Onward to 2022: Replacing the North American Datum 1983 & North American Vertical Datum 1988

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NOAA's National Geodetic Survey
geodesy.noaa.gov

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

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

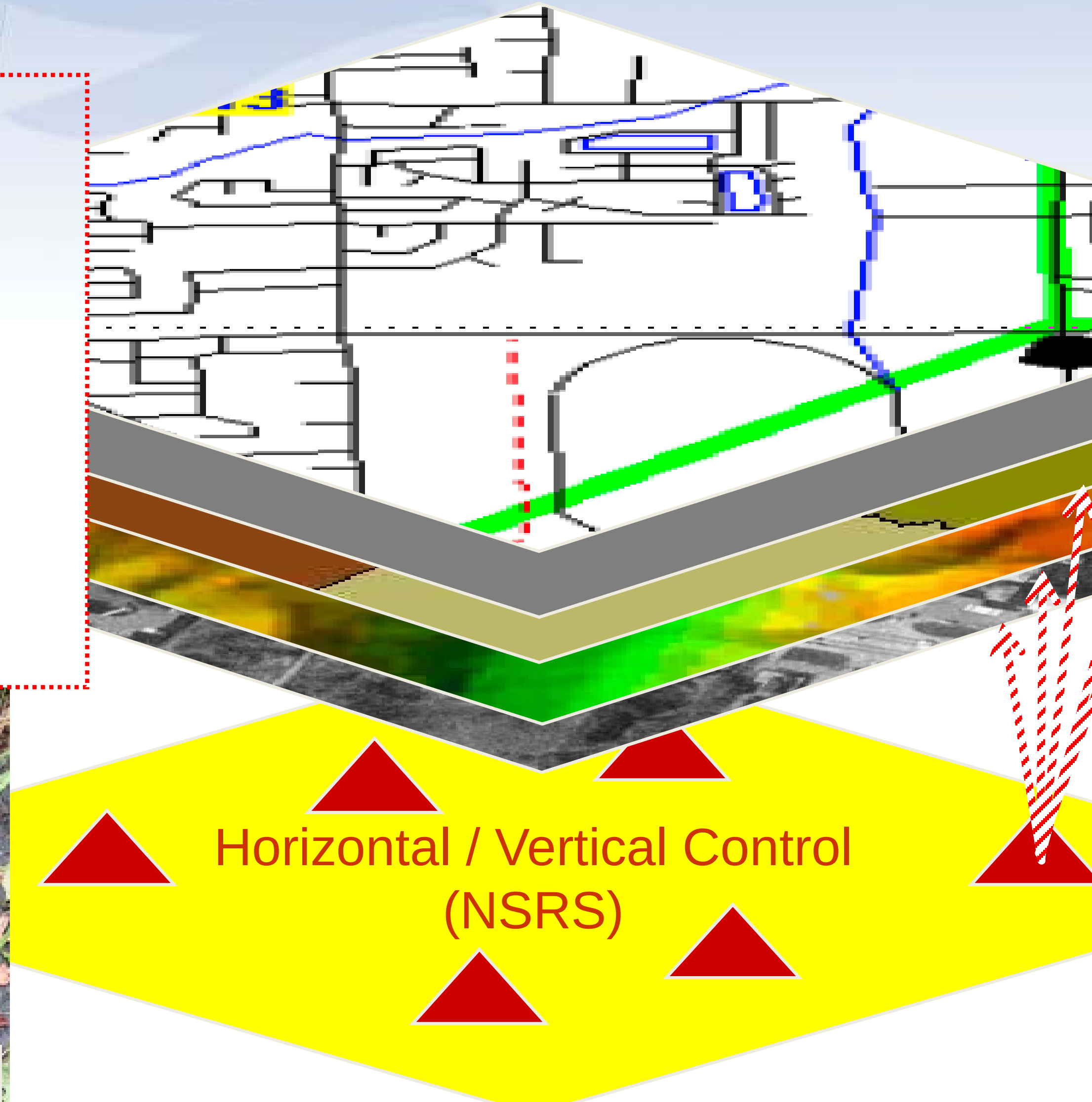
& their time variations

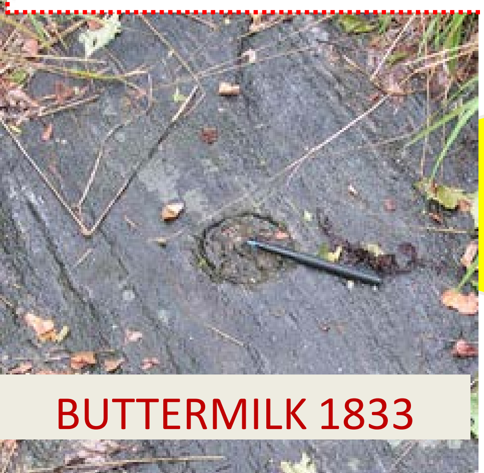
(& National Shoreline, etc.)

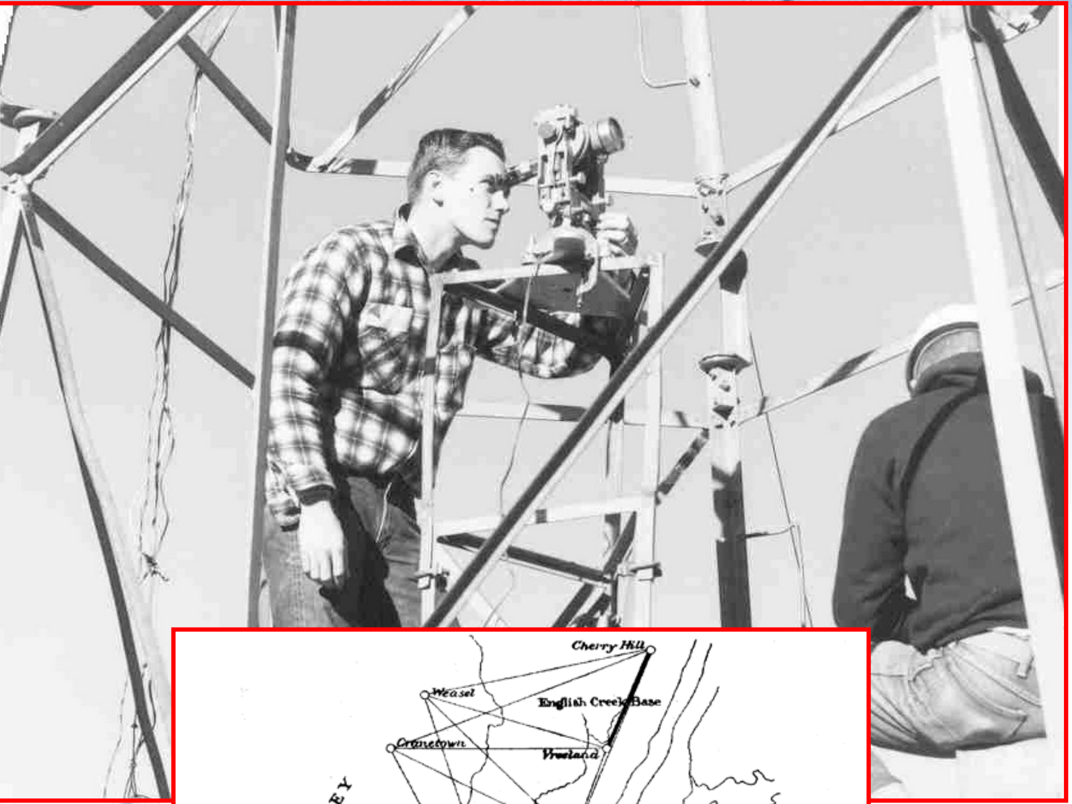
- ➢ North American Datum of 1983 (NAD83)
- ➢ North American Vertical Datum of 1988 (NAVD88)

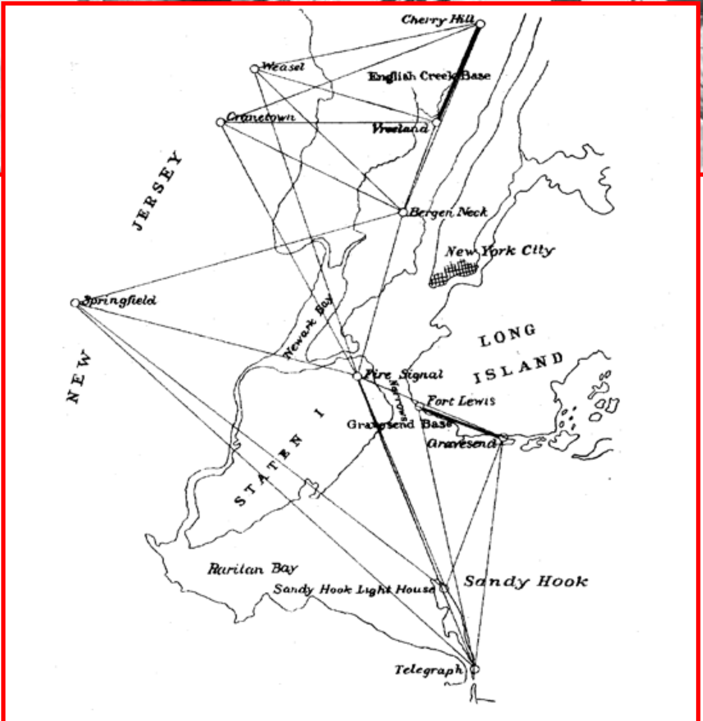
National Spatial Reference System - Ties It All Together

- LiDAR
- Digital Terrain Model
- Aerial Photography
- Cartography
- Parcels
- Engineering
- Laser Scan Model
- Satellite Imagery
- Hydrography
- Natural Resources

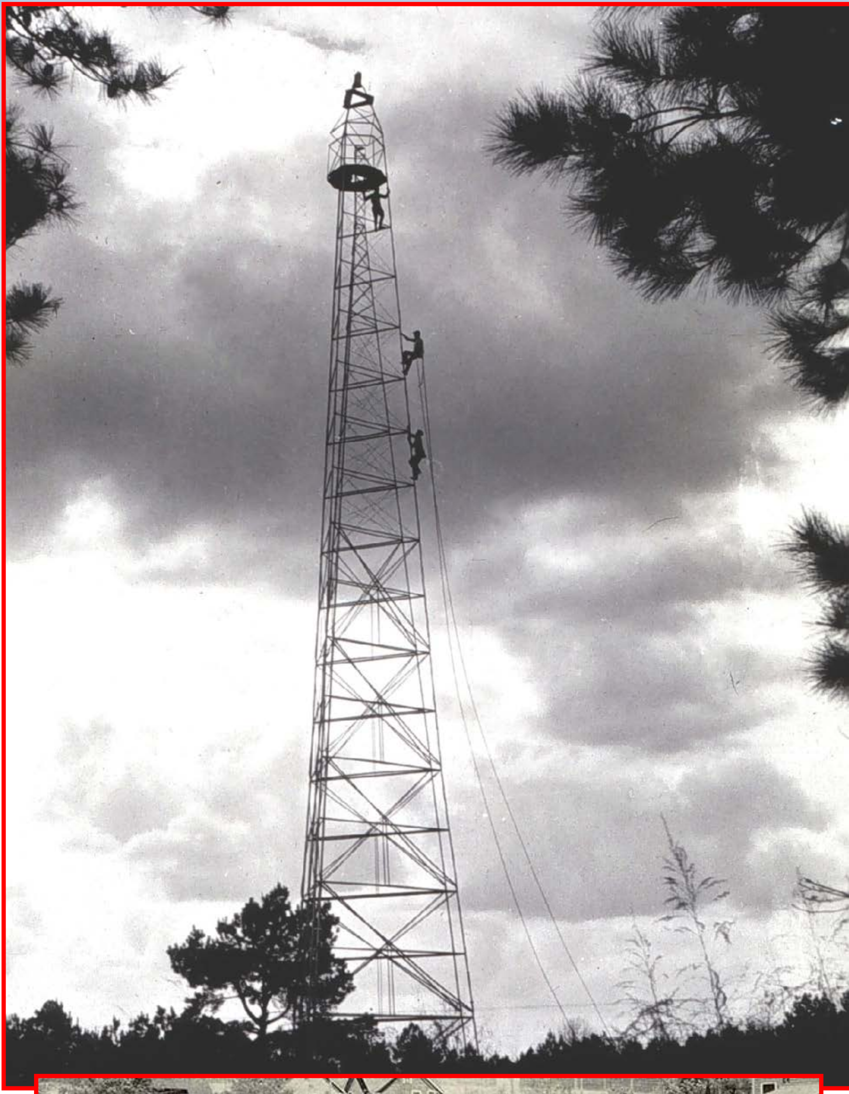






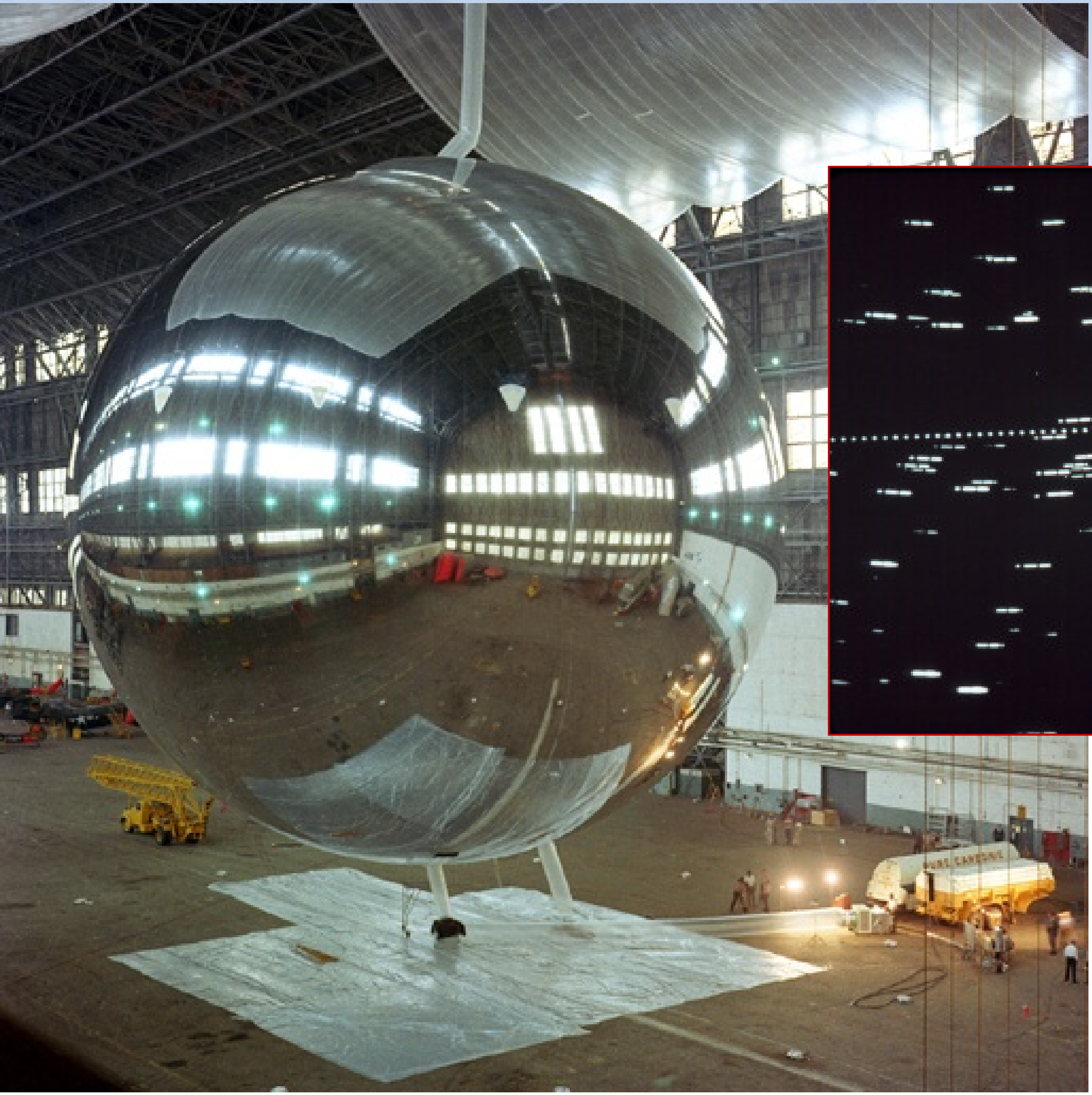


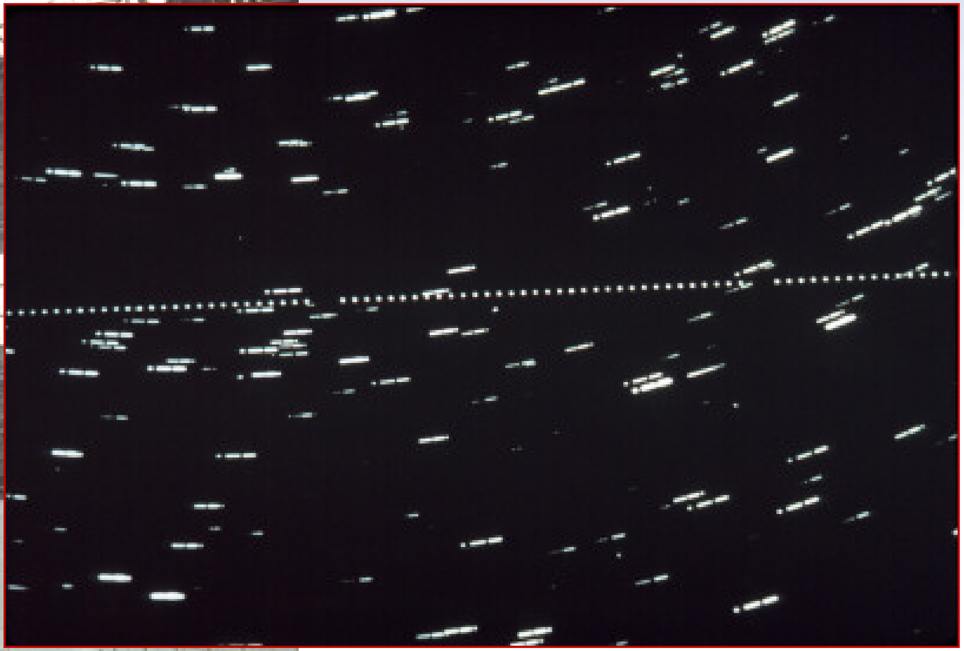
Hassler's First Field Work, 1816–1817



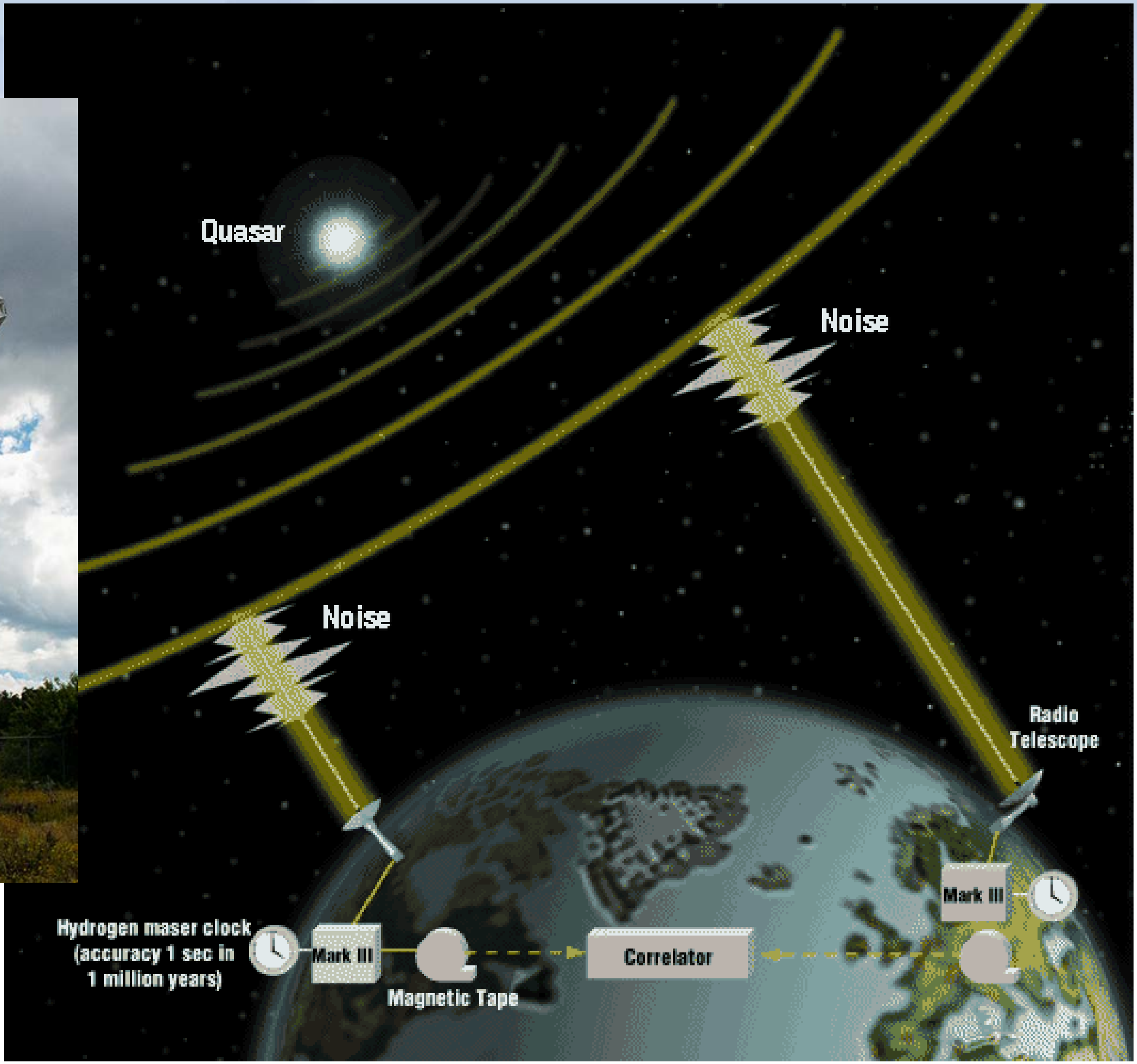
Electronic Distance Measuring Instruments - Using light and microwaves to measure distances – 1950s

Echo Balloon Satellite 1960 - photographed by BC-4 cameras





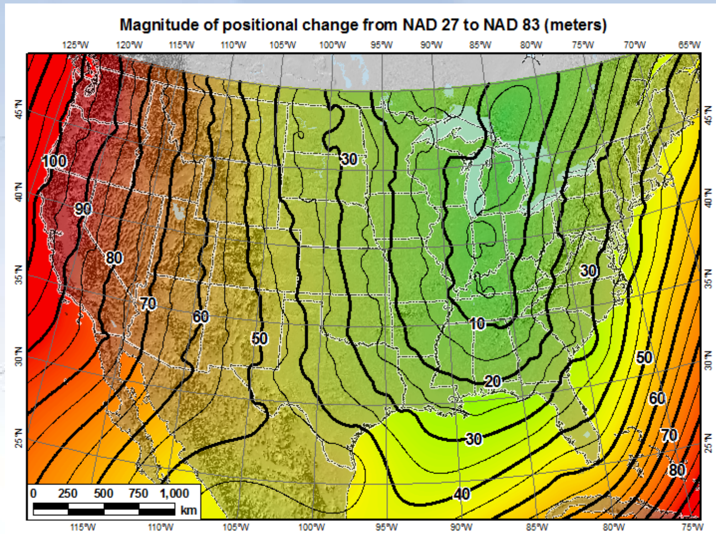
Very Long Baseline Interferometry (VLBI)



Passive NAD83 Horizontal Control Network


```
CBN            -  This is a Cooperative Base Network Control Station.
DESIGNATION -  SATELLITE TRI STA 110
PID            -  EQ0111
STATE/COUNTY-  NM/BERNALILLO
COUNTRY        -  US
USGS QUAD      -  MOUNT WASHINGTON (1995)

                         *CURRENT SURVEY CONTROL
_______________________________________________________________________
* NAD 83(2011) POSITION- 34 56 43.60712(N) 106 27 35.93278(W)   ADJUSTED
* NAD 83(2011) ELLIP HT-  1810.284 (meters)        (06/27/12)   ADJUSTED
* NAD 83(2011) EPOCH   -  2010.00
* NAVD 88 ORTHO HEIGHT -  1830.407 (meters)    6005.26  (feet) ADJUSTED
_______________________________________________________________________
GEOID HEIGHT     -         -20.106 (meters)                     GEOID12B
NAD 83(2011) X   - -1,483,421.715 (meters)                     COMP
NAD 83(2011) Y   - -5,020,822.758 (meters)                     COMP
NAD 83(2011) Z   -  3,633,944.527 (meters)                     COMP
LAPLACE CORR     -          15.43  (seconds)                    DEFLEC12B
DYNAMIC HEIGHT   -        1827.890 (meters)    5997.00  (feet) COMP
MODELED GRAVITY  -    979,194.0   (mgal)                        NAVD 88

VERT ORDER       -  FIRST     CLASS II

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    0.29   0.90              0.13   0.10   0.46     -0.07464762
-----------------------------------------------------------------------
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 differential leveling and
.adjusted by the NATIONAL GEODETIC SURVEY
```

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



U.S. Standard Datum — NAD27 — NAD83 (1986) — NAD83 (HARN / 199X) — NAD83 (2007) — **NAD83 (2011)**

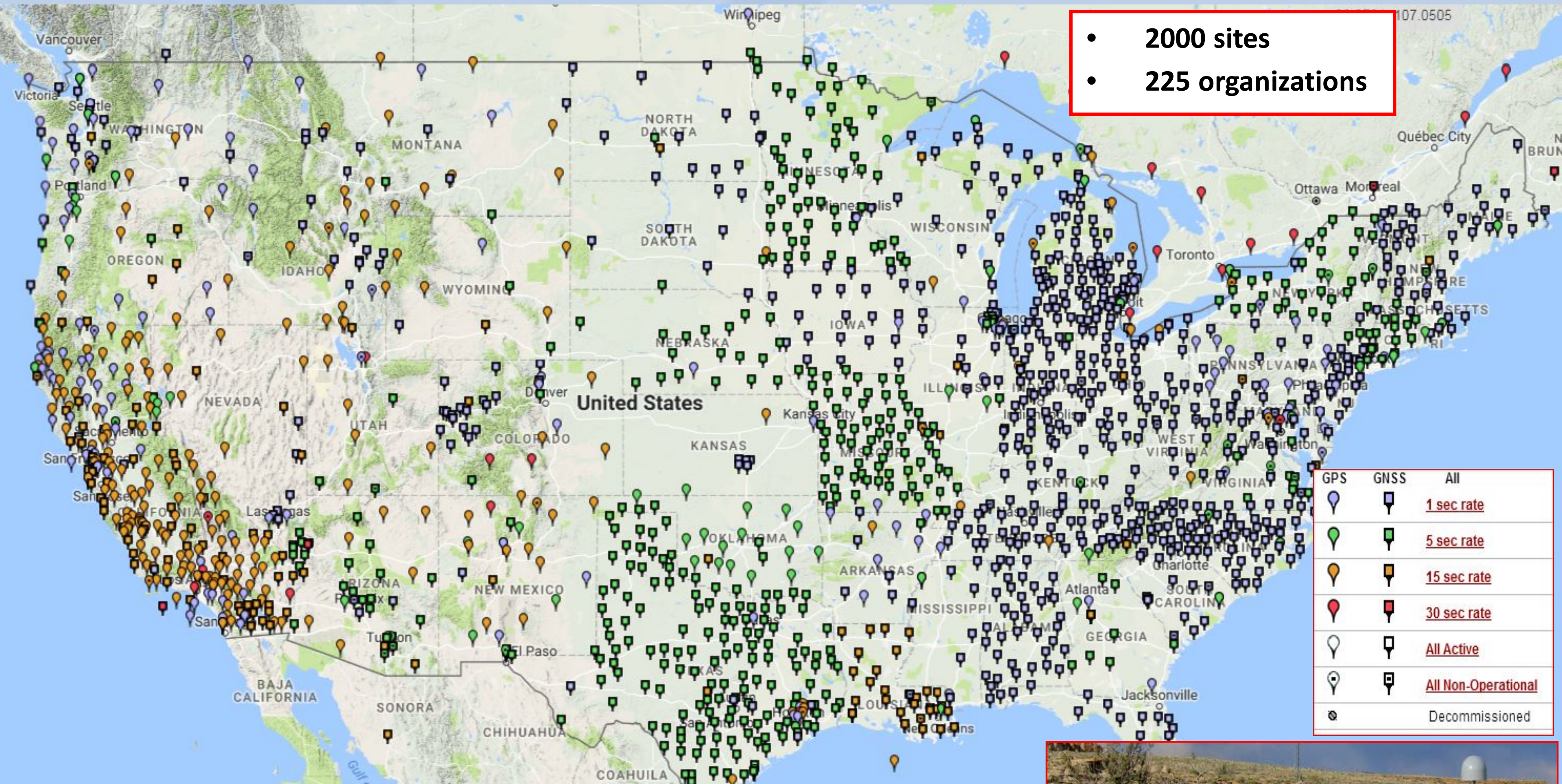
time

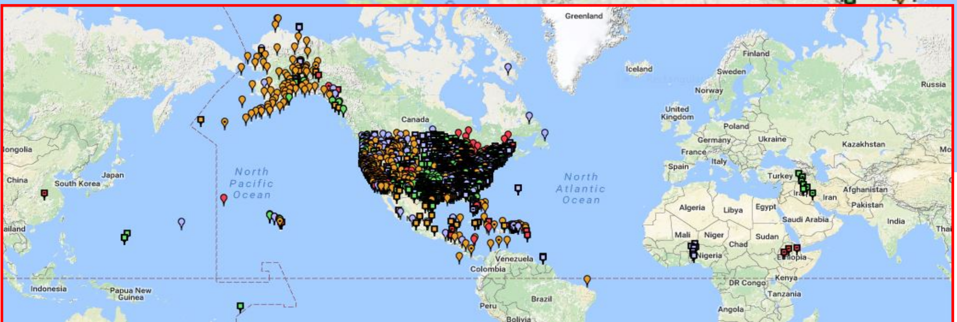
shift: < 10 m | tens of meters | few 0.1m | few 0.01m | few 0.01m

Continuously Operating Reference Station (CORS)

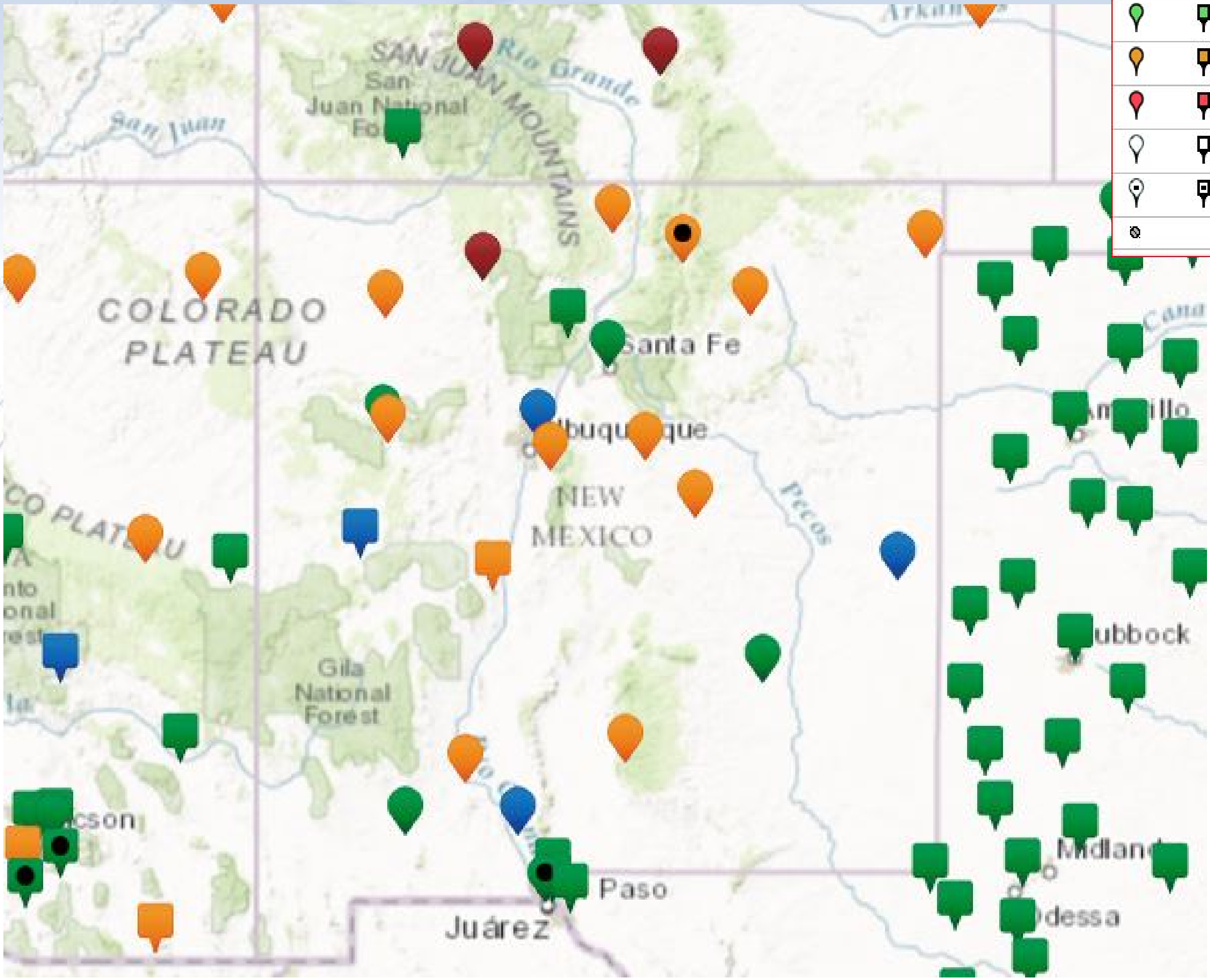
Continuously Operating Reference Station (CORS) Network

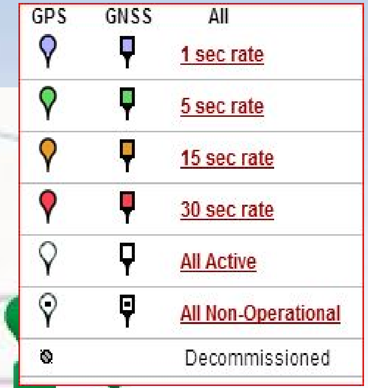
- 2000 sites
- 225 organizations





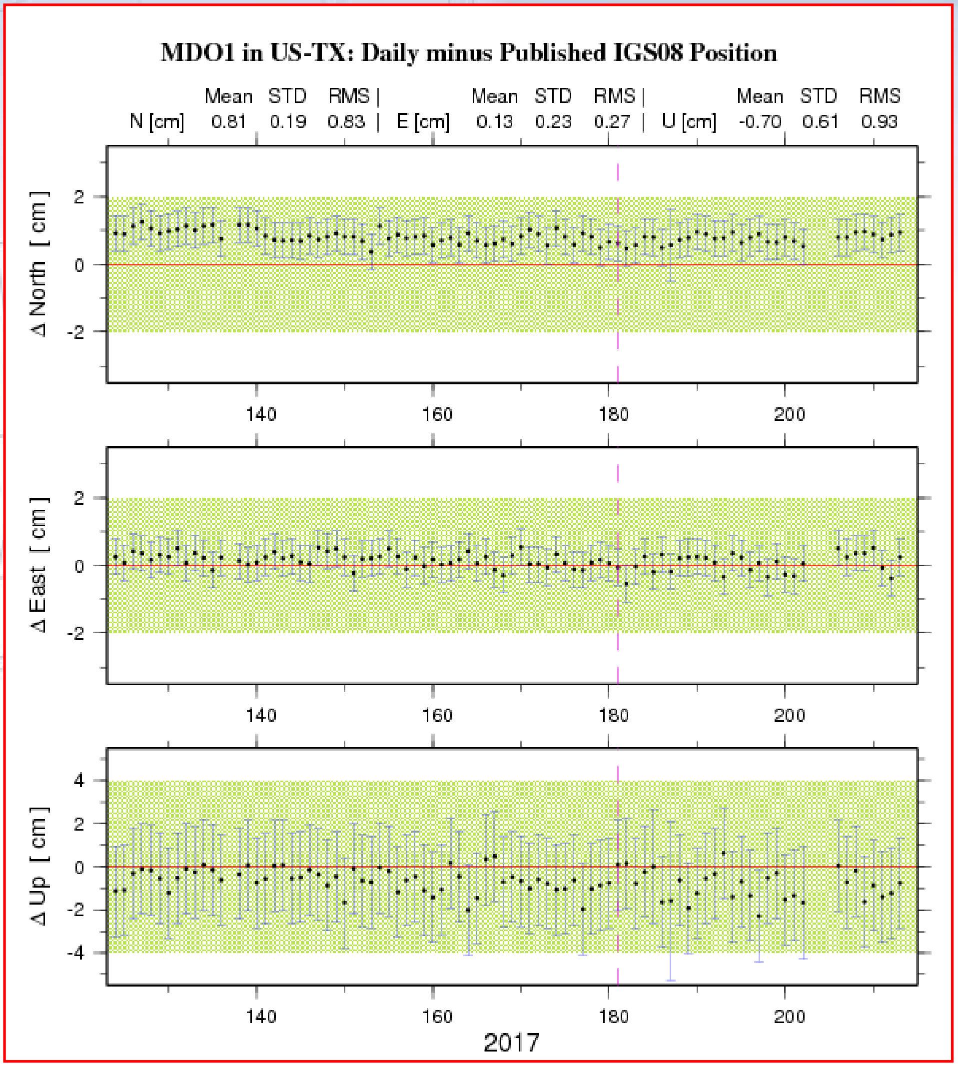
Continuously Operating Reference Station (CORS) Network – New Mexico Region



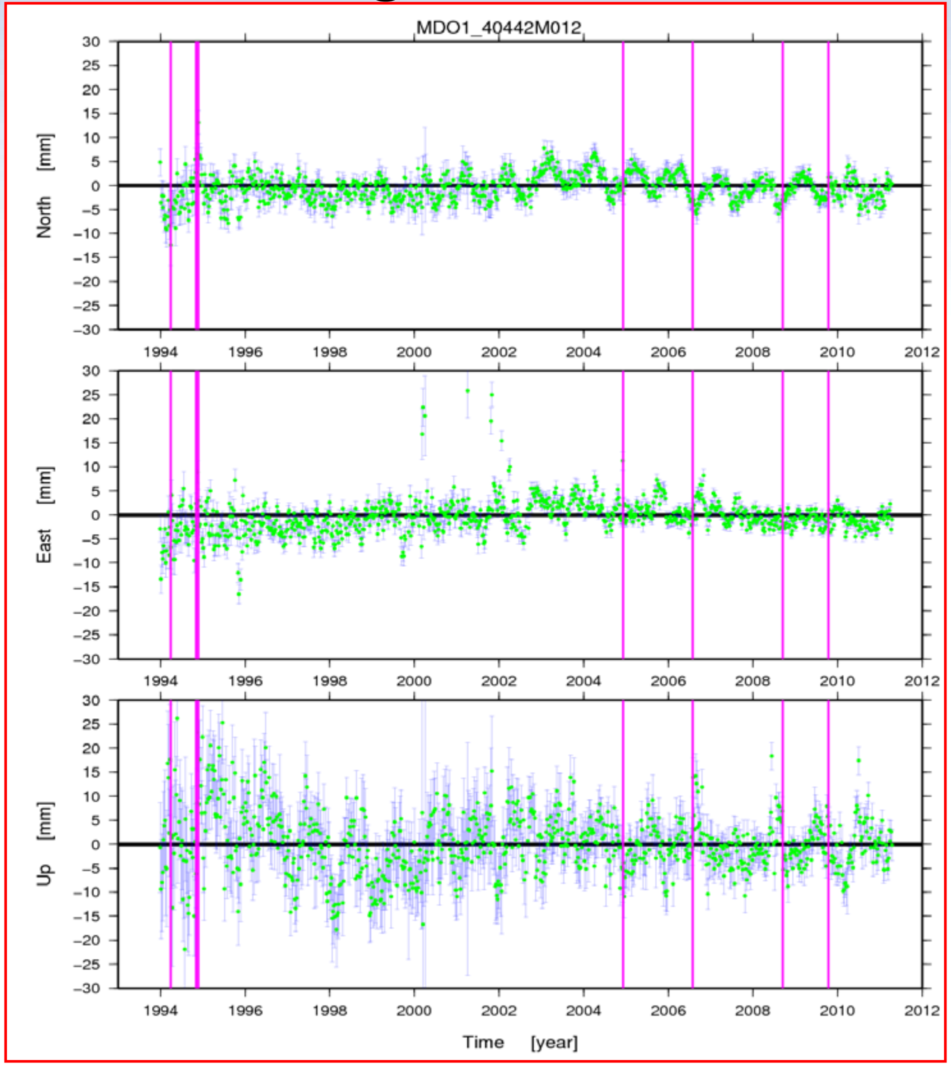


CORS Time Series Plots

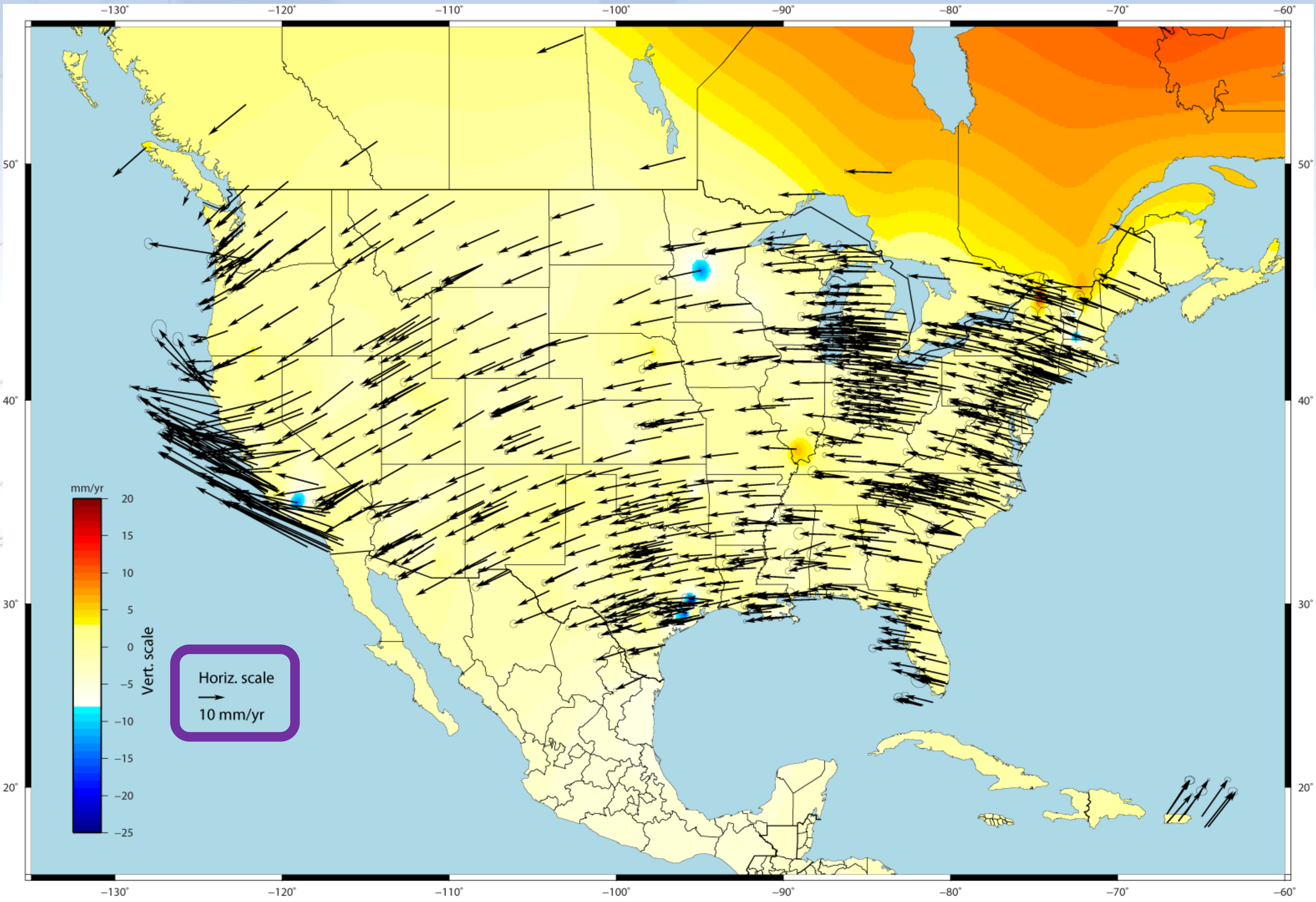
short-term



long-term



CORS Velocity Field – ITRF2008 (IGS08 epoch 2005.0)



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

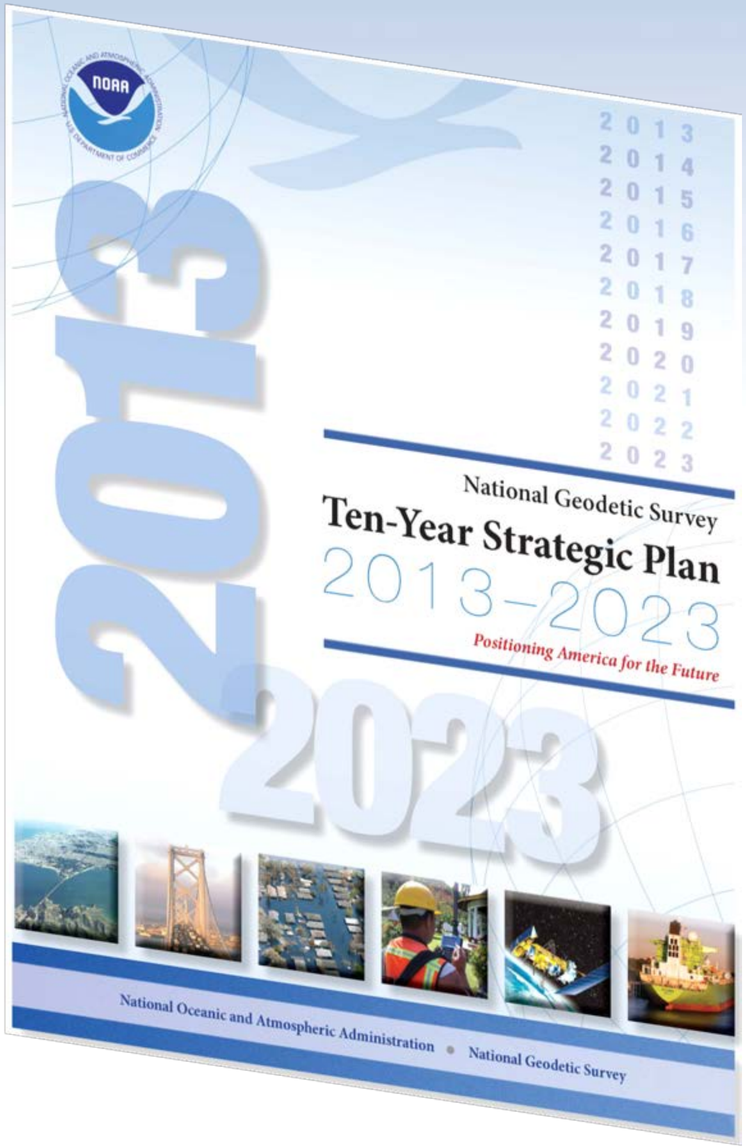
  "**Replace NAD83**"

(NAD83 = North American Datum 1983)

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

  "**Replace NAVD88**"

(NAVD88 = North American Vertical Datum 1988)



https://geodesy.noaa.gov/web/about_ngs/info/tenyearfinal.shtml

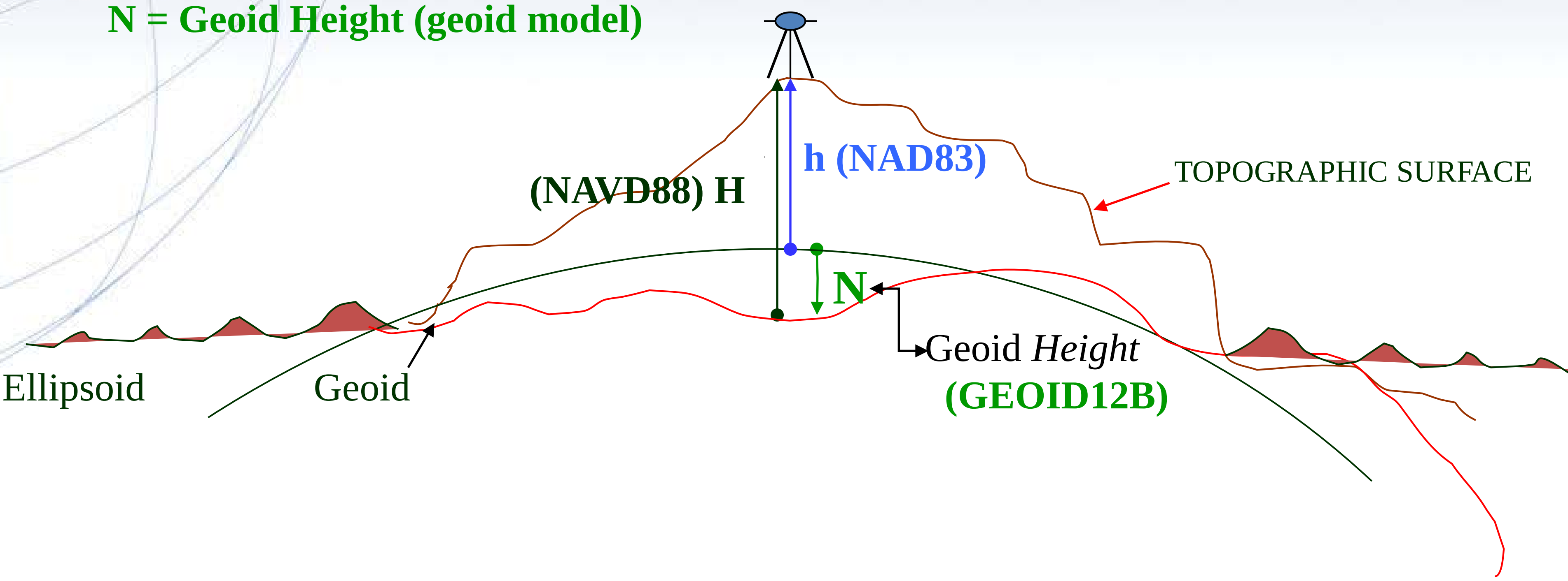
Ellipsoid, Geoid & Orthometric Heights

H = Orthometric Height [aka Elevation] (leveling)

h = Ellipsoidal Height (GPS)

N = Geoid Height (geoid model)

H = h - N



International Terrestrial Reference Frame I T R F

International Terrestrial Reference Frame (ITRF)

4 Global Independent Positioning Technologies

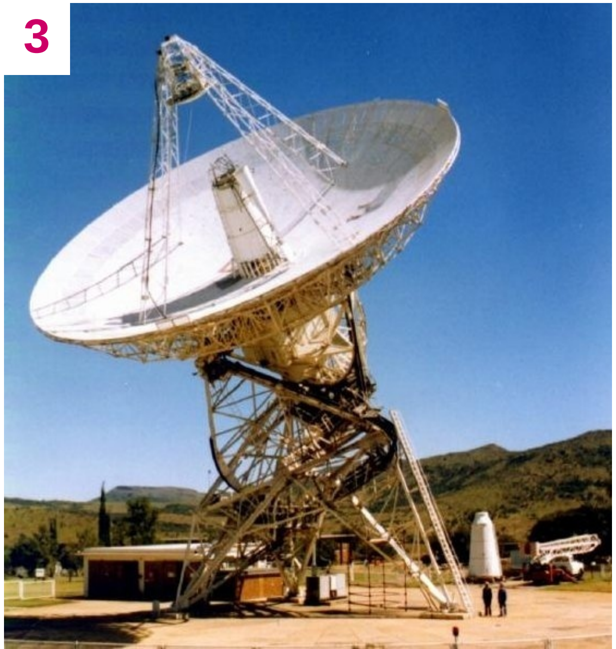
- 1. Global Navigation Satellite Systems (GNSS)
- 2. Satellite Laser Ranging (SLR)
- 3. Very Long Baseline Interferometry (VLBI)
- 4. Doppler Orbitography & Radiopositioning Integrated by Satellite (DORIS)

4

1

2

3



NOAA's **National Geodetic Survey** Positioning America for the Future

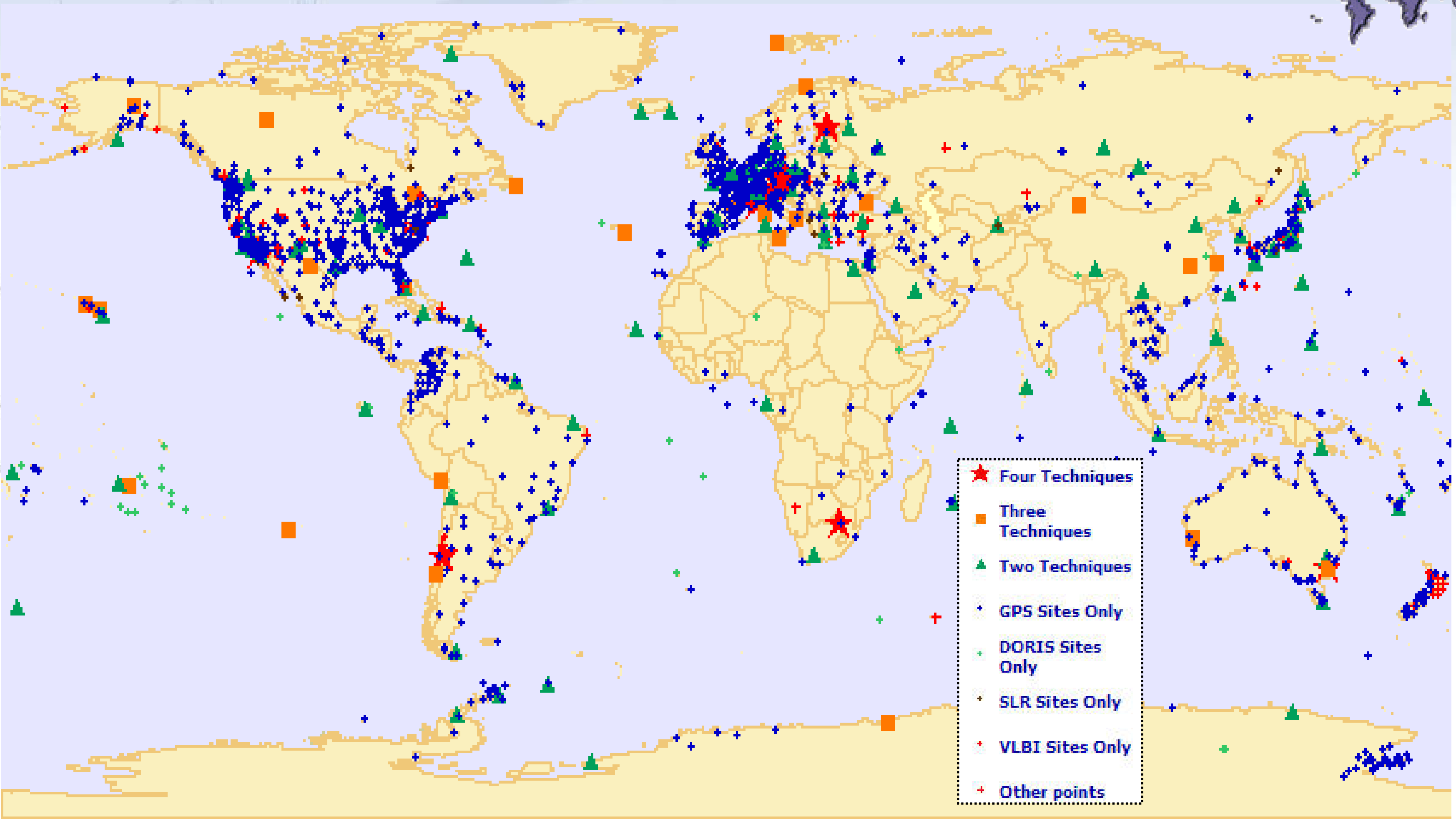
National Radio Astronomy Observatory
Enabling forefront research into the Universe at radio wavelengths

International Terrestrial Reference Frame (ITRF)

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

[International GNSS Service 2008 (IGS08) = GNSS-only realization]

Current version: ITRF2008 (epoch 2005.0)

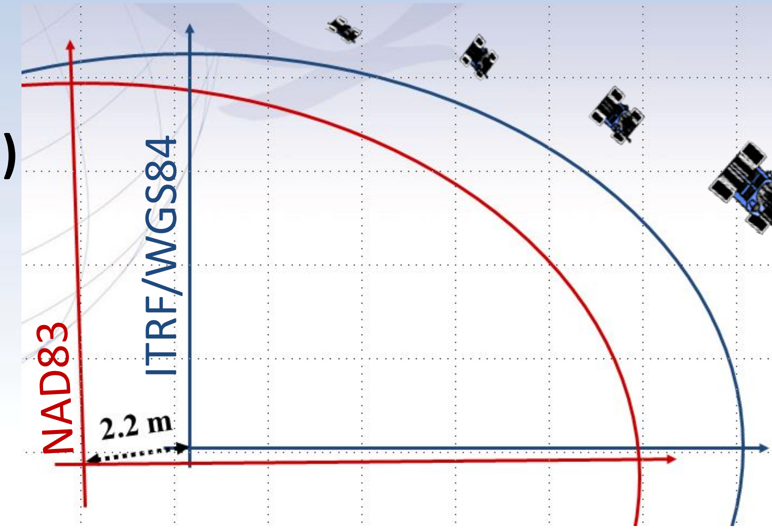


International Earth Rotation and Reference System Service (IERS)

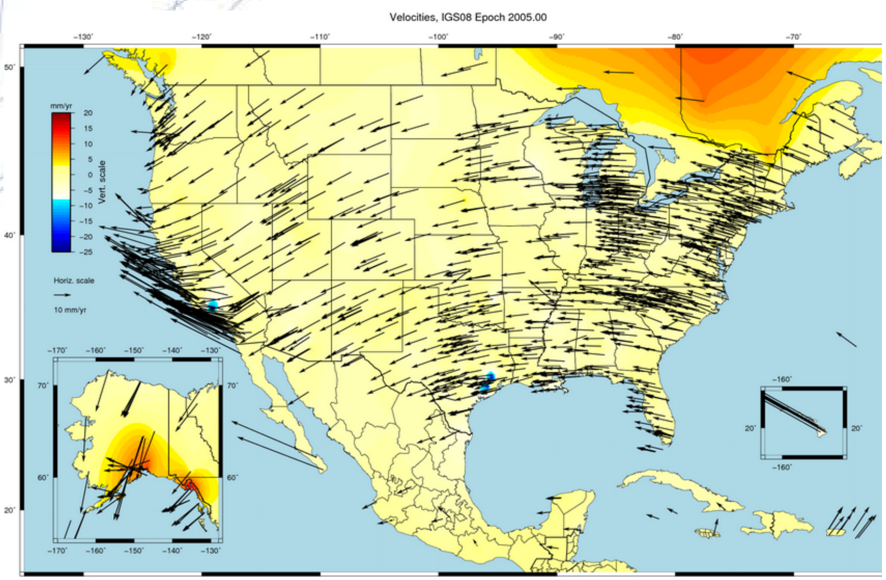
[(http://www.iers.org)](http://www.iers.org)

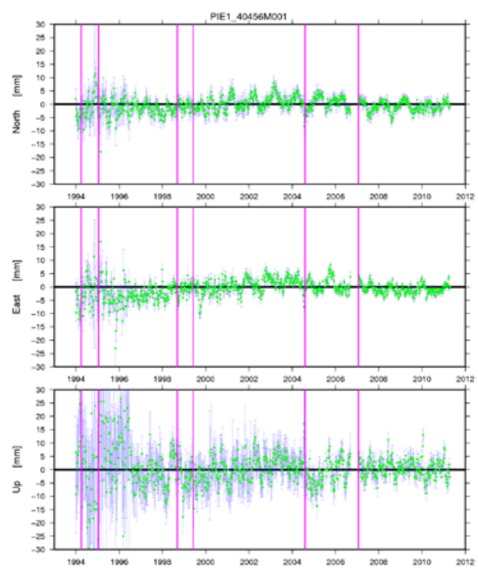
NAD83 Shortcomings

- **2.2 m offset – NAD83 vs.**
  - **International Terrestrial Reference Frame (ITRF) [~ International GNSS Service (IGS)]**
  - **World Geodetic System 1984 (WGS84)**

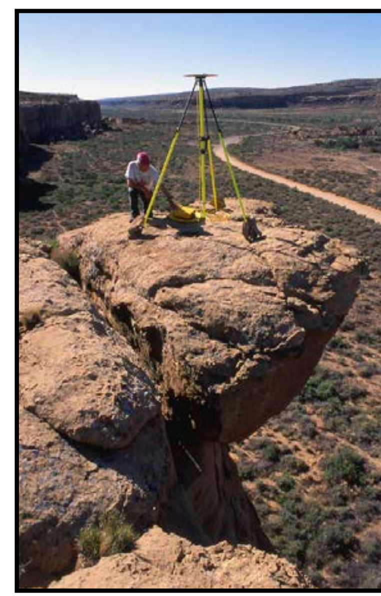


- **CORS <> passive network "disconnect"**





vs.



Future Geometric (3-D) Reference Frames

- replace NAD83 with new geometric reference frames – by 2022
- CORS-based, accessed via GNSS observations
- coordinates & velocities in global & new US reference frames
- passive control tied to new reference frame
- transformation tool will relate historical <> new US reference frames

Introducing…

North American Terrestrial Reference Frame of 2022 (NATRF2022)

(& Pacific / Mariana / Caribbean Terrestrial Reference Frame of 2022)
(PATRF2022 / MATRF2022 / CATRF2022)

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

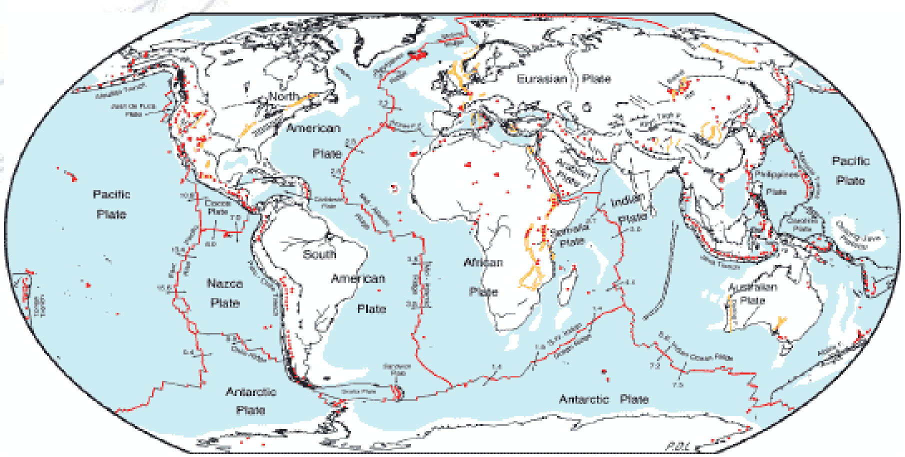
[e.g. IGS14 = International GNSS Service 2014]

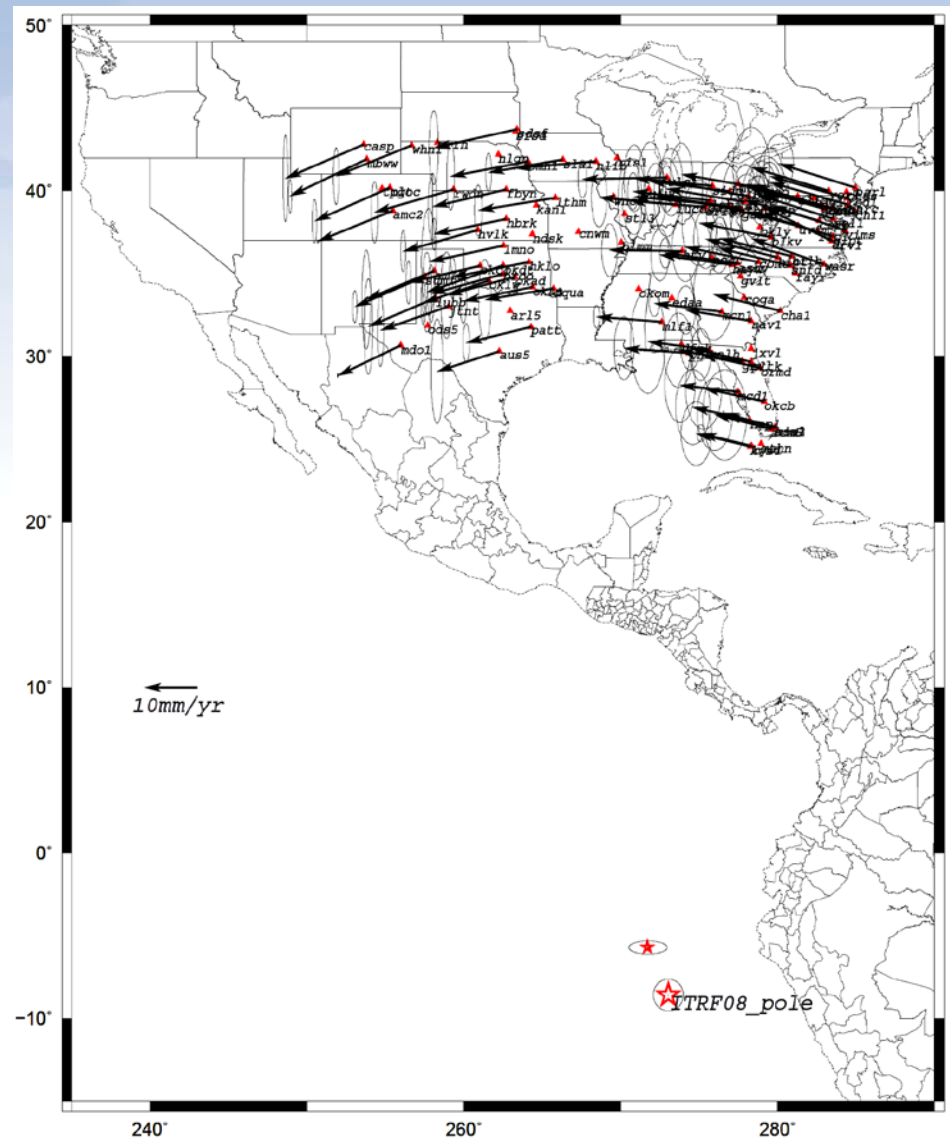
Euler Pole

Each reference frame will get:

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

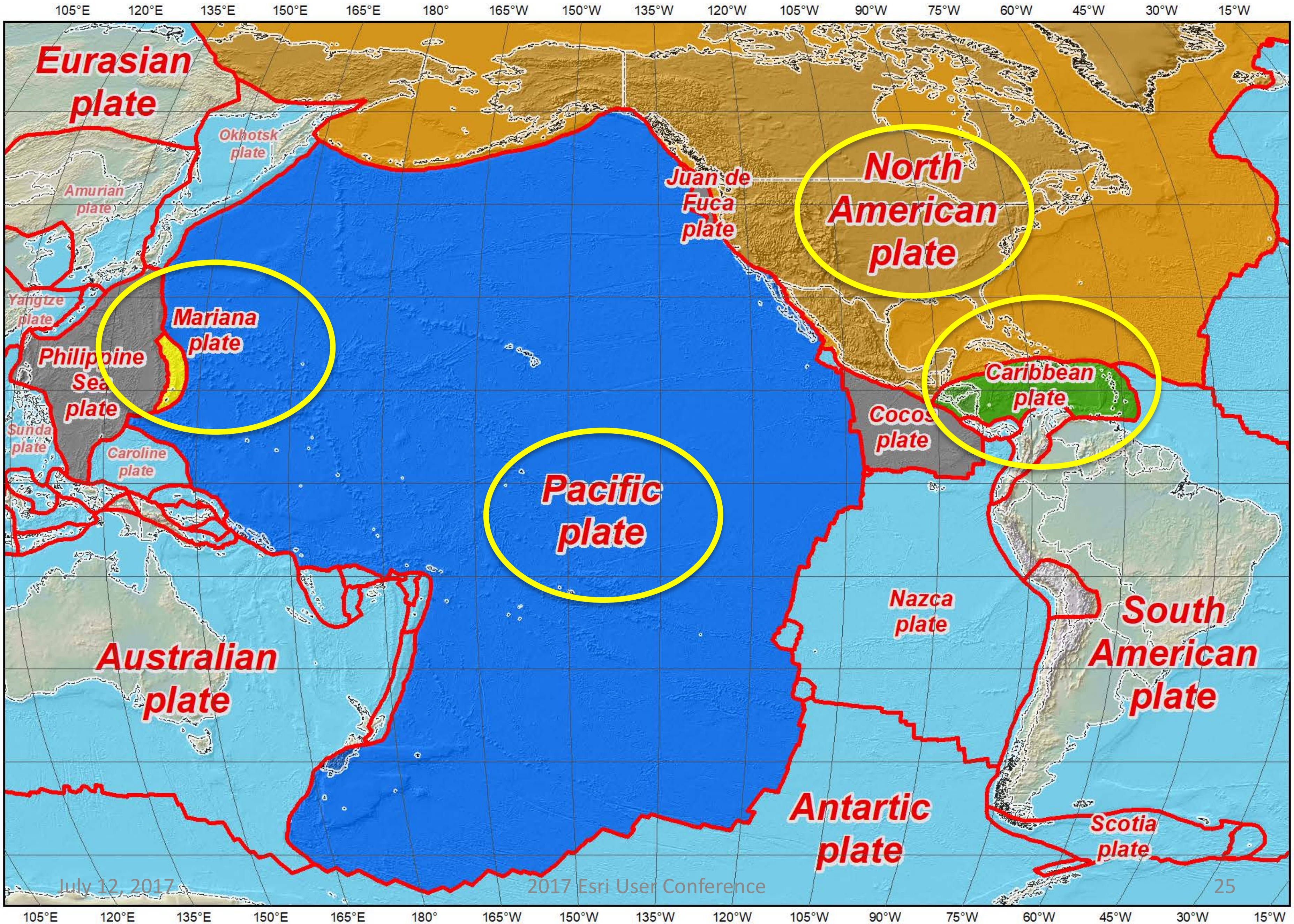
Used to compute time-dependent TRF2022 coordinates from time-dependent global (IGS) coordinates





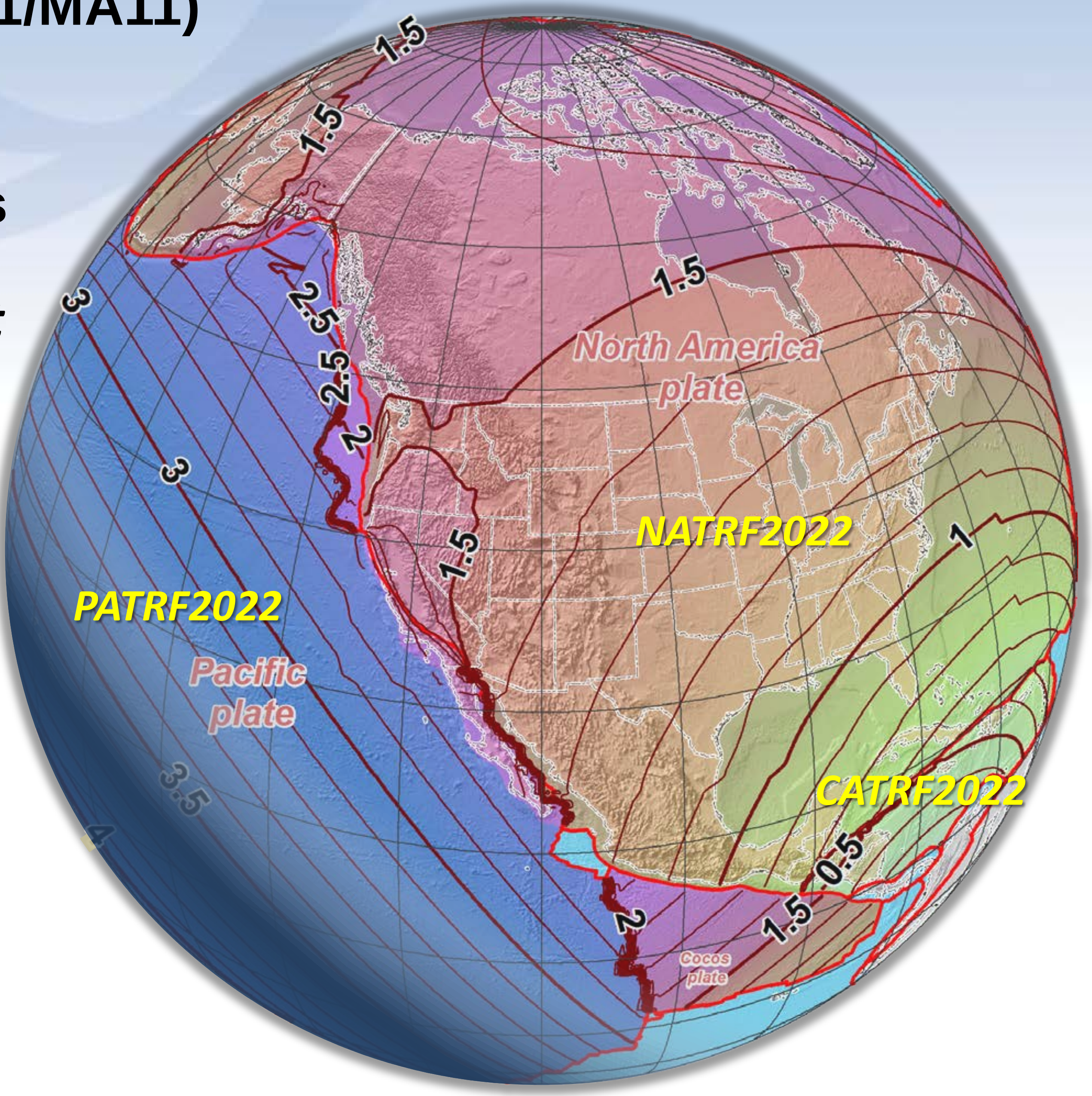
Euler's fixed point theorem states: any motion of a rigid body on the surface of a sphere may be represented as a rotation about an appropriately chosen rotation pole ("Euler Pole")

The four tectonic plates "fixed" for the 2022 terrestrial reference frames



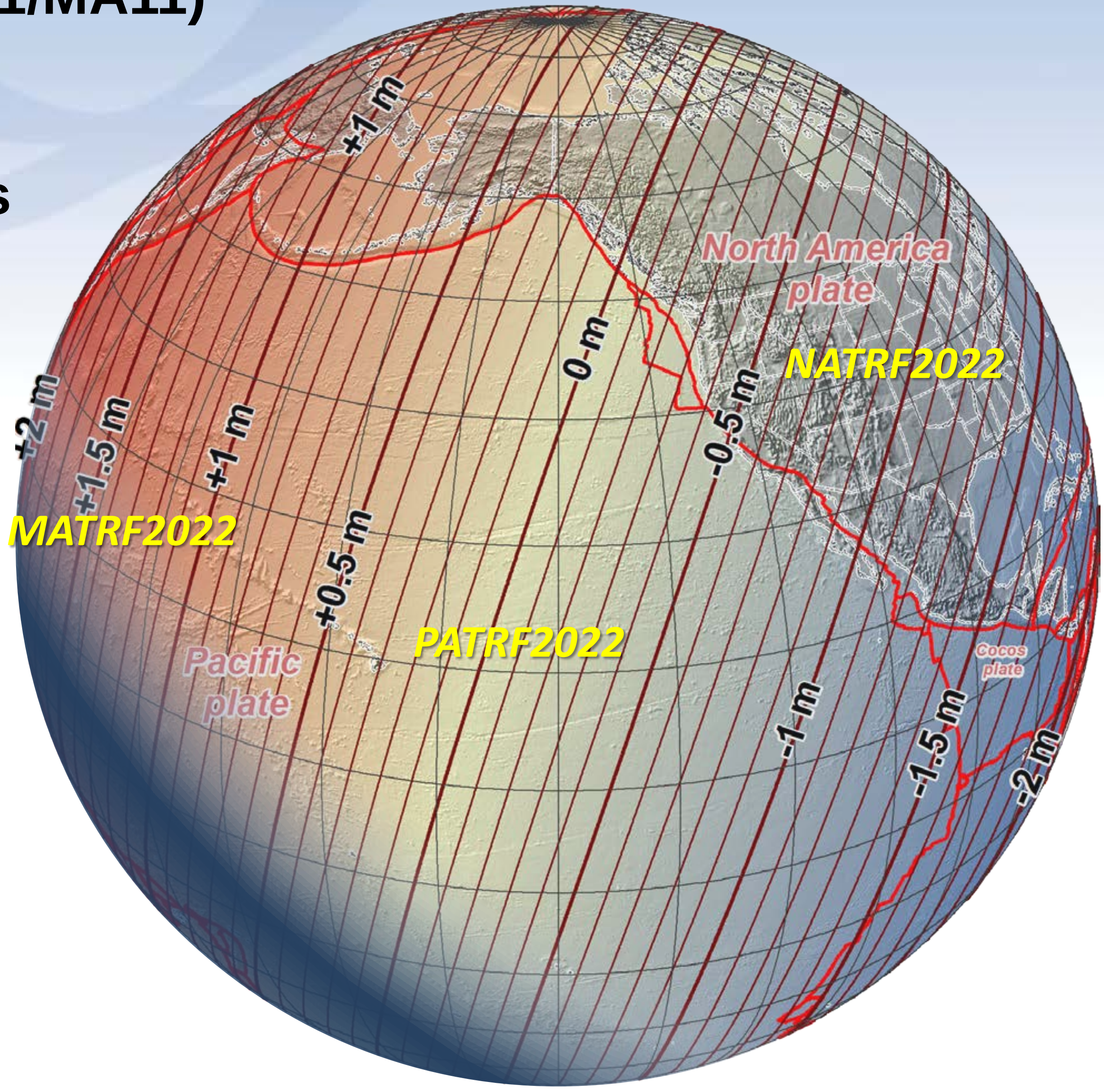
NAD 83 (2011/PA11/MA11) epoch 2010.00 → 2022 Terrestrial Reference Frames

Horizontal change at epoch 2022.00
(contours in meters)

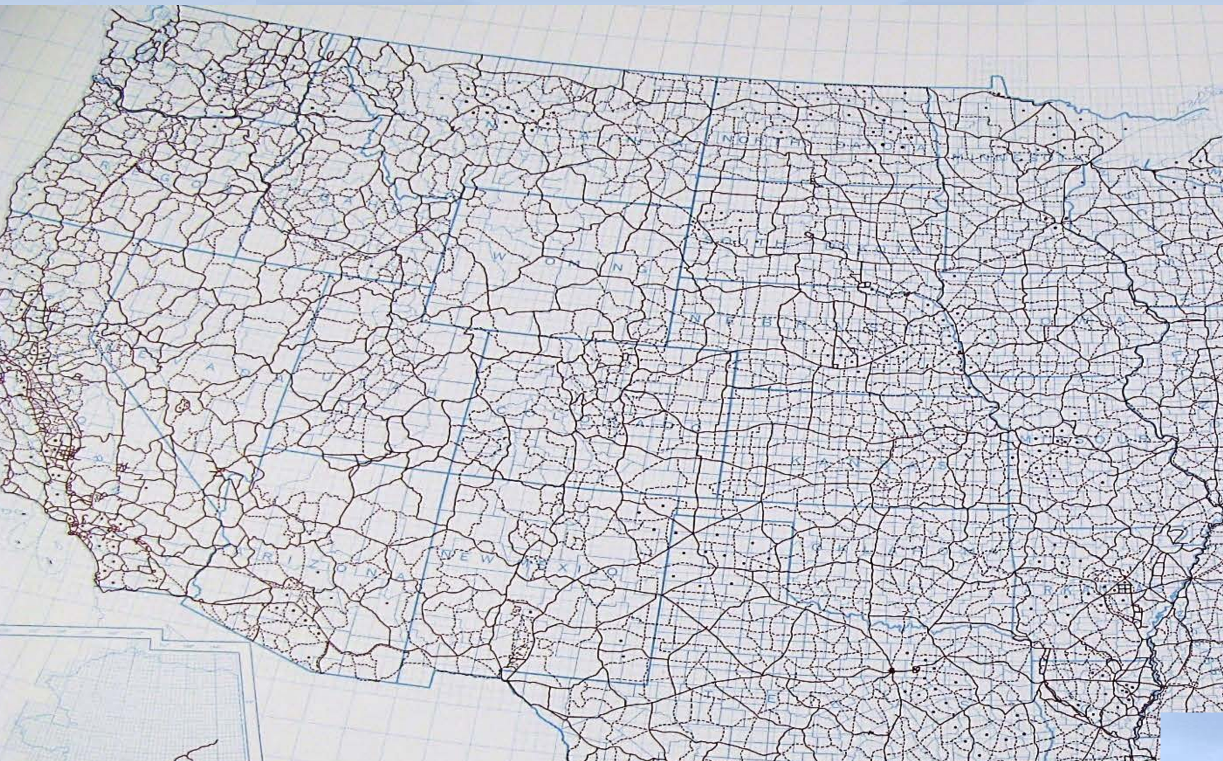


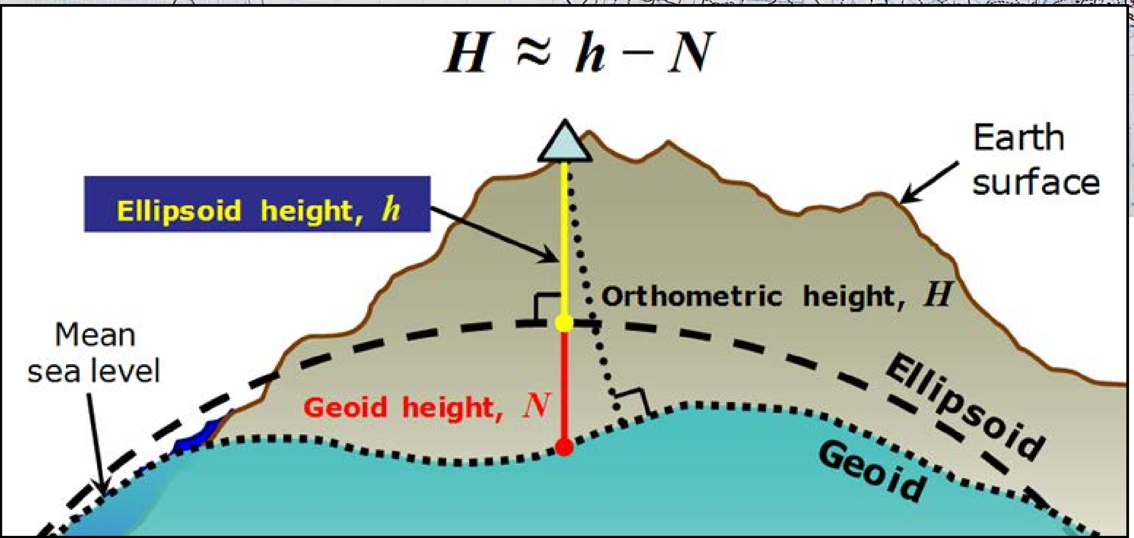
NAD 83 (2011/PA11/MA11) epoch 2010.00 → 2022 Terrestrial Reference Frames

Change in ellipsoid heights at epoch 2022.00
(contours in meters)



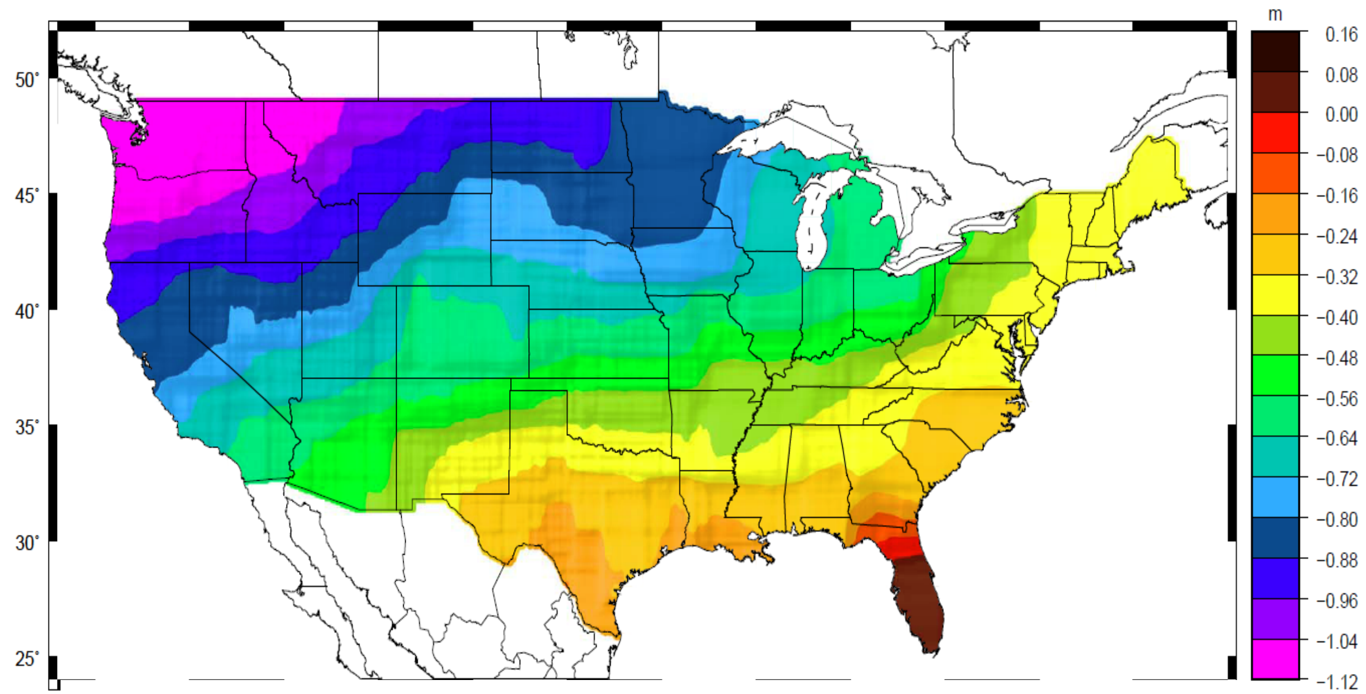
NORTH AMERICAL VERTICAL DATUM 1988 (NAVD88)





North American Vertical Datum 1988 (NAVD88) Shortcomings

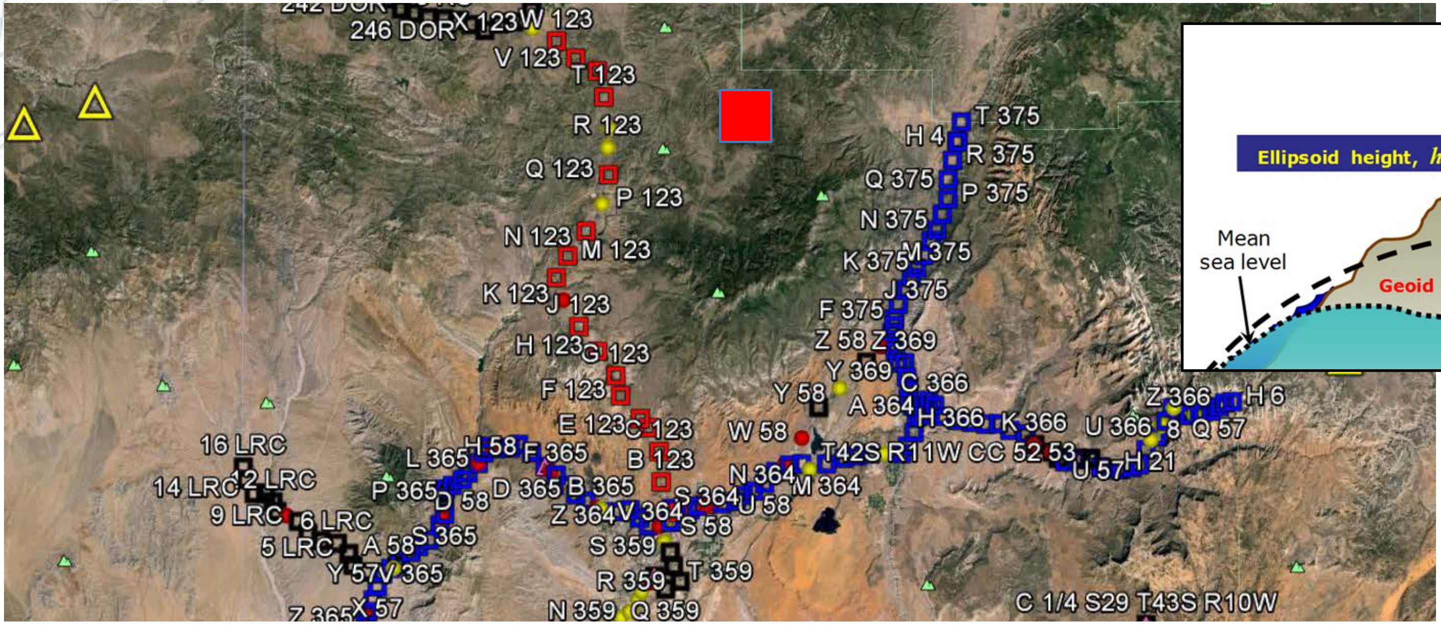
- Cross-country errors (1-m tilt)
- 0.5 m bias in reference surface vs. global mean sea level
- Subsidence, uplift, freeze/thaw invalidate BM elevations
- LIMITED AVAILABILITY / ACCESS

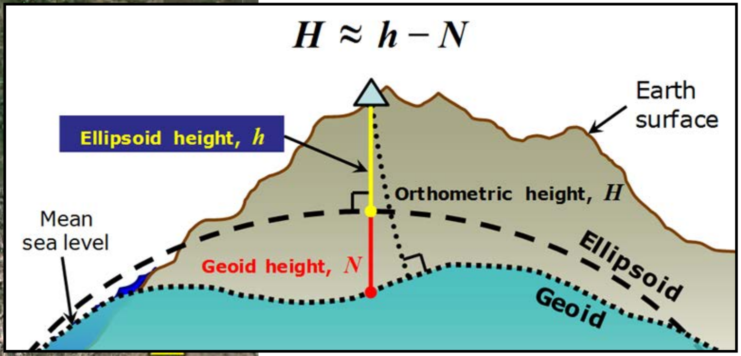


Approximate Geoid Mismatch in the NAVD88 H=0 surface

Future Geopotential (Vertical) Datum

- replace NAVD88, etc. – by 2022
- accessed by GNSS & gravimetric geoid
- monitor time-varying nature of gravity field
- most accurate continental gravimetric geoid model ever built: 1 cm (goal)





Current Vertical Datums / Models

Orthometric Heights	NAVD 88
Normal Orthometric Heights	PRVD 02
	VIVD09
	ASVD02
	NMVD03
	GUVD04
Dynamic Heights	IGLD 85
Gravity	IGSN71
Geoid Heights	GEOID12B
Deflections of the Vertical	DEFLEC12B

one vertical datum

pole-to-equator

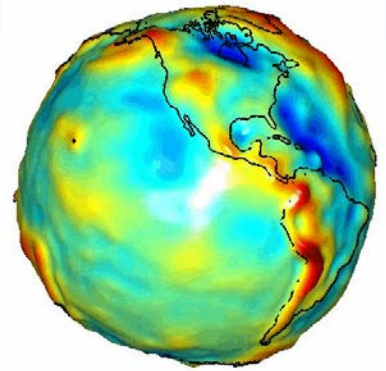
Introducing...

North American-Pacific Geopotential Datum of 2022 (NAPGD2022)

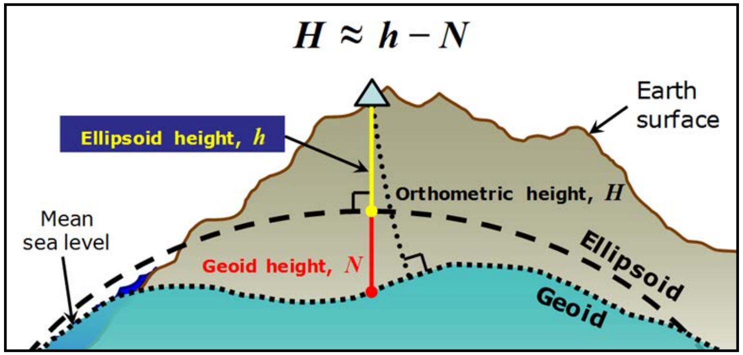
&

GEOID2022

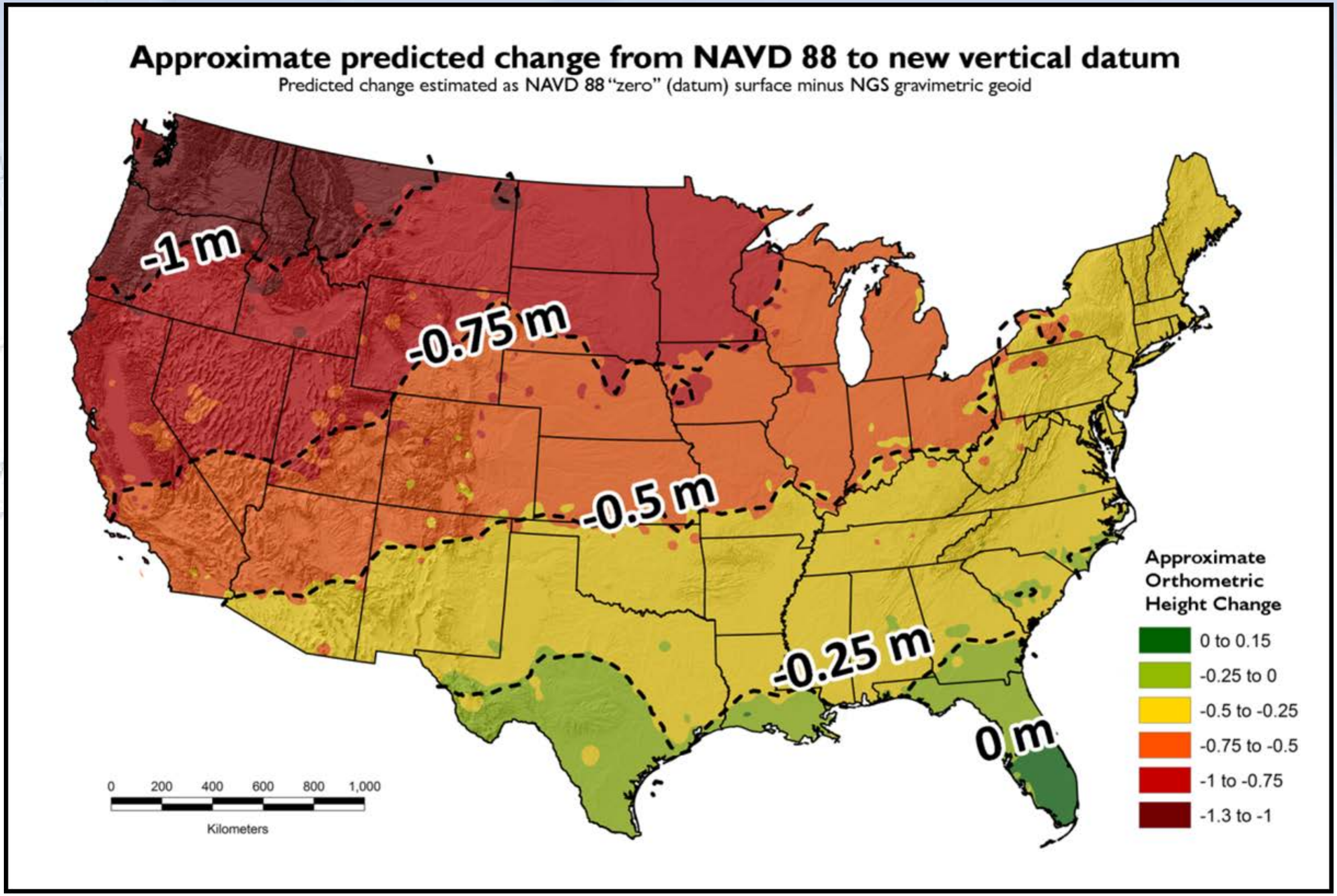
(gravimetric geoid)



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

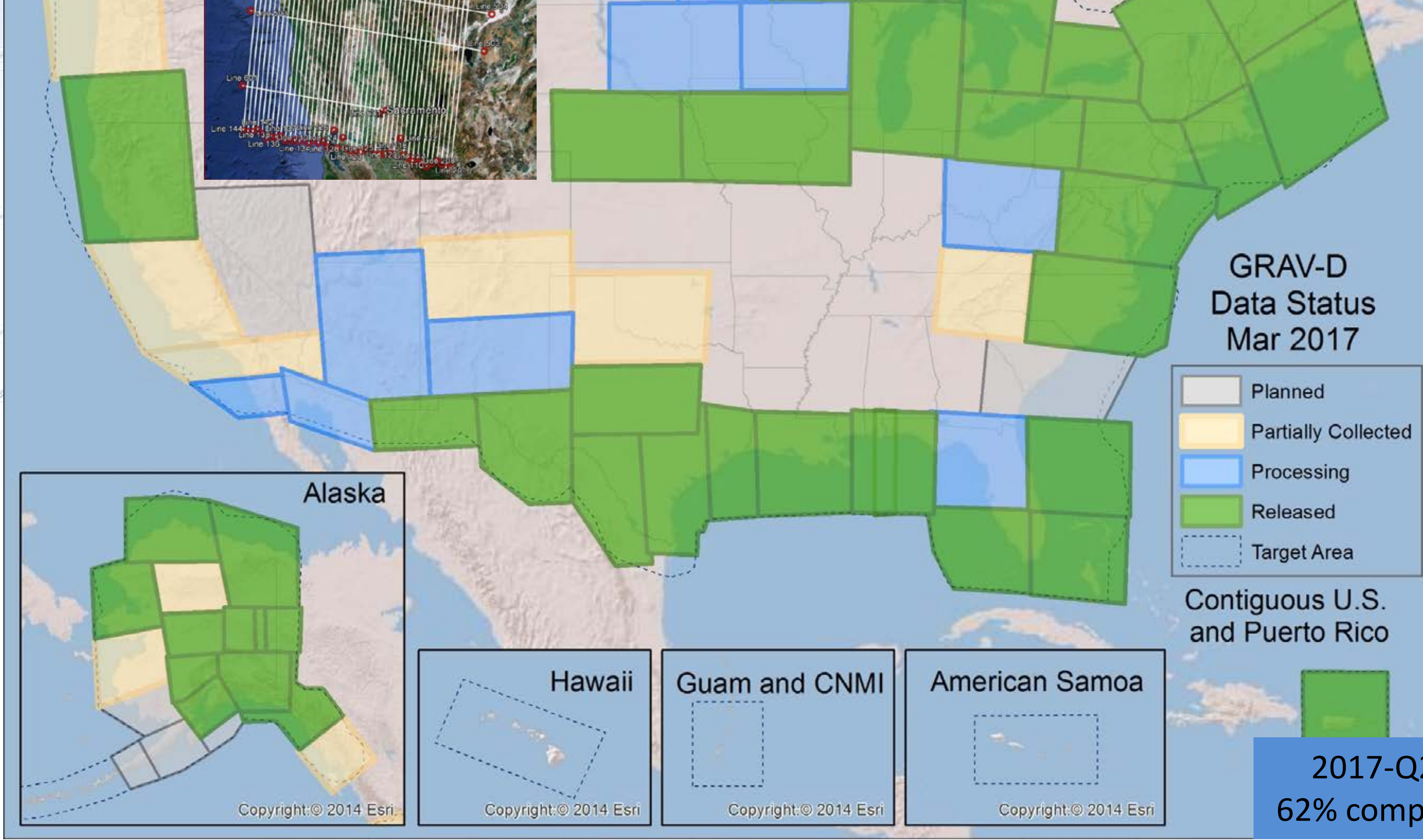


Predicted Change – NAVD88 to NAPGD2022



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

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



2017-Q2:
62% complete

Geoid Slope Validation Surveys:

validate gravimetric geoid model accuracy

Phase 1 - GSVS11

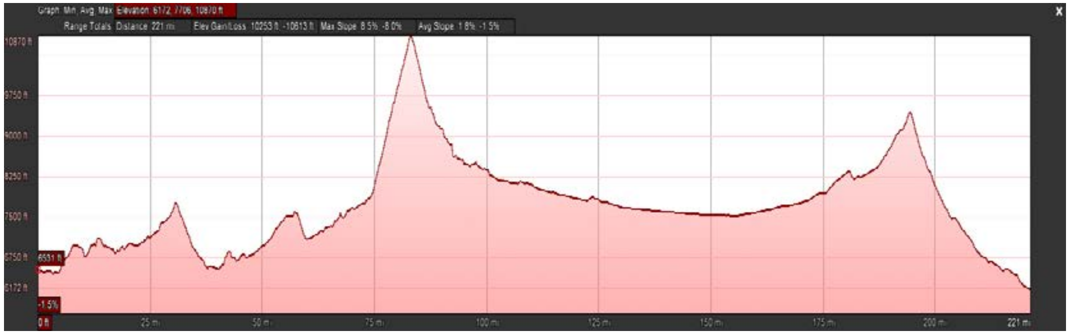
- 2011; Low/Flat/Simple: **Texas**

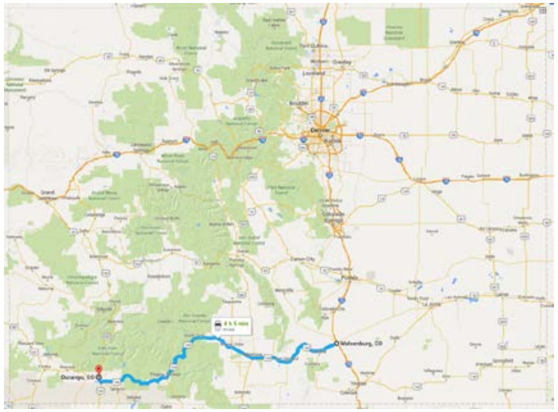
Phase 2 - GSVS14

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

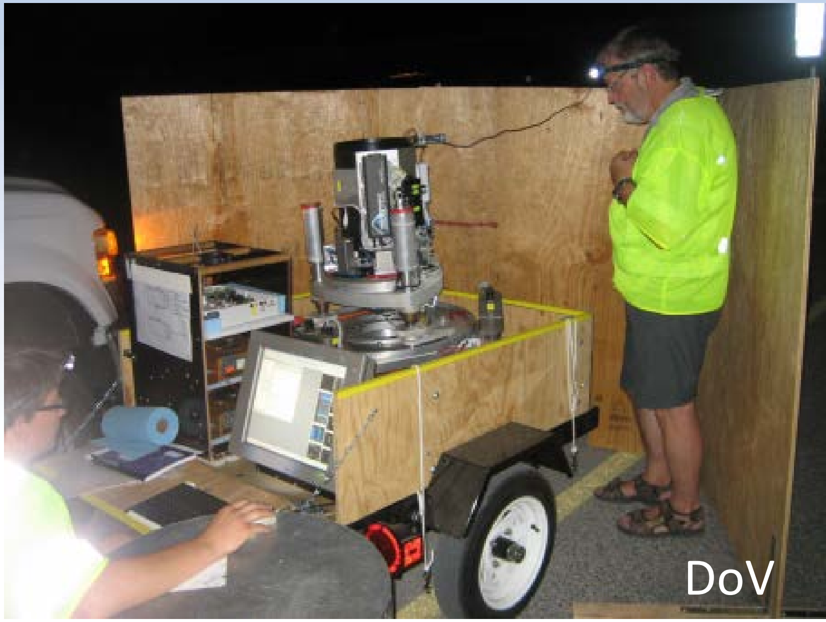
Phase 3 - GSVS17

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

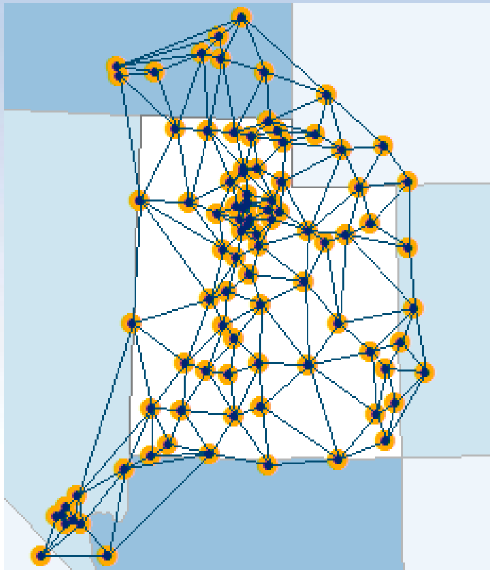




Geoid Slope Validation Surveys



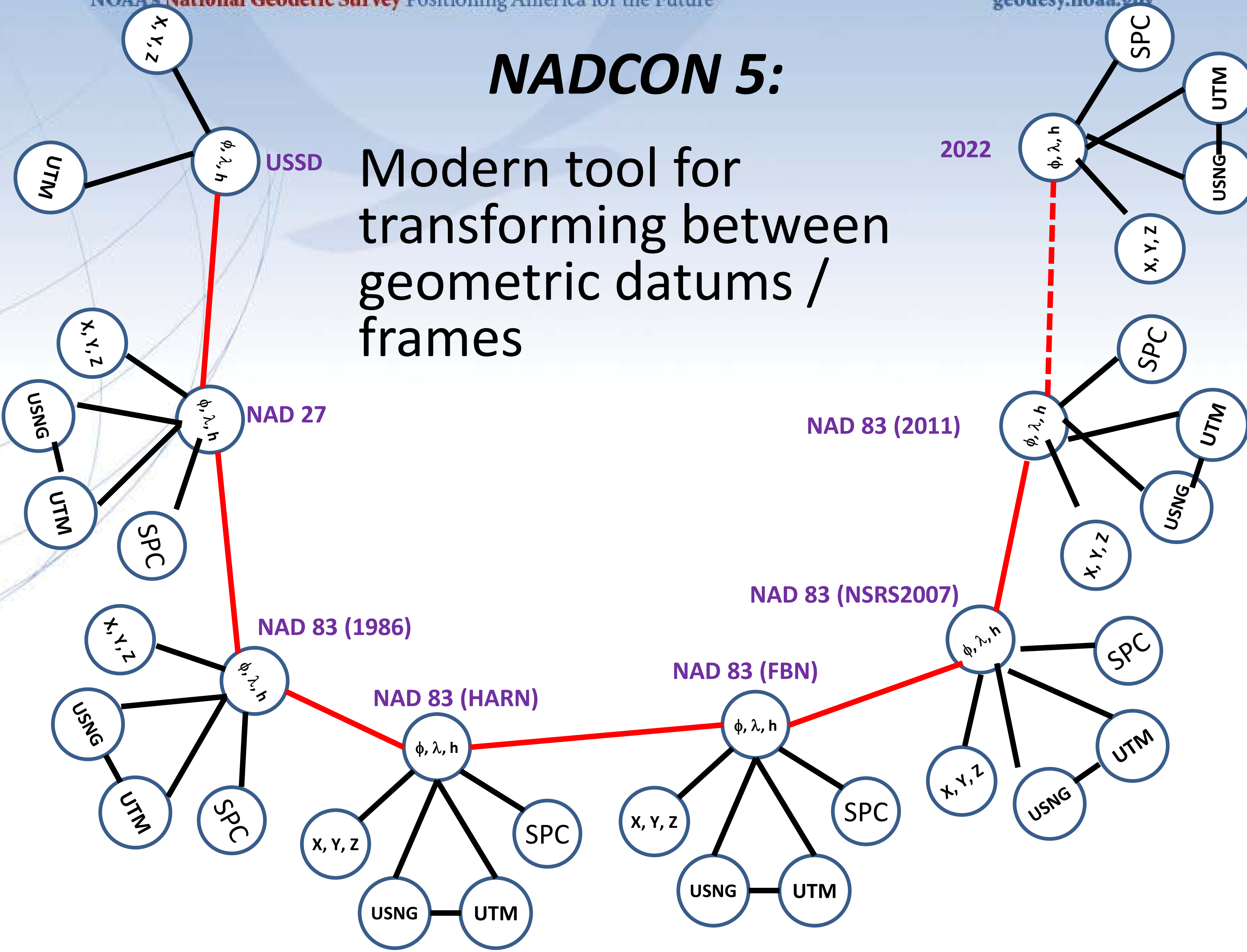
How to Plan for 2022



- **Move to NAD 83(2011) epoch 2010.00**
  - via surveys (or *possibly* via NADCON)
- **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, etc.
- **Use OPUS-Share/Database for GPSBMs & NAD83(2011) ties**
  - improve next geoid model & relationship with new datum
- **METADATA!!!!**

NADCON 5:

Modern tool for transforming between geometric datums / frames



geodesy.noaa.gov

National Geodetic Survey

Positioning America for the Future

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Coming in 2022: New Datums! Learn more...

NOAA's National Geodetic Survey (NGS) provides the framework for all positioning activities in the Nation. The foundational elements of latitude, longitude, elevation, shoreline information impact a wide range of important activities.

Learn more about:

- Data and tools we provide
- Activities in your area
- Applications of geodesy

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Looking for Bench Marks?

Notices

Beta Release: NADCON 5

Beta Release: CORS & OPUS Share Maps

Previous Notices

In the News

06/22/2017 - NGS Recognized at Boulder, CO, Public Art Dedication

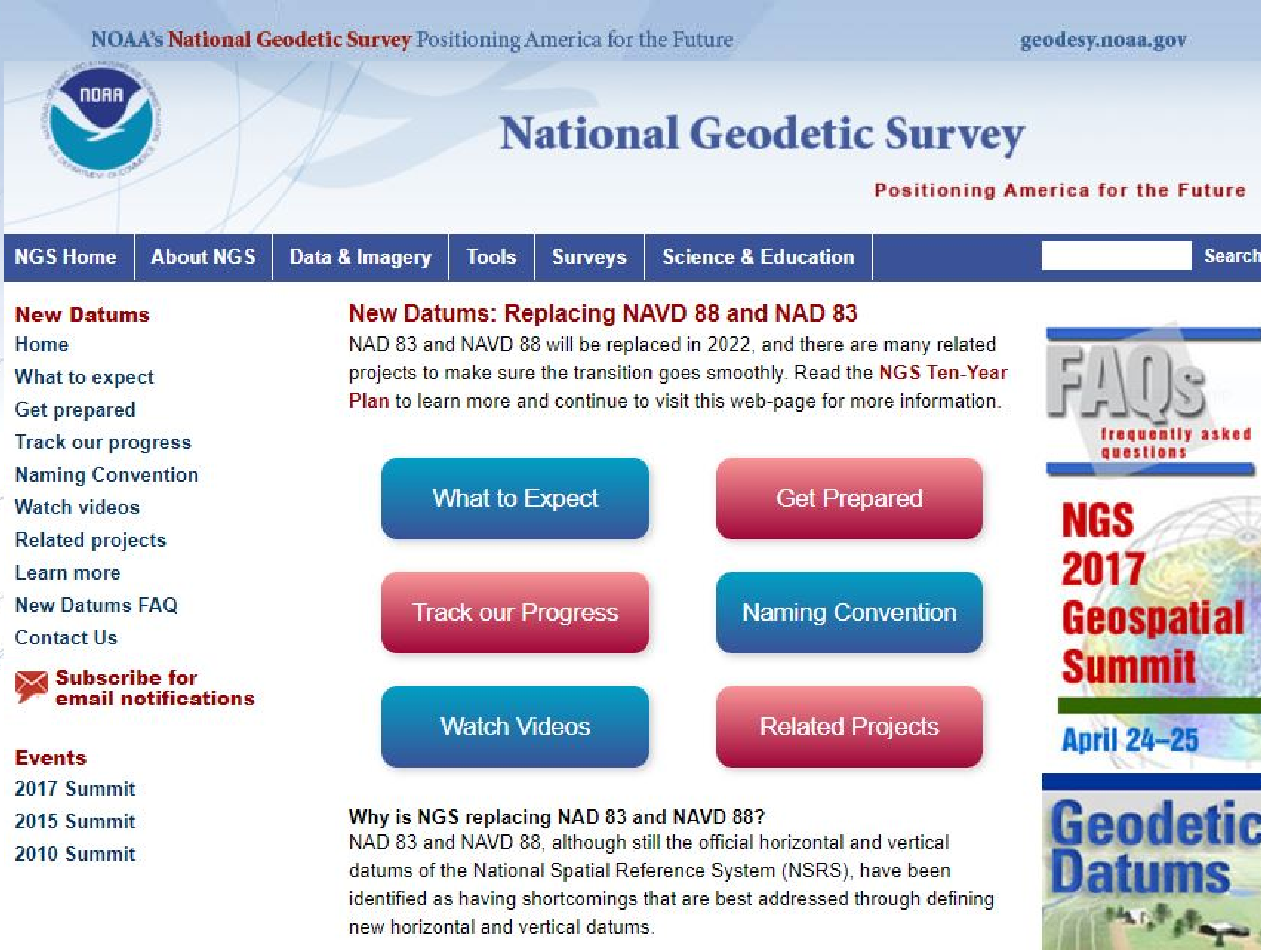
06/15/2017 - 'Foundations of Global Navigation Satellite Systems' Online Lesson

06/08/2017 - New Tool for Easy, Consistent Coordinate Transformations

06/01/2017 - NGS Participates in the International Federation of Surveyors Conference in Helsinki, Finland

Previous News Stories

Website Owner: National Geodetic Survey / Last modified by NGS.webmaster Jun 12 2017



https://geodesy.noaa.gov/datums/newdatums/

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Issue 8, July 2017

NSRS Modernization News

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

Acronyms

We have received substantial stakeholder requests to change the official acronyms of the new terrestrial reference frames, originally announced in January 2017 as NATRF2022, PTRF2022, MTRF2022 and CTRF2022. The requests focused primarily on easier pronunciation and consistent character length. After careful consideration, and in agreement with the Canadian Geodetic Survey, we are pleased to announce the official acronyms have been changed to:

NATRF2022
North American Terrestrial Reference Frame of 2022

PATRF2022
Pacific Terrestrial Reference Frame of 2022

MATRF2022
Mariana Terrestrial Reference Frame of 2022

CATRF2022
Caribbean Terrestrial Reference Frame of 2022

Blueprints

We are finalizing **NOAA Technical Report NOS NGS 64, "Blueprint for 2022, Part 2: Geopotential Coordinates,"** for an August 2017 release. The document describes the year 2022 replacement of all vertical datums and other NSRS geopotential quantities. It will serve as a companion document to **NOAA Technical Report NOS NGS 62, "Blueprint for 2022, Part 1: Geometric Coordinates,"** released in March of this year. Work has begun on **Part 3** to address the re-invention of Bluebooking.

New Projects

We continue to initiate new projects for completion prior to 2022 as part of the rollout of the modernized NSRS. Details on the four latest projects are below.

Euler Poles

Project Manager: Dr. Daniel Roman
To determine the Euler Pole Parameters that define the angular rotation, relative to the IGS frame, of the four tectonic plates associated with each of the four 2022 NSRS terrestrial reference frames.

Scoping study for Intra-frame Velocity Models

Project Manager: Dr. Daniel Roman
This one-year effort will investigate how various methods may be used to provide Intra-frame Velocity Models for each terrestrial reference frame. The goal is to determine a recommended way forward by addressing accuracy needs, methodologies, capabilities, and budget.

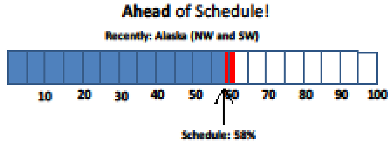
VERTCON 3

Project Manager: Dr. Dru Smith
To improve and replace VERTCON 2.1 and DYN_HT, as well as to prepare for the roll-out of the **North American-Pacific Geopotential Datum of 2022** (NAPGD2022).

Comprehensive Toolkit Improvements

Project Manager: Dr. Dru Smith
A five-year effort to overhaul the entire Geodetic Toolkit, improving, replacing, and (where possible) integrating all code into more modern tools, and focusing on improved customer interaction and the removal of duplicate functions residing in multiple tools.

GRAV-D progress last quarter: up 2.3% to 61.9%
Ahead of Schedule!



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

NOAA Technical Report NOS NGS 62

Blueprint for 2022, Part 1: Geometric Coordinates

and … coming soon:

Blueprint for 2022, Part 2: Geopotential 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:

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

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:

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

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

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

NGS Video Library

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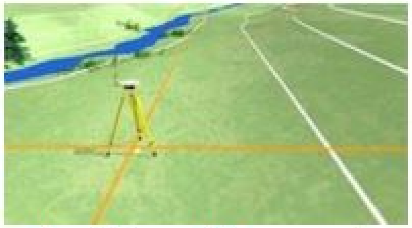
What are Geodetic Datums?

How Were Geodetic Datums Established?

What Is the Status of Today's Geodetic Datums?

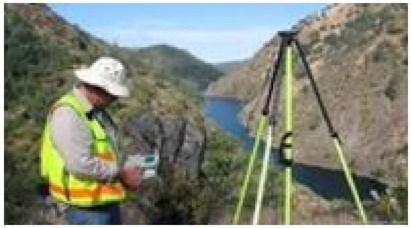
What's Next for Geodetic Datums?



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

Accurate positioning begins with *accurate* coordinates

Source: Zurich-American Insurance Group