Geodesy, Geoids, and Vertical Datums: A Perspective from the U.S. National Geodetic Survey

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Paper 3768

National Geodetic Survey

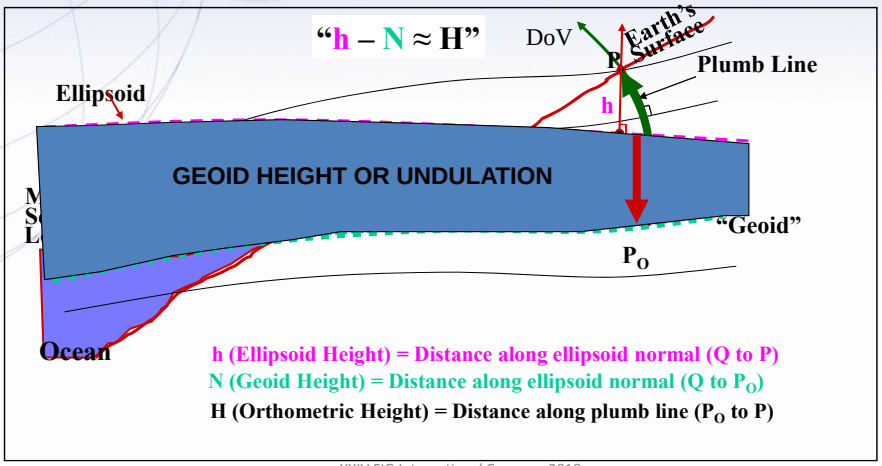
- An Office with the National Ocean Service in the National Oceanic and Atmospheric Administration
- Responsible for maintaining elements of and access to the National Spatial Reference System including:
  - North American Datum of 1983 (NAD 83)
  - North American Vertical Datum of 1988 (NAVD 88)
- NGS developed geoid height models for easier access
  - GEOID90 - the earliest regional gravimetric geoid heights
  - USGG2009 – most recent gravimetric heights (ITRF00)
  - GEOID09 – "hybrid" geoid heights (NAD 83 to NAVD 88)
  - Model development paralleled evolution of GNSS

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

Relationship between ellipsoid, geoid and orthometric heights.

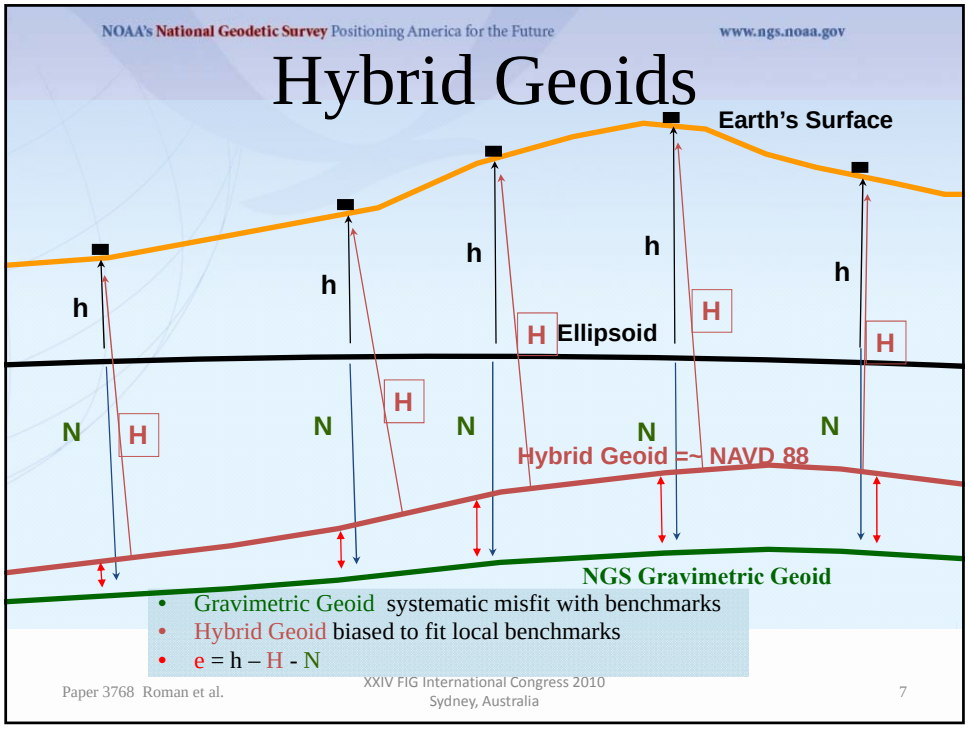


Model Development

	USGG2009	USGG2003
•	Ellipsoid: ITRF00/GRS-80	ITRF00/GRS-80
•	Base Model: EGM2008	EGM96
•	Gravity Data: 2.1 million	2.6 million
•	Kernel: mod. (120/6 ex. AK)	unmodified
•	DEM: SRTM 3”(except AK)	mixed 30”/3”(PNW)
•	Terrain: EGM08 implicit 5’	TC’s
•	Altimetry: DNSC08	GSFC00.1
•	Method: R-C-R	R-C-R
•	Format: 1’ grid/1-line header	1’ grid/1-line header

GEOID09 Development

- Starts from USGG2009 model
- Convert to NAD 83 (NSRS2007, PAC00, MAR00)
  USGG2009 – TOITRF00 => USGG2009*
- Interpolate at GPSBM locations
- Residual = h(NAD83)–H(NAVD88)–N(USGG2009*)
- Use MMLSC to generate math model to fit residuals
- Use same math model to predict on even grid (15’)
- Interpolate grid to 1’
- Conv. Surf. = 1’ grid + bias + trend + TOITRF00
- GEOID09 = USGG2009 – Conversion Surface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Hybrid Geoids
Earth's Surface
h
H
Ellipsoid
N
Hybrid Geoid =~ NAVD 88
NGS Gravimetric Geoid
• Gravimetric Geoid systematic misfit with benchmarks
• Hybrid Geoid biased to fit local benchmarks
• e = h – H - N
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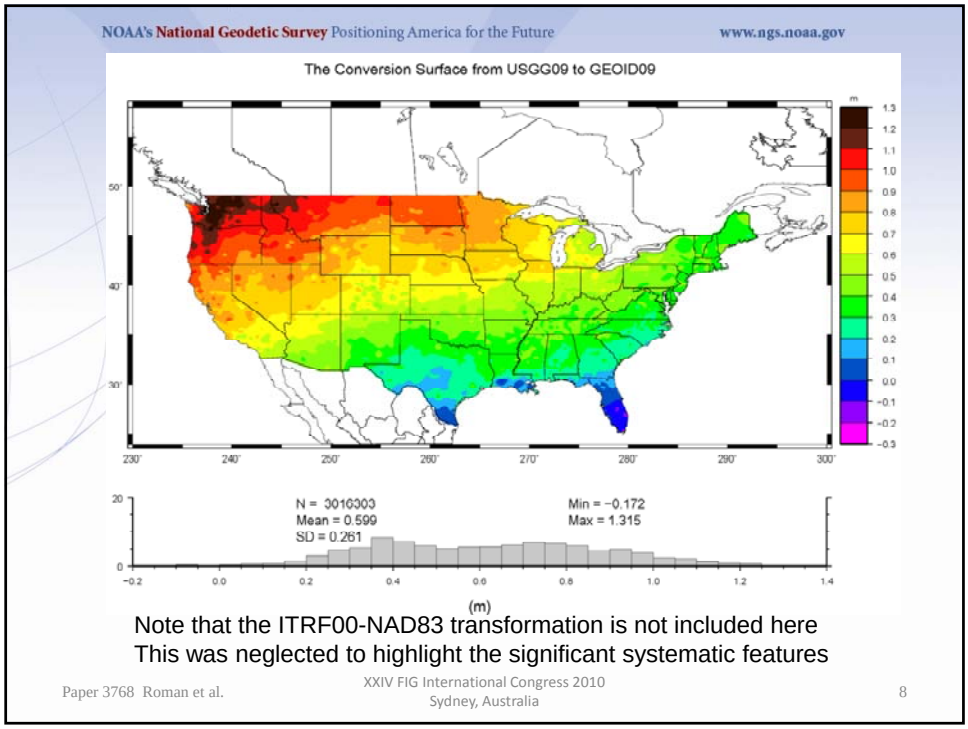
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The Conversion Surface from USGG09 to GEOID09
N = 3016303
Mean = 0.599
SD = 0.261
Min = −0.172
Max = 1.315
(m)
Note that the ITRF00-NAD83 transformation is not included here
This was neglected to highlight the significant systematic features
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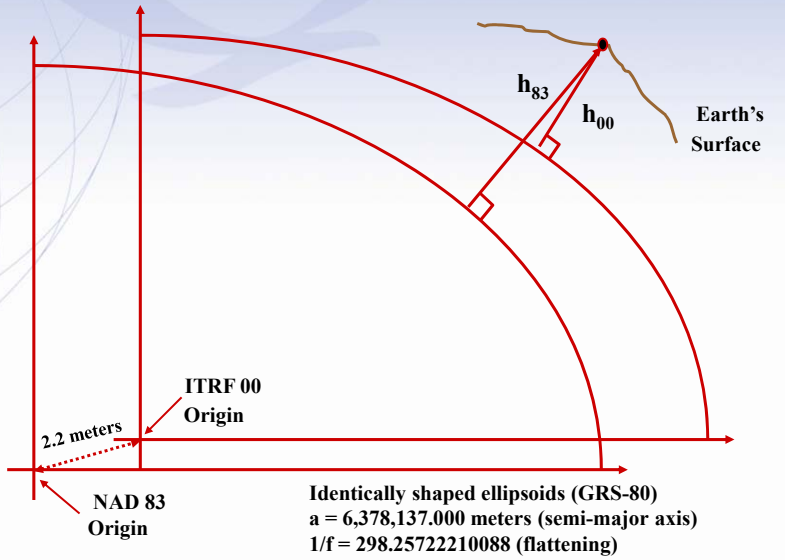
The NGS Ten Year Plan

- Calls for replacing both NAD 83 and NAVD 88
- Both have significant (meter level) systematic errors
- NAD 83 replacement needs to be more geocentric
- NAVD 88 replacement needs to be a geoid surface
- Both new datums would work together
- CORS/OPUS tools to access GNSS coordinates
- Geoid height model determines orthometric heights
- Goal of cm-level accuracy in non-mountainous areas
- Targeted timeline is for end of next decade (~2018)

- Why do all this? Is there really a need?

Simplified Concept of ITRF 00 vs. NAD 83



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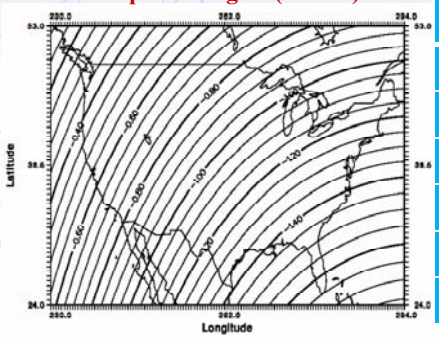
Positional Shifts of Geocenter: NAD 83 to ITRS Realizations Relative to Epoch 1997.0

Shift from NAD83 to ITRF00 in Ellipsoid Heights (meters)



Reference Frame	X Shift (m)	Y Shift (m)	Z Shift (m)	Total Shift (m)
ITRF92	-0.983	1.909	0.505	2.206
ITRF93	-1.011	1.906	0.505	2.216
ITRF96	-0.991	1.907	0.513	2.210
ITRF97	-0.989	1.907	0.503	2.206
ITRF00	-0.996	1.901	0.521	2.208
ITRF05	-0.996	1.902	0.522	2.210

Notes: Used HTDP for transformations (http://www.ngs.noaa.gov/TOOLS/Htdp/Htdp.shtml)
Relative change in coordinates for last two models is at millimeter level (quasi-stable)
Determination of a gravimetric geoid is made using a geocentric ellipsoid (KISS)

Vertical Control Network NAVD 88

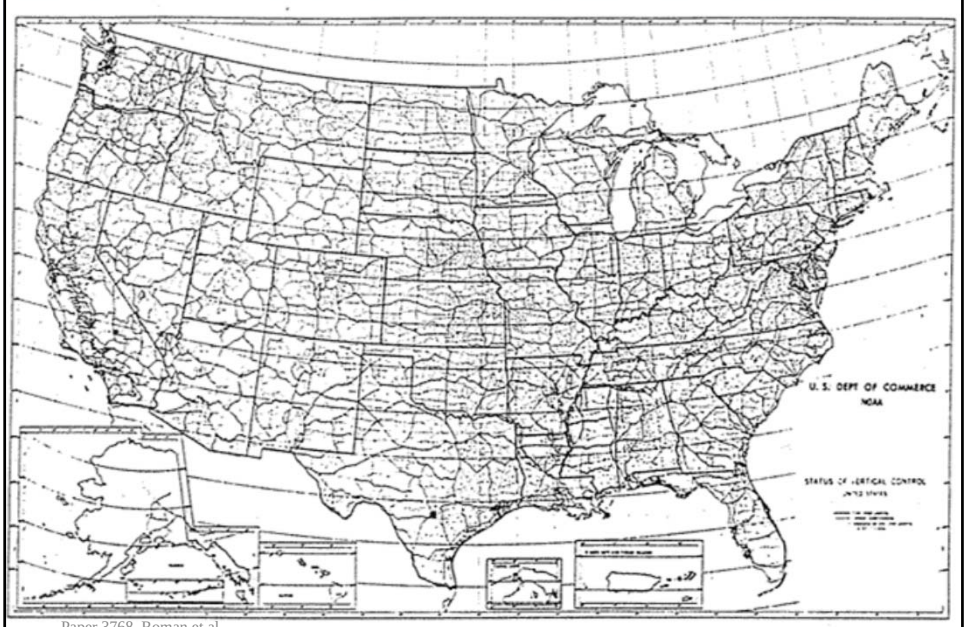
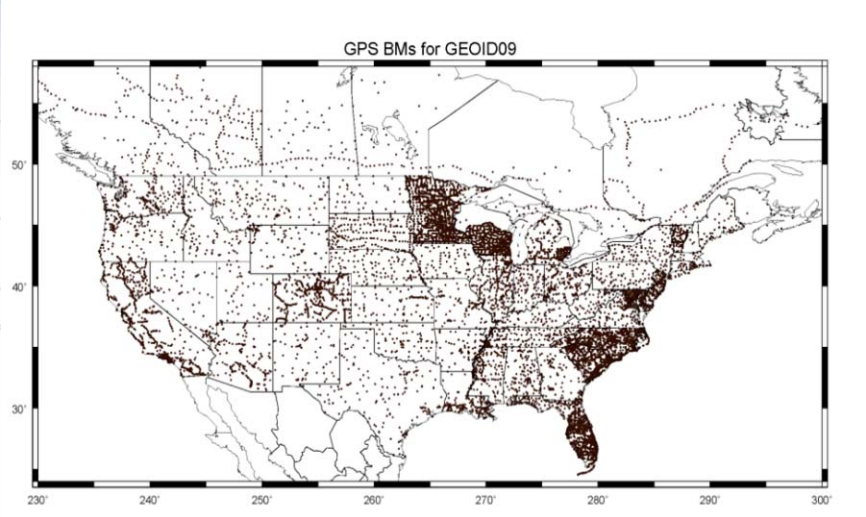


Figure 3. Vertical control used in 1988 adjustment.

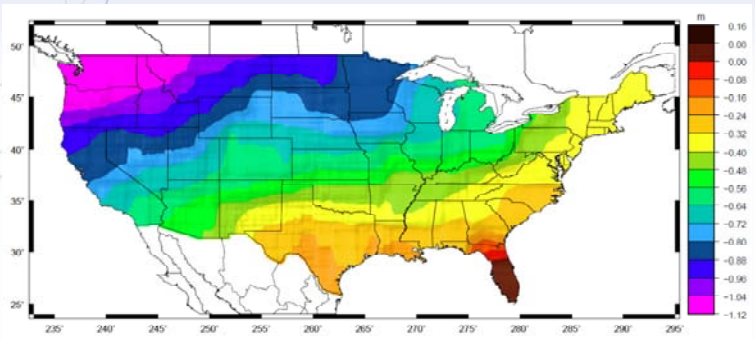
450,000 BM's over 1,001,500 km

GPSBM2009 (GEOID09 Control Data)



20446 total less 1003 rejected leaves 18,867 (CONUS) plus 576 (Canada)

Why isn't NAVD 88 good enough anymore?



Approximate level of error known to exist in the NAVD 88 zero elevation surface

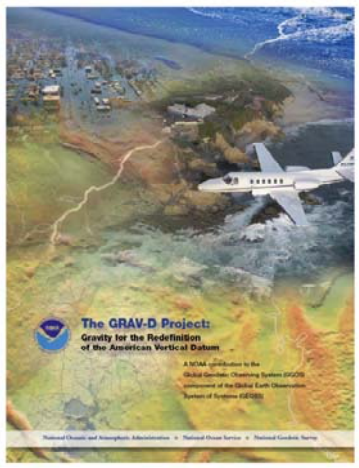
Possible ways to fix NAVD 88

- Long term fix: **Re-level some/all of NAVD 88**
  - 81,500 km of 1st order leveling at least
  - 625,000 km of mixed 1st and 2nd order leveling
  - About $3000 / km (average contract cost)
- Re-leveling NAVD 88 would cost between ***$200 Million*** and ***$2 Billion***
- This wouldn't fix all of the problems associated with the use of bench marks though

Possible ways to fix NAVD 88

- Long term fix: **Replace NAVD 88**
- Find a method of defining a vertical datum that seeks to fix all of the known issues with NAVD 88
- Best option: Define the datum as a given geoid height model and realize it through GNSS technology
  - **GRAV-D**

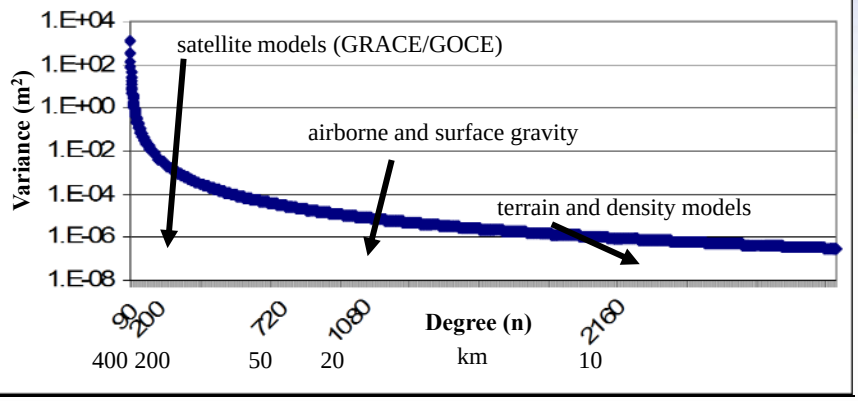
What is GRAV-D?



- *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 2018 (if fully funded beginning in 2009)*
- *Part of the NGS 10 year plan (2008-2018)*
- *Target: 2 cm accuracy orthometric heights from GNSS and a geoid model*

Geoid Power and Potential Sources

Work with many groups to obtain other data sets as well as what we observe



- Spectrally merge the data sources to obtain a seamless gravity field
- Work with neighbors to incorporate regional data (North American Geoid/IAG CP 2.2)
- Use rigorous geodetic theory and/or forward modeling to make a geoid height model

CONCLUSIONS

- Current models are precise but not accurate
  - NAD 83 & NAVD 88 have significant systematic errors
  - NGS Ten Year Plan aims to replace both by about 2018
- The geoid height model will be determined through GRAV-D
  - Aerogravity will be tied to satellite data (GRACE/GOCE)
  - Combined aerogravity/satellite model will fix surface data
  - Merged gravity data will provide seamless gravity field
  - Improved theory will rigorously transform to geoid heights
- Future vertical control accessed by GNSS and geoid heights
  - Tim varying aspects will be incorporated
  - Span of the model should cover all of North America

Questions?

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- Simon Holmes, Ph.D.

Aerogravity Collection/Processing
- Vicki A. Childers, Ph.D.
- Theresa Diehl, Ph.D.
- Sandra A. Preaux

Programming/IT Support
- William Waickman

Websites
- http://www.ngs.noaa.gov/GEOID/
- http://www.ngs.noaa.gov/GRAV-D/