in the dataset with coordinates of the same points from an independent source of higher accuracy. Vertical accuracy shall be tested by comparing the elevations in the dataset with elevations of the same points as determined from an independent source of higher accuracy.

Errors in recording or processing data, such as reversing signs or inconsistencies between the dataset and independent source of higher accuracy in coordinate reference system definition, must be corrected before computing the accuracy value.

A minimum of 20 check points shall be tested, distributed to reflect the geographic area of interest and the distribution of error in the dataset.<sup>4</sup> When 20 points are tested, the 95% confidence level allows one point to fail the threshold given in product specifications.

- From: <https://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3>

# POSITIONAL UNCERTAINTIES IN XYZ COORDINATES

- Horizontal & Vertical Accuracies summarized with RMSE
- Example from: Appendix 3-A of FGDC Geospatial Positioning Accuracy Standards

## Vertical Accuracy

Let:

$$\text{RMSE}_z = \sqrt{\sum (z_{\text{data } i} - z_{\text{check } i})^2 / n}$$

where

$z_{\text{data } i}$  is the vertical coordinate of the  $i$  th check point in the dataset.

$z_{\text{check } i}$  is the vertical coordinate of the  $i$  th check point in the independent source of higher accuracy

$n$  = the number of points being checked

$i$  is an integer from 1 to  $n$

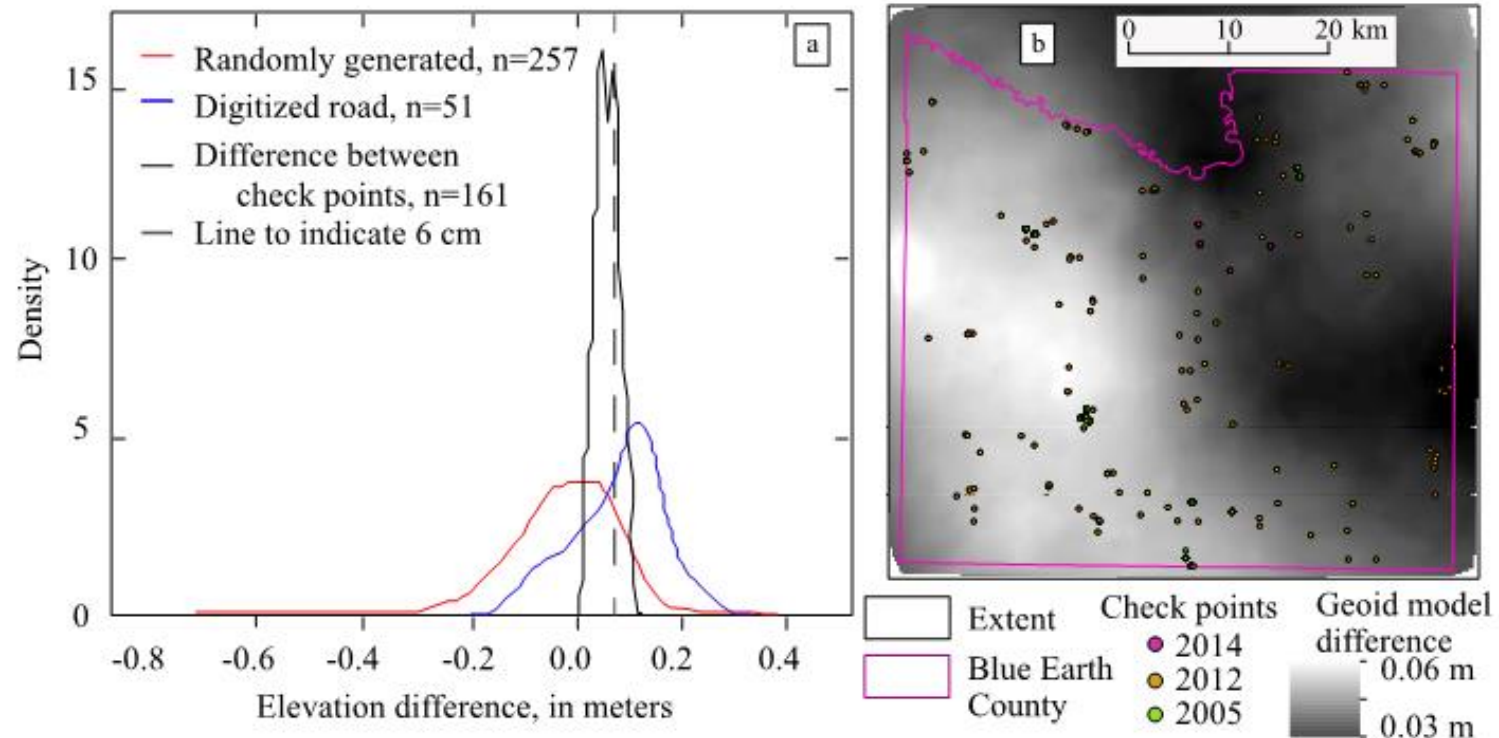
It is assumed that systematic errors have been eliminated as best as possible. If vertical error is normally distributed, the factor 1.9600 is applied to compute linear error at the 95% confidence level (Greenwalt and Schultz, 1968). Therefore, vertical accuracy,  $\text{Accuracy}_z$ , reported according to the NSSDA shall be computed by the following formula:

$$\text{Accuracy}_z = 1.9600 * \text{RMSE}_z.$$



# CHECK POINTS: rtkGPS vs. LIDAR

- Accuracy assessment reported for LiDAR... rtkGPS used as 'independent source of higher accuracy'





# CHECK-POINT REPEAT OBSERVATION

- Re-survey same 5 check points multiple times during each survey (e.g. beginning and end of day)
- Use simple statistics of variance as proxies for error

	2004	2005	2006	Combined
$\sigma_{\mu}$ Easting (m)	0.015	0.034	0.007	0.020
$\sigma_{\mu}$ Northing (m)	0.014	0.037	0.012	0.020
$\sigma_{\mu}$ Elevation (m)	0.007	0.018	0.004	0.010
n Repeat Observations	257	110	15	382
n of Control Points	6	5	5	16

TABLE 4.2: Variance in repeat GPS observation of control points over three years (n=382 observations). Standard deviations ( $\sigma$ ) of each coordinate component were calculated for each control point and then averaged over the number of control points to produce  $\sigma_{\mu}$ . The fifth column shows an average standard deviation for each coordinate component that was weighted by the number of observations from that year (row 5).

# REVIEW

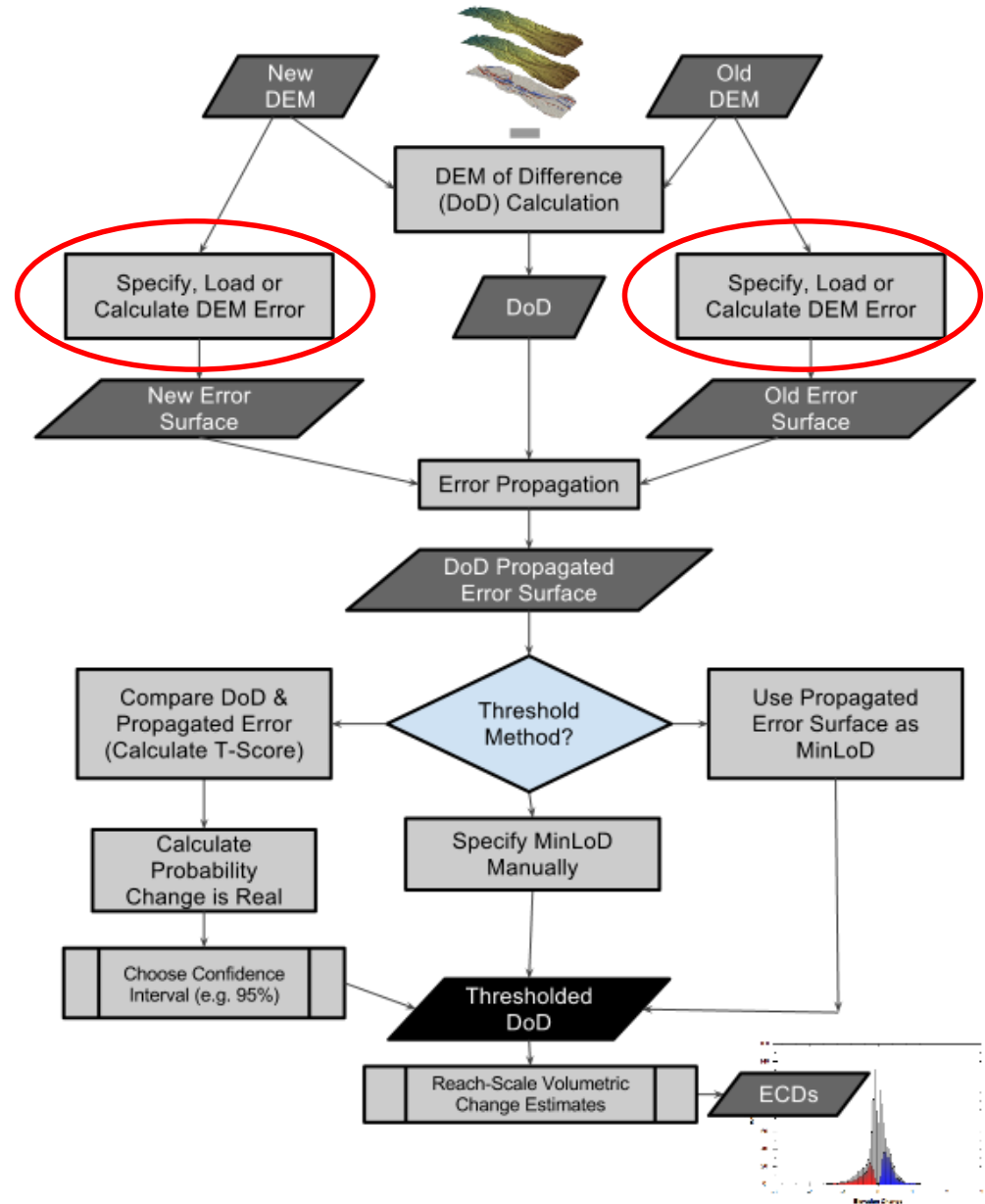
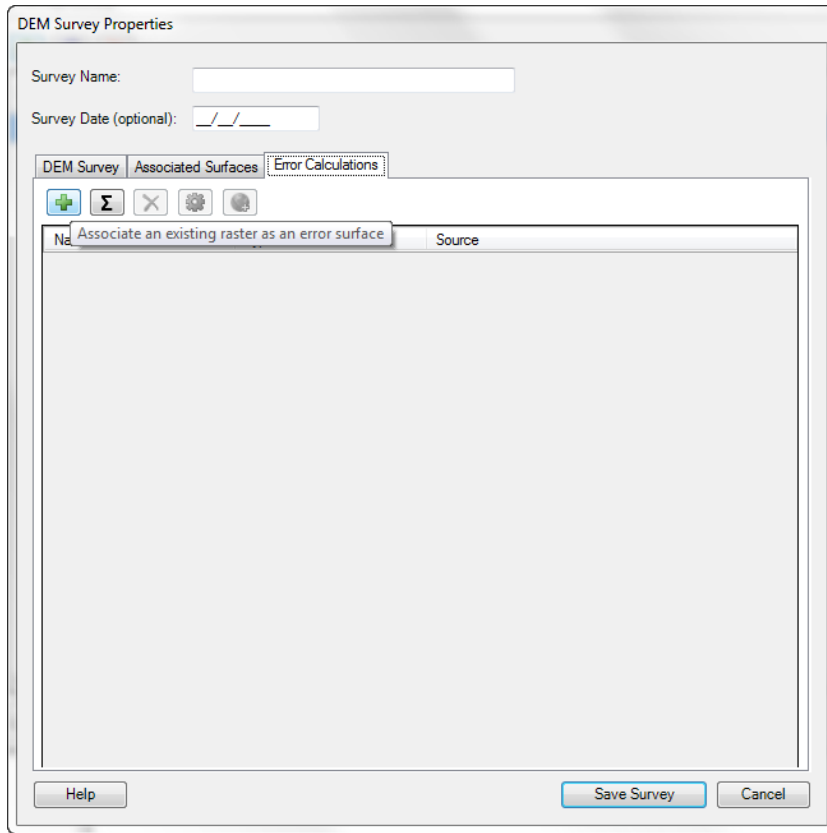
---

- What is the difference between point accuracy and DEM accuracy?
- What is the FGDC standard apply to? Points or Surfaces?
- Is an accuracy assessment  $\approx \delta z$  (i.e. DEM error)?



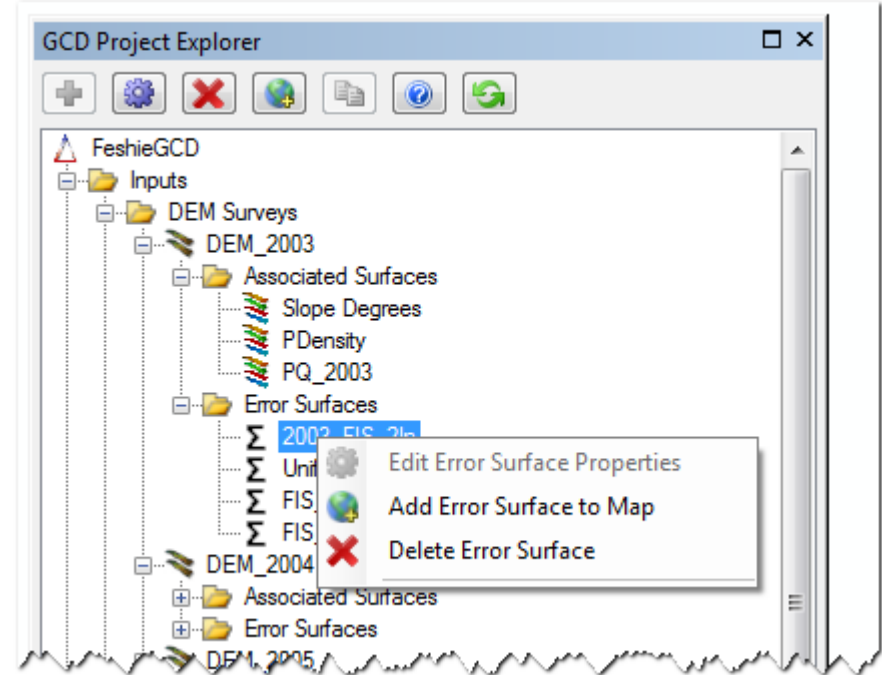
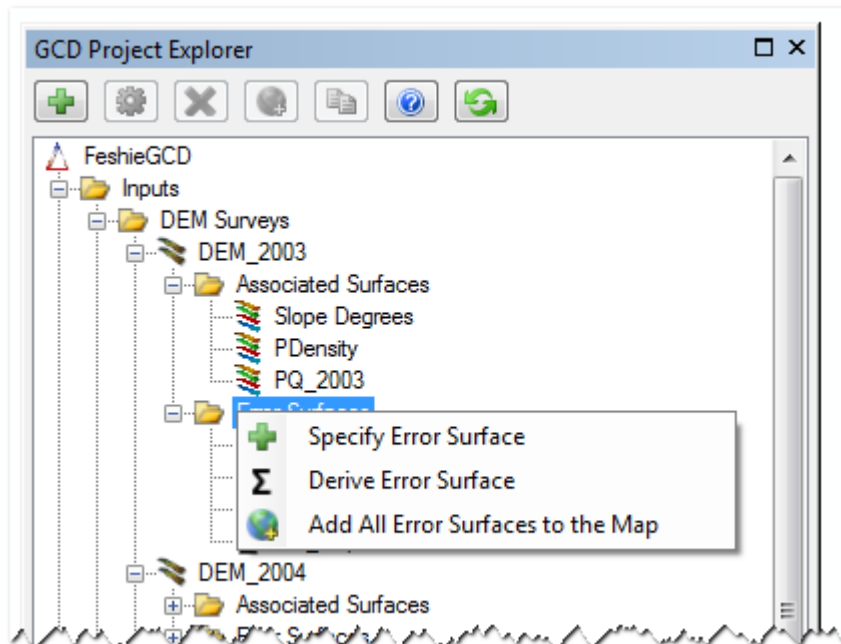
# WHERE DOES THIS FIT IN GCD WORKFLOW?

- New DEM Error
- Old DEM Error



# IN GCD, DEM ERRORS ARE PART OF SURVEY

- Each survey can have multiple DEM Errors

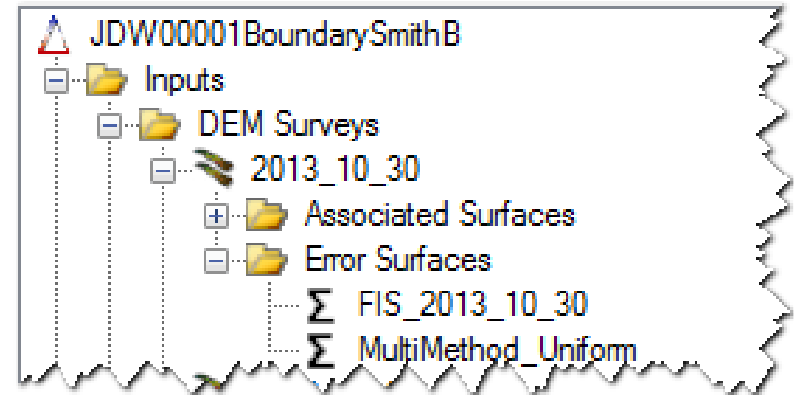


- 'Specify' means to load an existing
- 'Derive' means to build your own



# PART OF POINT OF HAVING A PROJECT IS TO EXPLORE IMPACT OF DIFFERENT ERROR MODELS

- GCD allows you to have multiple Error models for every DEM survey



Error Calculation Properties

Name:

Project raster:

Error Calculation Methods

Survey Method	Error Type
Entire DEM Extent	Uniform Error

Error Calculation Definition For Selected Survey Method

☒ Uniform error value (m)

☐ FIS error model

FIS Input

Save FIS for Current Method

Help

Derive Error Surface Cancel

# WET-DRY AREAS....

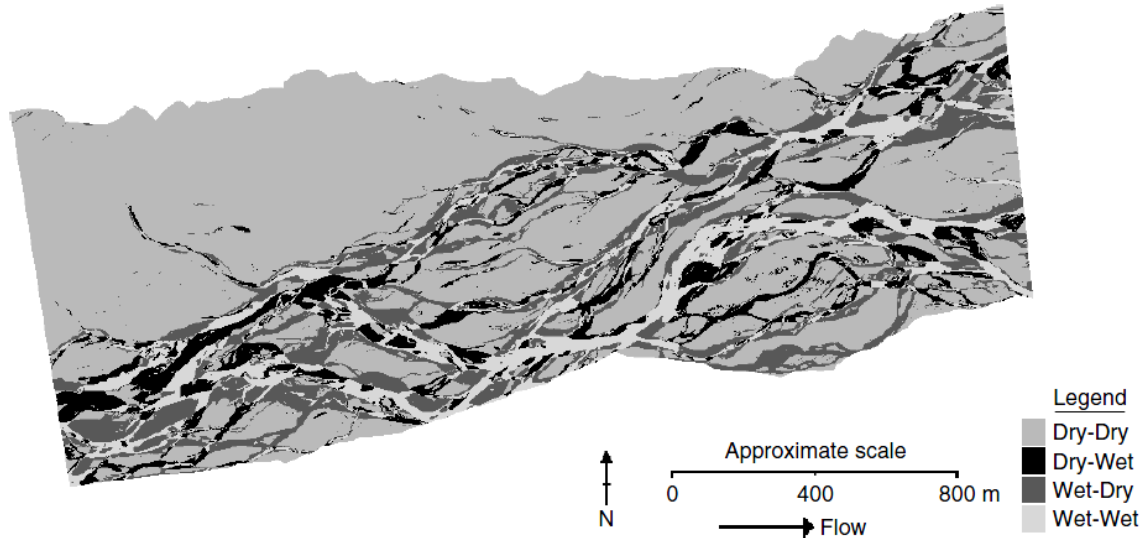


Figure 4. Classified patterns of change for the annual DEM of difference used to apply the level of detection information in Table V

- Wet areas have one error value, dry have another.
- With propagation, four possible combinations
- Derived from check points

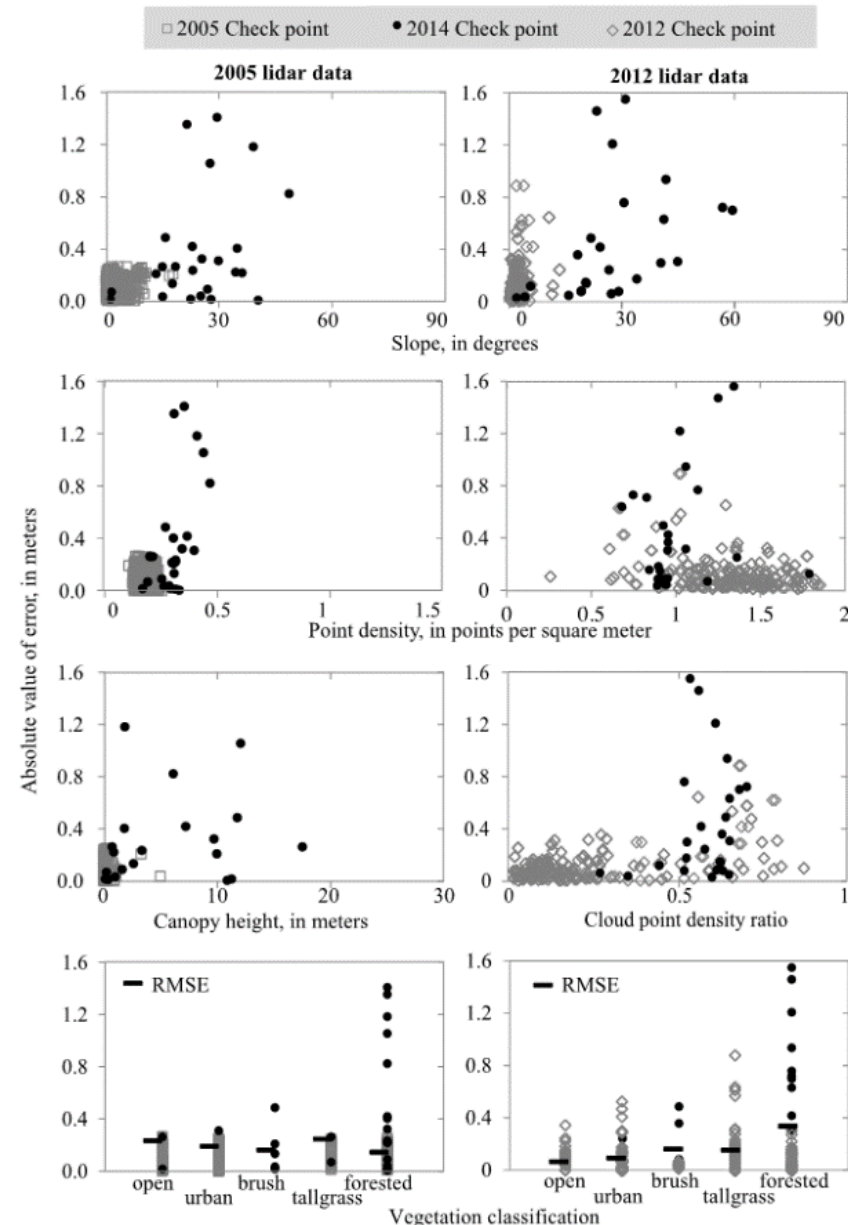
Table III. Measures of surface precision estimated from a theoretical basis, from photocontrol point data (PCP-based), from independently acquired check data, and from overlap analysis

DEM	Theoretical precision (m)	PCP-based precision (m)	Check data precision (m)		Overlap analysis precision (m)
			Dry-bed	Wet-bed	
Photogrammetry: February 1999	±0.070	±0.052	±0.261	±0.318	±0.192
Photogrammetry: March 1999	±0.070	±0.051	±0.257	±0.256	±0.174
Photogrammetry: February 2000	±0.056	±0.049	±0.131	±0.219	±0.177
Laser altimetry: May 2000	n/a	n/a	±0.100	±0.250	±0.218



# RMSE FROM LIDAR BY LANDCOVER TYPES

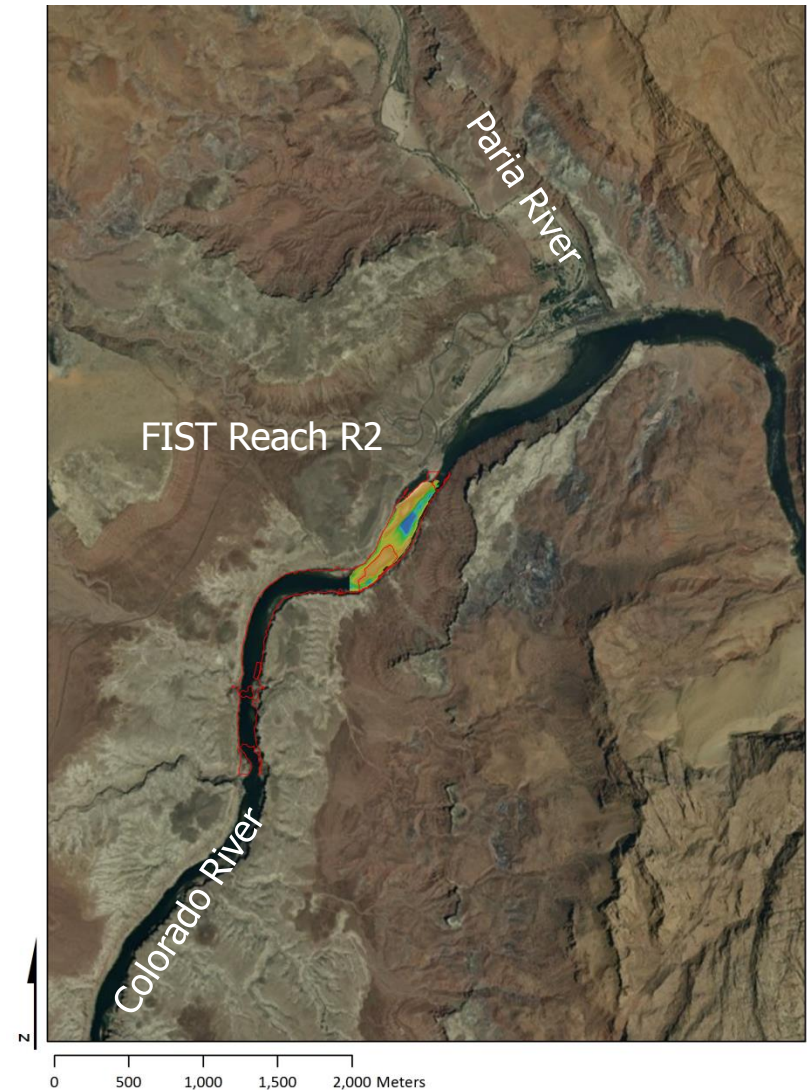
- Clear differences not just between surveys (different vendors, different specs), but also between landcover types
- RMSE varied for:
  - Open
  - Urban
  - Brush
  - Tall Grass
  - Forested



In Revision. Schaffrath K, Belmont P and **Wheaton JM**. Landscape-scale geomorphic change detection: Quantifying spatially-variable uncertainty and circumventing legacy data issues.

# GRAND CANYON EXAMPLE

- Paria Reach
  - FIST Reach R2
  - Six Surveys over four years (2000 to 2004); five epochs:
    - 2000 August
    - 2000 September
    - **2002 May**
    - **2004 May**
    - 2004 November
    - 2004 December
  - Used 121,843 of 311,371 points for 2002 & 86,142 of 251,739 points for 2004



Courtesy of Matt Kaplinski &  
Joe Hazel

# UNCERTAINTY ESTIMATES

$$\delta(z)_{DEM} = f(x, y, method)$$

**Table 8.** Summary statistics of singlebeam interpolation uncertainty used in this study along the Colorado River corridor within Glen, Marble, and Grand Canyons, Arizona.

[MEz, mean error in elevation; MAEz, mean absolute error in elevation; RMSEz, root-mean-square error in elevation at the 68-percent confidence level; RMSEz 95%, root-mean-square error in elevation at the 95-percent confidence level; m, meters; n, number of observations]

Survey date	n	MEz (m)	MAEz (m)	RMSE (m)	RMSE 95% (m)	Std. dev. (m)	Skewness
August 2000	159	-0.01	0.13	0.24	0.47	0.24	-0.09
September 2000	210	0.01	0.07	0.09	0.17	0.09	-0.20

The total uncertainty applied to regions of the DEMs constructed from singlebeam surveys was obtained by computing the quadratic sum of the individual error components (Taylor, 1997) using the following equation:

$$\text{total uncertainty} = \sqrt{(\text{survey precision})^2 + (\text{interpolation uncertainty})^2}.$$

**Table 10.** Uncertainty estimates assigned to each data source category in final digital elevation models (DEMs) for the Colorado River corridor within Glen, Marble, and Grand Canyons, Arizona.

[m<sup>3</sup>/s, cubic meters per second; n.a., not applicable]

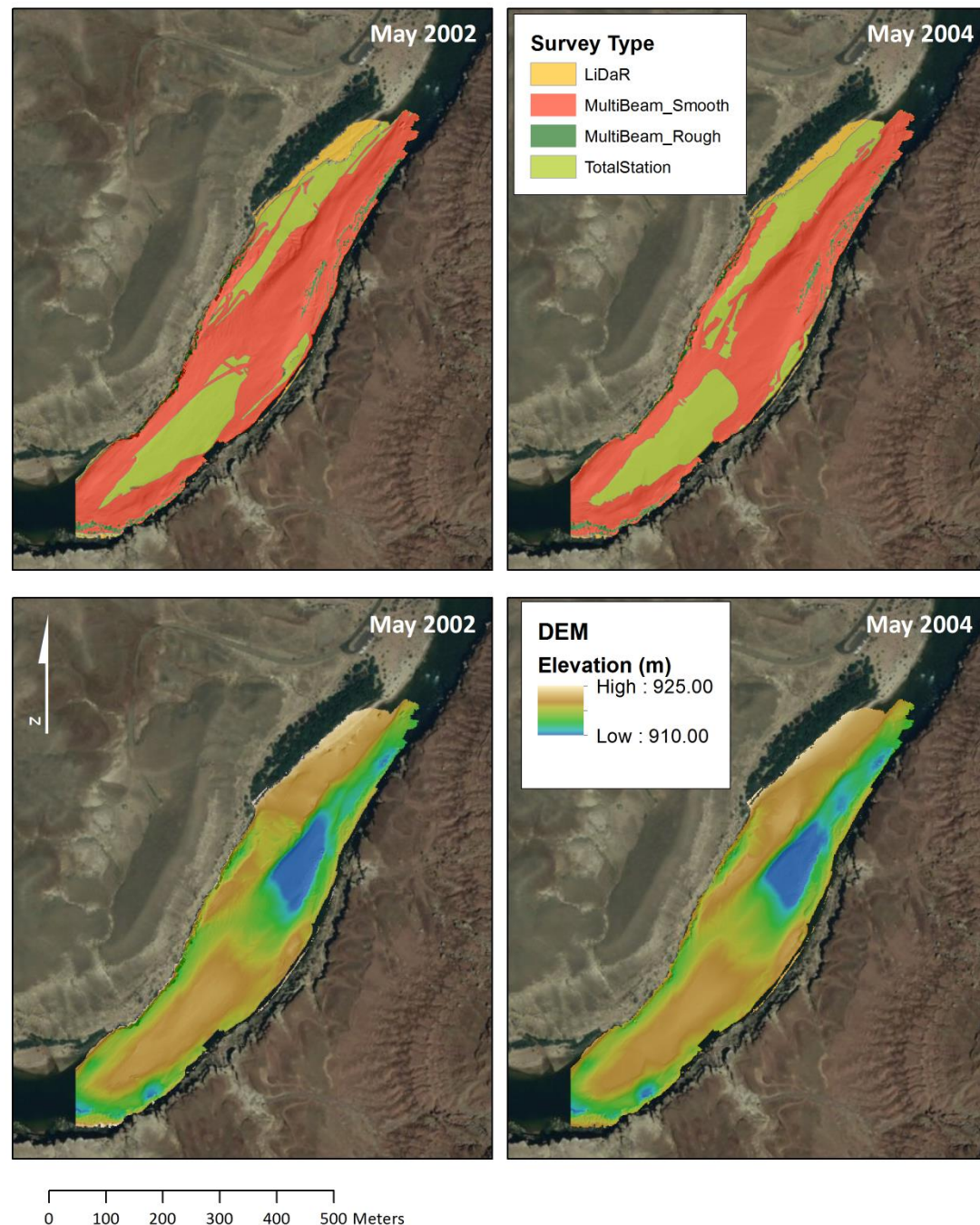
Data source category <sup>1</sup>	August 2000	September 2000	May 2002	May 2004	November 2004	December 2004
Lidar	0.18	0.18	n.a.	n.a.	0.17	0.17
Photogrammetry	n.a.	n.a.	0.21	n.a.	n.a.	n.a.
Multibeam—smooth	0.08	0.08	0.06	0.07	0.06	0.06
Multibeam—rough	0.34	0.33	0.25	0.24	0.22	0.23
Singlebeam	0.15	0.10	n.a.	n.a.	n.a.	n.a.
Total station above 227 m <sup>3</sup> /s	0.18	0.18	0.21	0.10	0.17	0.17
Total station below 227 m <sup>3</sup> /s	0.08	0.08	0.06	0.07	0.06	0.06
Interpolated above 227 m <sup>3</sup> /s	0.18	0.18	0.21	0.10	0.17	0.17
Interpolated below 227 m <sup>3</sup> /s	0.08	0.08	0.06	0.07	0.06	0.06

<sup>1</sup>MAEz (root-mean-square error in elevation at the 68-percent confidence level) statistics from tables 5 through 8 were used for each data source category.



# SUBSET OF DATA

- Hybrid Data Types
  - LiDaR ( $\sigma = 15$  cm)
  - Multibeam Smooth ( $\sigma = 3$  cm)
  - Multibeam Rough ( $\sigma = 12$  cm)
  - Total Station ( $\sigma = 6$  cm)
- What to do?



Courtesy of Matt Kaplinski &  
Joe Hazel



# WHAT IF ERROR VARIES IN SPACE?

- Maybe used different survey methods to make a hybrid DEM
- Differences between
  - Wet & Dry areas
  - Vegetated & Unvegetated

$$\delta(z)_{DEM} = f(x, y, \dots)$$

DEM Survey Properties

Survey Name: 2013\_10\_30 Survey Date/Time: Not Set

Folder: H:\CHaMP\GCD\JDW00001-Boundary Smith B\Nov2013\Topo\GCD\inputs\20131030

DEM Survey Associated Surfaces Error Calculations

Source

Raster source: inputs\20131030\20131030.tif

☒ Single method survey

Total Station

☐ Multi-method survey

Mask:

Identifier field:

Survey Raster Properties

-- GCD Raster Properties --

Left: 715,443

Top: 4,951,589

Right: 715,642

Bottom: 4,951,399

Cell size: 0.1

Width: 199

Height: 190

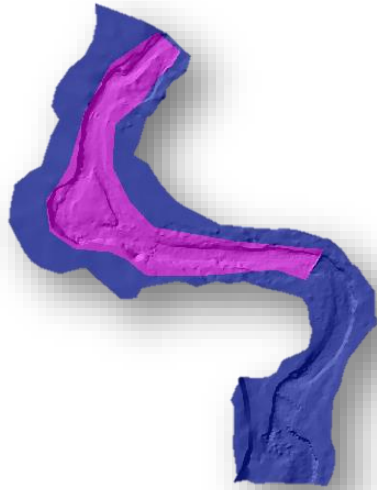
Rows: 1,900

Columns: 1,990

Help Save Survey and Close



# PROVIDE A SHAPEFILE FOR DIFFERENT AREAS



- Change to multi-method and add a polygon mask with a text field

DEM Survey Properties

Survey Name: 2013\_10\_30 Survey Date/Time: 2013 Oct

Folder: H:\CHaMP\GCD\JDW00001-Boundary Smith B\Nov2013\Topo\GCD\inputs\20131030

DEM Survey Associated Surfaces Error Calculations

Source

Raster source: inputs\20131030\20131030.tif

☐ Single method survey

Total Station

☒ Multi-method survey

Mask: inputs\20131030\Masks\20131030\_Mask.shp

Identifier field: Method

Survey Raster Properties

Top: 715,443  
Right: 715,642  
Bottom: 4,951,399

Cell size: 0.1

Width: 199  
Height: 190

Rows: 1,900  
Columns: 1,990

Table

Example\_MultiMethod

OBJECTID *	SHAPE *	SHAPE_Length	SHAPE_Area	Method
1	Polygon	789.560338	5241.565709	rtkGPS
2	Polygon	292.036617	1745.32338	TotalStation

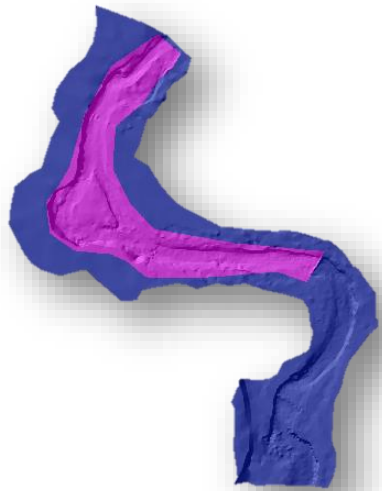
(0 out of 2 Selected)

Example\_MultiMethod

Help Save Survey and Close



# THEN, DERIVE ERROR SURFACE



GCD Project Explorer

Table Of Contents

- JDW00001BoundarySmithB
  - Inputs
    - DEM Surveys
      - 2013\_10\_30
      - 2012\_11\_01

Layers

- JDW00001BoundarySmithB
  - Inputs
    - 2013\_10\_30
    - Error Surfaces

DEM Survey Properties

Survey Name: 2013\_10\_30 Survey Date/Time: 2013 Oct

Folder: H:\CHaMP\GCD\JDW00001-Boundary Smith B\Nov2013\Topo\GCD\Inputs\20131030

DEM Survey Associated Surfaces Error Calculations

Name	Type	Source
FIS_2013_10_30	Single Error Raster	Inputs\20131030\ErrorSurfaces\FIS20131030\FIS_2013...

Error Calculation Properties

Name: MultiMethod\_Uniform

Project raster: inputs\20131030\ErrorSurfaces\MultiMethodUniform\MultiMe

Error Calculation Methods

Survey Method	Error Type
rtkGPS	Uniform Error
TotalStation	Uniform Error

Error Calculation Definition For Selected Survey Method

☒ Uniform error value (m) 0.04

☐ Associated error surface

☐ FIS error model

FIS Input Associated Surface

Help Derive Error Surface Cancel

GCD Project Explorer

FeshieGCD

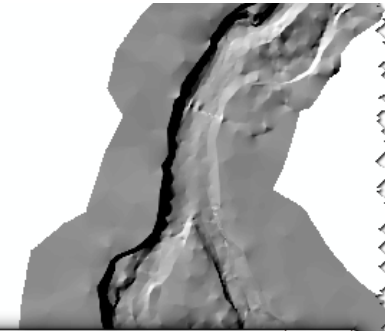
- Inputs
  - DEM Surveys
    - DEM\_2003
      - Associated Surfaces
        - Slope Degrees
        - PDensity
        - PQ\_2003

Specify Error Surface

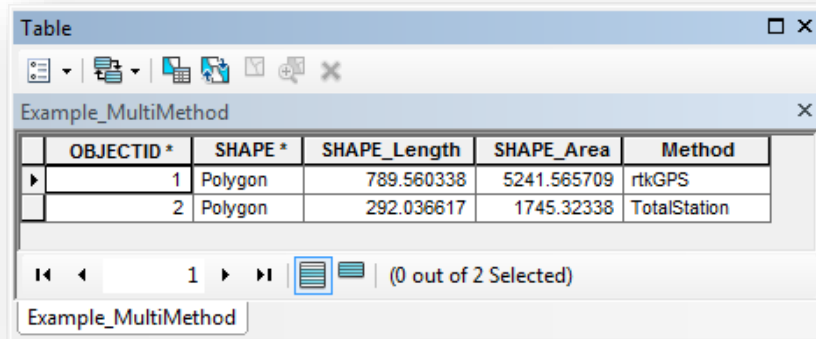
Derive Error Surface

Add All Error Surfaces to the Map

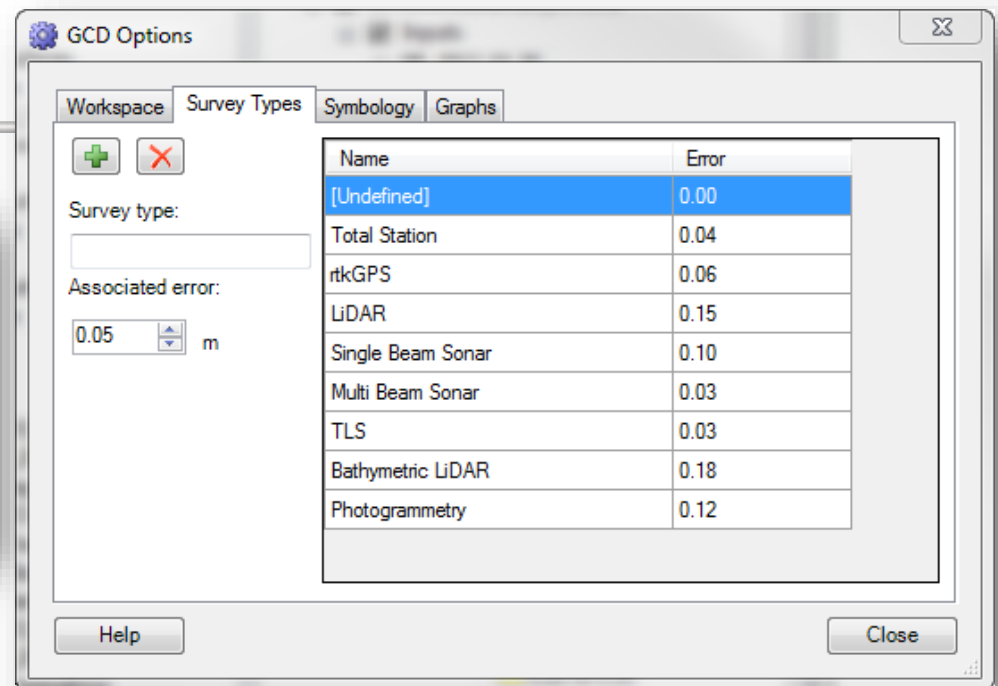
- DEM\_2004
  - Associated Surfaces



# A LITTLE TRICK...



OBJECTID *	SHAPE *	SHAPE_Length	SHAPE_Area	Method
1	Polygon	789.560338	5241.565709	rtkGPS
2	Polygon	292.036617	1745.32338	TotalStation



GCD Options

Workspace Survey Types Symbology Graphs

Survey type:

Associated error: 0.05 m

Name	Error
[Undefined]	0.00
Total Station	0.04
rtkGPS	0.06
LiDAR	0.15
Single Beam Sonar	0.10
Multi Beam Sonar	0.03
TLS	0.03
Bathymetric LiDAR	0.18
Photogrammetry	0.12

Help Close

- If text field matches (exact case) your Survey Types names, it will auto-populate with default value.
- If not, it is set to zero and can be manually specified.



# EXERCISE J: MULTI-METHOD

---

C:\0\_GCD\Exercices\J\_MultiMethod

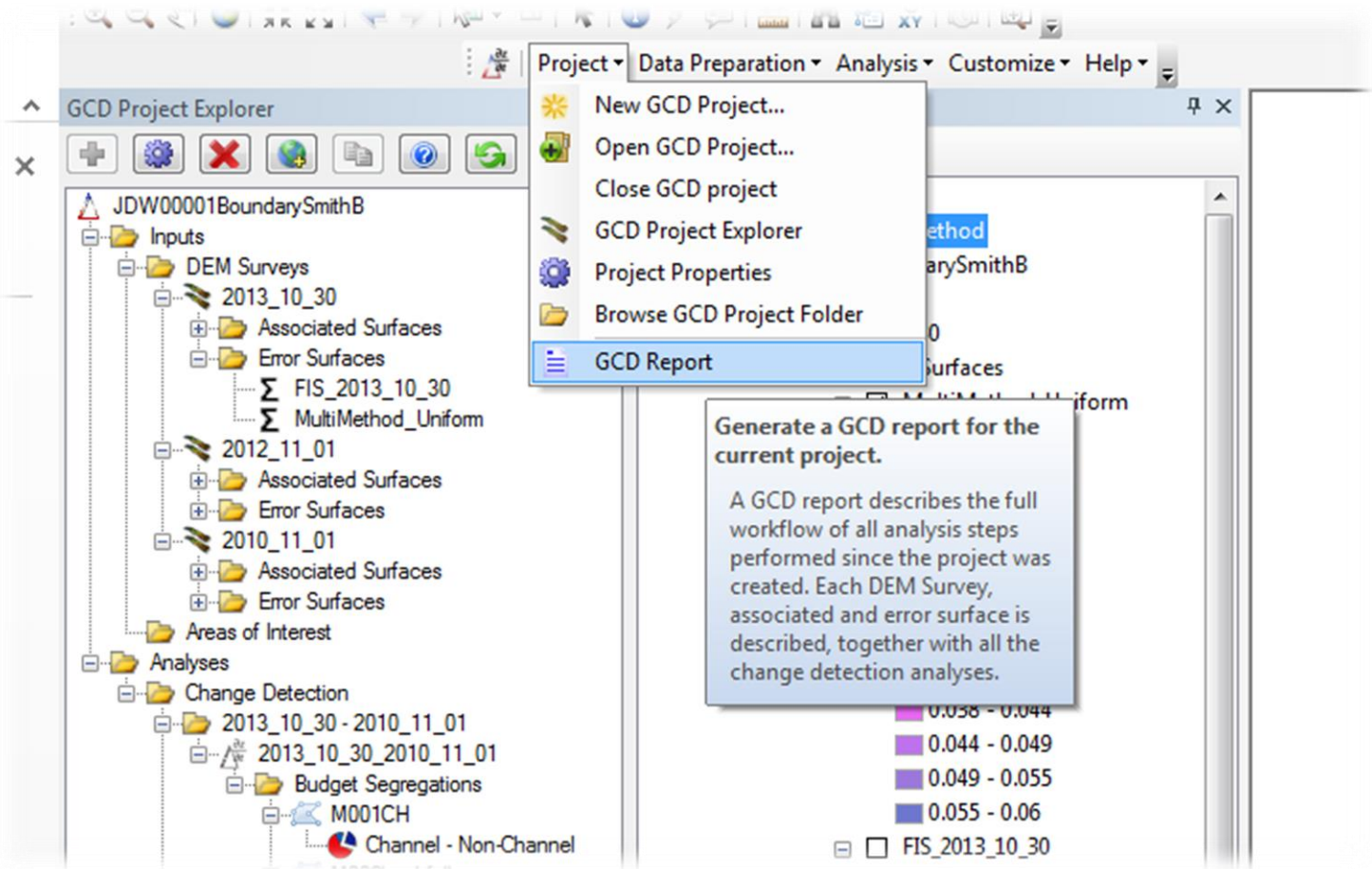
1. Start New ArcMap Document
2. Create New GCD Project – Paria in K
3. Add two survey DEMs (2002 and 2004)
4. For survey method, select multi-method and load survey method shapefile
5. Derive Errors for each using multi-method
6. Perform probabilistic change detection

$$\delta(z)_{DEM} = f(x, y, method)$$



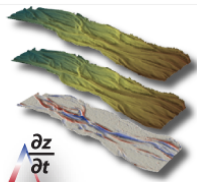
# IF YOU FORGET WHERE IT CAME FROM...

- Run GCD Report or Edit DEM Survey Properties



# GCD REPORT (BETA)

- Shows a visual of output, lists sources, method, etc.



JDW00001Bounda  
GCD Analysis Report

## Table of Contents:

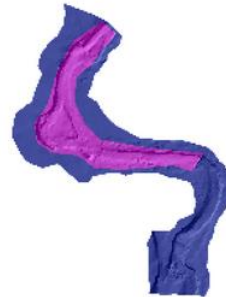
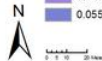
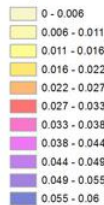
- Project Overview
- DEM Surveys
  - 2013\_10\_30
    - Associated Surfaces
      - Point Density
      - Slope Degrees
      - Interpolation Error
    - Error Surfaces
      - FIS\_2013\_10\_30
      - MultiMethod\_Uniform
  - 2010\_11\_01
    - Associated Surfaces
      - Point Density
      - Slope Degrees
      - Interpolation Error
    - Error Surfaces
      - FIS\_2010\_11\_01
  - 2012\_11\_01
    - Associated Surfaces
      - Point Density
      - Slope Degrees

## MultiMethod\_Uniform

The following are the Error Surfaces generated from survey one used in the change detection analysis

Name	Value
Name	MultiMethod_Uniform
Type	Multiple
Source	inputs\20131030\ErrorSurfaces\MultiMethodUniform\MultiMethodUniform.tif
MultiErrorProperties	1 rtkGPS 0.06 4 Uniform Error 0
MultiErrorProperties	2 TotalStation 0.04 4 Uniform Error 0

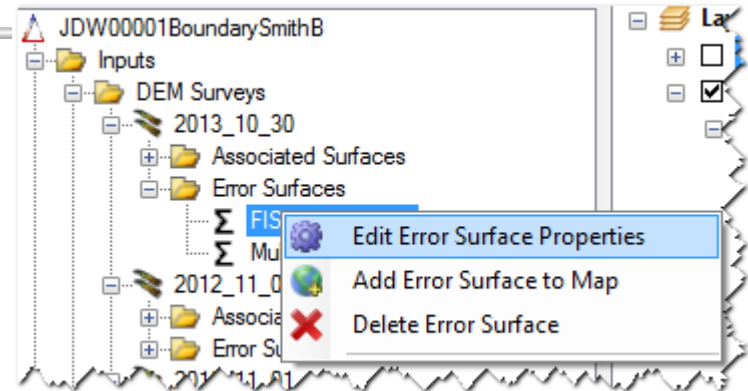
### Legend



Error Surface Methodology - Multiple

# EDIT DEM SURVEY PROPERTIES

- Read only view...



Error Calculation Properties

Name: MultiMethod\_Uniform

Project raster: inputs\20131030\ErrorSurfaces\MultiMethodUniform\MultiMe

Error Calculation Methods

Survey Method	Error Type
rtkGPS	Uniform Error
TotalStation	Uniform Error

Error Calculation Definition For Selected Survey Method

☒ Uniform error value (m) 0.06

☐ Associated error surface

☐ FIS error model

FIS Input	Associated Surface
-----------	--------------------

Help Save Cancel