National Geodetic Survey Positioning America for the Future geodesy.noaa.gov

GPS Vertical Accuracies, Theory, Practice, Myths

Connecticut Association of Land Surveyors
November 01, 2013

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www.aot.state.vt.us/geodetic/Advisor/advisorpresent.htm

Accuracy vs. Precision

Not Accurate, Not Precise

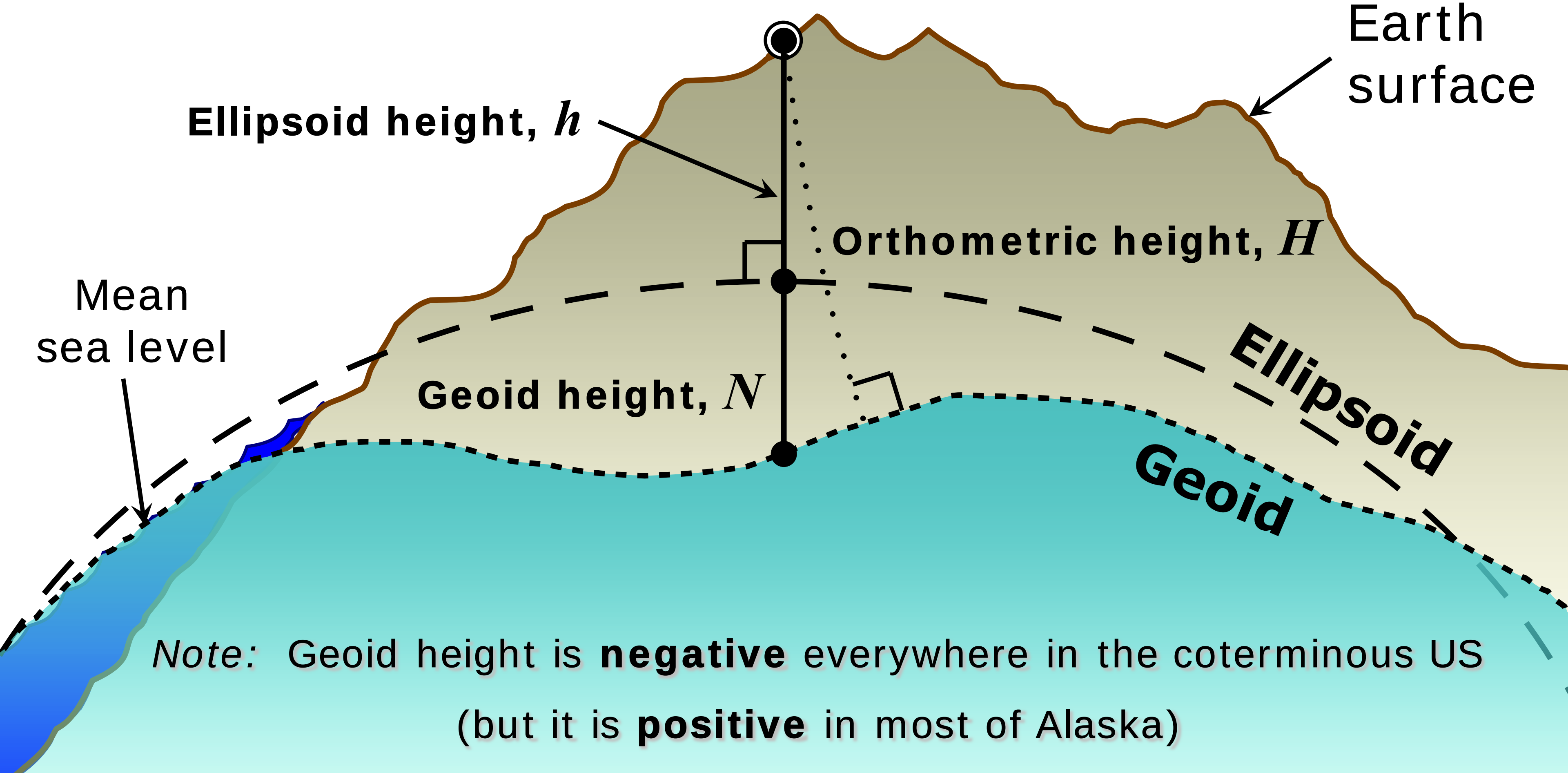
Accurate, Not Precise

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/atmosphereic 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?

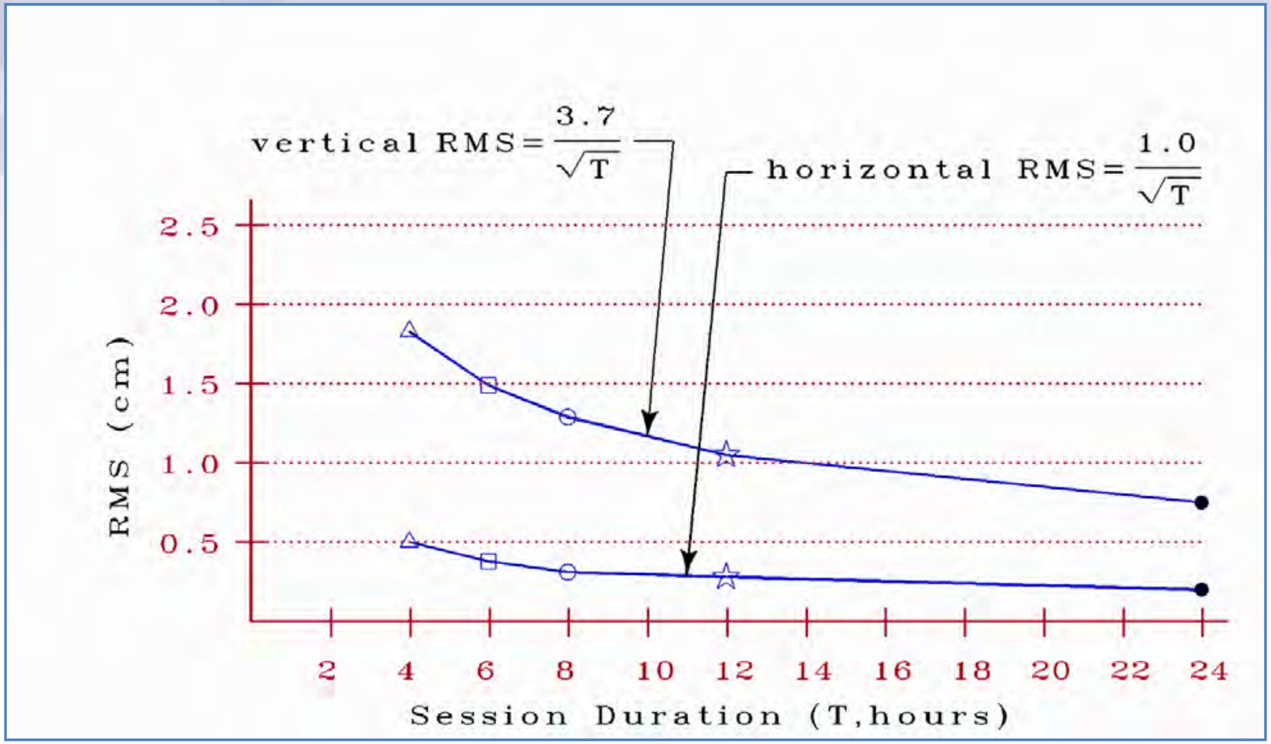
OPUS-S reliably addresses the more historically conventional requirements for GPS data processing. It typically yields accuracies of:

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.

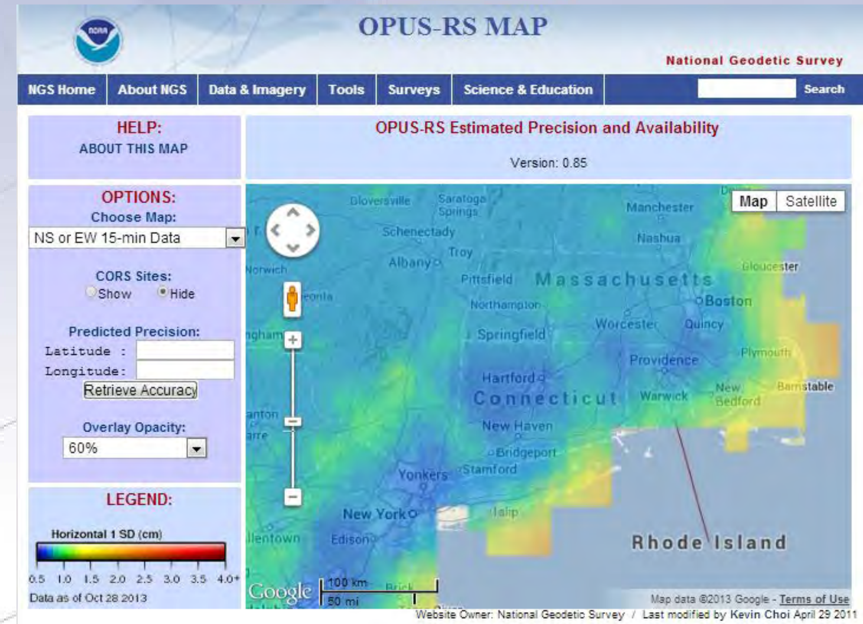
How Good Can I Do With OPUS-S?

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



Eckl et al., 2001, "Accuracy of GPS-derived relative positions as a function of interstation distance and observing-session duration", J. of Geod. 75, 633-640).

Their results provide a good "rule of thumb" for accuracy versus session duration when using OPUS-S and in many other applications.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HELP:
ABOUT THIS MAP
OPUS-RS Estimated Precision and Availability
Version: 0.85
OPTIONS:
Choose Map:
NS or EW 15-min Data
CORS Sites:
Show
Hide
Predicted Precision:
Latitude :
Longitude:
Retrieve Accuracy
Overlay Opacity:
60%
LEGEND:
Horizontal 1 SD (cm)
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0+
Data as of Oct 28 2013
Map
Satellite
Massachusetts
Connecticut
Rhode Island
Boston
Hartford
New York
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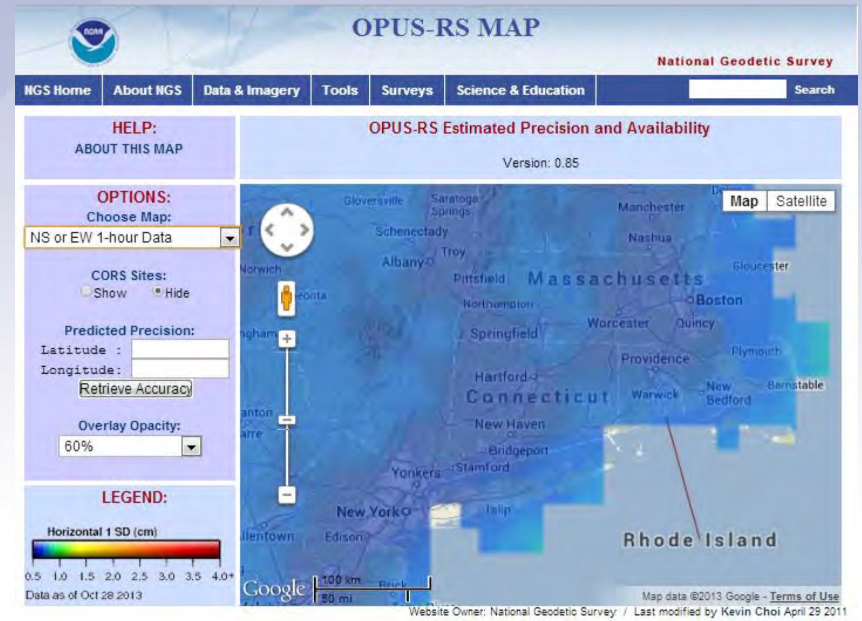
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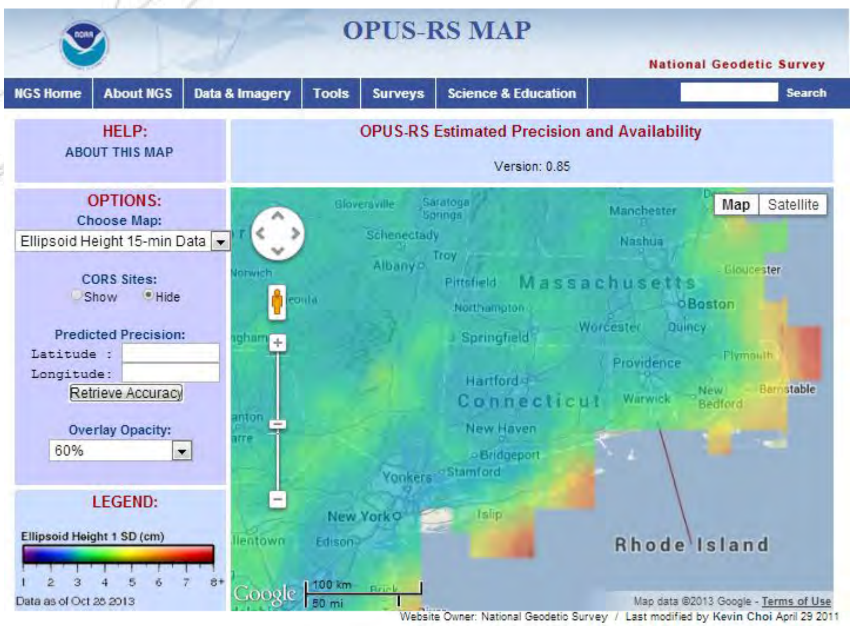
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Overlay Opacity:
60%
LEGEND:
Ellipsoid Height 1 SD (cm)
1 2 3 4 5 6 7 8+
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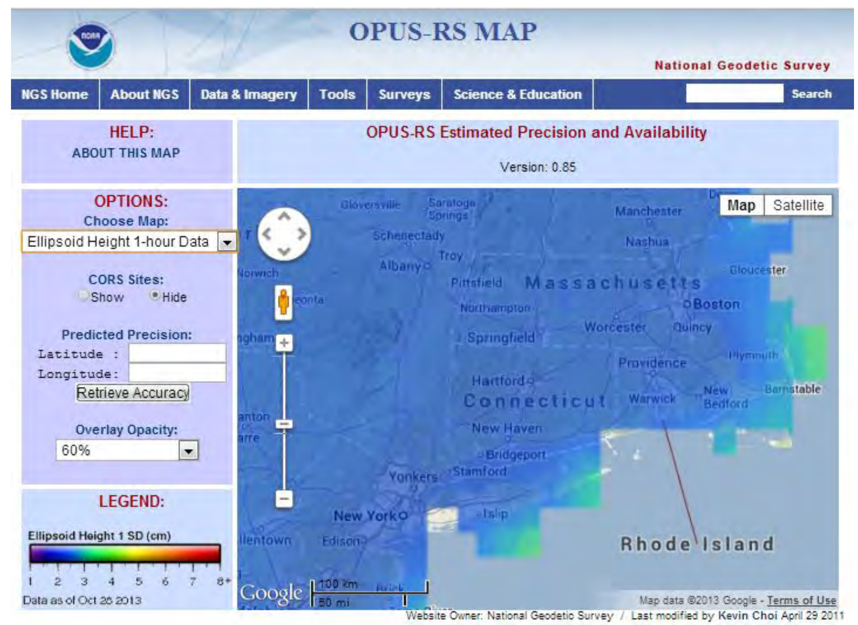
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Longitude:
Retrieve Accuracy
Overlay Opacity:
60%
LEGEND:
Ellipsoid Height 1 SD (cm)
1 2 3 4 5 6 7 8+
Data as of Oct 28 2013
Map
Satellite
Massachusetts
Connecticut
Rhode Island
Boston
Hartford
New York
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Differences from OPUS

PID: LX3418
Designation: 846 1490 K TIDAL
Stamping: 1490 K 1979
Stability: Most reliable; expected to hold position well
Setting: In rock outcrop or ledge
Mark Condition: G
Description: IN 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 WINTHROP STREET, 46.94 M (154.0 FT) NORTHWEST OF THE NORTHWEST BRIDGE ABUTMENT OF THE WESTERNMOST STEEL SPAN OVER RAILROAD TRACKS, 10.39 M (34.1 FT) NORTH-NORTHWEST OF THE CENTERLINE OF STATE PIER ROAD, 6.43 M (21.1 FT) SOUTH-SOUTHEAST OF THE SOUTH RAIL OF THE SOUTHERNMOST TRACKS AND 0.30 M (1.0 FT) ABOVE GROUND.
Observed: 2009-11-19T14:59:00Z See Also 2005-04-10 See Also Original
Source: OPUS - page5 1209.04


Close-up View

REF_FRAME: NAD_83(2011)	EPOCH: 2010.0000	SOURCE: NAVD88 (Computed using GEOID12A)	UNITS: m	SET PROFILE	DETAILS

LAT:	41° 21' 42.99721"	± 0.004	m
LON:	-72° 5' 41.02139"	± 0.005	m
ELL HT:	-21.745	± 0.031	m
X:	1473920.497	± 0.009	m
Y:	-4561910.515	± 0.025	m
Z:	4192662.037	± 0.018	m
ORTHO HT:	8.809	± 0.055	m

	UTM 18	SPC 600(CT)
NORTHING:	4583010.711m	211314.337m
EASTING:	743009.674m	359628.129m
CONVERGENCE:	1.92078063°	0.43448419°
POINT SCALE:	1.00032682	0.99998761
COMBINED FACTOR:	1.00033023	0.99999102

PID: LX3418
Designation: 846 1490 K TIDAL
Stamping: 1490 K 1979
Stability: Most reliable; expected to hold position well
Setting: In rock outcrop or ledge
Mark Condition: G
Description: IN 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 WINTHROP STREET, 46.94 M (154.0 FT) NORTHWEST OF THE NORTHWEST BRIDGE ABUTMENT OF THE WESTERNMOST STEEL SPAN OVER RAILROAD TRACKS, 10.39 M (34.1 FT) NORTH-NORTHWEST OF THE CENTERLINE OF STATE PIER ROAD, 6.43 M (21.1 FT) SOUTH-SOUTHEAST OF THE SOUTH RAIL OF THE SOUTHERNMOST TRACKS AND 0.30 M (1.0 FT) ABOVE GROUND.
Observed: 2009-11-19T14:59:00Z See Also 2005-04-10 See Also Latest
Source: OPUS - page5 0909.08


Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

LAT:	41° 21' 42.99772"	± 0.016	m
LON:	-72° 5' 41.02234"	± 0.023	m
ELL HT:	-21.726	± 0.028	m
X:	1473920.477	± 0.020	m
Y:	-4561910.525	± 0.017	m
Z:	4192662.061	± 0.025	m
ORTHO HT:	8.835	± 0.045	m

	UTM 18	SPC 600(CT)
NORTHING:	4583010.726m	211314.352m
EASTING:	743009.651m	359628.107m
CONVERGENCE:	1.92078046°	0.43448401°
POINT SCALE:	1.00032682	0.99998761
COMBINED FACTOR:	1.00033023	0.99999102

8.809
8.835
8.836

The NGS Data Sheet

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

```
PROGRAM = datasheet95, VERSION = 8.3
1        National Geodetic Survey,   Retrieval Date = OCTOBER 30, 2013
 LX3418 ***********************************************************************
 LX3418  TIDAL BM      -  This is a Tidal Bench Mark.
 LX3418  DESIGNATION -  846 1490 K TIDAL
 LX3418  PID         -  LX3418
 LX3418  STATE/COUNTY-  CT/NEW LONDON
 LX3418  COUNTRY     -  US
 LX3418  USGS QUAD   -  NEW LONDON (1984)
 LX3418
 LX3418                         *CURRENT SURVEY CONTROL
 LX3418  ______________________________________________________________________
 LX3418* NAD 83(2011) POSITION- 41 21 42.99760(N) 072 05 41.02161(W)   ADJUSTED
 LX3418* NAD 83(2011) ELLIP HT-   -21.712 (meters)          (06/27/12)   ADJUSTED
 LX3418* NAD 83(2011) EPOCH   -  2010.00
 LX3418* NAVD 88 ORTHO HEIGHT -     8.836  (meters)      28.99  (feet) ADJUSTED
 LX3418  ______________________________________________________________________
```

Draft NGS Accuracy Classes

	ACCURACY CLASS SUMMARY TABLE			
	CLASS RT1	CLASS RT2	CLASS RT3	CLASS RT4
ACCURACY (TO BASE)	0.015 HORIZONTAL., 0.025 VERTICAL	0.025 HORIZONTAL., 0.04 VERTICAL	0.05 HORIZONTAL., 0.06 VERTICAL	0.15 HORIZONTAL., 0.25 VERTICAL
REDUNDANCY	≥ 2 LOCATIONS, 4-HOUR DIFFERENTIAL	≥ 2 LOCATIONS, 4-HOUR DIFFERENTIAL	NONE	NONE
BASE STATIONS	≥ 2 , IN CALIBRATION PROJECT CONTROL	RECOMMEND 2 IN CALIBRATION	≥ 1 , IN CALIBRATION	≥ 1 , IN CALIBRATION RECOMMENDED
PDOP	≤ 2.0	≤ 3.0	≤ 4.0	≤ 6.0
RMS	≤ 0.01 M	≤ 0.015 M	≤ 0.03 M	≤ 0.05 M
COLLECTION INTERVAL	1 SECOND FOR 3-MINUTES	5 SECONDS FOR 1-MINUTE	1 SECOND FOR 15 SECONDS	1 SECOND FOR 10 SECONDS
SATELLITES	≥ 7	≥ 6	≥5	≥ 5
BASELINE DISTANCE	≤ 10 KM	≤ 15 KM	≤ 20 KM	ANY WITH FIXED SOLUTION
TYPICAL APPLICATIONS	PROJECT CONTROL CONSTRUCTION CONTROL POINTS CHECK ON TRAVERSE, LEVELS SCIENTIFIC STUDIES PAVING STAKE OUT	DENSIFICATION CONTROL TOPOGRAPHIC CONTROL PHOTOPOINTS UTILITY STAKE OUT	TOPOGRAPHY CROSS SECTIONS AGRICULTURE ROAD GRADING SITE GRADING	SITE GRADING WETLANDS GIS POPULATION MAPPING ENVIRONMENTAL

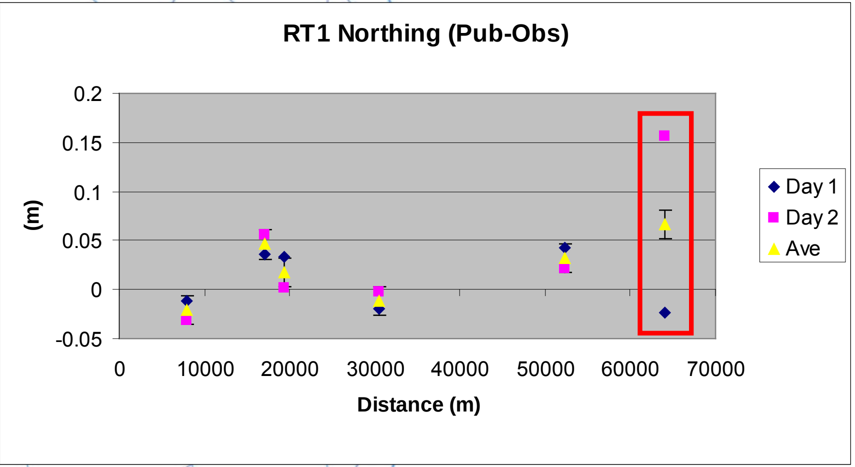
Collection Procedures (3 Observers)

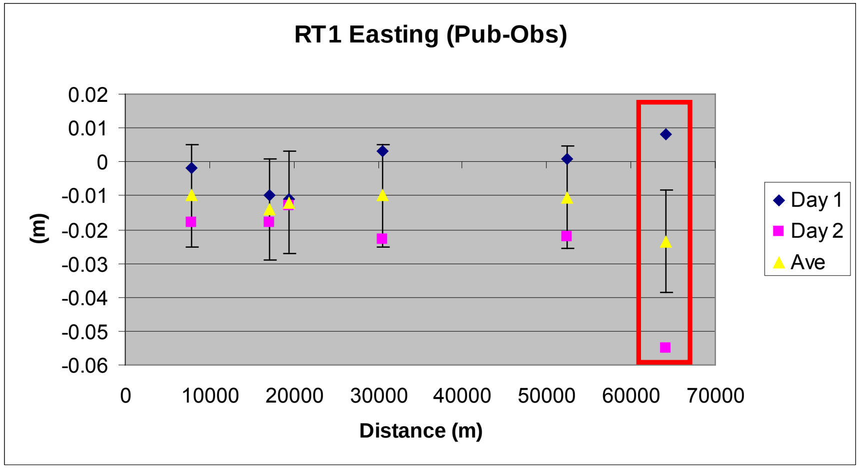
1. Setup bipod/antenna and start survey
2. Initialize to nearest CORS
3. Collect observation using the duration criteria for RT1, RT2, RT3 and RT4 in rapid succession (regardless of field conditions)
4. End survey
5. Start new survey
6. Initialize to a different CORS
7. Repeat steps 3-6 using a number 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)

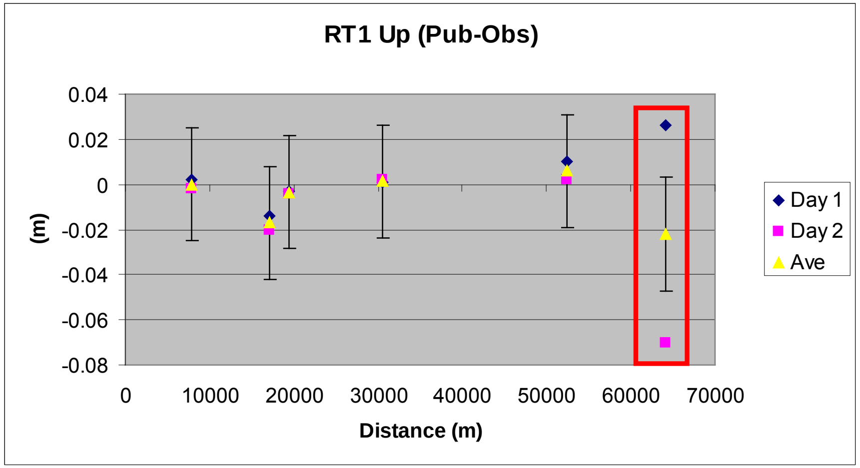
Test Stations and Vector Lengths

CORS	Field Station	Distance (m)
VCAP	SKYL	7888
VCAP	SOBA	11263
VTC1	LLCZ	17140
VCAP	LLCZ	19400
VTC1	SOBA	27097
VTC1	SKYL	30536
VTWR	LLCZ	52358
VTWR	SOBA	60397
VTUV	SOBA	63773
VTWR	SKYL	64112

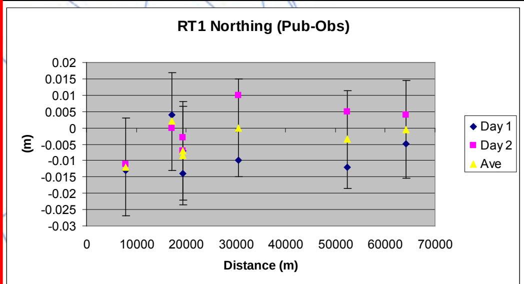
Observer 1 – Example of BAD Initialization
Y Error bars indicate RT1 accuracy cutoff

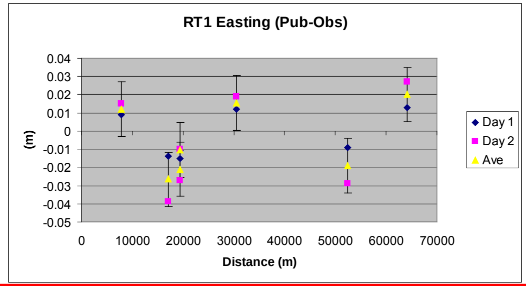


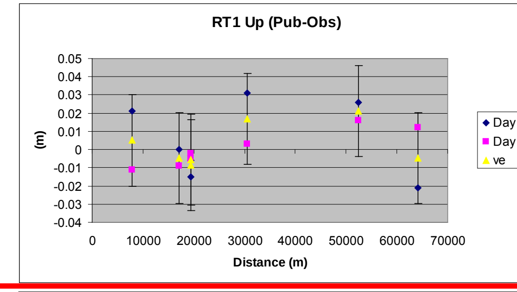


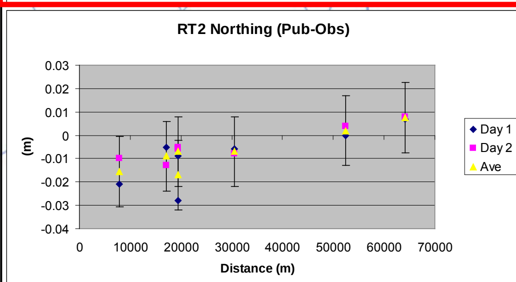


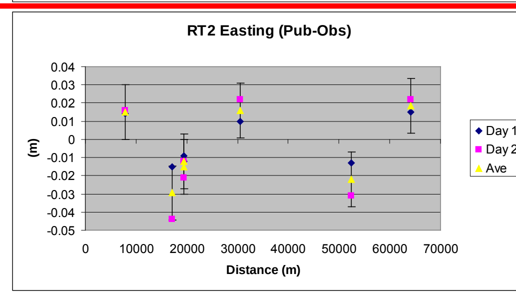
Observer 2 Data

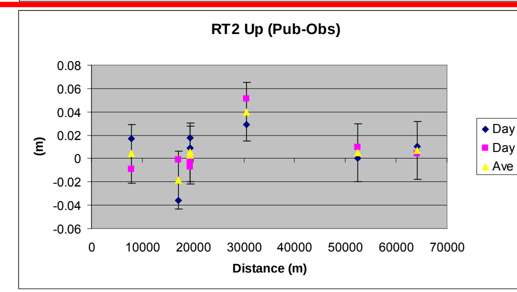


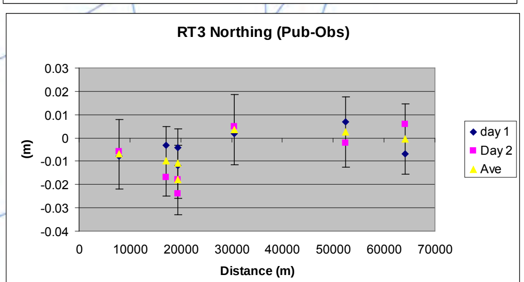


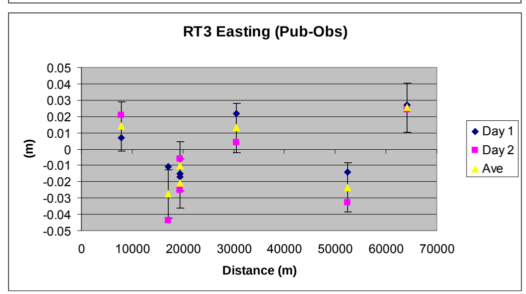


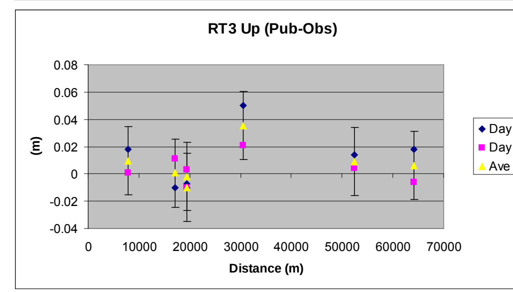


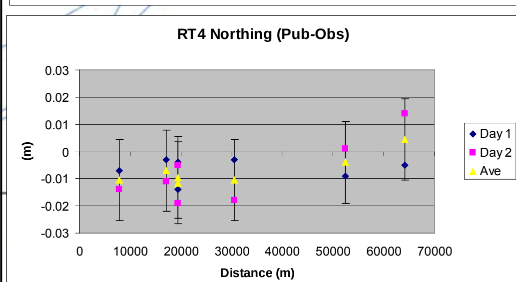


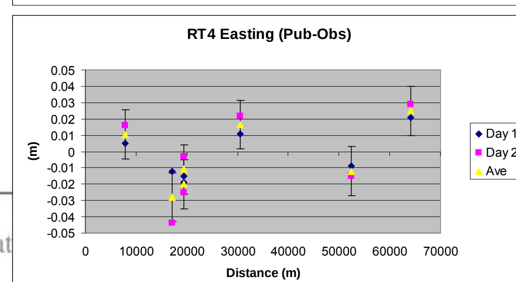


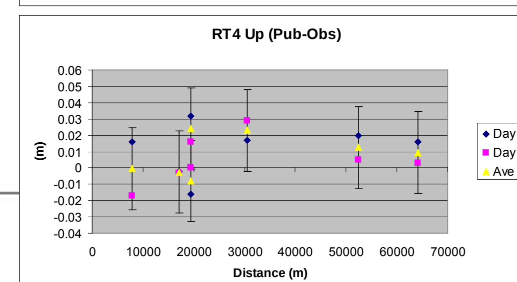




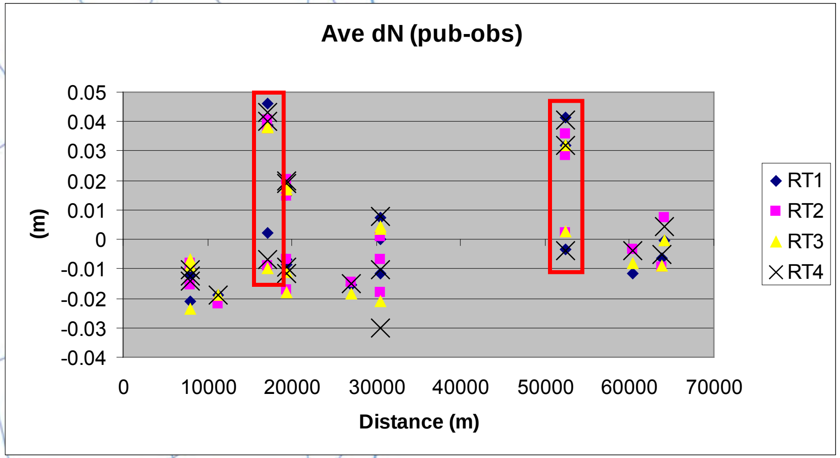


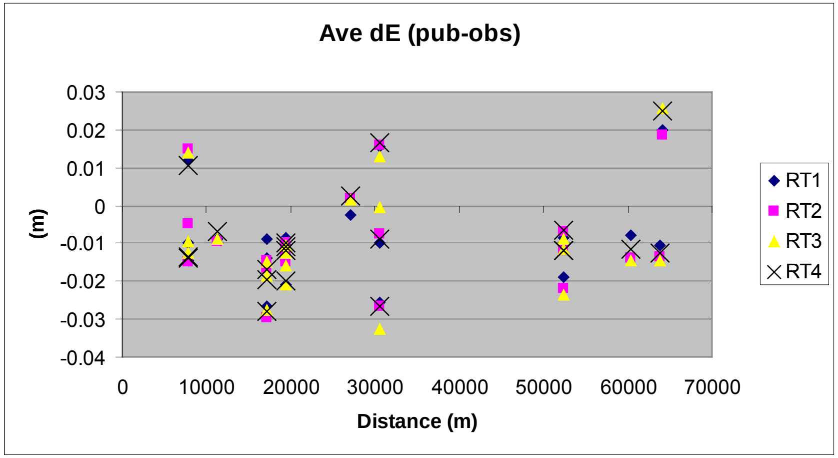


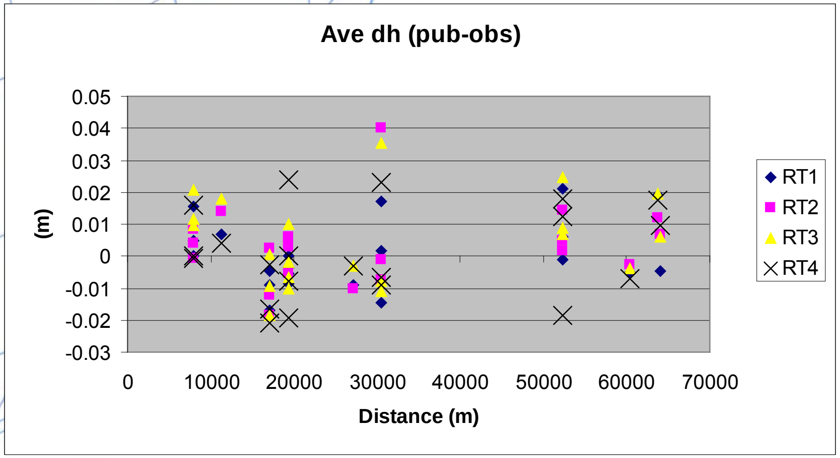




Combined Data - Average of each observers Day1 and Day2 observations



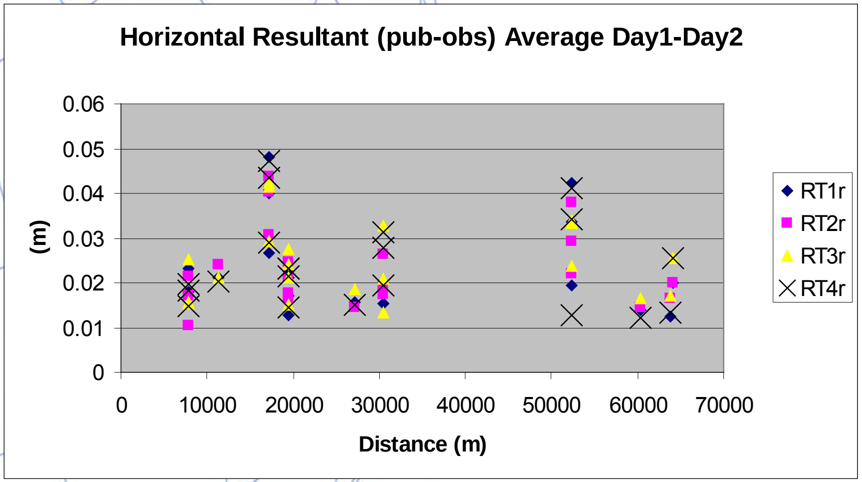


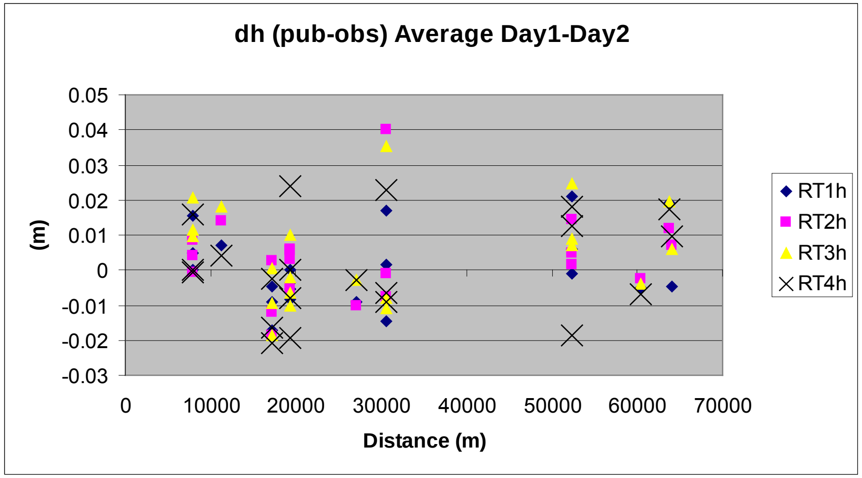


	σ N (m)	σ E (m)	σ h (m)
RT1	0.021	0.012	0.011
RT2	0.020	0.013	0.012
RT3	0.020	0.014	0.014
RT4	0.021	0.013	0.014

How does Precision translate to Accuracy

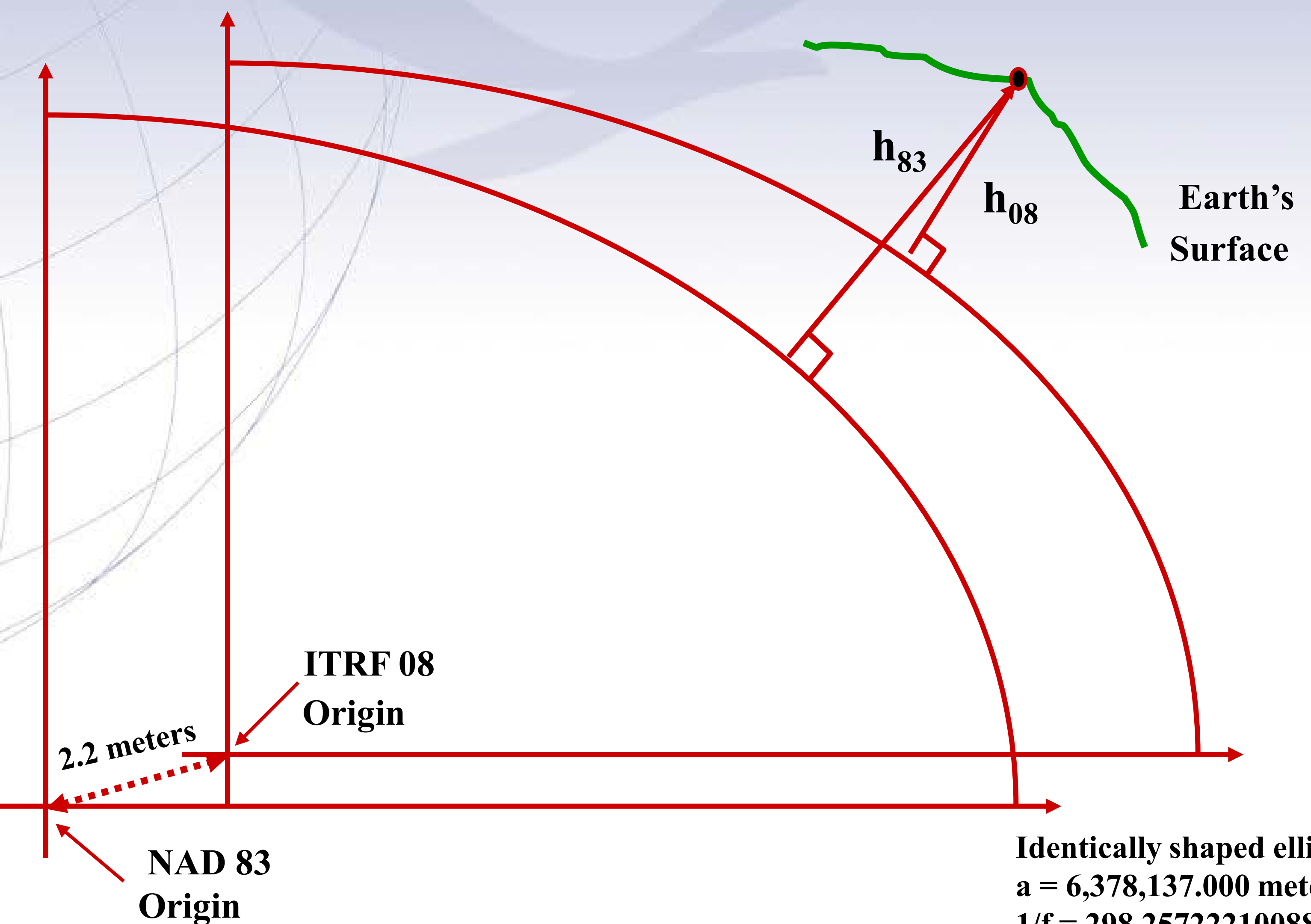
- NGS Accuracy Classes defined by 2d horizontal, 1d vertical precision (Repeatability) at 95% per redundant observation set





	2σ Horizontal	2σ Vertical
RT1	0.024663	0.020933
RT2	0.021754	0.023475
RT3	0.020684	0.027002
RT4	0.025223	0.027488

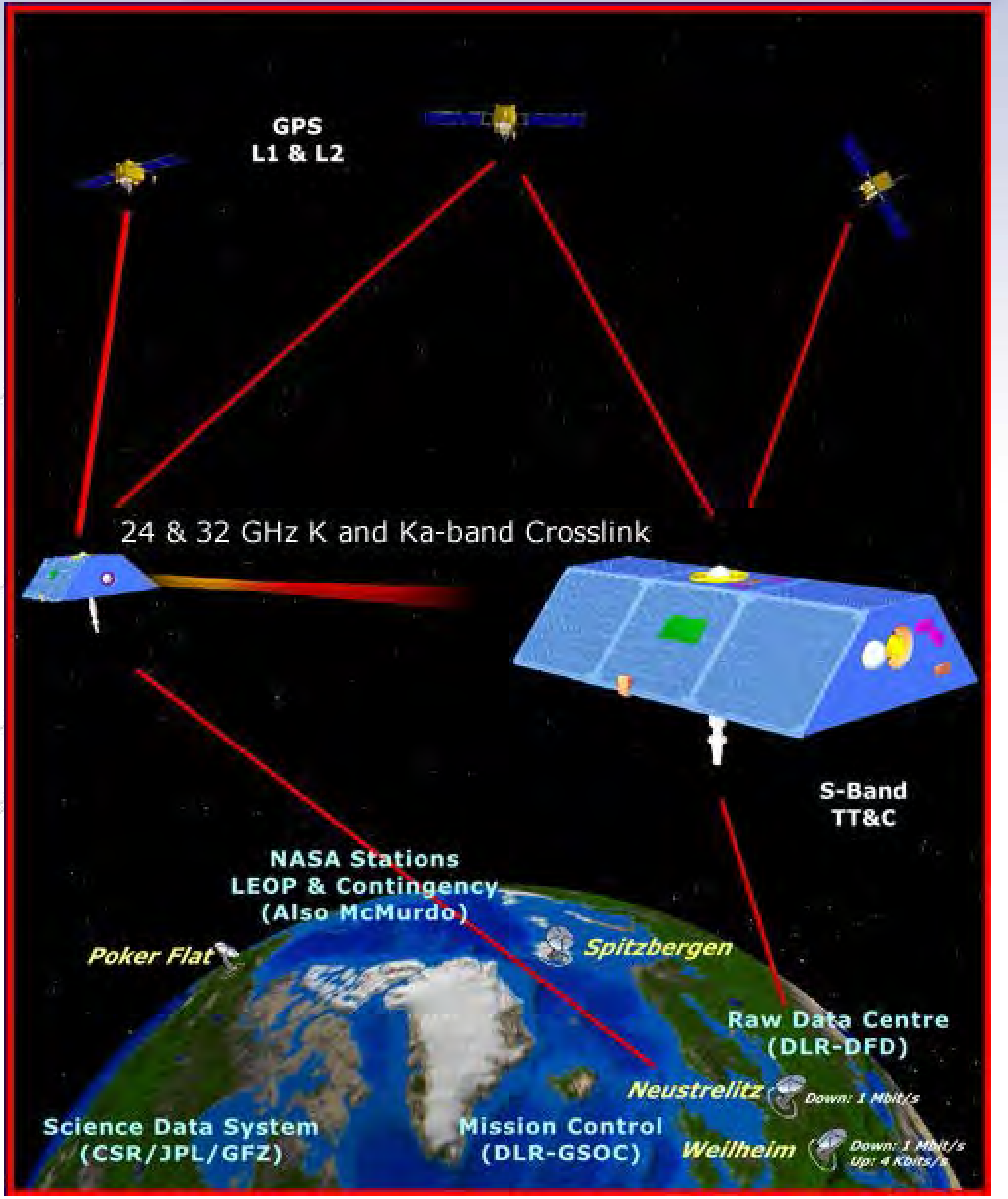
Simplified Concept of NAD 83 vs. ITRF08



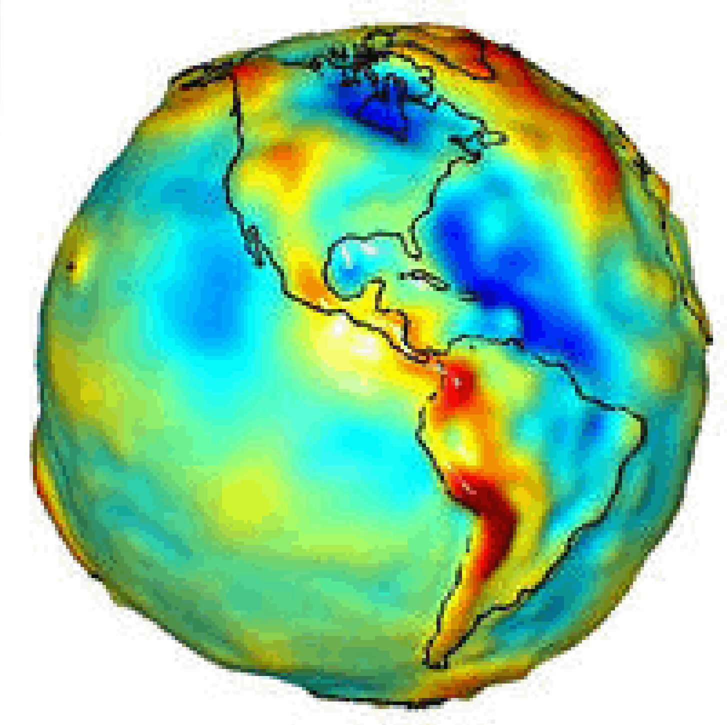
Identically shaped ellipsoids (GRS-80)
a = 6,378,137.000 meters (semi-major axis)
1/f = 298.25722210088 (flattening)

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

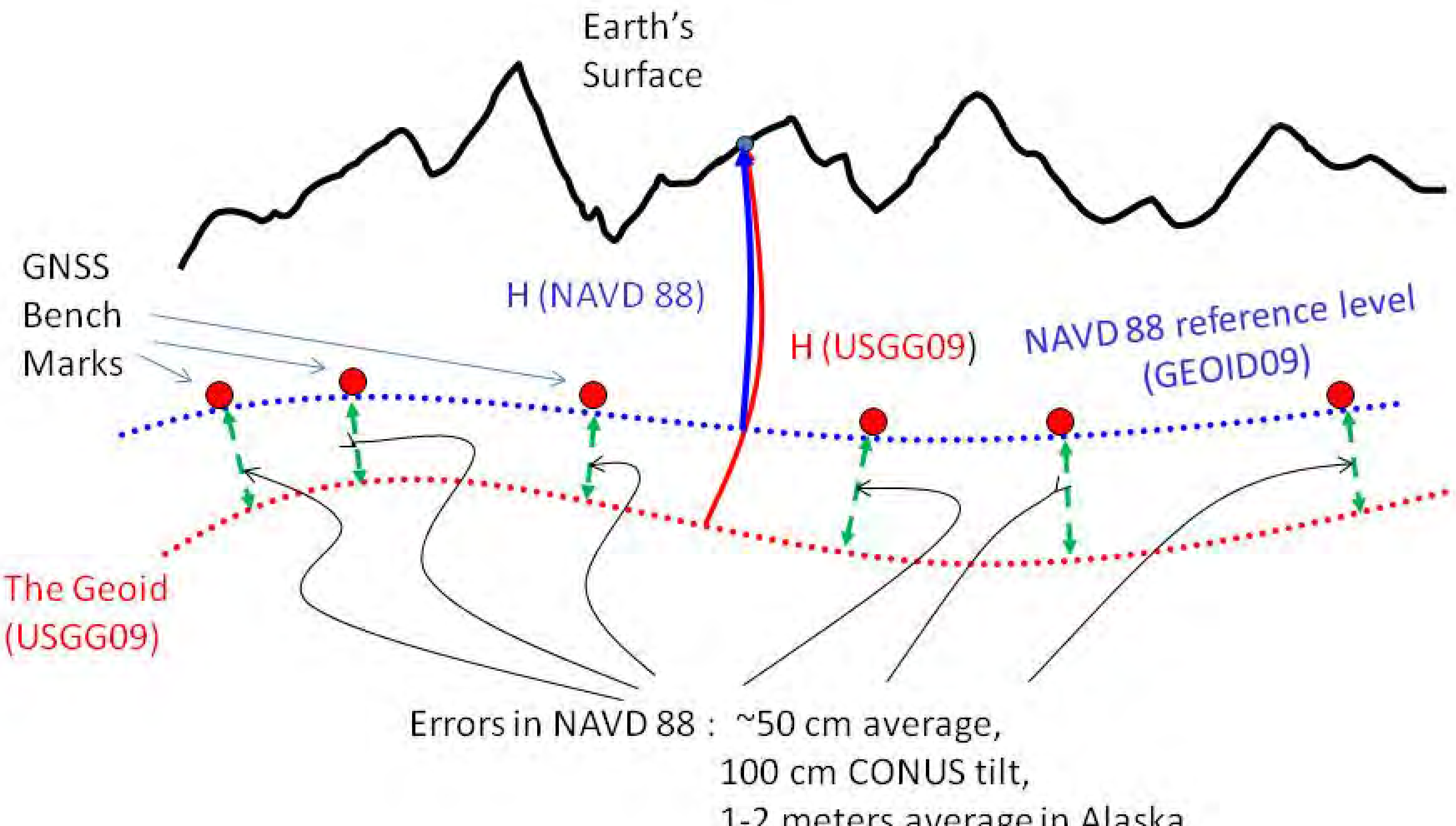


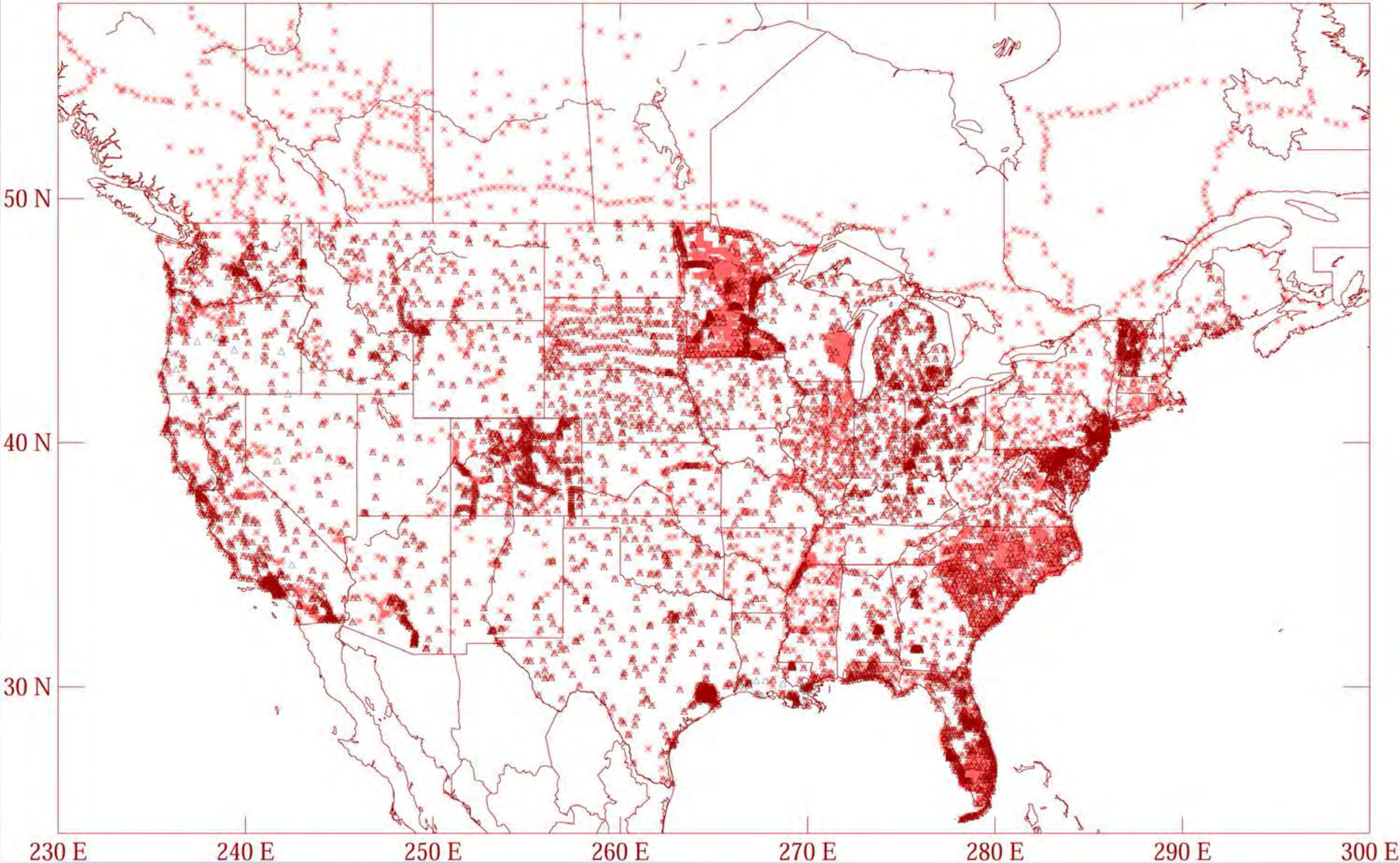
GRACE – Gravity Recovery and Climate Experiment



Hybrid Geoid Model

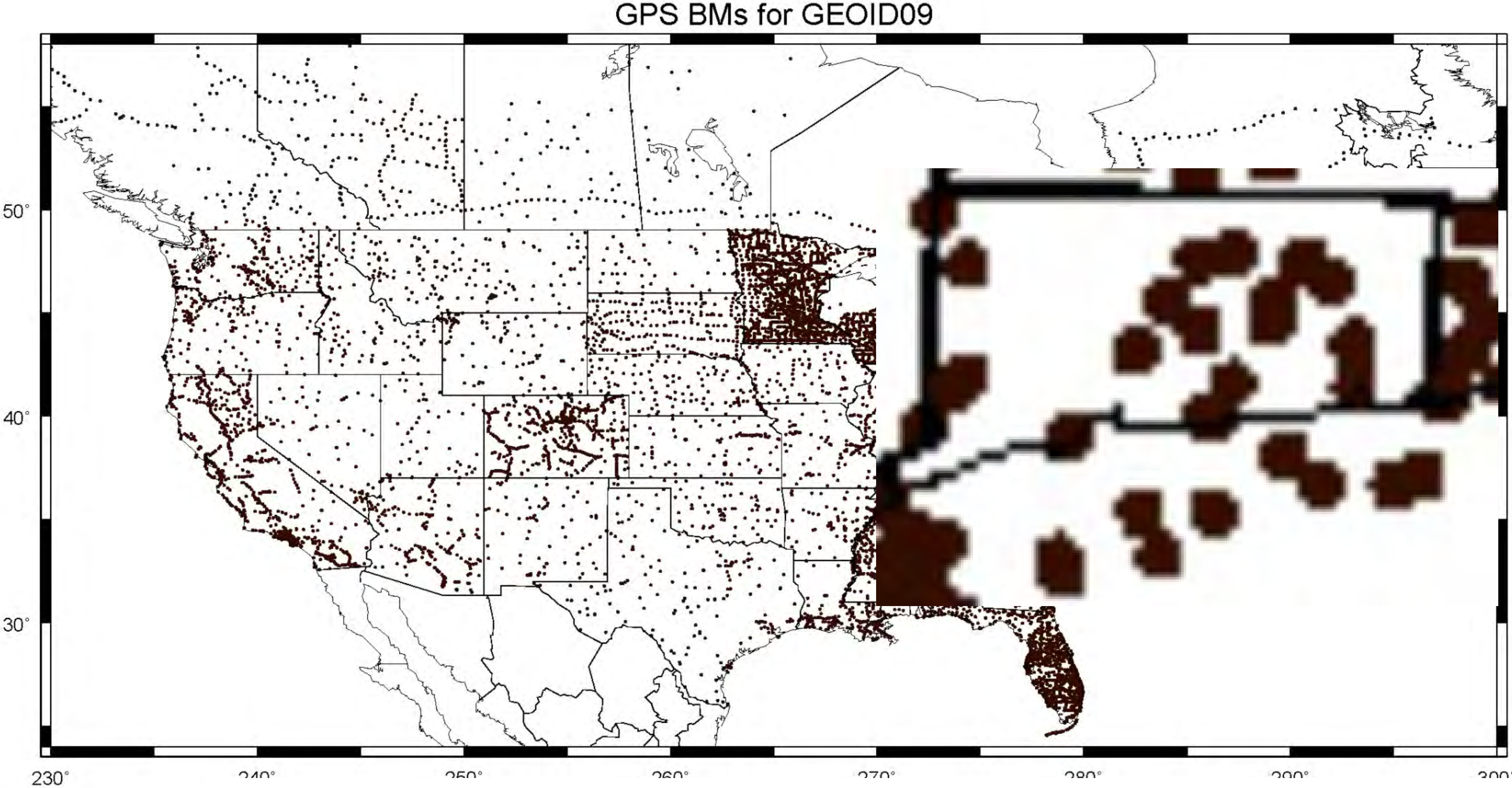
(How It's "Built")



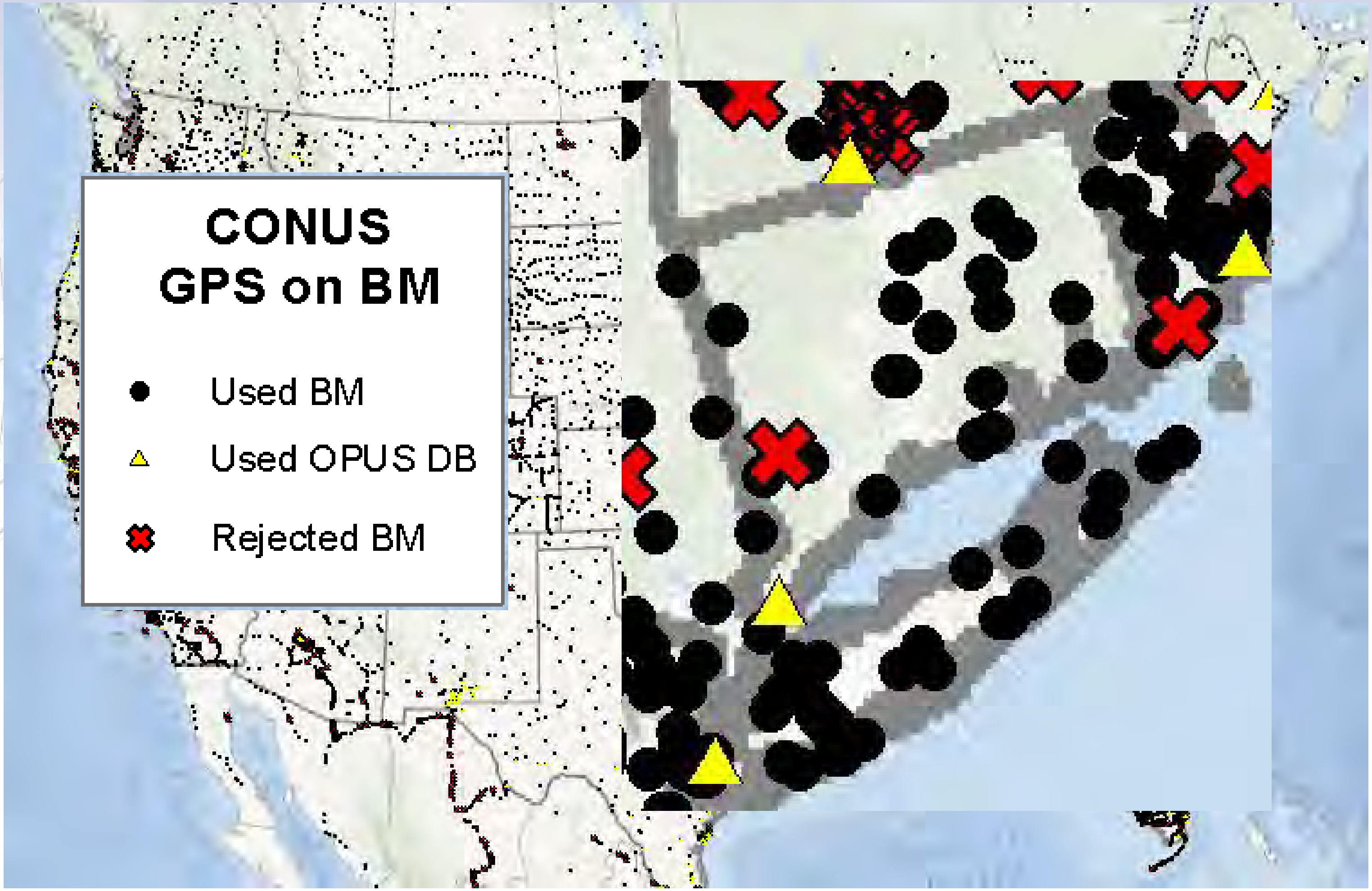


GGPSBM1999: 6,169 total 0 Canada STDEV 9.2 cm (2σ)

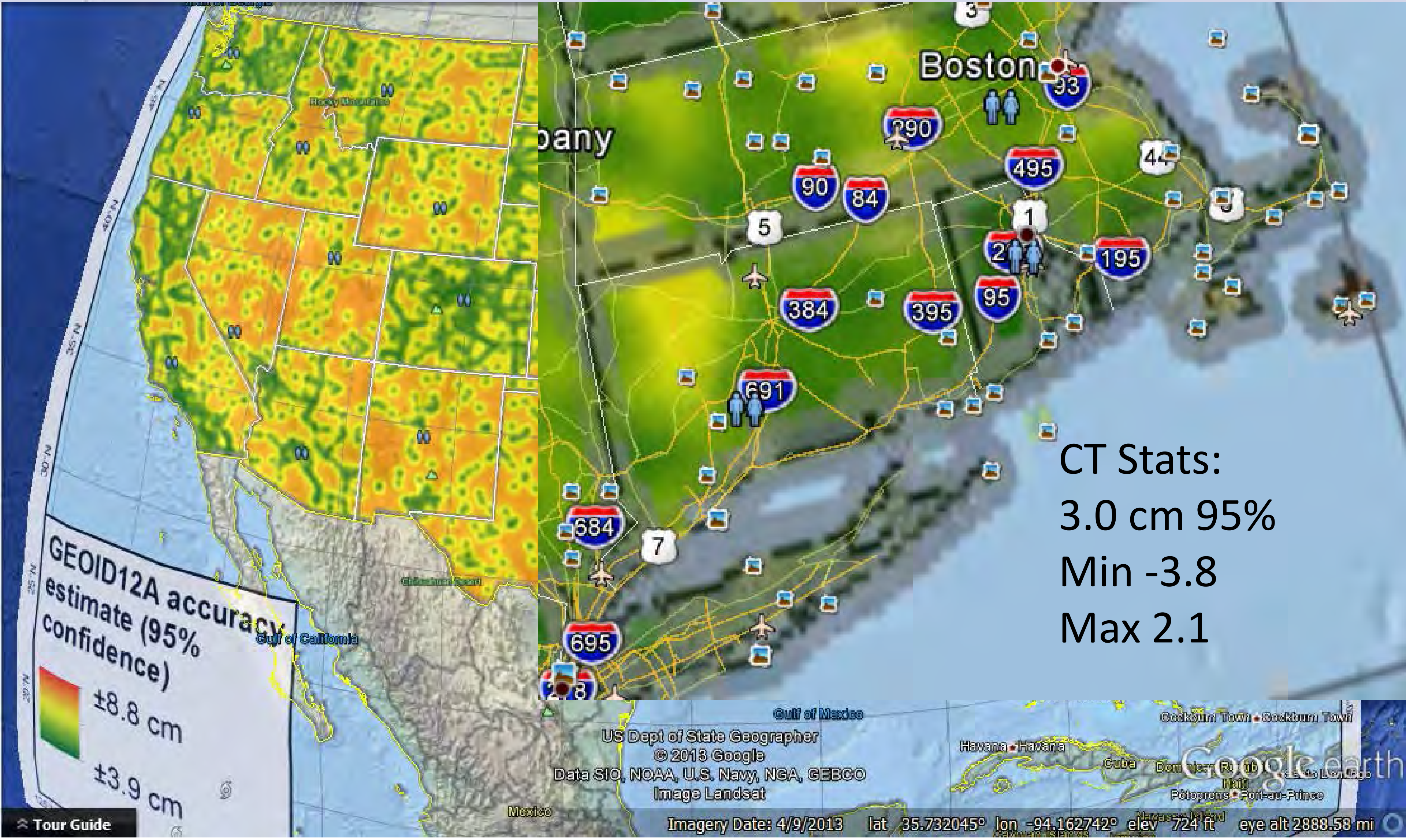
GGPSBM2003: 14,185 total 579 Canada STDEV 4.8 cm (2 σ)



GGPSBM2009: 18,398 STDEV 2.8 cm (2σ)



GGPSBM2012A: 23,961 (CONUS) STDEV 3.4 cm (2σ)
499 (OPUS on BM)
574 (Canada)
177 (Mexico)


GEOID12A accuracy estimate (95% confidence)
±8.8 cm
±3.9 cm
Boston
CT Stats:
3.0 cm 95%
Min -3.8
Max 2.1
Gulf of California
Gulf of Mexico
US Dept of State Geographer
© 2013 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat
Imagery Date: 4/9/2013 lat 35.732045° lon -94.162742° elev 724 ft eye alt 2888.58 mi
Tour Guide

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
- <u>Accuracy of orthometric height is dependent on accuracy of the geoid model</u> – 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 ?

$$\Delta H = \Delta h - \Delta N$$

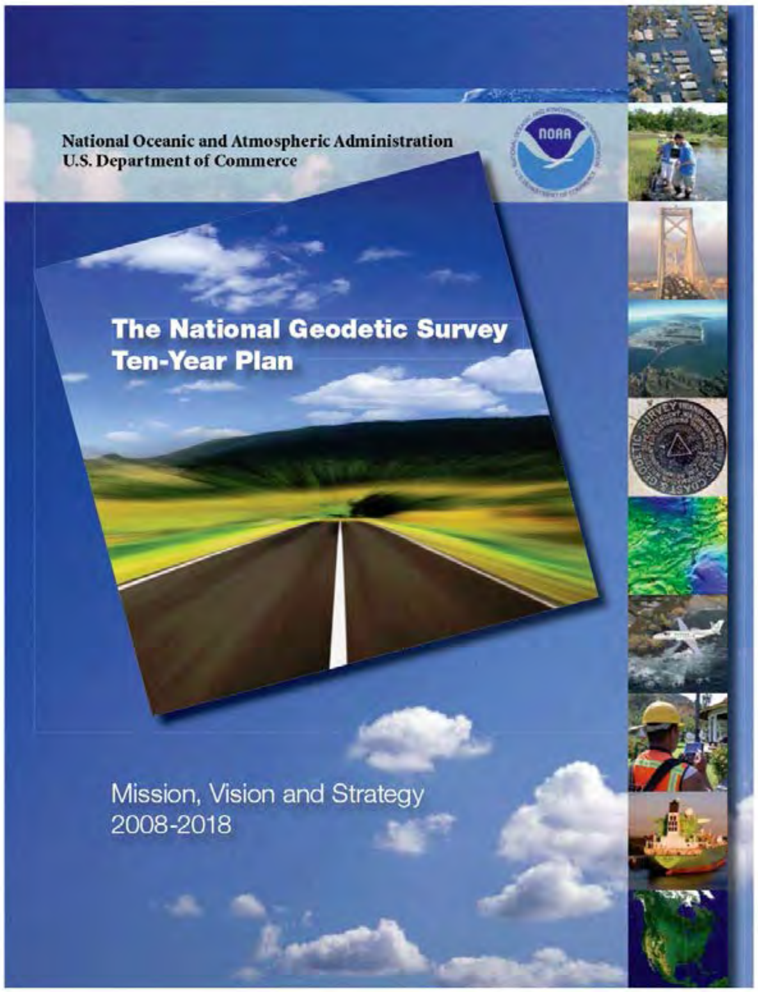
- If "shape" of geoid is correct, then geoid bias will cancel
- NOS NGS 58 and 59 Guidelines
  - 2cm local 5cm network
- Uses ties to existing NAVD 88 control
- Classical "network" approach
- 100% redundancy (repeat baselines) occupied at different times on different days
- Least squares adj with orthometric 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**

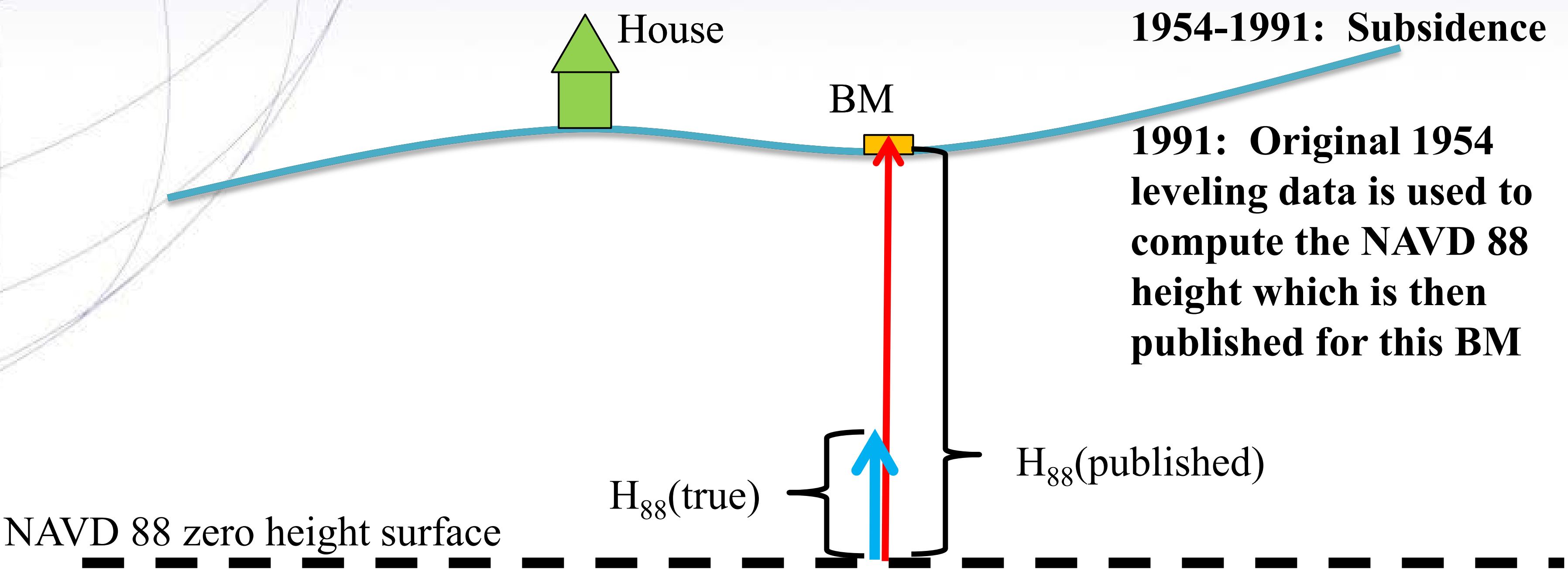
How will I access the new vertical datum?

Example 1: Flood insurance survey

1954: Leveling performed to bench mark

1954-1991: Subsidence

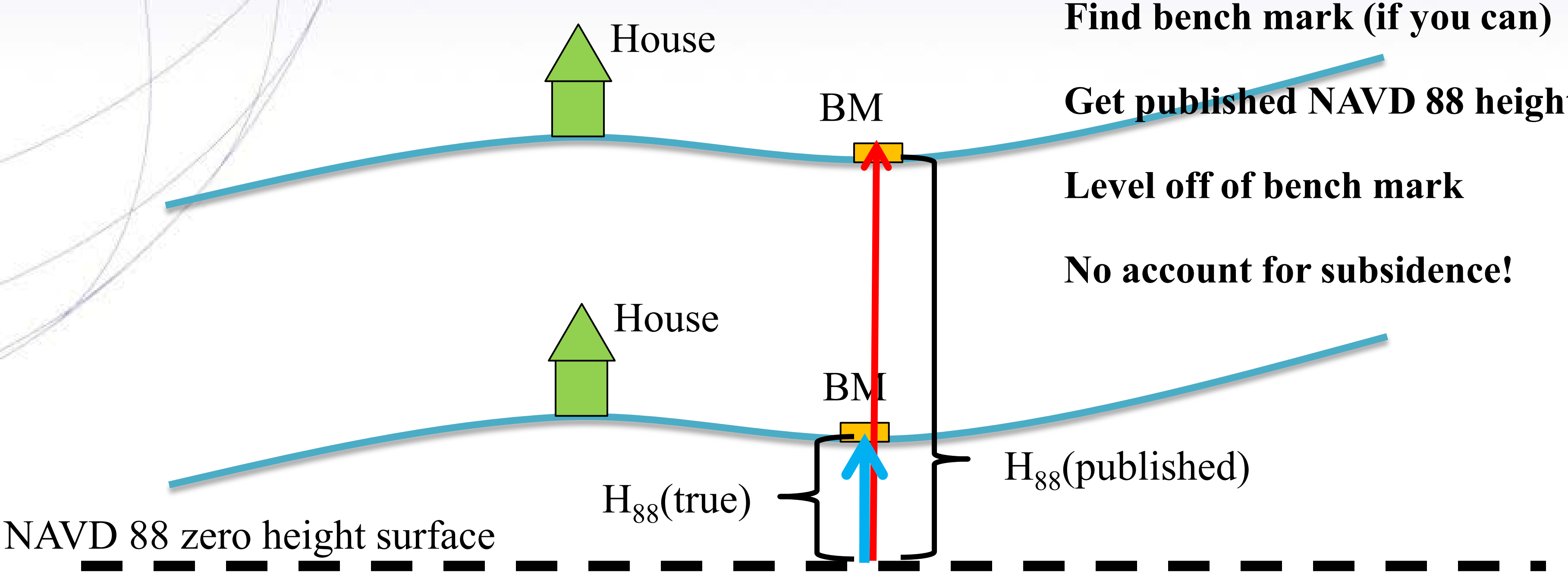
1991: Original 1954 leveling data is used to compute the NAVD 88 height which is then published for this BM



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

How will I access the new vertical datum?

Example 1: Flood insurance survey



Using <u>Existing</u> Techniques:

Find bench mark (if you can)

Get published NAVD 88 height

Level off of bench mark

No account for subsidence!

How will I access the new vertical datum?

Example 1: Flood insurance survey

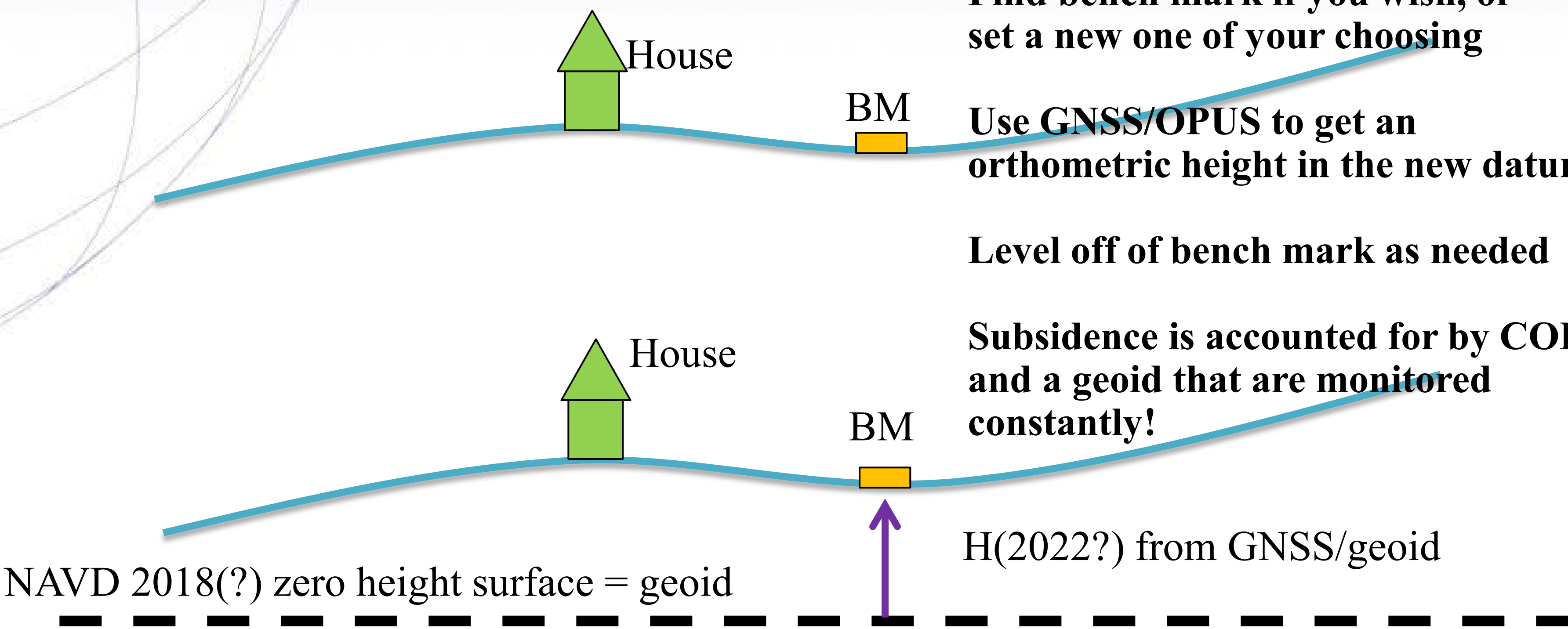
Using <u>Future</u> Techniques:

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

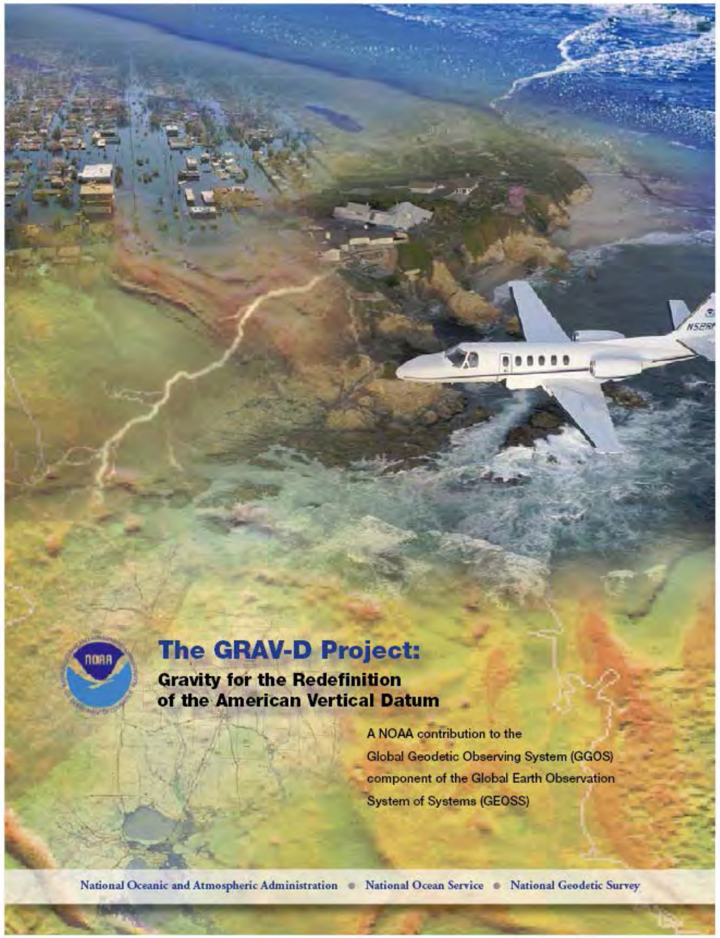
Level off of bench mark as needed

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



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)