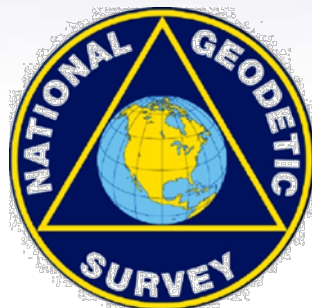




# Journey to the Moving Center of the Earth



## The Evolution of the National Spatial Reference System

VSLS Fall Conference

September 18, 2015

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**240-676-4762**

# U.S. Department of Commerce National Oceanic & Atmospheric Administration **National Geodetic Survey**

*Mission:* To define, maintain & provide access to the  
***National Spatial Reference System (NSRS)***

to meet our Nation's economic, social & environmental needs

## National Spatial Reference System

- Latitude
- Longitude
- Height
- Scale
- Gravity
- Orientation

***& their time variations***

# The National Spatial Reference System supports



**Nautical charts**, among many other geospatial applications  
National Oceanic and Atmospheric Administration



**Emergency Response Imagery,**  
**Flood zones** for the National Flood Insurance Program  
Federal Emergency Management Agency



**Levee Safety Program** to determine levee heights & positions  
United States Army Corps of Engineers



**Topographic Maps** and interior water data for the nation  
United States Geological Survey



**NSRS gravity data** for the geospatial mission of NGA  
National Geospatial-Intelligence Agency



**Aeronautical Data Quality Assurance**  
Federal Aviation Administration

# 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

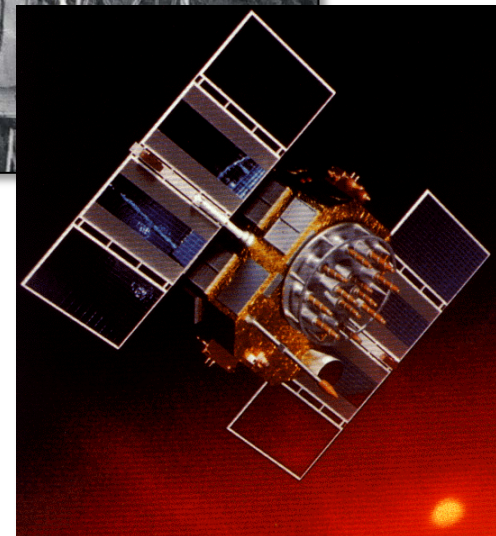
(e.g. NAD 83 (1996), NAD 83 (2007), NAD 83 (CORS96) NAD 83 (2011))

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 above, 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(95) based on new and old observations and same system (HARN)
- 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 VT?

- 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 (epoch 2005)



# COORDINATE CHANGES

ADJUSTMENT	YEARS	LOCAL ACCURACY	NETWORK ACCURACY
NAD 27	1927 – 1986	1:100,000	10 m
NAD 83 (1986)	1986 – 1992	1:100,000	1 m
NAD 83 (1992) (HARN)	1992 – 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

# NEW STANDARDS FOR GEODETIC CONTROL (FGDC)

## 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**

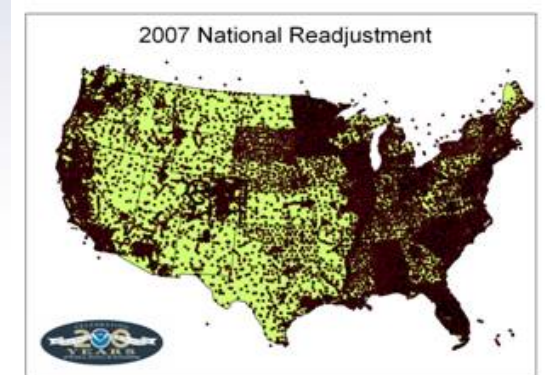


# The NSRS has evolved



1 Million  
Monuments  
(Separate Horizontal  
and Vertical Systems)

70,000  
Passive Marks  
(3-Dimensional)



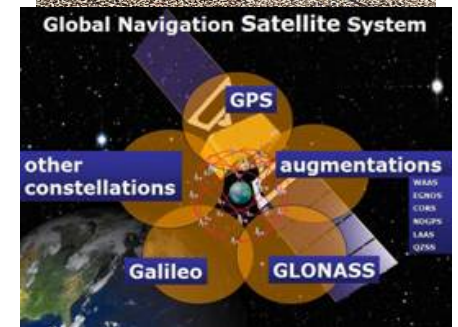
Passive  
Marks  
(Limited  
Knowledge of  
Stability)



≈ 2,000 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.

# 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**).

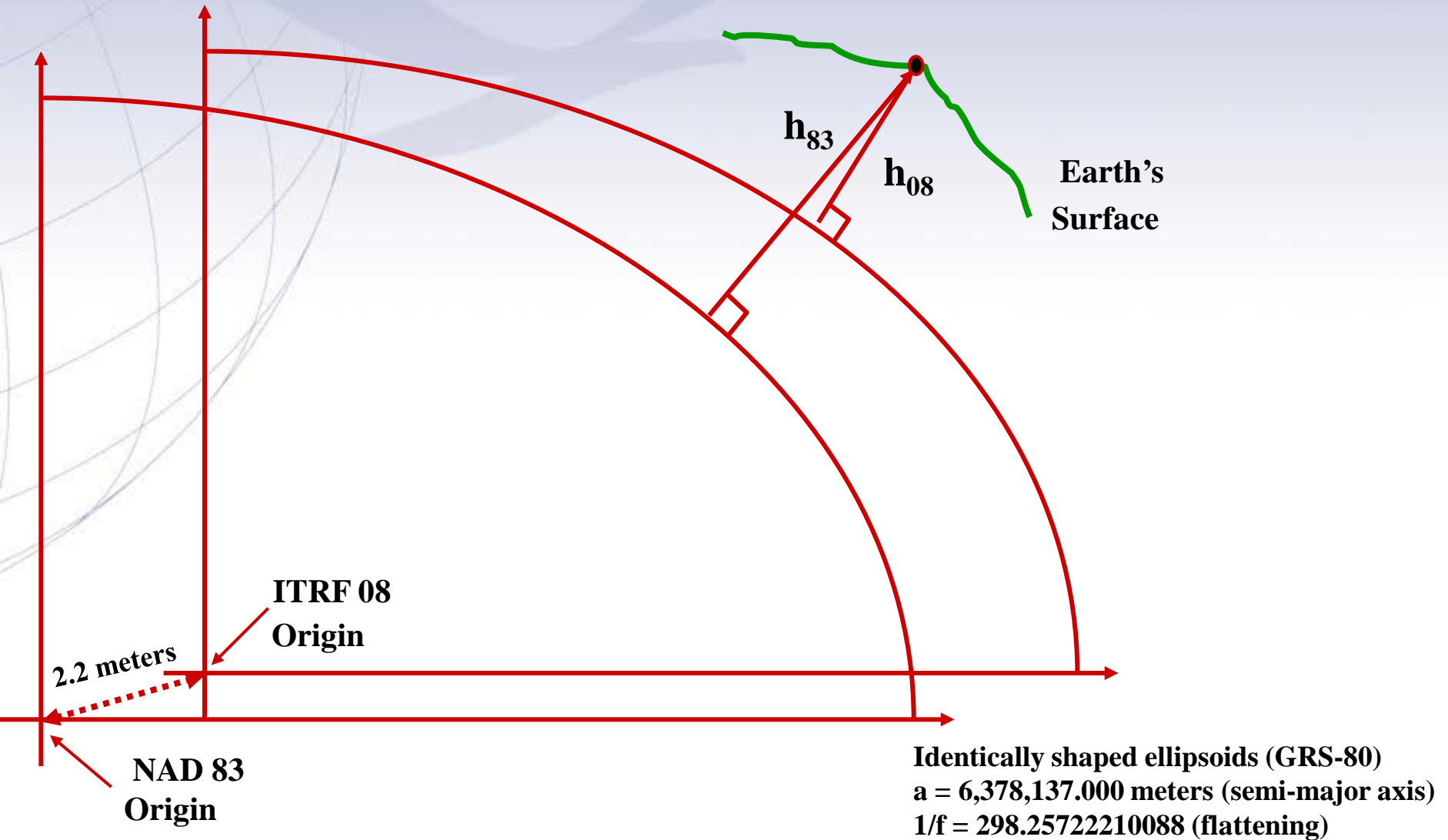
**ITRF89, ITRF90, ITRF91, ITRF92, ITRF93, ITRF94, ITRF95, ITRF96, ITRF97,  
ITRF2000, ITRF2005, ITRF2008**

# 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.

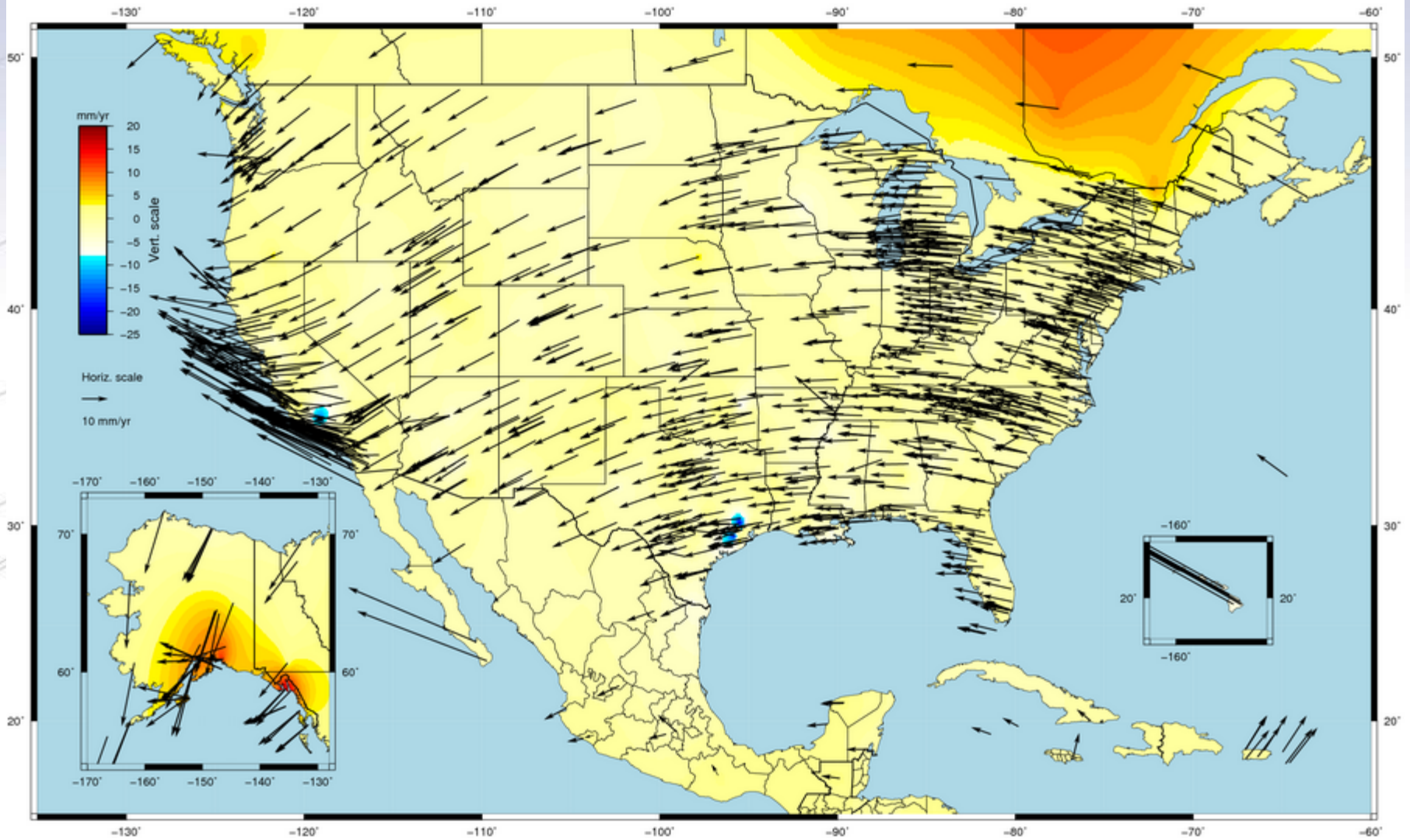
Other organizations can take that information, add additional marks, perform their own adjustment and align their results to the ITRF2008 (A.K.A. densifying).

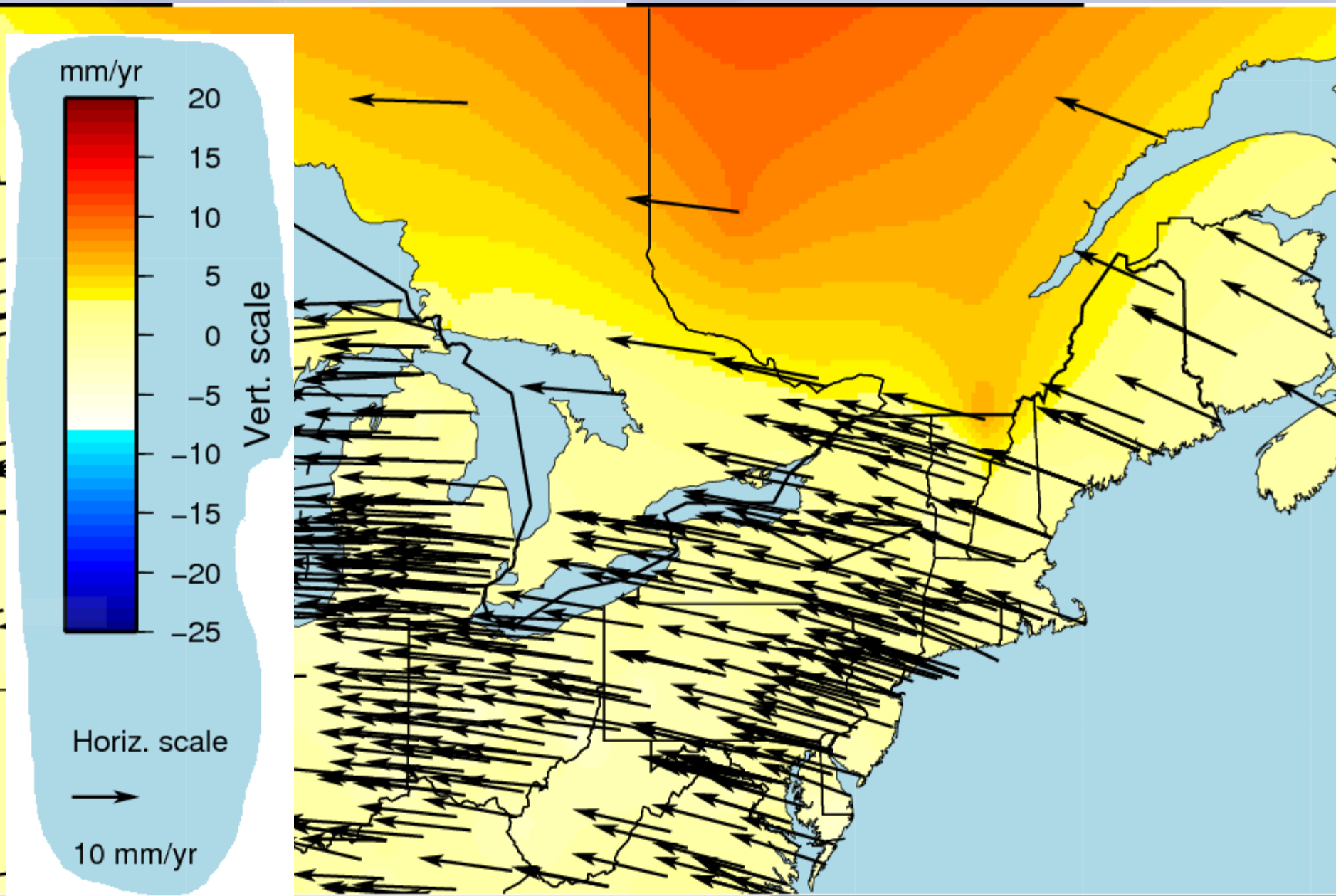
The variants try to be as consistent with the ITRF2008 as possible, but in the most formal sense, they are unique from the ITRF2008. Therefore, they are given unique names.

# The IGS08

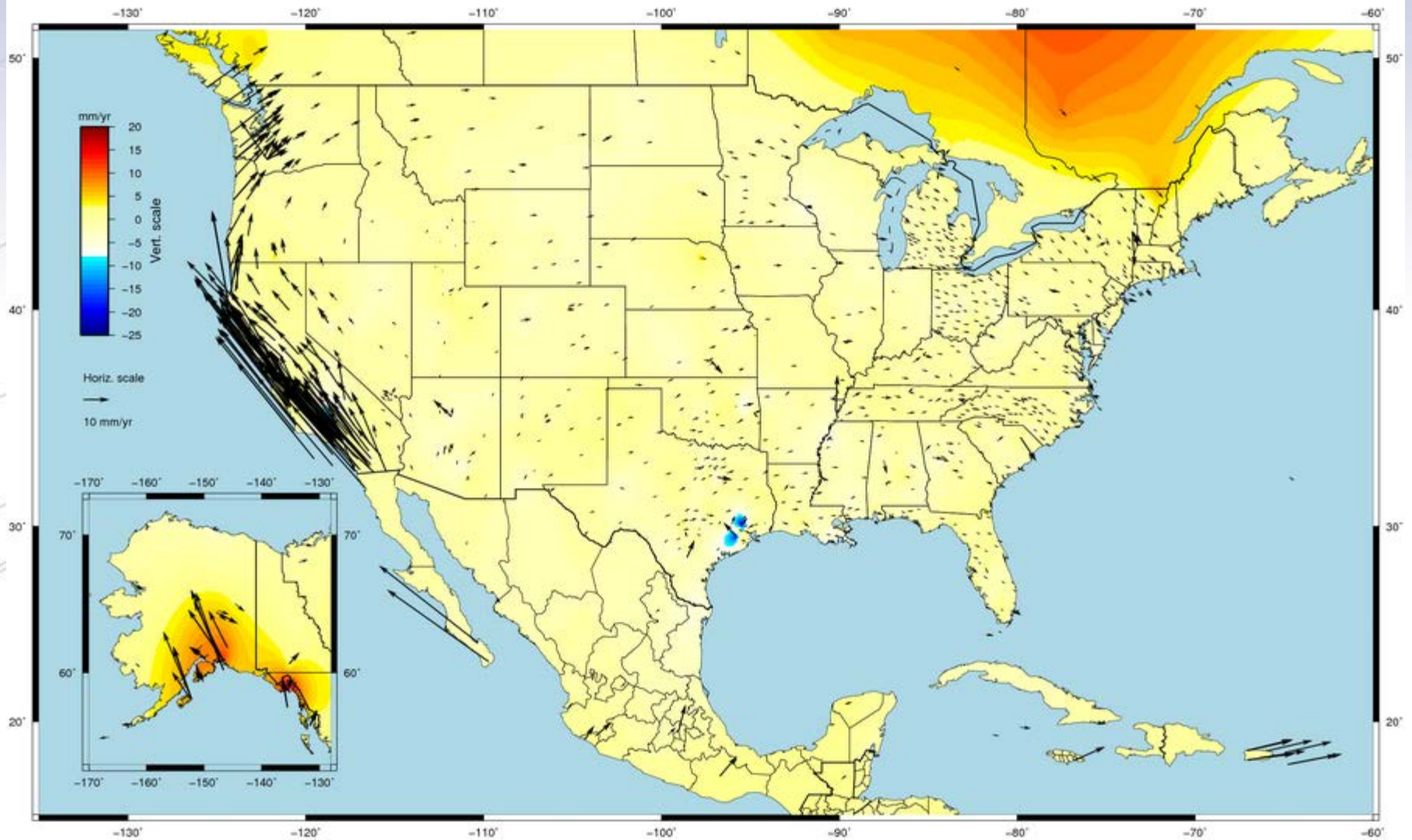
The IGS has densified reference frame with much larger, global subset of GNSS tracking sites thereby creating a GNSS-only expression of the ITRF2008 called the IGS08. All IGS products have been recreated so as to be consistent with the IGS08 including GNSS ephemerides and antenna models. Information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

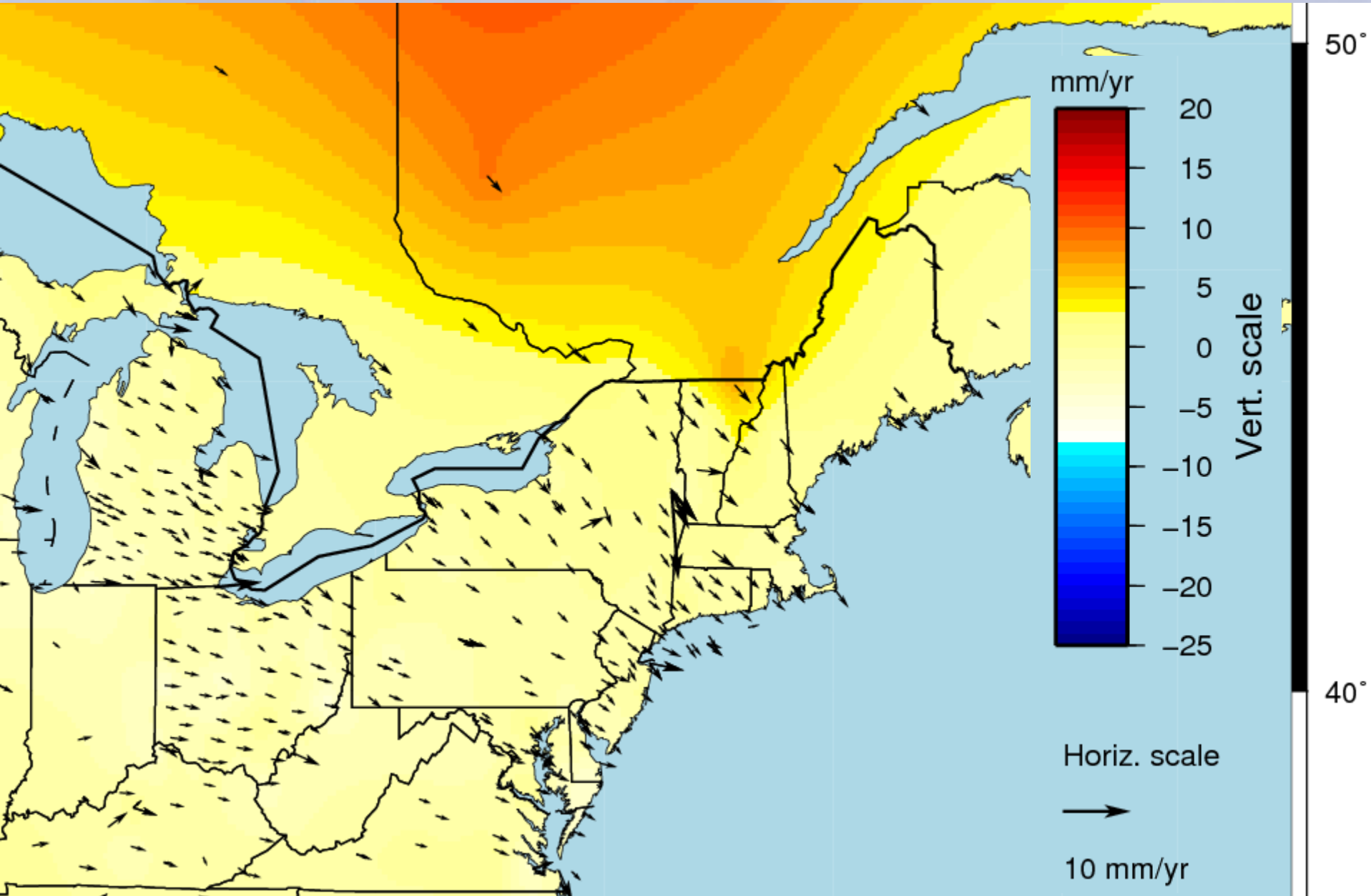
Velocities, IGS08 Epoch 2005.00





Velocities, NAD 83(2011) Epoch 2010.00





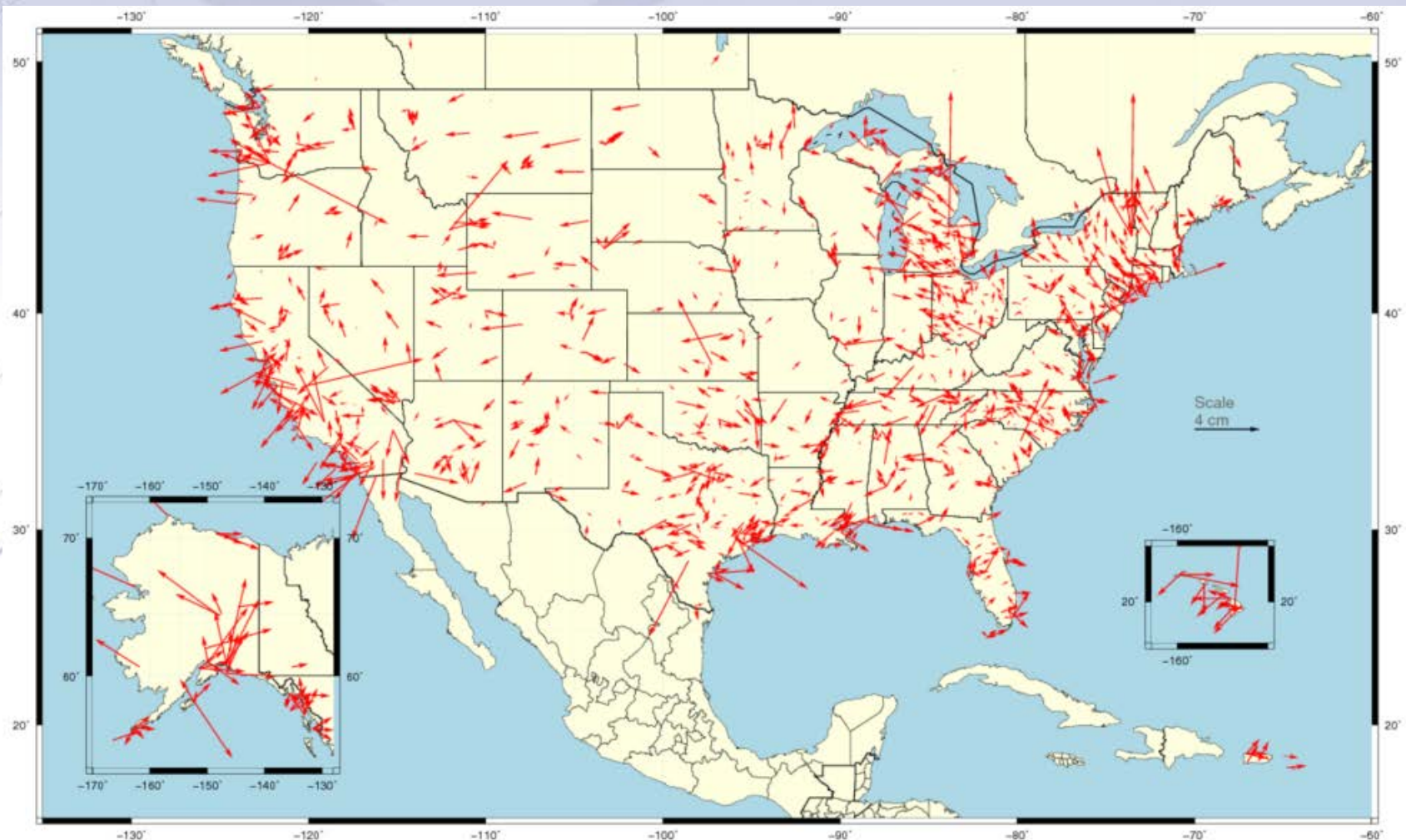
# Multi-Year CORS Solution (MYCS)

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](http://geodesy.noaa.gov/CORS/coords.shtml).

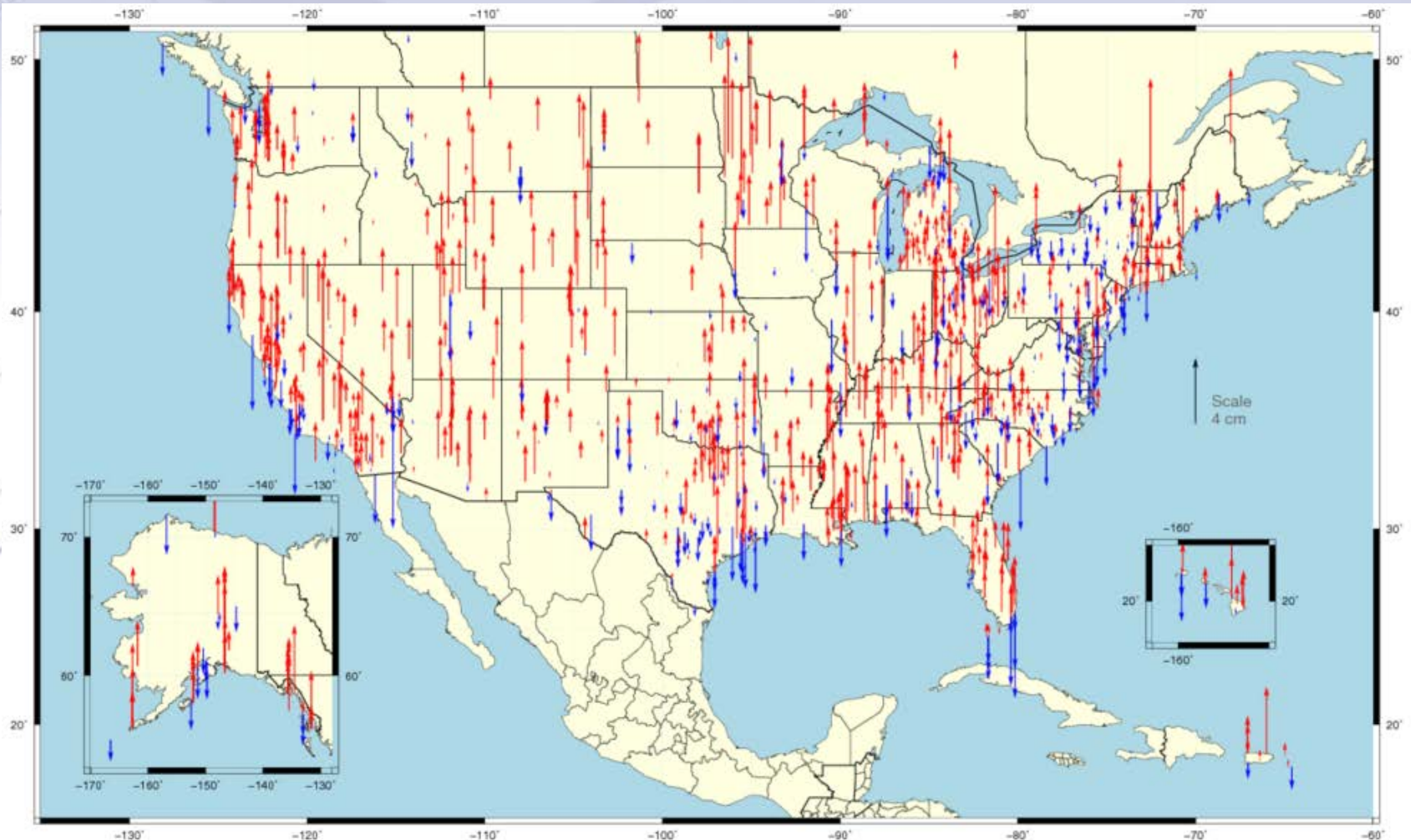
# Horizontal Differences In CORS Positions



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



# Vertical Differences In CORS Positions



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

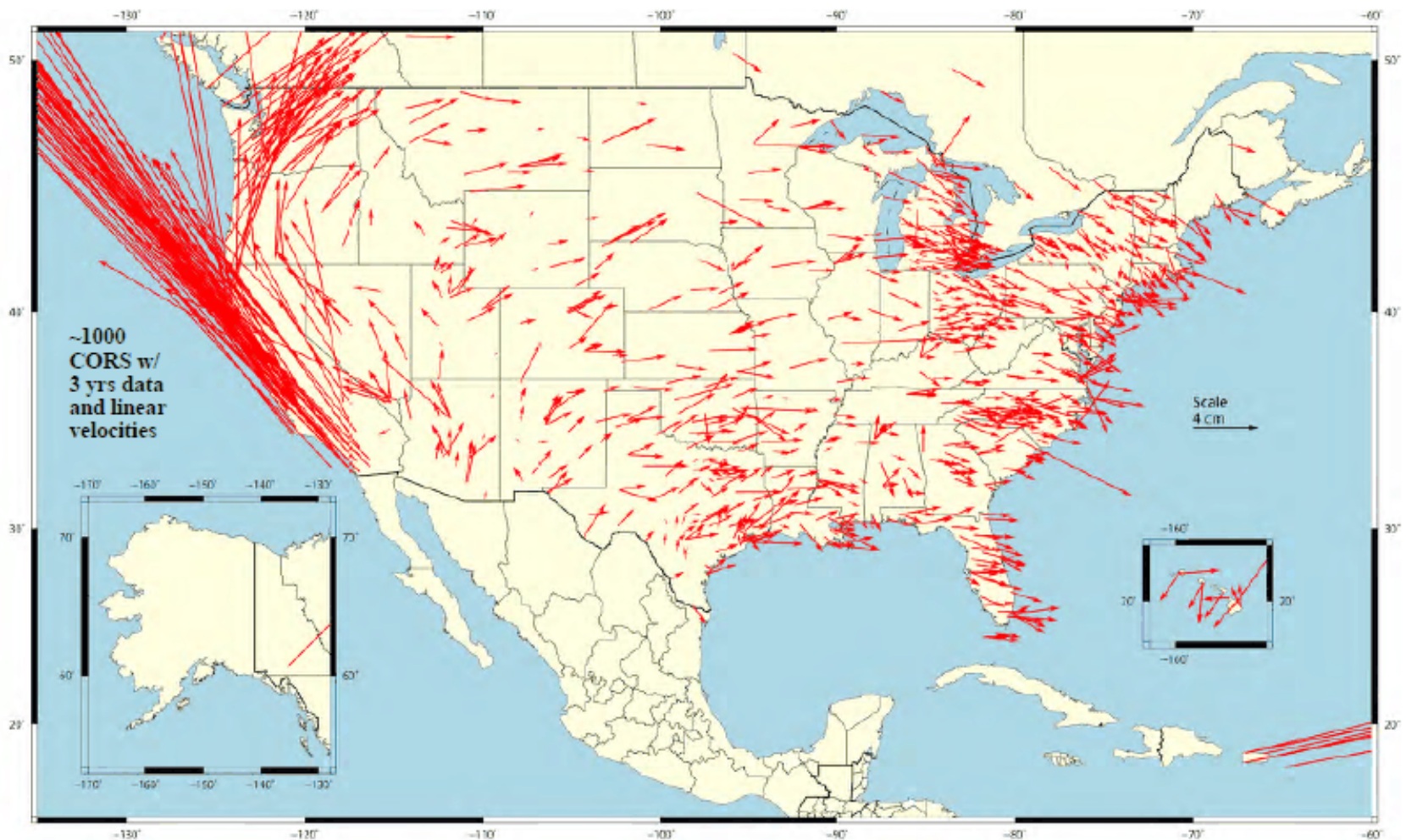


# Change in horizontal NAD 83 CORS coordinates

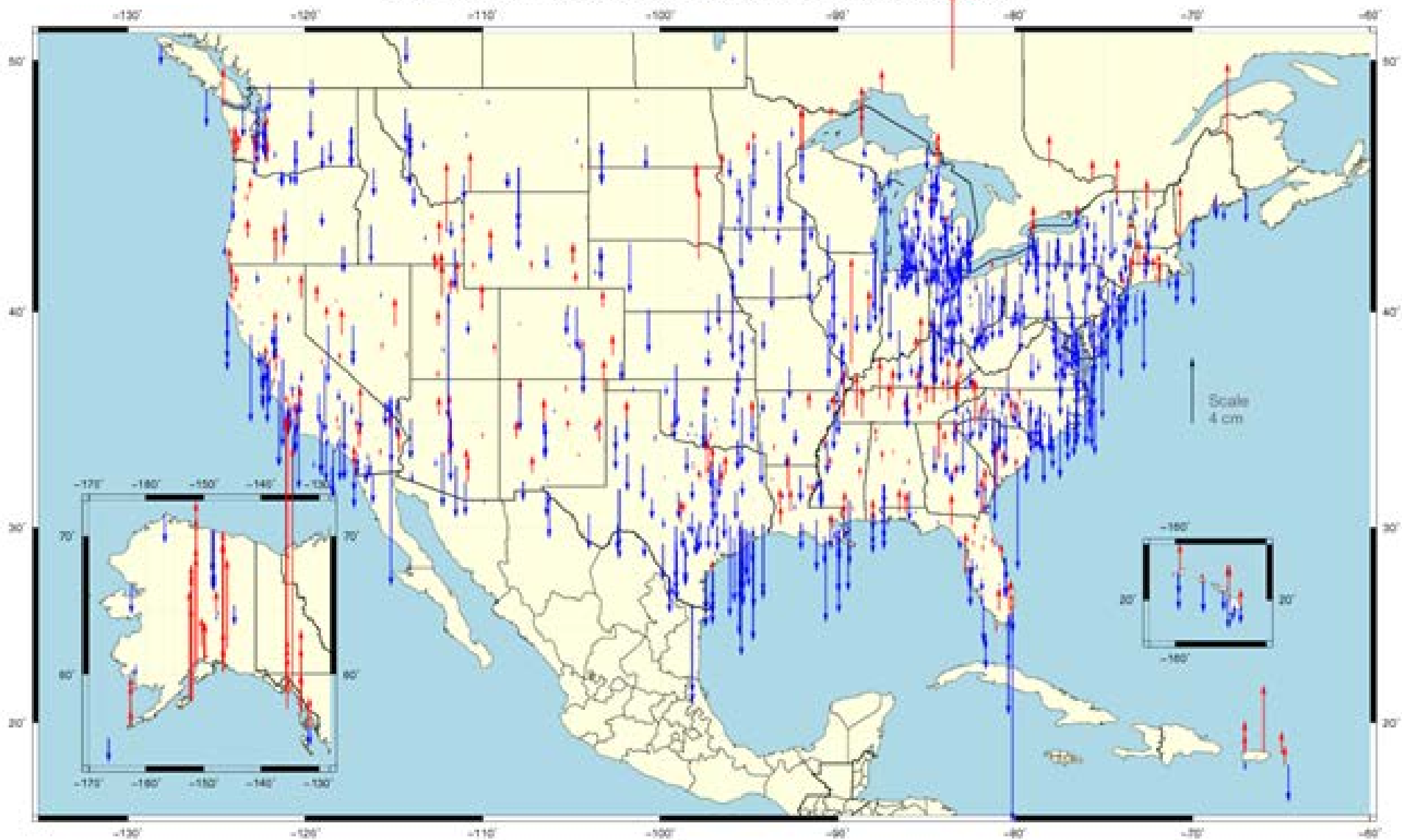
NAD 83(CORS96) epoch 2002.00 → NAD 83(2011) epoch 2010.00

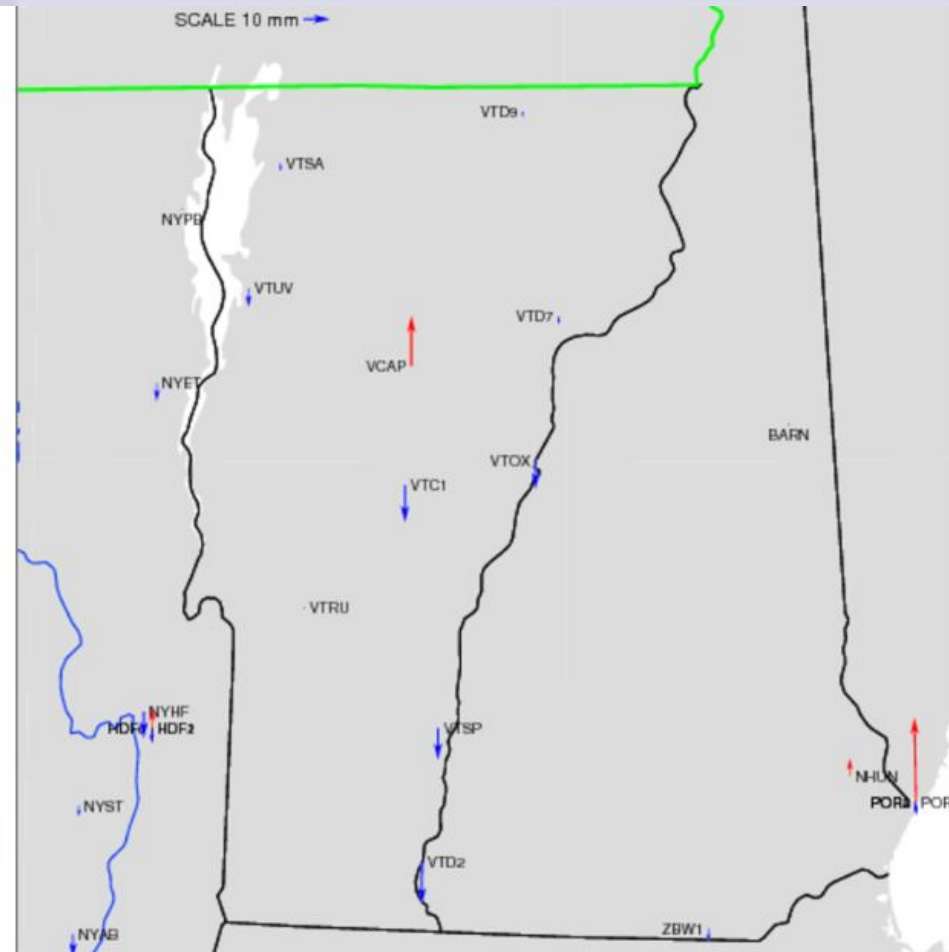
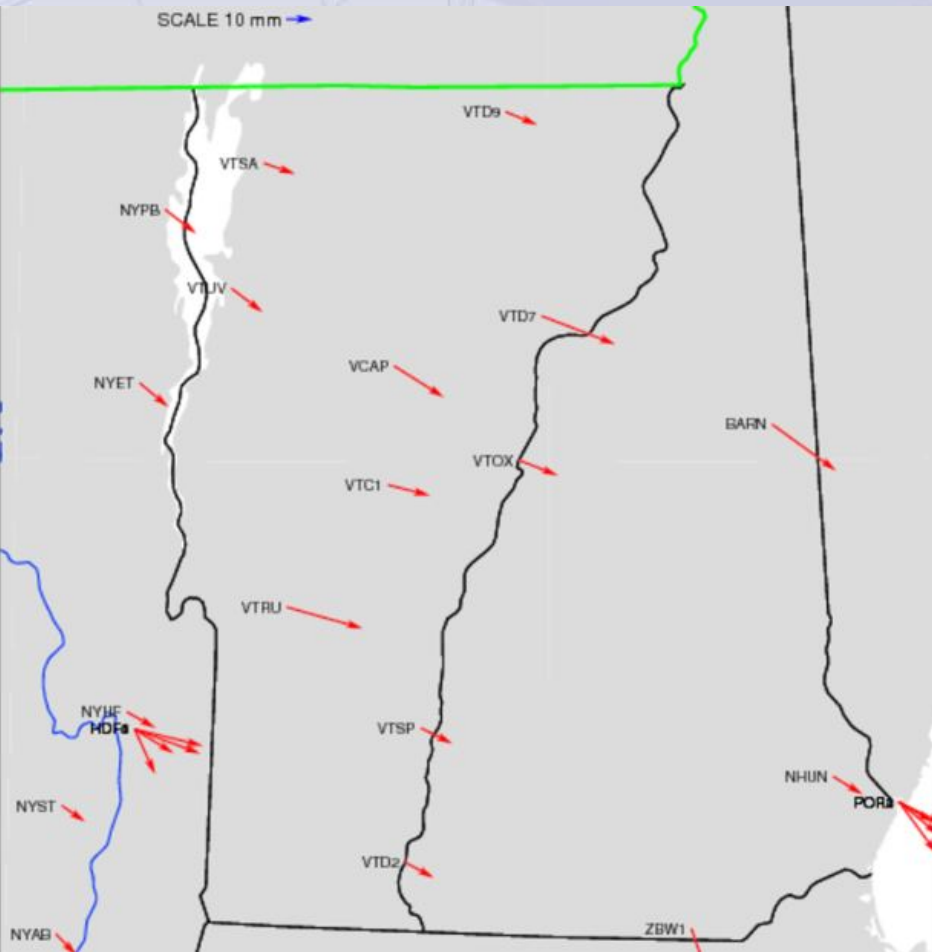
**Avg shifts (cm):**  $\Delta N = 2.0 (\pm 6.4)$ ;  $\Delta E = 0.2 (\pm 5.9)$ ;  $\Delta U = -0.9 (\pm 2.0)$

- 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)



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





# ***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](mailto:michael.dennis@noaa.gov)**

# NAD 83 (2011) And Passive Control Marks

In addition, approximately 80,000 passive control marks were readjusted to provide the best possible consistency with the improved CORS coordinates and velocities.

Known as the National Adjustment of 2011 (NA2011), these results were released in June 2012 and are now available through the datasheets.

For more information, visit

[geodesy.noaa.gov/web/news/NA2011\\_Project.shtml](http://geodesy.noaa.gov/web/news/NA2011_Project.shtml)

[geodesy.noaa.gov/web/surveys/NA2011/NA2011\\_FAQ.shtml](http://geodesy.noaa.gov/web/surveys/NA2011/NA2011_FAQ.shtml)

April 13, 2015

# Introducing...

## NAD 83(2011) epoch 2010.00

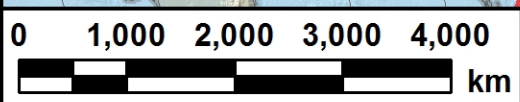
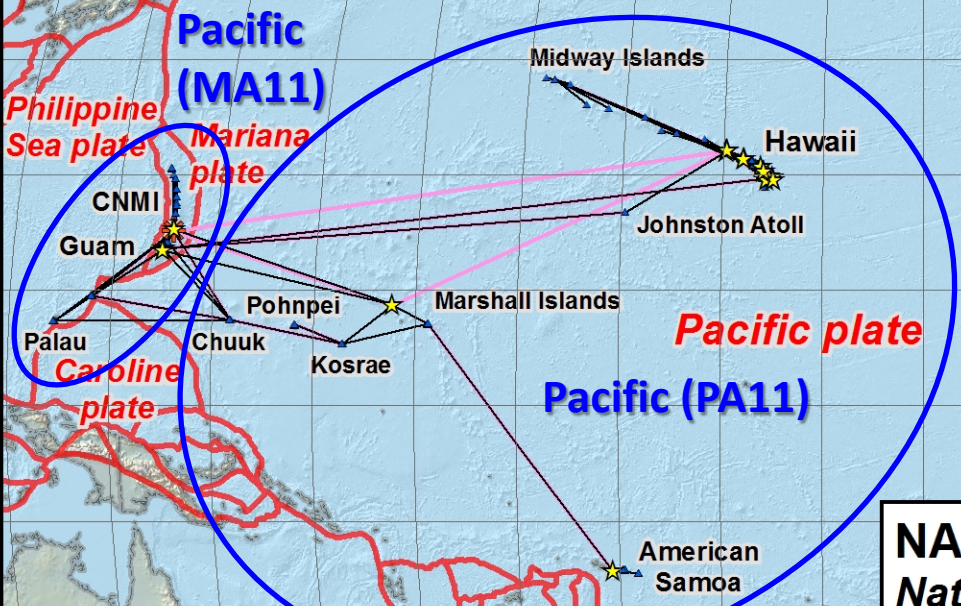
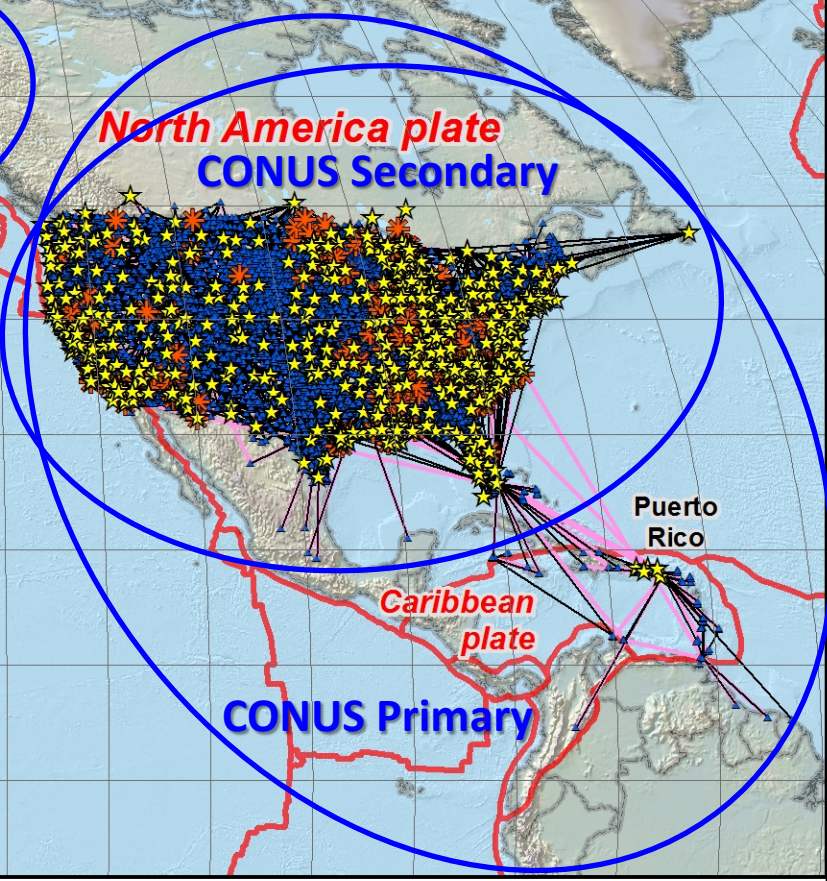
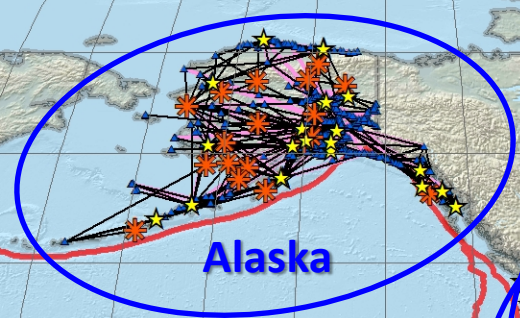
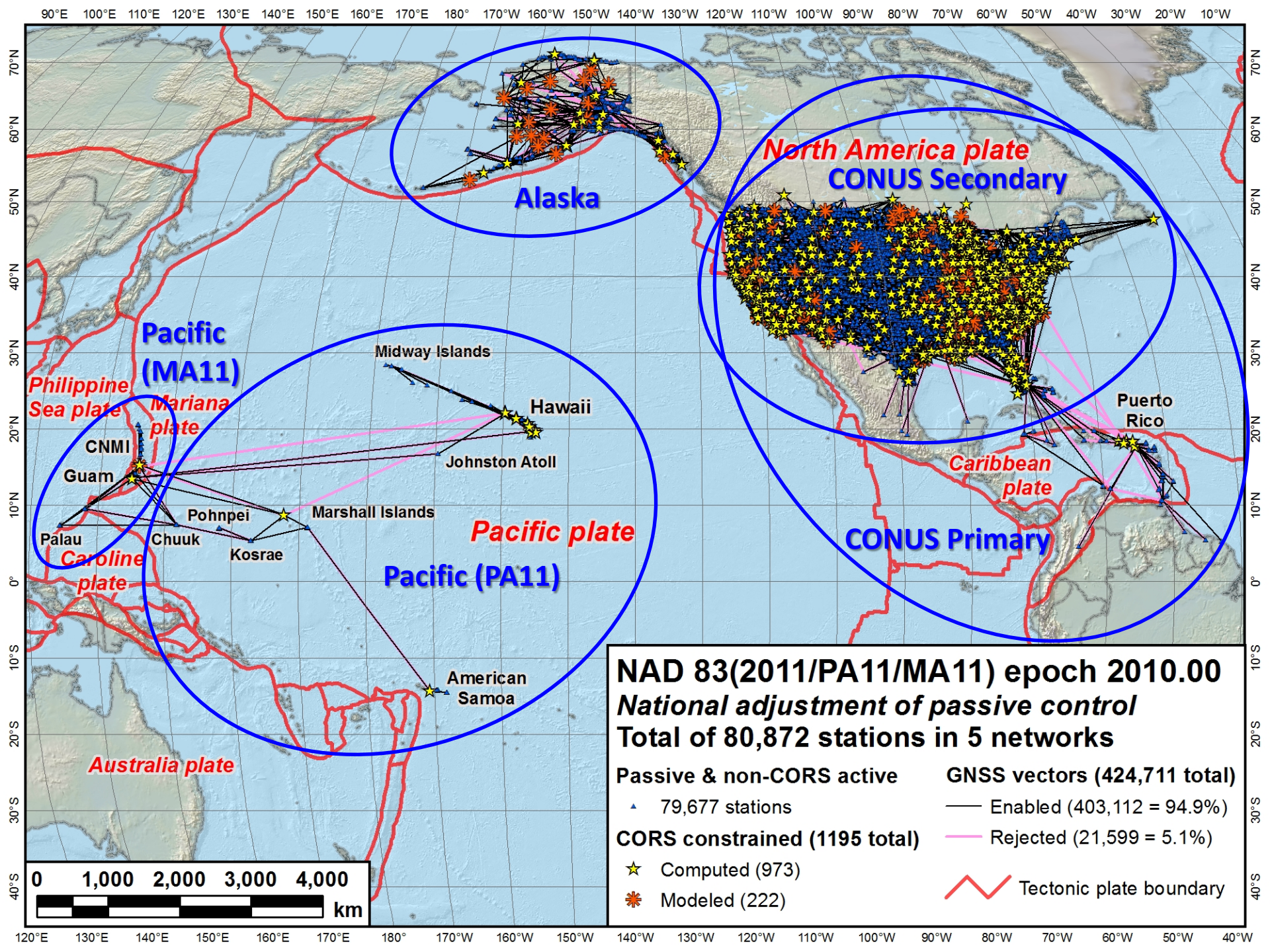
- **Multi-Year CORS Solution (MYCS)**
  - Continuously Operating Reference Stations
  - Reprocessed all CORS GPS data Jan 1994-Apr 2011
  - 2264 CORS & global stations
  - NAD 83 computed by *transformation* from IGS08
- **2011 national adjustment of passive control**
  - New adjustment of GNSS passive 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 *Best Available Methods***



**NAD 83(2011/PA11/MA11) epoch 2010.00**  
**National adjustment of passive control**  
**Total of 80,872 stations in 5 networks**

**Passive & non-CORS active**

- ▲ 79,677 stations

**CORS constrained (1195 total)**

- ★ Computed (973)
- ★ Modeled (222)

**GNSS vectors (424,711 total)**

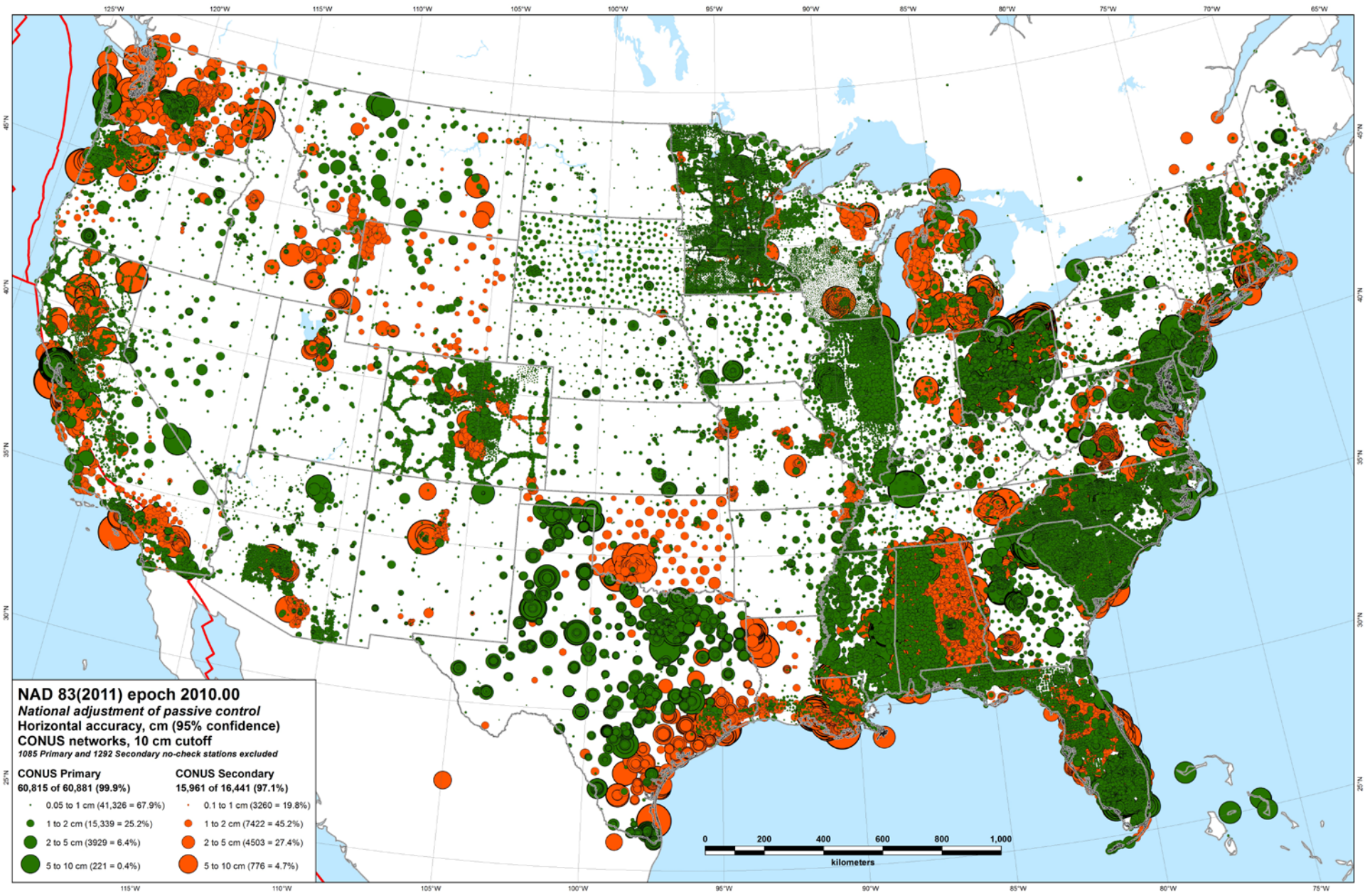
- Enabled (403,112 = 94.9%)
- Rejected (21,599 = 5.1%)

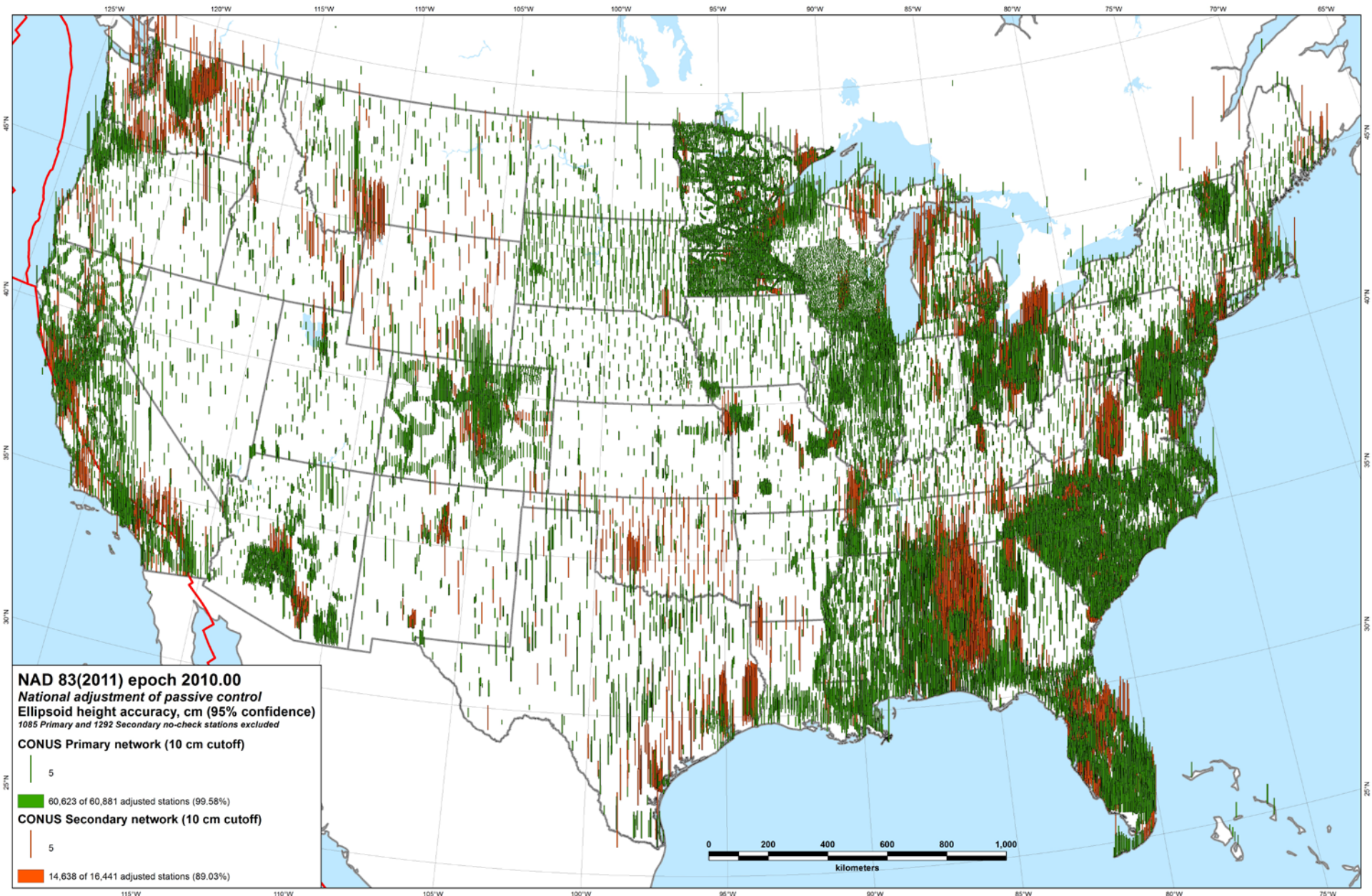
**Tectonic plate boundary**

# 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)



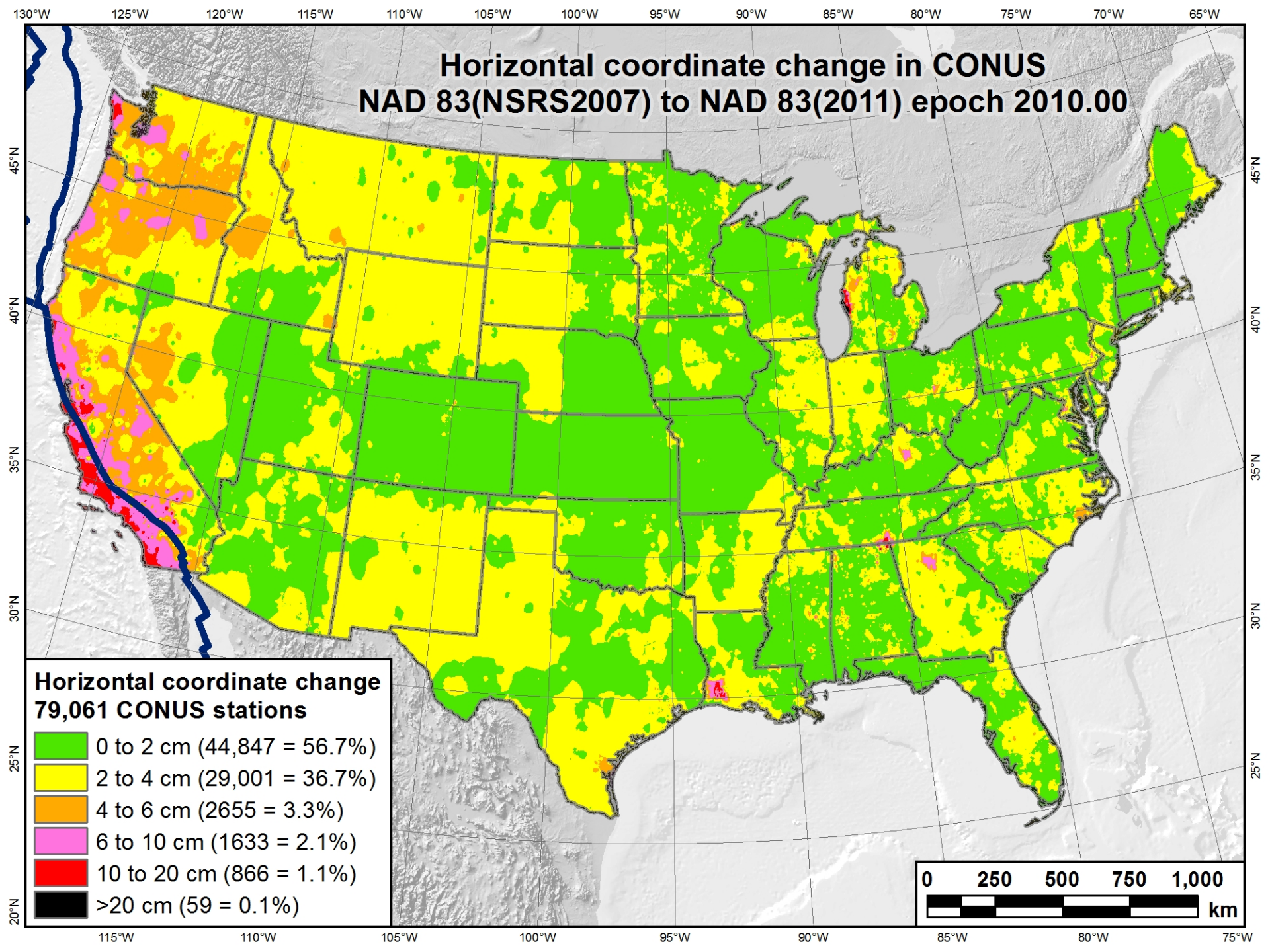


# NAD 83(2011/PA11/MA11) epoch 2010.00

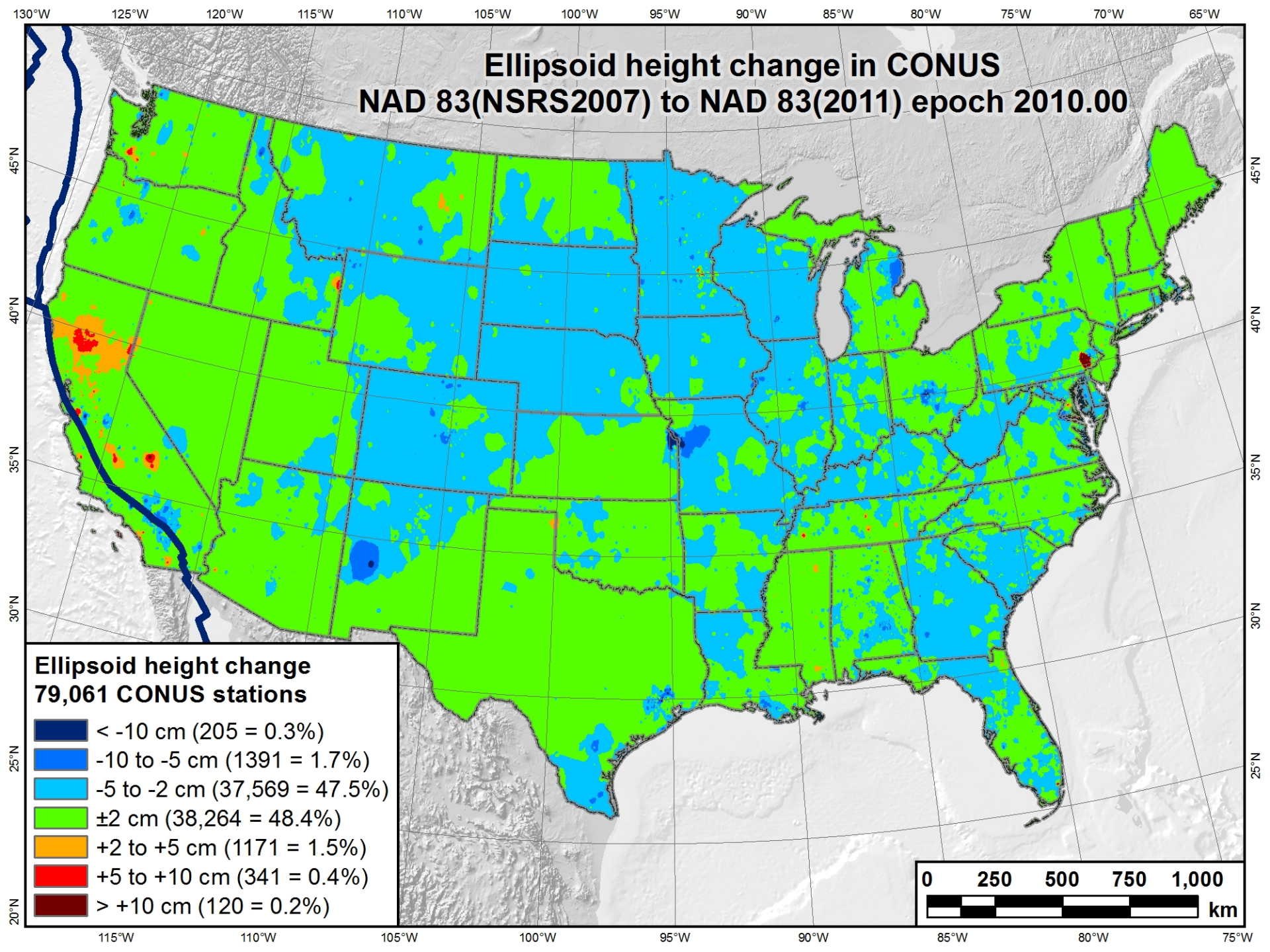
## *Passive control results summary*

- 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*

# Horizontal coordinate change in CONUS NAD 83(NSRS2007) to NAD 83(2011) epoch 2010.00



# Ellipsoid height change in CONUS NAD 83(NSRS2007) to NAD 83(2011) epoch 2010.00





# 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  $\leftrightarrow$  NSRS2007  $\leftrightarrow$  2011
  - GEOCON GEOCON11
  - 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

# Network adjustment results as GIS features provide powerful analysis capabilities...

The screenshot shows a GIS application window with a map of Tucson, Arizona, overlaid with a network of points and lines. The points are represented by green circles of varying sizes, indicating different accuracy levels. The lines represent network connections, with some highlighted in cyan. The interface includes a Table of Contents on the left, a main map area, and an Identify window on the right.

**Table of Contents:**

- Stations\_Primary\_FINAL\_const
- Boundaries
- Horiz accuracy (10 cm cutoff)
  - 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
- Vectors
  - Vectors\_Primary\_FINAL\_const
    - Reject
    - <Null>
  - GNSS vectors (420,023 total)
    - Reject
    - <Null>
    - R
  - Horiz accuracy (5 cm cutoff)
  - Horiz accuracy (10 cm cutoff)

**Identify Window:**

Identify from: <Top-most layer>

Location: [Field]

Click on or drag a box over a feature or place on the map you want to identify. Its attributes will be listed here.

Use the dropdown list to control which layer(s) will be identified.

Press the SHIFT key to add features to the current list.

The Location field shows you the coordinates of the feature.

No identified features

**Table - Vectors\_Primary\_FINAL\_const**

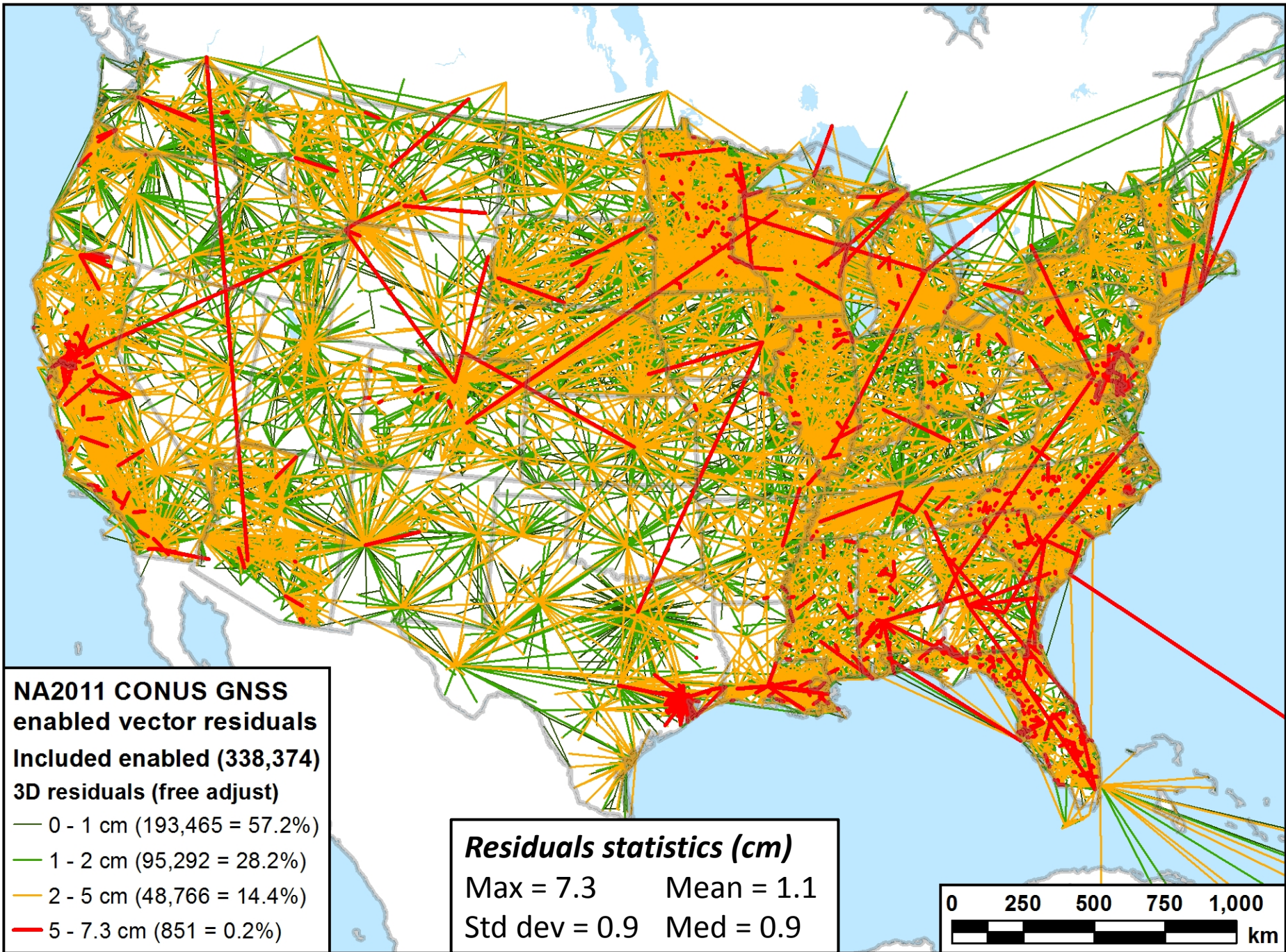
Vector	const_vectors_from : Stations_Primary_FINAL_const	const_vectors_to : Stations_Primary_FINAL_const	To_sta	From PID *	To PID *	From SSN	To SSN	BaselineID	Num_vec_BL	Duplicate	Vector_dX	Sigma_X	Vector_dY	Sigma_Y	Vector_dZ	Sigma_Z
669331	TUCSON CORS ARPpa	M 421	AI3680	CF0234	1027	1036	AI3680_CF0234	6	1	102118.0091	0.0008	-79490.0413	0.0021	-61844.3628	0.0015	X00011
66953	TUCSON CORS ARPpa	M 421	AI3680	CF0234	1027	1036	AI3680_CF0234	6	1	102118.01	0.0019	-79490.0496	0.0048	-61844.3518	0.003	X00011
66973	TUCSON CORS ARPpa	M 421	AI3680	CF0234	1027	1036	AI3680_CF0234	6	1	102117.9976	0.0011	-79490.052	0.0028	-61844.3495	0.0019	X00011
66986	TUCSON CORS ARPpa	M 421	AI3680	CF0234	1027	1036	AI3680_CF0234	6	1	102118.0114	0.0007	-79490.0964	0.0018	-61844.3456	0.0013	X00011
68149	Q 363	TUCSON CORS ARPpa	CZ1032	AI3680	0011	1027	AI3680_CZ1032	4	1	45083.5619	0.0016	-56061.1291	0.0038	-55655.1119	0.0025	X00000
68163	Q 363	TUCSON CORS ARPpa	CZ1032	AI3680	0011	1027	AI3680_CZ1032	4	1	45083.5547	0.001	-56061.165	0.0024	-55655.0835	0.0018	X00000
68175	Q 363	TUCSON CORS ARPpa	CZ1032	AI3680	0011	1027	AI3680_CZ1032	4	1	45083.5592	0.0011	-56061.1377	0.0027	-55655.1028	0.0018	X00000

1 (39 out of 335530 Selected)

Vectors\_Primary\_FINAL\_const Stations\_Primary\_FINAL\_const

Drawing: [Tools] [Layers] [Scale: 10] [Font: Arial]

110°11'8.935"W 31°30'1.518"N



# 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 is a Vertical Datum?

- Strictly speaking, a vertical datum is a *surface* representing zero elevation
- Traditionally, a vertical datum is a *system* for the determination of heights above a zero elevation surface
- Vertical datum comprised of:
  - Its *definition*: Parameters and other descriptors
  - Its *realization*: Its physical method of accessibility



"topographic map." Online Art.  
Britannica Student Encyclopædia.  
17 Dec. 2008  
<<http://student.britannica.com/ebi/art-53199>>

# 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

# NGVD29

The National Geodetic Vertical Datum of 1929 is referenced to 26 tide gauges in the US and Canada





# Current Vertical Datum in the USA



Father Point  
Lighthouse, Quebec

- **NAVD 88:** North American Vertical Datum of 1988
- **Definition:** The surface of equal gravity potential to which orthometric heights shall refer in North America\*, and which is 6.271 meters (along the plumb line) below the geodetic mark at “Father Point/Rimouski” (NGSIDB PID TY5255).
- **Realization:** Over 500,000 geodetic marks across North America with published Helmert orthometric heights, most of which were originally computed from a minimally constrained adjustment of leveling and gravity data, holding the geopotential value at “Father Point/Rimouski” fixed.

*\*Not adopted in Canada*

# 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

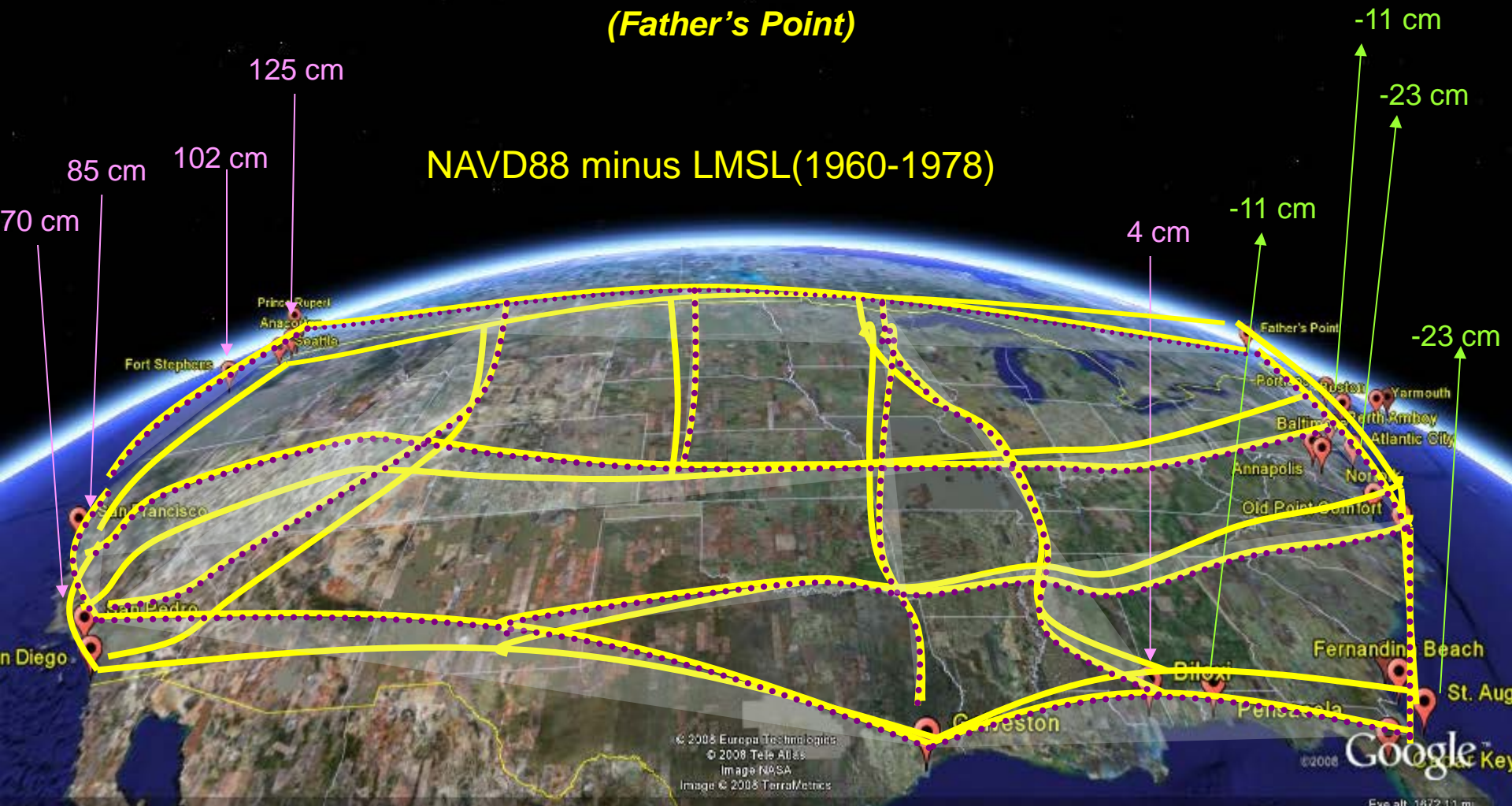
- **NAVD 88** (continued)
  - Use of one fixed height removed local sea level variation problem of NGVD 29
  - Use of one fixed height did open the possibility of unconstrained cross-continent error build up
  - But the  $H=0$  surface of NAVD 88 was supposed to be parallel to the geoid...(close again)

# NAVD 88

Reference to 26 Tide Gages

(Father's Point)

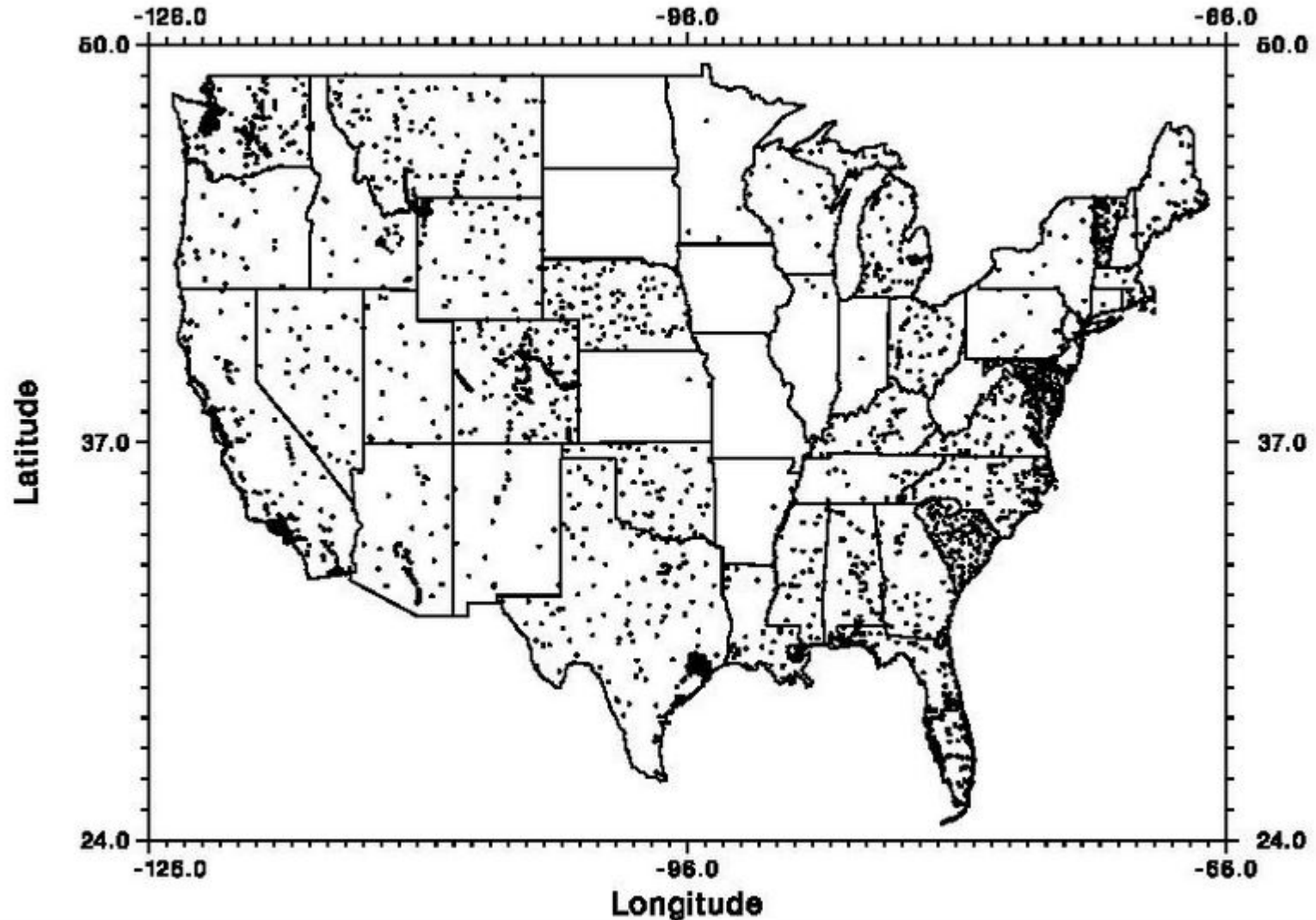
NAVD88 minus LMSL(1960-1978)



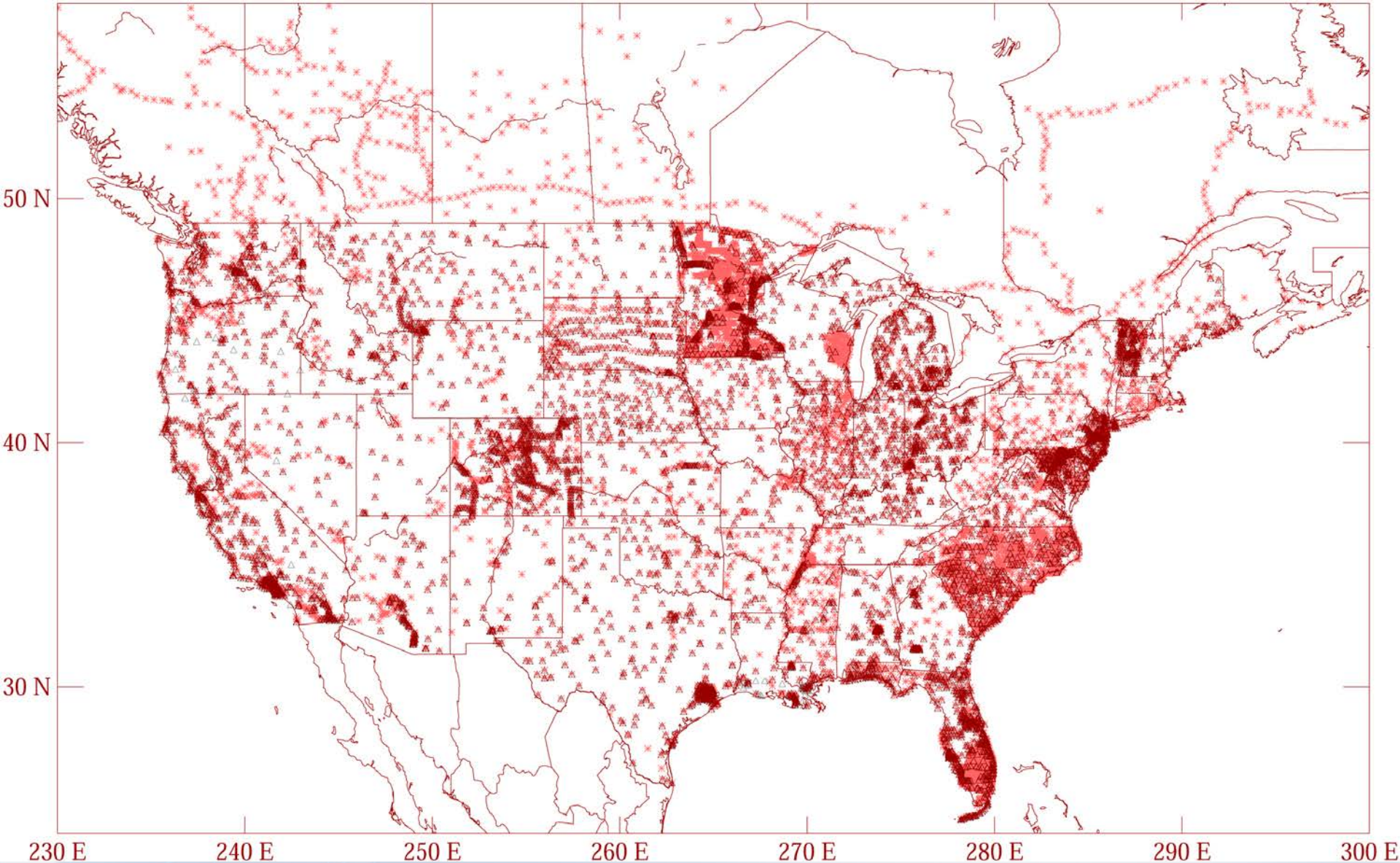
# Types Uses and History of Geoid Height Models

- 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

### GPS NAVD88 Benchmarks (16-Sep-96)



GPSBM1996: 2,951total 0 Canada STDEV  $\approx 5$  cm ( $2\sigma$ )



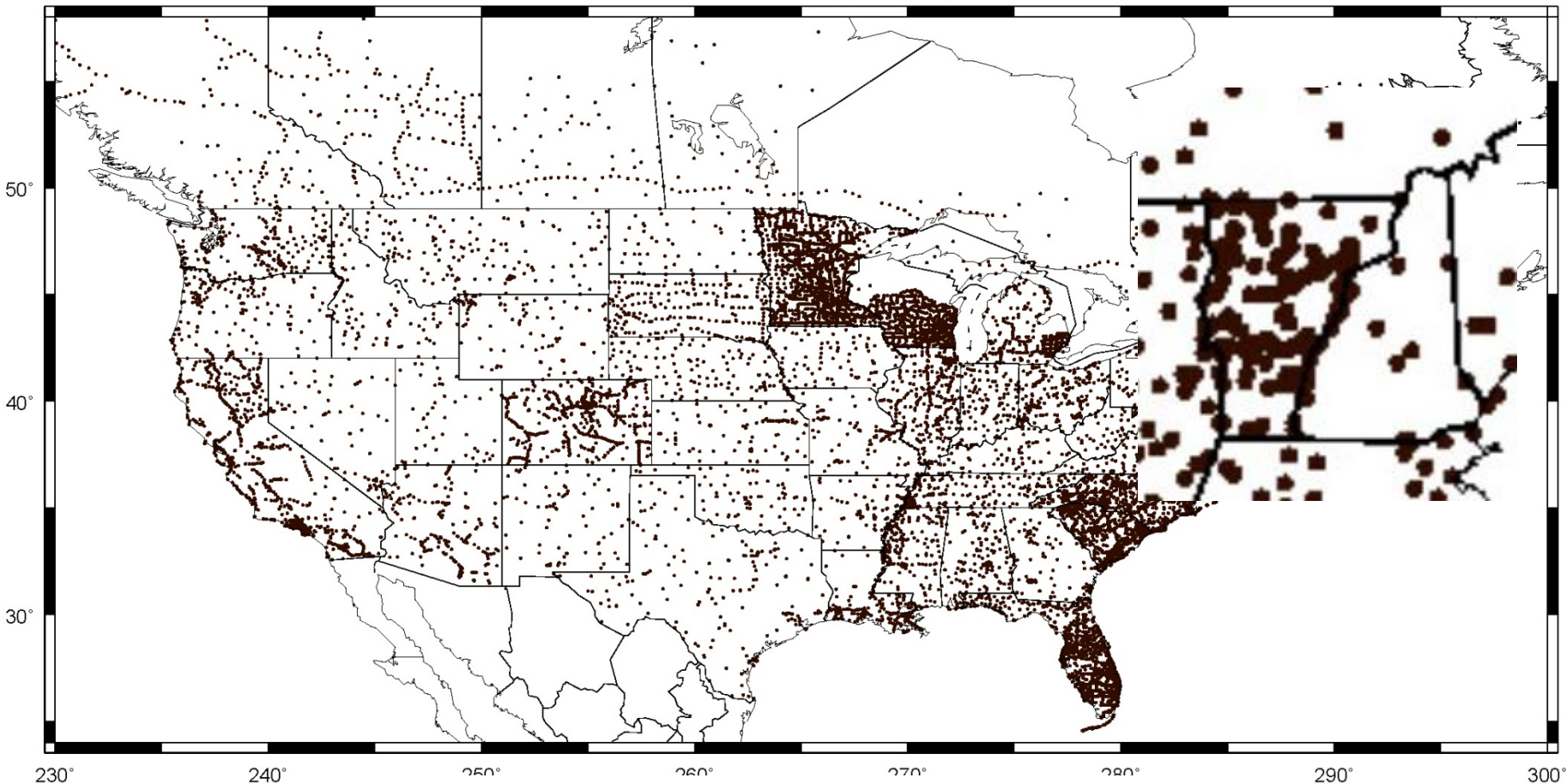
GPSBM1999: 6,169 total 0 Canada STDEV 9.2 cm ( $2\sigma$ )

GPSBM2003: 14,185 total 579 Canada STDEV 4.8 cm ( $2\sigma$ )



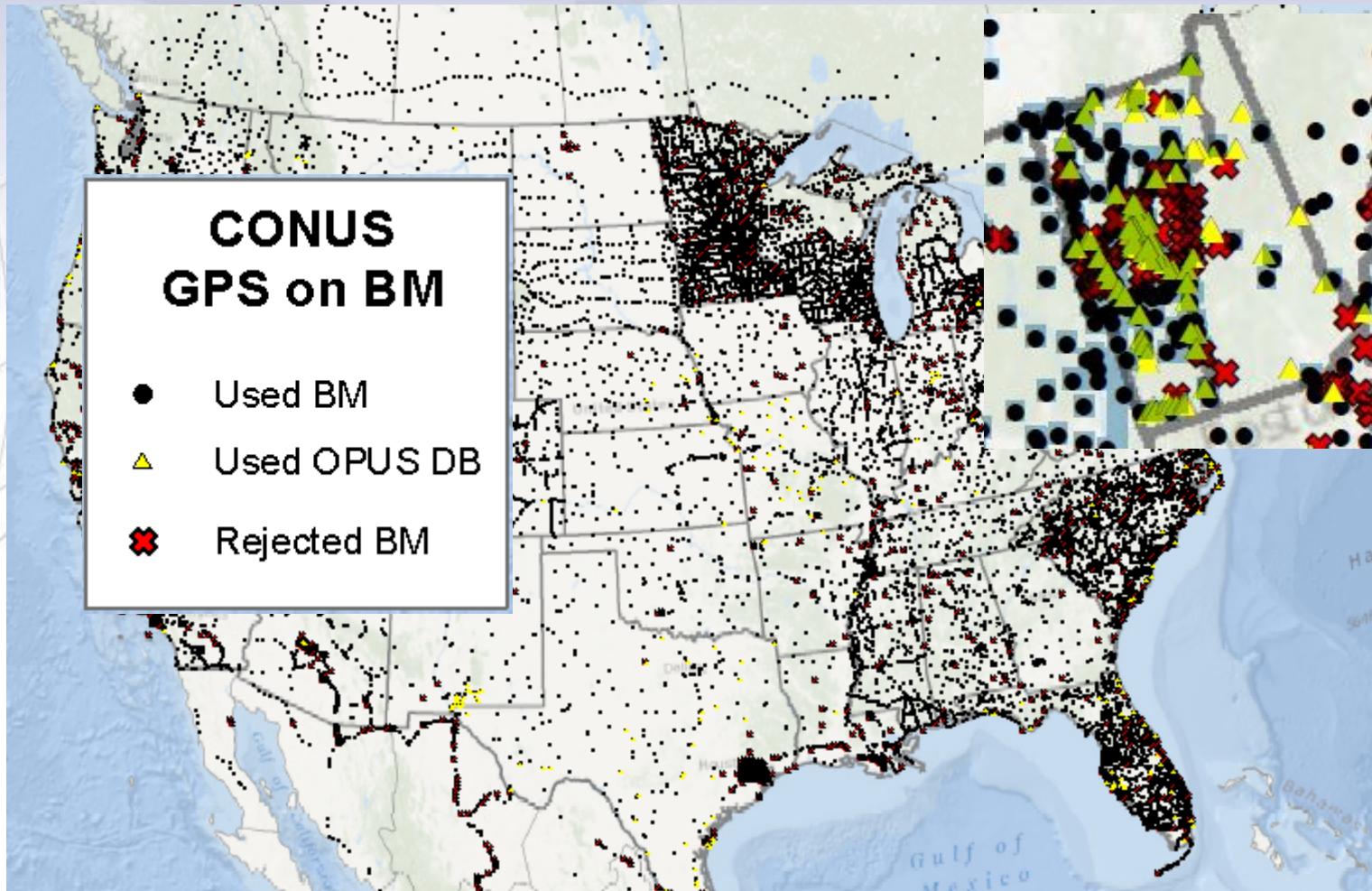
Nati

### GPS BMs for GEOID09



GPSBM2009: 18,398 STDEV 2.8 cm ( $2\sigma$ )





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

# Which Geoid for Which NAD 83?

- NAD 83(2011)
- NAD 83(2007)
- NAD 83(1996) & CORS96
- Geoid12A/12B
- Geoid09
- Geoid06 (AK only)
- Geoid03
- Geoid99
- Geoid96

# 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

# Party Time, We're Done!



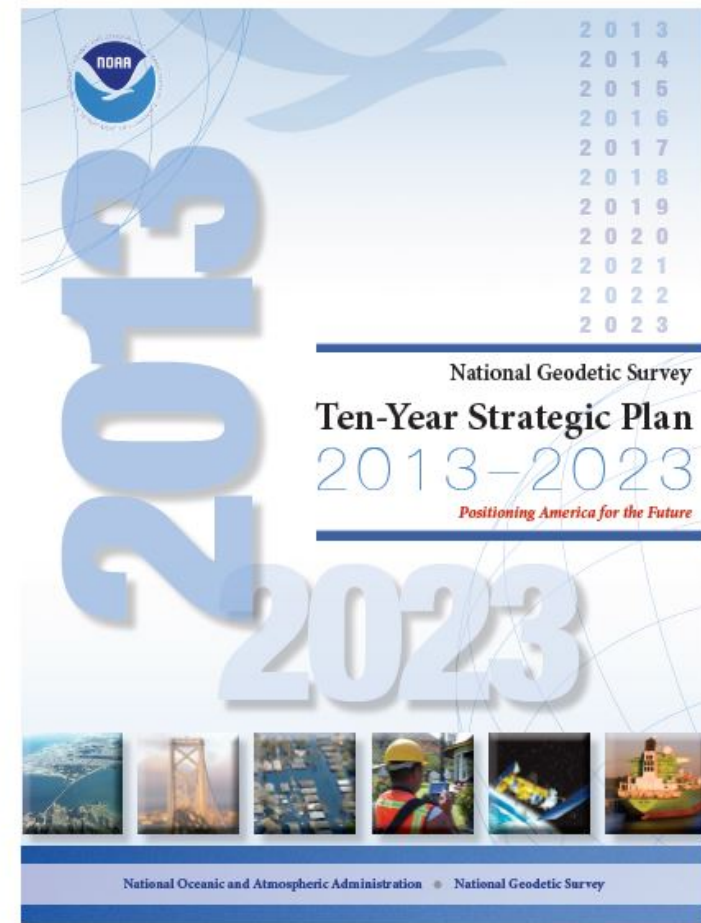
# Problems with NAD 83 and NAVD 88

- **NAD 83** is not as geocentric as it could be (approx. 2 m)
  - Positioning Professionals 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 re-leveled in at least 40 years.
- **NAVD 88** does not account for local vertical velocities (subsidence and uplift)
  - Post glacial isostatic readjustment (uplift)
  - Subsurface fluid withdrawal (subsidence)
  - Sediment loading (subsidence)
  - 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, 2013-2023

<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*
- *2022 Targets:*
  - *NAD 83 and NAVD 88 re-defined*
  - *Cm-accuracy access to all coordinates*
  - *Customer-focused agency*
  - *Global scientific leadership*



# Terminology

- ~~Horizontal Datum~~
  - Geometric Reference Frame
    - Geocentric X, Y, Z
    - Latitude, Longitude, Ellipsoid Height
- ~~Vertical Datum~~
  - Geopotential Reference Frame
    - Geoid undulation
    - Orthometric height
    - Gravity
    - Deflection of the Vertical

# Future Geometric Reference Frame

- CORS-based, via GNSS
- coordinates & velocities in ITRF and official US datum
- (NAD83 replacement: plate-fixed or “ITRF-like”?) & relationship
- replace NAD83 with new geometric reference frame – by 2022
- 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
- support development of real-time networks



# Future Geopotential Reference Frame

- replace NAVD88 with new geopotential reference frame – 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 Reference Frames?

## ❑ 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

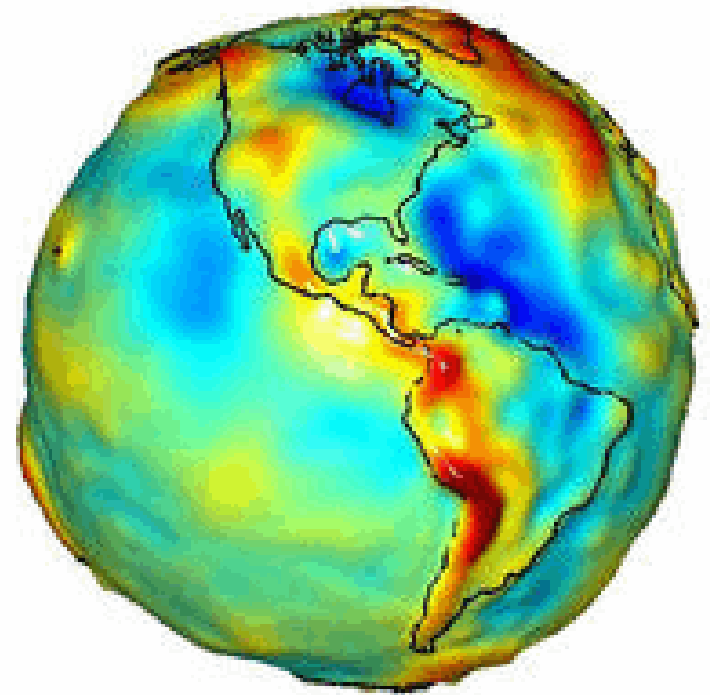
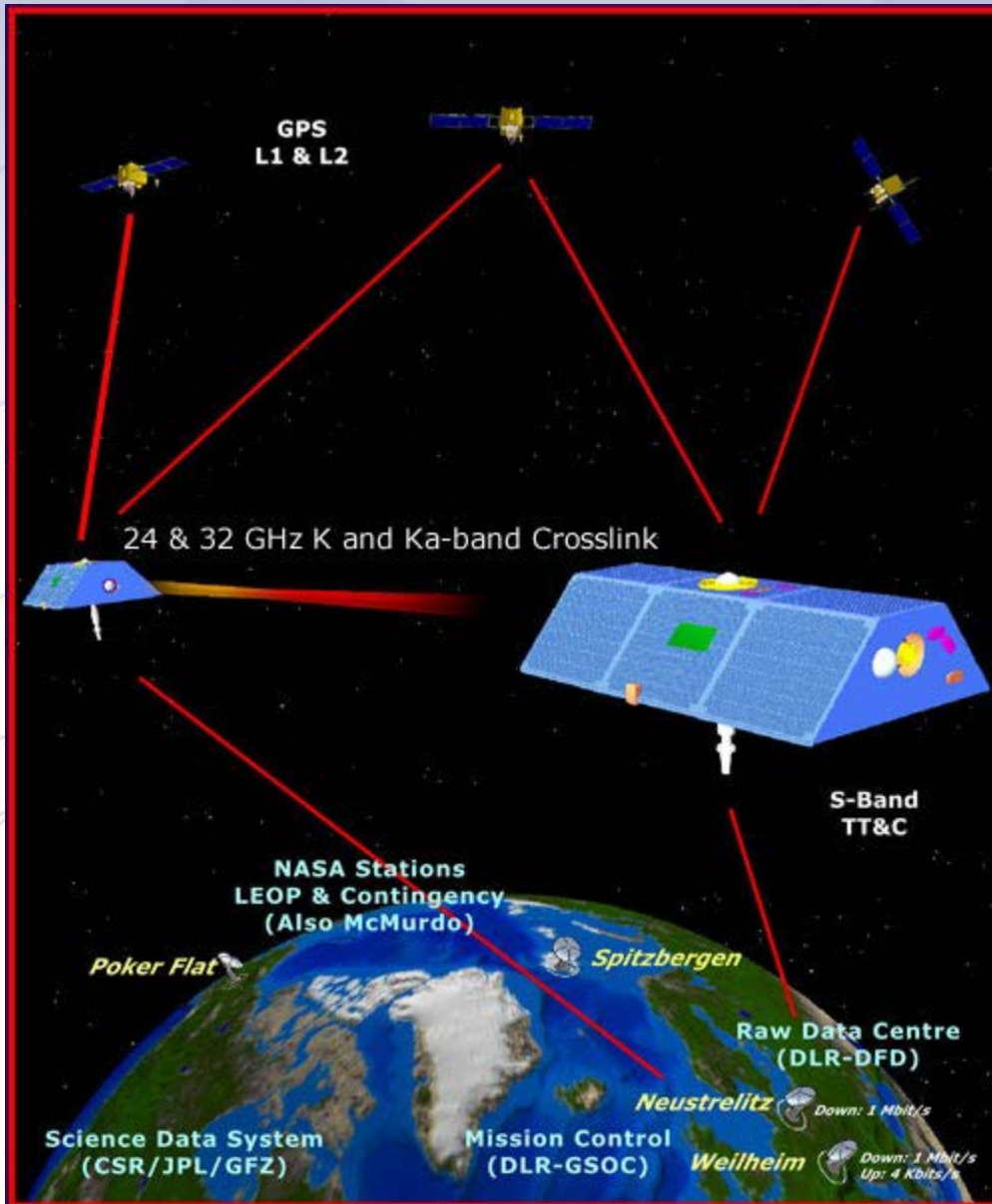
## ❑ NAVD 88

- ❑ 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

# Why isn't NAVD 88 good enough anymore

- **NAVD 88 suffers from use of bench marks 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

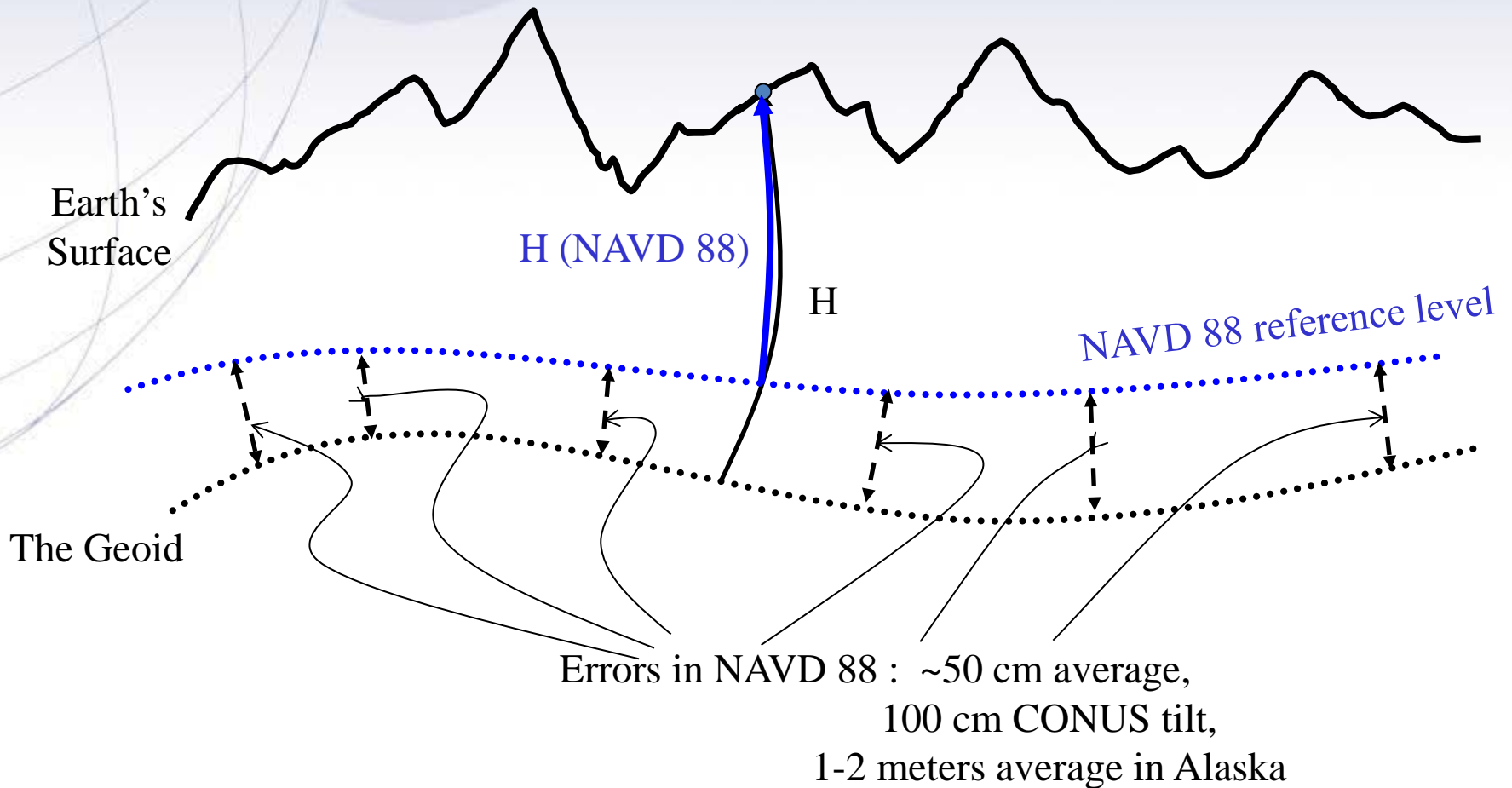


# Why isn't NAVD 88 good enough anymore?

## NAVD 88 suffers from:

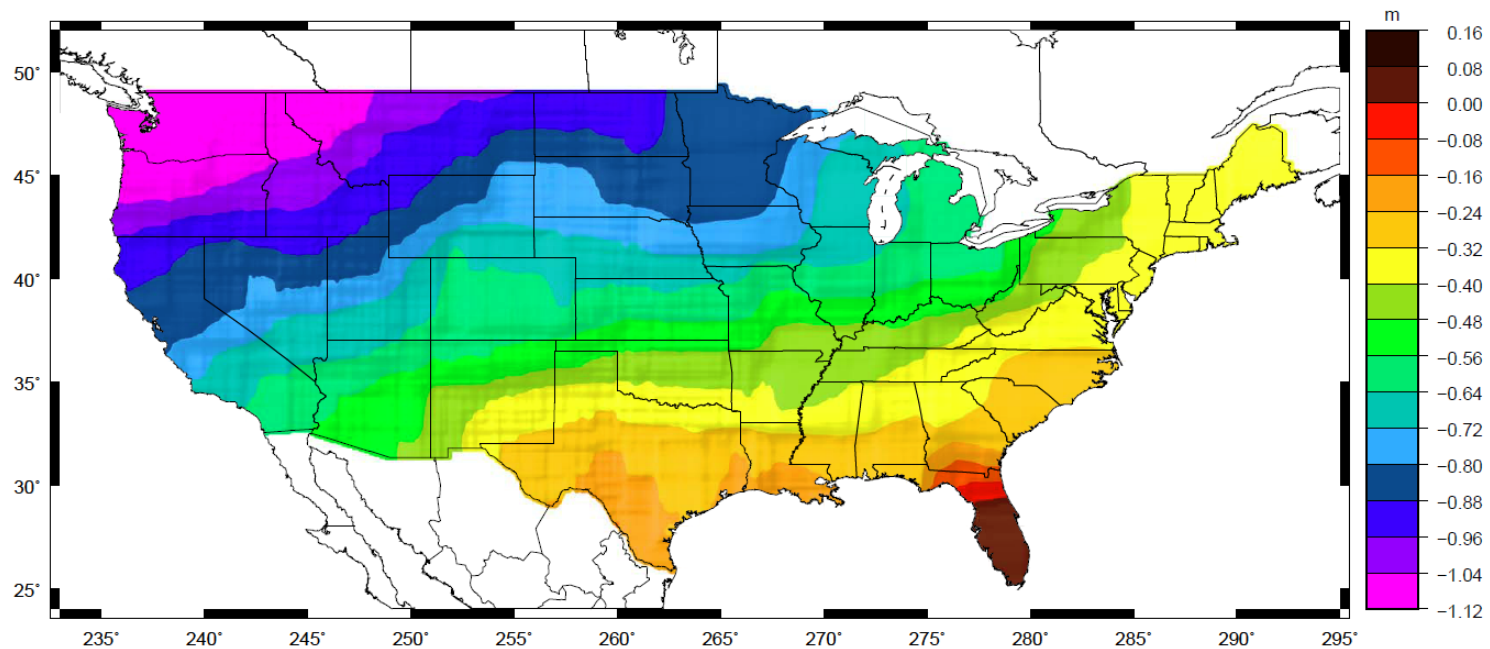
- A zero height surface that:
  - Has been proven to be ~50 cm biased from the latest, best geoid models (GRACE satellite)
  - Has been proven to be ~ 1 meter tilted across CONUS (again, based on the independently computed geoid from the GRACE satellite)

# Why isn't NAVD 88 good enough anymore?



# Why isn't NAVD 88 good enough anymore?

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



# 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



# Height-Mod means More Marks?



# Height Modernization



**Differential Leveling**



*Height Modernization*

- faster
- cheaper



**GNSS + ...**

# 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.

# How Good Can I Do With OPUS Static?

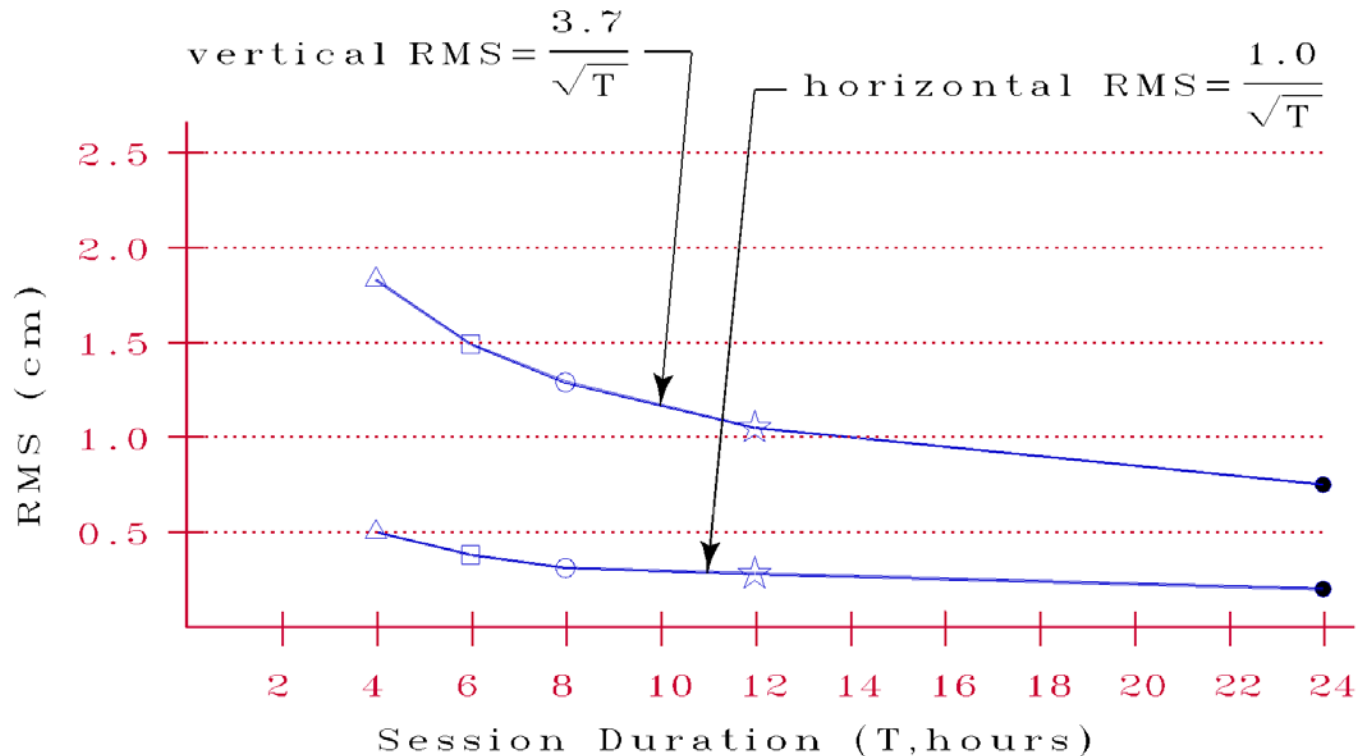
OPUS Static reliably addresses the more historically conventional requirements for GPS data processing. It typically yields accuracies of:

1 – 2 cm horizontally  
2 – 4 cm vertically

- 4-7 mm differential ellipsoid height accuracy in GSVS11
- New ellipsoid height accuracy estimates will be included in a planned update to HTMOD guidelines for a number of GNSS techniques.

# Positioning Error vs. Duration of the Observing Session

Dual-frequency GPS carrier-phase observations



# National CORS Accuracy

Vertical Precision Using Dual-Frequency

GPS Carrier Phase Observations 95% Confidence Level





# OPUS-RS MAP

National Geodetic Survey

## HELP: ABOUT THIS MAP

### OPTIONS:

Choose Map:

NS or EW 15-min Data

CORS Sites:

Show  Hide

Predicted Precision:

Latitude : 19.857173223801

Longitude: -147.36328125

Overlay Opacity:

60%

### LEGEND:

Horizontal 1 STD (cm)

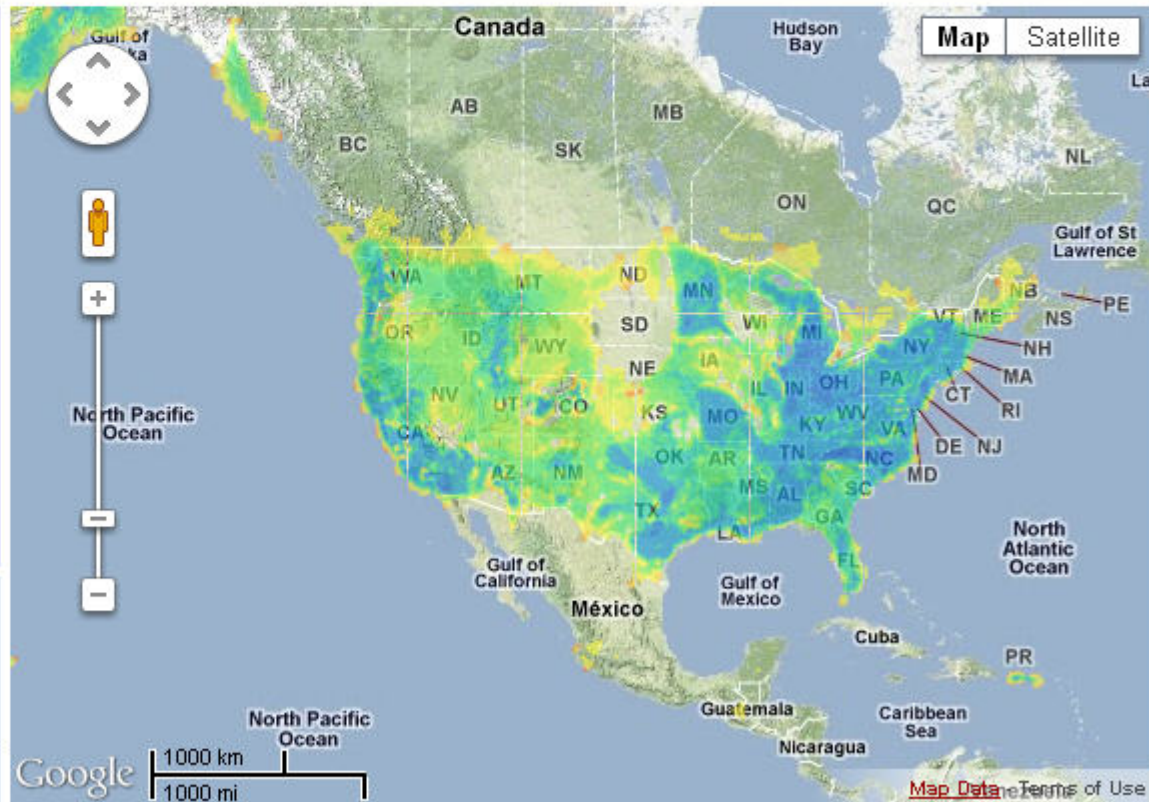


0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0+

Data as of Nov 7 2011

## OPUS-RS Estimated Precision and Availability

Version: 0.85



Website Owner: National Geodetic Survey / Last modified by Kevin Choi April 29 2011





## 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:

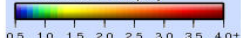
Retrieve Accuracy

Overlay Opacity:

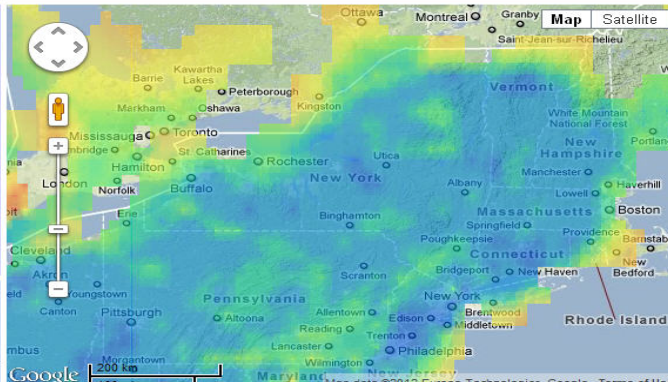
60%

**LEGEND:**

Horizontal 1 STD (cm)



Data as of Jan 2 2012



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## OPUS-RS MAP

National Geodetic Survey

**HELP:**  
ABOUT THIS MAP

### OPUS-RS Estimated Precision and Availability

Version: 0.85

**OPTIONS:**

Choose Map:

Ellipsoid Height 15-min Data

CORS Sites:  
 Show  Hide

Predicted Precision:

Latitude:

Longitude:

Retrieve Accuracy

Overlay Opacity:

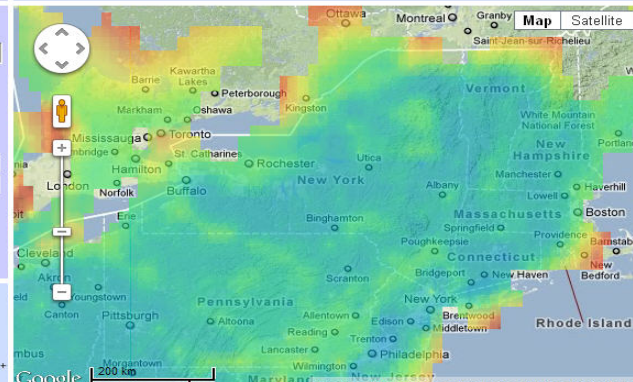
60%

**LEGEND:**

Ellipsoid Height 1 STD (cm)



Data as of Jan 2 2012



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## 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 1-hour Data

CORS Sites:  
 Show  Hide

Predicted Precision:

Latitude:

Longitude:

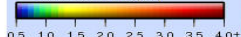
Retrieve Accuracy

Overlay Opacity:

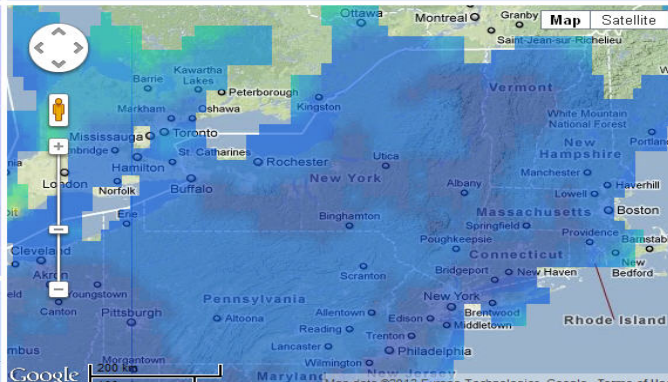
60%

**LEGEND:**

Horizontal 1 STD (cm)



Data as of Jan 2 2012



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## OPUS-RS MAP

National Geodetic Survey

**HELP:**  
ABOUT THIS MAP

### OPUS-RS Estimated Precision and Availability

Version: 0.85

**OPTIONS:**

Choose Map:

Ellipsoid Height 1-hour Data

CORS Sites:  
 Show  Hide

Predicted Precision:

Latitude:

Longitude:

Retrieve Accuracy

Overlay Opacity:

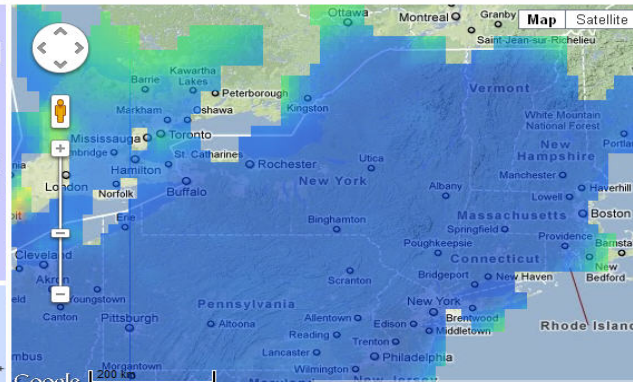
60%

**LEGEND:**

Ellipsoid Height 1 STD (cm)



Data as of Jan 2 2012



Website Owner: National Geodetic Survey / Last modified by Kevin Choi April 29 2011

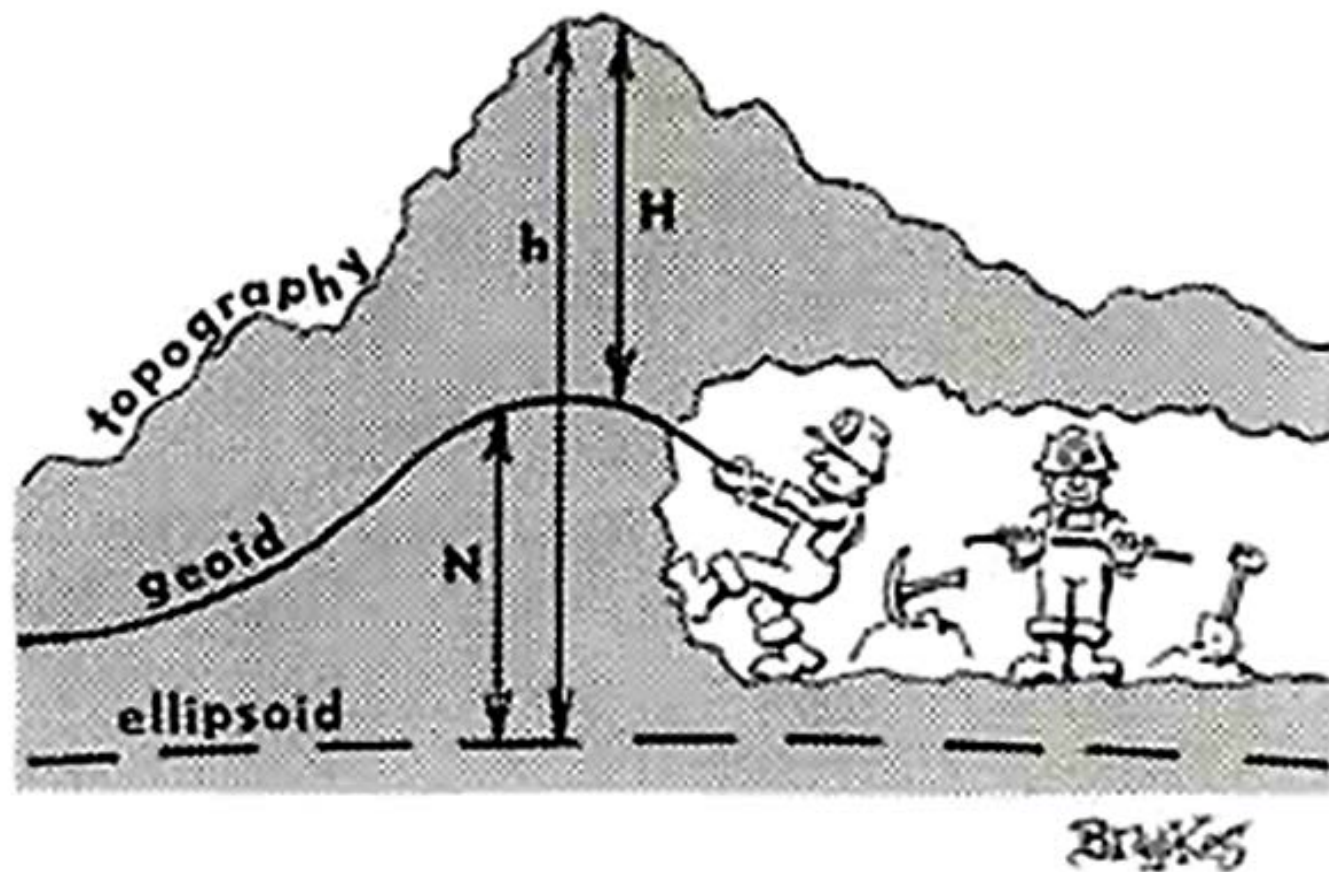
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# Height Modernization Bottom line

1. Using GNSS is cheaper, easier than leveling
2. To use GNSS we need a good geoid model



In Search of the Geoid

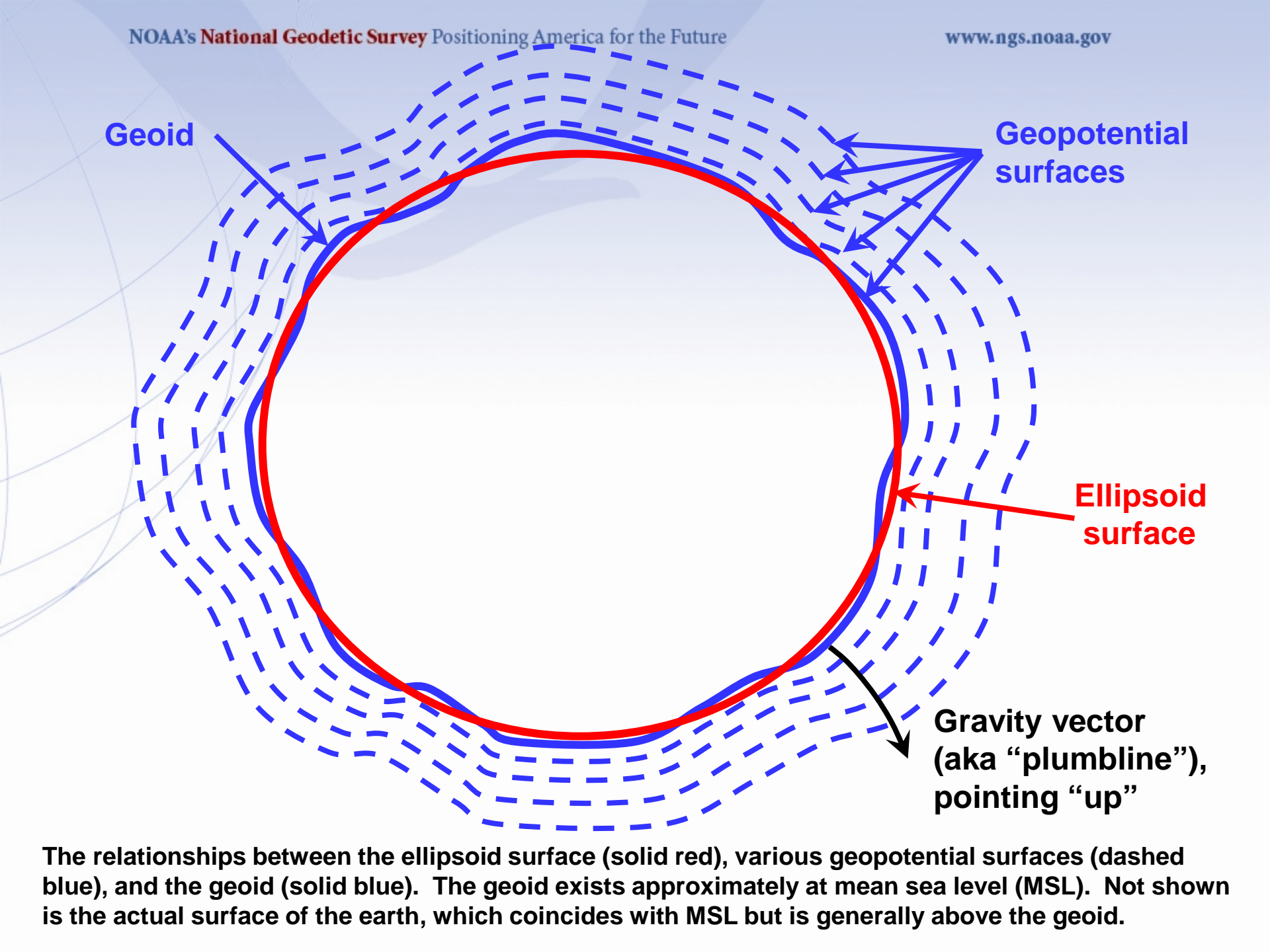
Geoid

Geopotential surfaces

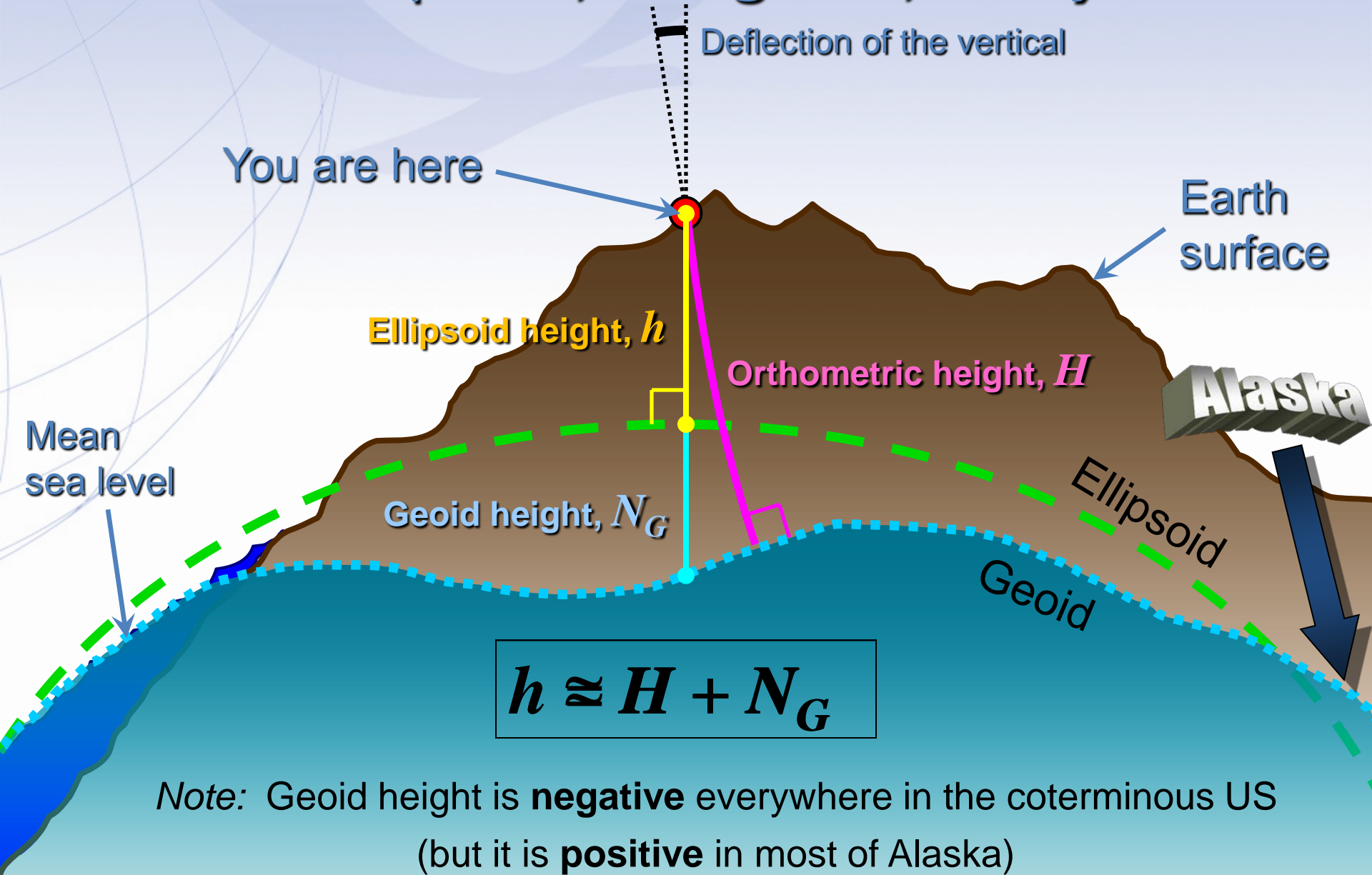
Ellipsoid surface

Gravity vector  
(aka "plumbline"),  
pointing "up"

The relationships between the ellipsoid surface (solid red), various geopotential surfaces (dashed blue), and the geoid (solid blue). The geoid exists approximately at mean sea level (MSL). Not shown is the actual surface of the earth, which coincides with MSL but is generally above the geoid.



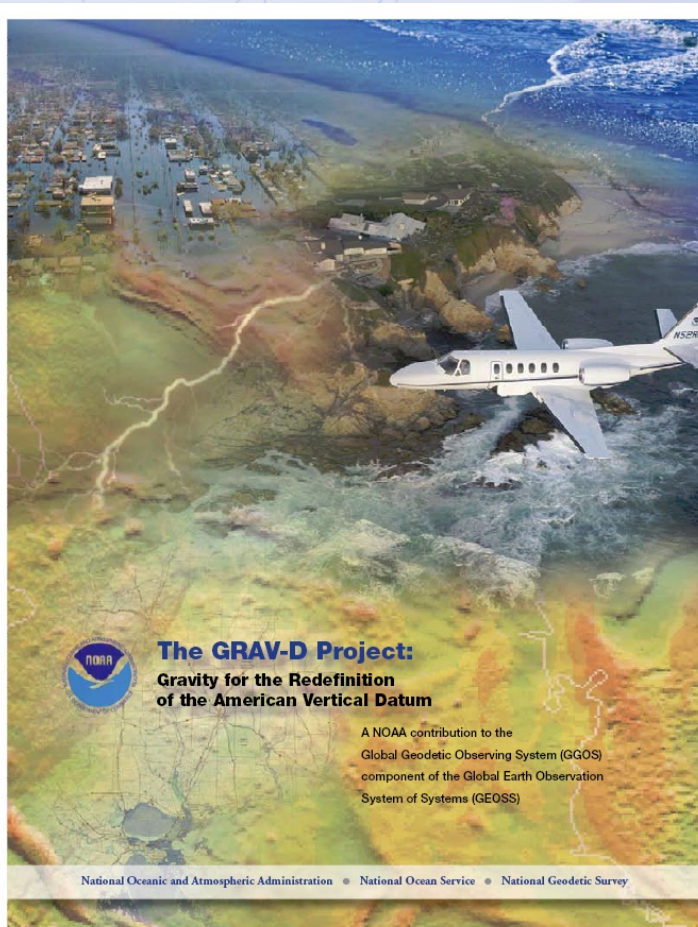
# The ellipsoid, the geoid, and *you*



$$h \approx H + N_G$$

Note: Geoid height is **negative** everywhere in the coterminous US (but it is **positive** in most of Alaska)

# Gravity for the Redefinition of the American Vertical Datum (GRAV-D)



- Replace the Vertical Datum of the USA by 2022 (at today's funding) with a **gravimetric geoid accurate to 1 cm**
- Orthometric heights accessed via GNSS accurate to 2 cm
- Three thrusts of project:
  - Airborne gravity survey of entire country and its holdings
  - Long-term monitoring of geoid change
  - Partnership surveys
- Working to launch a collaborative effort with the USGS for simultaneous magnetic measurement

***Gravity and Heights are  
inseparably connected***

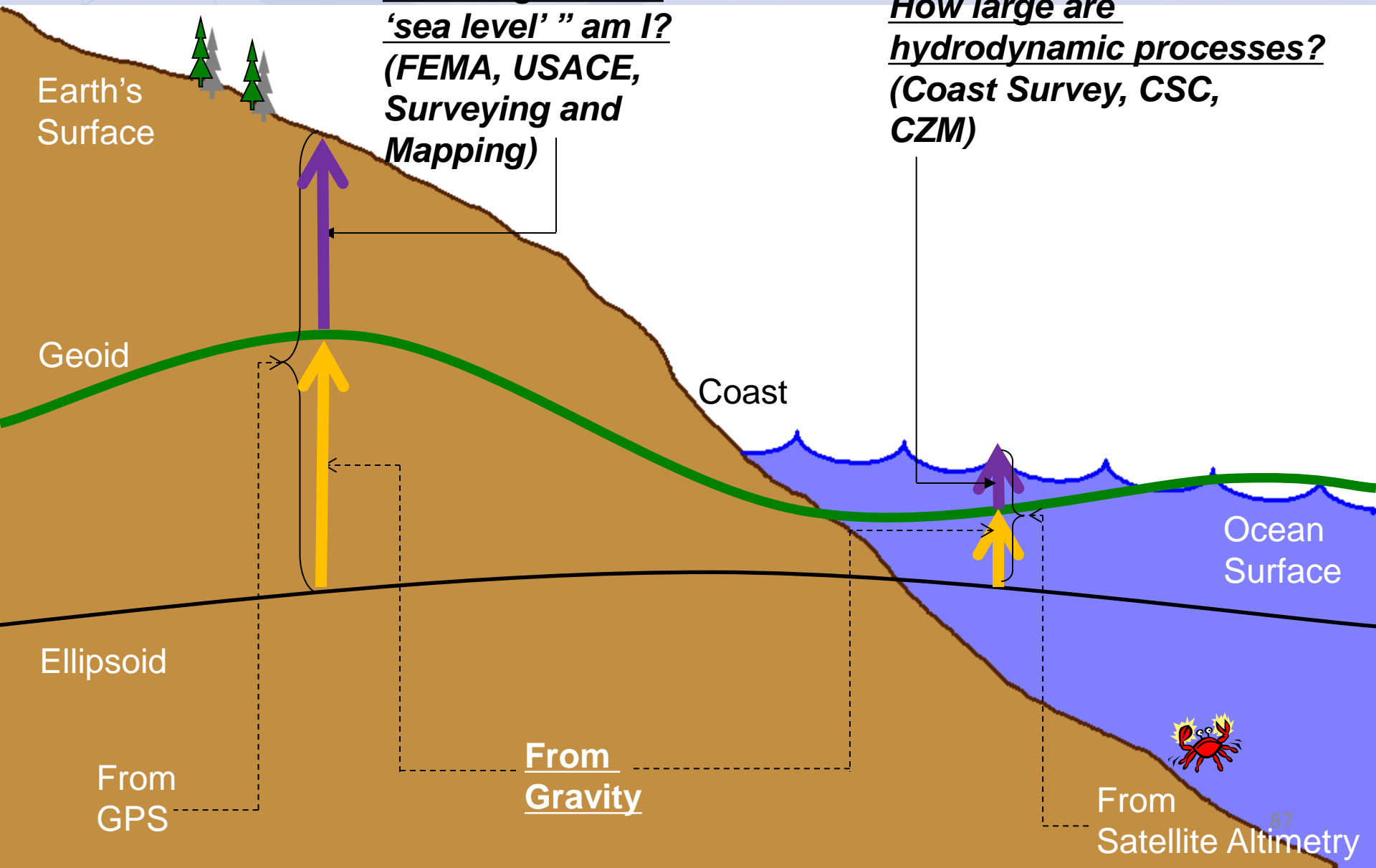
# What is GRAV-D?

- **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

# Gravity measurements help answer two big questions...

How "high above 'sea level' " am I?  
(FEMA, USACE, Surveying and Mapping)

How large are hydrodynamic processes?  
(Coast Survey, CSC, CZM)



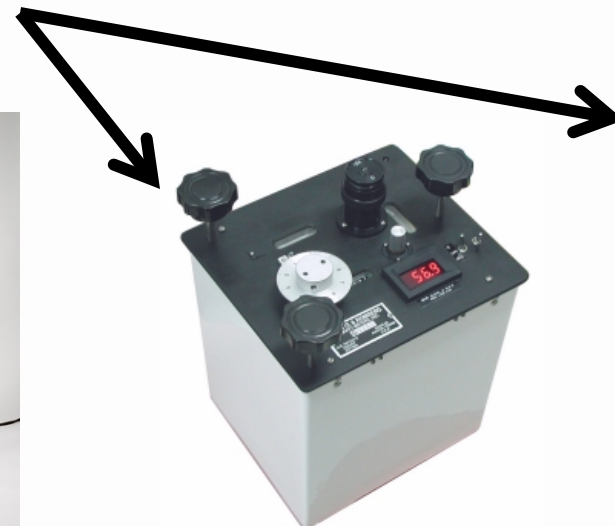
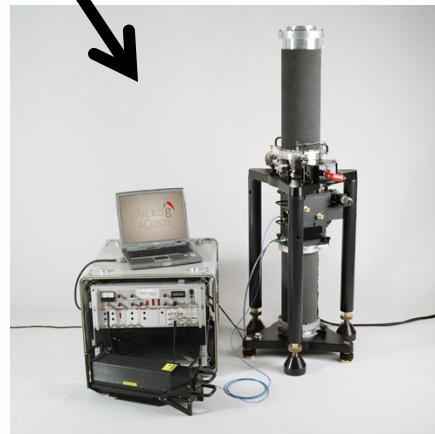
From GPS

From Gravity

From Satellite Altimetry

# 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





# GPRA\* Performance Metric For Airborne Surveys

FY09 Baseline	Targets vs Actual												
	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
6.14%	7.5%	12%	20%	28%	36%	45%	52%	60%	68%	76%	84%	92%	100% and Implement
6.14	7.8	14.7	23.9	31.0	38.1	45.2							

Oct. 2014 through Jun. 2015

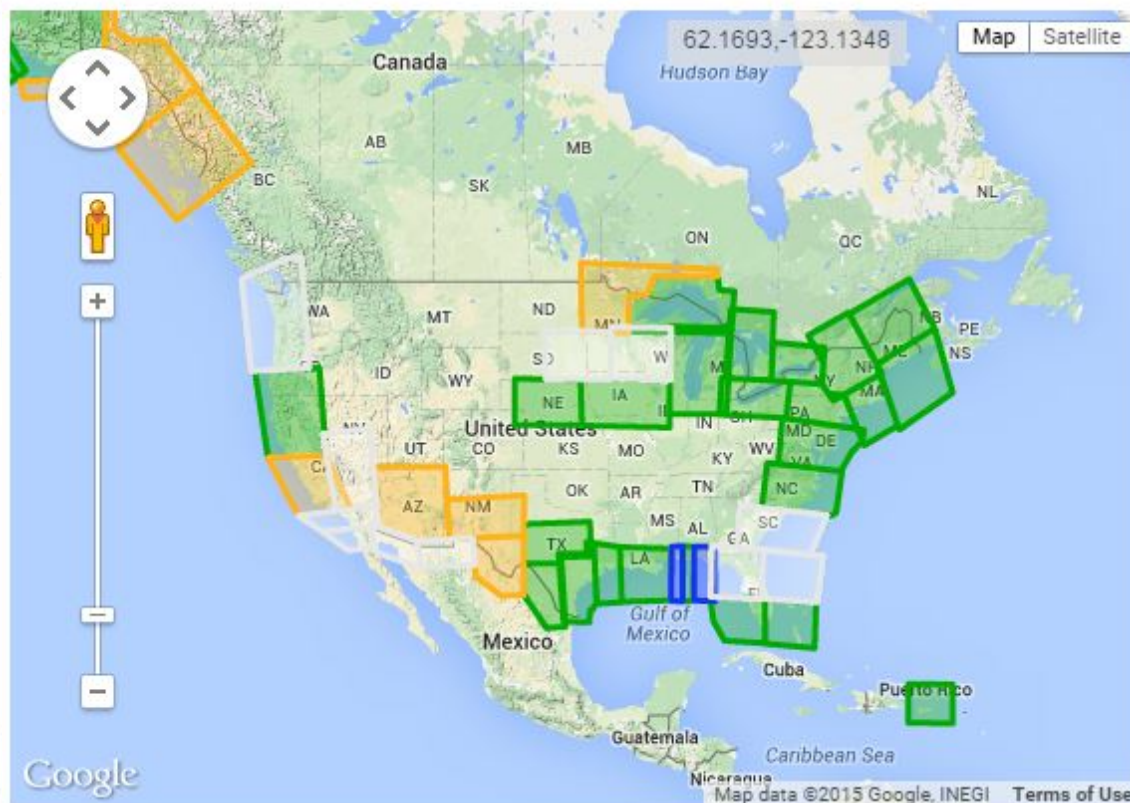
- **Measure:** Percentage of the U.S. and its territories with GRAV-D data available to support a 1 cm geoid supporting 2 cm orthometric heights.

\*GPRA = Government Performance and Results Act of 1993

# Airborne Gravity Current Coverage

## Map Key - Airborne Gravity Data

- Green: Available data and metadata
- Blue: Data being processed
- Orange: Data collection underway
- White: Planned for data collection



## Data Block Status

- Complete
- Processing
- Collecting
- Planned

As of July 1, 2015

# Validating Geoid Accuracy

**“...the gravimetric geoid used in defining the *future vertical datum of the United States* should have an absolute accuracy of 1 centimeter at any place and at any time.”**

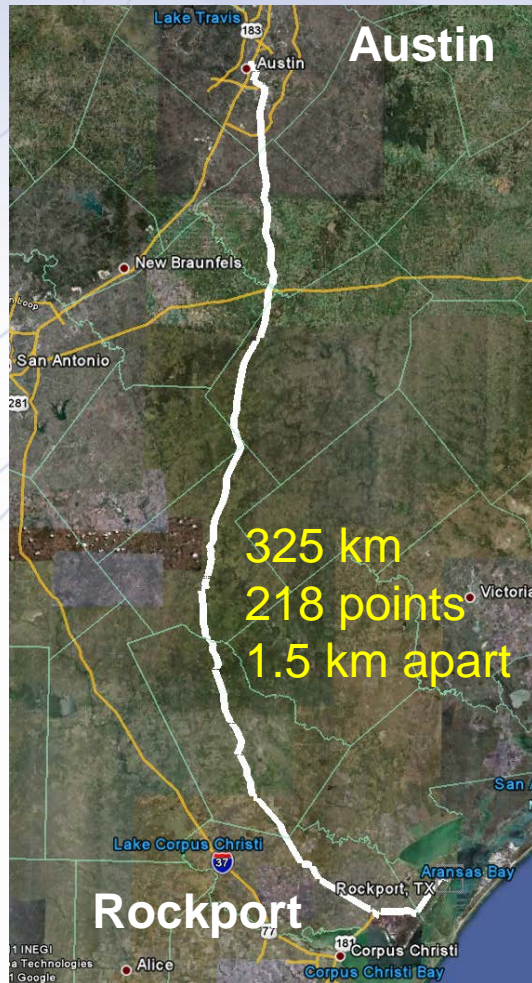
**-- The NGS 10 year plan  
(2008-2018)**

**Admirable!...Achievable?**

# Validating Geoid Accuracy

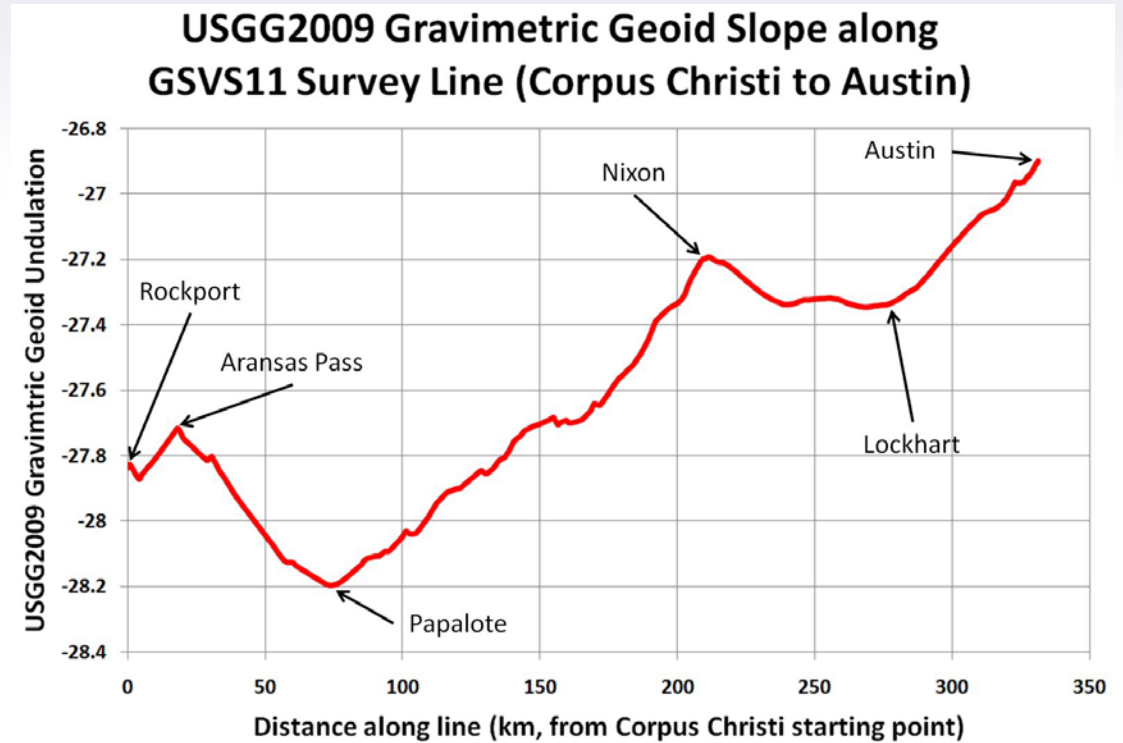
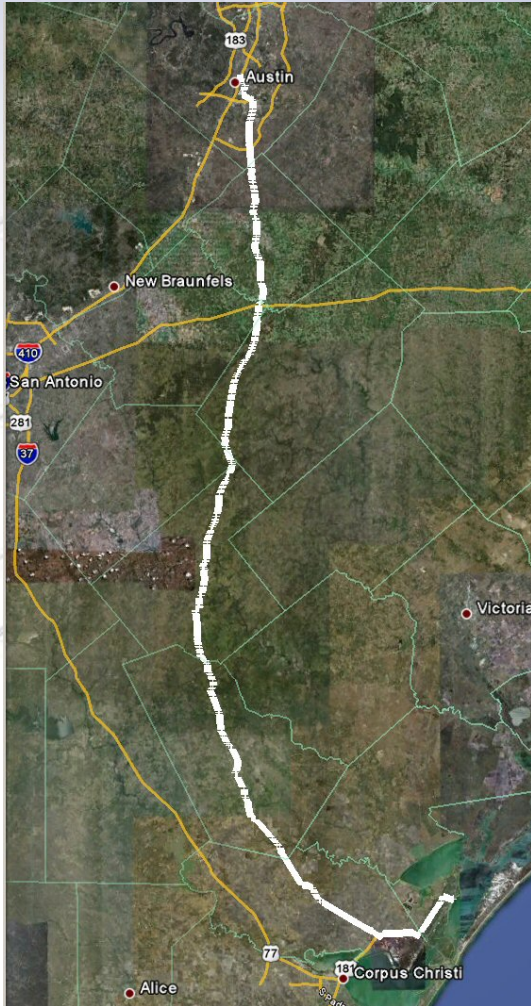
- NGS plans up to 3 surveys to validate the accuracy of the gravimetric geoid model
  - GSVS11
    - 2011; Low/Flat/Simple: **Texas**; Done; Success!
  - GSVS14
    - 2014; High/Flat/Complicated: **Iowa**; Field work Complete
  - GSVS1x
    - 2016?; High/Rugged/Complicated: **Colorado**

# Geoid Slope Validation Survey



- Observe geoid shape (slope) using multiple independent terrestrial survey methods
  - GPS + Leveling
  - Deflections of the Vertical
- Compare **observed** slopes (from terrestrial surveys) to **modeled** slopes (from gravimetry or satellites)
  - With / Without new GRAV-D airborne gravity

# Geoid Slope Validation Survey of 2011 (GSVS11)



# Surveys Performed

- GPS: 20 identical units, 10/day leapfrog, 40 hrs ea.
- Leveling: 1<sup>st</sup> order, class II, digital barcode leveling
- Gravity: FG-5 and A-10 anchors, 4 L/R in 2 teams
- DoV: ETH Zurich DIADEM GPS & camera system
- LIDAR: Riegl Q680i-D, 2 pt/m<sup>2</sup> spacing, 0.5 km width
- Imagery: Applanix 439 RGB DualCam, 5000' AGL
- Other: RTN, short-session GPS, extra gravity marks around Austin, gravity gradients



GPS



LIDAR/  
Imagery



DoV



Leveling



Gravity



# Geoid Slope Survey Conclusions

J Geod (2013) 87:885–907  
DOI 10.1007/s00190-013-0653-0

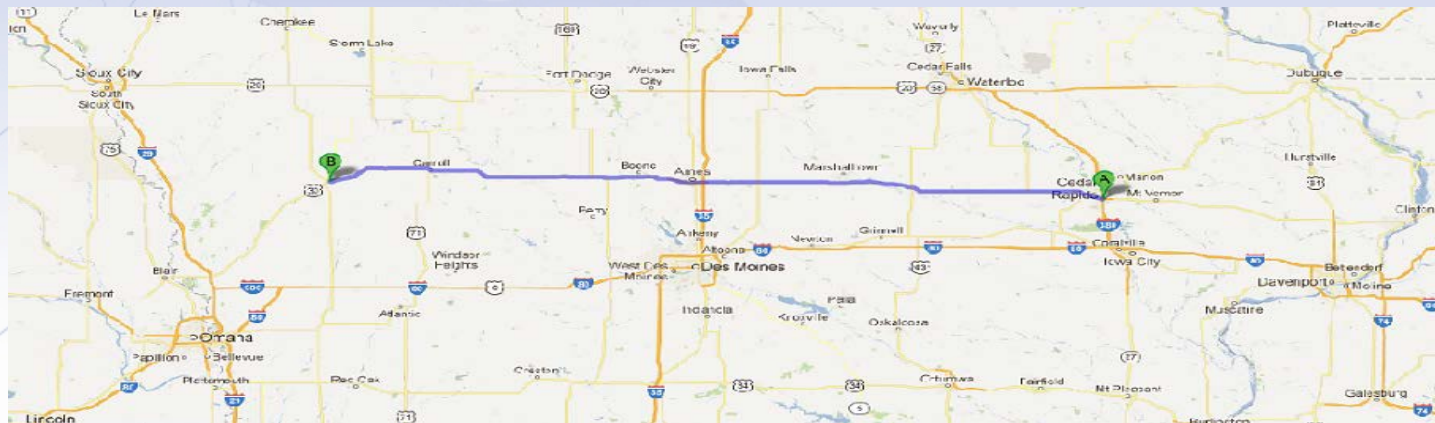
ORIGINAL ARTICLE

## Confirming regional 1 cm differential geoid accuracy from airborne gravimetry: the Geoid Slope Validation Survey of 2011

Dru A. Smith · Simon A. Holmes · Xiaopeng Li · Sébastien Guillaume · Yan Ming Wang · Beat Bürki · Daniel R. Roman · Theresa M. Damiani

- Including airborne gravity data improves geoid slope accuracy at nearly all distances <325 km
- The NGS geoid in the TX survey meets the 1 cm accuracy objective only if airborne data are included
  - No other model achieved 1 cm accuracy
- Gravimetric geoid models and GPS are a viable alternative to long-line leveling

# GSVS14 Line



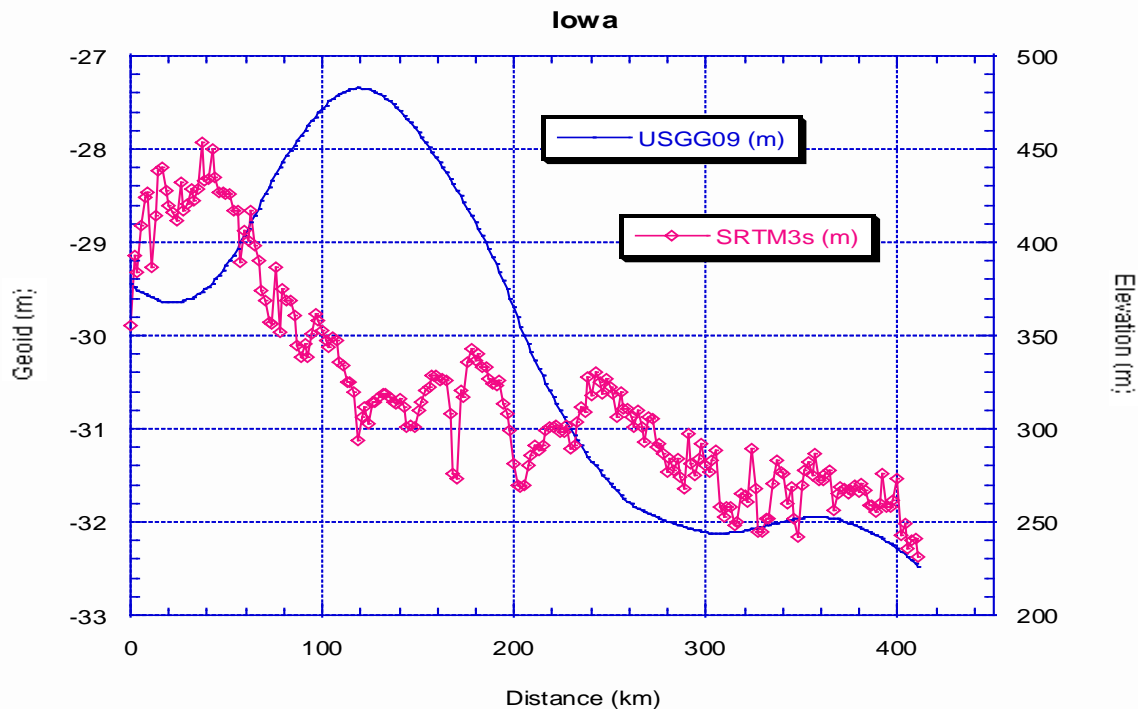
Goal: Same as GSVS11

Region: Moderate terrain  
More complex gravity

Data: Same as GSVS11

Timeline: Fiscal year 2014  
field season

IA (Cedar Rapids to Denison)



# Accessing the New Vertical Datum

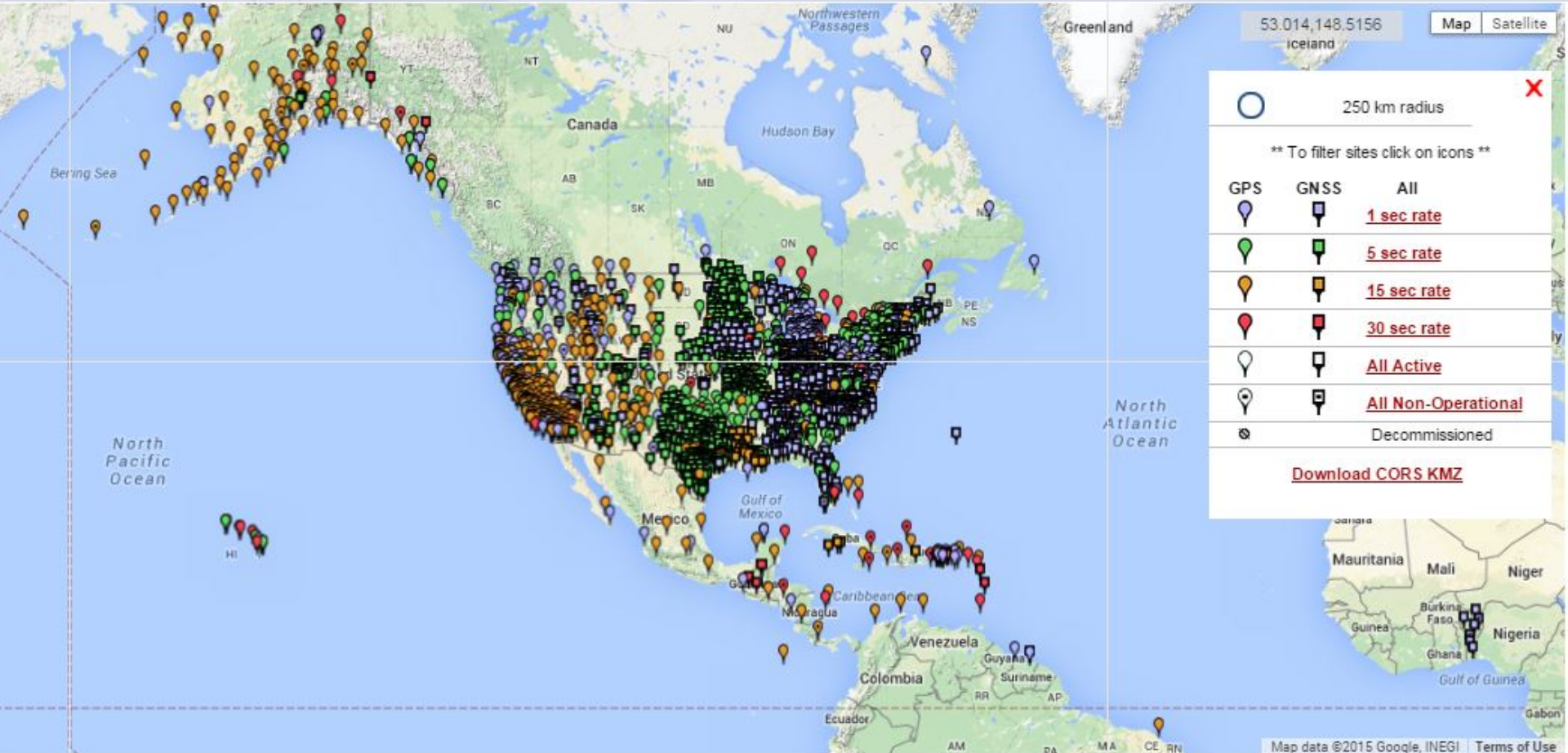
- **Primary access** (NGS mission)
  - Users with geodetic quality GNSS receivers will continue to use OPUS suite of tools
  - Ellipsoid heights computed, and then a gravimetric geoid removed to provide orthometric heights in the new datum
  - No passive marks needed
  - But, could be used to position 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

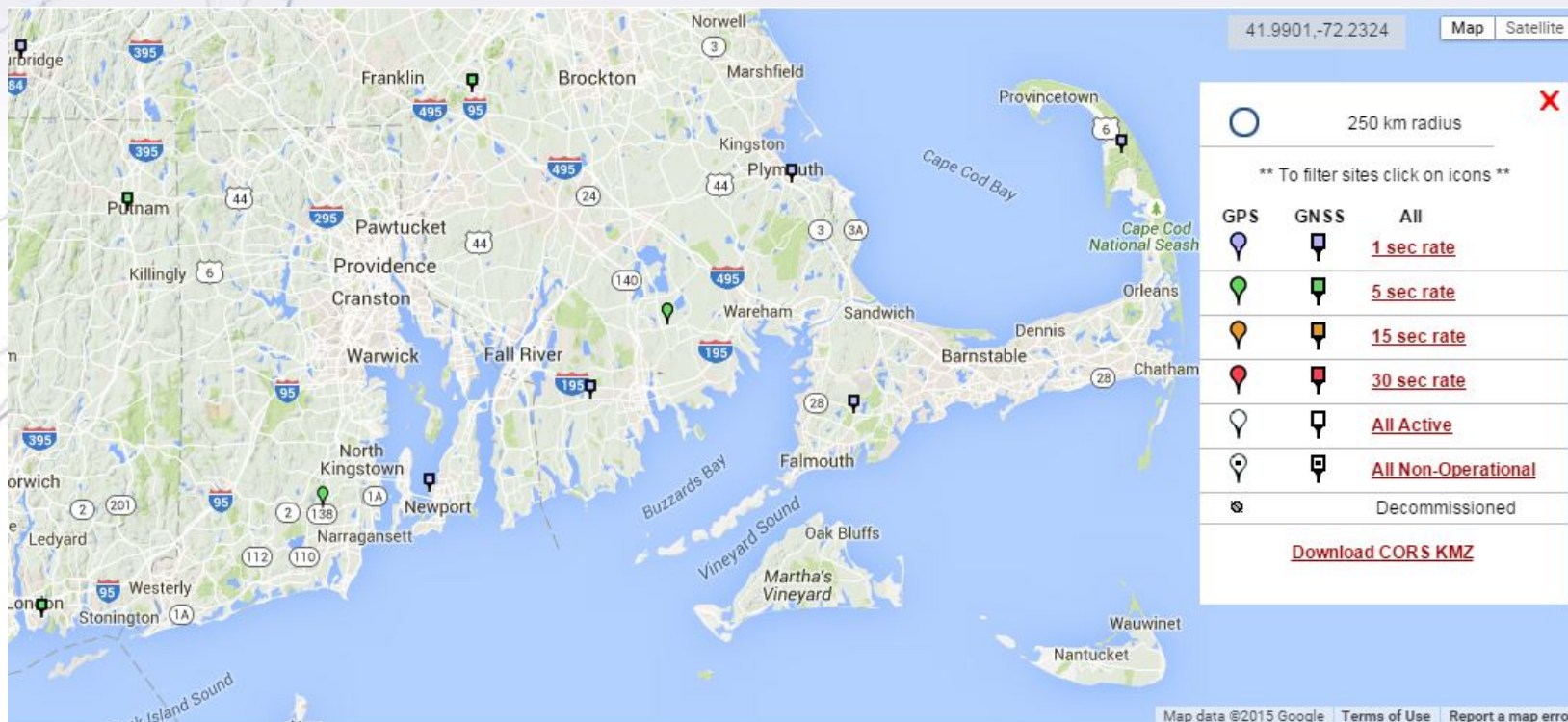


# Accessing the New Vertical Datum

- **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



Antenna Reference Point (ARP): VERMONT CAPITAL CORS ARP

-----  
PID = AF9563

IGS08 POSITION (EPOCH 2005.0)

Computed in Aug 2011 using data through gpwsk 1631.

X =	1369550.251 m	latitude	=	44 15 43.14089 N
Y =	-4365534.848 m	longitude	=	072 34 56.56587 W
Z =	4429096.713 m	ellipsoid height	=	159.387 m

IGS08 VELOCITY

Computed in Aug 2011 using data through gpwsk 1631.

VX =	-0.0156 m/yr	northward	=	0.0045 m/yr
VY =	-0.0024 m/yr	eastward	=	-0.0156 m/yr
VZ =	0.0040 m/yr	upward	=	0.0011 m/yr

NAD\_83 (2011) POSITION (EPOCH 2010.0)

Transformed from IGS08 (epoch 2005.0) position in Aug 2011.

X =	1369550.955 m	latitude	=	44 15 43.10641 N
Y =	-4365536.270 m	longitude	=	072 34 56.55478 W
Z =	4429096.755 m	ellipsoid height	=	160.539 m

NAD\_83 (2011) VELOCITY

Transformed from IGS08 velocity in Aug 2011.

VX =	0.0024 m/yr	northward	=	-0.0020 m/yr
VY =	-0.0008 m/yr	eastward	=	0.0021 m/yr
VZ =	-0.0014 m/yr	upward	=	0.0001 m/yr

IGS08 - NAD 83(2011)

DHoriz = 1.092 m

DEHt = 1.152 m

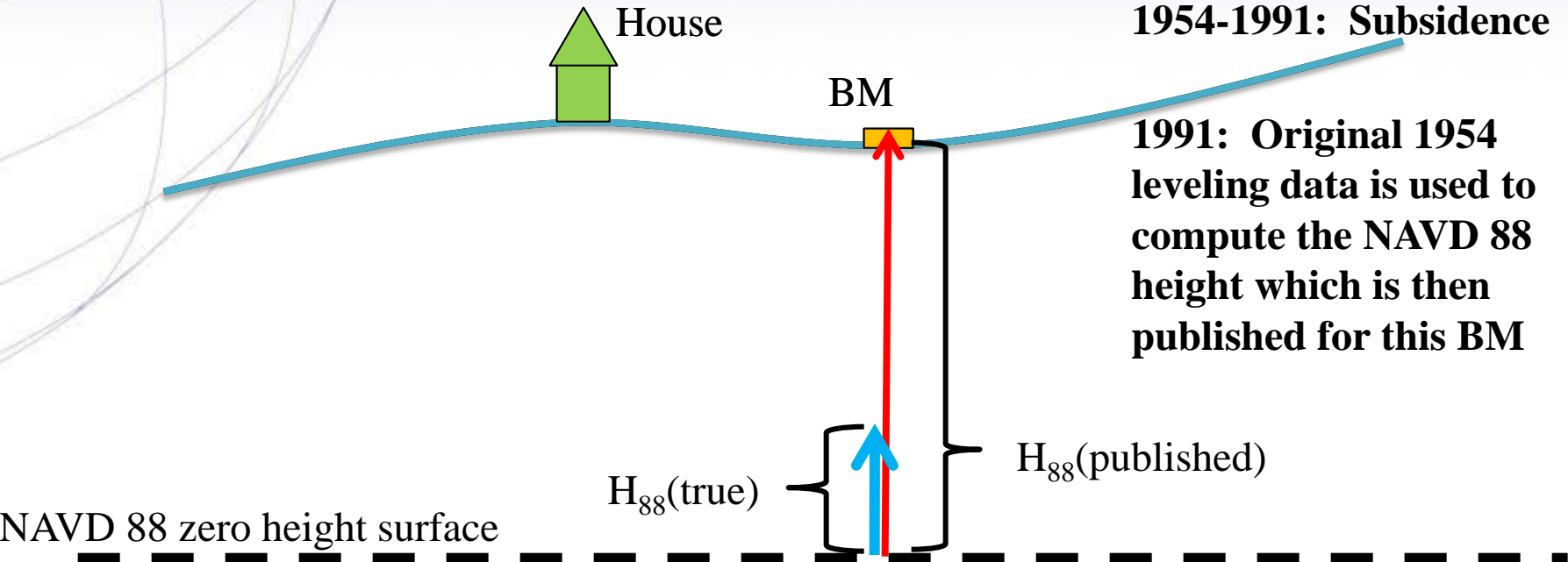
# How will I access the new vertical datum?

## 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**

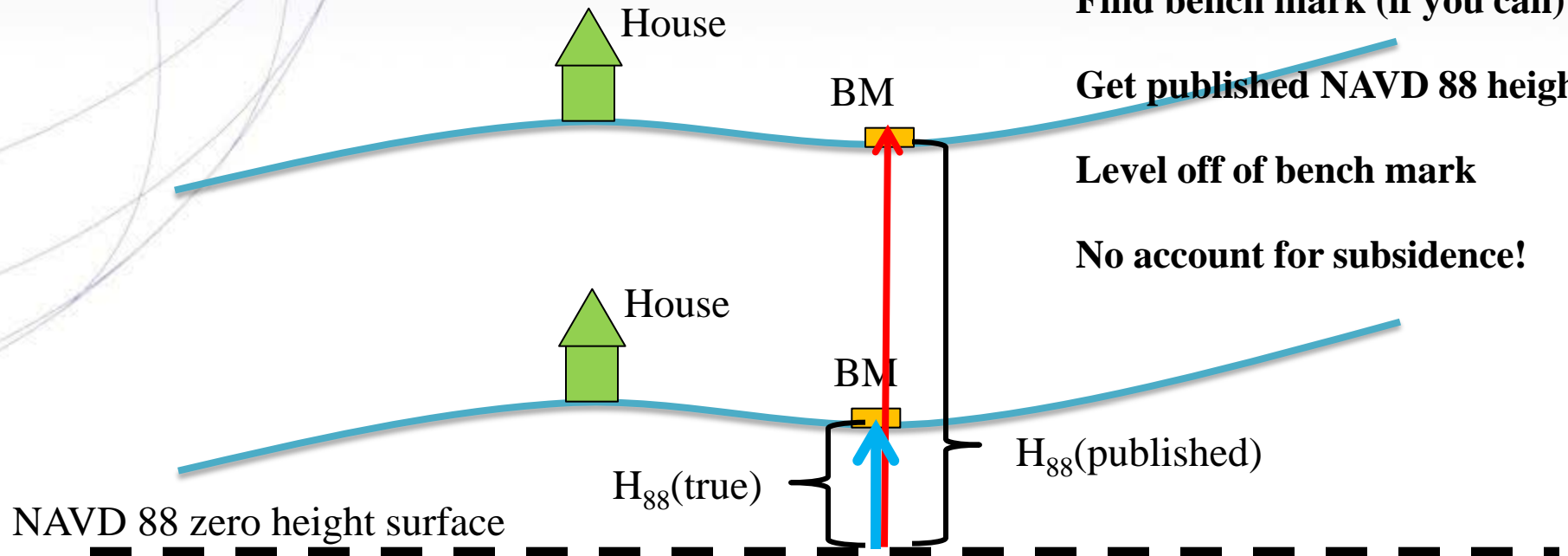


*Clearly the true height relative to the NAVD 88 zero surface is not the published NAVD 88 height*



# How will I access the new vertical datum?

## Example 1: Flood insurance survey



*Using Existing 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

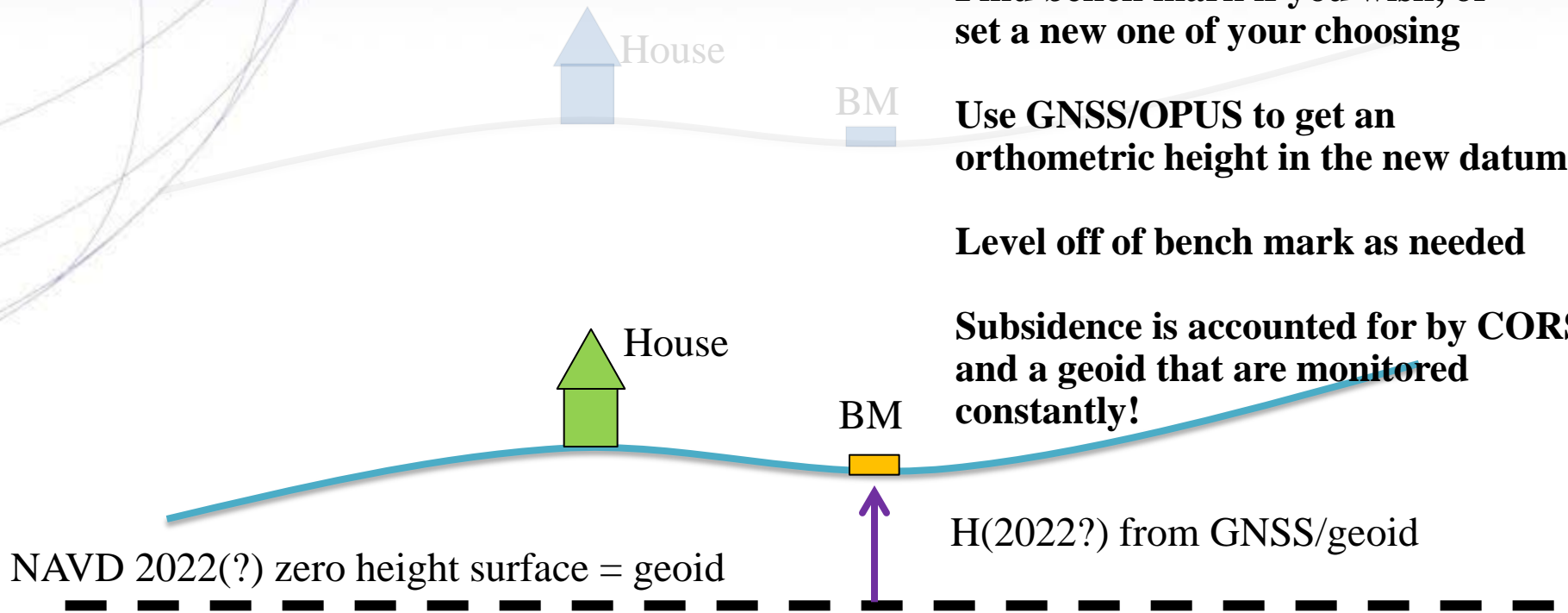
*Using Future Techniques:*

**Find bench mark if you wish, or set a new one of your choosing**

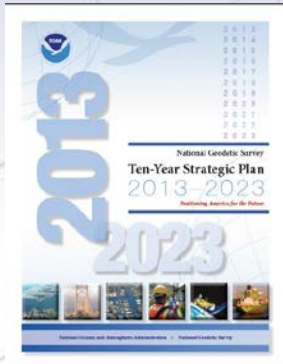
**Use GNSS/OPUS to get an orthometric height in the new datum**

**Level off of bench mark as needed**

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



# Additional Information

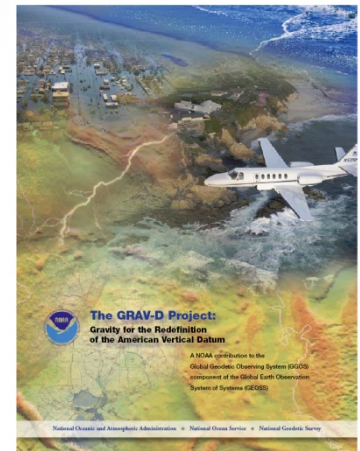


The NGS 10 year plan (2013-2023)

<http://www.geodesy.noaa.gov/INFO/NGS10yearplan.pdf>

The GRAV-D Project

<http://www.geodesy.noaa.gov/GRAV-D>



Socio-Economic Benefits Study:  
Scoping the Value of CORS and GRAV-D

Irving Leveson



FINAL REPORT

December 22, 2008

Prepared for the National Geodetic Survey

Socio-Economic Benefits of CORS and GRAV-D

[http://www.geodesy.noaa.gov/PUBS\\_LIB/Socio-EconomicBenefitsofCORSandGRAV-D.pdf](http://www.geodesy.noaa.gov/PUBS_LIB/Socio-EconomicBenefitsofCORSandGRAV-D.pdf)

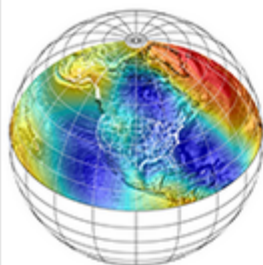


## New Datums

National Geodetic Survey

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January 14, 2015



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[2010 Federal Geospatial Summit Proceedings](#)

### Replacing NAVD 88 and NAD 83

NAD 83 and NAVD 88 will be replaced in 2022, and there are many related projects to make sure the transition goes smoothly. Read the [NGS Ten-Year Plan](#) to learn more and continue to visit this web-page for more information.

#### More resources



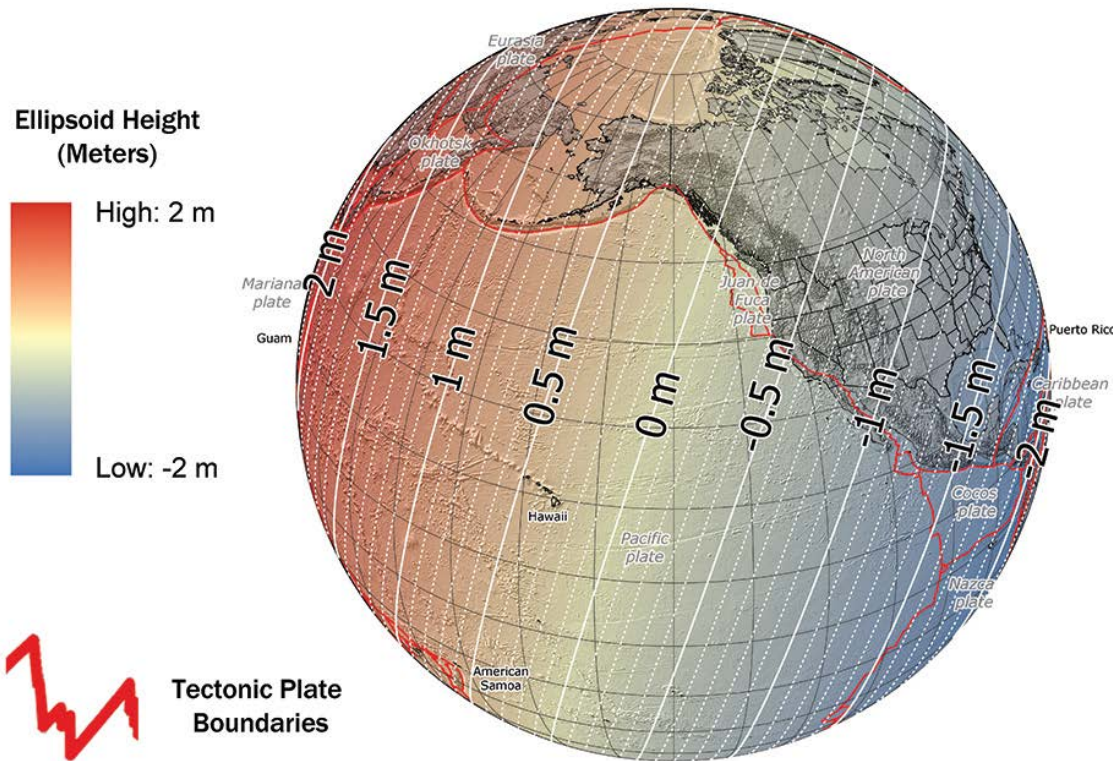
#### Related projects and programs

**Gravity for the Redefinition of the American Vertical Datum or "GRAV-D"** is NGS' ambitious enterprise to re-define the vertical datum of the United States by the year 2022. In the first stage of the project, NGS will collect a high-resolution "snapshot" of gravity in the United States by acquiring new airborne gravity data. Then, NGS will create a low-resolution "movie" of gravity changes primarily through terrestrial gravity observations. [Visit the webpage to learn more.](#)

**Foundation CORS:** To support future requirements and prepare for the transition to the new datums, NGS is constructing a small number of ultra-stable Foundation CORS (Continuously Operating Reference Stations). NGS expects to establish one to two new Foundation CORS per year and will oversee the

# How will the new datums affect you?

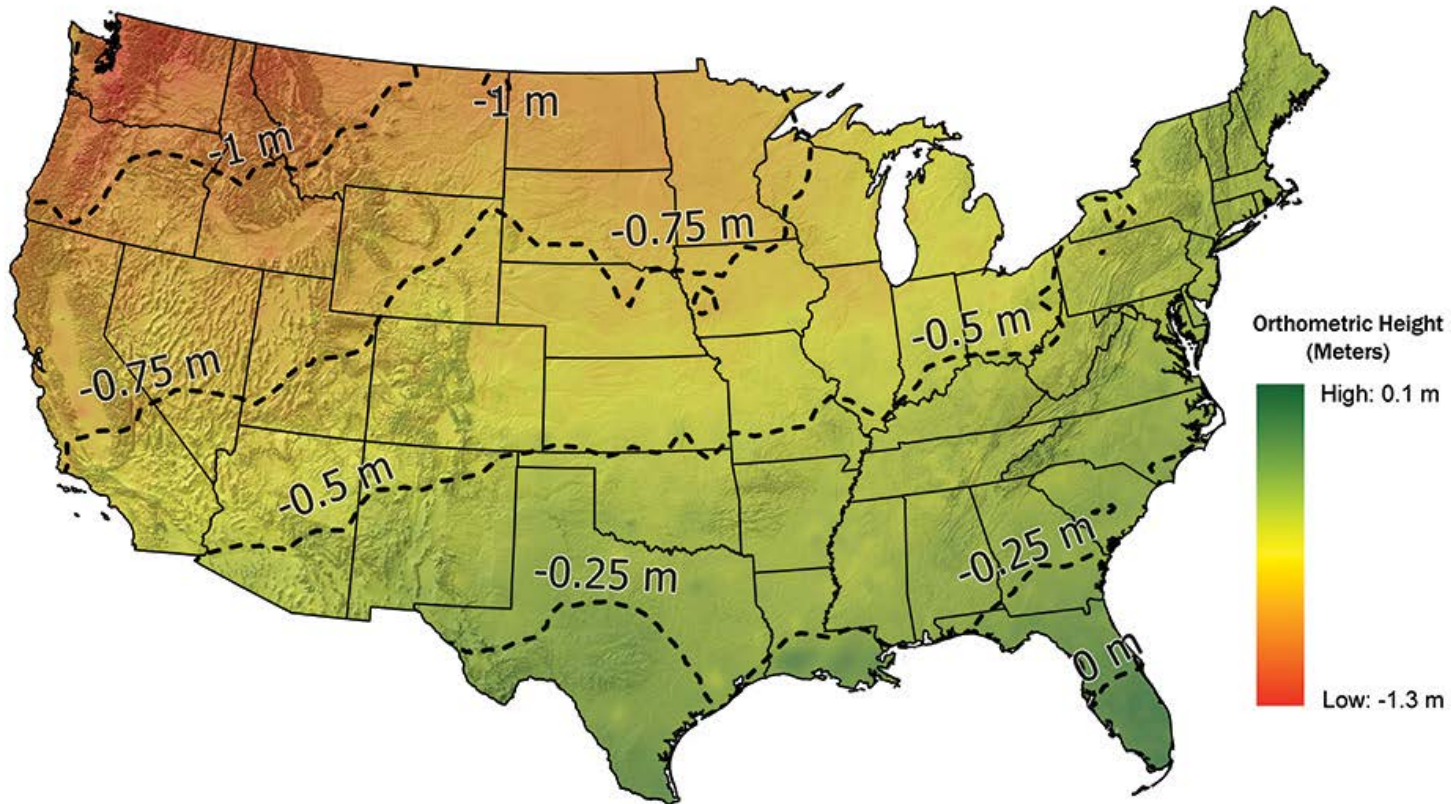
## Approximate Ellipsoid Height Change



The new geometric datum will change latitude, longitude, and ellipsoid height in CONUS and AK between 1 and 2 meters.

# How will the new datums affect you?

## Approximate Orthometric Height Change



The new vertical (geopotential) datum will change heights on average 50 cm with a 1m tilt towards the Pacific Northwest.

# Predicted Positional Changes in 2022

## Vicinity of Montpelier, VT.

(Computed for station MAY, pid AA9705)PG2656

**HORIZONTAL = 1.25 m (4.1 ft)**

**ELLIPSOID HEIGHT = - 1.15 m (- 3.8 ft)**

Predicted with **HTDP**

**ORTHOMETRIC HEIGHT = - 0.37 m (- 1.2 ft)**

Predicted with **HTDP** and **xGEOID15B**

**HTDP**

“Coping with Tectonic Motion”

R. Snay & C. Pearson

American Surveyor Magazine, December 2010

[www.Ameriserv.com](http://www.Ameriserv.com)

# Old vs New Datums

- Step 1: Do the best scientific positioning work we can in ITRF
  - Before any discussion of “plate fixed” or “map projections”
  - NGS’s core goal must be the *scientific integrity of positions*
  - **New database**
  - **Replacement of static vector-based GNSS processing**



# Old vs New Datums

- Step 2: Consider the question of “plate fixed”:
  - Why do users want this?
    - Fixed latitude and longitude?
  - Nothing is “fixed” though
    - Plate is not just rotating; more than 1 plate
  - Who wins? Who defines “fixed”? Must all points maintain zero change?
    - Model and remove all real motion? (aka “HTDP”)
      - If not removing *all* motion, why remove *any* motion?
        - » ITRF minus plate rotation vs just ITRF

# State Plane Coordinates

- Barring user-requested changes, NGS may use existing SPC projections, boundaries and equations, but with new false northings & eastings (to distinguish from NAD 27 and NAD 83)
- User-provided plug-ins (pre-written code) for SPC or other projections may be possible

# Old vs New Datums: Access

- Old datums used passive control as the primary access
  - CORS / OPUS helped, but “datasheets” remain the largest download, far and away more than OPUS is used

# Old vs New Datums: Access

- New datums
  - Primary access: GNSS + geoid model
  - Secondary access: Passive control
- Fixed:
  - CORS + geoid (coords and velocities both)

# Old vs New Datums: Passive Control

- Roll of passive control in the future:
  - Control for projects
    - Depending on accuracy needs, new coordinates should be determined, rather than relying on published coordinates based on old surveys
  - Monitoring sites for motion
  - Calibrating RTNs

# metadata to the rescue

- your positional metadata should include:
  - datum
  - epoch
  - source
- these will facilitate transforming from current to new datum
- maintaining your original survey data will provide more accurate results

# Measures of Success

- FGDC votes to adopt the new datum for U.S. geospatial data.
- All NOAA geospatial products are consistent with the new datum.
- NOAA geospatial products are understood and accepted by users.
- Tools exist which facilitate modernization of legacy data.
- New datums replace NAD83/NAVD88 in state and local regulations, documentation

## Risks

- “Existing datums are good enough”, reduces enthusiasm for adopting the new.
- Access to global (ITRF) & local (RTN, LDP) frames reduces the utility of a NAREF frame.
- [Das Unheimliche](#); frustration and cognitive dissonance increase with accuracy.

## Assumptions

- IERS will continue to provide an ITRF common to all GNSS & other navigation systems.
- GIS vendors will provide user-friendly solutions to modernize legacy data.

# What's Next for Geodetic Datums?



[https://www.youtube.com/playlist?list=PLsyDI\\_aqUTdFY6eKURmiCBBk-mP4R10Dx](https://www.youtube.com/playlist?list=PLsyDI_aqUTdFY6eKURmiCBBk-mP4R10Dx)



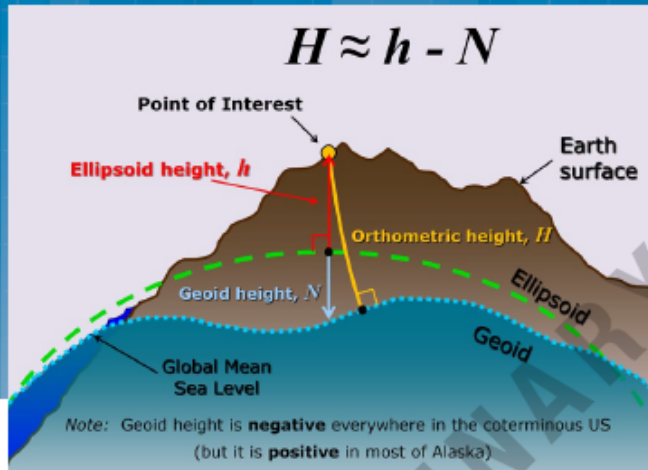


Figure 5. The relationship between orthometric height ( $H$ ), ellipsoid height ( $h$ ), and geoid height ( $N$ ). Note that the geoid is below the reference ellipsoid in the coterminous US, hence the geoid height is negative (i.e.,  $H > h$ ). Both ellipsoid and geoid heights are determined from the ellipsoid; the orthometric height is determined from the geoid.



Find the article(s) in the Archives at:  
<http://www.amerisurv.com>

# Frames for the Future

New Datum Definitions for Modernization of the U.S. National Spatial Reference System

## Replacing NAVD 88—The Role of Geoid Models (Part 2 of 4)

### Background

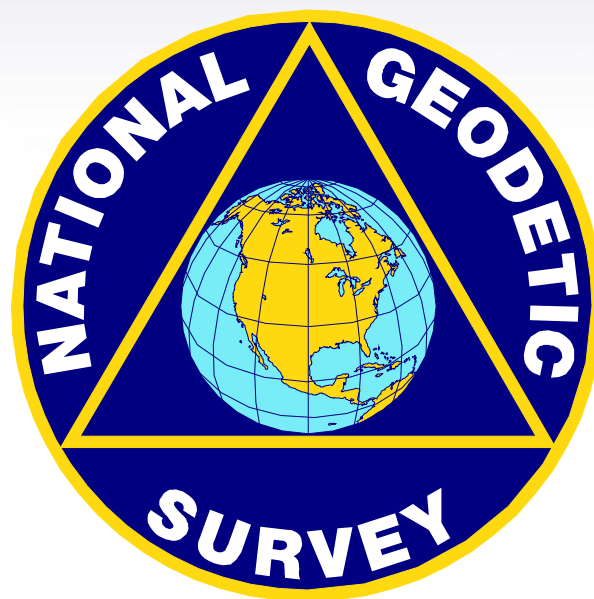
Assuming funding allows the planned schedule, a new gravity geopotential-based vertical datum to replace NAVD 88 could be defined and nationally adopted by 2022 (since this is highly dependent on funding availability, the reader should consider this date somewhat tentative). This datum will reference a purely gravimetric geoid model, rather than a hybrid geoid model like GEOID09 and its precursors (this difference is discussed later). Like NAVD 88, the heights will be orthometric heights but, unlike NAVD 88, leveling data and other data on passive marks (such as gravity observations) will not be the primary observational data set used to define the datum. In fact, the role of leveling in defining the new datum has not yet been fully determined (Smith, 2011). The relationship between orthometric height, ellipsoid height, and geoid height is shown in Figure 5.

Strictly speaking, the reader should note that NAVD 88 is not purely an orthometric height system. The primary parameters, determined when NAVD 88 was first defined, were geopotential numbers determined from leveling and the nationwide NAVD 88 surface gravity model (derived from surface gravity measurements). For NAVD 88, a specific approximation to true orthometric heights, known as "Helmert orthometric heights" were computed from the geopotential numbers and the NAVD 88 surface gravity model (dynamic heights were also computed from the geopotential numbers, and required no surface gravity). Although NAVD 88 is based on geopotential numbers which can in turn be used to compute other types of heights (such as dynamic heights), it is common to equate NAVD 88 with orthometric heights, and that typical usage will be followed for the remainder of this paper.

>> By David H. Minkel and Michael L. Dennis



# GOOD COORDINATION BEGINS WITH GOOD COORDINATES



GEOGRAPHY WITHOUT GEODESY IS A FELONY