Guidelines for Establishing GPS-Derived Ellipsoid and Orthometric Heights

Static GPS/RTN Best Practices Seminar

Lindy C. Boggs International Conference Center

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Acknowledgements

Borrowed slides from several presentations by the following NGS employees:

Edward Carlson	Curtis Smith
Dan Roman	Dru Smith
Joe Evjen	Kevin Choi

And

Myself (when I was employed by NGS)

Topics To Be Discussed

- **<u>Review of types of heights and their accuracies</u>**
- **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?**

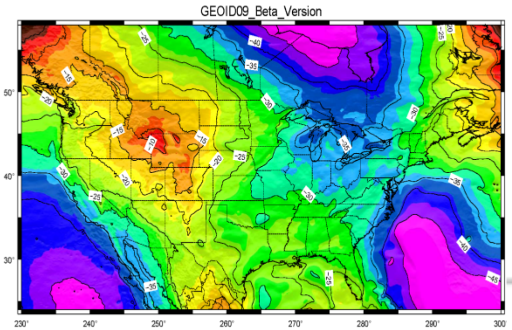
3) **How accurately can these heights be determined?**

Types of Heights Involved

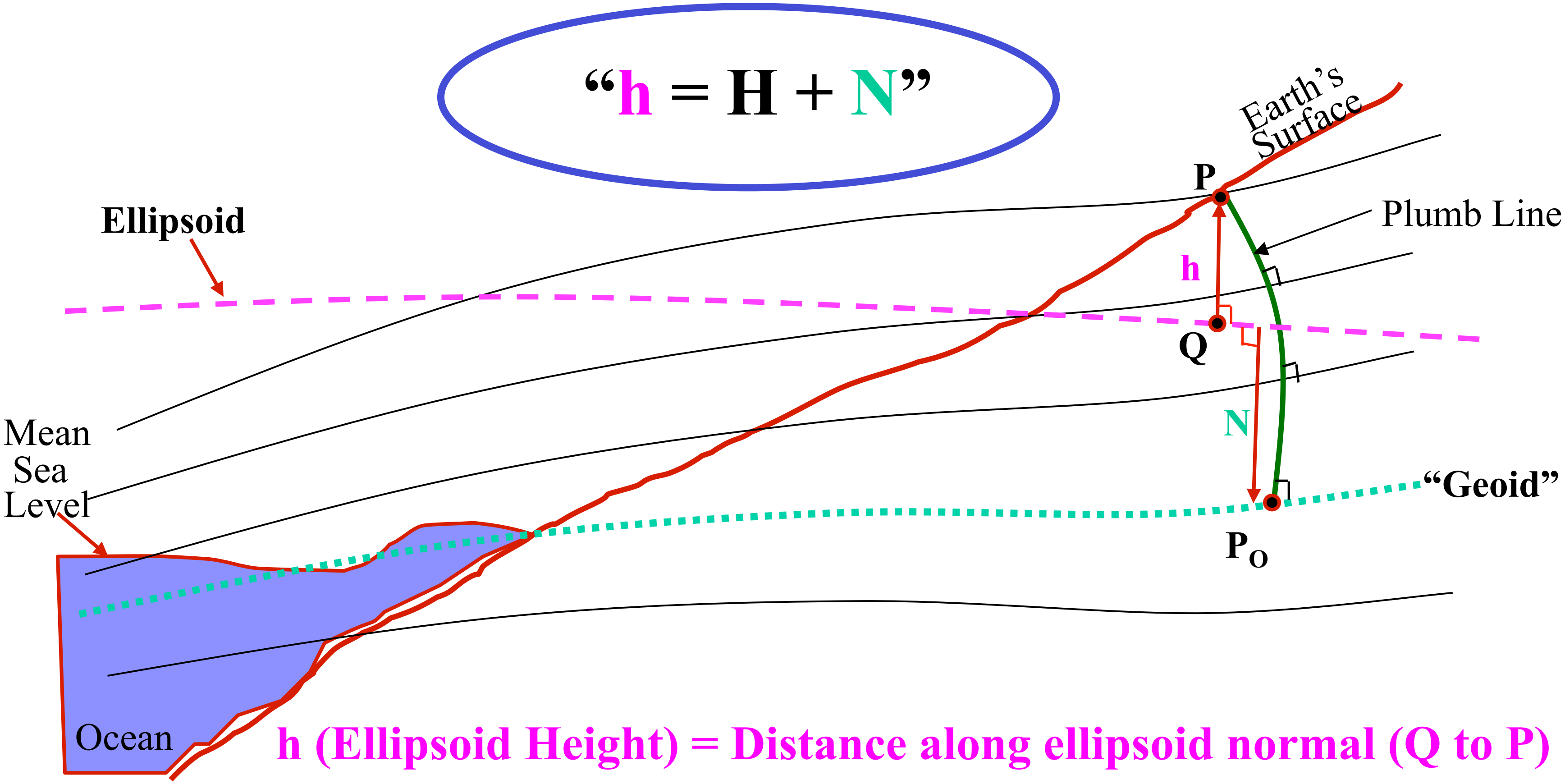
Ellipsoid
(GPS)

Orthometric
(Leveling)

Geoid
(Gravity & Modeling)



Ellipsoid, Geoid, and Orthometric Heights

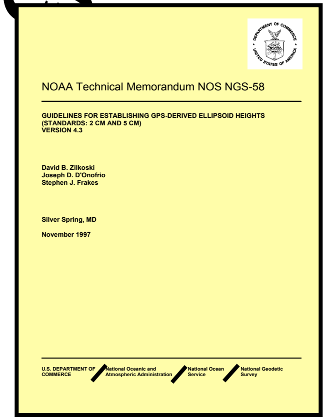


h (Ellipsoid Height) = Distance along ellipsoid normal (Q to P)

N (Geoid Height) = Distance along ellipsoid normal (Q to P_O)

H (Orthometric Height) = Distance along plumb line (P_O to P)

Expected Accuracies


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
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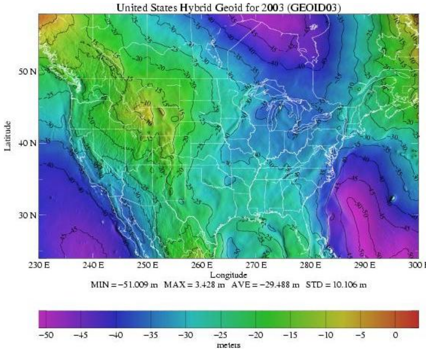
Silver Spring, MD

November 1997

U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Ocean Service / National Geodetic Survey

- **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

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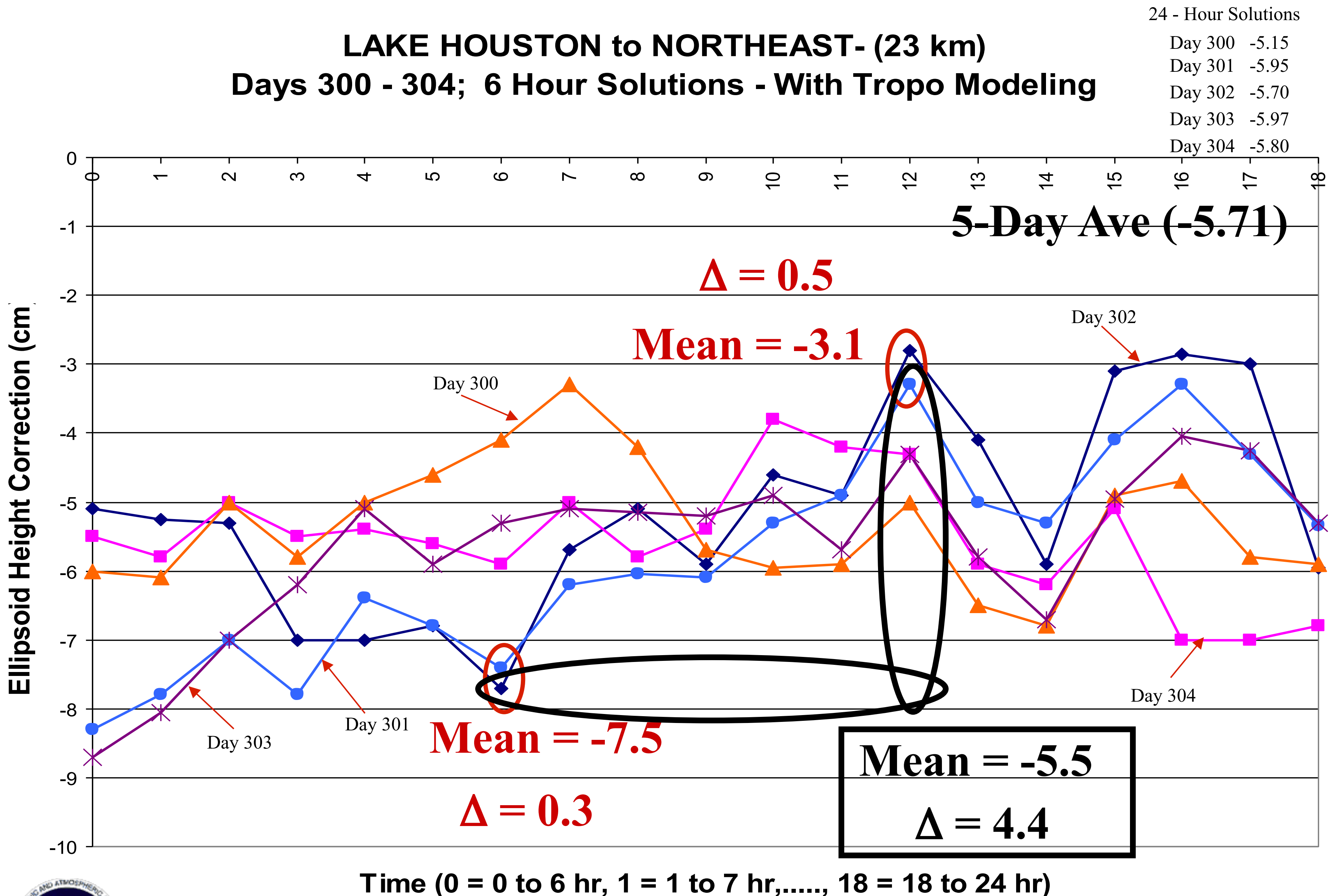
Execution of Surveys; Sources of Error

- **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**

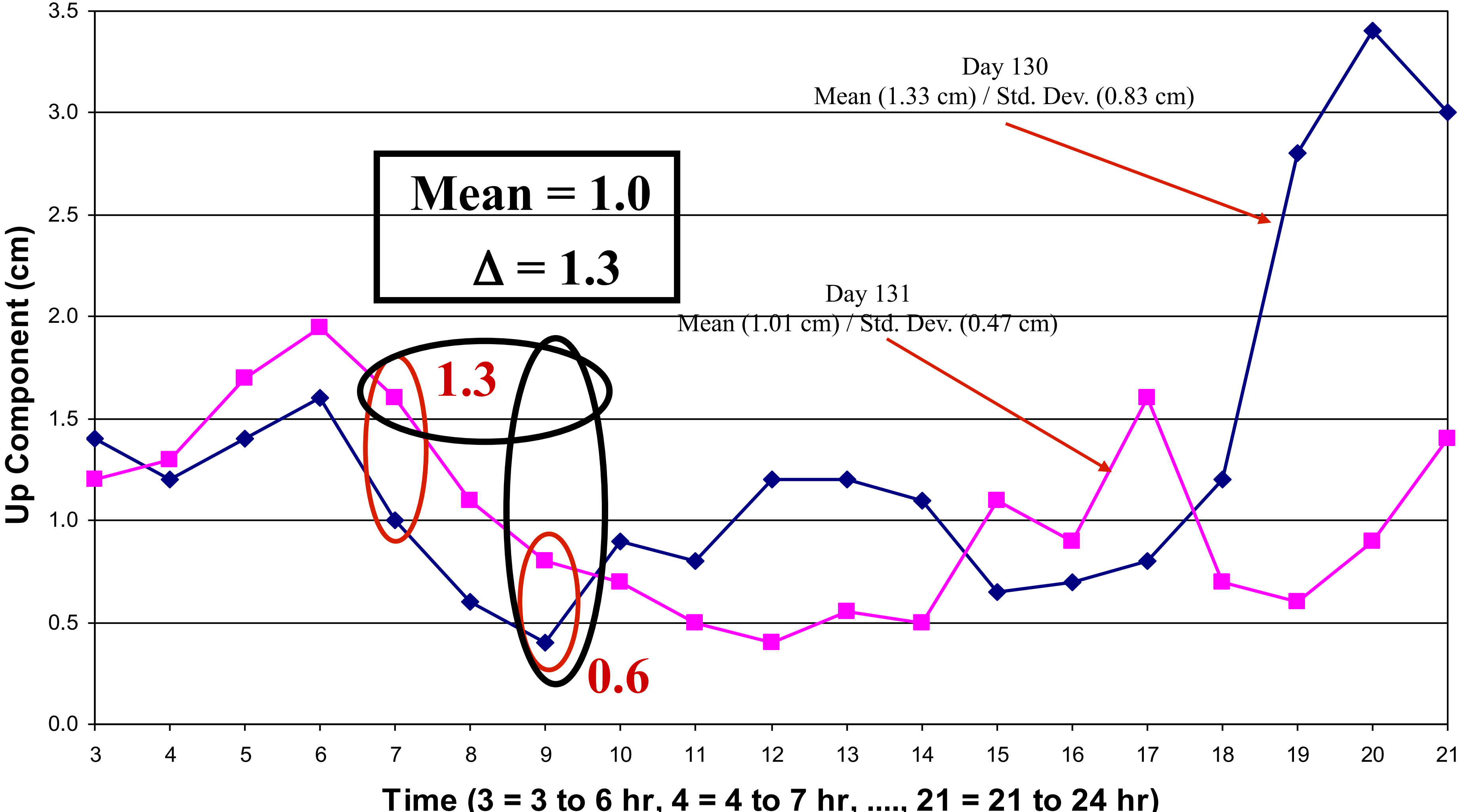
GUIDELINES

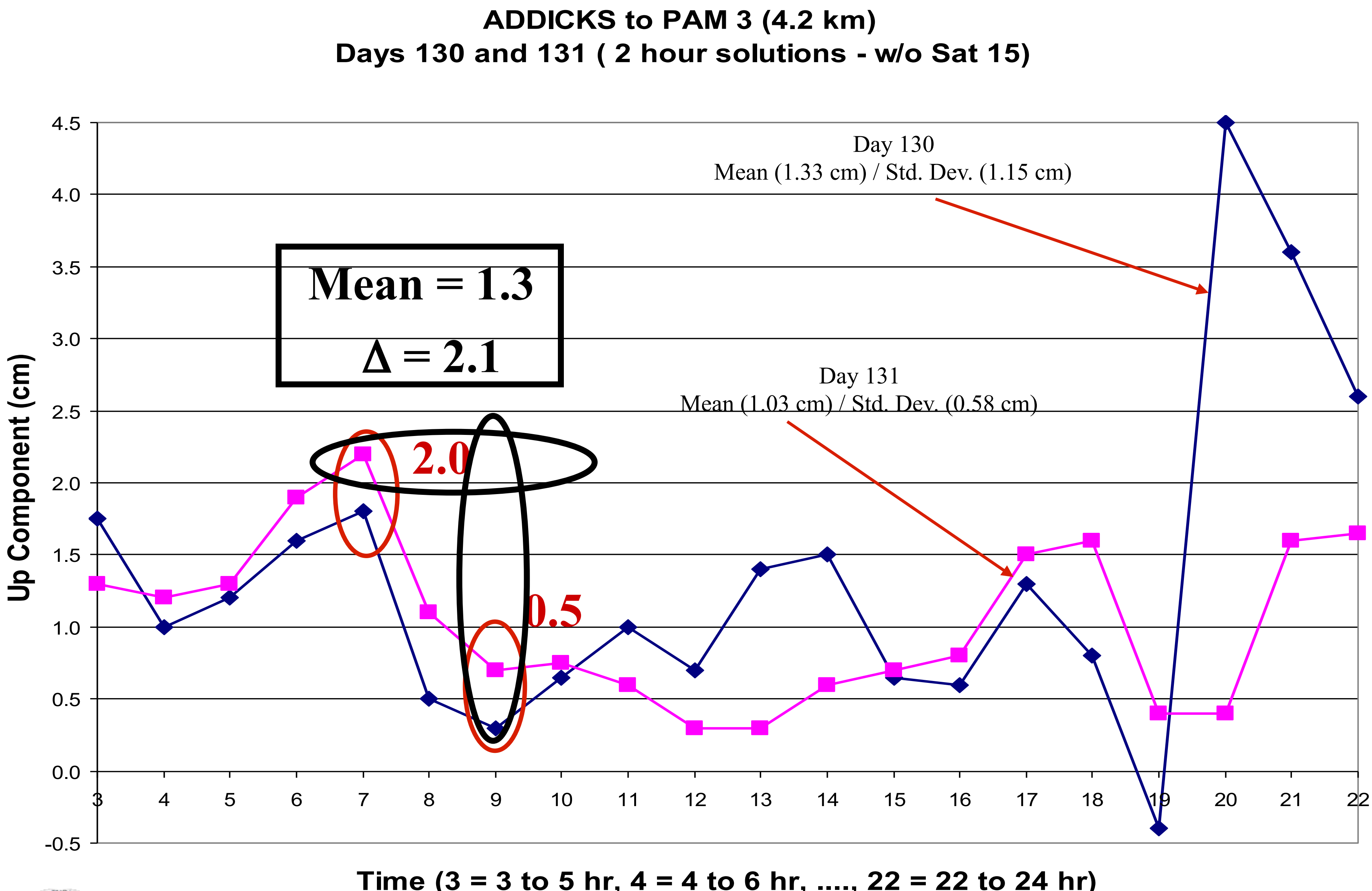
- **Guidelines Help to Detect, Reduce, and/or Eliminate Error Sources**
- **Special Projects Are Performed to Develop Guidelines**
- **Guidelines Are Modified as Procedures, Equipment, and Models Improve**

LAKE HOUSTON to NORTHEAST- (23 km)
Days 300 - 304; 6 Hour Solutions - With Tropo Modeling

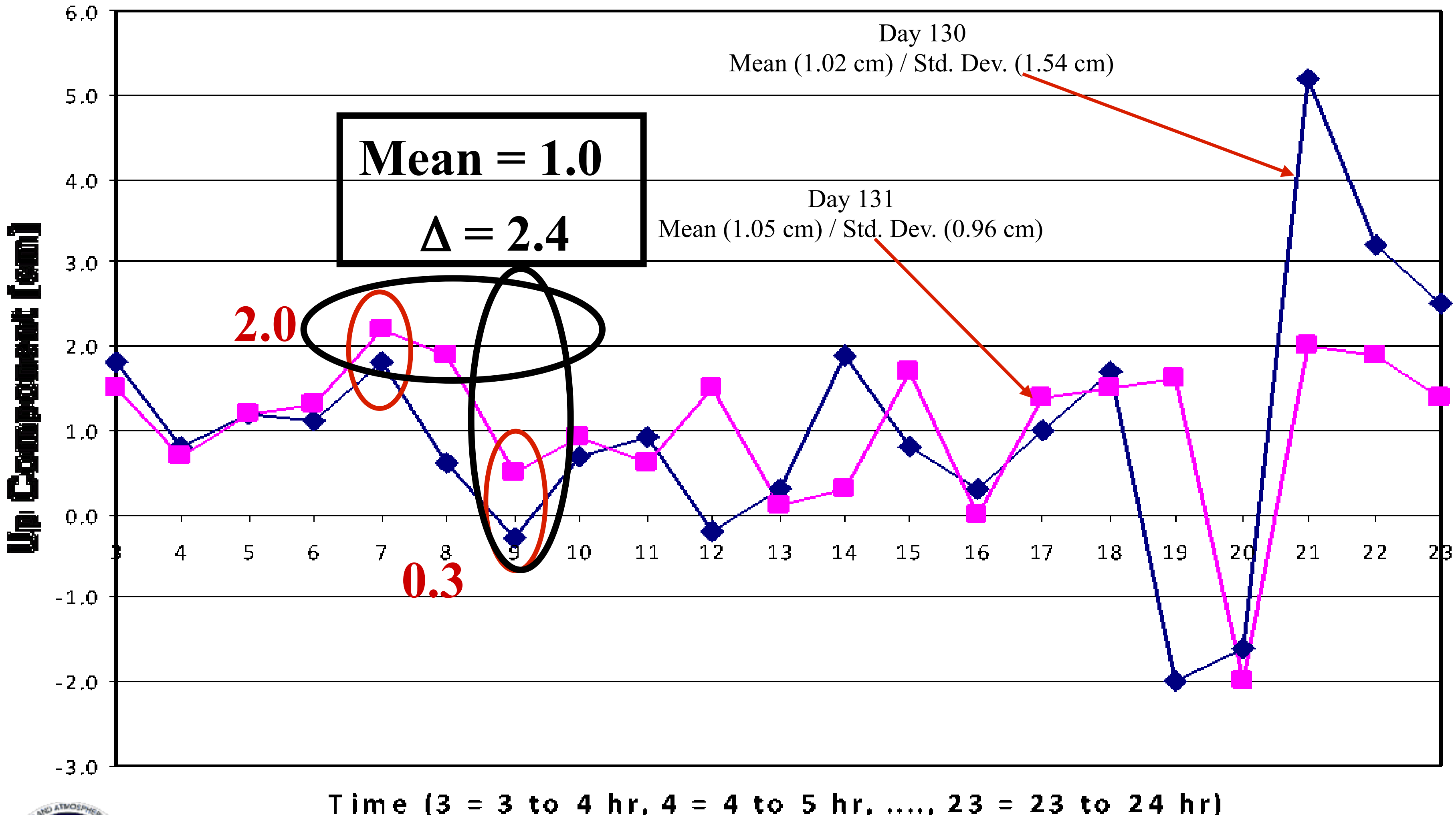


ADDICKS to PAM 3 (4.2 km)
Days 130 and 131 (3 hour solutions - w/o Sat 15)




ADDICKS to PAM 3 (4.2 km)
Days 130 and 131 (2 hour solutions - w/o Sat 15)
Day 130
Mean (1.33 cm) / Std. Dev. (1.15 cm)
Mean = 1.3
Δ = 2.1
Day 131
Mean (1.03 cm) / Std. Dev. (0.58 cm)
2.0
0.5
Up Component (cm)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (3 = 3 to 5 hr, 4 = 4 to 6 hr, ..., 22 = 22 to 24 hr)

ADDICKS to PAM 3 (4.2 km)
Days 130 and 131 (1 hour solutions - w/o Sat 15)



Two Days/Different Times

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									
Day 264	dh (m)	Hours Diff.	Day 265	dh (m)	Day 264 minus Day 265 (cm)	* diff >2 cm	Mean dh (m)	Mean dh minus "Truth" (cm)	* diff >2 cm
14:00-14:30									
14:30-15:00									
15:00-15:30									
15:30-16:00									
16:00-16:30									
16:30-17:00									
17:00-17:30									
17:30-18:00									
18:00-18:30	-9.216	20hrs	14:00-14:30	-9.205					
18:30-19:00	-9.228	20hrs	14:30-15:00	-9.220	-0.8		-9.224	-0.6	
19:00-19:30	-9.219	20hrs	15:00-15:30	-9.193	-2.6		-9.206	1.2	
19:30-20:00	-9.203	20hrs	15:30-16:00	-9.208	0.5		-9.206	1.2	
20:00-20:30	-9.184	20hrs	16:00-16:30	-9.185	0.1		-9.185	3.3	*
20:30-21:00	-9.210	20hrs	16:30-17:00	-9.186	-2.4	*	-9.198	2.0	
							"Truth"		
18:00-21:00	-9.217		14:00-17:00	-9.218	0.1		-9.218		

-9.184 > -9.185
-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**
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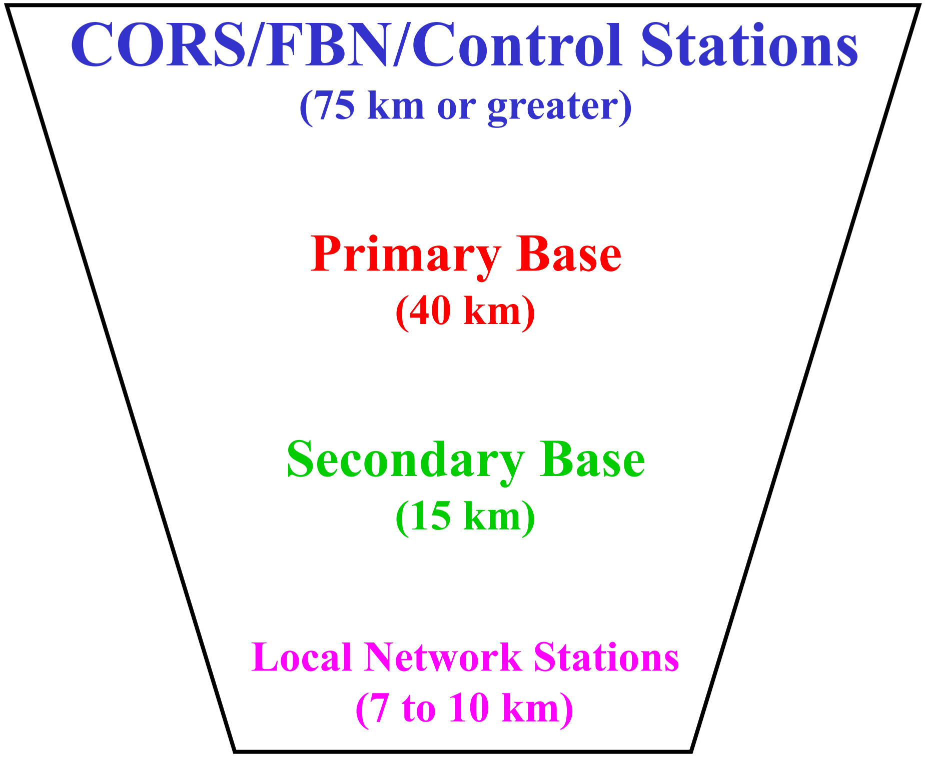
Guidelines for Establishing GPS-Derived Ellipsoid Heights

(Standards: 2 cm and 5 cm)

Available "On-Line" at the NGS Web Site:

www.ngs.noaa.gov

GPS Ellipsoid Height Hierarchy



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**

Sample Project Showing Connections

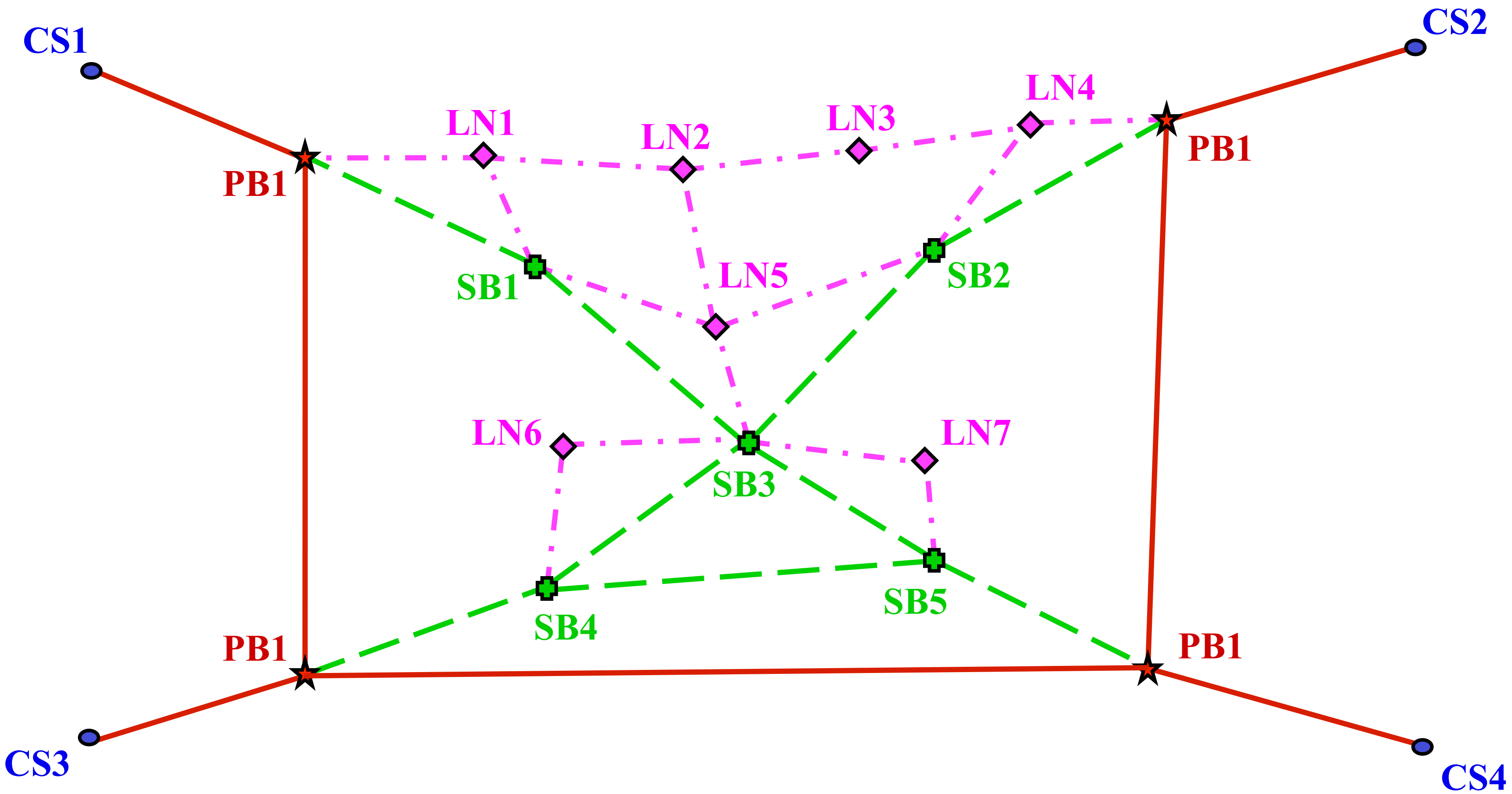


Table 1. -- Summary of Guidelines

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	Control 2 and 5 cm	Primary Base 2 cm	Primary Base 5 cm	Secondary Base 2 cm	Secondary Base 5 cm	Local Network 2 cm	Local Network 5 cm
Dual Frequency Required	Yes, if base line is greater than 10 km	Yes, if base line is greater than 10 km	Yes, if base line is greater than 10 km	Yes, if base line is greater than 10 km	Yes, if base line is greater than 10 km	Yes, if base line is greater than 10 km	Yes, if base line is greater than 10 km
Geodetic Quality Antenna with Ground Plane	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Min. Number of Stations	3	3	3	No Minimum	No Minimum	No Minimum	No Minimum
Occupation Time	5 Hours	5 Hours	5 Hours	30 Minutes[1]	30 Minutes[1]	30 Minutes[1]	No Minimum[1]
Number of Days Station Is Occupied	3	3	3	2[2]	2[2]	2[2]	2[2]
Max. Distance Between Same or Higher-Order Stations	75 km	40 km	50 km	15 km	20 km	10 km	20 km
Average Distance Between Stations	No Maximum	No Maximum	No Maximum	No Maximum	No Maximum	7 km	10 km
Repeat "Base Line"	**YES**[3]	**YES**[3]	**YES**[3]	**YES**[3]	**YES**[3]	**YES**[3]	**YES**[3]
Collect Met Data	Yes	Yes	Yes	Yes	Yes	No	No
Fixed Height Pole	Yes	Yes	No	Yes	No	Yes	No
Rubbing of Mark	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Precise Ephemerides	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fix Integers	Yes[4]	Yes[5]	Yes[5]	Yes	Yes	Yes	Yes

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

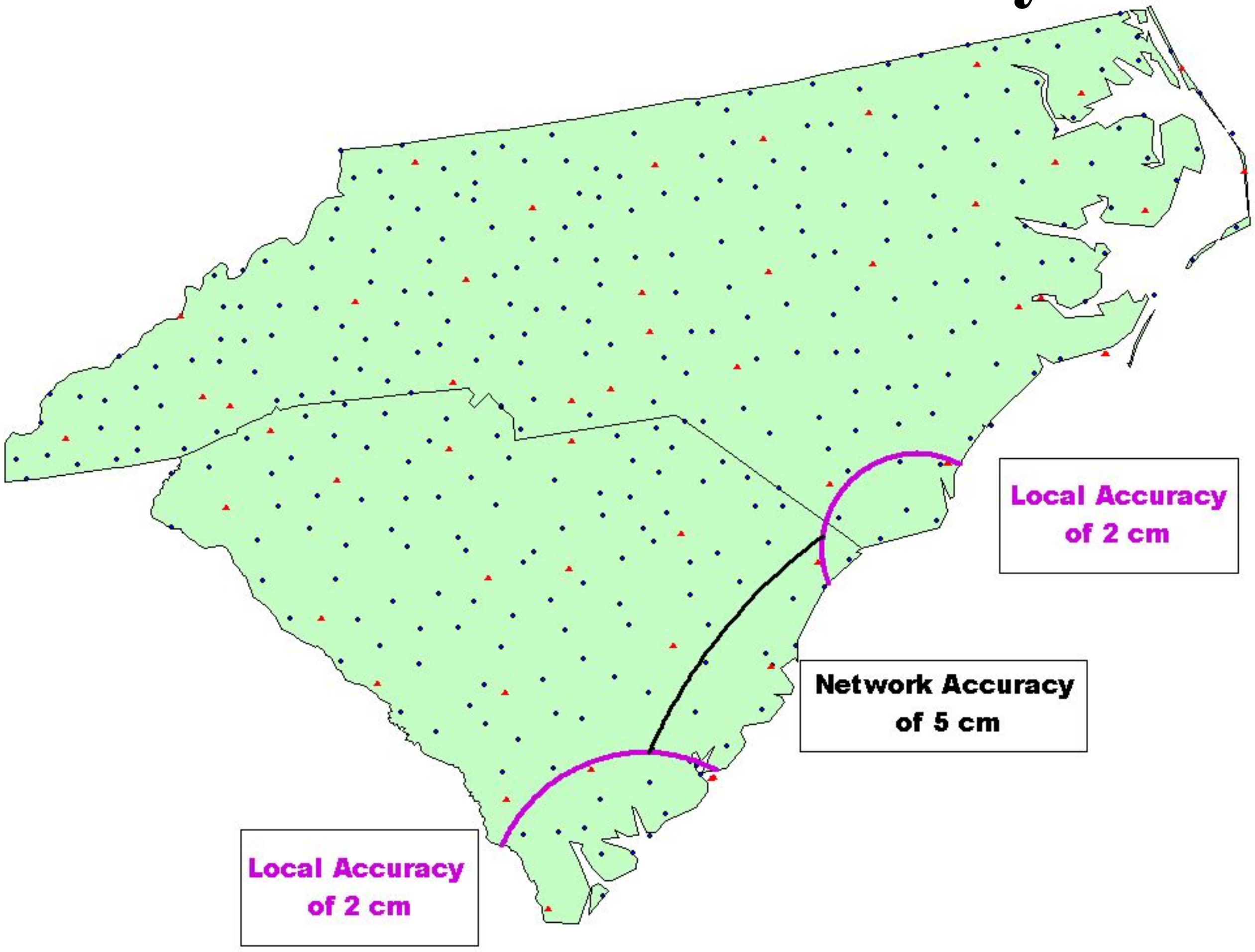
Basic Concept of Guidelines

- **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**

Network / Local Accuracy



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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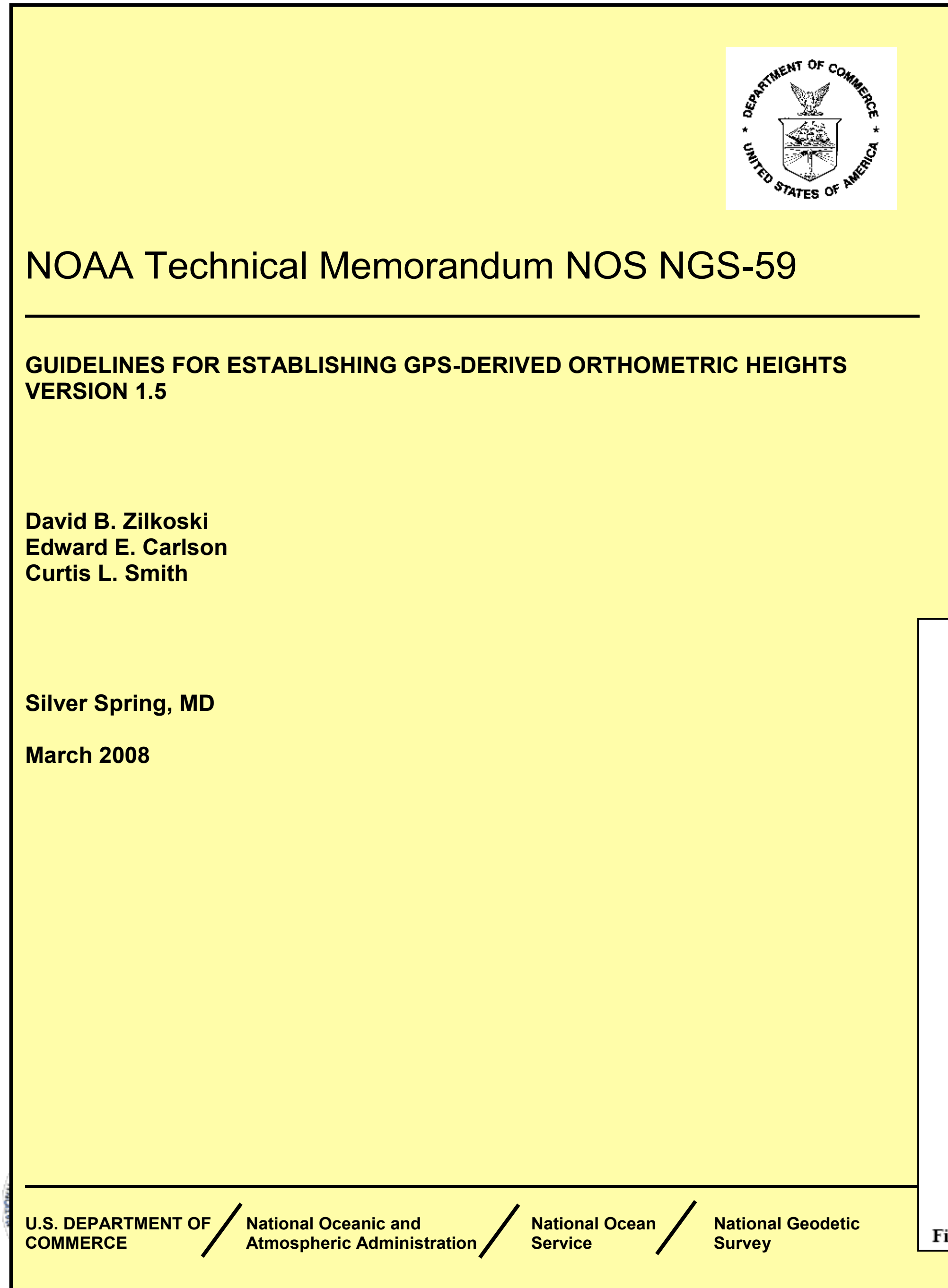
Guidelines for Establishing GPS-Derived Orthometric Heights



NOAA Technical Memorandum NOS NGS-59

GUIDELINES FOR ESTABLISHING GPS-DERIVED ORTHOMETRIC HEIGHTS
VERSION 1.5

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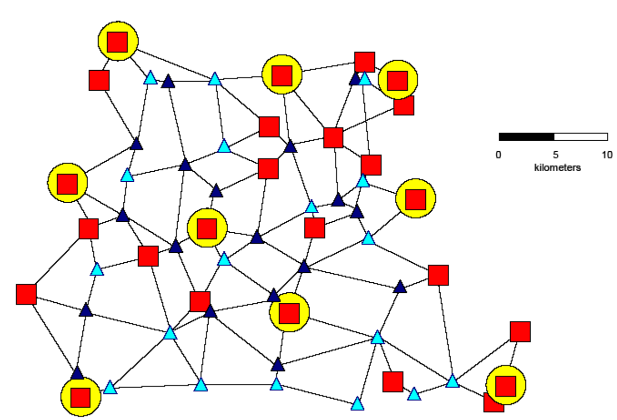
March 2008

U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Ocean Service / National Geodetic Survey

NAVD 88 Bench Marks Occupied with GPS



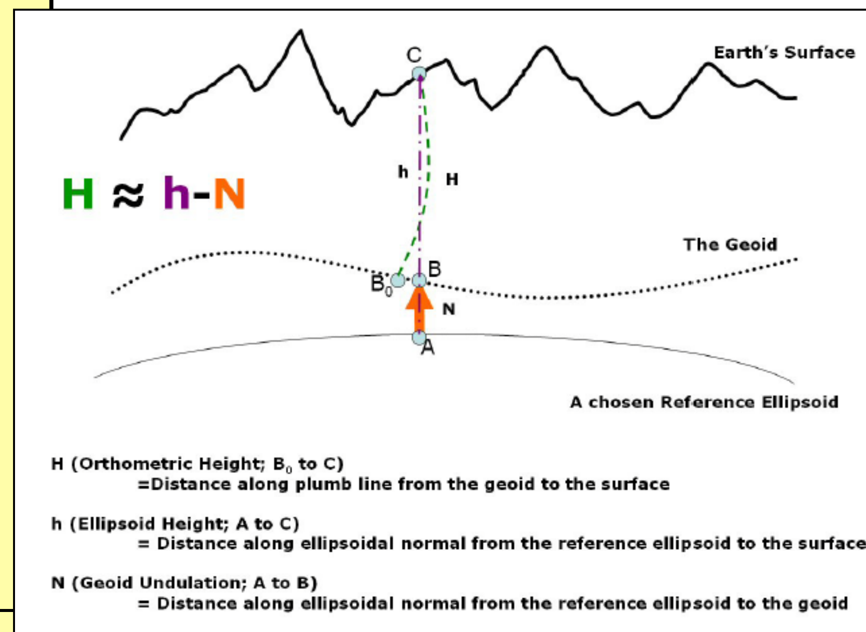


Figure 1: Relationship between Orthometric, Ellipsoid and Geoid Heights

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

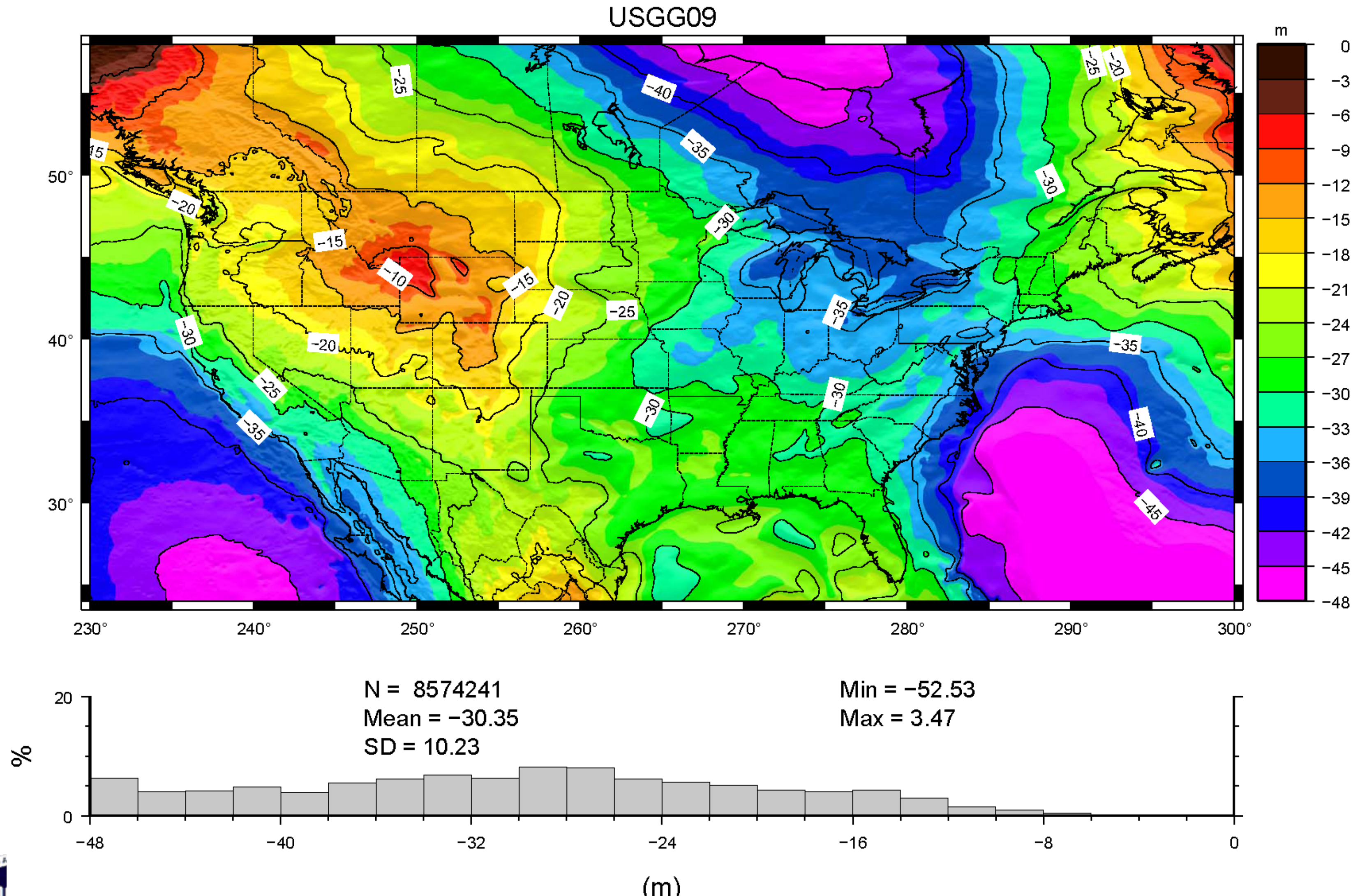
FIG Paper 3768

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 <u>not</u> interchangeable).

*Definition from the Geodetic Glossary, September 1986

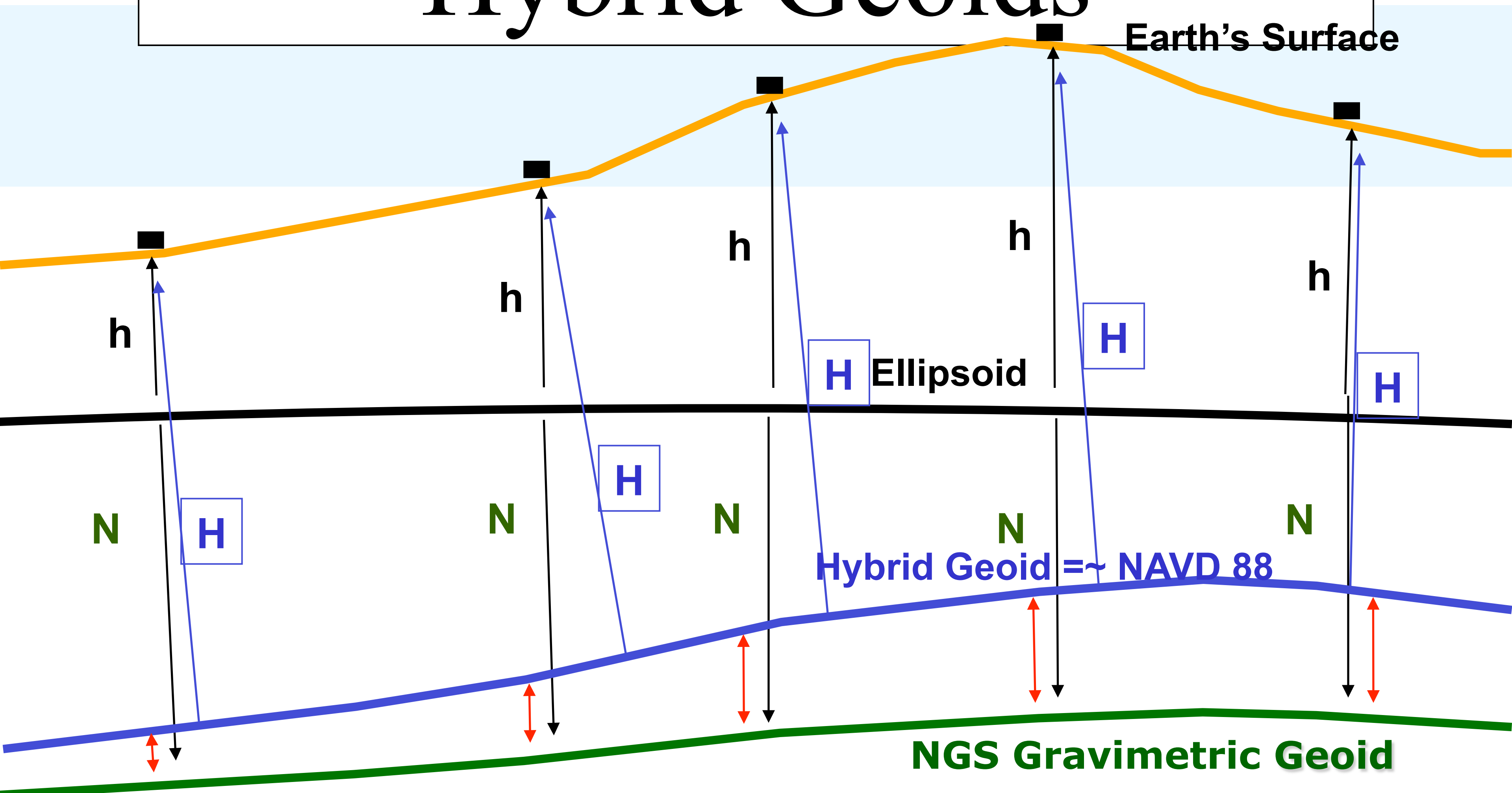
USGG09 Geoid Model



National Ocean Service

National Geodetic Survey

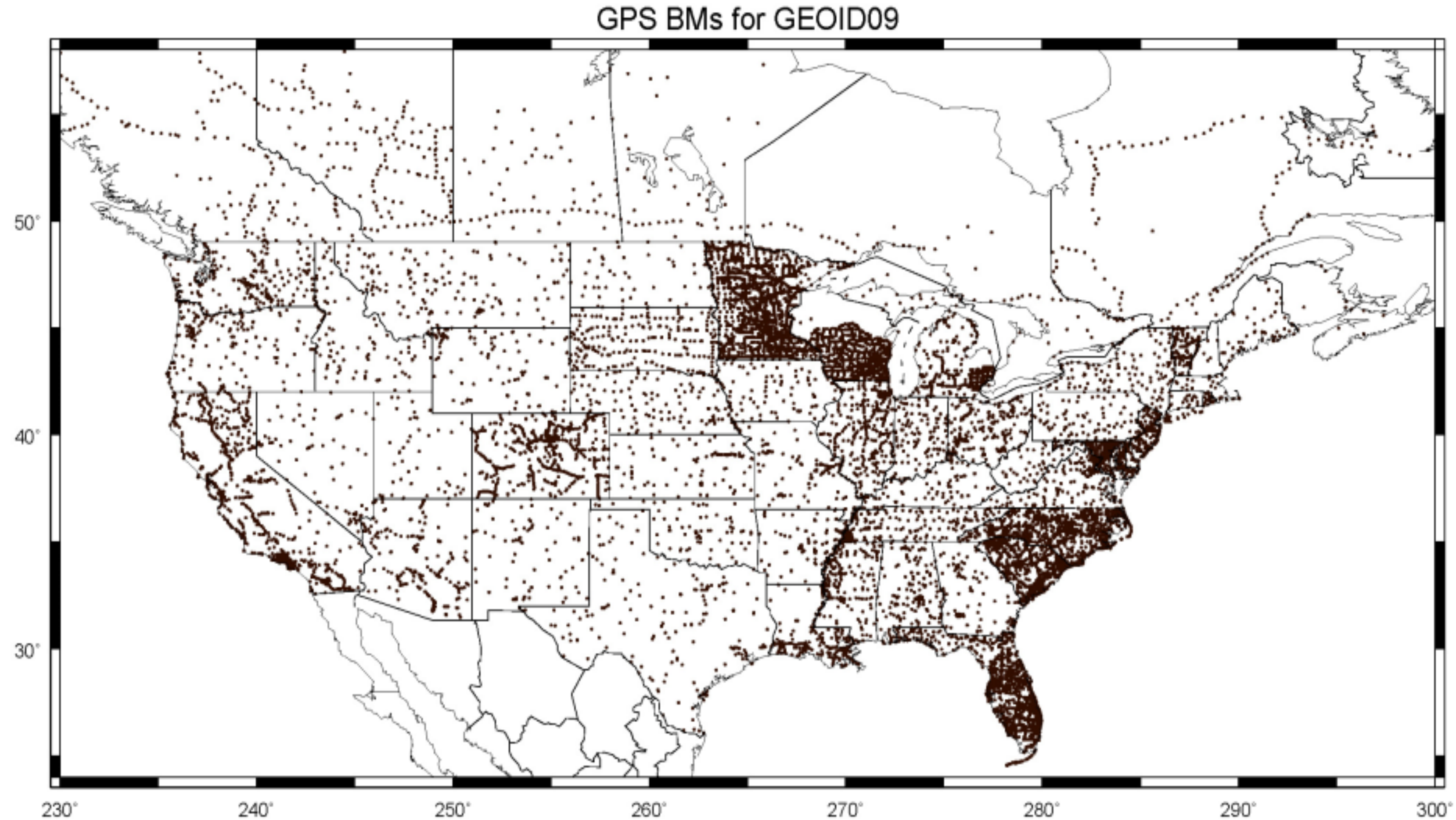
Hybrid Geoids



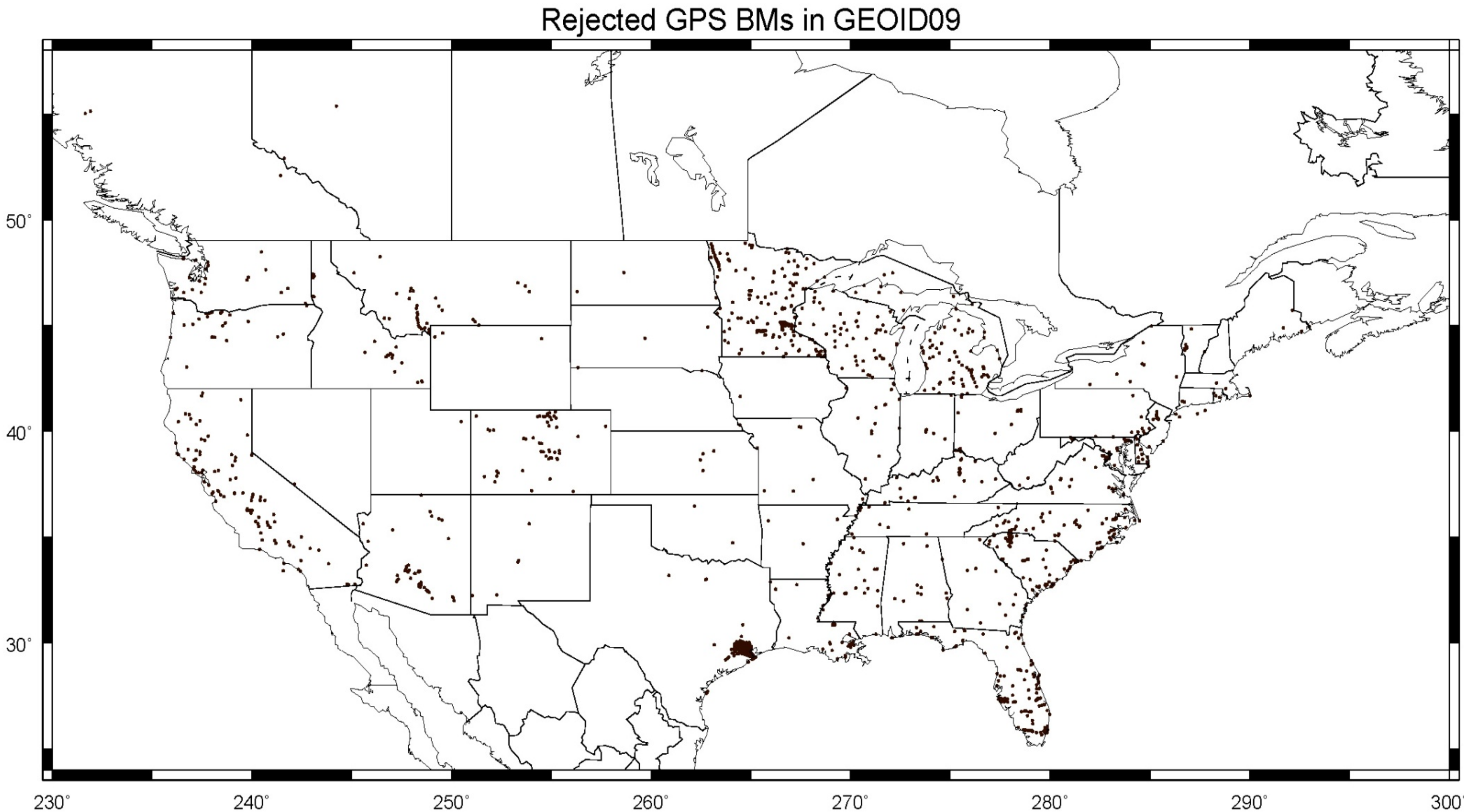
- Gravimetric Geoid systematic misfit with benchmarks
- Hybrid Geoid biased to fit local benchmarks
- e = h – H - N

GPSBM2009 (GEOID09 Control Data)

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

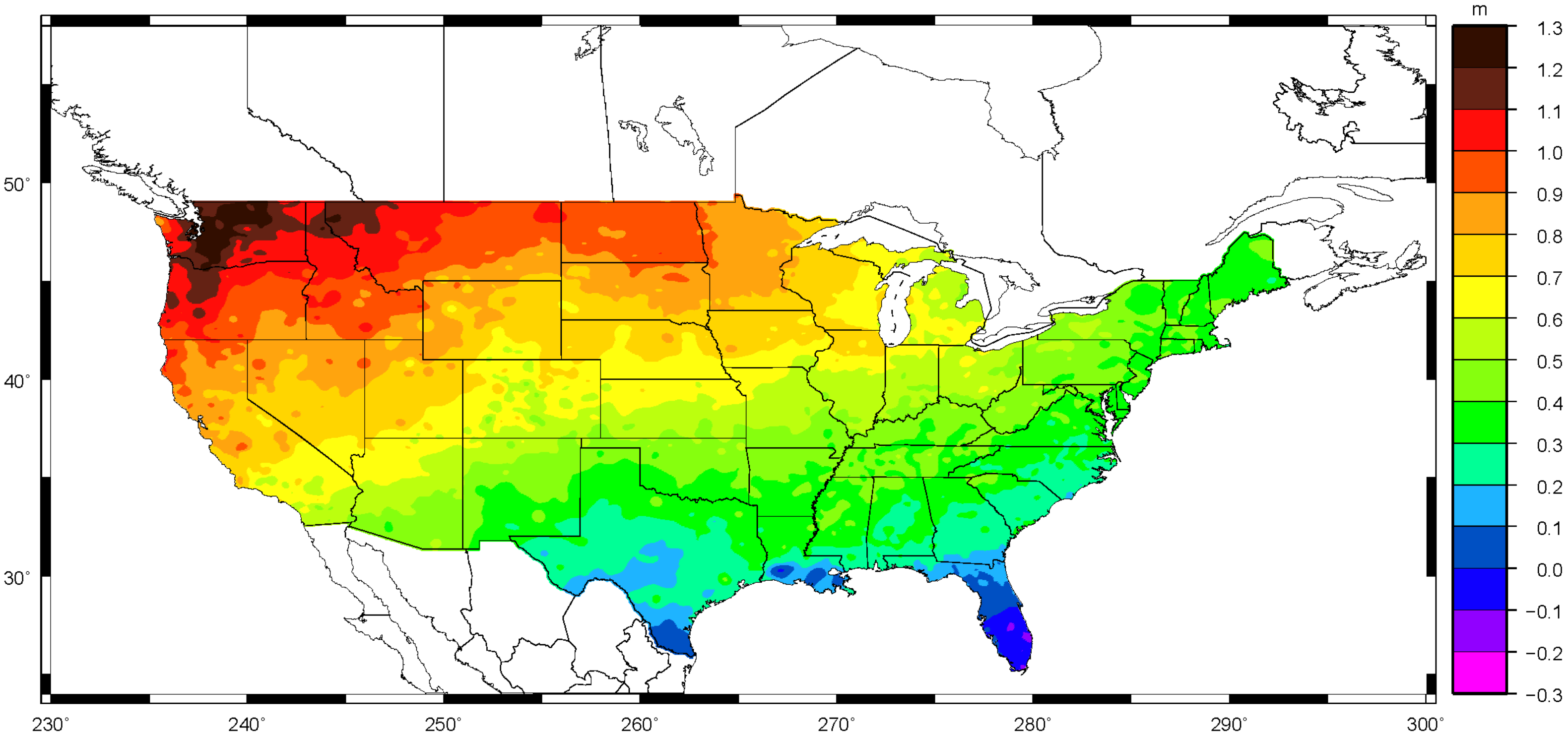


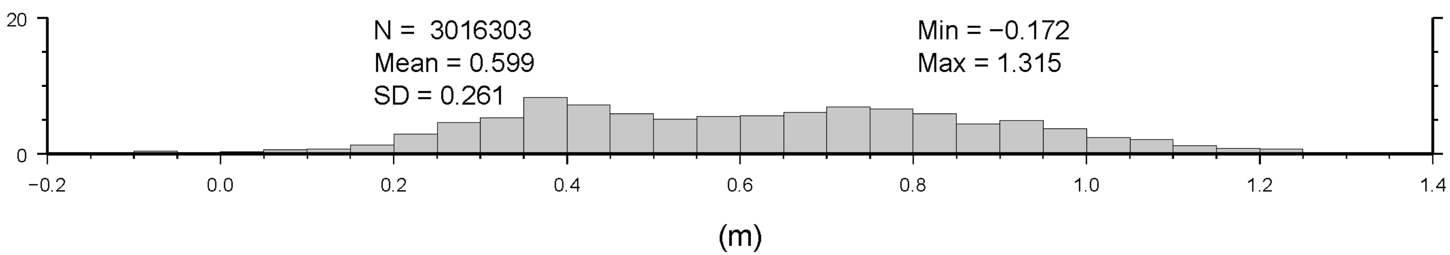
Rejected GPS Bench Marks in GEOID09



Conversion Surface from USGG09 to GEOID09

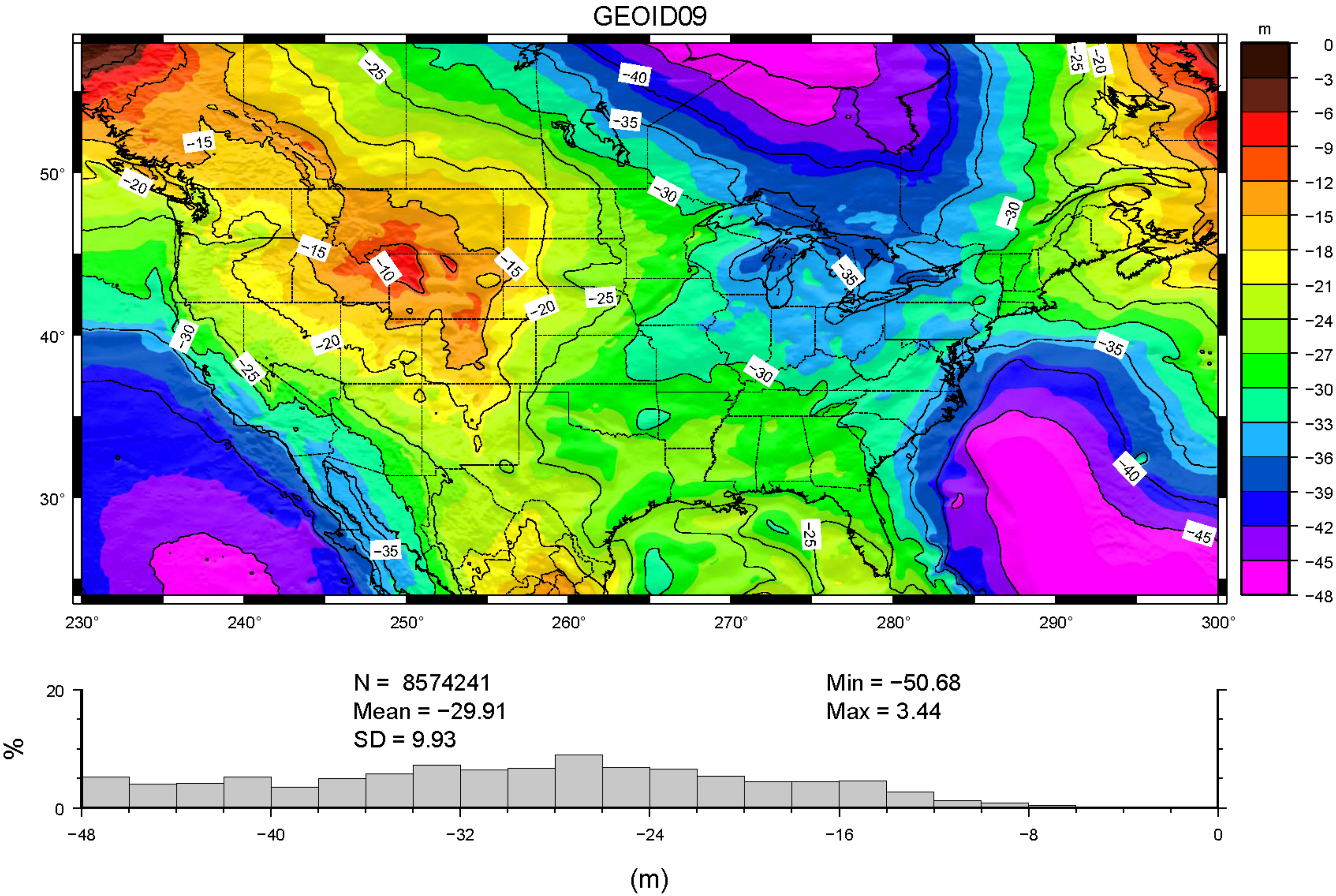
The Conversion Surface from USGG09 to GEOID09





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

GEOID09 Geoid Model



National Ocean Service

National Geodetic Survey

Comparisons For CONUS Regions

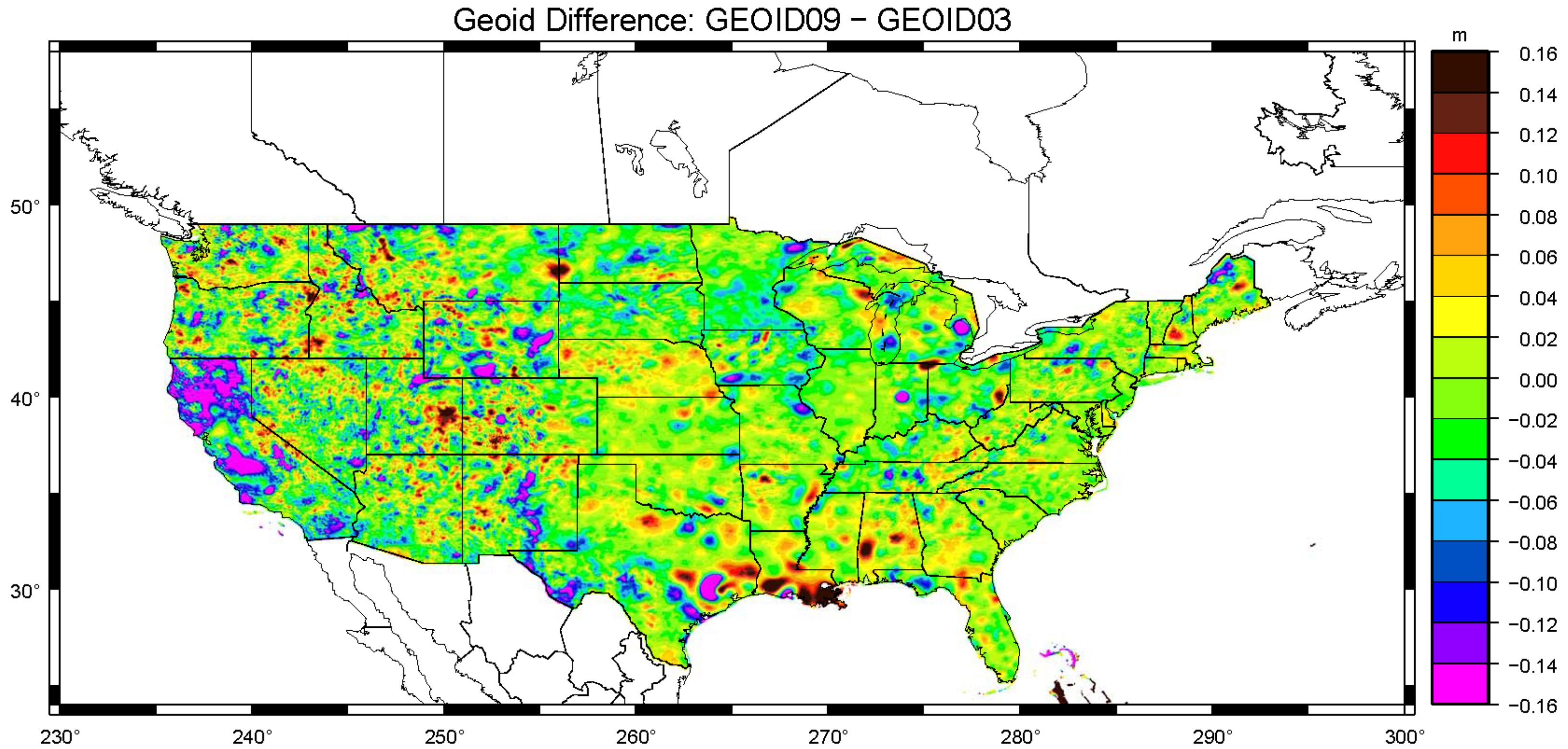
ST ID	No. Pts.	USGG2009		GEOID09		ST ID	No. Pts.	USGG2009		GEOID09	
		Ave (m)	SD (m)	Ave (m)	SD (m)			Ave (m)	SD (m)	Ave (m)	SD (m)
AL	283	-0.206	0.050	0.000	0.011	IN	119	0.026	0.057	0.000	0.013
AZ	227	0.015	0.087	0.000	0.016	IA	100	0.189	0.060	-0.001	0.009
AR	133	-0.116	0.034	0.001	0.018	KS	105	0.070	0.058	0.000	0.009
CA	738	0.234	0.132	0.000	0.022	KY	123	-0.086	0.038	-0.001	0.013
CO	562	0.106	0.083	0.000	0.025	LA	217	-0.355	0.106	-0.001	0.012
CT	20	-0.142	0.035	0.000	0.015	ME	65	-0.144	0.043	0.000	0.011
DE	35	-0.179	0.046	0.001	0.012	MD	511	-0.126	0.037	0.000	0.016
DC	16	-0.118	0.021	0.004	0.020	MA	35	-0.163	0.041	0.000	0.012
FL	2181	-0.541	0.083	0.000	0.014	MI	410	0.087	0.043	0.000	0.015
GA	137	-0.265	0.064	0.000	0.014	MN	4089	0.309	0.038	0.000	0.009
ID	97	0.469	0.079	0.001	0.011	MS	243	-0.151	0.048	0.000	0.019
IL	334	0.106	0.091	0.001	0.011	MO	138	0.008	0.074	0.000	0.010

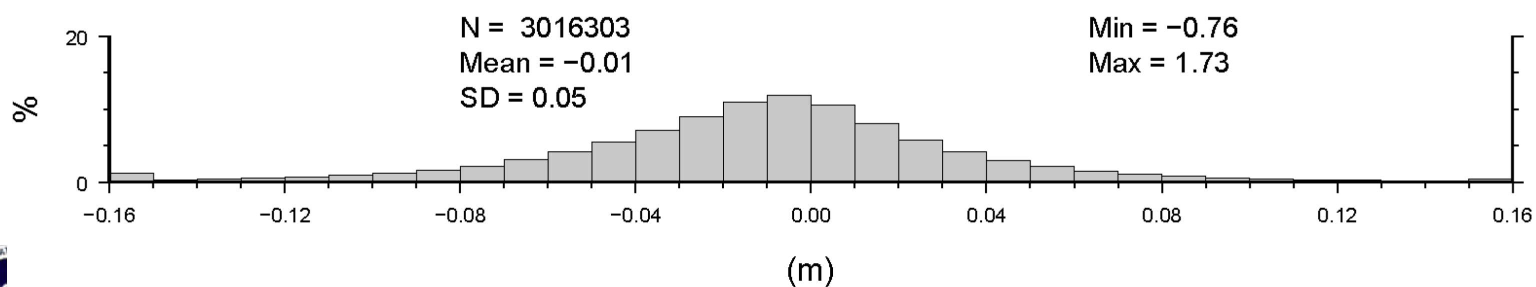
Comparisons For CONUS Regions

ST ID	No. Pts.	USGG2009		GEOID09		ST ID	No. Pts.	USGG2009		GEOID09	
		Ave (m)	SD (m)	Ave (m)	SD (m)			Ave (m)	SD (m)	Ave (m)	SD (m)
MT	151	0.469	0.091	0.000	0.009	RI	29	-0.147	0.023	0.000	0.018
NE	145	0.177	0.047	0.000	0.007	SC	1315	-0.221	0.057	0.000	0.012
NV	70	0.247	0.089	0.001	0.012	SD	242	0.285	0.062	0.000	0.008
NH	14	-0.141	0.018	-0.003	0.009	TN	302	-0.106	0.031	0.000	0.018
NJ	326	-0.144	0.028	0.000	0.011	TX	218	-0.257	0.085	0.000	0.012
NM	107	-0.103	0.091	0.000	0.015	UT	55	0.223	0.090	0.000	0.016
NY	185	-0.104	0.064	0.000	0.011	VT	317	-0.141	0.030	0.000	0.013
NC	1676	-0.226	0.046	0.000	0.015	VA	434	-0.141	0.040	0.000	0.021
ND	47	0.412	0.033	0.001	0.007	WA	259	0.610	0.083	0.000	0.017
OH	297	0.022	0.047	0.000	0.022	WV	55	-0.059	0.045	0.001	0.013
OK	79	-0.089	0.057	0.000	0.008	WI	758	0.172	0.036	0.000	0.007
OR	202	0.523	0.081	0.000	0.015	WY	101	0.270	0.089	-0.001	0.017
PA	96	-0.080	0.045	-0.001	0.013	CONUS	18398	-0.010	0.063	0.000	0.014

CONUS Fit = 1.4 cm

Geoid Differences: GEOID09 – GEOID03





Sample Datasheet: Montgomery County Airport (CXO)

```
National Geodetic Survey, Retrieval Date = JANUARY 29, 2010 BL2014
********************************************************************** 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 ___________________________________________________________________
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 (fe
```

H

h

N

NAVD88 – Ellip 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

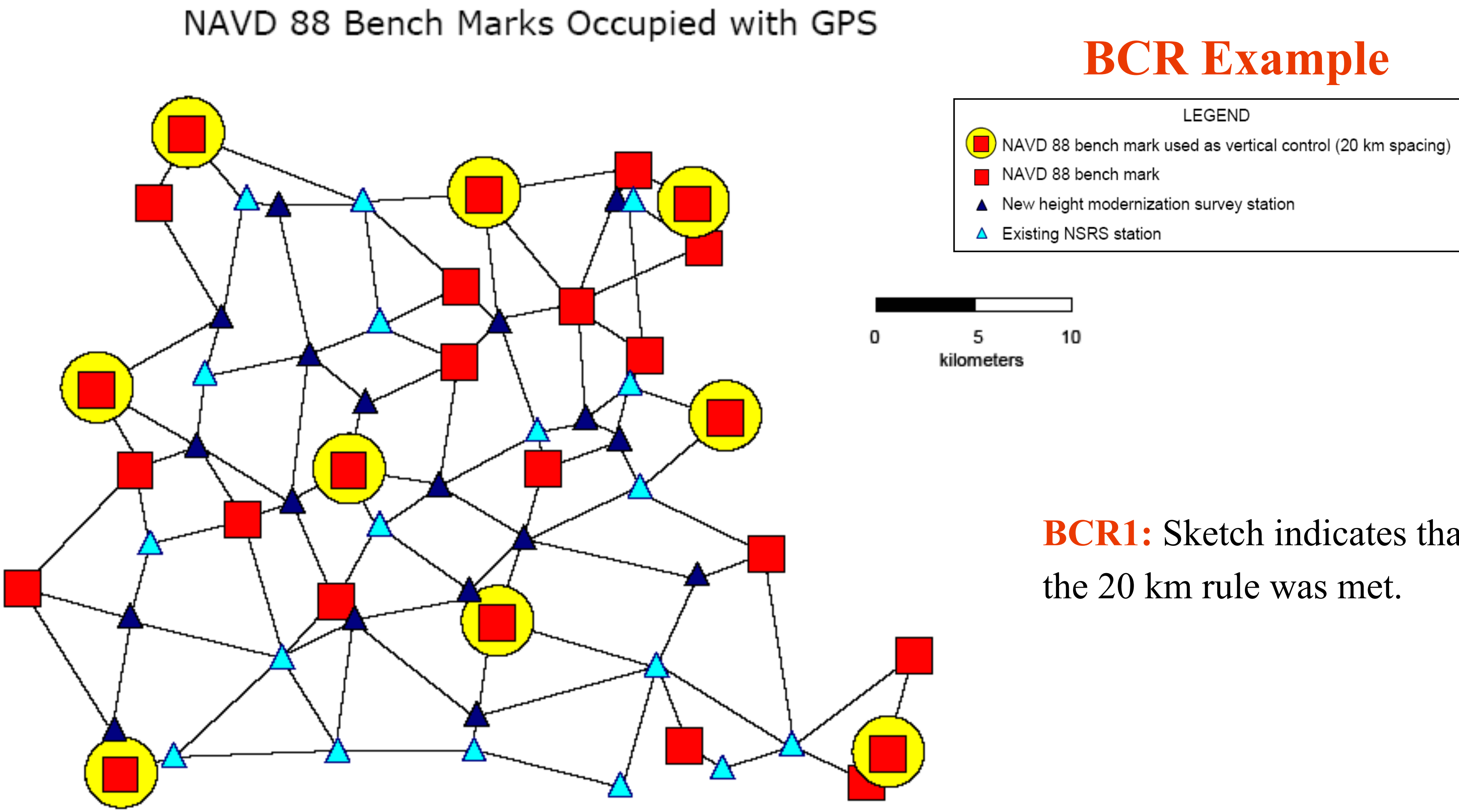
Largely driven by GPSBM changes

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**

BCR Example



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.

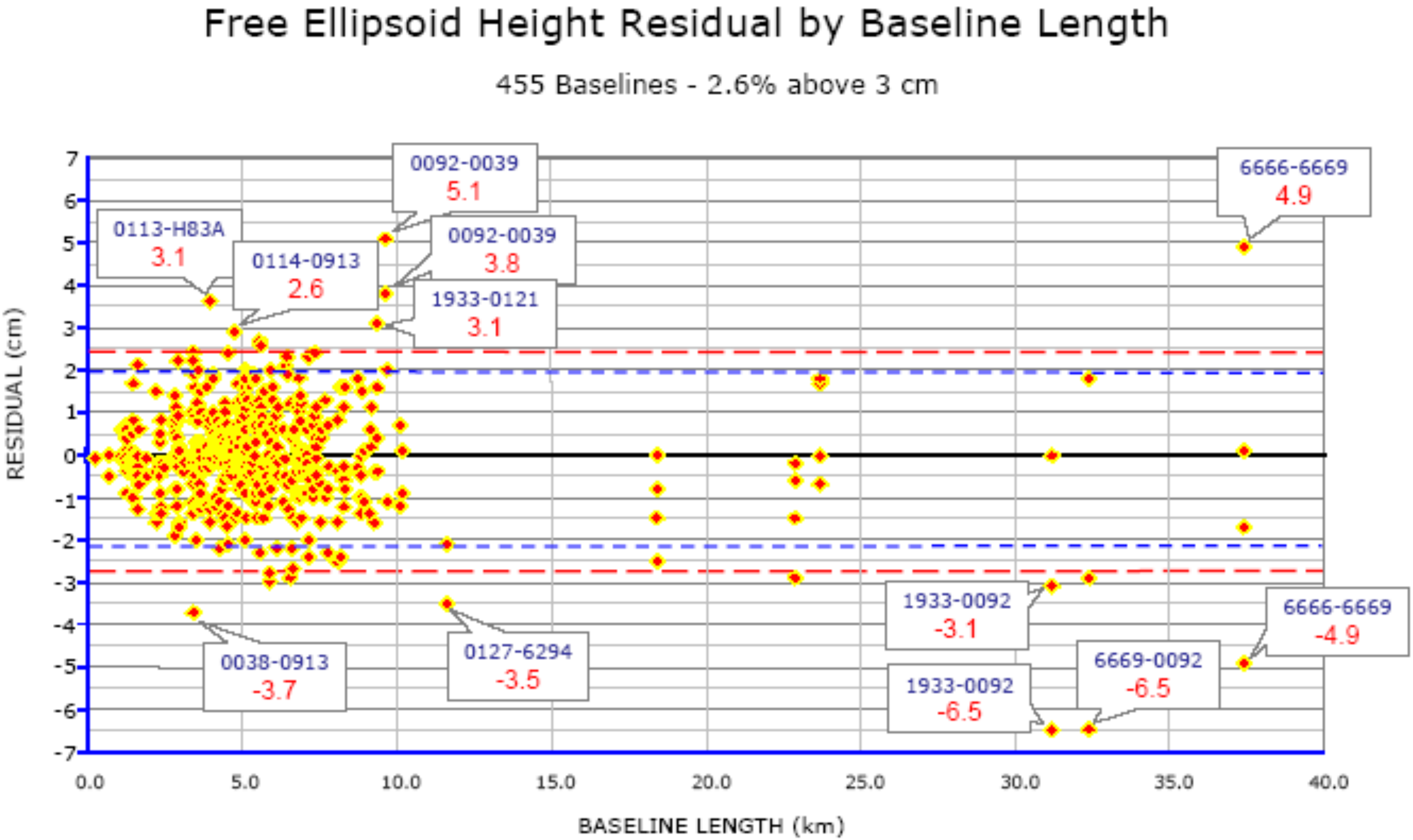
BCR3: Circled bench marks are mandatory. Analysis must indicate bench marks have valid NAVD 88 heights. Other BMs can be substituted but user must adhere to 20 km requirement.

BCR4: This requirement is not applicable because project is not in a mountainous region.

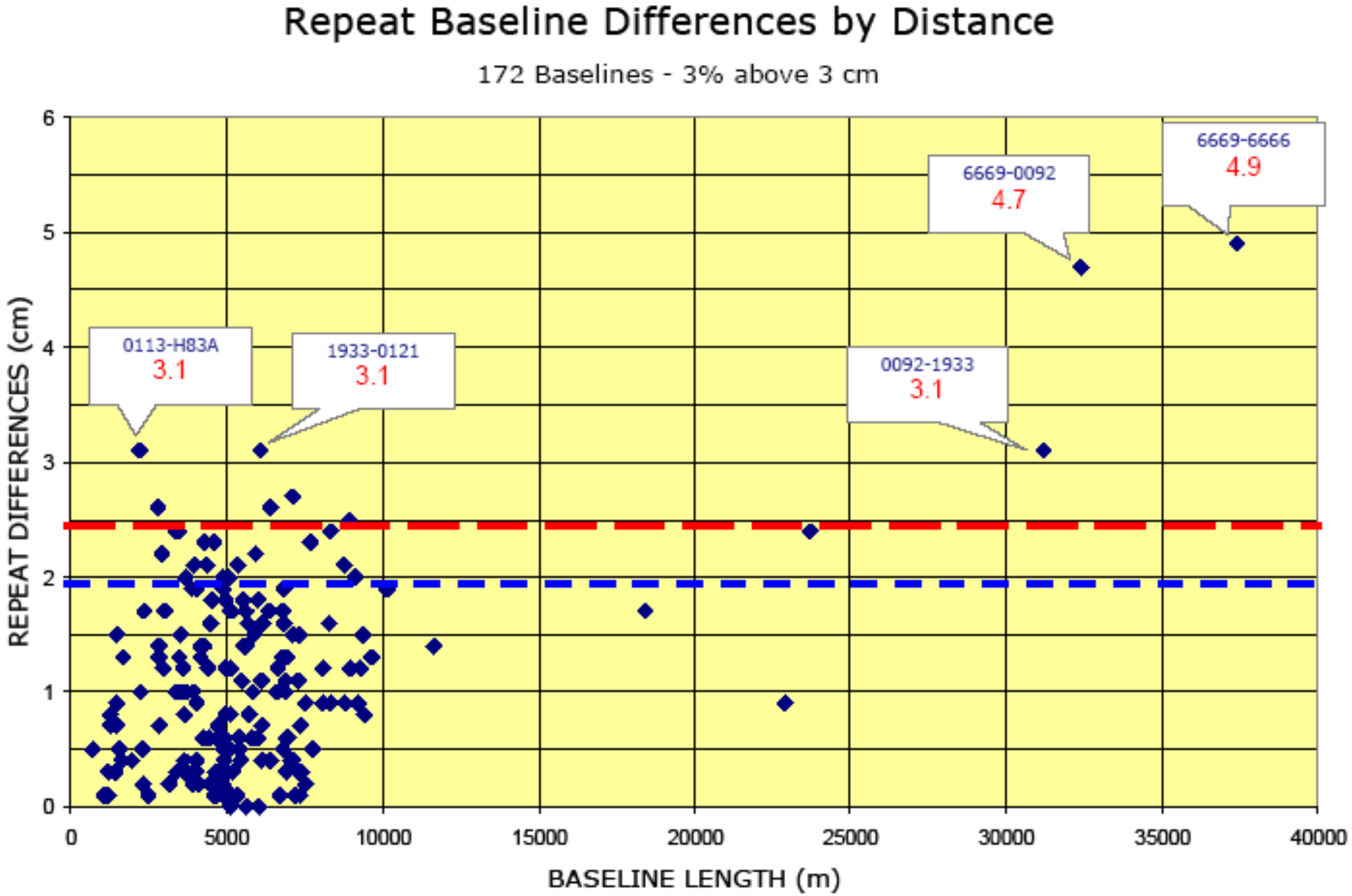
Five Basic Adjustment Procedures

- **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.

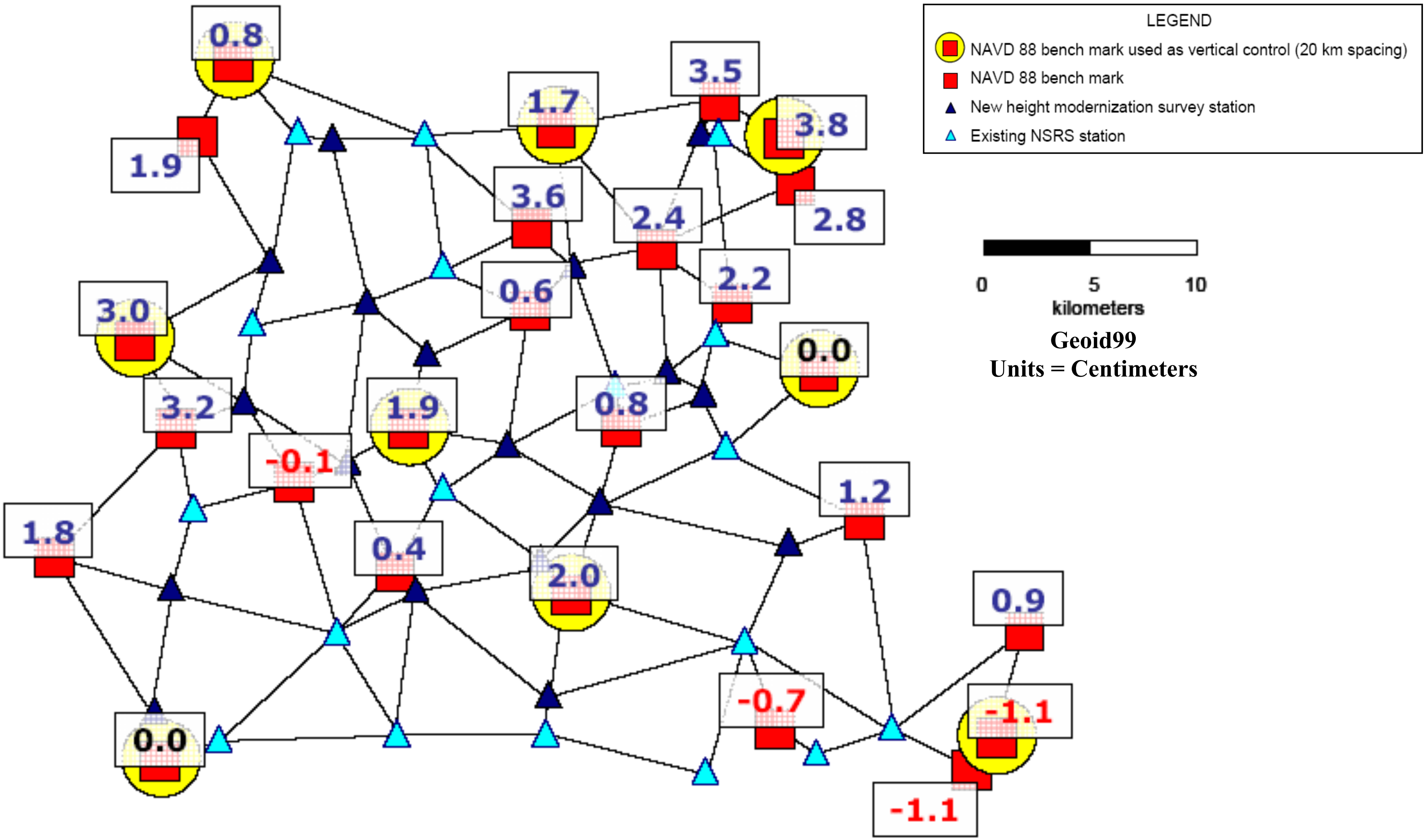


Station pairs with large residuals, i.e., greater than 2.5 cm, also have large repeat base line differences. NGS guidelines for estimating GPS-derived ellipsoid heights require user to re-observe these base lines. Following NGS guidelines provides enough redundancy for adjustment process to detect outliers 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**

GPS-Derived Orthometric Heights Minus NAVD88 Heights



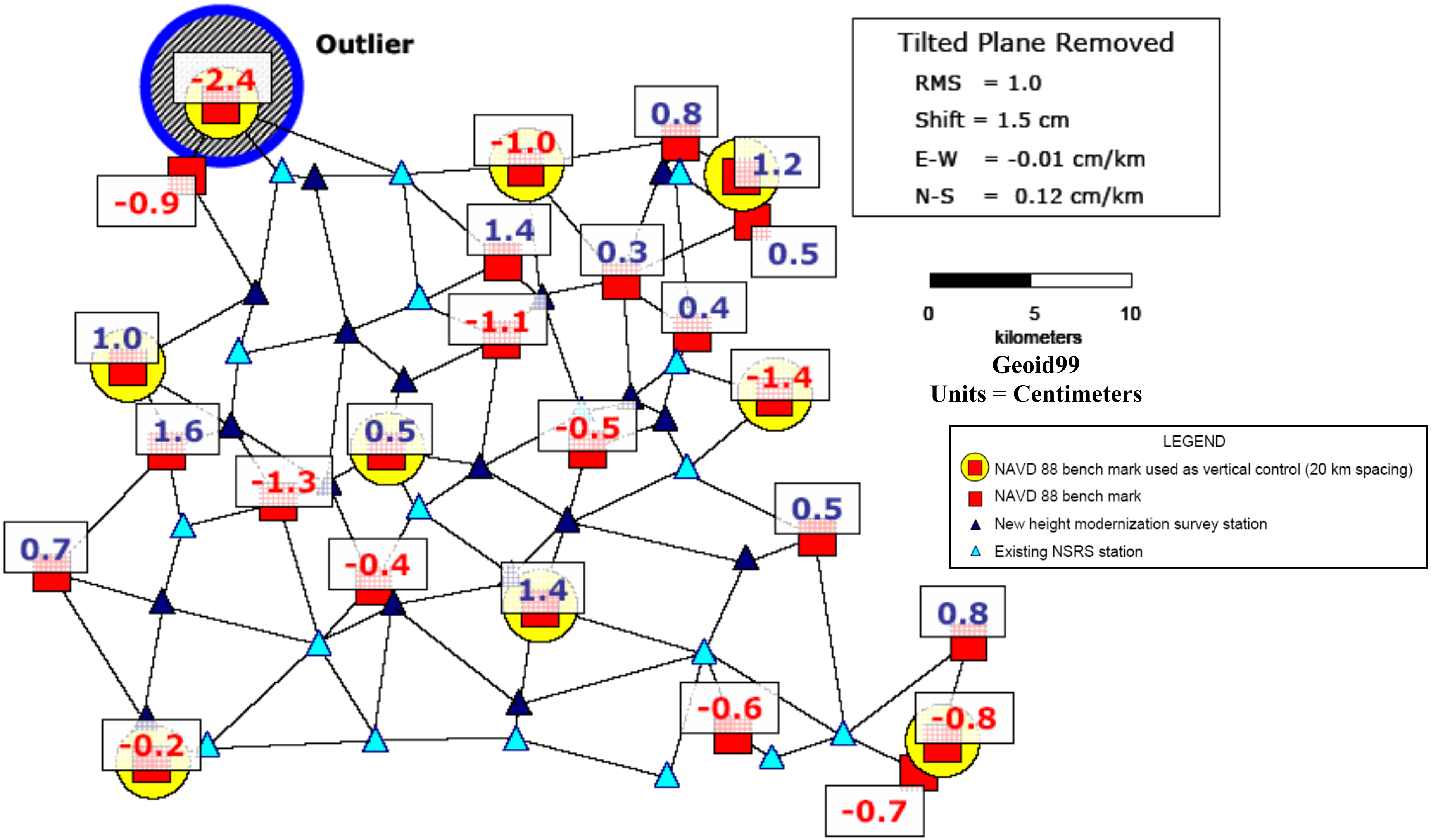
All height differences are under 5 cm and most are less than 2 cm. Almost all relative height differences between adjacent station pairs are less than 2 cm. However, most of the height differences appear to be positive relative to the southwest corner of the project.

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**

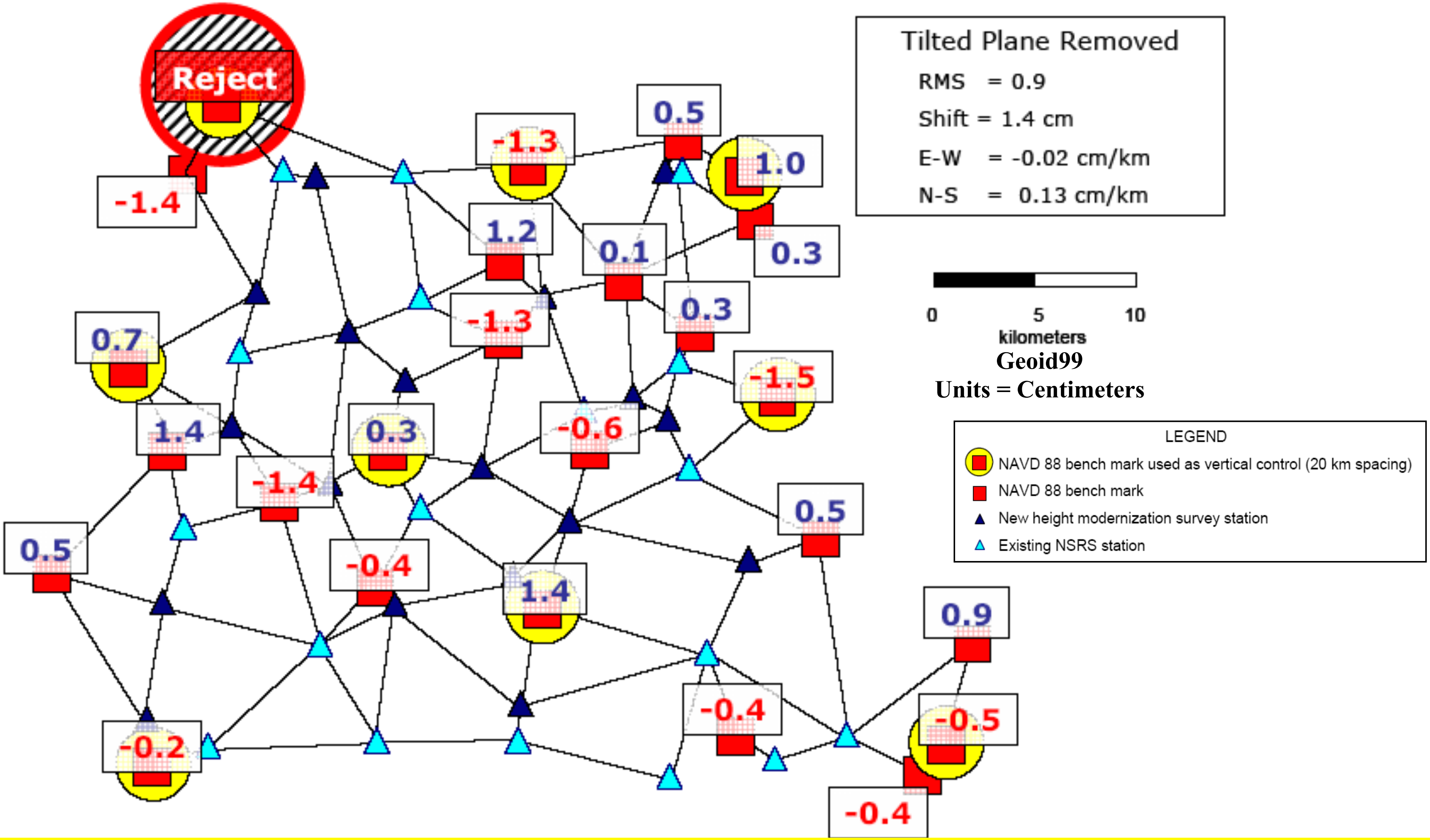
- **BAP-5: Perform constrained adjustment with results from BP-4**
  - **Constrain 1 latitude, 1 longitude, all valid orthometric height values**
  - **Ensure final heights not distorted in adjustment**

GPS-Derived Orthometric Heights Minus NAVD88 Heights



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.

GPS-Derived Orthometric Heights Minus NAVD88 Heights



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.

Elevation published to centimeters

- The NGS Data SheetSee 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 ***
- 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* NAD 83(2007)- 37 50 41.57945(N) 120 30 24.15335(W) ADJUSTED
- DF8611* NAVD 88 - 336.56 (meters) 1104.2 (feet) GPS OBS
- DF8611 ____
- 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 ------- Accuracy Estimates (at 95% Confidence Level in cm) --------
- DF8611 Type PID Designation North East Ellip
- DF8611 ---
- DF8611 NETWORK DF8611 KEYS 0.35 0.41 1.25
- DF8611 ---
- 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
- 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

H (published) – (h - N) GEOID09 = 0.00 m

Orthometric height determined by GPS

The NGS Data Sheet

Elevation published to centimeters.

H (published) – (h - N)

GEOID03 = 0.02 m

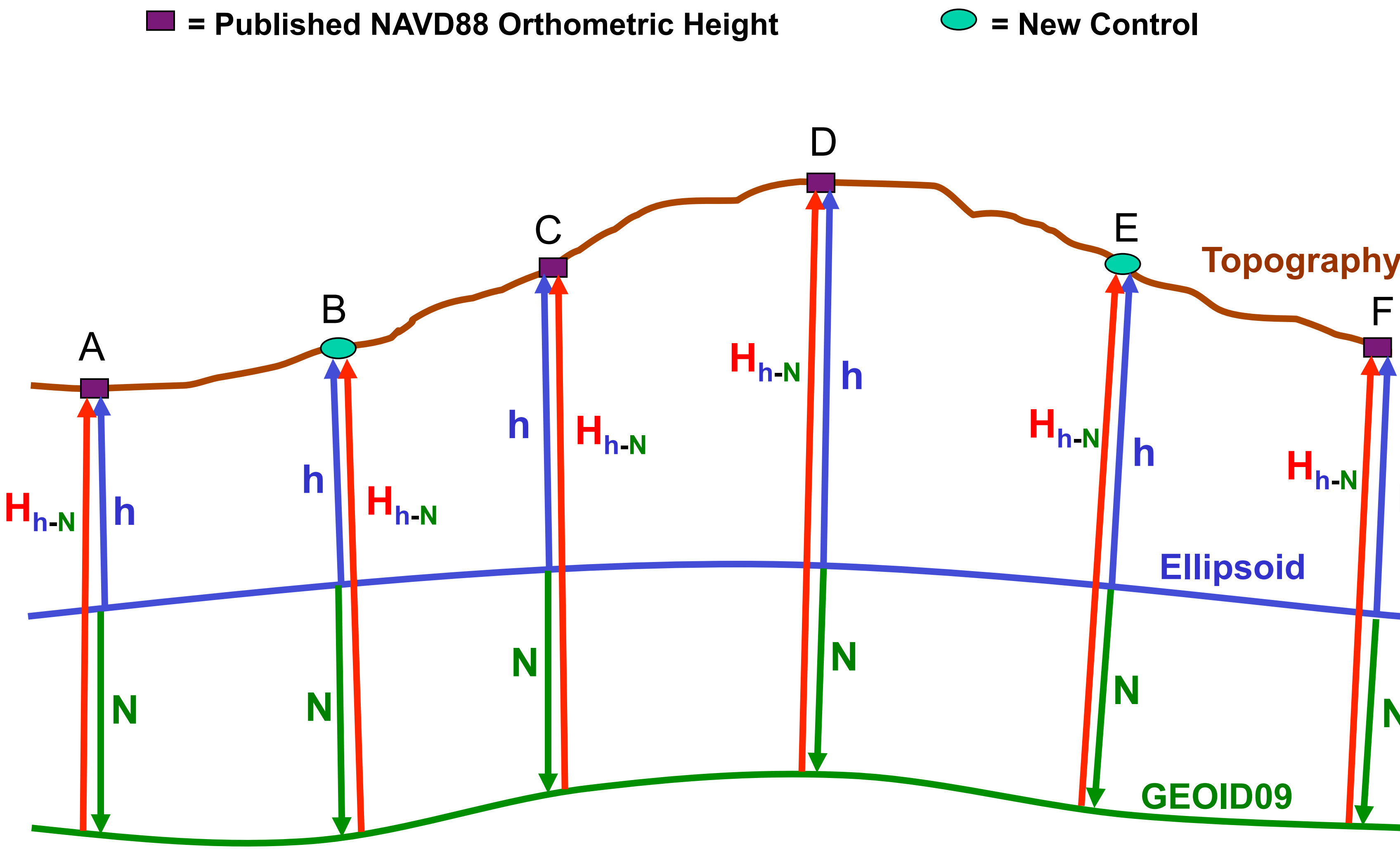
GEOID09 = 0.00 m

Orthometric height determined by GPS.

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

```
DATABASE = Sybase ,PROGRAM = datasheet, VERSION = 7.07
1          National Geodetic Survey,   Retrieval Date = OCTOBER 14, 2004
 DF8611 ***********************************************************************
 DF8611  DESIGNATION -  KEYS
 DF8611  PID         -  DF8611
 DF8611  STATE/COUNTY-  CA/TUOLUMNE
 DF8611  USGS QUAD   -  KEYSTONE (1987)
 DF8611
 DF8611                          *CURRENT SURVEY CONTROL
 DF8611  ___________________________________________________
 DF8611* NAD 83(1998)-  37 50 41.57829(N)    120 30 2
 DF8611* NAVD 88     -       336.56   (meters)    110
 DF8611  ___________________________________________________
 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)                    DEFLEC99
 DF8611  ELLIP HEIGHT-          306.91  (meters)          (10/24/03) GPS OBS
 DF8611  GEOID HEIGHT-          -29.63  (meters)                     GEOID03
 DF8611
 DF8611  HORZ ORDER  -  B
 DF8611  ELLP ORDER  -  FOURTH    CLASS I
 DF8611
 DF8611.The horizontal coordinates were established by GPS observations
 DF8611.and adjusted by the National Geodetic Survey in October 2003.
 DF8611.This is a SPECIAL STATUS position.  See SPECIAL STATUS under the
 DF8611.DATUM ITEM on the data sheet items page.
 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
 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 DEFLEC99 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 GEOID03.
```

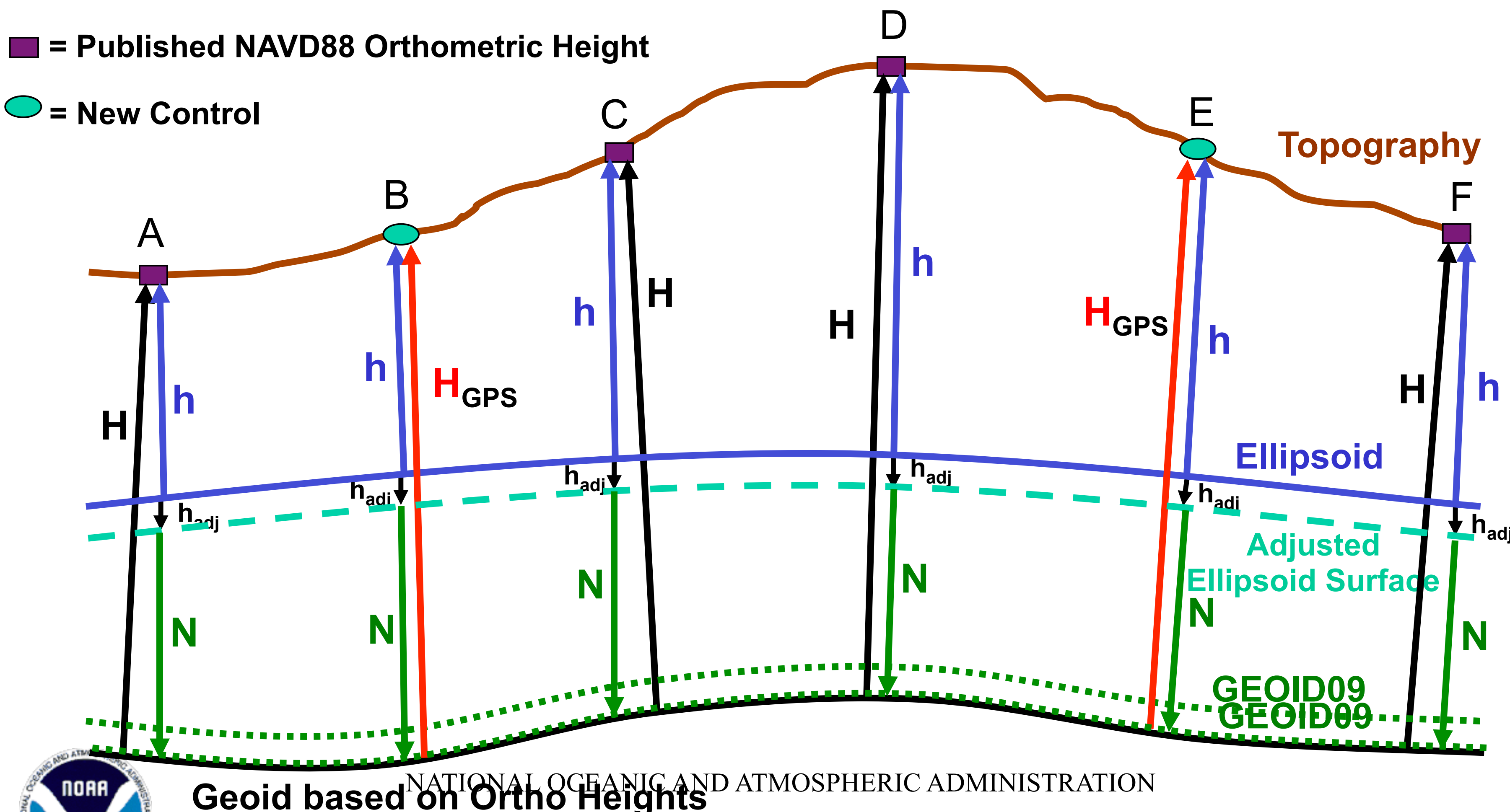
GPS-Derived Heights from GEOID09 Separation



Constrained Vertical Adjustment

Ellipsoid Height Adjusted to Fit Constrained Orthometric Heights

GPS-Derived Orthometric Heights



NGS Data Sheet – GEOID96 through GEOID09 Published NAVD88 to GPS Derived

GEOID96 = 0.17 m
GEOID99 = 0.11 m
GEOID03 = 0.05 m
GEOID09 = 0.02 m

$$H = h - N$$

$$102.431 = 69.78 - (-32.60)$$

$$102.431 \neq 102.38$$

```
H          S 1320
H          HT2268
H          CA/SAN FRANCISCO
H          SAN FRANCISCO NORTH (1975)
H
H                  *CURRENT SURVEY CONTROL
HT2268
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
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
HT2268  HORZ ORDER  -   FIRST
HT2268  VERT ORDER  -   FIRST      CLASS I
HT2268  ELLP ORDER  -   FOURTH     CLASS I
HT2268
```

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**

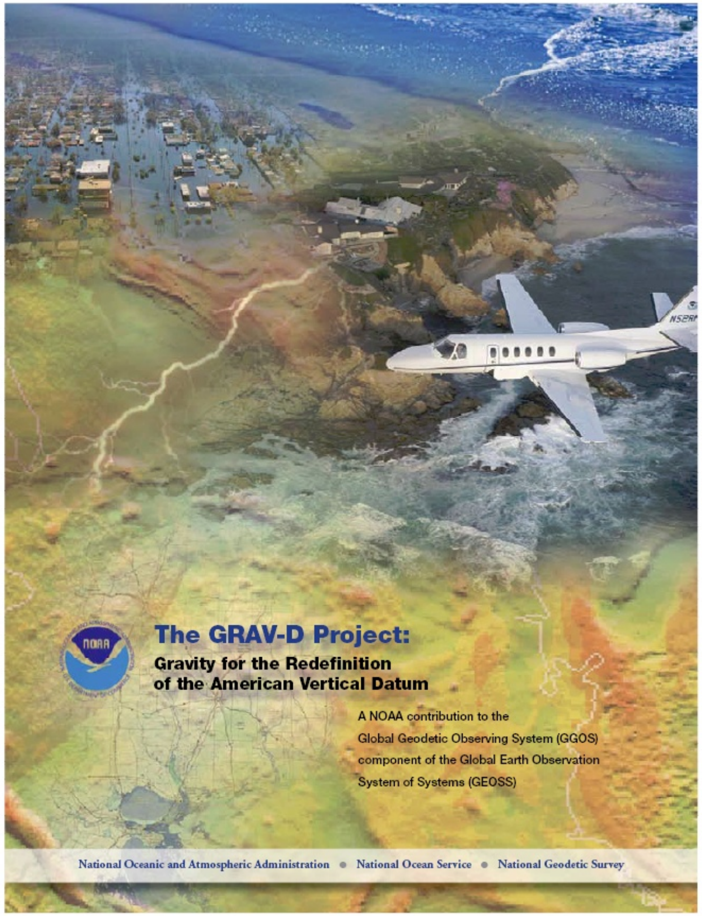
Ten-Year Milestones (2022)

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

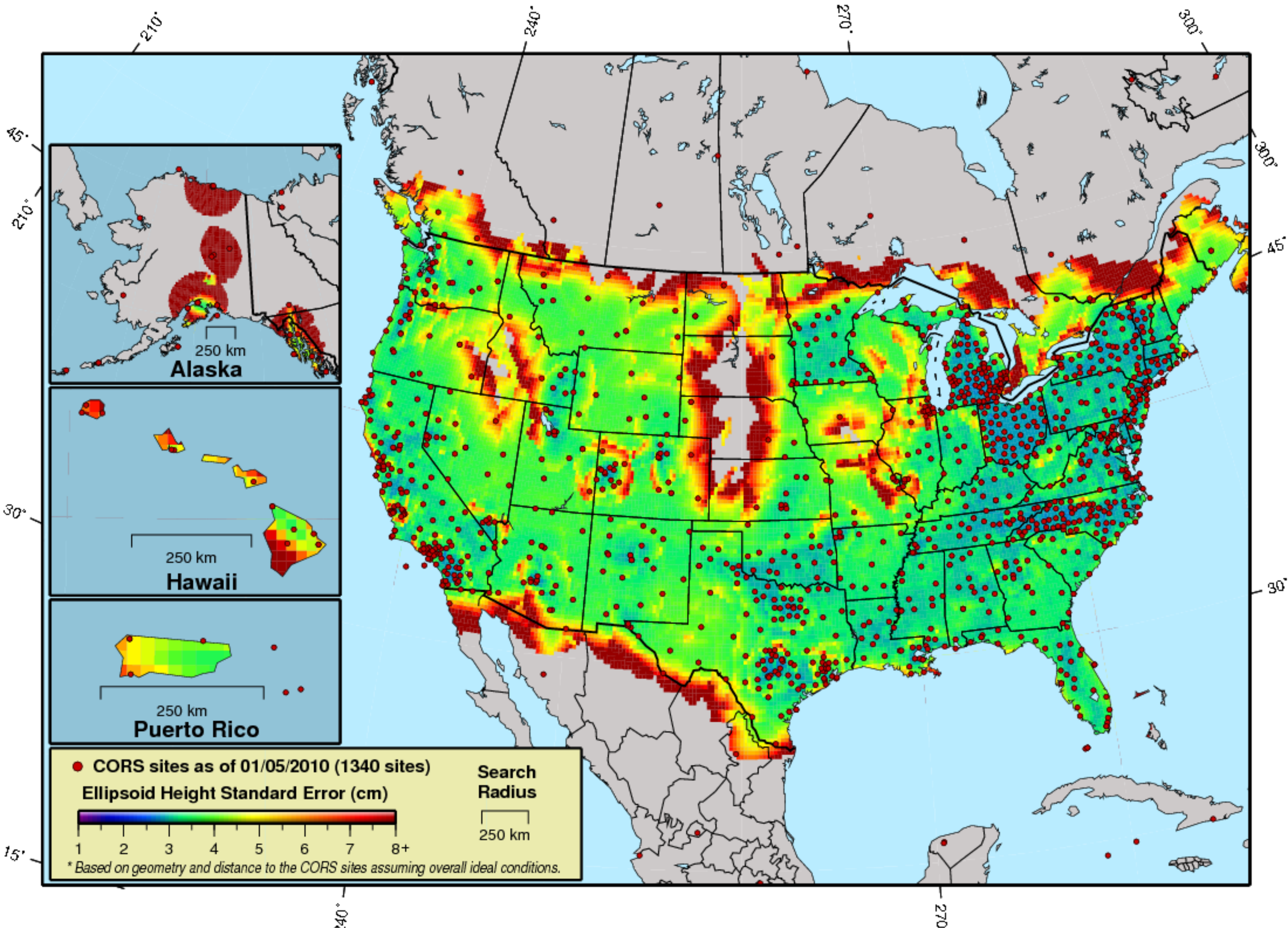
OPUS-DB
$$ Receivers
4 Hours of data
Results shared

OPUS Tool Box

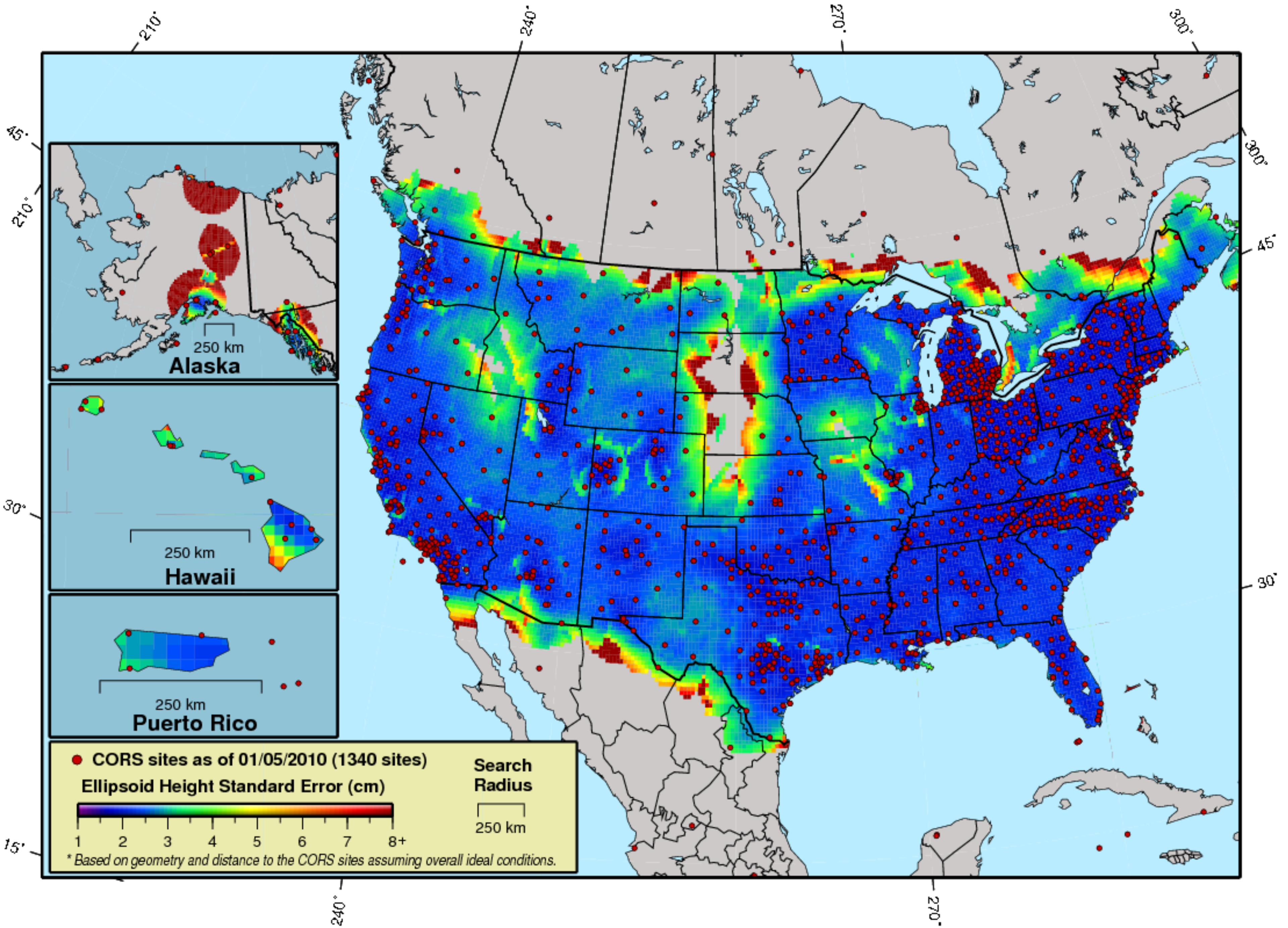
OPUS-Projects
$$ Receivers
2-4 Hours of data
Multiple Receivers
Network Solution
Results shared or not

LOCUS
Digital Bar-Code Leveling
Integration with GPS?
Results shared or not

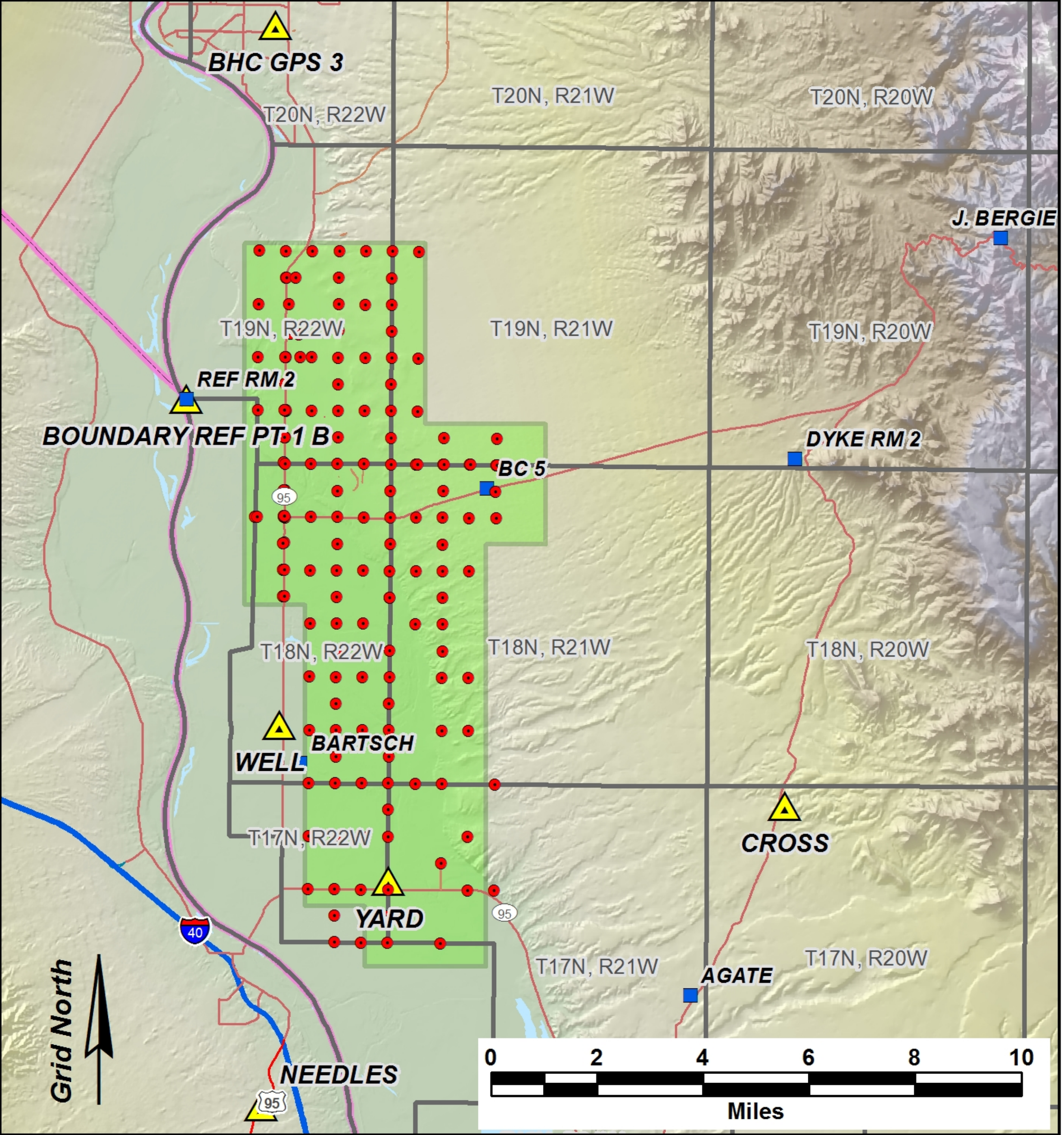
Predicted OPUS–RS Standard Error for Ellipsoid Height (15–min data)*



Predicted OPUS–RS Standard Error for Ellipsoid Height (1–hour data)*



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

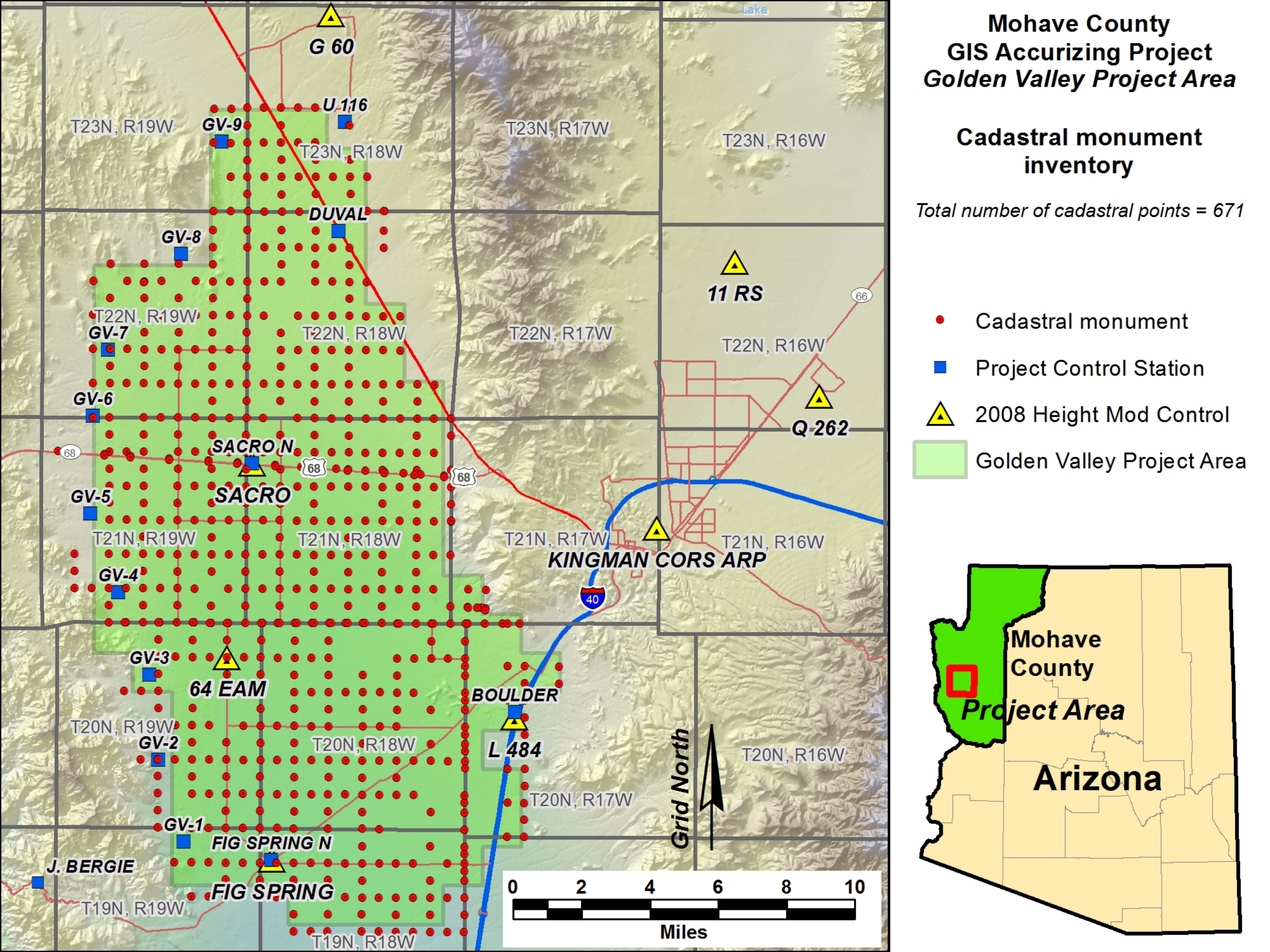
- Cadastral monument
- Project Control Station
- 2008 Height Mod Control
- Mohave Valley Project Area

Integrated and Collaborative Organizations Create Geospatial Solutions

	E	F	G	K	L	O
1	**Base station name** Control Station	**Rover station name**	**Vector Length (km)**	**Duration of rover occupation**	**Midpoint time of rover occupation**	**dU residual (cm) - constrained adj**
2	BC 5	10237_20191	3.02	0:00:30	2010-06-01 04:47:43 PM	-1.31
3	BNDY REF PT 1B	10237_20191	6.52	0:00:29	2010-05-26 01:44:59 PM	0.94
4	BC 5	10240_20183	5.41	0:00:30	2010-06-01 12:56:37 PM	1.53
5	BNDY REF PT 1B	10240_20183	4.28	0:00:29	2010-05-26 02:17:42 PM	-0.63
6	BNDY REF PT 1B	10247_30303	8.10	0:00:30	2010-05-26 04:39:23 PM	3.32
7	WELL	10247_30303	5.73	0:00:32	2010-06-03 01:23:32 PM	-2.77
8	BNDY REF PT 1B	10250_30307	6.94	0:00:37	2010-05-27 01:31:27 PM	1.11
9	WELL	10250_30307	4.99	0:01:48	2010-06-03 03:39:34 PM	-1.19
10	BNDY REF PT 1B	10251_30306	7.56	0:03:44	2010-05-27 01:43:47 PM	0.40
11	WELL	10251_30306	4.24	0:04:12	2010-06-03 03:23:55 PM	-0.63
12	BNDY REF PT 1B	10252_30308	6.43	0:00:51	2010-05-27 01:56:16 PM	0.25
13	WELL	10252_30308	4.78	0:00:32	2010-06-03 03:47:13 PM	-0.57
14	BC 5	10257_20172	7.81	0:00:30	2010-06-01 02:28:42 PM	-0.08
15	BNDY REF PT 1B	10257_20172	5.91	0:00:30	2010-05-26 04:02:27 PM	3.66
16	BC 5	10258_20173	8.02	0:00:30	2010-06-01 04:08:58 PM	-1.86
17	BNDY REF PT 1B	10258_20173	2.51	0:00:30	2010-05-26 04:43:34 PM	4.34
18	BC 5	10263_20184	3.74	0:00:36	2010-06-01 01:29:48 PM	0.04
19	BC 5	10263_20184	3.74	0:00:30	2010-06-01 05:52:31 PM	0.00

	E	F	G	K	L	O
1	Base station name Control Station	Rover station name Control Station	Vector Length (km)	Duration of rover occupation	Midpoint time of rover occupation	dU residual (cm) - constrained adj
2	BC 5	BNDY REF PT 1B	9.54	0:00:30	2010-06-01 11:55:47 AM	-0.58
3	BC 5	BNDY REF PT 1B	9.54	0:00:30	2010-06-01 12:31:46 PM	2.21
4	BC 5	BNDY REF PT 1B	9.54	0:00:27	2010-06-01 05:58:14 PM	-1.39
5	BC 5	BNDY REF PT 1B	9.54	0:00:32	2010-06-01 06:36:28 PM	-2.10
6	BC 5	BNDY REF PT 1B	9.54	0:00:30	2010-06-02 11:00:39 AM	-0.07
7	BC 5	BNDY REF PT 1B	9.54	0:00:40	2010-06-02 06:11:52 PM	1.20
8	BC 5	BNDY REF PT 1B	9.54	0:01:04	2010-06-03 05:21:18 PM	0.40
9	BC 5	BNDY REF PT 1B	9.54	0:00:42	2010-06-07 11:12:25 AM	1.42
10	BC 5	BNDY REF PT 1B	9.54	0:00:30	2010-06-07 05:26:10 PM	-3.27
11	WELL	NEEDLES	11.59	0:00:30	2010-06-03 12:15:19 PM	-0.17
12	WELL	NEEDLES	11.59	0:00:35	2010-06-03 04:53:24 PM	-4.41
13	YARD	NEEDLES	7.85	0:00:30	2010-05-26 11:16:52 AM	0.43
14	YARD	NEEDLES	7.85	0:00:34	2010-06-01 11:28:21 AM	-1.43
15	YARD	NEEDLES	7.85	0:00:30	2010-06-01 05:23:54 PM	-1.10
16	YARD	NEEDLES	7.85	0:00:30	2010-06-02 11:15:43 AM	-2.25
17	YARD	NEEDLES	7.85	0:00:30	2010-06-02 05:45:44 PM	0.74
18	BC 5	REF RM 2	9.52	0:00:39	2010-06-03 11:44:11 AM	1.92
19	BNDY REF PT 1B	REF RM 2	0.02	0:00:30	2010-05-26 11:02:47 AM	0.39
20	BNDY REF PT 1B	REF RM 2	0.02	0:00:42	2010-05-26 11:04:11 AM	-0.30
21	BNDY REF PT 1B	REF RM 2	0.02	0:00:30	2010-05-26 05:31:39 PM	-0.17
22	BNDY REF PT 1B	REF RM 2	0.02	0:00:34	2010-05-27 10:52:46 AM	-0.21
23	BNDY REF PT 1B	REF RM 2	0.02	0:00:30	2010-05-27 11:28:38 AM	0.25
24	BNDY REF PT 1B	REF RM 2	0.02	0:00:29	2010-05-27 04:56:41 PM	-0.02
25	BNDY REF PT 1B	REF RM 2	0.02	0:00:30	2010-05-27 04:58:14 PM	0.51
26	BNDY REF PT 1B	REF RM 2	0.02	0:00:34	2010-06-08 12:23:20 PM	-0.32
27	BNDY REF PT 1B	REF RM 2	0.02	0:00:30	2010-06-08 05:29:55 PM	0.17
28	BNDY REF PT 1B	REF RM 2	0.02	0:00:30	2010-06-09 11:39:58 AM	-1.04
29	BNDY REF PT 1B	REF RM 2	0.02	0:00:30	2010-06-09 02:52:31 PM	-0.46

Geospatial


Mohave County
GIS Accurizing Project
Golden Valley Project Area
Cadastral monument inventory
Total number of cadastral points = 671
Cadastral monument
Project Control Station
2008 Height Mod Control
Golden Valley Project Area
G 60
U 116
GV-9
T23N, R19W
T23N, R18W
T23N, R17W
T23N, R16W
DUVAL
GV-8
11 RS
T22N, R19W
GV-7
T22N, R18W
T22N, R17W
T22N, R16W
GV-6
Q 262
SACRO N
SACRO
GV-5
T21N, R19W
T21N, R18W
T21N, R17W
T21N, R16W
KINGMAN CORS ARP
GV-4
GV-3
64 EAM
BOULDER
L 484
T20N, R19W
GV-2
T20N, R18W
T20N, R17W
T20N, R16W
Grid North
GV-1
FIG SPRING N
J. BERGIE
FIG SPRING
T19N, R19W
T19N, R18W
0 2 4 6 8 10
Miles
Mohave County
Project Area
Arizona

Base station name Control Station	Rover station name	Vector length (km)	Duration of rover occupation	Midpoint time of rover occupation	dU residual (cm) - constrained adj
SACRO	10001_20005_16	1.20	0:01:02	2010-05-04 01:39:55 PM	-0.34
SACRO	10001_20005_16	1.20	0:01:00	2010-05-04 03:04:15 PM	-0.10
SACRO	10001_20005_16	1.20	0:00:30	2010-05-05 02:49:22 PM	0.43
64 EAM	10002_30107	1.84	0:01:24	2010-05-11 02:03:39 PM	-0.26
SACRO	10002_30107	7.52	0:01:01	2010-05-04 02:07:54 PM	0.20
64 EAM	10003_30093	2.29	0:00:33	2010-05-10 04:31:51 PM	0.97
SACRO	10003_30093	7.53	0:01:02	2010-05-04 02:34:59 PM	-0.56
FIG SPRING	10007_30006	1.58	0:01:16	2010-05-04 03:07:51 PM	-0.73
SACRO	10007_30006	17.20	0:01:04	2010-05-04 04:34:12 PM	0.96
FIG SPRING	10016_30007	2.35	0:01:00	2010-05-04 03:17:00 PM	-0.06
SACRO	10016_30007	16.39	0:00:32	2010-05-05 12:25:58 PM	0.26
FIG SPRING	10017_30008	3.14	0:01:09	2010-05-04 03:23:43 PM	0.51
SACRO	10017_30008	15.59	0:03:09	2010-05-05 12:38:04 PM	-0.88
FIG SPRING	10018_30027	3.94	0:01:36	2010-05-05 03:13:01 PM	-0.11
SACRO	10018_30027	14.78	0:01:11	2010-05-05 12:44:21 PM	0.20
FIG SPRING	10030_20040	6.67	0:07:12	2010-05-06 10:39:29 AM	0.11
FIG SPRING	10030_20040	6.67	0:01:31	2010-05-06 02:05:33 PM	-1.35
FIG SPRING	10036_30026	4.73	0:00:41	2010-05-05 02:58:21 PM	-0.55
SACRO	10036_30026	13.98	0:00:32	2010-05-06 03:02:29 PM	1.05
FIG SPRING	10037_30054	5.53	0:01:19	2010-05-06 04:04:28 PM	-0.80
SACRO	10037_30054	13.18	0:00:30	2010-05-06 03:08:00 PM	0.69
FIG SPRING	10038_30055	6.33	0:01:08	2010-05-06 04:11:20 PM	-0.79
SACRO	10038_30055	12.37	0:00:30	2010-05-06 03:13:14 PM	1.05
64 EAM	10039_30068	2.92	0:00:30	2010-05-10 11:54:08 AM	-0.29
SACRO	10039_30068	11.57	0:00:36	2010-05-06 03:19:50 PM	0.16

Integrated and Collaborative Organizations Create Geospatial Solutions

Base station name Control Station	Rover station name Control Station	Vector length (km)	Duration of rover occupation	Midpoint time of rover occupation	dU residual (cm) - constrained adj
DUVAL	64 EAM	20.77	0:00:30	2010-05-18 12:37:44 PM	-2.33
FIG SPRING	64 EAM	9.79	0:01:32	2010-05-04 02:01:46 PM	0.35
FIG SPRING	64 EAM	9.79	0:00:58	2010-05-04 05:22:06 PM	-0.28
FIG SPRING	64 EAM	9.79	0:00:46	2010-05-05 05:19:50 PM	0.13
FIG SPRING	64 EAM	9.79	0:00:34	2010-05-06 05:14:48 PM	-0.39
FIG SPRING	BOULDER	13.44	0:00:30	2010-05-13 10:54:16 AM	3.12
FIG SPRING	BOULDER	13.44	0:00:34	2010-05-13 04:54:14 PM	4.00
FIG SPRING	BOULDER	13.44	0:00:30	2010-05-17 10:54:53 AM	0.73
FIG SPRING	BOULDER	13.44	0:00:51	2010-05-17 04:54:05 PM	-3.28
FIG SPRING	BOULDER	13.44	0:00:44	2010-05-18 10:05:26 AM	-3.03
FIG SPRING	BOULDER	13.44	0:00:52	2010-05-18 01:40:41 PM	3.36
L 484	BOULDER	0.29	0:00:32	2010-05-13 10:35:35 AM	0.47
L 484	BOULDER	0.29	0:00:30	2010-05-13 10:43:27 AM	0.61
L 484	BOULDER	0.29	0:00:30	2010-05-13 06:01:01 PM	0.99
L 484	BOULDER	0.29	0:00:30	2010-05-13 06:22:47 PM	-0.93
64 EAM	FIG SPRING	9.79	0:00:30	2010-05-10 10:31:41 AM	1.04
DUVAL	G 60	10.21	0:00:43	2010-05-25 10:38:08 AM	1.64
64 EAM	L 484	13.86	0:00:44	2010-05-11 10:39:03 AM	0.47
64 EAM	L 484	13.86	0:01:11	2010-05-11 04:57:43 PM	-0.42
64 EAM	L 484	13.86	0:00:37	2010-05-12 10:14:09 AM	0.11
64 EAM	L 484	13.86	0:00:40	2010-05-12 04:41:20 PM	1.52
BOULDER	L 484	0.29	0:00:30	2010-05-20 09:56:26 AM	-1.84
FIG SPRING	L 484	13.27	0:01:40	2010-05-17 10:43:27 AM	0.65
FIG SPRING	L 484	13.27	0:01:00	2010-05-17 10:46:43 AM	-0.10

- **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?