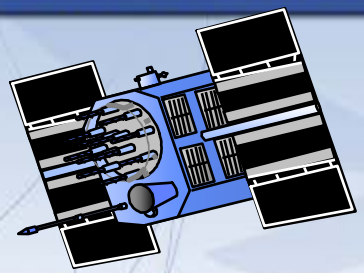

Modernizing the National Spatial Reference System

William Stone
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NOAA's National Geodetic Survey
geodesy.noaa.gov

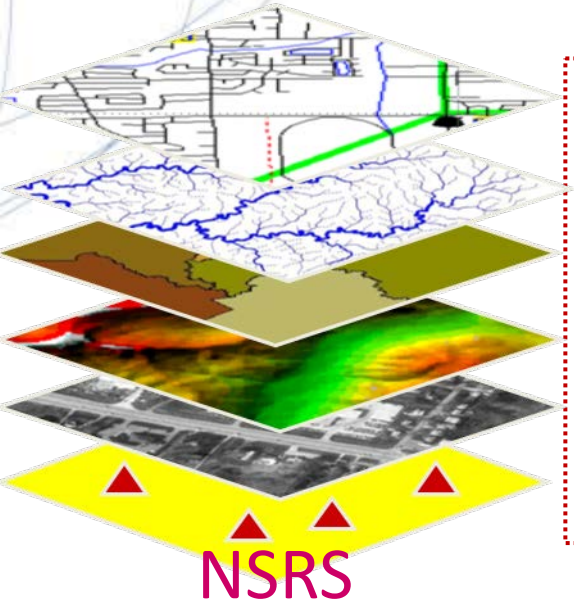
ASCE PIPELINES CONFERENCE
PHOENIX, ARIZONA | AUG 6–9, 2017

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

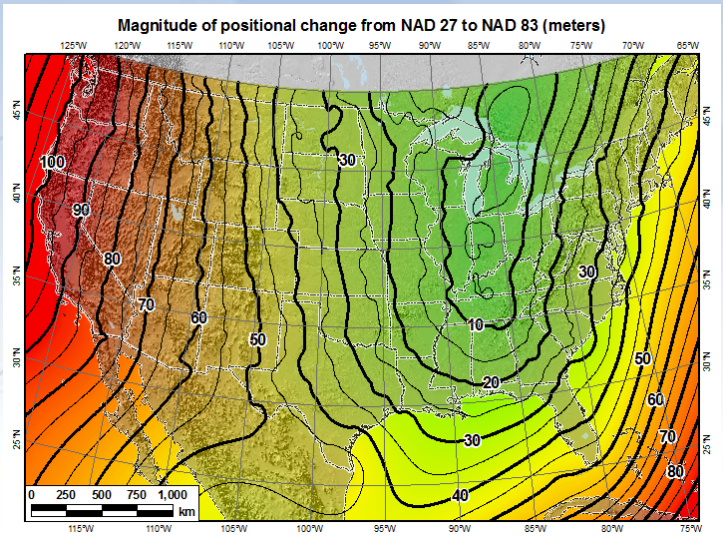
(& National Shoreline, etc.)

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

Accurate positioning begins with *accurate* coordinates

Source: Zurich-American Insurance Group

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



U.S. Standard Datum

NAD27

NAD83 (1986)

NAD83 (HARN /199X)

NAD83 (2007)

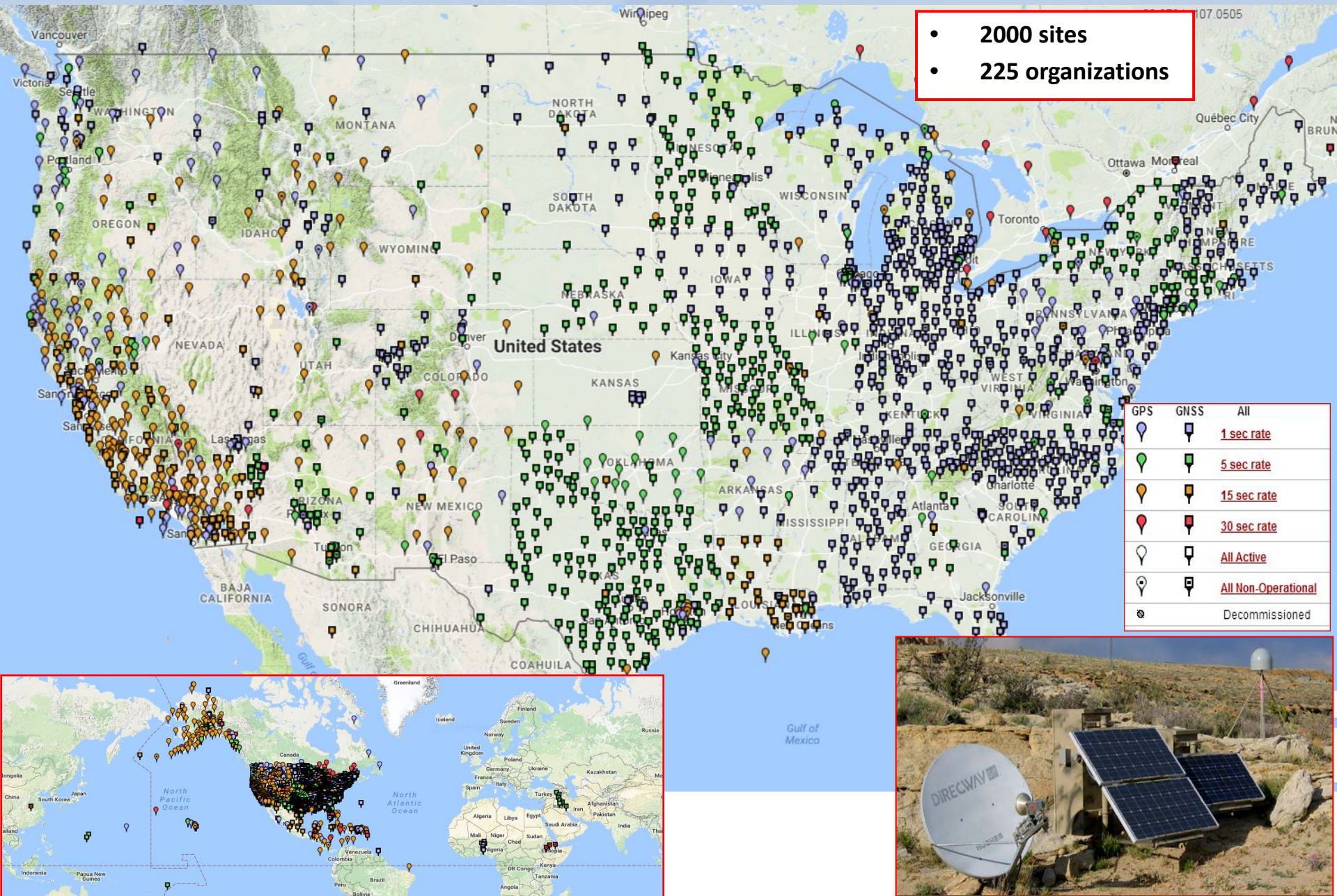
NAD83 (2011)

time

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

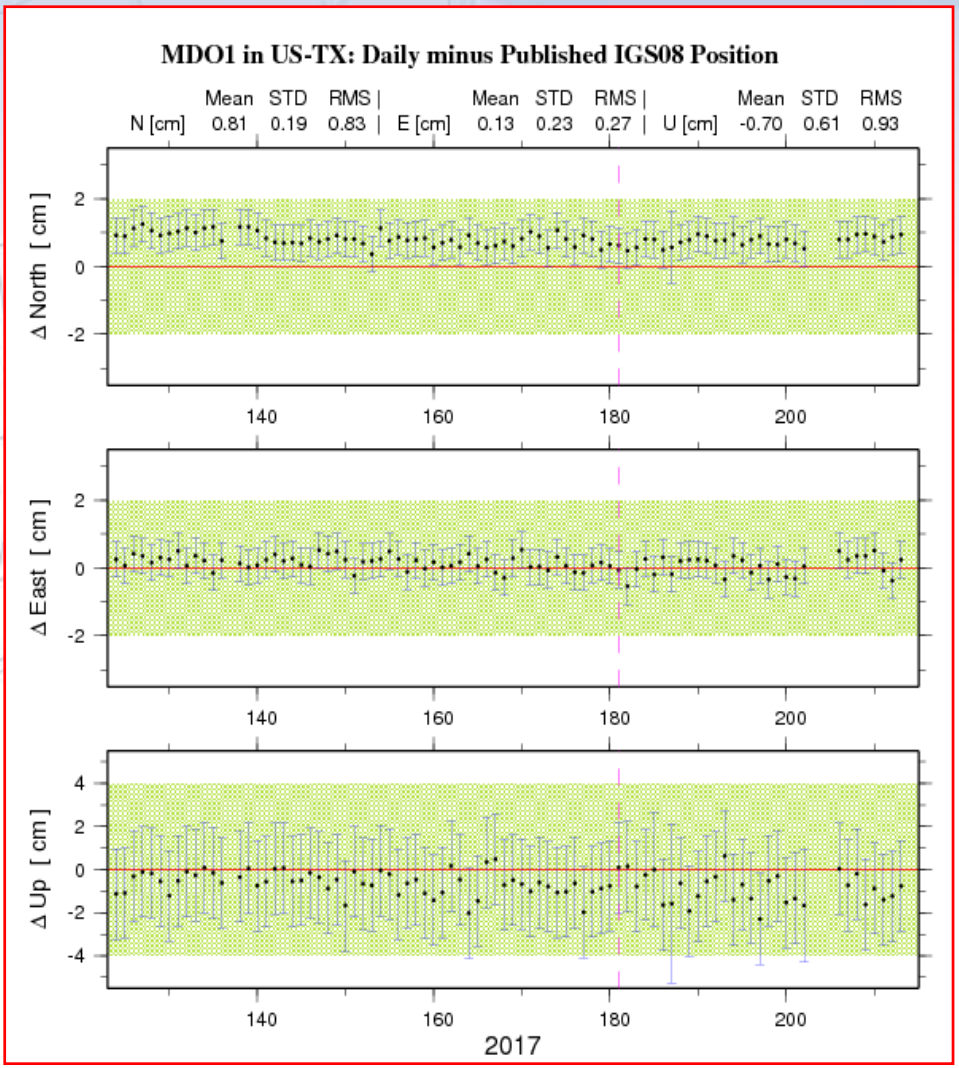
Continuously Operating Reference Station (CORS) Network

- 2000 sites
- 225 organizations

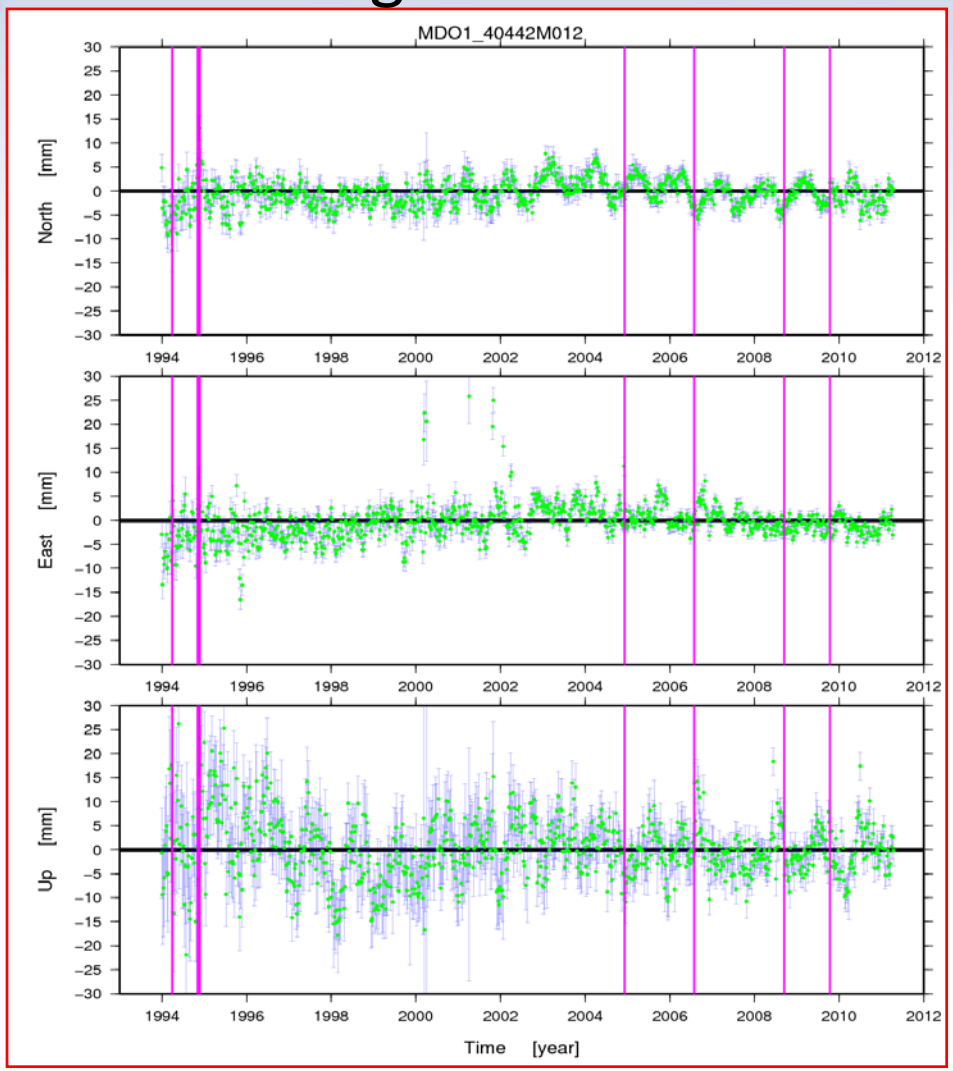


CORS Time Series Plots

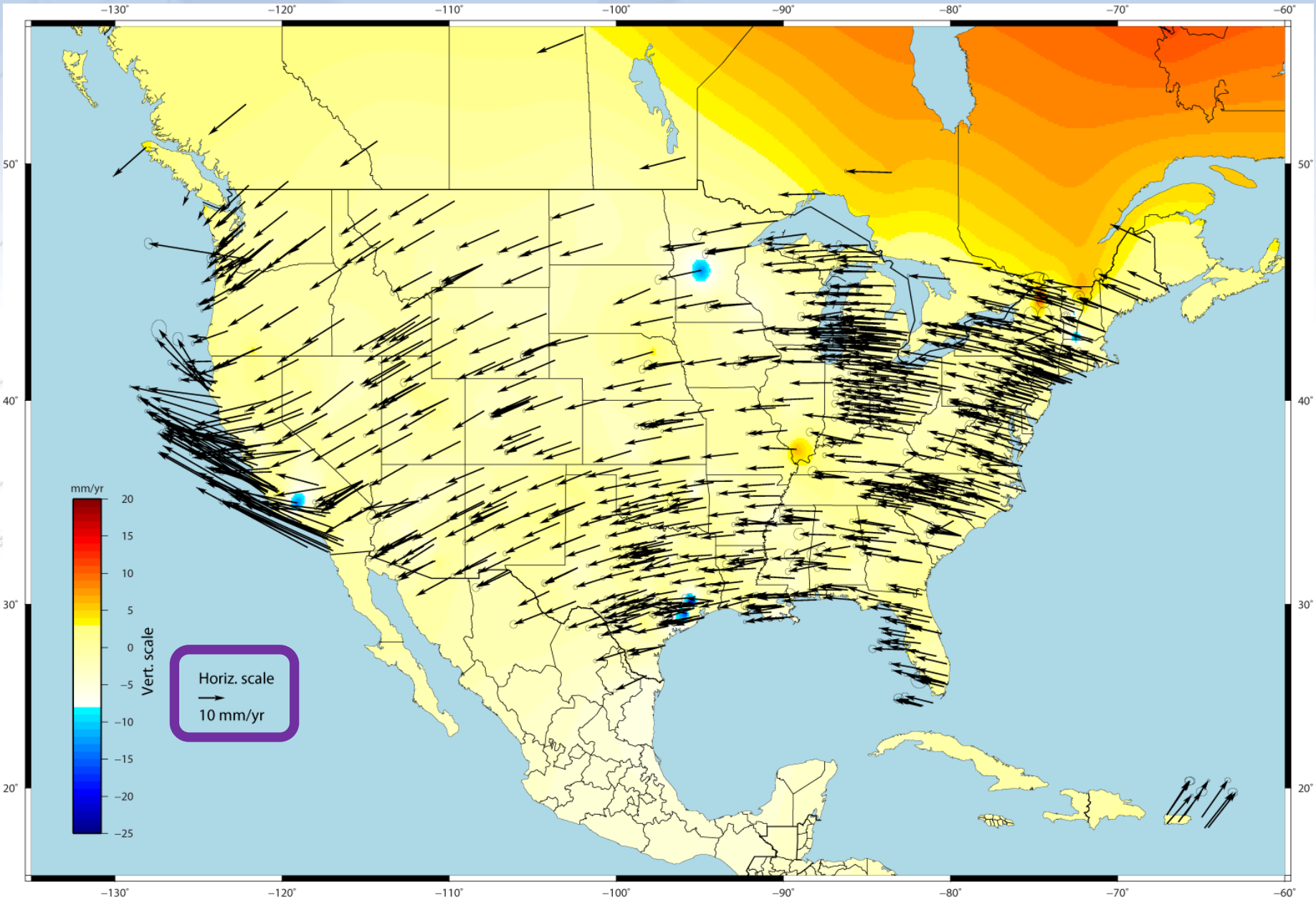
short-term



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

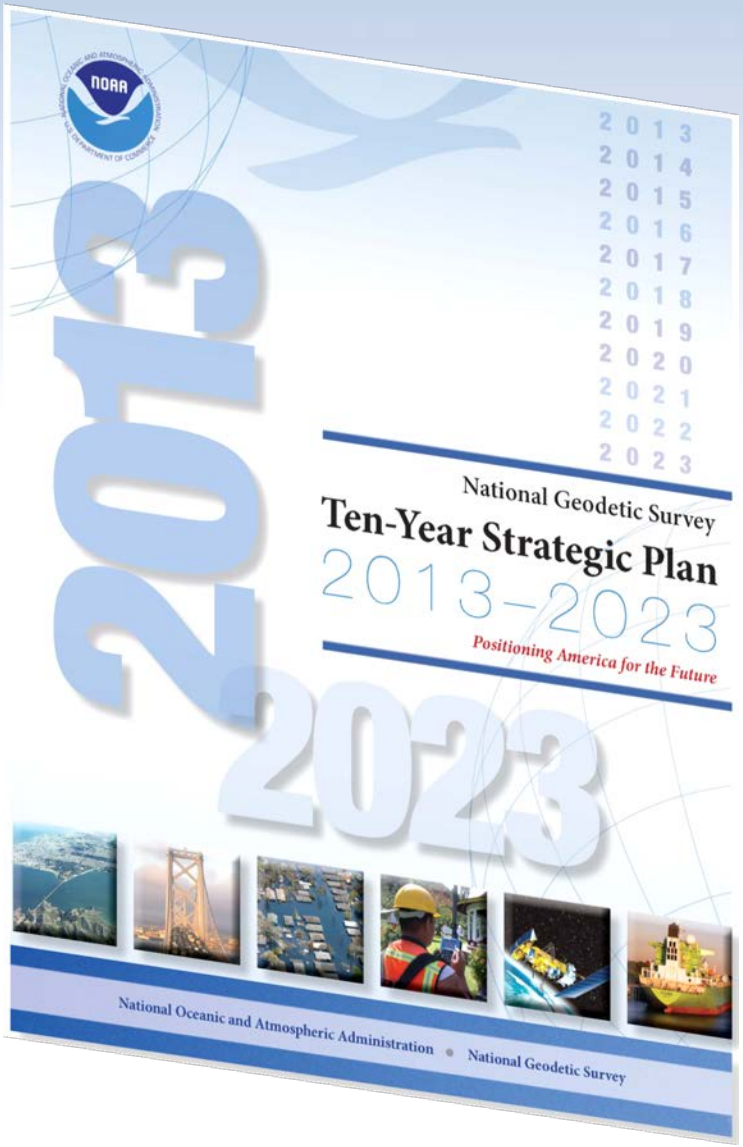
  "**Replace NAD83**"

(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**"

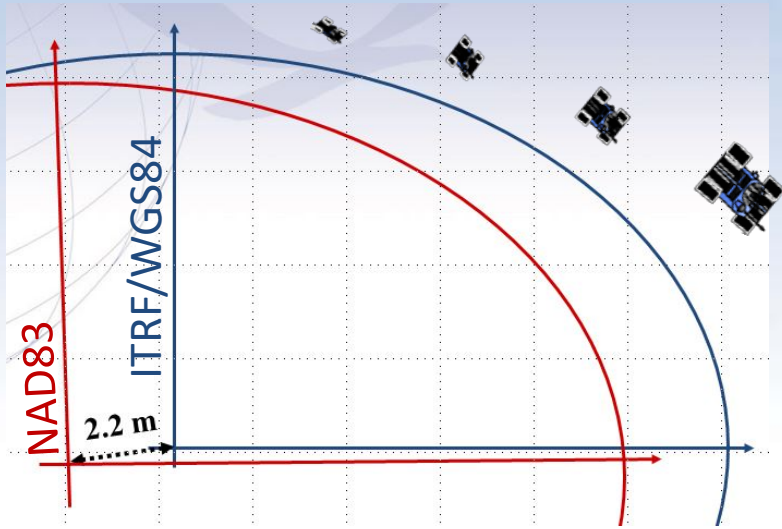
(NAVD88 = North American Vertical Datum 1988)



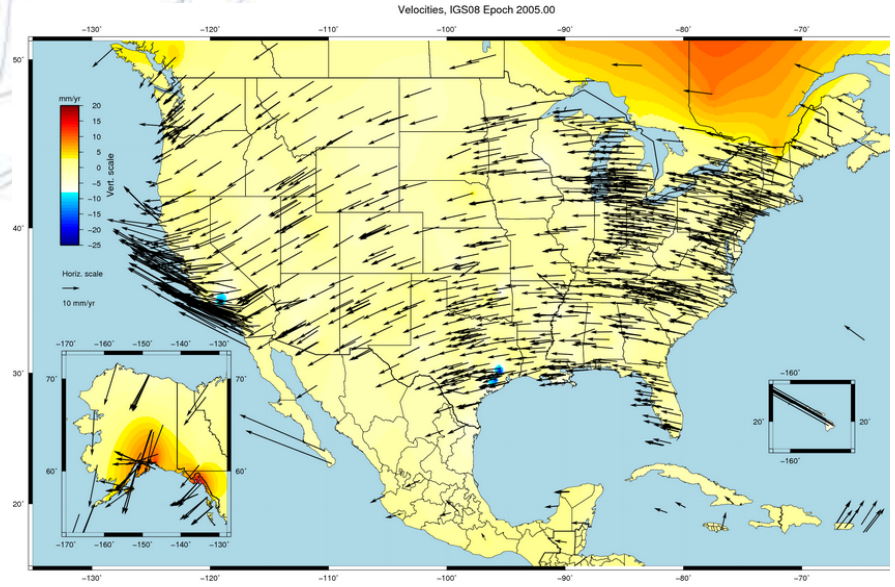
https://geodesy.noaa.gov/web/about_ngs/info/tenyearfinal.shtml

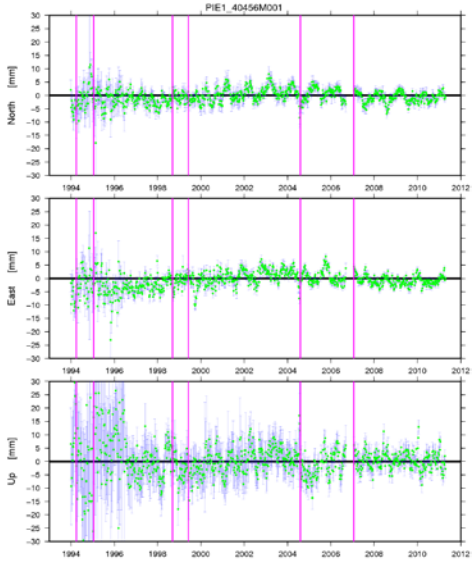
NAD83 Shortcomings

- **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 (NADCON 5.0)

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)

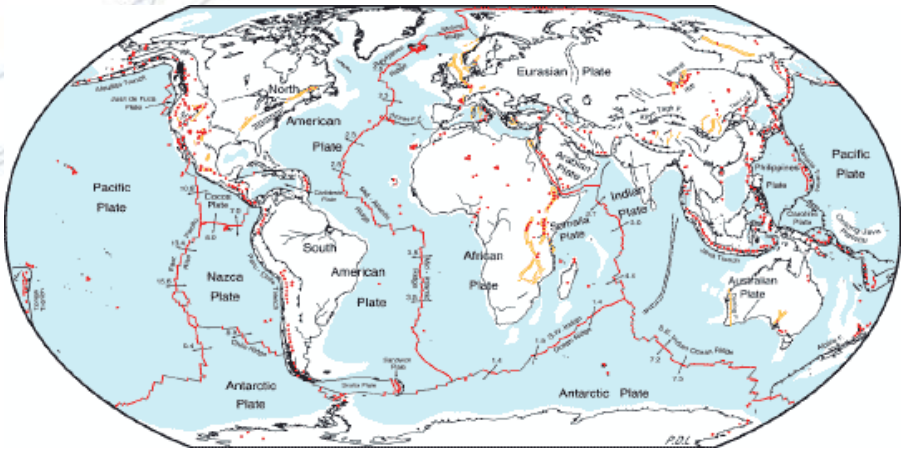
[e.g. IGS14 = International GNSS Service 2014]

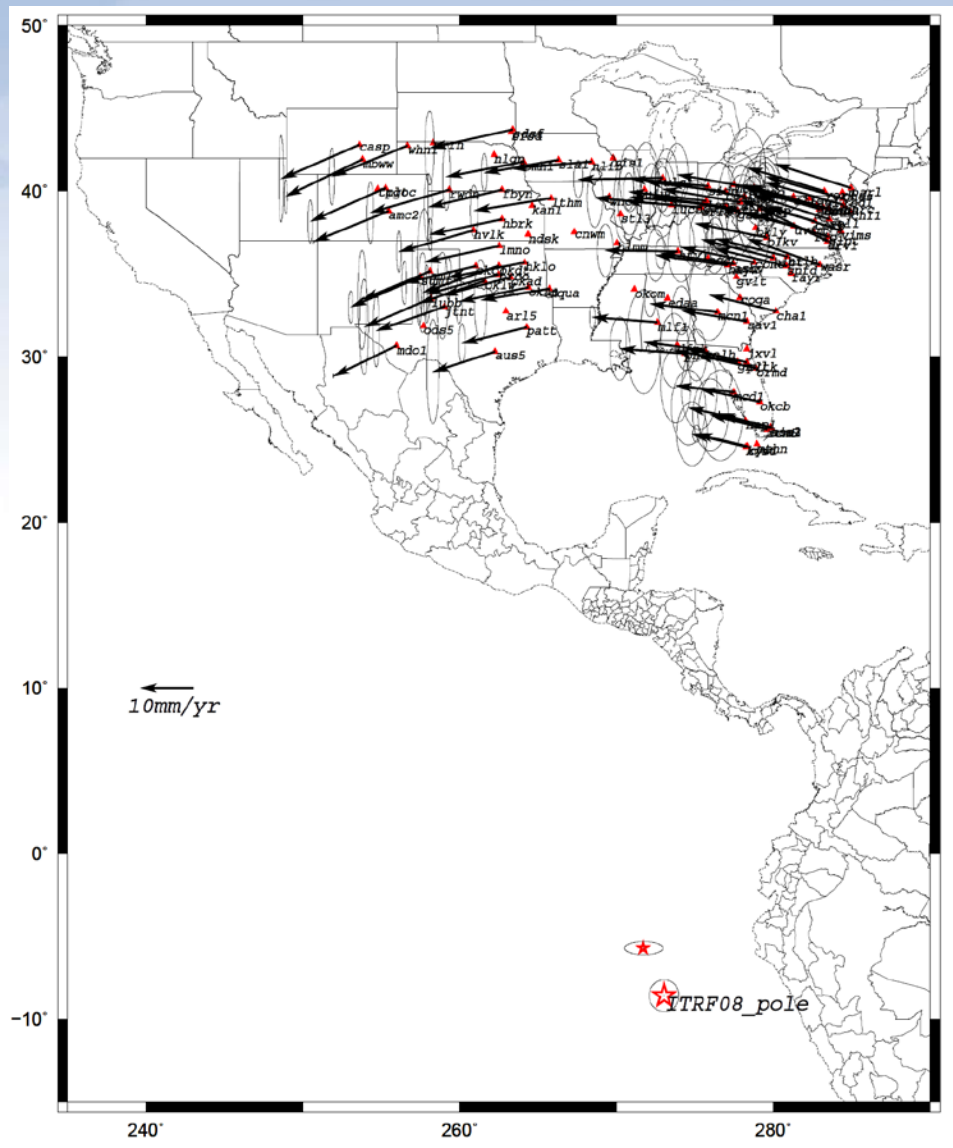
Euler Pole

Each reference frame will get:

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

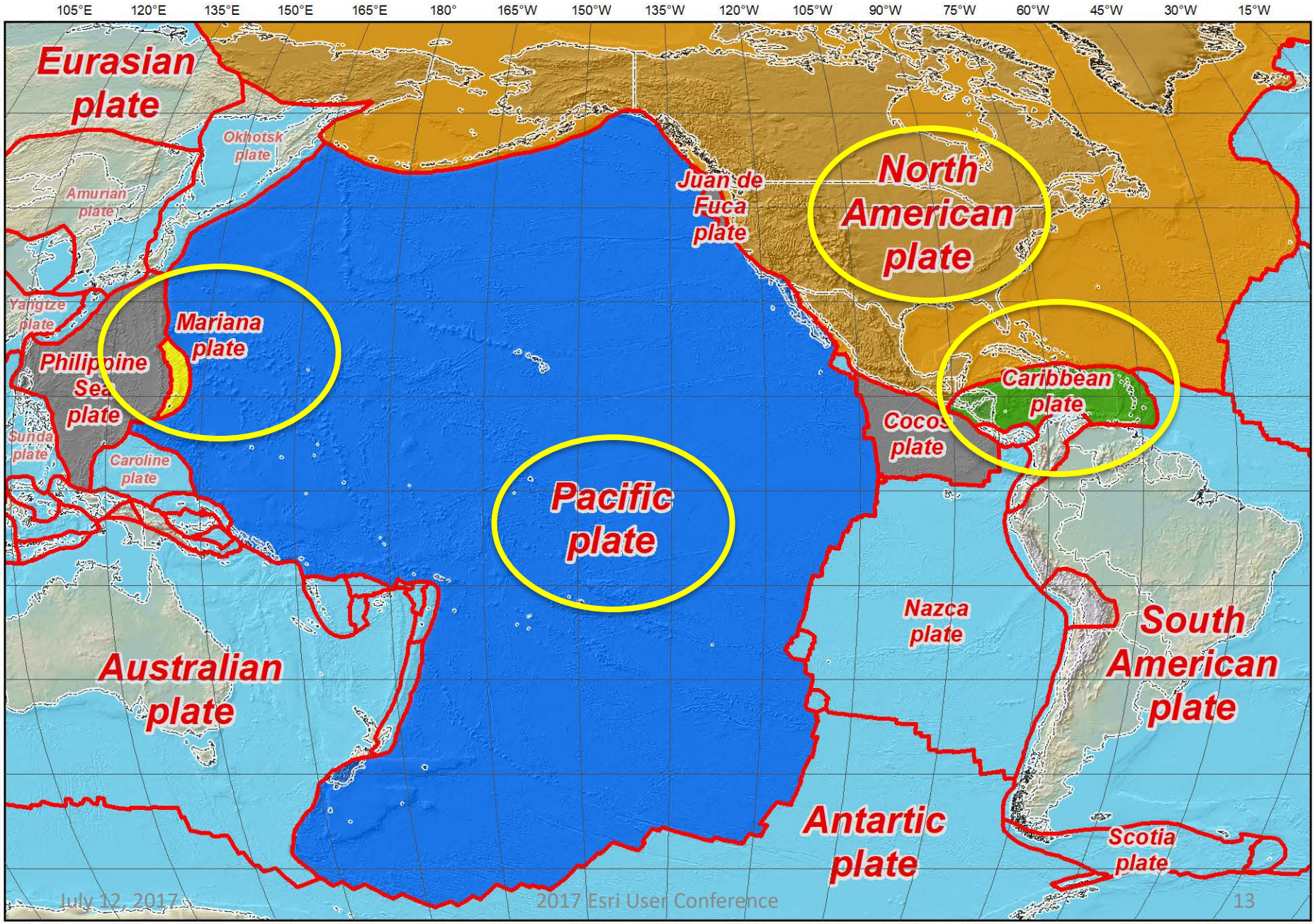
Used to compute time-dependent TRF2022 coordinates from time-dependent global (IGS) coordinates





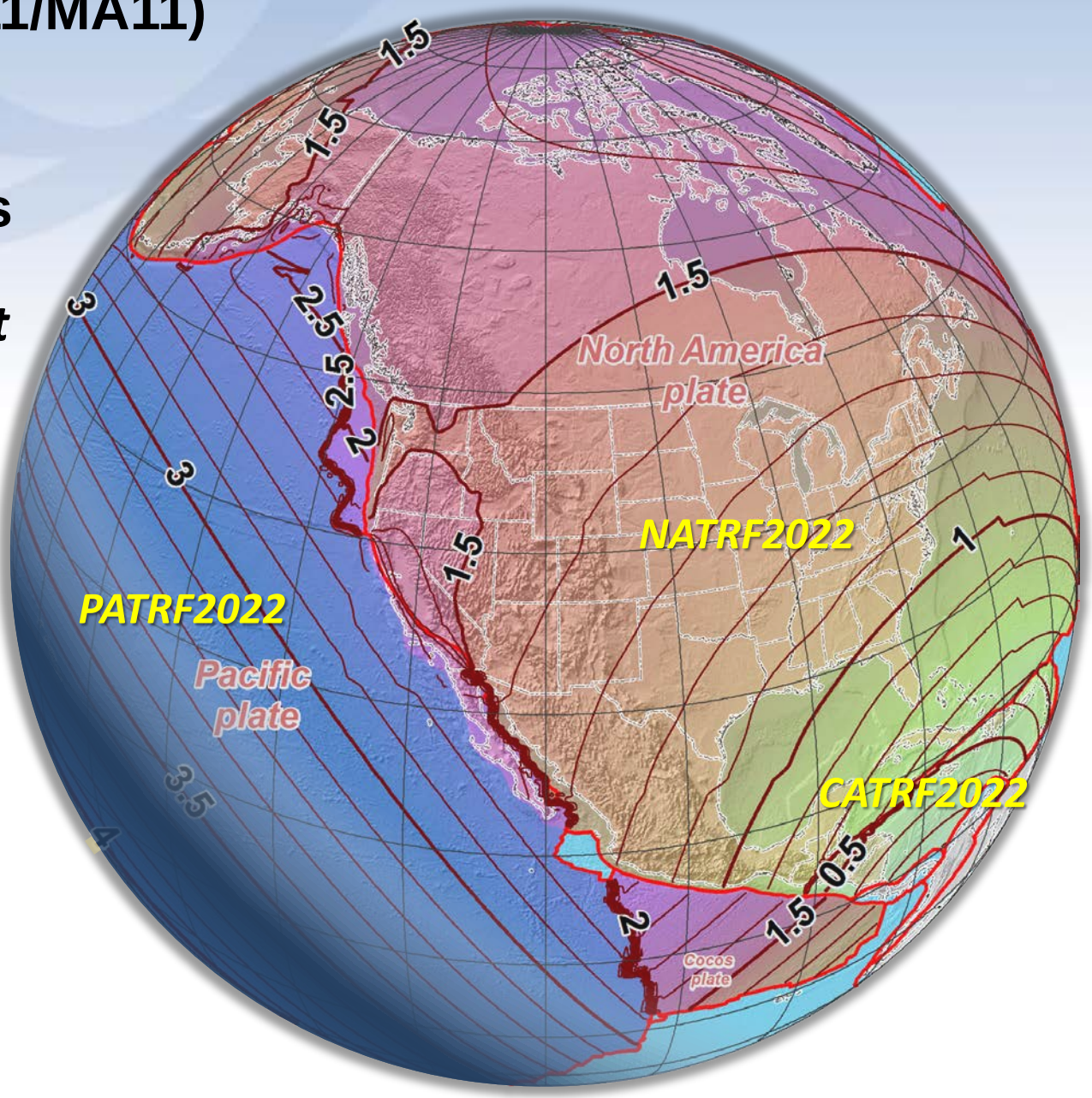
Euler's fixed point theorem states: any motion of a rigid body on the surface of a sphere may be represented as a rotation about an appropriately chosen rotation pole ("Euler Pole")

The four tectonic plates “fixed” for the 2022 terrestrial reference frames



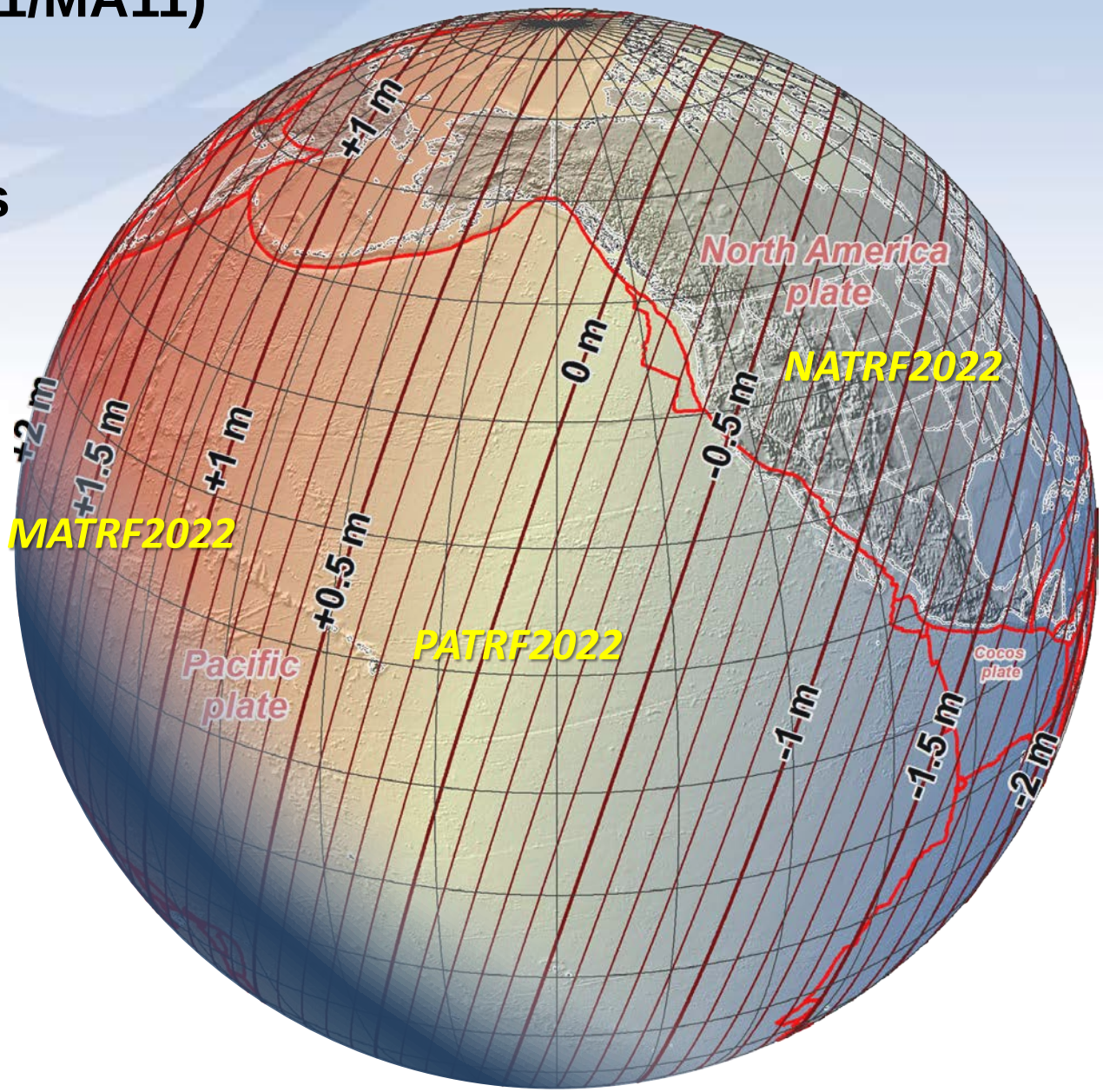
NAD 83 (2011/PA11/MA11) epoch 2010.00 → 2022 Terrestrial Reference Frames

Horizontal change at epoch 2022.00
(contours in meters)

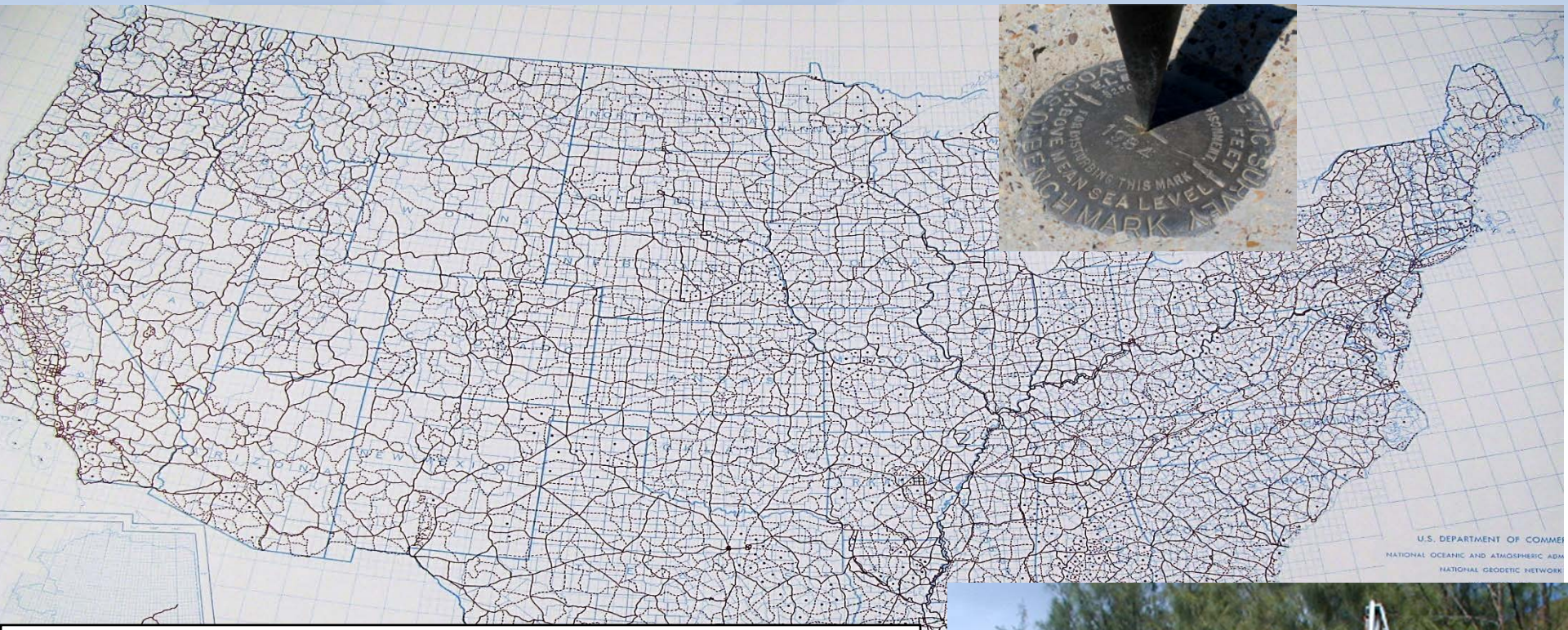


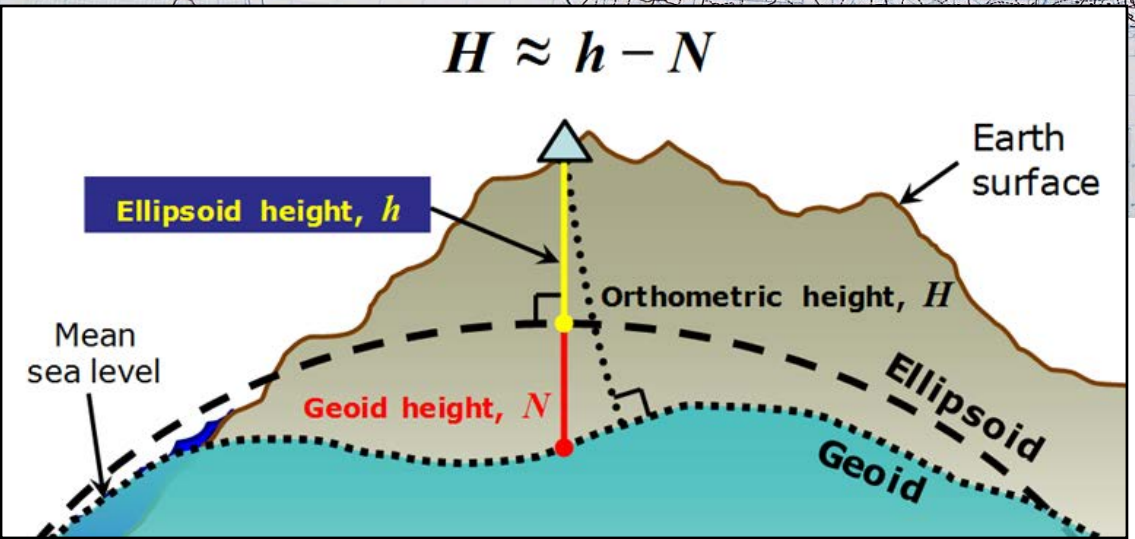
NAD 83 (2011/PA11/MA11) epoch 2010.00 → 2022 Terrestrial Reference Frames

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



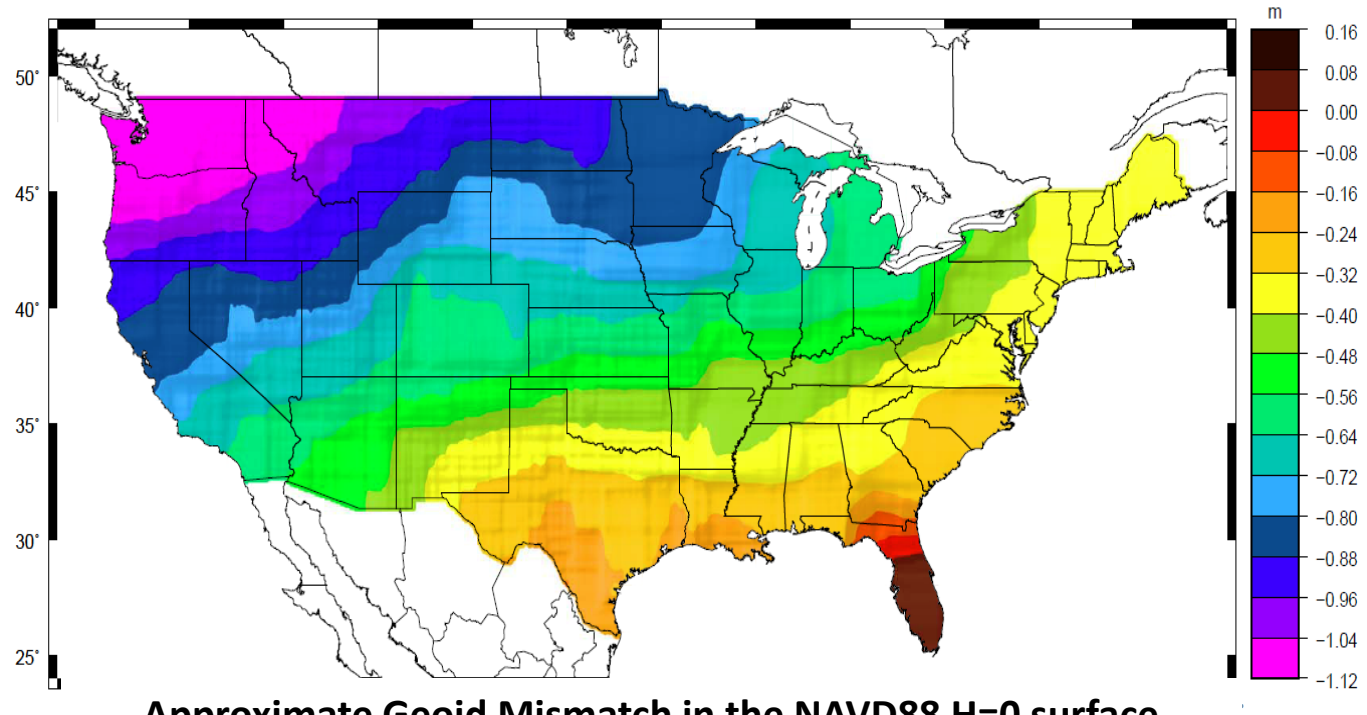
NORTH AMERICAL VERTICAL DATUM 1988 (NAVD88)





North American Vertical Datum 1988 (NAVD88) Shortcomings

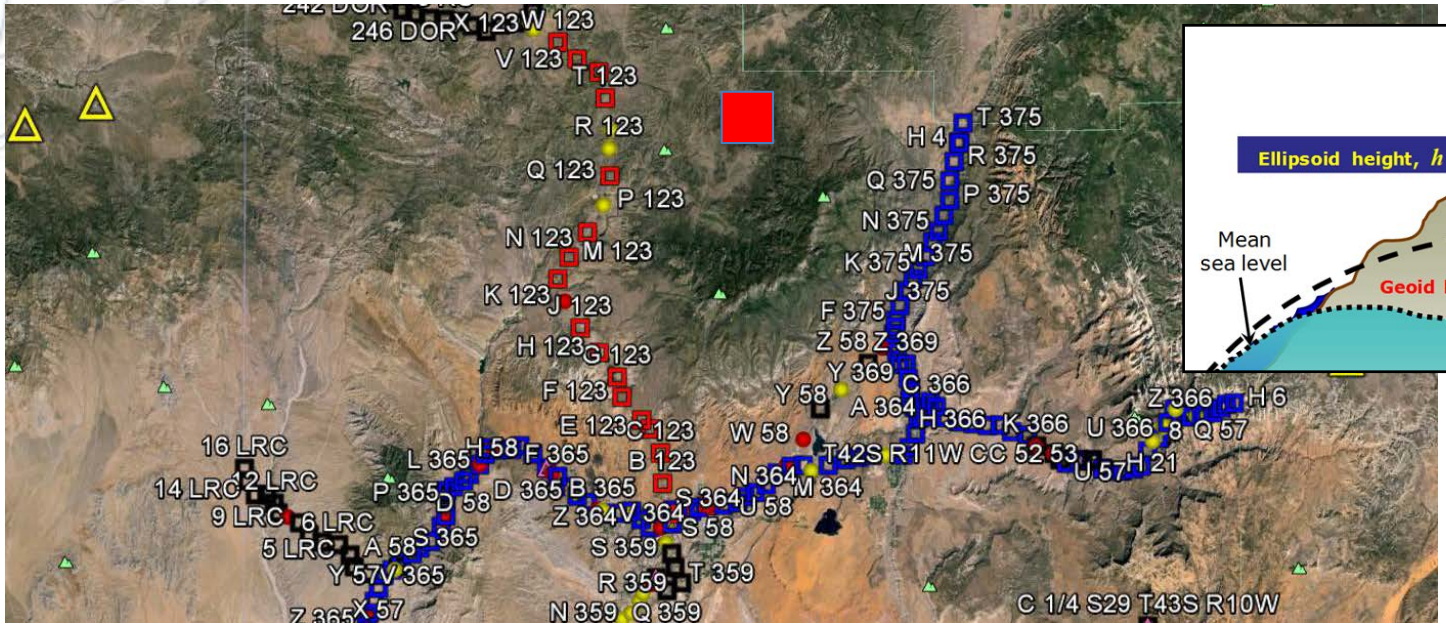
- Cross-country errors (1-m tilt)
- 0.5 m bias in reference surface vs. global mean sea level
- Subsidence, uplift, freeze/thaw invalidate BM elevations
- LIMITED AVAILABILITY / ACCESS

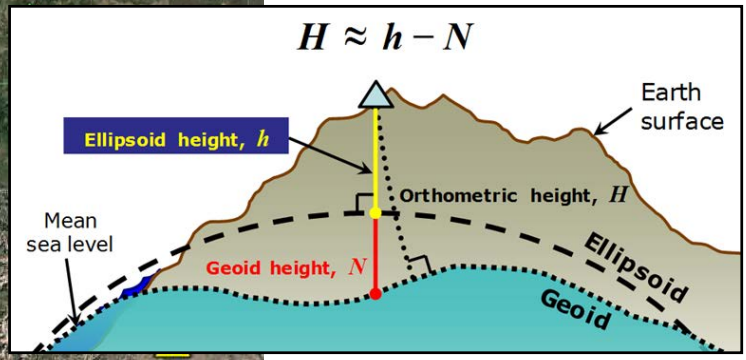


Approximate Geoid Mismatch in the NAVD88 H=0 surface

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

PRVD 02

VI

Normal Orthometric Heights

IVD0

ASVD02

NMVD03

GUVD04

Dynam ights

IGLD 85

Gravity

GSN71

Geoid Heights

GEOID12B

Deflections of the Vertical

DEFLEC12B

one vertical datum

pole-to-equator

Introducing…

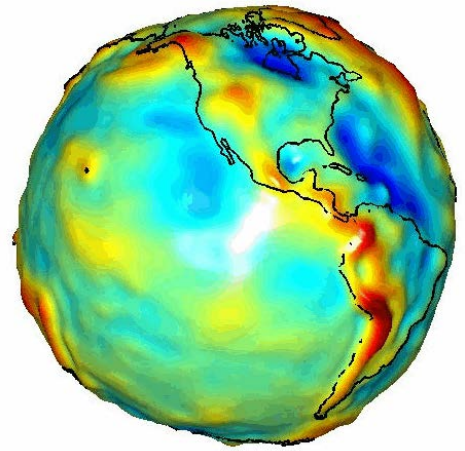
North American-Pacific Geopotential Datum of 2022 (NAPGD2022)

&

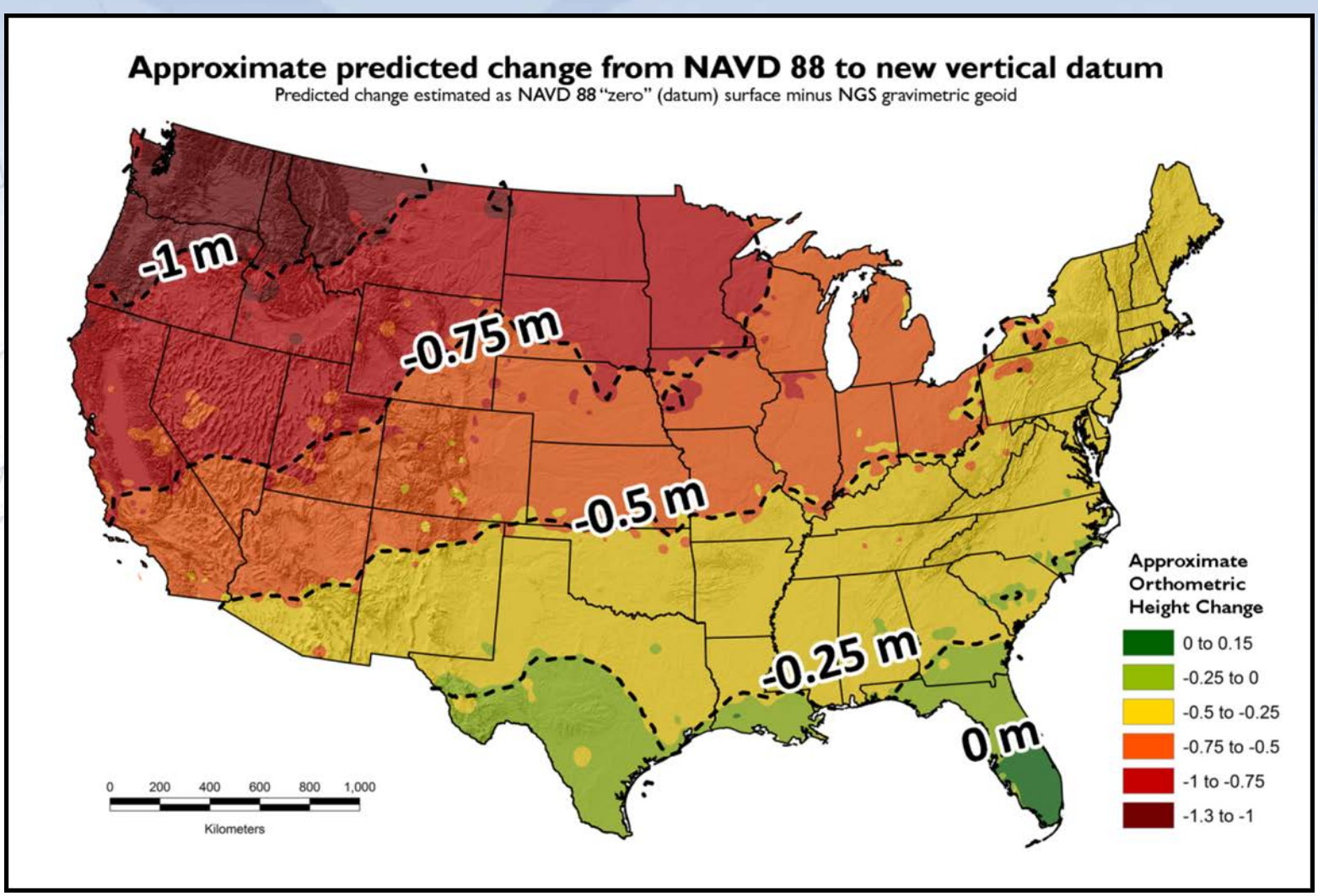
GEOID2022

(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




NON SEQUITUR
REAL LIFE PHYSICS
TODAY'S LESSON: GRAVITY
NO MATTER WHICH WAY YOU TURN A TRASH BAG TO PREVENT IT FROM FALLING OVER, YOU'LL BE WRONG
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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

GRAV-D Data Status Mar 2017

- Planned
- Partially Collected
- Processing
- Released
- Target Area

Contiguous U.S. and Puerto Rico

Alaska

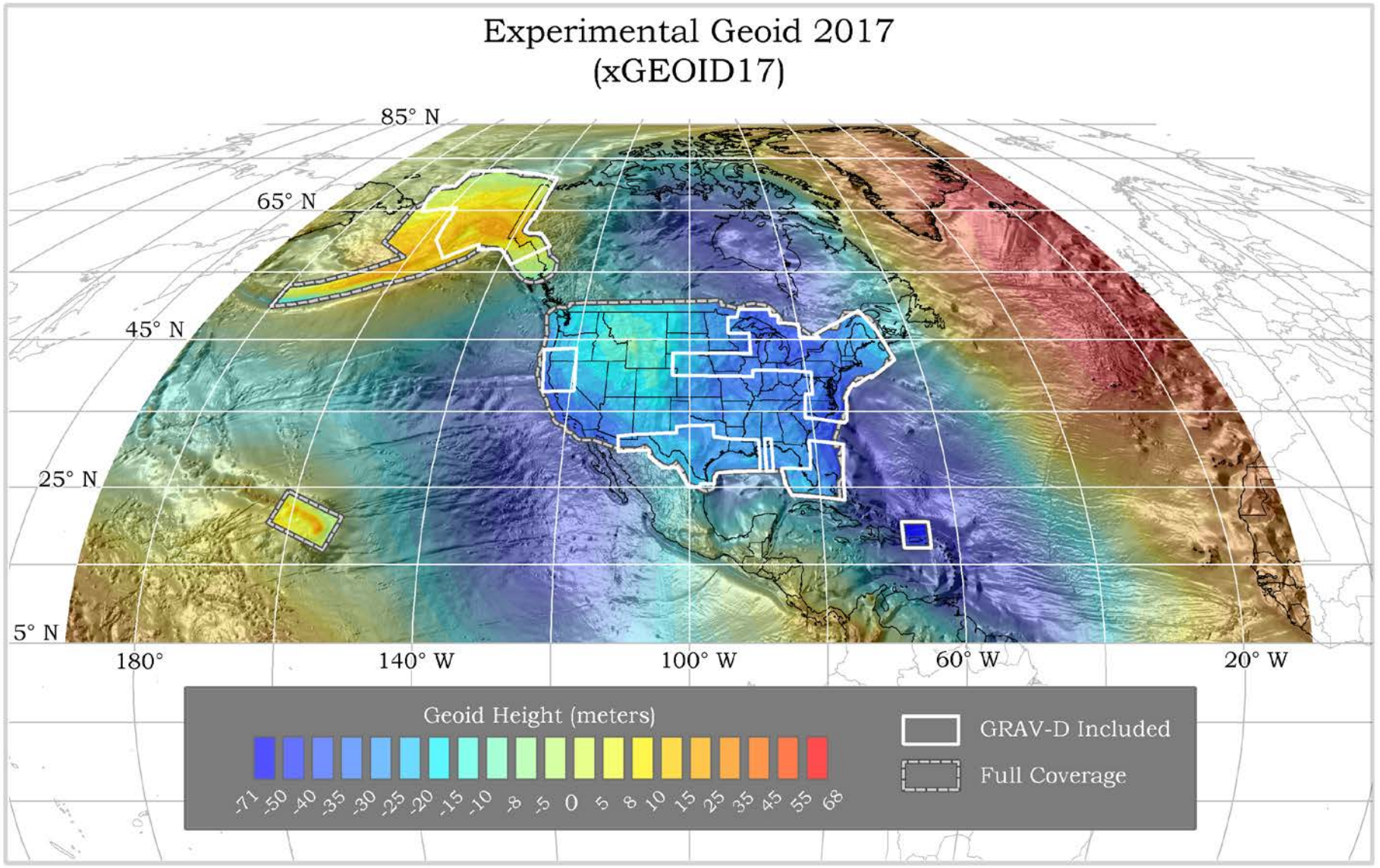
Hawaii

Guam and CNMI

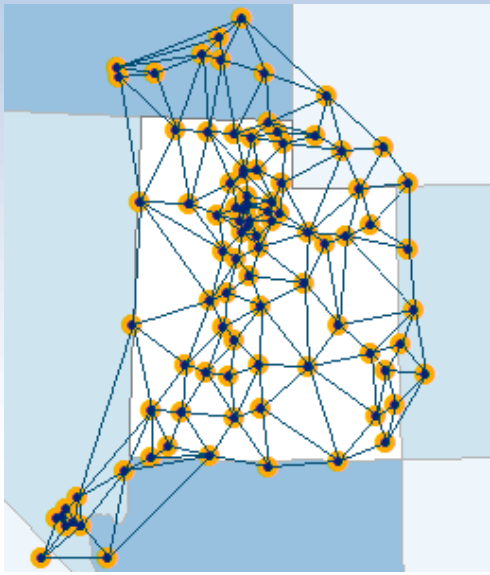
American Samoa

2017-Q2: 62% complete

Annual Experimental Geoids



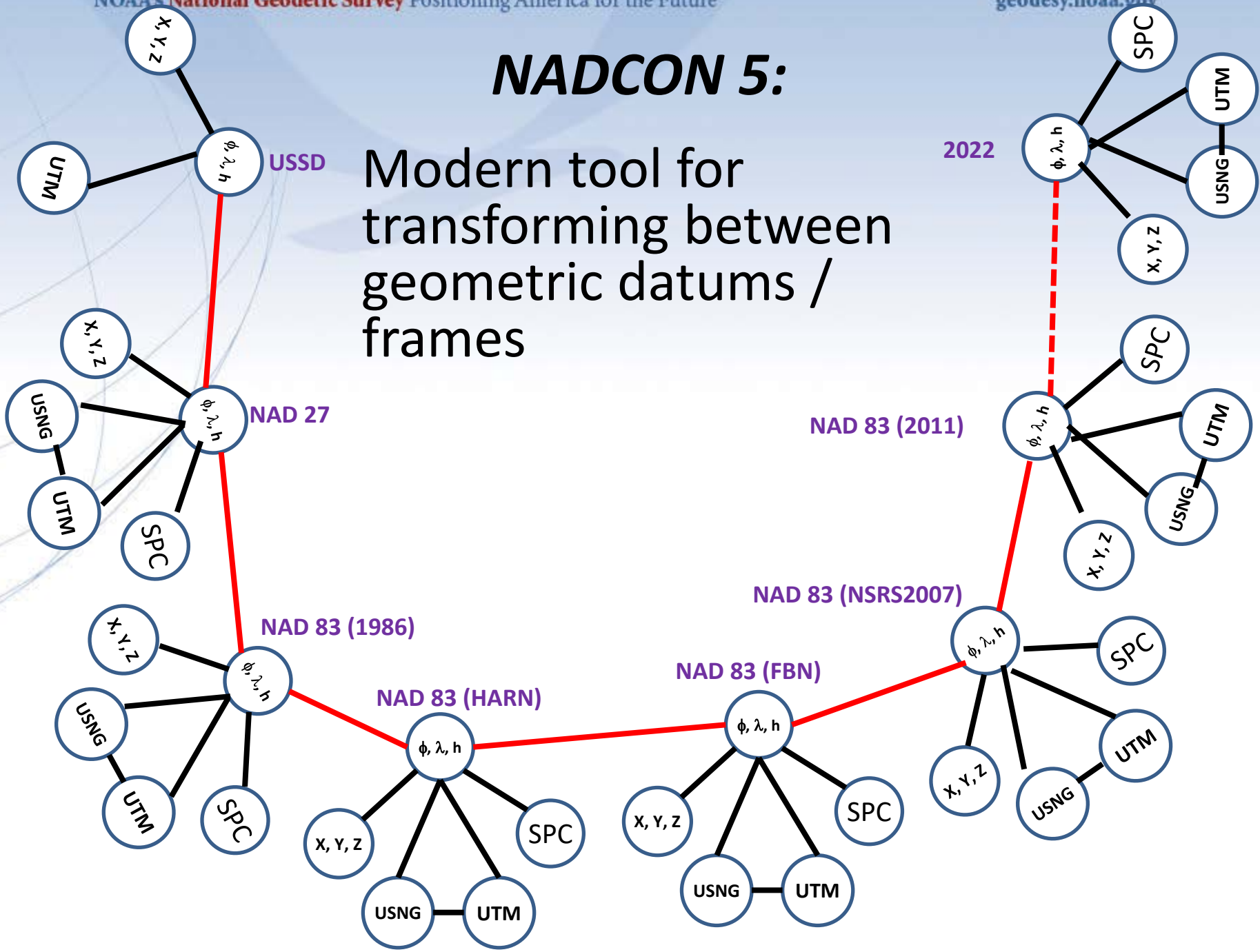
How to Plan for 2022



- **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



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National Geodetic Survey

Positioning America for the Future

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Quick Links

- OPUS
- CORS
- Survey Mark Datasheets
- NGS Data Explorer
- OPUS Projects
- Geodetic Tool Kit
- State Plane Coordinates
- Antenna Calibration
- UFCORS
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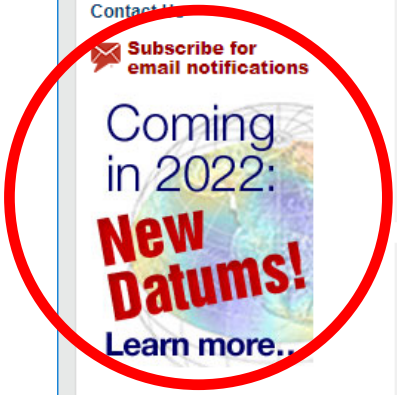


NOAA's National Geodetic Survey (NGS) provides the framework for all positioning activities in the Nation. The foundational elements of latitude, longitude, elevation, shoreline information impact a wide range of important activities.

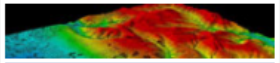
Learn more about:

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

GNSS & GPS Data

Get coordinate information and the tools you need to work independently.

Learn More



Remote Sensing

Download data and critical information into nautical charts.

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Land Surveying

View guidelines and get tools to support land surveyors.

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Geodesy

NGS works closely with the global researchers advancing geodetic science.

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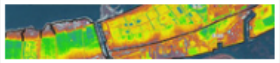
Training & Education

Classes and educational resources on scientific topics relating to geodesy.

Learn More



Datums & Transformations

NGS defines datums to help align data and tools to transform coordinates.

Learn More

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

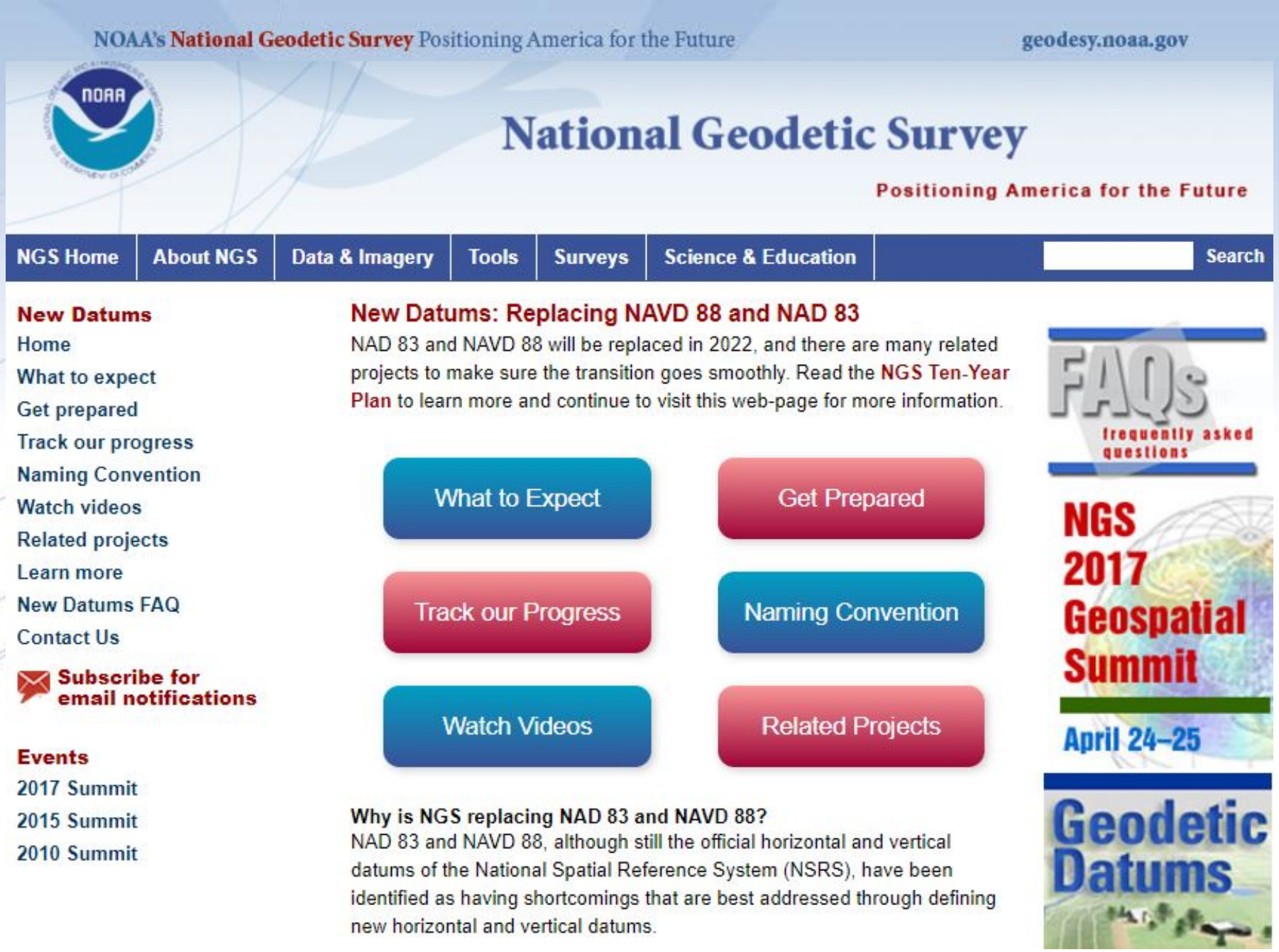
06/15/2017 - 'Foundations of Global Navigation Satellite Systems' Online Lesson

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.

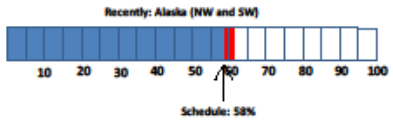
VERTCON 3

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:

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

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:

$$\omega_X(t_0) + (\Delta t)\dot{\omega}_X = [\dot{\omega}_0 \Delta t]cos\lambda_0 sin\theta_0 \qquad (46)$$
$$\omega_Y(t_0) + (\Delta t)\dot{\omega}_Y = [\dot{\omega}_0 \Delta t]sin\lambda_0 sin\theta_0 \qquad (47)$$
$$\omega_Z(t_0) + (\Delta t)\dot{\omega}_Z = [\dot{\omega}_0 \Delta t]cos\theta_0 \qquad (48)$$

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