Evolution of the NSRS

Maine Society of Land Surveyors
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GEODETIC DATUMS

HORIZONTAL

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

VERTICAL

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

GEOMETRIC

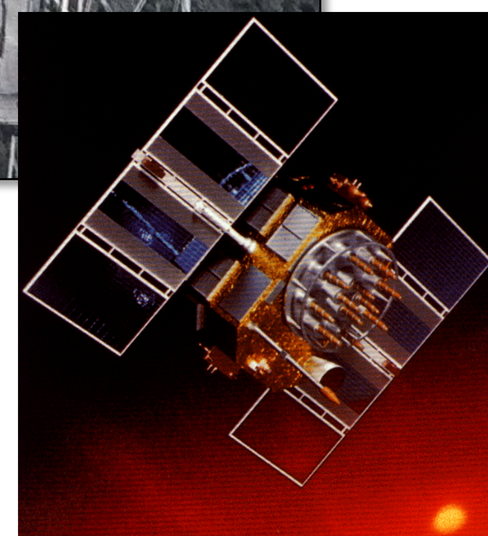
3 D (Latitude, Longitude and Ellipsoid Height)
Fixed and Stable - Coordinates seldom change
(e.g. NAD 83 (1996), NAD 83 (2007), NAD 83 (CORS96))

also

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

A (very) brief history of NAD 83

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



Why change datums/Realizations

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

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

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

COORDINATE CHANGES

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

The NSRS has evolved

1 Million Monuments (Separate Horizontal and Vertical Systems) → 70,000 Passive Marks (3-Dimensional)

Passive Marks (Limited Knowledge of Stability) → 1,897 GPS CORS (Time Dependent System Possible; 4-Dimensional)

GPS CORS → GNSS CORS

ITRF2008, IGS08 AND NAD 83(2011)

ITRF2008

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

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

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

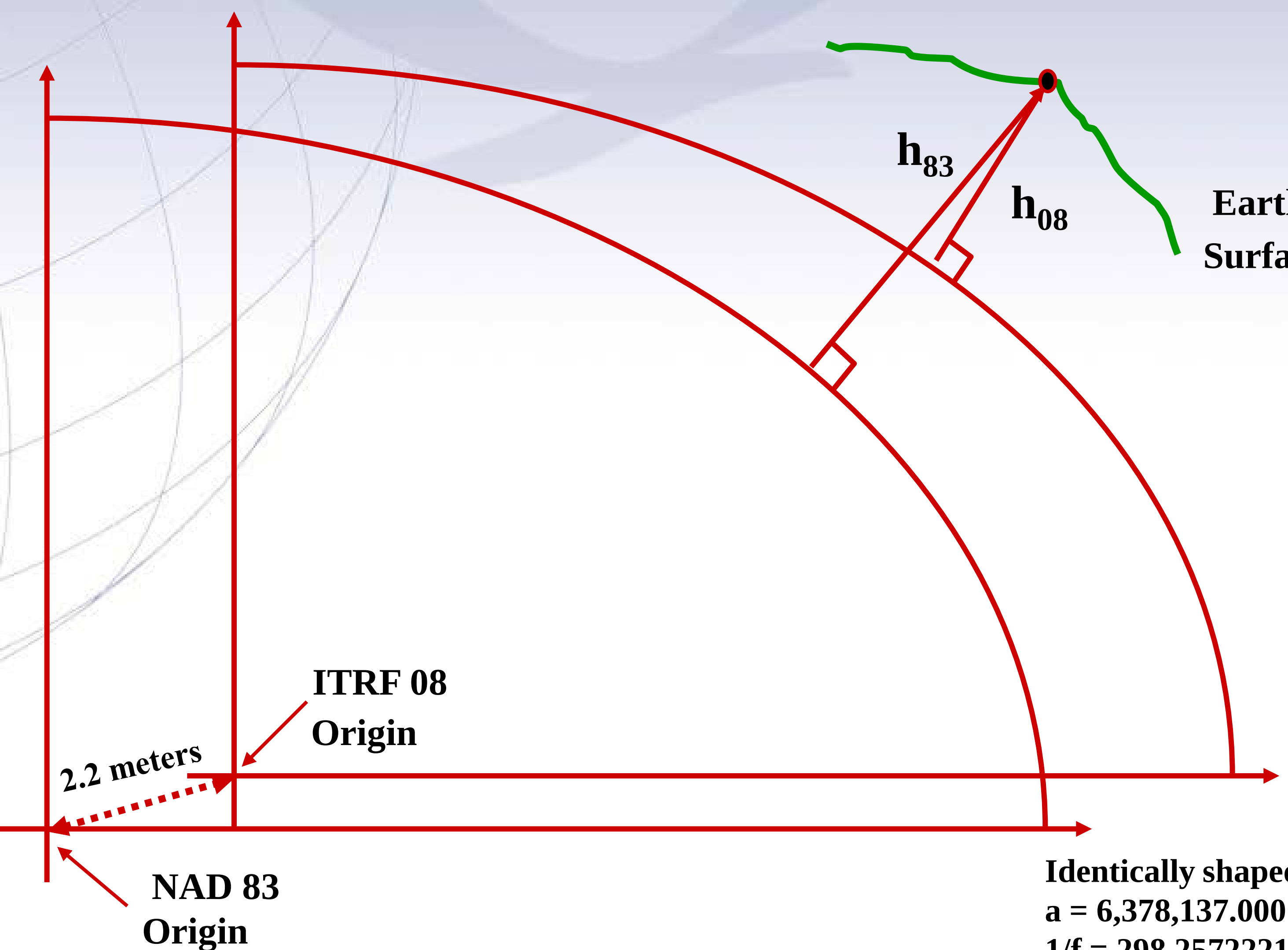
ITRS is realized by the International Terrestrial Reference Frame (**ITRF**) based upon estimated coordinates and velocities of a set of stations observed by Very Long Baseline Interferometry (**VLBI**), Satellite Laser Ranging (**SLR**), Global Positioning System and GLONASS (**GNSS**), and Doppler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

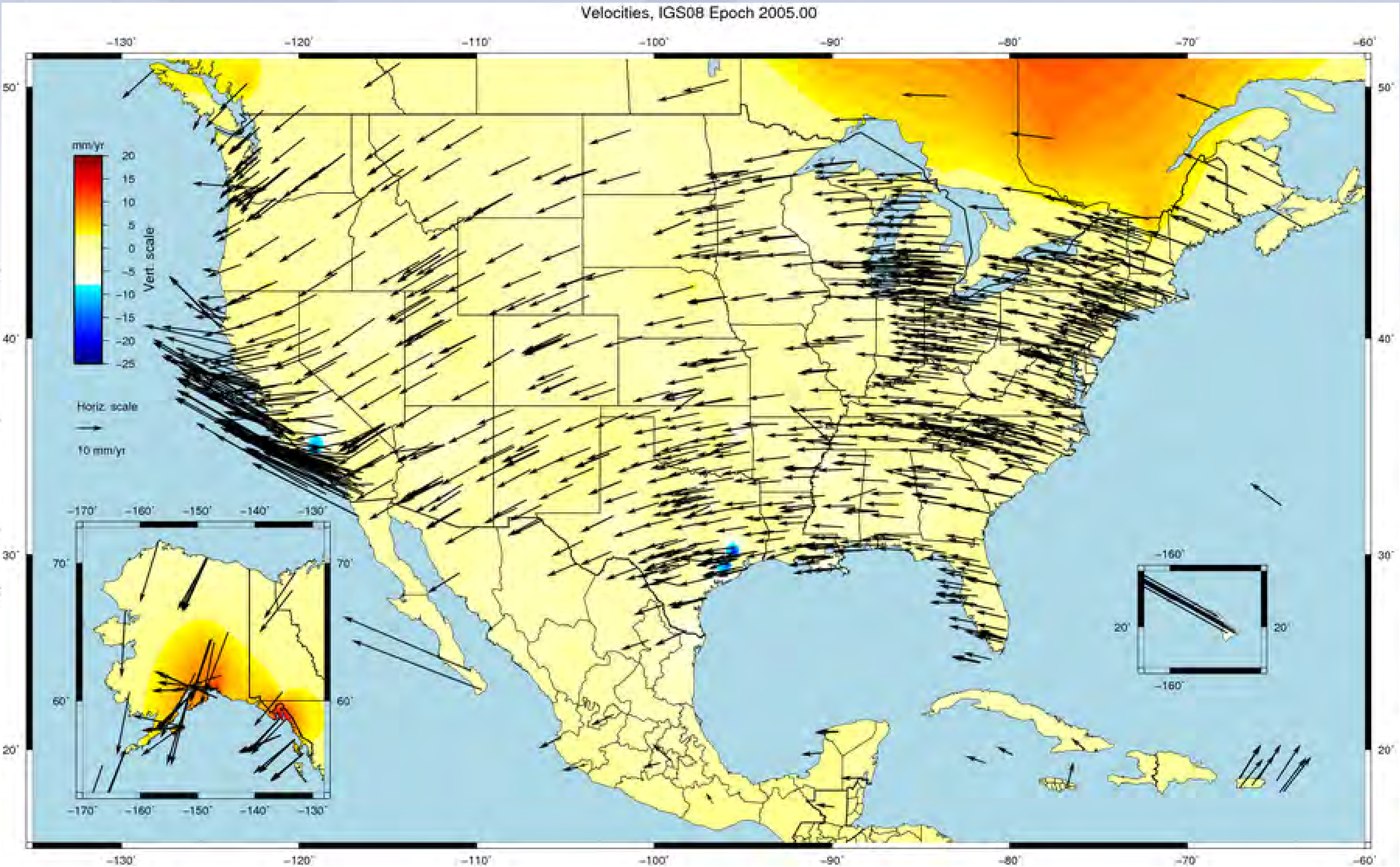
The ITRF2008 is expressed through the coordinates and velocities of marks on the ground plus ancillary data.

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
20
15
10
5
0
-5
-10
-15
-20
-25
Vert. scale
Horiz. scale
10 mm/yr
-130˚
-120˚
-110˚
-100˚
-90˚
-80˚
-70˚
-60˚
50˚
40˚
30˚
20˚
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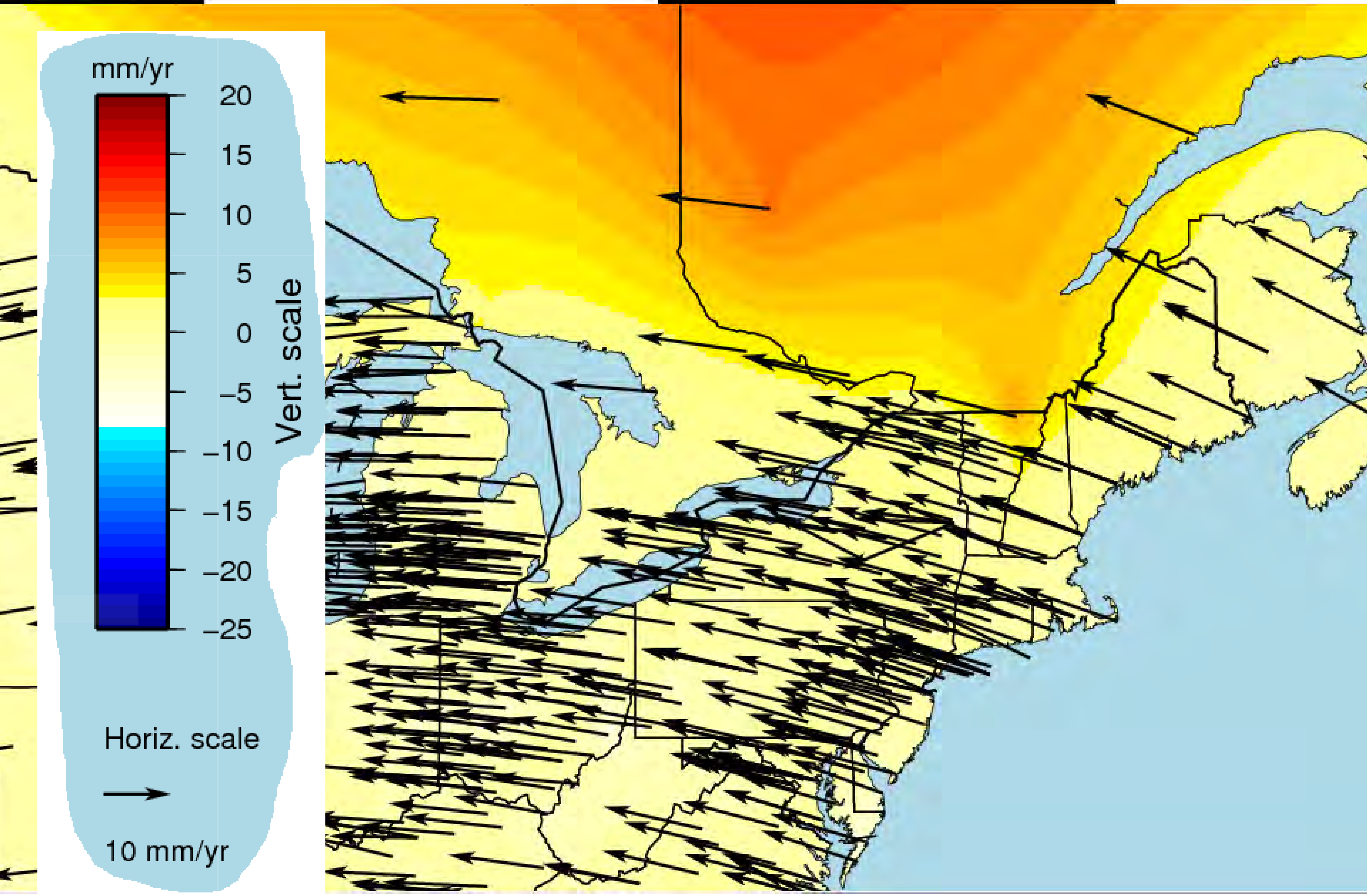
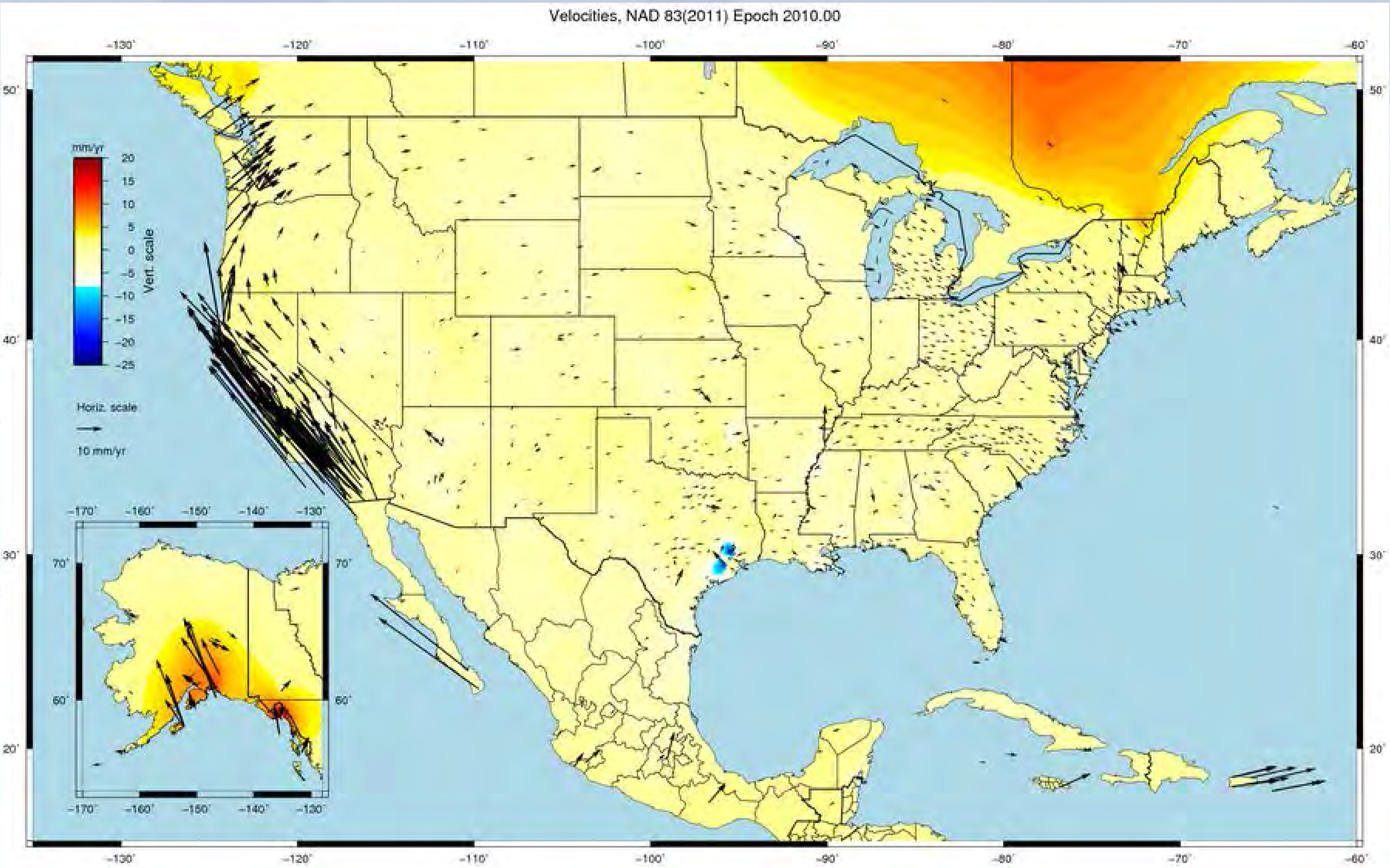
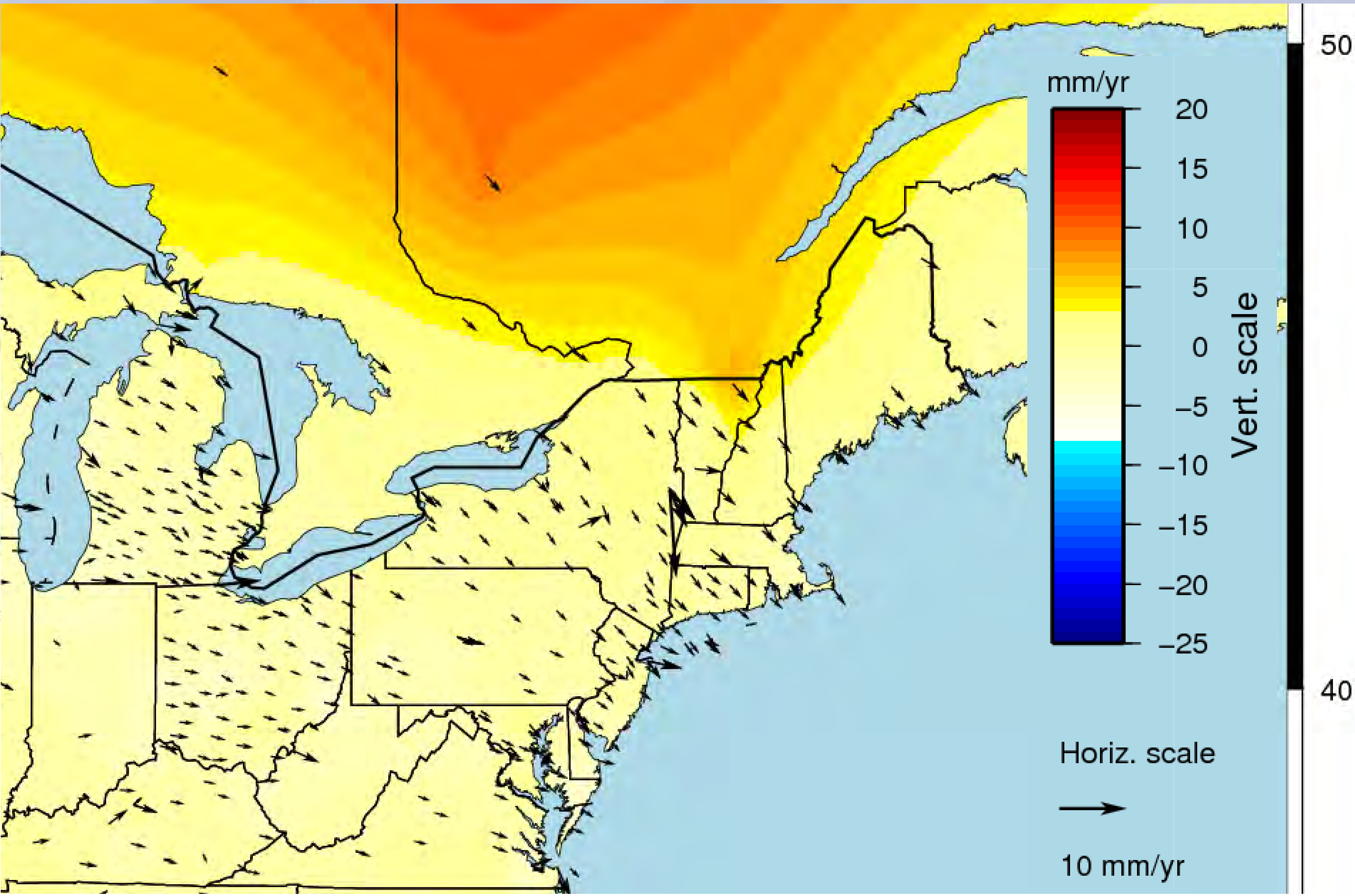
-150˚
-140˚
70˚
60˚


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


Velocities, NAD 83(2011) Epoch 2010.00
mm/yr
20
15
10
5
0
-5
-10
-15
-20
-25
Vert. scale
Horiz. scale
10 mm/yr
-130˚
-120˚
-110˚
-100˚
-90˚
-80˚
-70˚
-60˚
50˚
40˚
30˚
20˚
-170˚
-160˚
-150˚
-140˚
70˚
60˚



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

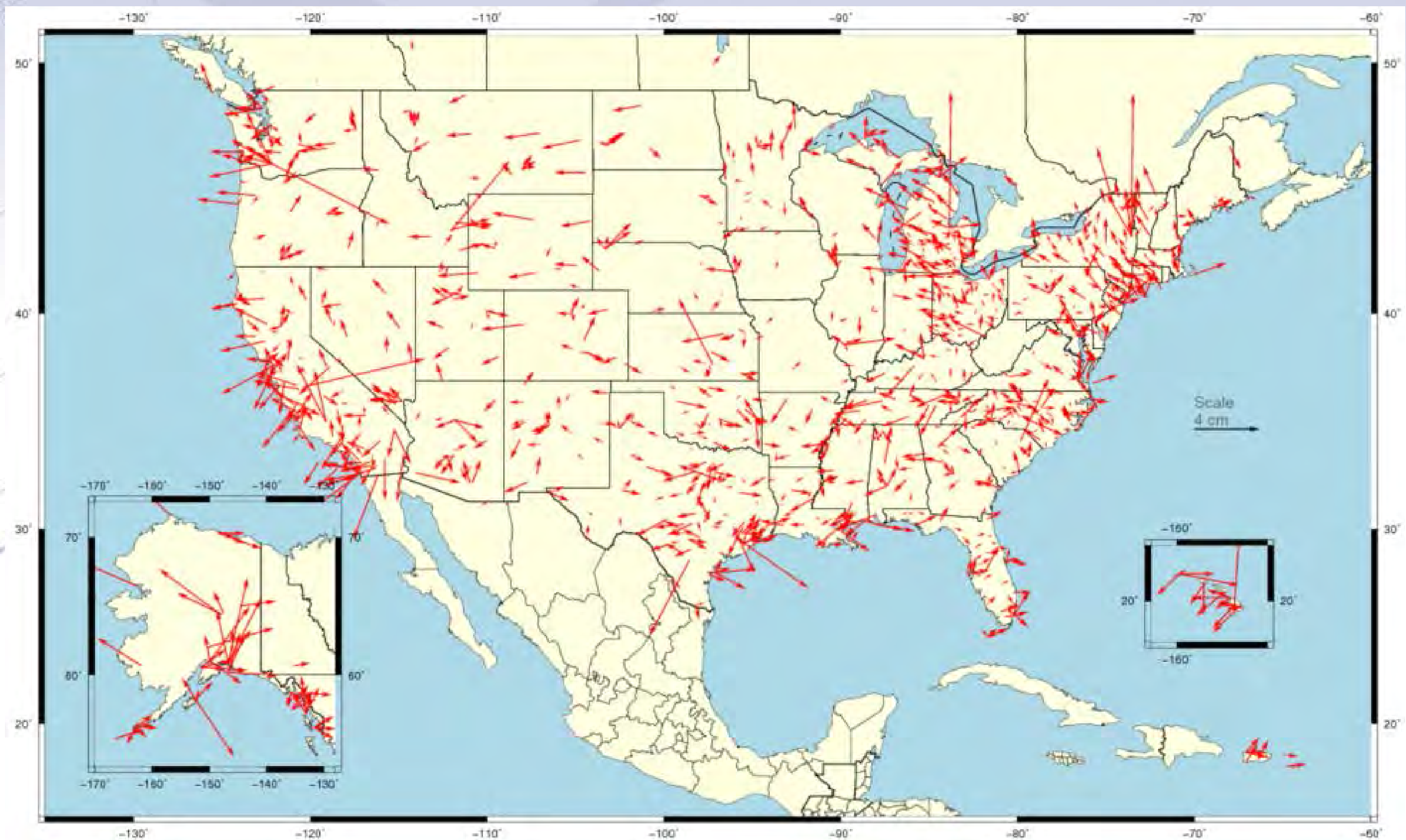
NAD 83 (2011)

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

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

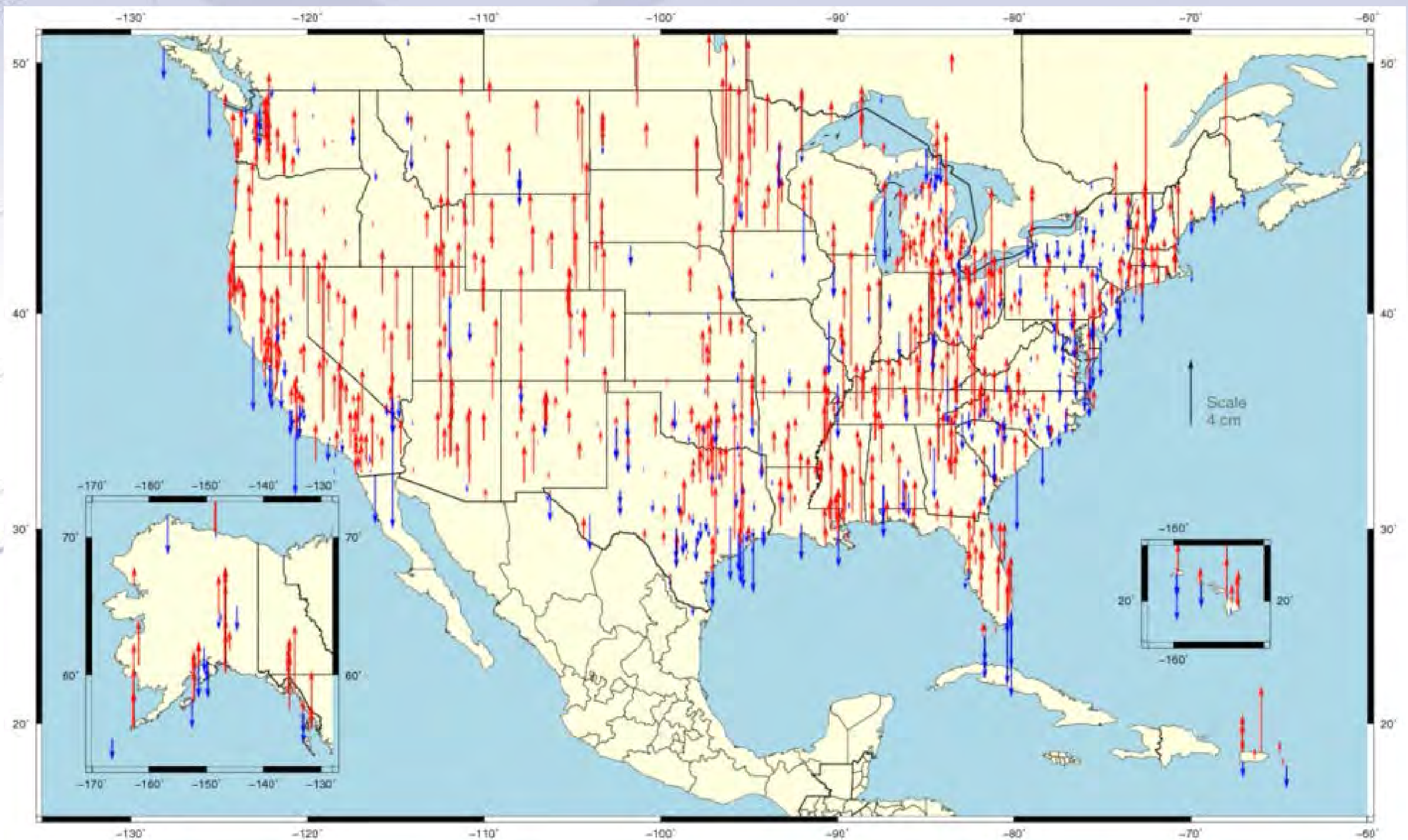
In September 2011, NGS formally released IGS08 and NAD 83 (2011) coordinates and velocities for the CORS. Information about the IGS08 and NAD 83 (2011) can be found at geodesy.noaa.gov/CORS/coords.shtml.

Horizontal Differences In CORS Positions



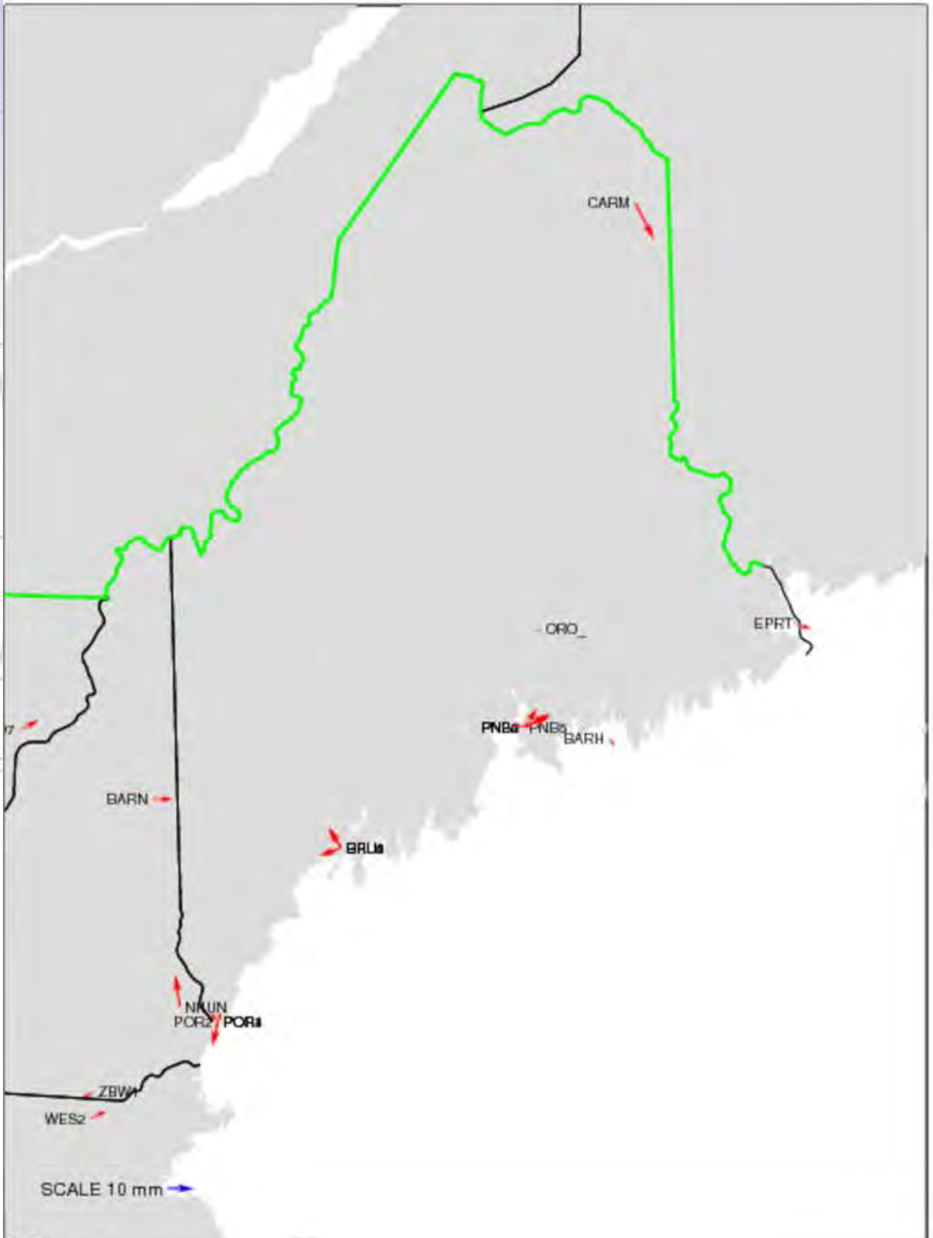
Horizontal difference in positions of NAD 83(2011) epoch 2002.00 minus NAD 83(CORS96) epoch 2002.00.

Vertical Differences In CORS Positions

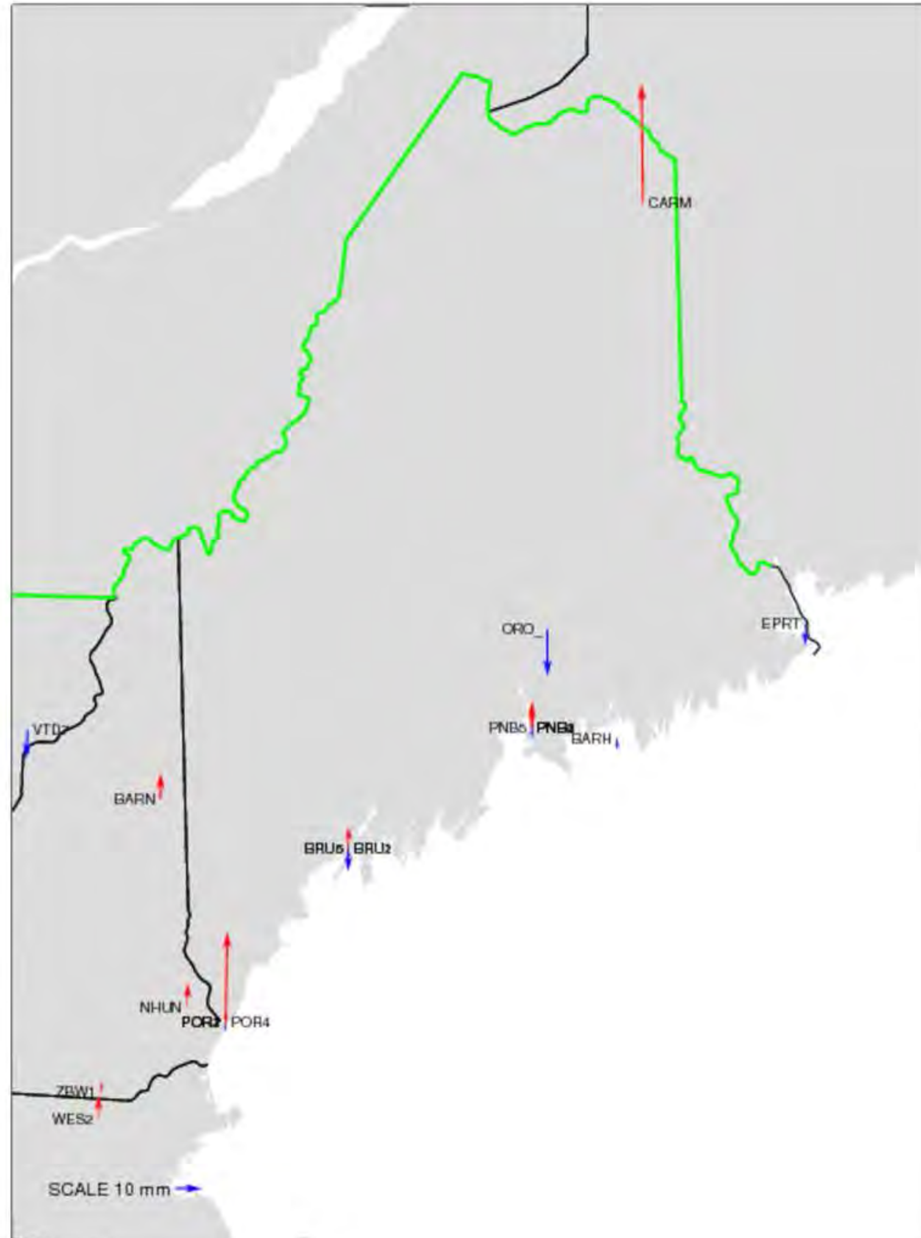


Vertical difference in positions of NAD 83(2011) epoch 2002.00 minus NAD 83(CORS96) epoch 2002.00.

ME Horizontal POSITIONS NAD 83(2011) 2002.00 minus NAD 83(CORS96) 2002.00



ME Vertical POSITIONS NAD 83(2011) 2002.00 minus NAD 83(CORS96) 2002.00

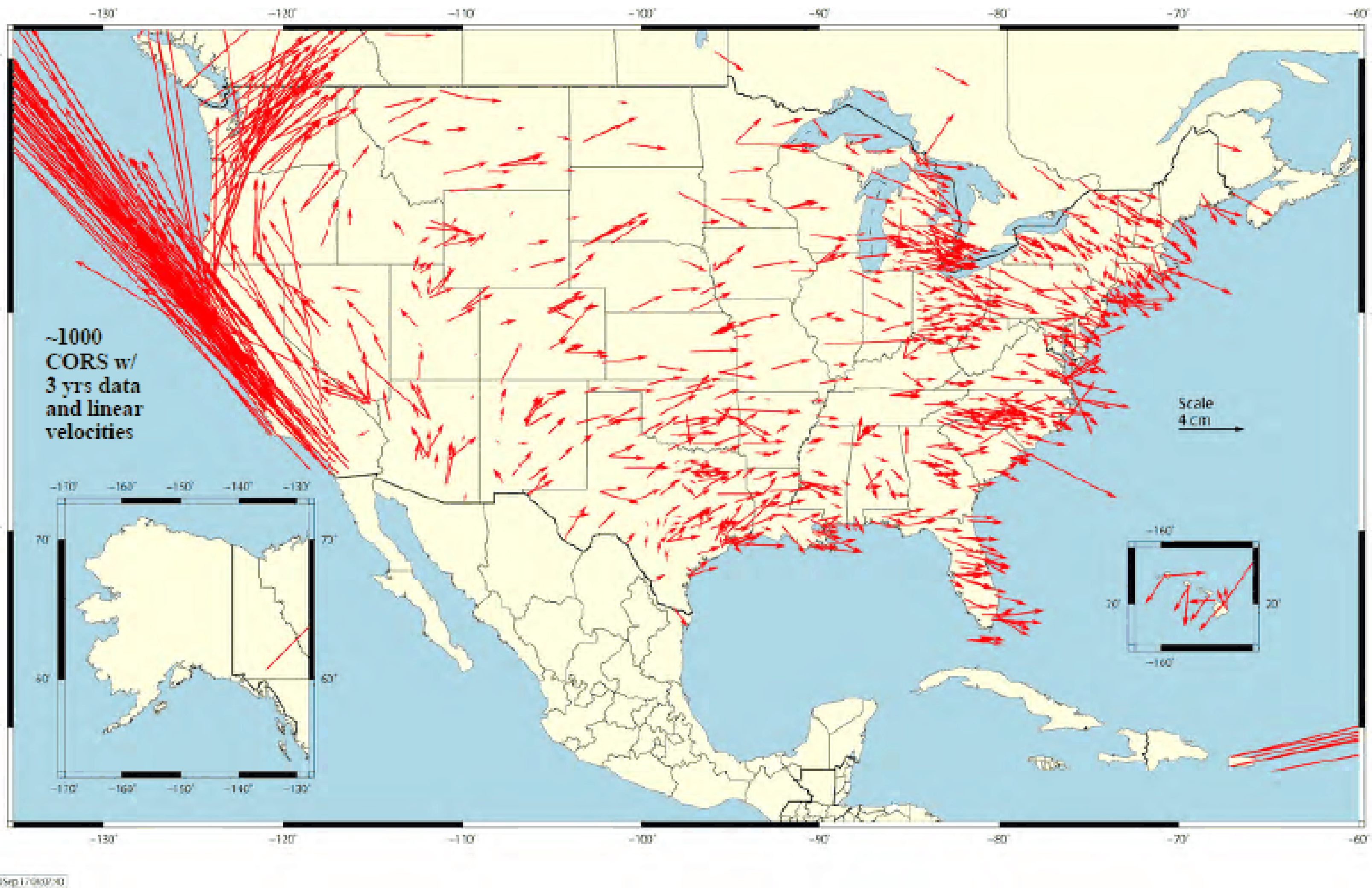


Change in horizontal NAD 83 CORS coordinates

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

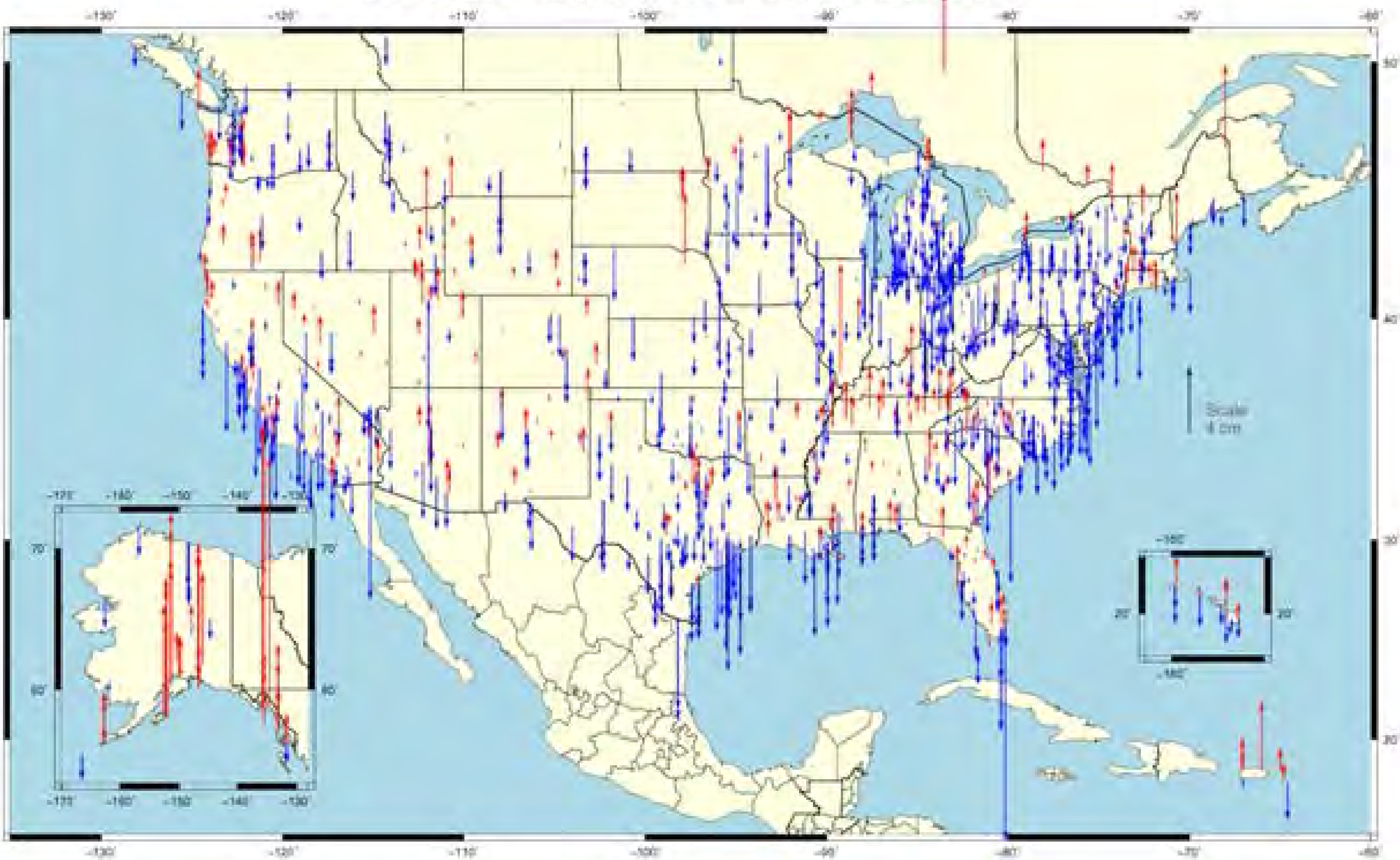
Avg shifts (cm): ΔN = 2.0 (±6.4); ΔE = 0.2 (±5.9); ΔU = -0.9 (±2.0)

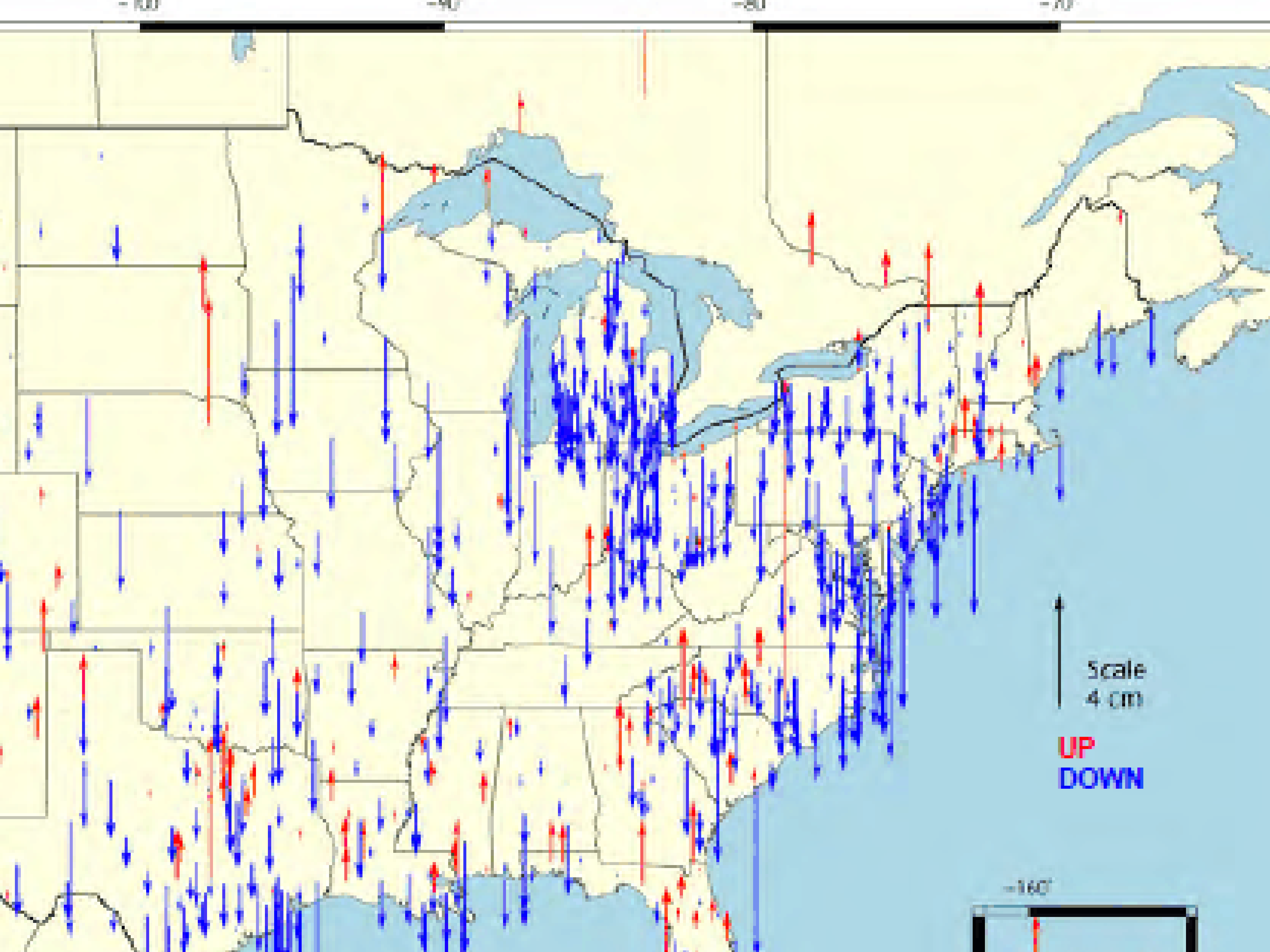
- large shifts in western U.S. due to crustal deformation
- apparent rotation in "stable" U.S. likely due to errors in NUVEL-1A (used in HTDP)



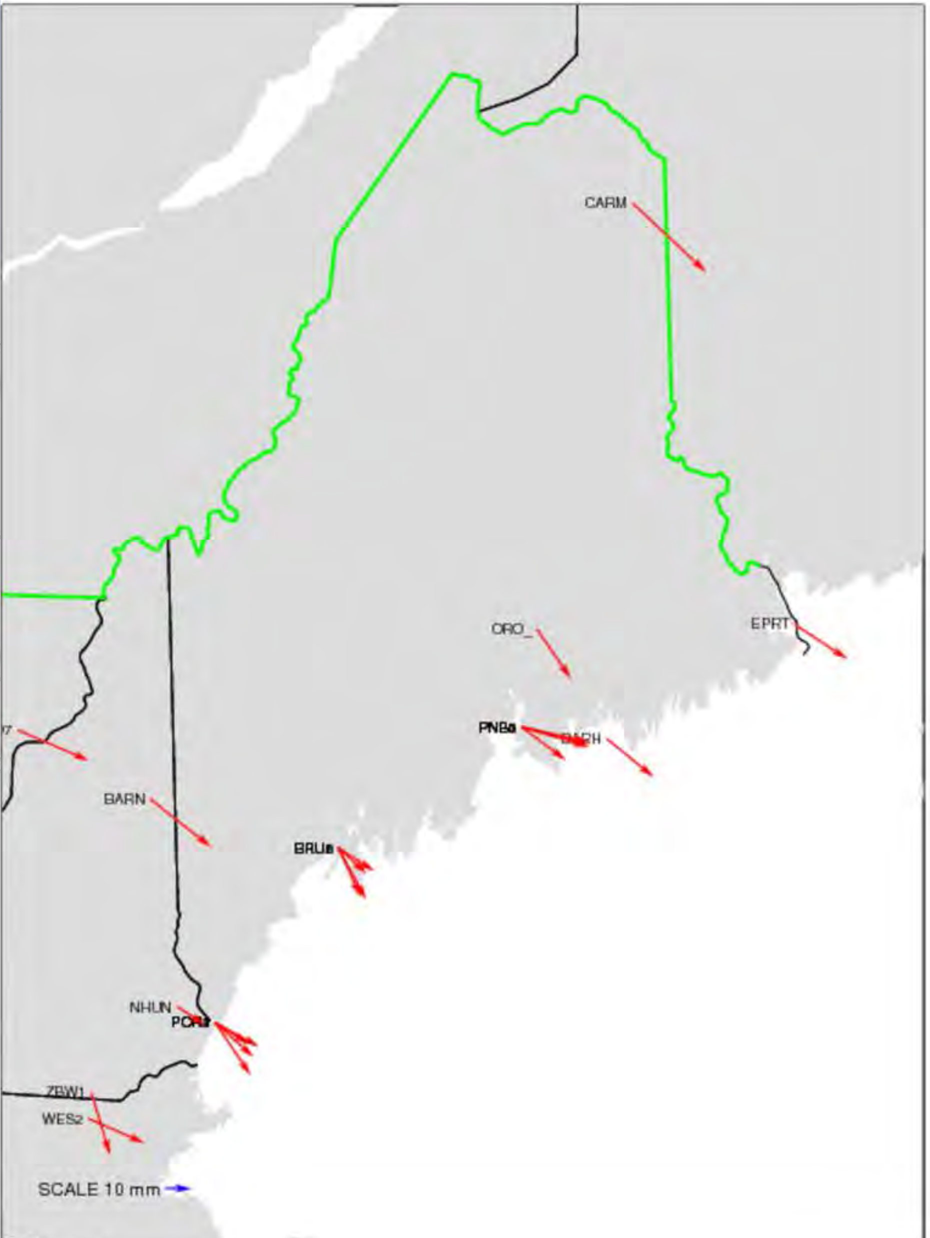

Scale
4 cm

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

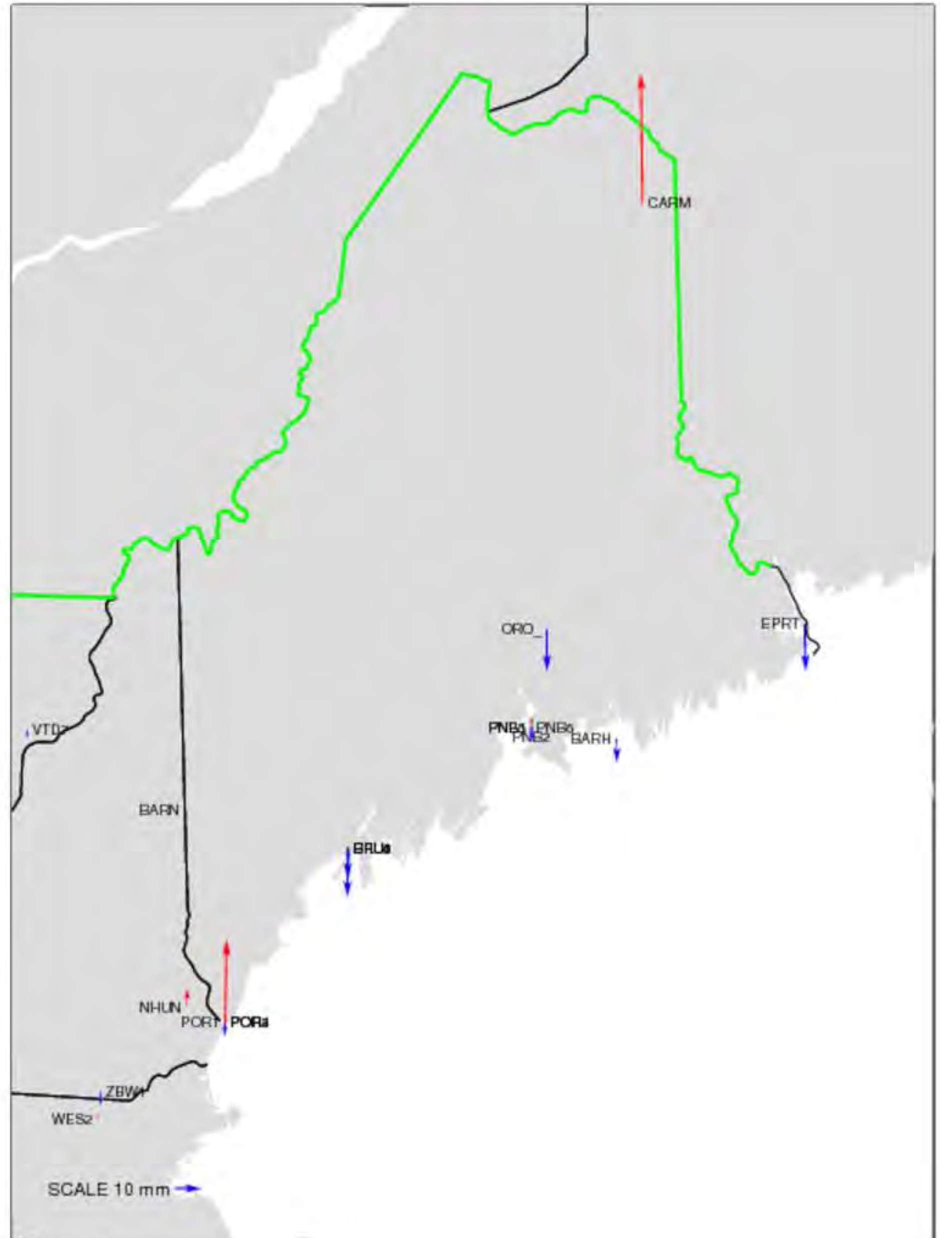



Scale
4 cm
UP
DOWN

ME Horizontal POSITIONS NAD 83(2011) 2010.00 minus NAD 83(CORS96) 2002.00



ME Vertical POSITIONS NAD 83(2011) 2010.00 minus NAD 83(CORS96) 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
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The Plan

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

The Basics

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

Introducing…

NAD 83(2011) epoch 2010.00

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

Why a new NAD 83 realization?

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

Approach

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

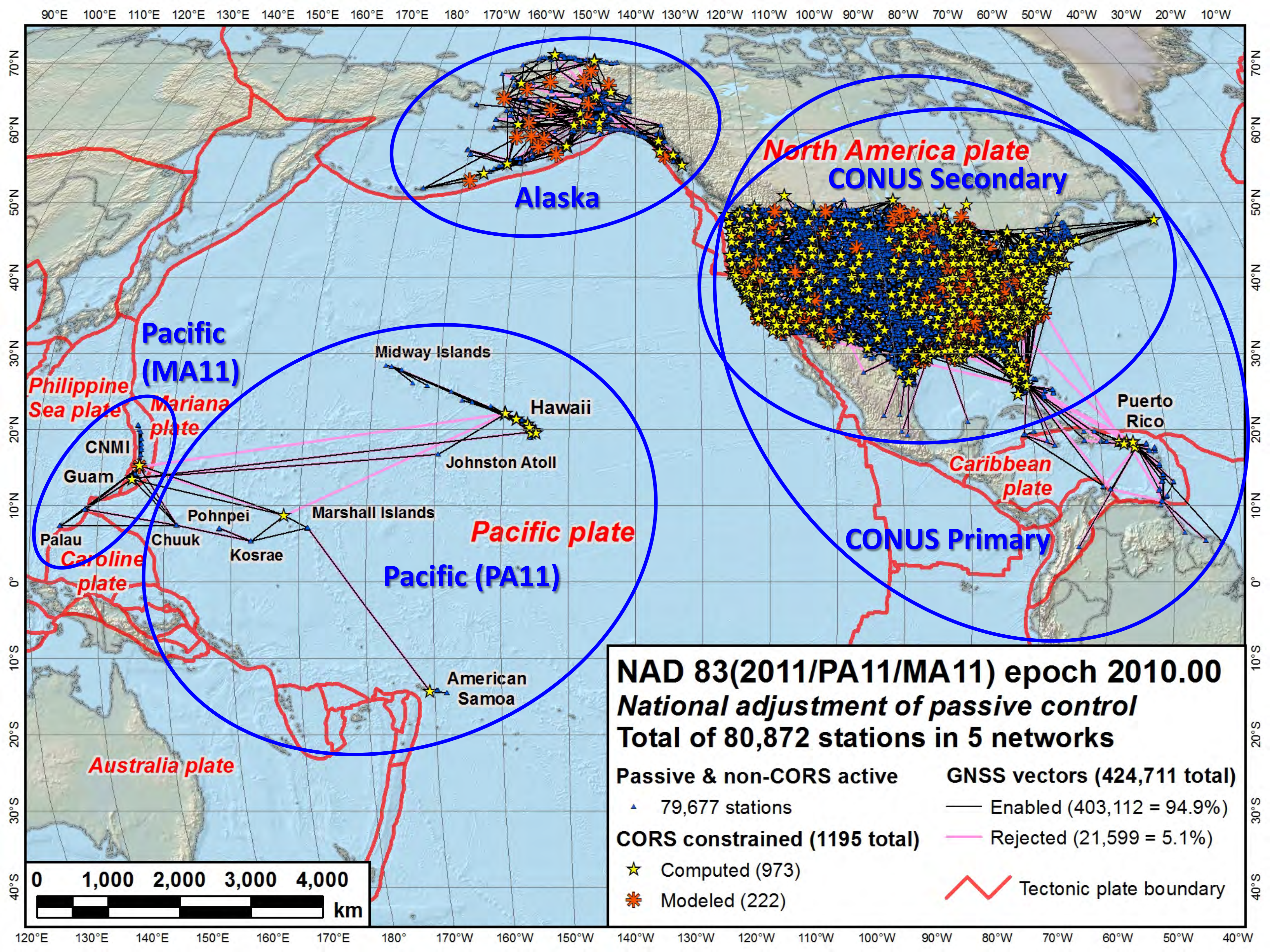
What's in a name?

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

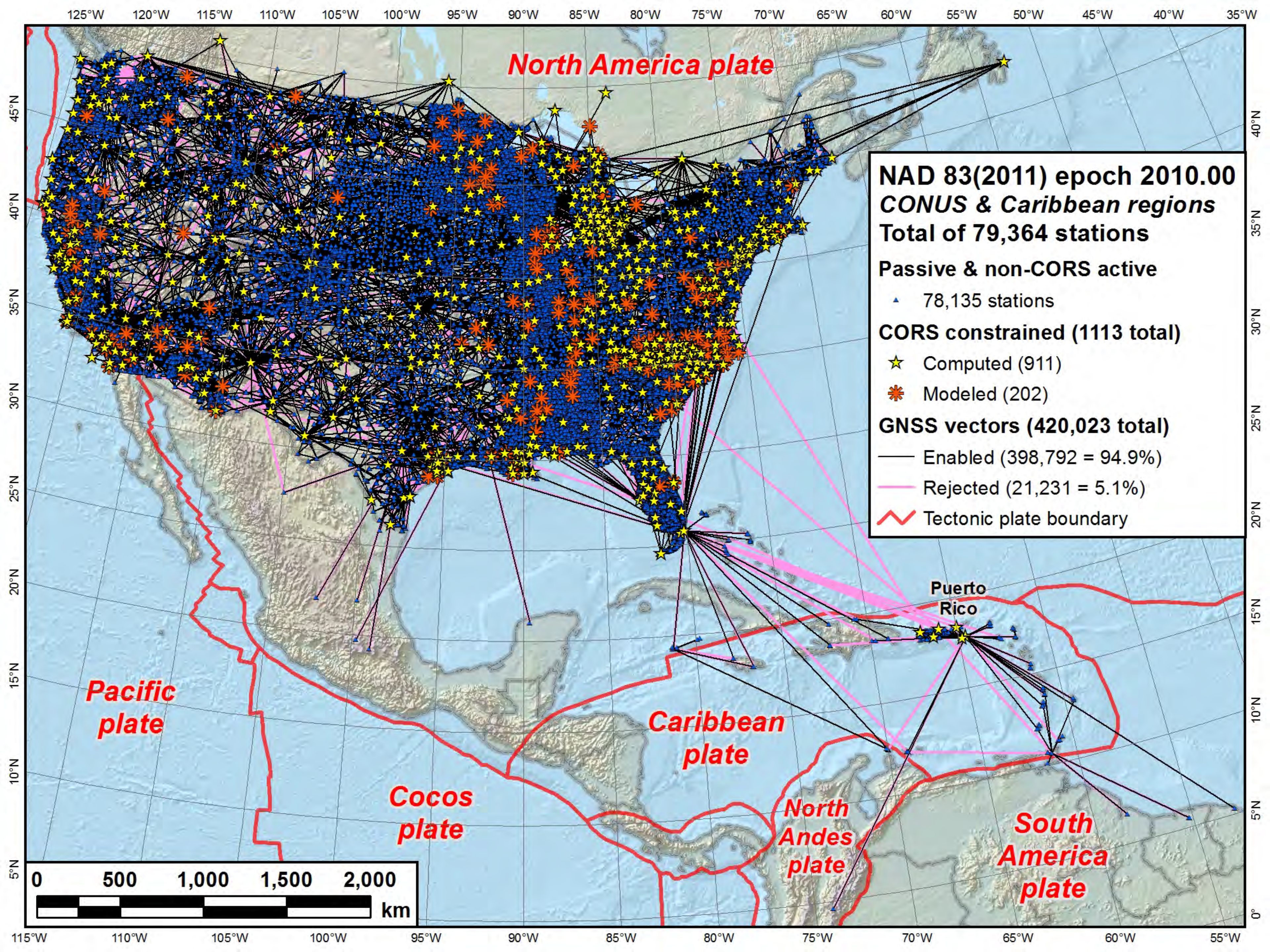
- **NAD 83(2011) epoch 2010.00**
  - "2011" is datum tag → year adjustment complete
  - "2010.00" is "epoch date" (January 1, 2010)
    - Date associated with coordinates of control station
  - Frame fixed to North America tectonic plate
    - Includes California, Alaska, Puerto Rico, and US Virgin Islands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

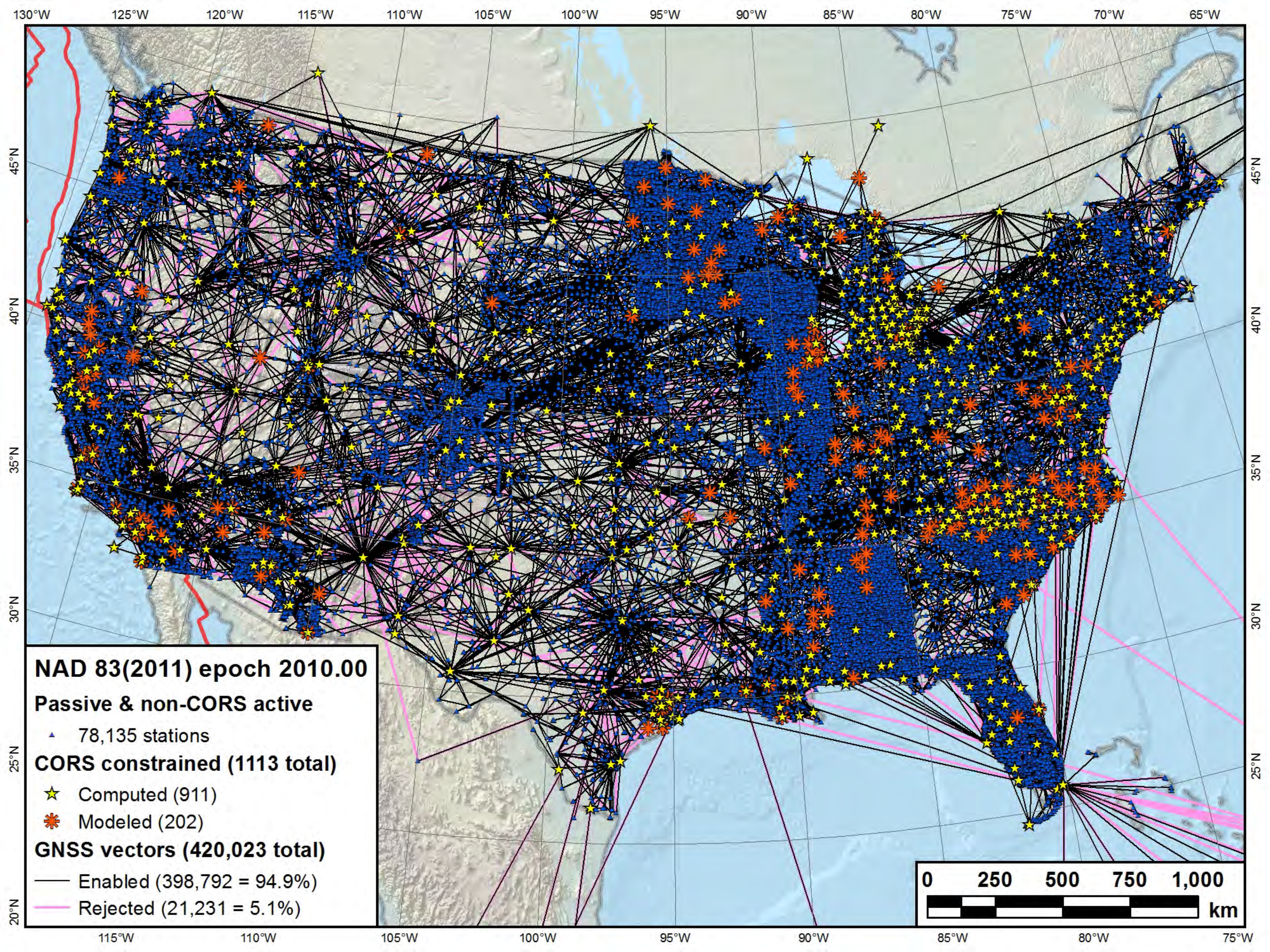
National adjustment of passive control

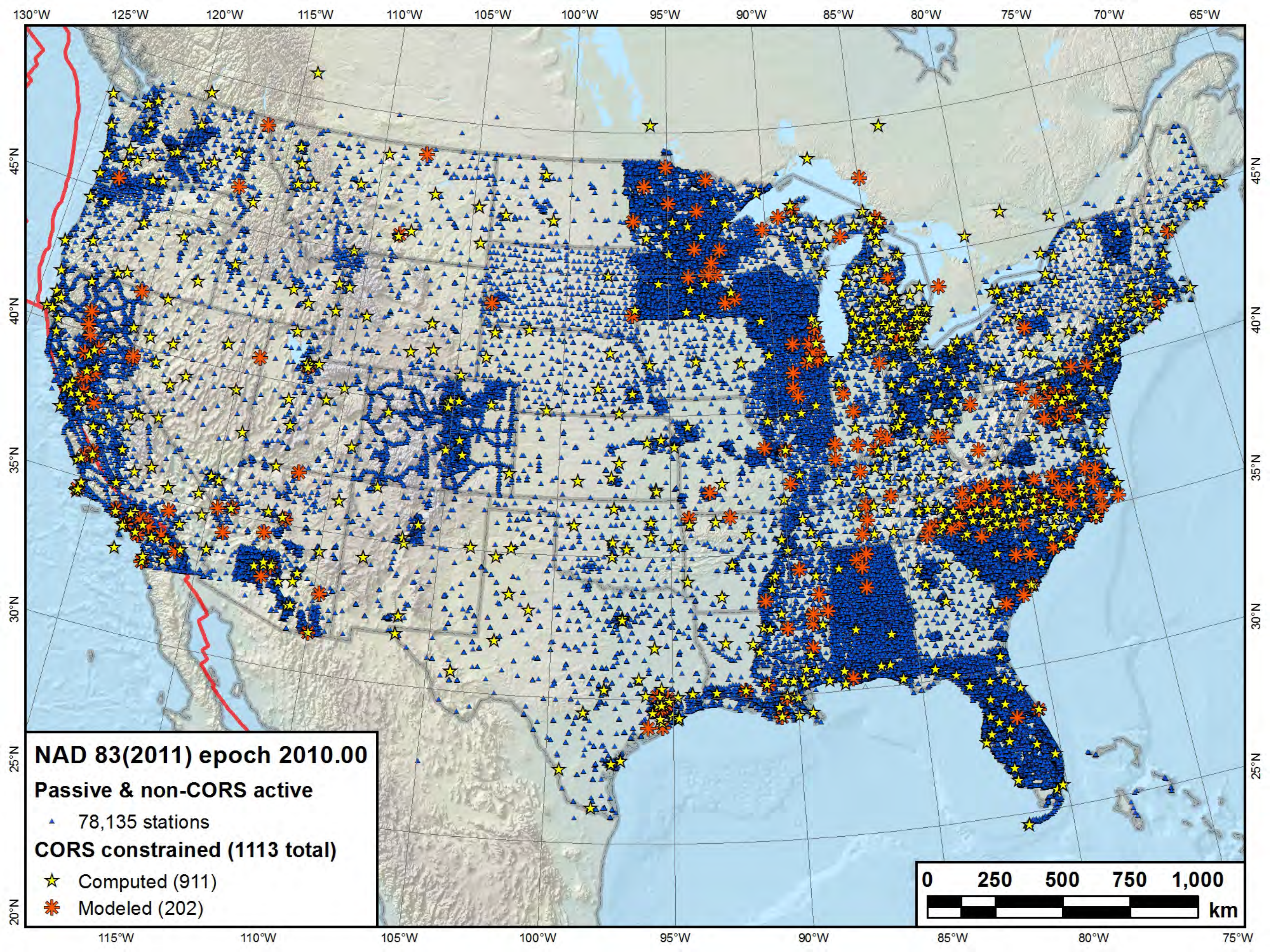
- 4267 GPS projects; 80,872 stations; 424,711 vectors
  - Observations from April 1983 thru Dec 2011
  - Includes 1195 CORS with Multi-Year CORS Solution coordinates
- CONUS and Caribbean adjusted together (79,364 stations)
  - Both referenced to North America tectonic plate
  - Split into Primary (62,024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

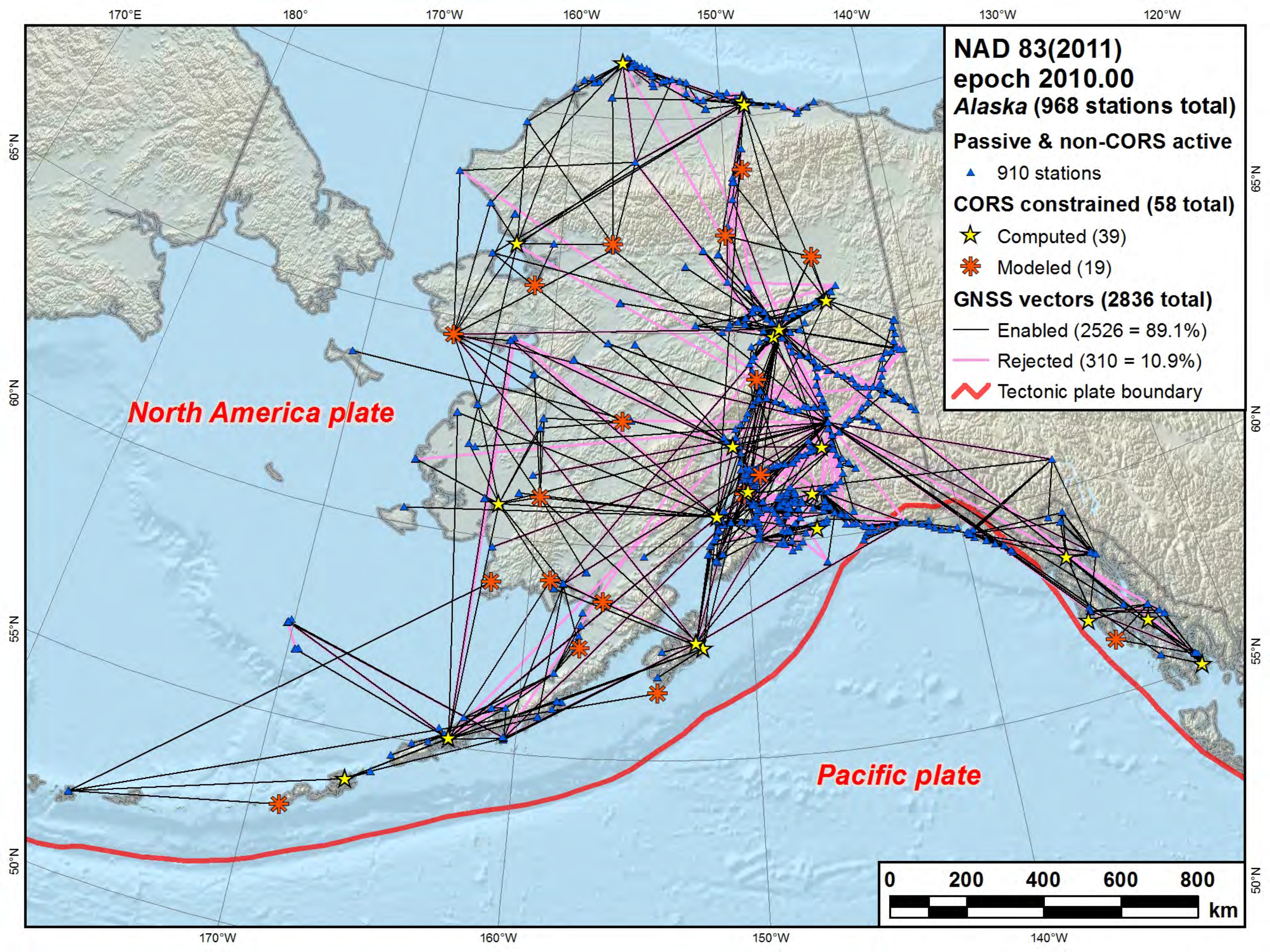


Alaska
North America plate
CONUS Secondary
CONUS Primary
Pacific (MA11)
Philippine Sea plate
Mariana plate
CNMI
Guam
Palau
Chuuk
Caroline plate
Pohnpei
Kosrae
Marshall Islands
Midway Islands
Hawaii
Johnston Atoll
Pacific plate
Pacific (PA11)
American Samoa
Australia plate
Puerto Rico
Caribbean plate
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

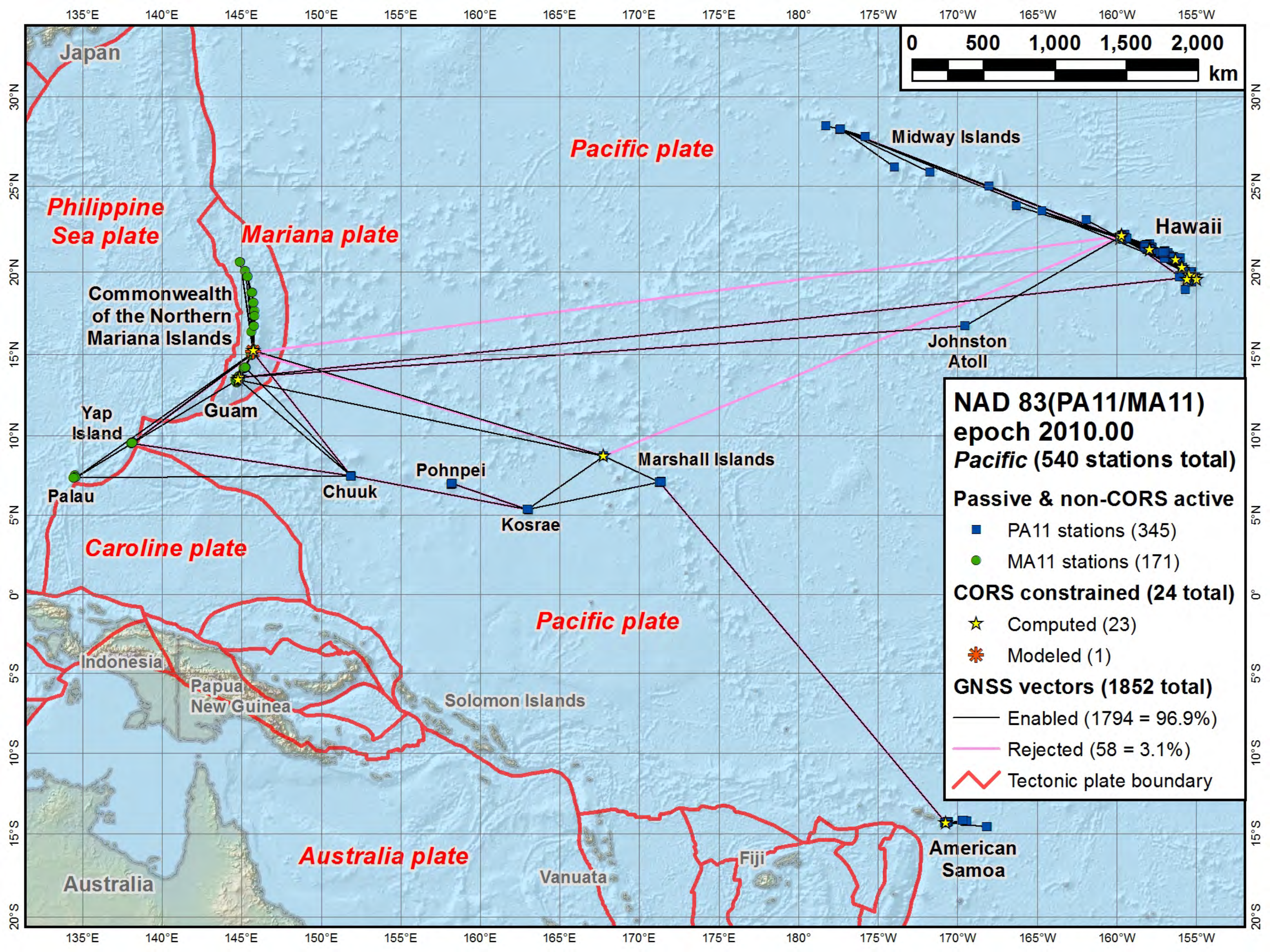

NAD 83(2011) epoch 2010.00
CONUS & Caribbean regions
Total of 79,364 stations
Passive & non-CORS active
78,135 stations
CORS constrained (1113 total)
Computed (911)
Modeled (202)
GNSS vectors (420,023 total)
Enabled (398,792 = 94.9%)
Rejected (21,231 = 5.1%)
Tectonic plate boundary
North America plate
Pacific plate
Cocos plate
Caribbean plate
North Andes plate
South America plate
Puerto Rico
0 500 1,000 1,500 2,000 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
NAD 83(2011) epoch 2010.00
Passive & non-CORS active
78,135 stations
CORS constrained (1113 total)
Computed (911)
Modeled (202)
GNSS vectors (420,023 total)
Enabled (398,792 = 94.9%)
Rejected (21,231 = 5.1%)
0 250 500 750 1,000
km


NAD 83(2011) epoch 2010.00
Passive & non-CORS active
78,135 stations
CORS constrained (1113 total)
Computed (911)
Modeled (202)
0 250 500 750 1,000 km
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
115°W 110°W 105°W 100°W 95°W 90°W 85°W 80°W 75°W
20°N 25°N 30°N 35°N 40°N 45°N



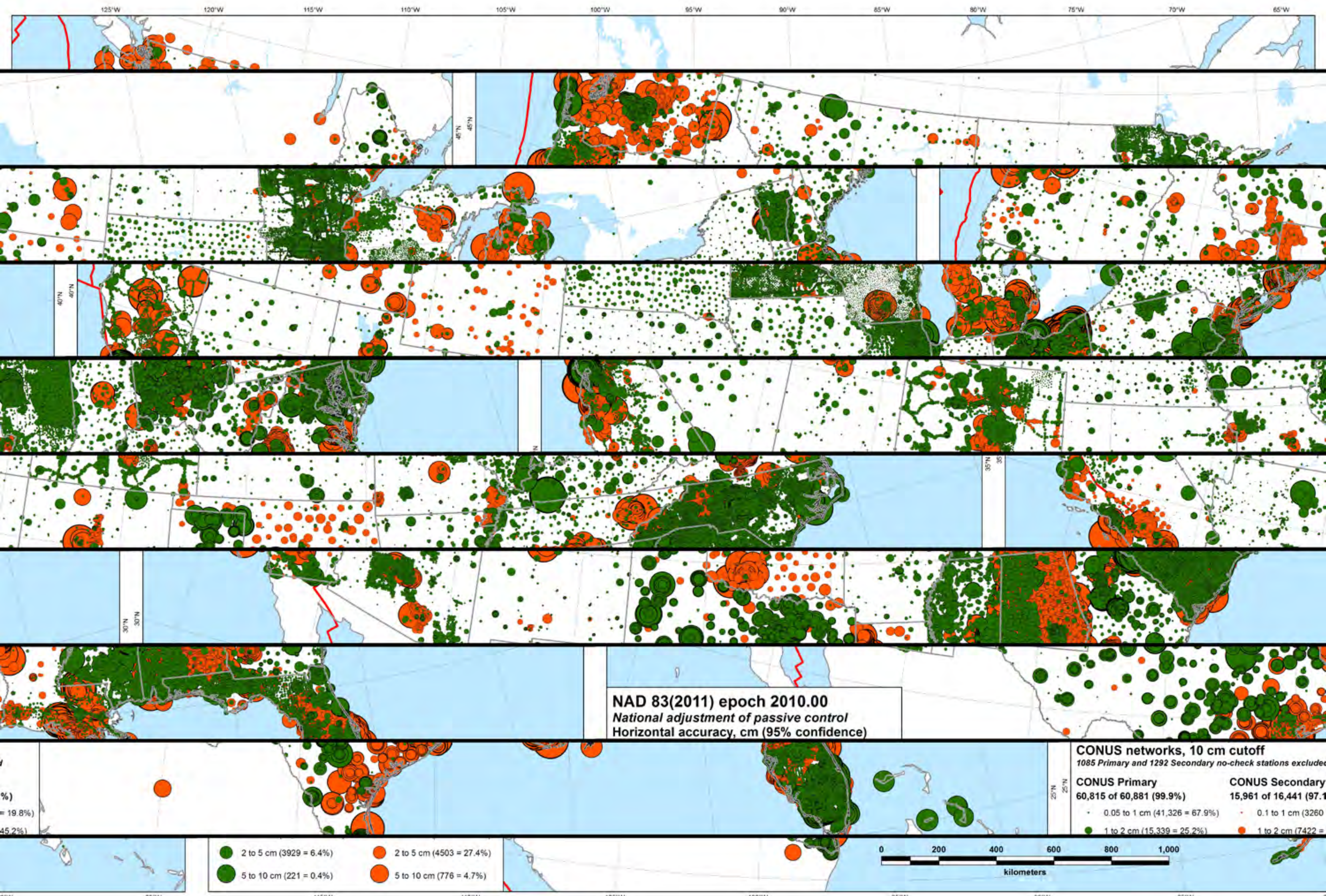
NAD 83(2011)
epoch 2010.00
Alaska (968 stations total)
Passive & non-CORS active
910 stations
CORS constrained (58 total)
Computed (39)
Modeled (19)
GNSS vectors (2836 total)
Enabled (2526 = 89.1%)
Rejected (310 = 10.9%)
Tectonic plate boundary
North America plate
Pacific plate
0 200 400 600 800
km
170°E
180°
170°W
160°W
150°W
140°W
130°W
120°W
65°N
60°N
55°N
50°N

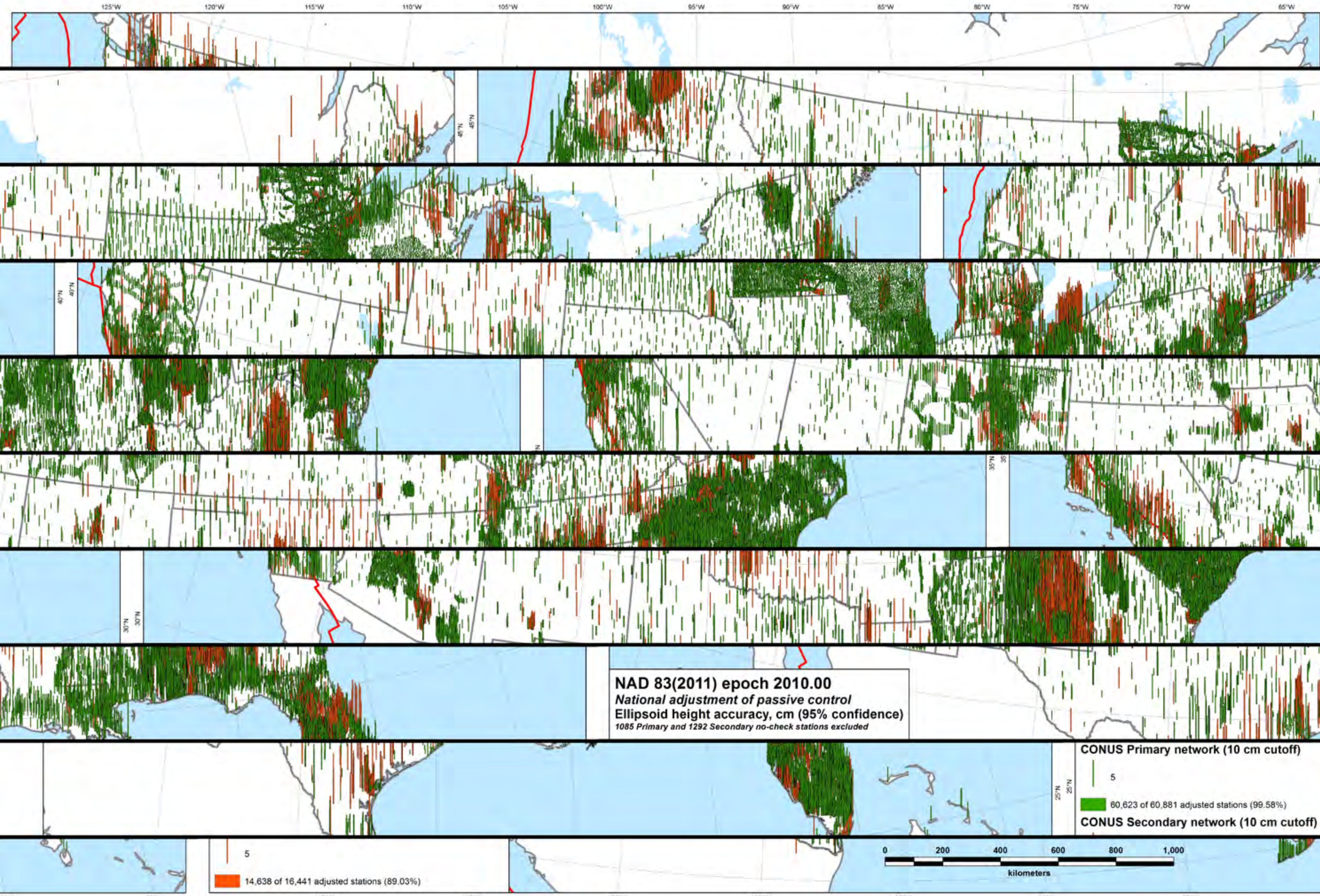


NAD 83(PA11/MA11)
epoch 2010.00
Pacific (540 stations total)
Passive & non-CORS active
PA11 stations (345)
MA11 stations (171)
CORS constrained (24 total)
Computed (23)
Modeled (1)
GNSS vectors (1852 total)
Enabled (1794 = 96.9%)
Rejected (58 = 3.1%)
Tectonic plate boundary
0 500 1,000 1,500 2,000
km
Japan
Philippine Sea plate
Mariana plate
Pacific plate
Caroline plate
Australia plate
Commonwealth of the Northern Mariana Islands
Guam
Yap Island
Palau
Chuuk
Pohnpei
Kosrae
Marshall Islands
Midway Islands
Hawaii
Johnston Atoll
American Samoa
Indonesia
Papua New Guinea
Solomon Islands
Vanuata
Fiji
Australia
135°E
140°E
145°E
150°E
155°E
160°E
165°E
170°E
175°E
180°
175°W
170°W
165°W
160°W
155°W
30°N
25°N
20°N
15°N
10°N
5°N
0°
5°S
10°S
15°S
20°S

NAD 83(2011/PA11/MA11) epoch 2010.00 ***Passive control results summary***

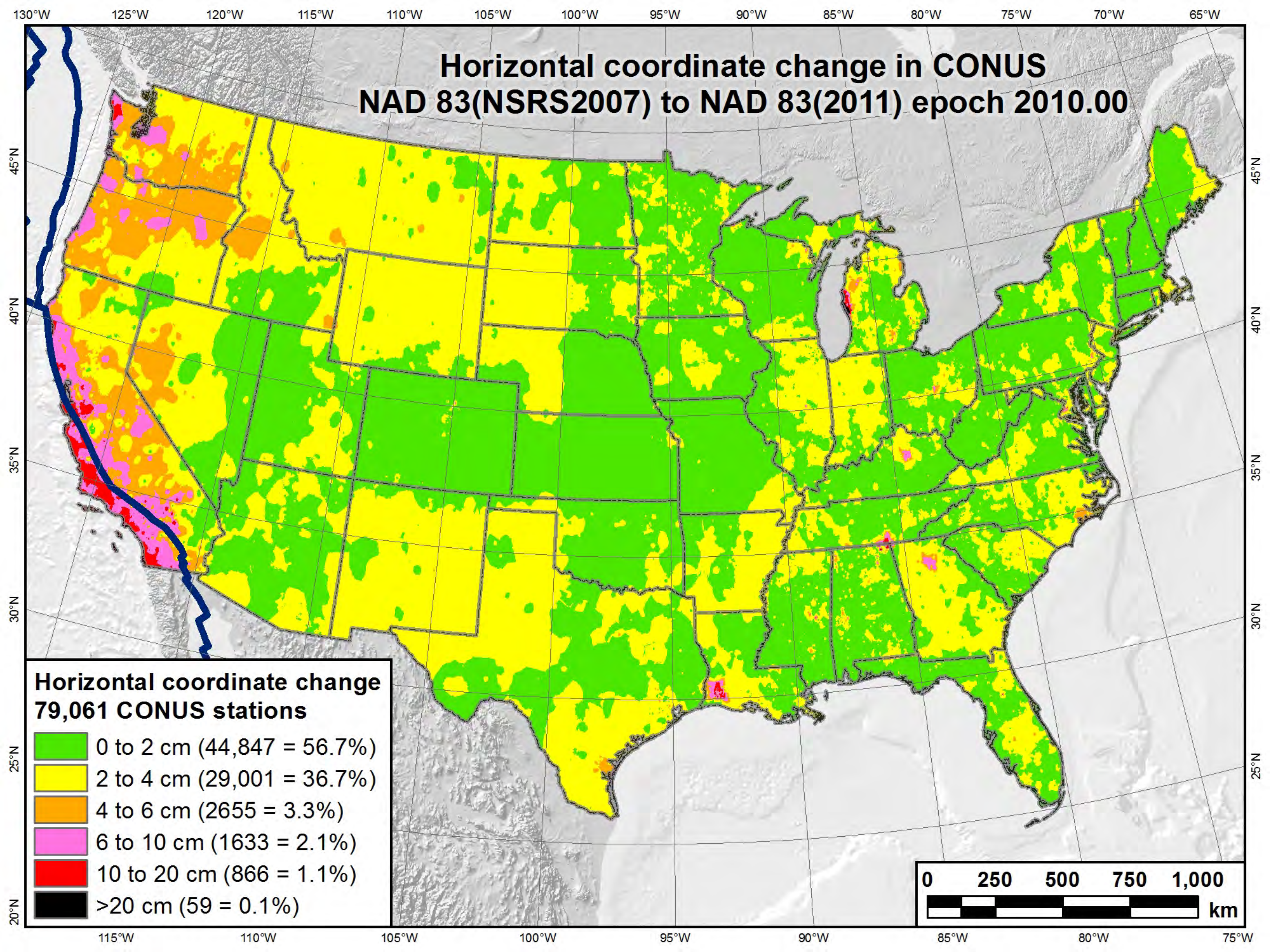
- Station network accuracies (95% confidence)
  - Overall median: ***0.9 cm horiz***, ***1.5 cm height*** (78,709)
    - ***90% < 2.3 cm horizontal and 4.8 cm ellipsoid height***
    - Does ***NOT*** include 2163 no-check stations
  - Median accuracies by network
    - CONUS Primary: ***0.7 cm horiz,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

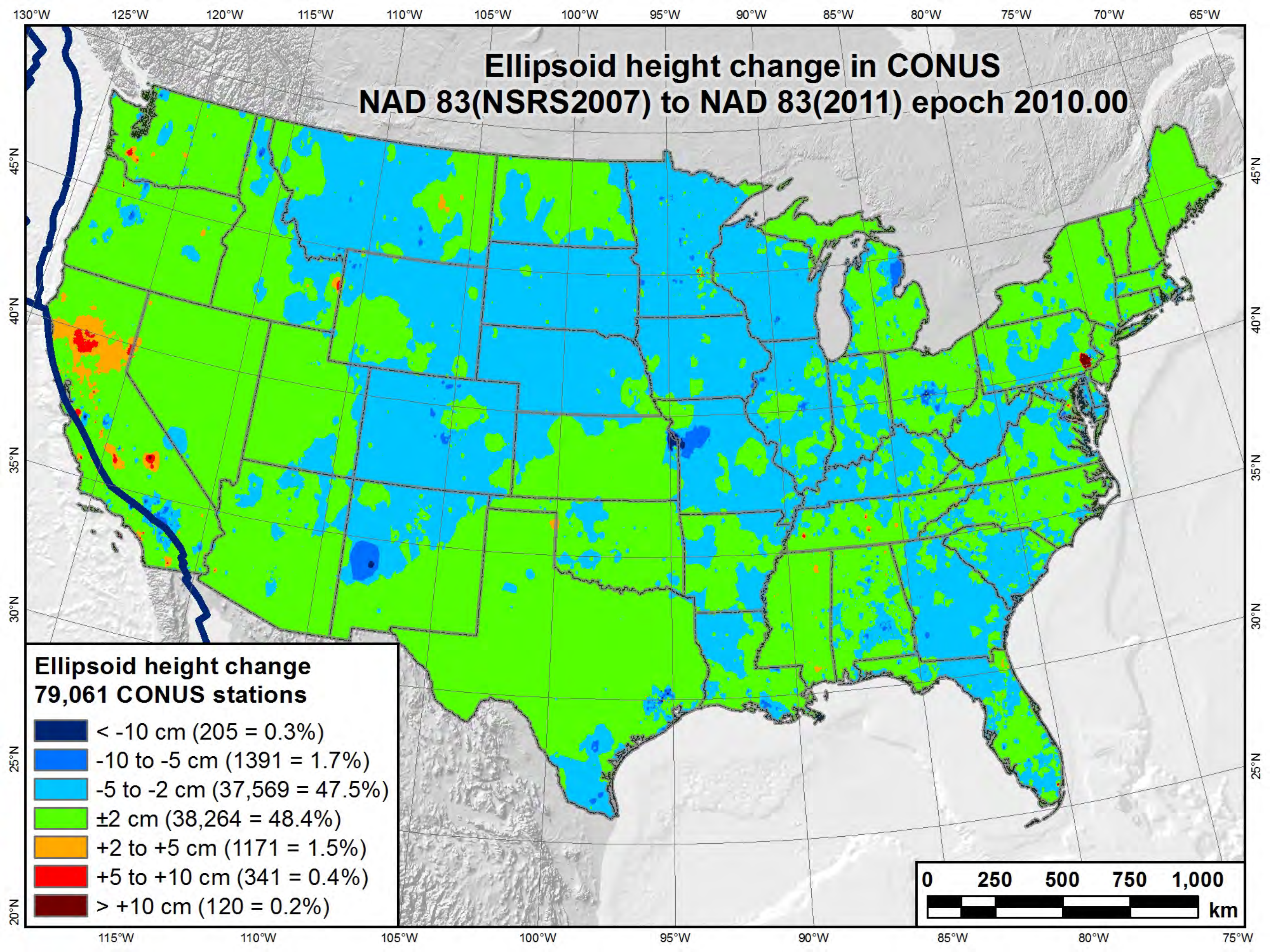

NAD 83(2011) epoch 2010.00
National adjustment of passive control
Horizontal accuracy, cm (95% confidence)
CONUS networks, 10 cm cutoff
1085 Primary and 1292 Secondary no-check stations excluded
CONUS Primary
60,815 of 60,881 (99.9%)
0.05 to 1 cm (41,326 = 67.9%)
1 to 2 cm (15,339 = 25.2%)
2 to 5 cm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


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
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

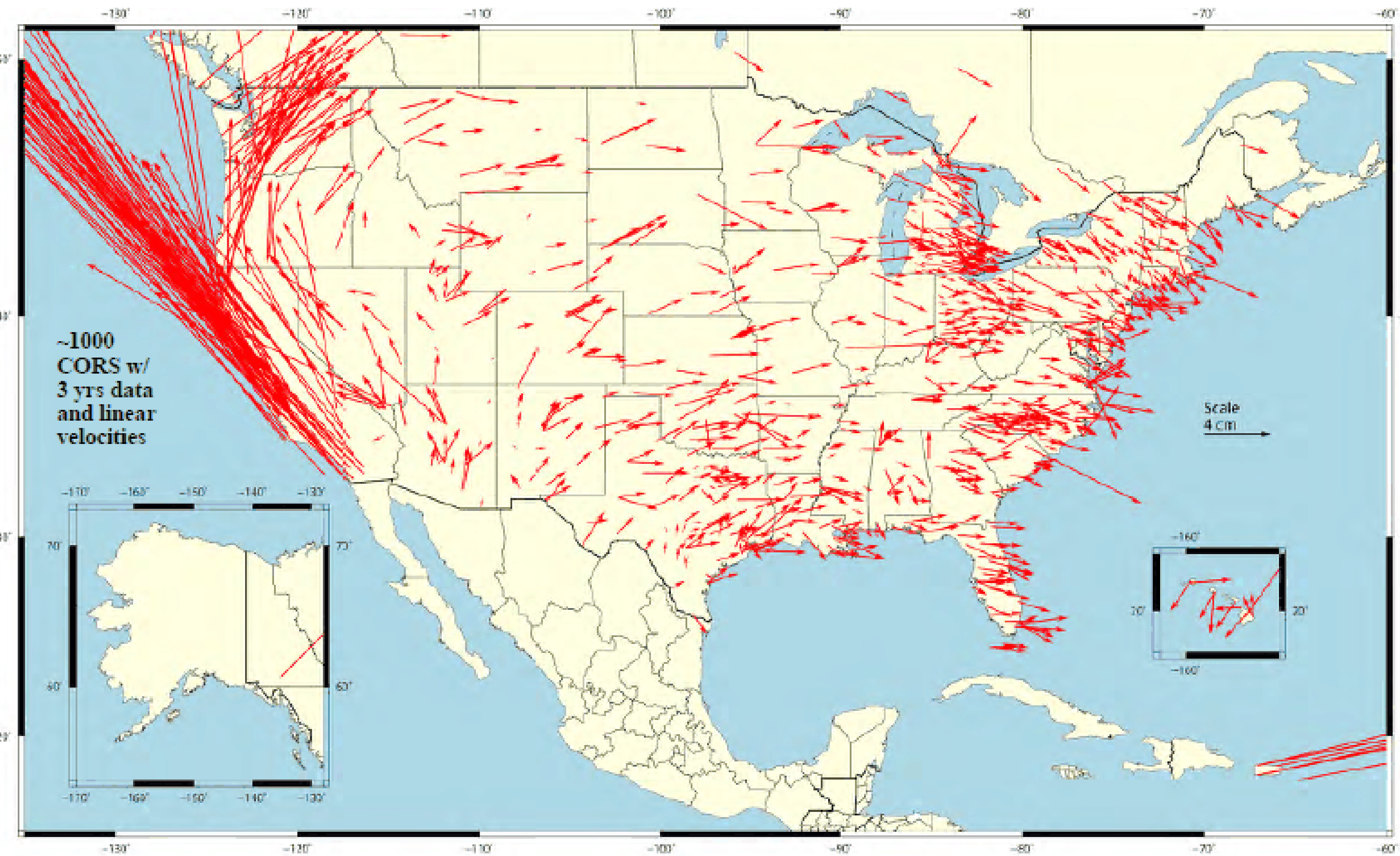

Ellipsoid height change in CONUS
NAD 83(NSRS2007) to NAD 83(2011) epoch 2010.00
Ellipsoid height change
79,061 CONUS stations
< -10 cm (205 = 0.3%)
-10 to -5 cm (1391 = 1.7%)
-5 to -2 cm (37,569 = 47.5%)
±2 cm (38,264 = 48.4%)
+2 to +5 cm (1171 = 1.5%)
+5 to +10 cm (341 = 0.4%)
> +10 cm (120 = 0.2%)
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
115°W 110°W 105°W 100°W 95°W 90°W 85°W 80°W 75°W

Change in horizontal NAD 83 CORS coordinates

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

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

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



Related Tasks, Products & Deliverables

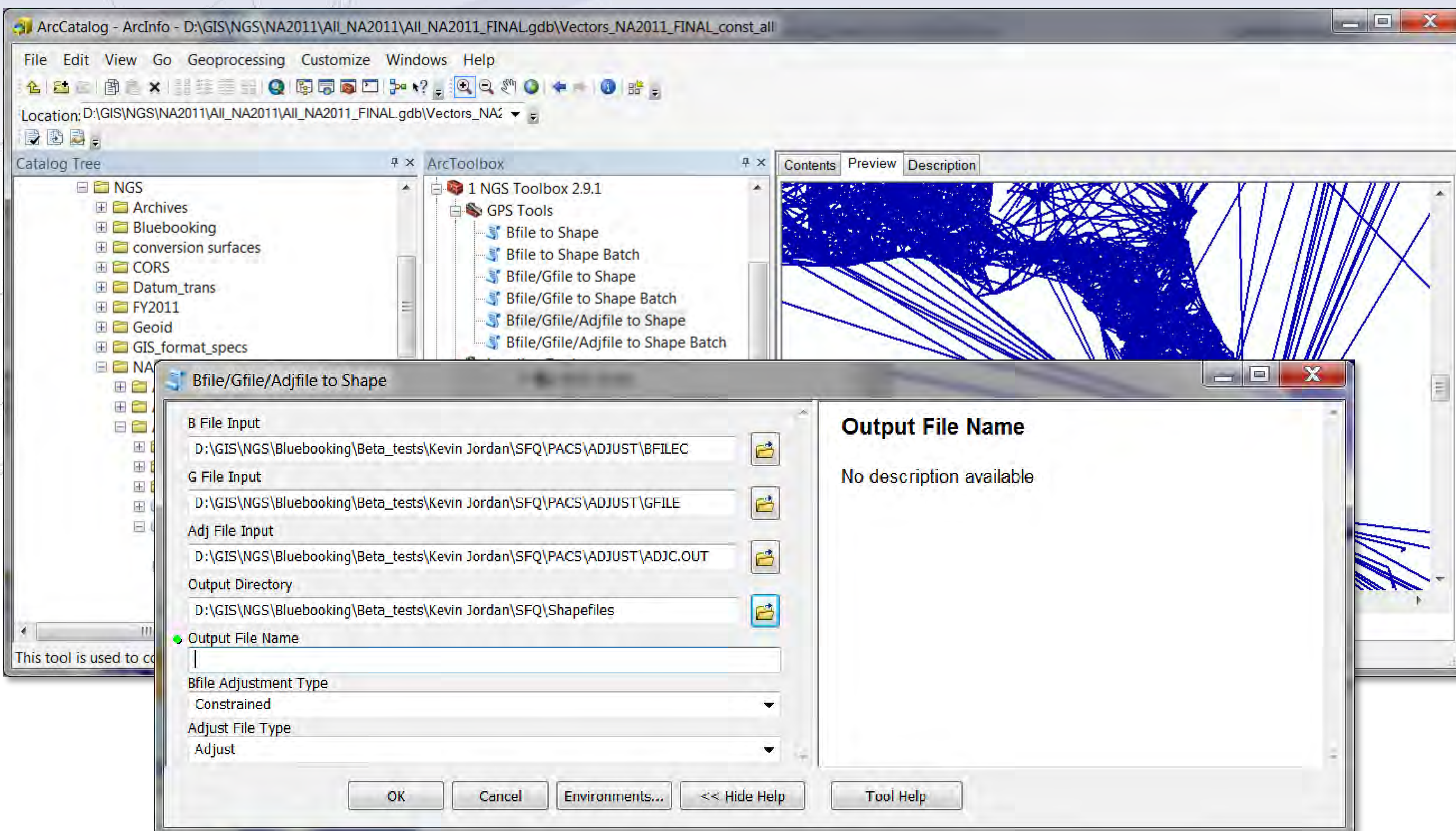
- OPUS (Online Positioning User Service)
  - Solutions for NAD 83(2011/PA11/MA11) epoch 2010.00
- New hybrid geoid model (GEOID12A)
  - NAD 83(2011) ellipsoid heights on leveled NAVD 88 BMs
- New process for Bluebooking GPS projects
  - Currently under development
  - New version of "ADJUST" program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

Related Tasks, Products & Deliverables

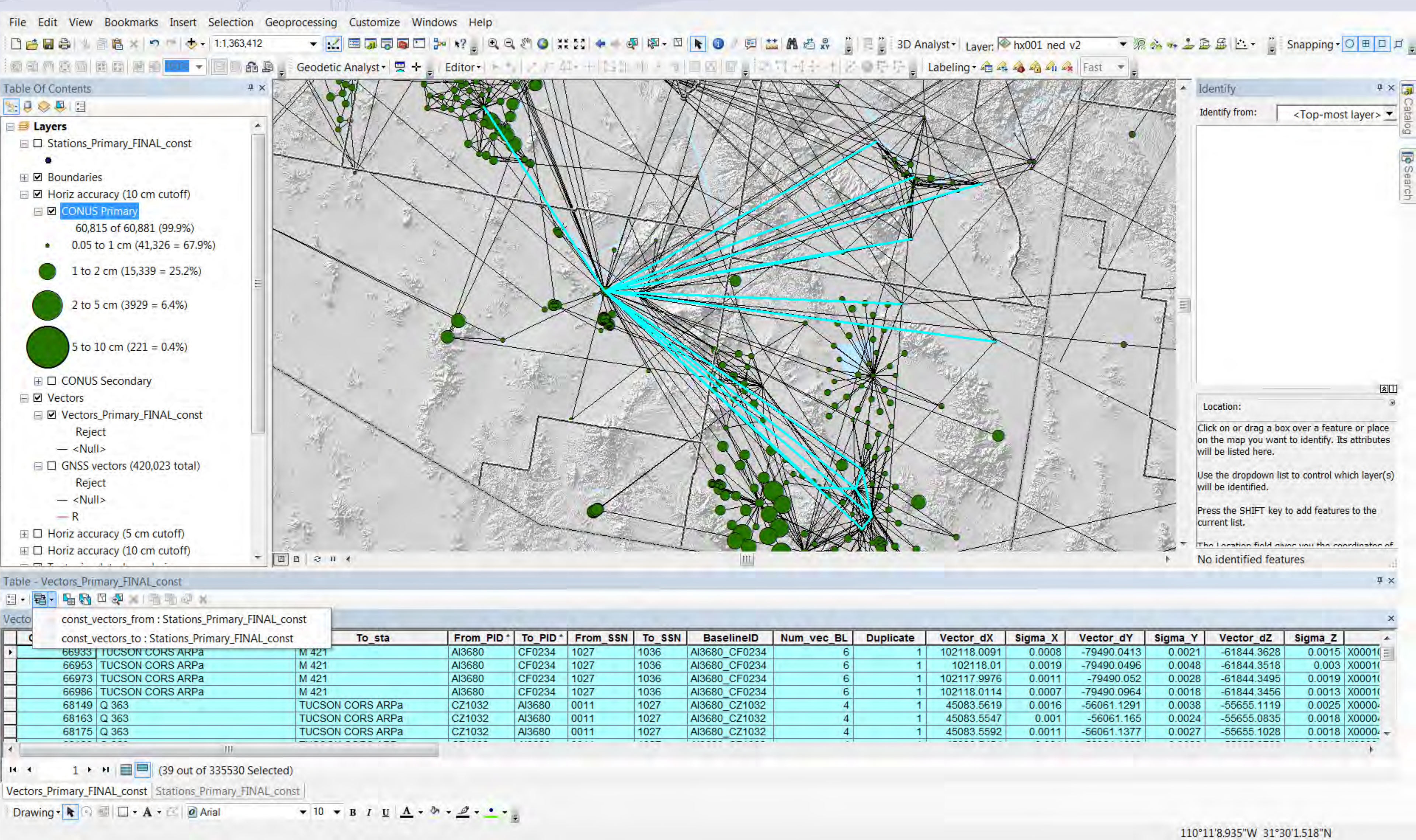
- New Geodetic GIS tools
  - Use standard NGS ASCII output files as input
  - Convert to point, line, and polygon features
  - Attribute-rich features in standard GIS format
  - Used for display and analysis of results
- Two new GIS tools in development
  - GPS and leveling network adjustment → GIS features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

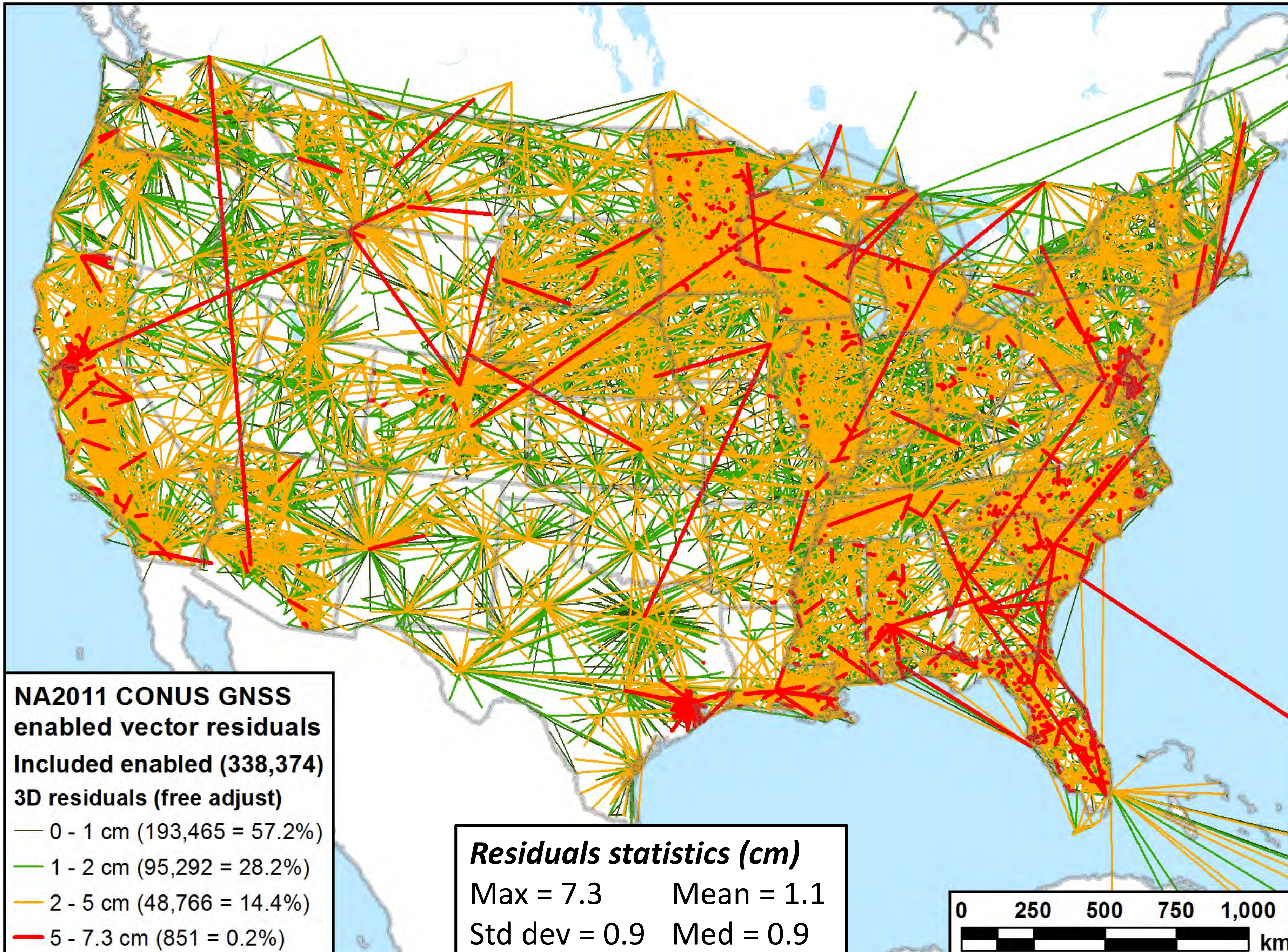
Related Tasks, Products & Deliverables

- New Geodetic GIS tools

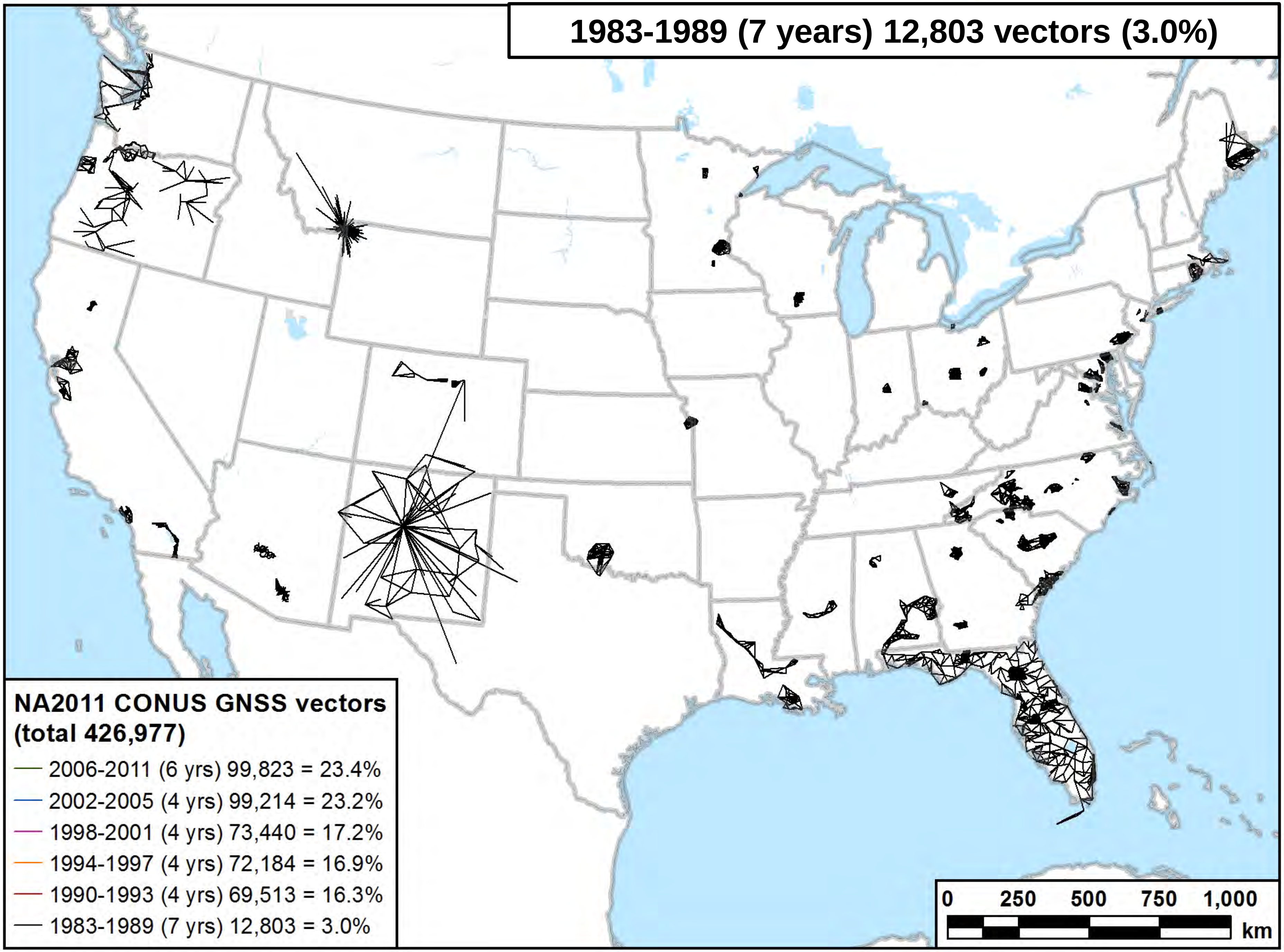


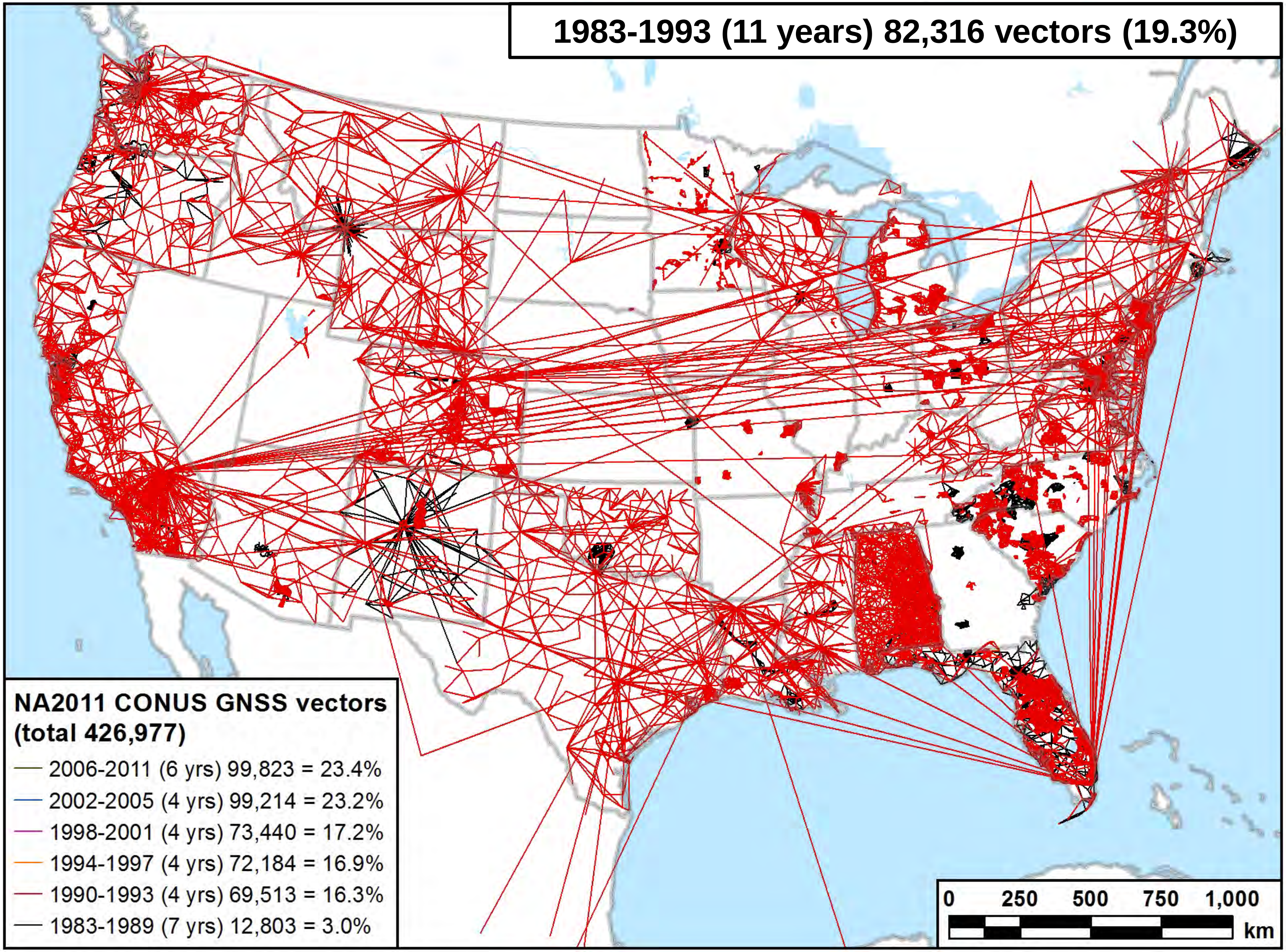
Network adjustment results as GIS features provide powerful analysis capabilities…

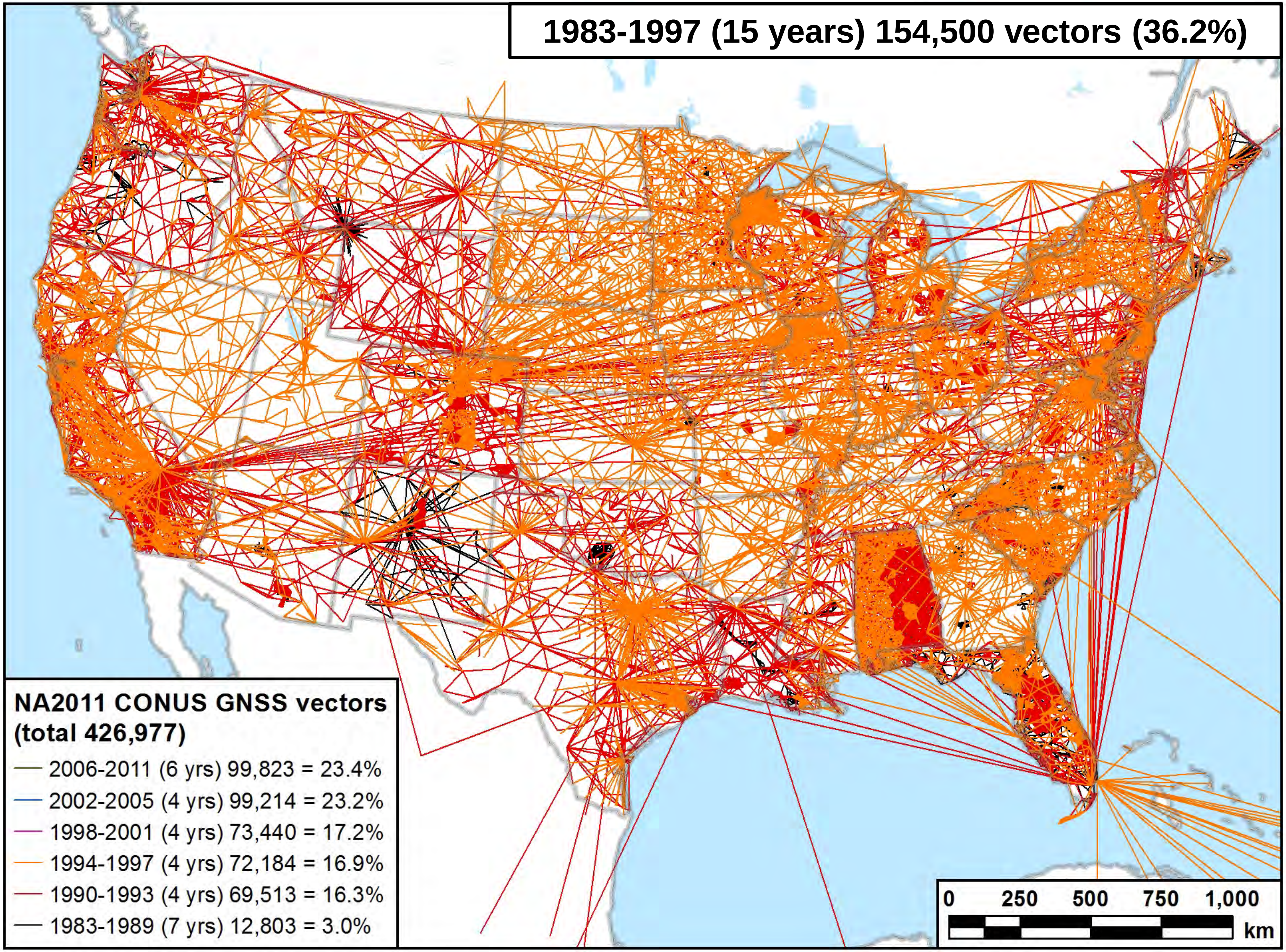


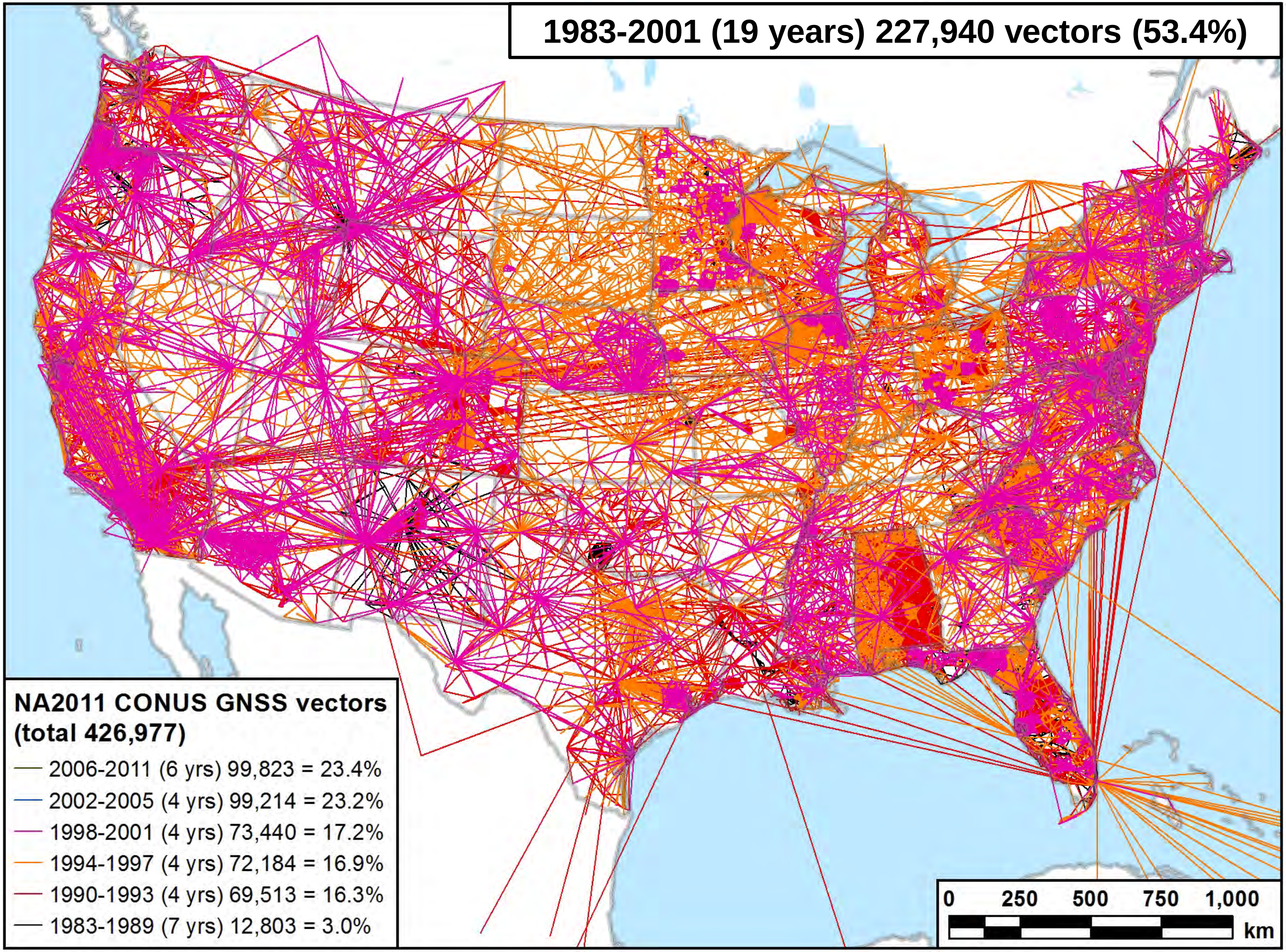


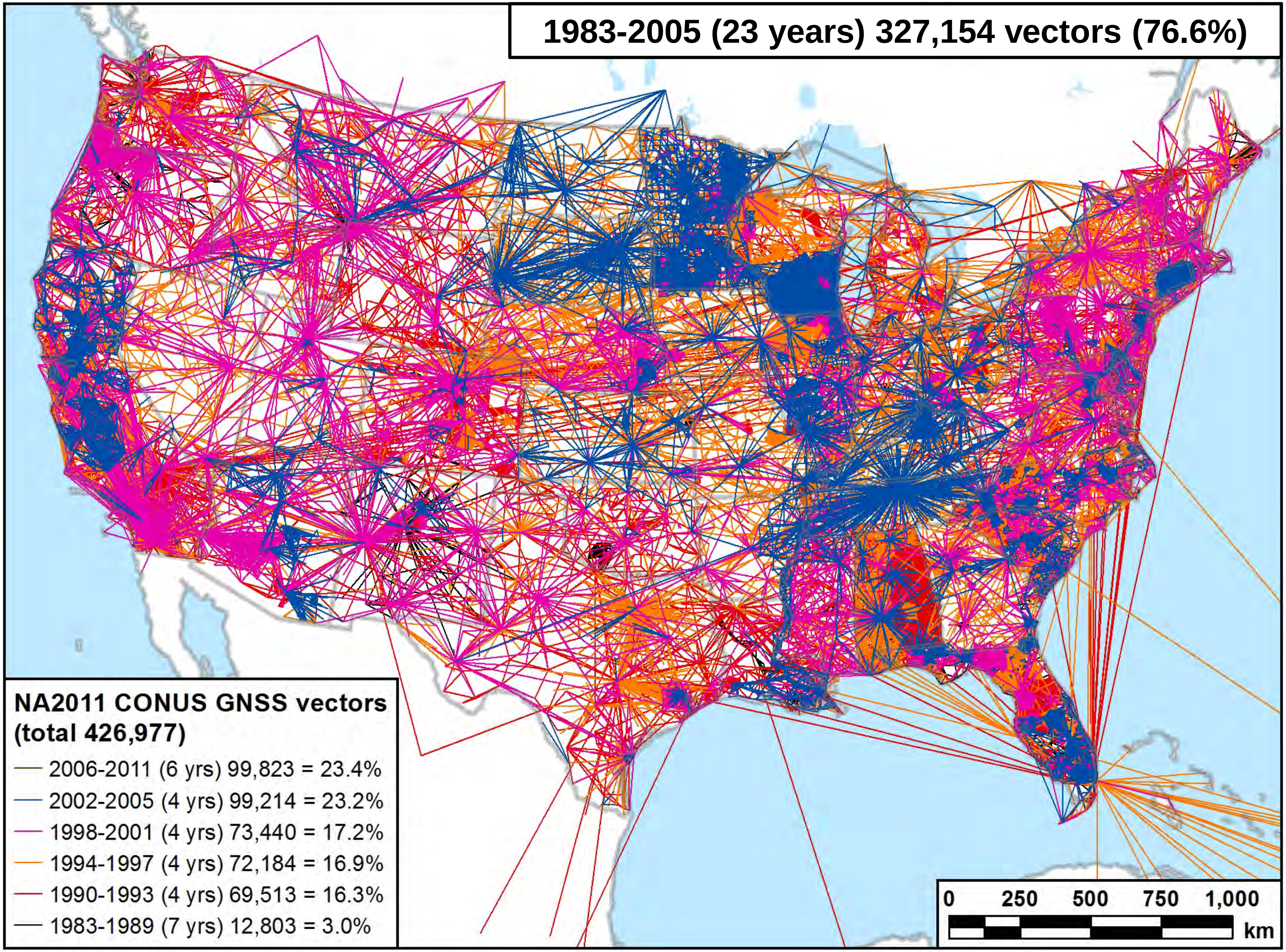
NA2011 CONUS GNSS enabled vector residuals
Included enabled (338,374)
3D residuals (free adjust)
0 - 1 cm (193,465 = 57.2%)
1 - 2 cm (95,292 = 28.2%)
2 - 5 cm (48,766 = 14.4%)
5 - 7.3 cm (851 = 0.2%)
Residuals statistics (cm)
Max = 7.3
Mean = 1.1
Std dev = 0.9
Med = 0.9
0
250
500
750
1,000
km


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

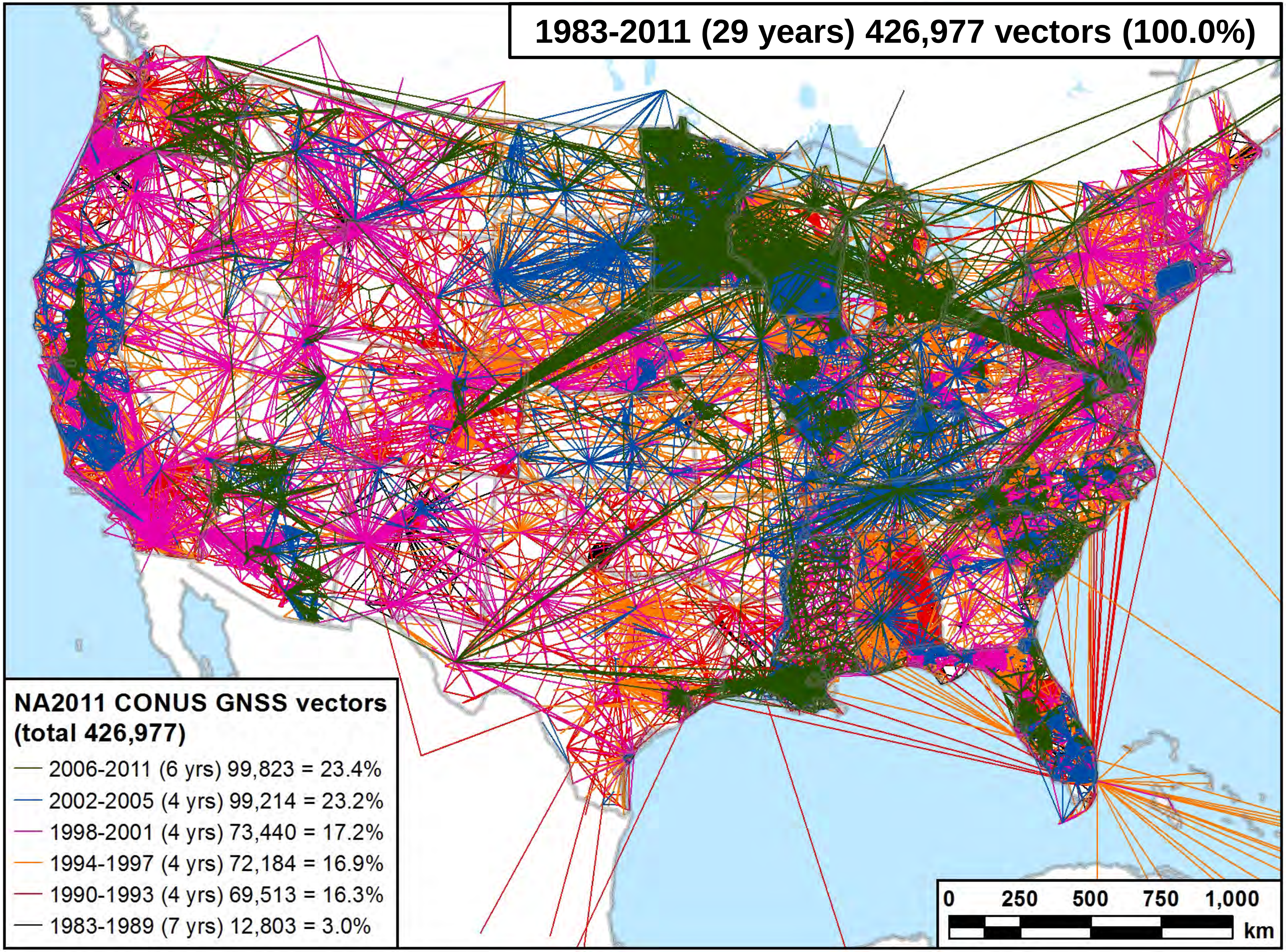

1983-1993 (11 years) 82,316 vectors (19.3%)
NA2011 CONUS GNSS vectors
(total 426,977)
2006-2011 (6 yrs) 99,823 = 23.4%
2002-2005 (4 yrs) 99,214 = 23.2%
1998-2001 (4 yrs) 73,440 = 17.2%
1994-1997 (4 yrs) 72,184 = 16.9%
1990-1993 (4 yrs) 69,513 = 16.3%
1983-1989 (7 yrs) 12,803 = 3.0%
0 250 500 750 1,000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


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


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



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


1983-2011 (29 years) 426,977 vectors (100.0%)
NA2011 CONUS GNSS vectors (total 426,977)
2006-2011 (6 yrs) 99,823 = 23.4%
2002-2005 (4 yrs) 99,214 = 23.2%
1998-2001 (4 yrs) 73,440 = 17.2%
1994-1997 (4 yrs) 72,184 = 16.9%
1990-1993 (4 yrs) 69,513 = 16.3%
1983-1989 (7 yrs) 12,803 = 3.0%
0 250 500 750 1,000
km

Recap: The fundamental questions

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

What about orthometric heights?

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

History of vertical datums in the USA

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

History of vertical datums in the USA

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

NGVD29

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

NAVD88

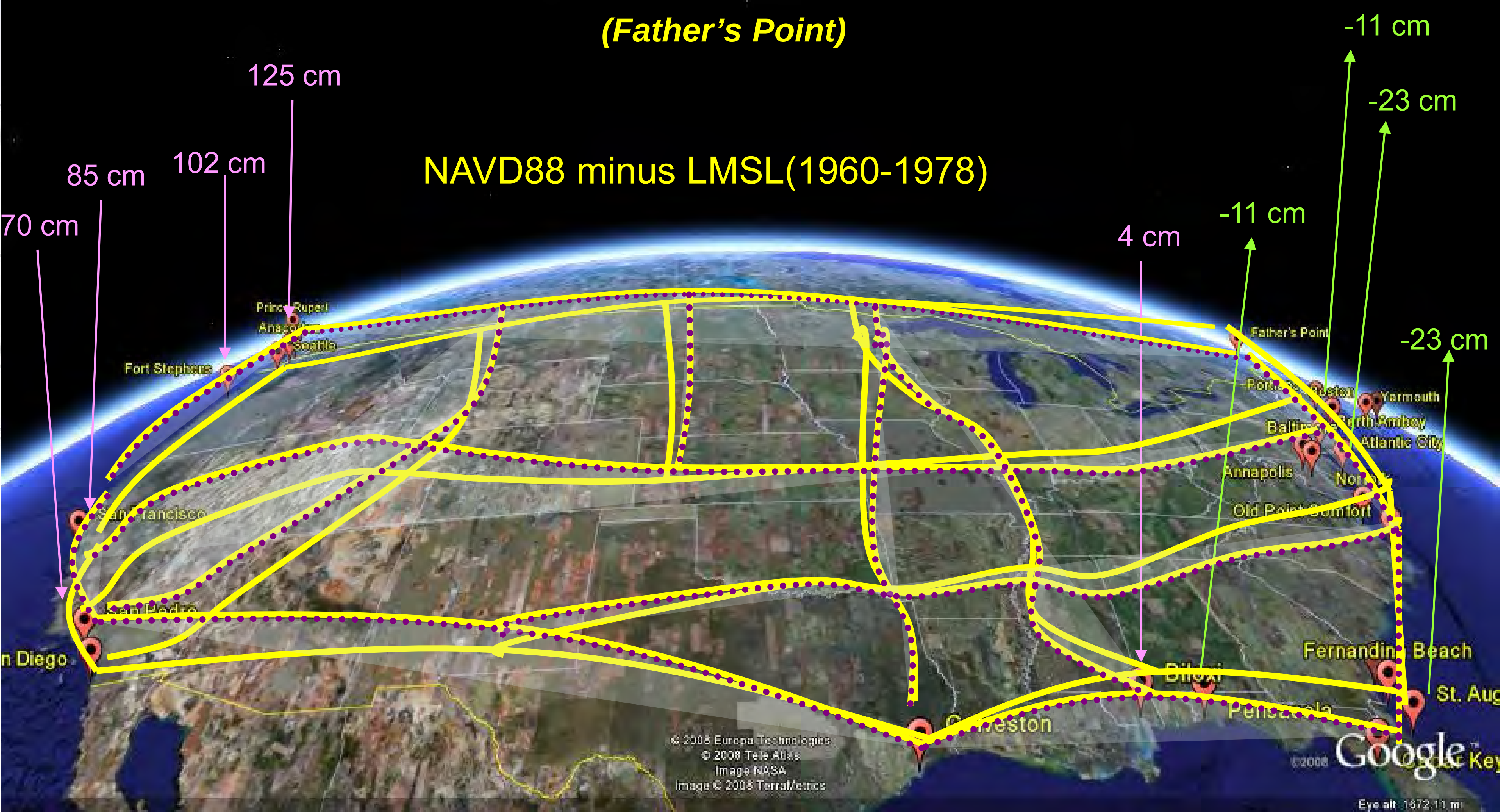
The North American Vertical Datum of 1988 is referenced to a single tide gauge in Canada

NGVD 29
NAVD 88

Referenced to 26 Tide Gages

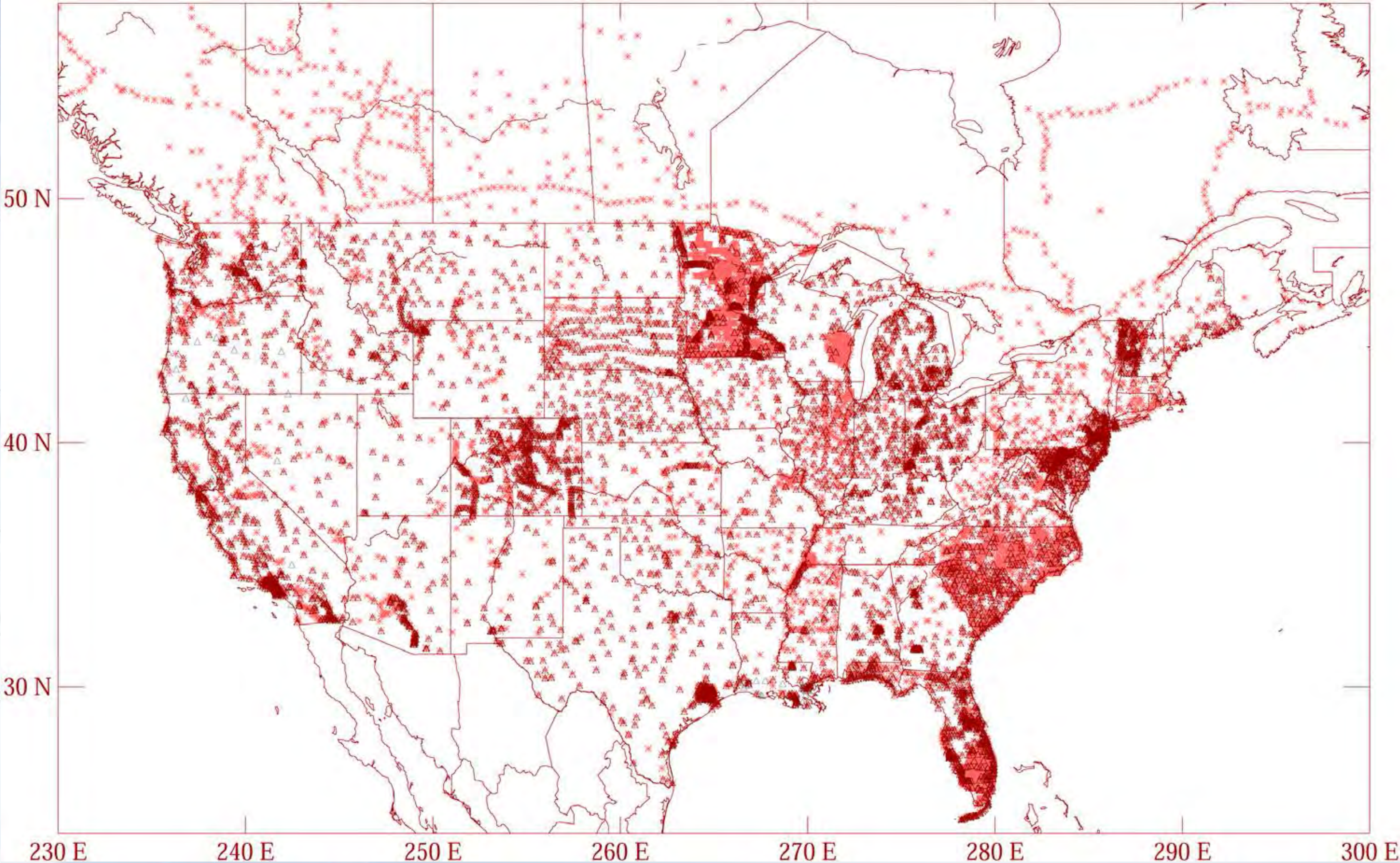
(Father's Point)

NAVD88 minus LMSL(1960-1978)



Types and Uses of Geoid Height Models

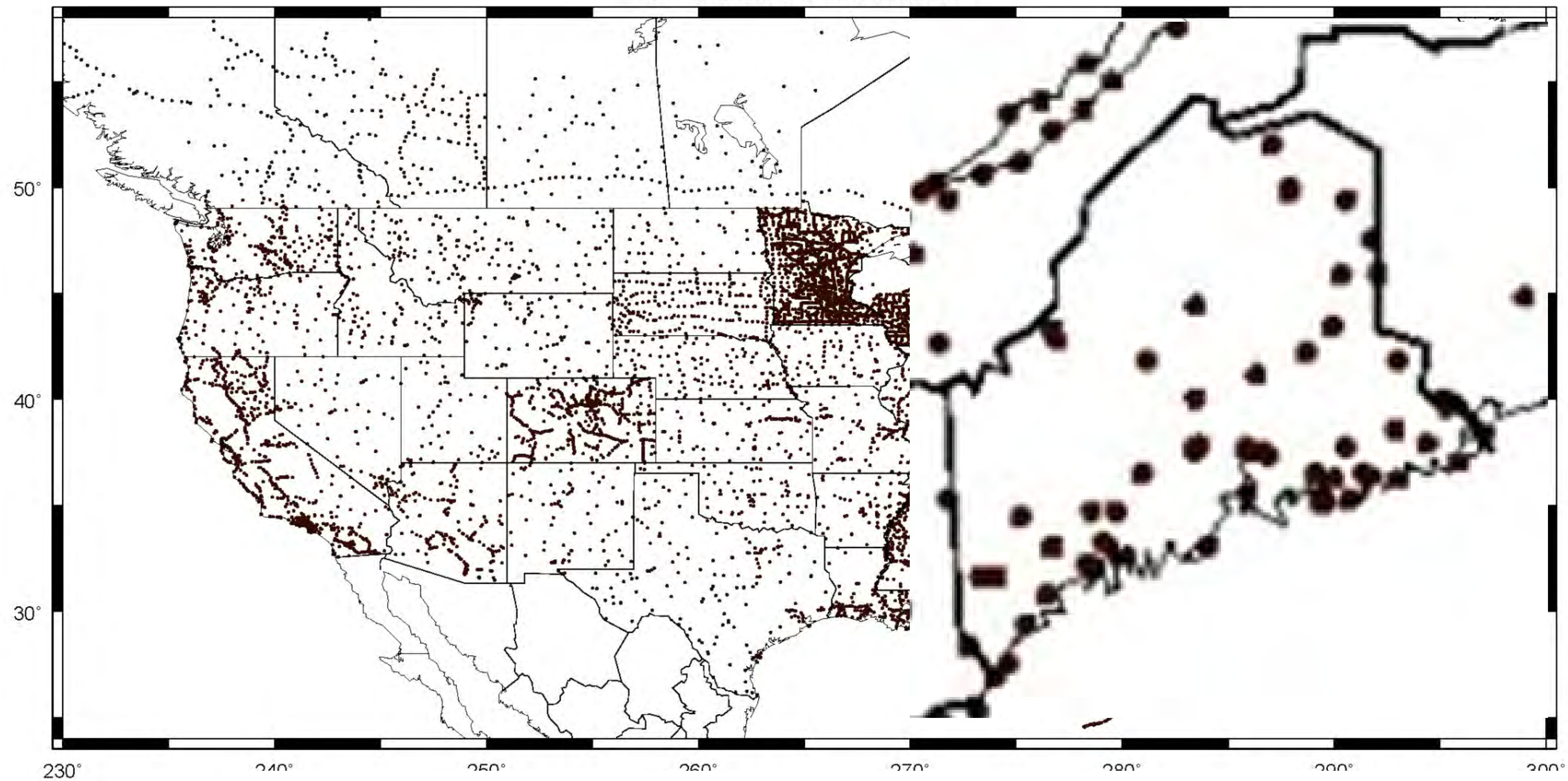
- Gravimetric (or Gravity) Geoid Height Models
  - Defined by gravity data crossing the geoid
  - Refined by terrain models (DEM's)
  - Scientific and engineering applications
- Composite (or Hybrid) Geoid Height Models
  - Gravimetric geoid defines most regions
  - Warped to fit available GPSBM control data
  - Defined by legislated ellipsoid (NAD 83) and local vertical datum (NAVD 88, PRVD02, etc.)
  - May be statutory for some surveying & mapping applications



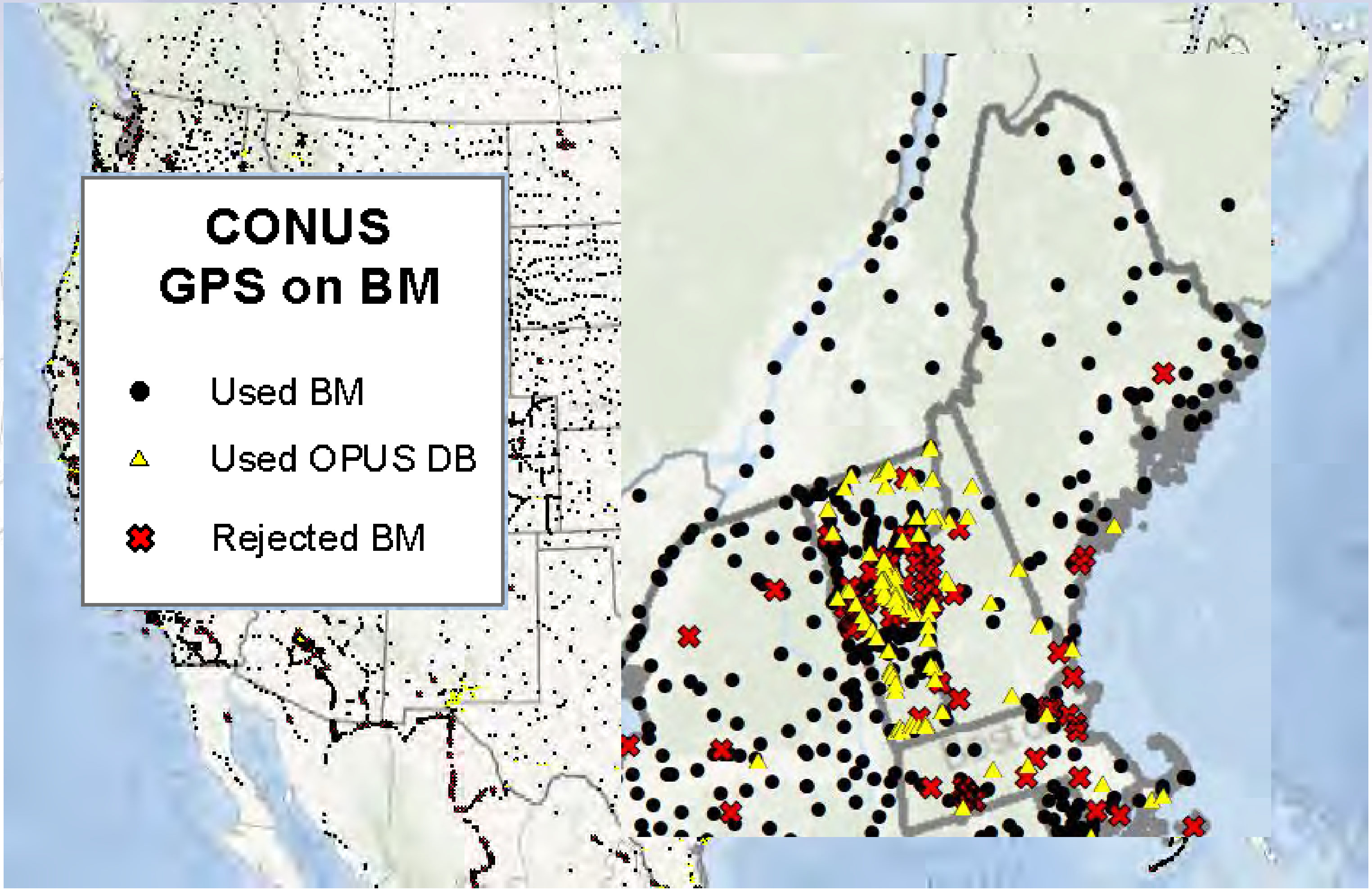
GGPSBM1999: 6,169 total 0 Canada STDEV 9.2 cm (2σ)

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

GPS BMs for GEOID09



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	Geoid
NAD 83(2011)	Geoid12A
NAD 83(2007)	Geoid09 Geoid06 (AK only)
NAD 83(1996) & CORS96	Geoid03 Geoid99 Geoid96
NAD 83(1992)	Geoid93

Mission and Vision of NGS

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

Problems with NAD 83 and NAVD 88

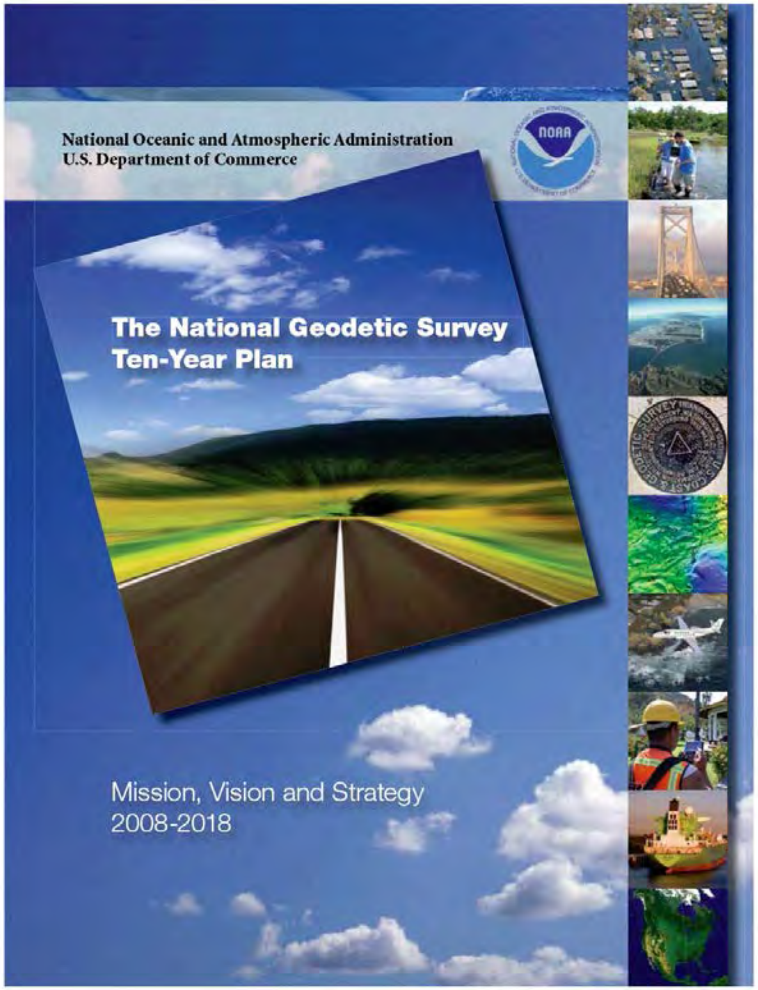
- **NAD 83** is not as geocentric as it could be (approx. 2 m)
  - Surveyors don't see this - **Yet**
- **NAD 83** is not well defined with positional velocities
- **NAVD 88** is realized by passive control (bench marks) most of which have not been releveled in at least 40 years.
- **NAVD 88** does not account for local vertical velocities (subsidence and uplift)
  - Post glacial isostatic readjustment
  - Subsurface fluid withdrawal
  - Sediment loading
  - Sea level rise (0.6 ft per 100 years)
    - **Seavey Island, ME 1.8 mm/yr (0.006 ft/yr) 1926-2001**
    - **Portland, ME 1.8 mm/yr (0.006 ft/yr) 1912-2006**
    - **Bar Harbor, ME 2.0 mm/yr (0.007 ft/yr) 1947-2006**
    - **Eastport, ME 2.0 mm/yr (0.007 ft/yr) 1929-2006**

The National Geodetic Survey 10 year plan Mission, Vision and Strategy 2008 – 2018

http://www.ngs.noaa.gov/INFO/NGS10yearplan.pdf

- *Official NGS policy as of Jan 9, 2008*
  - *Modernized agency*
  - *Attention to accuracy*
  - *Attention to time-changes*
  - *Improved products and services*
  - *Integration with other fed missions*

- *2018 Targets: (now 2022)*
  - *NAD 83 and NAVD 88 re-defined*
  - *Cm-accuracy access to all coordinates*
  - *Customer-focused agency*
  - *Global scientific leadership*



Future Geometric (3-D) Datum

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

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

• **lat / long / ellipsoid height of defining points accurate to 1 mm, anytime**

• **CORS coordinates computed / published daily; track changes**

Future Geopotential (Vertical) Datum

- **replace NAVD88 with new geopotential datum – by 2022**
- **gravimetric geoid-based, in combination with GNSS**
- **monitor time-varying nature of gravity field**
- **develop transformation tools to relate to NAVD88**

- **build most accurate ever continental gravimetric geoid model (GRAV-D)**
- **determine gravity with accuracy of 10 microGals, anytime**
- **support both orthometric and dynamic heights**
- **Height Modernization is fully supported**

Why New Datums?

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

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

- Leveling the country can not be done again
  - Too costly in time and money (Estimated ~ $1B)
- Leveling yields cross-country error build-up; problems in the mountains
- Leveling requires leaving behind passive marks
  - Bulldozers and crustal motion do their worst

Why isn't NAVD 88 good enough anymore

- **NAVD 88 suffers from 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

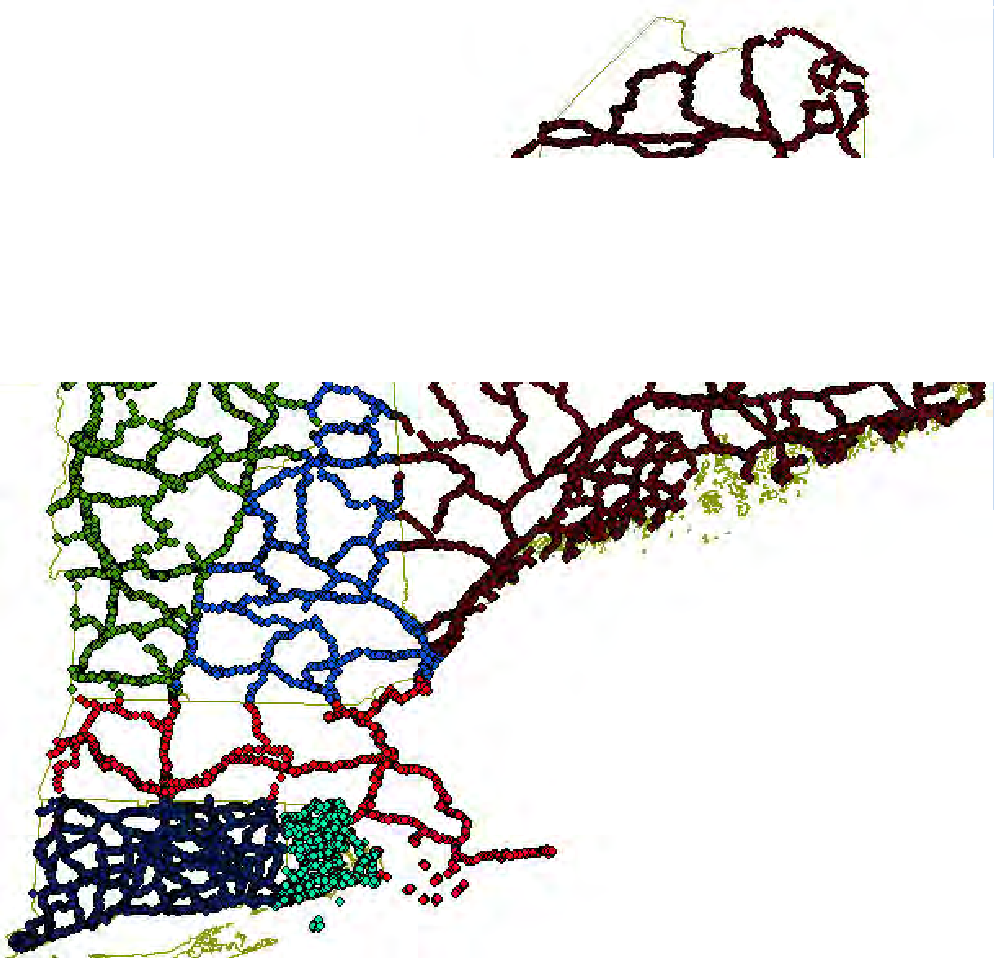
Why isn't NAVD 88 good enough anymore?

NAVD 88 suffers from:

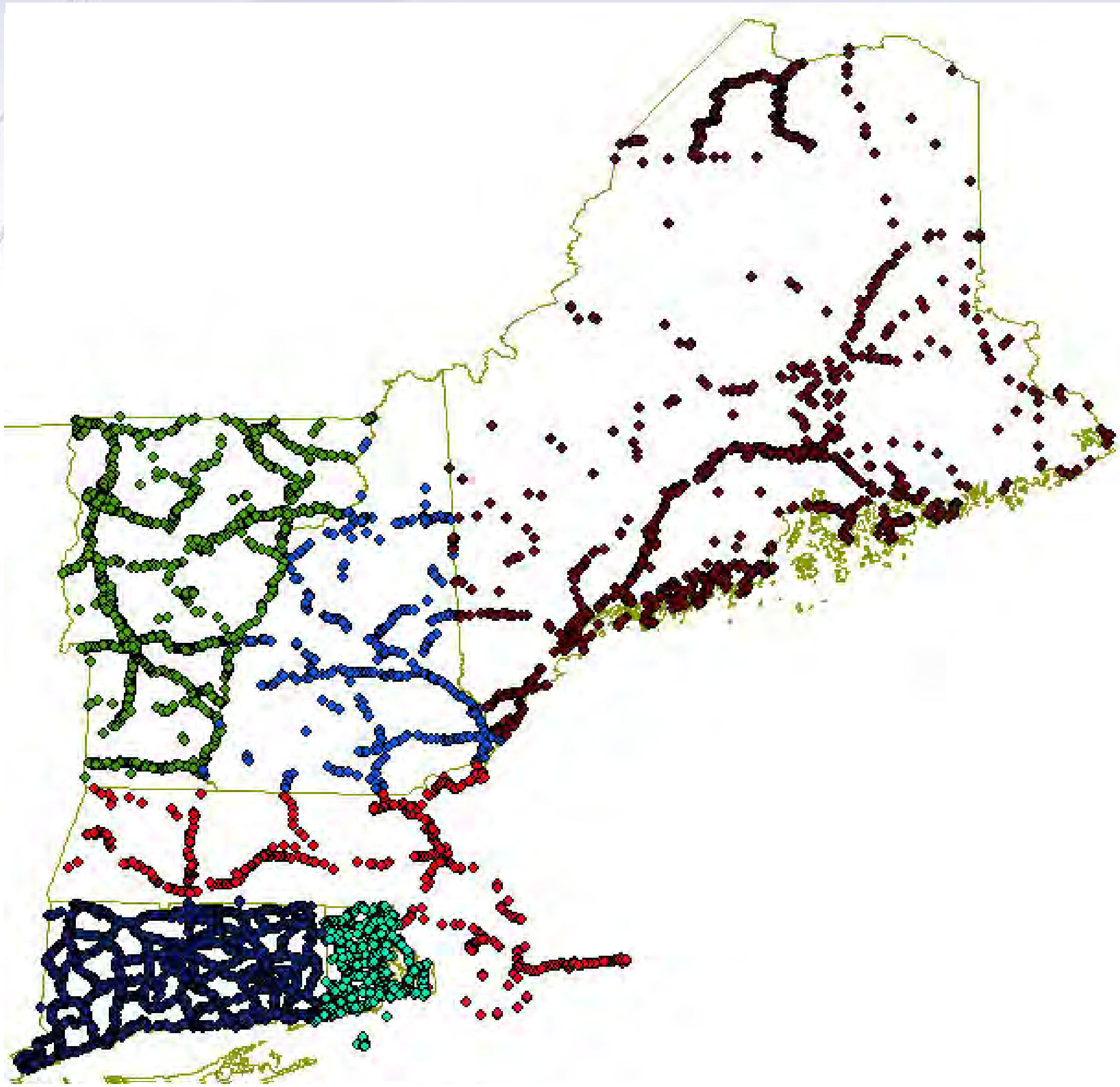
- A zero height surface that:
  - Has been proven to be ~50 cm biased from the latest, best geoid models (GRACE satellite)
  - Has been proven to be ~ 1 meter tilted across CONUS (again, based on the independently computed geoid from the GRACE satellite)

NGSIDB BM Status (1st, 2nd order)

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



NE Vertical Control



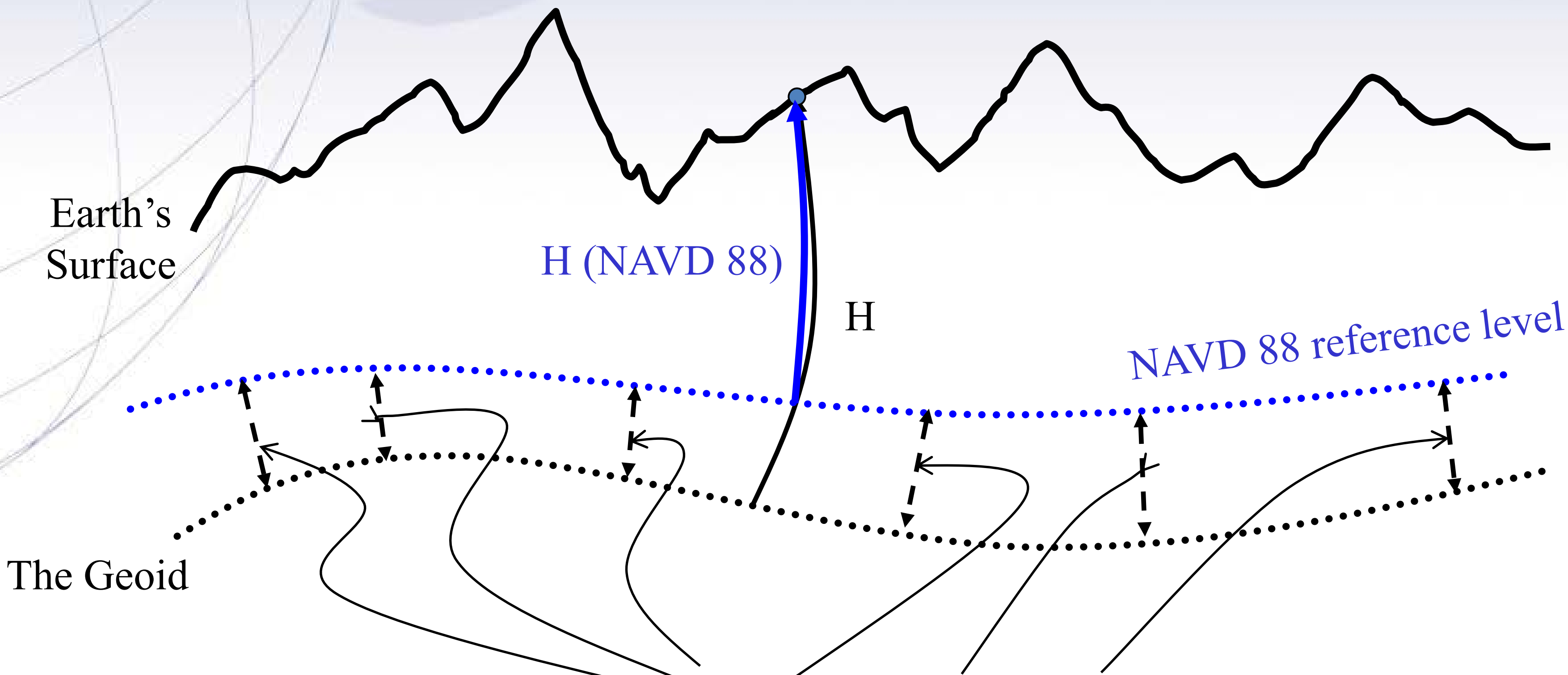
Height-Mod means More Marks

Height Modernization Bottom line

1. Using GNSS is cheaper, easier than leveling

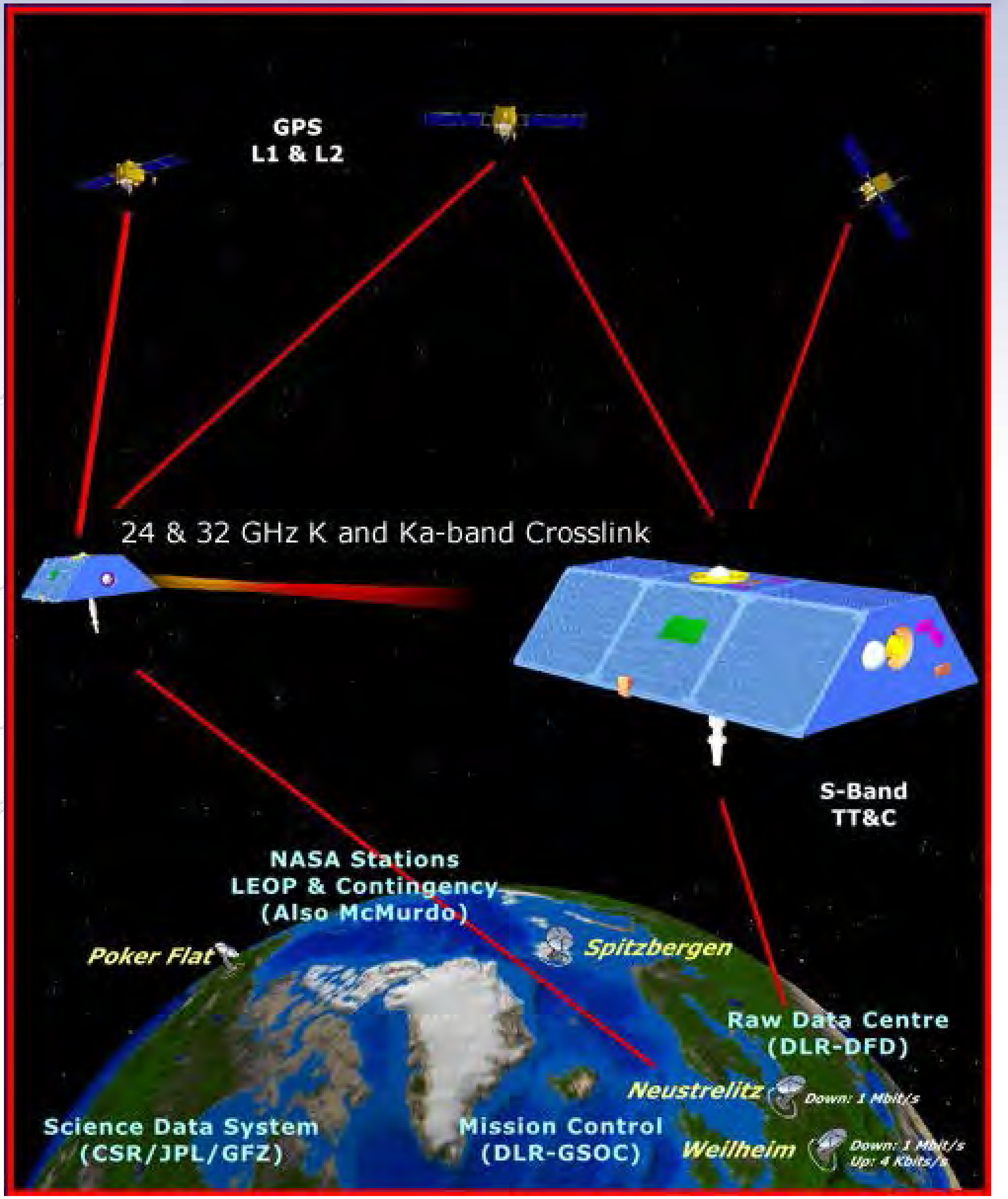
2. To use GNSS we need a good geoid model

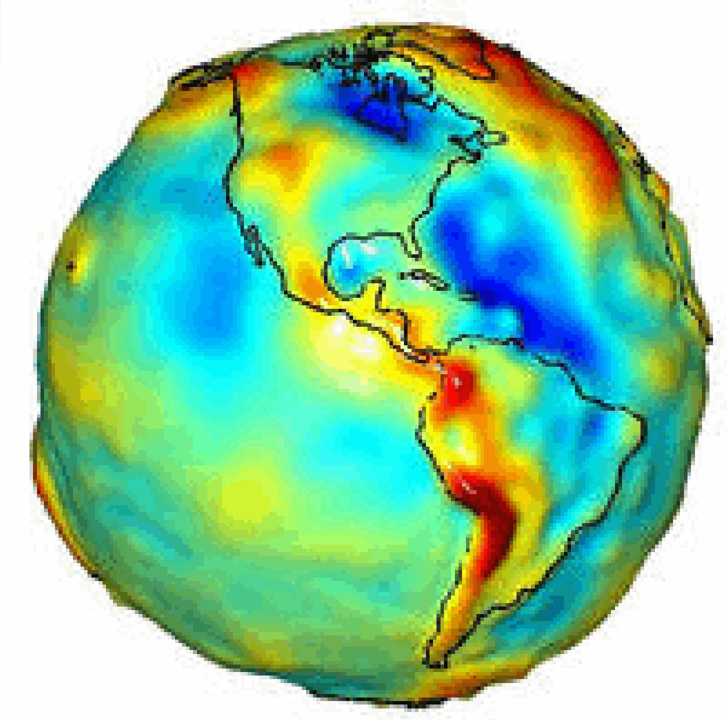
Why isn't NAVD 88 good enough anymore?



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

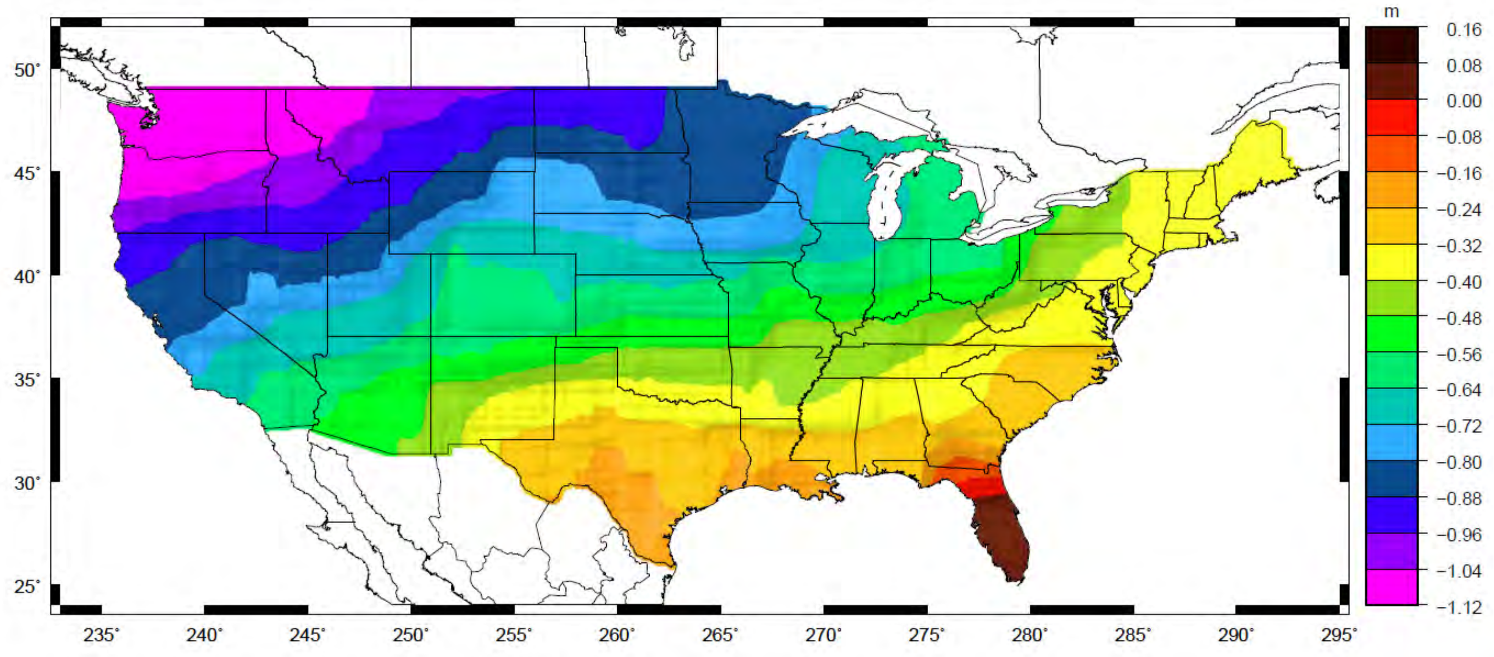
GRACE – Gravity Recovery and Climate Experiment





Why isn't NAVD 88 good enough anymore?

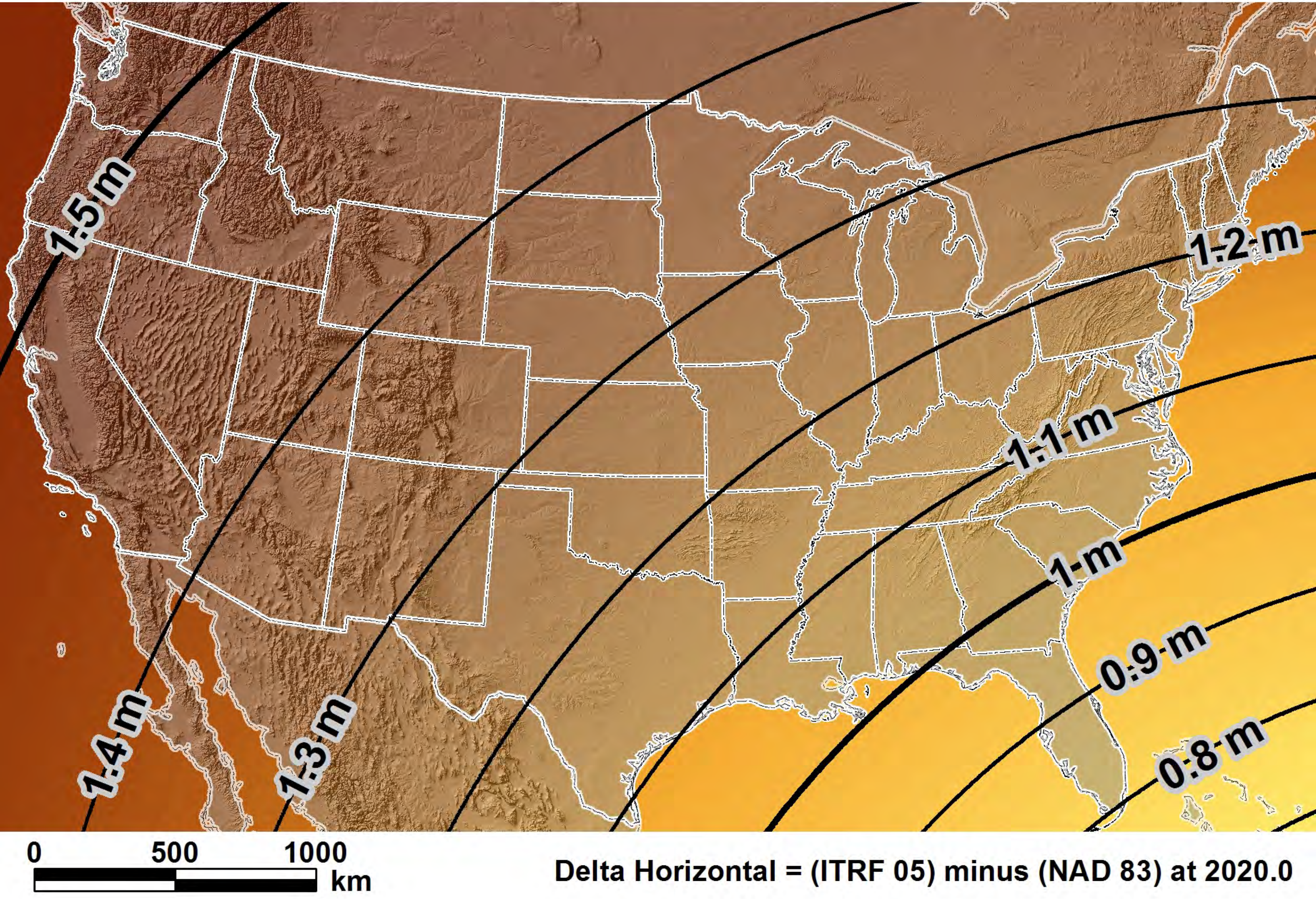
- **Approximate level of geoid mismatch known to exist in the NAVD 88 zero surface:**



How accurate is a GPS-derived Orthometric Height?

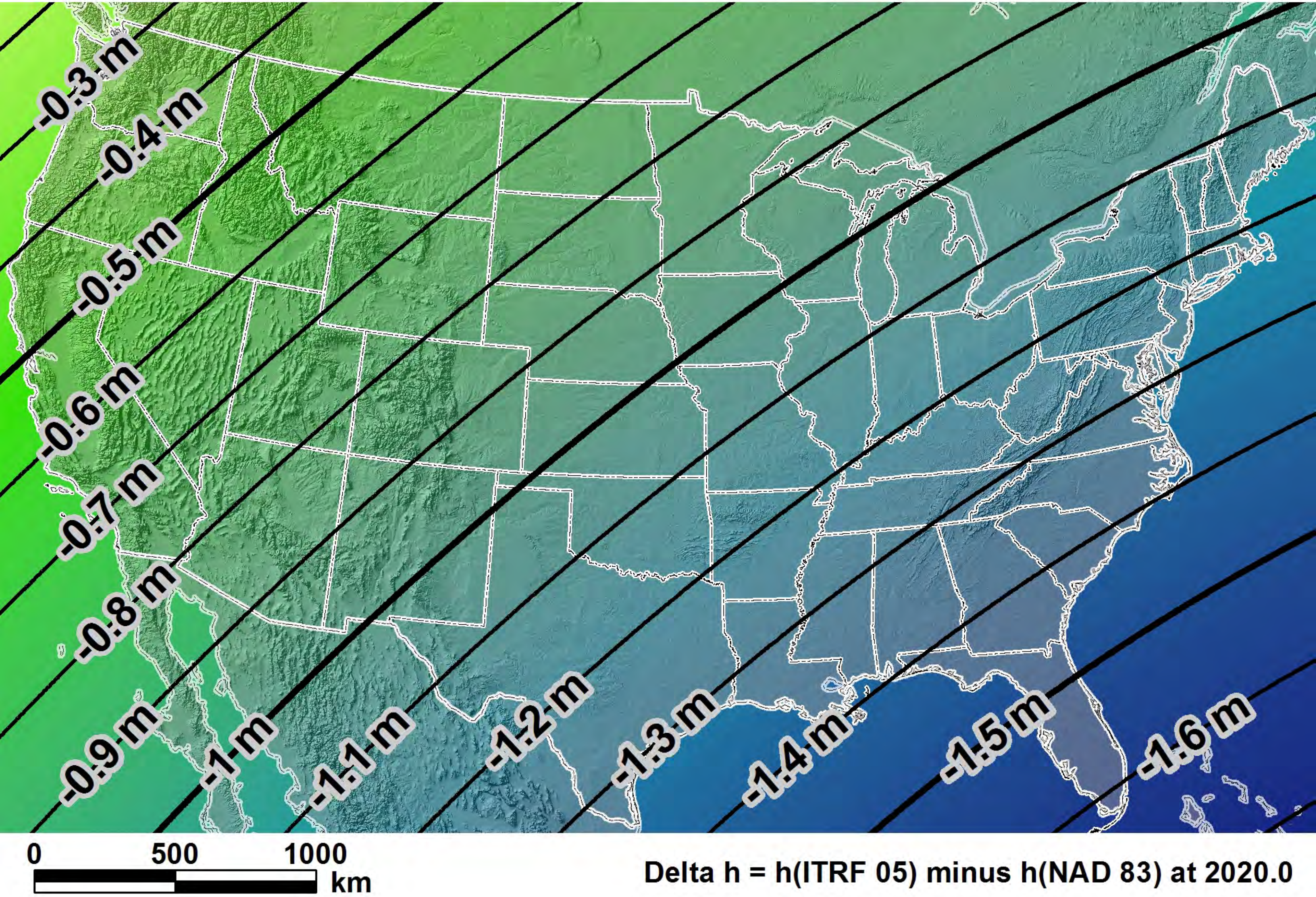
- Relative (local) accuracy in ellipsoid heights between adjacent points can be better than 2 cm, at 95% confidence level
- Network accuracy (relative to NSRS) in ellipsoid heights can be better than 5 cm, at 95% confidence level
- Accuracy of orthometric height is dependent on accuracy of the geoid 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
- Geoid09 can have an uncertainty in the 2-5 cm range.

Estimated horizontal change from NAD 83 to new geometric datum



Delta Horizontal = (ITRF 05) minus (NAD 83) at 2020.0

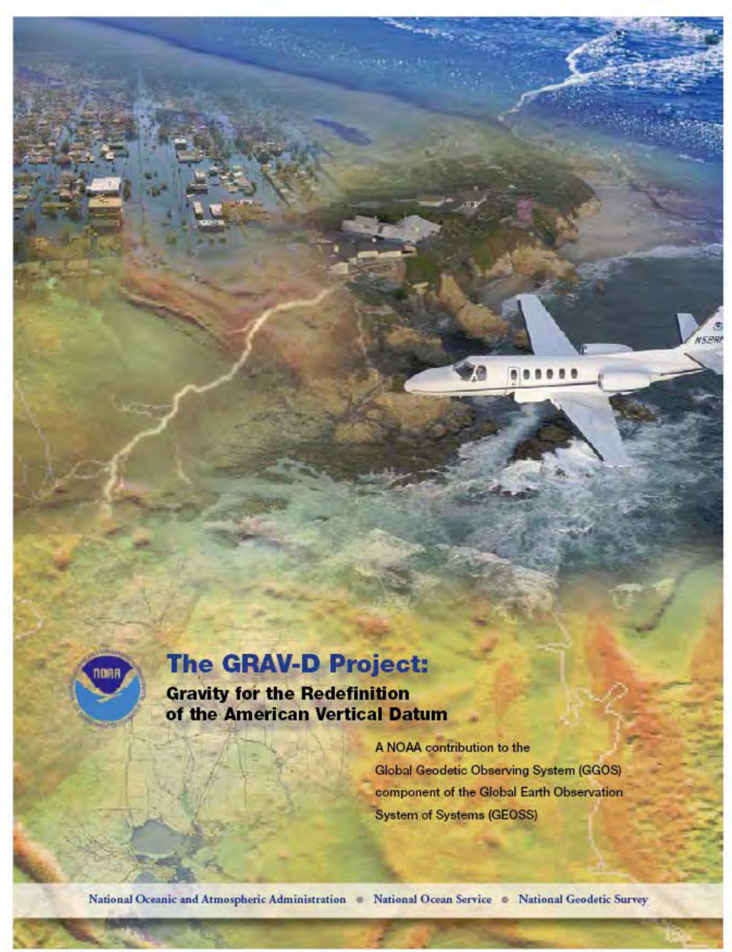
Estimated ellipsoid height change from NAD 83 to new geometric datum



Delta h = h(ITRF 05) minus h(NAD 83) at 2020.0

Transition to the Future – GRAV-D

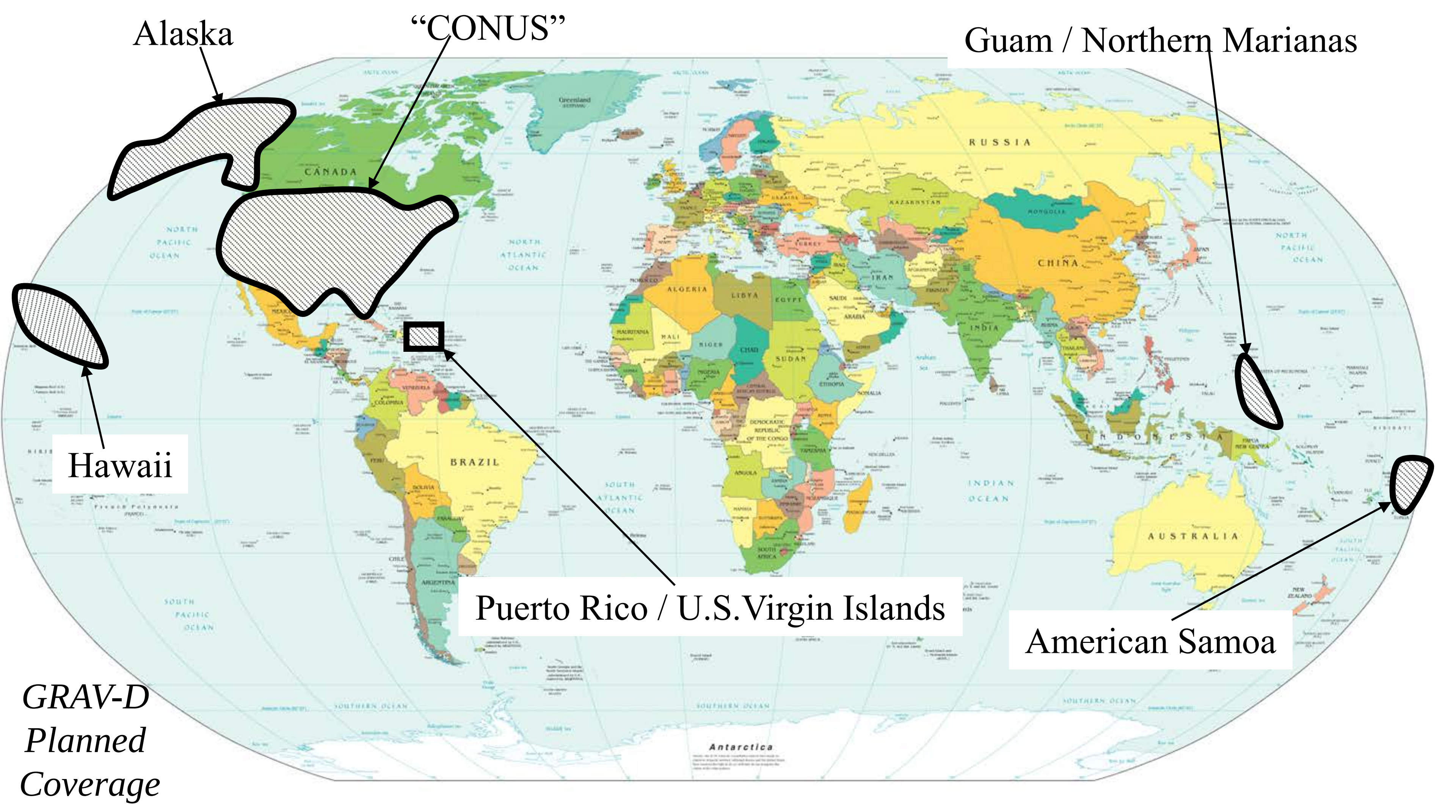
Gravity for the Redefinition of the American Vertical Datum



- Official NGS policy as of Nov 14, 2007
  - $38.5M over 10 years
- Airborne Gravity Snapshot
- Absolute Gravity Tracking
- Re-define the Vertical Datum of the USA by 2018

  (2022 more likely due to funding issues)

What is GRAV-D?



GRAV-D Planned Coverage

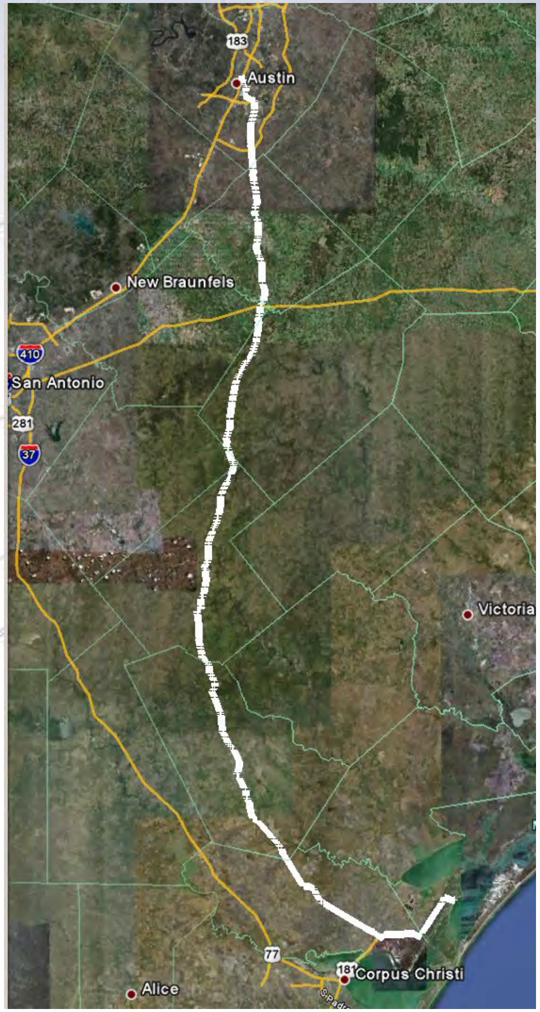
Gravity Survey Plan

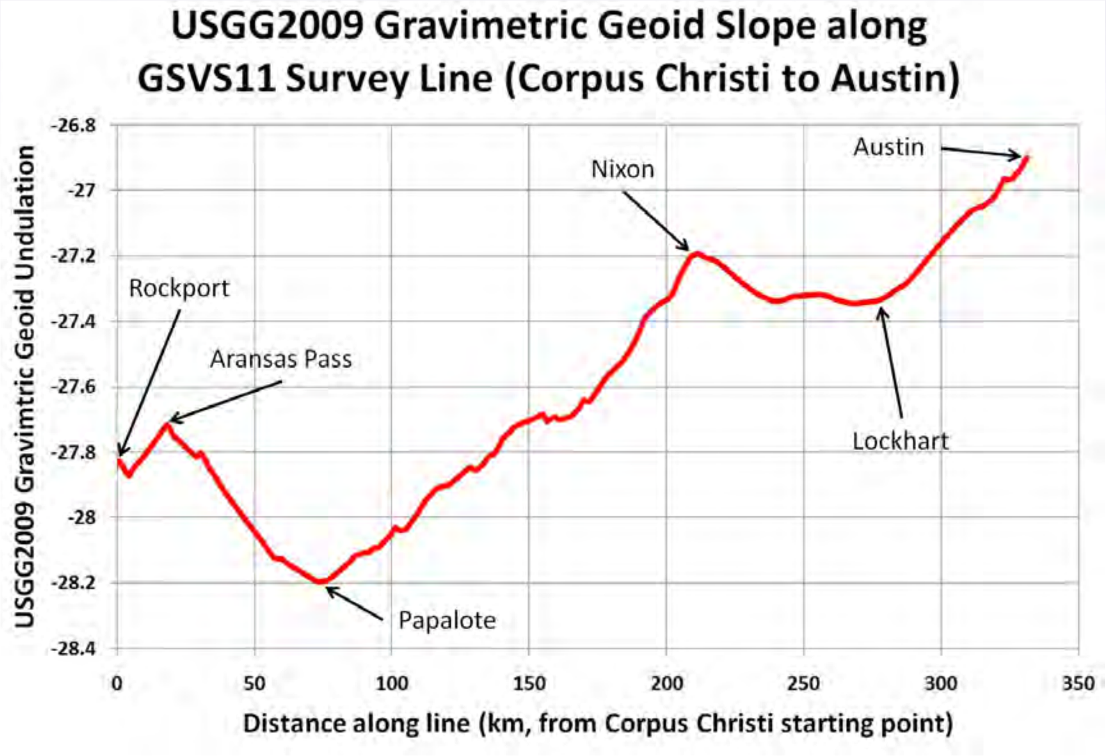
- National Scale Part 1
  - Predominantly through airborne gravity
  - With Absolute Gravity for ties and checks
  - Relative Gravity for expanding local regions where airborne shows significant mismatch with existing terrestrial

What is GRAV-D?

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

Geoid Slope Validation Survey of 2011 (GSVS11)





GSVS11 Components

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