NGS Onward to 2022: Replacing NAD83 & NAVD88

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

Dana Caccamise
Pacific Southwest Region (CA, NV) Geodetic Advisor
dana.caccamise@noaa.gov

CLSA 2018 Conference
March 27
Sacramento

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

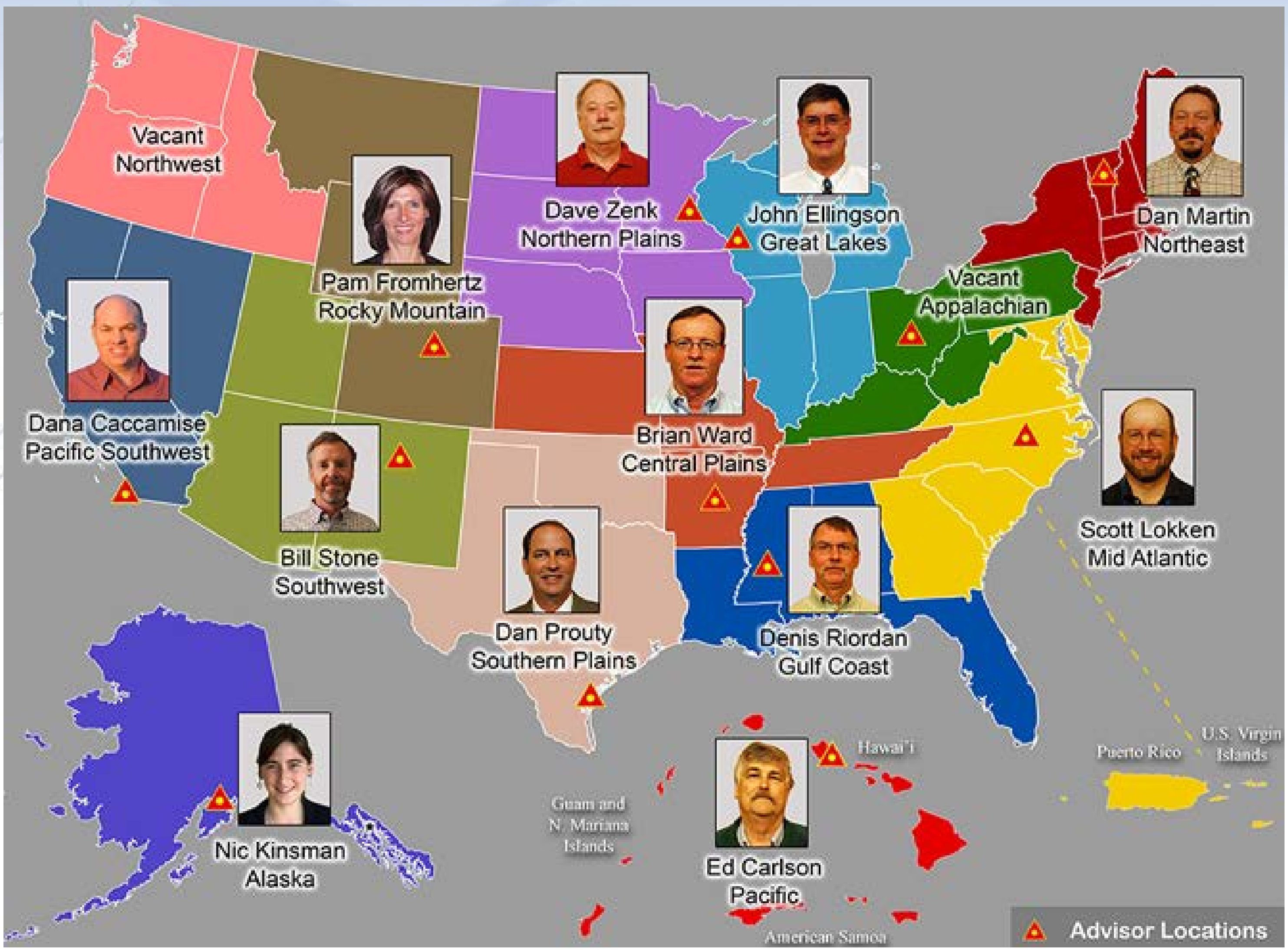
- **Latitude**
- **Longitude**
- **Height**
- Gravity
- Orientation
- Scale

& their time variations

(& National Shoreline, etc.)

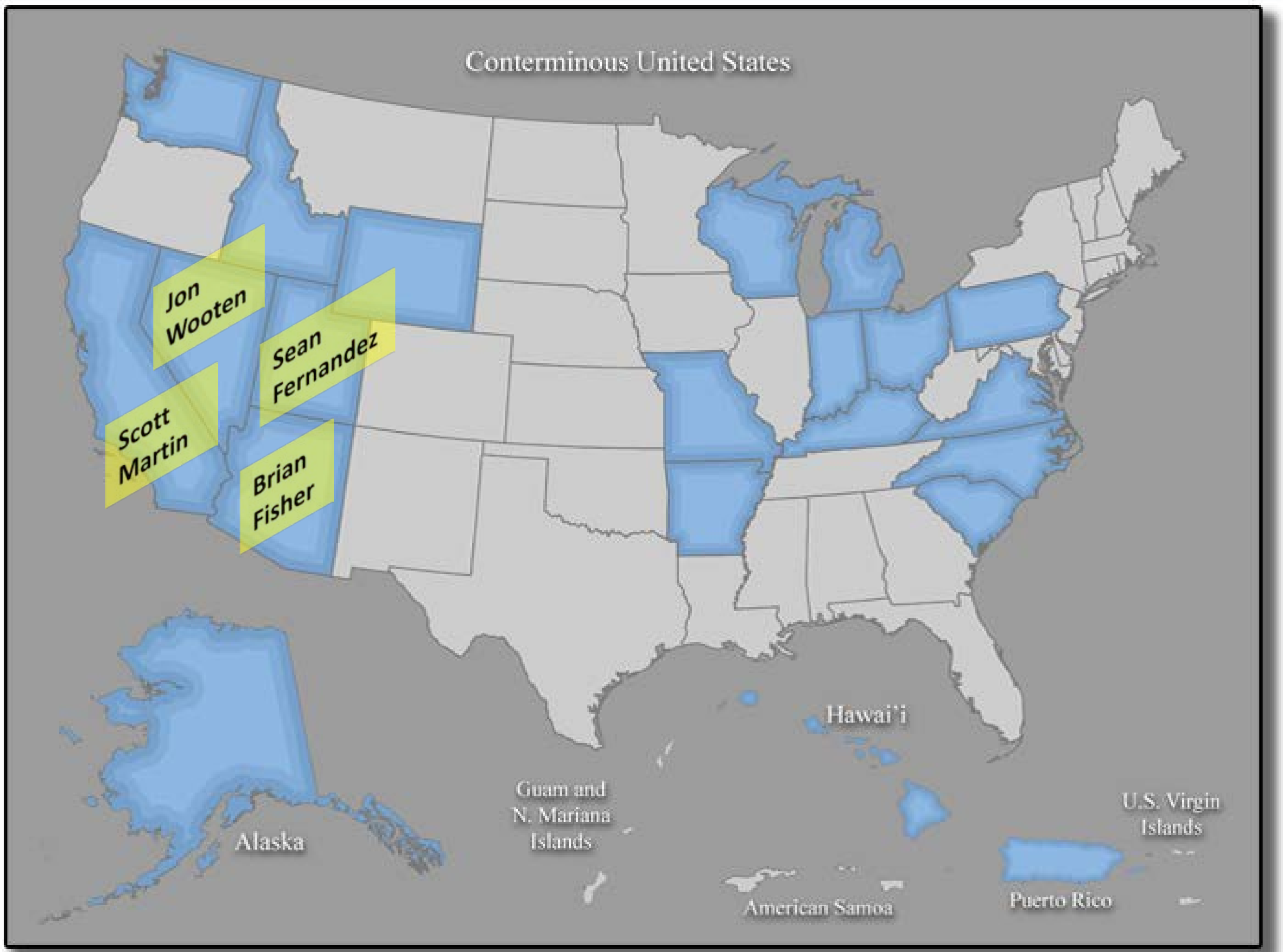
- North American Datum of 1983 (NAD83)
- North American Vertical Datum of 1988 (NAVD88)

National Geodetic Survey – Regional Geodetic Advisors



https://geodesy.noaa.gov/ADVISORS/index.shtml

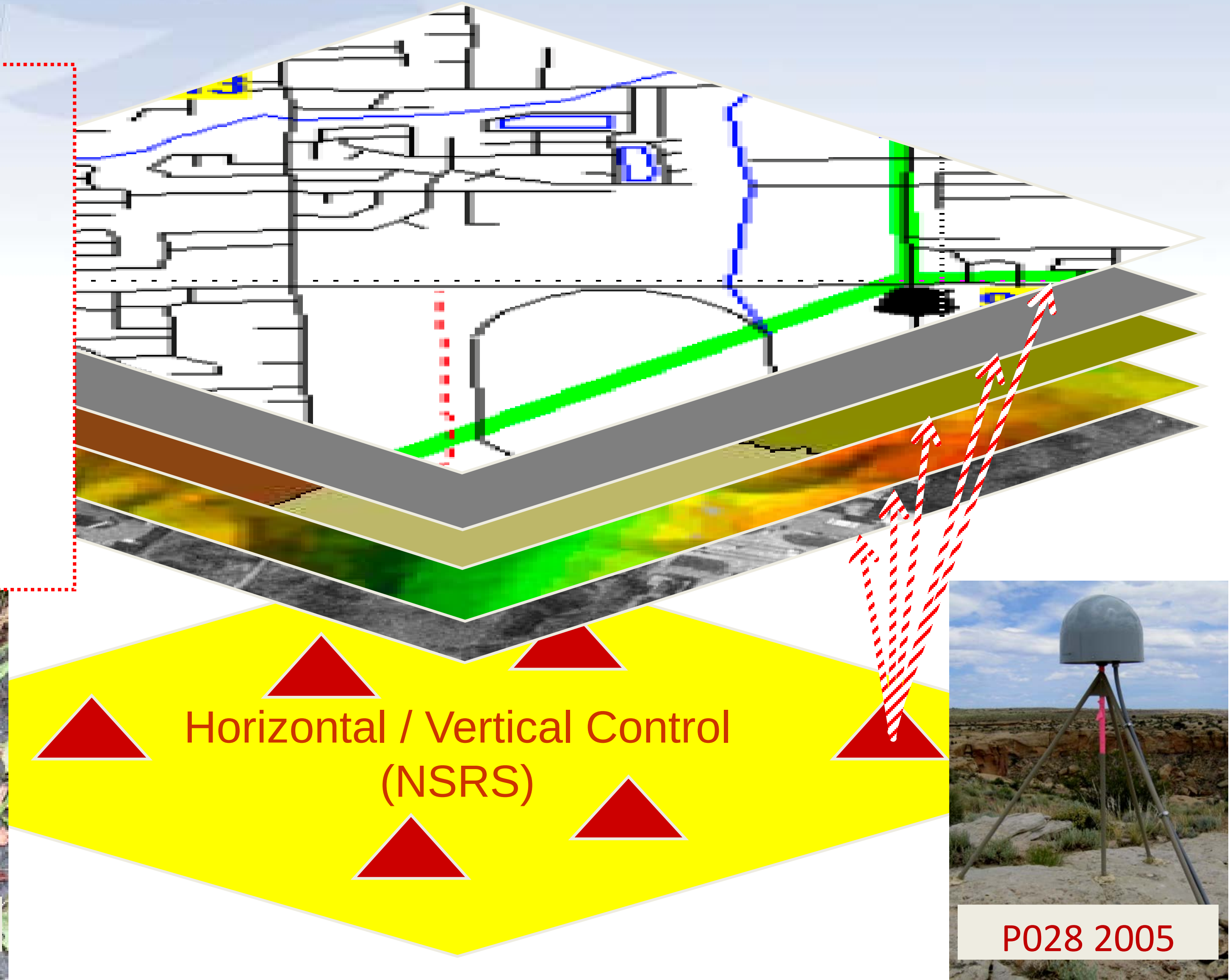
National Geodetic Survey – State Geodetic Coordinators



https://geodesy.noaa.gov/ADVISORS/state-geodetic-coordinators.shtml

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



P028 2005

BUTTERMILK 1833

A New State Plane Coordinate System for 2022

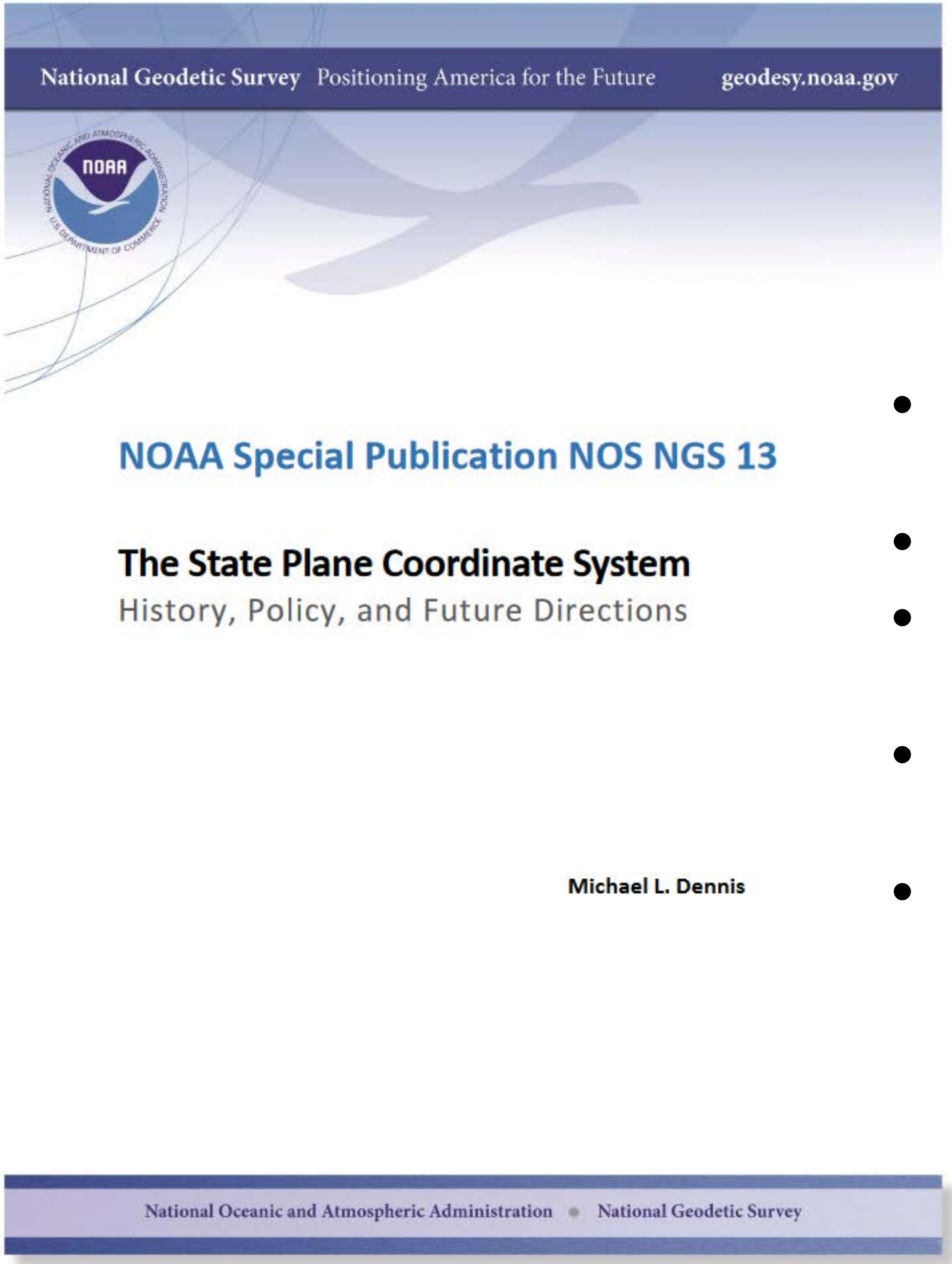
THANKS TO:

Michael Dennis, RLS, PE
NGS Geodesist

New State Plane Coordinate System

- ***State Plane Coordinate System of 2022 (SPCS2022)***
  - Referenced to new 2022 Terrestrial Reference Frames (TRFs)
  - Based on same reference ellipsoid (GRS 80)
  - Same 3 ***conformal*** projection types as NAD27/83
    - Lambert Conformal Conic (LCC)
    - Transverse Mercator (TM)
    - Oblique Mercator (OM)
- NGS in process of specifying SPCS2022 characteristics
  - Draft policy and procedures for public comment
  - Federal Register Notice (FRN) on policy and procedures
  - New report on State Plane history, policy, and future
- **NOTE: SPCS2022 characteristics currently in review**
  - ***Approved version may differ from what is presented here***

SPCS Special Publication



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

NOAA Special Publication NOS NGS 13

The State Plane Coordinate System

History, Policy, and Future Directions

Michael L. Dennis

National Oceanic and Atmospheric Administration • National Geodetic Survey

- History of NGS projections (1853 to present)
- SPCS policies and legislation
- Departures from policy and convention
- Recent developments in projected coordinate systems
- Appendices
  - Defining parameters for ALL zones of ALL versions of SPCS, plus additional information
  - Status of SPCS 83 legislation & foot conversions

Draft SPCS2022 Policy & Procedures

- Release for public comment (Federal Register Notice)
  - Deadline for comment: **August 31, 2018 (anticipated)**
- Stakeholder input from states for their zones
  - DOTs, GIS offices, professional societies, universities
  - Deadlines:
    - **Dec 31, 2019 for requests and proposals**
    - **Dec 31, 2020 for submitted designs**
  - Consensus input ***REQUIRED***
- Federal agency input through FGCS
  - But input for specific zones is from state stakeholders
  - Can coordinate with state stakeholders

SPCS2022 characteristics *(draft)*

- Technical requirements
  - ***Linear distortion*** design criterion at topographic surface (*not* at ellipsoid surface)
    - Difference in distance between "ground" and "grid"
  - Use 1-parallel definition for LCC projections
- Other characteristics
  - Default designs (if no consensus stakeholder input)
  - "Layered" zones
  - Low-distortion projections (LDPs)
  - "Special purpose" zones

Default SPCS2022 designs *(draft)*

- Default needed in absence of stakeholder input
- Same projections and zones for most SPCS 83 zones
- Performance and coverage very similar to SPCS 83
- Characteristics that differ from SPCS 83:
  - Projection scale modified to minimize distortion at ground
  - Lambert Conformal Conic converted to one-parallel type
  - Most geodetic origins with arc-minutes evenly divisible by 3
  - A few zones with different projection & zone extents

SPCS2022 Summary

- Main characteristics
  - Designed with respect to "ground"
  - Default designs similar to existing State Plane
  - Can include a statewide zone plus a sub-zone layer
  - LDPs can be used but must be designed by others
- Stakeholder input on zones for their states
  - *REQUIRES* consensus input
- Federal agency input through FGCS
  - Can coordinate with states stakeholders
- **NGS webinars on March 8 and April 12 – register at:**

https://geodesy.noaa.gov/web/science_edu/webinar_series/Webinars.shtml

NOTE: SPCS2022 policy and procedures released SOON

NGS News

New State Plane Coordinate System (SPCS) Materials Availabl

Publicati
Read "State
Future Direc
13). This rep
how it might
parameters
State Plane

Online R
Visit refresh
Coordinate S
maps, a link
and docume

View Webinars to Learn More

A series of State Plane webinars is under development, with one complete and more planned!

History and Status of SPCS

View the recording from the March 8th webinar, "The State Plane Coordinate System: History, Policy and Future Directions."
and an ove

View March Webinar

Future c
Register fo
Coordinate
detail abou
(SPCS202

Coming Soon: Send Us Feedback!

NGS wants to know what you want for the State Plane Coordinate System of 2022 (SPCS2022).

Review Draft SPCS2022 Policy & Procedures

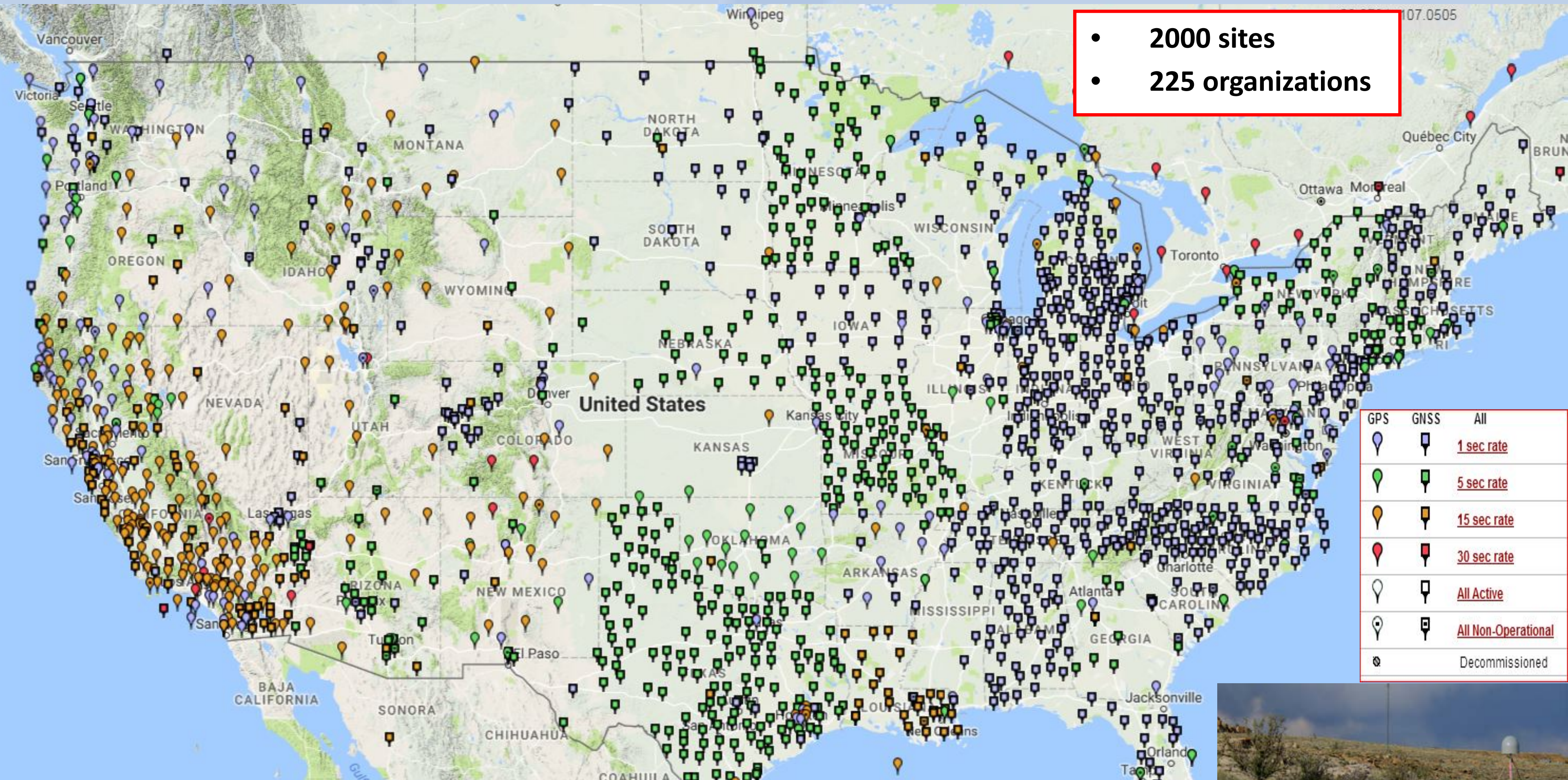
These soon-to-be-released documents lay out the proposed characteristics and requirements for SPCS2022, including how you may share your preferences with NGS. A federal register notice (FRN) will announce when they are available for comment.

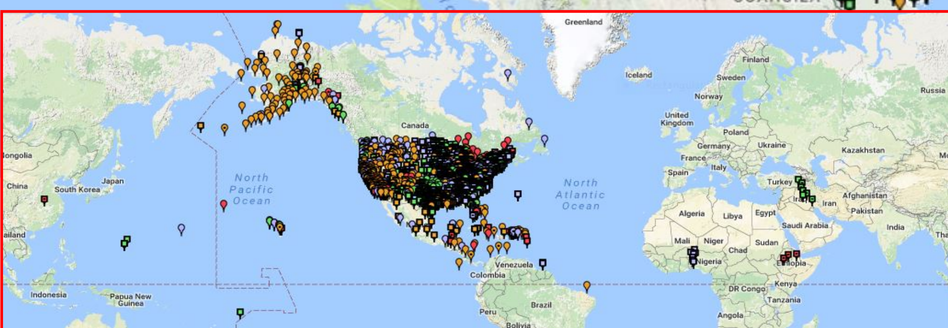
Develop Statewide Responses

Although the FRN is pending, now is a good time to start coordinating stakeholders and begin thinking about what you want for SPCS2022. Definitions of stakeholder groups and other details are coming soon!

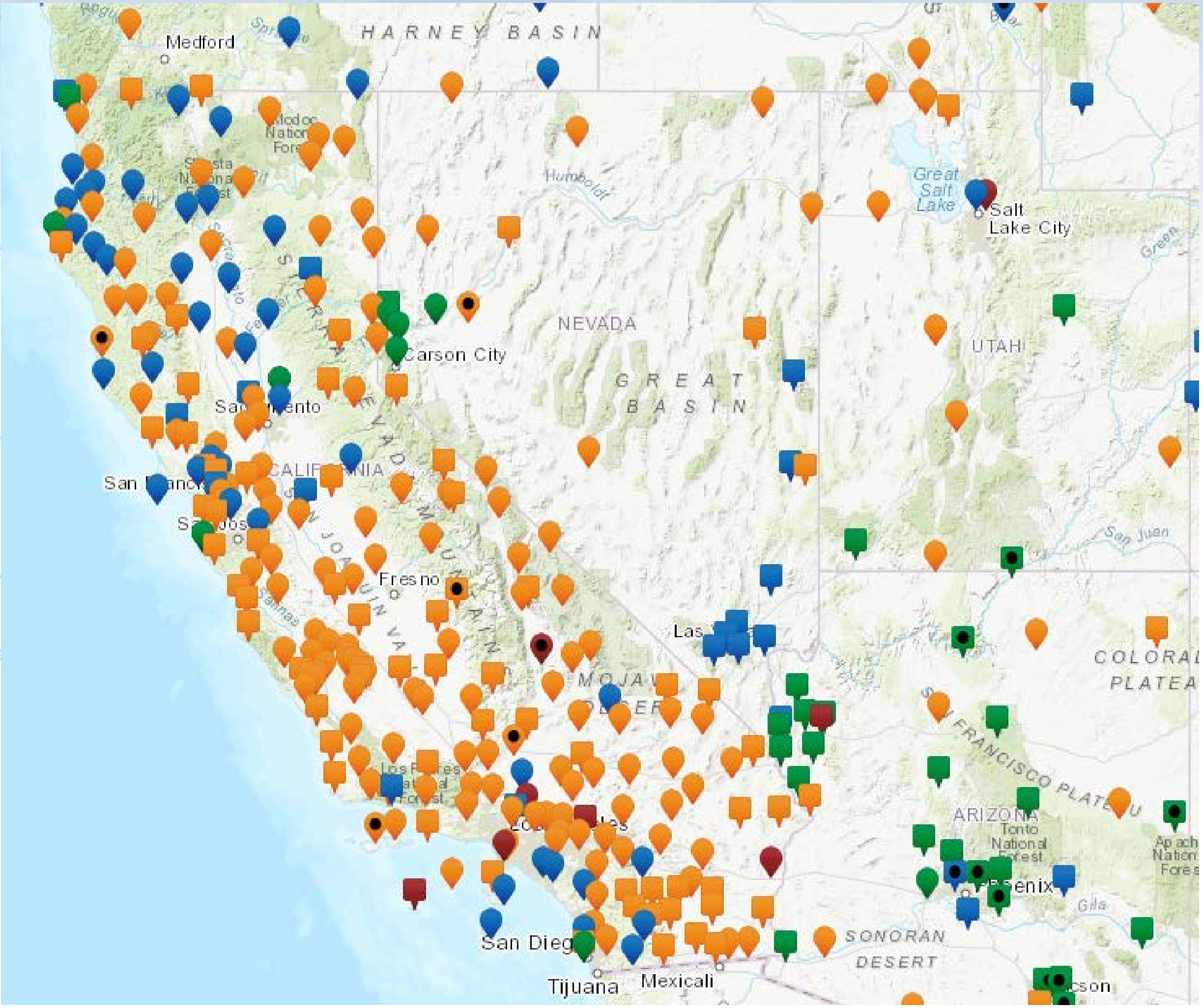
Continuously Operating Reference Station (CORS) Network

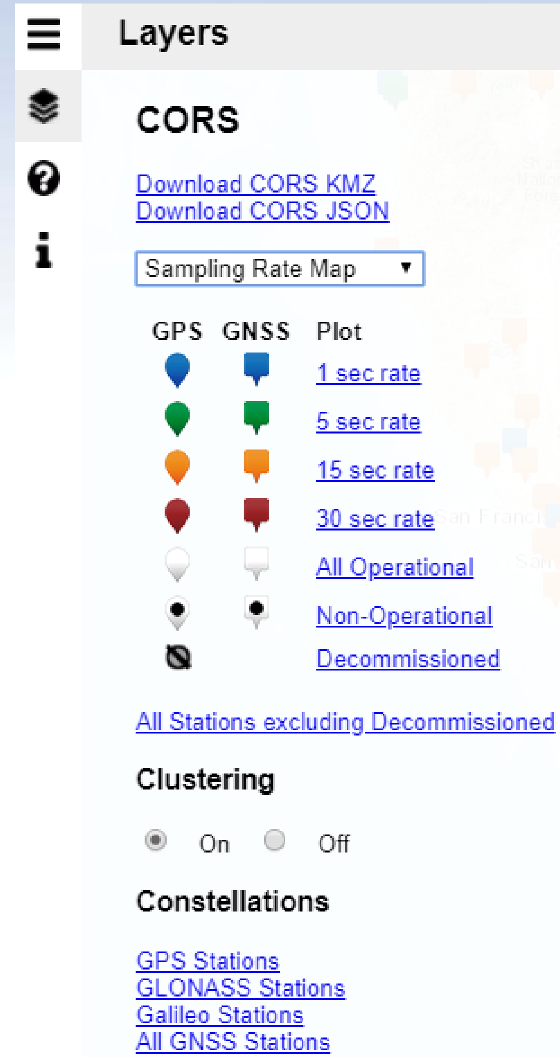
- 2000 sites
- 225 organizations





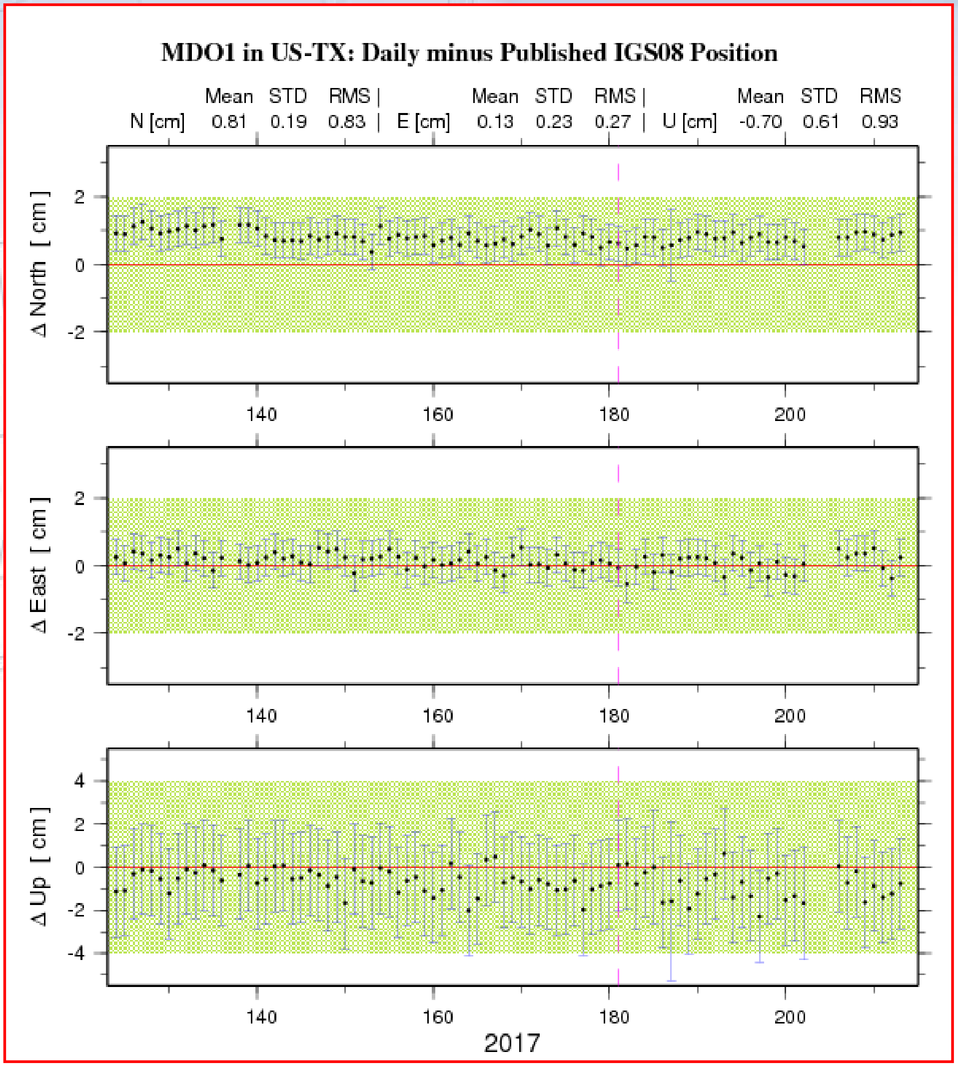
Continuously Operating Reference Station (CORS) Network



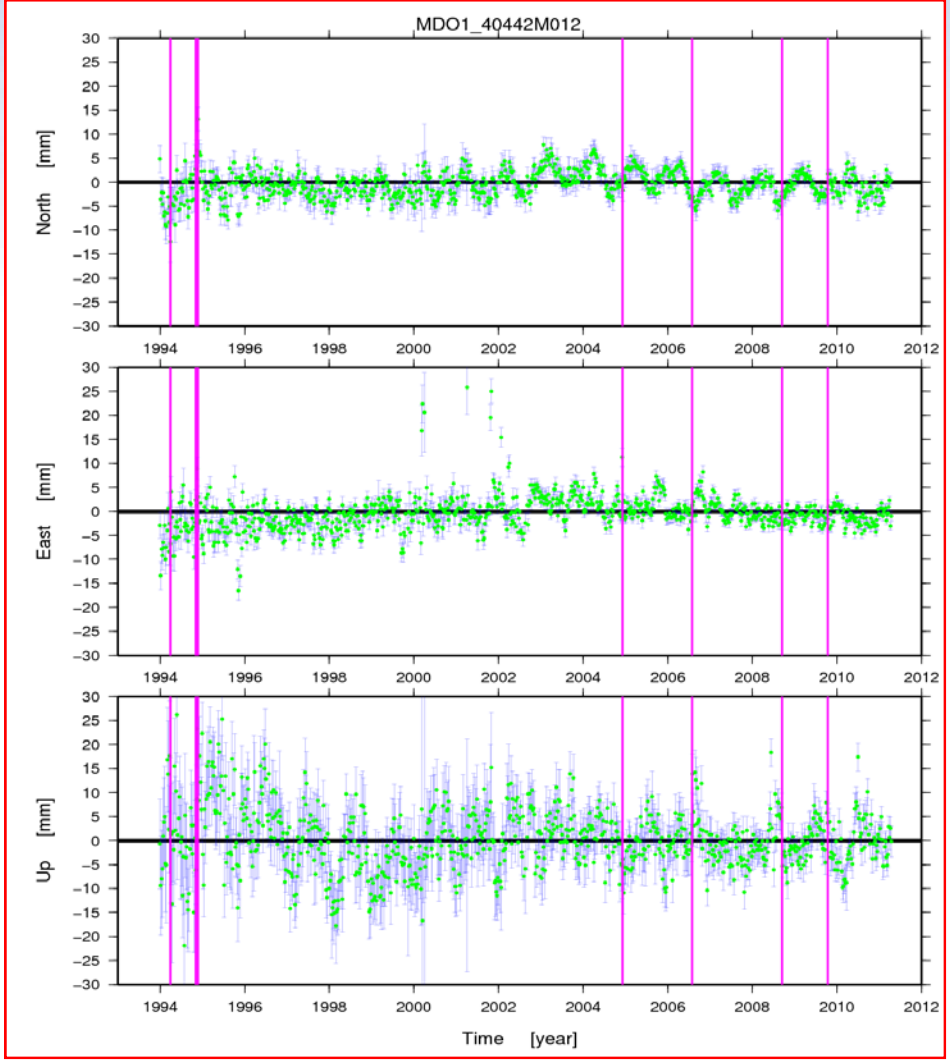


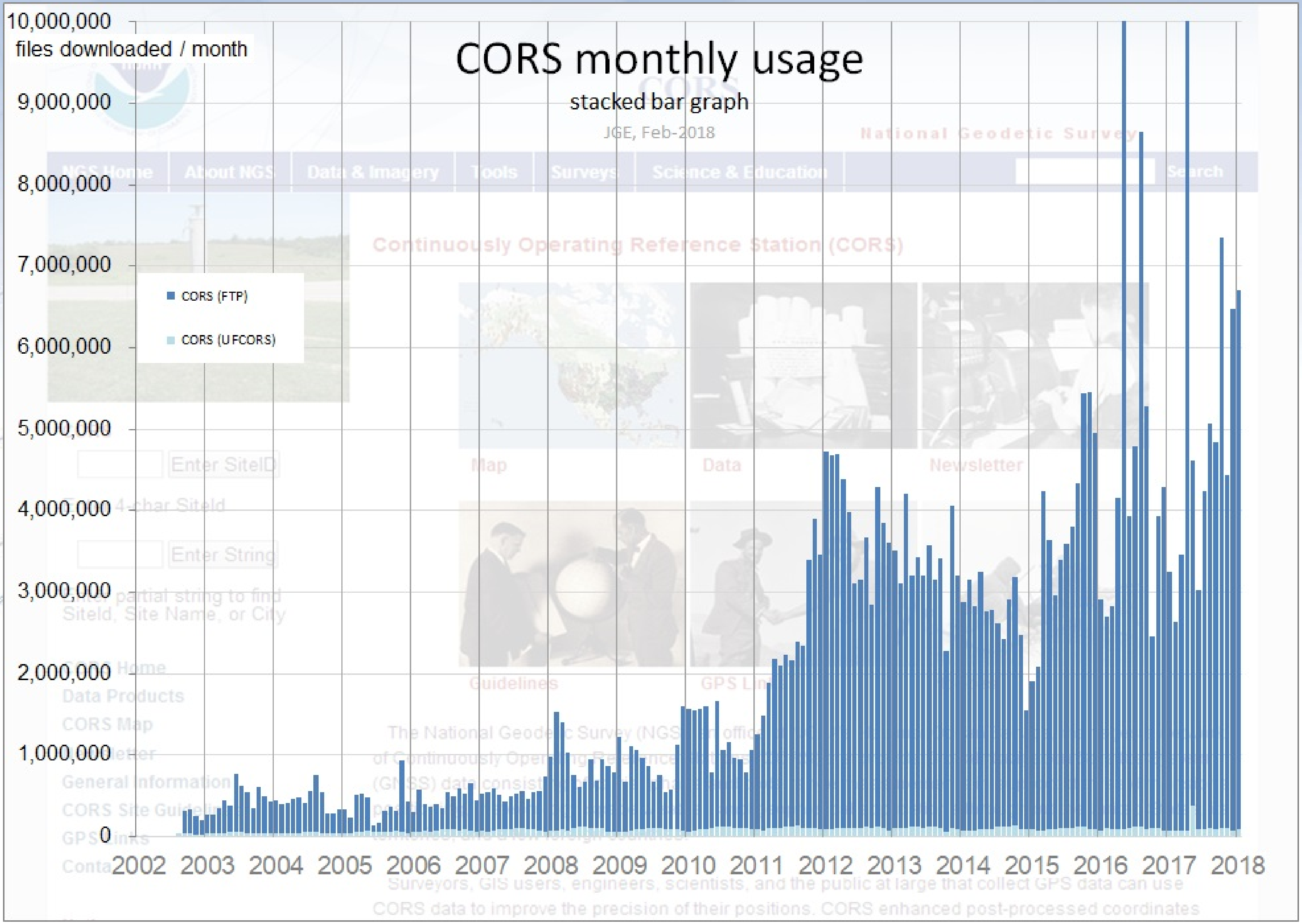
CORS Time Series Plots

short-term

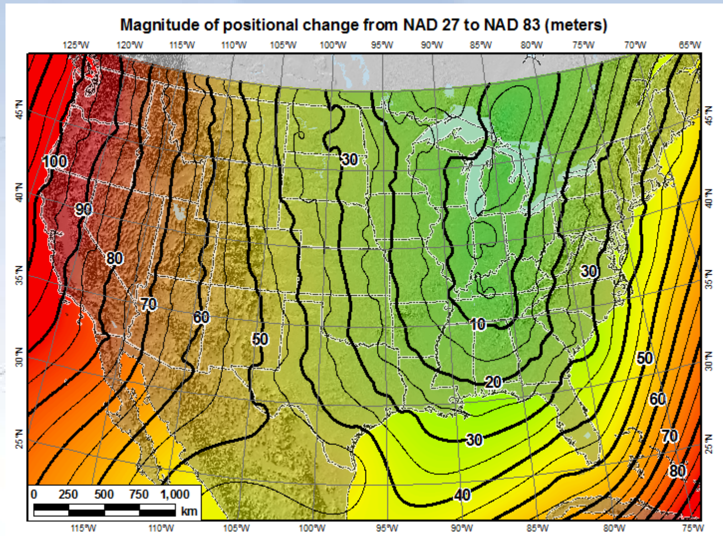


long-term




CORS monthly usage
stacked bar graph
JGE, Feb-2018
files downloaded / month
10,000,000
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
CORS (FTP)
CORS (UFCORS)
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018

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



U.S. Standard Datum

NAD27

NAD83 (1986)

NAD83 (HARN/HPGN/199X)

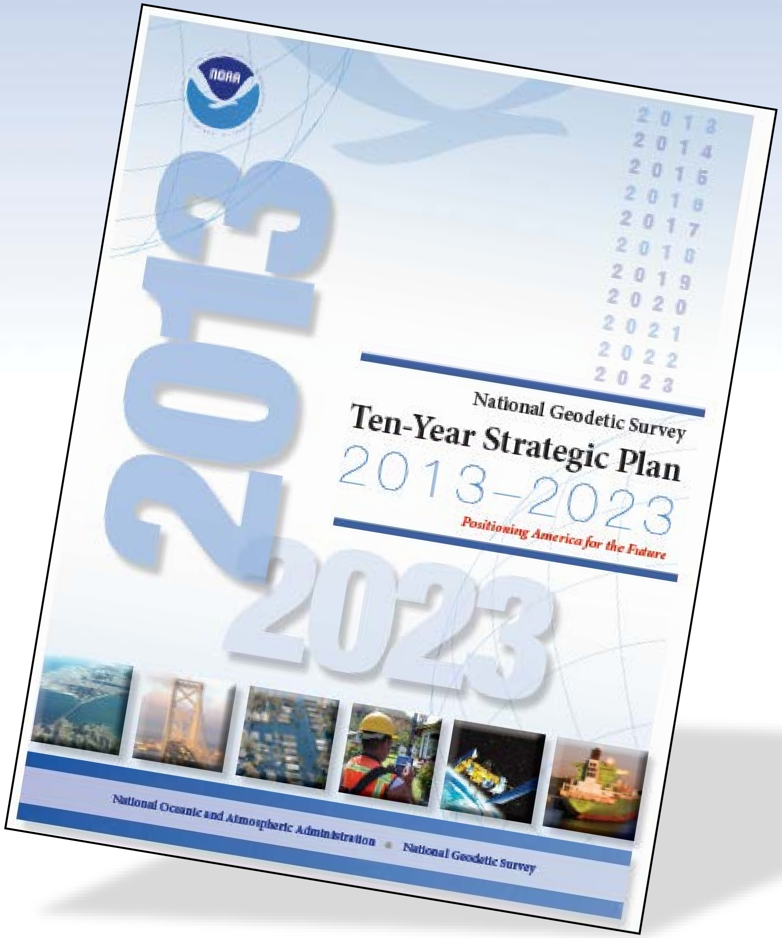
NAD83 (2007)

NAD83 (2011)

time

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

The National Geodetic Survey Ten-Year Plan



Support the users of the National Spatial Reference System.

Modernize and improve the National Spatial Reference System. ***(Replace NAD83 & NAVD88)***

Expand the National Spatial Reference System stakeholder base through partnerships, education, and outreach.

Develop and enable a workforce with a supportive environment.

Improve organizational and administrative functionality.

2013, *NGS Ten-Year Strategic Plan* objective:
"Achieve a fully **staffed regional advisor program by 2016**."

International Terrestrial Reference Frame (ITRF)

4 Global Independent Positioning Technologies

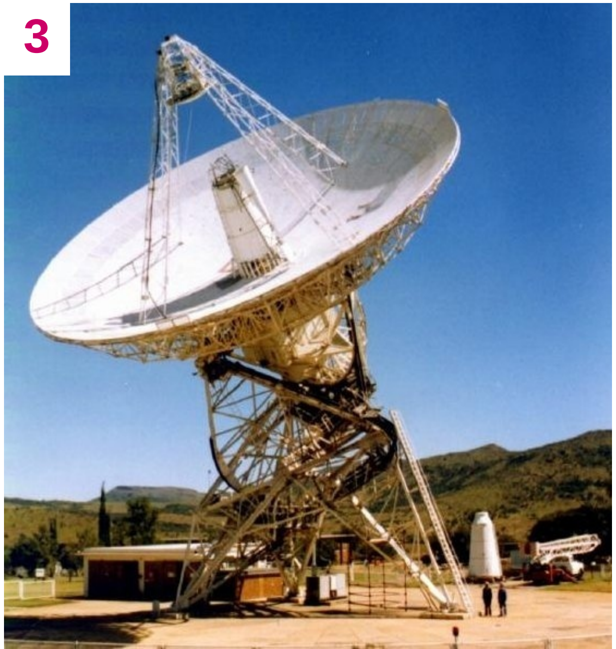
- 1. Global Navigation Satellite Systems (GNSS)
- 2. Satellite Laser Ranging (SLR)
- 3. Very Long Baseline Interferometry (VLBI)
- 4. Doppler Orbitography & Radiopositioning Integrated by Satellite (DORIS)

4

1

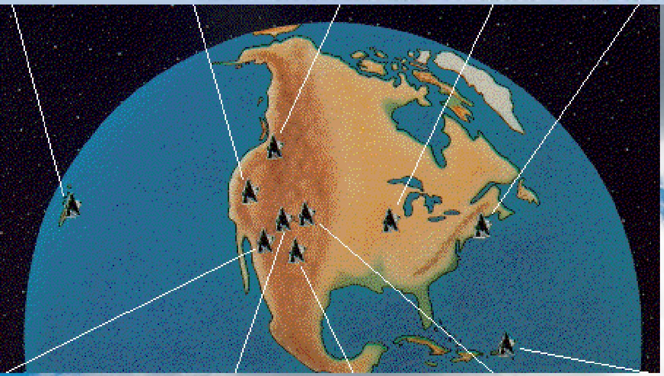
2

3



NOAA's National Geodetic Survey Positioning America for the Future

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

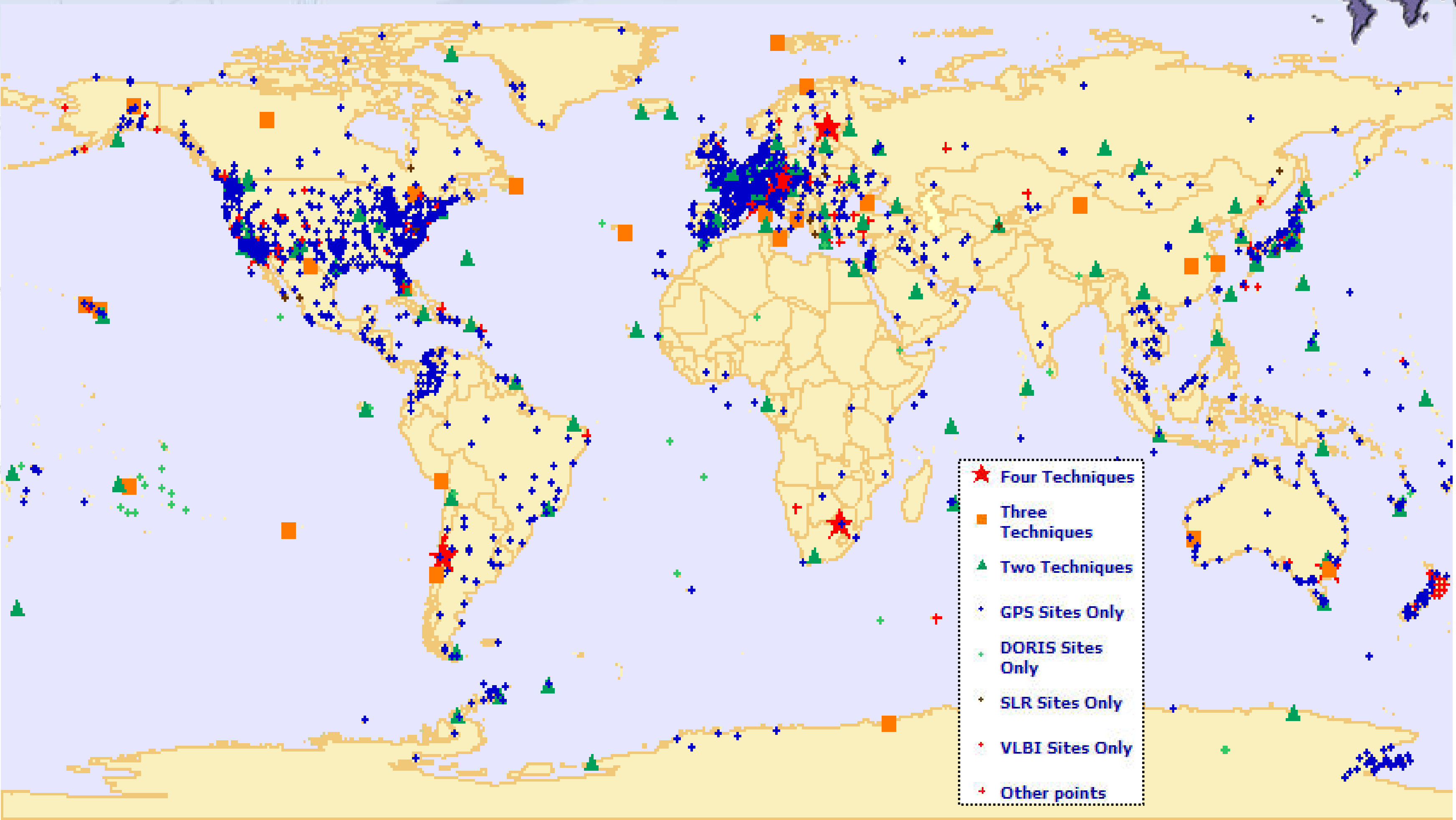


International Terrestrial Reference Frame (ITRF)

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

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

Current version (@NGS): ITRF2008 (epoch 2005.0)



International Earth Rotation and Reference System Service (IERS)

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

CORS Coordinates – PUC2

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

IGS08 epoch 2005.0 = International GNSS Service 2008 (@ January 1, 2005) (GNSS-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 >>

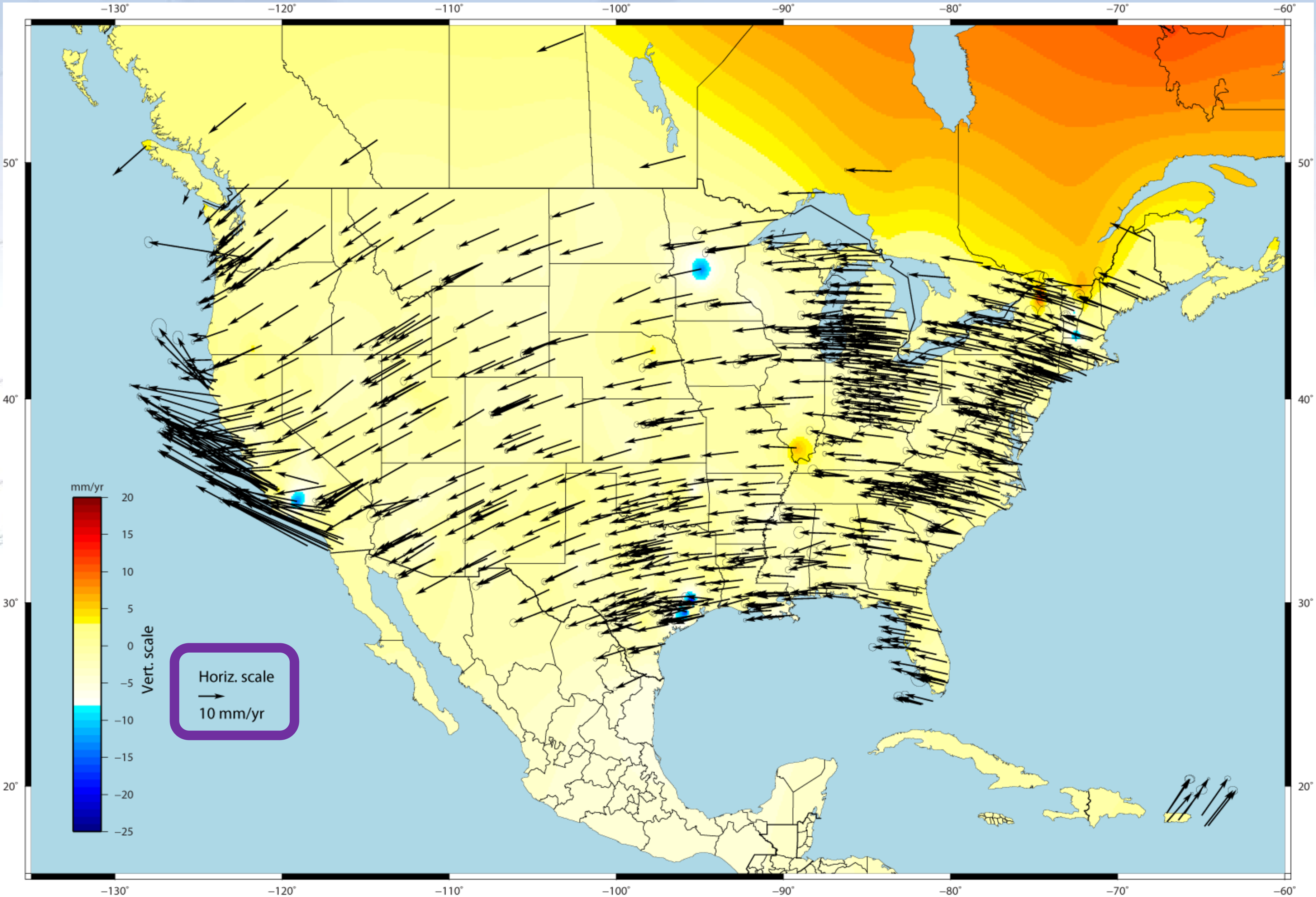
```
NAD_83 (2011) POSITION (EPOCH 2010.0)
Transformed from IGS08 (epoch 2005.0) position in Sep 2015.
    X = -1745061.768 m     latitude    =  39 35 38.10058 N
    Y = -4603214.452 m     longitude   = 110 45 41.52524 W
    Z =  4044436.534 m     ellipsoid height = 1714.255   m
```

NAD83 Velocity >>

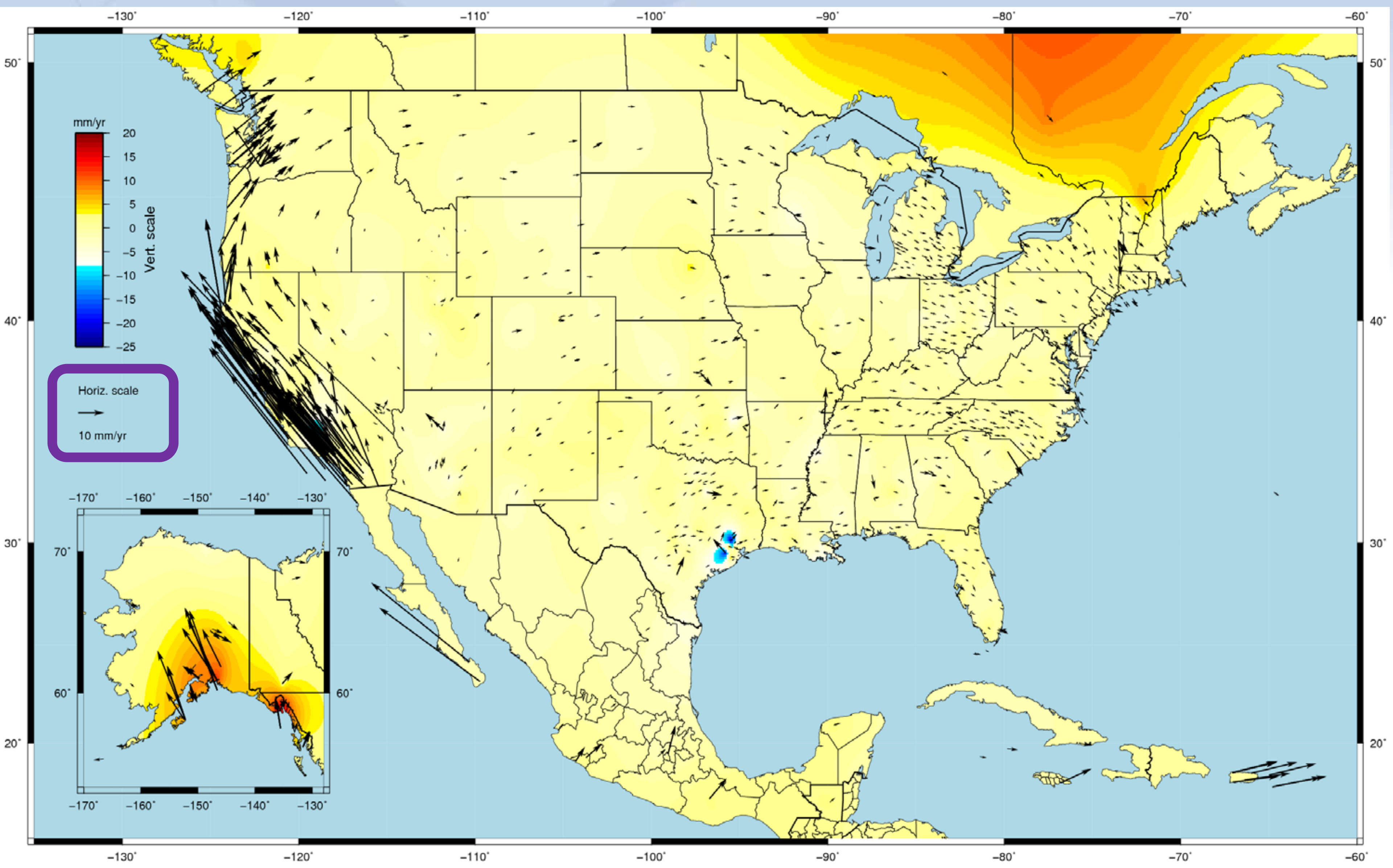
```
NAD_83 (2011) VELOCITY
Transformed from IGS08 velocity in Sep 2015.
    VX =   0.0019 m/yr     northward =   0.0018 m/yr
    VY =   0.0016 m/yr     eastward  =   0.0012 m/yr
    VZ =   0.0006 m/yr     upward    =  -0.0013 m/yr
```

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

CORS Velocity Field – IGS08 epoch 2005.0



CORS Velocity Field – NAD83(2011) epoch 2010.00

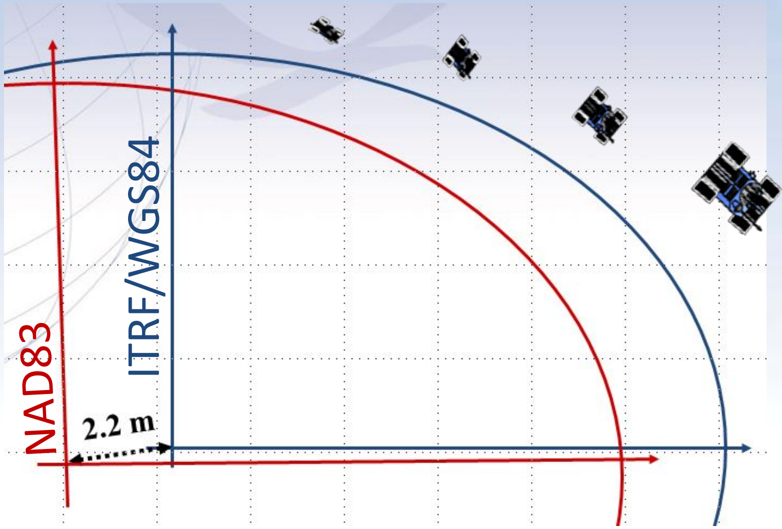


Why replace NAVD 88 and NAD 83?

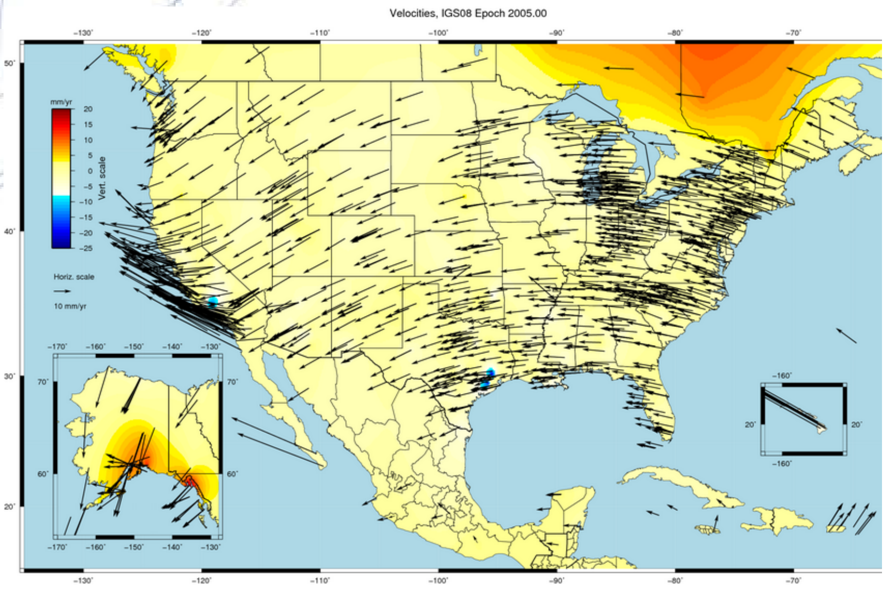
- **Main driver:** ***Global Navigation Satellite System (GNSS)***
- **ACCESS!**
  - GNSS equipment is fast, inexpensive, reliable (and improving)
  - Reduces reliance on finding survey control ("bench marks")
- **ACCURACY!**
  - Insensitive to distance-dependent errors; reliable
  - Immune to bench mark instability (referenced to CORS)
- **CONSISTENCY!**
  - Eliminates systematic errors in current datums
  - Aligned with global reference frames
  - Integrated system for both positions and heights ("elevations")

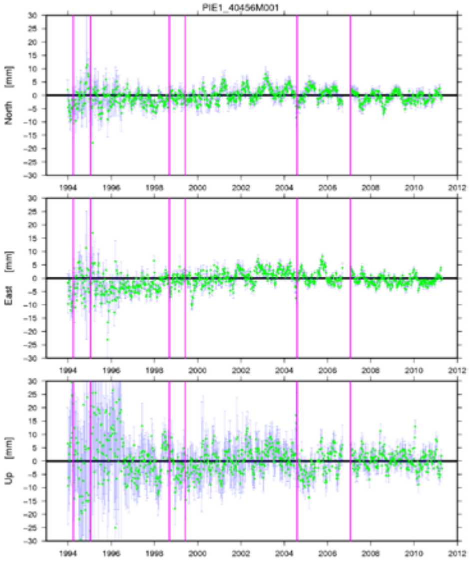
NAD83 Shortcomings

- **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.

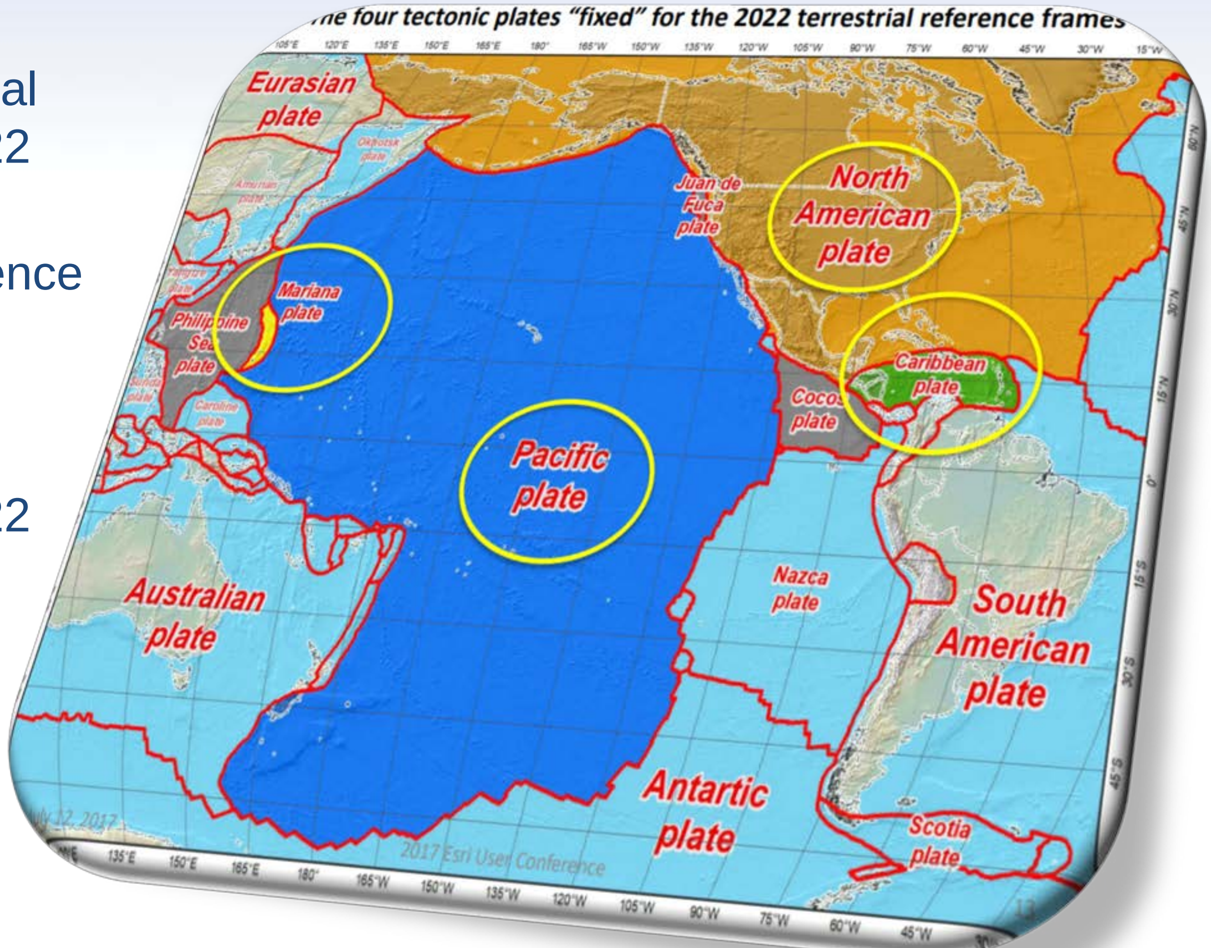
Future Geometric (3-D) Reference Frames

- 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

Four Tectonic Plates NGS Monitors

In 2022, the National Spatial Reference System will be modernized and will contain
4 new geometric reference frames:

- ✓ North American Terrestrial Reference Frame of 2022 (NATRF2022)
- ✓ Pacific Terrestrial Reference Frame of 2022 (PATRF2022)
- ✓ Caribbean Terrestrial Reference Frame of 2022 (CATRF2022)
- ✓ Mariana Terrestrial Reference Frame of (MATRF2022)



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 (2020.0?)
- 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)

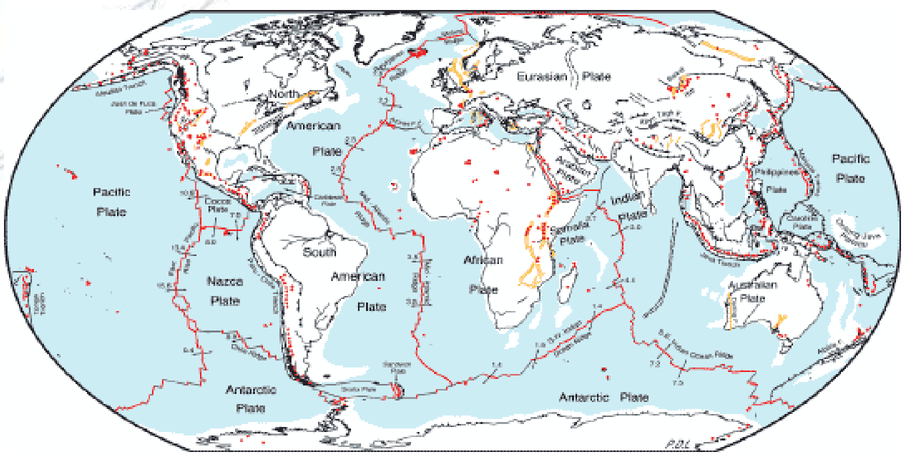
[likely IGS14 = International GNSS Service 2014]

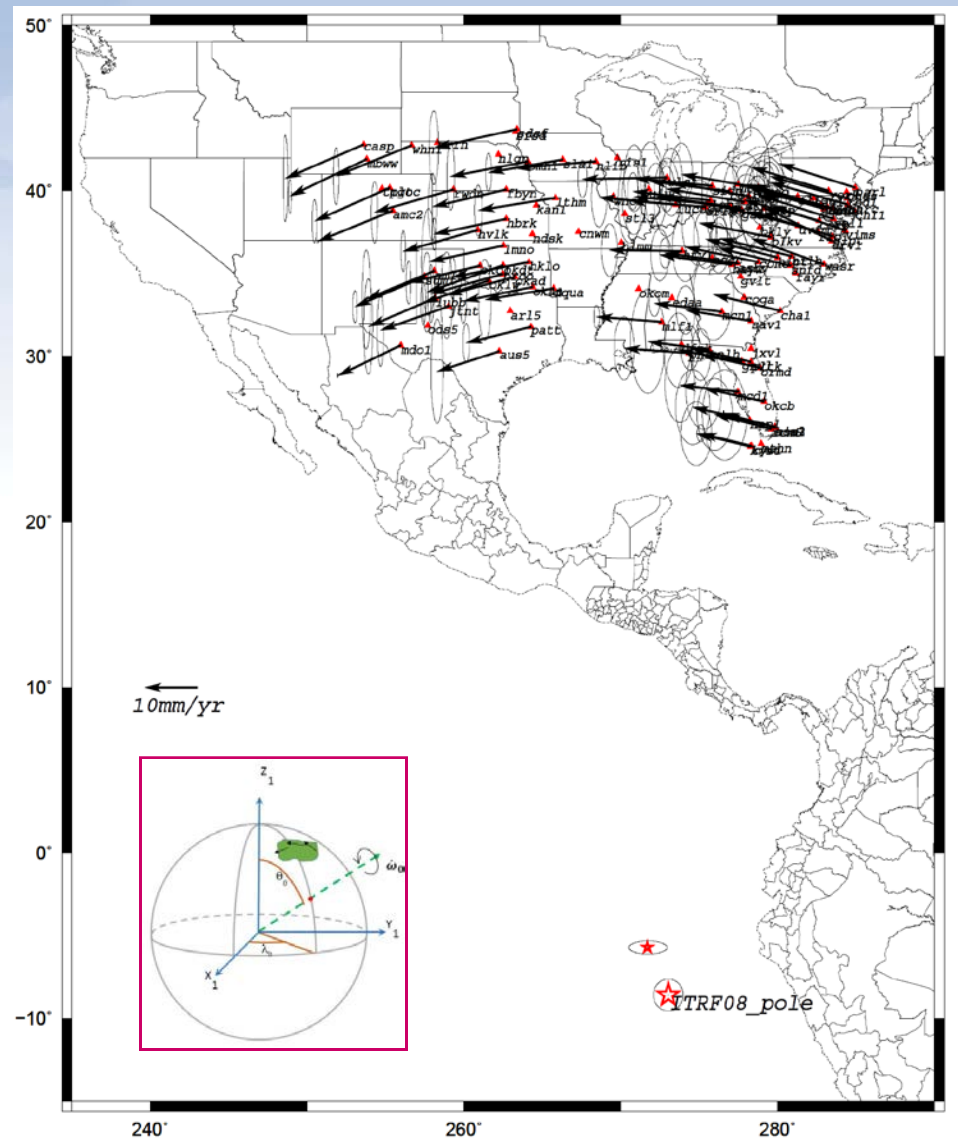
Euler Pole

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

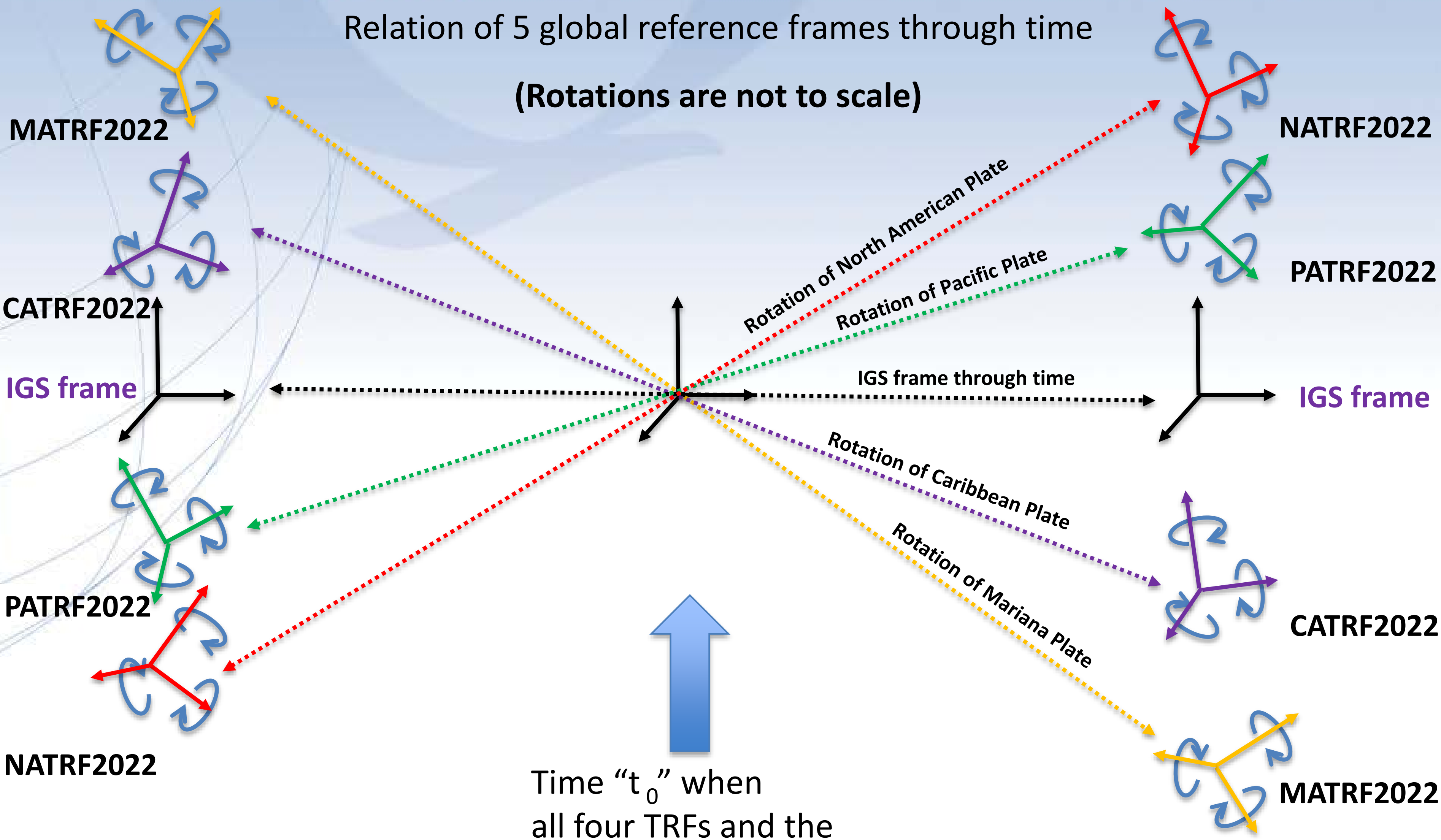




Euler's fixed point theorem states: any motion of a rigid body on the surface of a sphere may be represented as a rotation about an appropriately chosen rotation pole ("Euler Pole")

Relation of 5 global reference frames through time

(Rotations are not to scale)



$t=t_0-\Delta t$
("the past")

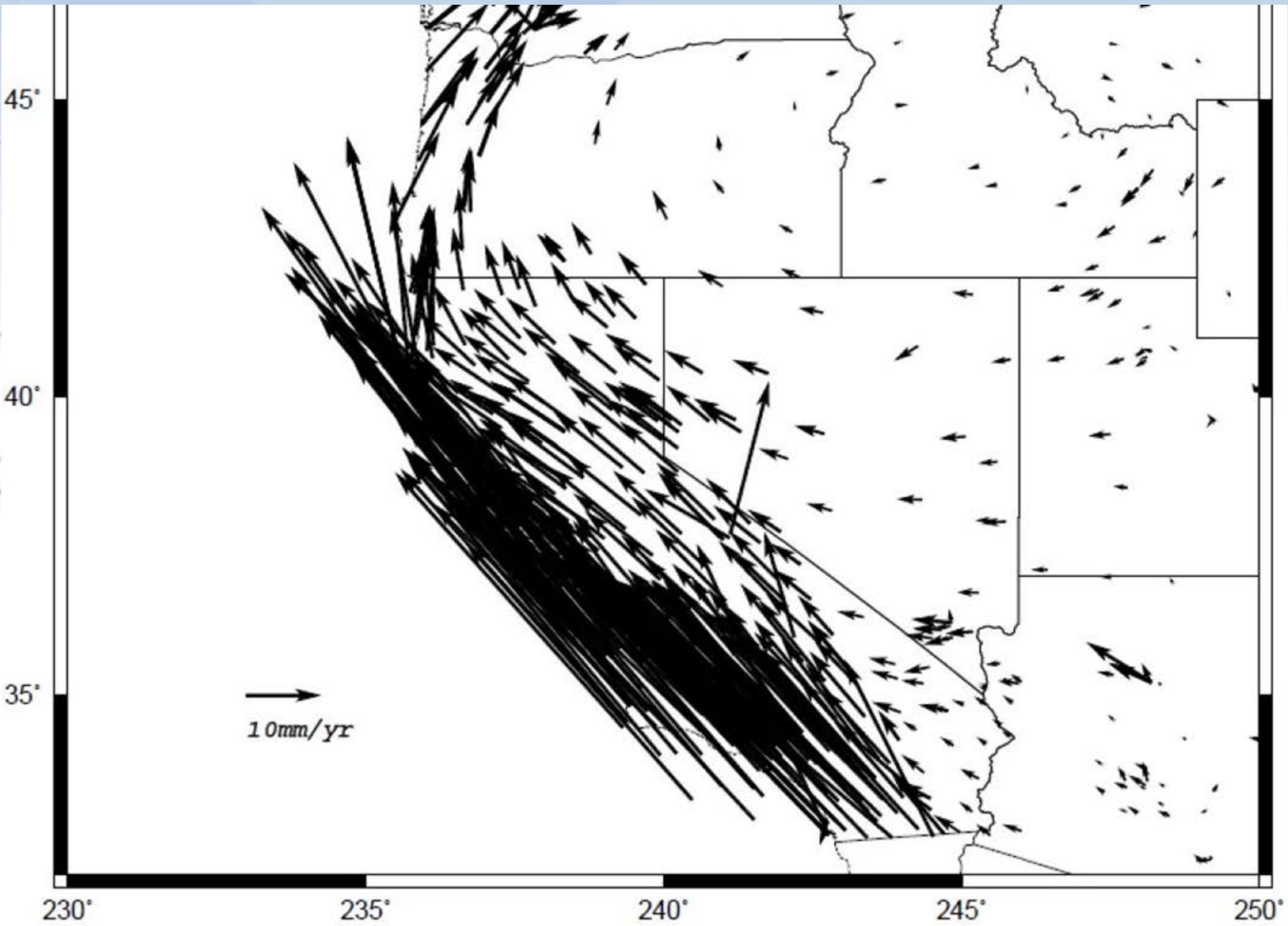
Time "t_0" when
all four TRFs and the
IGS are identical.
(maybe 2020.0?)

$t=t_0+\Delta t$
("the future")

Intra-frame Velocity Models (IFVMs)

- Consider "NATRF2022"
  - It will be a ***global*** reference frame
    - ***(In practice*** it can be applied anywhere, since it is a "simple" 3-parameter transformation from the global IGS frame)
  - It is named after the N. American plate
  - The IFVM for NATRF2022 will be a ***global*** velocity model
    - (Though, ***in practice***, it will likely only have data in USA territories)
  - It will reflect all motions on all points (globally) which are ***not*** due to the Euler Pole Rotation of the N. American plate. Thus:
    - All vertical motions, anywhere
    - All horizontal motions not due to N. American Euler Pole rotation
    - Small motion of points in Kansas relative to stable N. American plate
    - Horizontal manifestation of GIA relative to stable N. American plate
    - Motion of Hawaii points relative to stable N. American plate
    - Motion of S. California points relative to stable N. American plate

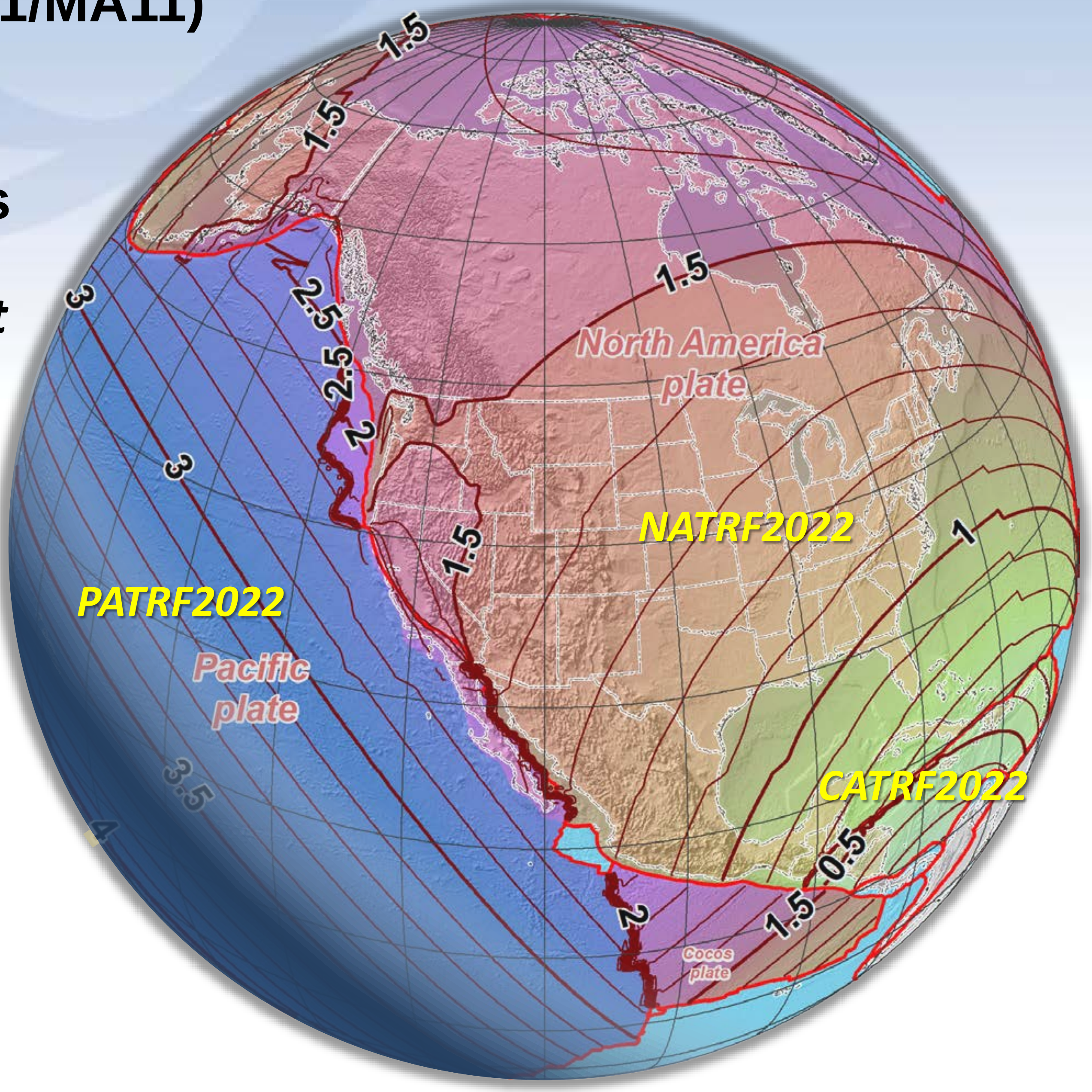
Intra-frame 3-D Velocity Model



Non-Eulerian velocities in southwestern U.S. - following removal of North America plate rotation; will be modeled by intra-frame 3-D velocity model

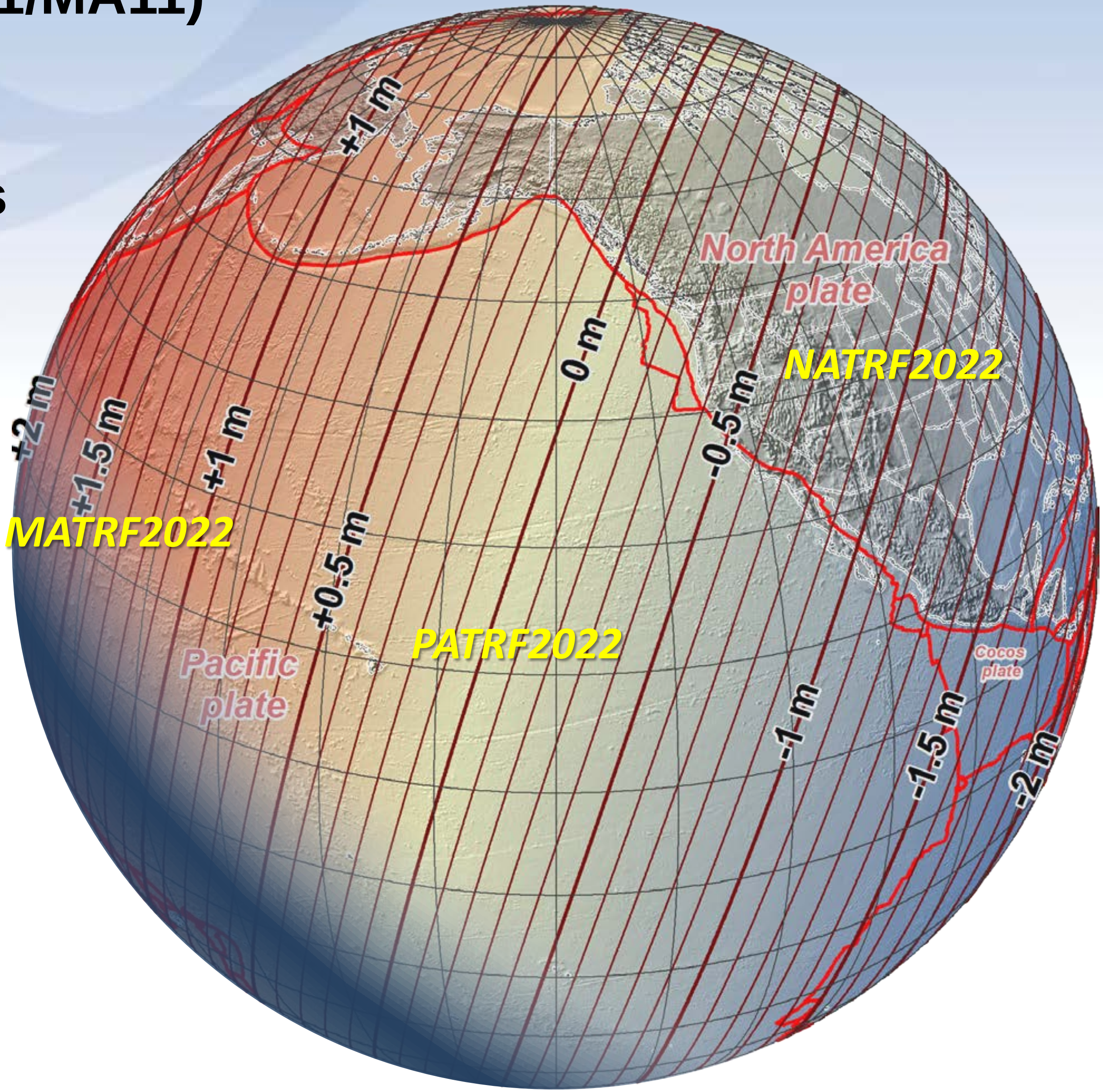
NAD 83 (2011/PA11/MA11) epoch 2010.00 → 2022 Terrestrial Reference Frames

Horizontal change at epoch 2022.00
(contours in meters)

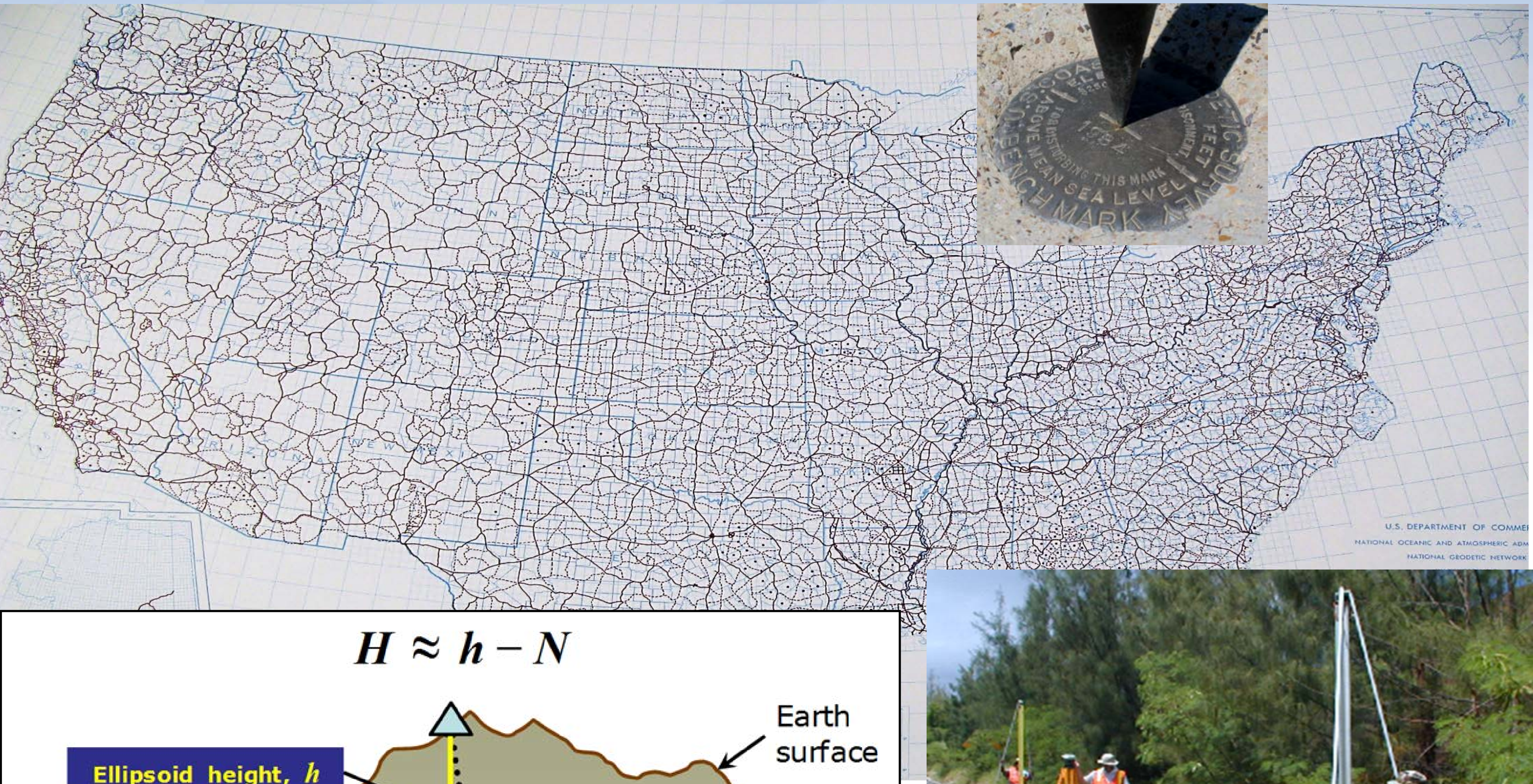


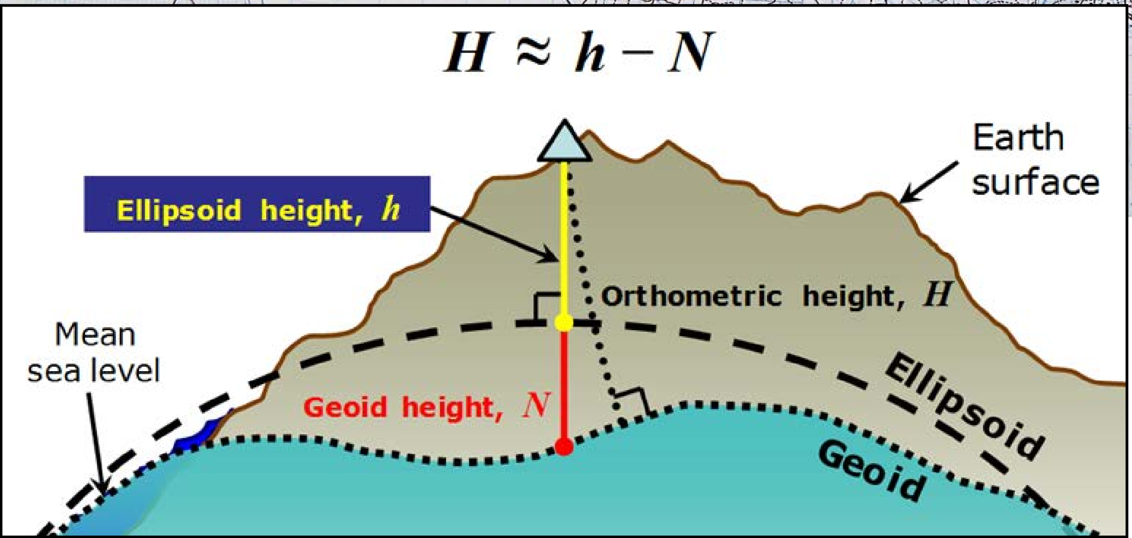
NAD 83 (2011/PA11/MA11) epoch 2010.00 → 2022 Terrestrial Reference Frames

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



NORTH AMERICAL VERTICAL DATUM 1988 (NAVD88)





NGVD 29

NAVD 88

Referenced to 26 Tide Gauges

(Father's Point)

NAVD88 minus LMSL(1960-1978)

70 cm

85 cm

102 cm

125 cm

4 cm

-11 cm

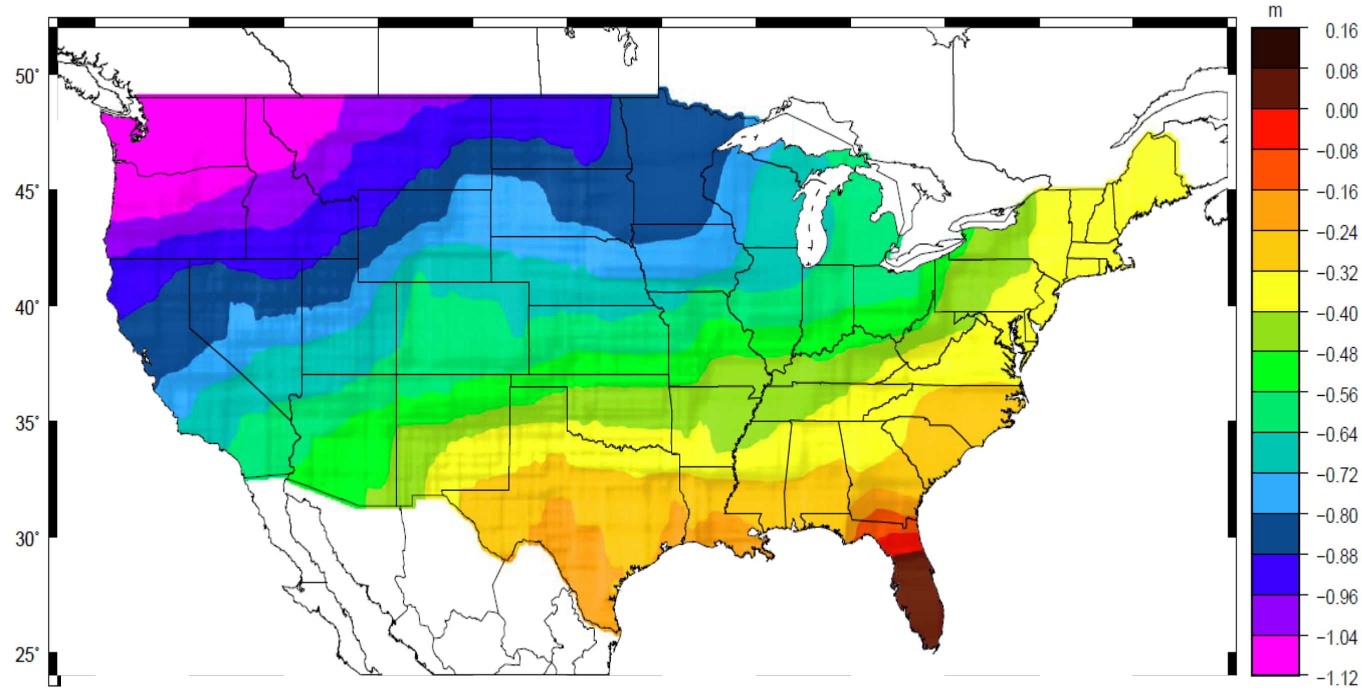
-11 cm

-23 cm

-23 cm

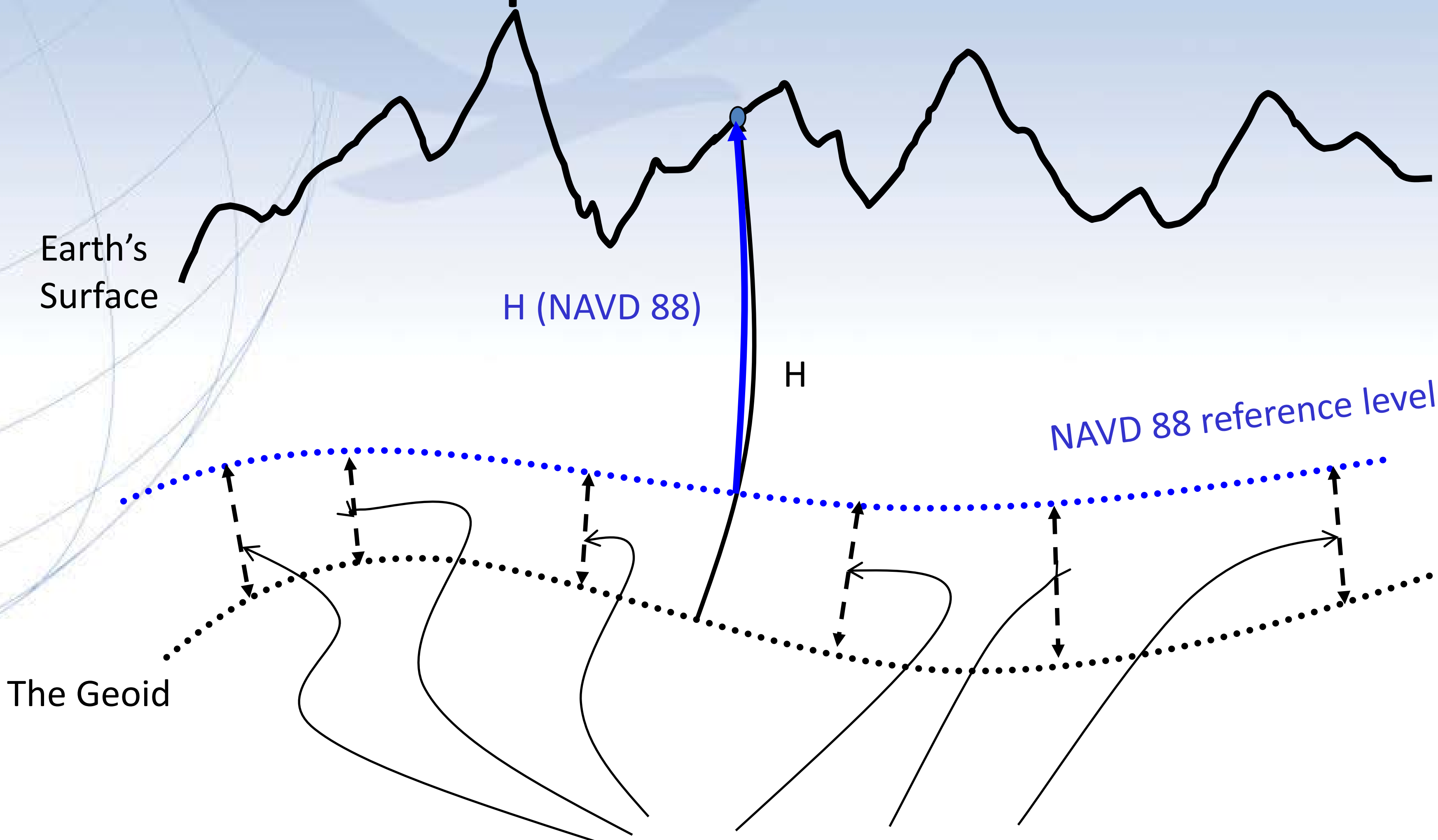
North American Vertical Datum 1988 (NAVD88) Shortcomings

- 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

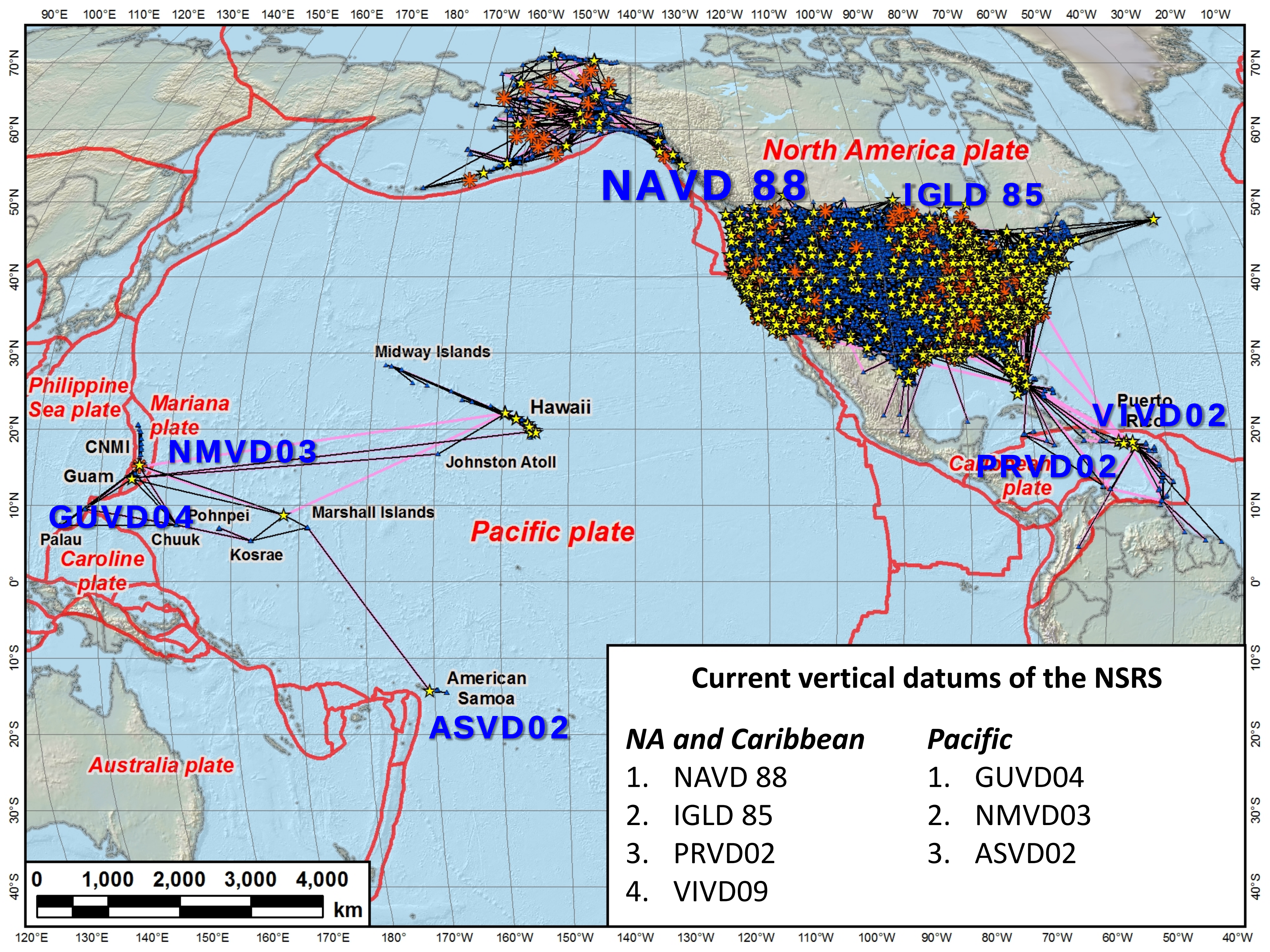


Approximate Geoid Mismatch in the NAVD88 H=0 surface

Replace NAVD 88

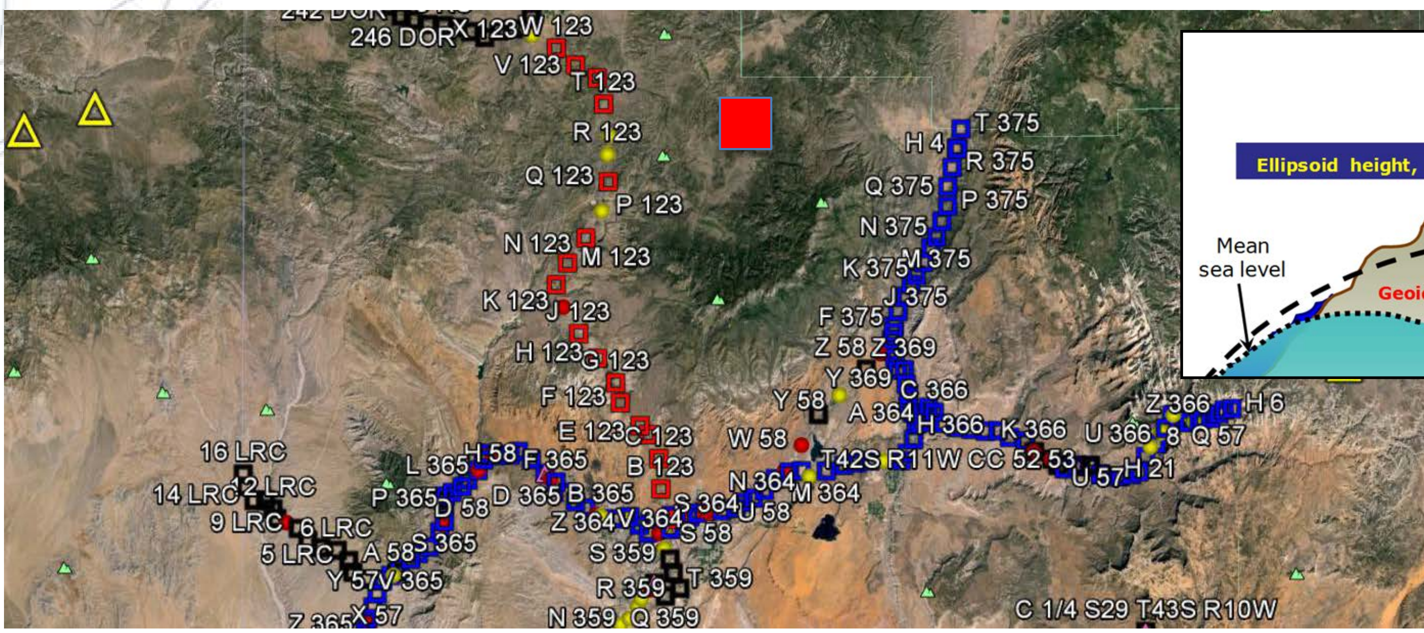


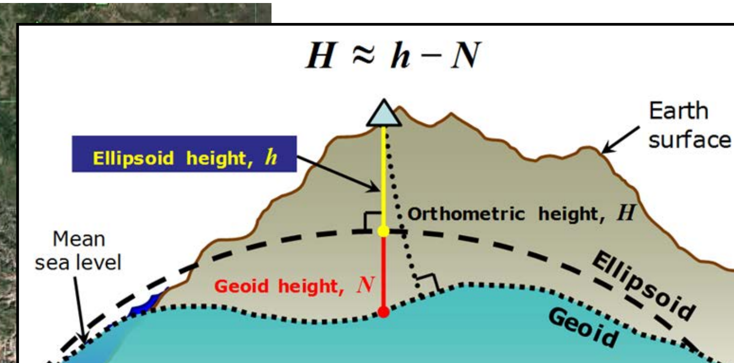
Errors in NAVD 88 : ~50 cm average, 100 cm CONUS tilt, 1-2 meters average in Alaska, NO tracking


North America plate
NAVD 88
IGLD 85
Philippine Sea plate
Mariana plate
Midway Islands
Hawaii
CNMI
NMVD03
Johnston Atoll
Guam
GUVD04
Pohnpei
Marshall Islands
Palau
Chuuk
Kosrae
Caroline plate
Pacific plate
Puerto Rico
VIVD02
PRVD02
Caribbean plate
American Samoa
ASVD02
Australia plate
0 1,000 2,000 3,000 4,000
km
Current vertical datums of the NSRS
NA and Caribbean
1. NAVD 88
2. IGLD 85
3. PRVD02
4. VIVD09
Pacific
1. GUVD04
2. NMVD03
3. ASVD02

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)

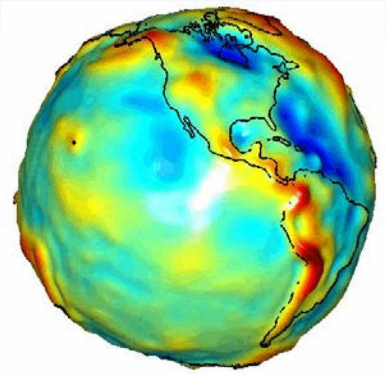




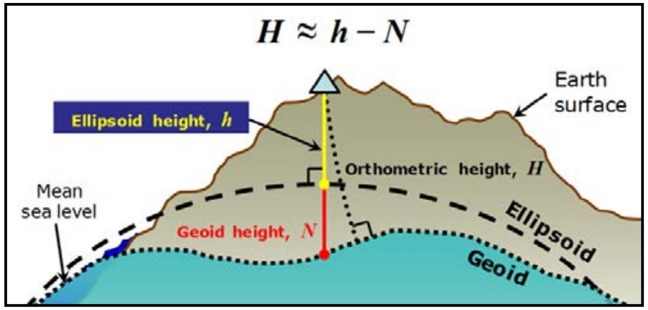
North American-Pacific Geopotential Datum of 2022 (NAPGD2022)

&

GEOID2022 (gravimetric geoid)



- NAPGD2022 will contain information for:
  - Orthometric heights
  - Geoid undulations (GEOID2022)
  - Gravity anomalies (GRAV2022)
  - Deflections of the vertical (DEFLEC2022)
  - Global geopotential field model (GM2022)



Replacing NAVD 88 (and the others…)

- One gravity geopotential datum will replace:
  - Seven vertical datums
  - One gravity datum
  - Several gravimetric and hybrid geoid and vertical deflection models
- Aligned and consistent with the TRFs
- Main access to "elevations" via GNSS
  - Orthometric heights using geoid model (GEOID2022)
  - Dynamic heights will also be available (e.g., for Great Lakes)
  - Replaces leveling as primary access
- GEOID2022 coordinated with Canada and Mexico
  - Set to mean sea level at a specific epoch
  - Will update epoch as needed, based on sea level change
- Geopotential datum will include time-dependent component

Agreement with Canada on W_0 Value for New Vertical Datum

Agreement: The U.S. National Geodetic Survey and The Canadian Geodetic Survey

March 14, 2012

The U.S. National Geodetic Survey and Natural Resources Canada's Geodetic Survey Division, via conference call held 2012/02/17, **agree**:

- To ***define*** the common (a unique) vertical datum for the United States of America (USA) and Canada (CA) through use of an equipotential surface, realized through one commonly (jointly) computed geoid model, corresponding to the mean coastal sea level for North America by 2022. Adoption is subject to National decisions;
- To ***compute*** the potential W_0 of this equipotential surface using Global Positioning System (GPS) data on tidal benchmarks, by April 1, 2012 and to ***use*** this value, for the realization of geoid models in the USA and CA until 2022;
- To ***maintain*** this equipotential surface as one option to adopt as the vertical datum even if this surface diverges (departs) from the true mean coastal sea level for (around) North America over time;
- To ***monitor*** differences between the above-mentioned equipotential surface and the mean sea level via Global Navigation Satellite Systems (GNSS) on tidal benchmarks, altimetry or other means as required;
- To ***provide*** to the public, deformational velocities (*N-dot*) of the equipotential surface W_0;
- To ***collaborate*** in the realization of geoid models, through the sharing of data and related information:
- To ***compute*** updated geoid models and geoid deformation models with improved realizations as needed;
- To ***inform*** each other when large discrepancies (outside 95% confidence region) are found in overlapping regions; and
- To ***choose*** a threshold value (in alignment with both stakeholder needs and scientific integrity) in 2022, between predicted (modeled) geoid change and true geoid change (including deformation and sea level change) which will warrant new realization of the vertical datum.

Denis Hains
Director
Geodetic Survey Division
Canada Centre for Remote Sensing
Natural Resources Canada Ressources naturelles Canada
Canada

Juliana P. Blackwell
Director
National Geodetic Survey

Entente: National Geodetic Survey des États-Unis et les Levés géodésiques du Canada

14 mars, 2012

Le National Geodetic Survey des États-Unis et la Division des levés géodésiques du ministère des Ressources naturelles du Canada, par un appel conférence tenu le 2012/02/17, se sont **entendus** :

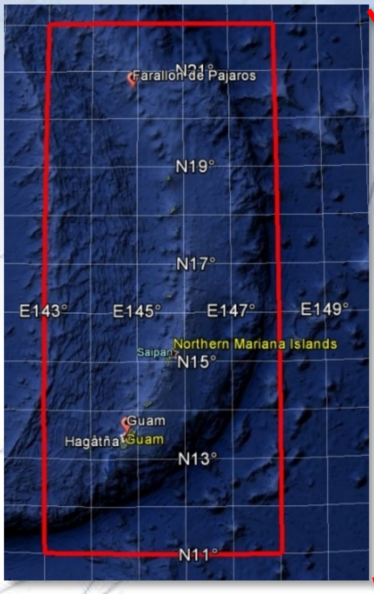
- À ***définir*** un datum vertical commun (unique) pour les États-Unis d'Amérique (USA) et le Canada (CA) par l'entremise d'une surface équipotentielle réalisée par un modèle du géoïde calculé en commun (ensemble), correspondant au niveau moyen des mers le long des côtes de l'Amérique du Nord par 2022. L'adoption est sujette aux décisions nationales;
- À ***calculer*** le potentiel W_0 de cette surface équipotentielle par mesures du Système de positionnement mondial (GPS) à des marégraphes avant le 1er avril 2012 et à ***utiliser*** cette valeur pour la réalisation des modèles du géoïde des USA et du CA jusqu'en 2022;
- À ***maintenir*** cette surface équipotentielle comme une option pour l'adoption d'un datum vertical même si cette surface diverge (s'écarte), avec le temps, du véritable niveau moyen des mers de (entourant) l'Amérique du Nord.
- À ***surveiller*** la différence entre la surface équipotentielle mentionnée ci-haut et le niveau moyen des mers par mesures des Systèmes mondiaux de navigation par satellites (GNSS) à des marégraphes, par altimétrie et par autres moyens requis;
- À ***fournir*** au public des vélocités (N-dot) de déformation de la surface équipotentielle W_0;
- À ***collaborer*** à la réalisation des modèles du géoïde en partageant des données et l'information reliée;
- À ***calculer*** des mises-à-jour des modèles du géoïde et de déformation au besoin;
- À ***s'informer*** mutuellement des écarts importants (à l'extérieur d'une marge de confiance de 95%) retrouvés en régions chevauchantes;
- À ***choisir*** une valeur seuil (cadrant avec les besoins des utilisateurs et scientifiquement rigoureuse) en 2022 entre les changements prédits et réels du géoïde (incluant sa déformation et le changement du niveau moyen des mers) qui justifieront une nouvelle réalisation du datum vertical.

Denis Hains
Directeur
Division des levés géodésiques
Centre canadien de télédétection
Ressources naturelles Canada Natural Resources Canada
Canada

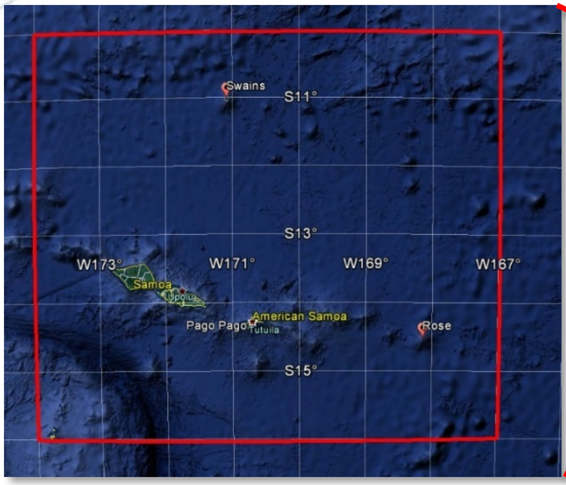
Juliana P. Blackwell
Directrice
National Geodetic Survey

Extent of NAPGD2022 Gravimetric Geoid Model (GEOID2022)

Guam and Northern Marianas Islands



American Samoa



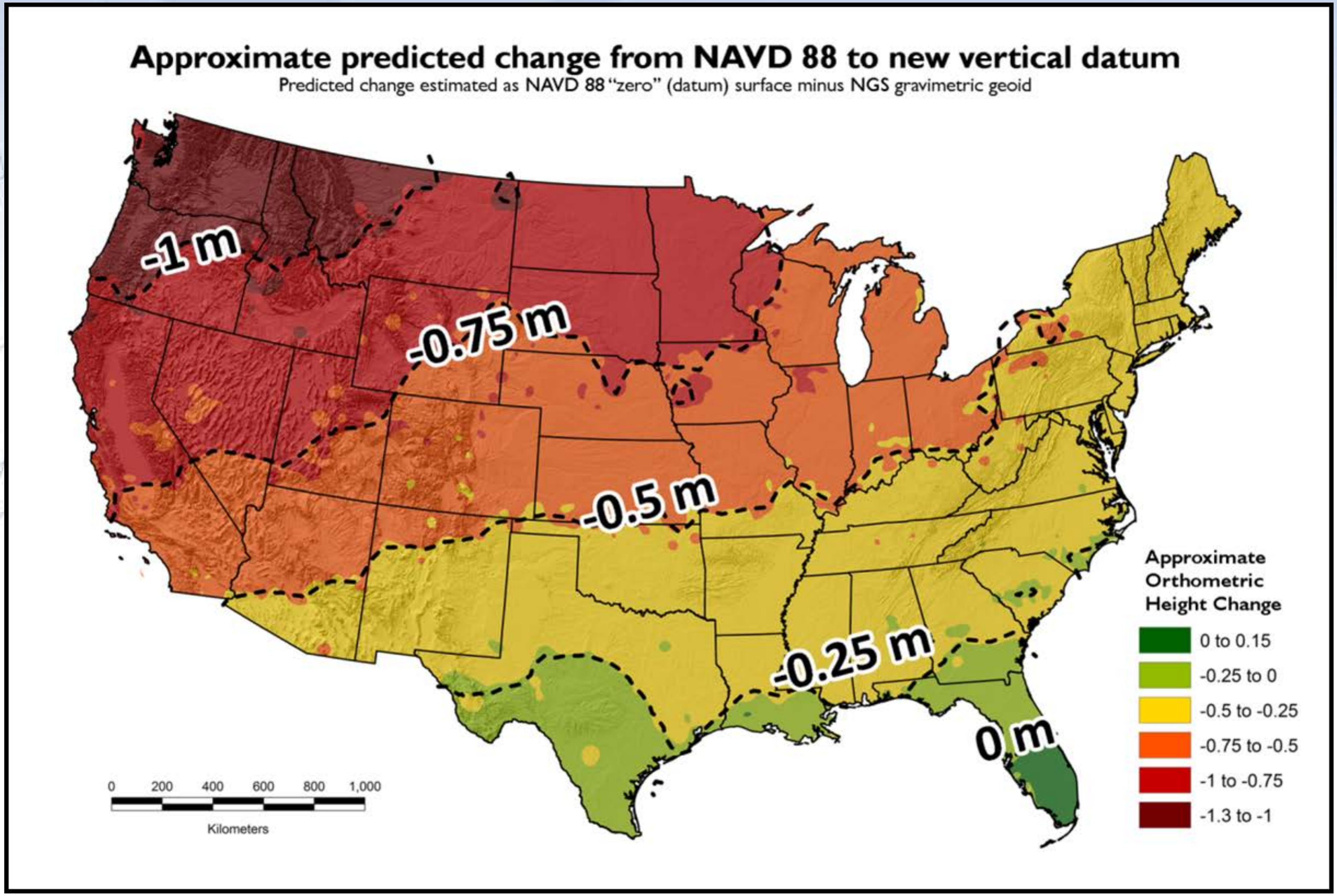
Current Vertical Datums / Models

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

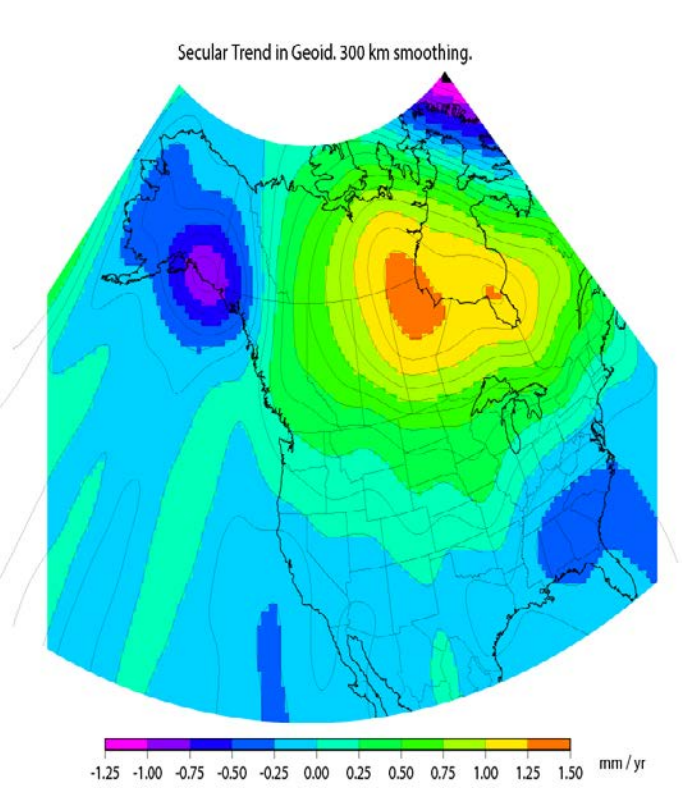
pole-to-equator

Predicted Change – NAVD88 to NAPGD2022



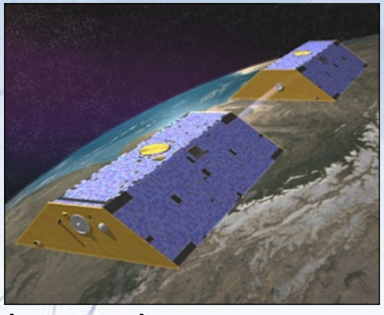
Time Dependencies

GEOID CHANGES CAUSE HEIGHT CHANGES



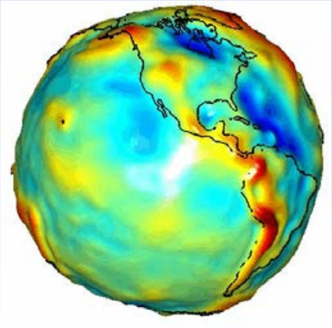
- The zero elevation surface will change with time
- Heights will be time tagged to respect:
  - Geoid change
  - Subsidence
- Possibly start a Geoid monitoring service?

Building a Gravity Field



GRACE/GOCE/Satellite Altimetry

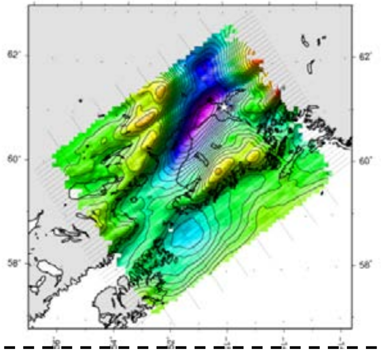
Long Wavelengths
(≥ 250 km)



+

Airborne Measurement

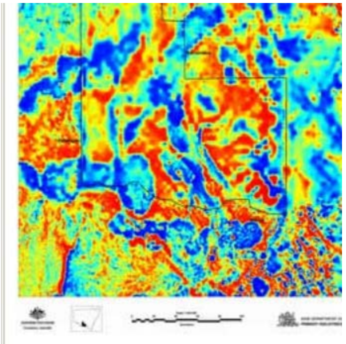
Intermediate Wavelengths
(300 km to 20 km)



+

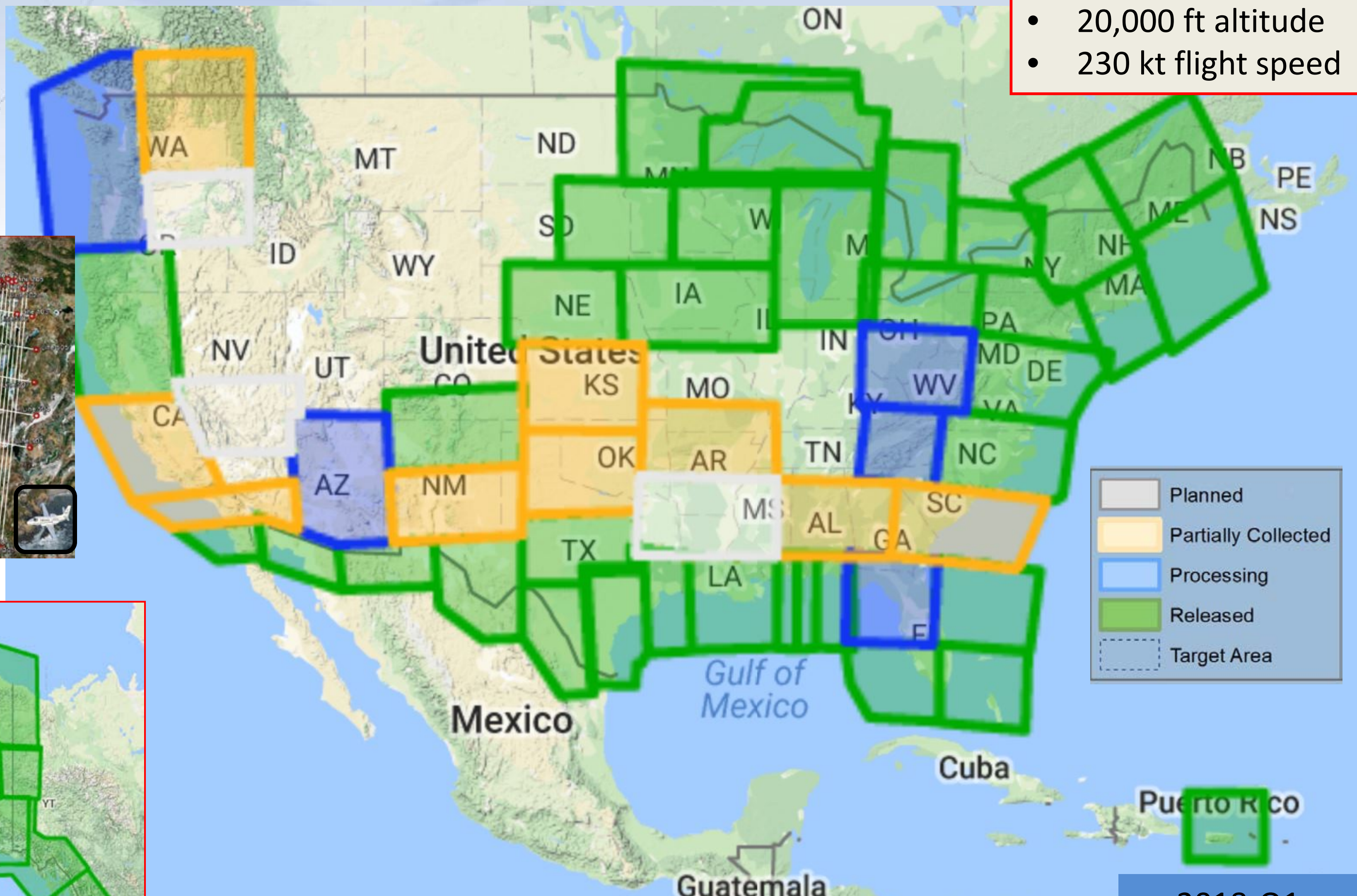
Surface Measurement and
Predicted Gravity from Topography

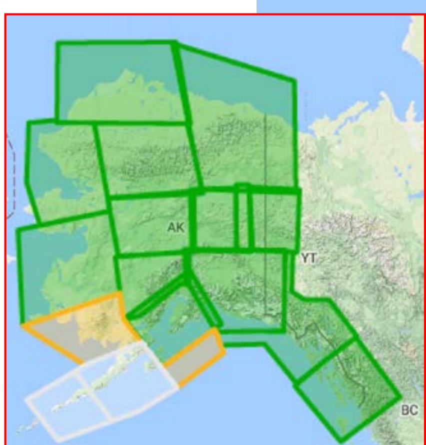
Short Wavelengths
(< 100 km)



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

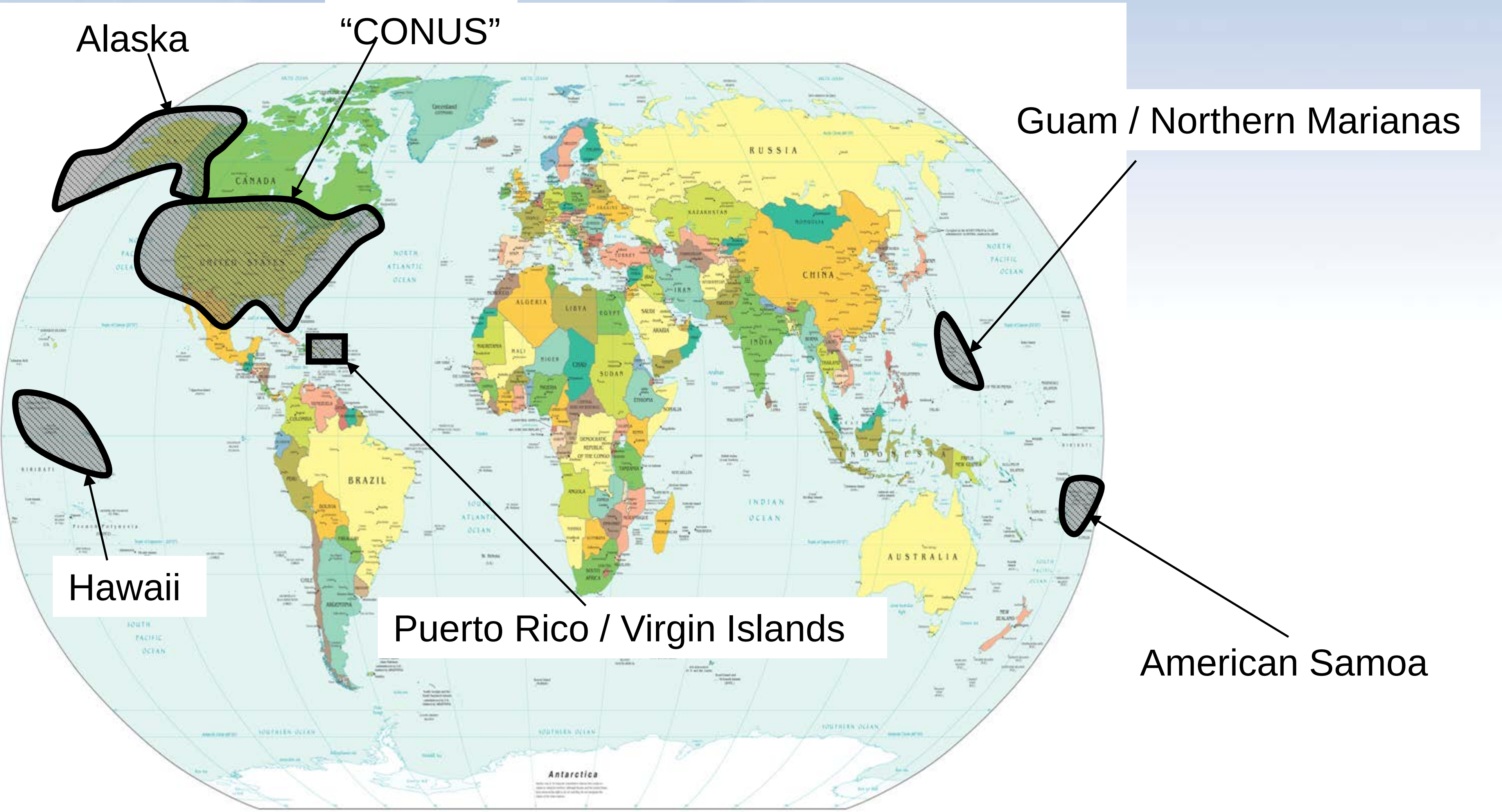
- 10 km data lines
- 70 km cross lines
- 20,000 ft altitude
- 230 kt flight speed



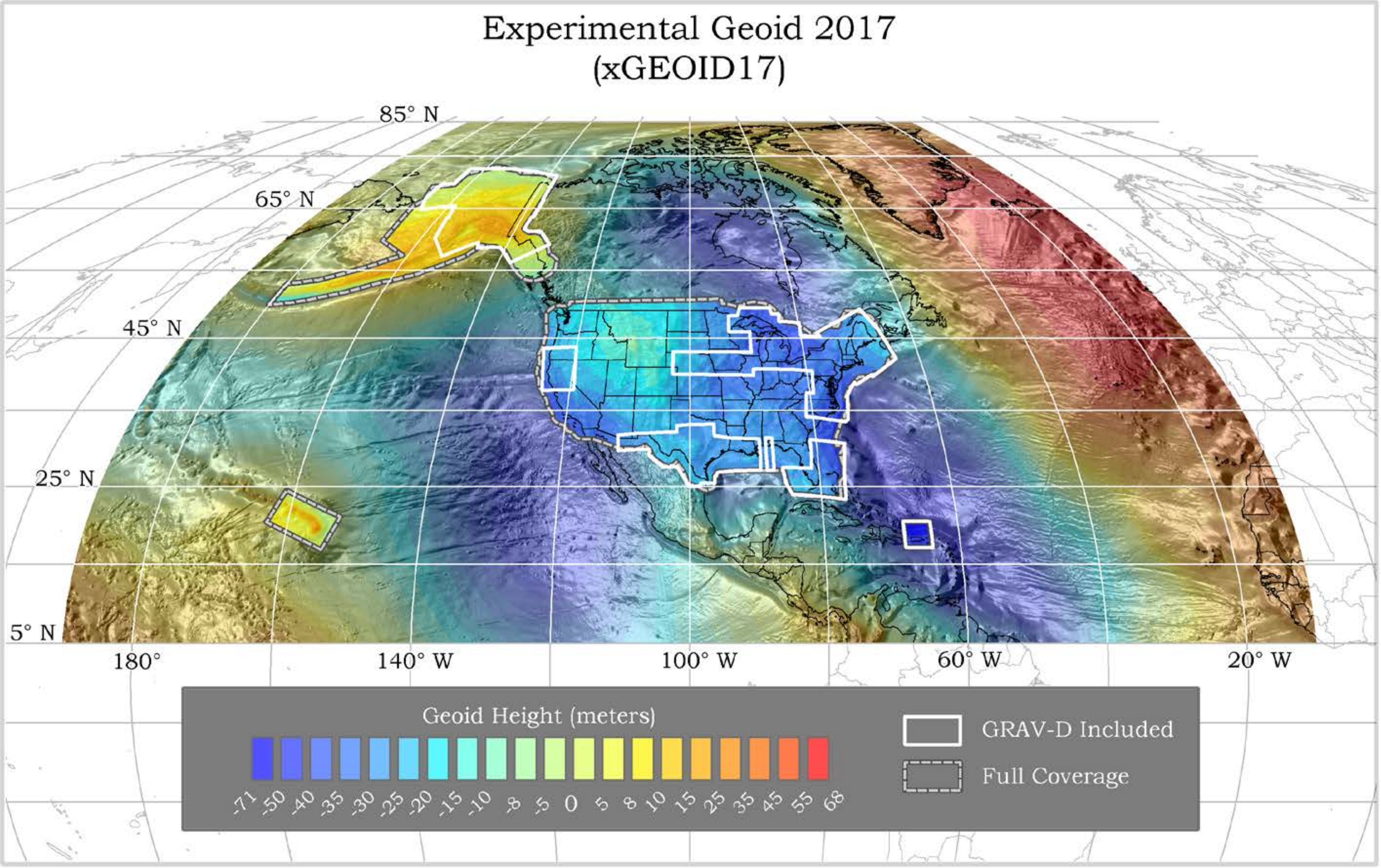


2018-Q1:
65% complete

GRAV-D Coverage



Annual Experimental Geoids



Annual Experimental Geoids

```
Note: The GRS80 ellipsoid is used for both NAD83 and IGS08.


Your input in NAD83 (2011) epoch 2010.00:
Latitude          Longitude          Ellipsoid Height        Station
40.3058249833     121.1431625444     1465.596                No Cal

Your Result in IGS08 epoch 2022.00:
Latitude          Longitude          Ellipsoid Height
40.3058282278     121.1431809194     1465.092

The geoid height of GEOID12B (with respect to NAD83):          -23.556 m
The orthometric height in NAVD88 (based on GEOID12B):          1489.152 m

Estimated orthometric height in North American-Pacific Geopotential Datum of 2022 (NAPGD2022)
based on different geoid models (all heights in meters):

Geoid Model          Geoid Height          Ortho Height          Ortho(model)-NAVD88(GEOID12B)
USGG2012                -23.267               1488.359                  -0.794
xGEOID17A               -23.329               1488.421                  -0.732
xGEOID17B               -23.339               1488.431                  -0.722
-----------------------------------------------------------------------------------------------
```

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: **778.115** (m)
[PROTOTYPE (Computed using xGeoid17B,GRS80,IGS08)]

*[for comparison, NAVD88 = **778.806** (m)]*

Geoid Slope Validation Surveys:

validate gravimetric geoid model accuracy

Phase 1 - GSVS11

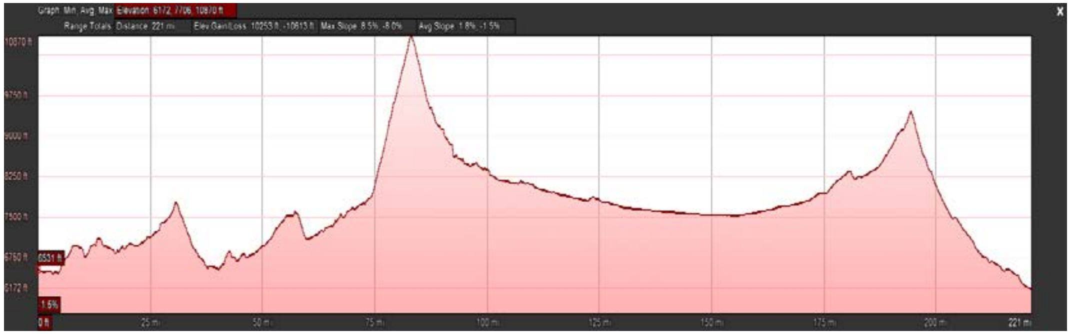
- 2011; Low/Flat/Simple: **Texas**

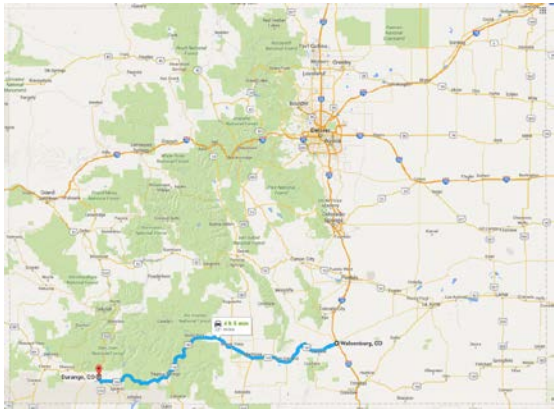
Phase 2 - GSVS14

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

Phase 3 - GSVS17

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





Geoid Slope Validation Surveys


GPS

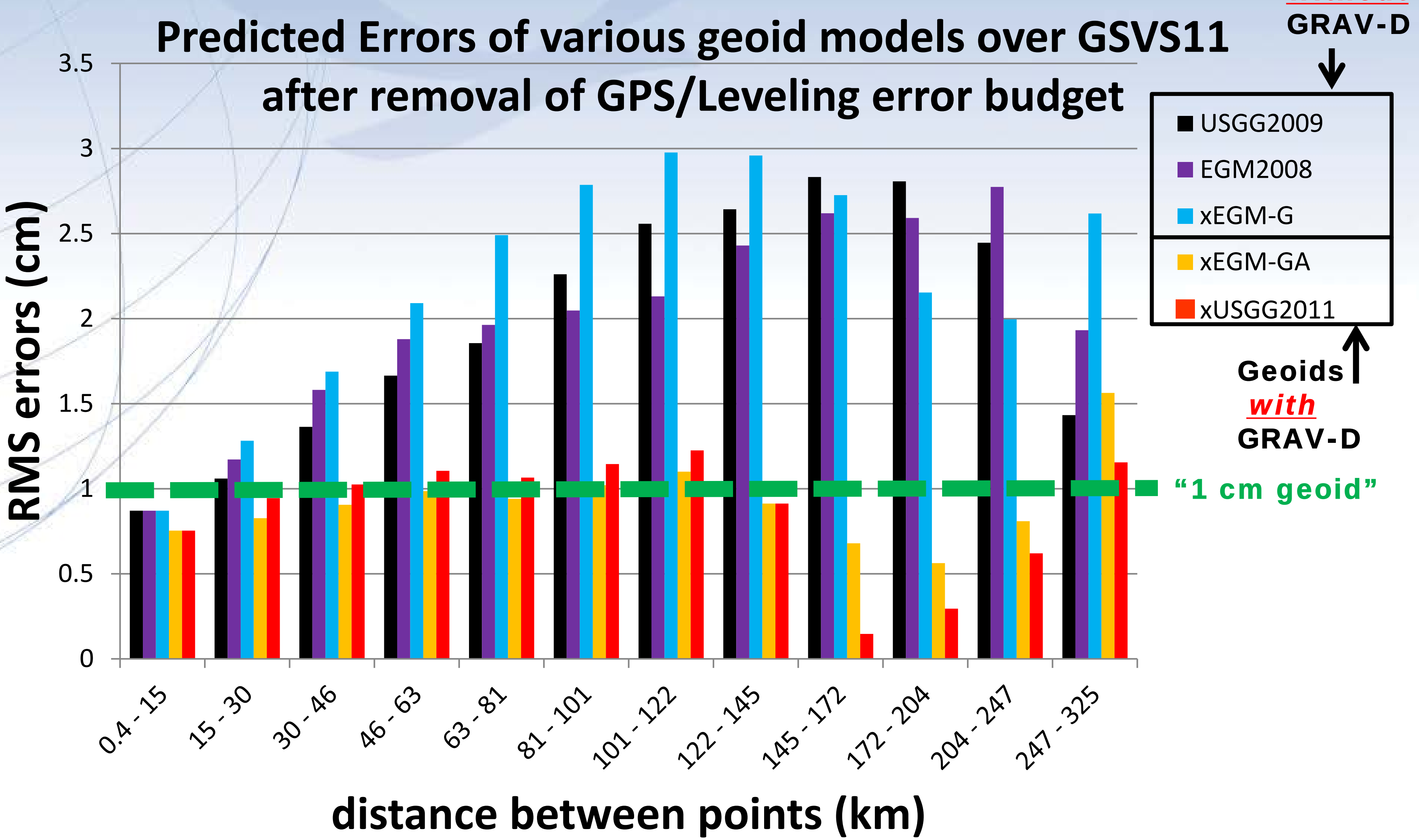

LIDAR/ Imagery


DoV


Gravity


Leveling

GSVS11


Predicted Errors of various geoid models over GSVS11
after removal of GPS/Leveling error budget
RMS errors (cm)
3.5
3
2.5
2
1.5
1
0.5
0
0.4 - 15
15 - 30
30 - 46
46 - 63
63 - 81
81 - 101
101 - 122
122 - 145
145 - 172
172 - 204
204 - 247
247 - 325
distance between points (km)
USGG2009
EGM2008
xEGM-G
xEGM-GA
xUSGG2011
Geoids without GRAV-D
Geoids with GRAV-D
"1 cm geoid"

International GNSS Service

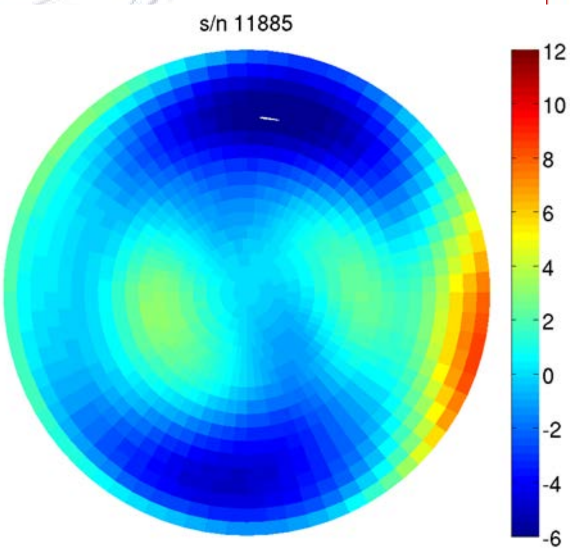
Formerly the International GPS Service

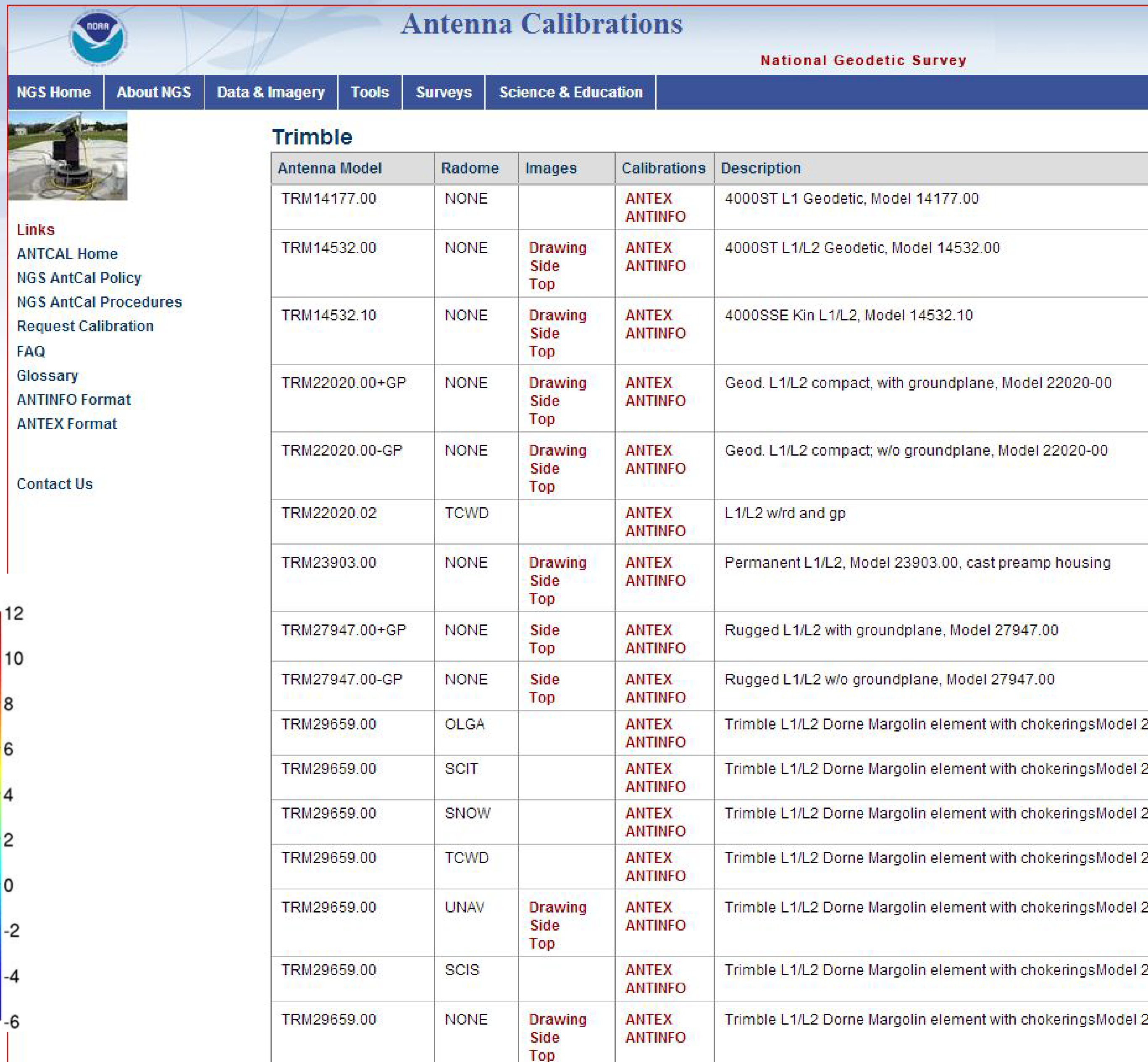
General GPS/GNSS questions?
Please visit resource links

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

Absolute GNSS Antenna Calibrations





Antenna Calibrations

National Geodetic Survey

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

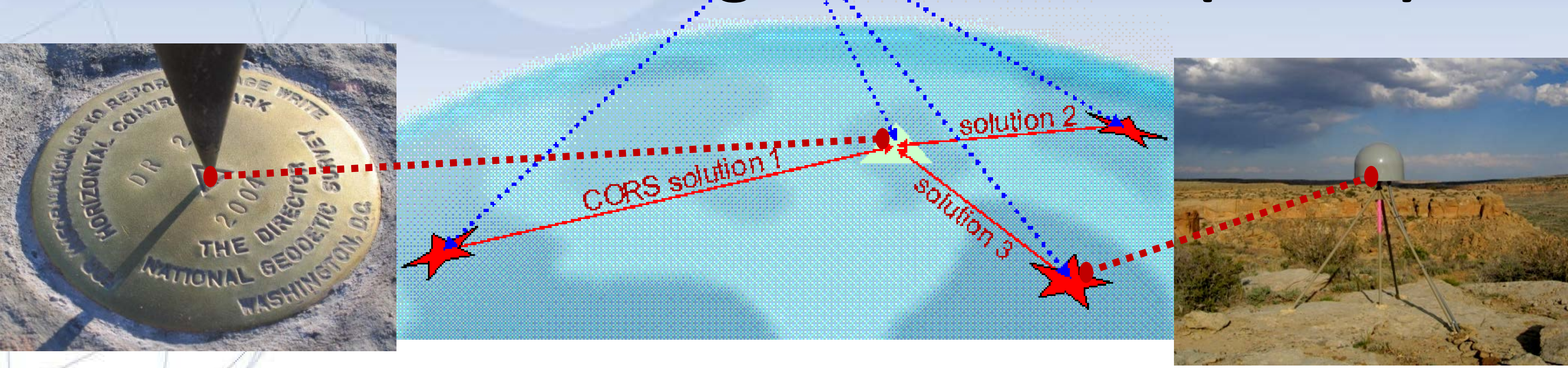
Links
- ANTCAL Home
- NGS AntCal Policy
- NGS AntCal Procedures
- Request Calibration
- FAQ
- Glossary
- ANTINFO Format
- ANTEX Format

Contact Us

Trimble

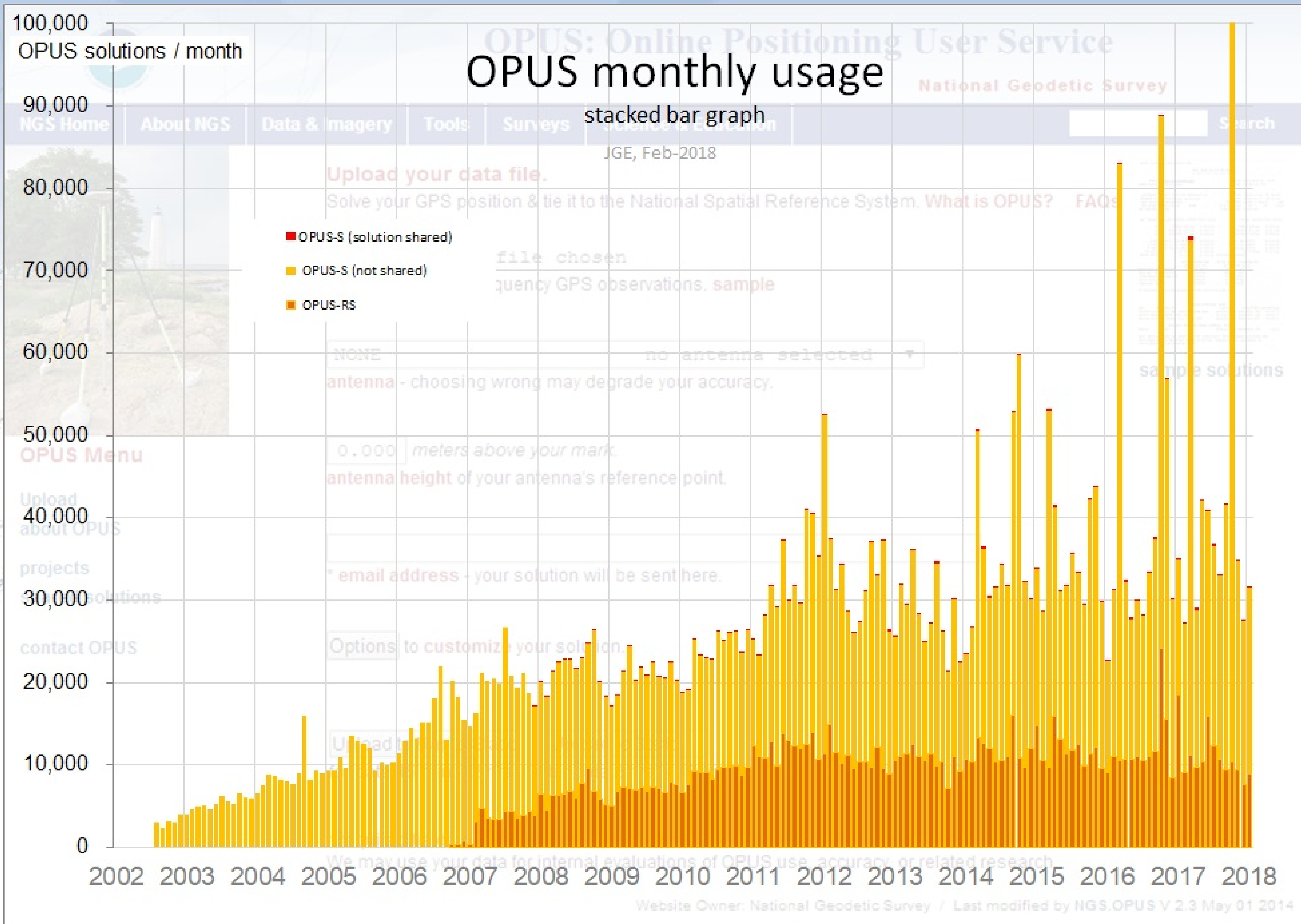
Antenna Model	Radome	Images	Calibrations	Description
TRM14177.00	NONE		ANTEX ANTINFO	4000ST L1 Geodetic, Model 14177.00
TRM14532.00	NONE	Drawing Side Top	ANTEX ANTINFO	4000ST L1/L2 Geodetic, Model 14532.00
TRM14532.10	NONE	Drawing Side Top	ANTEX ANTINFO	4000SSE Kin L1/L2, Model 14532.10
TRM22020.00+GP	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

Online Positioning User Service (OPUS)



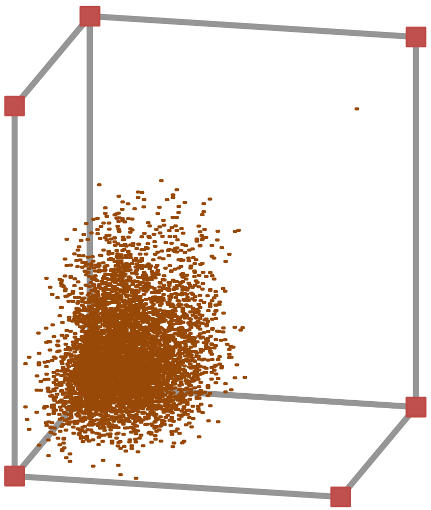
- upload L1/L2 GPS data >>> solution via email in minutes
  - ➢ OPUS-RS (Rapid Static) ----15 min to 2 hr (per CORS)
  - ➢ OPUS-S (Static) ---- 2 to 48 hr (anywhere)
  - ➢ OPUS-DB (Database) --- sharing of results
  - ➢ OPUS-Projects --- network of multi-stations/occupations

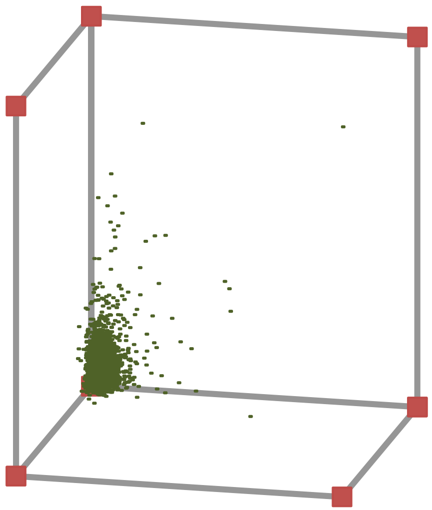
Fast, easy, consistent access to NSRS


OPUS monthly usage
stacked bar graph
JGE, Feb-2018
OPUS solutions / month
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
OPUS-S (solution shared)
OPUS-S (not shared)
OPUS-RS
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018

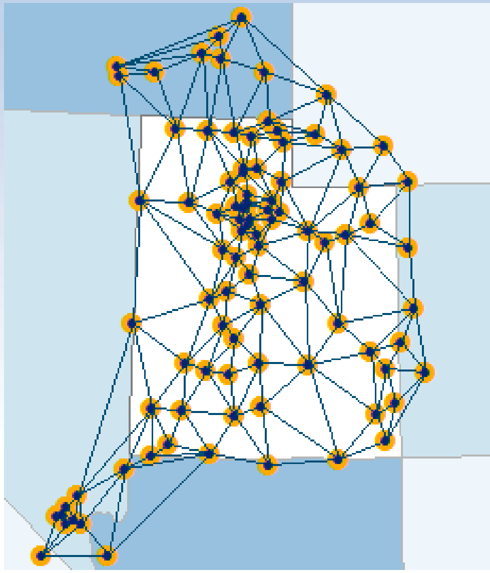
Improvement in Published OPUS solutions using NAD83(2011) epoch 2010.00 CORS coordinates

	original	new	improved
peak-to-peak LAT	0.013 m	0.004 m	**69 %**
peak-to-peak LON	0.015 m	0.004 m	**73 %**
peak-to-peak EL_HGT	0.024 m	0.008 m	**67 %**
% ambiguities fixed	93 %	95 %	2 %
% observations used	95 %	94 %	-1 %
RMS	0.014 m	0.014 m	0 %





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!!!!**

NGS Coordinate Conversion & Transformation Tool (NCAT)

BETA
This is a BETA Release Site

NGS Coordinate Conversion and Transformation Tool (NCAT)
National Geodetic Survey

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

Single Point Conversion | Multipoint Conversion | Web services | Downloads | About Conversion Tool

Convert from: (•) LLh ( ) SPC ( ) UTM ( ) XYZ ( ) USNG

Enter lat-lon in decimal degrees

Lat 39.2240867222

Lon -98.5421515000

or degrees-minutes-seconds

Lat N 39-13-26.71220

Lon W 098-32-31.74540

or drag map marker to a location of interest

Ellipsoid Height (m) 2,000.000

Input datum NAD83(2011)

Output datum NAD83(1986)

Converted coordinates will be in output datum.

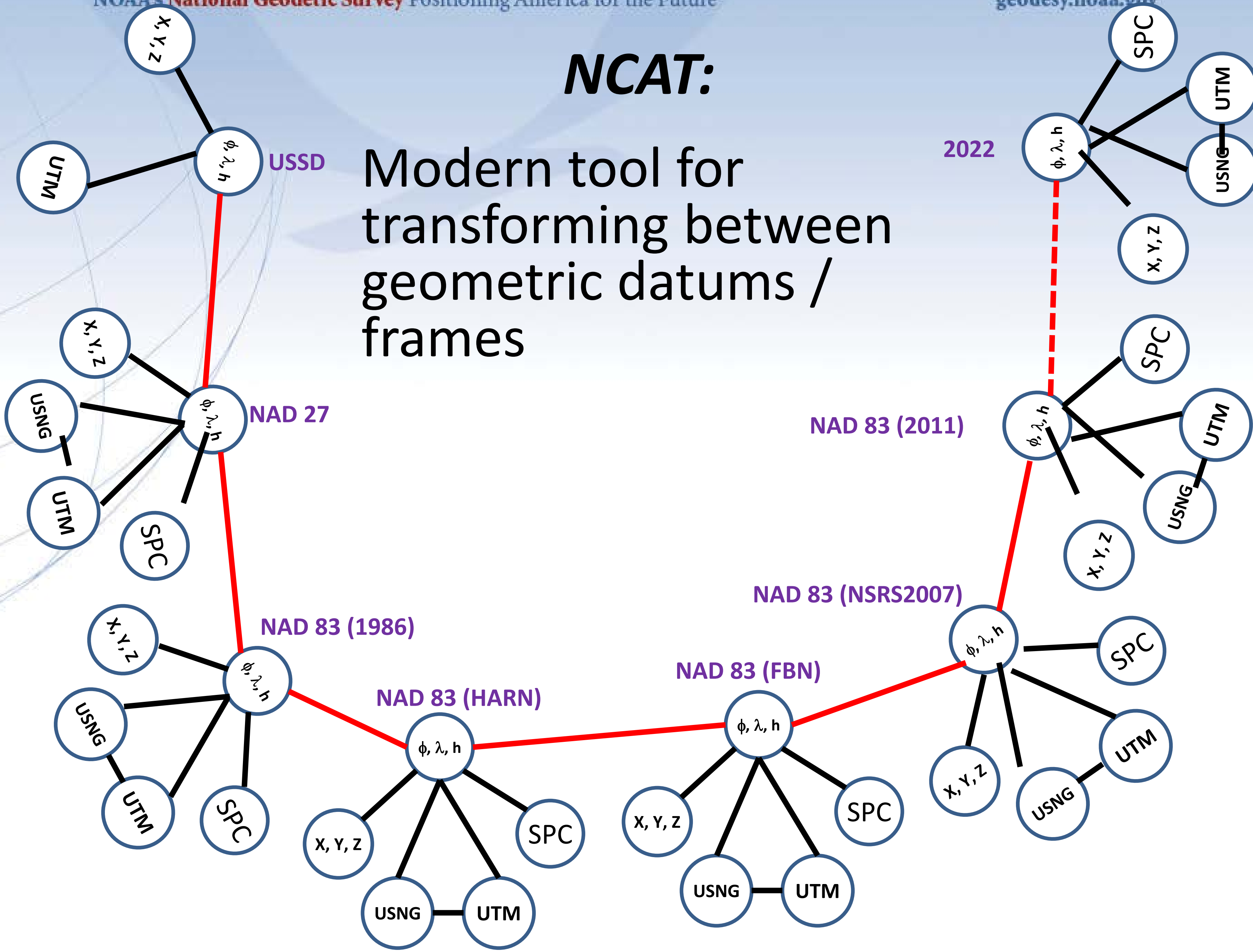
Convert

Export Results to

LLh		SPC		UTM (m)		XYZ (m)		USNG
SrcLat	39.2240867222 N391326.71220	Zone	KS N-1501	Zone	14	X	N/A	14SNJ3952041744
DestLat	N/A N/A	Northing (m)	99,023.851	Northing	4,341,744.059	Y	N/A	
Siglat	±N/A	Northing (usft)	324,880.751	Easting	539,520.632	Z	N/A	
				Convergence	00 17 22.30			

NCAT:

Modern tool for transforming between geometric datums / frames



geodesy.noaa.gov

National Geodetic Survey

Positioning America for the Future

New Datums
Home
What to expect
Get prepared
Track our progress
Naming Convention
Watch videos
Related projects
Learn more
New Datums FAQ
Contact Us

Subscribe for email notifications

Events
Industry Engagement
2017 Summit
2015 Summit
2010 Summit

New Datums: 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
Track our Progress | Naming Convention
Watch Videos | Related Projects

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.

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

Issue 10, January 2018

NSRS Modernization News

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

Blueprints

NOAA Technical Report NOS NGS 64, "Blueprint for 2022, Part 2: Geopotential Coordinates" was released on November 13th.

Foundation CORS

After a slow start, the Foundation CORS project is underway again. A formal project plan exists, outlining the strategies for completion of this network by December 2022. A significant portion of the network will be through incorporation and refurbishment of existing GNSS infrastructure. For more information, contact the Foundation CORS project manager, Dr. Kevin Choi.

Upcoming Outreach

In the next few months, two national conferences will host sessions on NSRS Modernization. They are:

- The ASPRS/ILMF conference in Denver, CO will have a panel session entitled ***North American Terrestrial Reference Frame of 2022 Modernization Program***, which is scheduled from 3:15 to 4:30 on February 6.
- The ASCE-UESI conference in Pomona, CA is holding a two-part session entitled ***NSRS Modernization*** from 1:45 2:40 and 3:30 to 4:50 on April 23.

Progress of Ongoing Projects

There are currently 18 ongoing projects directly related to NSRS modernization around NGS. Here are highlights from a select few:

State Plane Coordinates for 2022

Project Manager: Michael Dennis

Draft policy and procedures have been developed for SPCS2022, and they will be released for public comment within the next few weeks. A new report will also be published soon: ***NOAA Special Publication NOS NGS 13, "The State Plane Coordinate System of 1983: History, Policy, and Future Directions."*** This document includes definitions for every SPCS zone ever created by NGS. An NGS webinar on SPCS2022 is scheduled for March 8 (sign up at https://geodesy.noaa.gov/web/science_edu/webinar_series/Webinars.shtml).

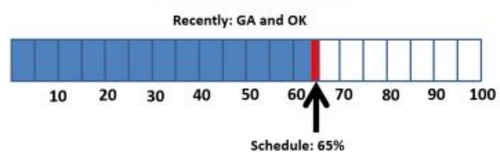
OP2IDB Project Manager: Dr. Mark Schenewerk

In November, 2017, BETA OPUS-Projects wrapped up its series of "quick start" training webinars and demos. The presentation (.ppt) and recording (.mp4) of these webinars are available here:
ftp://ftp.ngs.noaa.gov/pub/corbin/Beta%20OPUS%20Projects%20webinar%20material/

xGEOID Annual Project Manager: Dr. Yan Wang

xGEOID18 will come with enhancements not seen in previous xGEOID releases. Of note, all three areas which will eventually be covered by GEOID2022 (North American/Pacific, American Samoa and Guam/CNMI) will be covered. Additionally a companion deflection of the vertical model, xDEFLEC18 will be released with xGEOID18.

GRAV-D progress last quarter: up 1.3% to 65.2%
Ahead of Schedule!



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:

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

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, α(t) must be split into rotations among the three axes of the ideal frame, and since α(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 α(t) into its components, yields:

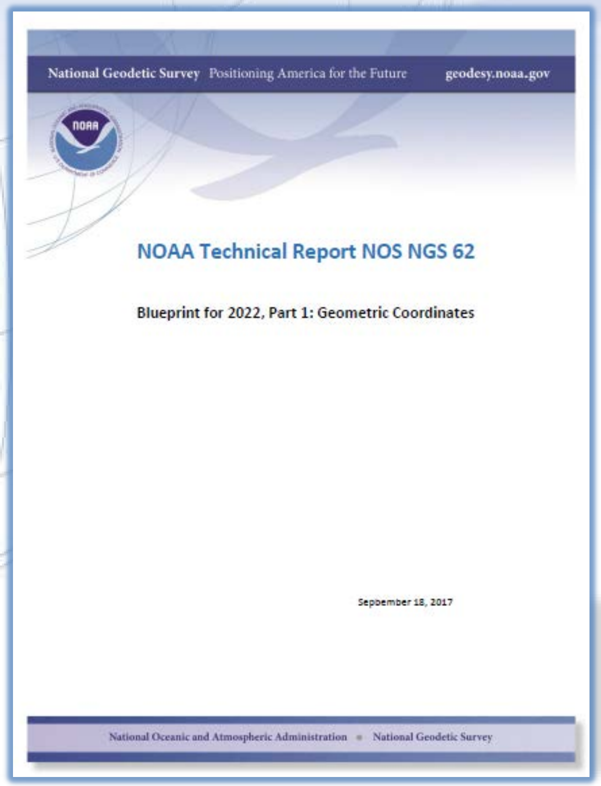
$$\omega_X(t_0) + (\Delta t)\dot{\omega}_X = [\dot{\omega}_0 \Delta t] cos\lambda_0 sin\theta_0 \qquad (46)$$

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

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

Modernizing the NSRS

The "blueprint" documents:
Your best source for information

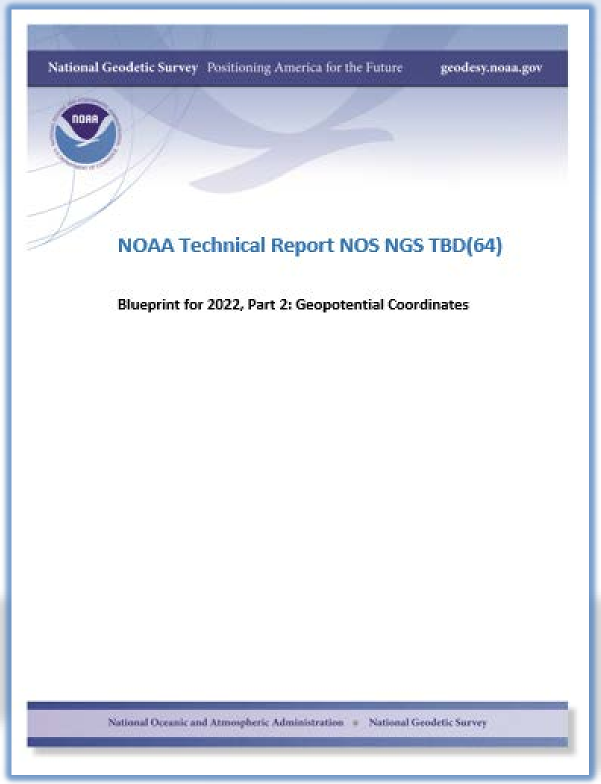

National Geodetic Survey Positioning America for the Future geodesy.noaa.gov

NOAA Technical Report NOS NGS 62

Blueprint for 2022, Part 1: Geometric Coordinates

September 18, 2017

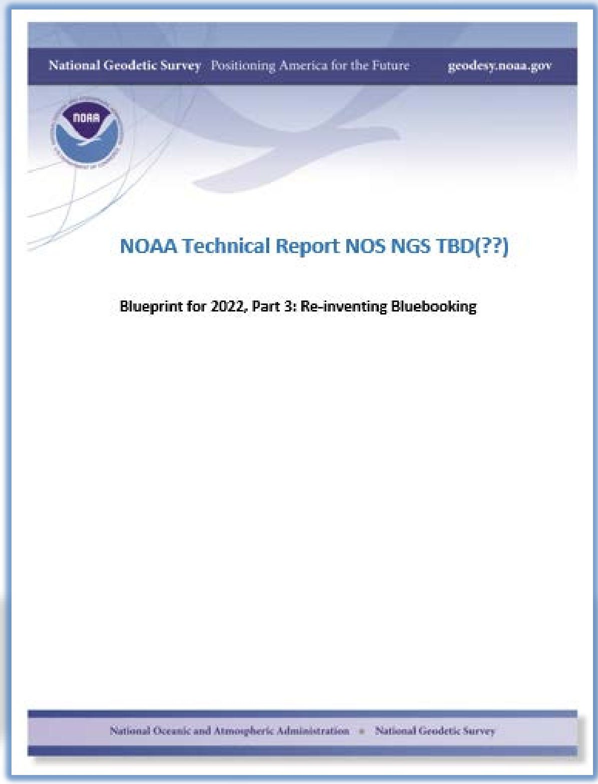
National Oceanic and Atmospheric Administration • National Geodetic Survey


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

NOAA Technical Report NOS NGS TBD(64)

Blueprint for 2022, Part 2: Geopotential Coordinates

National Oceanic and Atmospheric Administration • National Geodetic Survey


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

NOAA Technical Report NOS NGS TBD(??)

Blueprint for 2022, Part 3: Re-inventing Bluebooking

National Oceanic and Atmospheric Administration • National Geodetic Survey

#1 Geometric:
May 2017
(minor update Sep. 2017)

#2 Geopotential:
Oct. 2017

#3 Bluebooking:
Spring 2018

NGS Video Library

National Geodetic Survey

Educational Videos Quick Links

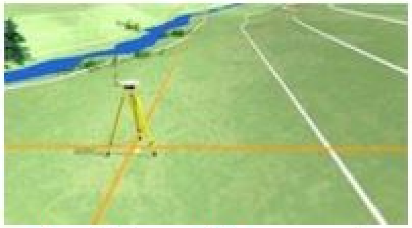
- Corbin Training Center
- Online Lessons
- Geospatial COMET MetED Resources
- National Ocean Service Lesson Plan Libary
- Other Videos +

What are Geodetic Datums?

How Were Geodetic Datums Established?

What Is the Status of Today's Geodetic Datums?

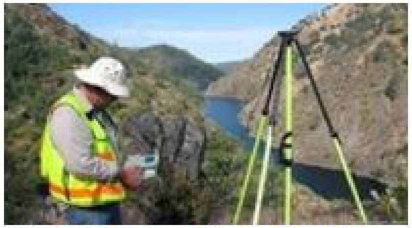
What's Next for Geodetic Datums?



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

Summary

- Primary access: GNSS
  - Based on CORS and gravimetric geoid model (not passive bench marks)
  - But also compatible with terrestrial methods
- Geometric (TRFs)
  - Fixed to 4 tectonic plates and aligned with global frame (ITRF/IGS/WGS 84)
  - Intraframe velocity models allow georeferencing to specific epochs
  - Includes new State Plane system
- Geopotential
  - Elevations derived from geopotential models using GNSS
  - Referenced to best estimates of mean sea level, updated as necessary
- Includes time-dependency
- Benefits
  - Integrated
  - Consistent
  - Accurate

Accurate positioning begins with *accurate* coordinates

Source: Zurich-American Insurance Group