U. S. Datums: Where We've Been, Where We're Going

Modernizing the National Spatial Reference System

Presentation Outline

1. - National Geodetic Survey.
2. - Geodetic Datums.
3. - New Reference Frames & Preparing for them.
4. - Update on NGS Products.
5. - Questions.

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 (NAD 83)
- North American Vertical Datum of 1988 (NAVD 88)

NGS MISSION - The NSRS

Define - National Coordinate Sys. (NSRS)

Maintain - the NSRS

Our Mission

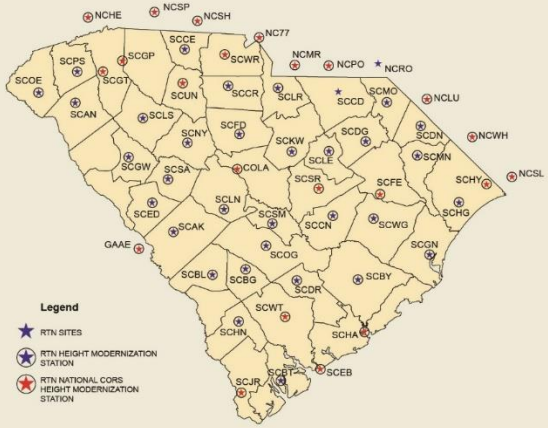
SOUTH CAROLINA GEODETIC SURVEY

The primary mission of the SC Geodetic Survey is to ensure the integrity of geodetic control throughout South Carolina so that land and land-related items can be accurately referenced to the national horizontal and vertical coordinate system. The SCGS accomplishes this through a program to upgrade county geodetic networks and operating a statewide Real-Time GPS Network.

The SC Geodetic Survey also supports the development and maintenance of an accurate, uniform statewide mapping system on a county-by-county basis. The county mapping systems provide a large-scale map base for county and state computerized land information systems that facilitate manipulating and storing land records for a multitude of purposes.

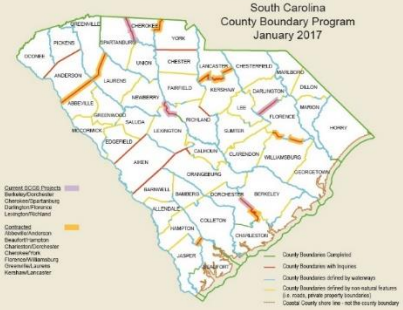
In addition, the SC Geodetic Survey assists the re-establishment of political boundaries that are ill-defined, unmarked or poorly marked.

Real-Time Network Base Stations



County Boundary Program

South Carolina
County Boundary Program
January 2017



Height Modernization Projects

Height Modernization, a program within NOAA's National Geodetic Survey (NGS), provides accurate height or data (± 2 cm) by integrating Global Positioning System (GPS) technology with existing survey techniques. Since 1988, the SCGS has used GPS to determine accurate horizontal positions; and, since 2001, by following Height Modernization standards, specifications and techniques, the SCGS has established 4073 Height Modernization control stations with accurate elevations for all types of positioning and navigational needs. SCGS follows the (± 2 cm) vertical specifications for all GPS Height Modernization Projects.

FUTURE PLANS

- Create Monumented Control using RTN
- Monitor the Passive Network
- Expand in-state National CORS Network
- Create in-house database
- Re-establish County Boundaries

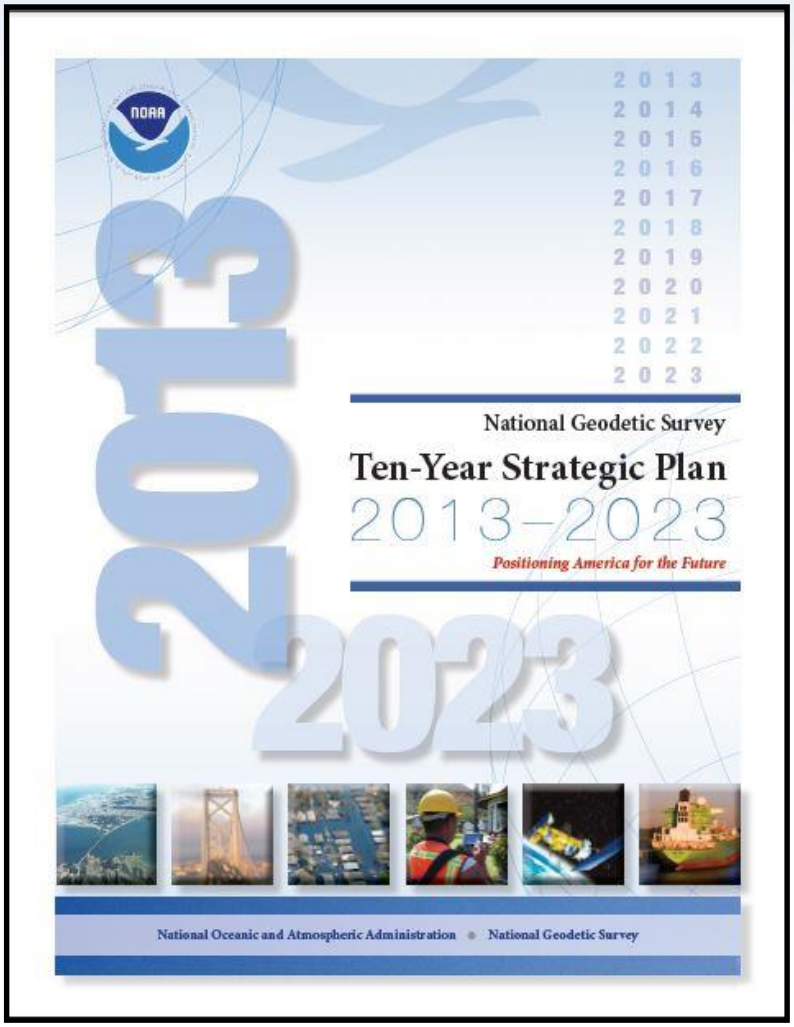
South Carolina Geodetic Survey • 5 Geology Road • Columbia, South Carolina 29212 • 803-896-7700 • www.rfa.sc.gov/geodetic

The National Geodetic Survey 10 year plan
Mission, Vision and Strategy
2013 – 2023

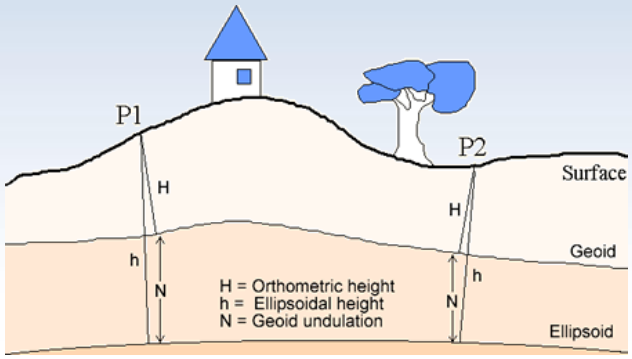
http://www.ngs.noaa.gov/INFO/NGS10yearplan.pdf

- *Official NGS policy as of Jan 9, 2008 (updated in 2013)*
  - *Modernized agency*
  - *Attention to accuracy*
  - *Attention to time-changes*
  - *Improved products and services*
  - *Integration with other fed missions*

- *2022 Targets:*
  - *Replace NAD 83 and NAVD 88*
  - *Cm-accuracy access to all coordinates*
  - *Customer-focused agency*
  - *Global scientific leadership*

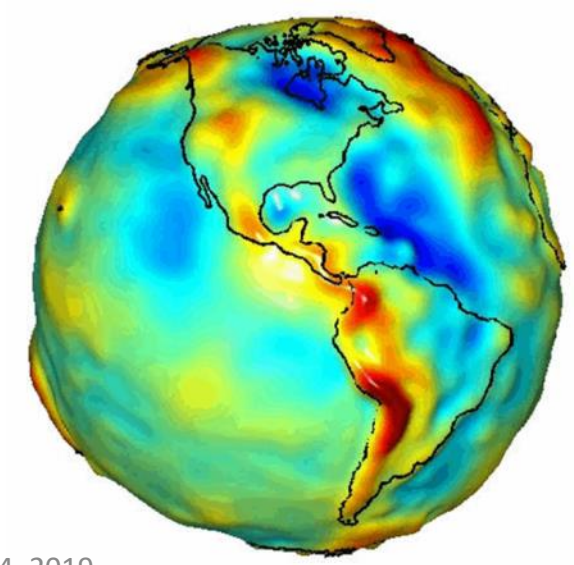


What is Geodesy?



Geodesy (geodetic control) is a foundational science that defines position & height

Why is Geodesy important?



The Earth is an irregular surface and is difficult to model. Accurate positions are required for a wide variety of applications

(e.g. monitoring climate change impacts/sea level change)

What is a Datum?

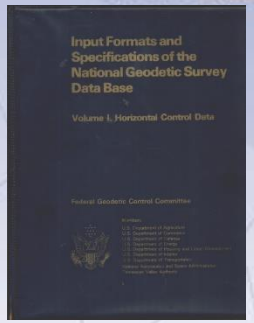
- "A set of constants specifying the coordinate system used for geodetic control, i.e., for calculating the coordinates of points on the Earth."
- "The datum, as defined above, together with the coordinate system and the set of all points and lines whose coordinates, lengths, and directions have been determined by measurement or calculation."
- NGS has used the first definition for NAD83

FAQs…

- What needs to be changed?
  - All horizontal datums and vertical datums in the NSRS
    - NAD 83 , NAVD 88 , PRVD02, etc
- Why do the datums need to be changed?
  - Predominantly to keep up with technology.
    - Global proliferation of real time cm-accuracy positioning is *rapidly* approaching.
      - Many surveying, mapping and navigation professionals already enjoy this accuracy.
    - The current datums have systematic errors exceeding 1 meter.
- When will the changes take place?
  - No later than December 31, 2022
- Will the changes be immediate or gradual?
  - Immediate

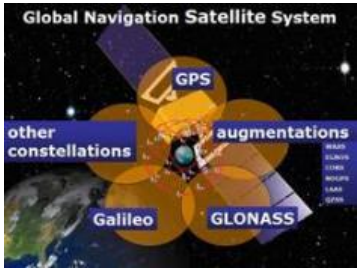
FAQs cont…

- What will be impacted?
  - Every historic position (on a map, chart, survey, etc) with an assumed accuracy of better than 1 meter will become obsolete
    - Transformations will exist before 2022 to help
  - Every piece of navigating, mapping and surveying software will require updates.
    - NGS is working with industry to get ahead of this
- What tools will be available to assist with the conversion between new and historic datums?
  - There will be digital products available to transform from old to new and are found on **Geodesy.noaa.gov** web page.



New Reference Systems Planned for 2022

- Replace NAD83 with an updated geocentric reference frame
- GNSS based
- Replace NAVD88 with a gravity based geoid



- Replace: bluebooking, database
- improve toolkit, surveying methodologies.

NSRS … do I have to use it?

- Office of Management and Budget: Circular A-16
  1) requires all Federal civilian agencies to utilize geodetic control for their geospatial activities
  2) Defines DoC & NOAA (NGS) in responsible charge of that control
  3) NGS has defined that control as the NSRS
  4) FGCS has issued requirements, via FRNs, to reference data to the ***most recent components*** of the NSRS
     - 1989 FRN designated NAD 83
     - 1993 FRN designated NAVD 88

Federal Users of the NSRS

Summary: The NSRS in 2022…

- Four semi-dynamic reference frames
- Geoid/GPS based vertical datum
- All data will be time tagged but defined at an epoch.
- All coordinates maintained in the NSRS will come from GNSS surveys.

GEODETIC DATUMS

VERTICAL

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

HORIZONTAL

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

GEOMETRIC

3 D (Latitude, Longitude and Ellipsoid Height)

Fixed and Stable - Coordinates seldom change

(e.g. NAD 83 (1994), NAD 83 (2007), NAD83 (2011))

also

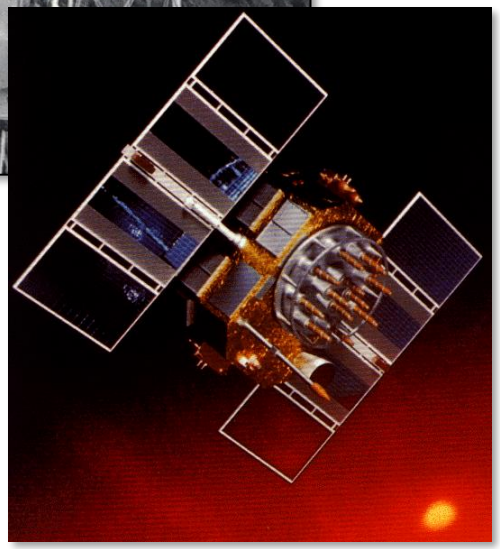
4 D (Latitude, Longitude, Ellipsoid Height, Velocities)
Coordinates change with time

(e.g. ITRF00, ITRF05, ITRF08)

U.S. Horizontal Datums

A (very) brief history of NAD 83

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

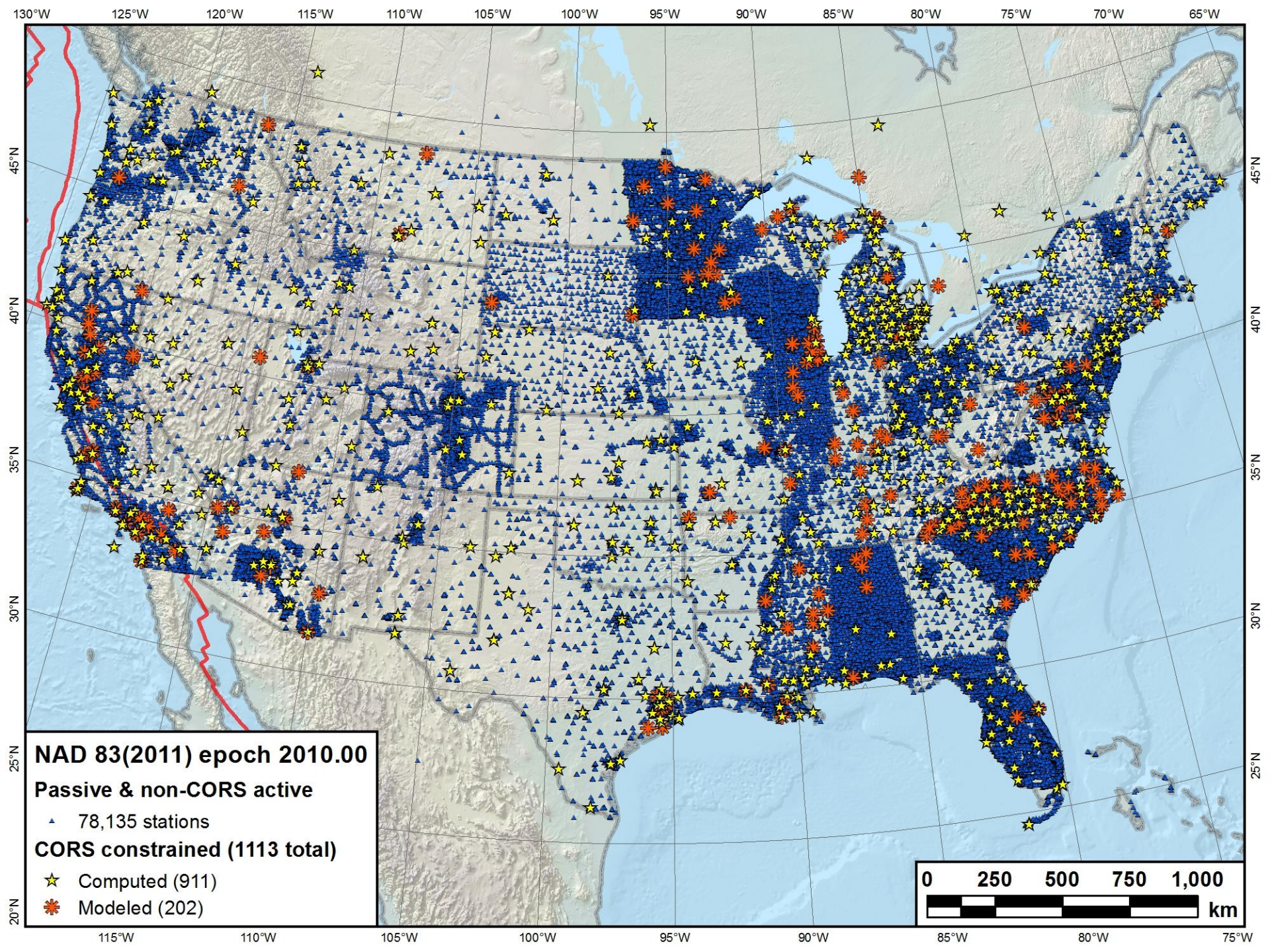


Why change datums/realizations

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

National Spatial Reference System(NSRS) Improvements in the Horizontal Datums

NETWORK	TIME SPAN	NETWORK ACCURACY	LOCAL ACCURACY
NAD 27	1927-1986	10 meter	(1 part in 100,000)
NAD83(86)	1986-1990	1 meter	(1 part in 100,000)
NAD83(199x)* HARN	1990-2007	0.1 meter	B-order (1 part in 1 million) A-order (1 part in 10 million)
NAD83(2007) (CORS)	2007 - 2011	0.01 meter	0.01 meter
NAD83(2011) (CORS)	2011 - 2022	0.01 meter	0.01 meter


130°W
125°W
120°W
115°W
110°W
105°W
100°W
95°W
90°W
85°W
80°W
75°W
70°W
65°W
45°N
40°N
35°N
30°N
25°N
20°N
NAD 83(2011) epoch 2010.00
Passive & non-CORS active
78,135 stations
CORS constrained (1113 total)
Computed (911)
Modeled (202)
0
250
500
750
1,000
km

Why Replace NAD83?

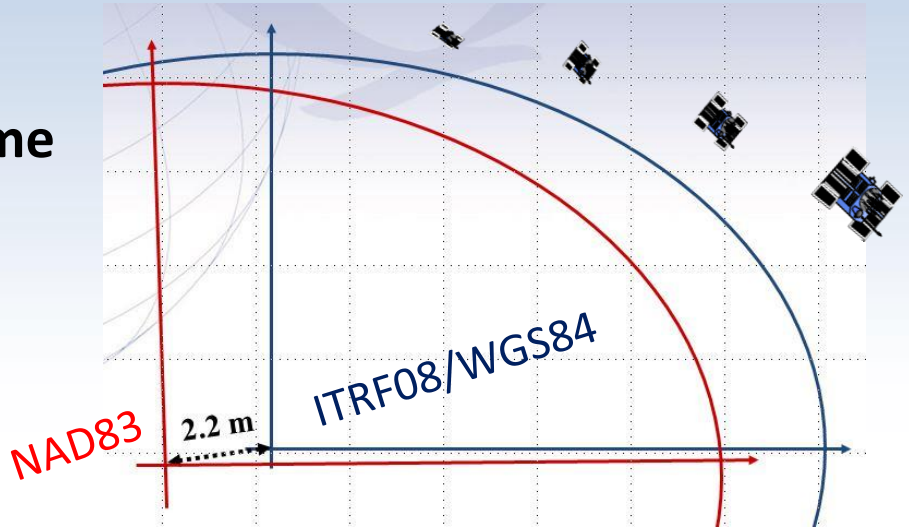
- NAD83 is NON-geocentric & hence inconsistent w/GNSS
- Difficult to maintain consistency between CORS & passive networks
- NAD 83 does not track/report passive mark motion
- Lack of monumentation stability / permanency
- Necessary for agreement with future ubiquitous positioning capability

North American Datum 1983 (NAD83) Shortcomings

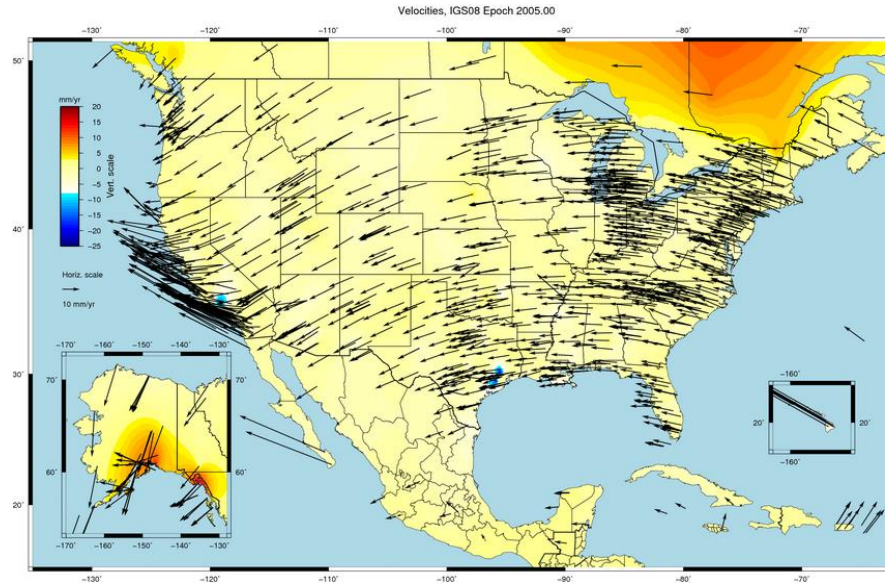
- Inconsistency of NAD83 vs.

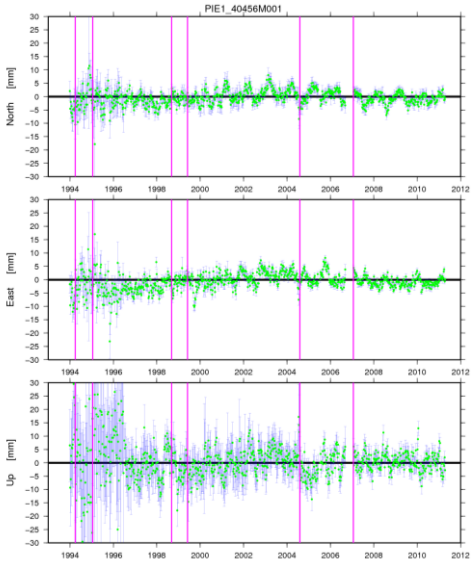
- International Terrestrial Reference Frame [ITRF08]

- World Geodetic System 1984 [WGS84 (G1762)]

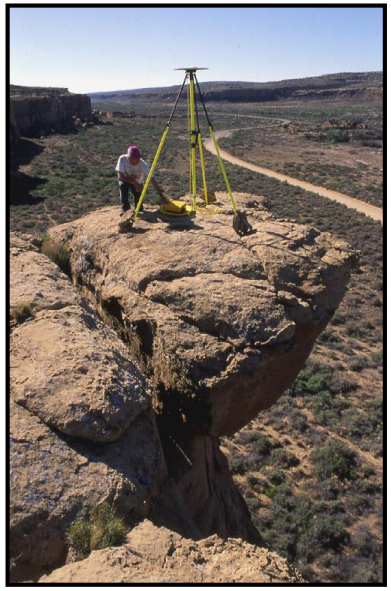


- CORS & passive network inconsistency / challenges





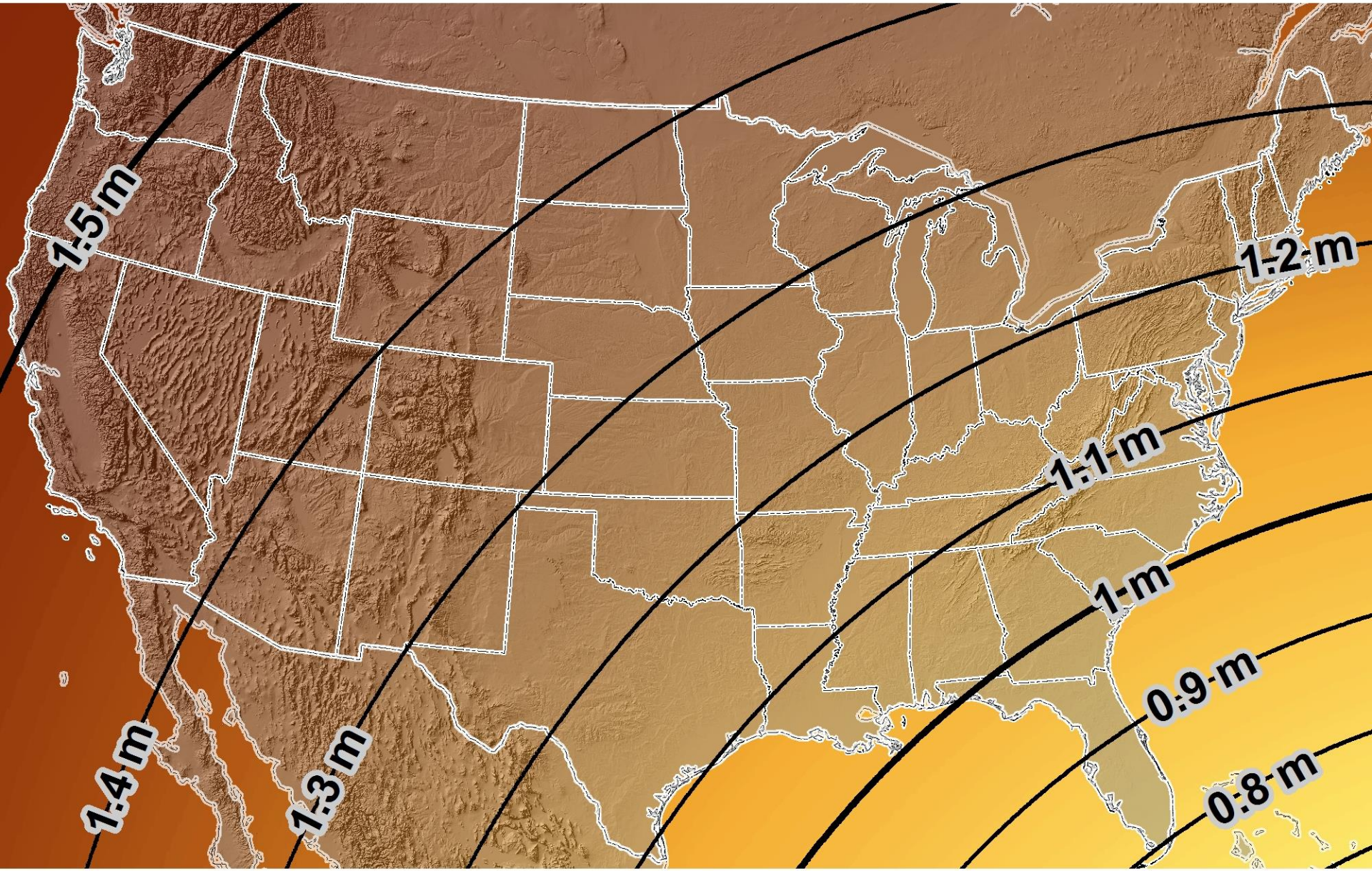
VS.



Future Geometric (3-D) Reference Frame

- Replace NAD83 with new geometric reference frame – 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 will relate NAD83 to new US reference frame (NADCON / GEOCON / GEOCON11 / …..)
    - NCAT – NGS Coordinate Conversion and Transformation Tool

Estimated horizontal change from NAD 83 to new geometric datum



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

U.S. Vertical Datums

History of vertical datums in the USA

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


NGVD29
The National Geodetic Vertical Datum of 1929 is referenced to 26 tide gauges in the US and Canada
Prince Rupert
Fort Stephens
San Francisco
San Diego
Galveston
Biloxi
Pensacola
Fernandina Beach
Brunswick
St. Augustine
Cedar Keys
Norfolk
Perth Amboy
Boston
Portland
Yarmouth
Halifax
Father's Point
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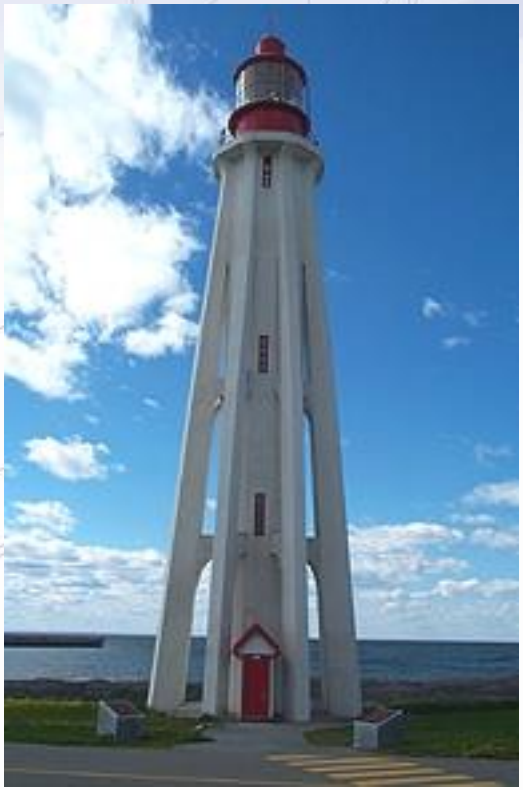
Google

Current Vertical Datum in the USA



Father Point Lighthouse, Quebec

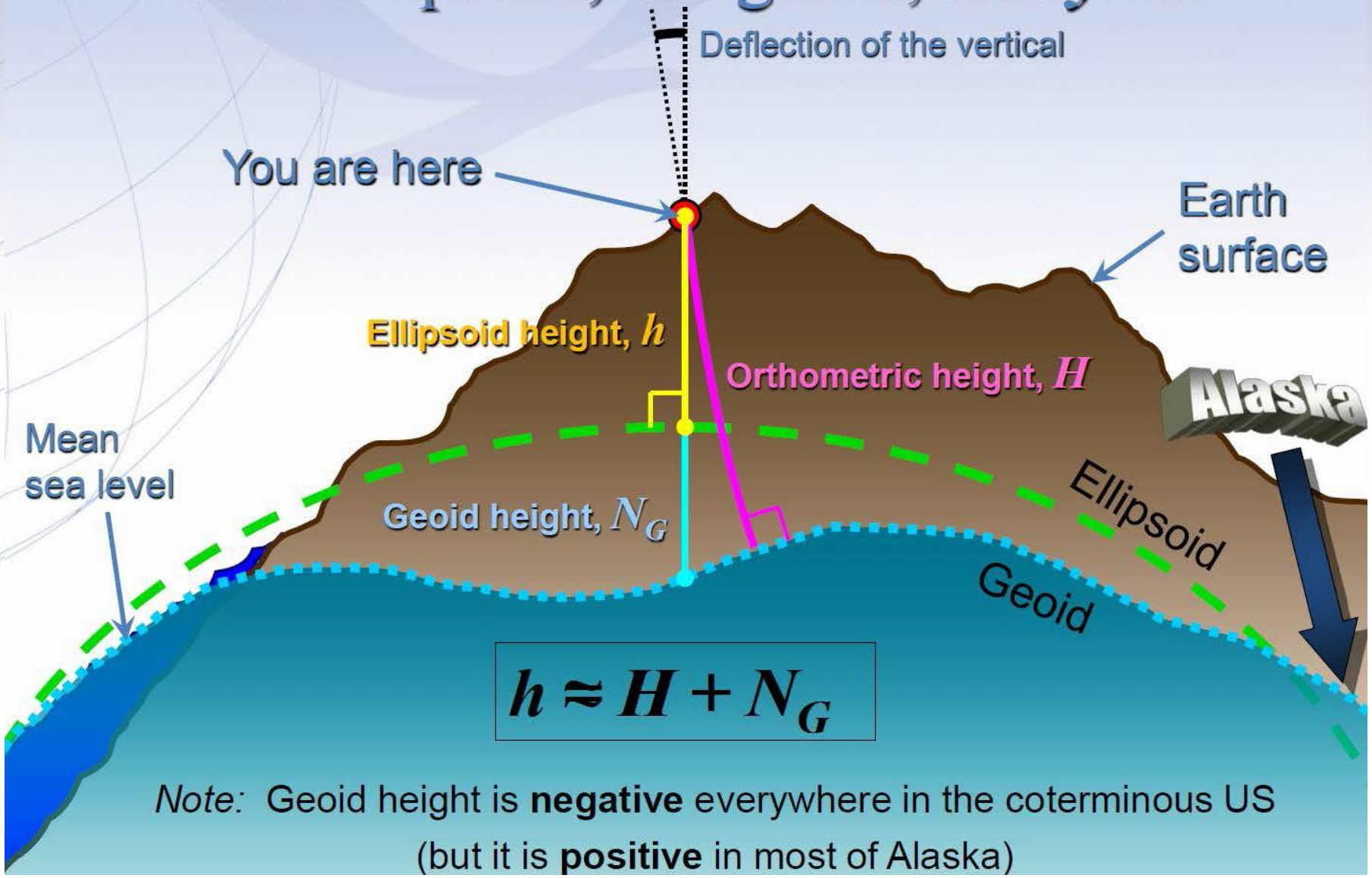
- **NAVD 88**: North American Vertical Datum of 1988
- ***Definition:*** The surface of equal gravity potential to which orthometric heights shall refer in North America*, and which is 6.271 meters (along the plumb line) below the geodetic mark at "Father Point/Rimouski" (NGSIDB PID TY5255).
- ***Realization:*** Over 500,000 geodetic marks across North America with published Helmert orthometric heights, most of which were originally computed from a minimally constrained adjustment of leveling and gravity data, holding the geopotential value at "Father Point/Rimouski" fixed.

**Not adopted in Canada*

History of vertical datums in the USA

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

The ellipsoid, the geoid, and *you*



Note: Geoid height is **negative** everywhere in the coterminous US (but it is **positive** in most of Alaska)

Which Geoid for Which NAD 83?

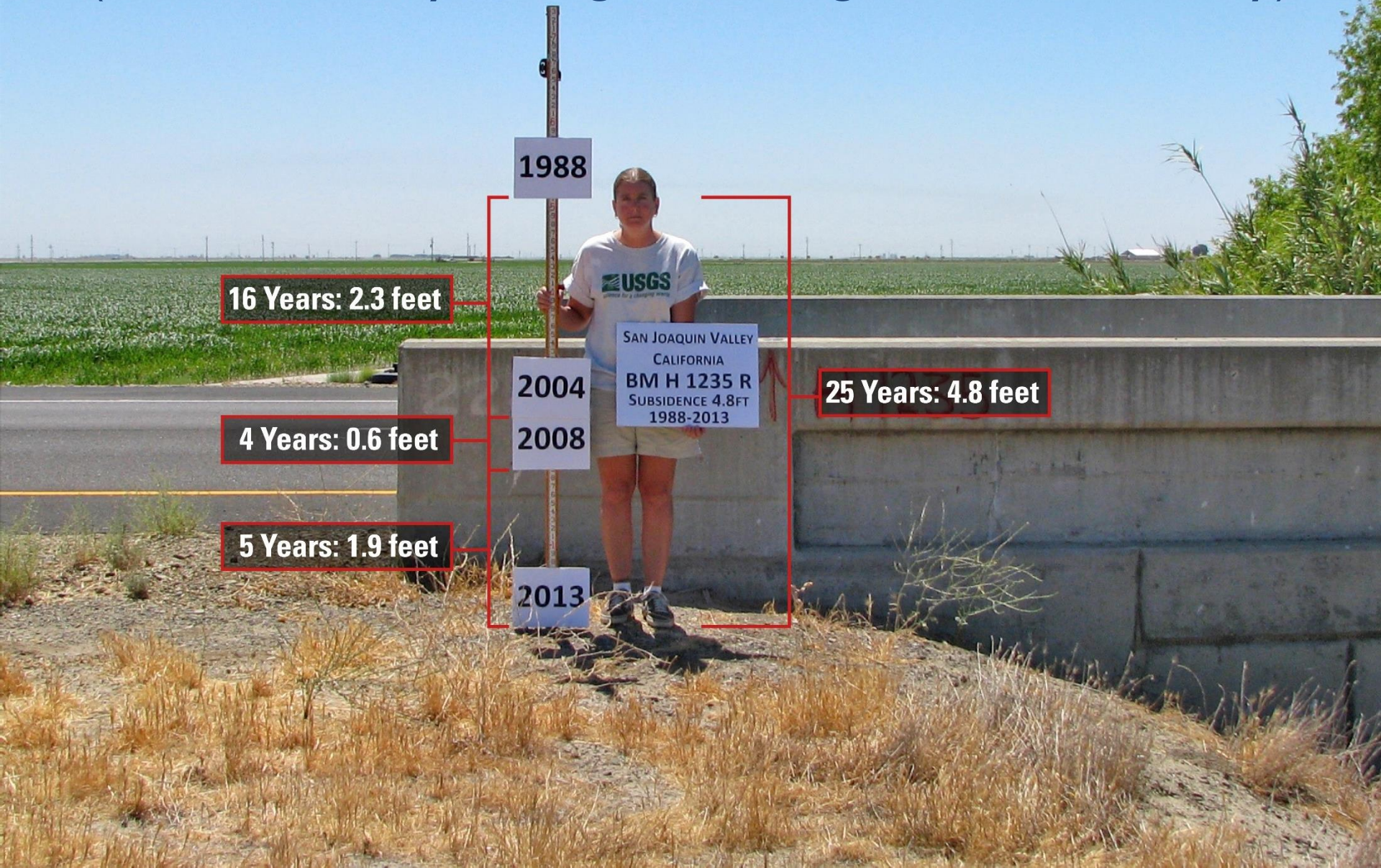
- NAD 83(2011)
- NAD 83(2007)
- NAD 83(1996) & CORS96

- Geoid12A/12B
- Geoid09
- Geoid06 (AK only)
- Geoid03
- Geoid99
- Geoid96

Problems with NAD 83 and NAVD 88

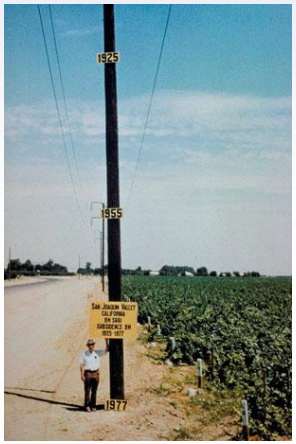
- **NAD 83** is not as geocentric as it could be (approx. 2 m)
  - Positioning Professionals don't see this - **Yet**
- **NAD 83** is not well defined with positional velocities
- **NAVD 88** is realized by passive control (bench marks) most of which have not been re-leveled in at least 40 years.
- **NAVD 88** does not account for local vertical velocities (subsidence and uplift)
  - Post glacial isostatic readjustment (uplift)
  - Subsurface fluid withdrawal (subsidence)
  - Sediment loading (subsidence)
  - Sea level rise

Passive marks may lie still… but they still may lie!
(small instability x long time = significant inaccuracy)



Why isn't NAVD 88 good enough anymore?

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



Can NAVD 88 be fixed?

- Long term fix: **Re-level some/all of NAVD 88**
  - –81,500 km of 1st order leveling at least
  - –625,000 km of mixed 1st and 2nd order leveling
- Re-leveling NAVD 88 estimated to cost between ***$200 Million*** and ***$2 Billion***
- Time factor in that amount of leveling
- Still would have problems related to passive control

NEW VERTICAL DATUM (Rationale)

- A move away from differentially leveled passive control as the defining mechanism of the reference surface
- To be consistent with the shift in the geometric reference frame/ellipsoid (2022)
- Improvement in our technical abilities in reference surface realization (geopotential gravimetric reference surface - 1cm accuracy of the geoid *(GNSS/GRAV-D)*)
- **Goal** - ability to establish 2cm orthometric height anywhere in U.S. using a minimum of 15 min. of GNSS data.
- The new geopotential reference surface will be aligned with the geometric reference frame/ellipsoid (i.e., no hybrid geoid)

Why replace NAVD 88 and NAD 83?

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

The National Geodetic Survey 10 year plan Mission, Vision and Strategy 2008 – 2018, 2013-2023

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

- *Official NGS policy as of Jan 9, 2008*
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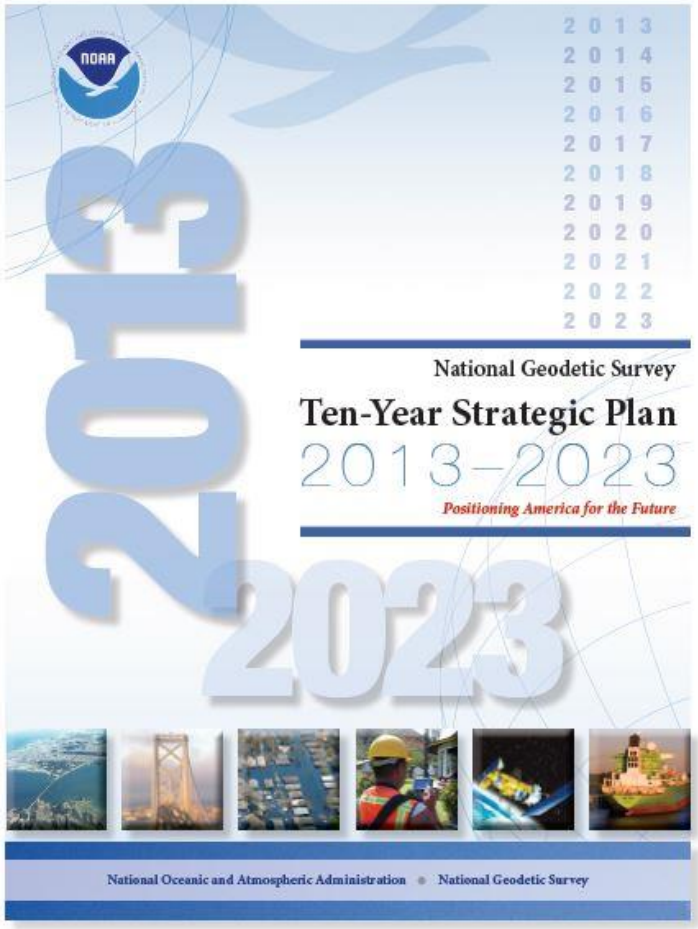
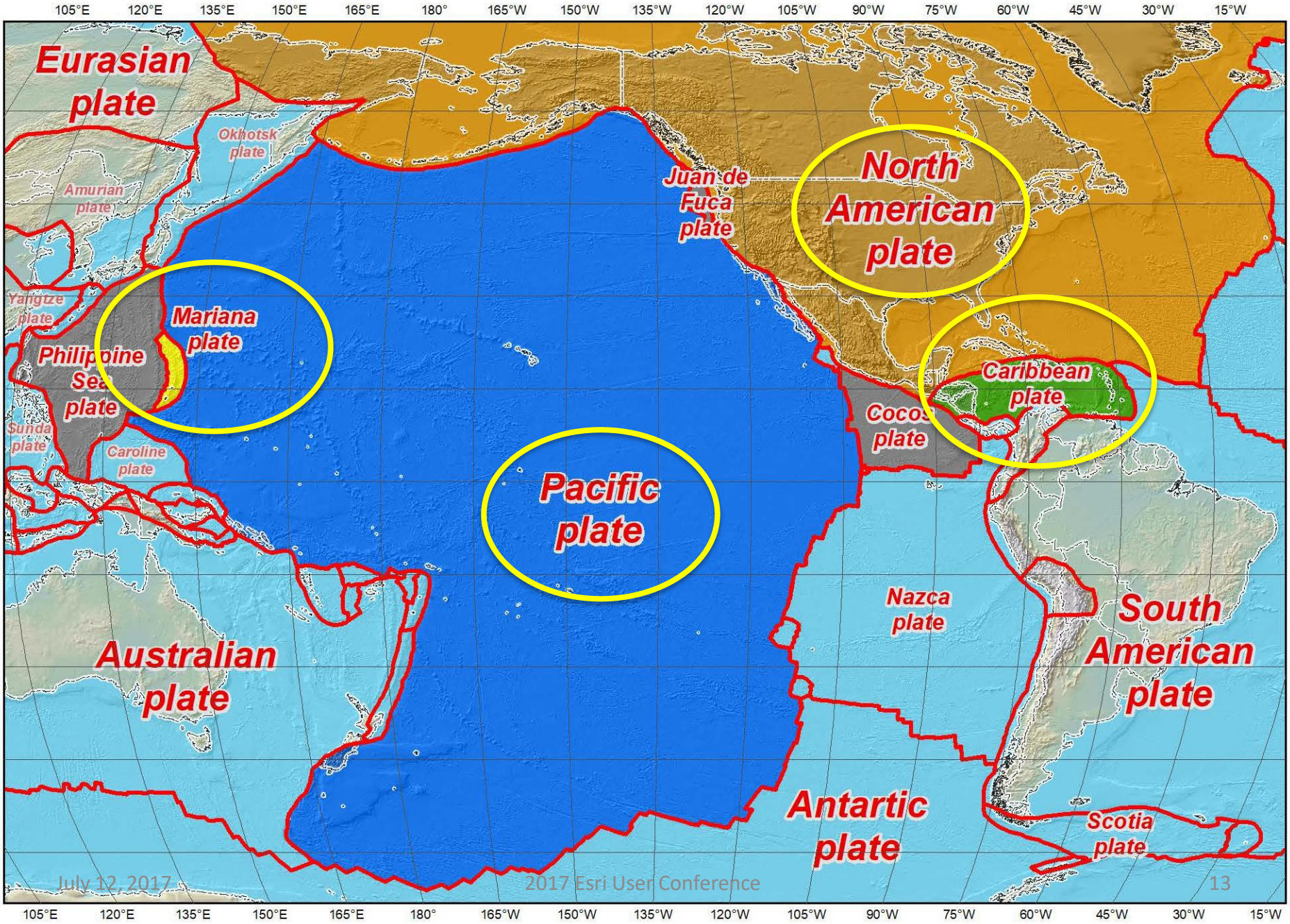


Scientific Decisions

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

Four Frames/Plates in 2022



Names (Geometric)

The Old:

NAD 83(2011)

NAD 83(PA11)

NAD 83(MA11)

The New:

The North American Terrestrial Reference Frame of 2022 (NATRF2022)

The Caribbean Terrestrial Reference Frame of 2022 (CATRF2022)

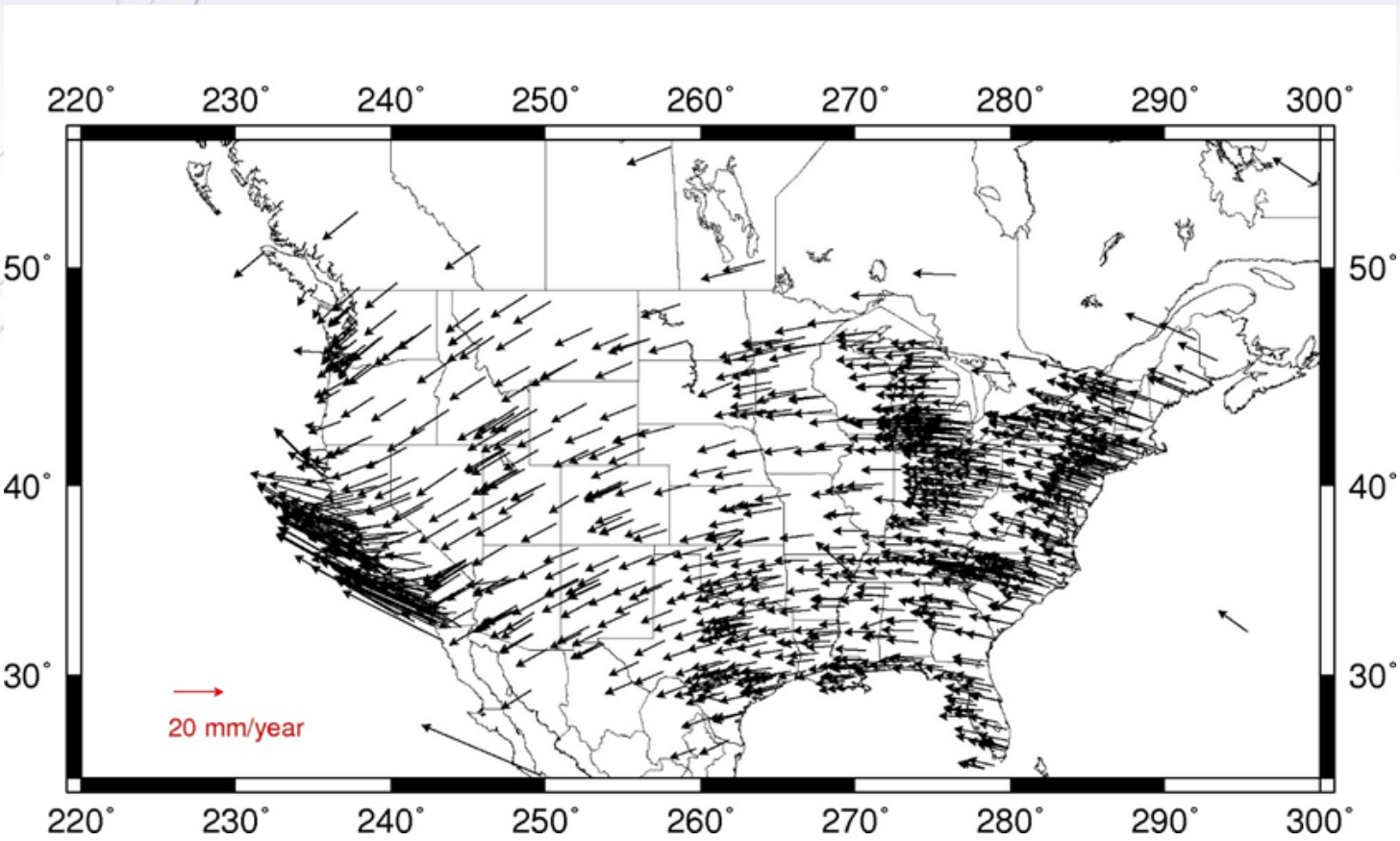
The Pacific Terrestrial Reference Frame of 2022 (PATRF2022)

The Mariana Terrestrial Reference Frame of 2022 (MATRF2022)

Future Geometric Reference Frame

- CORS-based, via GNSS
- coordinates & velocities in ITRF and official US datum
- four plate-fixed Terrestrial Reference Frames
  - and what "plate fixed" means
- replace NAD 83 with new geometric reference frame – by 2022
- passive control tied to new datum; not a component of new datum
- lat / long / ellipsoid height of defining points accurate to 1 mm, anytime
- CORS coordinates computed / published; track changes
- support development and validation of real-time networks

The "drift": *Annual* change to ITRF2014 coordinates

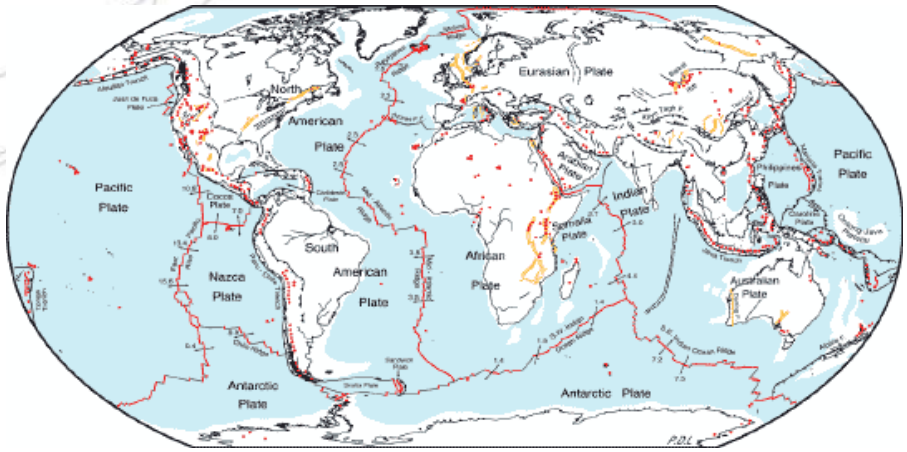


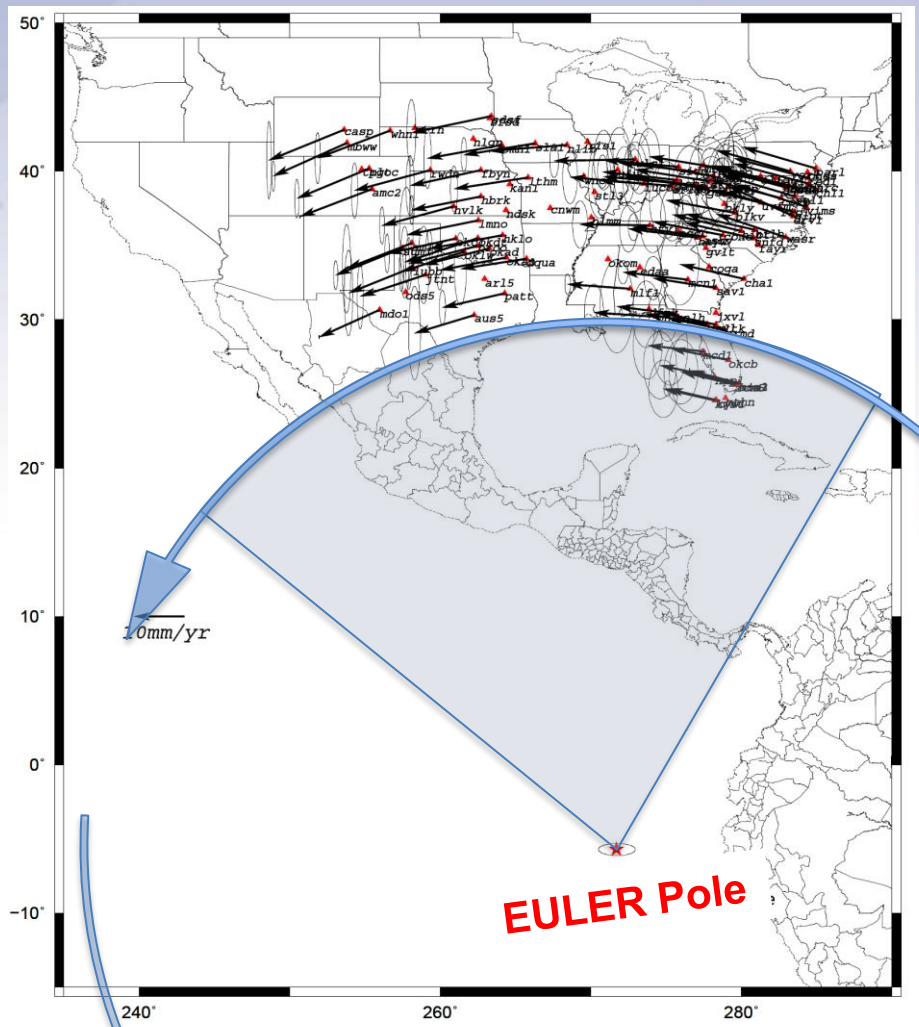
Euler Pole

Each reference frame will get:

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

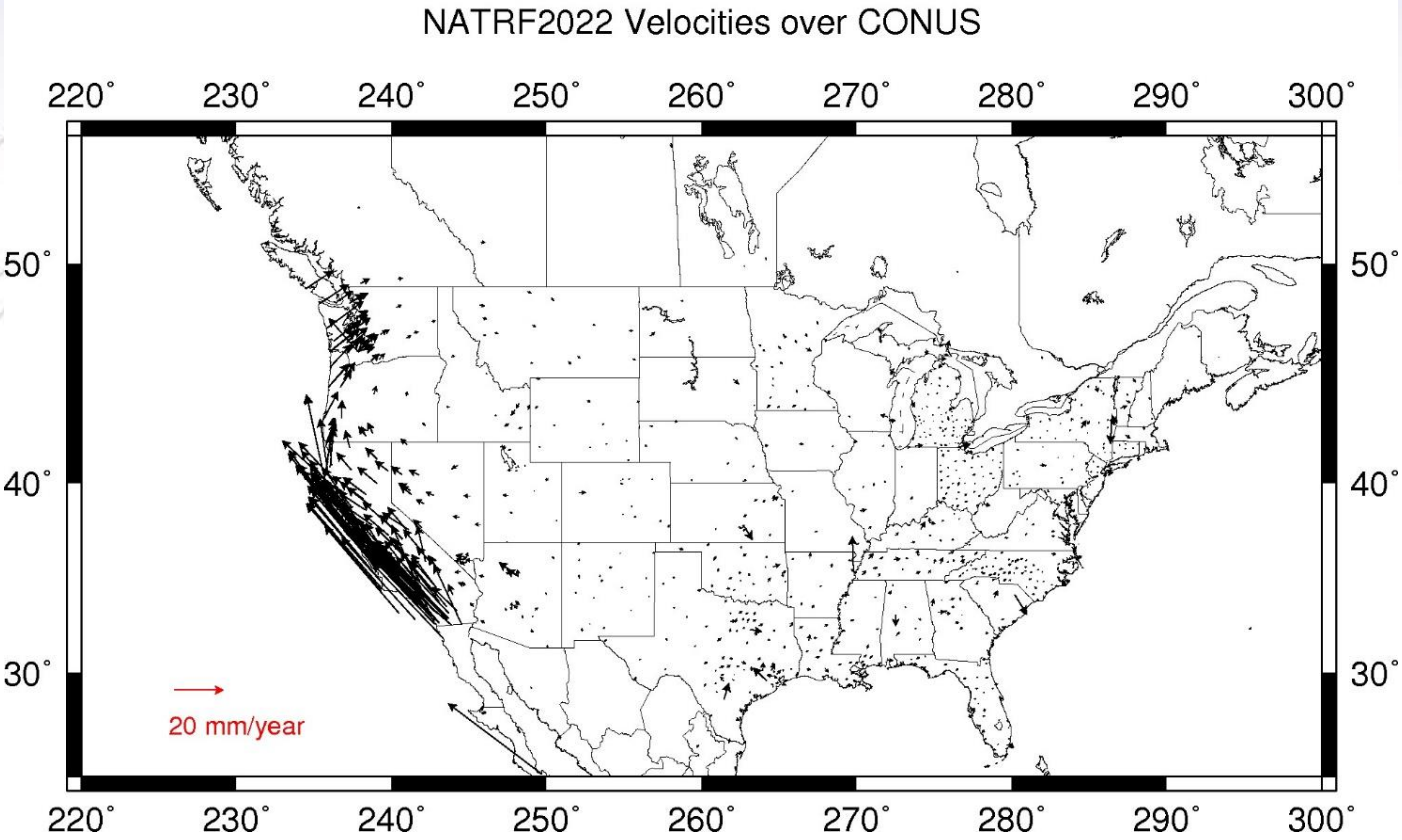
Used to compute time-dependent TRF2022 coordinates from time-dependent global (IGS) coordinates





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 "drift": *Annual* change to NATRF2014 coordinates



Scientific Decisions!!

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

Replacing NAVD 88

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

The New:

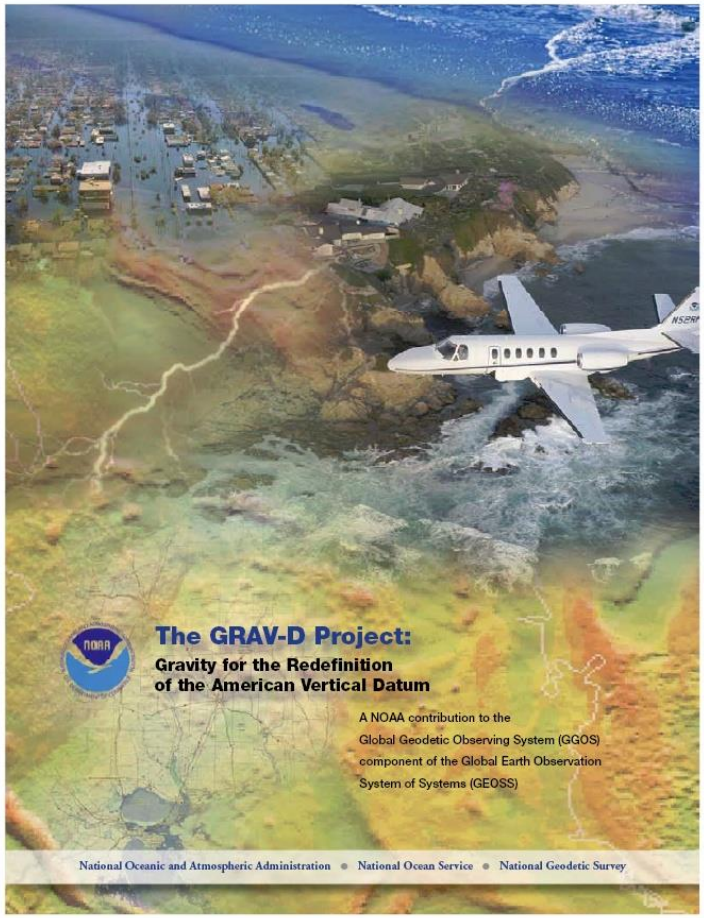
The North American-Pacific ***Geopotential Datum*** of 2022 (NAPGD2022)

- Will include GEOID2022

Future Geopotential Reference Frame

- replace NAVD88 with new geopotential reference frame – by 2022
- gravimetric geoid-based, in combination with GNSS
- monitor time-varying nature of gravity field
- develop transformation tools to relate to NAVD88
- build most accurate ever continental gravimetric geoid model (GRAV-D)
- support both orthometric and dynamic heights
- Height Modernization is fully supported

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



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

- Replace the Vertical Datum of the USA by 2022 (at today's funding) with a **gravimetric geoid accurate to 1 cm**
- Orthometric heights accessed via GNSS accurate to 2 cm
- Three thrusts of project:
  - Airborne gravity survey of entire country and its holdings
  - Long-term monitoring of geoid change
  - Partnership surveys
- Working to launch a collaborative effort with the USGS for simultaneous magnetic measurement

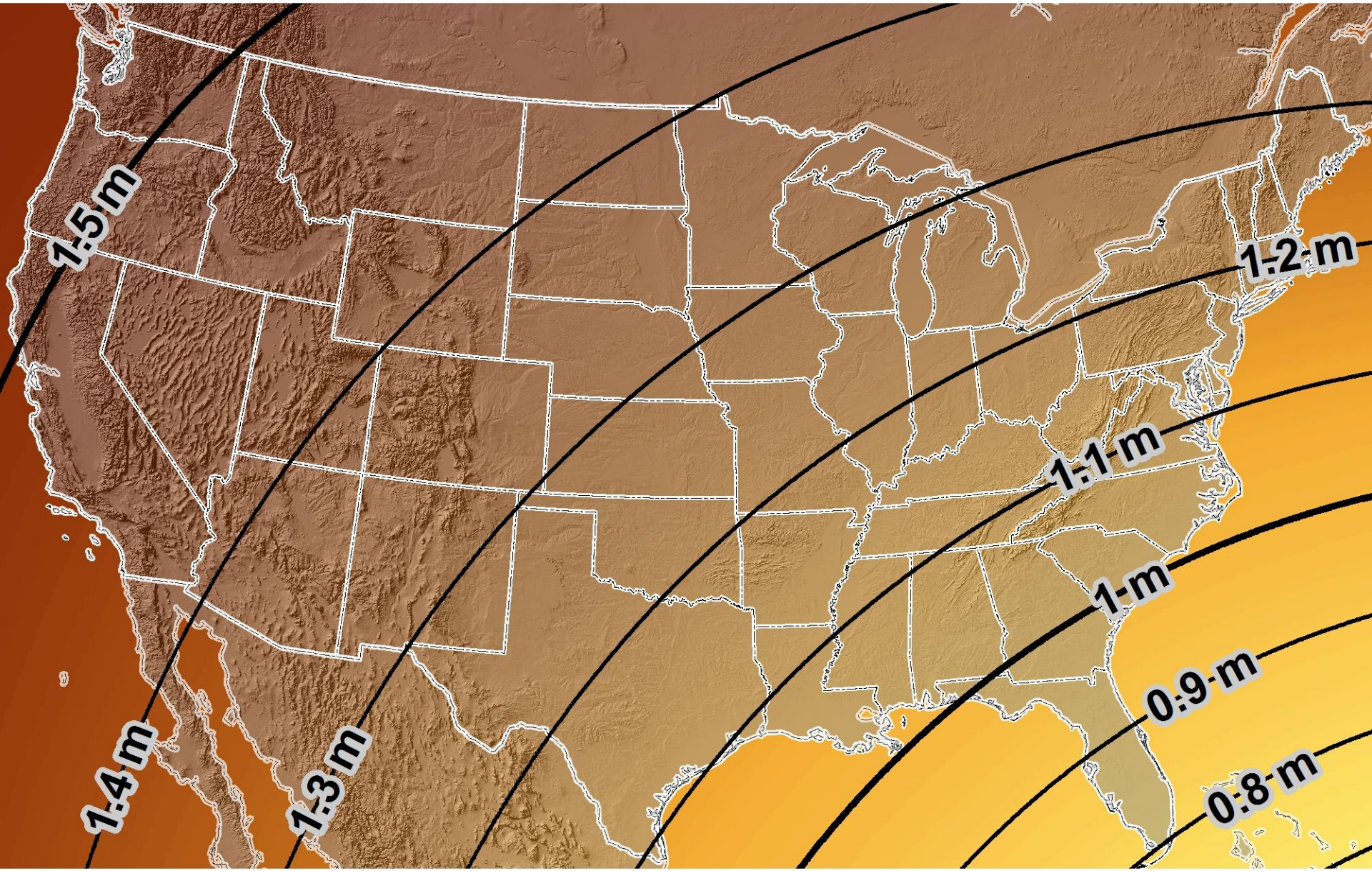
What is GRAV-D?

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

Accessing the New Datums

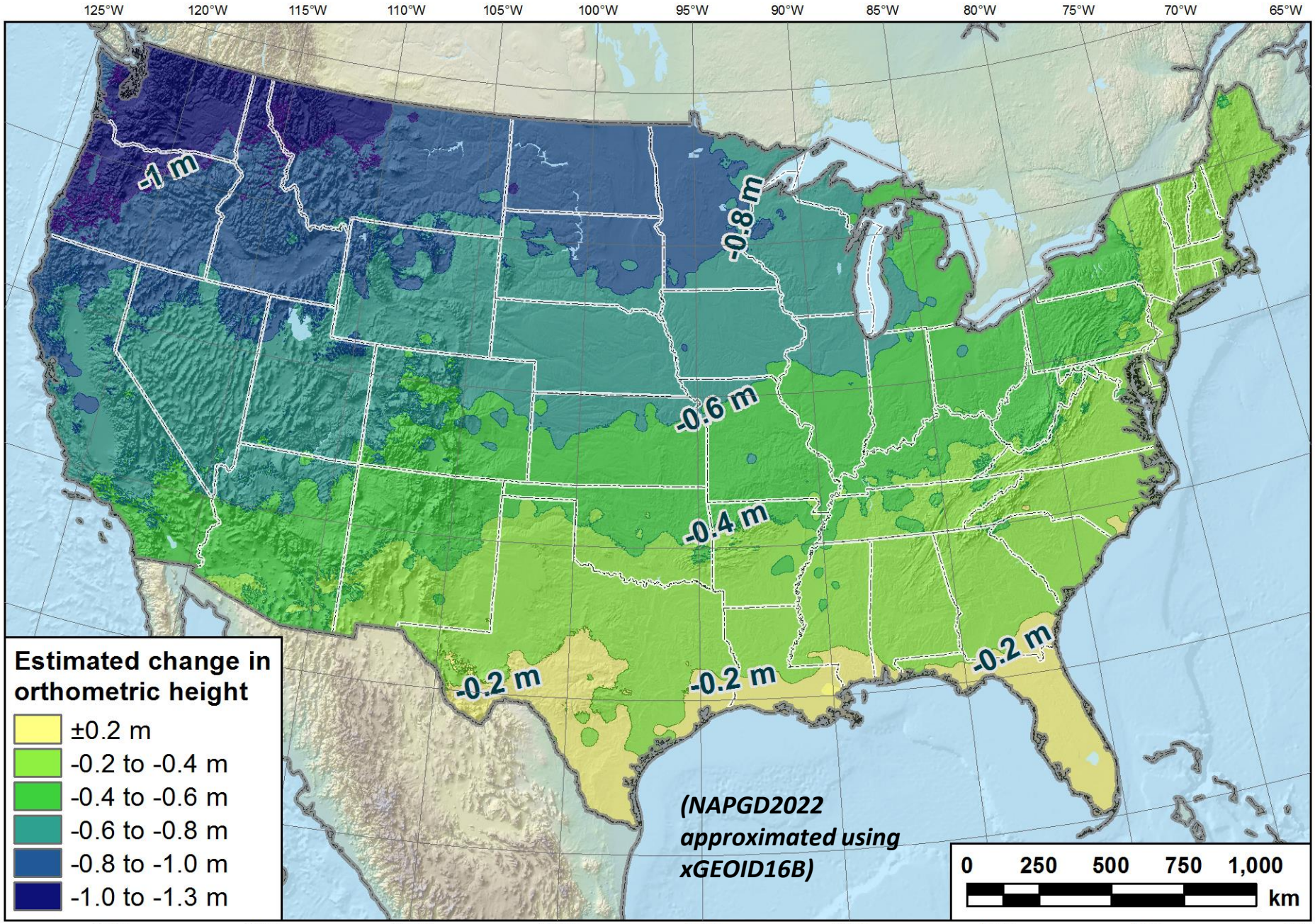
- **NAD 83 conversion to new datum**
  - A transformation will be provided
- **NAVD 88 conversion to new datum**
  - A transformation will be provided (VERTCON)
    - Only where recent GNSS ellipsoid heights exist to provide modern heights in the new datum

Estimated horizontal change from NAD 83 to new geometric datum



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

Estimated change in orthometric heights from NAVD88 to **NAPGD2022**



Predicted Positional Changes in 2022
Vicinity of Irmo, SC.

(Computed for station SURVEYS, pid EC2938)

HORIZONTAL = 1.04 m (3.41 ft)
ELLIPSOID HEIGHT = - 1.39 m (- 4.56 ft)
Predicted with HTDP

ORTHOMETRIC HEIGHT = - 0.30 m (- 0.98 ft)
Predicted with HTDP and xGEOID18B

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

Preparing for New Reference Frames

How to Plan for 2022

- **Move to newest realizations**
  - NAD 83(2011) epoch 2010.00
- **Move to NAVD 88**
- **Utilize passive marks that are up to date**
  - Stay aware of what marks are included in datum updates
  - Use OPUS & Hgt. Mod procedures to update mark positions
- **NGS Outreach Efforts**
  - Participate in NGS webinars, Geospatial summits, contact NGS Regional Advisor, etc.

Metadata is Critical

- Your positional metadata should include:
  - datum
  - epoch
  - source / methods
- These will facilitate transforming from current to new datum
- Maintaining your original survey data will provide more accurate results

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Sign up to receive these announcements.

Website Owner: National Geodetic Survey / Last modified by Vicki.Veilleux May 16 2017

Update on NGS Products

NADCON - Historical Overview

1989 : NAD 83(1986) released

1990: NADCON v1.0 released: NAD27 <--> NAD83 (86)

1990-1997: NADCON v2.1 NAD27 <--> NAD83 (HARN)

DOS based program, PC based

1997-2005: NADCON v2.1 NAD27 <--> NAD83 (HARN / FBN)

Only 19 states had significant shifts from HARN to FBN

Program expanded to handle FBN changes

Program still DOS / PC based

2004: NADCON v4.2 SAME TRANSFORMATIONS

Efforts made to improve NADCON, JAVA based / Windows driven menus

Program expanded to handle FBN changes

What is NCAT?

NGS Coordinate Conversion and Transformation Tool

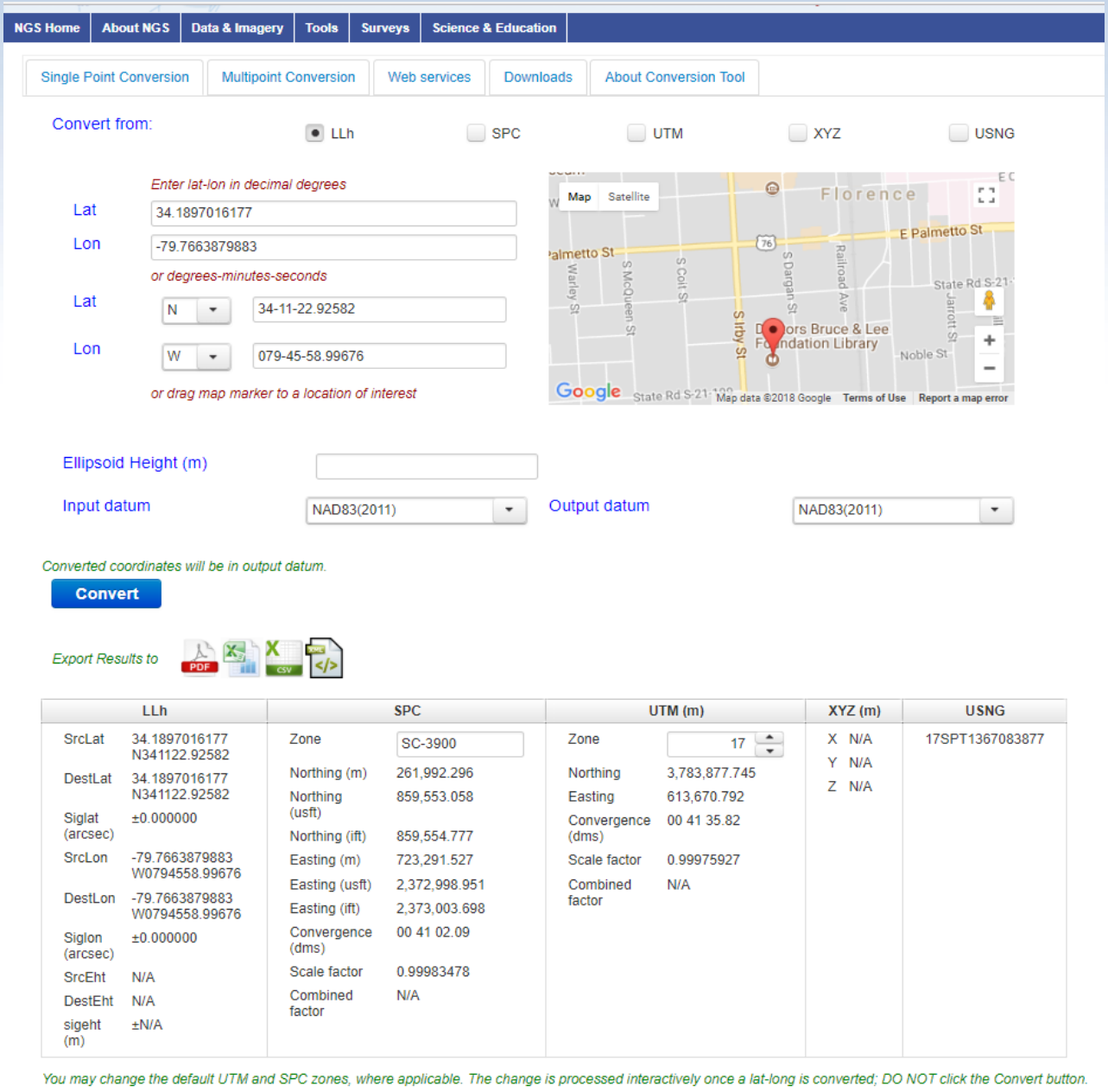
Transformations and error estimates for any point within a regional boundary, provided through biquadratic interpolation off of a grid

- Lat/lon in arcseconds
- Ellipsoidal height in meters

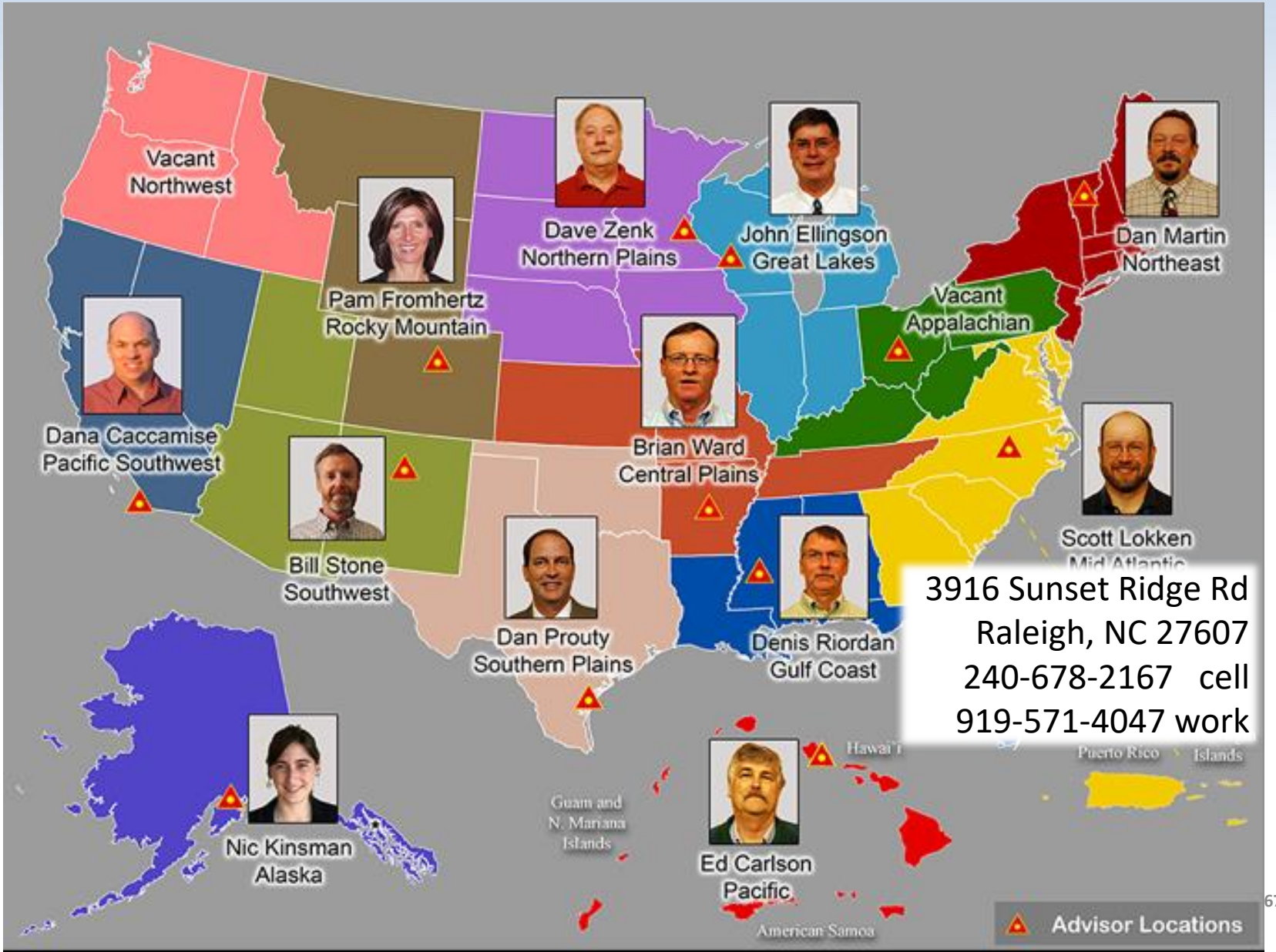
How?

- Fresh pull of IDB
- New suite of analysis tools
- New grids from scratch
- No realizations skipped
- Make available through Geodetic Toolkit

NCAT in the Geodetic Toolkit



NGS Regional Geodetic Advisors



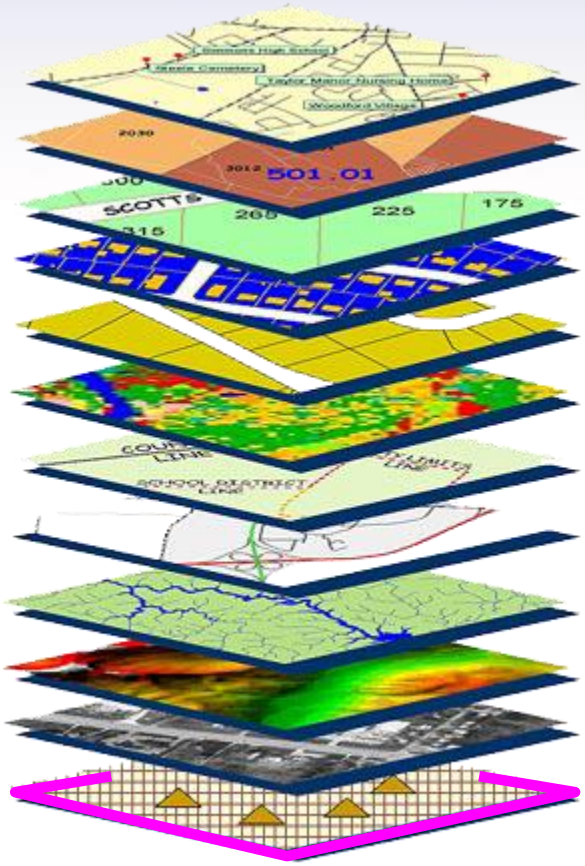
3916 Sunset Ridge Rd
Raleigh, NC 27607
240-678-2167 cell
919-571-4047 work

Accurate positioning begins with *accurate* coordinates

geodetic control (the NSRS) is the foundation for all geospatial products.

without Geodetic Control as a "base map" layer, GIS applications will not work properly

Source: Zurich-American Insurance Group



Thank You!

Matt Wellslager
SC Geodetic Survey
Matt.Wellslager@rfa.sc.gov
803.896.7715 – Office
803.528.4857 - Mobile