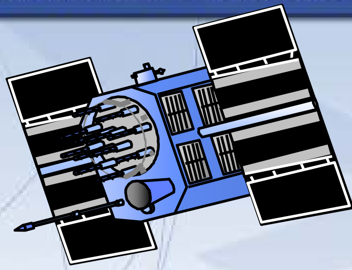


National Geodetic Survey Update – Preparing for Tomorrow (*New Datums are Coming!*)

William (Bill) Stone
Southwest Region (AZ, NM, UT) Geodetic Advisor
william.stone@noaa.gov

May 11, 2017
Park City

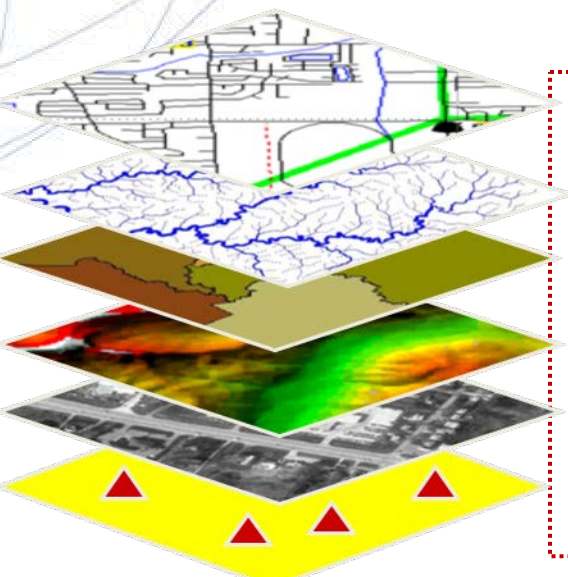
NOAA's National Geodetic Survey
geodesy.noaa.gov

UGIC
UTAH GEOGRAPHIC INFORMATION COUNCIL

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



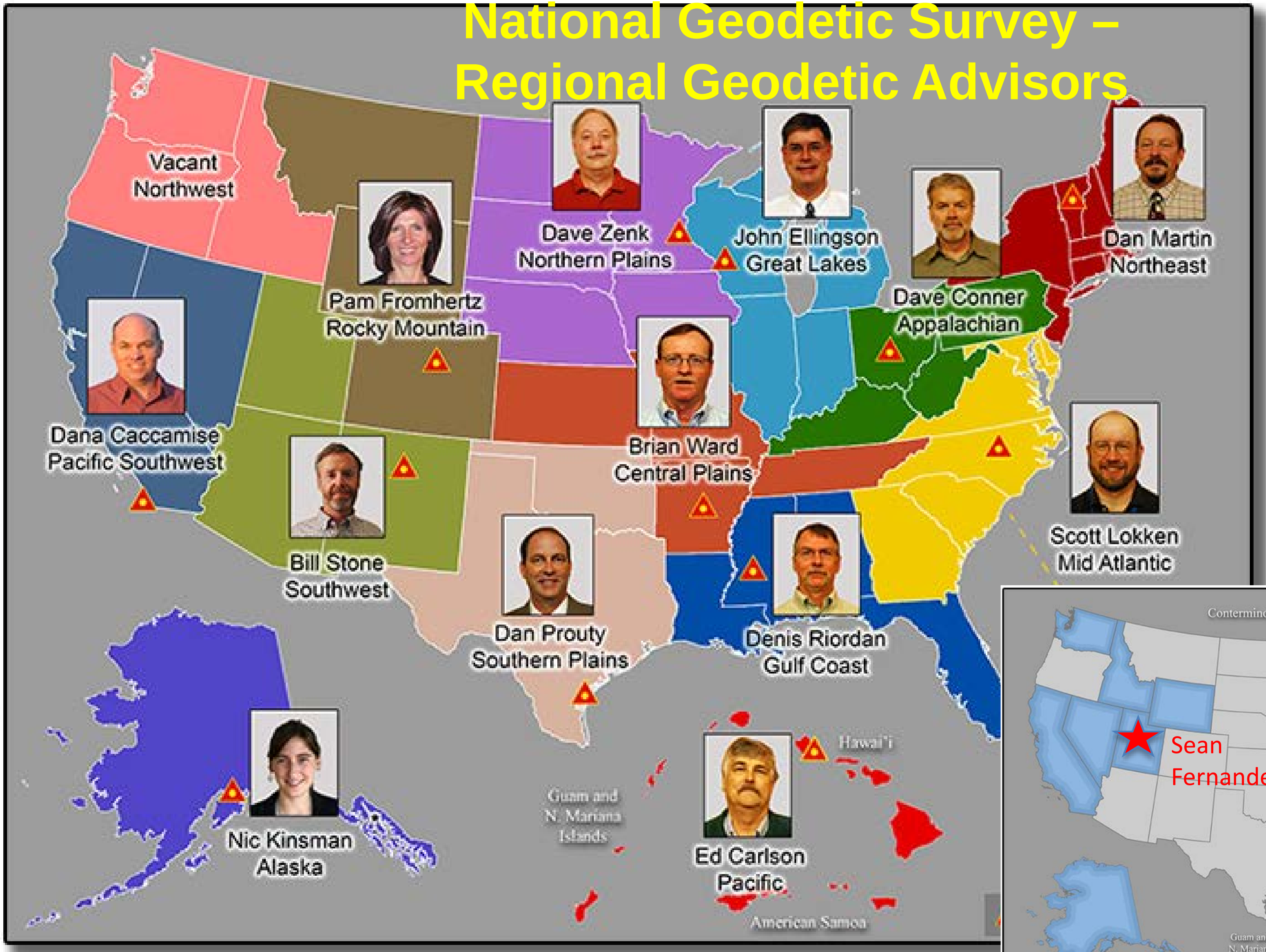
- **Latitude**
- **Longitude**
- **Height**
- Gravity
- Orientation
- Scale

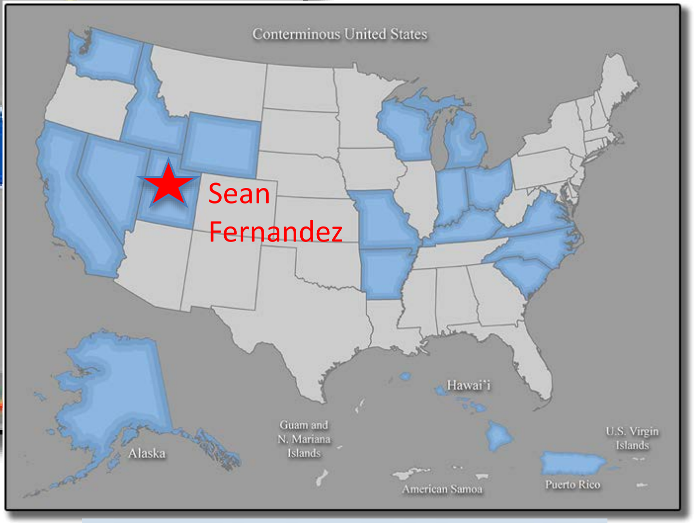
& their time variations

(& National Shoreline, etc.)

- North American Datum 1983 (NAD83)
- North American Vertical Datum 1988 (NAVD88)

National Geodetic Survey – Regional Geodetic Advisors

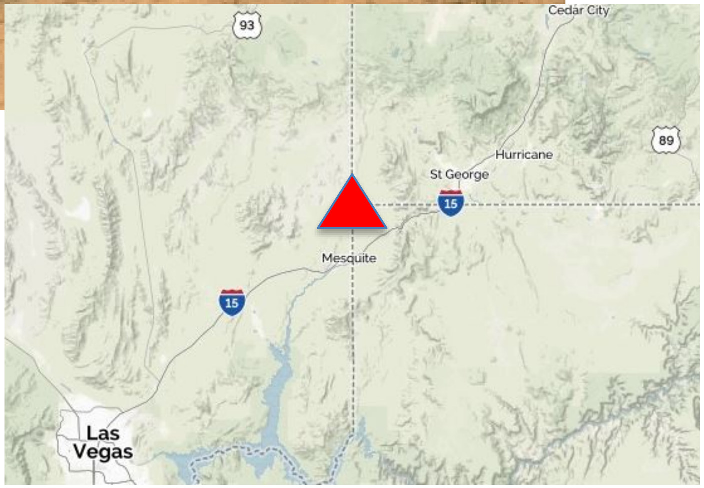




State Geodetic Coordinators

National Geodetic Survey


N
W
E
NEVADA
UTAH
ARIZONA
UCLS
Arizona - Nevada - Utah
Monument 2016
S


93
Cedar City
89
Hurricane
St George
15
Mesquite
15
Las
Vegas

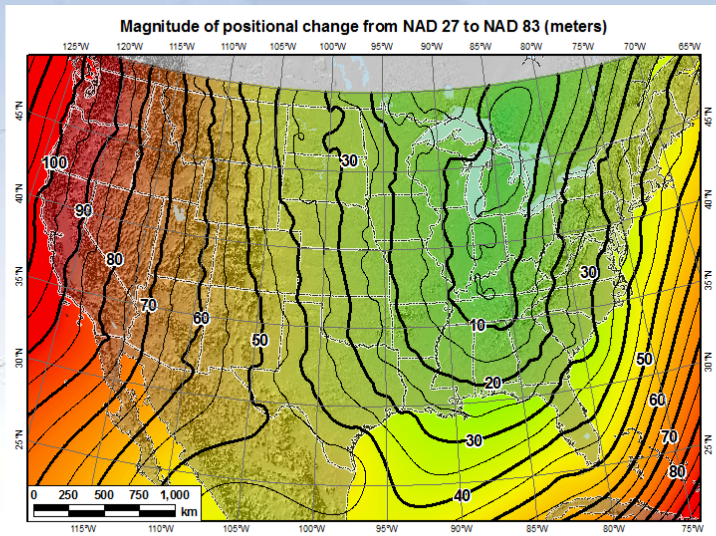
USER: william.stone@noaa.gov DATE: February 24, 2017
RINEX FILE: 3cor054u.17o TIME: 05:29:02 UTC

SOFTWARE: page5 1209.04 master52.pl 160321 START: 2017/02/23 20:52:00
EPHEMERIS: igu19374.eph [ultra-rapid] STOP: 2017/02/23 23:59:00
NAV FILE: brdc0540.17n OBS USED: 7658 / 8153 : 94%
ANT NAME: CHCX90D-OPUS NONE # FIXED AMB: 43 / 45 : 96%
ARP HEIGHT: 0.180 OVERALL RMS: 0.014(m)

REF FRAME: NAD_83(2011)(EPOCH:2010.0000)			IGS08 (EPOCH:2017.1478)	
X:	-2078663.057(m)	0.010(m)	-2078663.936(m)	0.010(m)
Y:	-4657799.043(m)	0.014(m)	-4657797.727(m)	0.014(m)
Z:	3817863.470(m)	0.003(m)	3817863.352(m)	0.003(m)

LAT:	37 0 0.69689	0.005(m)	37 0 0.71029	0.005(m)
E LON:	245 56 59.81599	0.015(m)	245 56 59.76184	0.015(m)
W LON:	114 3 0.18401	0.015(m)	114 3 0.23816	0.015(m)
EL HGT:	752.973(m)	0.009(m)	752.229(m)	0.009(m)
ORTHO HGT:	778.810(m)	0.021(m)	[NAVD88 (Computed using GEOID12B)]	

A (very) Brief History of U.S. Horizontal / Geometric Datums



U.S. Standard Datum

NAD27

NAD83 (1986)

NAD83 (HARN / 199X)

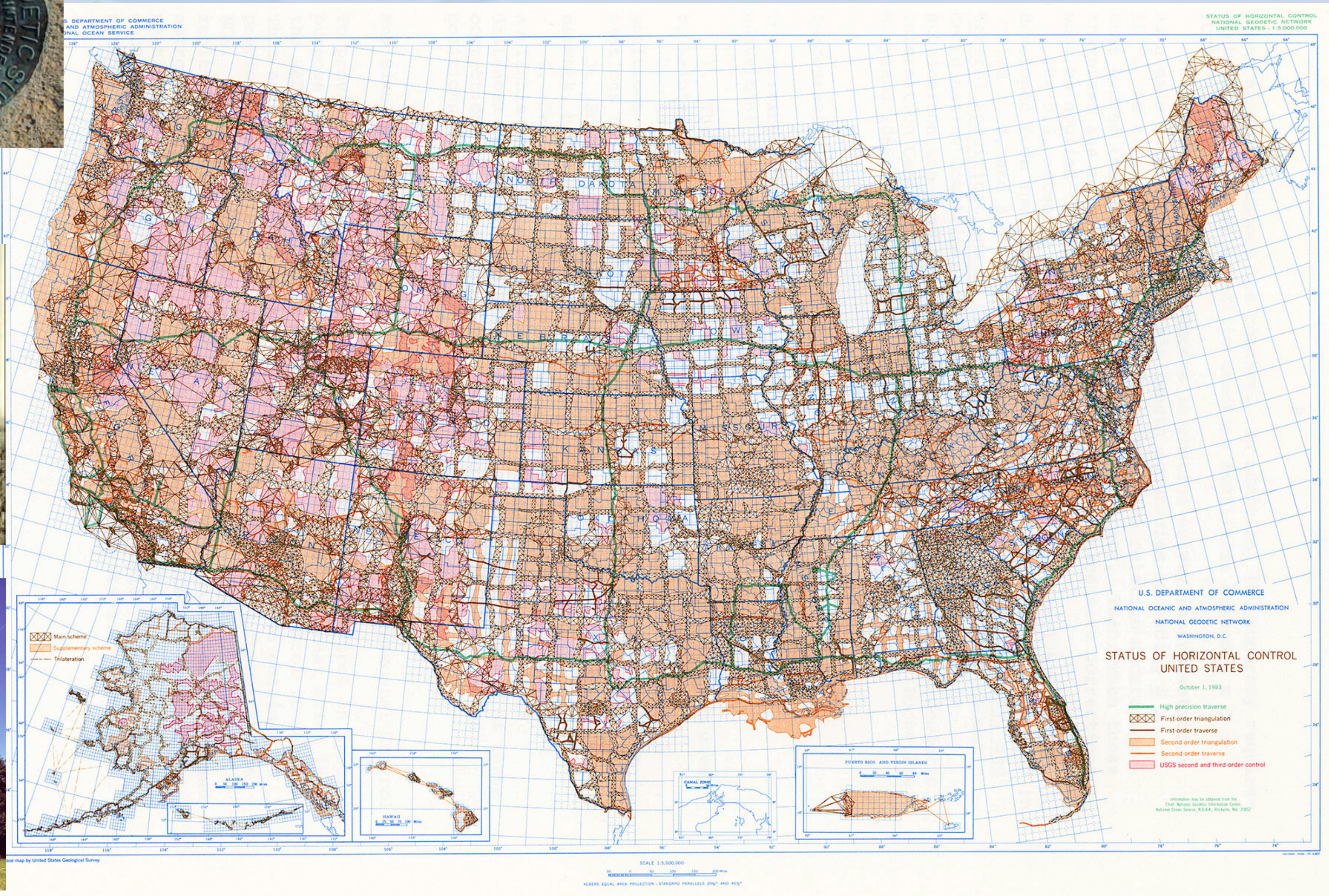
NAD83 (2007)

NAD83 (2011)

time

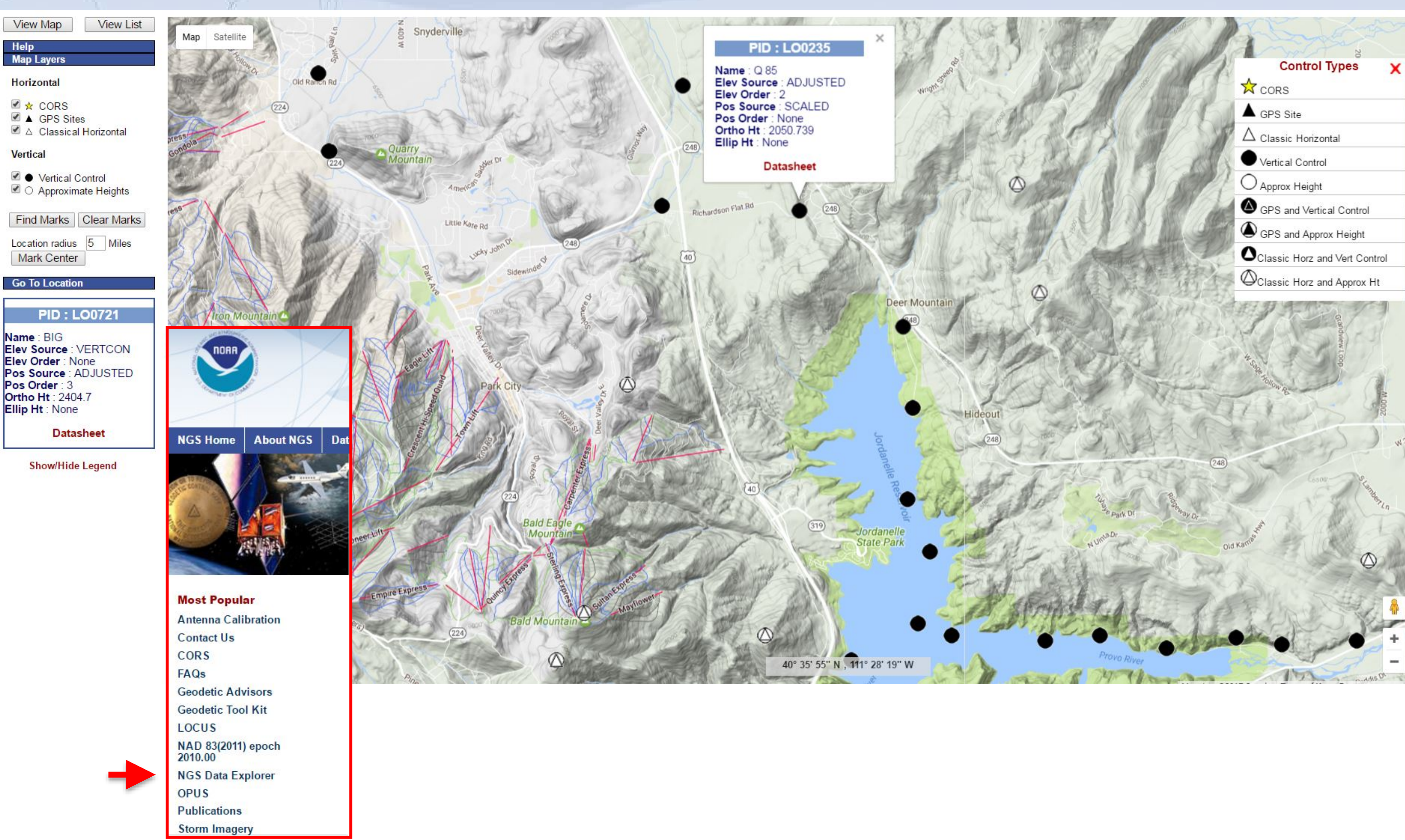
shift: < 10 m | tens of meters | few 0.1m | few 0.01m | few 0.01m

Status of Horizontal Control 1983



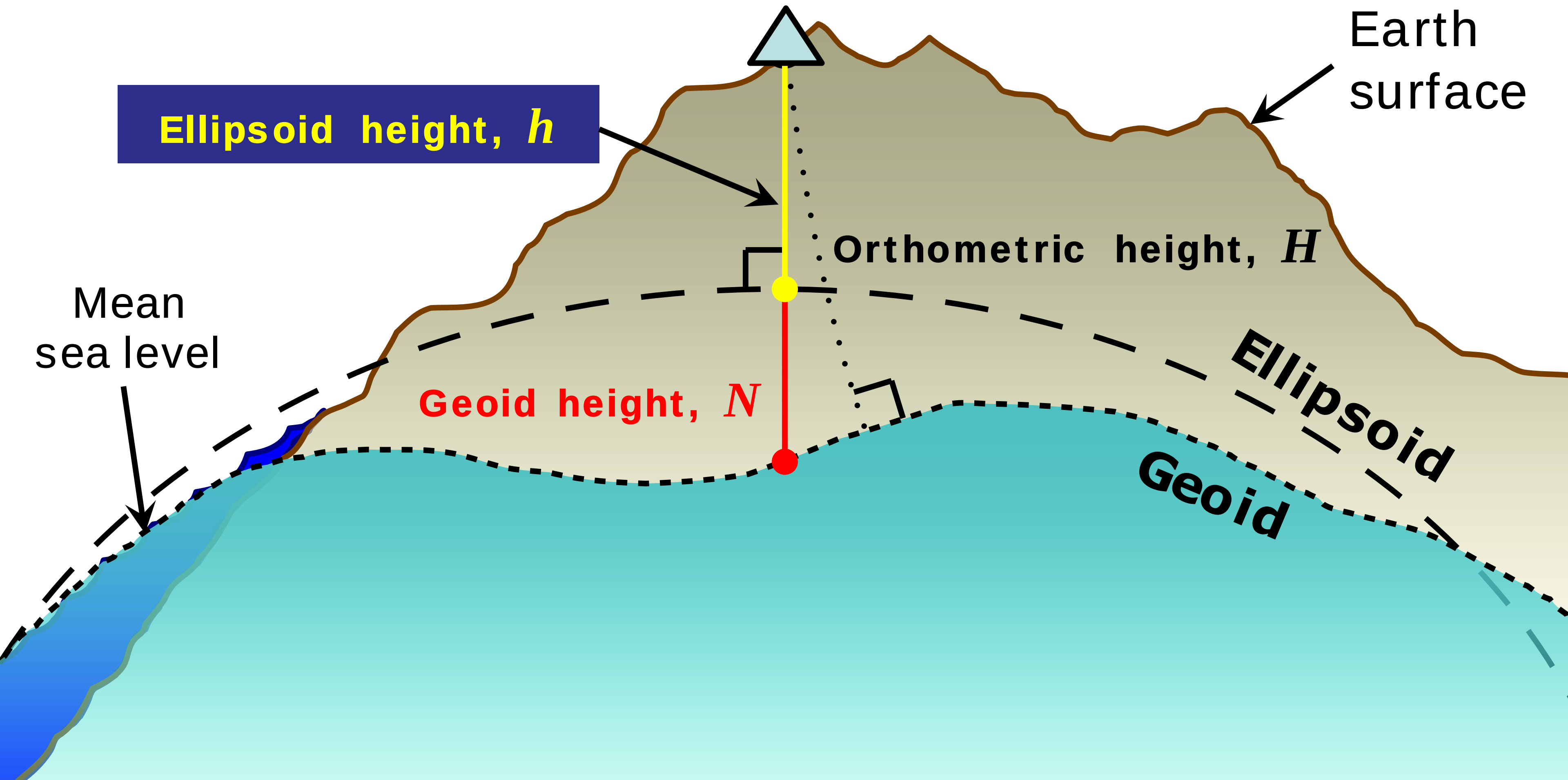
National Geodetic Survey Data Explorer

National Geodetic Survey



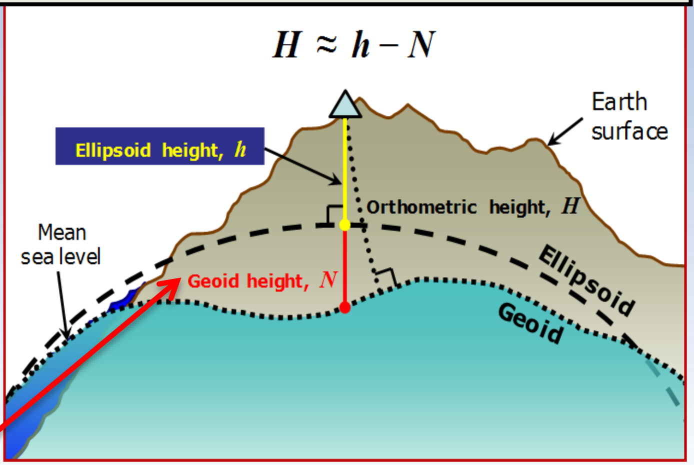
Heights 101

$$H \approx h - N$$

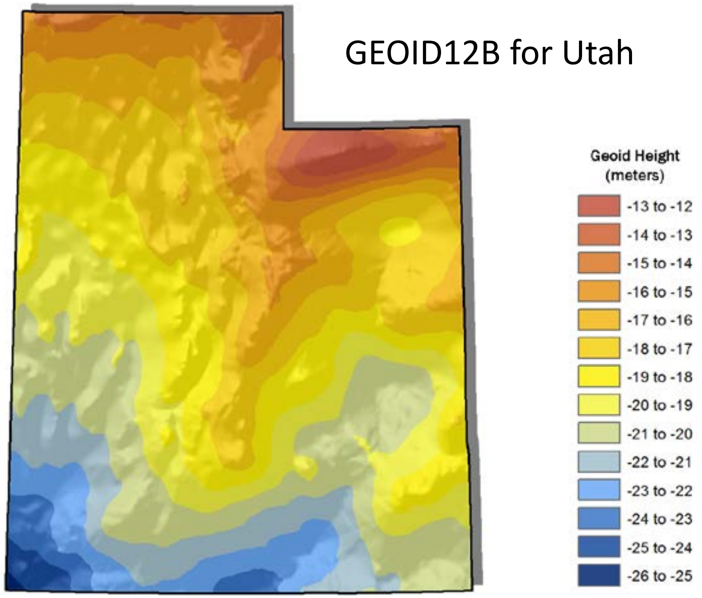


```
National Geodetic Survey,   Retrieval Date = MAY  4, 2017
***********************************************************************
 CBN           -  This is a Cooperative Base Network Control Station.
 DESIGNATION -  JORDANELLE
 PID           -  AA3699
 STATE/COUNTY-  UT/WASATCH
 COUNTRY       -  US
 USGS QUAD     -  HEBER CITY (1955)

                        *CURRENT SURVEY CONTROL
 ______________________________________________________________________
 NAD 83(2011) POSITION- 40 35 39.26175(N) 111 24 54.64568(W)   ADJUSTED
 NAD 83(2011) ELLIP HT-  1954.690 (meters)        (06/27/12)   ADJUSTED
 NAD 83(2011) EPOCH   -  2010.00
 NAVD 88 ORTHO HEIGHT -  1970.3   (meters)     6464.    (feet) GPS OBS
 ______________________________________________________________________
 NAVD 88 orthometric height was determined with geoid model    GEOID93
 GEOID HEIGHT    -            -15.28 (meters)                  GEOID93
 GEOID HEIGHT    -           -15.558 (meters)                  GEOID12B
 NAD 83(2011) X  - -1,771,402.357 (meters)                     COMP
 NAD 83(2011) Y  - -4,516,563.471 (meters)                     COMP
 NAD 83(2011) Z  -  4,129,583.726 (meters)                     COMP
 LAPLACE CORR    -             5.35  (seconds)                  DEFLEC12B

 Network accuracy estimates per FGDC Geospatial Positioning Accuracy
 Standards:
        FGDC (95% conf, cm)     Standard deviation (cm)     CorrNE
           Horiz  Ellip           SD_N   SD_E   SD_h      (unitless)
 -------------------------------------------------------------------
 NETWORK    1.46   2.43           0.69   0.45   1.24      -0.14921160
 -------------------------------------------------------------------
 Click here for local accuracies and other accuracy information.


The horizontal coordinates were established by GPS observations
and adjusted by the National Geodetic Survey in June 2012.

NAD 83(2011) refers to NAD 83 coordinates where the reference frame has
been affixed to the stable North American tectonic plate. See
NA2011 for more information.

The horizontal coordinates are valid at the epoch date displayed above
which is a decimal equivalence of Year/Month/Day.

The orthometric height was determined by GPS observations and a
high-resolution geoid model.
```

NAD 83(2011) epoch 2010.00



GEOID12B for Utah



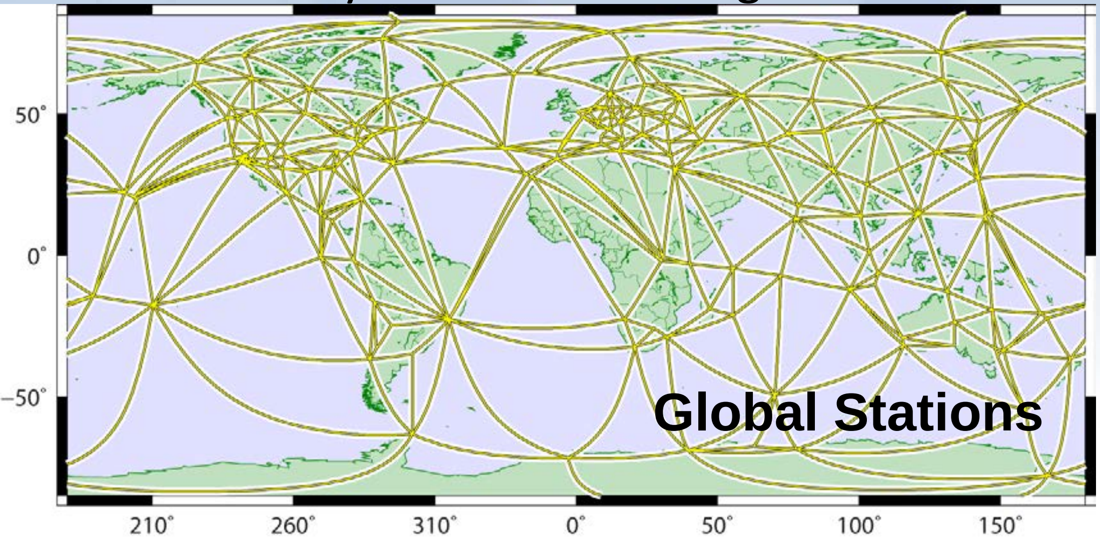
NAD 83(2011) epoch 2010.00

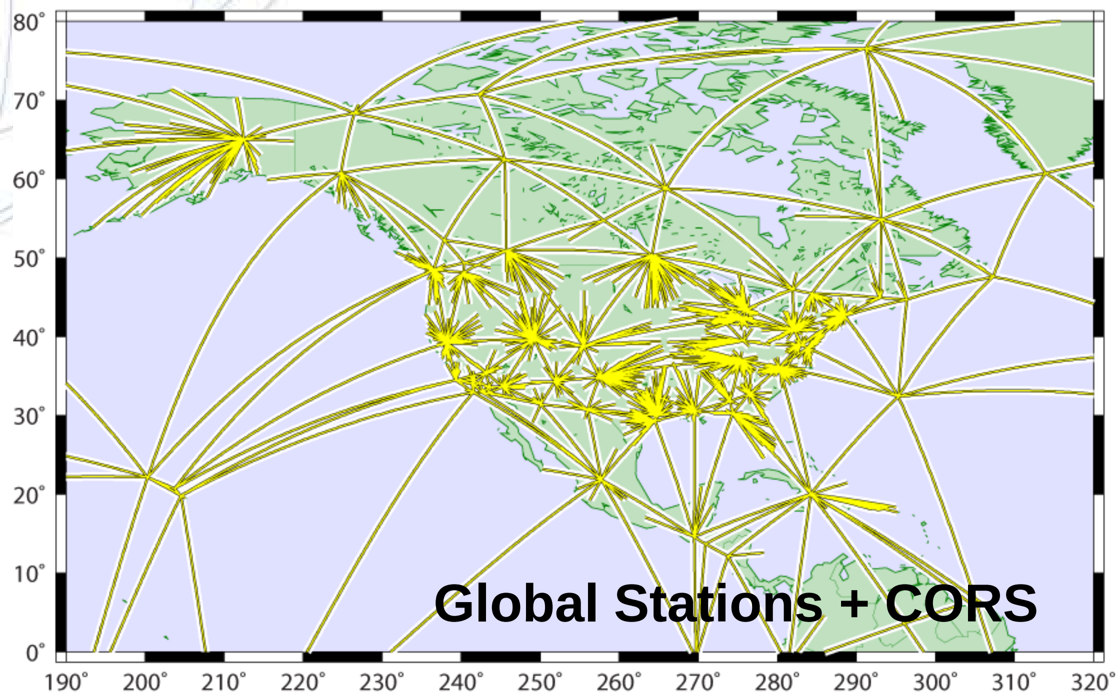
- **Multi-Year CORS Solution (MYCS)**
  - Reprocessed all CORS GPS data Jan 1994 - Apr 2011
  - 2264 CORS & global stations
  - NAD 83 computed by *transformation* from IGS08
  - Published September 2011

- **National Adjustment of 2011 (NA2011)**
  - New adjustment of GNSS passive control
  - GNSS vectors tied (and constrained) to CORS
  - 80,872 stations; 424,711 GNSS vectors
  - Median shifts: 1.9 cm H / 2.1 cm V
  - Published June 2012

Multi-Year CORS Solution: defining NAD83(2011) epoch 2010.00

5 years in the making >>> new CORS coordinates & velocities





- **global tracking network:**
  - **satellite orbits (15-min intervals)**
  - **terrestrial framework**
  - **Earth Orientation (EOPs)**
  - **global station positions (weekly averages)**
- **U.S. CORS tied to global framework via single baselines**
  - **minimizes frame distortions from local effects in dense regional networks**

✓ 1994-2010.5 tracking history

✓ 90 billion double-difference eqs.

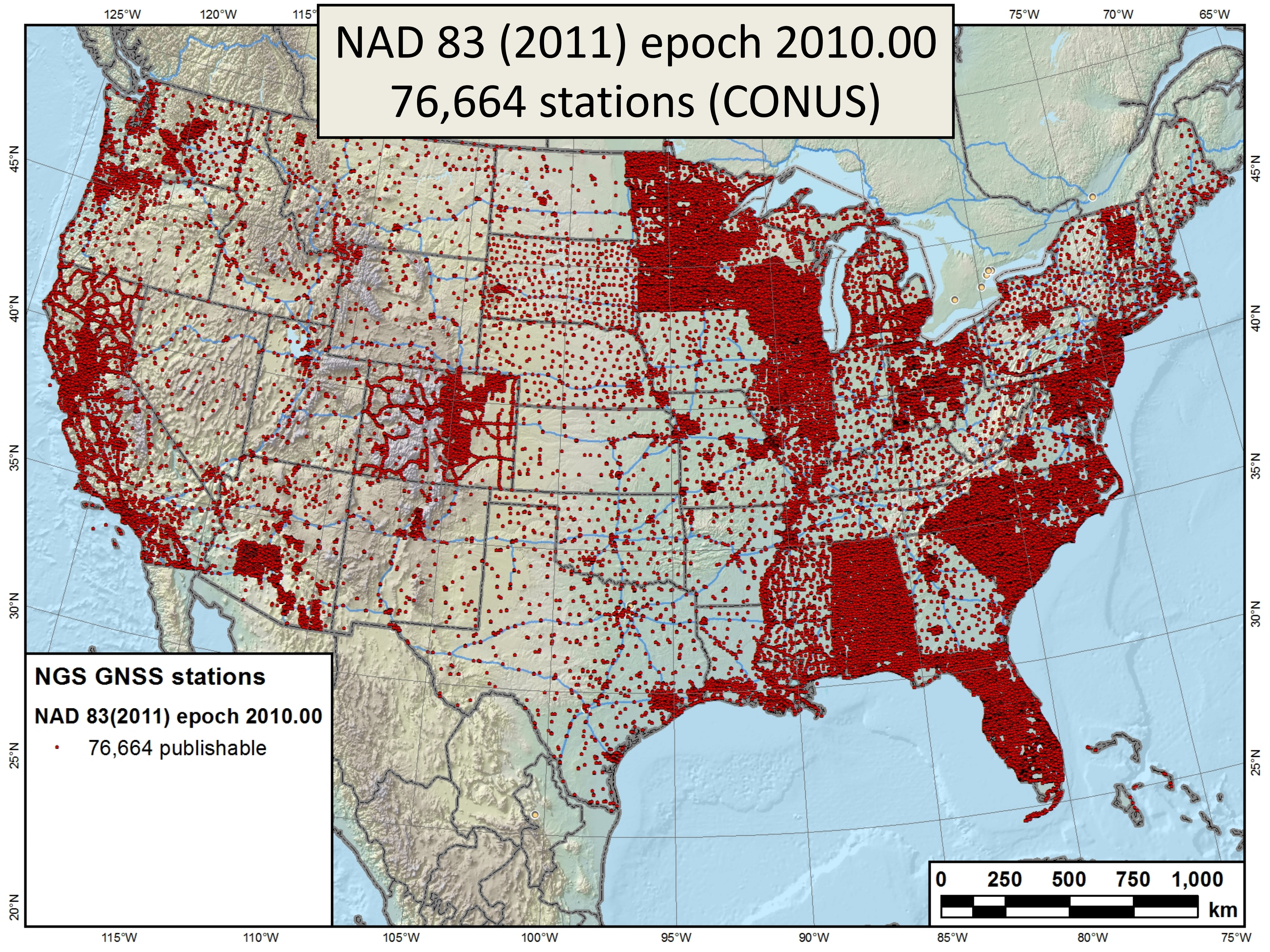
✓ relative >>> absolute antenna cals.

❑ ***NAD83 (2011) epoch 2010.00***

❑ ***IGS08 epoch 2005.0***

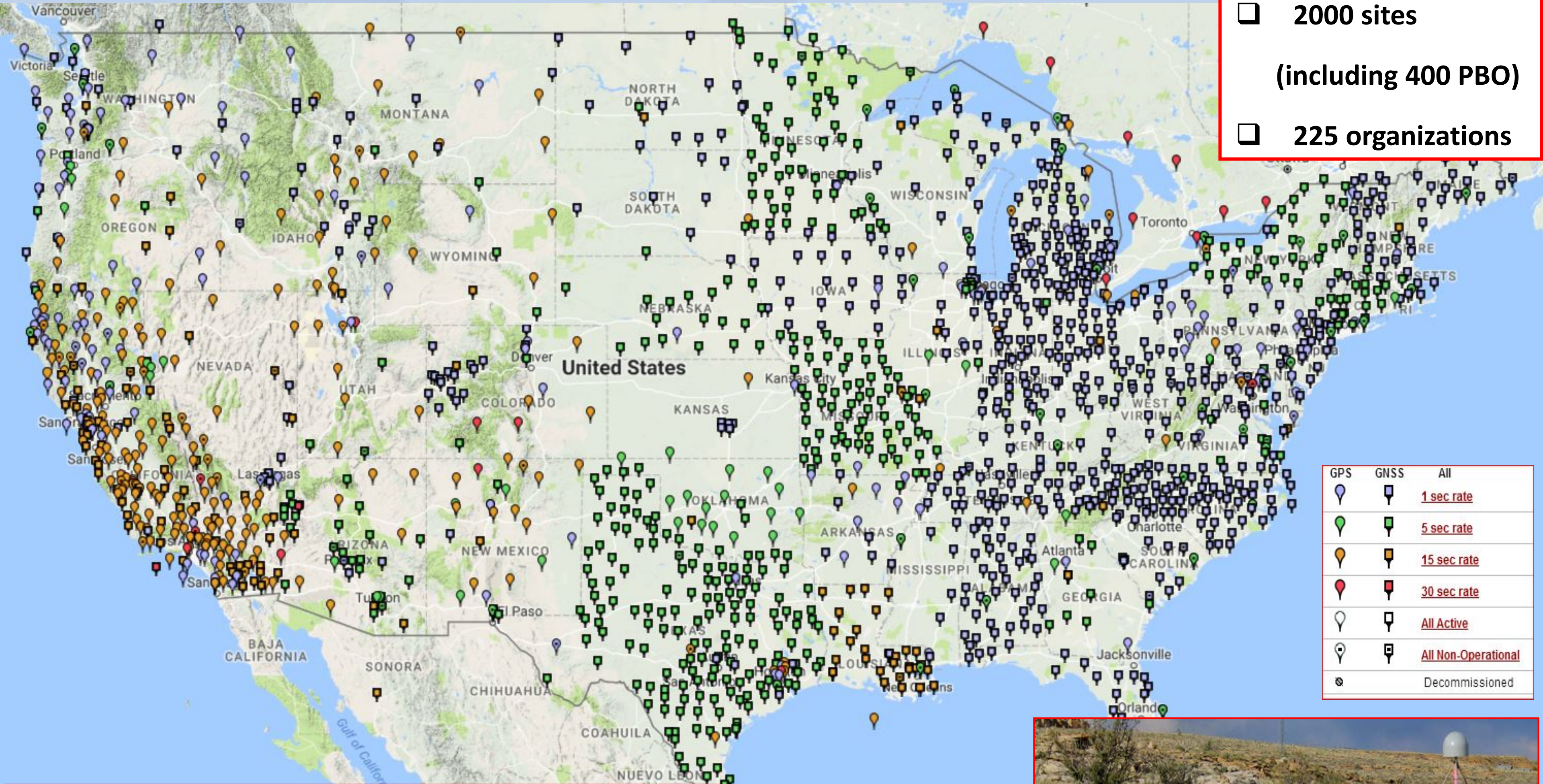
❑ ***"few cm" change from previous***

NAD 83 (2011) epoch 2010.00
76,664 stations (CONUS)

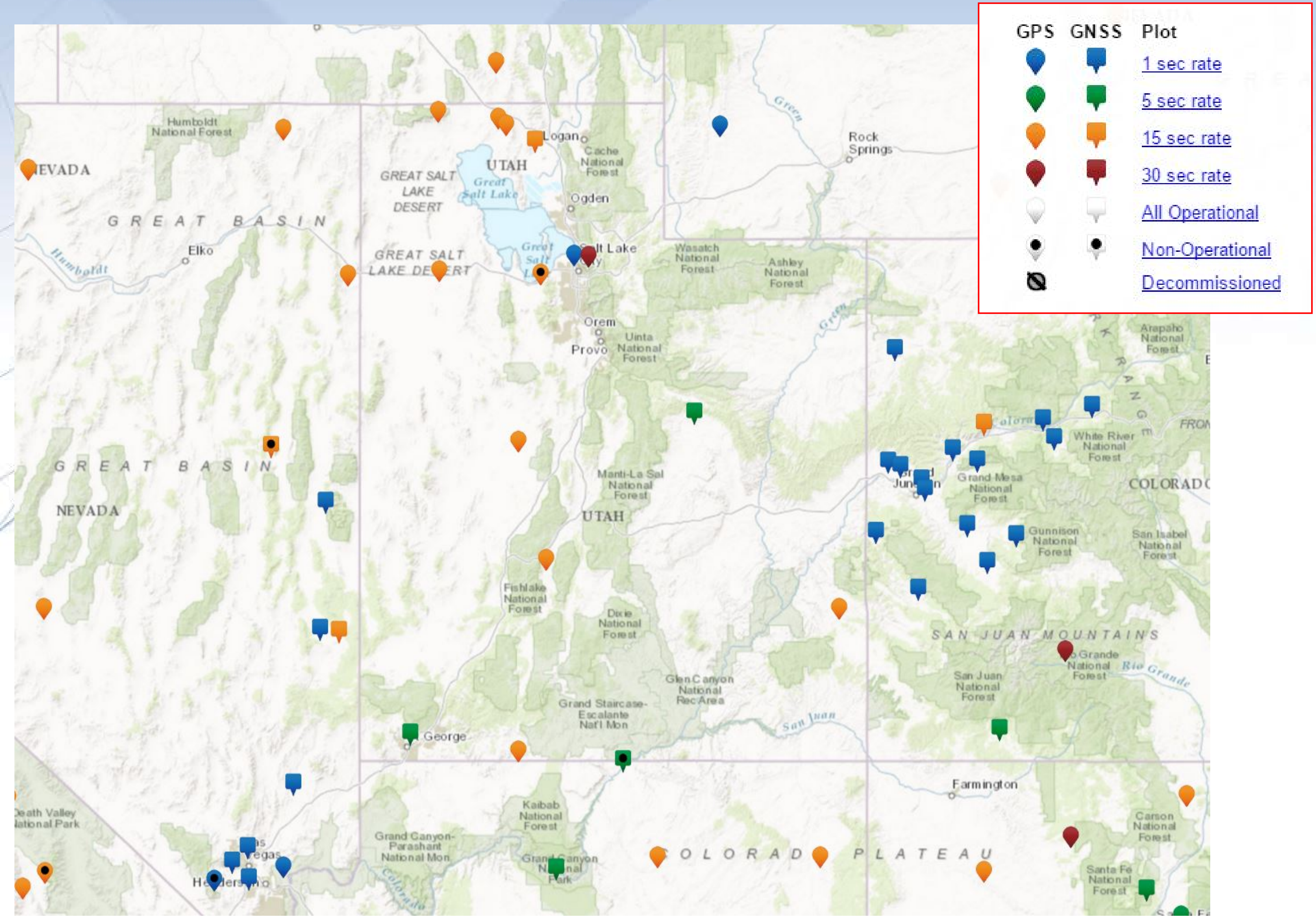


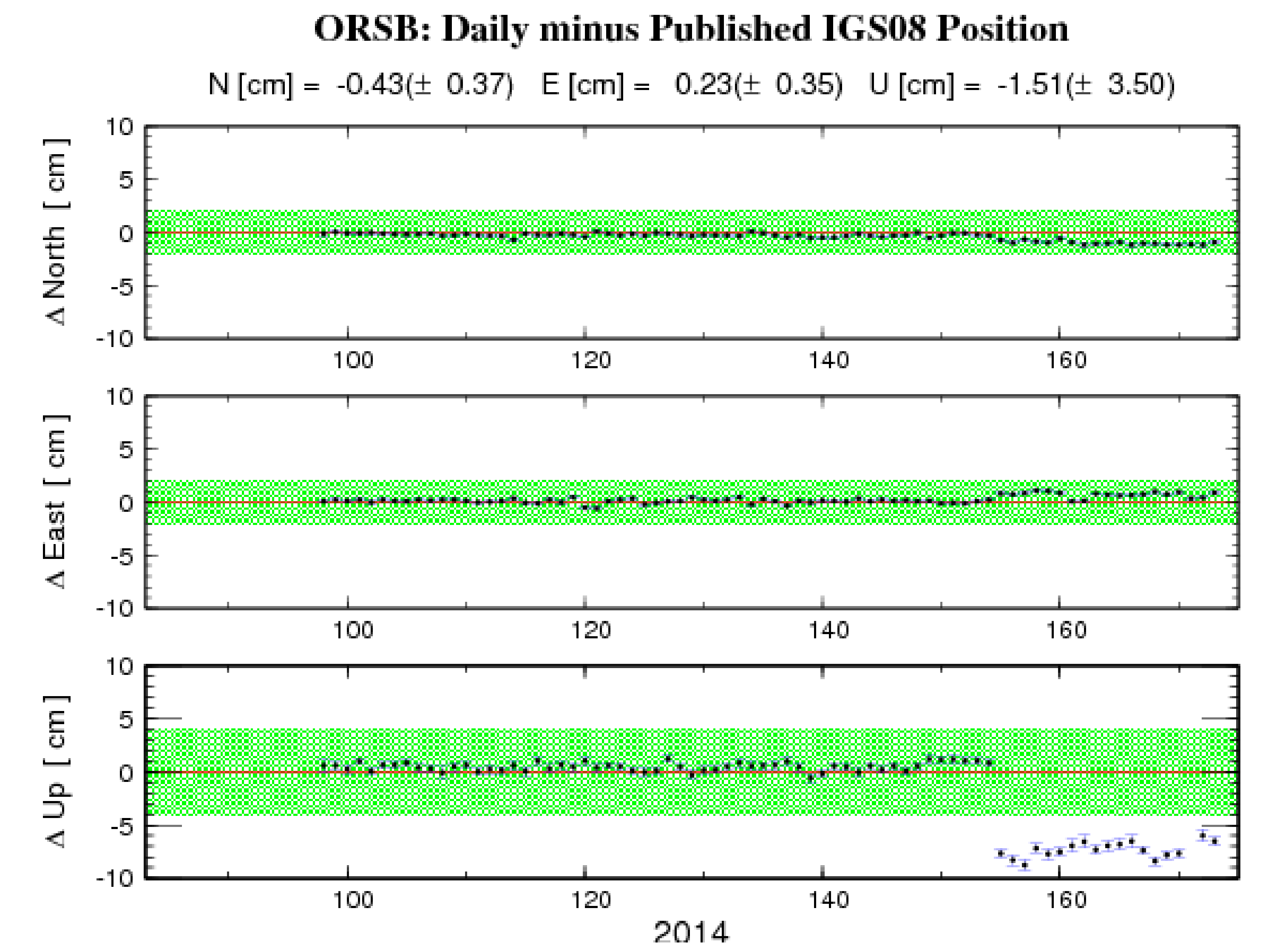
Continuously Operating Reference Station (CORS) Network

- 2000 sites
  (including 400 PBO)
- 225 organizations

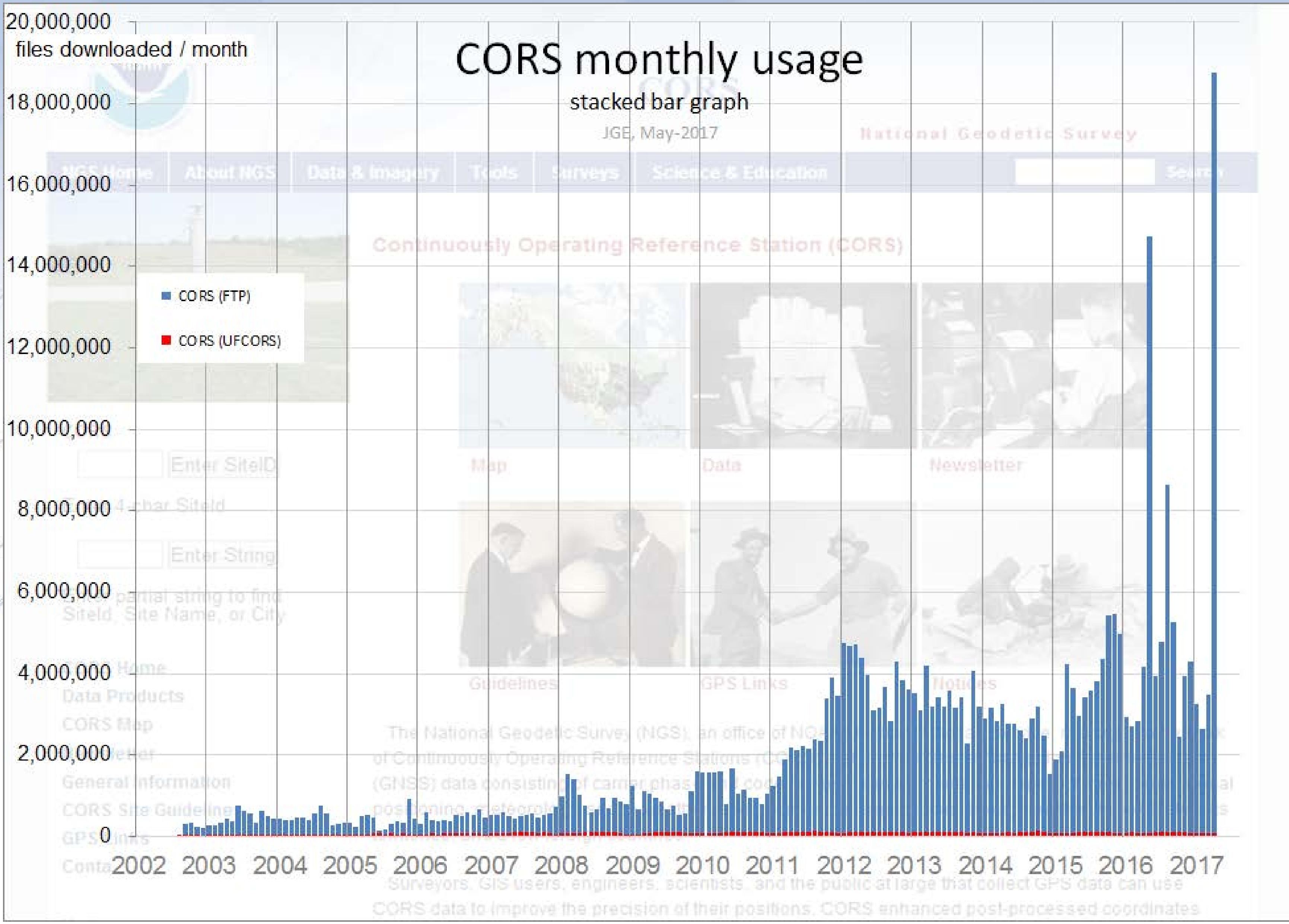


Continuously Operating Reference Station (CORS) Network




ORSB: Daily minus Published IGS08 Position
N [cm] = -0.43(± 0.37) E [cm] = 0.23(± 0.35) U [cm] = -1.51(± 3.50)
Δ North [cm]
Δ East [cm]
Δ Up [cm]
10
5
0
-5
-10
100
120
140
160
2014


Trimble
GNSS


CORS monthly usage
stacked bar graph
JGE, May-2017
files downloaded / month
20,000,000
18,000,000
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
CORS (FTP)
CORS (UFCORS)
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017

International Terrestrial Reference Frame I T R F

International Terrestrial Reference Frame (ITRF)

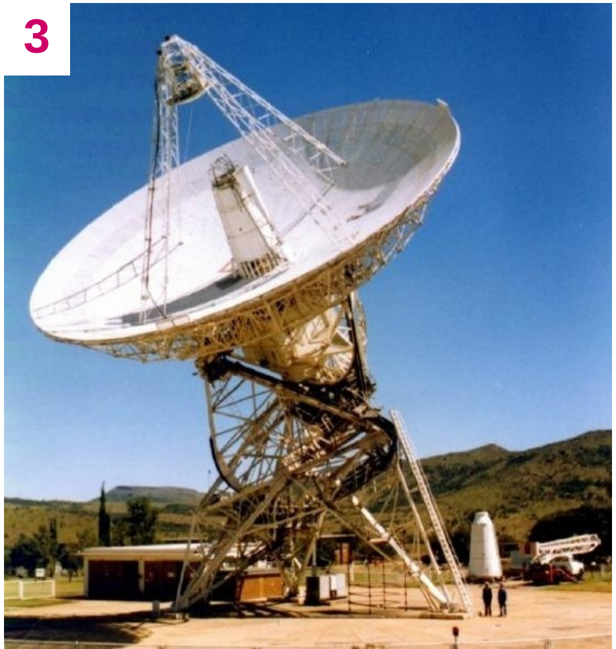
4 Global Independent Positioning Technologies

- 1. Global Navigation Satellite Systems (GNSS)
- 2. Satellite Laser Ranging (SLR)
- 3. Very Long Baseline Interferometry (VLBI)
- 4. Doppler Orbitography & Radiopositioning Integrated by Satellite (DORIS)


4


1


2


3

NOAA's National Geodetic Survey Positioning America for the Future

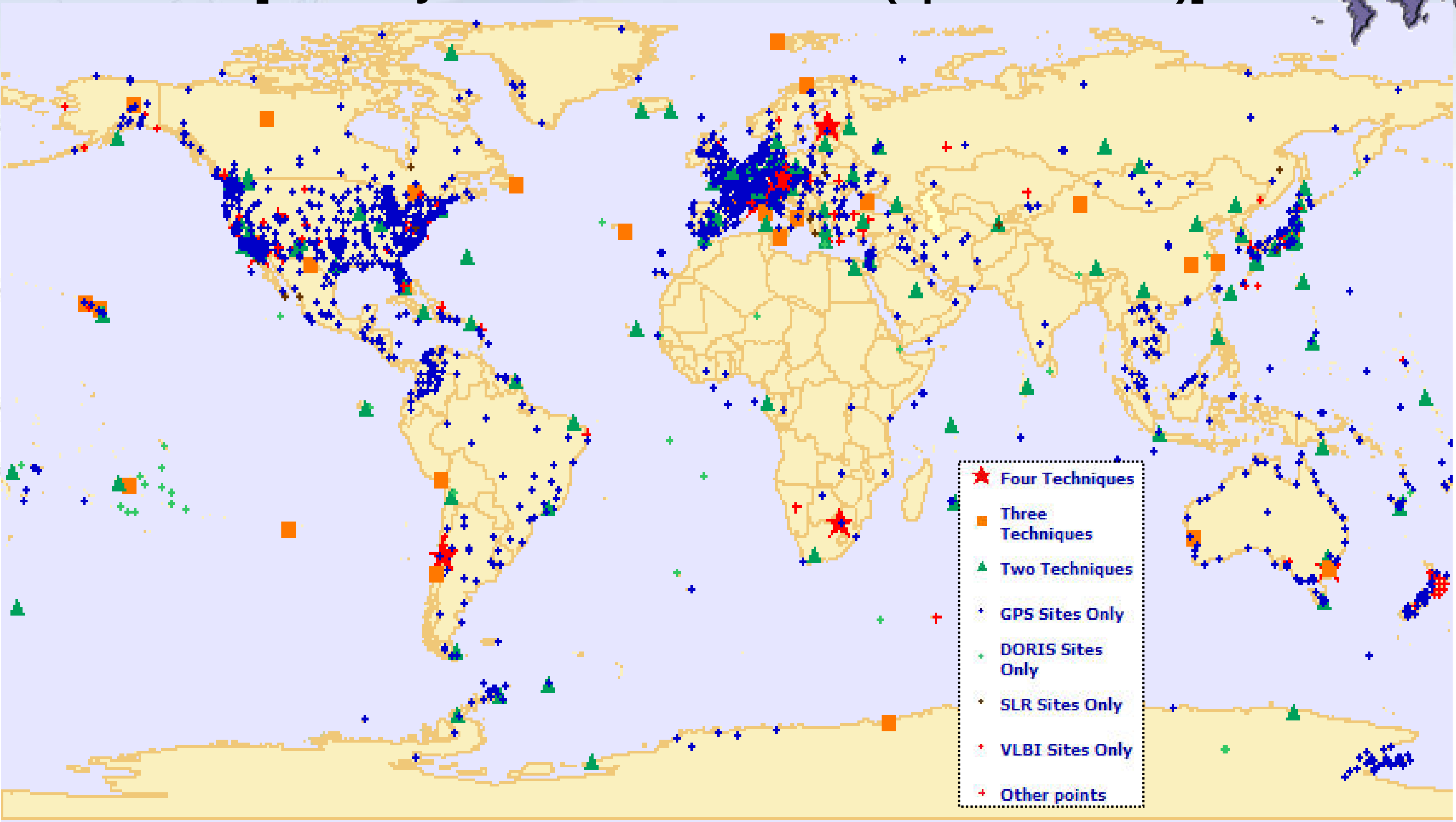
National Radio Astronomy Observatory
Enabling forefront research into the Universe at radio wavelengths

International Terrestrial Reference Frame (ITRF)

space-based techniques: VLBI, DORIS, SLR, GNSS

current version @ NGS: ITRF 2008 (epoch 2005.0)

[recently released: ITRF 2014 (epoch 2010.0)]



International Earth Rotation and Reference System Service (IERS)

(http://www.iers.org)

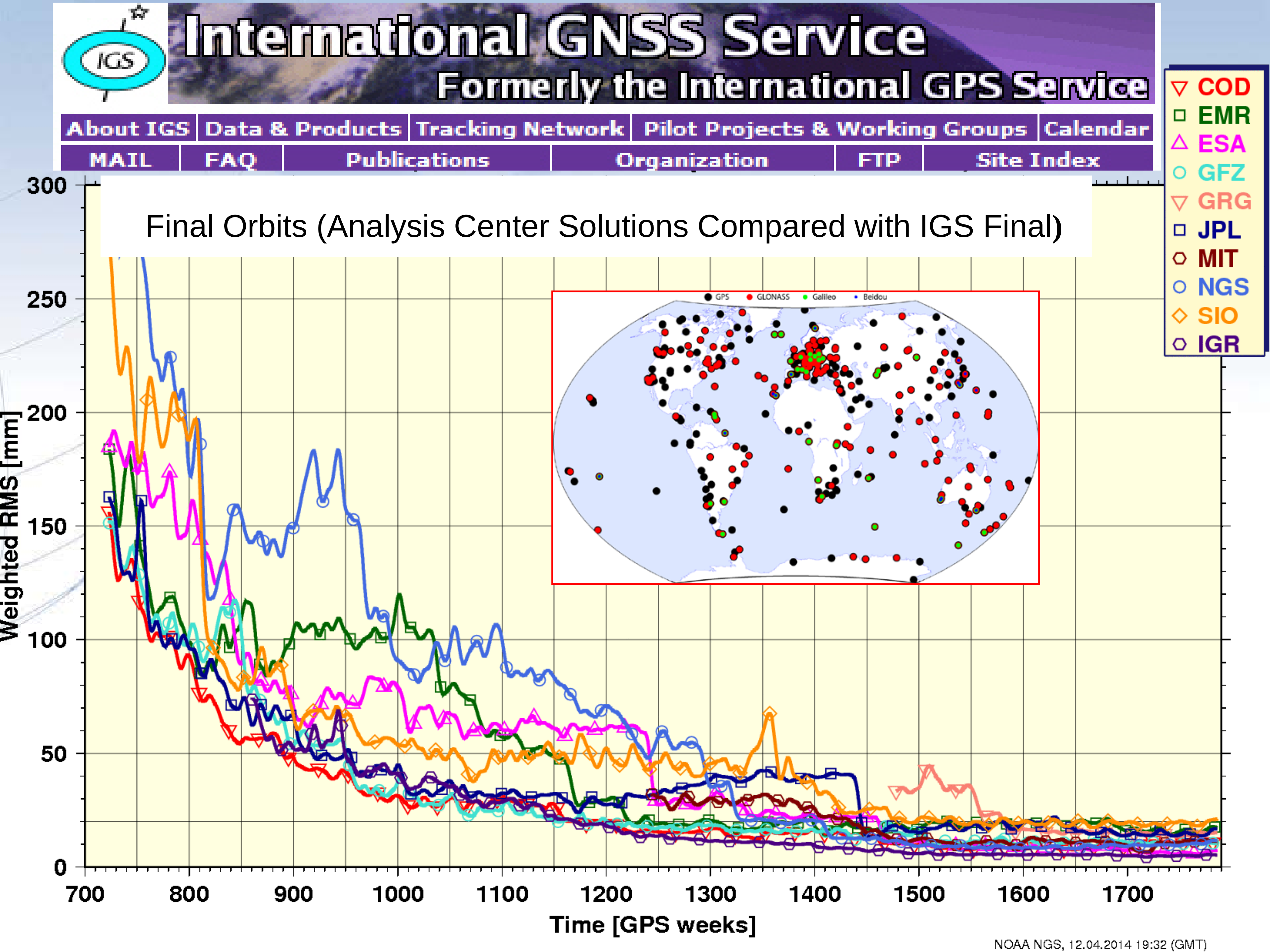
International GNSS Service

Formerly the International GPS Service

General GPS/GNSS questions?
Please visit resource links

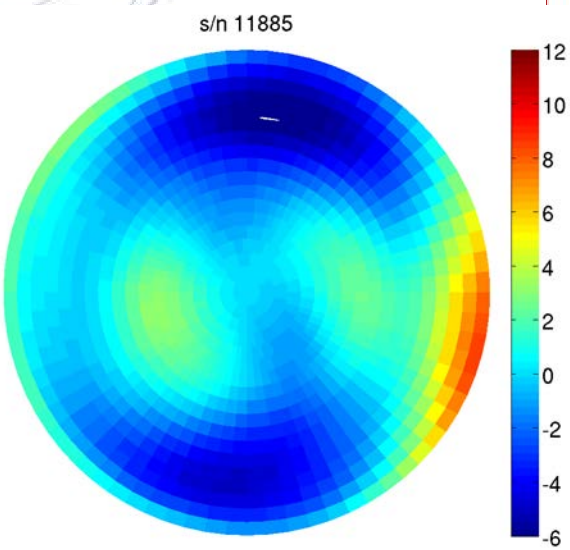
The International GNSS Service (IGS), formerly the International GPS Service, is a voluntary federation of more than 200 worldwide agencies that pool resources and permanent GPS & GLONASS station data to generate precise GPS & GLONASS products. The IGS is committed to providing the highest quality data and products as the standard for Global Navigation Satellite Systems (GNSS) in support of Earth science research, multidisciplinary applications, and education. Currently the IGS includes two GNSS, GPS and the Russian GLONASS, and intends to incorporate future GNSS. You can think of the IGS as the highest-precision international civilian GPS community.

- GPS satellite ephemerides
- GLONASS satellite ephemerides
- Earth rotation parameters
- IGS tracking station coordinates and velocities
- GPS satellite and IGS tracking station clock information
- Zenith tropospheric path delay estimates
- Global ionospheric maps



International GNSS Service
Formerly the International GPS Service
IGS
About IGS
Data & Products
Tracking Network
Pilot Projects & Working Groups
Calendar
MAIL
FAQ
Publications
Organization
FTP
Site Index
Final Orbits (Analysis Center Solutions Compared with IGS Final)
GPS
GLONASS
Galileo
Beidou
COD
EMR
ESA
GFZ
GRG
JPL
MIT
NGS
SIO
IGR
Weighted RMS [mm]
300
250
200
150
100
50
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
Time [GPS weeks]
NOAA NGS, 12.04.2014 19:32 (GMT)

Absolute GNSS Antenna Calibrations



Antenna Calibrations

National Geodetic Survey

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

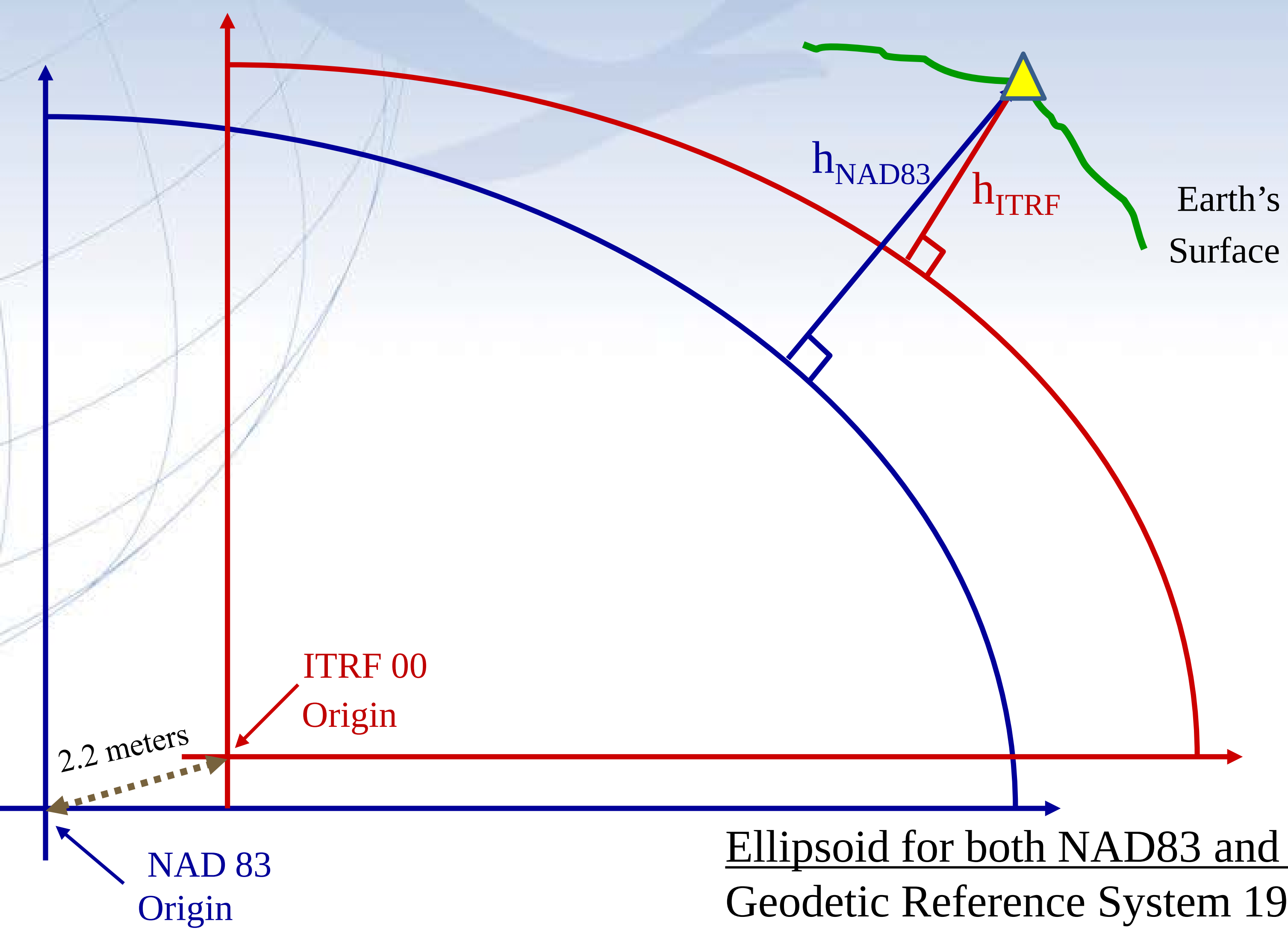
Links
- ANTCAL Home
- NGS AntCal Policy
- NGS AntCal Procedures
- Request Calibration
- FAQ
- Glossary
- ANTINFO Format
- ANTEX Format

Contact Us

Trimble

Antenna Model	Radome	Images	Calibrations	Description
TRM14177.00	NONE		ANTEX ANTINFO	4000ST L1 Geodetic, Model 14177.00
TRM14532.00	NONE	Drawing Side Top	ANTEX ANTINFO	4000ST L1/L2 Geodetic, Model 14532.00
TRM14532.10	NONE	Drawing Side Top	ANTEX ANTINFO	4000SSE Kin L1/L2, Model 14532.10
TRM22020.00+GP	NONE	Drawing Side Top	ANTEX ANTINFO	Geod. L1/L2 compact, with groundplane, Model 22020-00
TRM22020.00-GP	NONE	Drawing Side Top	ANTEX ANTINFO	Geod. L1/L2 compact; w/o groundplane, Model 22020-00
TRM22020.02	TCWD		ANTEX ANTINFO	L1/L2 w/rd and gp
TRM23903.00	NONE	Drawing Side Top	ANTEX ANTINFO	Permanent L1/L2, Model 23903.00, cast preamp housing
TRM27947.00+GP	NONE	Side Top	ANTEX ANTINFO	Rugged L1/L2 with groundplane, Model 27947.00
TRM27947.00-GP	NONE	Side Top	ANTEX ANTINFO	Rugged L1/L2 w/o groundplane, Model 27947.00
TRM29659.00	OLGA		ANTEX ANTINFO	Trimble L1/L2 Dorne Margolin element with chokeringsModel 2
TRM29659.00	SCIT		ANTEX ANTINFO	Trimble L1/L2 Dorne Margolin element with chokeringsModel 2
TRM29659.00	SNOW		ANTEX ANTINFO	Trimble L1/L2 Dorne Margolin element with chokeringsModel 2
TRM29659.00	TCWD		ANTEX ANTINFO	Trimble L1/L2 Dorne Margolin element with chokeringsModel 2
TRM29659.00	UNAV	Drawing Side Top	ANTEX ANTINFO	Trimble L1/L2 Dorne Margolin element with chokeringsModel 2
TRM29659.00	SCIS		ANTEX ANTINFO	Trimble L1/L2 Dorne Margolin element with chokeringsModel 2
TRM29659.00	NONE	Drawing Side Top	ANTEX ANTINFO	Trimble L1/L2 Dorne Margolin element with chokeringsModel 2

Simplified Concept of NAD 83 vs. ITRF



<u>Ellipsoid for both NAD83 and ITRF:</u>

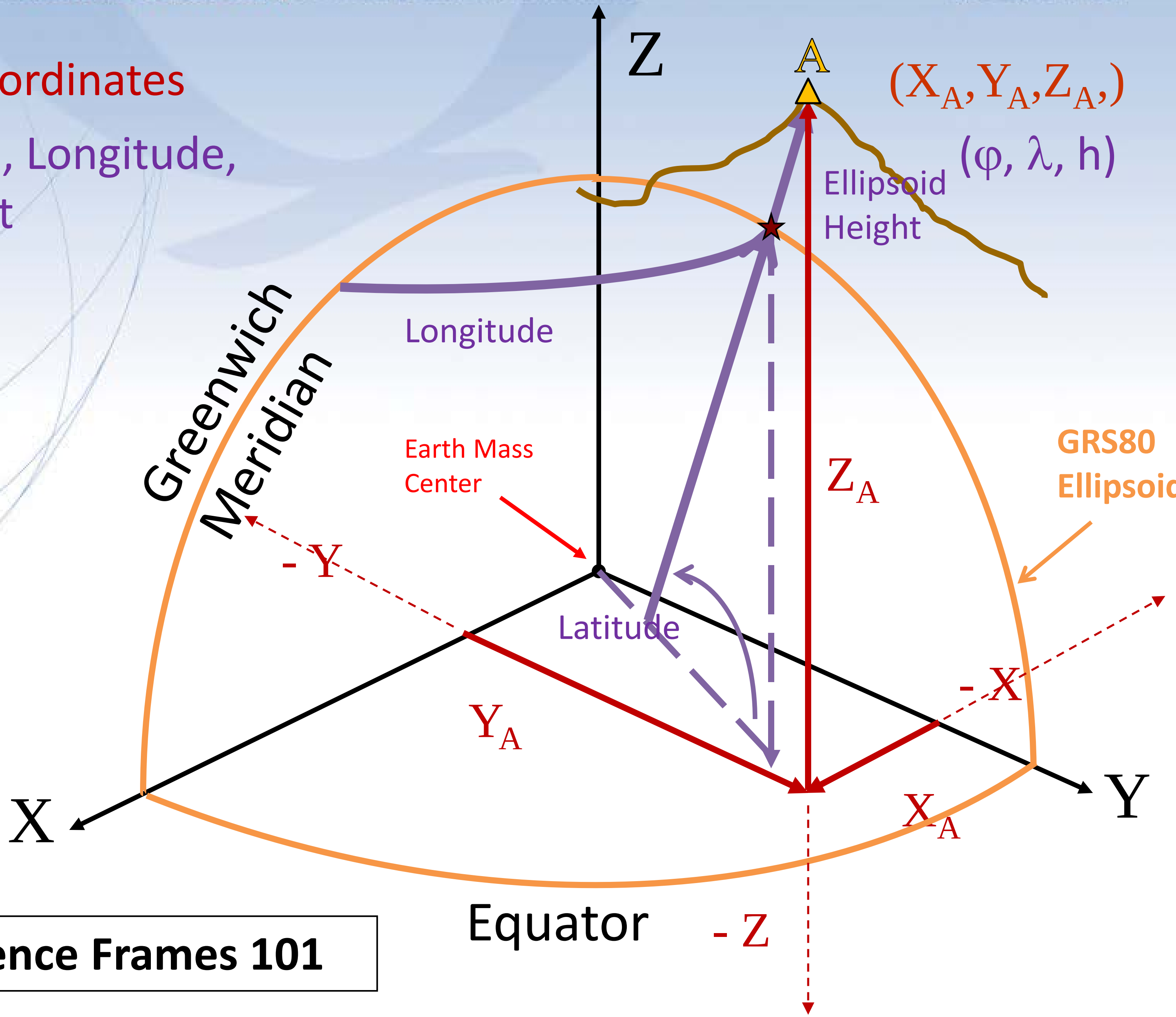
Geodetic Reference System 1980 (GRS80)

a = 6,378,137.000 meters (semi-major axis)

1/f = 298.25722210088 (flattening)

ECEF Coordinates

Latitude, Longitude, & Height



Reference Frames 101

CORS Coordinates

```
      Antenna Reference Point(ARP): CARBON COUNTY UT CORS ARP
      -----------------------------------------------------
                        PID = DP9024
```

IGS08 epoch 2005.0 =
International GNSS Service 2008
(@ January 1, 2005)
(GPS-only realization of ITRF2008)

IGS08 Position >>

```
IGS08 POSITION (EPOCH 2005.0)
Computed in Sep 2015 using 12 days of data.
    X =  -1745062.460 m     latitude     =  39 35 38.11967 N
    Y =  -4603213.161 m     longitude    = 110 45 41.57151 W
    Z =   4044436.503 m     ellipsoid height = 1713.494   m
```

IGS08 Velocity >>

```
IGS08 VELOCITY
Predicted with HTDP_3.2.3 Sep 2015.
    VX =  -0.0151 m/yr      northward =  -0.0071 m/yr
    VY =   0.0009 m/yr      eastward  =  -0.0144 m/yr
    VZ =  -0.0055 m/yr      upward    =  -0.0000 m/yr
```

NAD83 Position >>

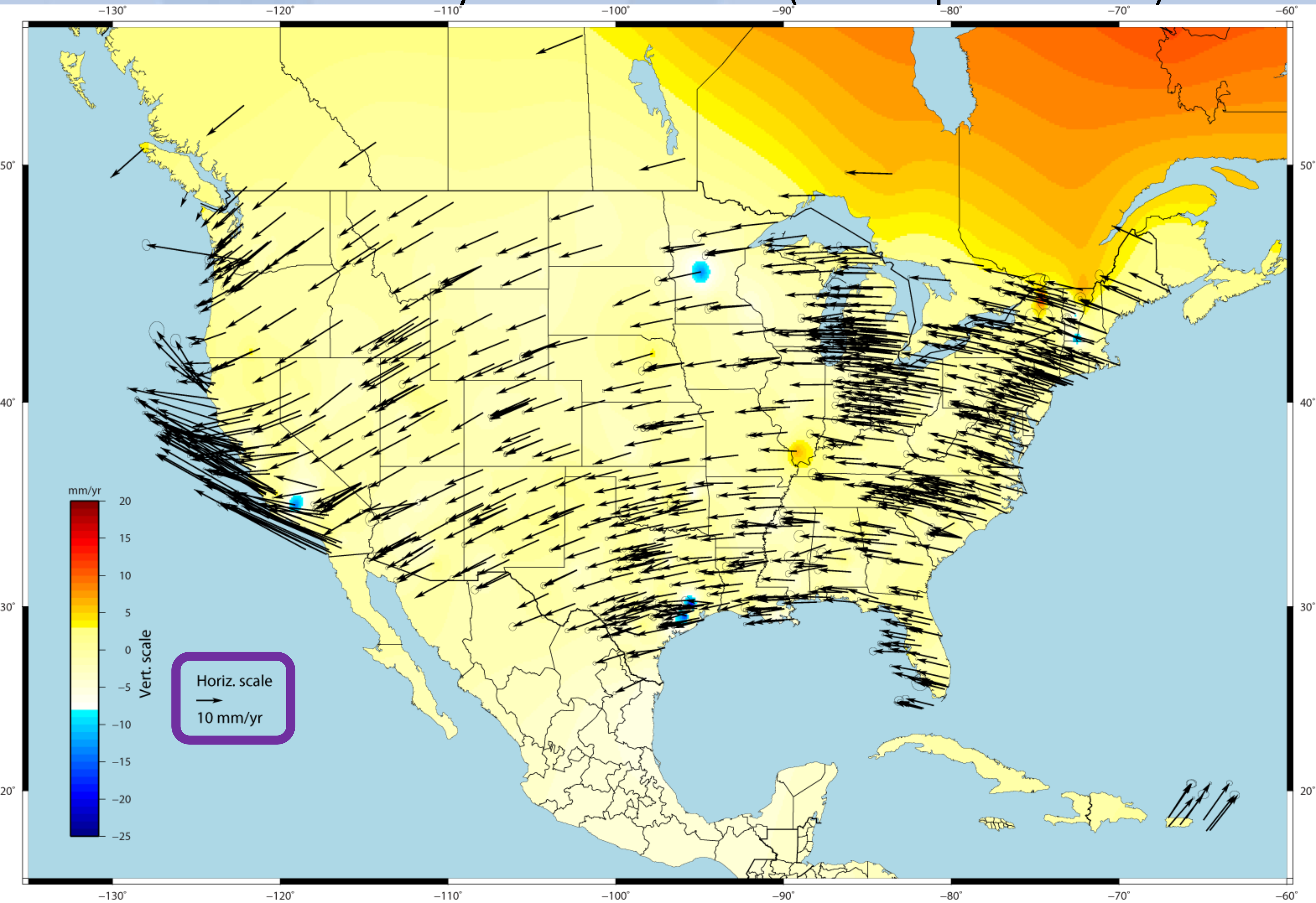
```
NAD_83 (2011) POSITION (EPOCH 2010.0)
Transformed from IGS08 (epoch 2005.0) position in Sep 2015.
    X =  -1745061.768 m     latitude     =  39 35 38.10058 N
    Y =  -4603214.452 m     longitude    = 110 45 41.52524 W
    Z =   4044436.534 m     ellipsoid height = 1714.255   m
```

NAD83 Velocity >>

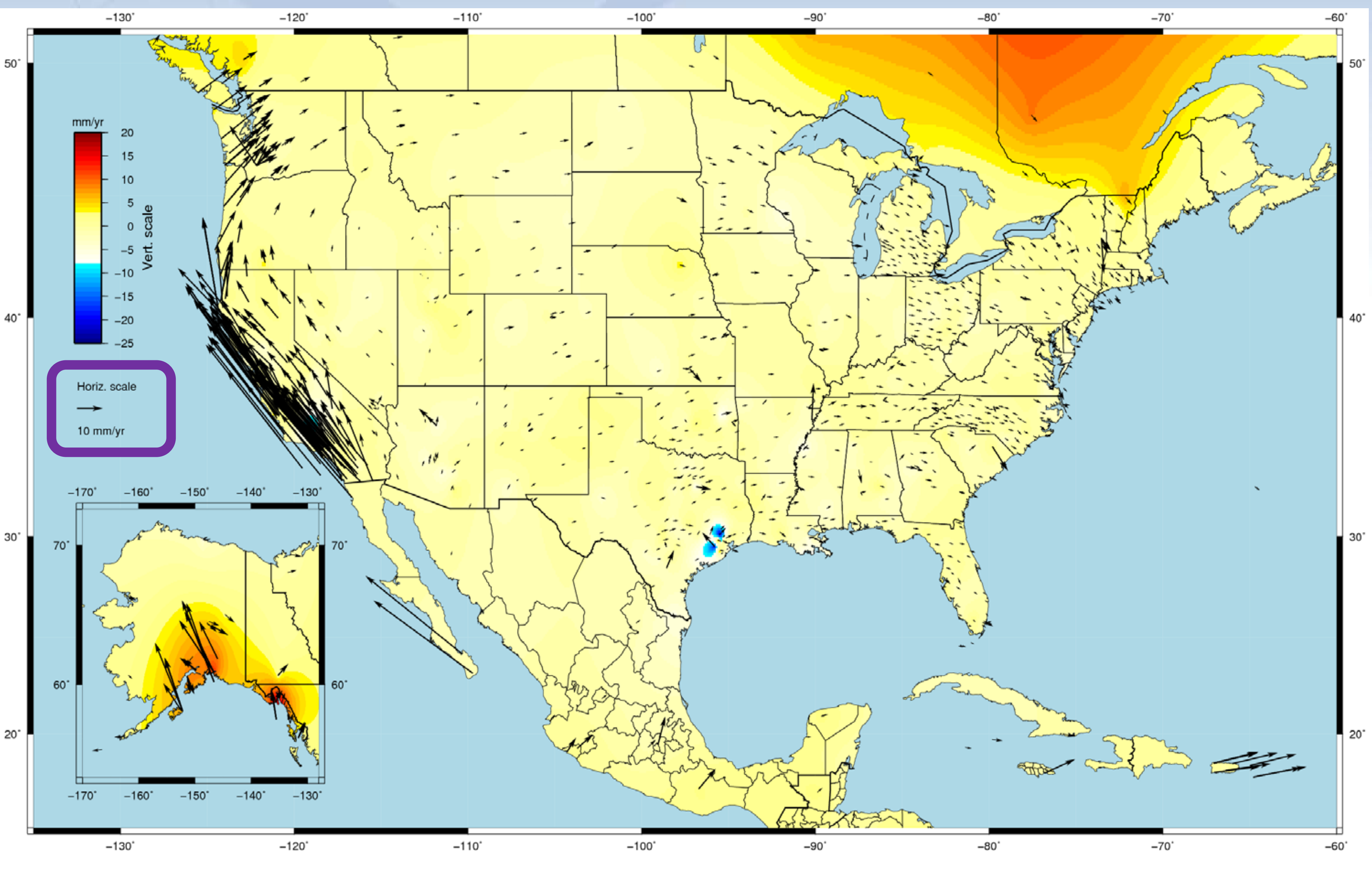
```
NAD_83 (2011) VELOCITY
Transformed from IGS08 velocity in Sep 2015.
    VX =   0.0019 m/yr      northward =   0.0018 m/yr
    VY =   0.0016 m/yr      eastward  =   0.0012 m/yr
    VZ =   0.0006 m/yr      upward    =  -0.0013 m/yr
```

NAD83 (2011) epoch 2010.00 =
North American Datum 1983 (2011)
(@ January 1, 2010)

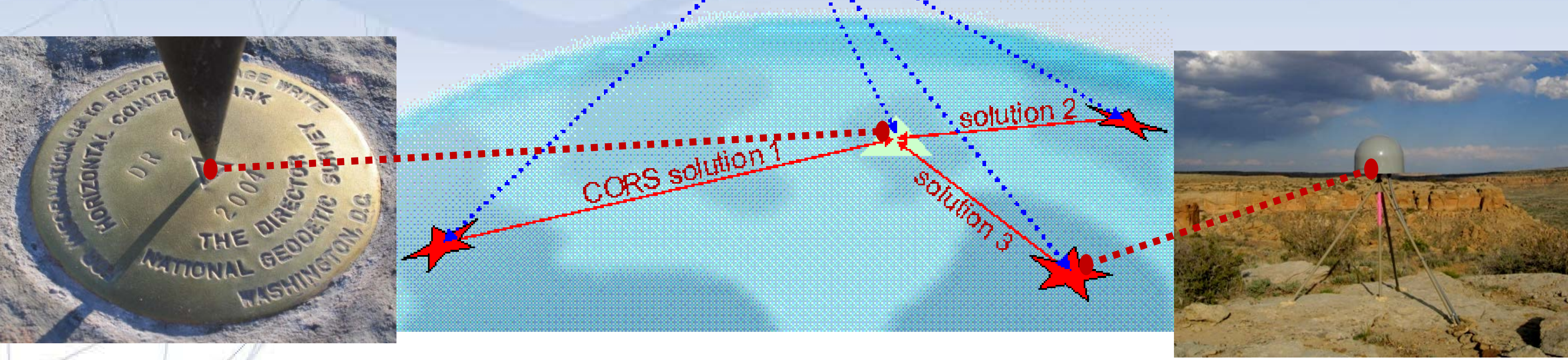
U.S. CORS Velocity Field – ITRF2008 (IGS08 epoch 2005.0)



U.S. CORS Velocity Field - NAD83(2011) epoch 2010.00



Online Positioning User Service (OPUS)



- upload L1/L2 GPS data >>> solution via email in minutes
  - ➢ OPUS-RS (Rapid Static) ----15 min to 2 hr (per CORS)
  - ➢ OPUS-S (Static) ---- 2 to 48 hr (anywhere)
  - ➢ OPUS-DB (Database) --- sharing of results
  - ➢ OPUS-Projects --- network of multi-stations/occupations

Fast, easy, consistent access to NSRS

OPUS – Share (aka OPUS-DB)

❑ **Sharing Criteria:**

- NGS-calibrated antenna
- > 4 hour data span
- > 70% observations used
- > 70% fixed ambiguities
- < 0.04m H peak-to-peak
- < 0.08m V peak-to-peak

❑ **Uses:**

- GPS on BMs
- PLSS / GCDB
- Data archive
- Data sharing

Shared Solution

PID: GT0228
Designation: F 72
Stamping: F 72 1928
Stability: Most reliable; expected to hold position well
Setting: In rock outcrop or ledge
Mark Condition: G
Description: The station is located 6.2 miles along the Mount Whitney Trail from the trailhead at the Whitney Portal, west of Lone Pine. It is located at Trail Camp, about 250 feet south of the south shore of a lake and about 50 feet south of the trail, opposite a 10-feet-tall boulder that sits directly along the north side of the trail. The station is a USCGS bench mark disk set flush in the top of a granite outcrop measuring about 75 feet by 25 feet and standing about 10 feet above the level of the trail.
Observed: 2010-08-17T16:53:00Z — See Also 1928
Source: OPUS - page5 1209.04

Close-up View

REF_FRAME: NAD_83(2011)	EPOCH: 2010.0000	SOURCE: NAVD88 (Computed using GEOID12A)	UNITS: m	SET PROFILE	DETAILS

LAT:	36° 33' 46.36644"	± 0.006 m
LON:	-118° 16' 46.29502"	± 0.003 m
ELL HT:	3645.963	± 0.013 m
X:	-2431390.178	± 0.006 m
Y:	-4519449.679	± 0.013 m
Z:	3780713.238	± 0.002 m
ORTHO HT:	3671.261	± 0.031 m

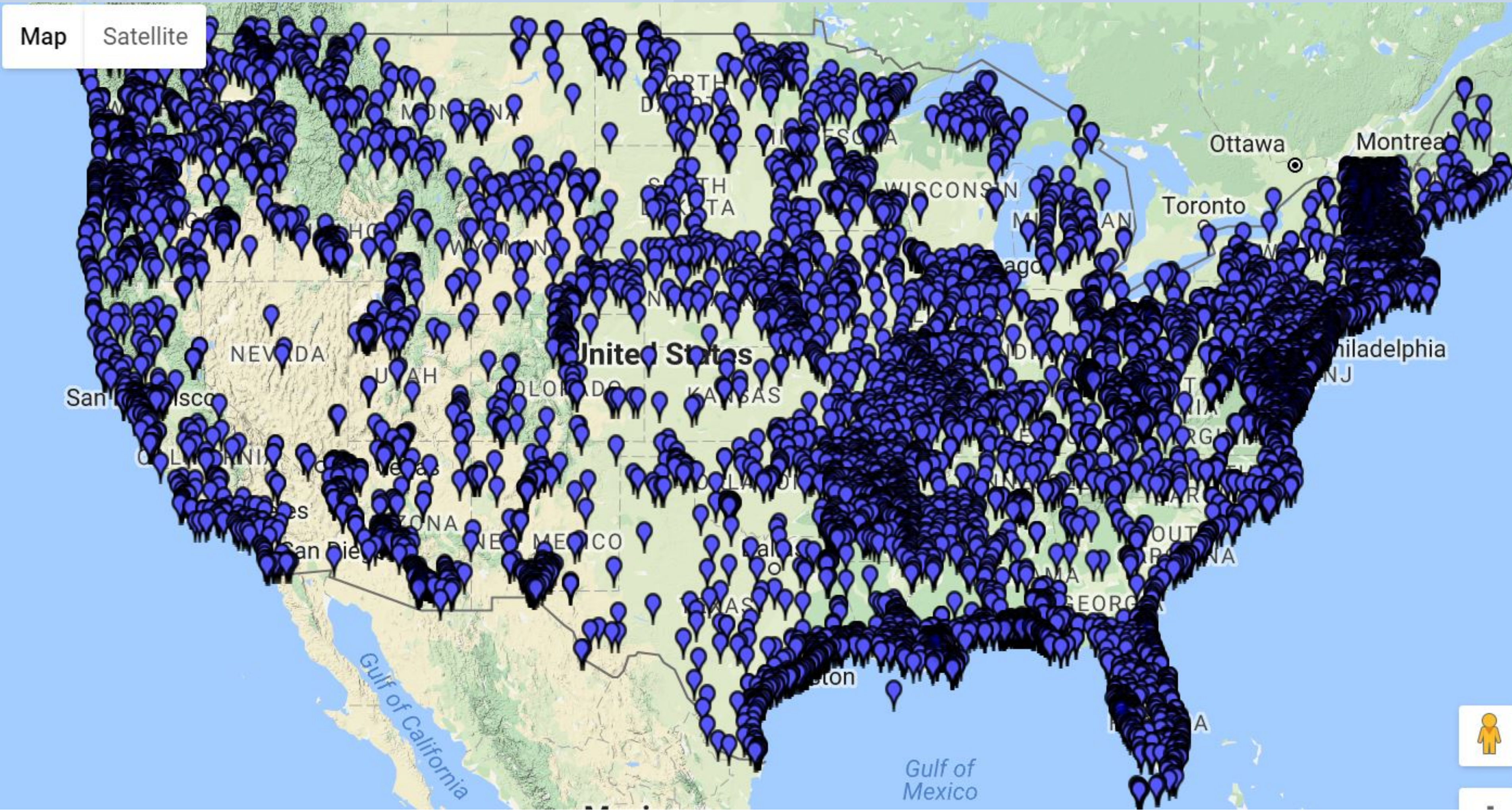
	UTM 11	SPC 404(CA 4)
NORTHING:	4047144.640m	636673.937m
EASTING:	385501.607m	2064491.407m
CONVERGENCE:	-0.76230261°	0.42982529°
POINT SCALE:	0.99976152	0.99994136
COMBINED FACTOR:	0.99918979	0.99936952

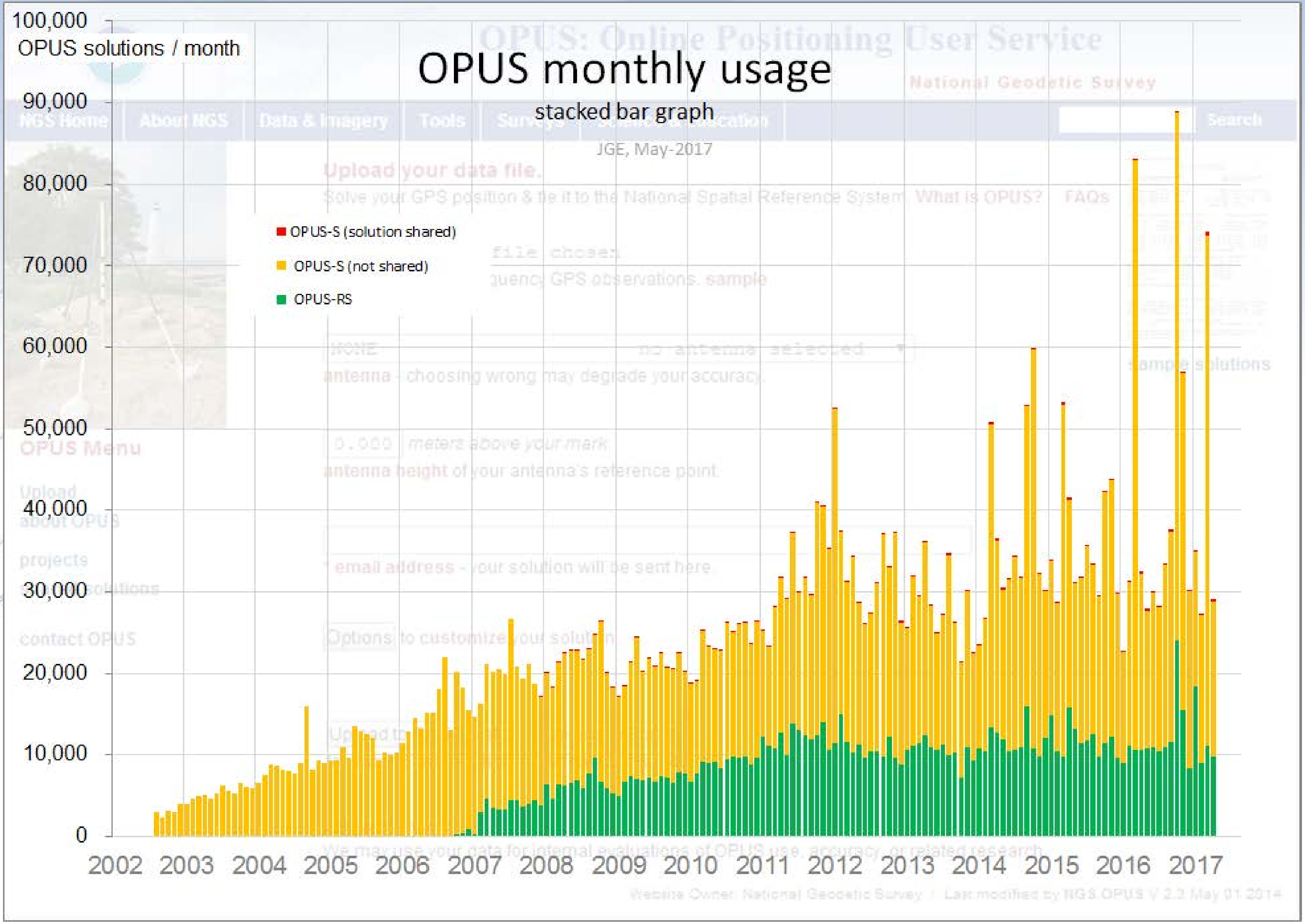
CONTRIBUTED BY

william.stone
National Geodetic Survey

Horizon View

Shared OPUS Solutions




OPUS monthly usage
stacked bar graph
JGE, May-2017
OPUS solutions / month
OPUS-S (solution shared)
OPUS-S (not shared)
OPUS-RS
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017

National Geodetic Survey ***Ten-Year Strategic Plan***

- By 2022, reduce all definitional & access-related errors in geometric reference frame to 1 cm when using 15 min of GNSS data

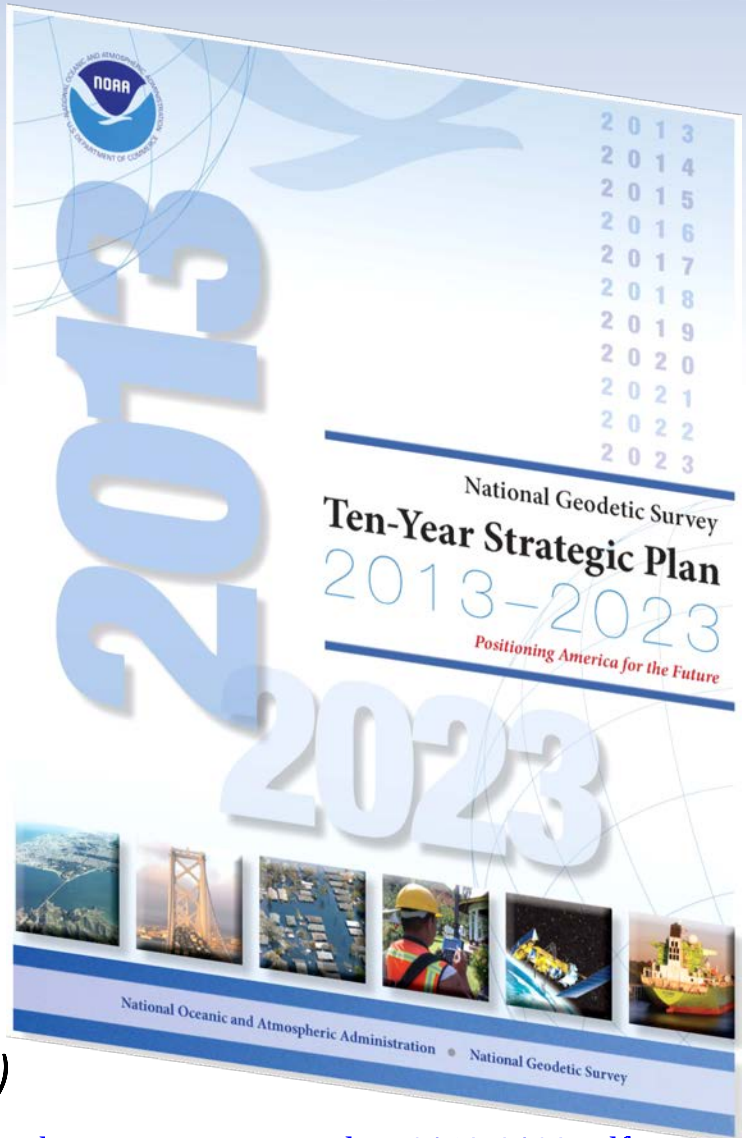
  "**Replace NAD83**"

(NAD83 = North American Datum 1983)

- By 2022, reduce all definitional & access-related errors in orthometric heights in geopotential reference frame to 2 cm when using 15 min of GNSS data

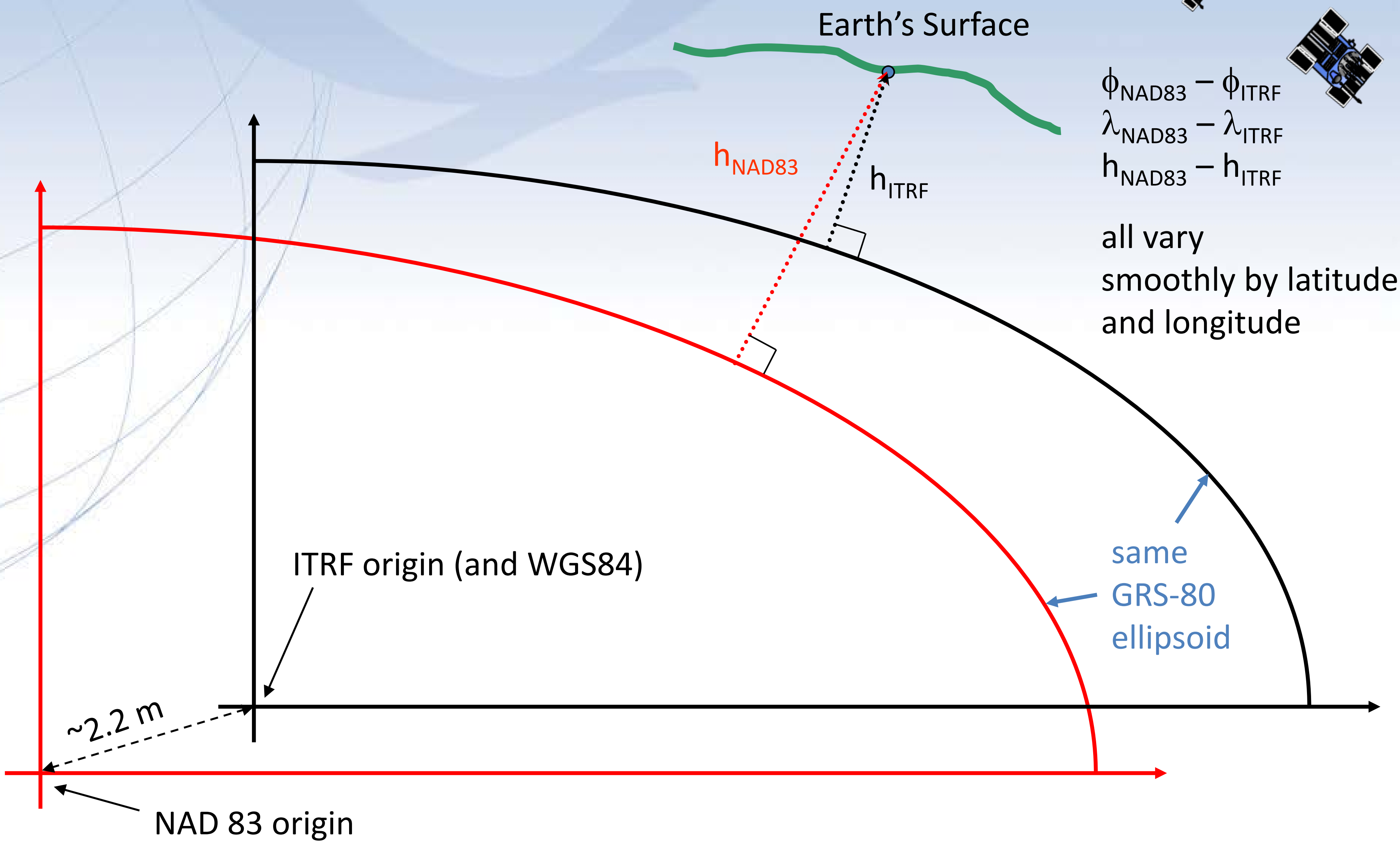
  "**Replace NAVD88**"

(NAVD88 = North American Vertical Datum 1988)



http://www.geodesy.noaa.gov/web/news/Ten_Year_Plan_2013-2023.pdf

NAD 83's non-geocentricity



Future Geometric (3-D) Reference Frame

- **replace NAD83 with new geometric reference frames – by 2022**
- **CORS-based, accessed via GNSS observations**
- **coordinates & velocities in ITRF & new US reference frame**
- **passive control tied to new reference frame (not a component)**
- **transformation tools to relate historical to new US reference frames**

(HTDP / NADCON / GEOCON ...)

And it shall be called…

North American Terrestrial Reference Frame of 2022 (NATRF2022)

(& Pacific/Mariana/Caribbean Terrestrial Reference Frame of 2022)

- 4 (essentially) tectonic-plate-fixed reference frames
- identical to IGS*XX* reference frame at TBD epoch (2022.0?)
- over time, will relate to IGS frame via *Euler Pole Rotation*
- all CORS velocities deviating from rigid-plate (Euler)
  rotation will be captured in 3-D velocity model
  (a secondary product to transform to fixed epoch)

Four Frames/Plates in 2022

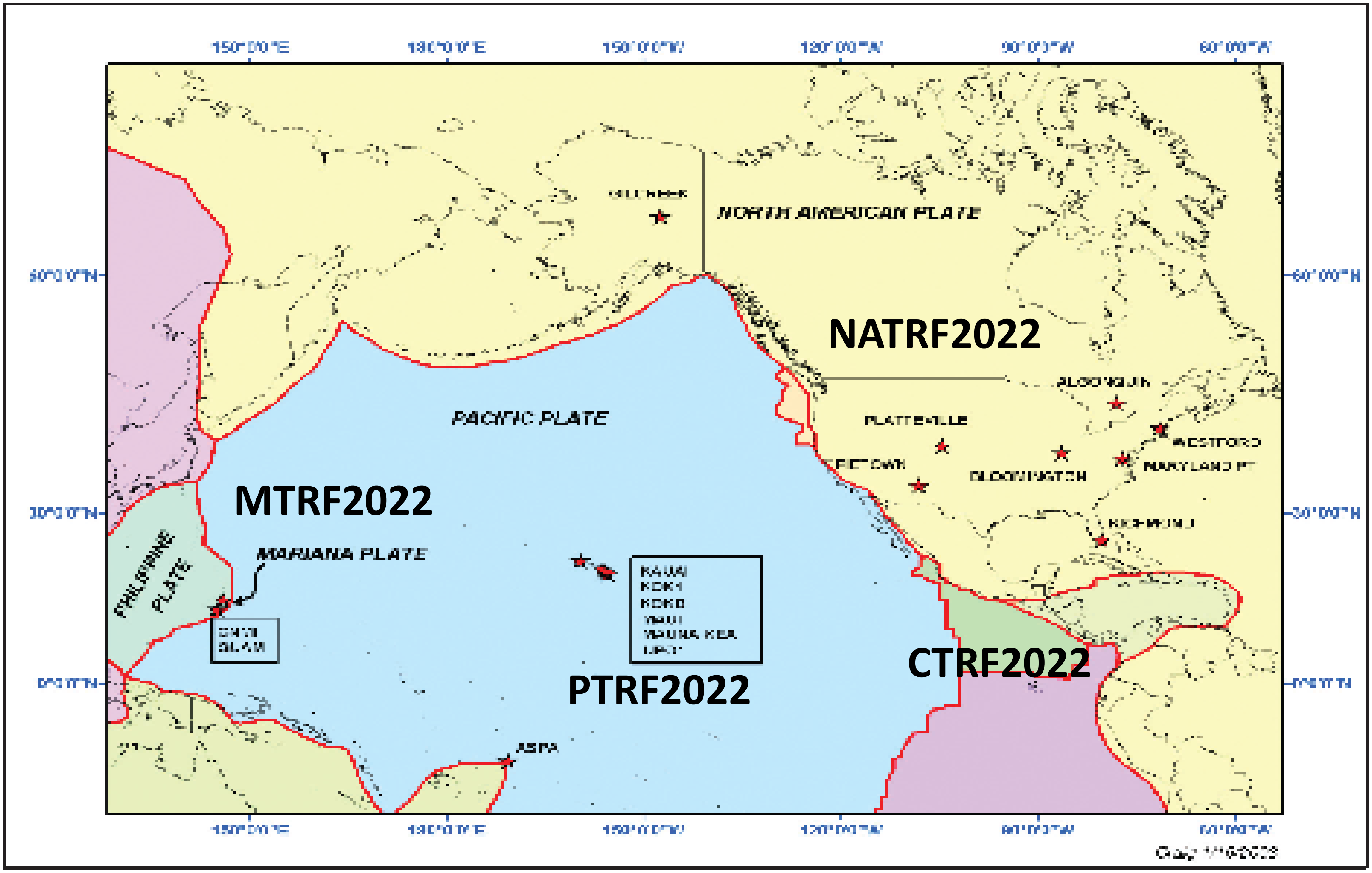
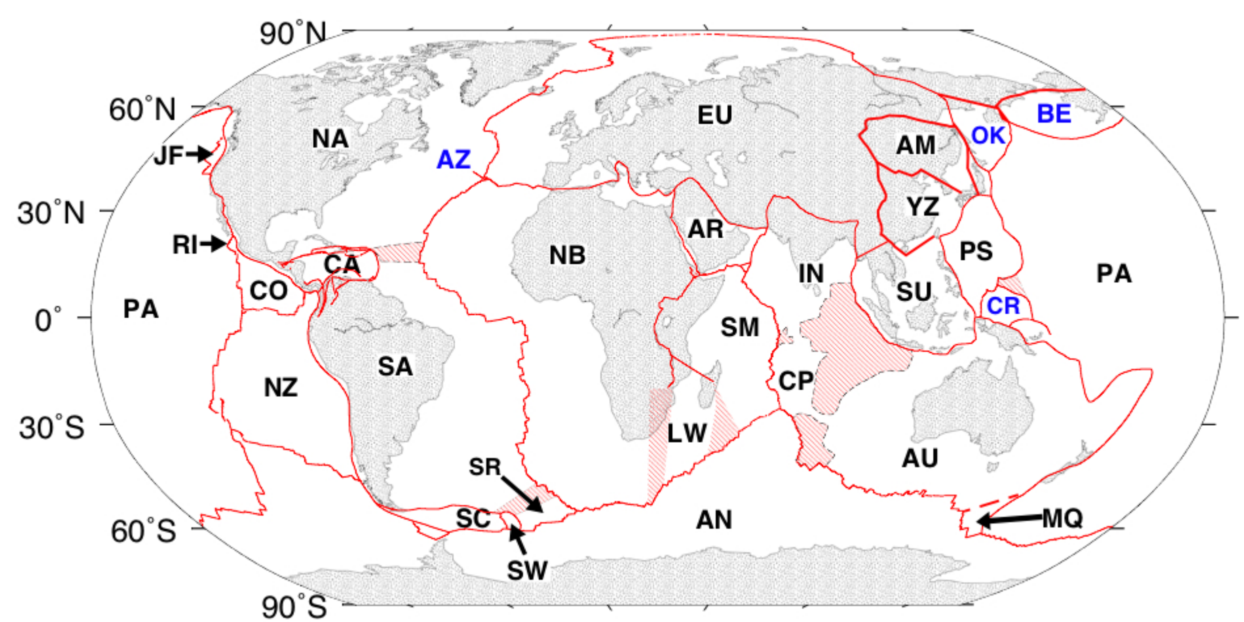


Image from Snay 2003

Euler Poles



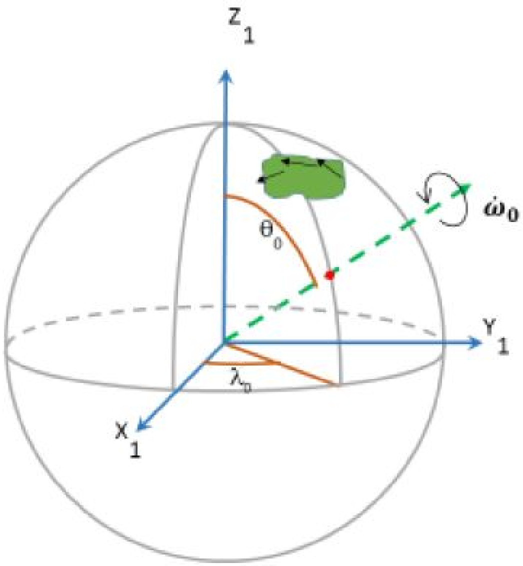


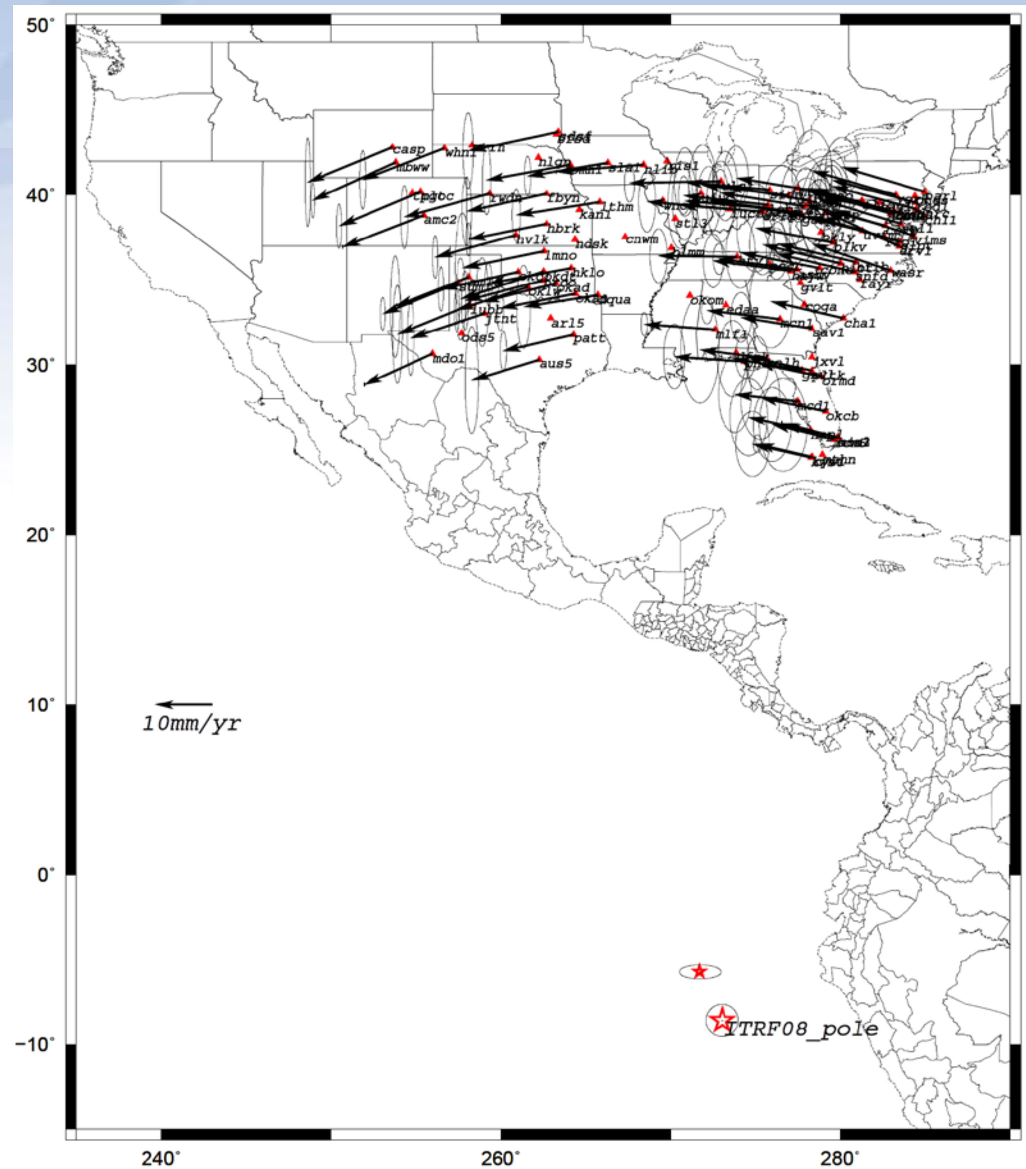
Figure 6: A rotating tectonic plate (green) and its Euler Pole (dashed green arrow and red dot).

Euler Pole

Each reference frame will get 3 parameters:

- Euler Pole Latitude
- Euler Pole Longitude
- Rotation rate (radians/year)

Used to compute time-dependent TRF2022 coordinates from time-dependent ITRF coordinates.



National Geodetic Survey Positioning America for the Future geodesy.noaa.gov

NOAA Technical Report NOS NGS 62

Blueprint for 2022, Part 1: Geometric Coordinates

$$[\widetilde{R_3^{\alpha}}]^{-1} = \begin{bmatrix} 1 & \alpha & 0 \\ -\alpha & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} + \begin{bmatrix} 0 & \alpha & 0 \\ -\alpha & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} = (I + A) \qquad (39)$$

Where the tilde is used to indicate "approximation". The reason for splitting the matrix into *I* and *A* components will be obvious soon.

Applying equation 39 to 35:

$$\begin{aligned} \widetilde{M^{-1}} &= \left[R_1^{\lambda_0}\right]^{-1}\left[R_2^{\theta_0}\right]^{-1}[\widetilde{R_3^{\alpha}}]^{-1}R_2^{\theta_0}R_1^{\lambda_0} = \left[R_1^{\lambda_0}\right]^{-1}\left[R_2^{\theta_0}\right]^{-1}(I+A)R_2^{\theta_0}R_1^{\lambda_0} \\ &= \left[R_1^{\lambda_0}\right]^{-1}\left[R_2^{\theta_0}\right]^{-1}(I)R_2^{\theta_0}R_1^{\lambda_0} + \left[R_1^{\lambda_0}\right]^{-1}\left[R_2^{\theta_0}\right]^{-1}(A)R_2^{\theta_0}R_1^{\lambda_0} \\ &= I + \alpha(t)\begin{bmatrix} 0 & cos\theta_0 & -sin\lambda_0 sin\theta_0 \\ -cos\theta_0 & 0 & cos\lambda_0 sin\theta_0 \\ sin\lambda_0 sin\theta_0 & -cos\lambda_0 sin\theta_0 & 0 \end{bmatrix} \end{aligned} \qquad (40)$$

See now that by splitting into I and A, the *I* portion of the equation collapses into another I, while the *A* component collapses into a simple skew symmetric matrix.

Acknowledging that the effect of the total rotation, $\alpha(t)$ must be split into rotations among the three axes of the ideal frame, and since $\alpha(t)$ is "small", it can be concluded that the axial rotations must also be small. Thus, matrix R_{ZYX} reduces to:

$$\widetilde{R_{ZYX}} = \begin{bmatrix} 1 & \omega_Z & -\omega_Y \\ -\omega_Z & 1 & \omega_X \\ \omega_Y & -\omega_X & 1 \end{bmatrix} \qquad (41)$$

Now equate the approximations of M^{-1} and R_{ZYX} to one another (applying equations 39 and 40 to equation 34):

$$I + \alpha(t)\begin{bmatrix} 0 & cos\theta_0 & -sin\lambda_0 sin\theta_0 \\ -cos\theta_0 & 0 & cos\lambda_0 sin\theta_0 \\ sin\lambda_0 sin\theta_0 & -cos\lambda_0 sin\theta_0 & 0 \end{bmatrix} = \begin{bmatrix} 1 & \omega_Z & -\omega_Y \\ -\omega_Z & 1 & \omega_X \\ \omega_Y & -\omega_X & 1 \end{bmatrix} \qquad (42)$$

Equation 42 allows for an easy solution to the three axial rotations in terms of the Euler Pole's location and angular velocity:

$$\omega_X = \alpha(t) cos\lambda_0 sin\theta_0 \qquad (43)$$

$$\omega_Y = \alpha(t) sin\lambda_0 sin\theta_0 \qquad (44)$$

$$\omega_Z = \alpha(t) cos\theta_0 \qquad (45)$$

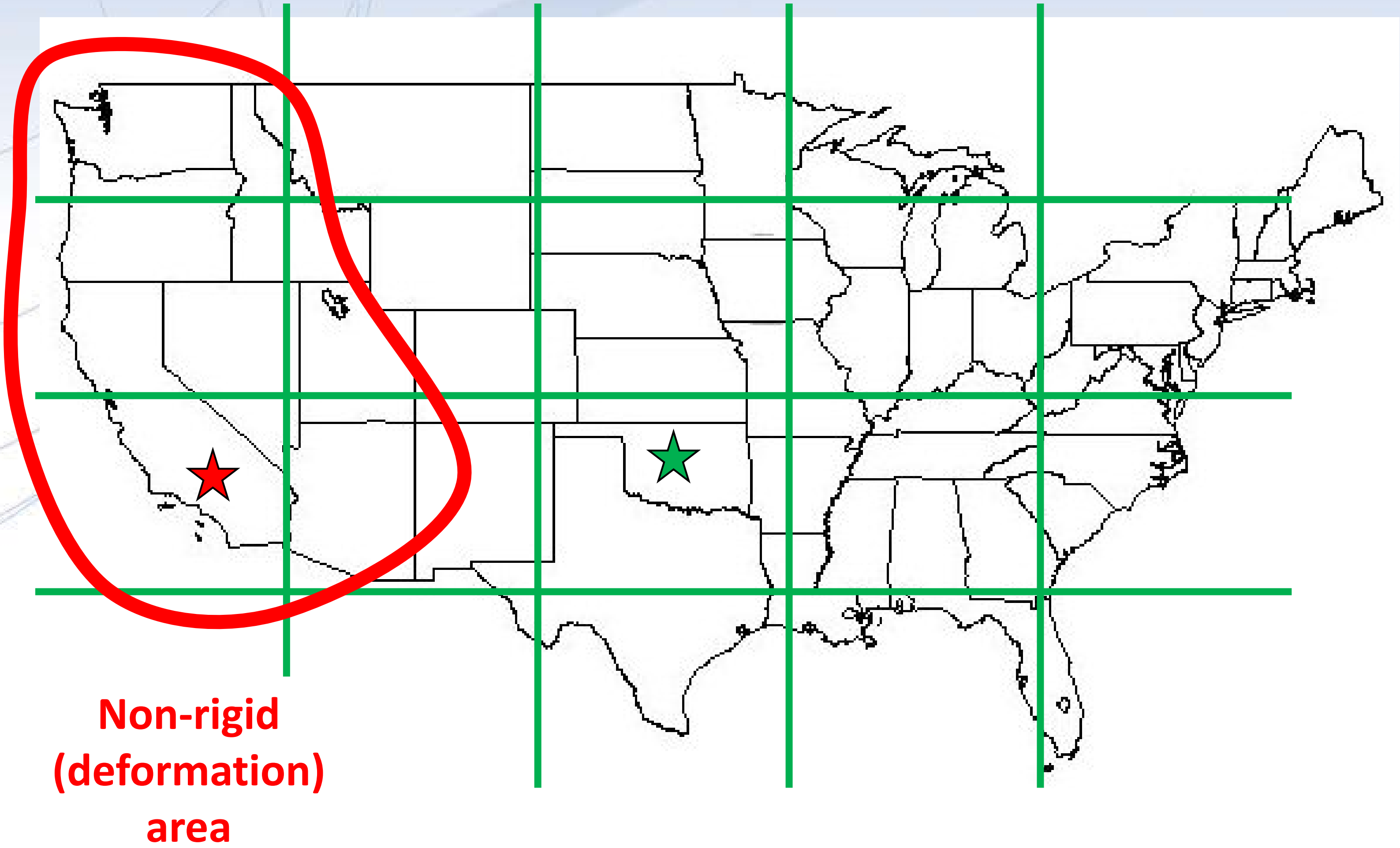
Recall, however, that the ω_X, ω_Y and ω_Z values are time-dependent (see equation 27). Applying equation 27 and also applying the expansion of $\alpha(t)$ into its components, yields:

$$\omega_X(t_0) + (\Delta t)\dot{\omega}_X = [\dot{\omega}_0 \Delta t] cos\lambda_0 sin\theta_0 \qquad (46)$$

$$\omega_Y(t_0) + (\Delta t)\dot{\omega}_Y = [\dot{\omega}_0 \Delta t] sin\lambda_0 sin\theta_0 \qquad (47)$$

$$\omega_Z(t_0) + (\Delta t)\dot{\omega}_Z = [\dot{\omega}_0 \Delta t] cos\theta_0 \qquad (48)$$

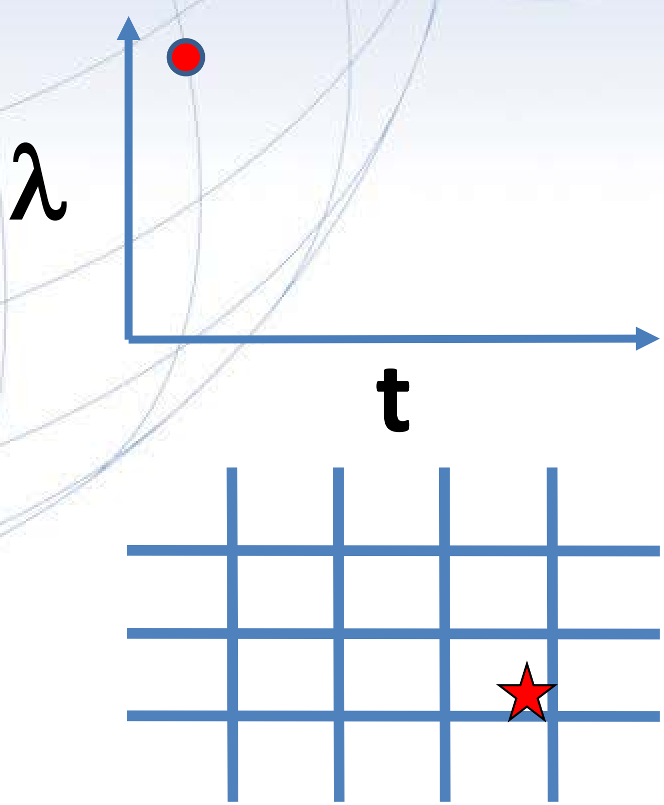
Frame is rigid and fixed to rigid part of plate



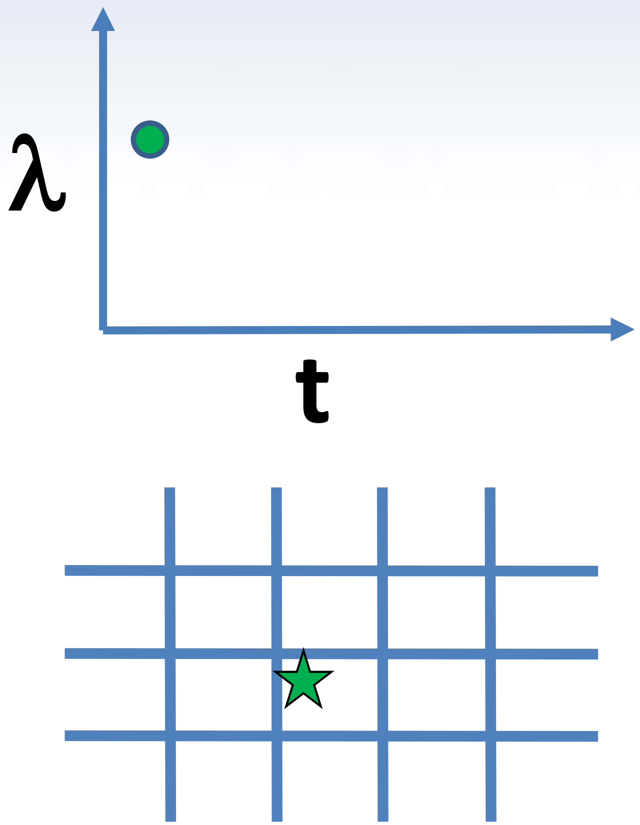
NATRF2022 coordinates over time

(Remember: The NATRF2022 *frame* is rigid)

Point on <u>deforming</u> part of plate



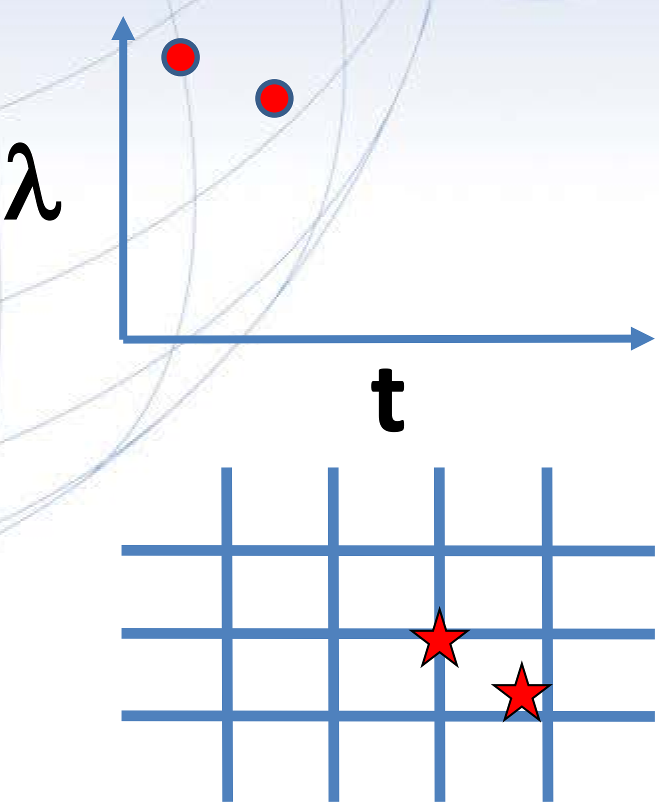
Point on <u>rigid</u> part of plate



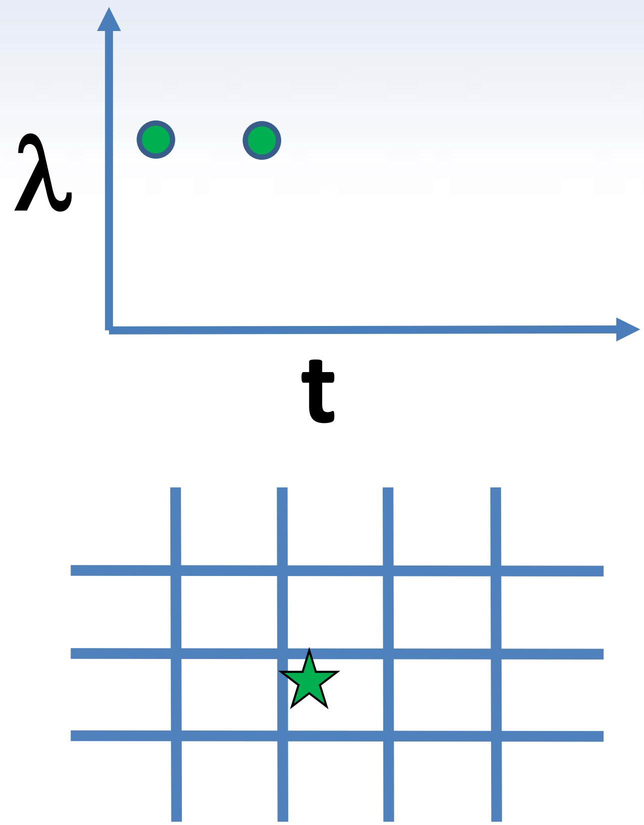
NATRF2022 coordinates over time

(Remember: The NATRF2022 *frame* is rigid)

★ Point on deforming part of plate

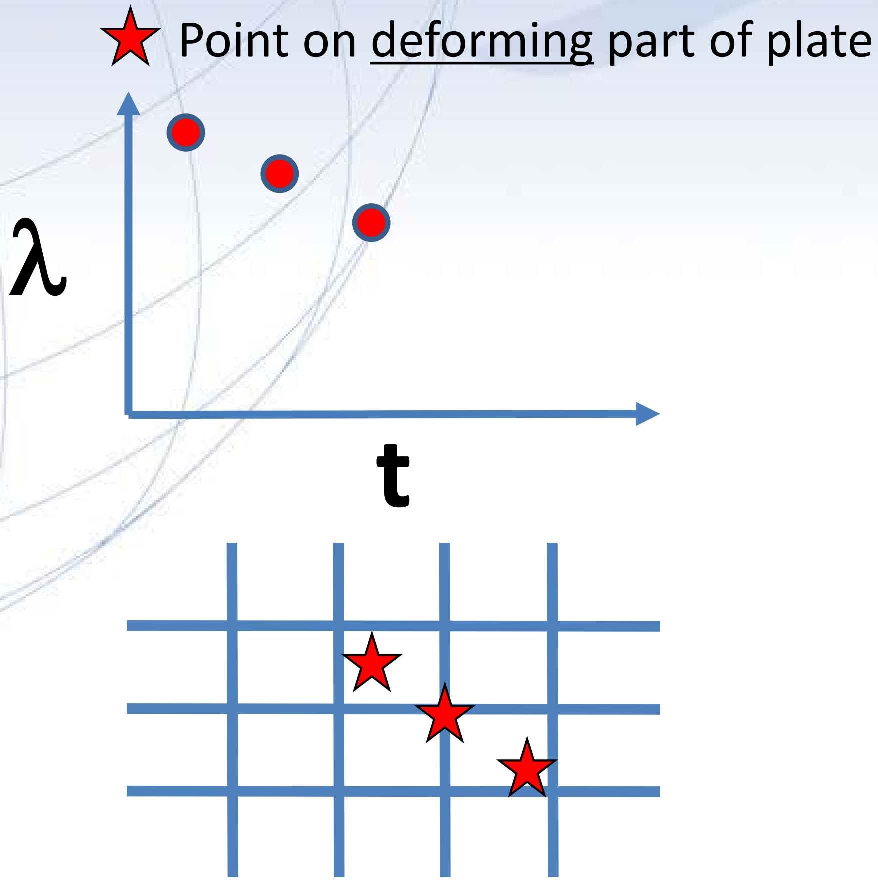


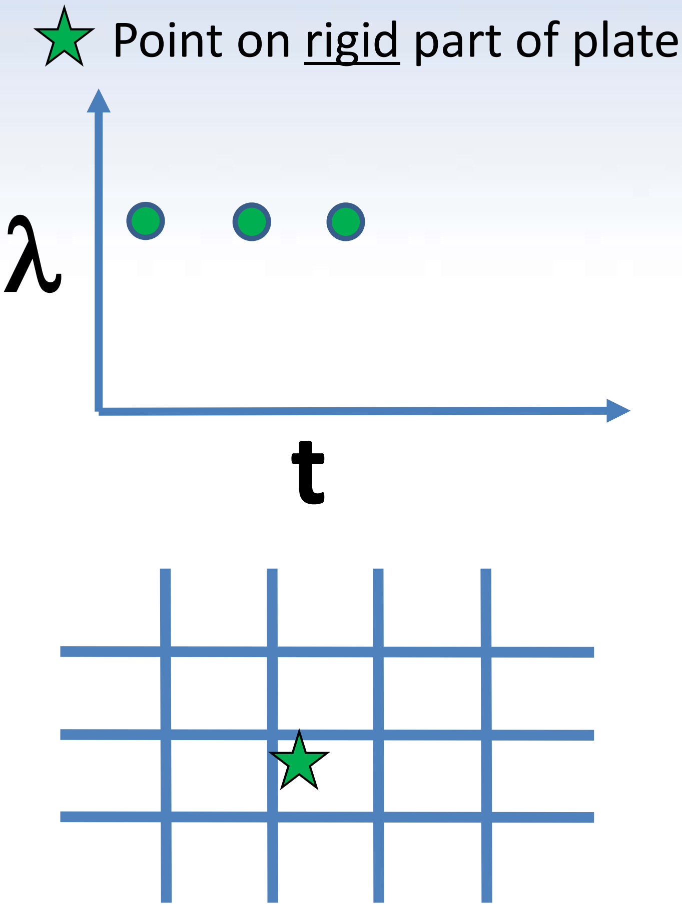
★ Point on rigid part of plate



NATRF2022 coordinates over time

(Remember: The NATRF2022 *frame* is rigid)

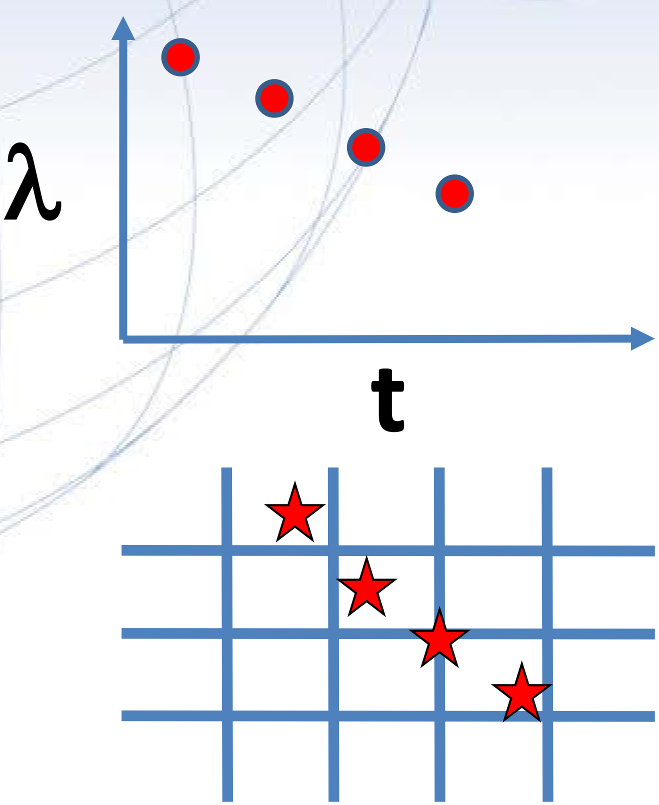




NATRF2022 coordinates over time

(Remember: The NATRF2022 *frame* is rigid)

★ Point on <u>deforming</u> part of plate



★ Point on <u>rigid</u> part of plate

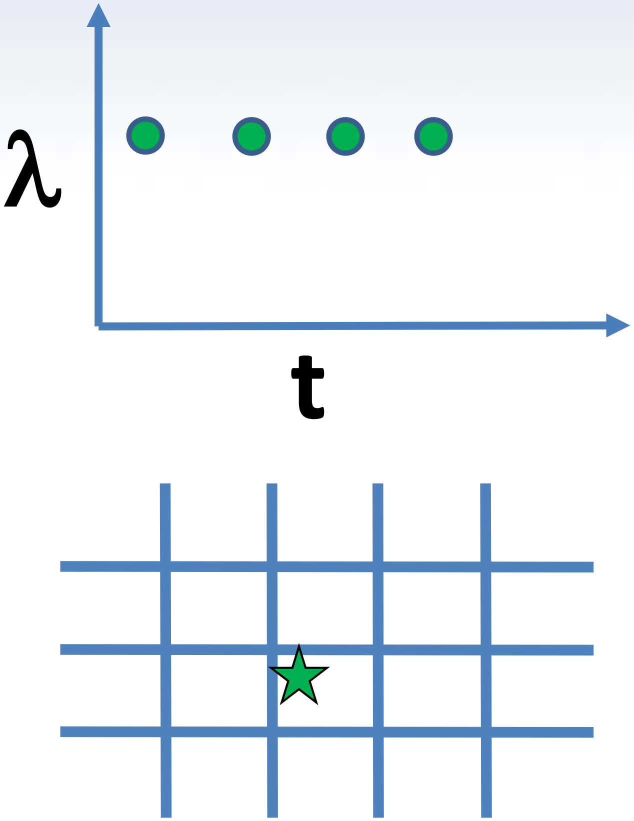
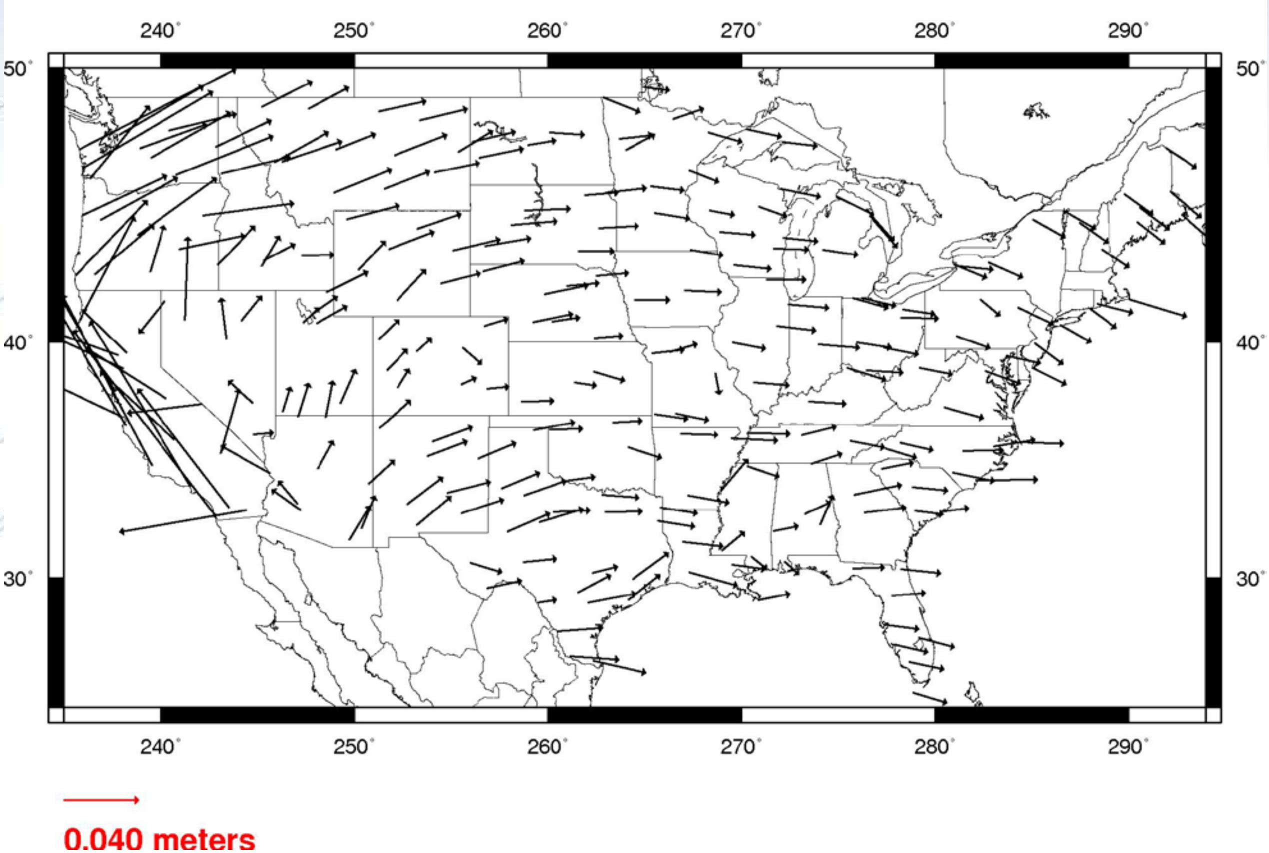


Plate-(pseudo)fixed frames

NAD 83(2011) minus NAD 83(NSRS2007)



NAD 83(NSRS2007)
- Epoch **2002.0**

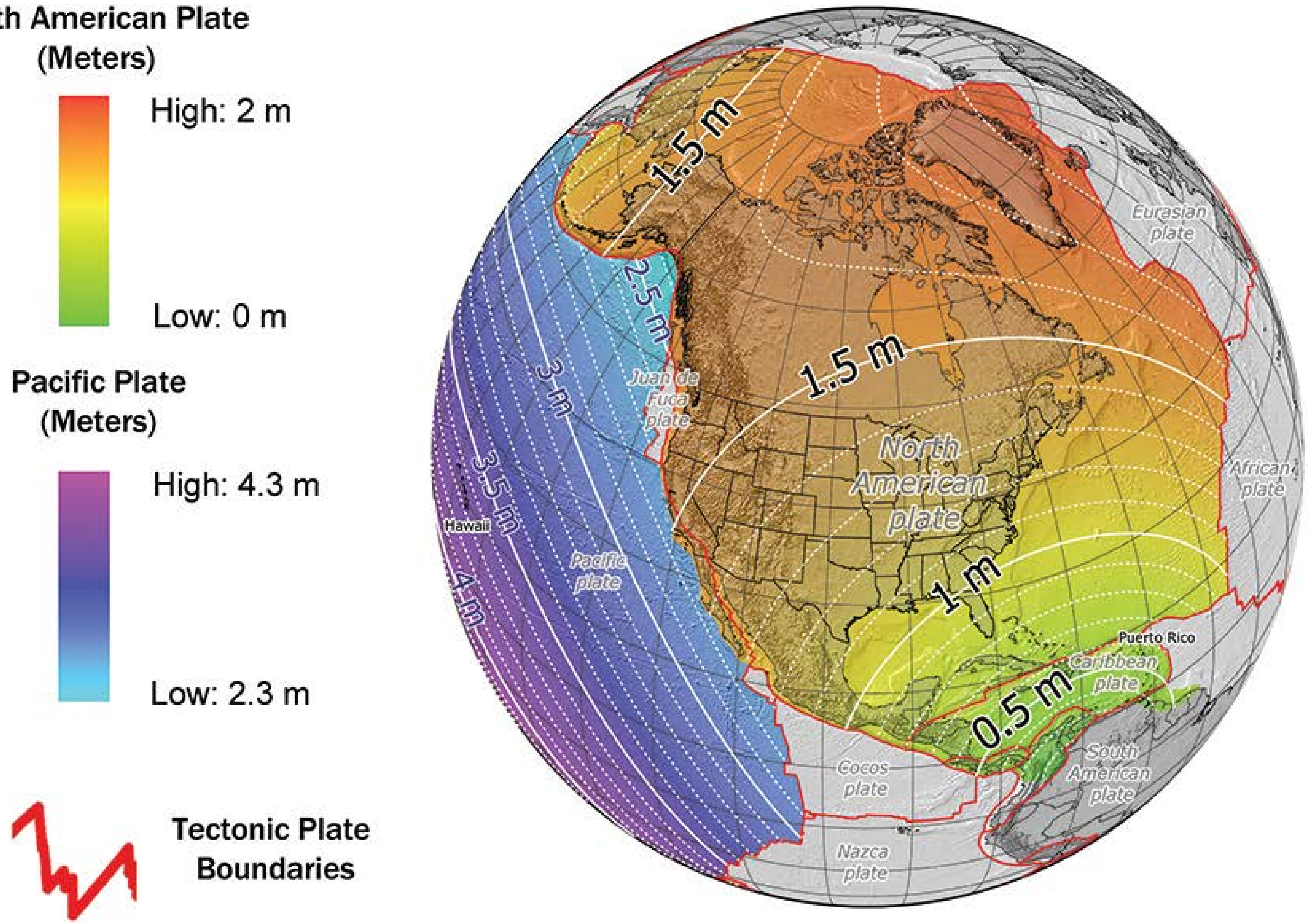
NAD 83(2011)
- Epoch **2010.0**

If NAD 83 were truly "plate fixed" then an 8 year epoch change would not yield the systematic plate rotation seen here.

(*)TRF2022 will determine a new Euler Pole rotation for each of 4 plates.

(*)=NA, C, T or P

Approximate Horizontal Change North American Plate



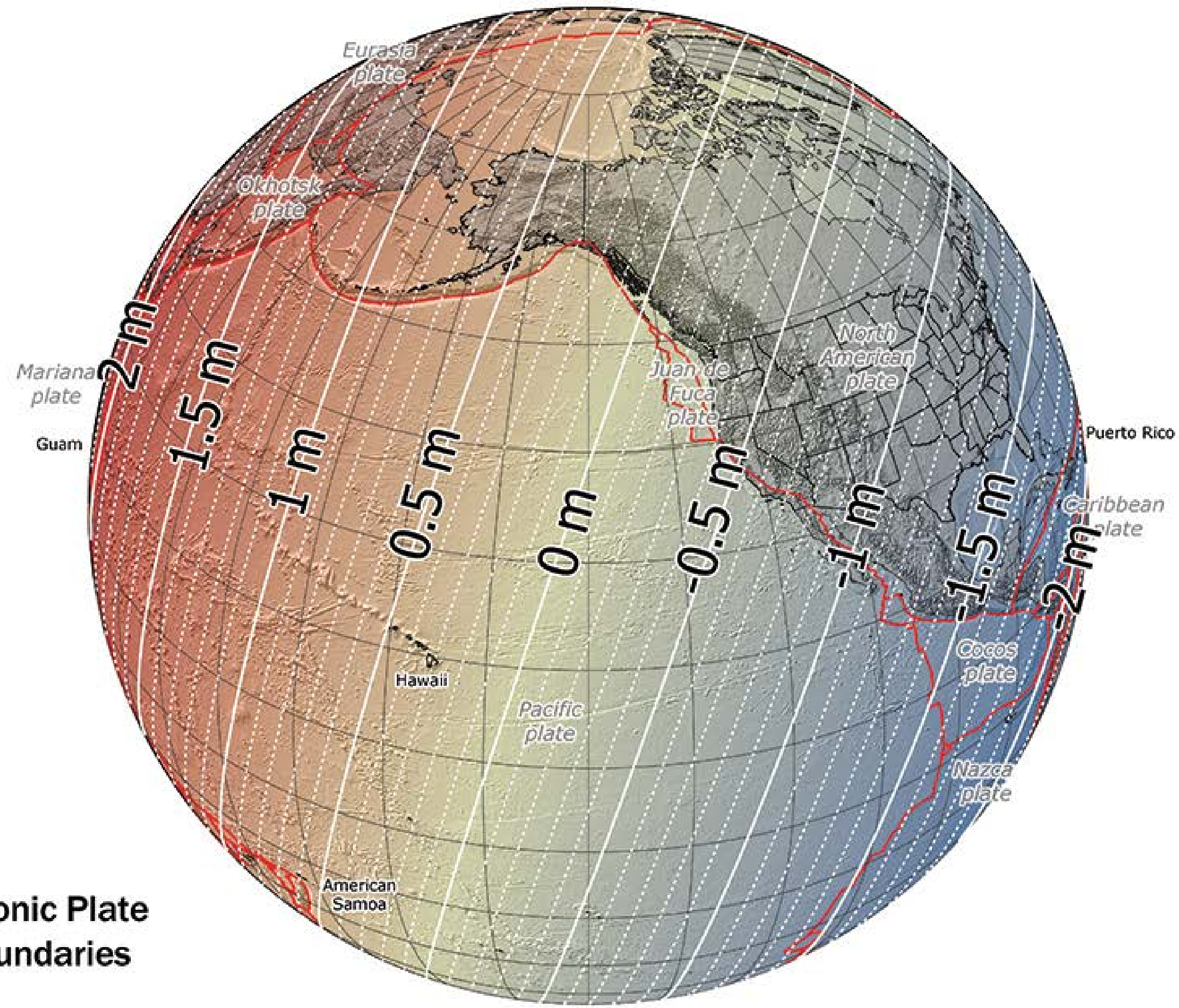
Approximate Ellipsoid Height Change

Ellipsoid Height (Meters)

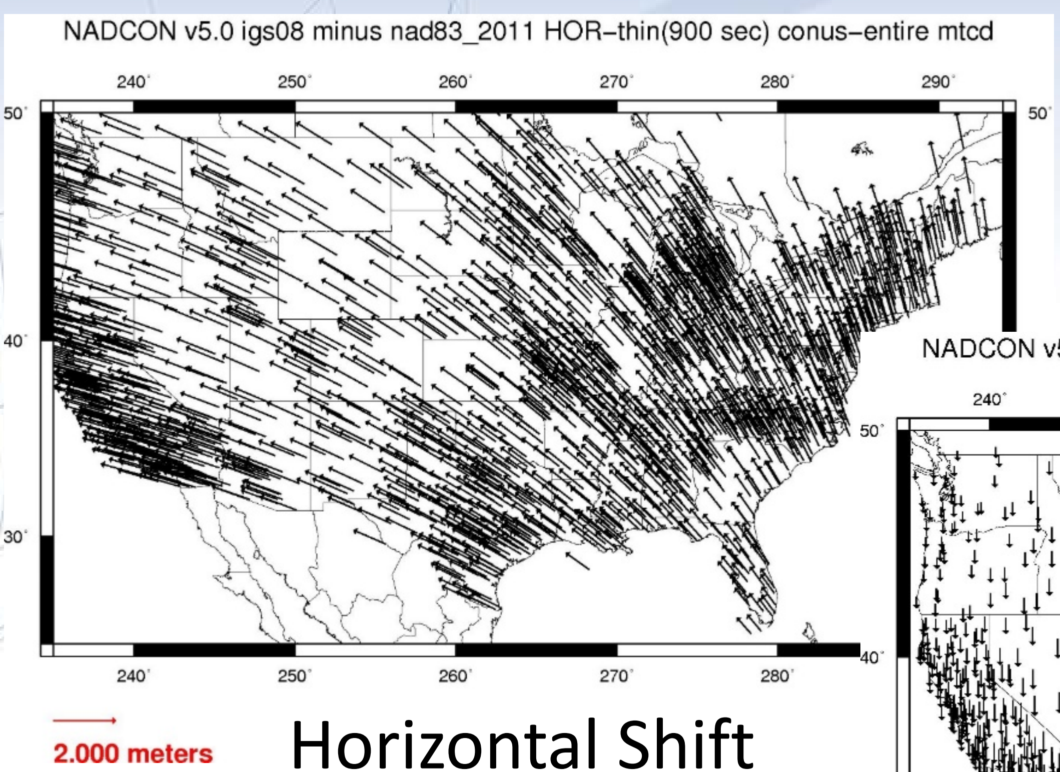
High: 2 m

Low: -2 m

Tectonic Plate Boundaries

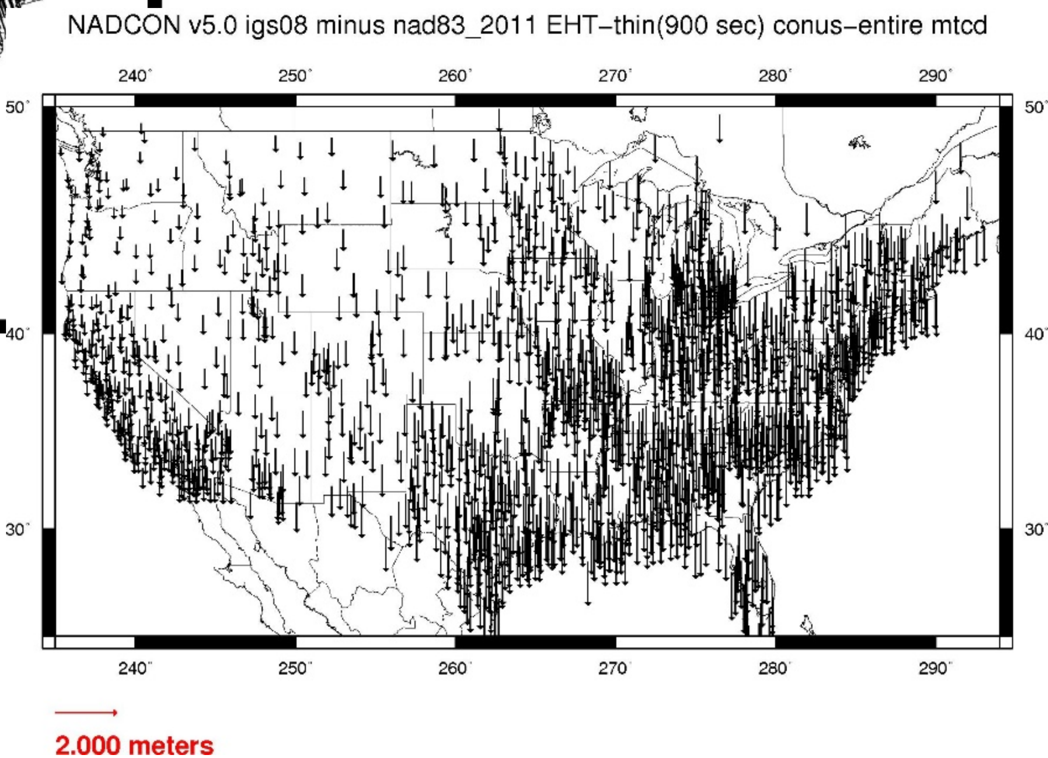


Fixed-Epoch Transformation NAD 83 to NATRF2022

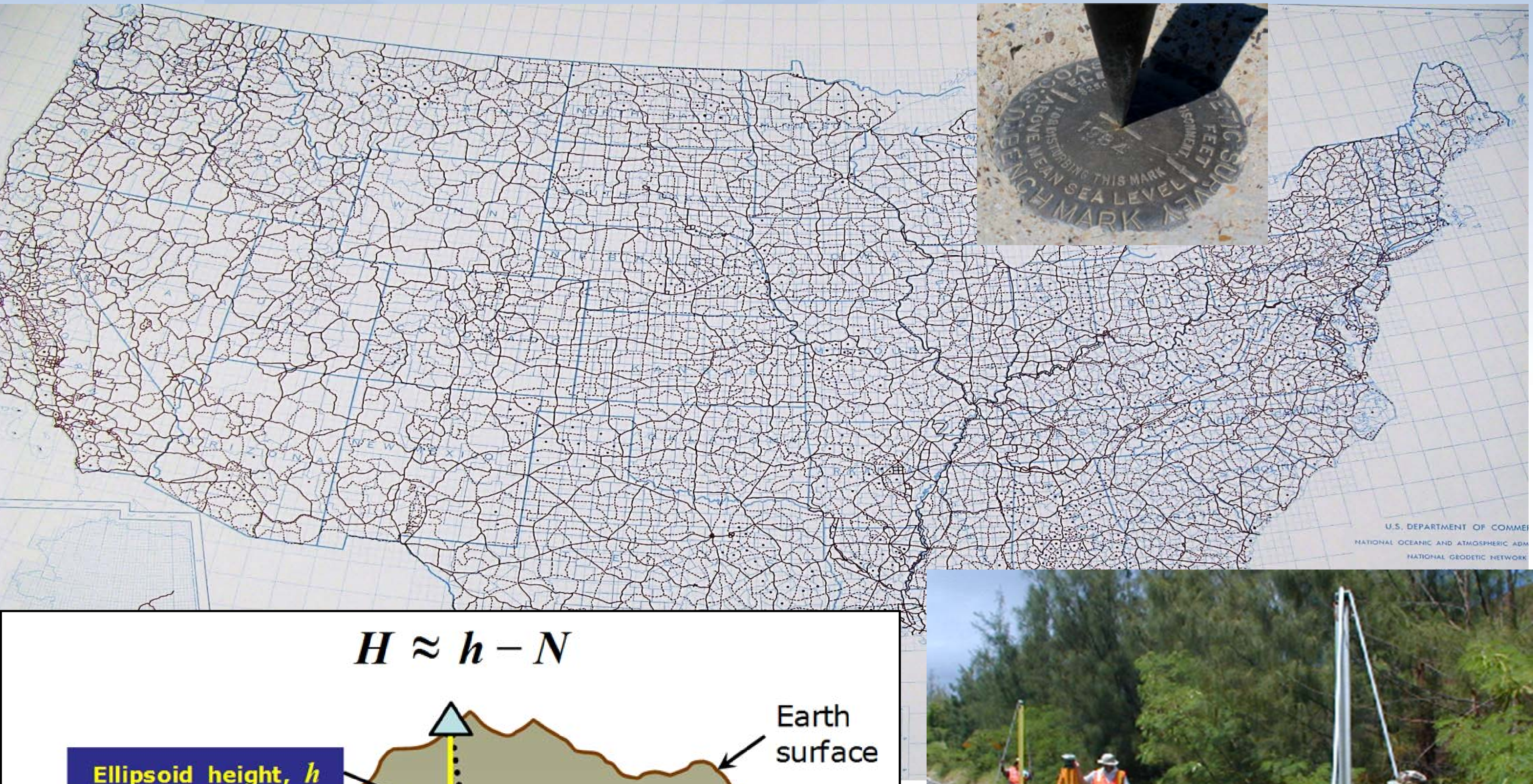


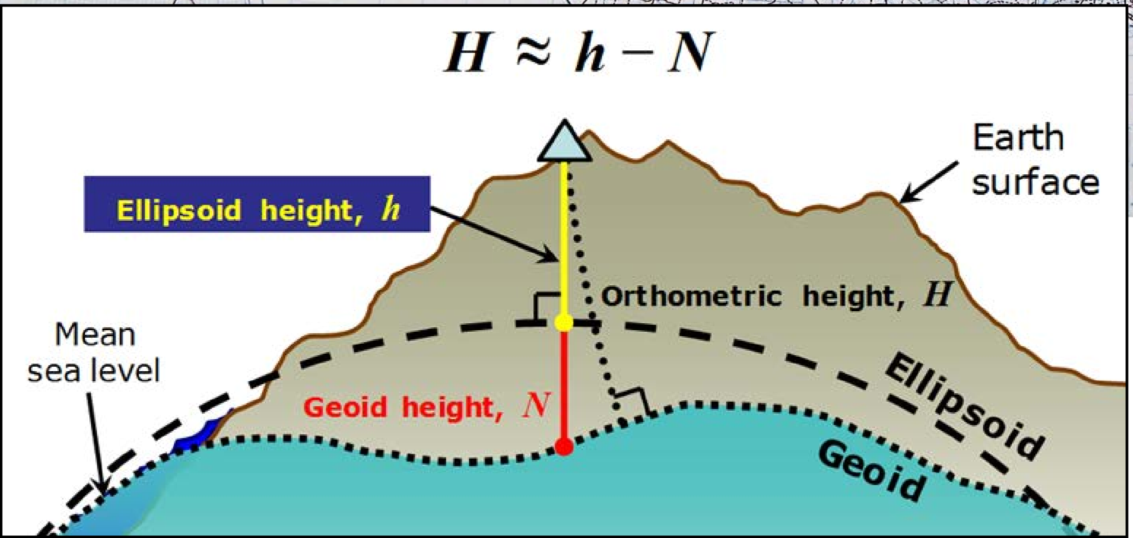
Horizontal Shift

Ellipsoid Height Shift

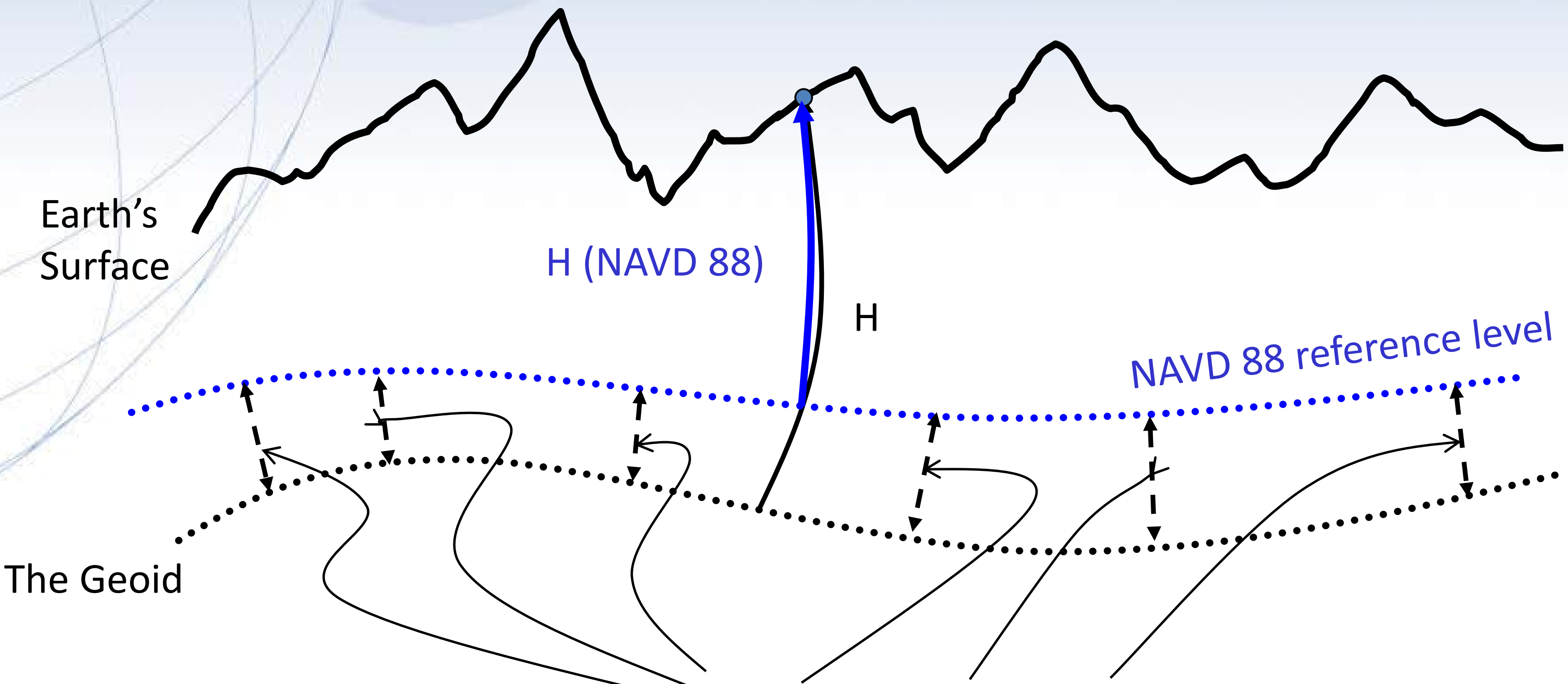


NORTH AMERICAL VERTICAL DATUM 1988 (NAVD88)





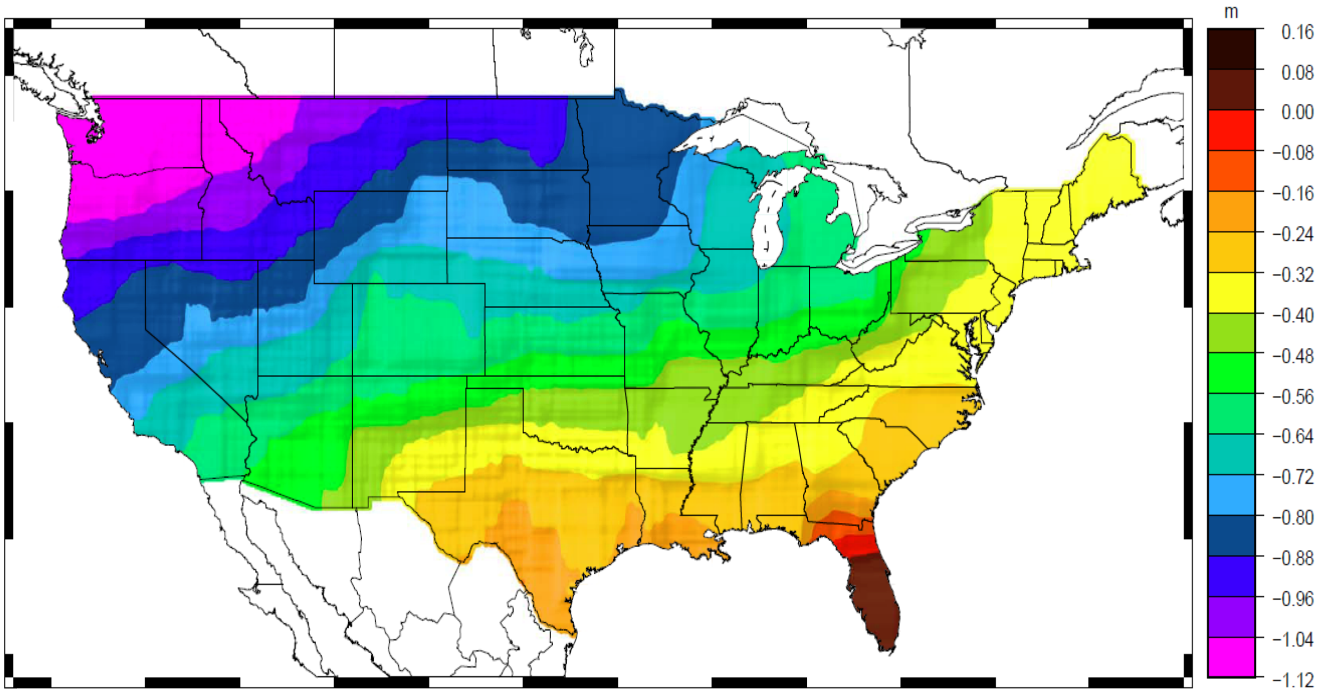
Why isn't NAVD 88 good enough anymore?



Errors in NAVD 88 : ~50 cm average,
100 cm CONUS tilt,
1-2 meters average in Alaska
NO tracking

North American Vertical Datum 1988 (NAVD88) Shortcomings

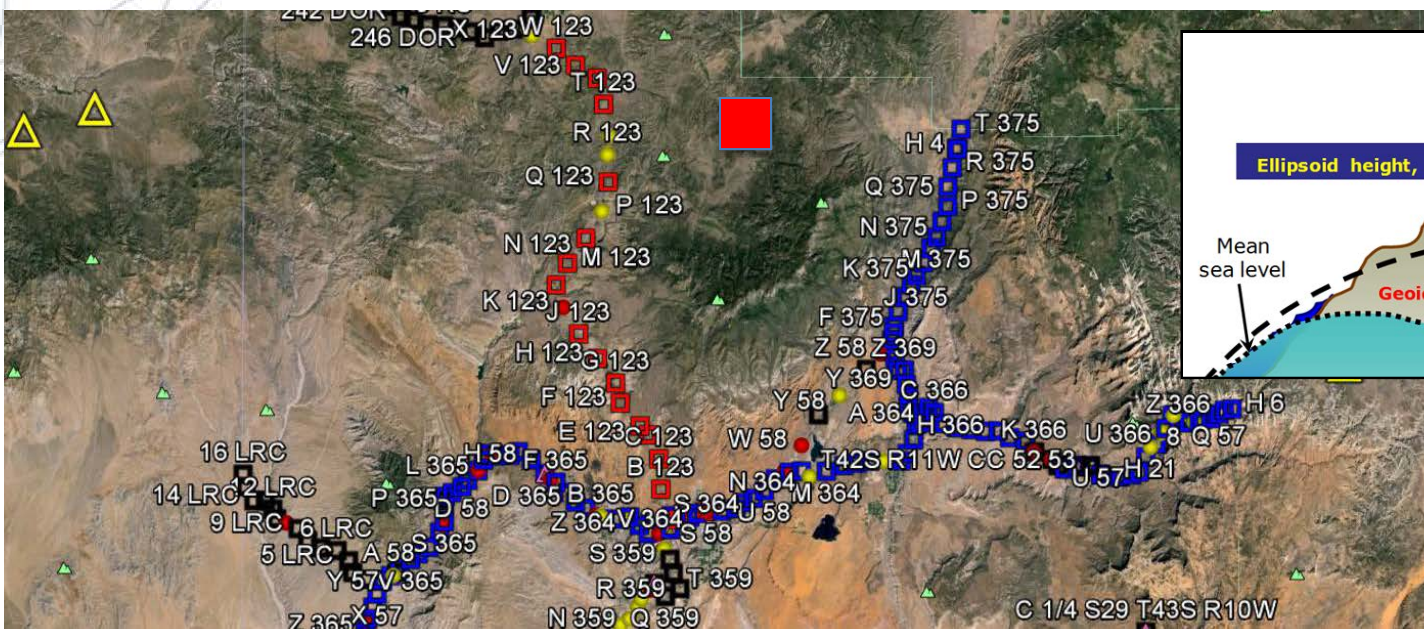
- **Cross-country errors (1-m tilt)**
- **0.5 m bias in reference surface vs. global mean sea level**
- **Subsidence, uplift, freeze/thaw invalidate BM elevations**
- **LIMITED AVAILABILITY / ACCESS**

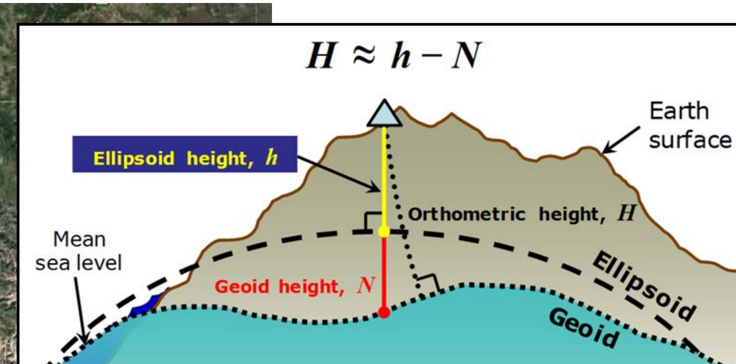


Approximate Geoid Mismatch in the NAVD88 H=0 surface

Future Geopotential (Vertical) Datum

- **replace NAVD88 – by 2022**
- **accessed by GNSS & gravimetric geoid**
- **monitor time-varying nature of gravity field**
- **most accurate continental gravimetric geoid model ever built: 1 cm**





And they shall be called…

North American-Pacific Geopotential Datum of 2022

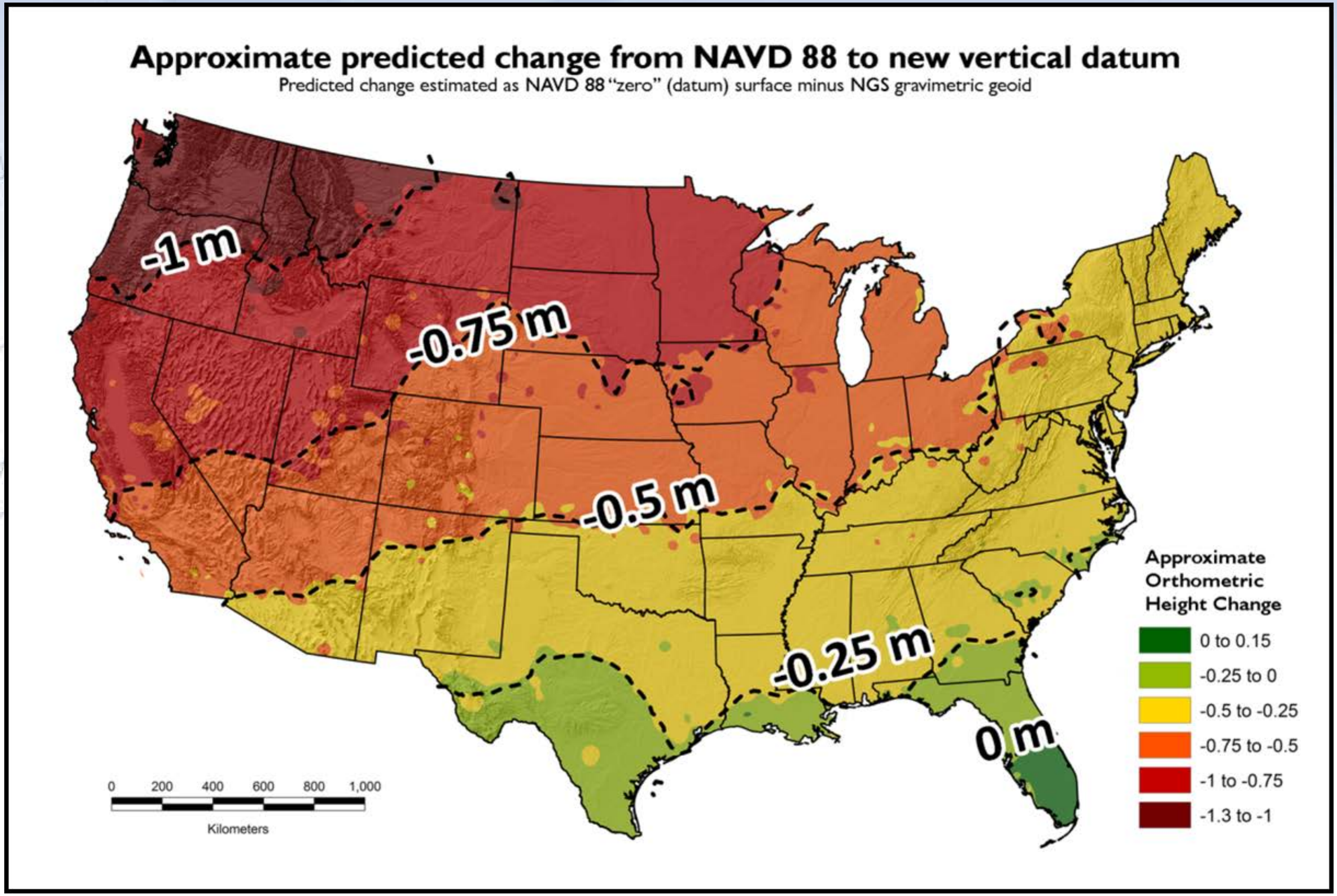
(NAPGD2022)

&

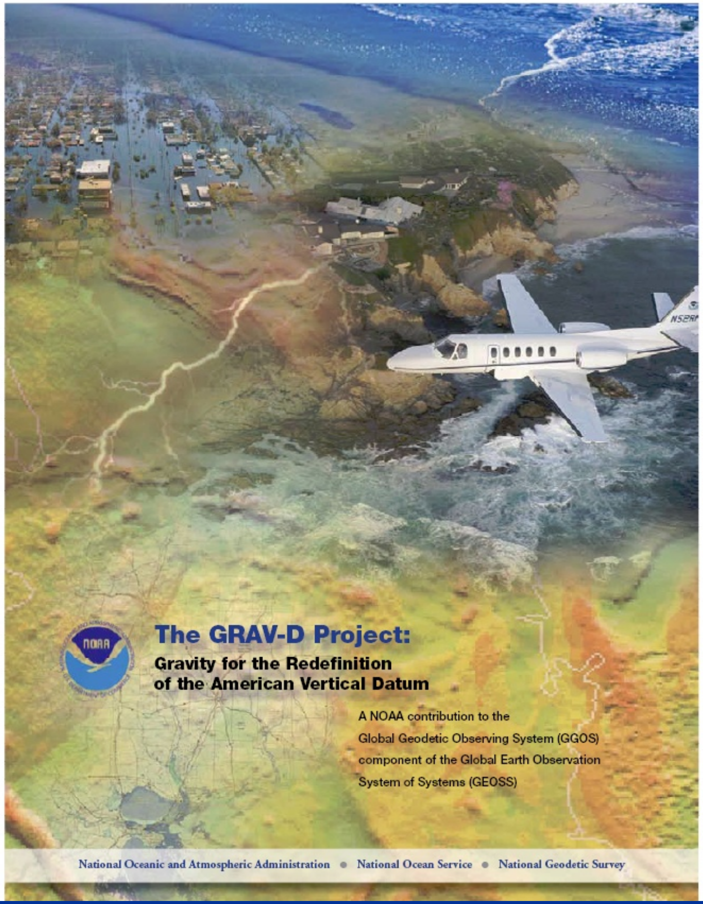
GEOID2022

- NAPGD2022 will contain information for:
  - Orthometric heights
  - Geoid undulations
  - Gravity anomalies
  - Deflections of the vertical
  - & other gravity field information
- GEOID2022 will be time-dependent

Future Geopotential (Vertical) Datum



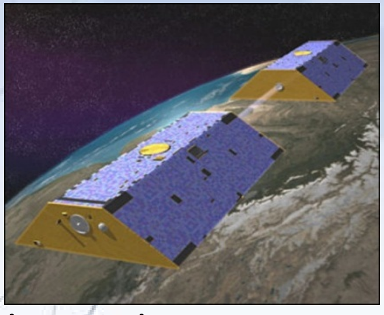
Gravity for the Redefinition of the American Vertical Datum (GRAV-D)



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

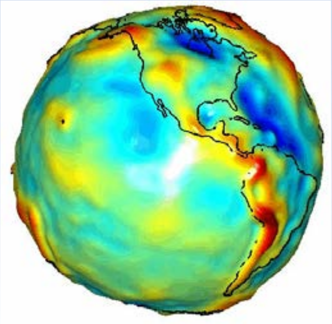
- Replace the national vertical datum (NAVD88) by 2022 with a ***1 cm accurate gravimetric geoid***
- Orthometric heights accessed via GNSS ***accurate to 2 cm***
- Thrusts of project:
  - Airborne gravity survey of entire country and its holdings
  - Long-term geoid change monitoring
  - Partnership surveys

Building a Gravity Field



GRACE/GOCE/Satellite Altimetry

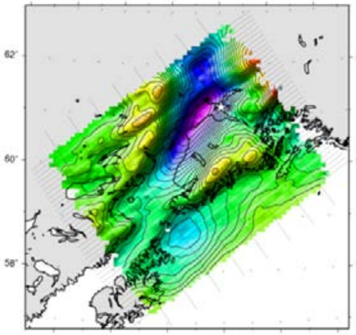
Long Wavelengths
(≥ 250 km)



+

Airborne Measurement

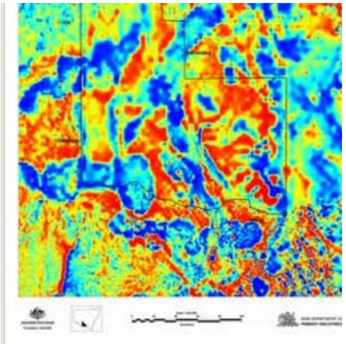
Intermediate Wavelengths
(300 km to 20 km)



+

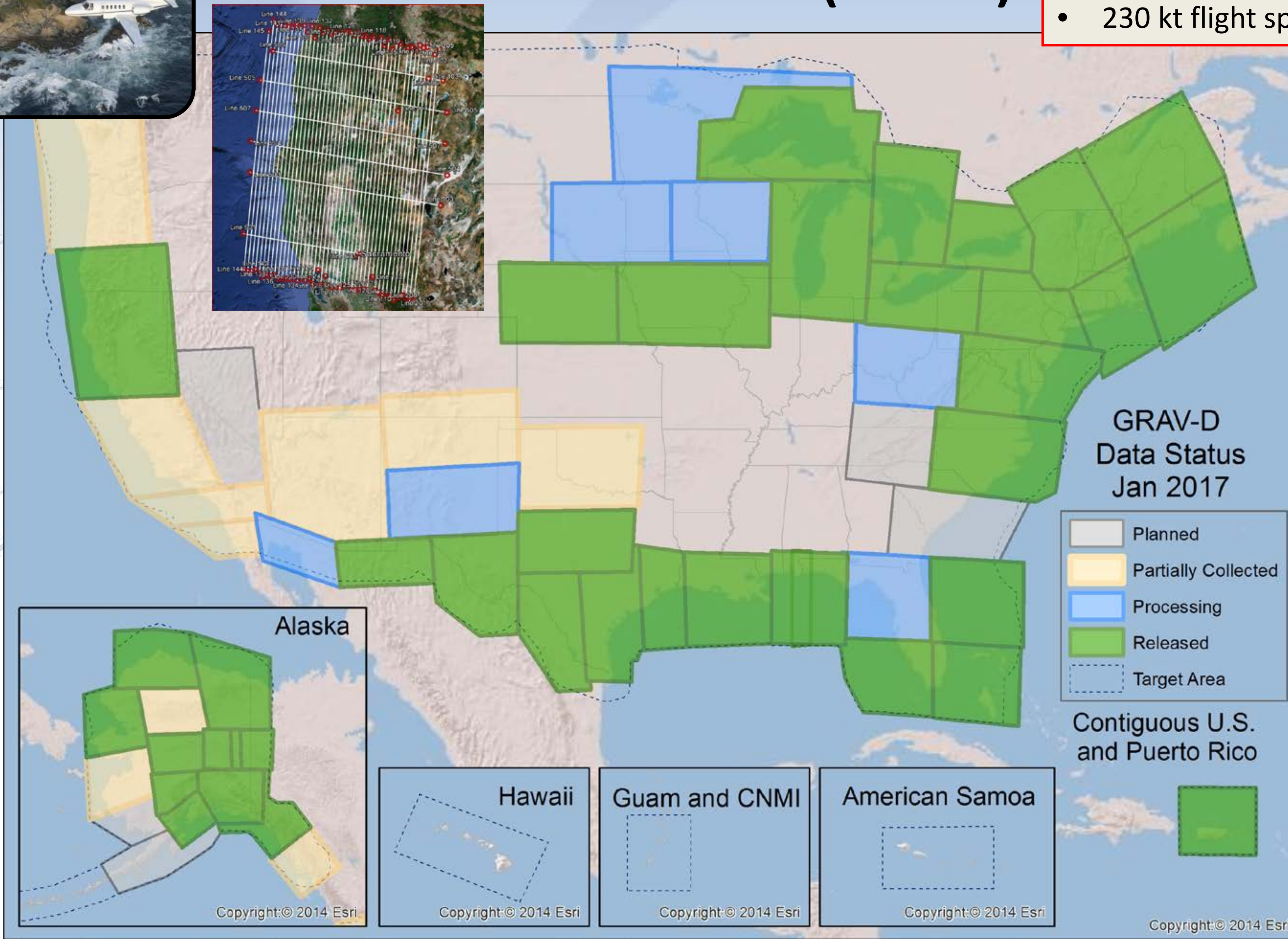
Surface Measurement and
Predicted Gravity from Topography

Short Wavelengths
(< 100 km)



GRAV-D Status (58%)

- 10 km data lines
- 70 km cross lines
- 20,000 ft altitude
- 230 kt flight speed

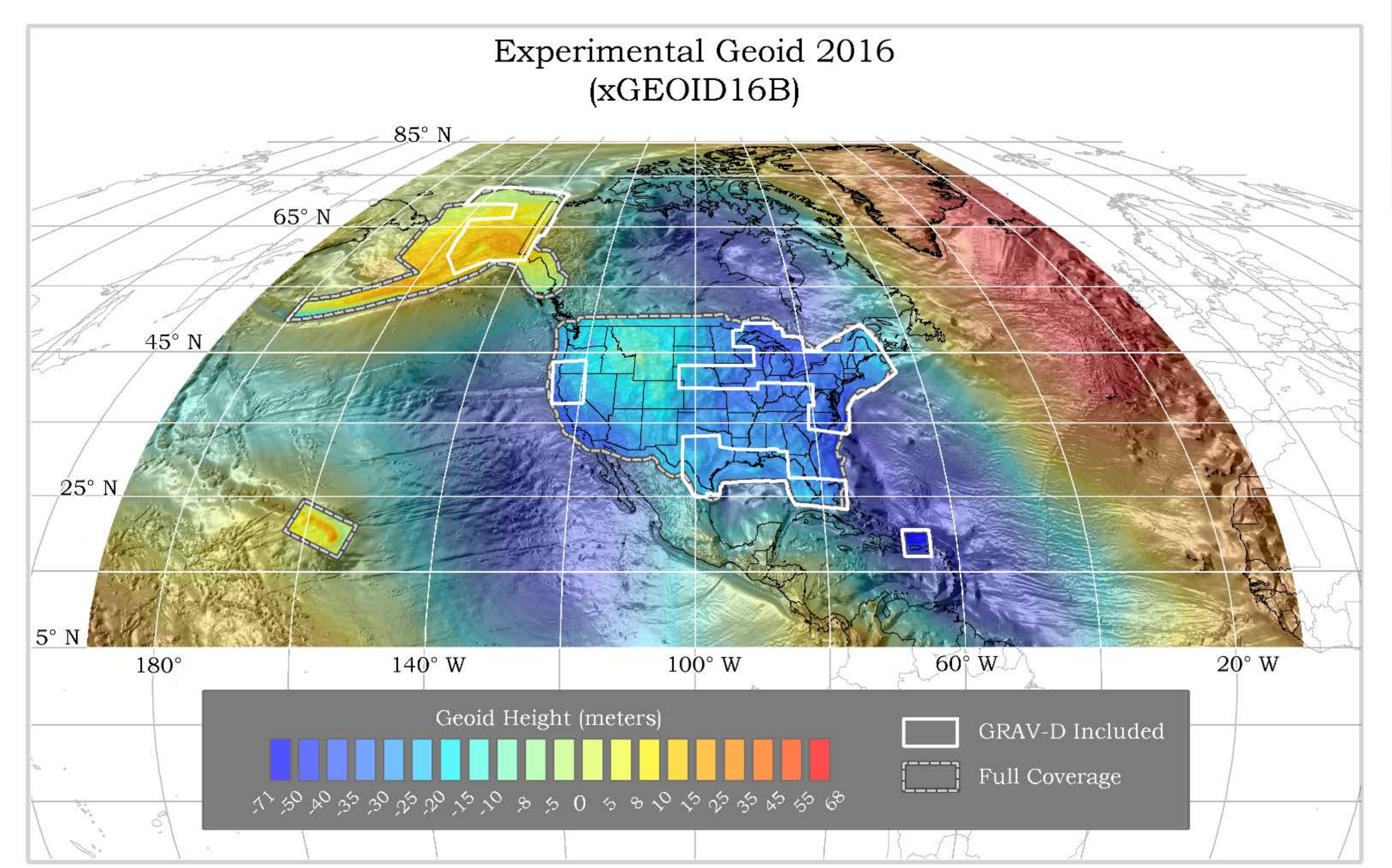


GRAV-D Data Collection Scope

- Entire U.S. and territories
  - Area: 15.6 million sq km
  - Initial target area for 2022
  - ~200 km buffer around territory or shelf break

Extent of 2022 gravimetric geoid model used for new geopotential reference frame

Experimental Geoid 2016
xGEOID16B



https://beta.ngs.noaa.gov/GEOID/xGEOID16/

OPUS – Extended Report

********** New Reference Frame Preview **********

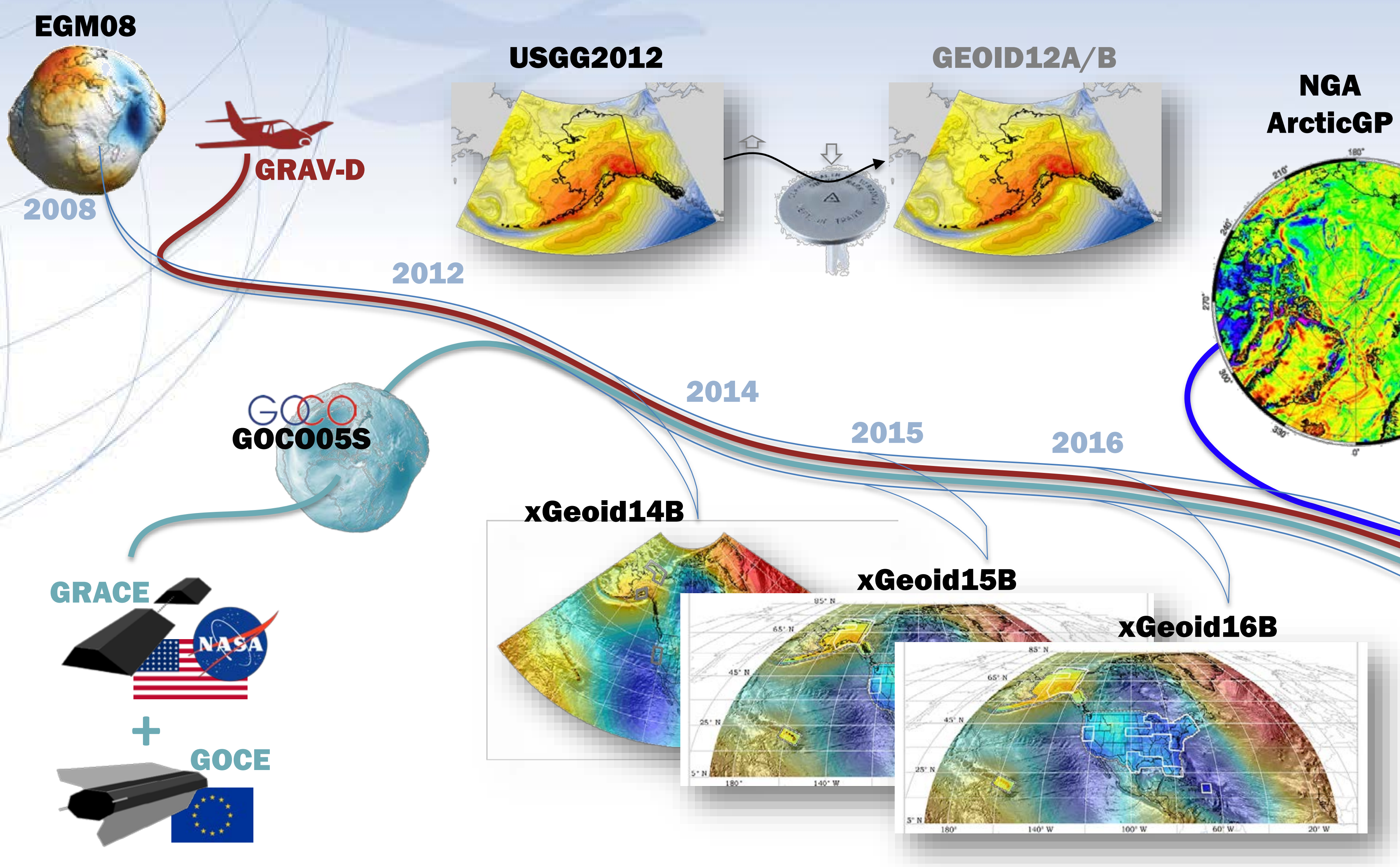
We are replacing the nation's NAD 83 and NAVD 88 datums, to improve access and accuracy of the National Spatial Reference System. More at https://geodesy.noaa.gov/datums/newdatums/

Below are approximate coordinates for this solution in the new frames:

APPROX ORTHO HGT: 778.126 (m) [PROTOTYPE (Computed using xGeoid16B,GRS80,IGS08)]

[for comparison, NAVD88 = 778.806 (m)]

Evolution of the Gravimetric Geoid



Geoid Slope Validation Survey: 3 phases to validate accuracy of the gravimetric geoid model

Phase 1- GSVS11

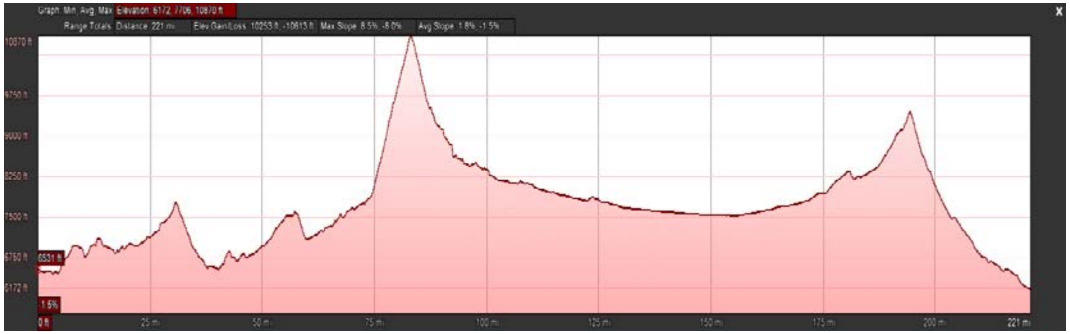
- 2011; Low/Flat/Simple: **Texas**

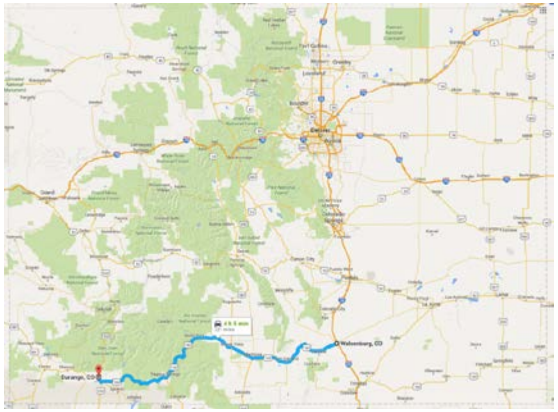
Phase 2- GSVS14

- 2014; High/Flat/Complicated: **Iowa**

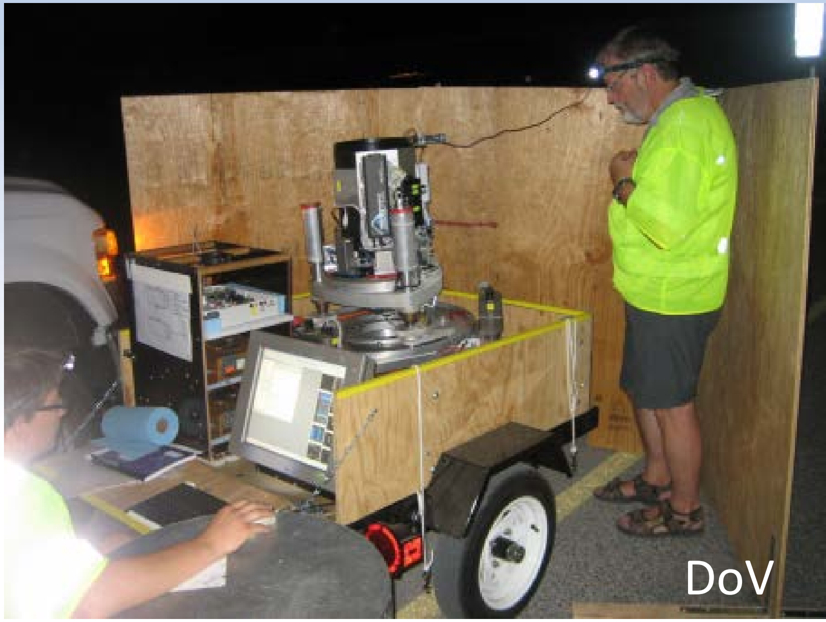
Phase 3 – GSVS17

- 2017; High/Rugged: **Colorado** (10,860ft)

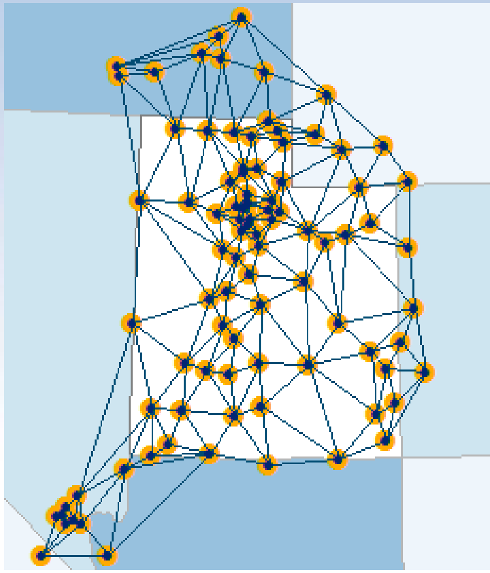




Geoid Slope Validation Surveys – 2011 & 2014

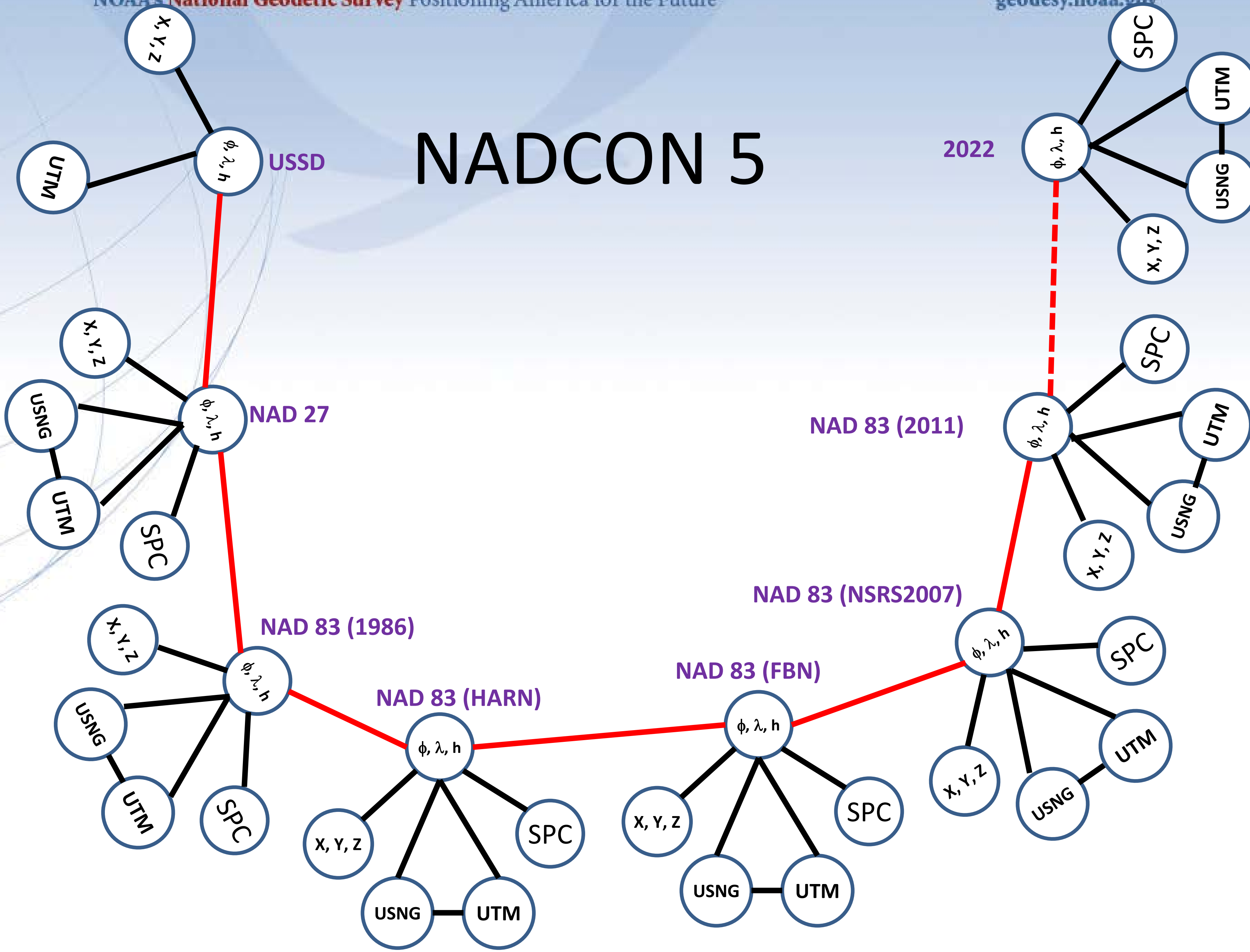


How to Plan for 2022



- **Move to NAD 83(2011) epoch 2010.00**
  - via surveys (or *possibly* via NADCON/GEOCON)
- **Move to NAVD 88**
  - via surveys (or *possibly* via VERTCON)
- **Move from reliance on passive marks to GNSS infrastructure**
  - utilize CORS, OPUS, real-time networks (eg TURN), etc.
- **Use OPUS-Share/Database for GPSBMs & NAD83(2011) ties**
  - improve next geoid model & relationship with new datum
- **METADATA!!!!**

NADCON 5


USSD
NAD 27
NAD 83 (1986)
NAD 83 (HARN)
NAD 83 (FBN)
NAD 83 (NSRS2007)
NAD 83 (2011)
2022
ϕ, λ, h
X, Y, Z
UTM
USNG
SPC

Legislation

- When NAD 83 replaced NAD 27, Federal NSRS users were required to switch to NAD 83
- Through the 1980s and 1990s NGS worked with *states* to update their laws
  - To encourage use of the new system beyond Feds
- 48 states now have laws that refer to NAD 83
  - A name which will be *retired* in 2022

Legislation

- In 2016, NSPS, AAGS, and NGS formed a committee to address this issue
  - The NSPS/AAGS/NGS Advisory Committee on National Spatial Reference System Legislation
- New Legislative Template completed June 2016
  - Generic terminology: "NSRS or its successor," etc.
  - NSPS will work with states to adopt new template
    - 2017 - 2022

Your NAD 83-Based State Plane-Legislated Coordinates *Will Not* Be Maintained after 2022!

NSPS

AAGS

NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

What will you and your fellow professionals do?
Panic? Ignore the Issue? *or Act?*
Please let us know!

What is changing?

The North American Datum of 1983 (NAD 83) will be replaced in 2022.
The new datum will have a different name.

The North American Vertical Datum of 1988 (NAVD 88) will also be replaced in 2022.
Its replacement will also have a new name.

Expected horizontal shifts from NAD 83 to the new datum are in the 1-2 meter range.
The National Geodetic Survey will provide a coarse, map-grade transformation tool (such as NADCON and GEOCON) to connect NAD 83 with the new datum.

Who will be affected?

All states and territories will be transitioned to the new datums.
Forty-eight states have a state-specific coordinate system law tied to NAD 83.
Your state law will not reflect the National Spatial Reference System after 2022.

Who can help?

The National Geodetic Survey (NGS), the National Society of Professional Surveyors (NSPS) and the American Association for Geodetic Surveying (AAGS) are here to help your state make these changes in legislation!

You can help by understanding your own state's laws and how these changes will impact you.

Should you change or modify your state law?

NGS, NSPS and AAGS believe it would benefit state surveyors and mapping professionals for laws or regulations to reflect the latest federal geodetic infrastructure, namely **the National Spatial Reference System.**

Why should you change or modify your state law?

1. Federal agencies will adopt the new datum, so national products like **Federal Emergency Management Agency (FEMA) flood insurance rate maps** will no longer reference NAD 83, nor NAVD 88. Using the current (most updated) datum will avoid confusion and increase consistency with federal engineering or constructions projects.

3. More geospatial data is being collected and shared every day. A consistent and regularly updated NSRS will provide greater efficiency across surveying and mapping sectors.

What do you think?

We welcome your feedback! Please provide any feedback you like to one of our committee members, below.

NSPS/AAGS/NGS Advisory Committee on National Spatial Reference System Legislation

J.B. Byrd	NSPS	jbyrd@jmpa.us
Dave Doyle	NSPS	base9geodesy@gmail.com

NGS 2017 Geospatial Summit

National Geodetic Survey

Positioning America for the Future

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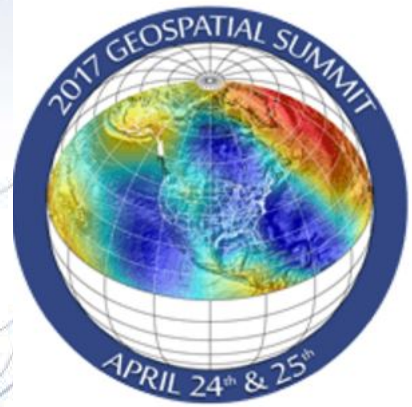

- 2017 Summit Home
- Summit Documents
- FAQs

Related Links

- NGS 10-year plan
- 2015 Summit Proceedings
- 2010 Summit Proceedings
- New Datums Web page

2017 Geospatial Summit

On April 24-25, 2017 NGS hosted the 2017 Geospatial Summit at the Silver Spring Civic Building at 1 Veterans Pl, Silver Spring, MD 20910.

The 2017 Geospatial Summit provided updated information about the planned modernization of the National Spatial Reference System (NSRS). Specifically, NGS plans to replace the North American Datum of 1983 (NAD 83) and the North American Vertical Datum of 1988 (NAVD 88) in 2022.

The Summit provided an opportunity for NGS to share updates and discuss the progress of projects related to NSRS Modernization. NGS also heard feedback and collected requirements from its stakeholders across the federal, public and private sectors. This event continued discussions from previous Geospatial Summits held in 2010 and 2015.

Additional information about the 2017 Geospatial Summit will be posted online. If you have questions or comments, contact us.

Website Owner: National Geodetic Survey / Last modified by NGS Infocenter May 02 2017

New Datums

National Geodetic Survey

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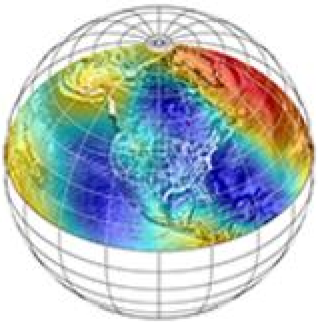


September 20, 2016

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.

What to Expect | Get Prepared

Related Projects | Track Our Progress

Watch Our Videos | Learn More

Why is NGS replacing NAD 83 and NAVD 88?

NAD 83 and NAVD 88, although still the official horizontal and vertical datums of the National Spatial Reference System (NSRS), have been identified as having shortcomings that are best addressed through defining new horizontal and vertical datums.

New Datums Quick Links

- Home
- What to expect
- Get prepared
- Track our progress
- Related projects
- Watch videos
- Learn more
- New Datums FAQ
- Contact Us
- Sign up for list-serve

Issue 6, January 2017

NSRS Modernization News

For all issues of **NSRS Modernization News**, visit:
geodesy.noaa.gov/datums/newdatums/TrackOurProgress.shtml

Decision Points

The National Geodetic Survey (NGS), through a series of both internal debates and external discussions with the Canadian Geodetic Survey, has finalized certain key decisions in the replacement of the three NAD 83 reference frames, and in the replacement of the various vertical datums of the NSRS. These decisions cover both the science and nomenclature of the changes coming in 2022.

Four Terrestrial Reference Frames

Replacing the three existing NAD 83 reference frames will be four plate-fixed *terrestrial reference frames.* The tectonic plate for each frame may be inferred from their names, which are:

North American Terrestrial Reference Frame of 2022 (NATRF2022)

Pacific Terrestrial Reference Frame of 2022 (PTRF2022)

Mariana Terrestrial Reference Frame of 2022 (MTRF2022)

Caribbean Terrestrial Reference Frame of 2022 (CTRF2022)

Relationship to the IGS Frame

Each of the above four frames will be identical to the latest IGS reference frame (as available in 2022) at an epoch to be determined. Away from that epoch, the four frames will relate to the IGS frame through the definition of an Euler Pole rotation specific to that plate. All Continuously Operating Reference Stations (CORS) velocities which deviate from the rotation of a rigid plate will be captured in a residual 3-D velocity model.

Heights and Other Physical Coordinates

A *geopotential datum* will be created which will contain all of the necessary information to provide mutually consistent orthometric heights, geoid undulations, gravity anomalies, deflections of the vertical, and all other geodetic coordinates related to the gravity field. This geopotential datum will be called:

North American-Pacific Geopotential Datum of 2022 (NAPGD2022)

Geoid Model

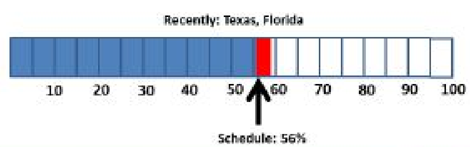
Within NAPGD2022, a variety of products will exist. The most prominent of these products will be a *time-dependent model of the geoid,* provided in three regions (the first covering the entirety of North and Central America, Hawaii, Alaska, Greenland, and the Caribbean; the second covering American Samoa; and the third covering Guam and the Commonwealth of the Mariana Islands). The name of this model will be:

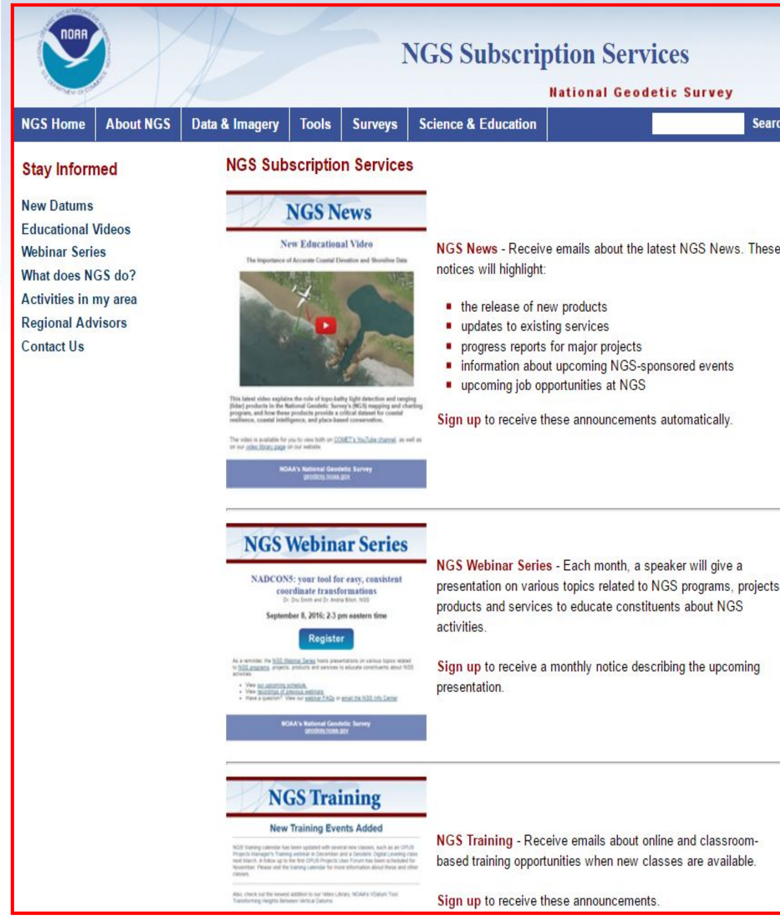
GEOID2022

Further Information

A comprehensive white paper, outlining the technical details of the above decisions, is currently being drafted in NGS and we plan for it to be ready by the upcoming 2017 Geospatial Summit. In addition, details may be released on the NGS website and through our email listserv.

GRAV-D progress last quarter: up 3.0% to 58.4%
Ahead of Schedule!





Attend a Monthly Webinar

NGS Webinar Series

National Geodetic Survey

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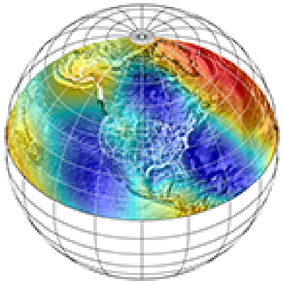


Webinar Series Quick Links

- Overview
- Upcoming Webinars
- Recorded Webinars
- Frequently Asked Questions (FAQ)

Contact information

- Email us
- Sign-up for webinar announcements
- Sign-up for list-serve

Overview

Each month, a speaker will give a presentation on various topics related to NGS programs, projects, products and services to educate constituents about NGS activities.

Webinars are held on the second Thursday of every month, from 2:00-3:00 p.m. East Coast time. You can register for any presentation on the "Upcoming Webinars" page, and you can sign-up to receive a monthly notice describing the upcoming presentation.

This webinar series is a continuation of monthly presentations sponsored by the National Height Modernization Program, and you can download previous presentations from the Program's online meeting archive.

Many additional NGS resources are available online, including:

- Continuously Operating Reference Station (CORS) weekly newsletter archive
- Ecosystem and Climate Operations newsletter archive
- Educational videos
- Height Modernization monthly meeting archive
- Online Learning Resources (e.g. recorded webinars and online training modules)
- Presentation library

NGS Video Library

National Geodetic Survey

Educational Videos Quick Links

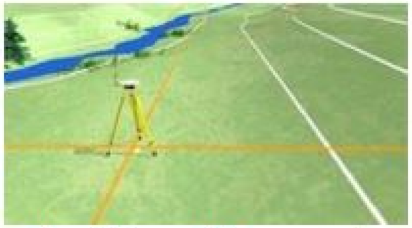
- Corbin Training Center
- Online Lessons
- Geospatial COMET MetED Resources
- National Ocean Service Lesson Plan Libary
- Other Videos +

What are Geodetic Datums?

How Were Geodetic Datums Established?

What Is the Status of Today's Geodetic Datums?

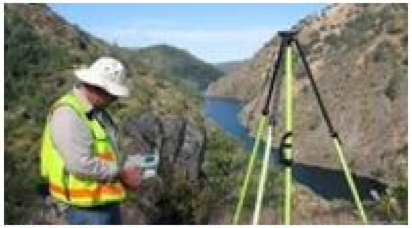
What's Next for Geodetic Datums?



Precision and Accuracy in Geodetic Surveying

Two Right Feet? U.S. Survey Feet vs. International Survey Feet

Geospatial Infrastructure for Coastal Communities: Informing Adaptation to Sea Level Rise



Best Practices for Minimizing Errors during GNSS Data Collection

The Importance of Accurate Coastal Elevation and Shoreline Data

Stay in Touch … Get More Email!

NGS Training

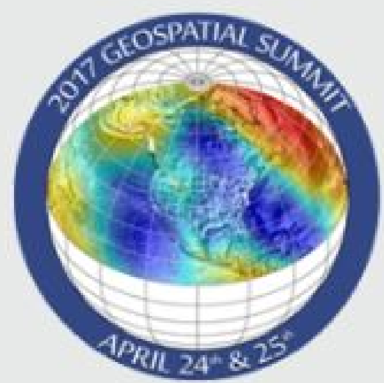
New Training Opportunities Posted

New training opportunities are available on the NGS Training Calendar.

OPUS Projects Manager's Training (webinar) - 5/16/17

OPUS Projects User Forum (webinar) - 6/7/17

Registration Open for 2017 Geospatial Summit April 24-25, Silver Spring, MD

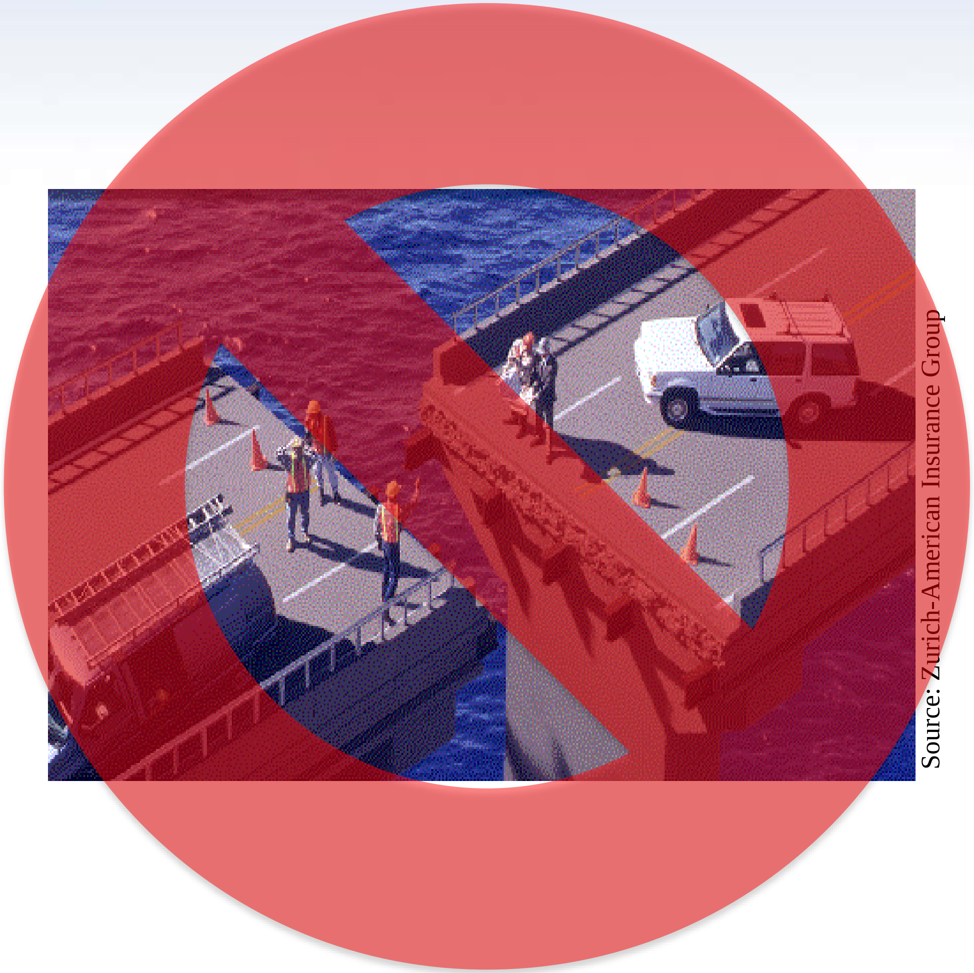


You're Invited!

NGS plans to replace the North American Datum of 1983 (NAD 83) and the North American Vertical Datum of 1988 (NAVD 88) in 2022.

We will share updates and discuss the progress of related modernization projects. Stakeholders across the federal, public, and private sectors will also be providing feedback on these efforts.

Accurate positioning begins with *accurate* coordinates



Source: Zurich-American Insurance Group