COMMON APPROACHES TO ESTIMATING DEM ERRORS
HOW DO WE SPECIFY DEM ERROR?

1. New DEM
2. Specify, Load or Calculate DEM Error
   - New Error Surface
3. DEM of Difference (DoD) Calculation
4. Old DEM
   - Specify, Load or Calculate DEM Error
   - Old Error Surface
5. DoD
6. Error Propagation
7. DoD Propagated Error Surface
   - Use Propagated Error Surface as MinLoD
8. Thresholded DoD
9. Reach-Scale Volumetric Change Estimates
10. ECDs
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.

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`.
How do I get something like this?
WHAT 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 >> 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)


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

<table>
<thead>
<tr>
<th>Class 1 Planimetric Accuracy Limiting RMSE (meters)</th>
<th>Map Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0125</td>
<td>1:50</td>
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<tr>
<td>0.025</td>
<td>1:100</td>
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<tr>
<td>0.050</td>
<td>1:200</td>
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<tr>
<td>0.125</td>
<td>1:500</td>
</tr>
<tr>
<td>0.25</td>
<td>1:1,000</td>
</tr>
<tr>
<td>0.50</td>
<td>1:2,000</td>
</tr>
<tr>
<td>1.00</td>
<td>1:4,000</td>
</tr>
<tr>
<td>1.25</td>
<td>1:5,000</td>
</tr>
<tr>
<td>2.50</td>
<td>1:10,000</td>
</tr>
<tr>
<td>5.00</td>
<td>1:20,000</td>
</tr>
</tbody>
</table>
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!

• User Choices (Structural Uncertainty)
  – Projections...
  – Methods for interpolation
  – Methods for cleaning
  – Sampling
• 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?
Bootstrapping test….

- Hold back some percentage (e.g. 5%) of points as check points (random sample)
- Build DEM with remaining points
- Use extract values at check points to derive a distribution of errors: $|z_{DEM} - z_{Check}|$
- You could derive different distributions for different ‘types’ of areas… (e.g. wet, dry, banks, vegetated)

From Wheaton (2008)
Federal Geographic Data Committee
Geospatial Positioning Accuracy Standards
Part 3: National Standard for Spatial Data Accuracy

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.¹

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.

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 the highest accuracy feasible and practicable to evaluate the accuracy of the dataset.²

The data producer shall determine the geographic extent of testing. Horizontal accuracy shall be tested by comparing the planimetric coordinates of well-defined points³ 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.⁴ When 20 points are tested, the 95% confidence level allows one point to fail the threshold given in product specifications.
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:

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

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.
- $n = \text{the number of points being checked}$
- $i$ 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, Accuracy$_z$, reported according to the NSSSDA shall be computed by the following formula:

$$\text{Accuracy}_z = 1.9600 \times \text{RMSE}_z.$$
CHECK POINTS: rtkGPS vs. LIDAR

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

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

Chapter 4: Accounting for DEM Uncertainty in Morphological Sediment Budgeting

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

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).

From Wheaton (2008):
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.