Journey to the Moving Center of the Earth

The Evolution of the National Spatial Reference System

CTDOT

July 30, 2018

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Session description and objectives

- In 2022, the National Geodetic Survey will be replacing the U.S. horizontal and vertical datums (NAD 83 and NAVD 88). We will discuss the history of these datums, their relationship to other reference frames, the reasons for the change, and how it affects surveyors and their access to these datums.
- Objective…gain a fundamental understanding of:
  - How and why our datums/reference frames have changed over time
  - The need to further modernize the US reference frames
  - How NGS will define new reference frames
  - How users will access the new reference frames

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

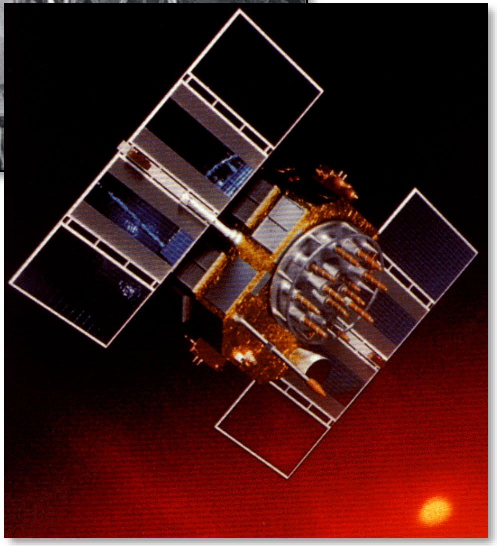
3 D (Latitude, Longitude and Ellipsoid Height)
Fixed and Stable - Coordinates seldom change
(e.g. NAD 83 (1996), NAD 83 (2007), NAD 83 (CORS96) NAD 83 (2011))

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 CT?

- NAD 27
- 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)
- WGS 84
  - Which one???
    - WGS 84 (1987)
    - WGS 84 (G730)
    - WGS 84 (G873)
    - WGS 84 (G1150)
    - WGS 84 (G1674)
    - WGS 84 (G1762)
- 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

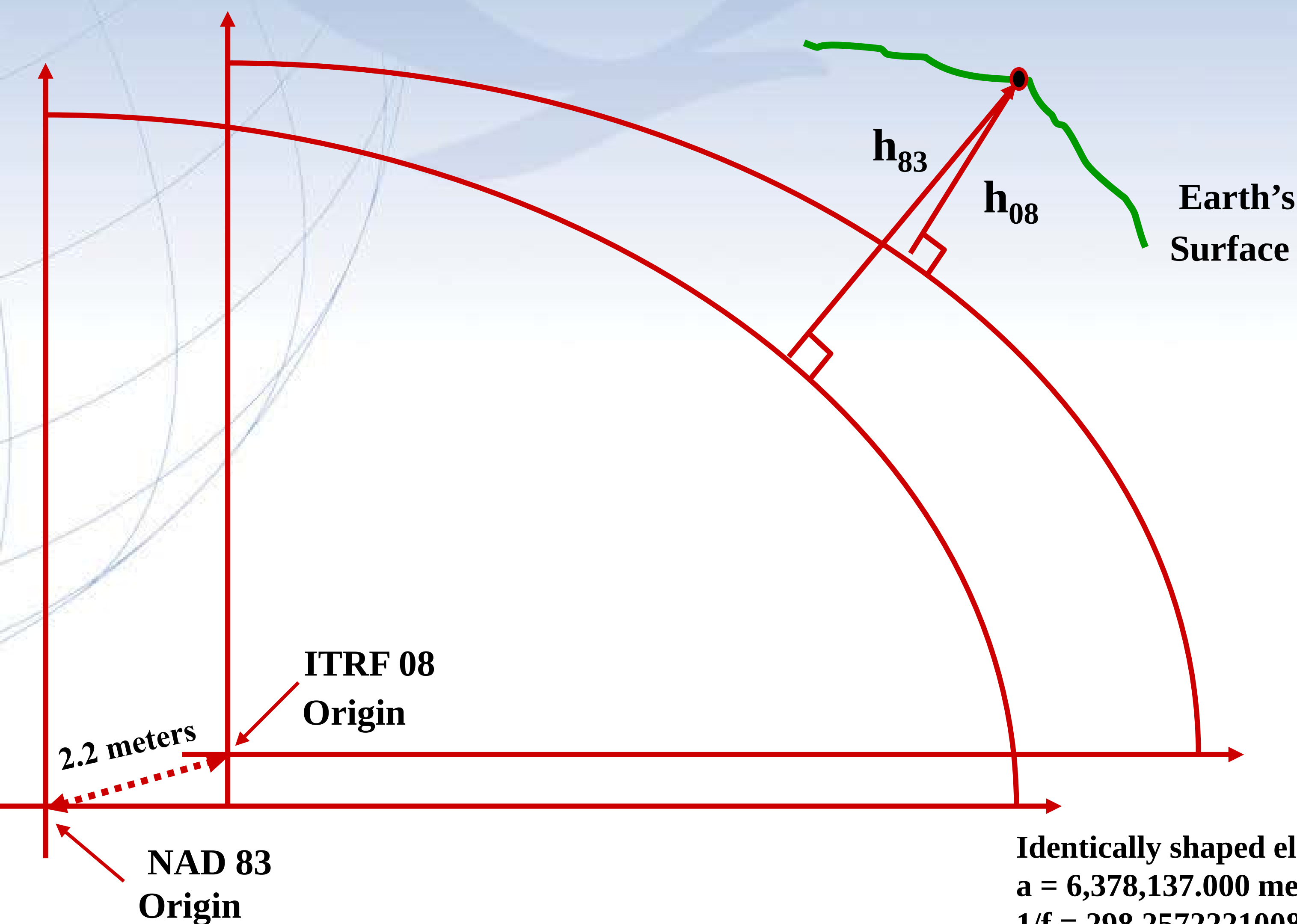
ITRS is realized by the International Terrestrial Reference Frame (**ITRF**) based upon estimated coordinates and velocities of a set of stations observed by Very Long Baseline Interferometry (**VLBI**), Satellite Laser Ranging (**SLR**), Global Positioning System and GLONASS (**GNSS**), and Doppler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



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

Densification

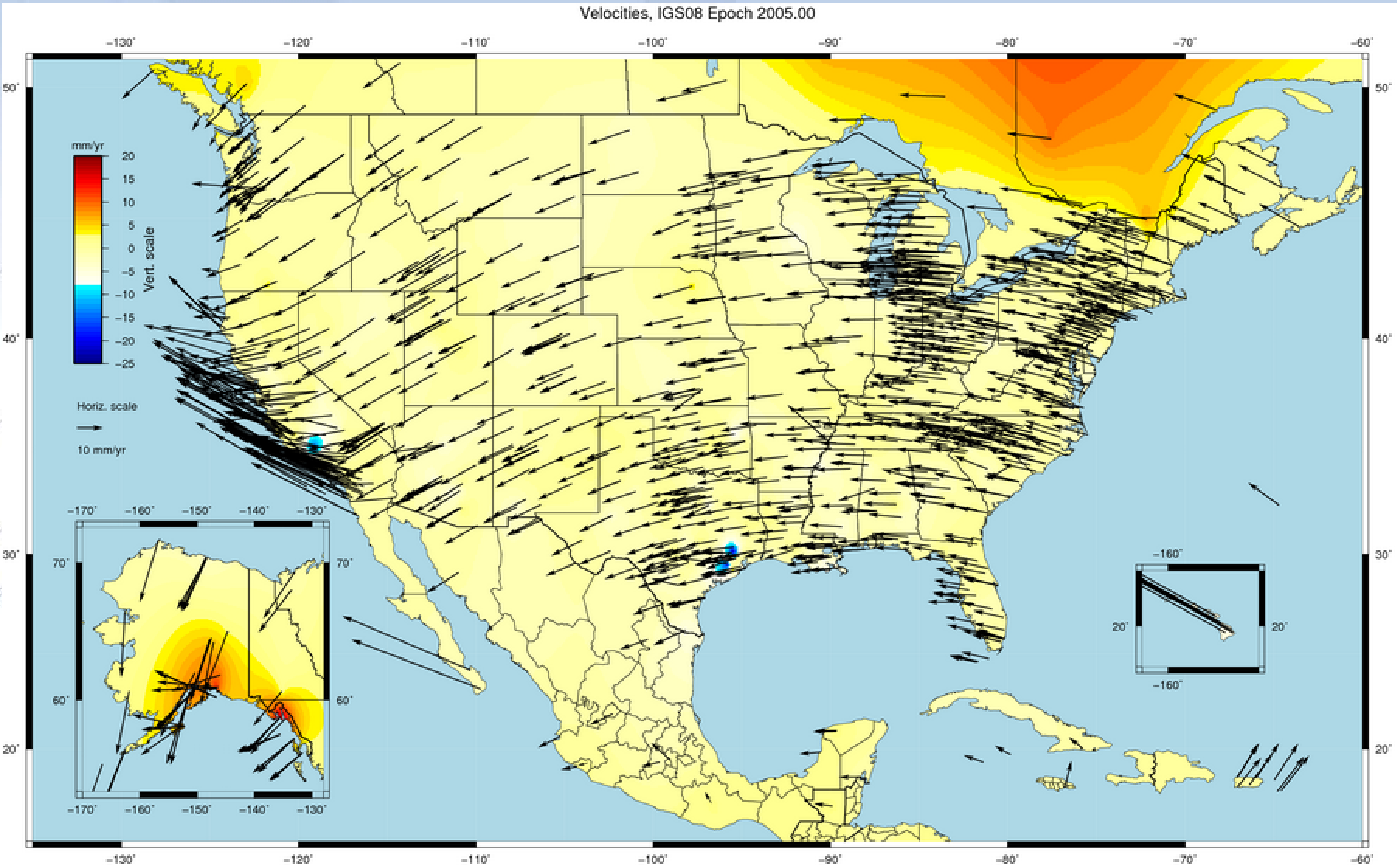
The ITRF2008 is expressed through the coordinates and velocities of marks on the ground plus ancillary data.

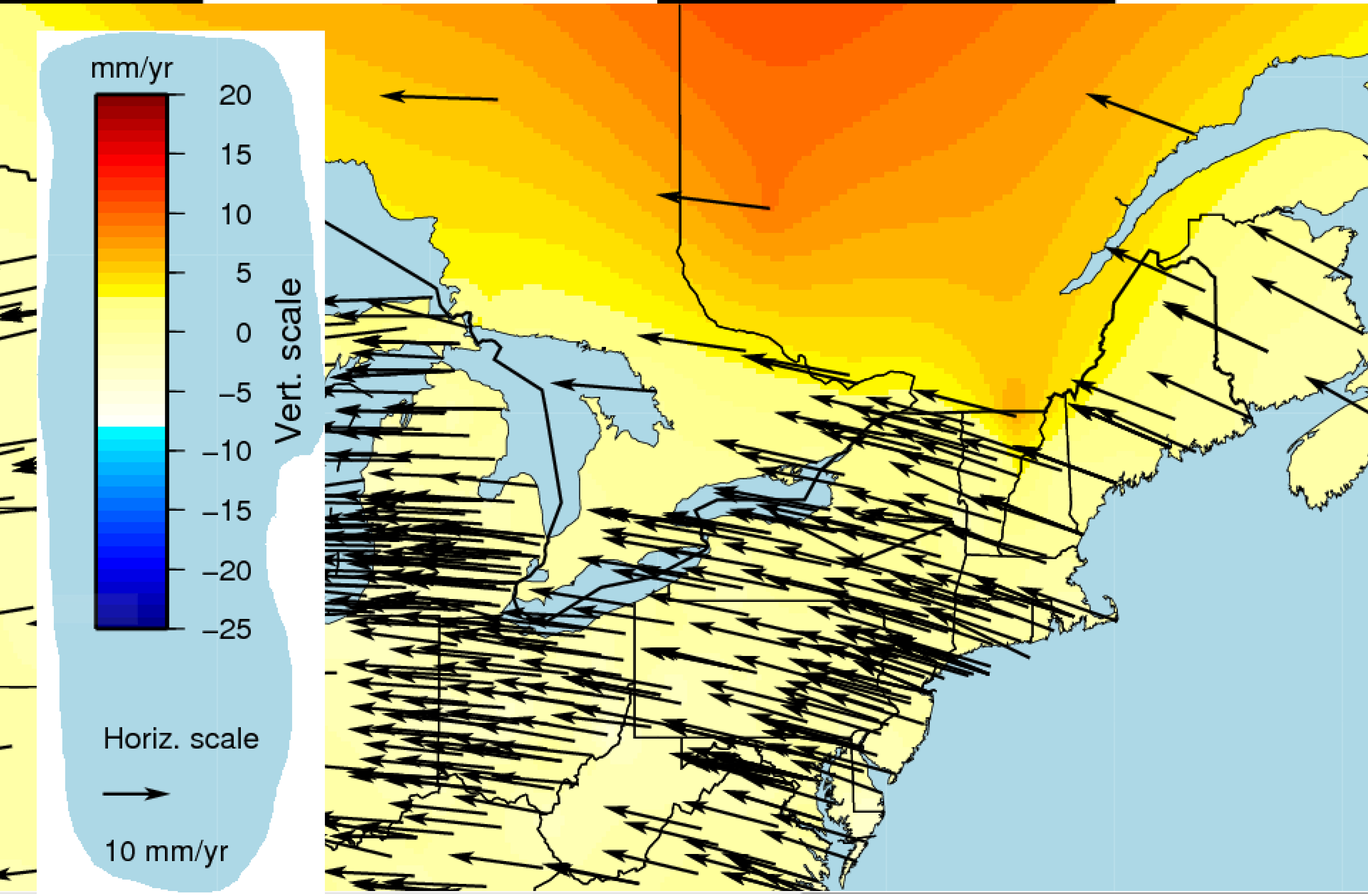
Other organizations can take that information, add additional marks, perform their own adjustment and align their results to the ITRF2008 (A.K.A. densifying).

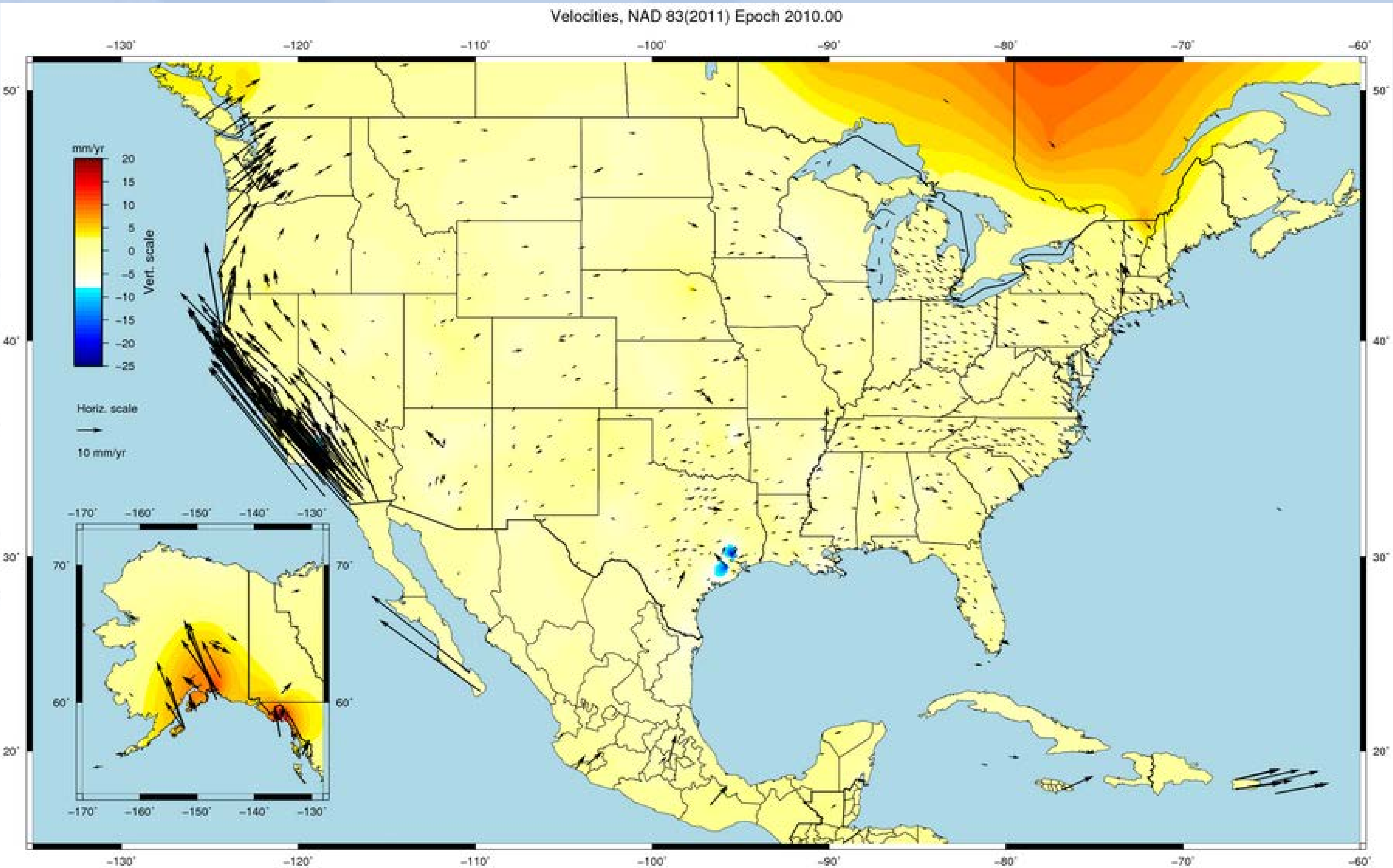
The variants try to be as consistent with the ITRF2008 as possible, but in the most formal sense, they are unique from the ITRF2008. Therefore, they are given unique names.

The IGS08

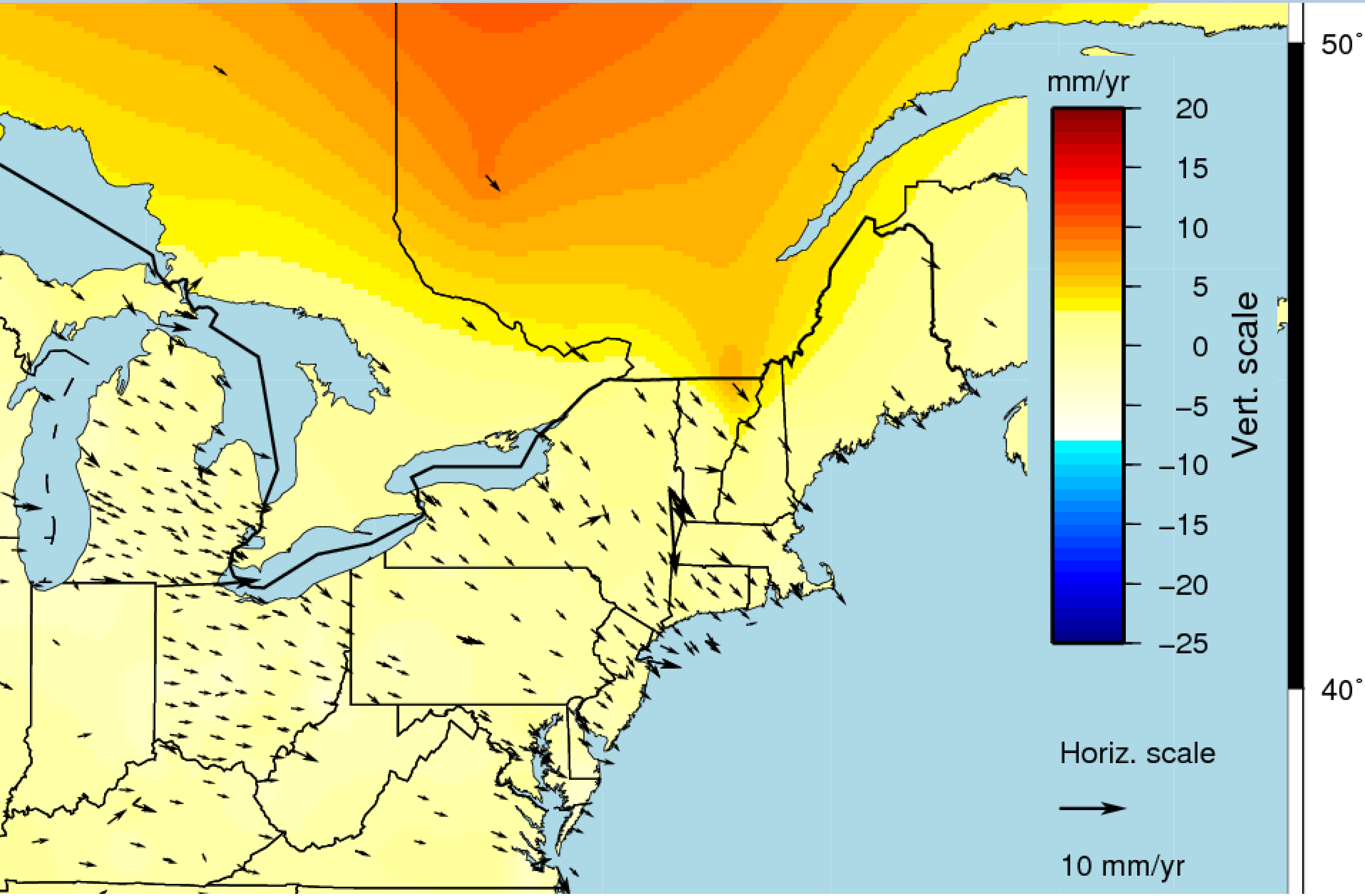
The IGS has densified reference frame with much larger, global subset of GNSS tracking sites thereby creating a GNSS-only expression of the ITRF2008 called the IGS08. All IGS products have been recreated so as to be consistent with the IGS08 including GNSS ephemerides and antenna models. Information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


Velocities, IGS08 Epoch 2005.00
mm/yr
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
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

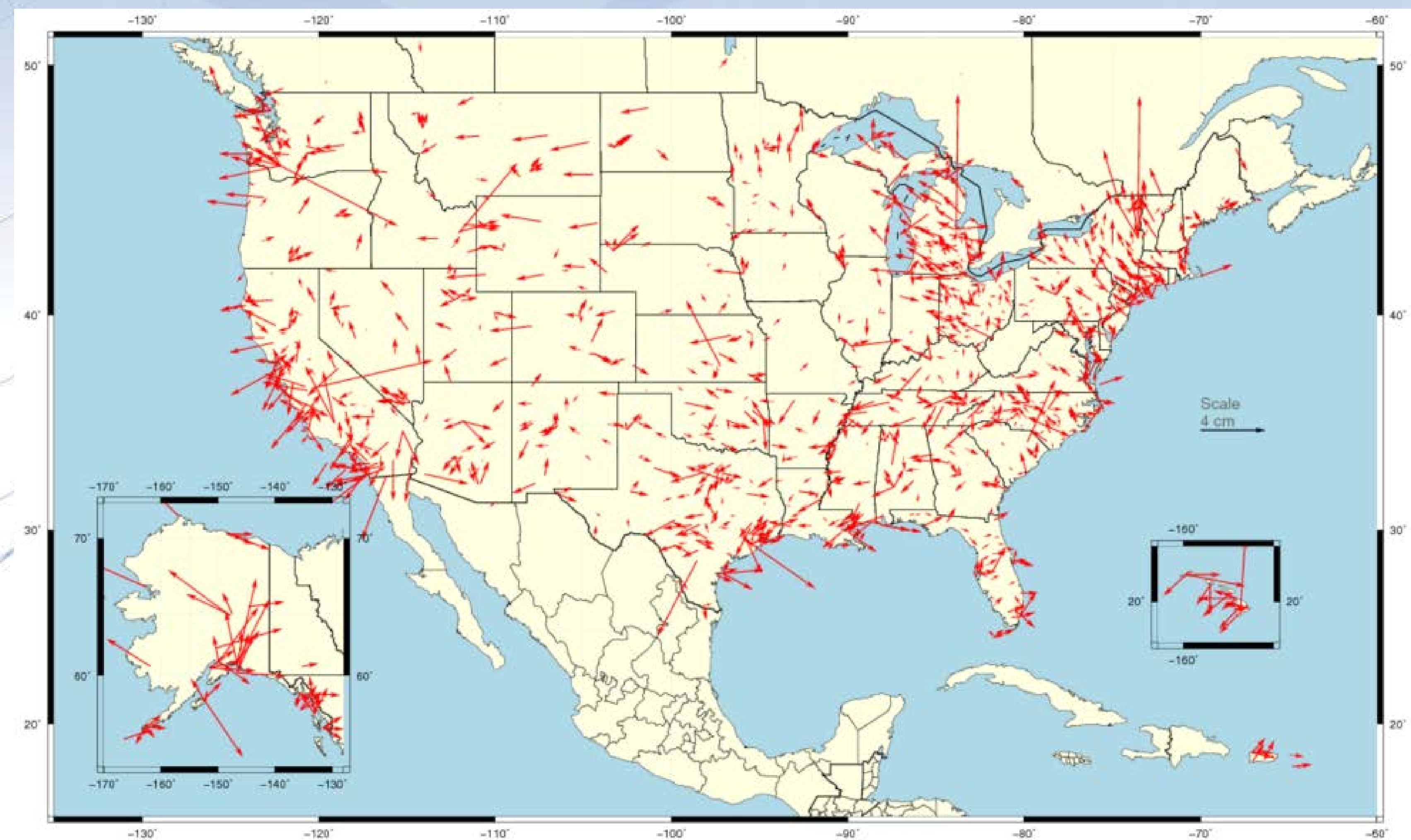
Multi-Year CORS Solution (MYCS)

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.

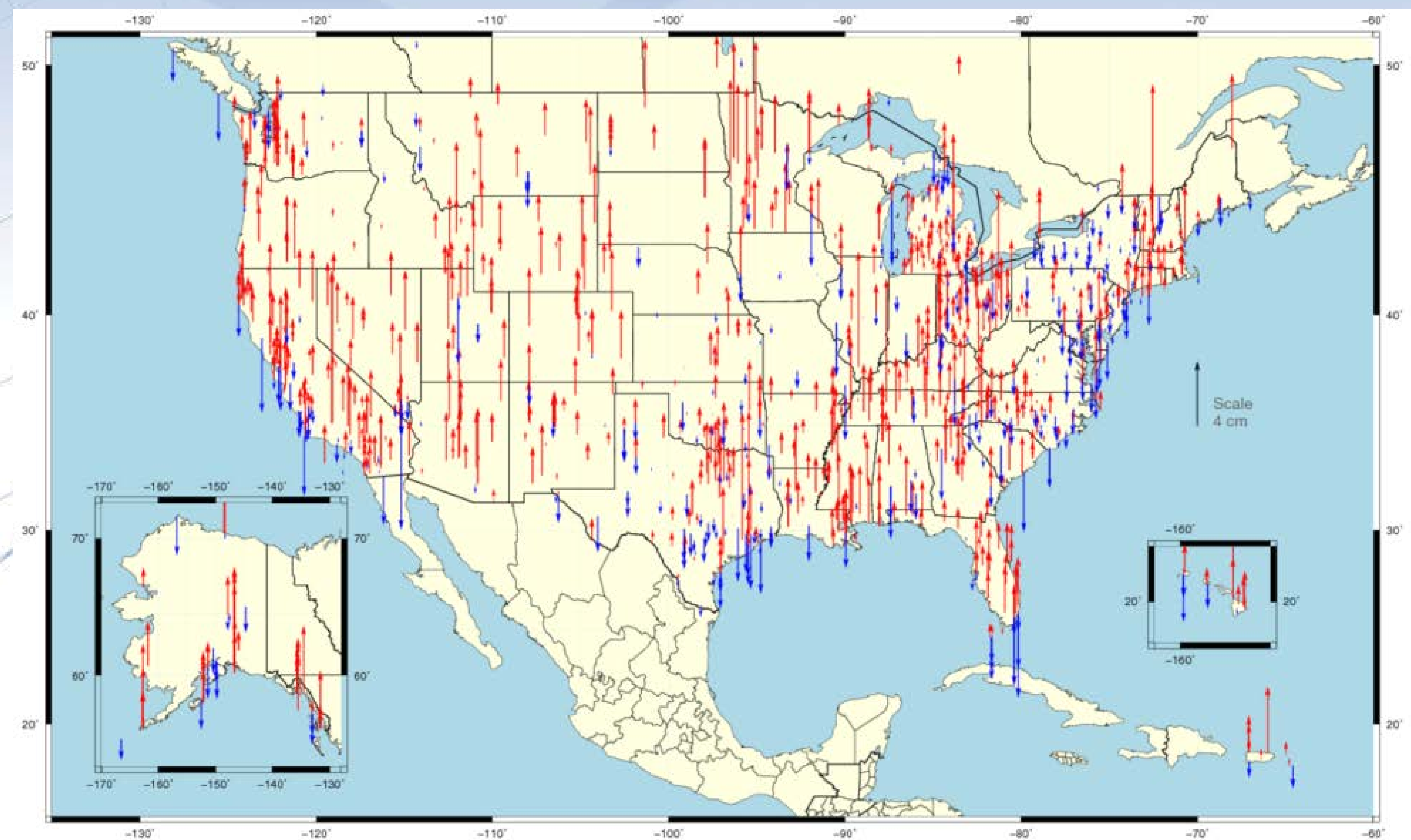
In September 2011, NGS formally released IGS08 and NAD 83 (2011) coordinates and velocities for the CORS. Information about the IGS08 and NAD 83 (2011) can be found at geodesy.noaa.gov/CORS/coords.shtml.

Horizontal Differences In CORS Positions



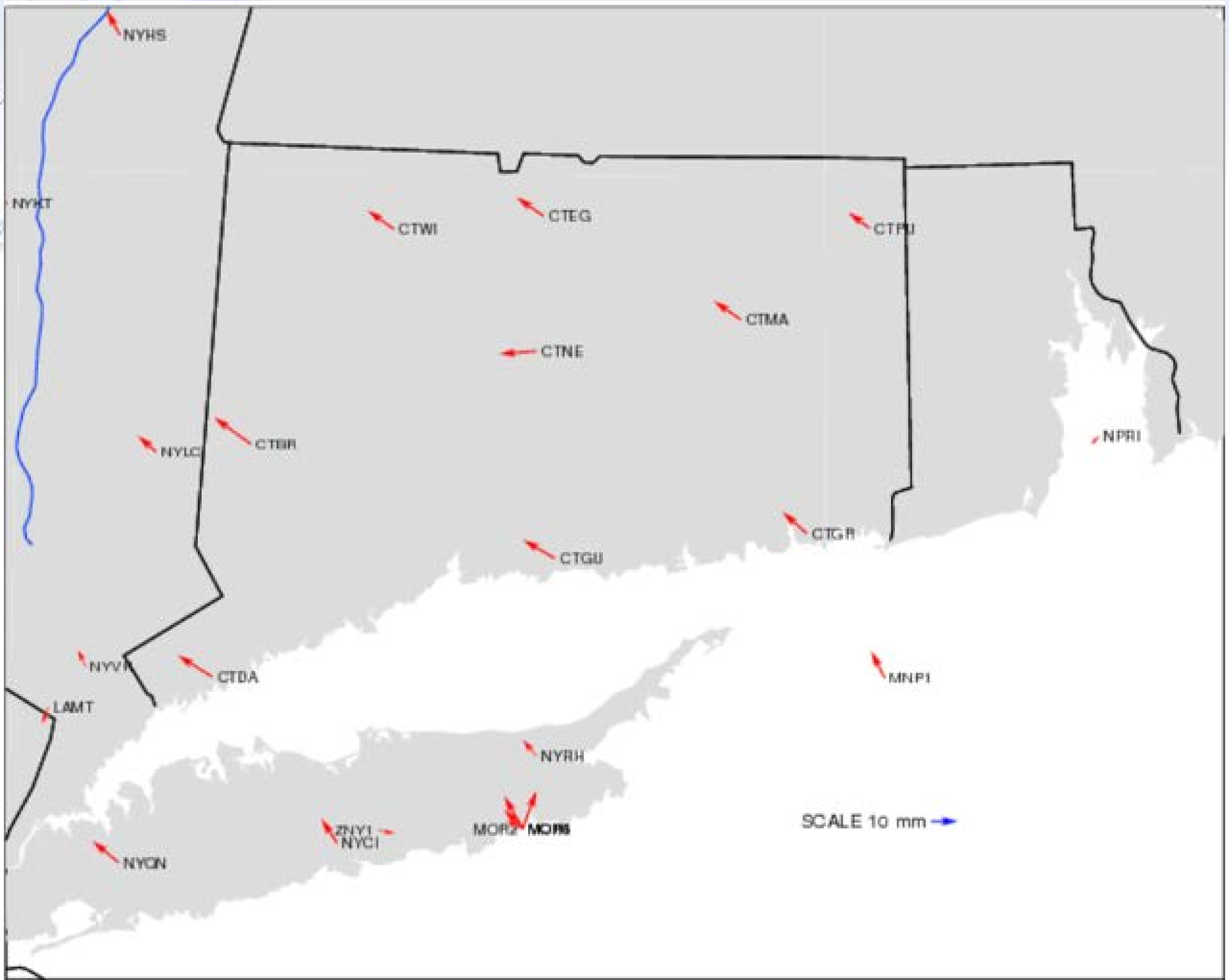
Horizontal difference in positions of NAD 83(2011) epoch 2002.00 minus NAD 83(CORS96) epoch 2002.00.

Vertical Differences In CORS Positions

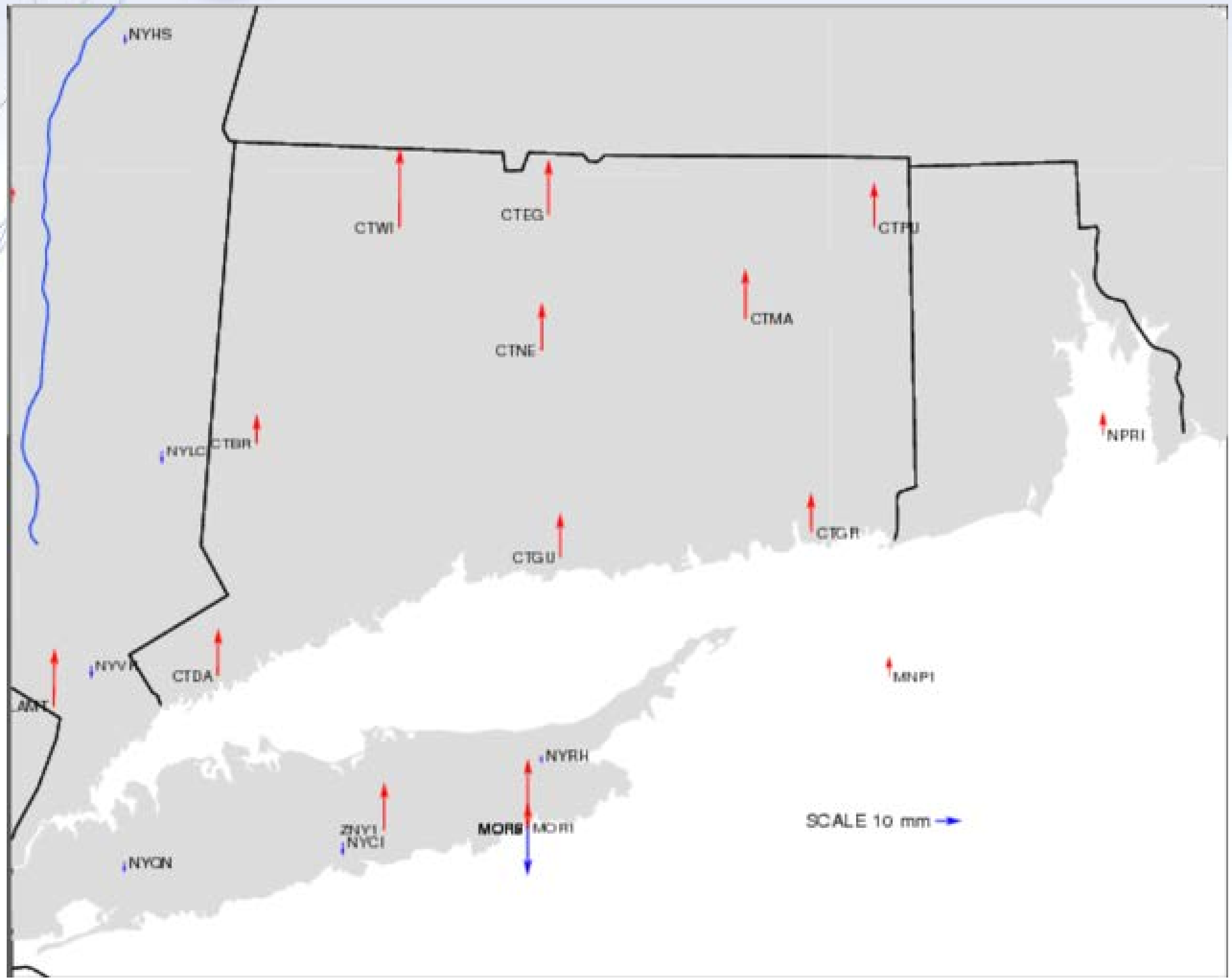


Vertical difference in positions of NAD 83(2011) epoch 2002.00 minus NAD 83(CORS96) epoch 2002.00.

Horizontal NAD 83(2011) epoch 2002.00 minus NAD 83(CORS96) epoch 2002.00



Vertical
NAD 83(2011) epoch 2002.00 minus NAD 83(CORS96) epoch 2002.00

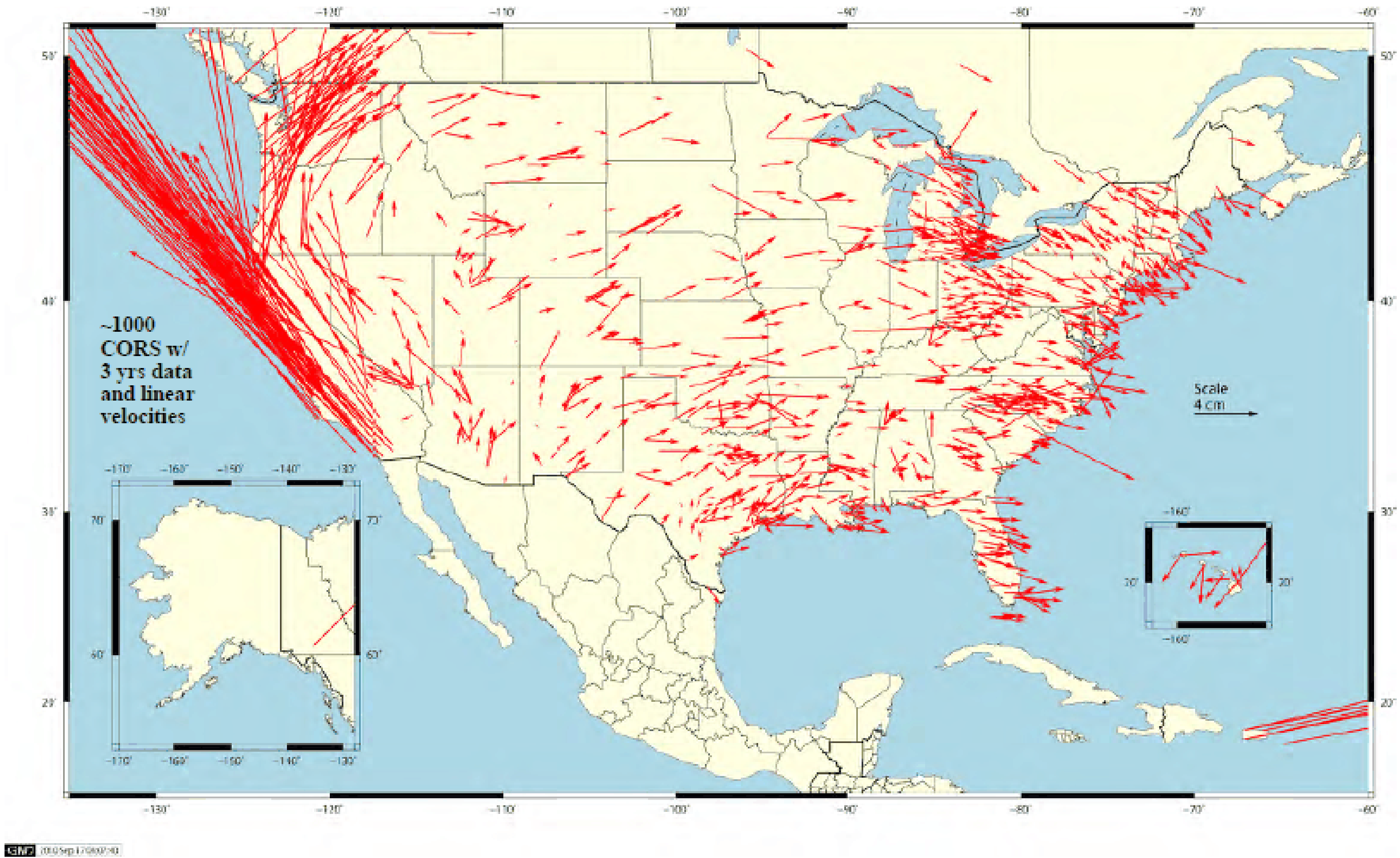


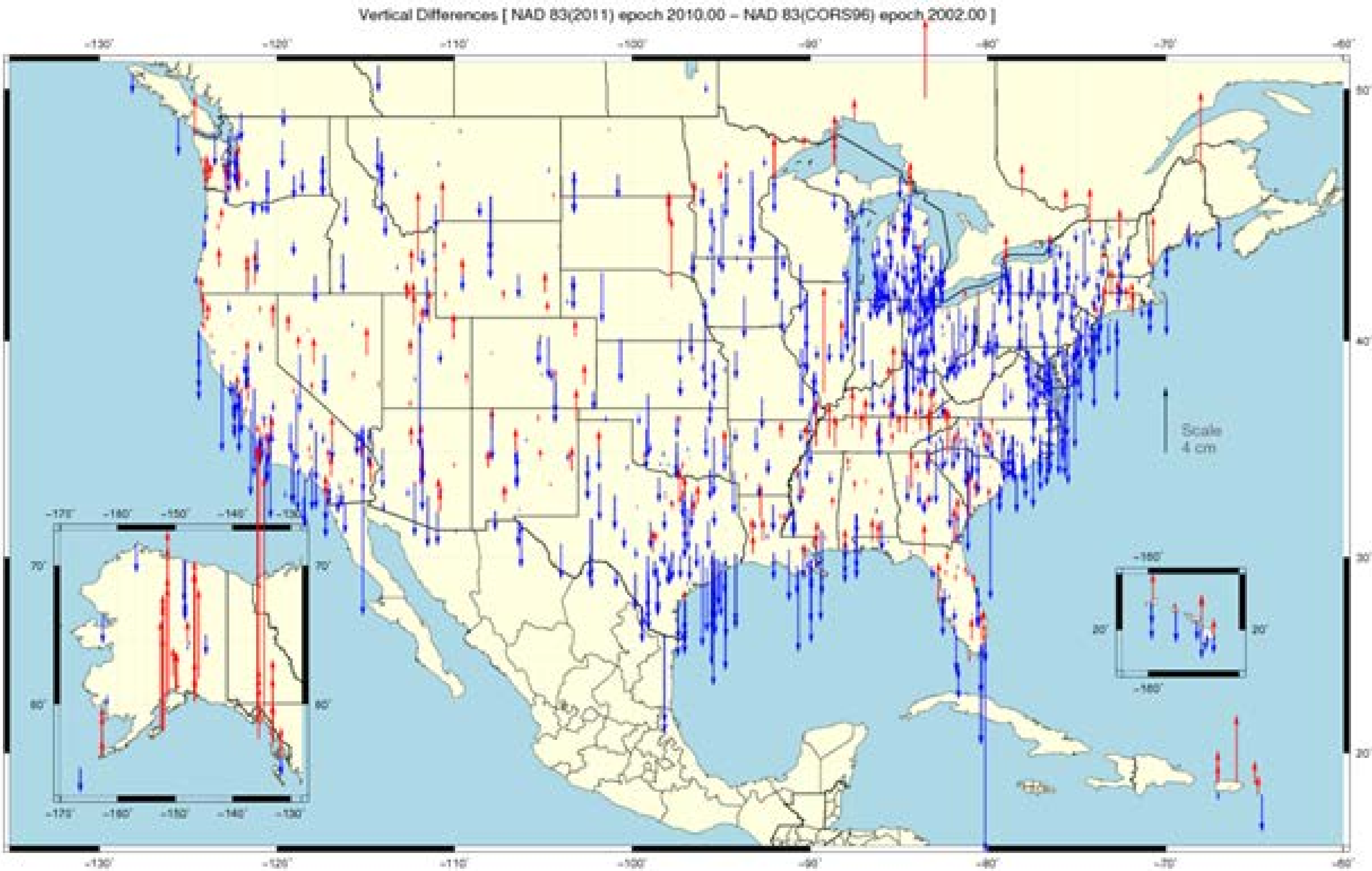
Change in horizontal NAD 83 CORS coordinates

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

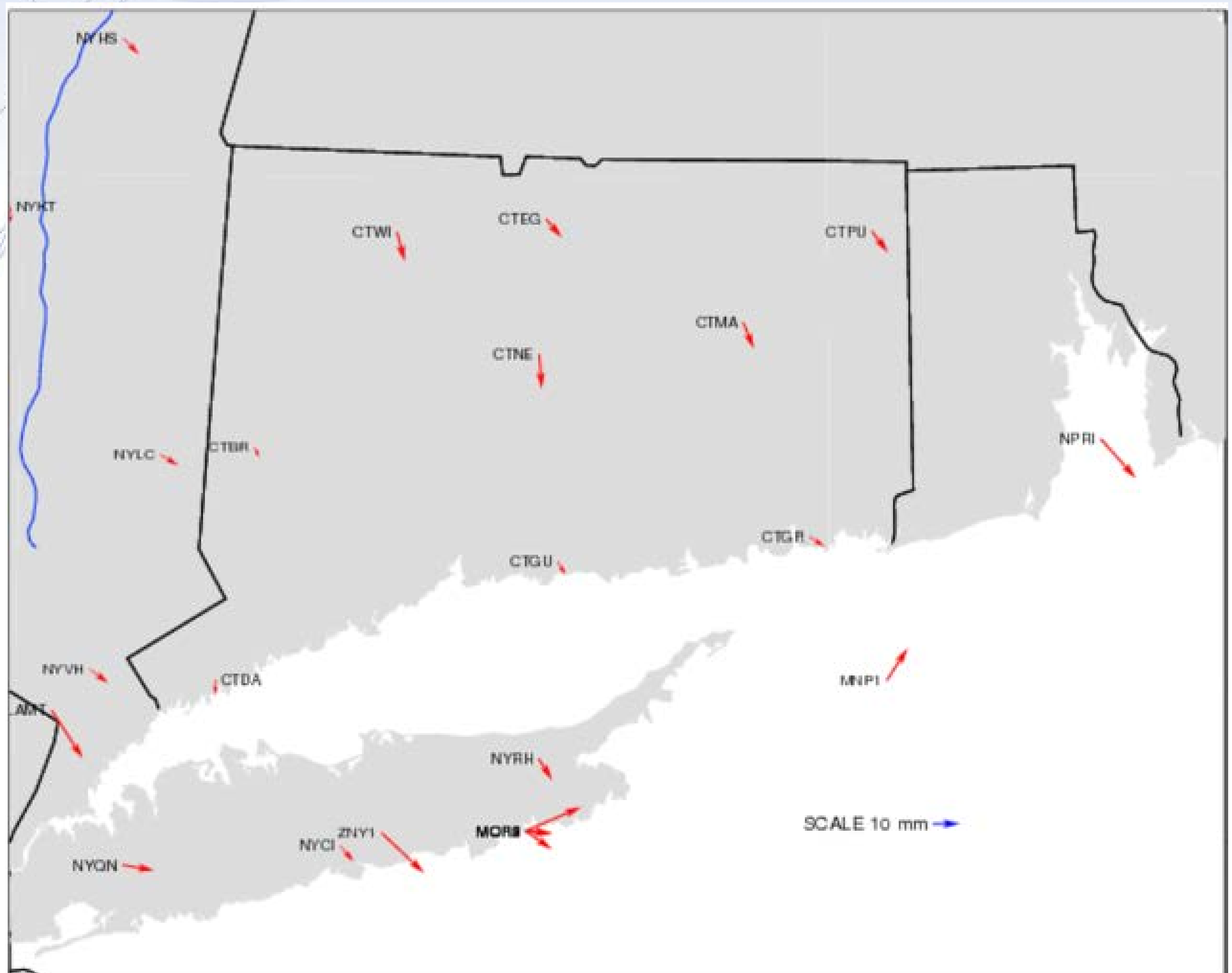
Avg shifts (cm): ΔN = 2.0 (±6.4); ΔE = 0.2 (±5.9); ΔU = -0.9 (±2.0)

- 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)

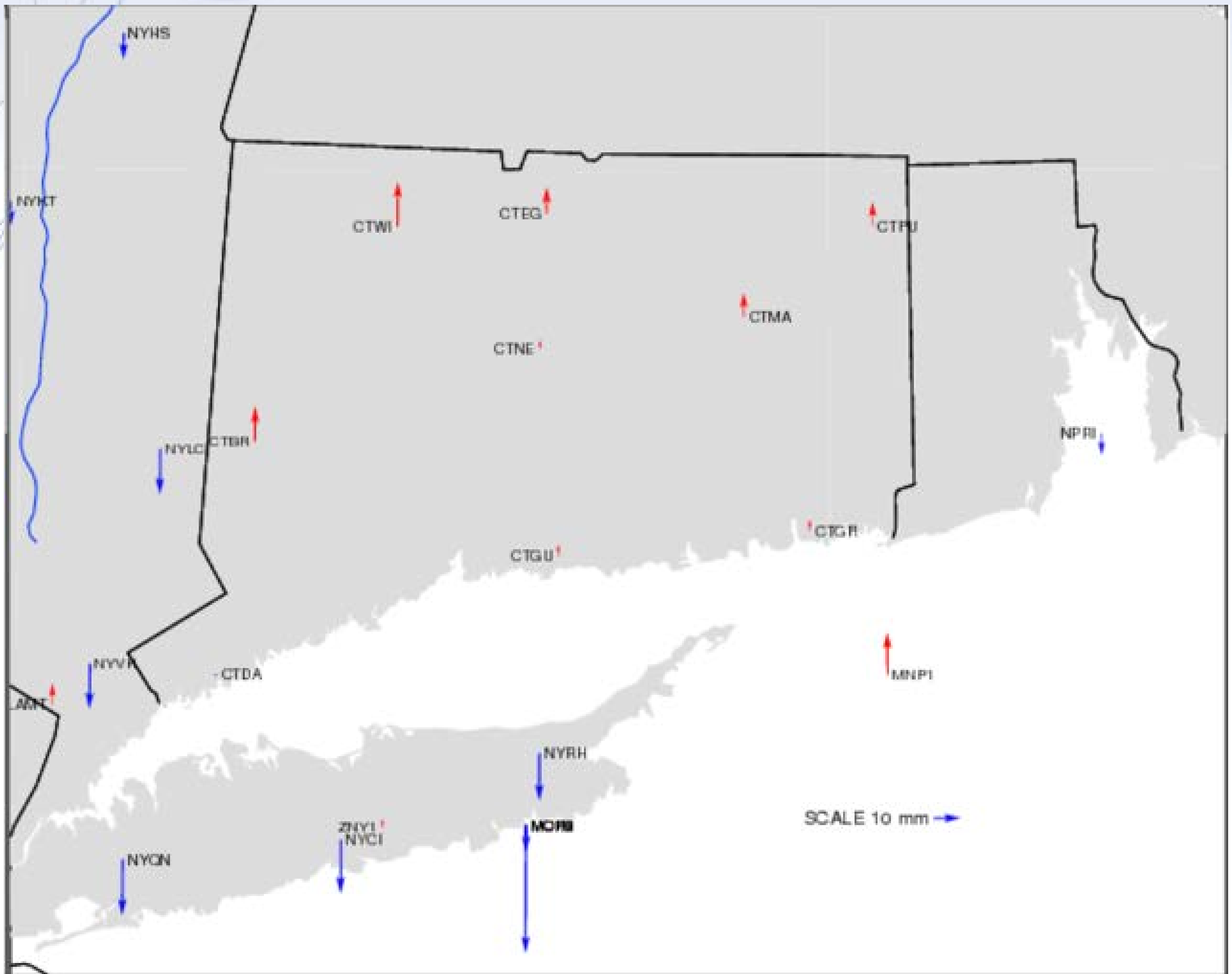



Vertical Differences [NAD 83(2011) epoch 2010.00 – NAD 83(CORS96) epoch 2002.00]
Scale
4 cm

Horizontal
NAD 83(2011) epoch 2010.00 minus NAD 83(CORS96) epoch 2002.00



Vertical
NAD 83(2011) epoch 2010.00 minus NAD 83(CORS96) epoch 2002.00



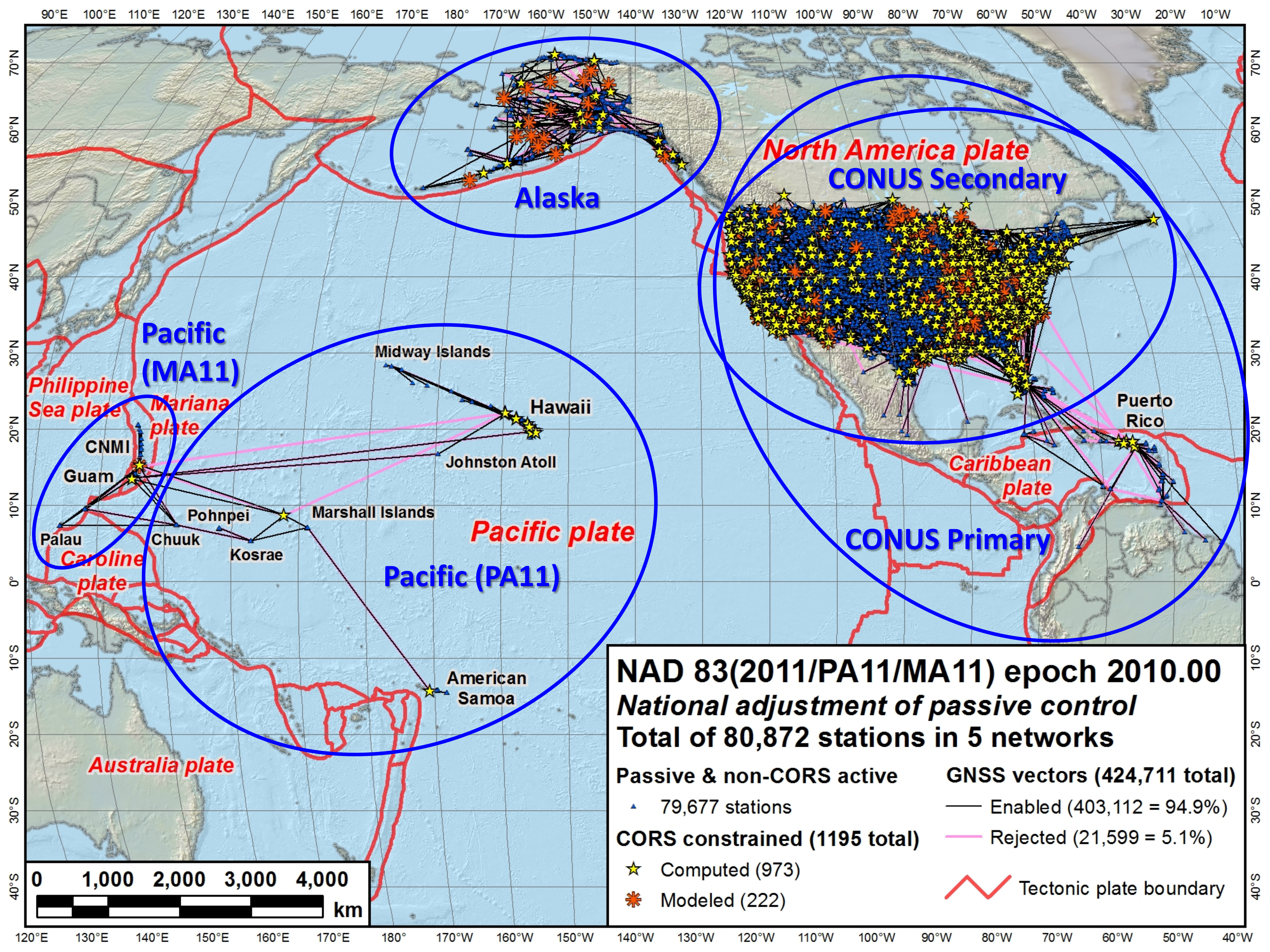
Introducing…

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?

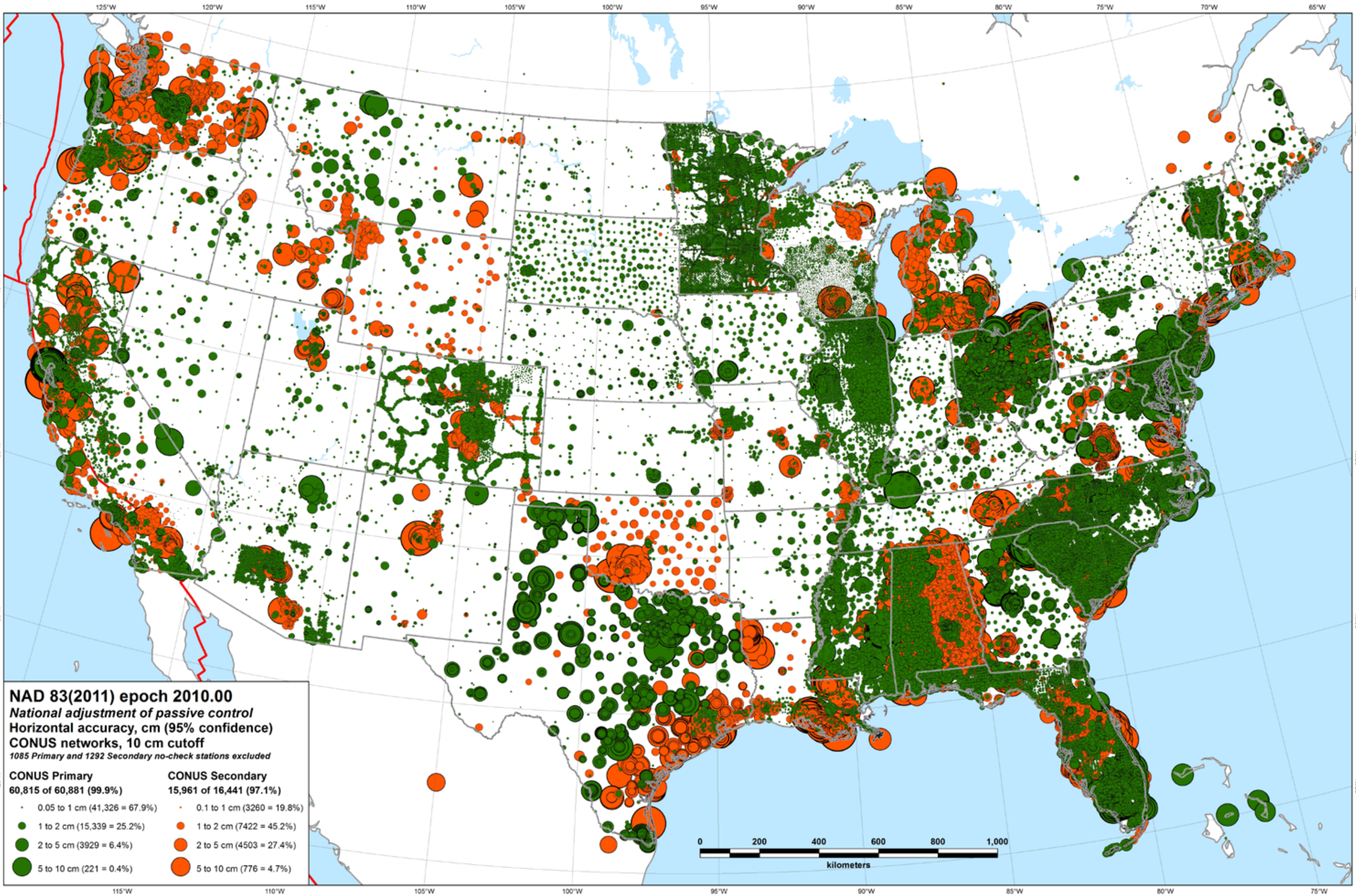
- Multi-Year CORS Solution
  - Previous NAD 83 CORS realization needed many improvements
  - Consistent coordinates *and* velocities from global solution
  - Aligned with most recent realization of global frame (IGS 08)
  - Major processing, modeling, and metadata improvements
    - Including new ***absolute 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**

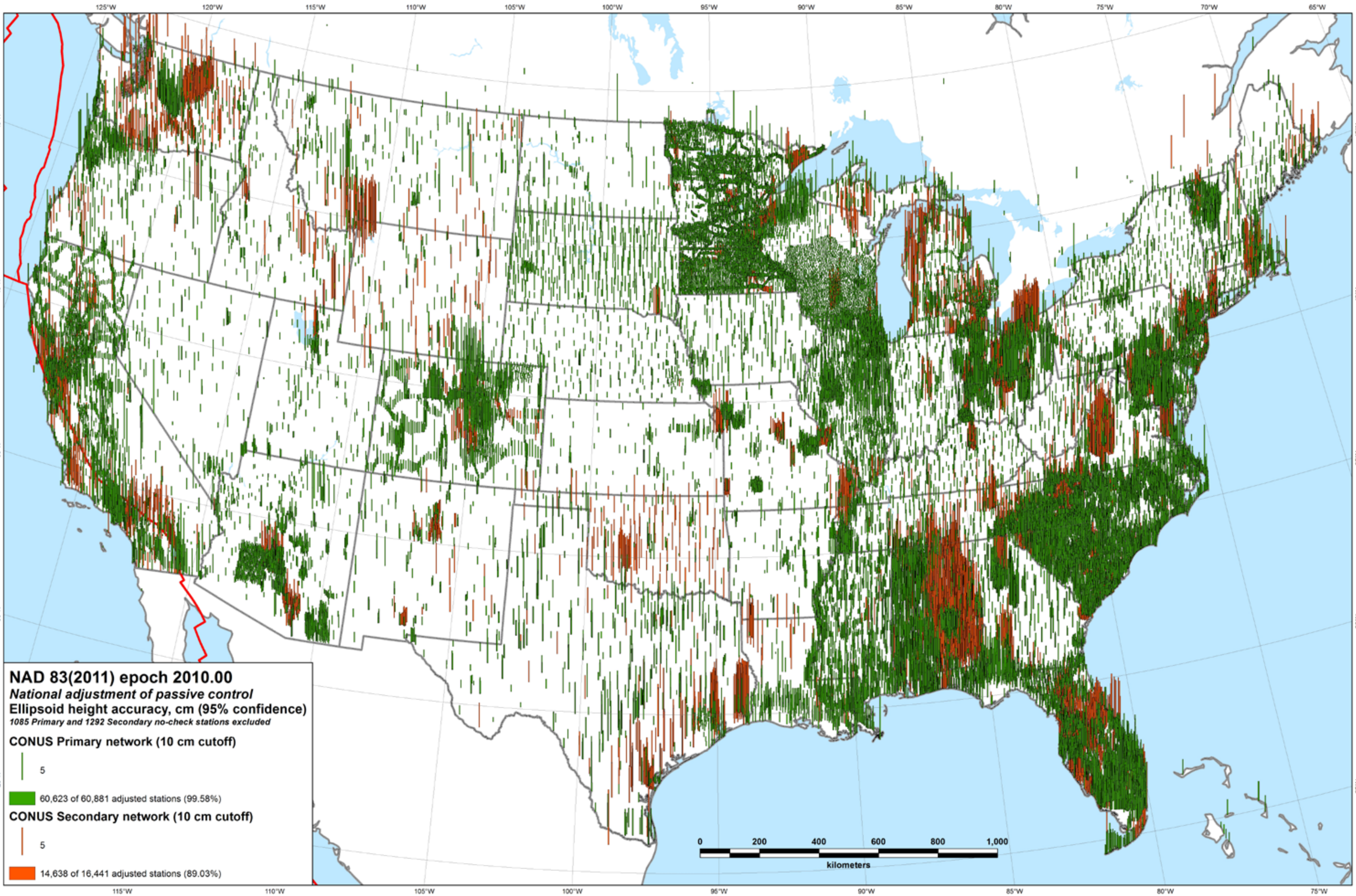


Alaska
North America plate
CONUS Secondary
CONUS Primary
Pacific (MA11)
Philippine Sea plate
Mariana plate
CNMI
Guam
Palau
Chuuk
Pohnpei
Kosrae
Caroline plate
Midway Islands
Hawaii
Johnston Atoll
Marshall Islands
Pacific plate
Pacific (PA11)
American Samoa
Puerto Rico
Caribbean plate
Australia plate
0 1,000 2,000 3,000 4,000 km
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***

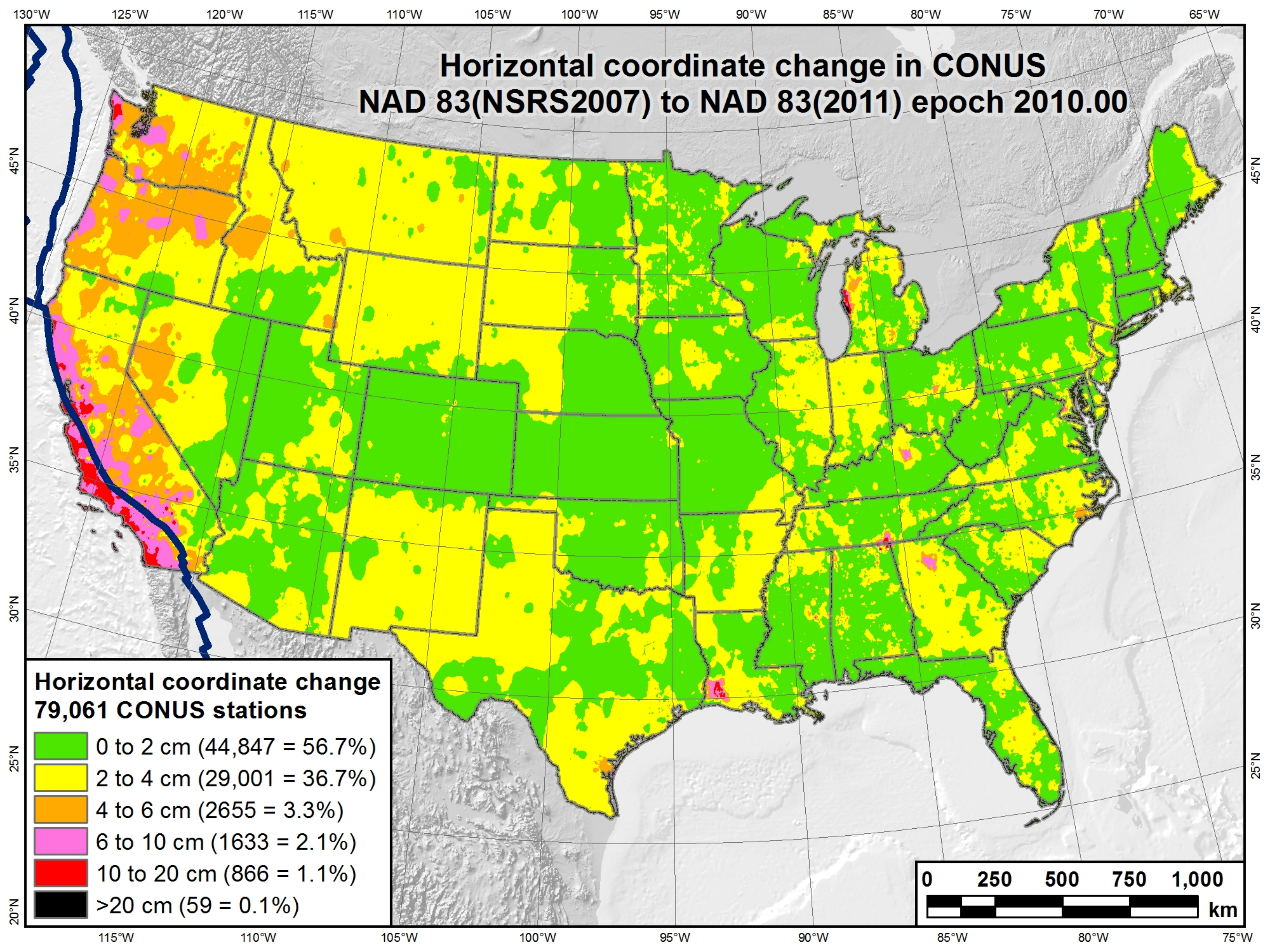
- Station network accuracies (95% confidence)
  - Overall median: ***0.9 cm horiz***, ***1.5 cm height*** (78,709)
    - ***90% < 2.3 cm horizontal and 4.8 cm ellipsoid height***
    - Does ***NOT*** include 2163 no-check stations
  - Median accuracies by network
    - CONUS Primary: ***0.7 cm horiz, 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) 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

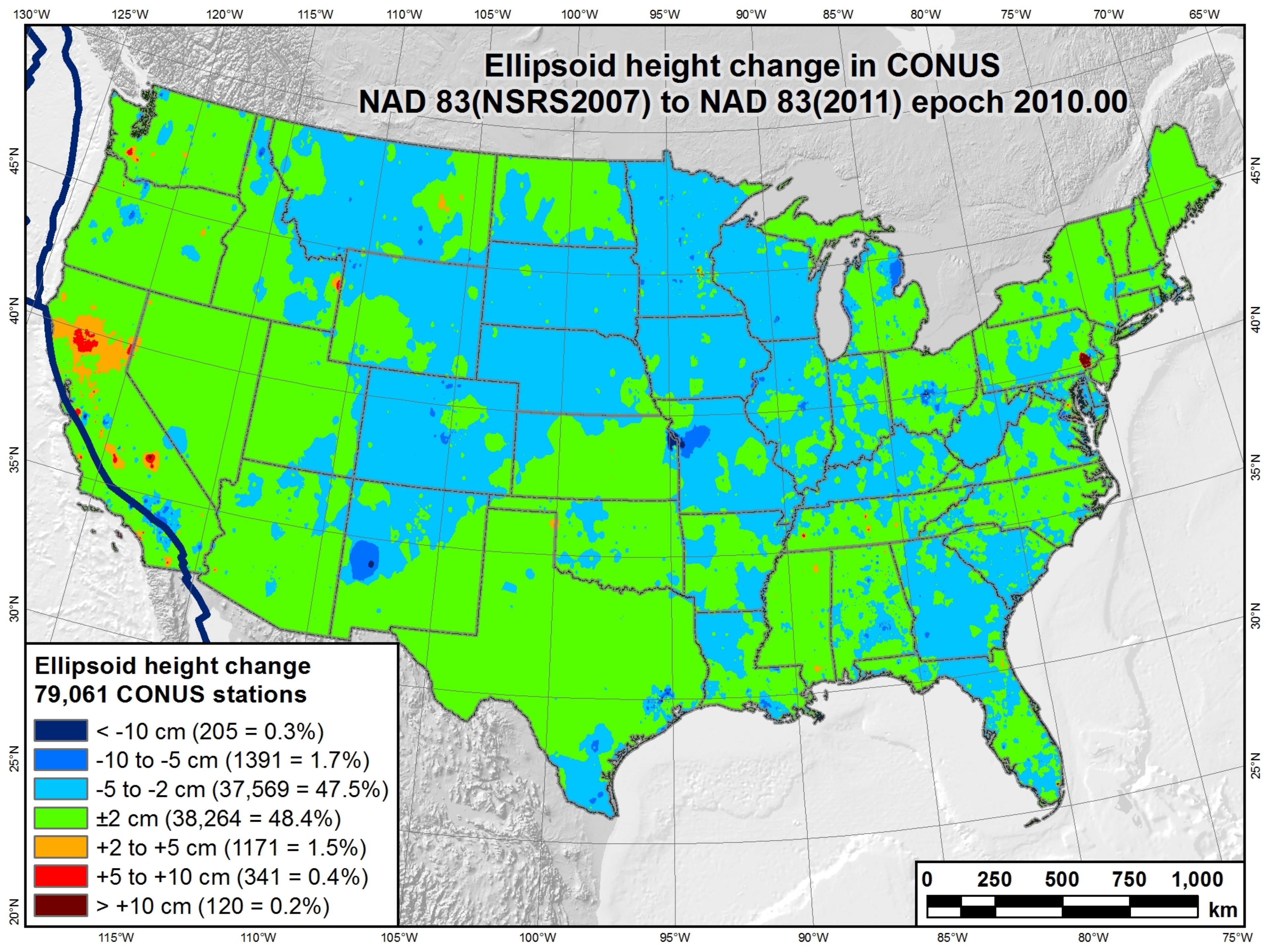

NAD 83(2011) epoch 2010.00
National adjustment of passive control
Ellipsoid height accuracy, cm (95% confidence)
1085 Primary and 1292 Secondary no-check stations excluded
CONUS Primary network (10 cm cutoff)
5
60,623 of 60,881 adjusted stations (99.58%)
CONUS Secondary network (10 cm cutoff)
5
14,638 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***



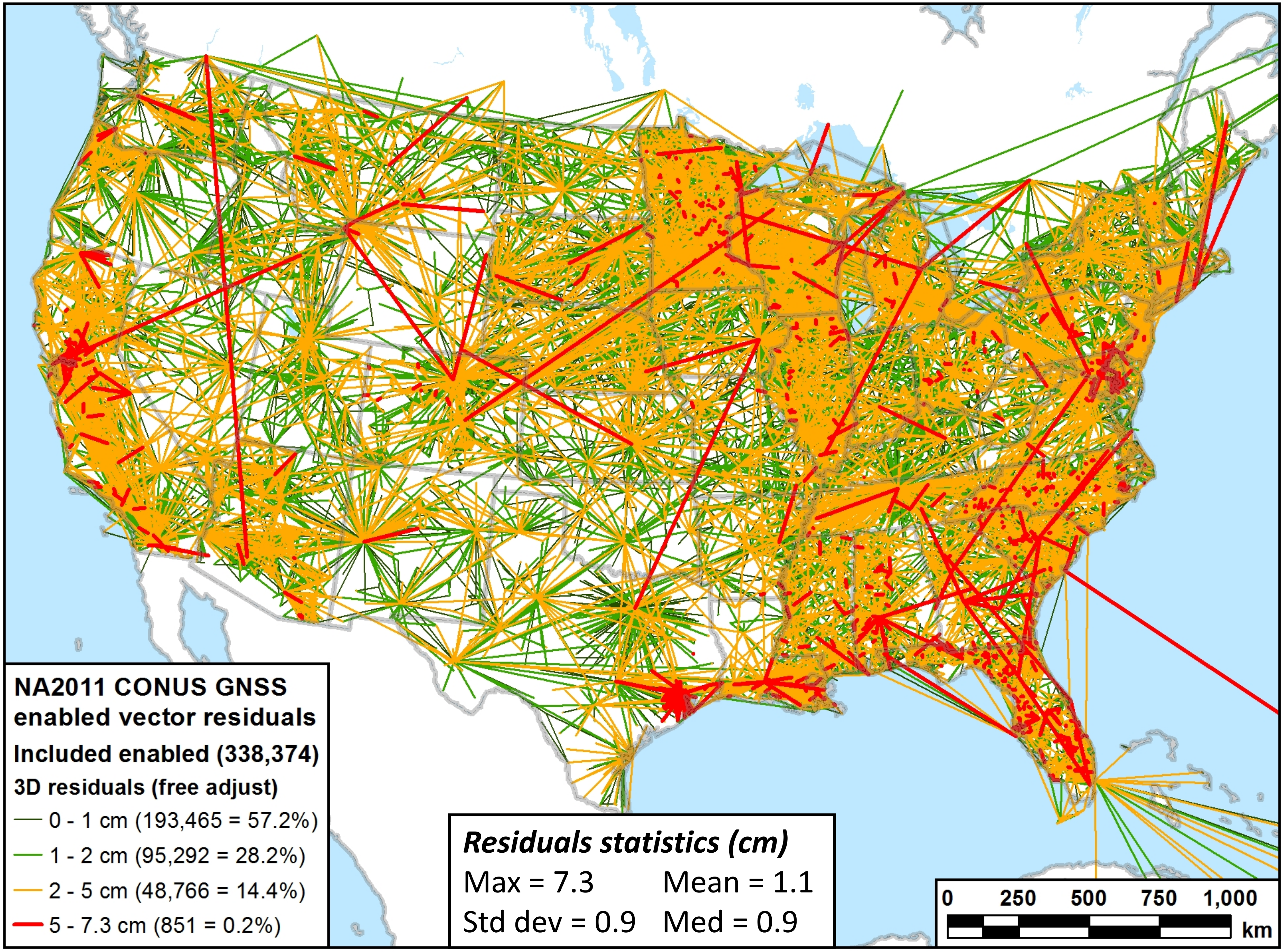
Horizontal coordinate change in CONUS
NAD 83(NSRS2007) to NAD 83(2011) epoch 2010.00
Horizontal coordinate change
79,061 CONUS stations
0 to 2 cm (44,847 = 56.7%)
2 to 4 cm (29,001 = 36.7%)
4 to 6 cm (2655 = 3.3%)
6 to 10 cm (1633 = 2.1%)
10 to 20 cm (866 = 1.1%)
>20 cm (59 = 0.1%)
0 250 500 750 1,000
km



Ellipsoid height change in CONUS
NAD 83(NSRS2007) to NAD 83(2011) epoch 2010.00
Ellipsoid height change
79,061 CONUS stations
< -10 cm (205 = 0.3%)
-10 to -5 cm (1391 = 1.7%)
-5 to -2 cm (37,569 = 47.5%)
±2 cm (38,264 = 48.4%)
+2 to +5 cm (1171 = 1.5%)
+5 to +10 cm (341 = 0.4%)
> +10 cm (120 = 0.2%)
0 250 500 750 1,000
km
130°W
125°W
120°W
115°W
110°W
105°W
100°W
95°W
90°W
85°W
80°W
75°W
70°W
65°W
45°N
40°N
35°N
30°N
25°N
20°N

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
  - 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

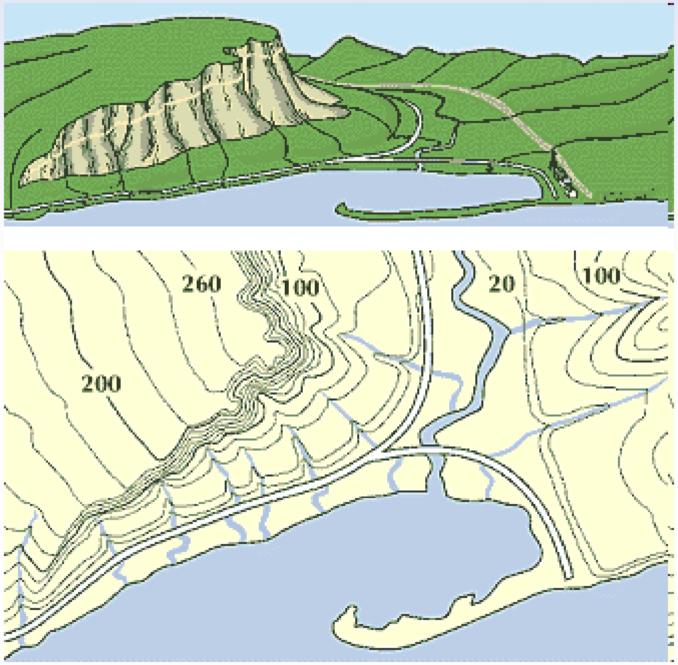

NA2011 CONUS GNSS enabled vector residuals
Included enabled (338,374)
3D residuals (free adjust)
0 - 1 cm (193,465 = 57.2%)
1 - 2 cm (95,292 = 28.2%)
2 - 5 cm (48,766 = 14.4%)
5 - 7.3 cm (851 = 0.2%)
Residuals statistics (cm)
Max = 7.3
Mean = 1.1
Std dev = 0.9
Med = 0.9
0 250 500 750 1,000
km

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.

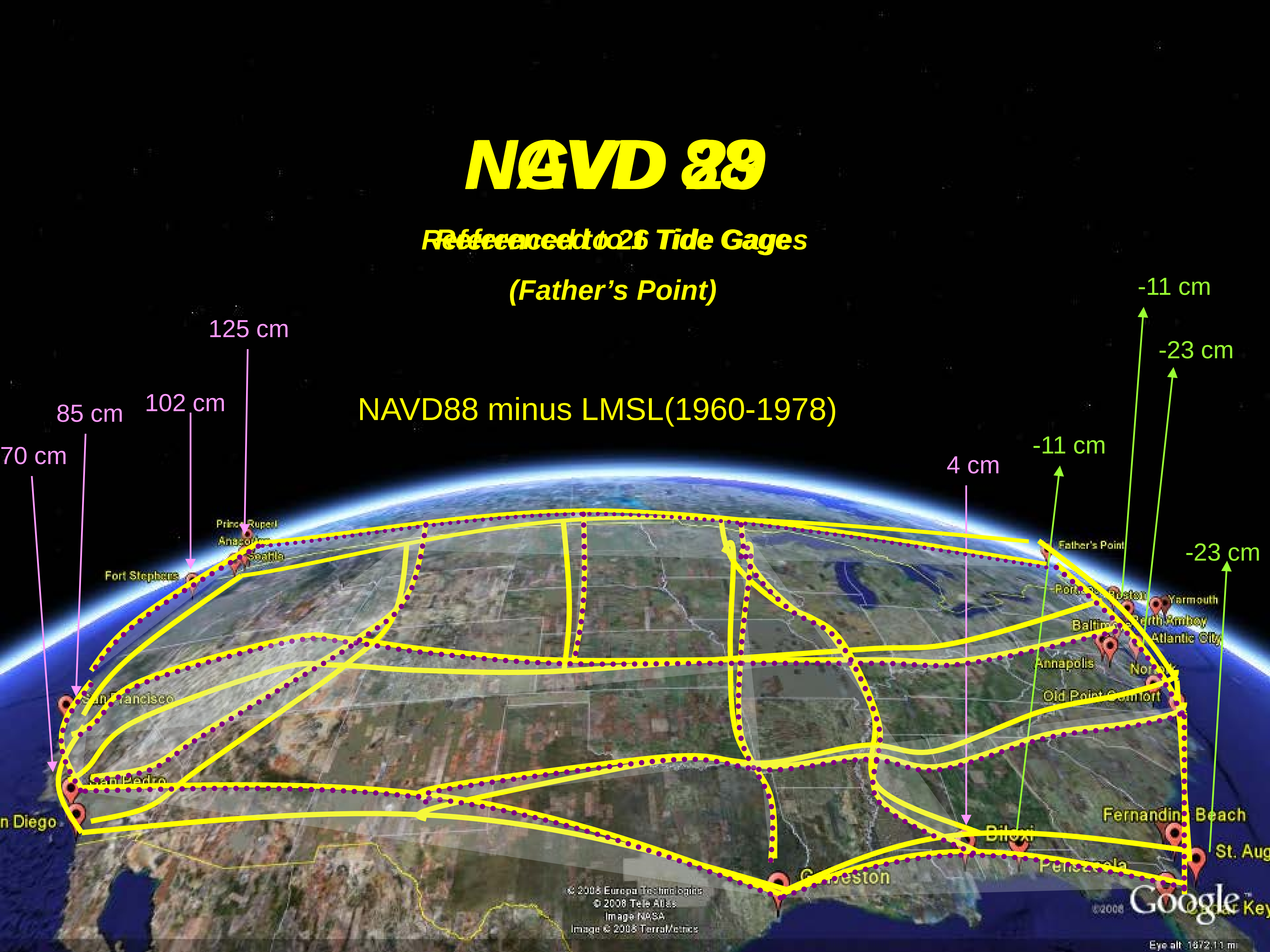
**Not adopted in Canada*

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

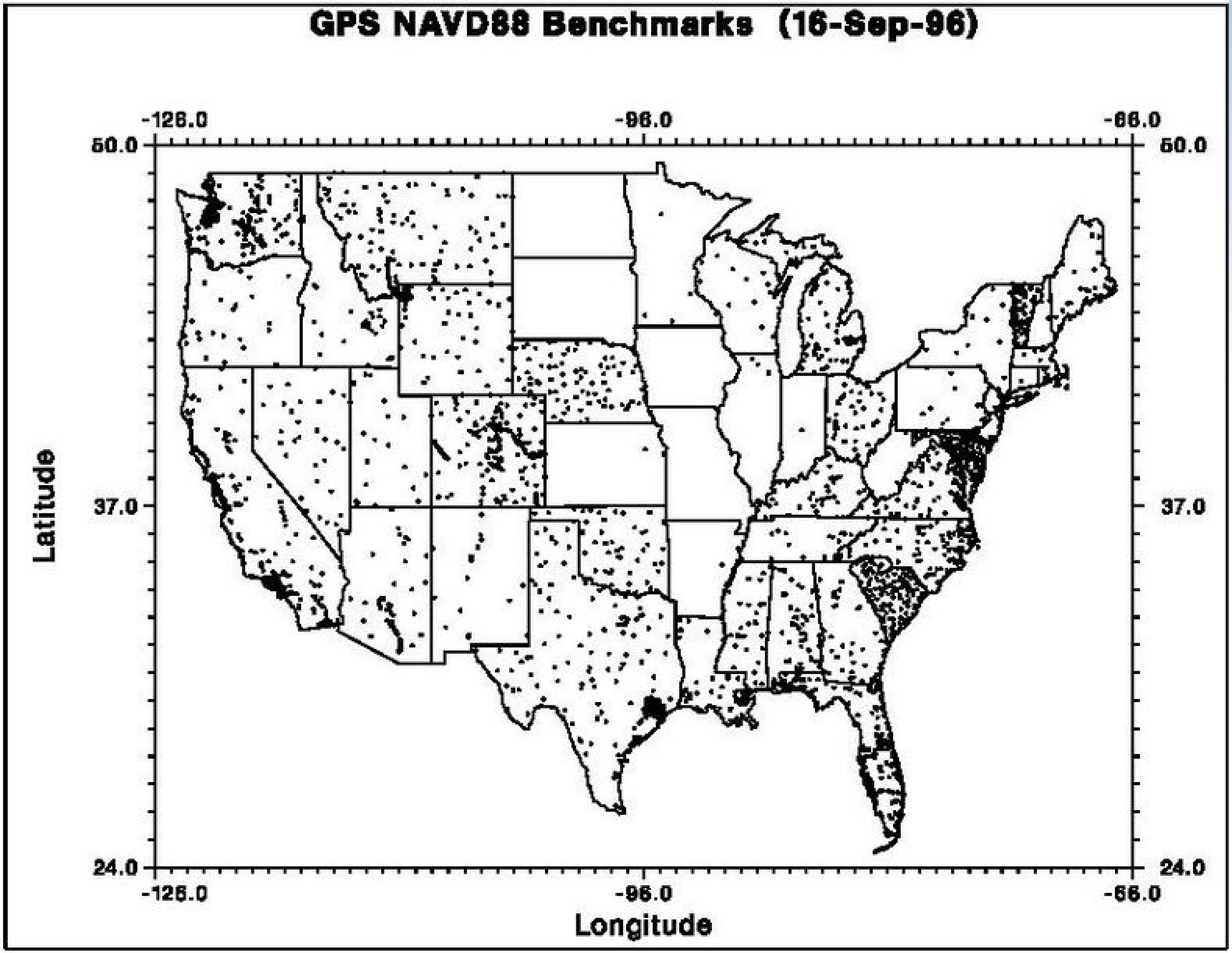
- **NAVD 88** (continued)
  - Use of one fixed height removed local sea level variation problem of NGVD 29
  - Use of one fixed height did open the possibility of unconstrained cross-continent error build up
  - But the H=0 surface of NAVD 88 was supposed to be parallel to the geoid…(close again)



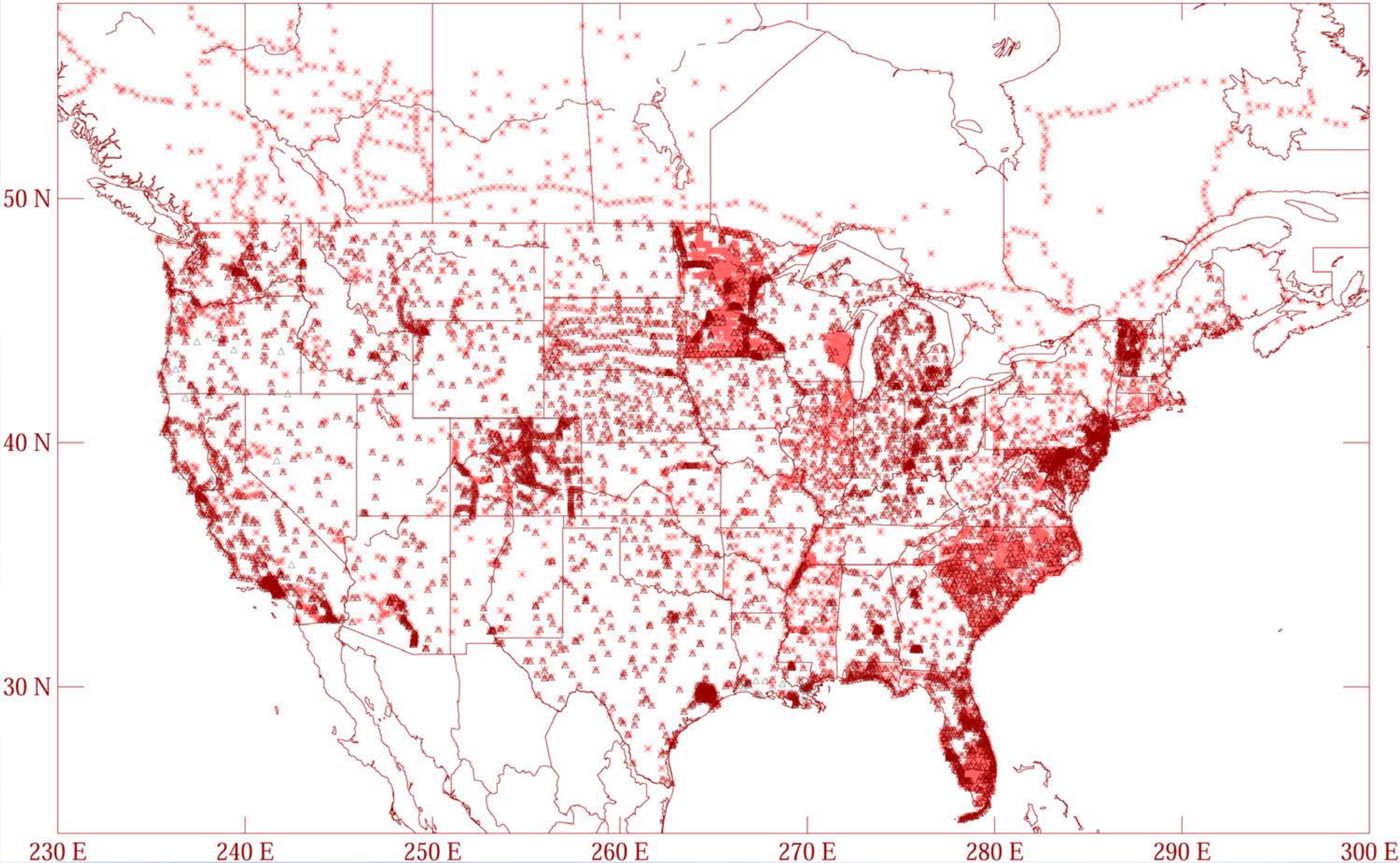
NGVD 29
NAVD 88
Referenced to 26 Tide Gages
(Father's Point)
NAVD88 minus LMSL(1960-1978)
125 cm
102 cm
85 cm
70 cm
4 cm
-11 cm
-11 cm
-23 cm
-23 cm
Prince Rupert
Seattle
Fort Stephens
San Francisco
San Pedro
n Diego
Father's Point
Portland
Boston
Yarmouth
Perth Amboy
Atlantic City
Baltimore
Annapolis
Norfolk
Old Point Comfort
Fernandina Beach
St. Aug
Biloxi
Pensacola
Galveston
Eye alt 1872.11 mi

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



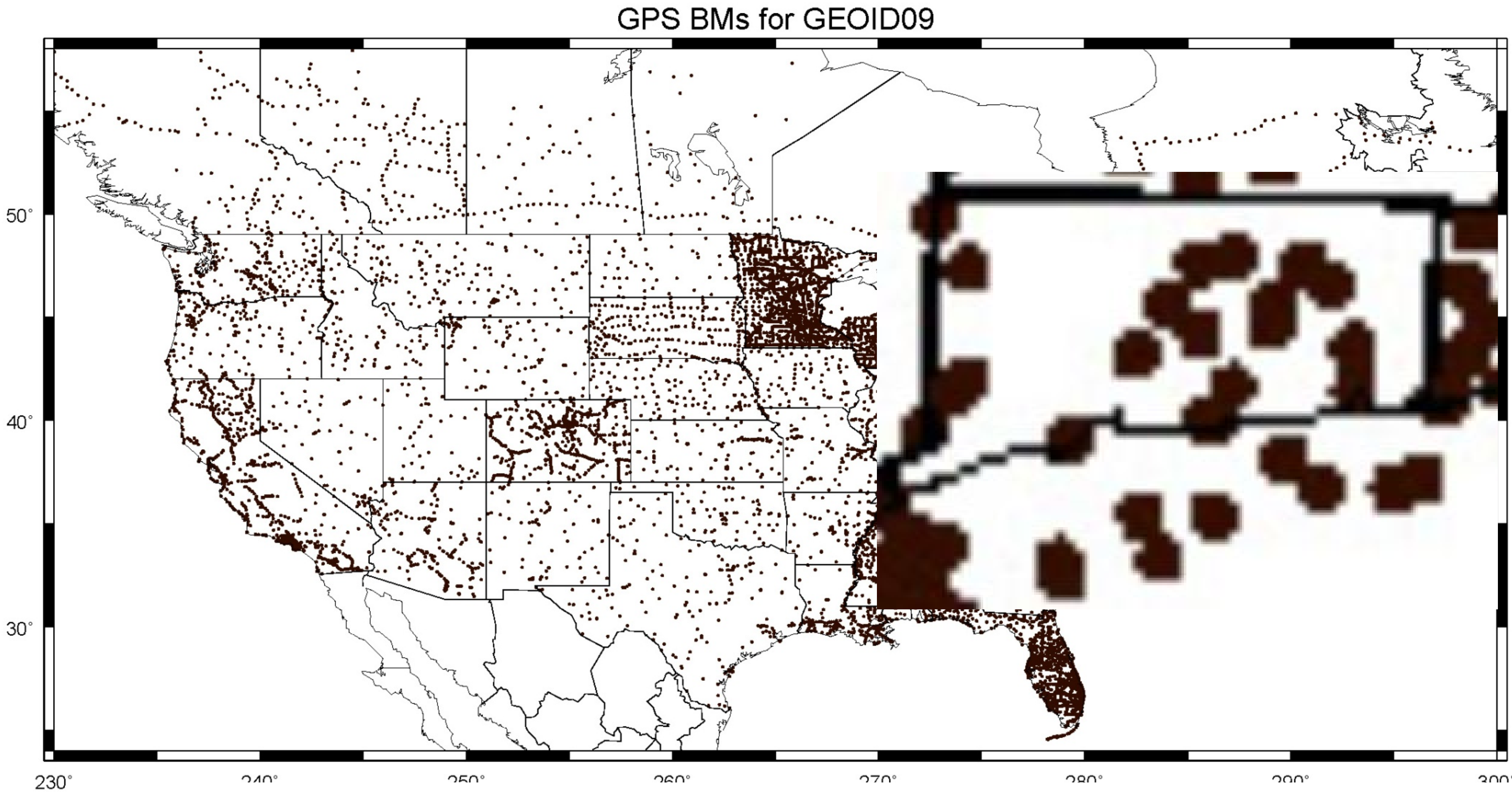
GPSBM1996: 2,951total 0 Canada STDEV ≈ 5 cm (2σ)



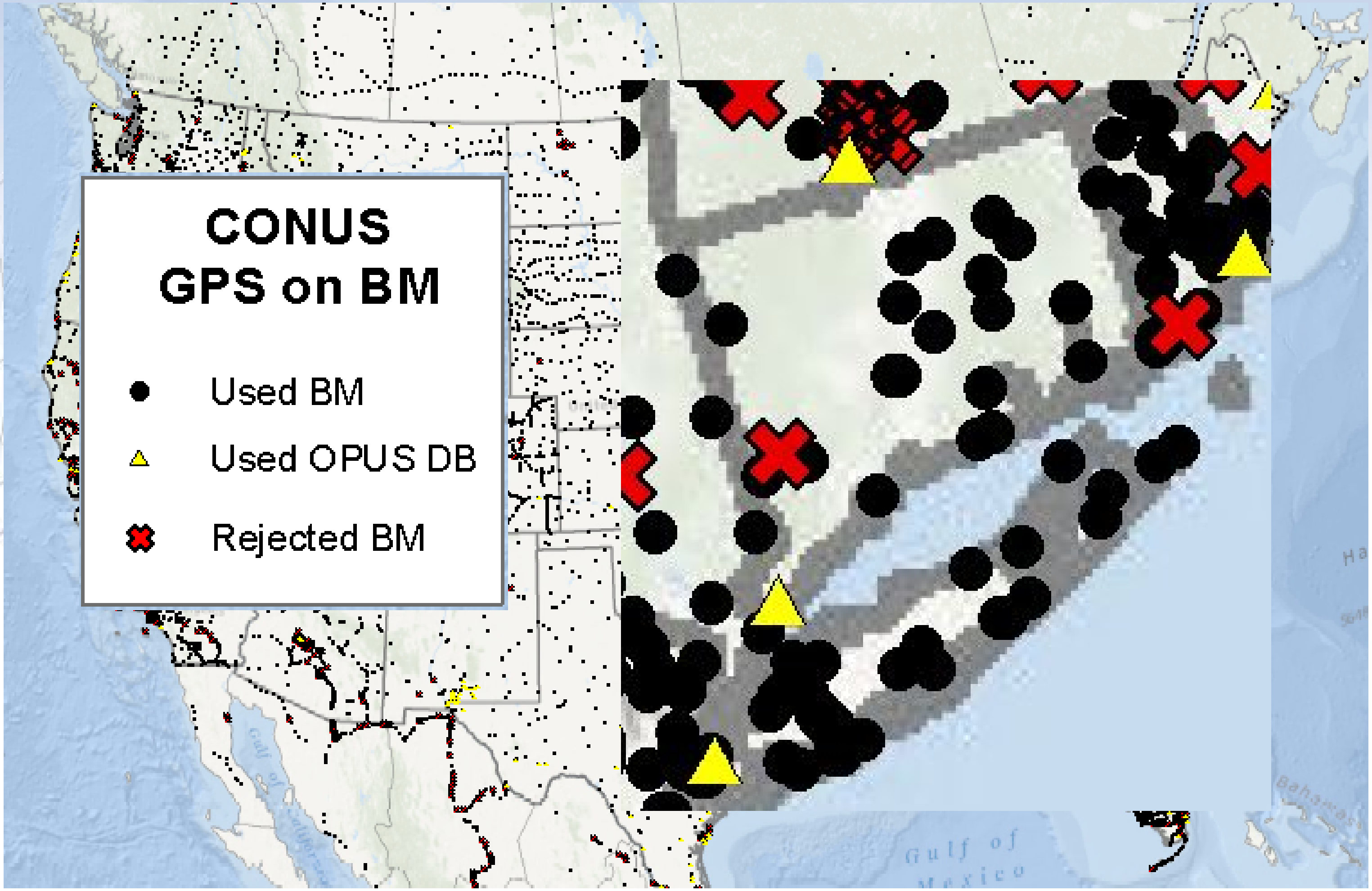
GPSBM1999: 6,169 total 0 Canada STDEV 9.2 cm (2σ)

GPSBM2003: 14,185 total 579 Canada STDEV 4.8 cm (2 σ)

Nati



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)
- 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

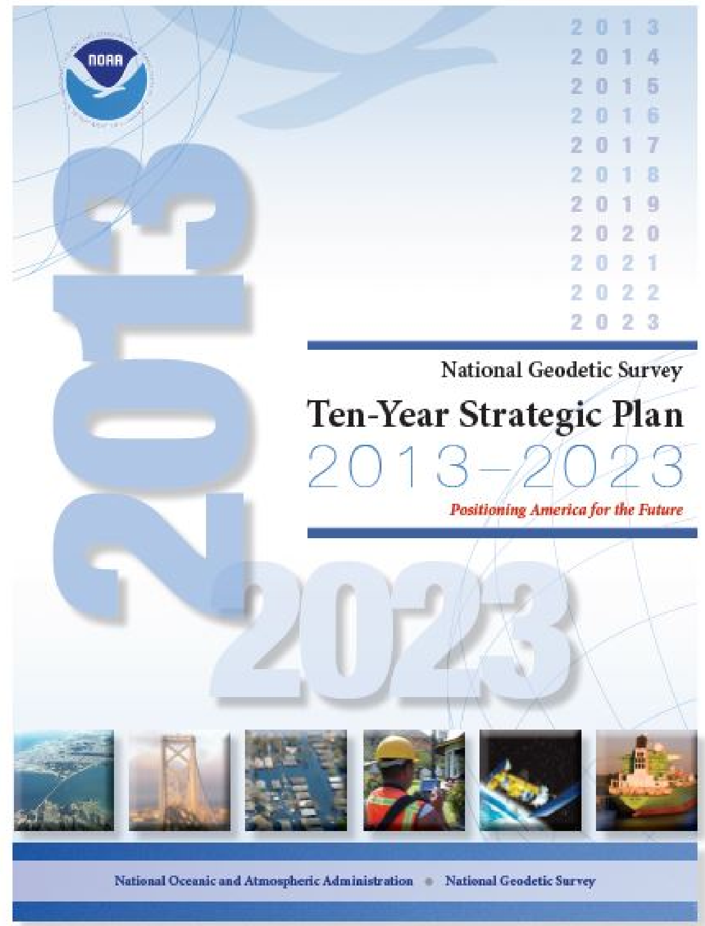
- **NAD 83** is not as geocentric as it could be (approx. 2 m)
  - Positioning Professionals don't see this - **Yet**
- **NAD 83** is not well defined with positional velocities
- **NAVD 88** is realized by passive control (bench marks) most of which have not been re-leveled in at least 40 years.
- **NAVD 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 in CT (0.84 ft – 0.92 ft per 100 years)
    - **Bridgeport, CT 2.88 mm/yr (0.009 ft/yr) 1964-2015**
    - **New London, CT 2.55 mm/yr (0.008 ft/yr) 1938-2015**

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*



Since 2008…

- NGS has had two "ten year plans"
  - Heavy on broad sweeping decisions
    - e.g. "Replace NAD 83"
  - Light on details
    - How? What do we call it?
  - 2016 was a good year for filling in those details

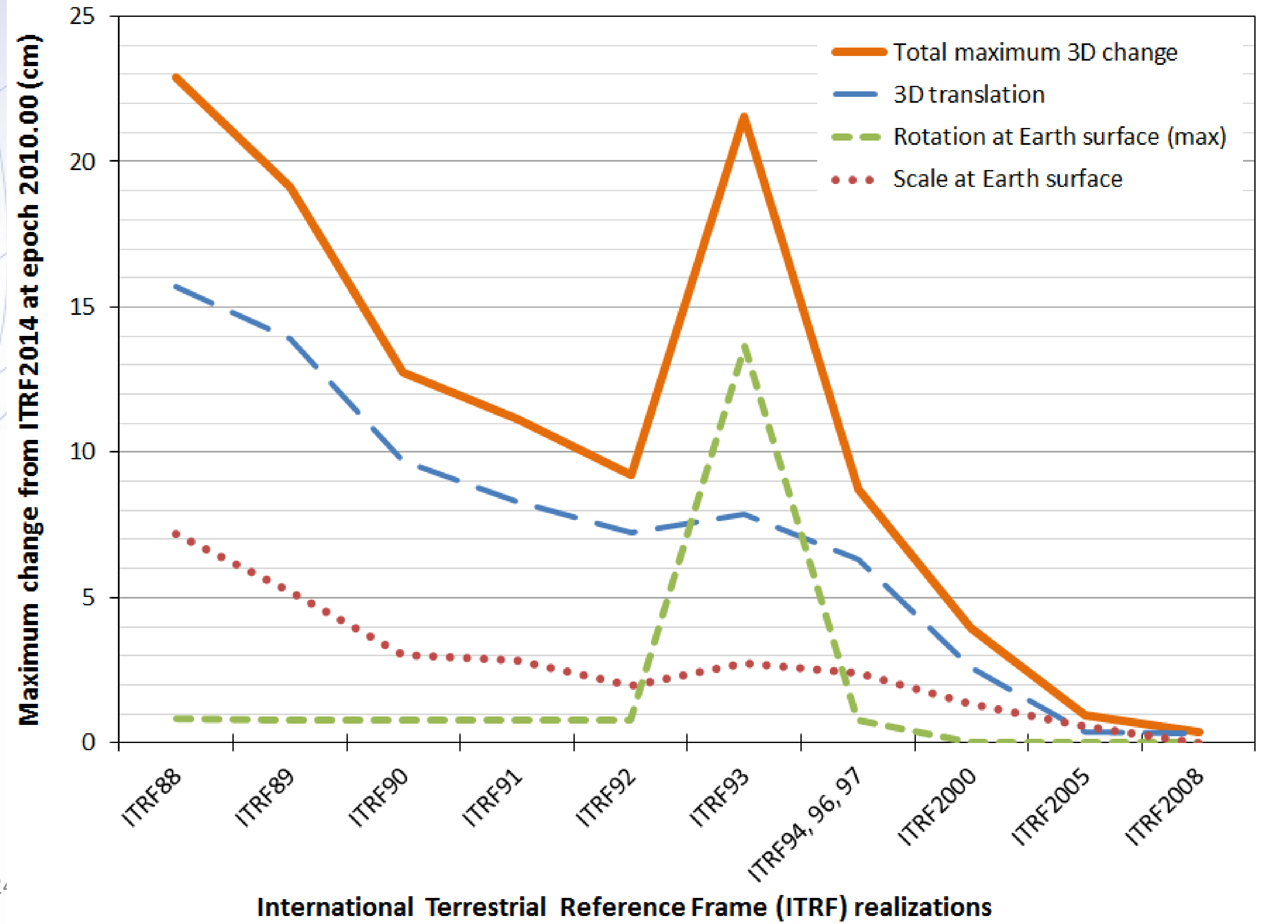
Scientific Decisions

- Blueprint for 2022, Part 1: Geometric
  - ✓Four plate-fixed Terrestrial Reference Frames
    - ✓And what "plate fixed" means
  - ✓Mathematical equation between IGS and TRFs
    - ✓Plate Rotation Model for each plate
    - ✓Coordinates at survey epoch
  - ✓Intra-frame velocity model
    - ✓To compare coordinates surveyed at different epochs

Replacing the NAD 83's

- Three plate-(*pseudo*)fixed frames will be replaced with four *plate-fixed* reference frames
  - N. Amer., Pacific, Mariana, Caribbean(new!)
- Remove long-standing non-geocentricity of NAD 83 frames
- All four : identical to IGSxx at a TBD epoch
  - 2020.00?
- All four : differ from IGSxx by plate rotation only
  - Updated Euler Pole determination for rigid plate only

ITRF is now mature

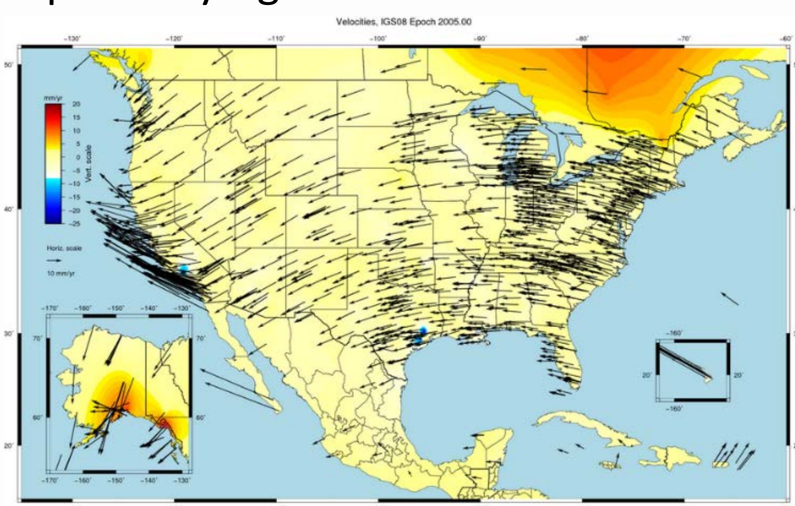


NAD 83 is not ITRF

- GPS & WAAS navigation uses WGS84, aligned to ITRF
- satellite orbits and other geospatial datasets use global frames

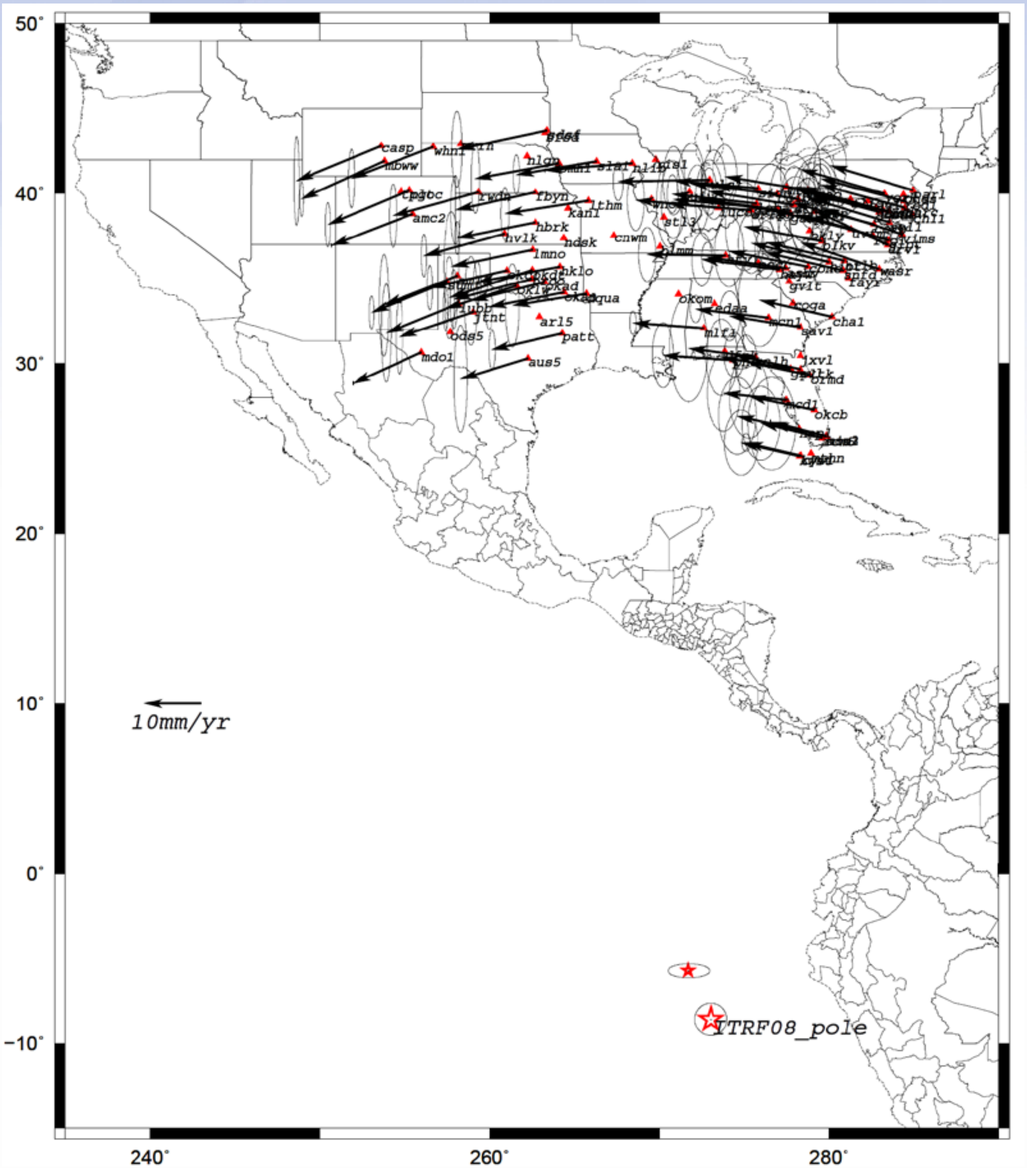
- our TRFs will agree with ITRF (specifically, IGSyy) at the initial epoch
- our TRFs will diverge from ITRF by a few cm each year to stay "plate-fixed"
  - difference is a simple Euler plate rotation
  - many areas will diverge further, as no plate is perfectly rigid

- plate-fixed **or** ITRF-fixed; can't have both



Each frame will get 3 parameters
- Euler Pole Latitude
- Euler Pole Longitude
- Rotation rate (radians / year)

This will be used to compute time-dependent TRF2022 coordinates from time-dependent IGS coordinates.



Names

The Old:

NAD 83(2011)

NAD 83(PA11)

NAD 83(MA11)

The New:

The North American Terrestrial Reference Frame of 2022 (NATRF2022)

The Caribbean Terrestrial Reference Frame of 2022 (CTRF2022)

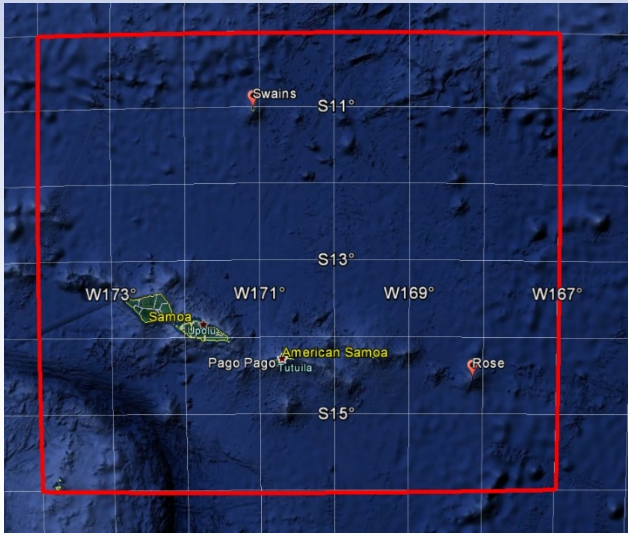
The Pacific Terrestrial Reference Frame of 2022 (PTRF2022)

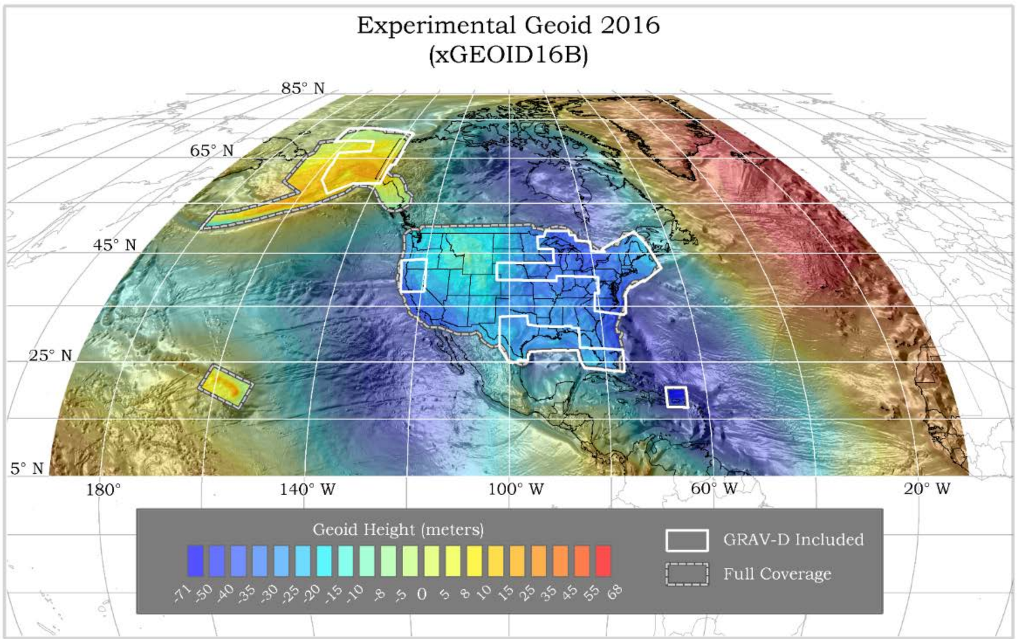
The Mariana Terrestrial Reference Frame of 2022 (MTRF2022)

Scientific Decisions!!

- Blueprint for 2022, Part 2: Geopotential
  - ✓Global 3-D Geopotential Model (GGM)
    - ✓Will contain all GRAV-D data
    - ✓Able to yield any physical value on/above surface
  - ✓Special high-resolution geoid, DoV and surface gravity products consistent with GGM
    - ✓Not global: NA/Pacific, American Samoa, Guam/CNMI
  - ✓Time-Dependencies
    - ✓Geoid monitoring service
      - ✓Impacts of deglaciation, sea level rise, earthquakes, etc

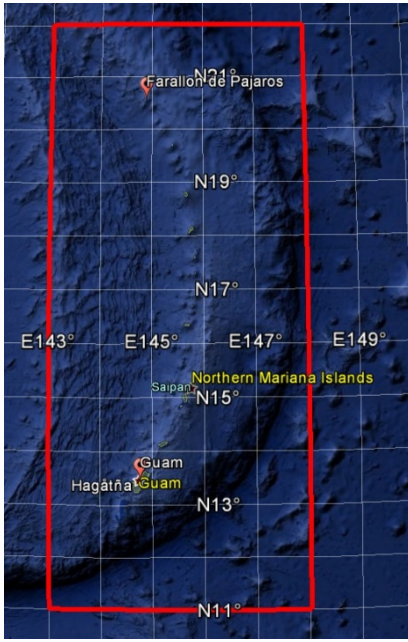
GEOID2022 (et al) over American Samoa:
-16 to -10, 186-193





GEOID2022 (et al) over the North America/Pacific/Caribbean/Central America/Greenland region will range from 0 to 90 latitude and from 170 to 350 longitude.

GEOID2022 (et al) over Guam/CNMI:
11-22, 143-148



Names

The Old:

Orthometric Heights
NAVD 88

PRVD 02
VIVD09
Normal Orthometric Heights
ASVD02
NMVD03
GUVD04

Dynamic Heights
IGLD 85

Gravity
IGSN71

Geoid Undulations
GEOID12B

Deflections of the Vertical
DEFLEC12B

The New:

The North American-Pacific Geopotential Datum of 2022 (NAPGD2022)

- Will include GEOID2022

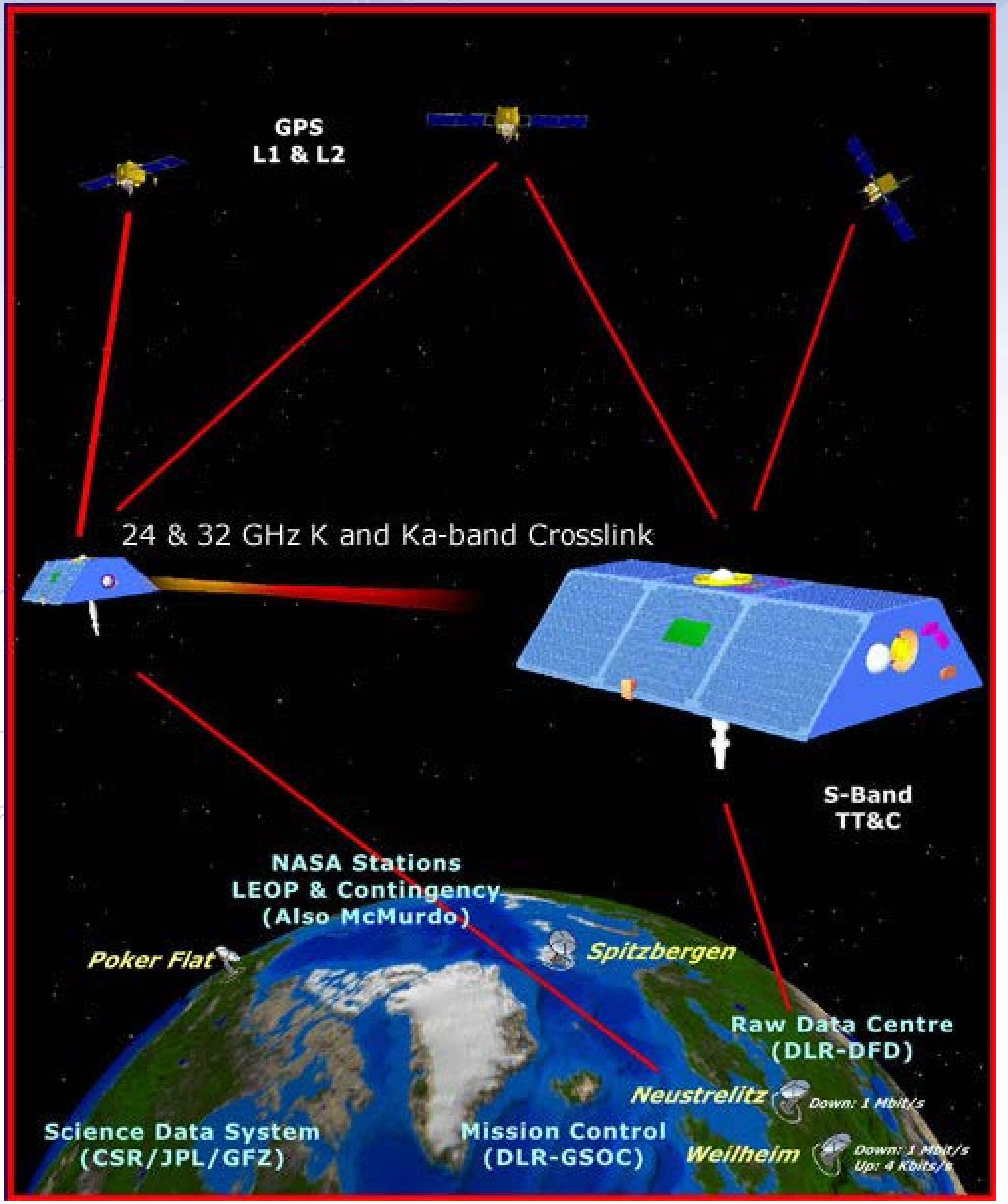
NAVD 88 is not alone

- NAVD 88 — North American Vertical Datum of 1988
- PRVD02 — Puerto Rico Vertical Datum of 2002
- ASVD02 — American Samoa Vertical Datum of 2002
- NMVD03 — Northern Marianas Vertical Datum of 2003, 3 each
- GUVD04 — Guam Vertical Datum of 2004
- VIVD09 — Virgin Islands Vertical Datum of 2009, 3 each
- Hawaii … — Hawaiian Islands Vertical Datum (coming soon)
- various — local datums, as national datum is inaccessible
- IGLD 85 — International Great Lakes Datum of 1985
- IGSN71 — gravity dataset
- GEOID12B — geoid undulations
- DEFLEC12B — deflection of the vertical

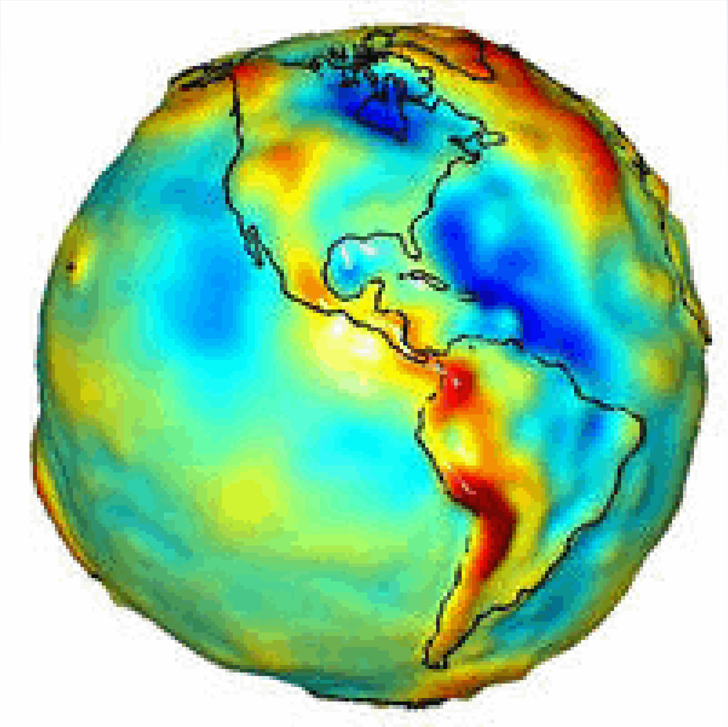
One vertical datum
pole-to-equator

Why New Reference Frames?

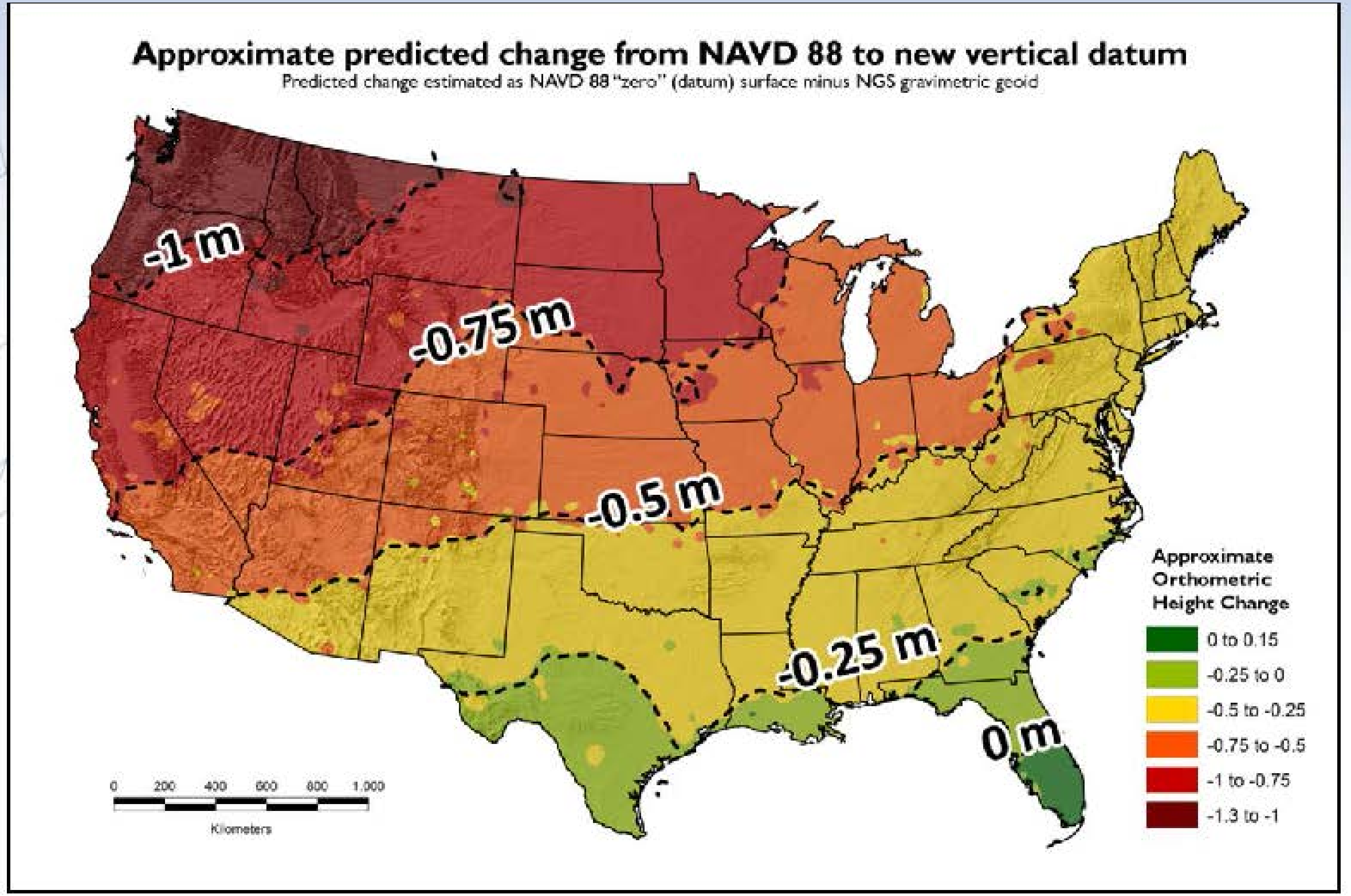
- NAD 83
  - non-geocentric, i.e. inconsistent with GNSS positioning
  - difficult to maintain consistency between CORS & passive network NAD 83 coordinates
  - lack of velocities, i.e. NAD 83 does not report station motion for passive marks
- NAVD 88
  - cross-country build up of errors ("tilt" or "slope") 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



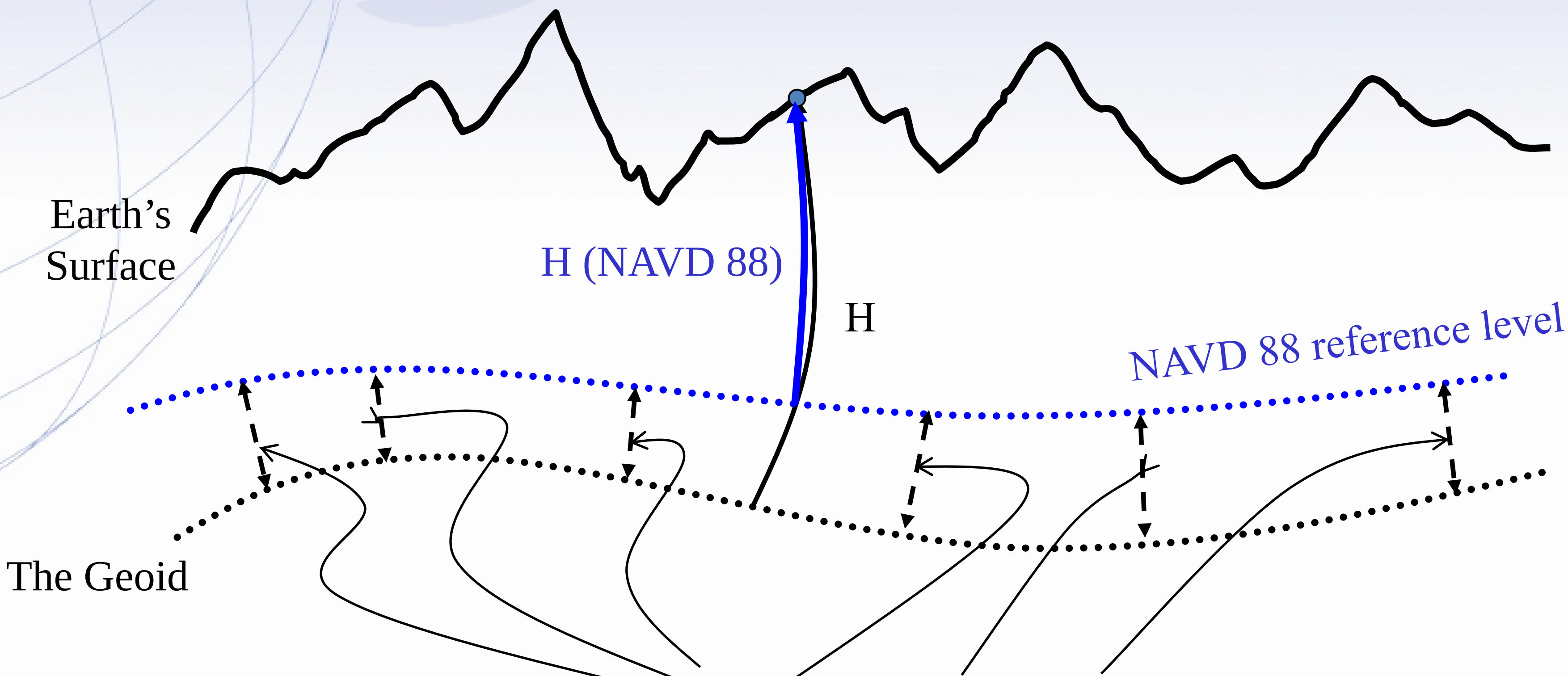
GRACE – Gravity Recovery and Climate Experiment



NAVD 88 is tilted and biased



Why isn't NAVD 88 good enough anymore?



Errors in NAVD 88 : ~50 cm average,
100 cm CONUS tilt,
1-2 meters average in Alaska

Why isn't NAVD 88 good enough anymore? STILL continued…

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…continued

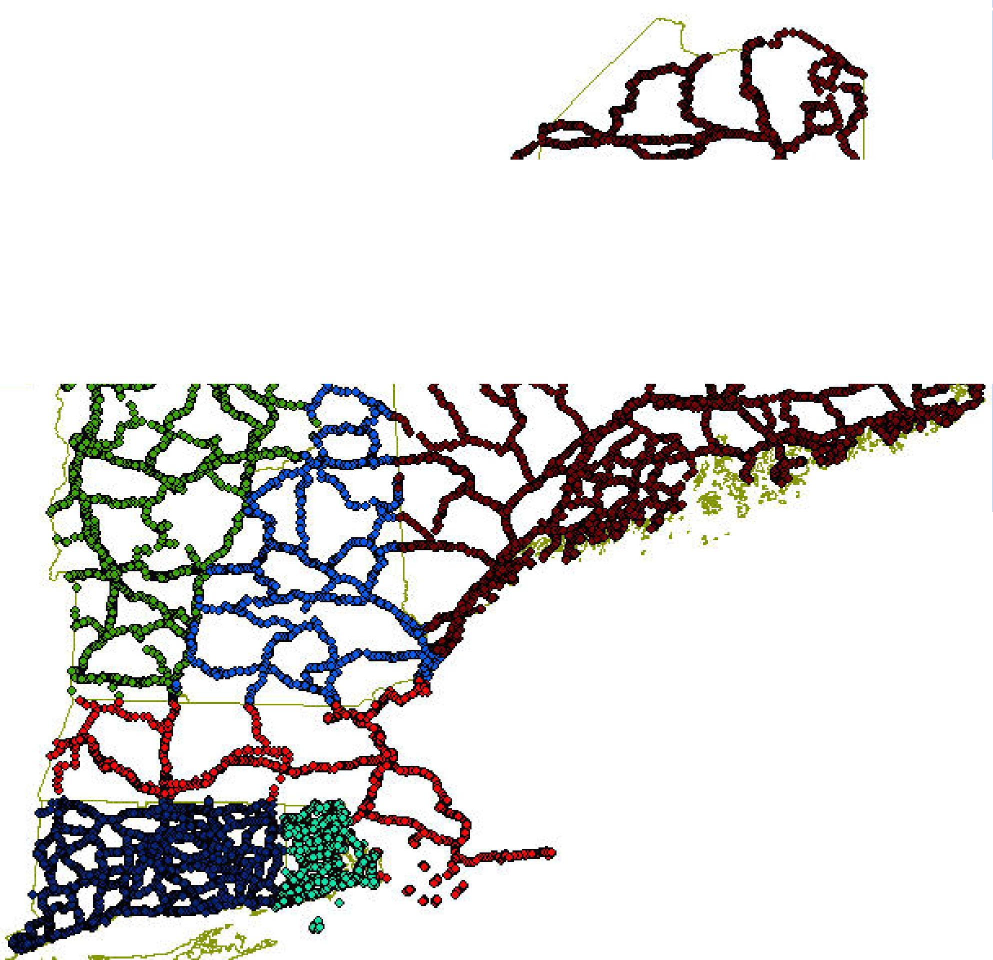
- **NAVD 88 suffers from use of bench marks that:**
  - Are almost never re-checked for movement
  - Disappear by the thousands every year
  - Are not funded for replacement
  - Are not necessarily in convenient places
  - Don't exist in most of Alaska
  - Weren't adopted in Canada
  - Were determined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

Why replace NAVD 88 and NAD 83?

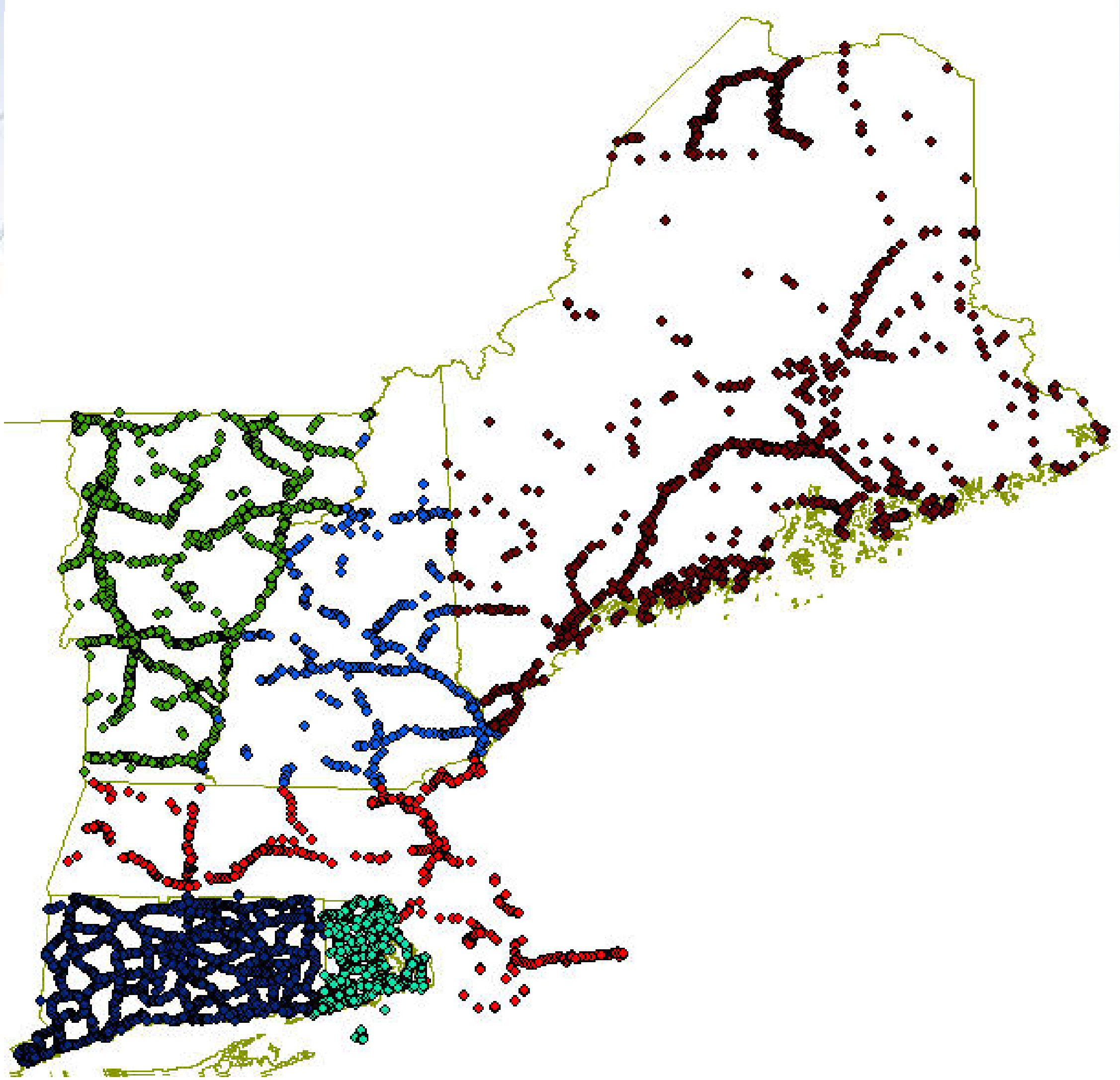
- **ACCESS!**
  - easier to find the sky than a 60-year-old bench mark
  - GNSS equipment is cheap and fast
- **ACCURACY!**
  - easier to trust the sky than a 60-year old bench mark
  - immune to passive mark instability
- **GLOBAL STANDARDS!**
  - systematic errors of many meters across the US
  - aligns with GPS, international efforts
  - aligns with Canada, Mexico

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?

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 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?

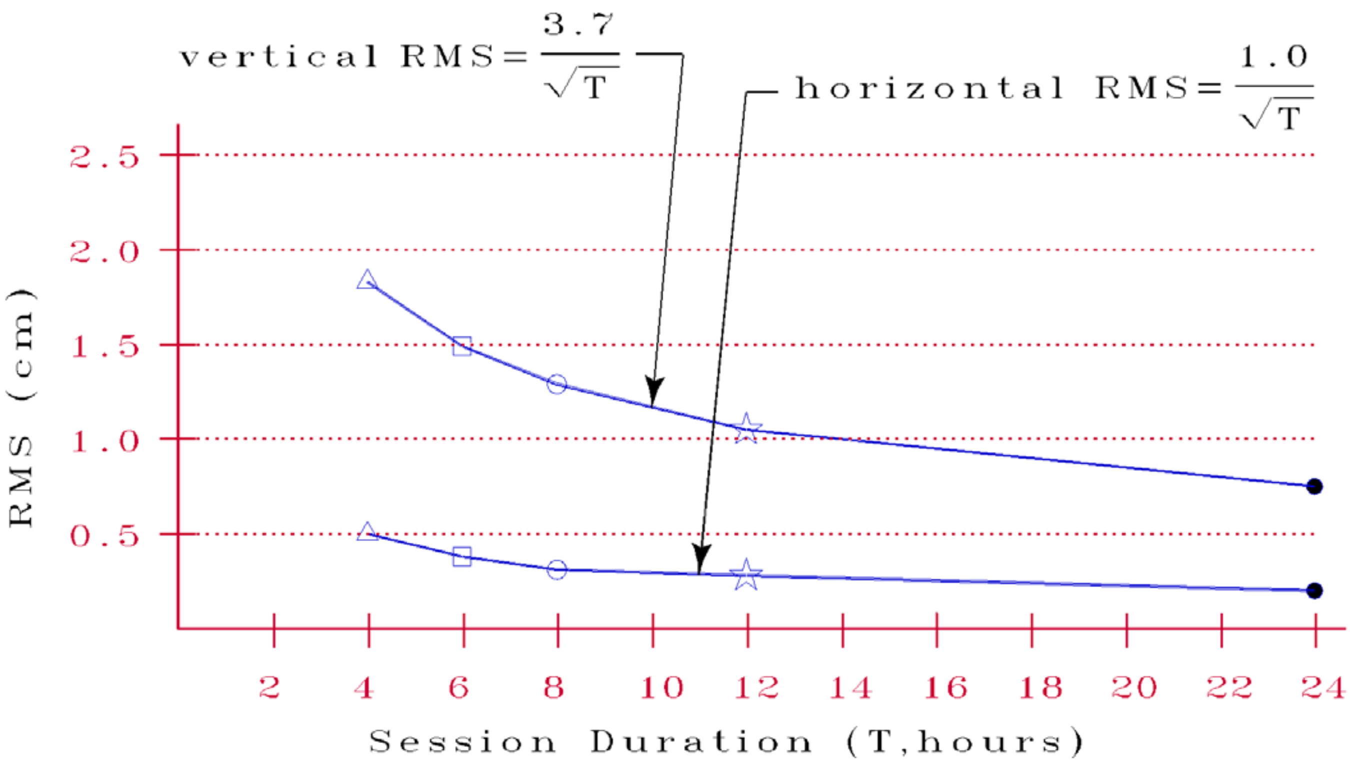
OPUS Static reliably addresses the more historically conventional requirements for GPS data processing. It typically yields accuracies of:

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

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 : 19.85717322380!

Longitude: -147.36328125

Retrieve Accuracy

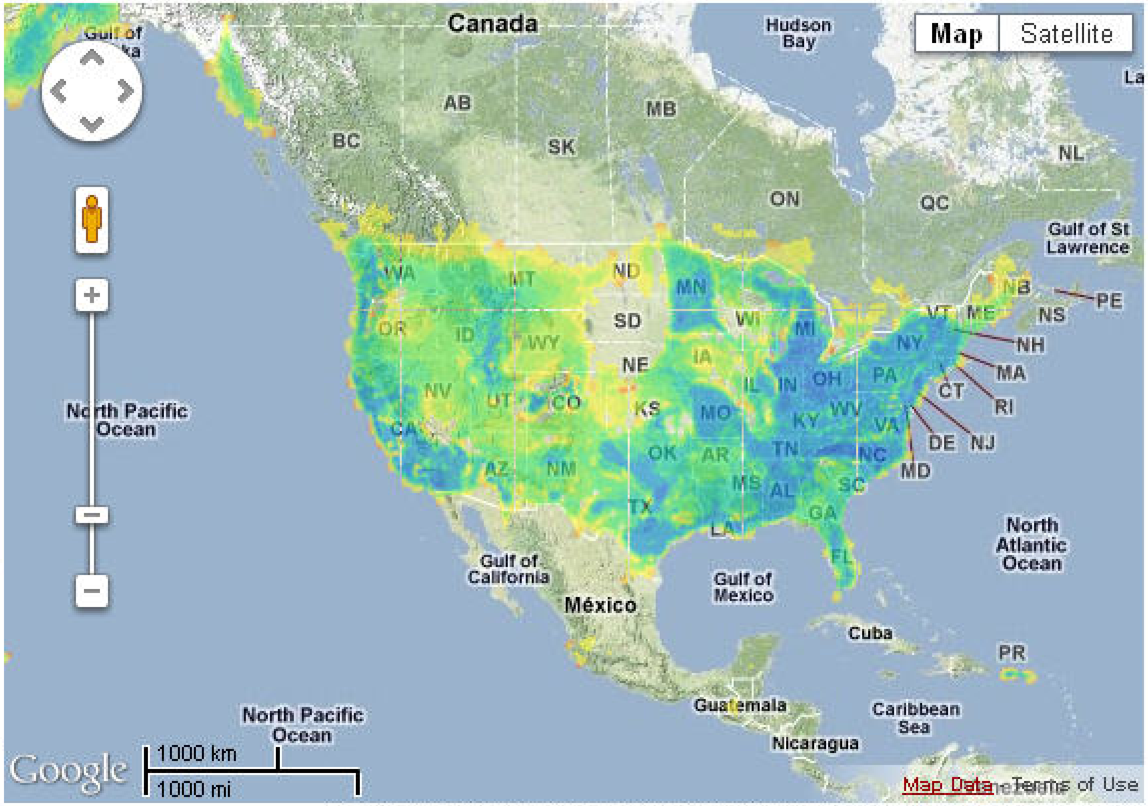
Overlay Opacity: 60%

LEGEND:

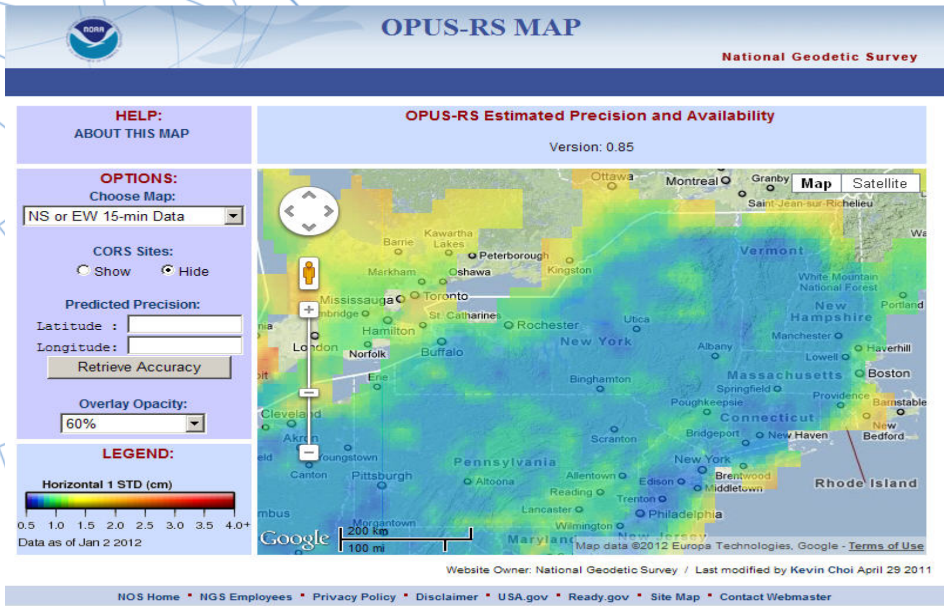
Horizontal 1 STD (cm)

0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0+

Data as of Nov 7 2011



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)
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0+
Data as of Jan 2 2012
Map Satellite
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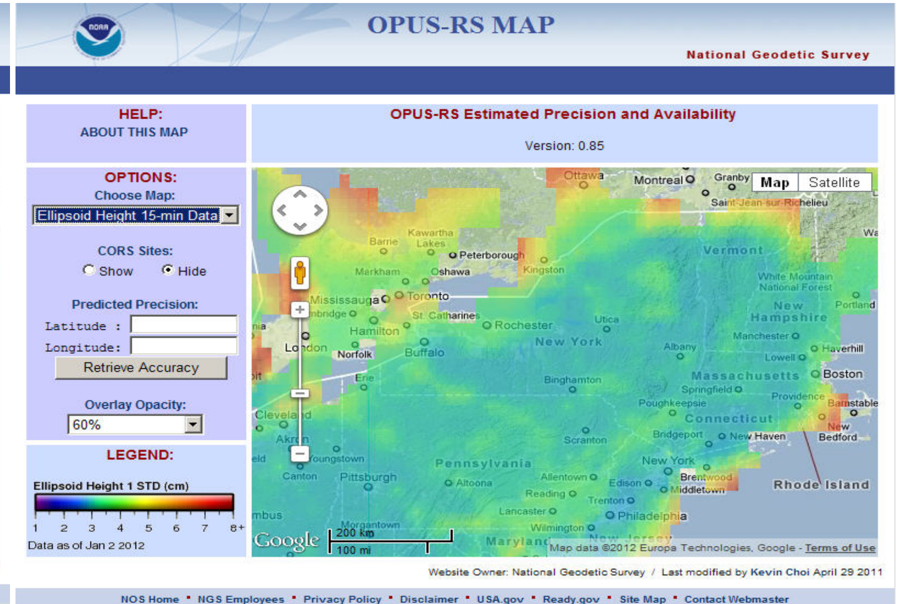
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National Geodetic Survey
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Ellipsoid Height 15-min Data
CORS Sites:
Show Hide
Predicted Precision:
Latitude :
Longitude:
Retrieve Accuracy
Overlay Opacity:
60%
LEGEND:
Ellipsoid Height 1 STD (cm)
1 2 3 4 5 6 7 8+
Data as of Jan 2 2012
Map Satellite
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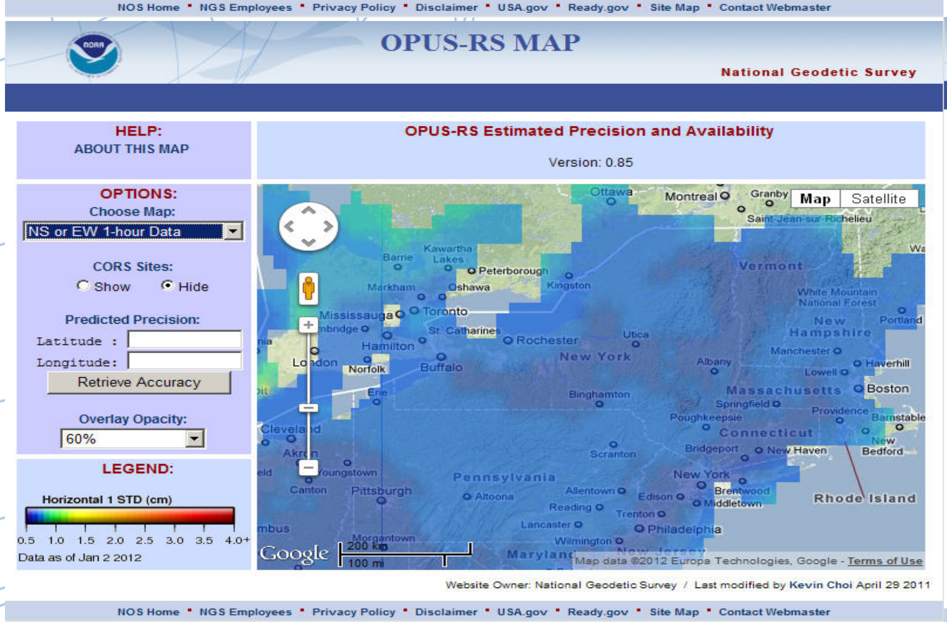
OPUS-RS MAP
National Geodetic Survey
HELP:
ABOUT THIS MAP
OPUS-RS Estimated Precision and Availability
Version: 0.85
OPTIONS:
Choose Map:
NS or EW 1-hour Data
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Show Hide
Predicted Precision:
Latitude :
Longitude:
Retrieve Accuracy
Overlay Opacity:
60%
LEGEND:
Horizontal 1 STD (cm)
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0+
Data as of Jan 2 2012
Map Satellite
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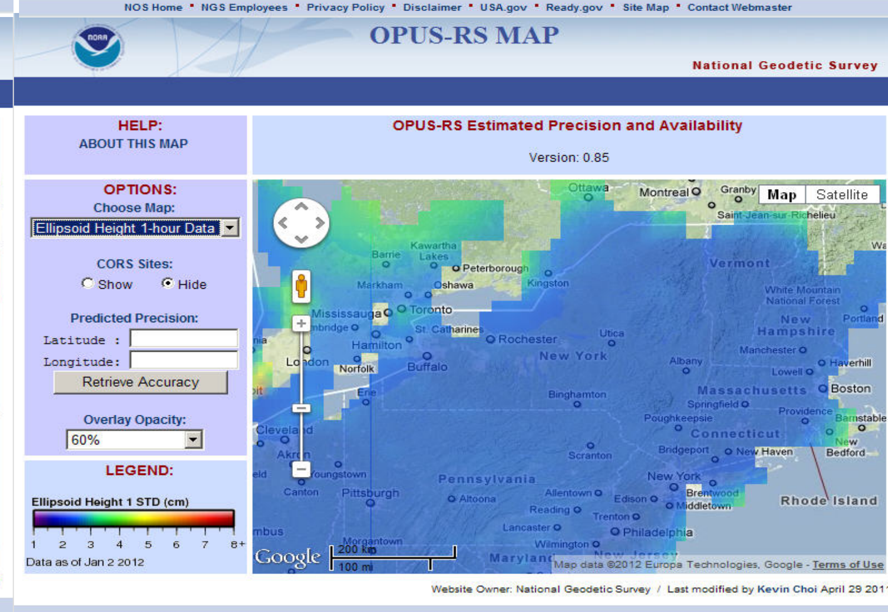
OPUS-RS MAP
National Geodetic Survey
HELP:
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Ellipsoid Height 1-hour Data
CORS Sites:
Show Hide
Predicted Precision:
Latitude :
Longitude:
Retrieve Accuracy
Overlay Opacity:
60%
LEGEND:
Ellipsoid Height 1 STD (cm)
1 2 3 4 5 6 7 8+
Data as of Jan 2 2012
Map Satellite
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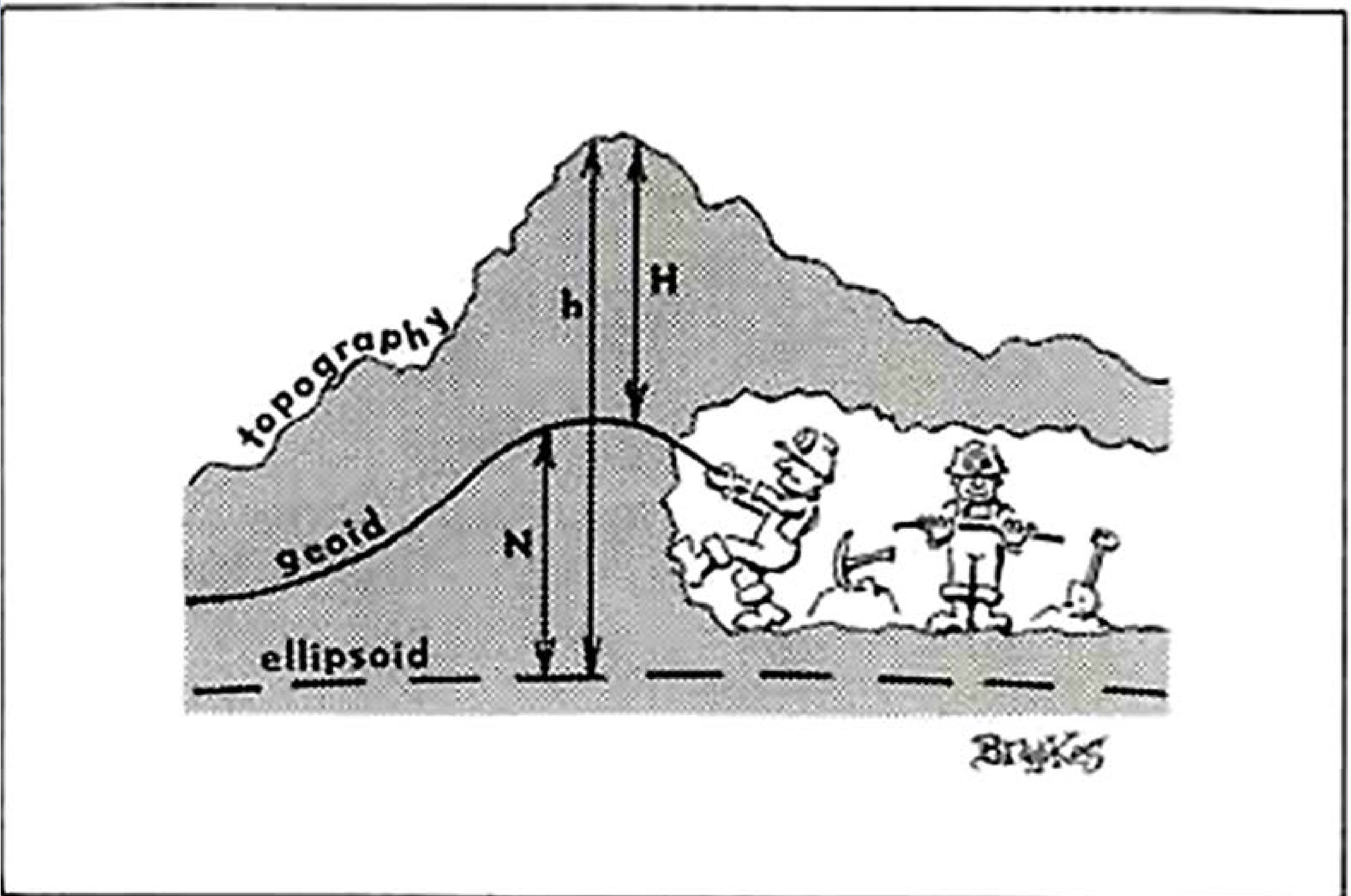
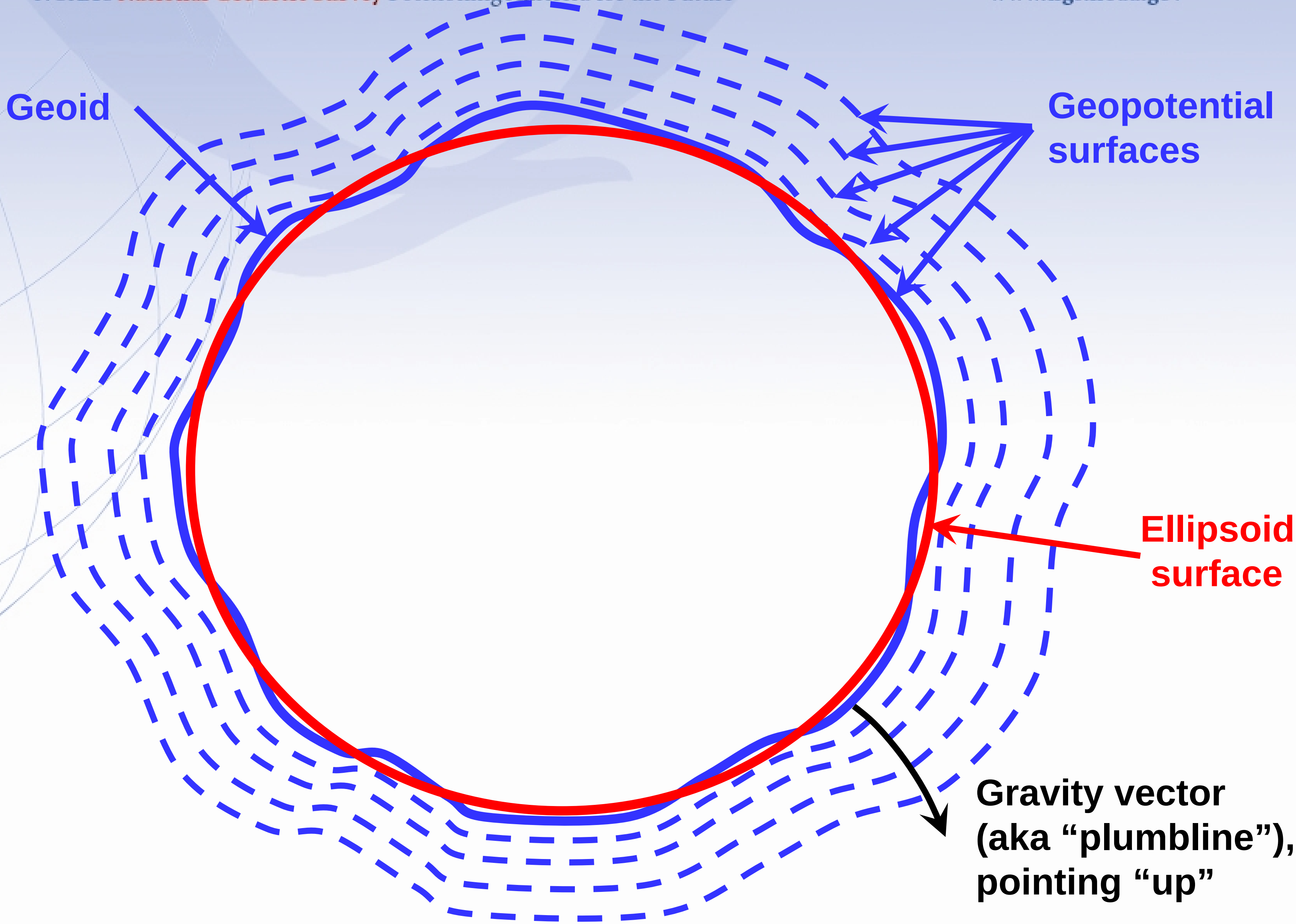
Height Modernization Bottom line

1. Using GNSS is cheaper, easier than leveling

2. To use GNSS we need a good geoid model

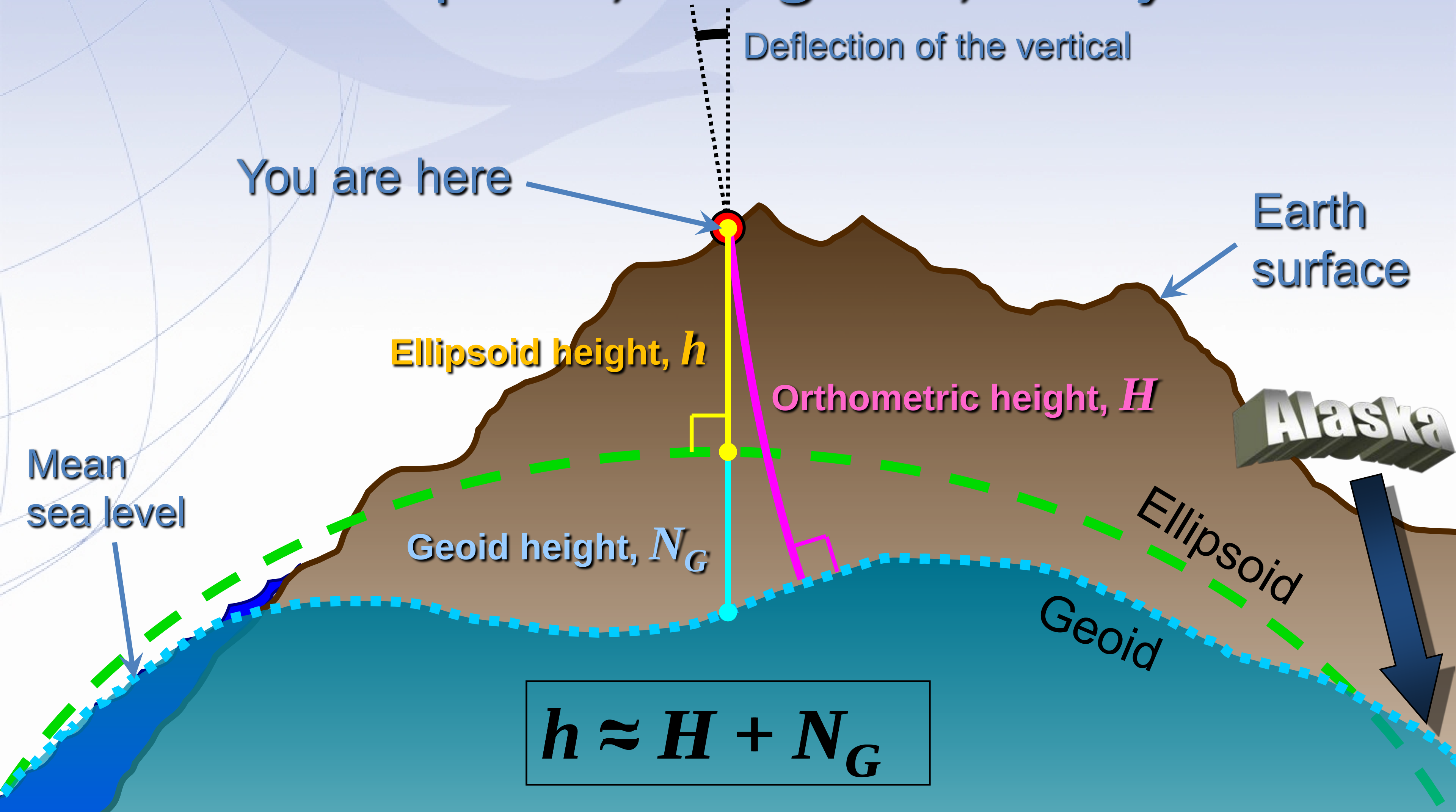


In Search of the Geoid



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.

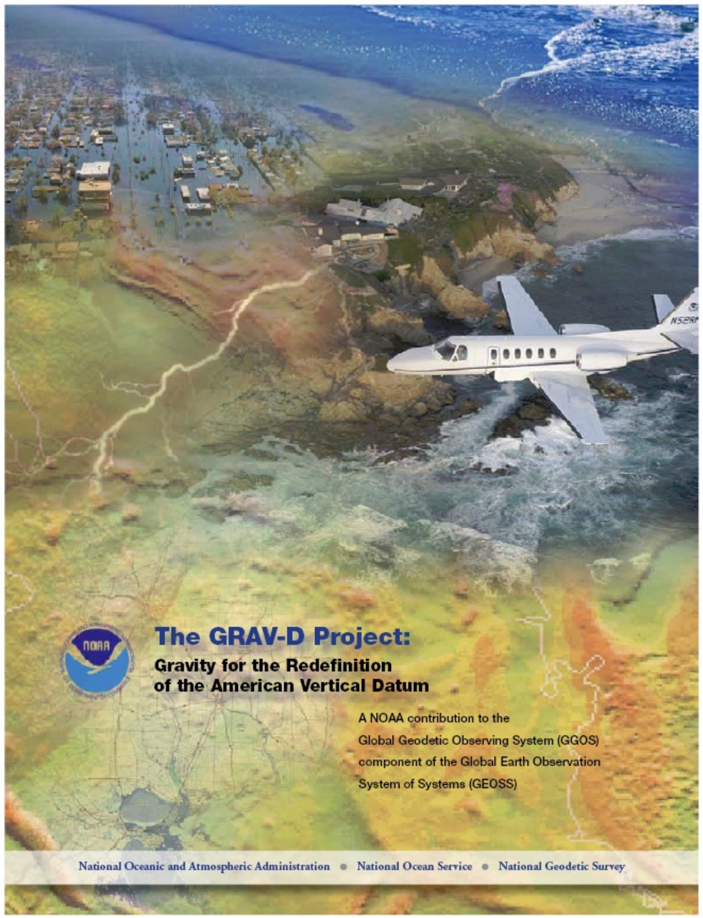
The ellipsoid, the geoid, and *you*



$$h \approx H + N_G$$

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)



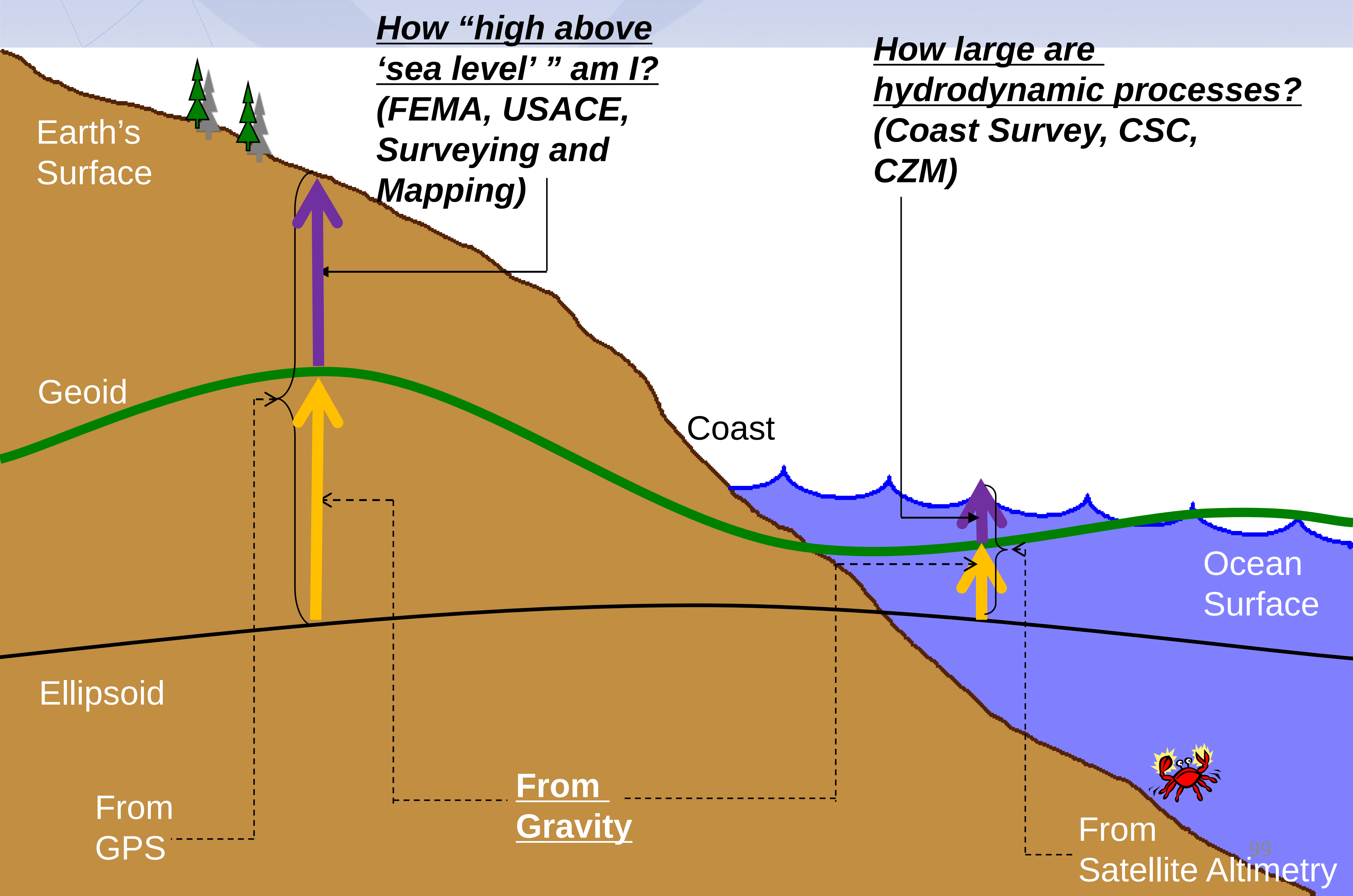
Gravity *and* ***Heights*** *are inseparably connected*

- 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

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…

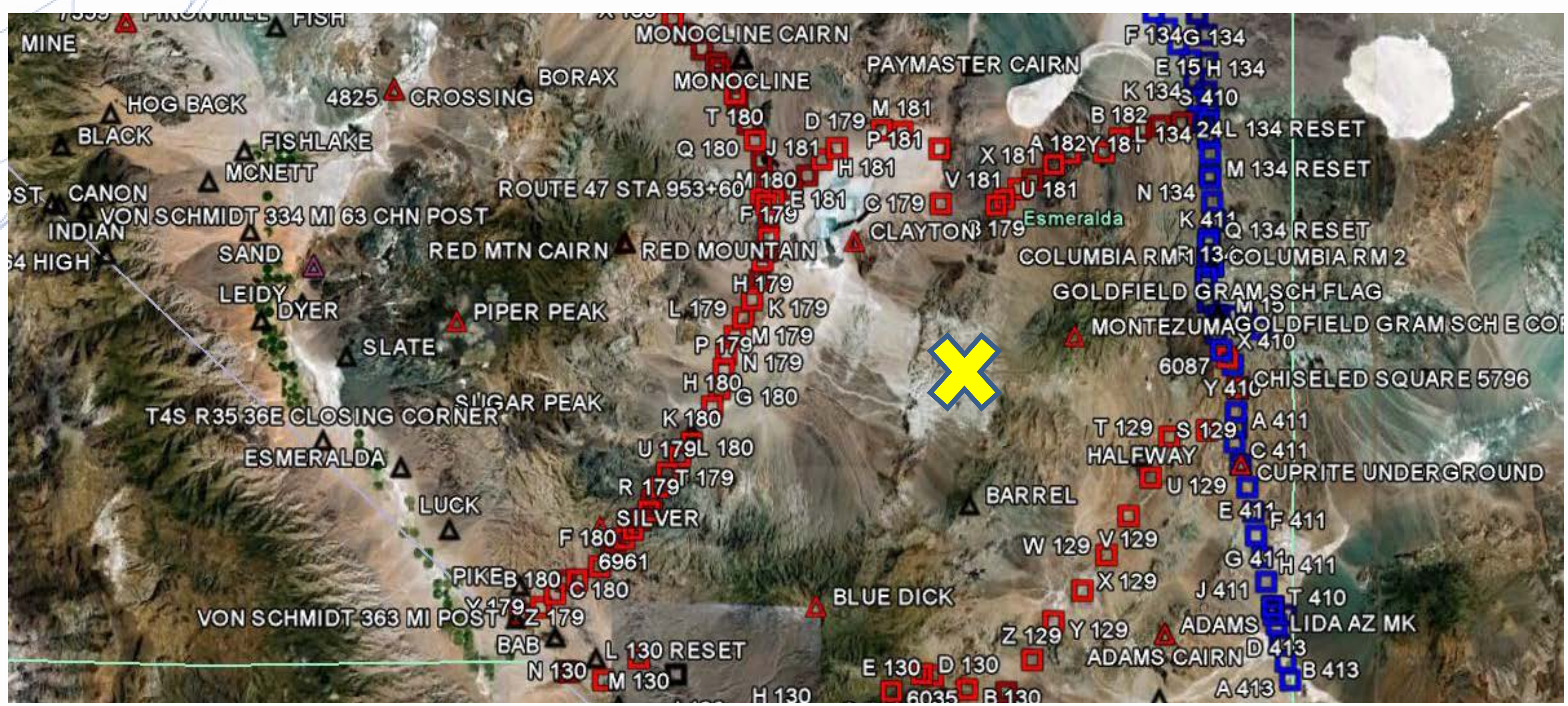


Gravity Survey Plan

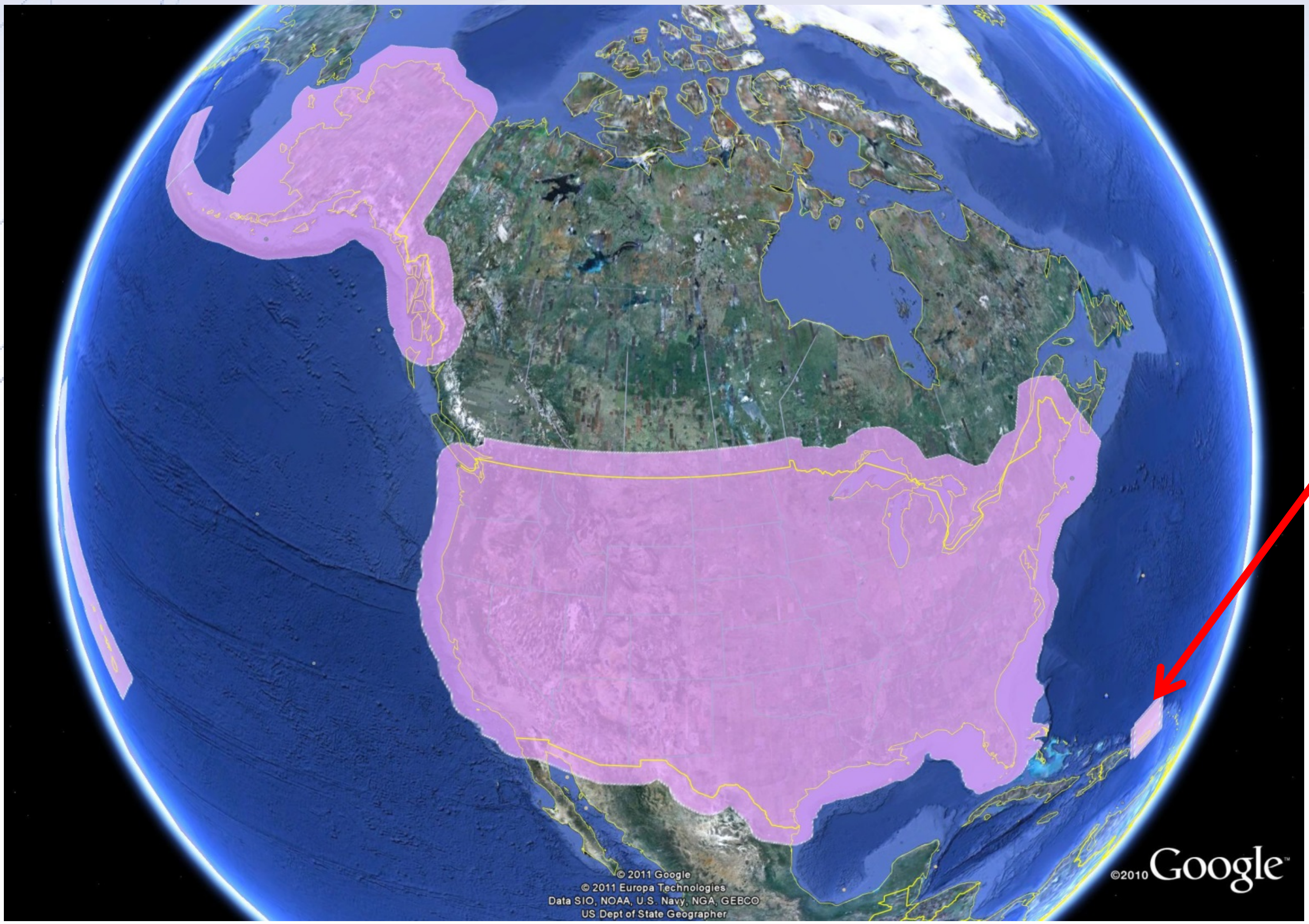
- National Scale Part 1
  - Predominantly through airborne gravity
  - With Absolute Gravity for ties and checks
  - Relative Gravity for expanding local regions where airborne shows significant mismatch with existing terrestrial

GRAV-D Goals

- ✓ <u>2 cm accuracy </u>orthometric heights -
  from GNSS (1 cm) + geoid model (1 cm)
- ✓ fast, accurate, consistent orthometric heights -
  everywhere in the USA



GRAV-D Expected Coverage

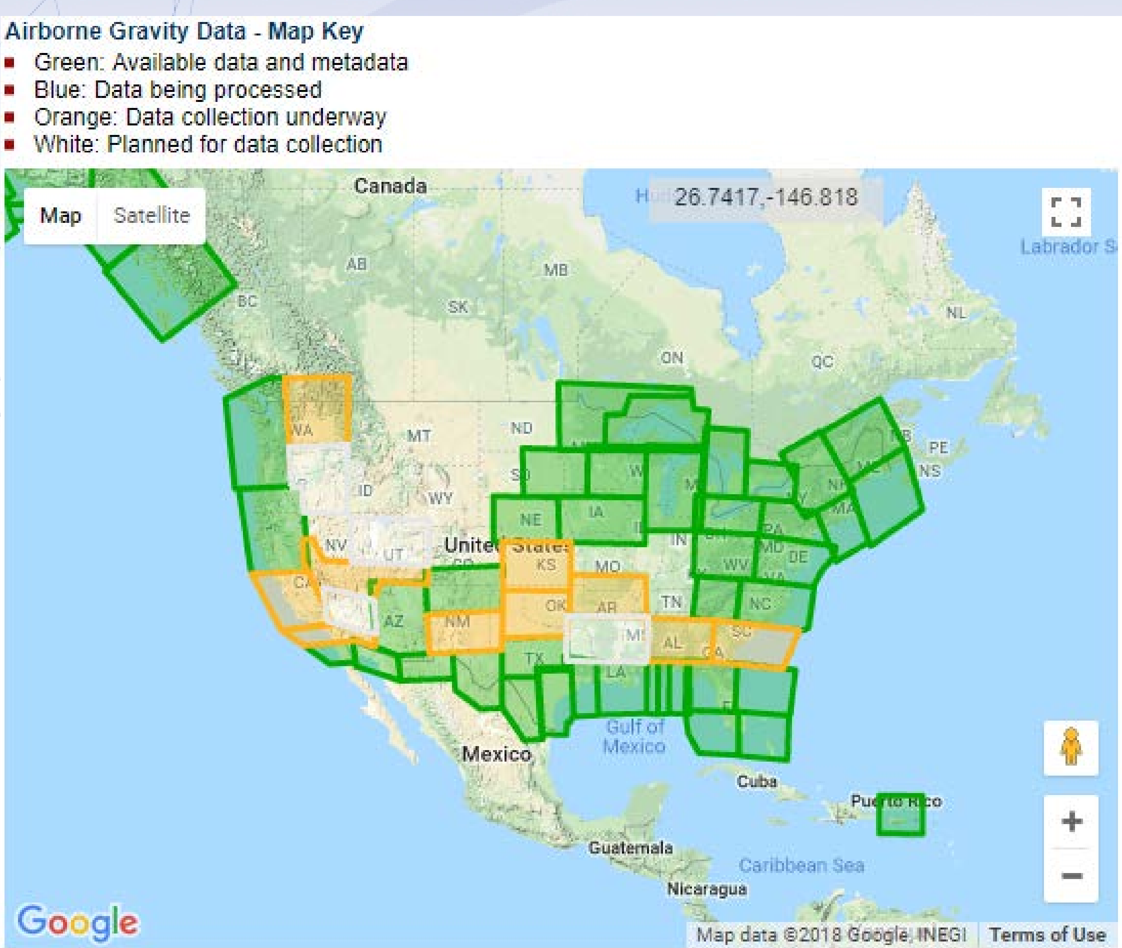


Puerto Rico
US Virgin Is.

Priority- Greatest Datum Need

- Alaska
- Puerto Rico/US Virgin Islands (PRVI)
- Coastal US and Great Lakes
  - Great Lakes
  - Gulf of Mexico & FL
  - Eastern Seaboard
  - Western Seaboard
- Hawaii and Pacific Islands
- Aleutian Islands
- Interior CONUS
  - Mountainous areas first

Airborne Gravity Current Coverage



Data Block Status

Complete
Processing
Collecting
Planned

As of July29, 2018

http://www.ngs.noaa.gov/GRAV-D/data_products.shtml

GRAV-D Aircraft

Bureau of Land Management
Pilatus PC-12

Dynamic Aviation King Air 200T

Fugro King Air E-90A

Naval Research Laboratory
King Air RC-12

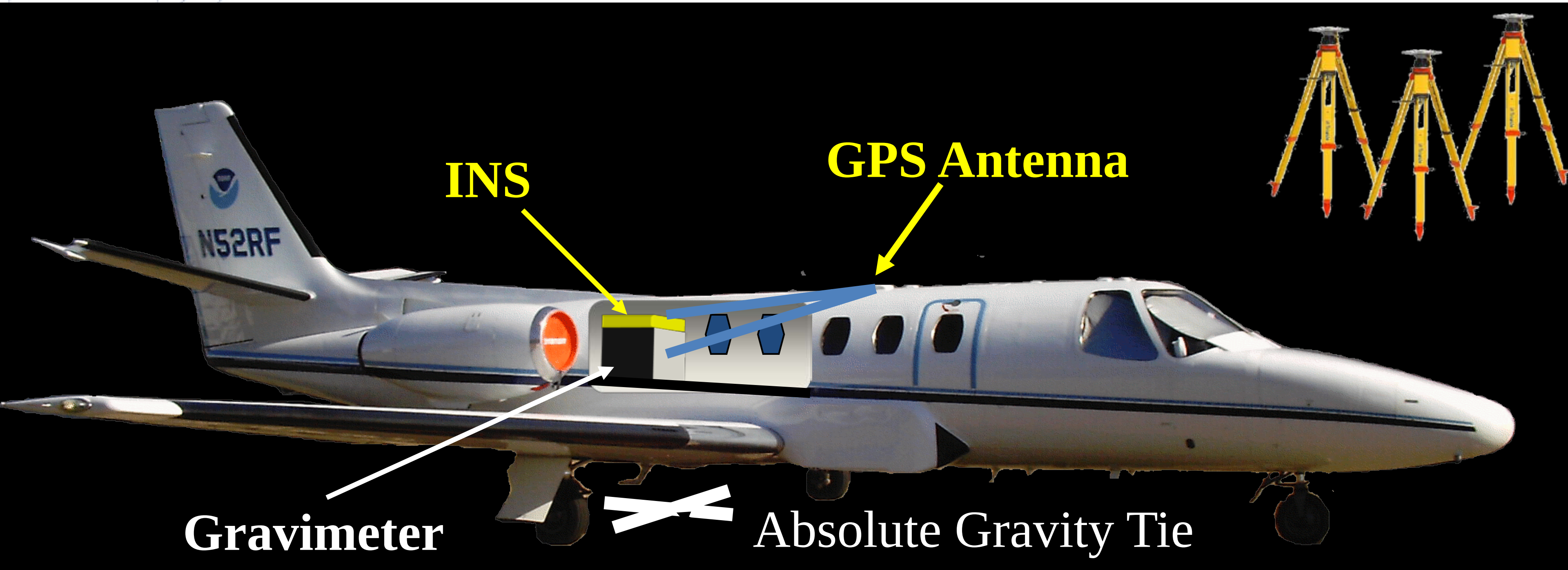
Aurora Flight Sciences Centaur
Optionally Piloted Aircraft

NOAA P-3 (background)
NOAA Turbo Commander (foreground)

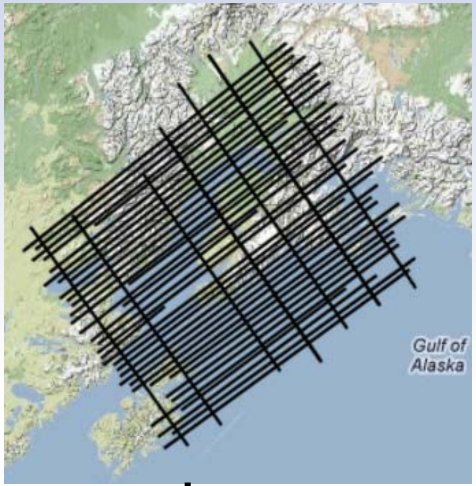
Fugro Cessna Conquest

Requirements

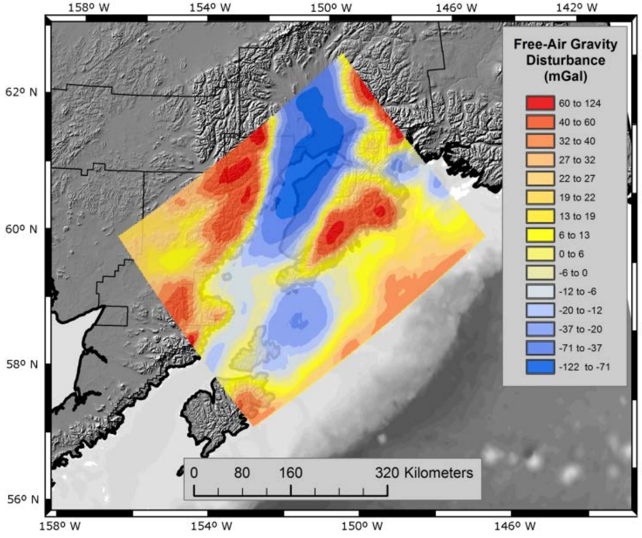
- Geodetic quality results require accurate aircraft positions, velocities, and accelerations
- High-altitude, high-speed, long baseline flights for gravimetry



From Measurement to Product

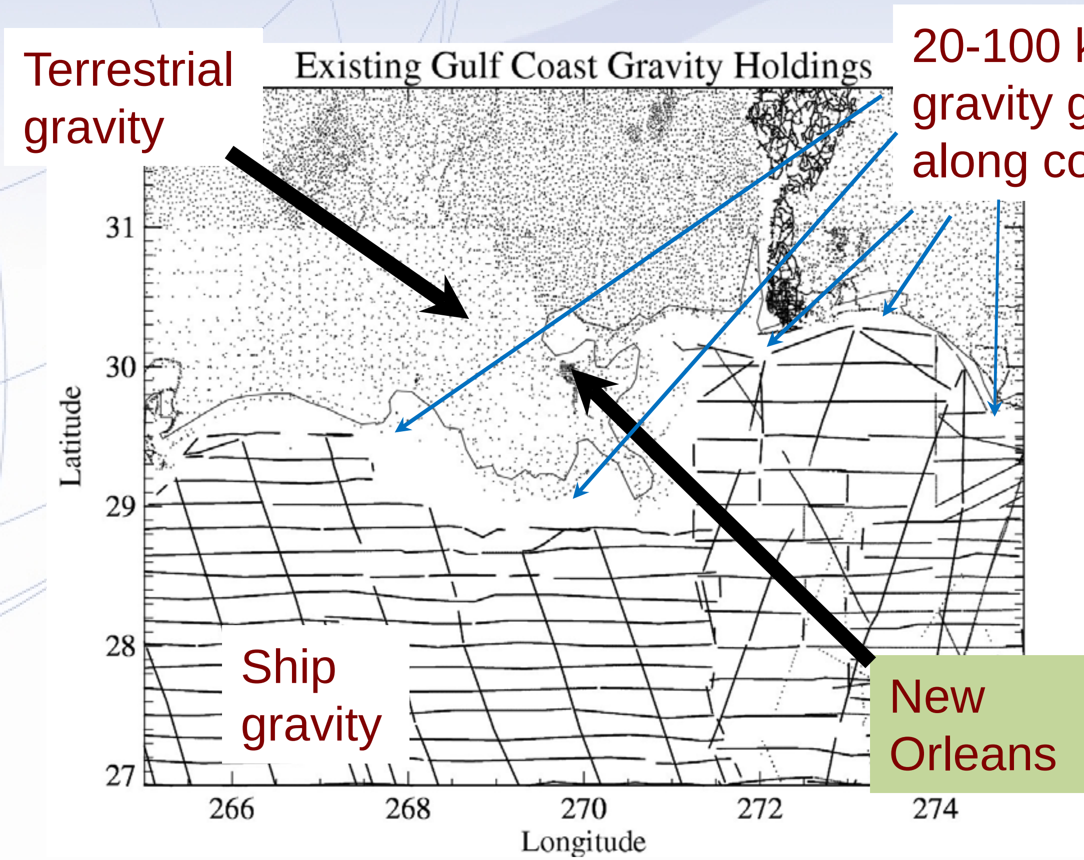


- Airborne Gravity Collection
- GPS and Gravity Data Processing
  - Kinematic positioning is critical
  - NGS-developed software
- More info:
  http://www.ngs.noaa.gov/corbin/class_description/GRAVD_0213.shtml

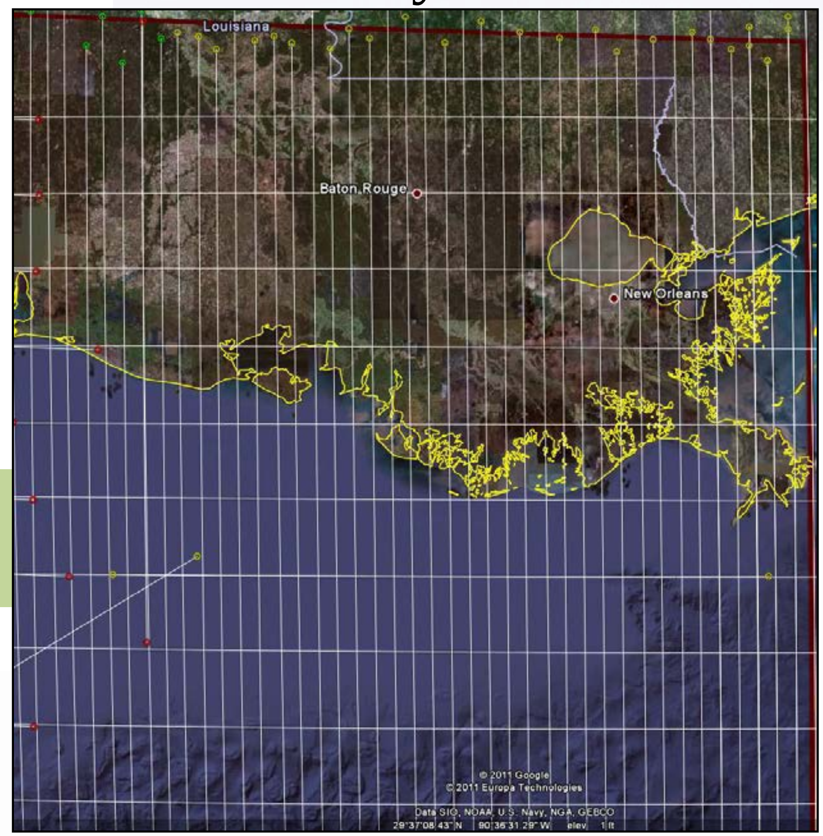


- Gravity Data Release to Public
- Inclusion in Yearly Experimental Gravimetric Geoid Models, e.g.,
  xGEOID17B

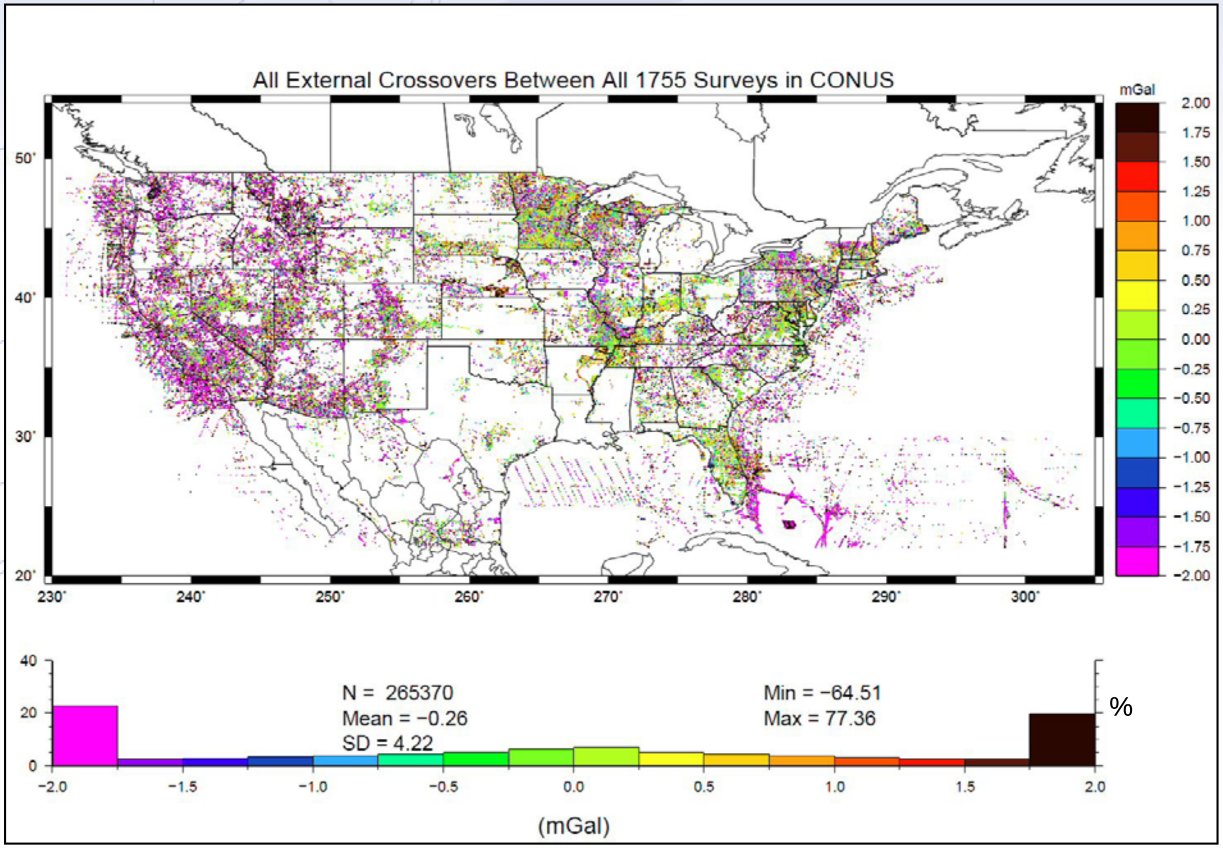
Problems with Gravity Holdings



- Field is not sampled uniformly



Problems with Gravity Holdings



- Decades of gravity surveys are inconsistent with one another
- Airborne gravity will provide a baseline for removing these inconsistencies

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 planed 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
  - GSVS17
    - 2016 - 2017; High/Rugged/Complicated: **Colorado**

Objective of the GSVSs

- How do we know that GRAV-D is working?
- The Geoid Slope Validation Surveys (GSVSs) use high precision, high resolution (~1.5km spacing), ground-based survey techniques to determine the **shape** of the geoid consistently along a large (~300km) distance.
- This allows for the direct comparison of the geoid shape predicted by various, gravity-based geoid models.
- This **also** allows for a quantification of the airborne gravity's contribution to the improvement of these models.

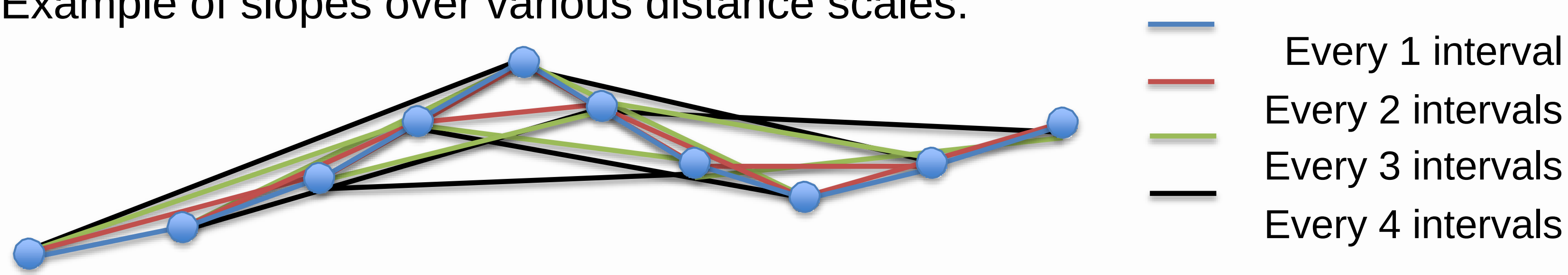
Objective of the GSVSs (cont.)

Why compare the **shape** of the models?

Rather than using "absolute" values of the geoid at specific locations to compare models, it is actually more useful to look at the changes in the shape of the geoid over various distance scales (i.e. looking at the **slope** between various pairs of survey points separated by 1, 2, 5, 10, 20, 50, 100, 200 km, etc.) .

Hence the name…

Example of slopes over various distance scales:

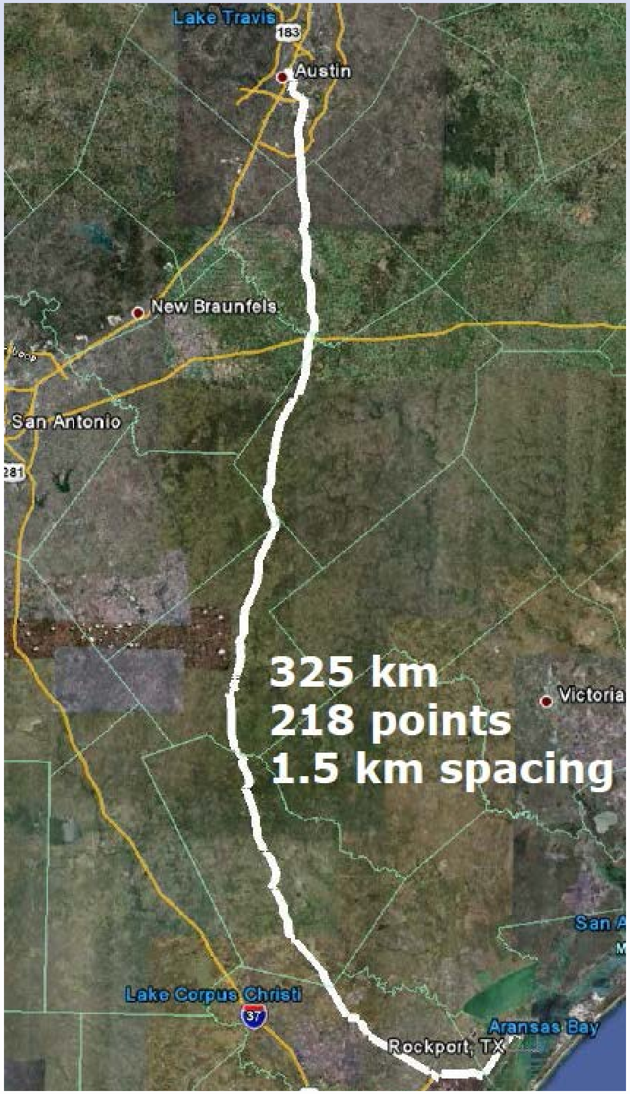


Choosing the Place and Time for a New Survey

- Criteria:
  - Significantly exceed 100 km
  - Under existing GRAV-D data
  - Avoid trees and woods
  - Along major roads
  - Cloud-free nights
  - No major bridges along the route
  - Low elevations
  - Significant geoid slope
  - Inexpensive travel costs

GSVS Survey Techniques

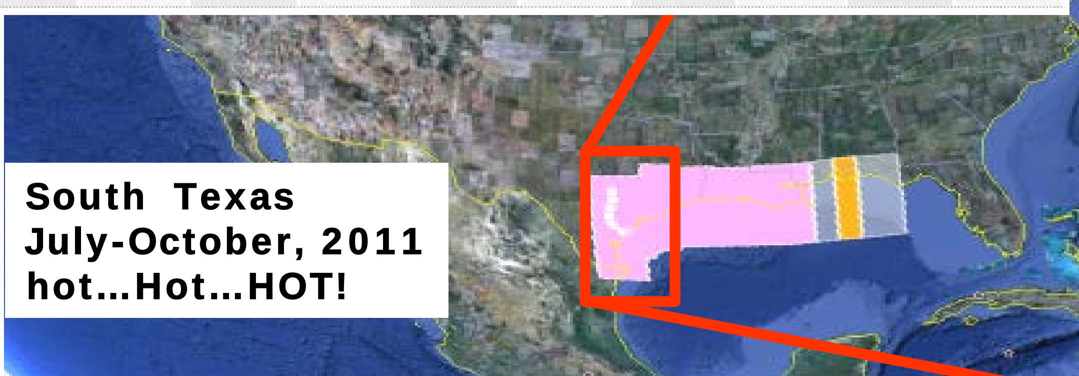
- Survey techniques employed:
  - Bechmarks installed ~1.5km
  - Leveling
  - Absolute/Relative Gravity
    - Vertical Gravity Gradient
  - Long-session GPS
  - Deflection of Vertical



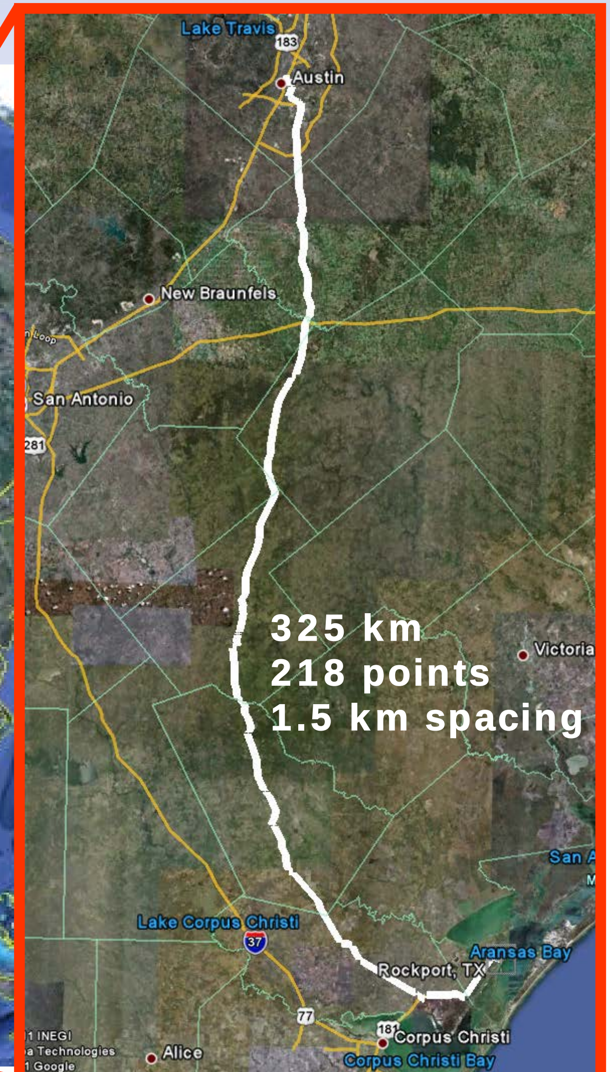
The Chosen Line in 2011

Today Aug 1	Tue 2	Wed 3	Thu 4	Fri 5	Sat 6	Sun 7	Mon 8	Tue 9	Wed 10
Sunny	Mostly Sunny	Sunny	Sunny	Sunny	Sunny	Mostly Sunny	Partly Cloudy	Partly Cloudy	Sunny
107°F High	108°	107°	106°	106°	106°	105°	105°	104°	104°
80° Low	80°	79°	78°	78°	78°	78°	77°	77°	78°

EXPAND GRAPH



South Texas
July-October, 2011
hot…Hot…HOT!

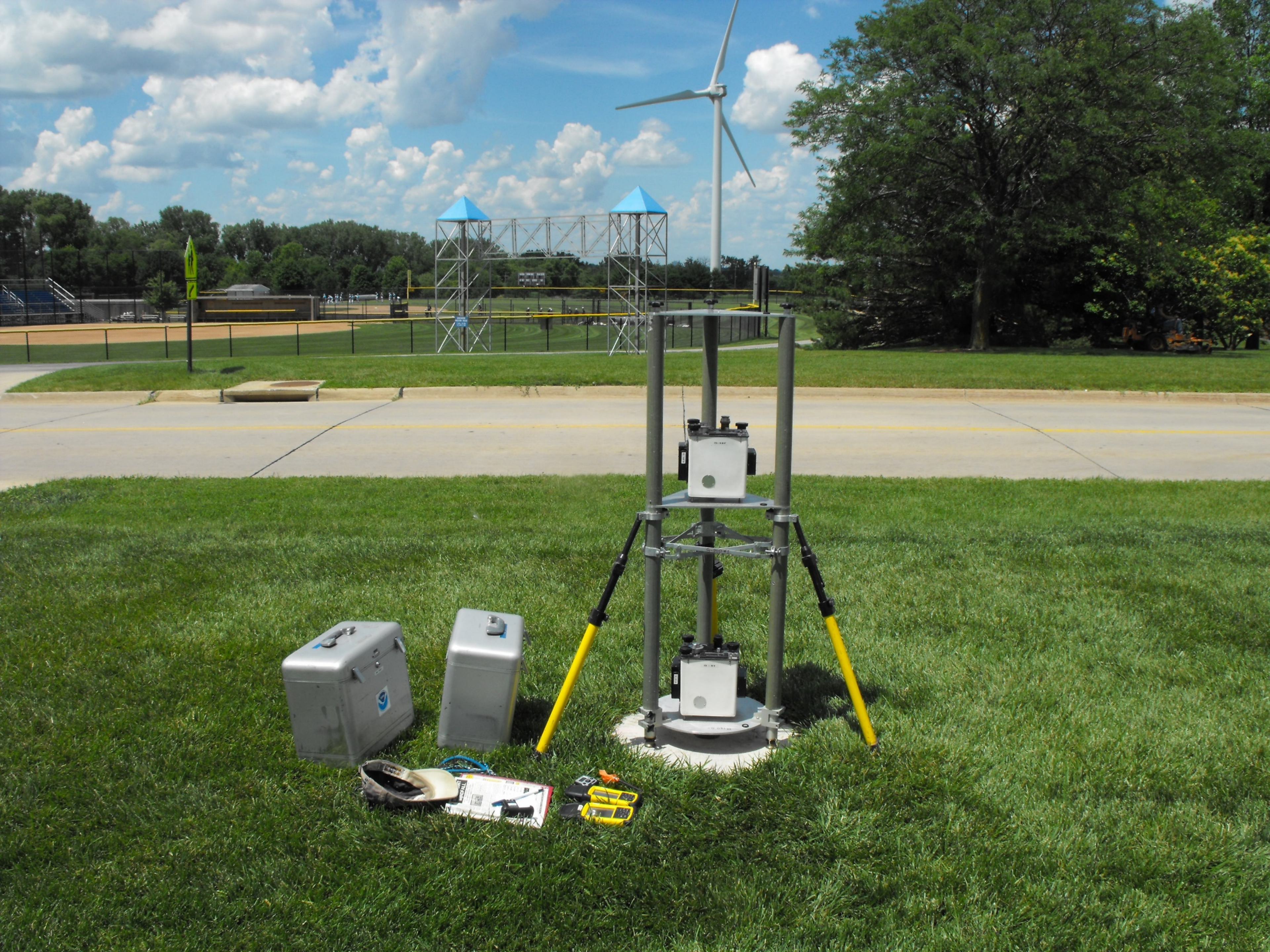


325 km
218 points
1.5 km spacing

Leveling and Gravity

- The entire line was leveled (double-run). Geodetic heights provided at each benchmark.
- Leveling and gravity are both needed for orthometric height determination. Usually gravity is modeled, but in this case was actually measured at every point.
  - Relative gravity and vertical gravity gradient at every benchmark
  - Absolute gravity (A10 and/or FG5) at ~every 7th benchmark

Geodetic Leveling



Gravity Observations

Long Period GPS

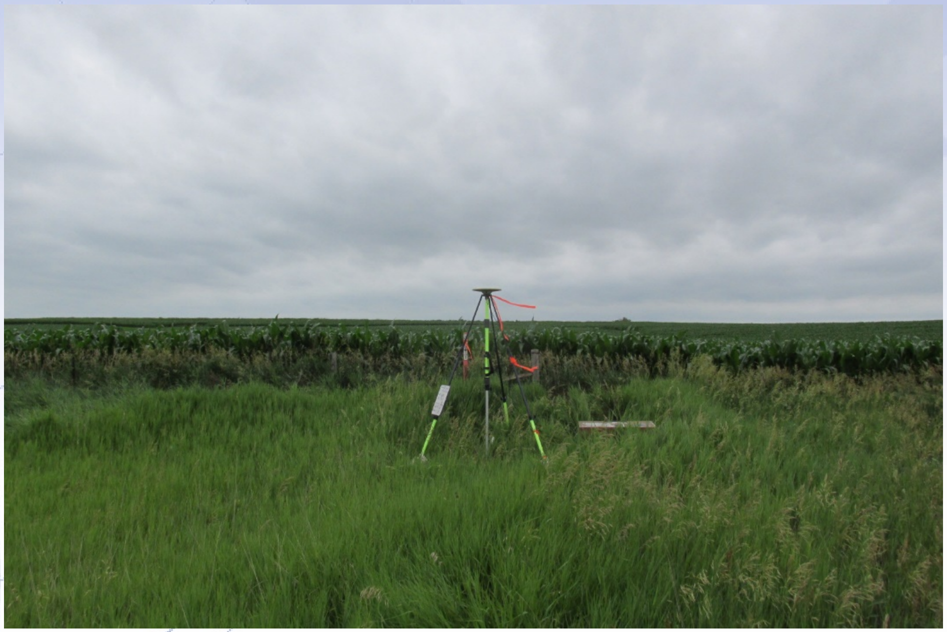
- Calibrated, fixed-height antennas, all identical models
- In Texas 2011:
  - 20 complete sets of equipment (2 parties, 10 sets each)
  - Each party observed 10 new stations each day
  - 20 hours of observation each day
  - Project processed with OPUS Projects

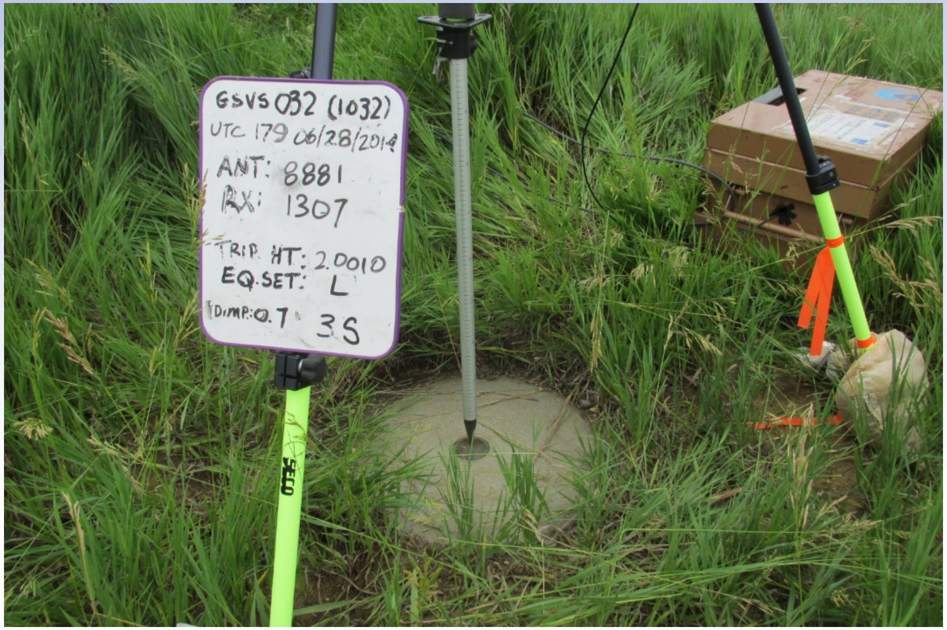
Campaign GPS

- Full antenna recalibration check before survey
- Each fixed height tripod height measured before and after
- 20 complete sets of equipment - 2 parties (10 sets each)
- Each party observe 5 new and 5 repeat stations each day
- 30 observation days
- Project processed with OP

ID	before	after	a - b	avg.
A	2.0028	2.0029	0.0001	2.0029
B	2.0019	2.0018	-0.0001	2.0018
C	2.0005	2.0002	-0.0003	2.0004
D	2.0079	2.0079	0.0000	2.0079
E	2.0011	2.0010	-0.0001	2.0010
F	1.9999	1.9998	-0.0001	1.9998
G	2.0006	2.0009	0.0003	2.0008
H	2.0016	2.0017	0.0001	2.0017
I	2.0020	2.0020	0.0000	2.0020
J	2.0041	2.0041	0.0000	2.0041
K	2.0003	2.0004	0.0001	2.0003
L	2.0010	2.0007	-0.0003	2.0008
M	2.0000	2.0002	0.0002	2.0001
N	1.9964	1.9963	-0.0001	1.9963
O	2.0005	2.0005	0.0000	2.0005
P	2.0003	2.0002	-0.0001	2.0002
Q	2.0024	2.0029	0.0005	2.0027
R	1.9999	1.9999	0.0000	1.9999
S	2.0052	2.0052	0.0000	2.0052
T	2.0026	2.0023	-0.0003	2.0024
U	2.0031	2.0031	0.0000	2.0031
V	1.9995	1.9995	0.0000	1.9995
W	2.0002	2.0003	0.0001	2.0003
X	2.0020	2.0022	0.0002	2.0021
Y	2.0053	2.0053	0.0000	2.0053
Z	2.0016	2.0014	-0.0002	2.0015

The "Dimple-ometer"




GSVS 032 (1032)
UTC 179 06/28/2014
ANT: 8881
RX: 1307
TRIP HT: 2.0010
EQ. SET: L
DIMP: 0.7 3S

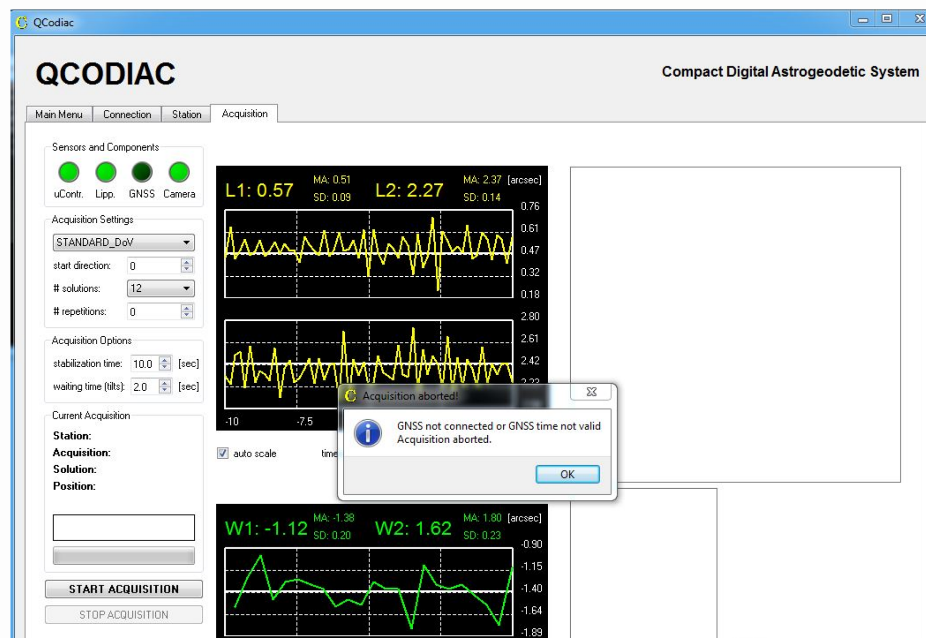

NATIONAL GEODETIC SURVEY • NOAA
GSVS
032
2013
GEODETIC CONTROL MARK


$70 FINE
PLUS COSTS
FOR DISPOSAL
OF LITTER
ON HIGHWAY

Deflection of the Vertical (DoV)

- Measure the slope of the geoid directly!
- Precision tilt meters provide alignment "level" to the geoid.
- Celestial almanacs provide predicted alignment with star field (relative to ellipsoid).
- The difference between the two vectors (broken into orthogonal components) are the Deflections of the Vertical (or "slopes").
- In Iowa 2014:
  - 228 stations (204 official points, 11 redundant observations, 3 reobservations)
  - 31 nights
  - 7 stations/night
  - Observing with Swiss CODIAC (COmpact DIgital Astrometric Camera)

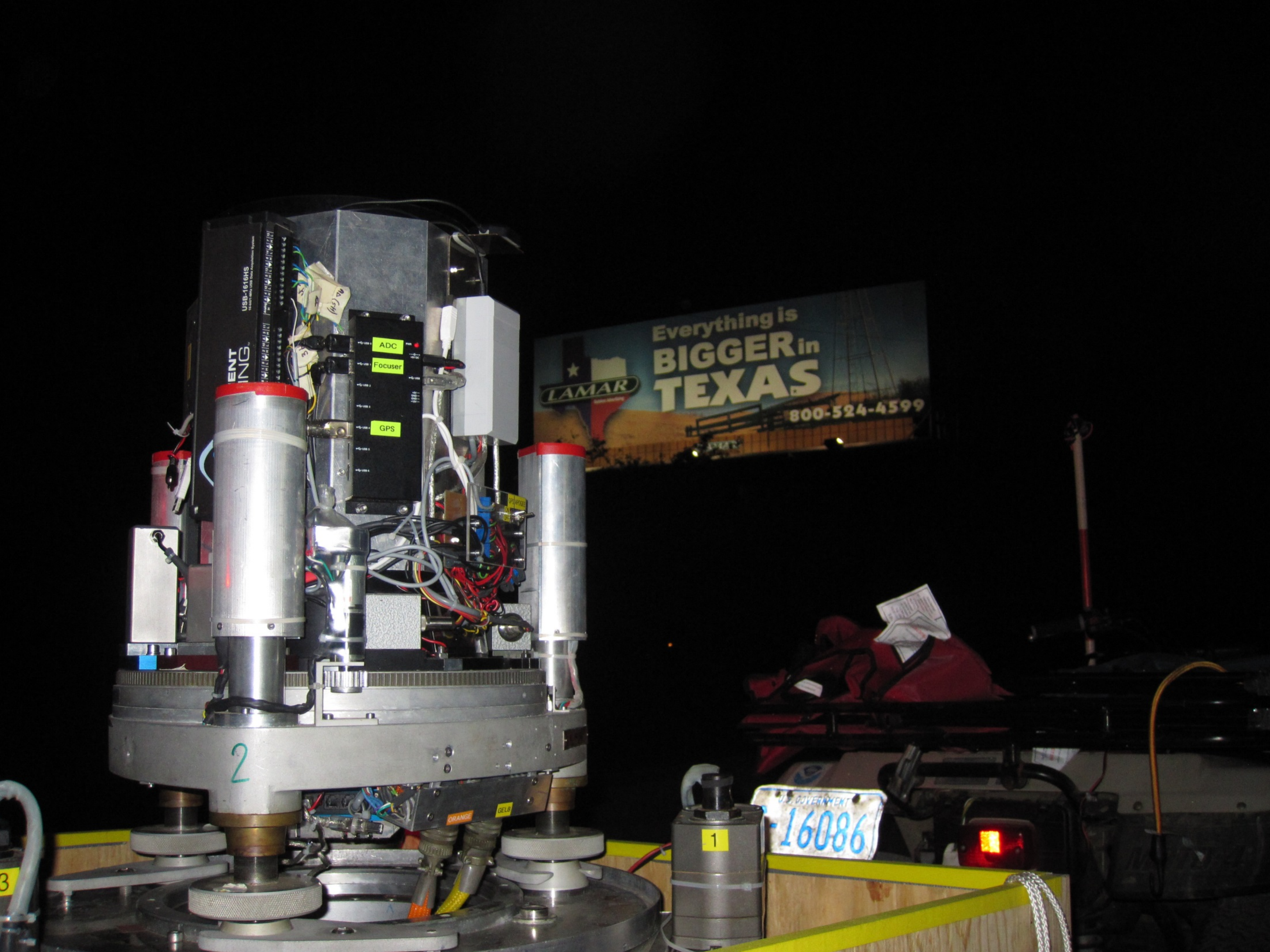
for th


QCodiac
QCODIAC
Compact Digital Astrogeodetic System
Main Menu
Connection
Station
Acquisition
Sensors and Components
uContr.
Lipp.
GNSS
Camera
Acquisition Settings
STANDARD_DoV
start direction: 0
solutions: 12
repetitions: 0
Acquisition Options
stabilization time: 10.0 [sec]
waiting time (tilts): 2.0 [sec]
Current Acquisition
Station:
Acquisition:
Solution:
Position:
START ACQUISITION
STOP ACQUISITION
L1: 0.57
MA: 0.51
SD: 0.09
L2: 2.27
MA: 2.37
SD: 0.14
[arcsec]
W1: -1.12
MA: -1.38
SD: 0.20
W2: 1.62
MA: 1.80
SD: 0.23
[arcsec]
auto scale
Acquisition aborted!
GNSS not connected or GNSS time not valid
Acquisition aborted.
OK
Options

or th

Field setup with wind-shield


SHERIFF
OFFICE


USB-1616HS
ADC
Focuser
GPS
Everything is
BIGGER in
TEXAS
LAMAR
800-524-4599
2
ORANGE
GELB
1
U.S. GOVERNMENT
16086

GSVS11, South Texas

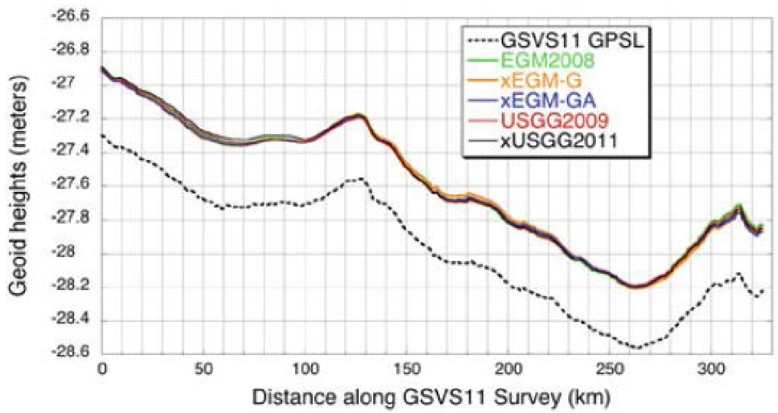


Fig. 11 Geoid profiles along the GSVS11 survey line

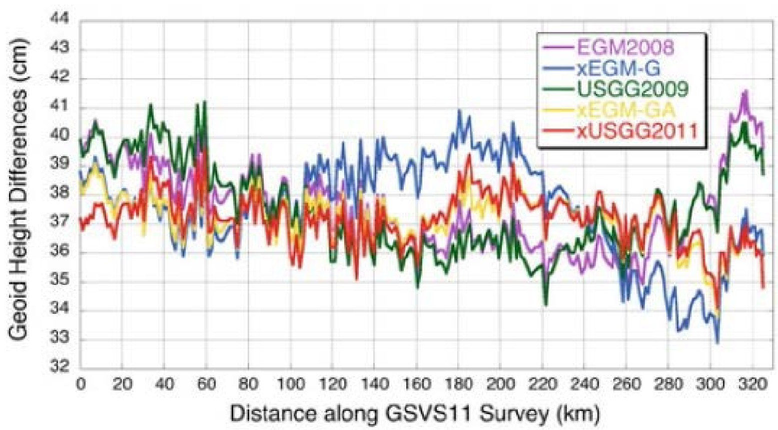


Fig. 12 Differences (cm) between Gravimetric Geoid Models and GPS/leveling along GSVS11

- The first survey was performed in south Texas in 2011
- Low (close to the geoid) and flat.

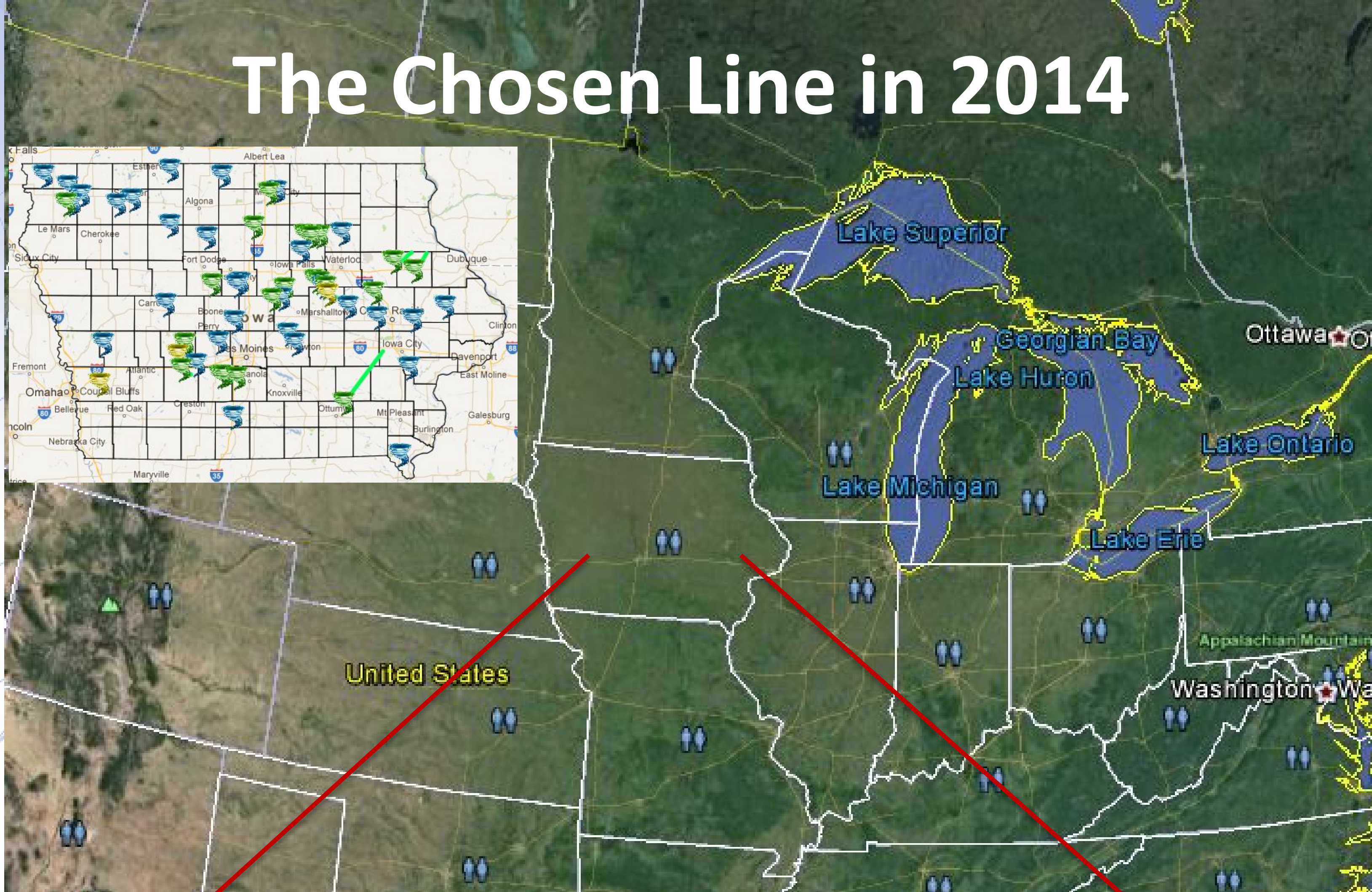
Results were excellent!

"Confirming regional 1 cm differential geoid accuracy from airborne gravimetry: the Geoid Slope Validation Survey of 2011", Smith *et al.*, Journal of Geodesy, 2013.

GSVS14 Iowa

- After the success of GSVS11, Iowa was chosen for the next test in 2014.
- Higher elevation and geologically interesting terrain (traversing the Midcontinent Rift System).
- (Very) similar survey techniques were employed.
- Preliminary results again show excellent (<2 cm geoid discrepancy) agreement and noticeable improvement when airborne data are included. March 2017: Accepted for publication in Journal of Geodesy

The Chosen Line in 2014



Central Iowa
330 km
205 points

Geodetic Leveling

- Two crews of 4-5 people/crew
- 1^{st} order Class II
- 749 km
- 105 crew days
- 7.1 km/day/crew

Gravity Observations

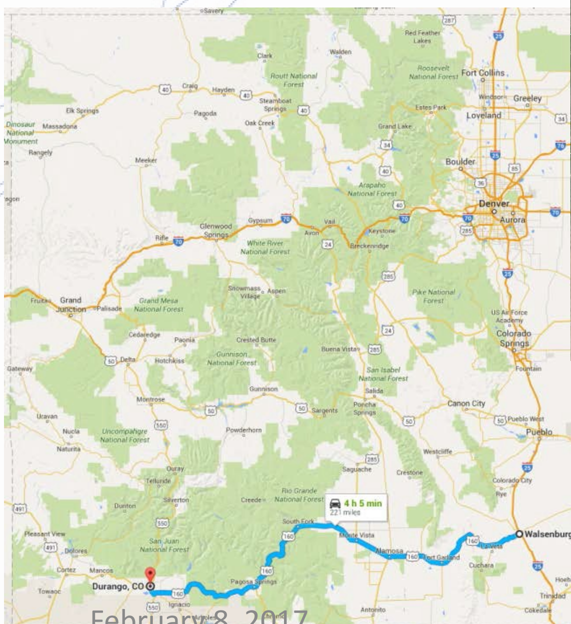
- 3 1st-order Class II stations
  - Dennison, Ames, Cedar Rapids
- A-10 Absolute stations (every 7th station)
- Gravity Gradients (every 7th station)
  - 2 stations per day, 31 days to observe
- Relative Gravity (205 stations)
  - 10 per day, 23 days to observe

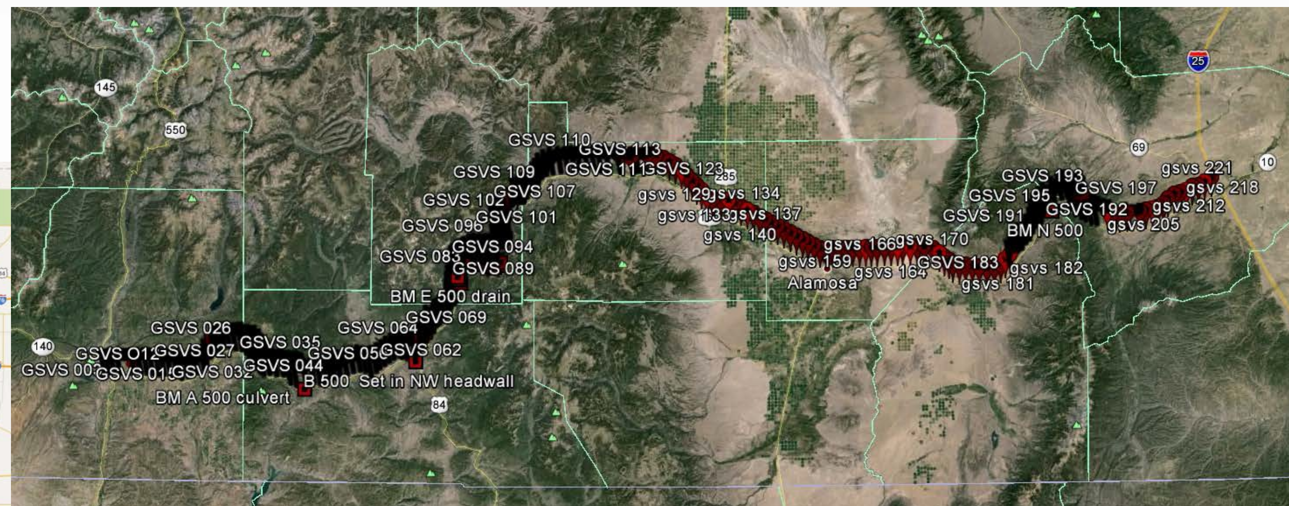
DoV

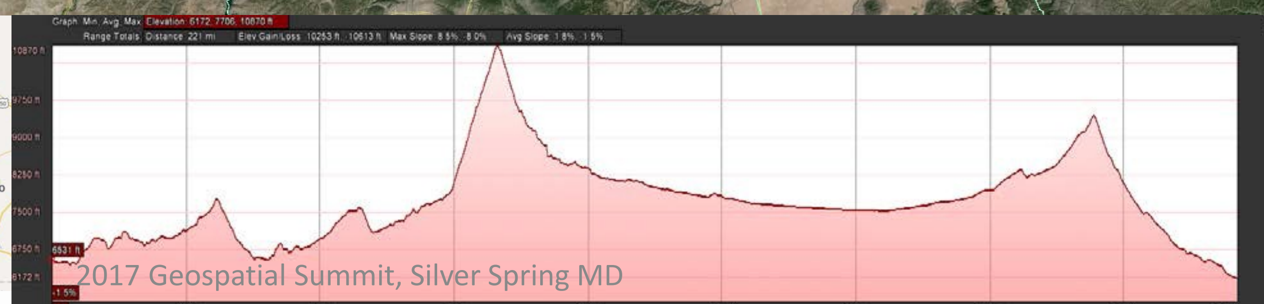
- 228 stations (204 official points, 11 redundant observations, 3 reobservations)
- 31 nights
- 7 stations/night
- Observing with Swiss CODIAC COmpact DIgital Astrometric Camera

GSVS17 Colorado

- The third (and likely final) GSVS will take place along US160, from Durango to Walsenburg, in southern Colorado.
- High elevation and rugged topography. “Worst case” for geoid modeling.
- Variation from 6,000’ (MSL) to 11,000’, over two passes.







GSVS17 Colorado (cont.)

- 220 benchmark locations (approximately 1 per mile) have been installed
- The survey will take place in overlapping phases beginning May 2017 and is expected to continue through September.

Differences with GSVS17

- Numerous "extra" bench marks had to be installed for leveling accuracy purposes (very steep terrain in some sections).
- Absolute gravity (A10) and quadratic (3 tier) gravity gradients measured at all benchmarks.
- Topographic corrections are being developed to aid in field DoV quality control as well as post-survey geoid modeling.

Conclusions – Problems (IA)

- Flooding (access to marks) in June
- One damaged fixed-height tripod
- Tall grass, ticks, mosquitoes
- Trains, Trains, Trains on Western 1/3rd of line

Conclusions-Successes (IA)

- Over a year of planning and preparation
- Two Co-Project Managers (Scientific/Admin)
- Single Team-Lead for each activity
- Frequent Team meetings (pre-deployment)
- Team-Leads wrote the project instructions
- Field work was successfully completed on time and was of high quality

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

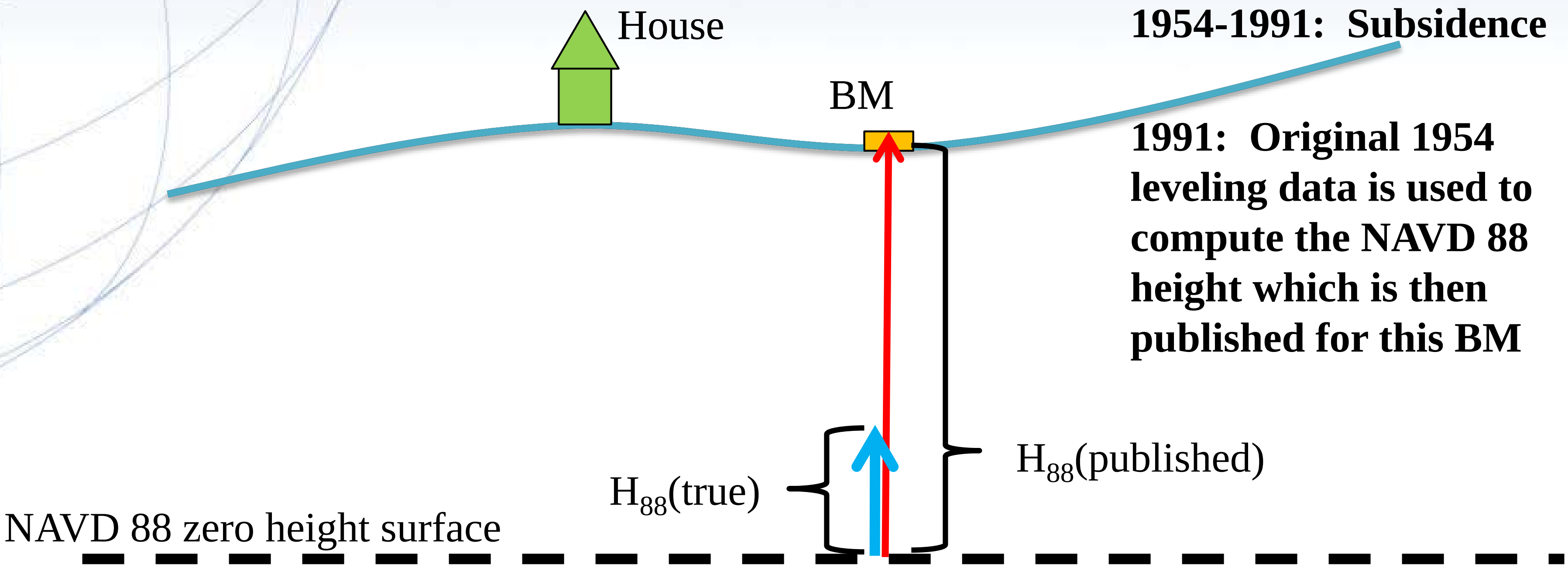
How will I access the new vertical datum?

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

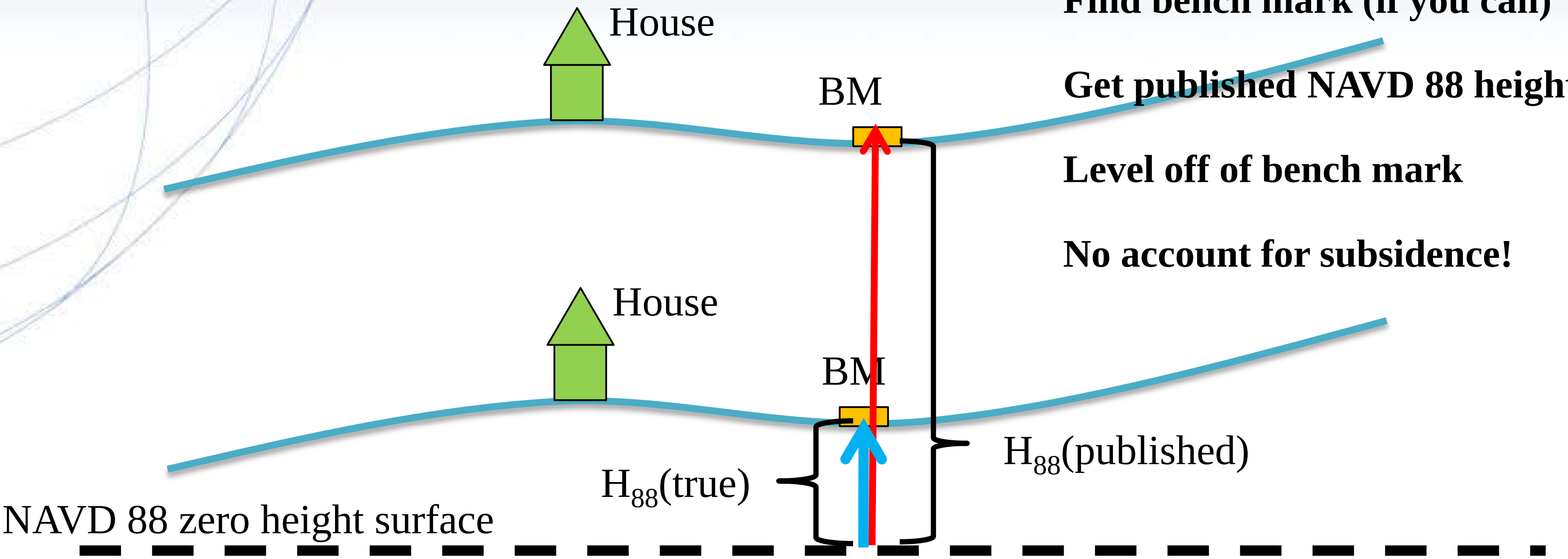
Using <u>Existing</u> Techniques:

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

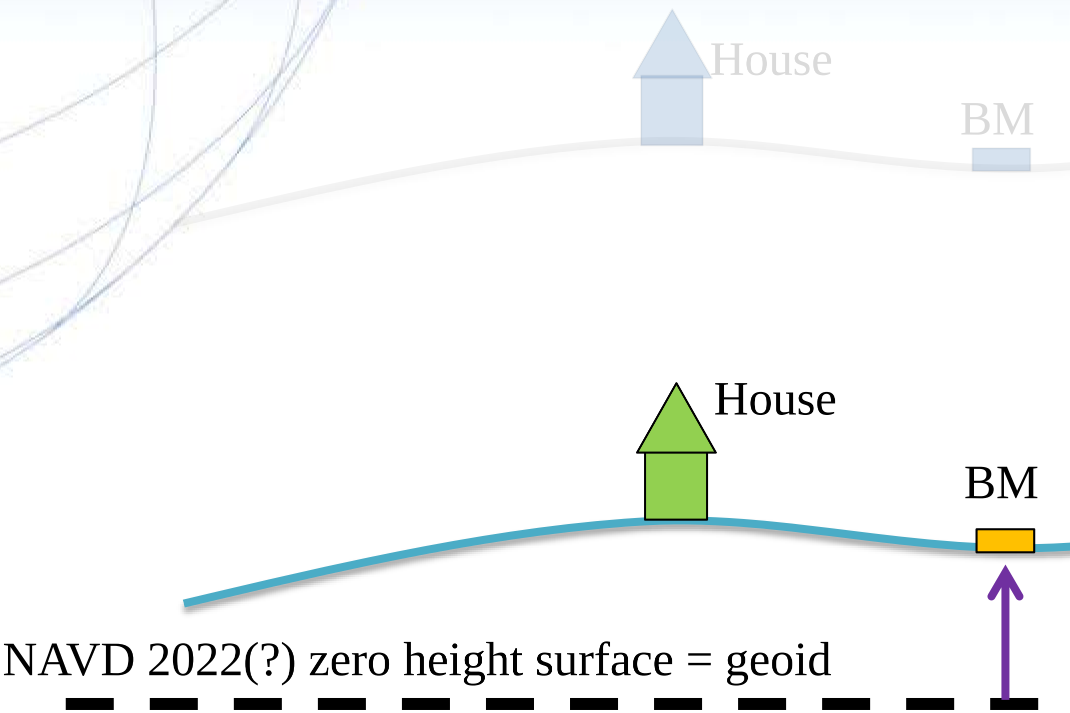
Using <u>Future</u> Techniques:

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

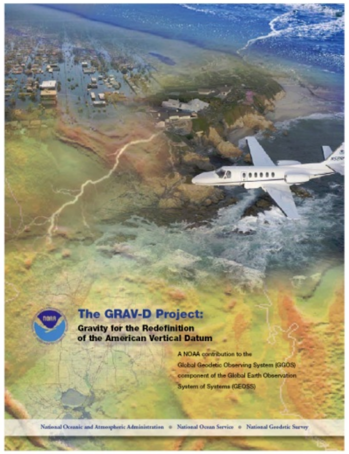
Level off of bench mark as needed

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

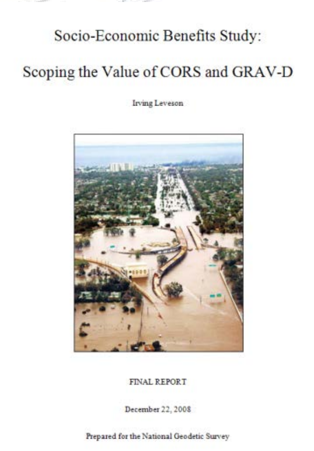


Additional Information

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

National Geodetic Survey × | National Oceanic and Atm ×

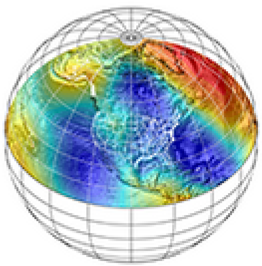
www.ngs.noaa.gov/datums/newdatums/NewDatums.shtml

Apps | Google Apps for GVT | OPUS and GPRA Sta... | National Geodetic S... | National Geodetic S...

New Datums

National Geodetic Survey

NGS Home | About NGS | Data & Imagery | Tools | Surveys | Science & Education | Search



Contact Us

Sign up for list-serve

2015 Geospatial Summit

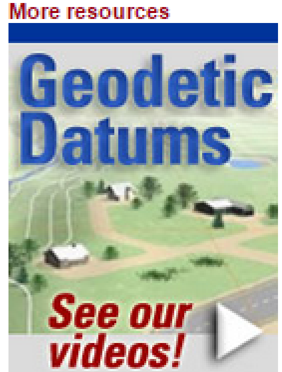
2010 Federal Geospatial Summit Proceedings

January 14, 2015

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 Refererence Stations). NGS expects to establish one to two new Foundation CORS per year and will oversee the

Predicted Positional Changes in 2022
Vicinity of New Britain,CT

(Computed for station W 91, pid LX3162)

HORIZONTAL = 1.20 m (3.9 ft)
ELLIPSOID HEIGHT = - 1.23 m (- 4.0 ft)
Predicted with HTDP

ORTHOMETRIC HEIGHT = - 0.32 m (- 1.1 ft)
Predicted with HTDP and xGEOID16B

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

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

What's Next for Geodetic Datums?

https://www.youtube.com/playlist?list=PLsyDl_aqUTdFY6eKURmiCBBk-mP4R10Dx

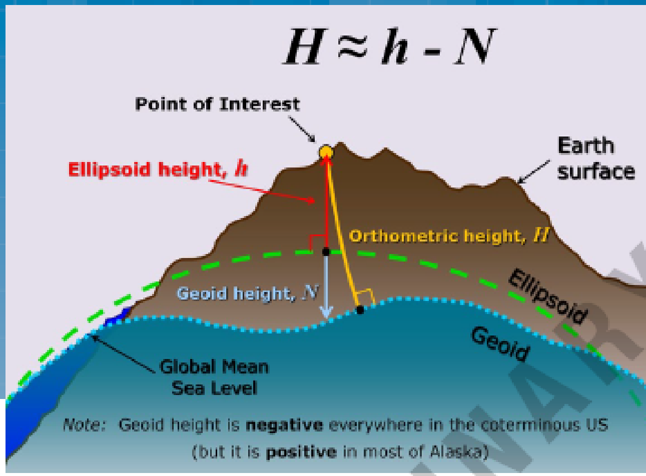


Figure 5. The relationship between orthometric height (H), ellipsoid height (h), and geoid height (N). Note that the geoid is below the reference ellipsoid in the coterminous US, hence the geoid height is negative (i.e., H > h). Both ellipsoid and geoid heights are determined from the ellipsoid; the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

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.

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