Guidelines for Establishing GPS-Derived Ellipsoid and Orthometric Heights

Static GPS/RTN Best Practices Seminar
Lindy C. Boggs International Conference Center
New Orleans, Louisiana
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Acknowledgements

Borrowed slides from several presentations by the following NGS employees:

Edward Carlson
Dan Roman
Joe Evjen

Curtis Smith
Dru Smith
Kevin Choi

And

Myself (when I was employed by NGS)
Topics To Be Discussed

• Review of types of heights and their accuracies

• How NGS guidelines can help to reduce, detect, and/or eliminate error sources

• Summary of NGS 58-Guidelines for Establishing GPS-Derived Ellipsoid Heights

• A step-by-step description of NGS 59-Guidelines for Establishing GPS-Derived Orthometric Heights

• Brief discussion of Why the New National Vertical Datum is Necessary
To understand how to achieve GPS-derived orthometric heights at centimeter-level accuracy, three questions must be answered.

1) **What types of heights are involved?**

2) **How are these heights defined and related?**

3) **How accurately can these heights be determined?**
Types of Heights Involved

- Ellipsoidal (GPS)
- Geoid (Gravity & Modeling)
- Orthometric (Leveling)
Ellipsoid, Geoid, and Orthometric Heights

“\( h = H + N \)”

- \( h \) (Ellipsoid Height) = Distance along ellipsoid normal (Q to P)
- \( N \) (Geoid Height) = Distance along ellipsoid normal (Q to \( P_0 \))
- \( H \) (Orthometric Height) = Distance along plumb line (\( P_0 \) to P)
Expected Accuracies

- **GPS-Derived Ellipsoid Heights**
  - Better than 2 centimeters

- **Geoid Heights (GEOID09)**
  - Relative differences should typically be less a few mm in 10 km
  - Total misfit is 1.4 cm squared

- **Leveling-Derived Heights**
  - Less than 1 cm in 10 km for third-order leveling
Topics To Be Discussed

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• A step-by-step description of NGS 59-Guidelines for Establishing GPS-Derived Orthometric Heights

• Brief discussion of Why the New National Vertical Datum is Necessary
Execution of Surveys;
Sources of Error

- Errors may be characterized as random, systematic, or blunders

  - Random error represents the effect of unpredictable variations in the instruments, the environment, and the observing procedures employed

  - Systematic error represents the effect of consistent inaccuracies in the instruments or in the observing procedures

  - Blunders or mistakes are typically caused by carelessness and are detected by systematic checking of all work through observational procedures and methodology designed to allow their detection and elimination
GUIDELINES

• Guidelines Help to Detect, Reduce, and/or Eliminate Error Sources

• Special Projects Are Performed to Develop Guidelines

• Guidelines Are Modified as Procedures, Equipment, and Models Improve
LAKE HOUSTON to NORTHEAST - (23 km)
Days 300 - 304; 6 Hour Solutions - With Tropo Modeling

Mean = -7.5
\( \Delta = 0.3 \)

Mean = -3.1
\( \Delta = 0.5 \)

Mean = -5.5
\( \Delta = 4.4 \)

Time (0 = 0 to 6 hr, 1 = 1 to 7 hr, ..., 18 = 18 to 24 hr)

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
National Ocean Service
National Geodetic Survey
ADDICKS to PAM 3 (4.2 km)
Days 130 and 131 (3 hour solutions - w/o Sat 15)

<table>
<thead>
<tr>
<th>Time (3 = 3 to 6 hr, 4 = 4 to 7 hr, ...., 21 = 21 to 24 hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up Component (cm)</td>
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</table>

Day 130
Mean (1.33 cm) / Std. Dev. (0.83 cm)

Day 131
Mean (1.01 cm) / Std. Dev. (0.47 cm)

Mean = 1.0
\( \Delta = 1.3 \)

0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

0.6
1.3
ADDICKS to PAM 3 (4.2 km)
Days 130 and 131 (2 hour solutions - w/o Sat 15)

Mean = 1.3
$\Delta = 2.1$

Day 130
Mean (1.33 cm) / Std. Dev. (1.15 cm)

Day 131
Mean (1.03 cm) / Std. Dev. (0.58 cm)

Time (3 = 3 to 5 hr, 4 = 4 to 6 hr, ..., 22 = 22 to 24 hr)

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
National Ocean Service
National Geodetic Survey
ADDICKS to PAM 3 (4.2 km)
Days 130 and 131 (1 hour solutions - w/o Sat 15)

Mean = 1.0
Δ = 2.4
Comparison of 30 Minute Solutions - Precise Orbit; Hopfield (0); IONOFREE
(30 Minute solutions computed on the hour and the half hour)

MOLA to YACH 12.9 Km

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<th>Day 264</th>
<th>dh (m)</th>
<th>Hours Diff.</th>
<th>Day 265</th>
<th>dh (m)</th>
<th>Day 264 minus Day 265 (cm)</th>
<th>* diff &gt;2 cm</th>
<th>Mean dh minus &quot;Truth&quot; (cm)</th>
<th>* diff &gt;2 cm</th>
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<td>14:30-15:00</td>
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<td></td>
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<td>-0.6</td>
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<td>20hrs</td>
<td>15:00-15:30</td>
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<td>-2.6</td>
<td></td>
<td>-9.206</td>
<td>1.2</td>
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<td>20hrs</td>
<td>15:30-16:00</td>
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<td></td>
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<tr>
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<td>20hrs</td>
<td>16:00-16:30</td>
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<td>-9.210</td>
<td>20hrs</td>
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<td>-9.218</td>
<td></td>
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</table>

Two Days/Different Times

-9.184 > -9.185

Difference = 0.1 cm

“Truth” = -9.218

Difference = 3.3 cm

Need a Network!

Line is greater than 10 km
Recommendations to Guidelines Based on Special Studies

• Must repeat base lines on different days and at different times of the day
• Must reobserve repeat base lines that disagree by more than 2 cm
• Must FIX integers
• Stations Must Be Connected to at Least its Two Nearest Neighbors
Topics To Be Discussed

- Review of types of heights and their accuracies
- How NGS guidelines can help to reduce, detect, and/or eliminate error sources
- **Summary of NGS 58-Guidelines for Establishing GPS-Derived Ellipsoid Heights**
- Brief discussion of Why the New National Vertical Datum is Necessary
NOAA Technical Memorandum NOS NGS-58

GUIDELINES FOR ESTABLISHING GPS-DERIVED ELLIPSOID HEIGHTS
(STANDARDS: 2 CM AND 5 CM)
VERSION 4.3

David B. Zilkoski
Joseph D. D'Onofrio
Stephen J. Frakes

Silver Spring, MD
November 1997

Guidelines for Establishing GPS-Derived Ellipsoid Heights
(Standards: 2 cm and 5 cm)
Available “On-Line” at the NGS Web Site:
www.ngs.noaa.gov
GPS Ellipsoid Height Hierarchy

CORS/FBN/Control Stations
(75 km or greater)

Primary Base
(40 km)

Secondary Base
(15 km)

Local Network Stations
(7 to 10 km)
Primary Base Stations

• Basic Requirements:

  – 5 Hour Sessions / 3 Days

  – Spacing between PBS cannot exceed 40 km

  – Each PBS must be connected to at least its nearest PBS neighbor and nearest control station
Secondary Base Stations

• Basic Requirements:
  – 30 Minute Sessions / 2 Days / Different times of day
  – **Used to Bridge Gap Between Primary and Local Control Stations**
  – Spacing between SBS cannot exceed 15 km (may need to be reobserved more often due to length)
  – All base stations (primary and secondary) must be connected to at least its 2 nearest primary or secondary base station neighbors
Local Network Stations

• Basic Requirements:
  – 30 Minute Sessions / 2 Days / Different times of the day
  – Spacing between LNS (or between base stations and local network stations) cannot exceed 10 km
  – All LNS must be connected to at least its two nearest neighbors
Local Network Stations

• Basic Requirement 30 Minute Sessions / 2 Days / Different times of the day

– NOTE: In order to obtain 30 minutes of good, valid data, the user should occupy the station for at least 45 minutes
Table 1. -- Summary of Guidelines

<table>
<thead>
<tr>
<th></th>
<th>Control 2 and 5 cm</th>
<th>Primary Base 2 cm</th>
<th>Primary Base 5 cm</th>
<th>Secondary Base 2 cm</th>
<th>Secondary Base 5 cm</th>
<th>Local Network 2 cm</th>
<th>Local Network 5 cm</th>
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</thead>
<tbody>
<tr>
<td>Dual Frequency Required</td>
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<td>Yes, if base line is greater than 10 km</td>
<td>Yes, if base line is greater than 10 km</td>
<td>Yes, if base line is greater than 10 km</td>
<td>Yes, if base line is greater than 10 km</td>
<td>Yes, if base line is greater than 10 km</td>
<td>Yes, if base line is greater than 10 km</td>
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<tr>
<td>Geodetic Quality</td>
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<td></td>
<td></td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Antenna with Ground Plane</td>
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<td>Yes</td>
<td>No Minimum</td>
<td>No Minimum</td>
<td>No Minimum</td>
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<td>Min. Number of Stations</td>
<td>3</td>
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<td>3</td>
<td>No Minimum</td>
<td>No Minimum</td>
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<td>Occupation Time</td>
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<td>5 Hours</td>
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<td>30 Minutes¹</td>
<td>30 Minutes¹</td>
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<td>Number of Days Station Is Occupied</td>
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<td>2²</td>
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<td>Max. Distance Between Same or Higher-Order Stations</td>
<td>75 km</td>
<td>40 km</td>
<td>50 km</td>
<td>15 km</td>
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<td>10 km</td>
<td>20 km</td>
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<td>Average Distance Between Stations</td>
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<td>No Maximum</td>
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<td>Repeat &quot;Base Line&quot;</td>
<td>Yes³</td>
<td>Yes³</td>
<td>Yes³</td>
<td>Yes³</td>
<td>Yes³</td>
<td>Yes³</td>
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<td>Yes</td>
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<td>Rubbing of Mark</td>
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<td>Yes</td>
<td>Yes</td>
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<td>Yes⁵</td>
<td>Yes⁵</td>
<td>Yes</td>
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<td>Yes</td>
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</table>

Notes for Table of Summary of Guidelines:

1. Analyses have indicated that when following all guidelines in this document, 30 minutes of observations over base lines that are typically less than 10 kilometers will meet the standards. For base lines greater than 10 km, but less than 15 km, 1 hour sessions should meet the standards. For observing sessions greater than 30 minutes, collect data at 15-second epoch interval. For sessions less than 30 minutes, collect data at 5-second epoch interval. Track satellites down to at least 10-degree elevation cut-off.

2. Base lines must be reobserved on different days with significantly different satellite geometry.

3. The observing scheme requires that all adjacent stations have base lines observed at least twice on two different days with significantly different geometry.

4. If base line is greater than 40 kilometers, a partially fixed or float solution is permitted.

5. For all station pairs except those involved with control stations (see note 4.
Basic Concept of Guidelines

- Stations in one local 3-dimensional network connected to another local network to better than 5 cm uncertainty

- Stations within a local 3-dimensional network connected to each other to at least 2 cm uncertainty

- Stations established following guidelines are published to centimeters by NGS
Why Follow the Guidelines?

• Repeat baselines rule helps to detect, reduce, and/or eliminate error sources

• Network approach helps to detect and reduce errors that may be introduced due to using short observing sessions
Topics To Be Discussed

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• Brief discussion of Why the New National Vertical Datum is Necessary
NOAA Technical Memorandum NOS NGS-59

GUIDELINES FOR ESTABLISHING GPS-DERIVED ORTHOMETRIC HEIGHTS
VERSION 1.5

David B. Zilkoski
Edward E. Carlson
Curtis L. Smith

Silver Spring, MD
March 2008

H \approx h - N

H (Orthometric Height; B, to C) = Distance along plumb line from the geoid to the surface
h (Ellipsoid Height; A to C) = Distance along ellipsoidal normal from the reference ellipsoid to the surface
N (Geoid Undulation; A to B) = Distance along ellipsoidal normal from the reference ellipsoid to the geoid

Figure 1: Relationship between Orthometric, Ellipsoid and Geoid Heights

www.ngs.noaa.gov
Guidelines for Establishing GPS-Derived Orthometric Heights

The 3-4-5 System

Three Basic Rules
Four Control Requirements
Five Basic Adjustment Procedures
Three Basic Rules

• Rule 1:
  – Follow NGS’ guidelines for establishing GPS-derived ellipsoid heights (Standards: 2 cm and 5 cm)

• Rule 2:
  – Use latest National Geoid Model, i.e., GEOID09

• Rule 3:
  – Use latest National Vertical Datum, i.e., NAVD 88
From: Geodesy, Geoids, and Vertical Datums: A Perspective from the U.S. National Geodetic Survey

Daniel R. ROMAN, Yan Ming WANG, Jarir SALEH, and Xiaopeng LI
FIG Paper 3768
Definitions: GEOIDS versus GEOID HEIGHTS

- “The *equipotential surface* of the Earth’s gravity field which best fits, in the least squares sense, (global) mean sea level.”*
- Can’t see the surface or measure it directly.
- Can be modeled from gravity data as they are mathematically related.
- Note that the geoid is a vertical *datum* surface.
- A geoid *height* is the ellipsoidal height from an ellipsoidal datum to a geoid.
- Hence, geoid height models are directly tied to the geoid and ellipsoid that define them (i.e., geoid height models are *not* interchangeable).

*Definition from the Geodetic Glossary, September 1986*
USGG09 Geoid Model

N = 8574241
Mean = -30.35
SD = 10.23
Min = -52.53
Max = 3.47

National Ocean Service
National Geodetic Survey
Hybrid Geoids

- Gravimetric Geoid systematic misfit with benchmarks
- Hybrid Geoid biased to fit local benchmarks
- \( e = h - H - N \)
GPSBM2009 (GEOID09 Control Data)

20,446 total less 1003 rejected leaves 18,867 (CONUS) plus 576 (Canada)
Rejected GPS Bench Marks in GEOID09

[Map showing rejected GPS Bench Marks across the United States]
Conversion Surface from USGG09 to GEOID09

Note that the ITRF00-NAD83 transformation is not included here. This was neglected to highlight the significant systematic features.
GEOID09 Geoid Model

N = 8574241
Mean = -29.91
SD = 9.93
Min = -50.68
Max = 3.44
## Comparisons For CONUS Regions

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<th>ST ID</th>
<th>No. Pts.</th>
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<th>GEOID09</th>
<th>USGG2009</th>
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<td>SD (m)</td>
<td>Ave (m)</td>
<td>SD (m)</td>
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<th>USGG2009 SD (m)</th>
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<th>GEOID09 SD (m)</th>
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CONUS Fit = 1.4 cm
Geoid Differences: GEOID09 – GEOID03

N = 3016303
Mean = -0.01
SD = 0.05
Min = -0.76
Max = 1.73

National Ocean Service
National Geodetic Survey
Sample Datasheet: Montgomery County Airport (CXO)

National Geodetic Survey, Retrieval Date = JANUARY 29, 2010 BL2014

PACS - This is a Primary Airport Control Station.

BL2014 DESIGNATION - CONPORT
BL2014 PID - BL2014
BL2014 STATE/COUNTY- TX/MONTGOMERY
BL2014 USGS QUAD - CONROE (1976)

BL2014

BL2014 *CURRENT SURVEY CONTROL

BL2014

BL2014 NAD 83(2007)- 30 21 11.32003(N) 095 25 02.13449(W) ADJUSTED
BL2014 NAVD 88 - 71.493 (meters) 234.56 (feet) ADJUSTED

BL2014 EPOCH DATE - 2002.00
BL2014 X - -520,058.592 (meters) COMP
BL2014 Y - -5,484,012.399 (meters) COMP
BL2014 Z - 3,204,238.567 (meters) COMP
BL2014 LAPLACE CORR- 0.08 (seconds) USDV2009

BL2014 ELLIP HEIGHT- 43.982 (meters) (02/10/07) ADJUSTED
BL2014 GEOID HEIGHT- -27.51 (meters) GEOID09
BL2014 DYNAMIC HT - 71.398 (meters) 234.24 (feet) COMP

NAV88 - Ellp Ht + Geoid Ht = ...
71.493 – 43.982 – 28.549 = -1.038 USGG2009
71.493 – 43.982 – 27.514 = -0.003 GEOID09
71.493 – 43.982 – 27.538 = -0.027 GEOID03
Summary

USGG2009 significantly differs from USGG2003

Future changes will likely not be as great

Similar to changes seen in ITRF series

Changes from GEOID03 to GEOID09 are significant

Largely driven by GPSBM changes

GEOID09 best matches heights in database now
Four Basic Control Requirements

- **BCR-1: Occupy stations with known NAVD 88 orthometric heights**
  - Stations should be evenly distributed throughout project

- **BCR-2: Project areas less than 20 km on a side, surround project with NAVD 88 bench marks**
  - i.e., minimum number of stations is four; one in each corner of project

- **BCR-3: Project areas greater than 20 km on a side, keep distances between GPS-occupied NAVD 88 bench marks to less than 20 km**

- **BCR-4: Projects located in mountainous regions, occupy bench marks at base and summit of mountains, even if distance is less than 20 km**
BCR1: Sketch indicates that the 20 km rule was met.

BCR2: This requirement is not applicable because the project is greater than 20 km on a side.

BCR3: Circled bench marks are mandatory. Analysis must indicate bench marks have valid NAVD 88 heights. Other BMs can be substituted but user must adhere to 20 km requirement.

BCR4: This requirement is not applicable because project is not in a mountainous region.
Five Basic Adjustment Procedures

• **BAP-1:** Perform 3-D minimum-constraint least squares adjustment of GPS survey project
  – Constrain 1 latitude, 1 longitude, 1 orthometric height

• **BAP-2:** Analyze adjustment results from BP-1
  – Detect and remove all data outliers
After performing minimum constraint adjustment, plot ellipsoid height residuals (or dU residuals) and investigate all residuals greater than 2 cm.
Station pairs with large residuals, i.e., greater than 2.5 cm, also have large repeat base line differences. NGS guidelines for estimating GPS-derived ellipsoid heights require user to re-observe these base lines. Following NGS guidelines provides enough redundancy for adjustment process to detect outliers and apply residual on appropriate observation, i.e., the bad vector.
Five Basic Procedures (continued)

- **BAP-3**: Compute differences between GPS-derived orthometric heights from minimum-constraint adjustment in BP-2 and published NAVD88 BMs
All height differences are under 5 cm and most are less than 2 cm. Almost all relative height differences between adjacent station pairs are less than 2 cm. However, most of the height differences appear to be positive relative to the southwest corner of the project.
Five Basic Procedures
(continued)

• **BAP-4: Determine which BMs have valid NAVD88 height values from results from BP-3**
  – Differences need to agree 2 cm for 2 cm survey
  – Differences need to agree 5 cm for 5 cm survey
  – May detect systematic tilt over large areas
    • Solve for geoidal slope and scale

• **BAP-5: Perform constrained adjustment with results from BP-4**
  – Constrain 1 latitude, 1 longitude, all valid orthometric height values
  – Ensure final heights not distorted in adjustment
To detect and remove any systematic trend, a tilted plane is best fit to the height differences (Vincenty 1987, Zilkoski and Hothem 1989). After a trend has been removed, all the differences are less than +/- 2 cm except for one and almost all relative differences between adjacent stations are less than 2 cm.
After rejecting the largest height difference (-2.4 cm), of all the closely spaced station pairs only 3 are greater than 2 cm, 1 is greater than 2.5 cm and none are greater than 3 cm.
The NGS Data Sheet file dsdata.txt for more information about the datasheet. DATABASE = , PROGRAM = datasheet, VERSION = 7.85

1 National Geodetic Survey, Retrieval Date = MAY 5, 2010

DF8611 HT_MOD - This is a Height Modernization Survey Station.

DF8611 DESIGNATION - KEYS

DF8611 PID - DF8611

DF8611 STATE/COUNTY - CA/TUOLUMNE

DF8611 USGS QUAD - KEYSTONE (1987)

DF8611

DF8611 * CURRENT SURVEY CONTROL

DF8611

DF8611* NAVD 88 - 336.56 (meters) 1104.2 (feet) GPS OBS

DF8611 EPOCH DATE - 2007.00

DF8611 X - -2,560,153.331 (meters) COMP

DF8611 Y - -4,345,114.316 (meters) COMP

DF8611 Z - 3,892,050.601 (meters) COMP

DF8611 LAPLACE CORR- 8.69 (seconds) DEFLEC09

DF8611 ELLIP HEIGHT- 306.911 (meters) (02/10/07) ADJUSTED

DF8611 GEOID HEIGHT- -29.65 (meters) GEOID09

DF8611

DF8611 Type PID Designation North East Ellip

DF8611 -----------------------------------------------

DF8611 NETWORK DF8611 KEYS 0.35 0.41 1.25

DF8611 -----------------------------------------------

DF8611 The horizontal coordinates were established by GPS observations

DF8611 and adjusted by the National Geodetic Survey in February 2007.

DF8611

DF8611 The datum tag of NAD 83(2007) is equivalent to NAD 83(NSRS2007).

DF8611 See National Readjustment for more information.

DF8611 The horizontal coordinates are valid at the epoch date displayed above.

DF8611 The epoch date for horizontal control is a decimal equivalence

DF8611 of Year/Month/Day.

DF8611 The orthometric height was determined by GPS observations and a

DF8611 high-resolution geoid model using precise GPS observation and

DF8611 processing techniques.

DF8611

DF8611 The X, Y, and Z were computed from the position and the ellipsoidal ht.

DF8611

DF8611 The Laplace correction was computed from DEFLEC09 derived deflections.

DF8611

DF8611 The ellipsoidal height was determined by GPS observations

DF8611 and is referenced to NAD 83.

DF8611

DF8611 The geoid height was determined by GEOID09

--- Accuracy Estimates (at 95% Confidence Level in cm) -------

Orthometric height determined by GPS

Elevation published to centimeters

H (published) – (h - N)

GEOID09 = 0.00 m
### The NGS Data Sheet

See file
_\texttt{dsdata.txt}_

for more information about the dataset.

```plaintext
DATABASE = Sybase, PROGRAM = datasheet, VERSION = 7.07
1. National Geodetic Survey, Retrieval Date = OCTOBER 14, 2004

| DF8611 | **designation** - KEYS
| DF8611 | **PID** - DF8611
| DF8611 | **STATE/COUNTY-** CA/TUOLUMNE
| DF8611 | **USGS QUAD** - KEYSTONE (1987)
| DF8611 | **CURRENT SURVEY CONTROL**
| DF8611 | **NAD 83(1998)** - 37 50 41.57829(N) 120 30 11.02522(4)
| DF8611 | **NAVD 88** - 336.56 (meters) 110 30 11.02522(4)

DF8611 | **EPOCH DATE** - 2002.82
| DF8611 | **X** - \(-2,560,153.311\) (meters)
| DF8611 | **Y** - \(-4,345,114.352\) (meters)
| DF8611 | **Z** - \(3,892,050.572\) (meters)
| DF8611 | **LAPLACE CORR** - 8.81 (seconds)
| DF8611 | **ELLIP HEIGHT** - 306.91 (meters) (10/24/03) GPS OBS
| DF8611 | **GEOID HEIGHT** - \(-29.63\) (meters) GEOID03
| DF8611 | **HORIZ ORDER** - B
| DF8611 | **ELLP ORDER** - FOURTH CLASS I

The horizontal coordinates were established by GPS observations and adjusted by the National Geodetic Survey in October 2003.

This is a SPECIAL STATUS position. See SPECIAL STATUS under the DATUM ITEM on the data sheet items page.

The horizontal coordinates are valid at the epoch date displayed above.

The epoch date for horizontal control is a decimal equivalence of Year/Month/Day.

The orthometric height was determined by GPS observations and a high-resolution geoid model using precise GPS observation and processing techniques.

The X, Y, and Z were computed from the position and the ellipsoidal ht.

The Laplace correction was computed from DEFLEC99 derived deflections.

The ellipsoidal height was determined by GPS observations and is referenced to NAD 83.

The geoid height was determined by GEOID03.
```

**Elevation published to centimeters.**

**Orthometric height determined by GPS.**

<table>
<thead>
<tr>
<th>GEOID03 = 0.02 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEOID09 = 0.00 m</td>
</tr>
</tbody>
</table>

H (published) – (h - N)
GPS-Derived Heights from GEOID09 Separation

- Purple square = Published NAVD88 Orthometric Height
- Green circle = New Control

Topography

Ellipsoid

GEOID09

A

B

C

D

E

F

H_{h-N} h h h h h

N N N N N N
Constrained Vertical Adjustment

Ellipsoid Height Adjusted to Fit Constrained Orthometric Heights

GPS-Derived Orthometric Heights

- \( h_{adj} \) = Published NAVD88 Orthometric Height
- = New Control

Geoid based on Ortho Heights

Ellipsoid Surface

Adjusted Ellipsoid Surface

GEOID09

GEOID09

\( H_{GPS} \)
NGS Data Sheet – GEOID96 through GEOID09
Published NAVD88 to GPS Derived

| HT2268 | NAD 83(1992) | 37 45 25.30727(N) | 122 28 36.34687(W) | ADJUSTED |
| HT2268 | NAVD 88      | 102.431 (meters)  | 336.06 (feet)      | ADJUSTED  |
| HT2268 | EPOCH DATE   | 1997.30           |                   |           |
| HT2268 | X            | -2,711,121.437     | (meters)           | COMP      |
| HT2268 | Y            | -4,259,419.310     | (meters)           | COMP      |
| HT2268 | Z            | 3,884,200.262      | (meters)           | COMP      |
| HT2268 | LAPLACE CORR-| 5.53 (seconds)     |                   | DEFLEC03  |
| HT2268 | ELLIP HEIGHT-| 69.78 (meters)     |                   | GPS OBS   |
| HT2268 | GEOID HEIGHT-| -32.60 (meters)    |                   | GEOID03   |
| HT2268 | DYNAMIC HT   | 102.363 (meters)   | 335.84 (feet)     | COMP      |
| HT2268 | MODELED GRAV-| 979,964.0 (mgal)   |                   | NAVD 88   |
| HT2268 | HORZ ORDER   | FIRST             |                   |           |
| HT2268 | VERT ORDER   | FIRST             | CLASS I           |
| HT2268 | ELLP ORDER   | FOURTH             | CLASS I           |

\[ H = h - N \]

\[
102.431 = 69.78 - (-32.60)
\]

\[
102.431 \neq 102.38
\]

\[
102.431 = 69.78 - (-32.60)
\]

\[
102.431 \neq 102.38
\]

\[
H = h - N
\]

\[
102.431 = 69.78 - (-32.60)
\]

\[
102.431 \neq 102.38
\]
Topics To Be Discussed

• Review of types of heights and their accuracies

• How NGS guidelines can help to reduce, detect, and/or eliminate error sources

• Summary of NGS 58-Guidelines for Establishing GPS-Derived Ellipsoid Heights

• A step-by-step description of NGS 59-Guidelines for Establishing GPS-Derived Orthometric Heights

• Brief discussion of Why the New National Vertical Datum is Necessary
Ten-Year Milestones (2022)

1) NGS will compute a pole-to-equator, Alaska-to-Newfoundland geoid model, preferably in conjunction with Mexico and Canada as well as other interested governments, with an accuracy of 1 cm in as many locations as possible

2) **NGS redefines the vertical datum based on GNSS and a gravimetric geoid**

3) **NGS redefines the national horizontal datum to remove disagreements with the ITRF**
What is GRAV-D?

- **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 2022**
- **Part of the NGS 10 year plan (2008-2018)**
- **Target: 2 cm accuracy orthometric heights from GNSS and a geoid model**
Why is the new datum important?
FLAVORS OF OPUS

- **OPUS-S**
  - $$ Receivers
  - 2 Hours of data
  - Results not shared

- **OPUS-RS**
  - $$ Receivers
  - 15 Minutes of data
  - Results not shared

- **OPUS-DB**
  - $$ Receivers
  - 4 Hours of data
  - Results shared

- **OPUS-Projects**
  - $$ Receivers
  - 2-4 Hours of data
  - Multiple Receivers
  - Network Solution
  - Results shared or not

- **LOCUS**
  - Digital Bar-Code Leveling
  - Integration with GPS?
  - Results shared or not
Using Height Modernization Project Control to Evaluate an RTK Survey
Mohave County GIS Accurizing Project
Mohave Valley Project Area

Cadastral monument inventory
Total number of cadastral points = 154

- Cadastral monument
- Project Control Station
- 2008 Height Mod Control
- Mohave Valley Project Area

Map showing the Mohave County GIS Accurizing Project area with various points and locations marked on a geographic grid.
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<th>F</th>
<th>G</th>
<th>K</th>
<th>L</th>
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<td>Duration of rover occupation</td>
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## Integrated and Collaborative Organizations Create Geospatial Solutions

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Geospatial Solutions by DBZ
• Are Your Results Precise or Accurate?
  • Always Repeat Baselines at Least Twice

• How Long is Long Enough?
  • Always Repeat Observations on a Different Day at a Different Time of Day

• Did You Detect, Reduce, and/or Eliminate Error Sources?
  • Always Follow Prescribed Guidelines
Questions?