# Evolution of the NSRS

**Massachusetts Association of Land Surveyors and Civil Engineers**
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# GEODETIC DATUMS

## HORIZONTAL

2 D (Latitude and Longitude) (e.g. NAD 27, NAD 83 (1986))

## VERTICAL

1 D (Orthometric Height) (e.g. NGVD 29, NAVD 88, Local Tidal)

## GEOMETRIC

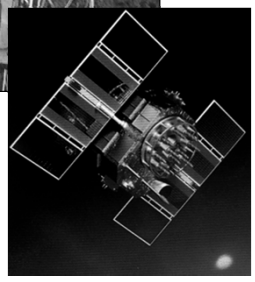
3 D (Latitude, Longitude and Ellipsoid Height)
Fixed and Stable - Coordinates seldom change
(e.g. NAD 83 (1996), NAD 83 (2007), NAD 83 (CORS96))

also

4 D (Latitude, Longitude, Ellipsoid Height, Velocities) Coordinates change with time
(e.g. ITRF00, ITRF08)

# A (very) brief history of NAD 83

- Original realization completed in 1986
  - Consisted (almost) entirely of classical (optical) observations
- "High Precision Geodetic Network" (HPGN) and "High Accuracy Reference Network" (HARN) realizations
  - Most done in 1990s, essentially state-by-state
  - Based on GNSS but classical stations included in adjustments
- National Re-Adjustment of 2007
  - NAD 83(CORS96) and (NSRS2007)
  - Simultaneous nationwide adjustment (GNSS only)
- ***New realization: NAD 83(2011) epoch 2010.00***



# What is a Datum?

- "A set of constants specifying the coordinate system used for geodetic control, i.e., for calculating the coordinates of points on the Earth."
- "The datum, as defined in (1), together with the coordinate system and the set of all points and lines whose coordinates, lengths, and directions have been determined by measurement or calculation."
- NGS has used the first definition for NAD83

## Why change datums/Realizations

- NAD27 based on old observations and old system
- NAD83(86) based on old observations and new system
- NAD83(92) based on new and old observations and same system
- NAD83(96) based on better observations and same system
- NAD83(NSRS2007) based on new observations and same system. Removed regional distortions and made consistent with CORS
- NAD83(2011) based on new observations and same system. Kept consistent with CORS

## Horizontal Datums/Coordinates…What do we (you) use in MA?

- NAD 83 (Lat-Lon) SPC
  - Which one???
    - NAD 83 (1986)
    - NAD 83 (1992)
    - NAD 83 (1996)
    - NAD 83 CORS96(2002)
    - NAD 83 (NSRS2007)
    - NAD 83 (2011)
- NAD 27
- WGS 84
  - Which one???
    - WGS 84 (1987)
    - WGS 84 (G730)
    - WGS 84 (G873)
    - WGS 84 (G1150)
    - WGS 84 (G1674)
- ITRF00 (epoch 97)
- IGS08

## COORDINATE CHANGES

| ADJUSTMENT | YEARS | LOCAL ACCURACY | NETWORK ACCURACY |
|---|---|---|---|
| NAD 27 | 1927 – 1986 | 1:100,000 | 10 m |
| NAD 83 (1986) | 1986 – 1990 | 1:100,000 | 1 m |
| NAD 83 (1992) (HARN) | 1990 – 1997 | 1:10,000,000 | 0.1 m |
| CORS | 1994 -------- | 0.01/0.02 m | 0.02/0.04 m |
| NAD 83 (1996) (FBN/CBN) | 1997 – 2007 | 0.05/0.05 m | 0.05/0.05 m |
| NAD 83 (NSRS 2007) | 2007 - 2012 | 0.01/0.02 m | 0.02/0.04 m |
| NAD 83 (2011) epoch 2010.0 | 2012 - ------- | | 0.009/0.015m |

National Geodetic Survey

## NEW STANDARDS FOR GEODETIC CONTROL

**TWO ACCURACY STANDARDS**

**local accuracy ---------- adjacent points**
**network accuracy ---------- relative to CORS**

**Numeric quantities, units in cm (or mm)**
**Both are relative accuracy measures**
**Do not use distance dependent expression**
**Horizontal accuracies are radius of 2-D 95% error circle**
**Ellipsoidal/Orthometric heights are 1-D (linear) 95% error**

National Oceanic and Atmospheric Administration

## The NSRS has evolved

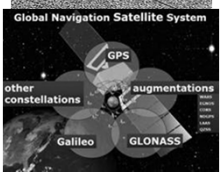
1 Million Monuments
(Separate Horizontal and Vertical Systems) →

70,000 Passive Marks
(3-Dimensional)


Passive Marks
(Limited Knowledge of Stability) →

1,897 GPS CORS
(Time Dependent System Possible; 4-Dimensional)

GPS CORS → GNSS CORS




# ITRF2008, IGS08 AND NAD 83(2011)

# ITRF2008

For the geodesy, geophysics and surveying communities, the best International Terrestrial Reference Frame is the “gold standard.”

The global community recently adopted an updated expression for the reference frame, the ITRF2008.

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## International Earth Rotation and Reference System Service (IERS)

**(http://www.iers.org)**

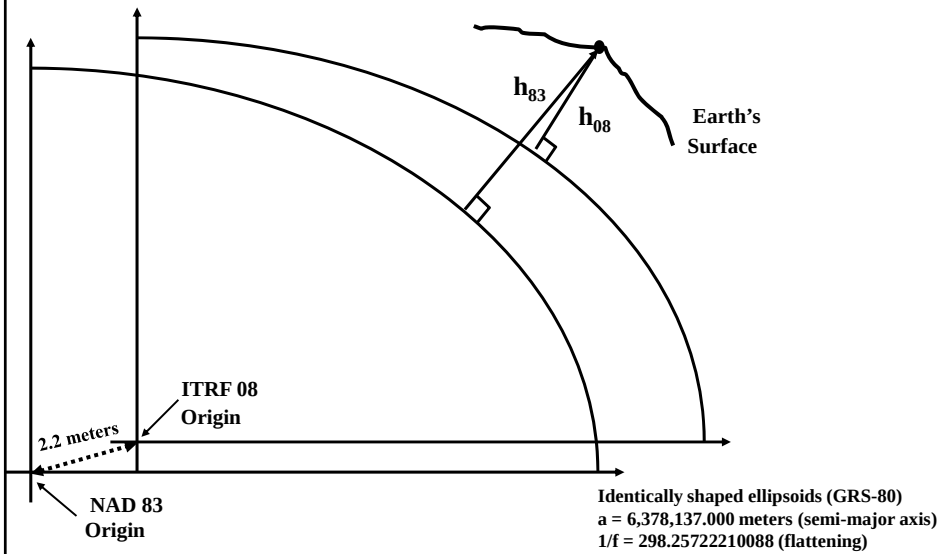
The International Terrestrial Reference System **(ITRS)** constitutes a set of prescriptions and conventions together with the modeling required to define origin, scale, orientation and time evolution

ITRS is realized by the International Terrestrial Reference Frame (**ITRF**) based upon estimated coordinates and velocities of a set of stations observed by Very Long Baseline Interferometry (**VLBI**), Satellite Laser Ranging ( **SLR**), Global Positioning System and GLONASS (**GNSS**), and Doppler Orbitography and Radio- positioning Integrated by Satellite ( **DORIS**).

**ITRF89, ITRF90, ITRF91, ITRF92, ITRF93, ITRF94, ITRF95, ITRF96, ITRF97, ITRF2000, ITRF2005, ITRF2008**

## International Terrestrial Reference Frame
## 4 Global Independent Positioning Technologies

## Simplified Concept of NAD 83 vs. ITRF08



# Densification

The ITRF2008 is expressed through the coordinates and velocities of marks on the ground plus ancillary data.

Other organizations can take that information, add additional marks, perform their own adjustment and align their results to the ITRF2008 (A.K.A. densifying).

The variants try to be as consistent with the ITRF2008 as possible, but in the most formal sense, they are unique from the ITRF2008. Therefore, they are given unique names.

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# The IGS08

The IGS has densified reference frame with much larger, global subset of GNSS tracking sites thereby creating a GNSS-only expression of the ITRF2008 called the IGS08. All IGS products have been recreated so as to be consistent with the IGS08 including GNSS ephemerides and antenna models. Information about the IGS08 can be found at the IGS web sites: igscb.jpl.nasa.gov. I would suggest starting with IGSMAIL-6354, -6355 and -6356, all dated 2011-03-07.

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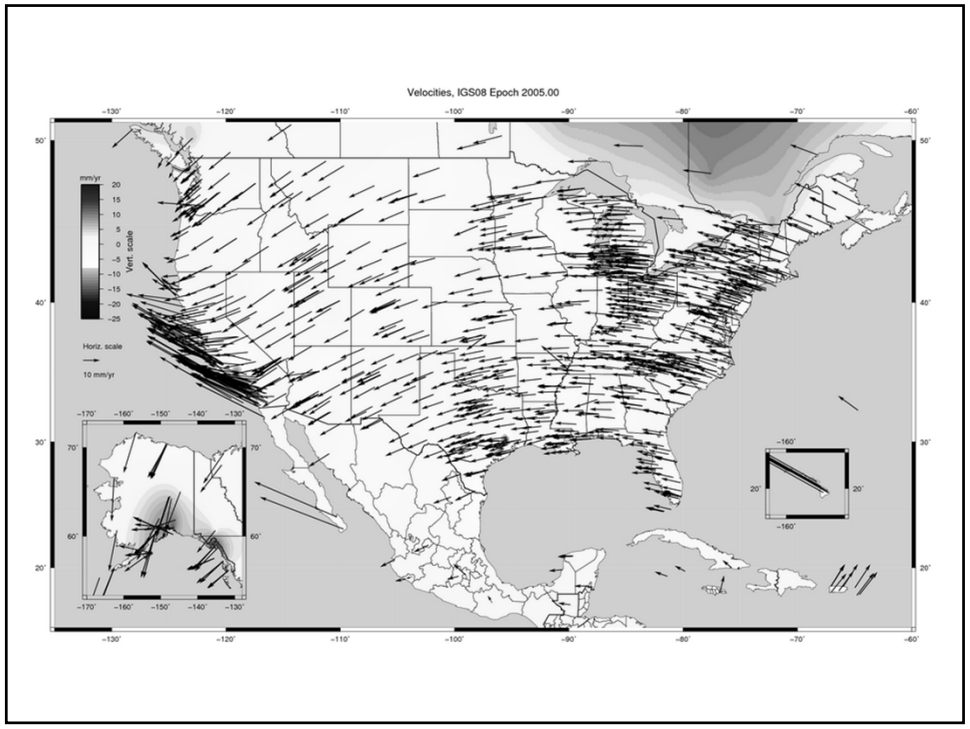
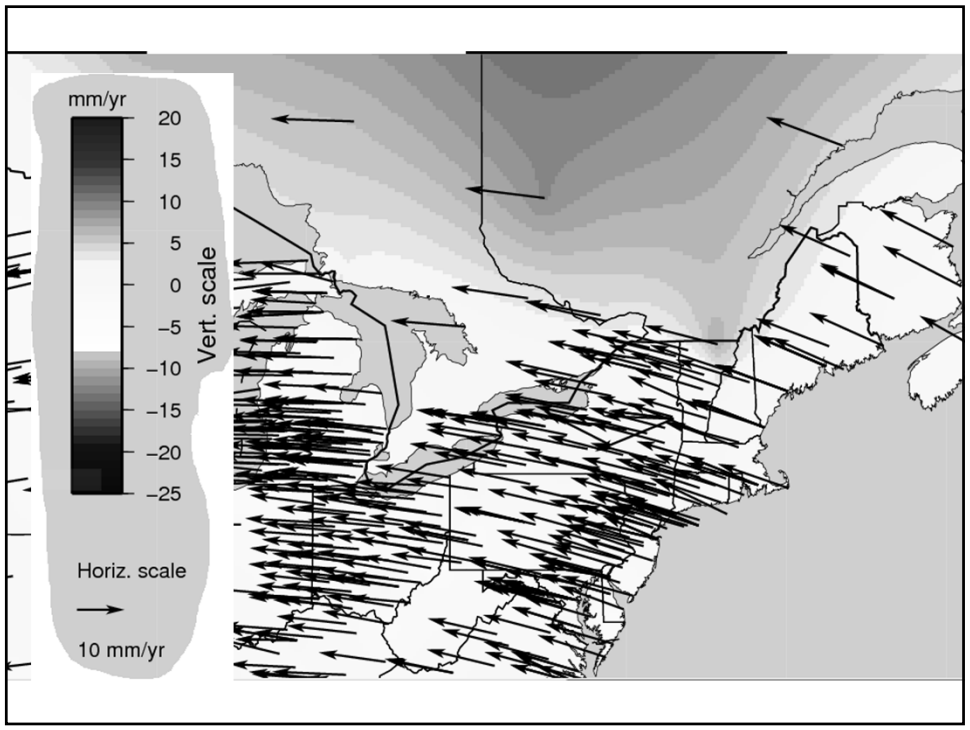
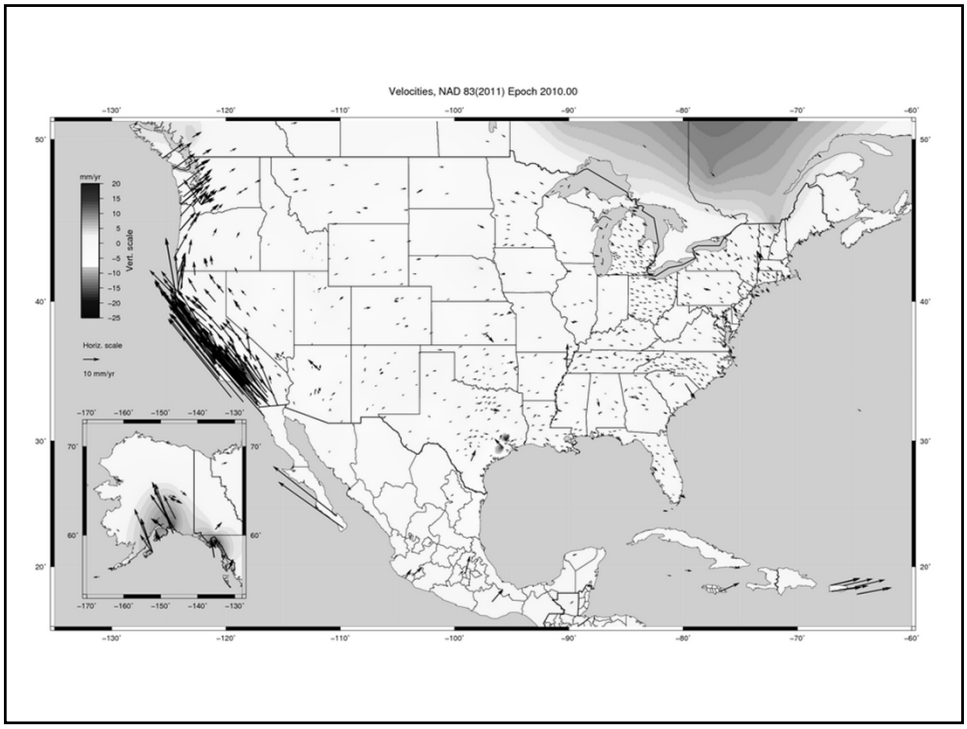
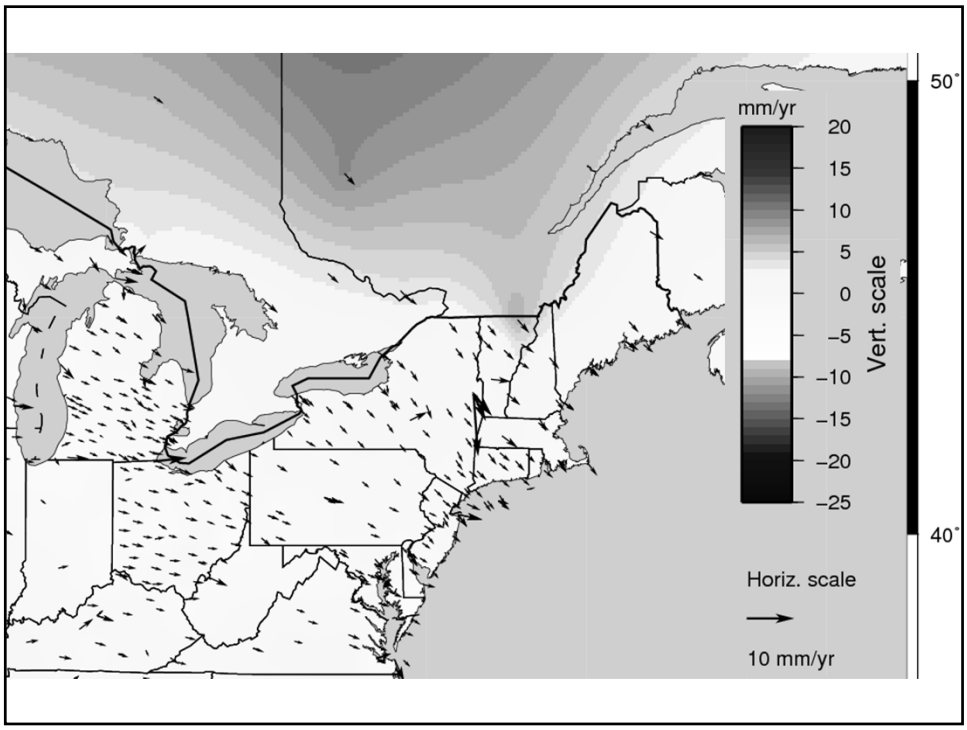

Velocities, IGS08 Epoch 2005.00
mm/yr
20
15
10
5
0
−5
−10
−15
−20
−25
Vert. scale
Horiz. scale
10 mm/yr


mm/yr
20
15
10
5
0
−5
−10
−15
−20
−25
Vert. scale
Horiz. scale
10 mm/yr


Velocities, NAD 83(2011) Epoch 2010.00
mm/yr
20
15
10
5
0
−5
−10
−15
−20
−25
Vert. scale
Horiz. scale
10 mm/yr


mm/yr
20
15
10
5
0
−5
−10
−15
−20
−25
Vert. scale
50˚
40˚
Horiz. scale
10 mm/yr

# NAD 83 (2011)

NGS used its contribution to the IGS08 plus the additional CORS to produce improved IGS08 coordinates and velocities for the CORS network. From this, improved CORS coordinates and velocities in the NAD 83 frame were defined.

To distinguish this from earlier realizations, this reference frame is called the NAD 83 (2011). This is *not* a new datum: the origin, scale and orientation are the same as in the previous realization.

In September 2011, NGS formally released IGS08 and NAD 83 (2011) coordinates and velocities for the CORS. Information about the IGS08 and NAD 83 (2011) can be found at geodesy.noaa.gov/CORS/coords.shtml.

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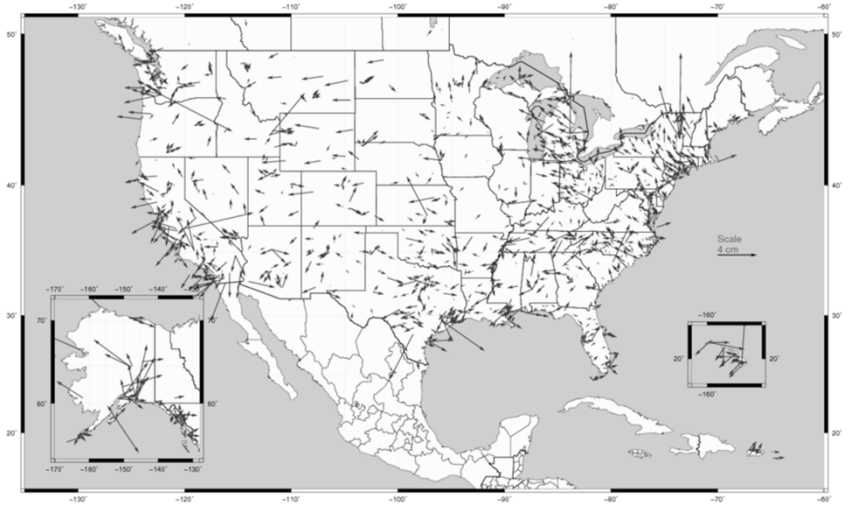
# Horizontal Differences In CORS Positions




Horizontal difference in positions of NAD 83(2011) epoch 2002.00 minus NAD 83(CORS96) epoch 2002.00.

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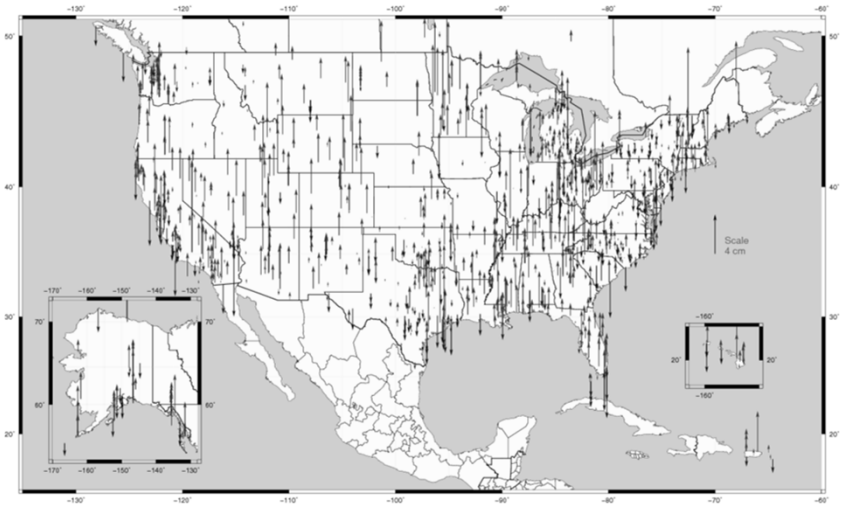
# Vertical Differences In CORS Positions




Vertical difference in positions of NAD 83(2011) epoch 2002.00 minus NAD 83(CORS96) epoch 2002.00.

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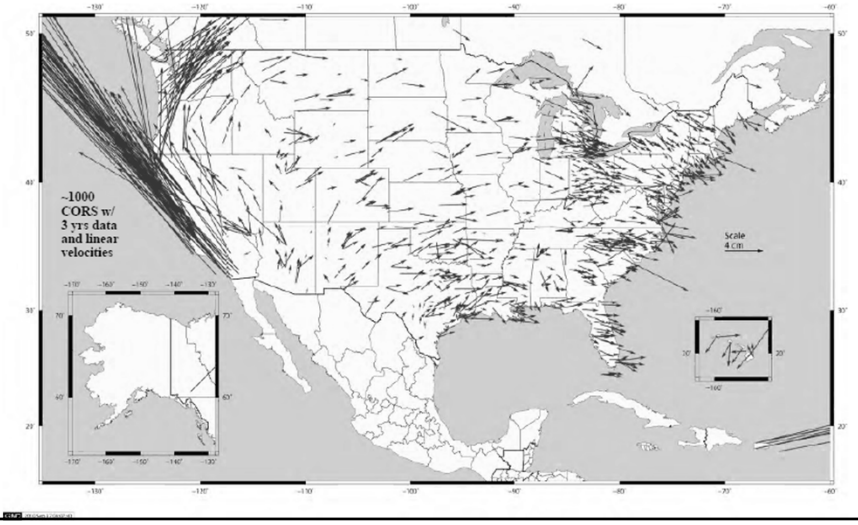
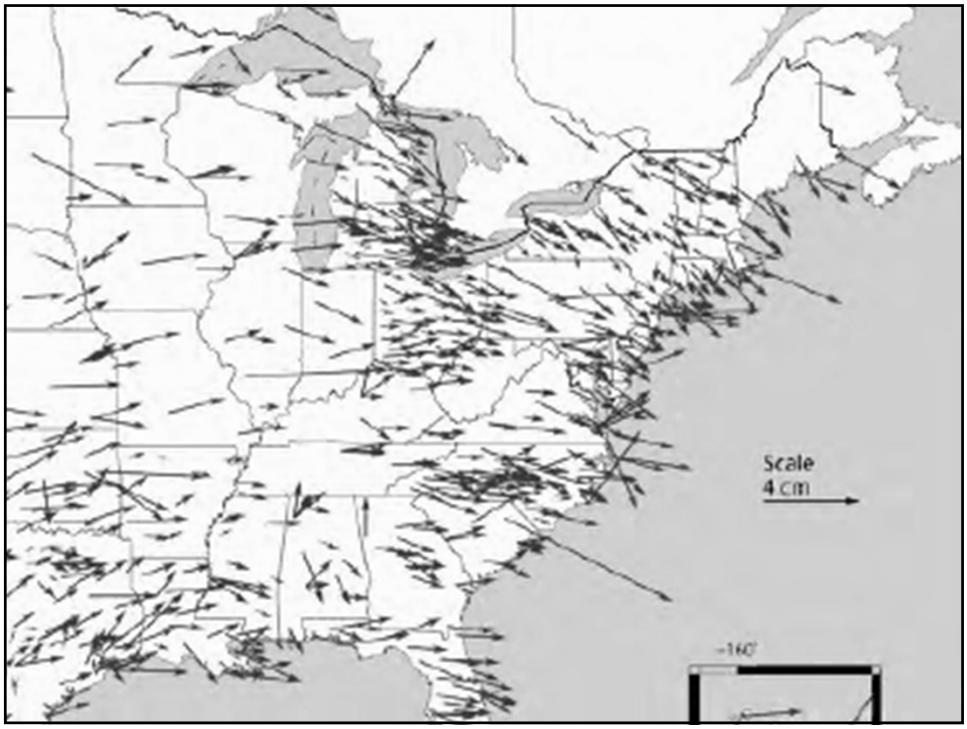
# Change in horizontal NAD 83 CORS coordinates

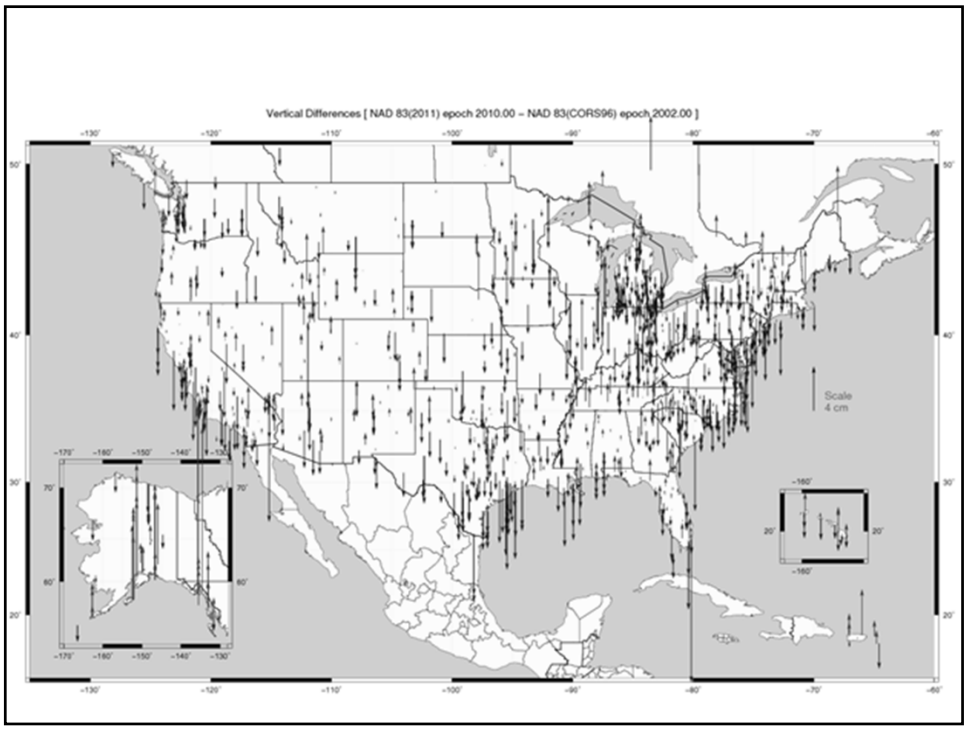
NAD 83(CORS96) **epoch 2002.00** → NAD 83(2011) **epoch 2010.00**

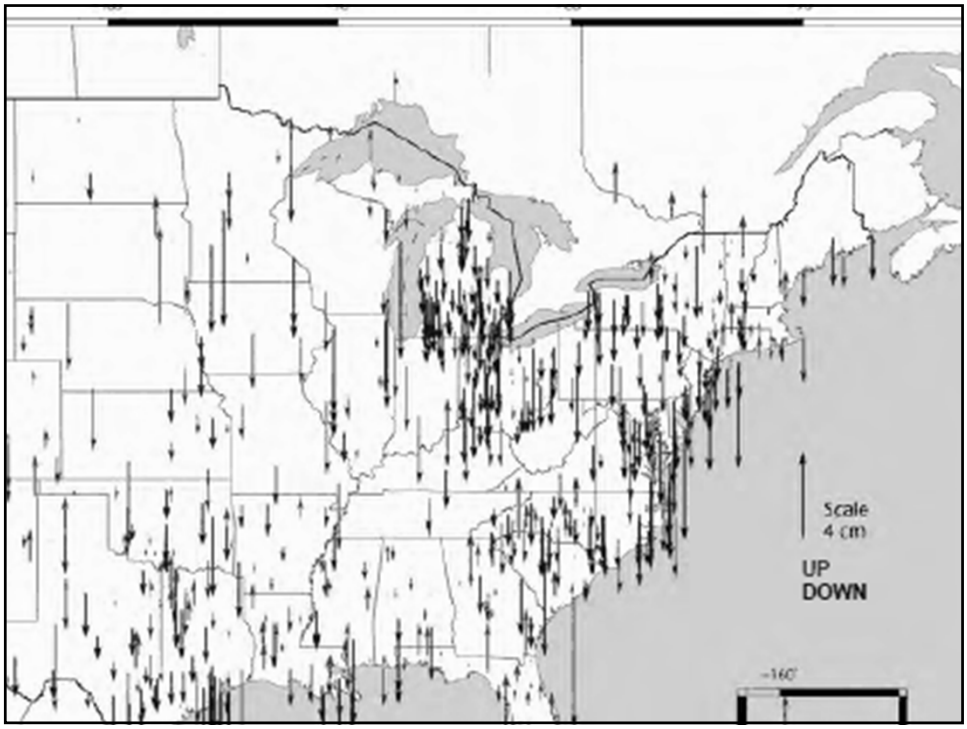
**Avg shifts (cm): ΔN = 2.0 (±6.4); ΔE = 0.2 (±5.9); ΔU = -0.9 (±2.0)**

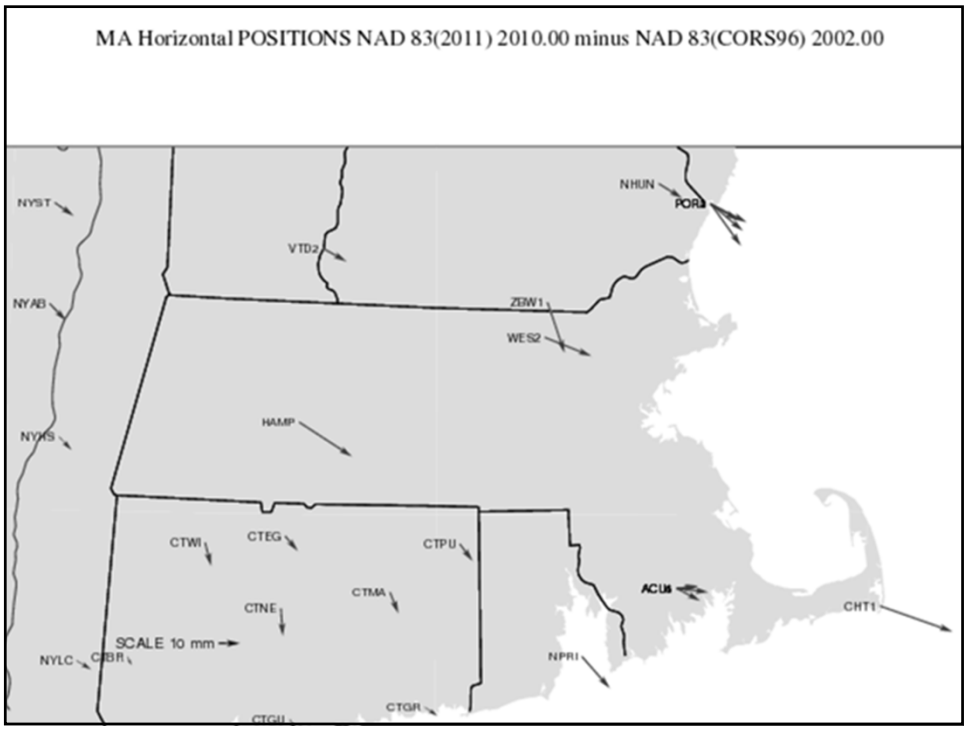
- **large shifts in western U.S. due to crustal deformation**
- **apparent rotation in "stable" U.S. likely due to errors in NUVEL-1A (used in HTDP)**

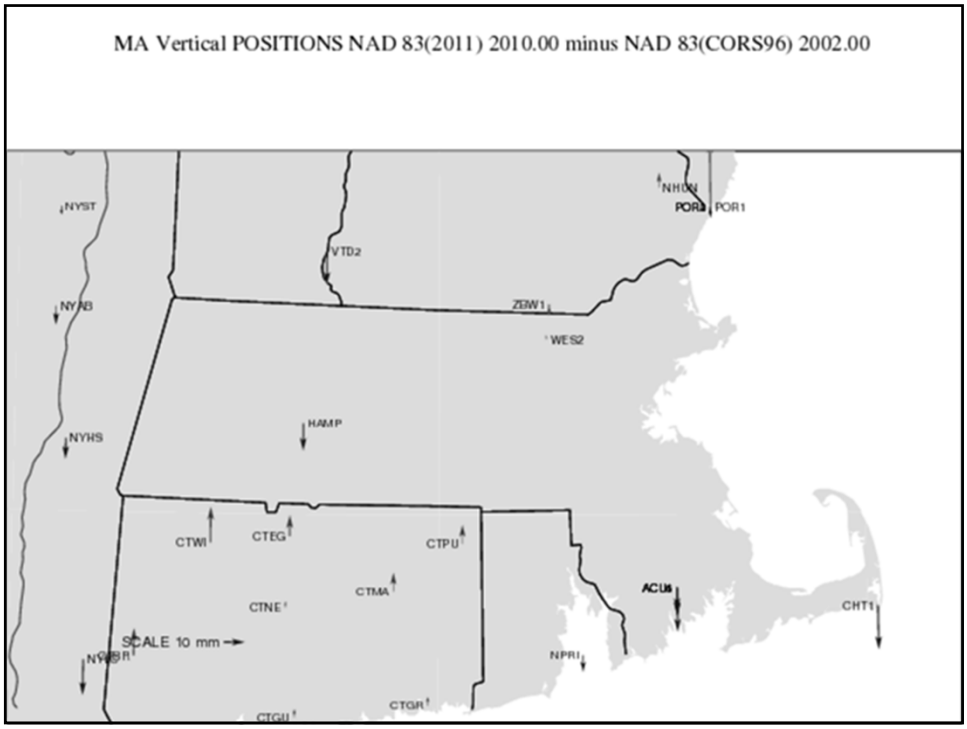



Scale
4 cm
-160°


Vertical Differences [ NAD 83(2011) epoch 2010.00 – NAD 83(CORS96) epoch 2002.00 ]
Scale
4 cm


Scale
4 cm
UP
DOWN


MA Horizontal POSITIONS NAD 83(2011) 2010.00 minus NAD 83(CORS96) 2002.00
NYST
NHUN
PORI
VTD2
NYAB
ZDW1
WES2
HAMP
NYNS
CTWI
CTEG
CTPU
CTMA
CTNE
ACUS
CHT1
SCALE 10 mm
NYLC
CTBR
NPRI
CTGR
CTGU




# *Update and Refinement of the North American Datum of 1983*

## NAD 83(2011/PA11/MA11) epoch 2010.00

***The 2011 national adjustment of passive control and its impact on NGS products and services***

**National Geodetic Survey**
**Height Modernization Program monthly meeting**
**October 11, 2012 ● Silver Spring, MD**

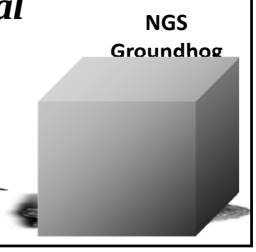
**Michael Dennis, RLS, PE**
**michael.dennis@noaa.gov**

# The Plan

- The ***National Spatial Reference System (NSRS)***
  - A (very) brief history of NAD 83
  - The latest realization: ***NAD 83(2011/PA11/MA11) epoch 2010.00***
- ***National adjustment of passive control***
- Related and dependant NGS products & services
  - The Multi-Year CORS Solution (MYCS)
  - Online Positioning User Service (OPUS)
  - New hybrid geoid model (GEOID12A)
  - New process for Bluebooking GPS project
  - New NAD 83 coordinate transformations
  - Role of GIS in national adjustment (and leveling)
- What about *orthometric* heights (aka "elevations")?

# The Basics

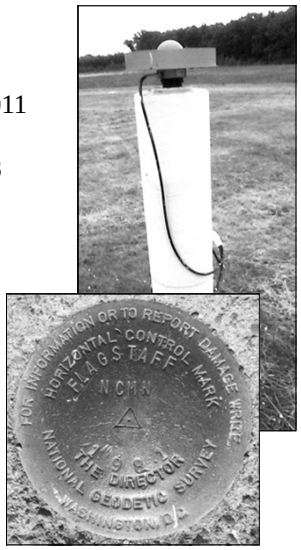
- When will it be done?
  - Publication completed on ***June 30, 2012***
    - ***Intent: Simultaneous with release of GEOID12A***
- How many stations? ***80,872***
- How much did the coordinates change?
  - Median: ***1.9 cm horiz, 2.1 cm vertical***
- How accurate are the results?
  - Median: ***0.9 cm horiz, 1.5 cm vertical*** (at 95% confidence level)




***…6 more weeks until it's done!***

## *Introducing…*
# NAD 83(2011) epoch 2010.00

- **Multi-Year CORS Solution (MYCS)**
  - Continuously Operating Reference Stations
  - Reprocessed all CORS GPS data Jan 1994-Apr 2011
  - 2264 CORS & global stations
  - NAD 83 computed by *transformation* from IGS08
- **2011 national adjustment of passive control**
  - New adjustment of GNSS passive control
  - GNSS vectors tied (and constrained) to CORS NAD 83(2011) epoch 2010.00
  - Over 80,000 stations and 400,000 GNSS vectors
- **Realization SAME for CORS *and* passive marks**
- **This is *NOT* a new datum! (still NAD 83)**




# Why a new NAD 83 realization?

- Multi-Year CORS Solution
  - Previous NAD 83 CORS realization needed many improvements
  - Consistent coordinates *and* velocities from global solution
  - Aligned with most recent realization of global frame (IGS 08)
  - Major processing, modeling, and metadata improvements
    - Including new ***absolute phase center antenna calibrations***
- National adjustment of passive control
  - Optimally align passive control with “active” CORS control
    - ***Because CORS provide the geometric foundation of the NSRS***
  - Incorporate new data, compute accuracies on all stations
  - Better results in tectonically active areas
- ***Bottom line***
  - **Must meet needs of users for highly accurate *and* consistent coordinates (*and* velocities) using *B*est *A*vailable *M*ethods**

# Approach

- Used a Helmert blocking strategy for CONUS
  - Over 80,000 points (> 240,000 unknowns)
  - Over 400,000 GNSS vectors (> 1.2 million observations)
- Individual projects weighted to account for variable error
  - Horiz and vertical std deviation scale factors computed for all projects
- Outlier detection (for rejecting vectors)
  - Used threshold 4 cm horizontal, 5 cm up
- Method for vector rejection
  - Rejection by *downweighting* vs. *removal*
- Challenges:
  - Tectonic tribulations
  - Mixing old and new observations (e.g., pre-1994)
  - CORS complications
  - Constraint conundrums ("weighted" vs. "rigid")
  - Subsidence
  - No-check stations
  - Duplicate stations, duplicate vectors

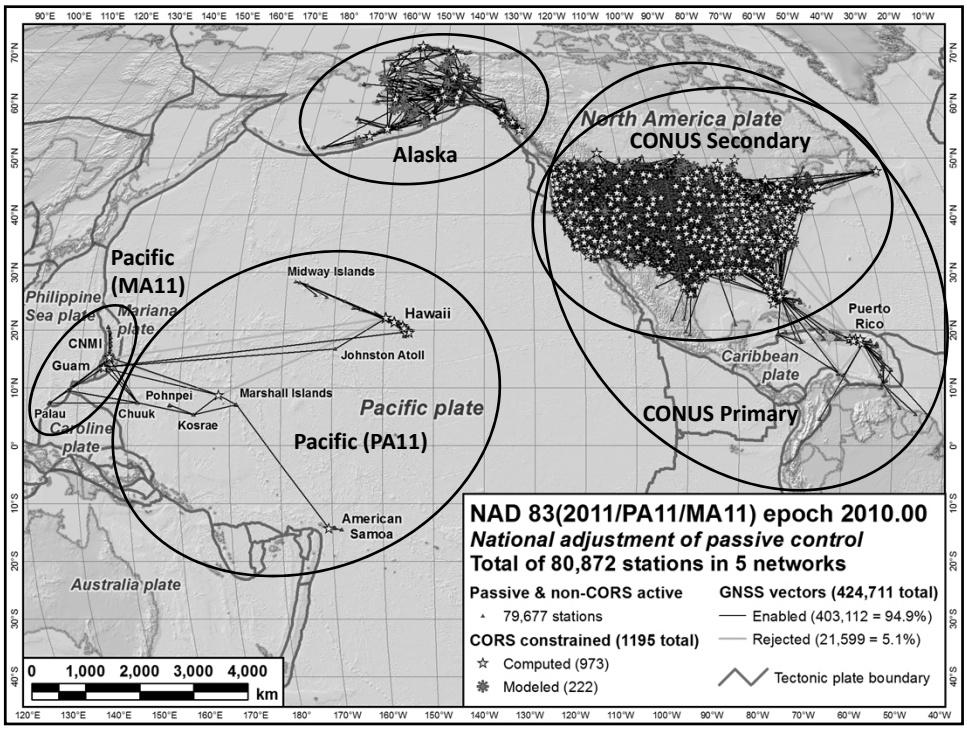

# What's in a name?

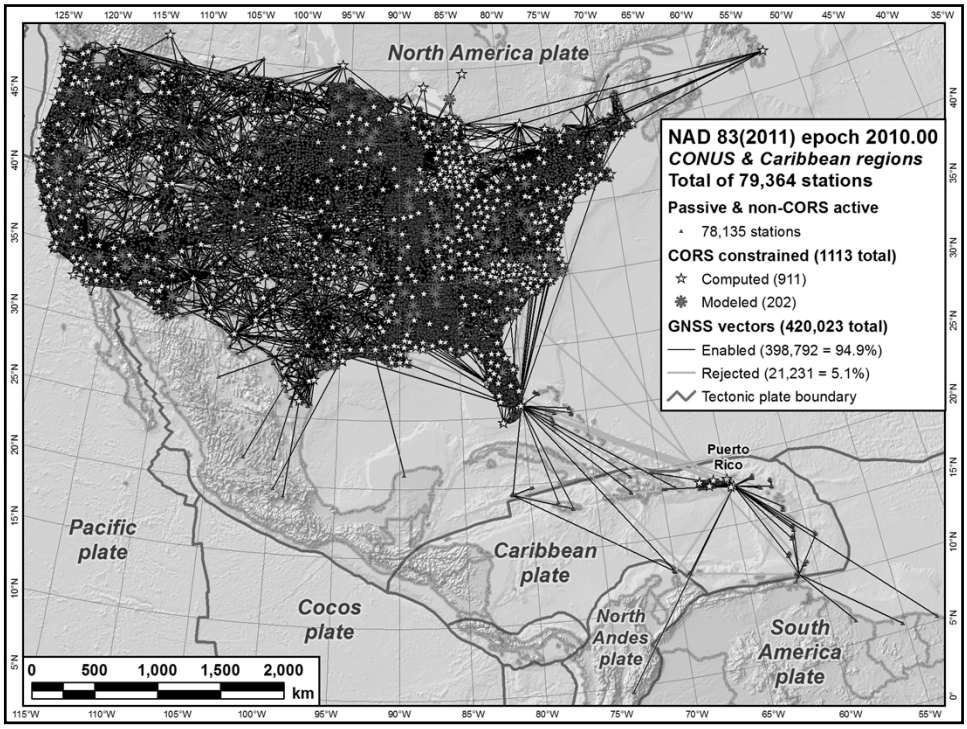
*That which we call a datum*
*By any other name would smell as sweet…*

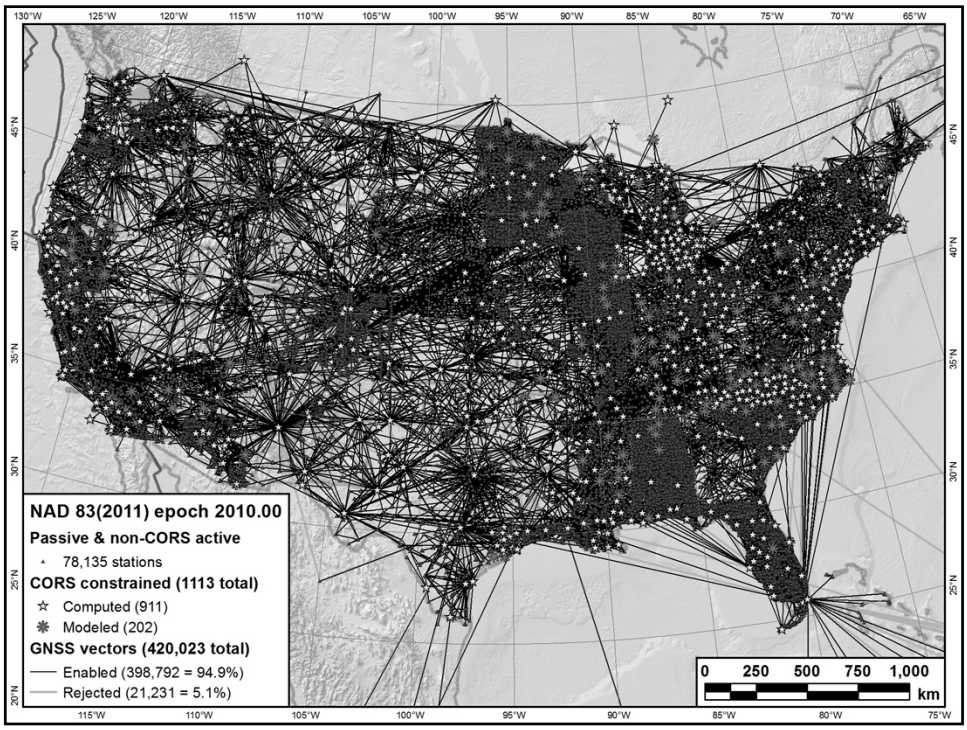
- **NAD 83(2011) epoch 2010.00**
  - "2011" is datum tag → year adjustment complete
  - "2010.00" is "epoch date" (January 1, 2010)
    - Date associated with coordinates of control station
  - Frame fixed to North America tectonic plate
    - Includes California, Alaska, Puerto Rico, and US Virgin Islands
- **NAD 83(PA11) epoch 2010.00**
  - Frame fixed to Pacific tectonic plate (Hawaii and American Samoa)
- **NAD 83(MA11) epoch 2010.00**
  - Frame fixed to Mariana tectonic plate (Guam and CNMI)

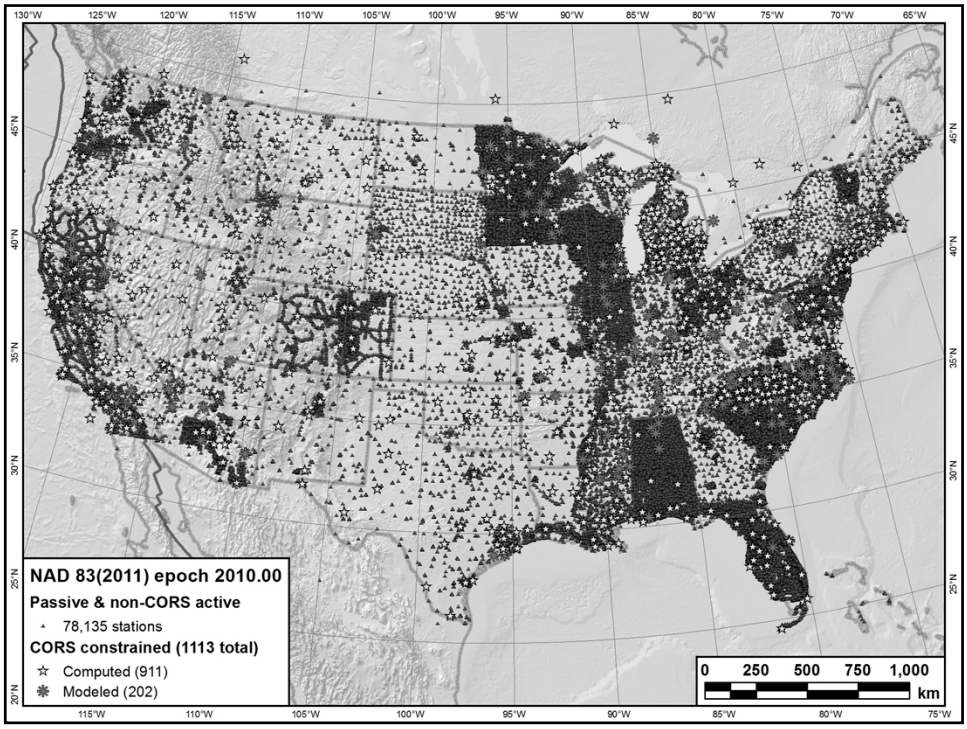
# National adjustment of passive control

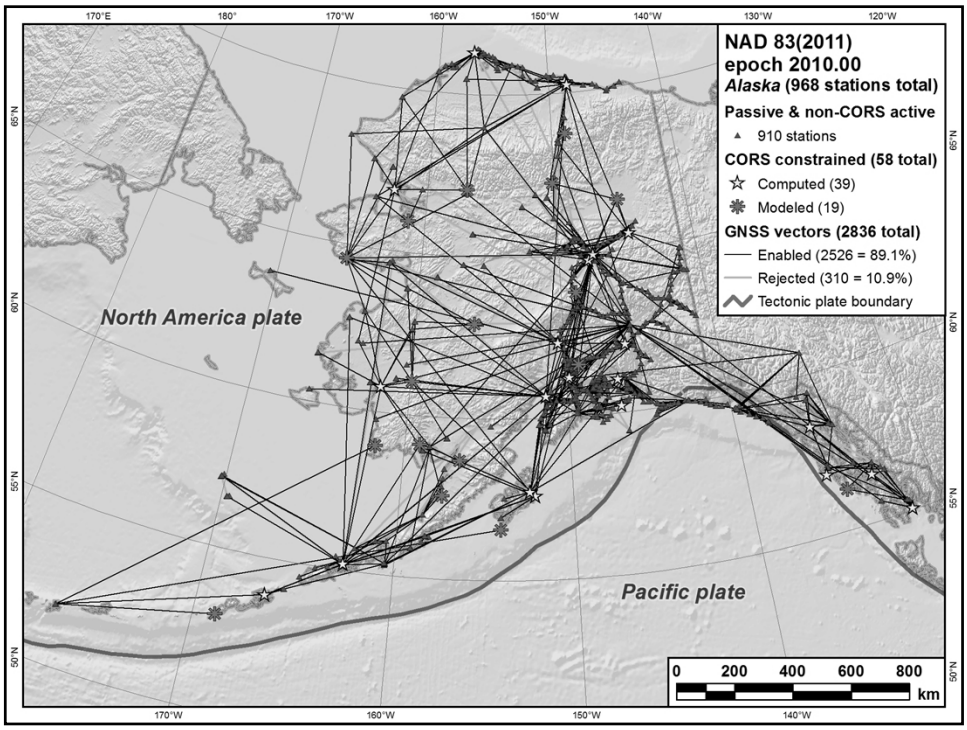
- 4267 GPS projects; 80,872 stations; 424,711 vectors
  - Observations from April 1983 thru Dec 2011
  - Includes 1195 CORS with Multi-Year CORS Solution coordinates
- CONUS and Caribbean adjusted together (79,364 stations)
  - Both referenced to North America tectonic plate
  - Split into Primary (62,024 stations) and Secondary (17,340 stations)
- AK adjusted separate from CONUS and Caribbean (968 stations)
  - No useable ties to CONUS
  - Also referenced to North America tectonic plate
- Pacific region also adjusted separately (540 stations)
  - Referenced to different tectonic plates
    - Hawaii, American Samoa, Marshall Is., etc. → **Pacific plate** (363 stations)
    - Guam, Northern Mariana Islands, Palau → **Mariana plate** (177 stations)
  - ***Pacific not included in 2007 national adjustment***

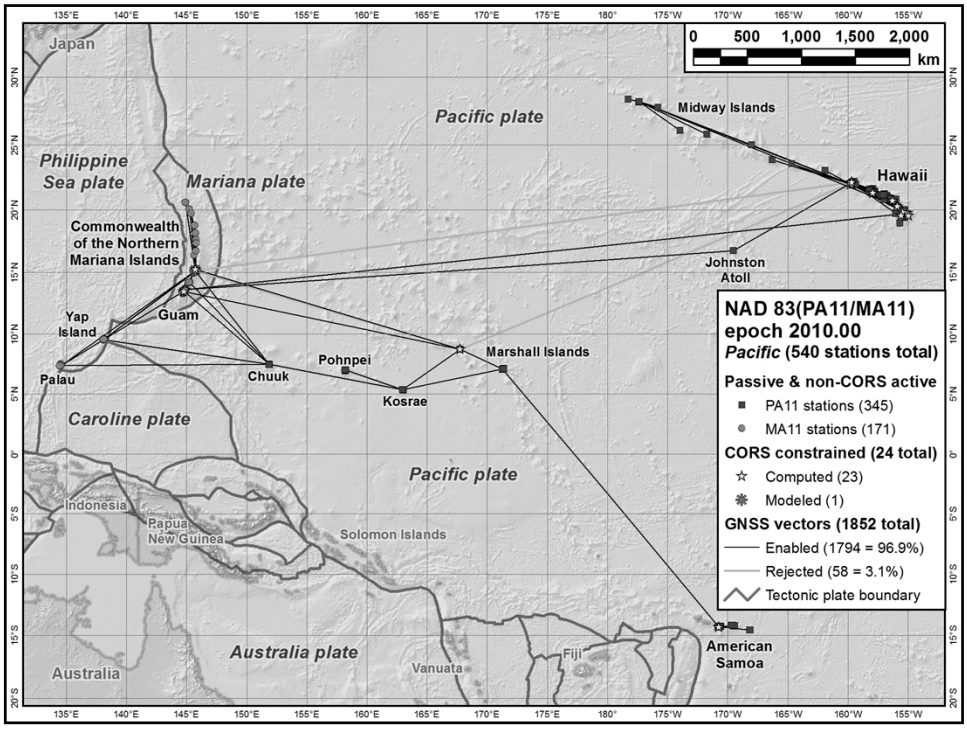



North America plate
Pacific plate
Cocos plate
Caribbean plate
North Andes plate
South America plate
Puerto Rico
NAD 83(2011) epoch 2010.00
CONUS & Caribbean regions
Total of 79,364 stations
Passive & non-CORS active
78,135 stations
CORS constrained (1113 total)
Computed (911)
Modeled (202)
GNSS vectors (420,023 total)
Enabled (398,792 = 94.9%)
Rejected (21,231 = 5.1%)
Tectonic plate boundary
0 500 1,000 1,500 2,000
km


NAD 83(2011) epoch 2010.00
Passive & non-CORS active
78,135 stations
CORS constrained (1113 total)
Computed (911)
Modeled (202)
GNSS vectors (420,023 total)
Enabled (398,792 = 94.9%)
Rejected (21,231 = 5.1%)
0 250 500 750 1,000
km


NAD 83(2011) epoch 2010.00
Passive & non-CORS active
78,135 stations
CORS constrained (1113 total)
Computed (911)
Modeled (202)
0 250 500 750 1,000
km

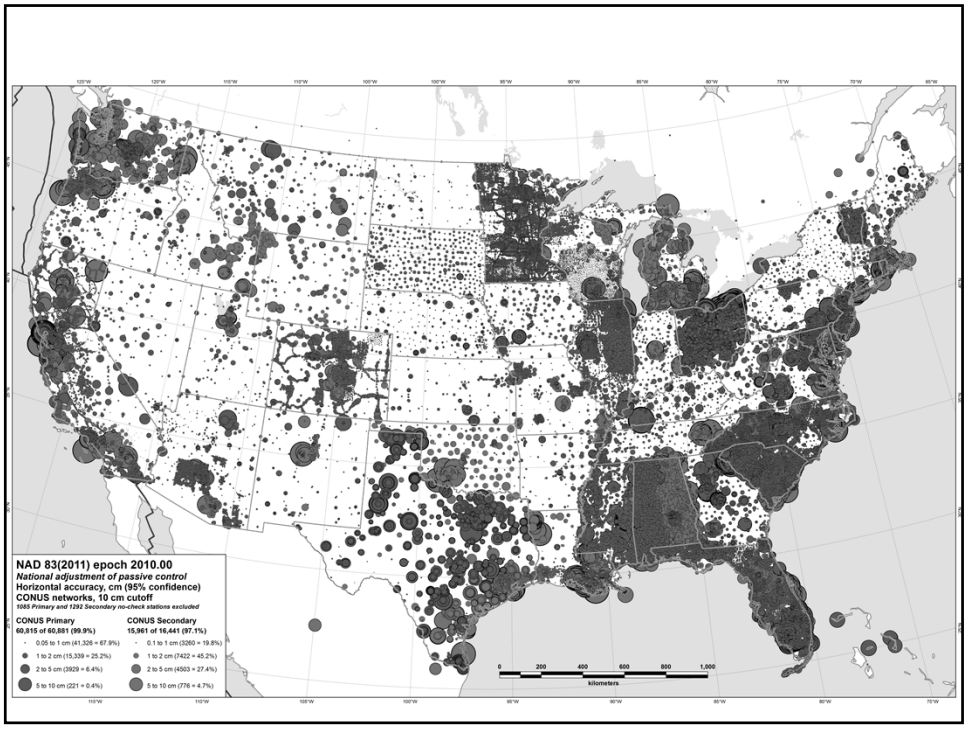

NAD 83(2011)
epoch 2010.00
Alaska (968 stations total)
Passive & non-CORS active
910 stations
CORS constrained (58 total)
Computed (39)
Modeled (19)
GNSS vectors (2836 total)
Enabled (2526 = 89.1%)
Rejected (310 = 10.9%)
Tectonic plate boundary
North America plate
Pacific plate
0 200 400 600 800
km

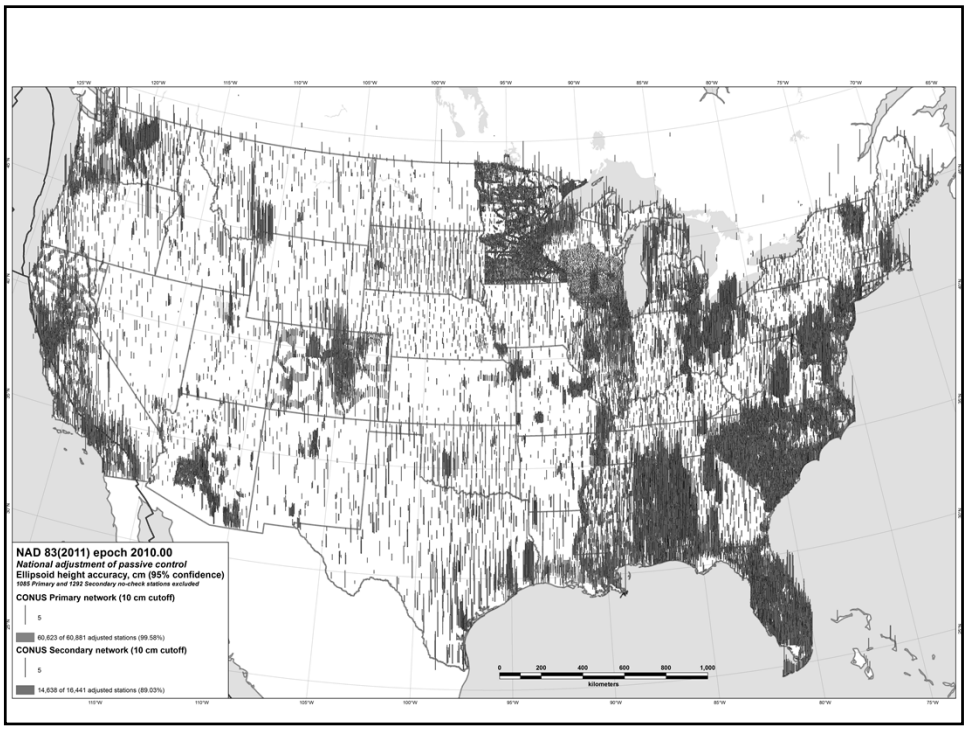



# NAD 83(2011/PA11/MA11) epoch 2010.00

## *Passive control results summary*

- Station network accuracies (95% confidence)
  - Overall median: ***0.9 cm horiz, 1.5 cm height*** (78,709)
    - ***90% < 2.3 cm horizontal and 4.8 cm ellipsoid height***
    - Does ***NOT*** include 2163 no-check stations
  - Median accuracies by network
    - CONUS Primary: ***0.7 cm horiz, 1.2 cm height*** (61,049)
    - CONUS Secondary: ***1.6 cm horiz, 3.4 cm height*** (16,441)
    - Alaska: ***3.2 cm horiz, 5.7 cm height*** (814)
    - Pacific (PA11): ***2.2 cm horiz, 5.0 cm height*** (282)
    - Pacific (MA11): ***1.8 cm horiz, 3.8 cm height*** (123)

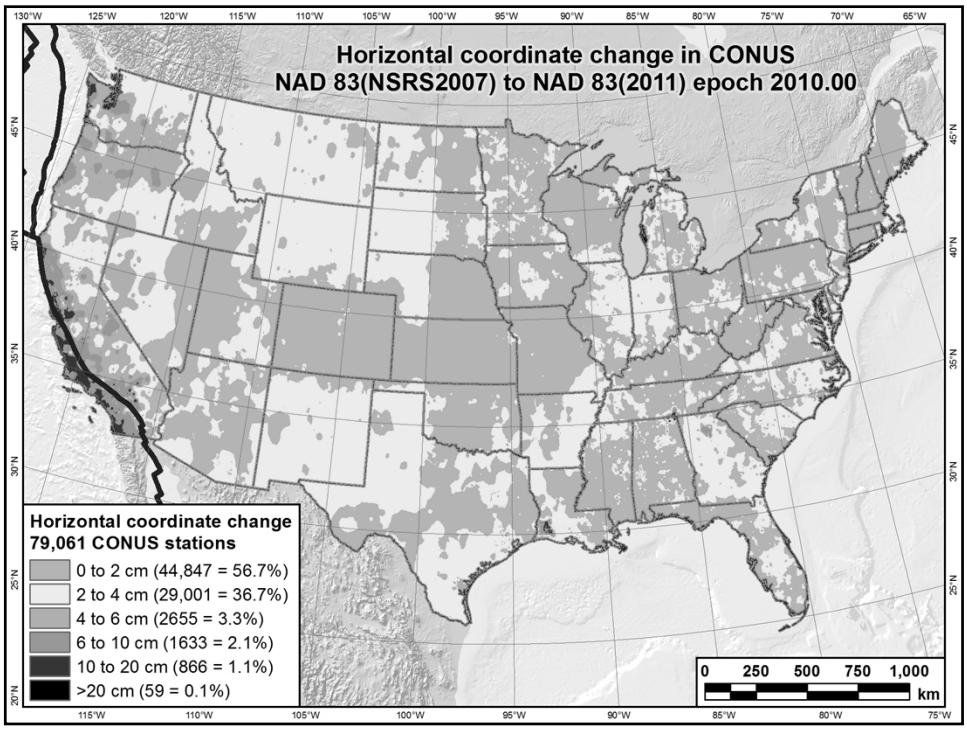

NAD 83(2011) epoch 2010.00
National adjustment of passive control
Horizontal accuracy, cm (95% confidence)
CONUS networks, 10 cm cutoff
1085 Primary and 1292 Secondary no-check stations excluded
CONUS Primary
60,815 of 60,881 (99.9%)
0.05 to 1 cm (41,326 = 67.9%)
1 to 2 cm (15,339 = 25.2%)
2 to 5 cm (3929 = 6.4%)
5 to 10 cm (221 = 0.4%)
CONUS Secondary
15,961 of 16,441 (97.1%)
0.1 to 1 cm (3260 = 19.8%)
1 to 2 cm (7422 = 45.2%)
2 to 5 cm (4503 = 27.4%)
5 to 10 cm (776 = 4.7%)
0 200 400 600 800 1,000
kilometers

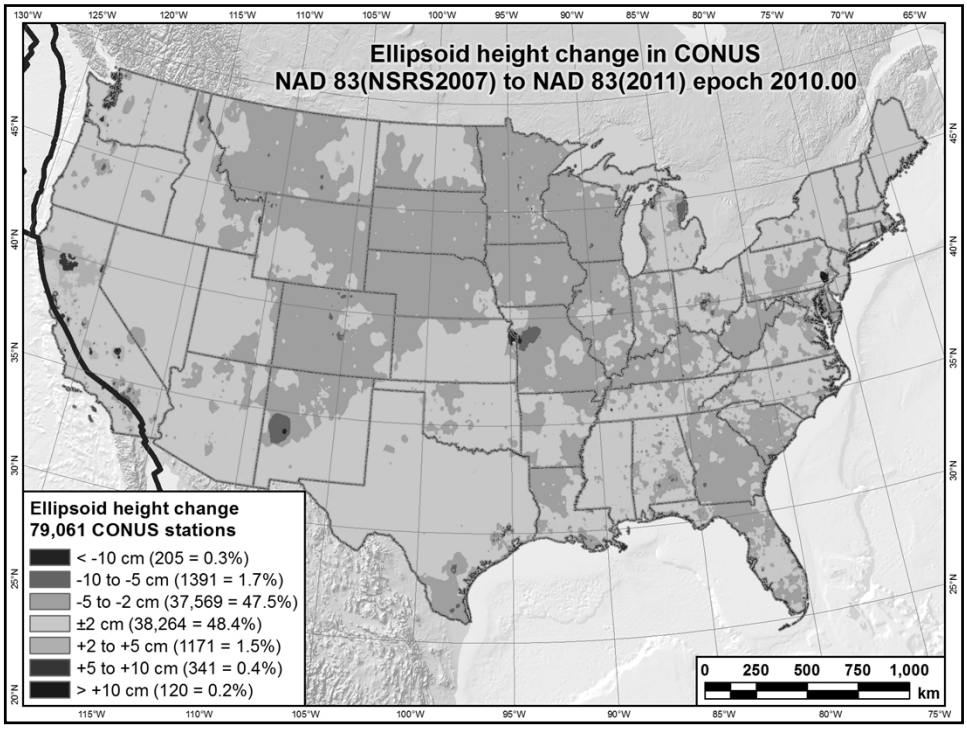

NAD 83(2011) epoch 2010.00
National adjustment of passive control
Ellipsoid height accuracy, cm (95% confidence)
1085 Primary and 1292 Secondary no-check stations excluded
CONUS Primary network (10 cm cutoff)
5
60,623 of 60,881 adjusted stations (99.58%)
CONUS Secondary network (10 cm cutoff)
5
14,638 of 16,441 adjusted stations (89.03%)
0 200 400 600 800 1,000
kilometers

# NAD 83(2011/PA11/MA11) epoch 2010.00

## *Passive control results summary*

- Station coordinate and height changes
  - Overall median: ***1.9 cm horiz, 2.1 cm height***
    - ***97% changed < 5 cm horizontally and vertically***
  - Median accuracies by network
    - CONUS: ***1.9 cm horiz, 2.1 cm height***
    - Alaska: ***6.3 cm horiz, 2.8 cm height***
    - Pacific (PA11): ***2.1 cm horiz, 2.3 cm height***
    - Pacific (MA11): ***2.5 cm horiz, 6.8 cm height***



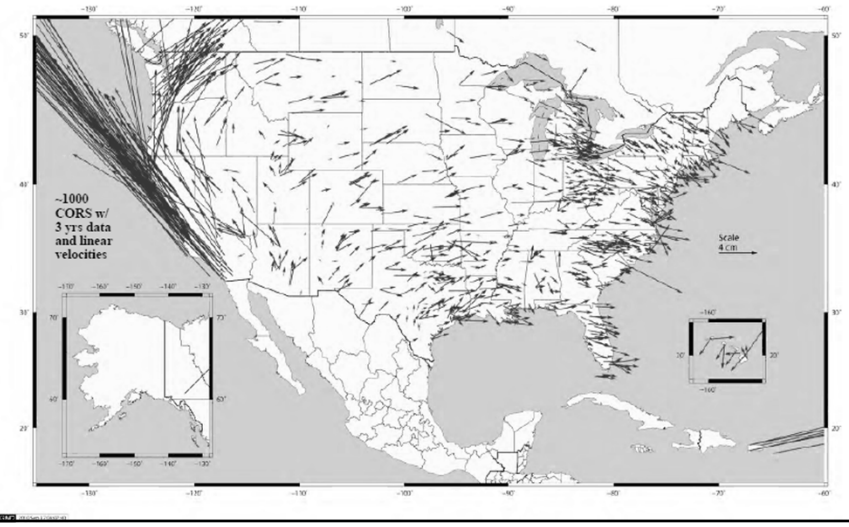



## Change in horizontal NAD 83 CORS coordinates

NAD 83(CORS96) **epoch 2002.00** → NAD 83(2011) **epoch 2010.00**

**Avg shifts (cm): ΔN = 2.0 (±6.4); ΔE = 0.2 (±5.9); ΔU = -0.9 (±2.0)**

- large shifts in western U.S. due to crustal deformation
- apparent rotation in "stable" U.S. likely due to errors in NUVEL-1A (used in HTDP)



## Related Tasks, Products & Deliverables

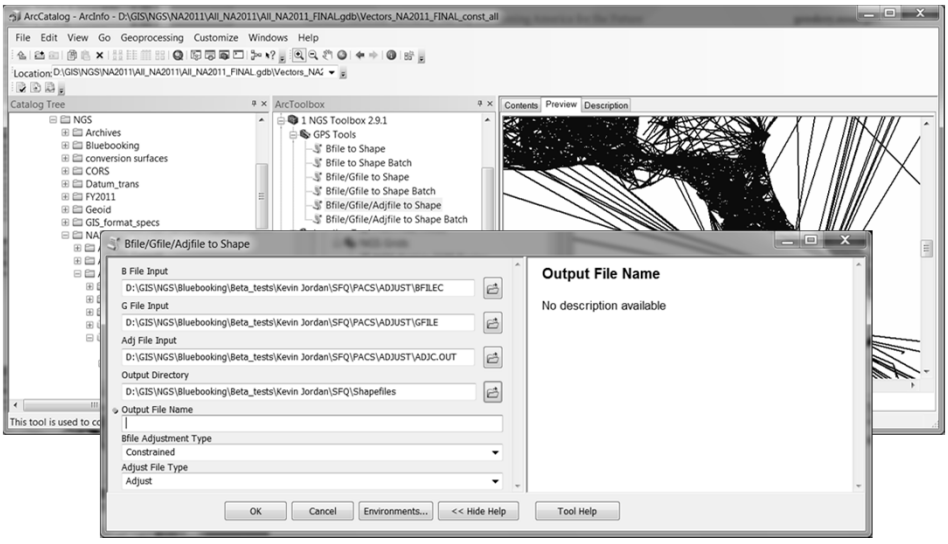
- OPUS (Online Positioning User Service)
  - Solutions for NAD 83(2011/PA11/MA11) epoch 2010.00
- New hybrid geoid model (GEOID12A)
  - NAD 83(2011) ellipsoid heights on leveled NAVD 88 BMs
- New process for Bluebooking GPS projects
  - Currently under development
  - New version of "ADJUST" program
  - Includes new GIS tools as part of adjustment process
- New NAD 83 coordinate transformation tools
  - HARN ←→ NSRS2007 ←→ 2011
  - Tools created but still needs to be implement
  - Both horizontal AND "vertical" (i.e., ellipsoid height)
  - Include output that indicates "quality" of transformation
    - Quantified using station within grid cell that is worst match with model

## Related Tasks, Products & Deliverables

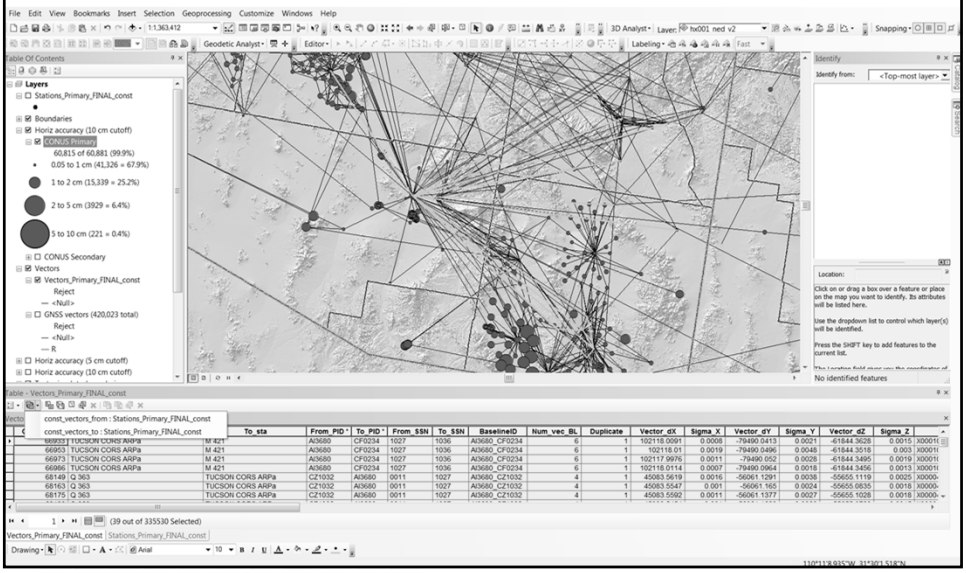
- New Geodetic GIS tools
  - Use standard NGS ASCII output files as input
  - Convert to point, line, and polygon features
  - Attribute-rich features in standard GIS format
  - Used for display and analysis of results
- Two new GIS tools in development
  - GPS and leveling network adjustment → GIS features
    - GPS files: positions, vectors, error estimates, residuals
    - Geodetic leveling: adjusted elevations, loop misclosures, residuals, etc.
  - Add more analysis and display functionality
    - Error ellipses, spatial analysis, displacement vectors
- May provide other NGS products in GIS format
  - Geoid models, transformation grids, variety of point datasets

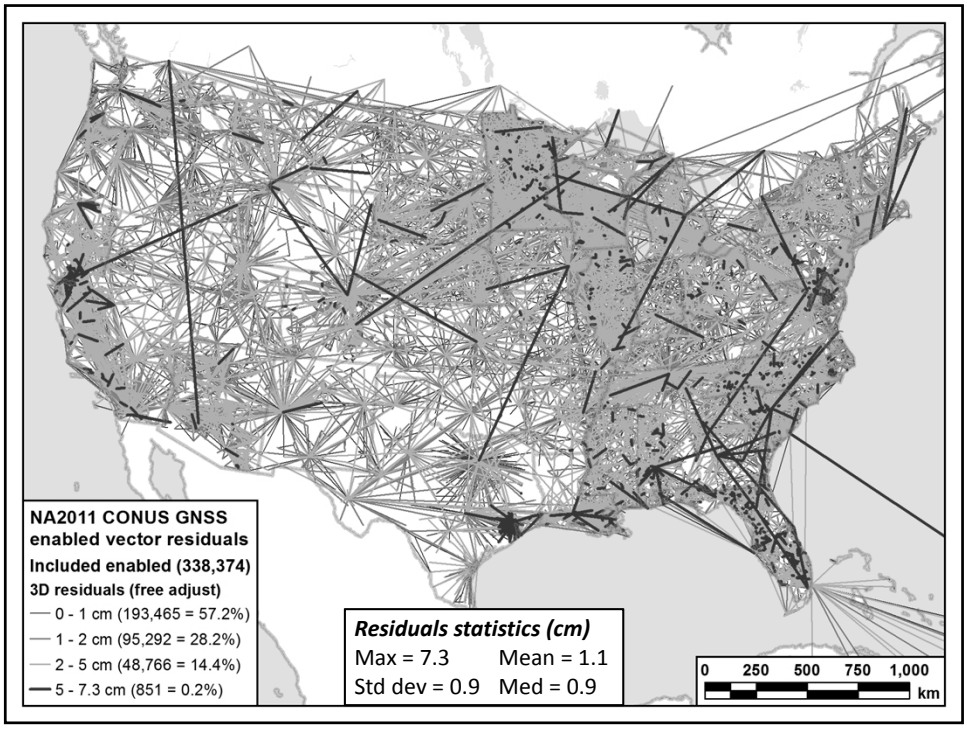
# Related Tasks, Products & Deliverables

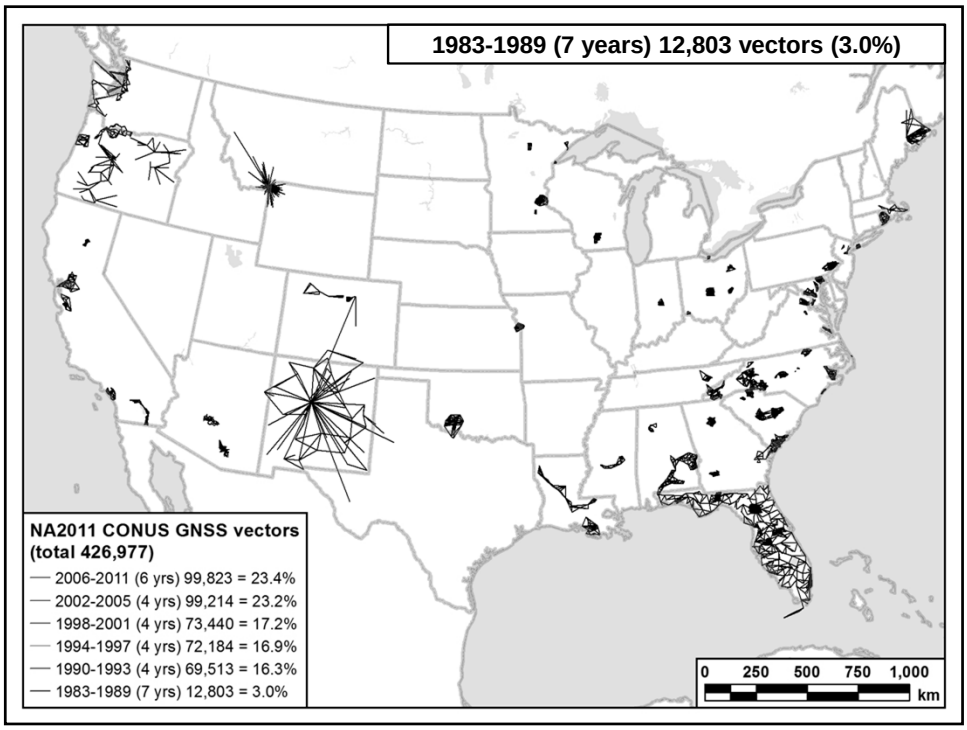
- New Geodetic GIS tools

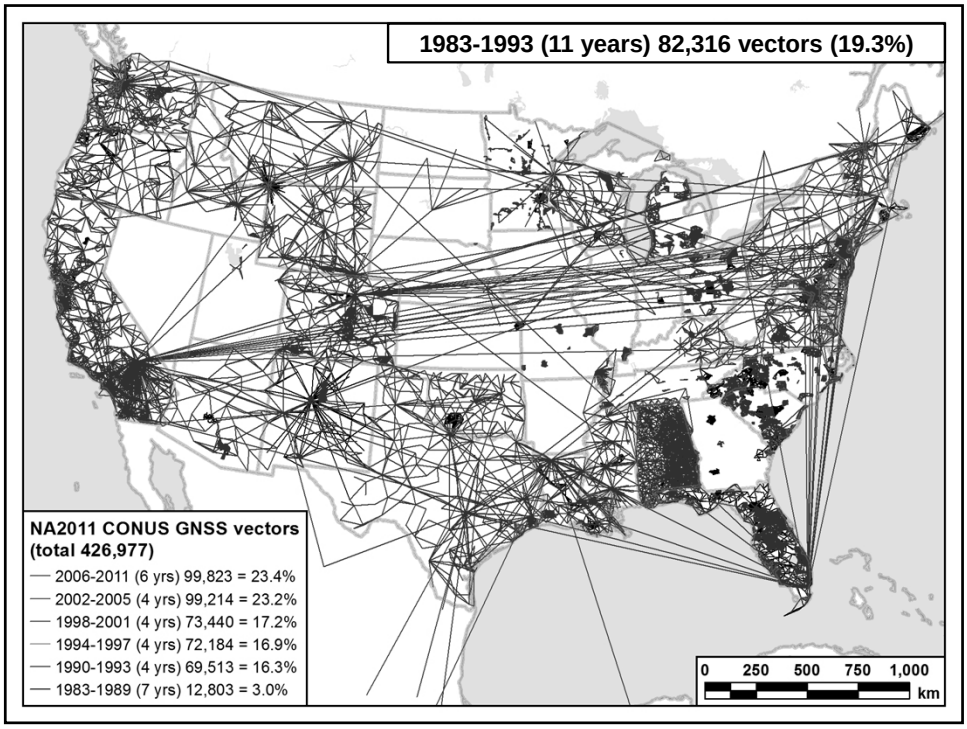


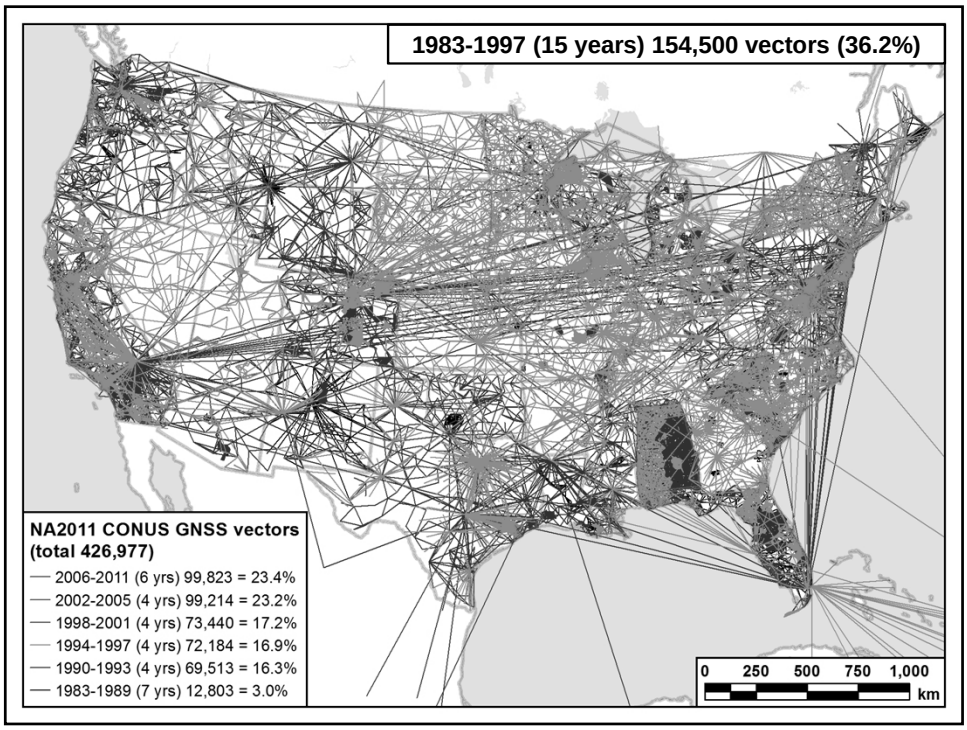

Network adjustment results as GIS features provide powerful analysis capabilities…

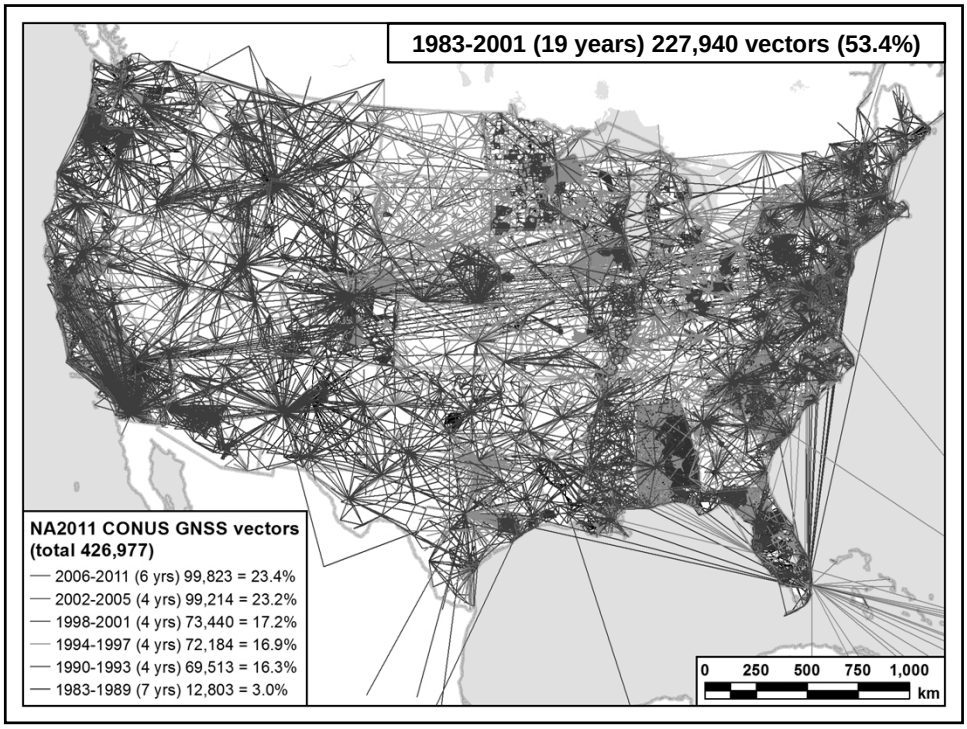


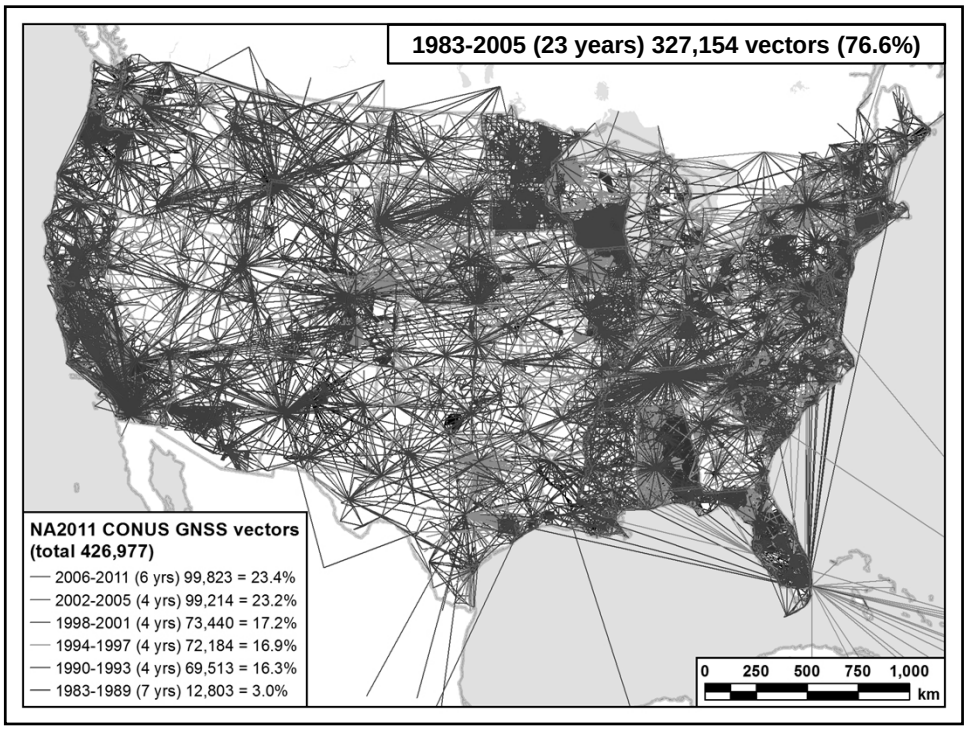

NA2011 CONUS GNSS enabled vector residuals
Included enabled (338,374)
3D residuals (free adjust)
0 - 1 cm (193,465 = 57.2%)
1 - 2 cm (95,292 = 28.2%)
2 - 5 cm (48,766 = 14.4%)
5 - 7.3 cm (851 = 0.2%)
Residuals statistics (cm)
Max = 7.3 Mean = 1.1
Std dev = 0.9 Med = 0.9
0 250 500 750 1,000
km

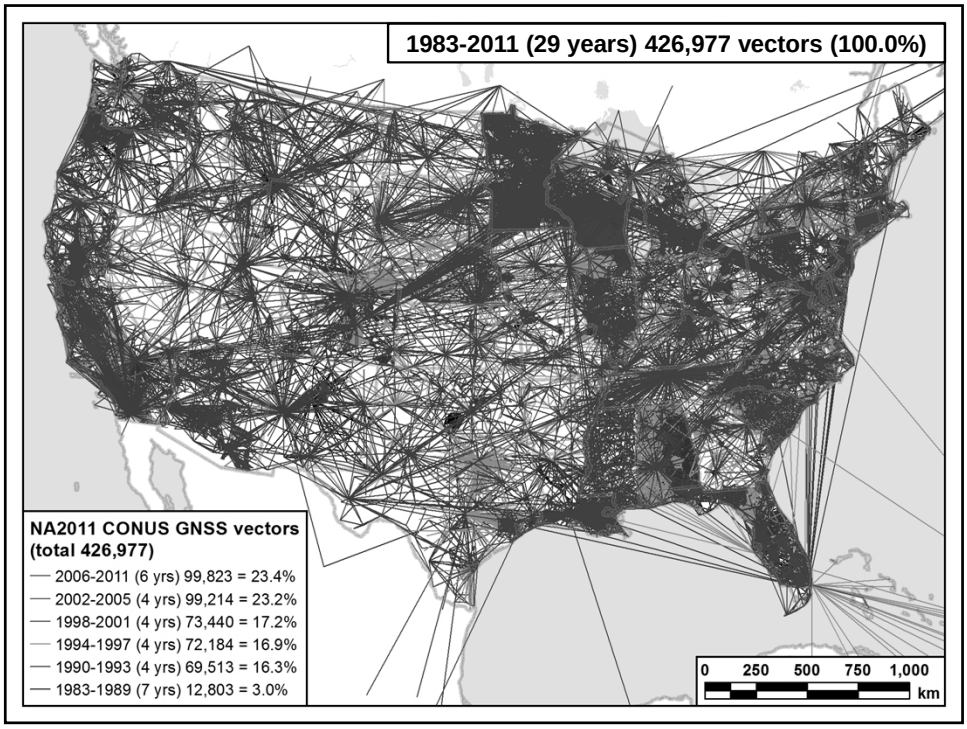

1983-1989 (7 years) 12,803 vectors (3.0%)
NA2011 CONUS GNSS vectors (total 426,977)
2006-2011 (6 yrs) 99,823 = 23.4%
2002-2005 (4 yrs) 99,214 = 23.2%
1998-2001 (4 yrs) 73,440 = 17.2%
1994-1997 (4 yrs) 72,184 = 16.9%
1990-1993 (4 yrs) 69,513 = 16.3%
1983-1989 (7 yrs) 12,803 = 3.0%
0 250 500 750 1,000
km


1983-1993 (11 years) 82,316 vectors (19.3%)
NA2011 CONUS GNSS vectors
(total 426,977)
2006-2011 (6 yrs) 99,823 = 23.4%
2002-2005 (4 yrs) 99,214 = 23.2%
1998-2001 (4 yrs) 73,440 = 17.2%
1994-1997 (4 yrs) 72,184 = 16.9%
1990-1993 (4 yrs) 69,513 = 16.3%
1983-1989 (7 yrs) 12,803 = 3.0%
0 250 500 750 1,000
km


1983-1997 (15 years) 154,500 vectors (36.2%)
NA2011 CONUS GNSS vectors
(total 426,977)
2006-2011 (6 yrs) 99,823 = 23.4%
2002-2005 (4 yrs) 99,214 = 23.2%
1998-2001 (4 yrs) 73,440 = 17.2%
1994-1997 (4 yrs) 72,184 = 16.9%
1990-1993 (4 yrs) 69,513 = 16.3%
1983-1989 (7 yrs) 12,803 = 3.0%
0 250 500 750 1,000
km


1983-2001 (19 years) 227,940 vectors (53.4%)
NA2011 CONUS GNSS vectors
(total 426,977)
2006-2011 (6 yrs) 99,823 = 23.4%
2002-2005 (4 yrs) 99,214 = 23.2%
1998-2001 (4 yrs) 73,440 = 17.2%
1994-1997 (4 yrs) 72,184 = 16.9%
1990-1993 (4 yrs) 69,513 = 16.3%
1983-1989 (7 yrs) 12,803 = 3.0%
0 250 500 750 1,000
km


1983-2005 (23 years) 327,154 vectors (76.6%)
NA2011 CONUS GNSS vectors
(total 426,977)
2006-2011 (6 yrs) 99,823 = 23.4%
2002-2005 (4 yrs) 99,214 = 23.2%
1998-2001 (4 yrs) 73,440 = 17.2%
1994-1997 (4 yrs) 72,184 = 16.9%
1990-1993 (4 yrs) 69,513 = 16.3%
1983-1989 (7 yrs) 12,803 = 3.0%
0 250 500 750 1,000
km




# Recap: The fundamental questions

- When was it done?
  - Publication completed on ***June 30, 2012***
    - ***Intent: Simultaneous with release of GEOID12A***
- How many control stations? ***80,872***
- How much did the coordinates change?
  - Median: ***1.9 cm horiz, 2.1 cm vertical***
- How accurate are the results?
  - Median: ***0.9 cm horiz, 1.5 cm vertical***
    (at 95% confidence level)
- How do I make use of the results?
  - Key is ***metadata:*** Know and identify what you have
  - Be consistent (i.e., don't mix realizations)
  - Understand your software (e.g., relationship to "WGS 84")
    - Latest WGS 84 is G1674 (week of Feb 5, 2012), epoch 2005.00

# What about orthometric heights?

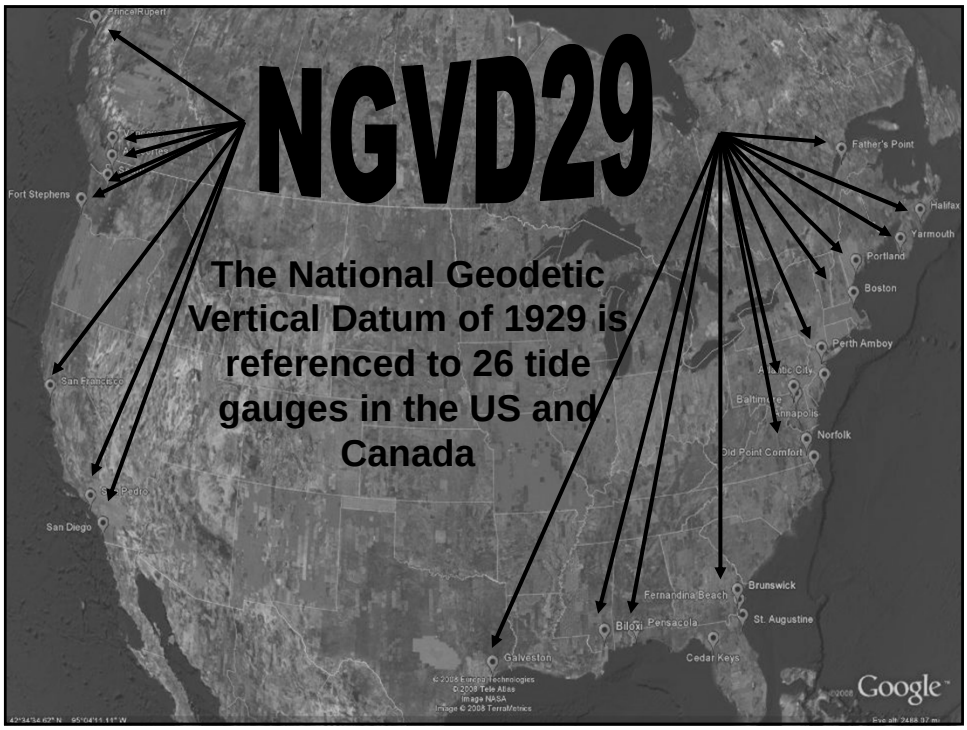
- National adjustment of passive control
  - NAD 83(2011/PA11/MA11) epoch 2010.00:
    - Latitude, longitude, and ellipsoid height
    - Network and "local" accuracies
- Orthometric heights ("elevations") ***NOT*** determined
  - Question: Will GPS-derived heights based on previous NAD 83 realizations and geoid models be consistent with those based on NAD 83(2011) and GEOID12A?
    - i.e., is the ***relative*** change in ellipsoid heights and/or geoid heights significant (too large to ignore)?
- Should NGS perform nationwide vertical adjustment?
  - Use GEOID12A model and national adjustment GNSS network
  - Constrain to leveled NAVD 88 benchmarks
  - Determine GPS-derived NAVD 88 heights on non-leveled marks
  - Will require significant analysis

## History of vertical datums in the USA

- **Pre-National Geodetic Vertical Datum of 1929 (NGVD 29)**
  - The first geodetic leveling project in the United States was surveyed by the Coast Survey from 1856 to 1857.
  - Transcontinental leveling commenced from Hagerstown, MD in 1877.
  - General Adjustments of leveling data yielded datums in 1900, 1903, 1907, and 1912. (Sometimes referenced as the Sandy Hook Datum)
  - NGS does not offer a utility which transforms from these older datums into newer ones (though some users still work in them!)

# History of vertical datums in the USA

- **NGVD 29**
  - National Geodetic Vertical Datum of 1929
  - Original name: “Sea Level Datum of 1929”
  - “Zero height” held fixed at 26 tide gauges
    - Not all on the same tidal datum epoch (~ 19 yrs)
  - Did not account for Local Mean Sea Level variations from the geoid
    - Thus, not truly a “geoid based” datum



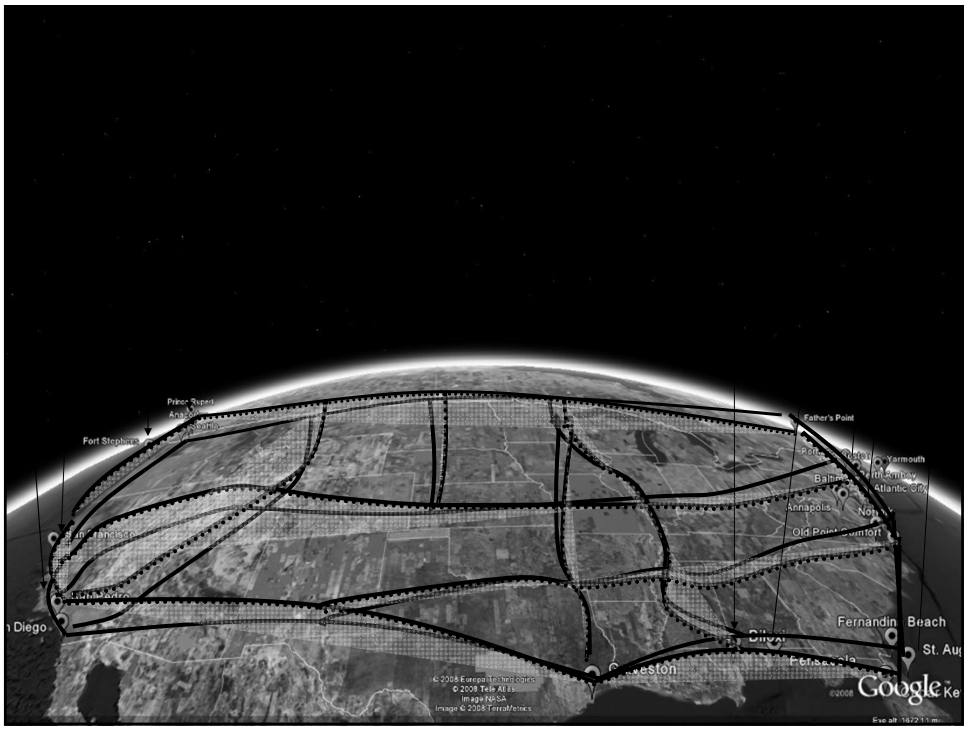
## History of vertical datums in the USA

- **NAVD 88**
  - North American Vertical Datum of 1988
  - One height held fixed at "Father Point" (Rimouski, Canada)
  - …height chosen was to minimize 1929/1988 differences on USGS topo maps in the eastern U.S.
  - Thus, the "zero height surface" of NAVD 88 wasn't chosen for its closeness to the geoid (but it was close…few decimeters)

## History of vertical datums in the USA

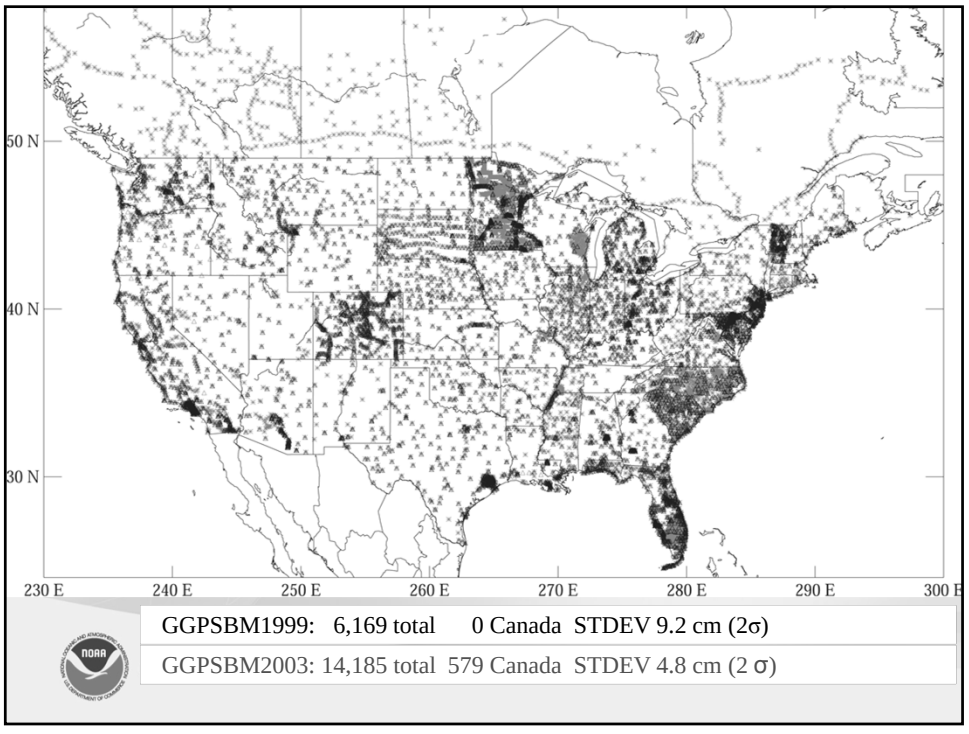
- **NAVD 88** (continued)
  - Use of one fixed height removed local sea level variation problem of NGVD 29
  - Use of one fixed height did open the possibility of unconstrained cross-continent error build up
  - But the H=0 surface of NAVD 88 was supposed to be parallel to the geoid…(close again)

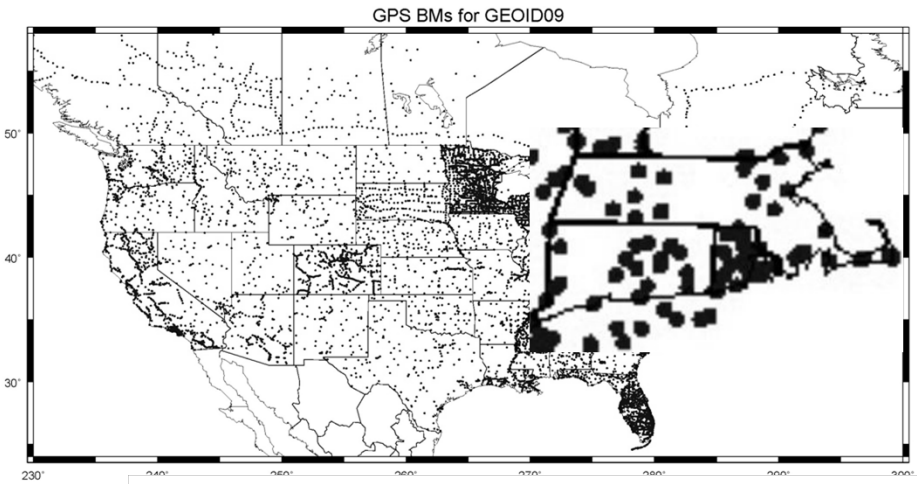

NAVD88
The North American Vertical Datum of 1988 is referenced to a single tide gauge in Canada
Prince Rupert
Vancouver
Anacortes
Seattle
Fort Stephens
San Francisco
San Pedro
San Diego
Father's Point
Halifax
Yarmouth
Portland
Boston
Perth Amboy
Atlantic City
Baltimore
Annapolis
Norfolk
Old Point Comfort
Brunswick
Fernandina Beach
St. Augustine
Biloxi
Pensacola
Cedar Keys
Galveston
Google


Prince Rupert
Fort Stephens
Father's Point
Yarmouth
Annapolis
Old Point Comfort
Fernandin Beach
Biloxi
Google

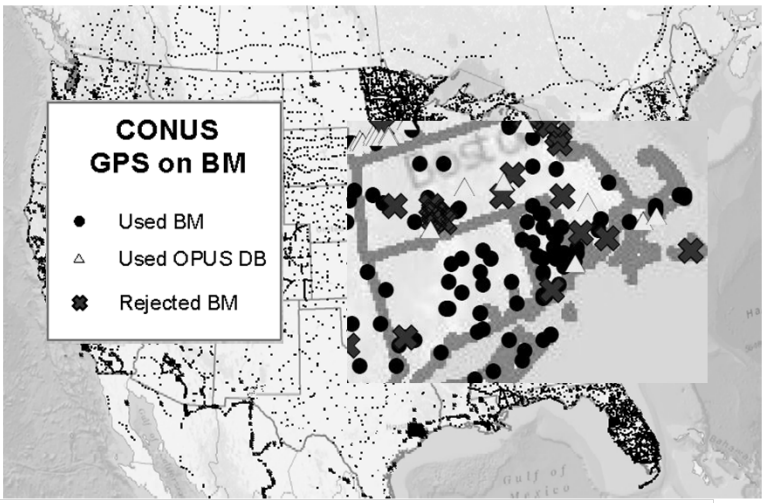
# Types and Uses of Geoid Height Models

- 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






GGPSBM2009: 18,398 STDEV 2.8 cm (2σ)




GGPSBM2012A: 23,961 (CONUS)
499 (OPUS on BM)
574 (Canada)
177 (Mexico)

# Which Geoid for Which NAD 83?

| | |
|---|---|
| • NAD 83(2011) | • Geoid12A |
| • NAD 83(2007) | • Geoid09 |
| | • Geoid06 (AK only) |
| • NAD 83(1996) & CORS96 | • Geoid03<br>• Geoid99<br>• Geoid96 |
| • NAD 83(1992) | • Geoid93 |

## Mission and Vision of NGS

- To define, maintain and provide access to the National Spatial Reference System to meet our nation's economic, social, and environmental needs
- "Maintain the NSRS" means "NGS must ***track all of the temporal changes*** to the defining points of the NSRS in such a way as to always maintain the accuracy in the NSRS definition."
- Vision - Modernize the Geopotential ("Vertical") and Geometric ("Horizontal") datums

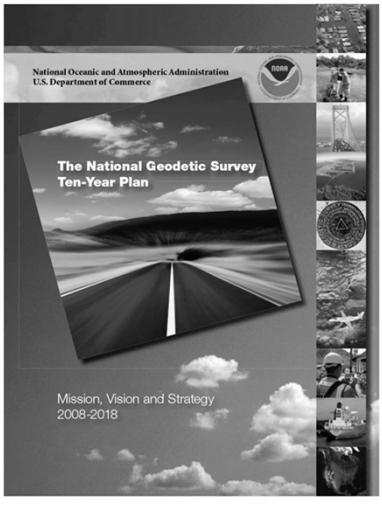
## Problems with NAD 83 and NAVD 88

- **NAD 83** is not as geocentric as it could be (approx. 2 m)
  - Surveyors don't see this - **Yet**
- **NAD 83** is not well defined with positional velocities
- **NAVD 88** is realized by passive control (bench marks) most of which have not been releveled in at least 40 years.
- **NAVD 88** does not account for local vertical velocities (subsidence and uplift)
  - Post glacial isostatic readjustment
  - Subsurface fluid withdrawal
  - Sediment loading
  - Sea level rise (0.86 ft – 0.97 ft per 100 years)
    - **Boston, MA 2.63 mm/yr (0.008 ft/yr) 1921-2006**
    - **Nantucket Island, MA 2.96 mm/yr (0.010 ft/yr) 1965-2006**
    - **Woods Hole, MA 2.61 mm/yr (0.008 ft/yr) 1932-2006**

## 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 Geometric (3-D) Datum

- **replace NAD83 with new geometric datum – by 2022**
- **CORS-based, via GNSS**
- **coordinates & velocities in ITRF and official US datum**

  **(NAD83 replacement: plate-fixed or "ITRF-like"?) & relationship**
- **passive control tied to new datum; not a component of new datum**
- **address user needs of datum coordinate *constancy vs. accuracy***

- **lat / long / ellipsoid height of defining points accurate to 1 mm, anytime**
- **CORS coordinates computed / published daily; track changes**

# 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**

# Why New Datums?

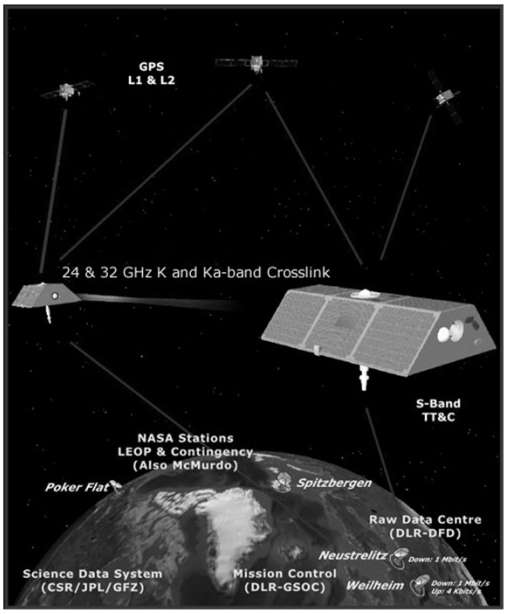
- **NAD 83**
  - **non-geocentric, i.e. inconsistent with GNSS positioning**
  - **difficult to maintain consistency between CORS & passive network NAD 83 coordinates**
  - **lack of velocities, i.e. NAD 83 does not report station motion for passive marks**
- **NAVD 88**
  - **cross-country build up of errors ("tilt" or "slope") from geodetic leveling**
  - **passive marks inconveniently located and vulnerable to disturbance and destruction**
  - **0.5 m bias in the NAVD 88 reference surface from the (best) geoid surface approximating global mean sea level**
  - **subsidence, uplift, freeze/thaw, and other crustal motions invalidate heights of passive marks, and can make it difficult to detect such motions**
  - **marks lacking adequate geophysical models - complicate sea level change detection**
  - **changes to Earth's gravity field cause changes in orthometric heights, but NAVD 88 does not account for those changes (NAVD88 based on a static gravity model)**
  - **gravity model and modeling techniques used to determine NAVD 88 are not consistent with those currently used for geoid modeling**

# Problems using traditional leveling (to define a National Vertical Datum)

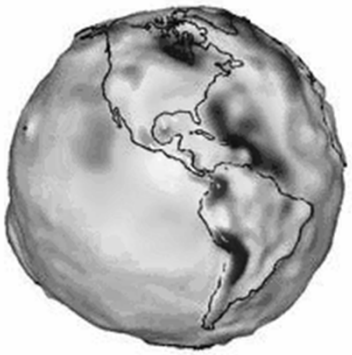
- Leveling the country can not be done again
  - Too costly in time and money
  - Leveling yields cross-country error build-up; problems in the mountains
- Leveling requires leaving behind passive marks
  - Bulldozers and crustal motion do their worst

# Why isn't NAVD 88 good enough anymore

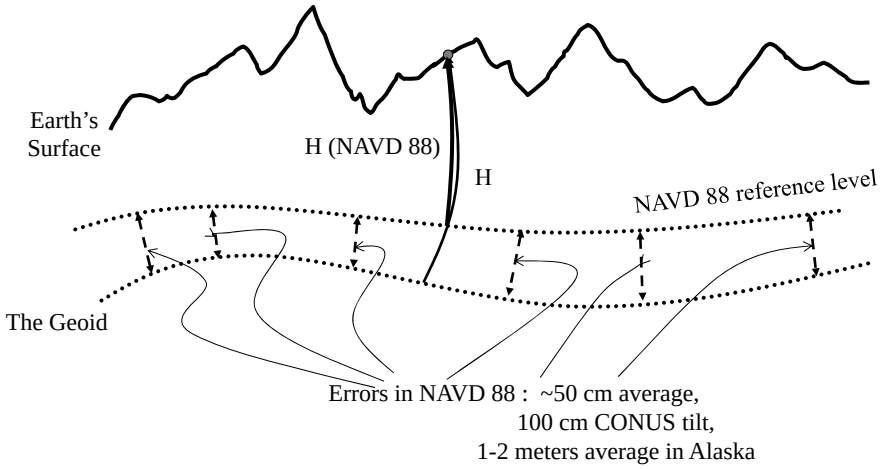
- **NAVD 88 suffers from <u>use of bench marks</u> that:**
  - Are almost never re-checked for movement
  - Disappear by the thousands every year
  - Are not funded for replacement
  - Are not necessarily in convenient places
  - Don't exist in most of Alaska
  - Weren't adopted in Canada
  - Were determined by leveling from a single point, allowing cross-country error build up




**GRACE – Gravity Recovery and Climate Experiment**



## Why isn't NAVD 88 good enough anymore?



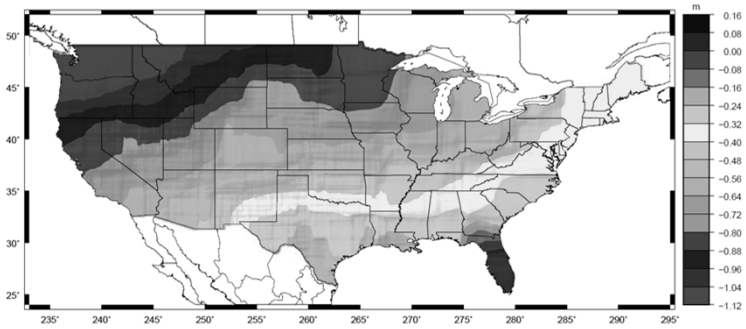

## Why isn't NAVD 88 good enough anymore?

**NAVD 88 suffers from:**

- A zero height surface that:
  - Has been proven to be ~50 cm biased from the latest, best geoid models (GRACE satellite)
  - Has been proven to be ~ 1 meter tilted across CONUS (again, based on the independently computed geoid from the GRACE satellite)

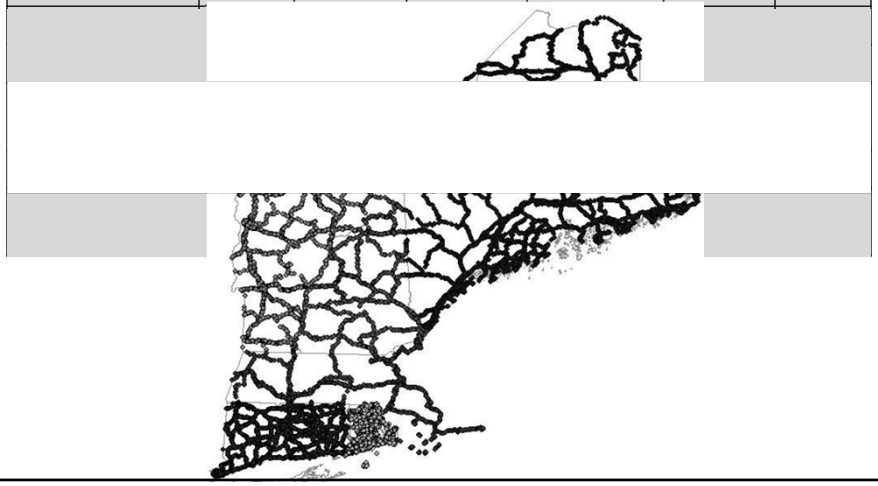
## Why isn't NAVD 88 good enough anymore?

- **Approximate level of geoid mismatch known to exist in the NAVD 88 zero surface:**

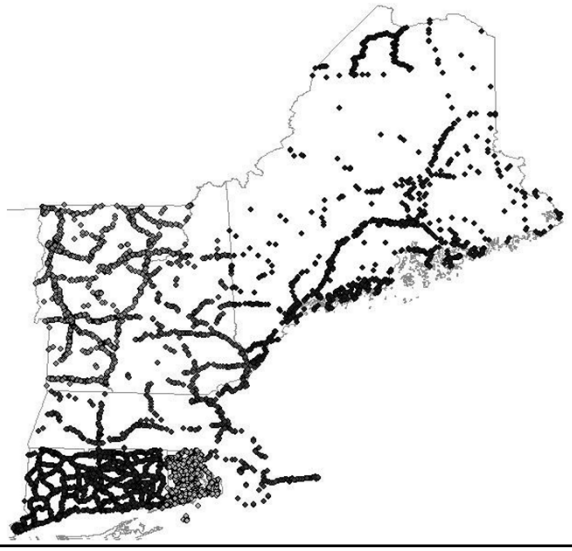



# NGSIDB BM Status (1st, 2nd order)

| | CT | MA | ME | NH | RI | VT |
|---|---|---|---|---|---|---|
| In NGSIDB | 2599 | 1125 | 5401 | 1092 | 1380 | 2158 |



# NE Vertical Control



# Height-Mod means More Marks

## Height Modernization Bottom line

1. Using GNSS is cheaper, easier than leveling

2. To use GNSS we need a good geoid model

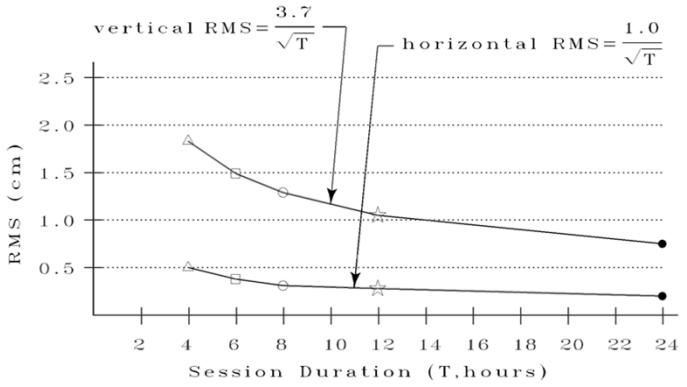
## How accurate is a GPS-derived Orthometric Height?

- 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
- Accuracy of orthometric height is dependent on accuracy of the geoid model – 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.

National Geodetic Survey

# Positioning Error vs. Duration of the Observing Session

Dual-frequency GPS carrier-phase observations

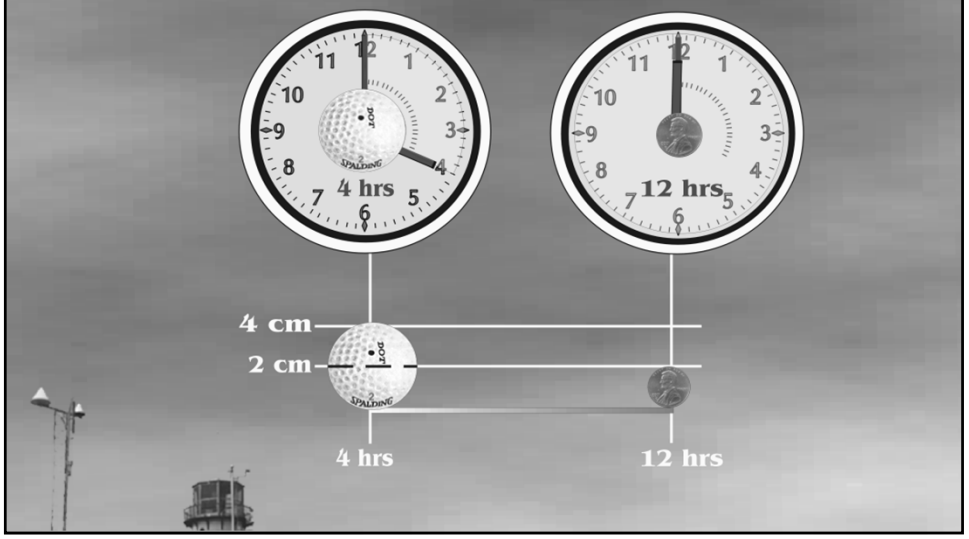



National Oceanic and Atmospheric Administration

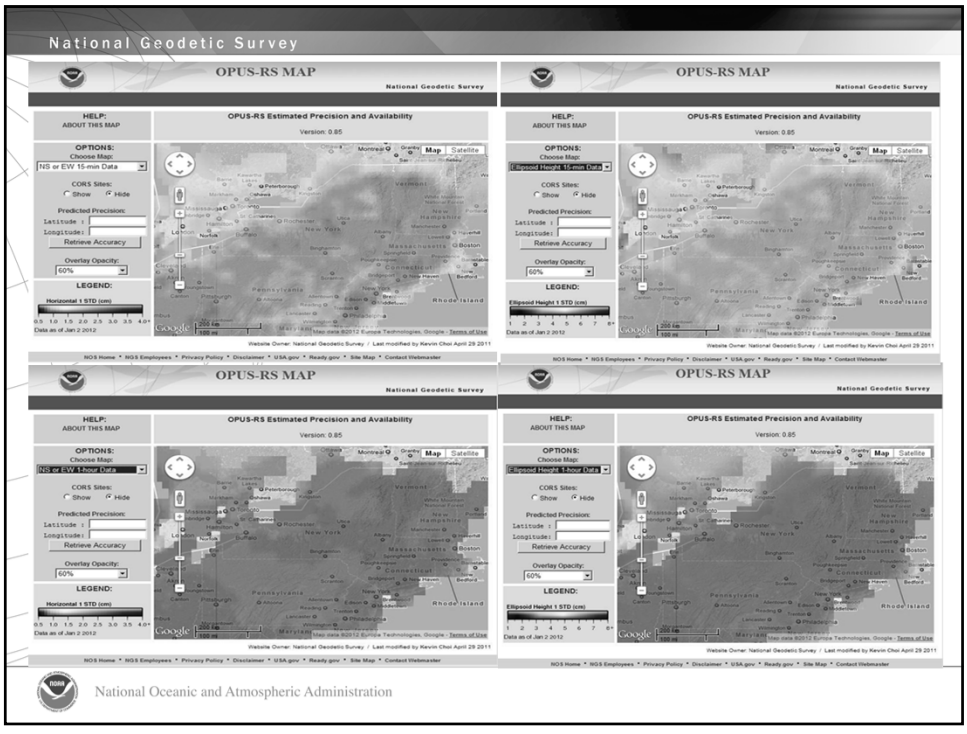
# National CORS Accuracy

Vertical Precision Using Dual-Frequency

GPS Carrier Phase Observations 95% Confidence Level




National Geodetic Survey
OPUS-RS MAP
National Geodetic Survey
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 STD (cm)
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0+
Data as of Nov 7 2011
Map
Satellite
Canada
Hudson Bay
North Pacific Ocean
Gulf of California
México
Gulf of Mexico
Cuba
Guatemala
Nicaragua
Caribbean Sea
North Atlantic Ocean
Gulf of St Lawrence
1000 km
1000 mi
Map Data
Terms of Use
Website Owner: National Geodetic Survey / Last modified by Kevin Choi April 29 2011
NOS Home • NGS Employees • Privacy Policy • Disclaimer • USA.gov • Ready.gov • Site Map • Contact Webmaster
National Oceanic and Atmospheric Administration


National Geodetic Survey
OPUS-RS MAP
National Geodetic Survey
OPUS-RS MAP
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OPUS-RS MAP
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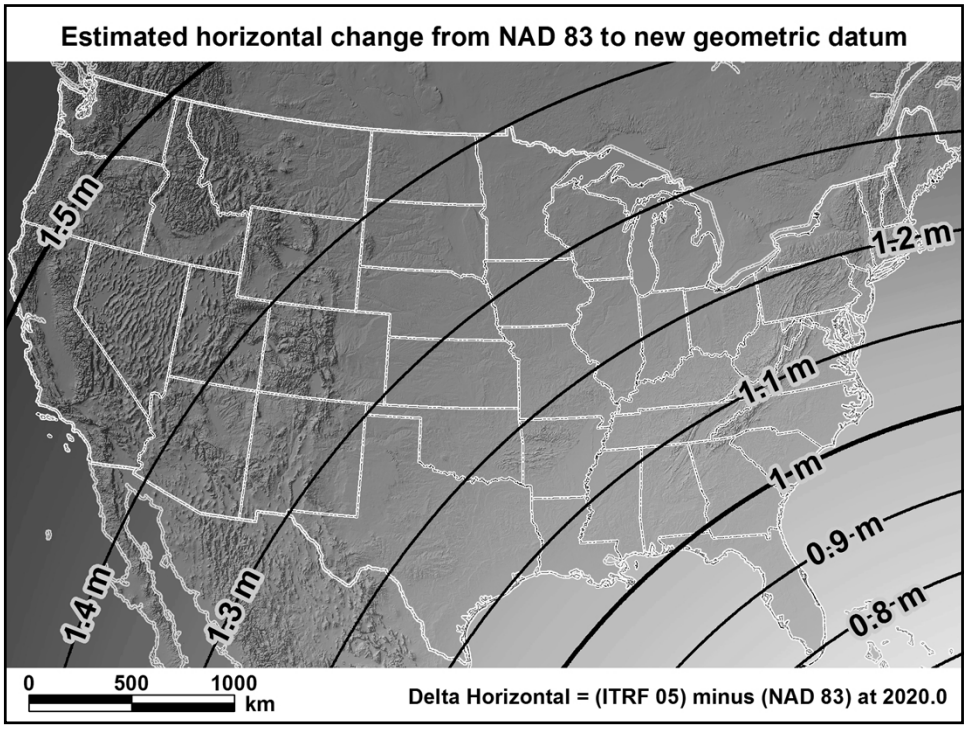
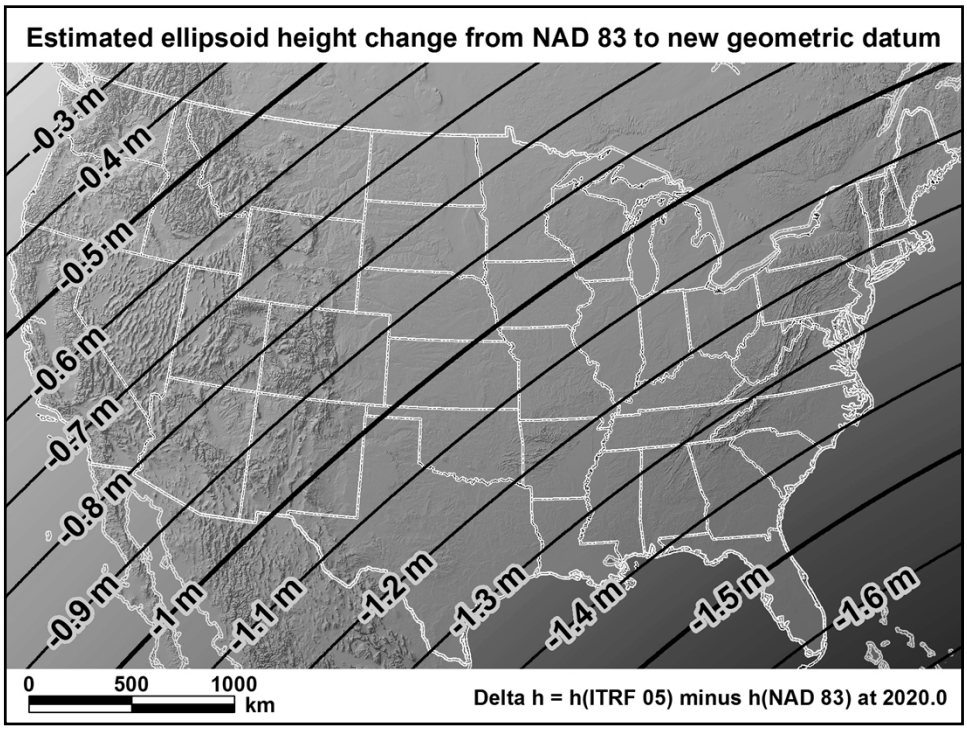
OPUS-RS MAP
National Geodetic Survey
National Oceanic and Atmospheric Administration

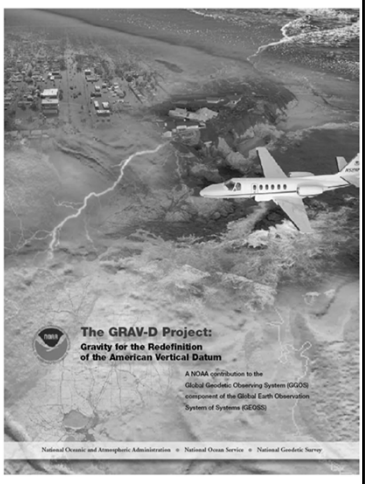

Estimated horizontal change from NAD 83 to new geometric datum
1.5 m
1.4 m
1.3 m
1.2 m
1.1 m
1 m
0.9 m
0.8 m
0
500
1000
km
Delta Horizontal = (ITRF 05) minus (NAD 83) at 2020.0


Estimated ellipsoid height change from NAD 83 to new geometric datum
-0.3 m
-0.4 m
-0.5 m
-0.6 m
-0.7 m
-0.8 m
-0.9 m
-1 m
-1.1 m
-1.2 m
-1.3 m
-1.4 m
-1.5 m
-1.6 m
0
500
1000
km
Delta h = h(ITRF 05) minus h(NAD 83) at 2020.0

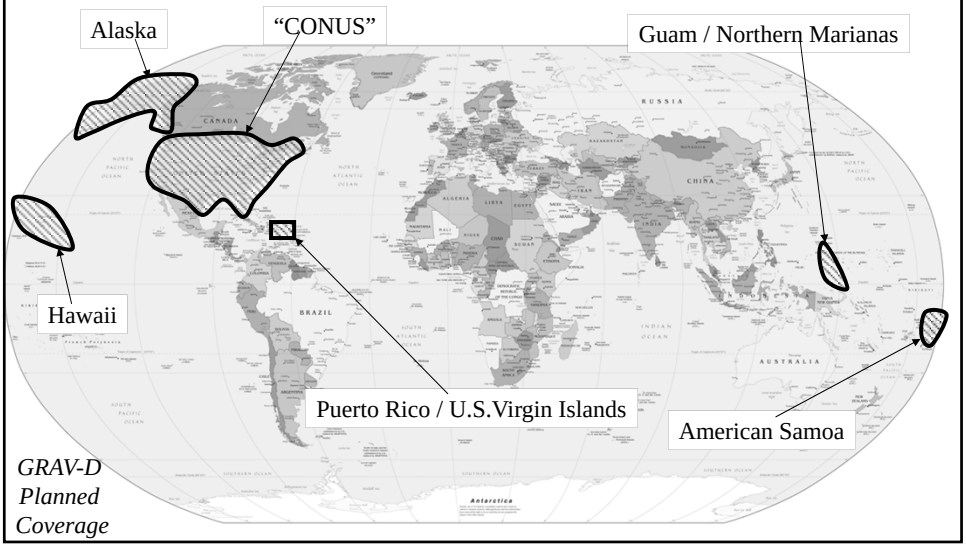
## Transition to the Future – GRAV-D

### 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)



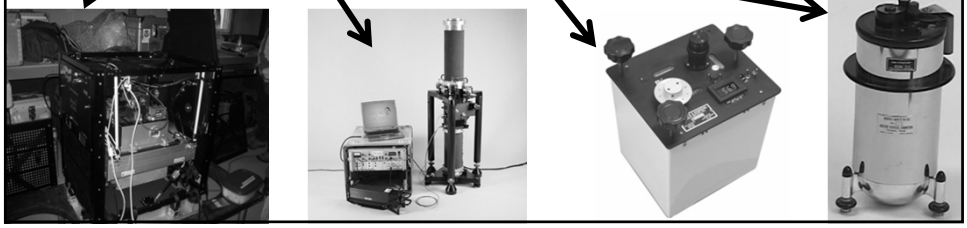

## What is GRAV-D?




*GRAV-D Planned Coverage*

Gravity Survey Plan

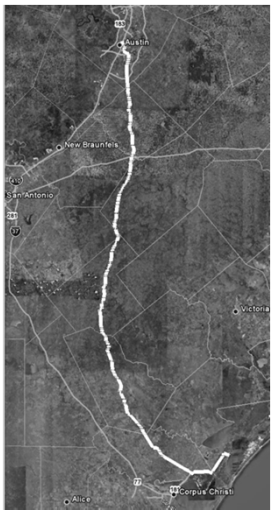
- National Scale Part 1
  - Predominantly through airborne gravity
  - With Absolute Gravity for ties and checks
  - Relative Gravity for expanding local regions where airborne shows significant mismatch with existing terrestrial

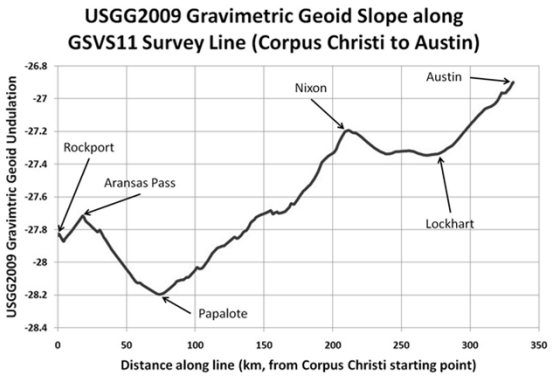


# What is GRAV-D?

- **GRAV-D will mean:**
  - As the H=0 surface, the geoid will be tracked over time to keep the datum up to date
  - The reliance on passive marks will dwindle to:
    - Secondary access to the datum
    - Minimal NGS involvement
      - Maintenance/checking in the hands of users
    - Use at your own risk

# Geoid Slope Validation Survey of 2011 (GSVS11)




# GSVS11 Components

- Differential Leveling
- Campaign GPS
- RTN-based and OPUS_RS
- Absolute Gravity
- Gravity Gradients
- Deflections of the Vertical
- Airborne LIDAR
- Airborne Imagery

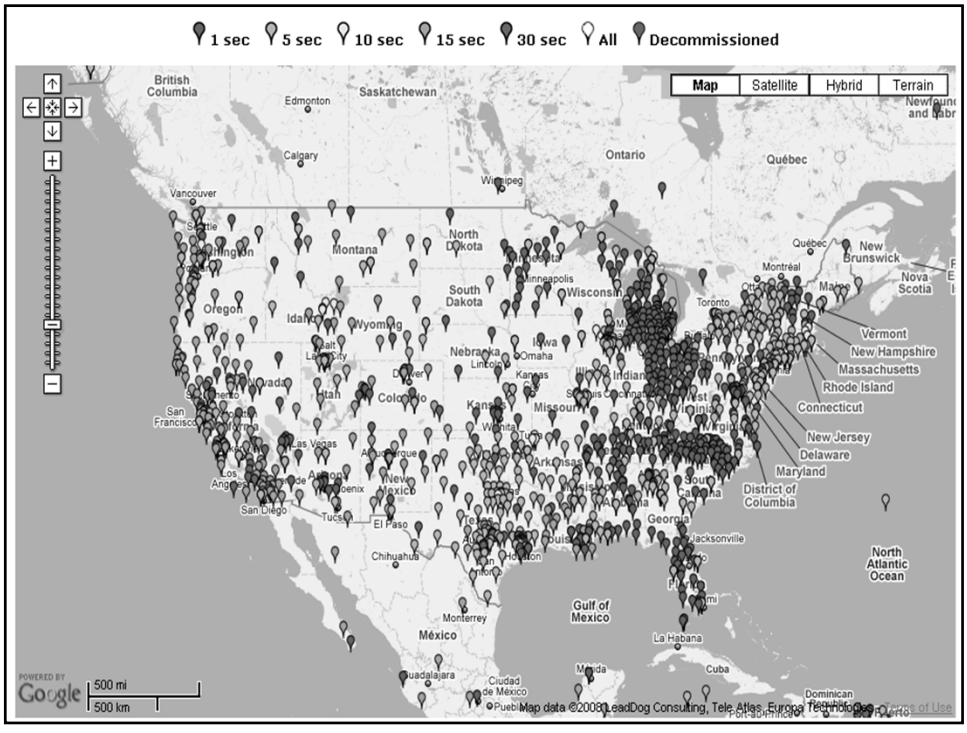
# Accessing the New Vertical Datum

- **Primary access** (NGS mission)
  - Users with geodetic quality GNSS receivers will continue to use OPUS suite of tools
  - Ellipsoid heights computed, and then a gravimetric geoid removed to provide orthometric heights in the new datum
  - No passive marks needed
  - But, could be used to position a passive mark
- **Secondary access** (Use at own risk)
  - Passive marks that have been tied to the new vertical datum
  - NGS will provide a "data sharing" service for these points, but their accuracy (due to either the quality of the survey or the age of the data) will not be a responsibility of NGS

Continuously Operating Reference Station

# Accessing the New Vertical Datum

- **NAVD 88 conversion to new datum**
  - A conversion will be provided between NAVD 88 and the new datum
    - Only where recent GNSS ellipsoid heights exist to provide modern heights in the new datum



# REGIONAL CORS NETWORK


***IGS 08***
WESTFORD (WES2), MASSACHUSETTS

Created on 31Aug2011 at 09:26:50.

Antenna Reference Point(ARP): WESTFORD CORS ARP
PID = AF9520

IGS08 POSITION (EPOCH 2005.0)
Published by the IGS in Nov 2010.

| | | | |
|---|---|---|---|
| X = | 1492233.247 m | latitude | = 42 36 48.00831 N |
| Y = | -4458089.489 m | longitude | = 071 29 35.97701 W |
| Z = | 4296046.035 m | ellipsoid height | = 85.014 m |

IGS08 VELOCITY
Published by the IGS in Nov 2010.

| | | | |
|---|---|---|---|
| VX = | -0.0156 m/yr | northward | = 0.0055 m/yr |
| VY = | -0.0013 m/yr | eastward | = -0.0152 m/yr |
| VZ = | 0.0041 m/yr | upward | = 0.0000 m/yr |

NAD_83 (2011) POSITION (EPOCH 2010.0)
Transformed from IGS08 (epoch 2005.0) position in Aug 2011.

| | | | |
|---|---|---|---|
| X = | 1492233.946 m | latitude | = 42 36 47.97476 N |
| Y = | -4458090.929 m | longitude | = 071 29 35.96800 W |
| Z = | 4296046.089 m | ellipsoid height | = 86.219 m |

NAD_83 (2011) VELOCITY
Transformed from IGS08 velocity in Aug 2011.

| | | | |
|---|---|---|---|
| VX = | 0.0019 m/yr | northward | = -0.0015 m/yr |
| VY = | 0.0003 m/yr | eastward | = 0.0019 m/yr |
| VZ = | -0.0017 m/yr | upward | = -0.0009 m/yr |

**IGS08 – NAD 83(2011)**
**DHoriz = 1.205 m**
**DEHt = 1.054 m**

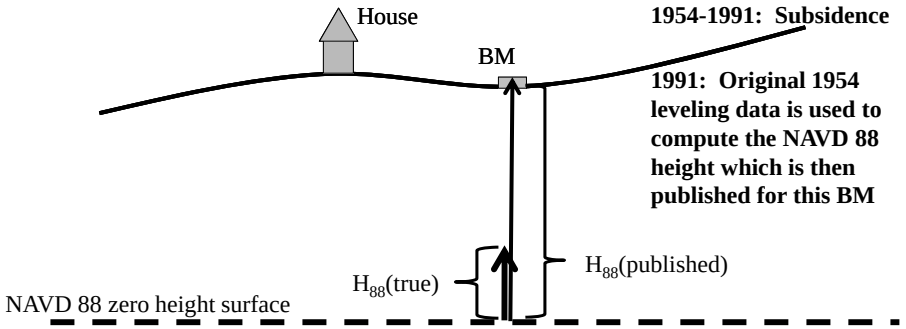
# How will I access the new vertical datum?

**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**

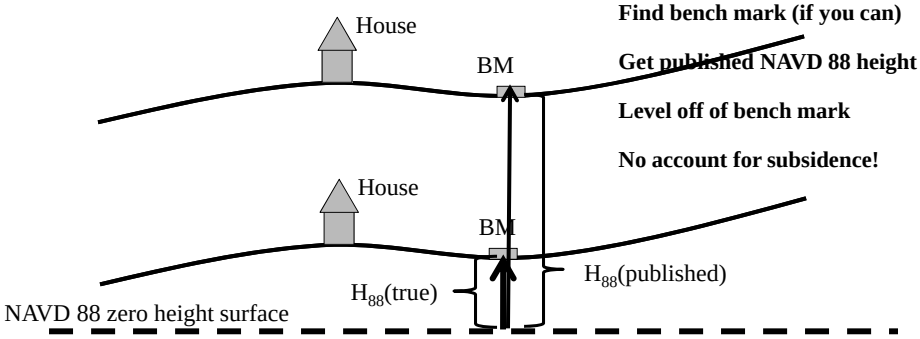
***Using <u>Existing</u> Techniques:***

**Find bench mark (if you can)**

**Get published NAVD 88 height**

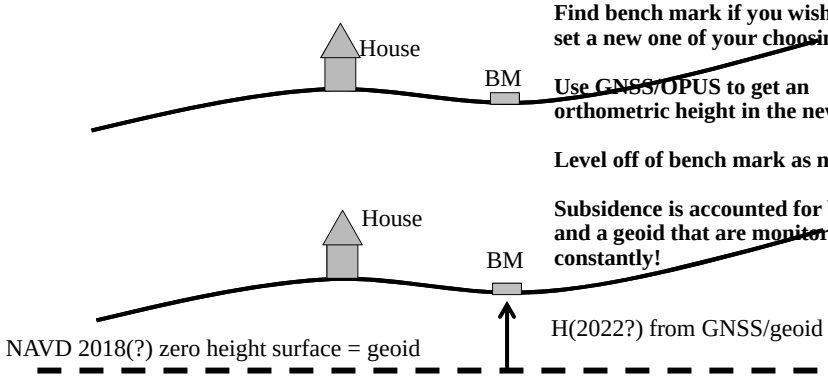
**Level off of bench mark**

**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!**

Last Updated 30 Nov 2009 (DAS)

# Additional Information

The NGS 10 year plan (2008-2018)
http://www.geodesy.noaa.gov/INFO/NGS10yearplan.pdf

The GRAV-D Project
http://www.geodesy.noaa.gov/GRAV-D

Socio-Economic Benefits of CORS and GRAV-D
http://www.geodesy.noaa.gov/PUBS_LIB/Socio-EconomicBenefitsofCORSandGRAV-D.pdf

Last Updated 30 Nov 2009 (DAS)

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# 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

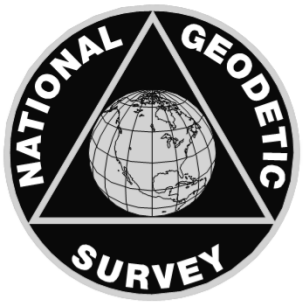
Predicted Positional Changes in 2022
Vicinity of Southborough, MA.
(Computed for station 11406, pid AA9705)

**HORIZONTAL = 1.21 m (4.0 ft)**
**ELLIPSOID HEIGHT = - 1.16 m (- 3.8 ft)**
**Predicted with HTDP**

**ORTHOMETRIC HEIGHT = - 0.37 m (- 1.2 ft)**
**Predicted with HTDP and USGG2012**

**HTDP**
"Coping with Tectonic Motion"
R. Snay & C. Pearson
American Surveyor Magazine, December 2010
www.Ameriserv.com

GOOD COORDINATION BEGINS WITH
GOOD COORDINATES




GEOGRAPHY WITHOUT GEODESY IS A FELONY