NAVD 88 Helmert Orthometric Heights from NAD 83
GPS heights and the GEOID99 high resolution
geoid height model

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- Review of Height Systems

- Status of HARN

- Creation of GEOID99 model

- Comparison with GEOID96

- Accuracy analysis of "GPS leveling"
The diagram illustrates the relationship between the Earth's surface, ellipsoid, and geoid. The equation $h = H + N$ describes the elevation at a point $h$ where $H$ is the height of the point above the ellipsoid and $N$ is the normal component. In the USA, $N < 0$.
Real Situation

Earth’s Surface

\[ h_{83} = H_{88} + N_{99} \]

In the USA: \( N_{99} < 0 \)

NAVD 88

H = 0

NAD 83 ELLIPSOID

\( H_{88} \)
STATUS of the HARNs

- 1998 : Last of original 48 CONUS HARNs

  NGS begins FBNVC (FBN Vertical Component)

- 1999 : Wisconsin FBNVC observed, processed, loaded into NGSIDB

  Washington and Oregon FBNVC observed and preliminarily processed. Not loaded into NGSIDB.

  GEOID99 released, reflecting 45 original HARNs and 3 FBNVC states (WI, WA, OR)
Differences in Ellipsoid Heights from the GPSBM(99) and GPSBM(96) Data Sets
GEOID99 basic information

**Input data**
- 2.0 Million gravity observations (1.6 from the NIMA evaluated gravity database)
- 0.6 Million altimetric gravity anomalies
- EGM96 (NASA/NIMA)
- 1 km DEM supplemented by
  30 m DEM in Northwest USA
- 6169 GPS heights on leveled benchmarks

**Theory**
- Faye anomalies $\cong$ Helmert anomalies
- Remove/Compute/Restore using EGM96 and 1-D FFT
- Collocation to model $h-H-N$ long wavelength systematic differences

**Output Grids**
- 1 arc-minute grids
- CONUS: up to 58 degrees North
- Alaska, Hawaii, Puerto Rico/Virgin Islands
30 meter DEM in Northwest USA

- USGS makes 30 meter DEMs available in 7.5 minute quadrangular areas on UTM grid

- NGS acquired, cleaned, and regridded the data onto 1 arcsecond grid in the region 39/49 North and 231/256 East (NGSDEM99)

- Decimated 3 arcsecond DEM used for terrain corrections

- Geoid impact of new DEM in Northwest USA:
  - ~14 cm (1 σ) locally (max +/- 40 cm)
  - ~7 ppm tilts (1 σ) (max +/- 200 ppm)
Differences between GEOID99 and GEOID96
### GEOID96 vs GEOID99

<table>
<thead>
<tr>
<th></th>
<th>GEOID96</th>
<th>GEOID99</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid</td>
<td>2'x2'</td>
<td>1'x1'</td>
</tr>
<tr>
<td>North edge</td>
<td>54</td>
<td>58</td>
</tr>
<tr>
<td>DEM</td>
<td>TOPO30 (30&quot;)</td>
<td>corrected TOPO30 and 1&quot; NGSDEM99</td>
</tr>
<tr>
<td>TCs</td>
<td>30&quot;</td>
<td>3&quot; and 30&quot;</td>
</tr>
<tr>
<td>GPS/BMs</td>
<td>2951</td>
<td>6169</td>
</tr>
<tr>
<td>NAVD 88 bias</td>
<td>-31 cm</td>
<td>-52 cm</td>
</tr>
<tr>
<td>RMS wrt GPS/BMs</td>
<td>5.5 cm</td>
<td>4.6 cm</td>
</tr>
</tbody>
</table>
Empirical Standard Deviation for ee_1km
Standard Deviation of differential (h-N)
# Differential (Single Tie) GPS-Derived Orthometric Height Accuracy

<table>
<thead>
<tr>
<th>Line</th>
<th>Description</th>
<th>5 km lines $\sigma$ (ppm)</th>
<th>10 km lines $\sigma$ (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>GEOID96</td>
<td>6.7 cm (13 ppm)</td>
<td>6.9 cm (6.9 ppm)</td>
</tr>
<tr>
<td>B</td>
<td>GEOID99</td>
<td>5.2 cm (10 ppm)</td>
<td>5.5 cm (5.5 ppm)</td>
</tr>
<tr>
<td>C</td>
<td>GEOID99* (WA, OR, WI)</td>
<td>4.7 cm (9.4 ppm)</td>
<td>4.1 cm (4.1 ppm)</td>
</tr>
<tr>
<td>D</td>
<td>GEOID Error only?</td>
<td>0.8 cm (1.6 ppm)</td>
<td>1.6 cm (1.6 ppm)</td>
</tr>
<tr>
<td>E</td>
<td>2nd order, class II</td>
<td>0.3 cm (0.6 ppm)</td>
<td>0.4 cm (0.4 ppm)</td>
</tr>
</tbody>
</table>

* = Experimental solution tailored to the 1 cm (1 \( \sigma \)) GPS in these states
DIFFERENTIAL GPS-DERIVED ORTHOMETRIC HEIGHT ACCURACY

σ can be reduced through:

- Multiple ties (4 ties = half the σ of a single tie)

- Better knowledge of the geoid (i.e. Baltimore county)

Local (<5 km) σ is hard to know due to lack of special studies
Standard Deviation of differential (h-N)
CONCLUSIONS

- GEOID99 has 4.6 cm RMS absolute agreement with GPS/BM (GEOID96 was 5.5 cm)

- Short lines (< 5 km) are hard to evaluate due to lack of data

- Medium lines (5-40 km) are 4-10 ppm with single-ties

- Longer lines (40+ km) may be influenced by leveling error

- Establishing NAVD 88 heights from GEOID99 and GPS can be improved if multiple ties are used and the geoid is better known
GEOID99 Availability

WWW (Sept. 30):
http://www.ngs.noaa.gov/GEOID/geoid99.html

CD-ROM (Mid-October):
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NOAA/National Geodetic Survey, N/NGS12
1315 East-West Highway, Station 9202
Silver Spring, MD 20910-3282
voice: 301-713-3242
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