Accuracy vs. Precision

Not Accurate, Not Precise

Accurate, Not Precise

Not Accurate, Precise

Accurate, Precise
The Relationship of Heights

\[ H \approx h - N \]

**Note:** Geoid height is **negative** everywhere in the coterminous US (but it is **positive** in most of Alaska)
How is H Derived with GNSS?

\[ H = h - N \]

- The ellipsoid height (\(h\)) and the geoid height (\(N\)) each have their own sources of error.
- The ellipsoid height error has many factors:
  - What GNSS method is being used?
  - Which orbits are being used?
  - What are the field/atmospheric conditions?
  - Tripods/Tribrachs in adjustment?
- Accuracy of \(N\) relative to NAVD 88 will vary depending on location.
Different GNSS Methods for GNSS-Derived H

• Absolute H (any method that derives h, then subtracts N)
  – OPUS, RTK, any GNSS survey that is not tied directly to a benchmark

• Relative H (any method that is tied directly to a benchmark)
  – Campaign style network
How Good Can I Do With OPUS-S?

OPUS-S reliably addresses the more historically conventional requirements for GPS data processing. It typically yields accuracies of:

1 – 2 cm horizontally
2 – 4 cm vertically

However, there is no guarantee that this stated accuracy will result from any given data set. Confirming the quality of the OPUS solution remains the user’s responsibility. That’s the “price” for automated processing.
How Good Can I Do With OPUS-S?

More generally, Eckl et al. (NGS, 1999) performed a similar but more extensive test using the same software but outside OPUS.

Their results provide a good “rule of thumb” for accuracy versus session duration when using OPUS-S and in many other applications.

## Differences from OPUS

<table>
<thead>
<tr>
<th>PID: LX3418</th>
<th>Designation: 846 1490 K TIDAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stamping: 1490 K 1979</td>
<td>Stability: Most reliable, expected to hold position well</td>
</tr>
<tr>
<td>Setting: In rock outcrop or ledge</td>
<td>Mark:</td>
</tr>
<tr>
<td>Condition:</td>
<td>Description: NEW LONDON, THE BENCH MARK IS SET IN BEDROCK, LOCATED 0.2 KM (0.1 MI) WEST ALONG STATE PIER ROAD FROM THE JUNCTION OF WESTHOP STREET, 6.944 M (1154 FT) NORTHWEST OF THE NORTHWEST BRIDGE ABUTMENT OF THE WESTERN MOST STEEL SPAN OVER RAILROAD TRACKS, 10.59 M (34.1 FT) NORTH-WEST OF THE CENTERLINE OF STATE PIER ROAD, 6.15 M (21.1 FT) SOUTH-SOUTHEAST OF THE SOUTH RAIL OF THE SOUTHERN MOST TRACKS AND 0.30 M (1.0 FT) ABOVE GROUND.</td>
</tr>
<tr>
<td>Source: OPUS - page 1209.04</td>
<td>Close-up View</td>
</tr>
</tbody>
</table>

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<th>Designation: 846 1490 K TIDAL</th>
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</tr>
<tr>
<td>Source: OPUS - page 1209.08</td>
<td>Close-up View</td>
</tr>
</tbody>
</table>

### The NGS Data Sheet

See file `dsdata.txt` for more information about the datasheet.

**PROGRAM** - `datashett35`, **VERSION** - 8.3

1 National Geodetic Survey, Retrieval Date - OCTOBER 30, 2013

**LX3418**

- **TIDAL BM** - This is a Tidal Benchmark.
- **DESIGNATION** - 846 1490 K TIDAL
- **PID** - LX3418
- **STATE/COUNTY** - CT/NEW LONDON
- **COUNTRY** - US
- **USGS QUAD** - NEW LONDON (1854)

*CURRENT SURVEY CONTROL*

- **LX3418**
  - **NAD 83 (2011) POSITION** - 41 21 42.99760 (M) 072 05 41.02161 (W) ADJUSTED
  - **ELLIP HT** - 21 712 (metres) (06/27/12) ADJUSTED
  - **EPOCH** - 2010.00
  - **NAVD 88 ORTHO HEIGHT** - 8.836 (metres) 28.99 (feet) ADJUSTED

- **CONVERGENCE** - 1.207806**e** 0.0016 m
  - **CONVERGENCE** - 30 244 0149
  - **POINT SCALE** - 1.000335023
  - **COMBINED FACTOR** - 0.99999102

- **LAT 41° 21.42.99721" N** - 0.004 m
- **LON -72° 54.41 02159" W** - 0.005 m
- **ELL HT** - 21.745 ± 0.031 m

- **X** - 1473920.497 ± 0.009 m
- **Y** - 4561910.353 ± 0.018 m
- **Z** - 27562.057 ± 0.055 m

- **ORTHO HT** - 8.809 ± 0.055 m

- **UTM 18**
  - **NORTHING** - 4583010.711 m 21134.337 m
  - **EASTING** - 745009.874 m 359628.129 m

- **CONVERGENCE** - 1.207806**e** 0.0016 m
  - **CONVERGENCE** - 30 244 0149
  - **POINT SCALE** - 1.000335023
  - **COMBINED FACTOR** - 0.99999102
## Draft NGS Accuracy Classes

<table>
<thead>
<tr>
<th><strong>ACCURACY CLASS SUMMARY TABLE</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CLASS RT1</strong></td>
</tr>
<tr>
<td><strong>ACCURACY (TO BASE)</strong></td>
</tr>
<tr>
<td><strong>REDUNDANCY</strong></td>
</tr>
<tr>
<td><strong>BASE STATIONS</strong></td>
</tr>
<tr>
<td><strong>PDOP</strong></td>
</tr>
<tr>
<td><strong>RMS</strong></td>
</tr>
<tr>
<td><strong>COLLECTION INTERVAL</strong></td>
</tr>
<tr>
<td><strong>SATELLITES</strong></td>
</tr>
<tr>
<td><strong>BASELINE DISTANCE</strong></td>
</tr>
<tr>
<td><strong>TYPICAL APPLICATIONS</strong></td>
</tr>
</tbody>
</table>
Collection Procedures (3 Observers)

1. Setup bipod/antenna and start survey
2. Initialize to nearest CORS
3. Collect observation using the duration criteria for RT1, RT2, RT3 and RT4 in rapid succession (regardless of field conditions)
4. End survey
5. Start new survey
6. Initialize to a different CORS
7. Repeat steps 3-6 using a number of CORS stations
8. End Survey
9. Move to different test locations and repeat steps 1-8
10. Repeat procedure steps 1-9 four or more hours later (preferably the next day)
## Test Stations and Vector Lengths

<table>
<thead>
<tr>
<th>CORS</th>
<th>Field Station</th>
<th>Distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCAP</td>
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<tr>
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<td>SOBA</td>
<td>11263</td>
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<td>VTC1</td>
<td>LLCZ</td>
<td>17140</td>
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<tr>
<td>VCAP</td>
<td>LLCZ</td>
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<td>VTC1</td>
<td>SKYL</td>
<td>30536</td>
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<tr>
<td>VTWR</td>
<td>LLCZ</td>
<td>52358</td>
</tr>
<tr>
<td>VTWR</td>
<td>SOBA</td>
<td>60397</td>
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<tr>
<td>VTUV</td>
<td>SOBA</td>
<td>63773</td>
</tr>
<tr>
<td>VTWR</td>
<td>SKYL</td>
<td>64112</td>
</tr>
</tbody>
</table>
Observer 1 – Example of BAD Initialization

Y Error bars indicate RT1 accuracy cutoff
Observer 2 Data

RT1 Northing (Pub-Obs)

RT1 Easting (Pub-Obs)

RT1 Up (Pub-Obs)

RT2 Northing (Pub-Obs)

RT2 Easting (Pub-Obs)

RT2 Up (Pub-Obs)

RT3 Northing (Pub-Obs)

RT3 Easting (Pub-Obs)

RT3 Up (Pub-Obs)

RT4 Northing (Pub-Obs)

RT4 Easting (Pub-Obs)

RT4 Up (Pub-Obs)
Combined Data - Average of each observers Day1 and Day2 observations

### Ave dN (pub-obs)

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>RT1</th>
<th>RT2</th>
<th>RT3</th>
<th>RT4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
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<tr>
<td>10000</td>
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<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
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<td>0.02</td>
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<td>30000</td>
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<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>40000</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>50000</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>60000</td>
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</tr>
<tr>
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<td>0.01</td>
<td>0.01</td>
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<td>0.01</td>
</tr>
</tbody>
</table>

### Ave dE (pub-obs)

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>RT1</th>
<th>RT2</th>
<th>RT3</th>
<th>RT4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
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<td>0.04</td>
</tr>
<tr>
<td>20000</td>
<td>0.03</td>
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</tr>
</tbody>
</table>

### Ave dh (pub-obs)

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>RT1</th>
<th>RT2</th>
<th>RT3</th>
<th>RT4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>10000</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>20000</td>
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<tr>
<td>70000</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

### Table: \( \sigma_N \) (m), \( \sigma_E \) (m), \( \sigma_h \) (m)

<table>
<thead>
<tr>
<th></th>
<th>( \sigma_N ) (m)</th>
<th>( \sigma_E ) (m)</th>
<th>( \sigma_h ) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT1</td>
<td>0.021</td>
<td>0.012</td>
<td>0.011</td>
</tr>
<tr>
<td>RT2</td>
<td>0.020</td>
<td>0.013</td>
<td>0.012</td>
</tr>
<tr>
<td>RT3</td>
<td>0.020</td>
<td>0.014</td>
<td>0.014</td>
</tr>
<tr>
<td>RT4</td>
<td>0.021</td>
<td>0.013</td>
<td>0.014</td>
</tr>
</tbody>
</table>
How does Precision translate to Accuracy

- NGS Accuracy Classes defined by 2d horizontal, 1d vertical precision (Repeatability) at 95% per redundant observation set

<table>
<thead>
<tr>
<th></th>
<th>2σ Horizontal</th>
<th>2σ Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT1</td>
<td>0.024663</td>
<td>0.020933</td>
</tr>
<tr>
<td>RT2</td>
<td>0.021754</td>
<td>0.023475</td>
</tr>
<tr>
<td>RT3</td>
<td>0.020684</td>
<td>0.027002</td>
</tr>
<tr>
<td>RT4</td>
<td>0.025223</td>
<td>0.027488</td>
</tr>
</tbody>
</table>

Graphs showing horizontal and vertical precision data for RT1 to RT4.
Identically shaped ellipsoids (GRS-80)
a = 6,378,137.000 meters (semi-major axis)
1/f = 298.25722210088 (flattening)
Types and Uses of Geoid Height Models

• Gravimetric (or Gravity) Geoid Height Models
  – Defined by gravity data crossing the geoid
  – Refined by terrain models (DEM’s)
  – Scientific and engineering applications

• Composite (or Hybrid) Geoid Height Models
  – Gravimetric geoid defines most regions
  – Warped to fit available GPSBM control data
  – Defined by legislated ellipsoid (NAD 83) and local vertical datum (NAVD 88, PRVD02, etc.)
  – May be statutory for some surveying & mapping applications
GRACE – Gravity Recovery and Climate Experiment
Hybrid Geoid Model  
(How It’s “Built”)

Errors in NAVD 88: ~50 cm average,  
100 cm CONUS tilt,  
1-2 meters average in Alaska
GGPSBM1999: 6,169 total 0 Canada STDEV 9.2 cm (2σ)

GGPSBM2003: 14,185 total 579 Canada STDEV 4.8 cm (2σ)
GGPSBM2009: 18,398 STDEV 2.8 cm (2σ)
GGPSBM2012A: 23,961 (CONUS) STDEV 3.4 cm (2\sigma)
499 (OPUS on BM)
574 (Canada)
177 (Mexico)
CT Stats:
3.0 cm 95%
Min -3.8
Max 2.1
Which Geoid for Which NAD 83?

- NAD 83(2011)
- NAD 83(2007)
- NAD 83(1996) & CORS96
- NAD 83(1992)
- Geoid12A
- Geoid09
- Geoid06 (AK only)
- Geoid03
- Geoid99
- Geoid96
- Geoid93
How accurate is a GPS-derived Orthometric Height?

• Relative (local) accuracy in ellipsoid heights between adjacent points can be better than 2 cm, at 95% confidence level

• Network accuracy (relative to NSRS) in ellipsoid heights can be better than 5 cm, at 95% confidence level

• Accuracy of orthometric height is dependent on accuracy of the geoid model – Currently NGS is improving the geoid model with more data, i.e. Gravity and GPS observations on leveled bench marks from Height Mod projects

• Geoid12A can have an uncertainty in the 2-5 cm range.
Another H Derived with GNSS?

\[ \Delta H = \Delta h - \Delta N \]

• If “shape” of geoid is correct, then geoid bias will cancel
• NOS NGS 58 and 59 Guidelines
  – 2cm local 5cm network
• Uses ties to existing NAVD 88 control
• Classical “network” approach
• 100% redundancy (repeat baselines) occupied at different times on different days
• Least squares adj with orthometric constraints
The National Geodetic Survey 10 year plan
Mission, Vision and Strategy
2008 – 2018

http://www.ngs.noaa.gov/INFO/NGS10yearplan.pdf

- Official NGS policy as of Jan 9, 2008
  - Modernized agency
  - Attention to accuracy
  - Attention to time-changes
  - Improved products and services
  - Integration with other fed missions

- 2018 Targets: (now 2022)
  - NAD 83 and NAVD 88 re-defined
  - Cm-accuracy access to all coordinates
  - Customer-focused agency
  - Global scientific leadership
Future Geopotential (Vertical) Datum

- replace NAVD88 with new geopotential datum – by 2022
- gravimetric geoid-based, in combination with GNSS
- monitor time-varying nature of gravity field
- develop transformation tools to relate to NAVD88
  - build most accurate ever continental gravimetric geoid model (GRAV-D)
  - determine gravity with accuracy of 10 microGals, anytime
  - support both orthometric and dynamic heights
  - Height Modernization is fully supported
How will I access the new vertical datum?

Example 1: Flood insurance survey

1954: Leveling performed to bench mark

1954-1991: Subsidence

1991: Original 1954 leveling data is used to compute the NAVD 88 height which is then published for this BM

Clearly the true height relative to the NAVD 88 zero surface is not the published NAVD 88 height

Last Updated 30 Nov 2009 (DAS)
How will I access the new vertical datum?

Example 1: Flood insurance survey

Using Existing Techniques:

Find bench mark (if you can)
Get published NAVD 88 height
Level off of bench mark
No account for subsidence!

Last Updated 30 Nov 2009 (DAS)
How will I access the new vertical datum?

Example 1: Flood insurance survey

Using Future Techniques:

Find bench mark if you wish, or set a new one of your choosing

Use GNSS/OPUS to get an orthometric height in the new datum

Level off of bench mark as needed

Subsidence is accounted for by CORS and a geoid that are monitored constantly!

NAVD 2018(?) zero height surface = geoid

H(2022?) from GNSS/geoid

Last Updated 30 Nov 2009 (DAS)
Transition to the Future – GRAV-D

Gravity for the Redefinition of the American Vertical Datum

- Official NGS policy as of Nov 14, 2007 – $38.5M over 10 years

- Airborne Gravity Snapshot

- Absolute Gravity Tracking

- Re-define the Vertical Datum of the USA by 2018
  (2022 more likely due to funding issues)