Determining Positions After 2022

Institute of Navigation GNSS
Civil GPS Service Interface Committee Meeting
Miami, FL

September 16, 2019

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NOAA, National Geodetic Survey
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U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Geodetic Survey

Mission: To define, maintain & provide access to the ***National Spatial Reference System (NSRS)*** to meet our Nation's economic, social & environmental needs

National Spatial Reference System

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

& their variations in time

New U.S. Geometric Datums in 2022

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

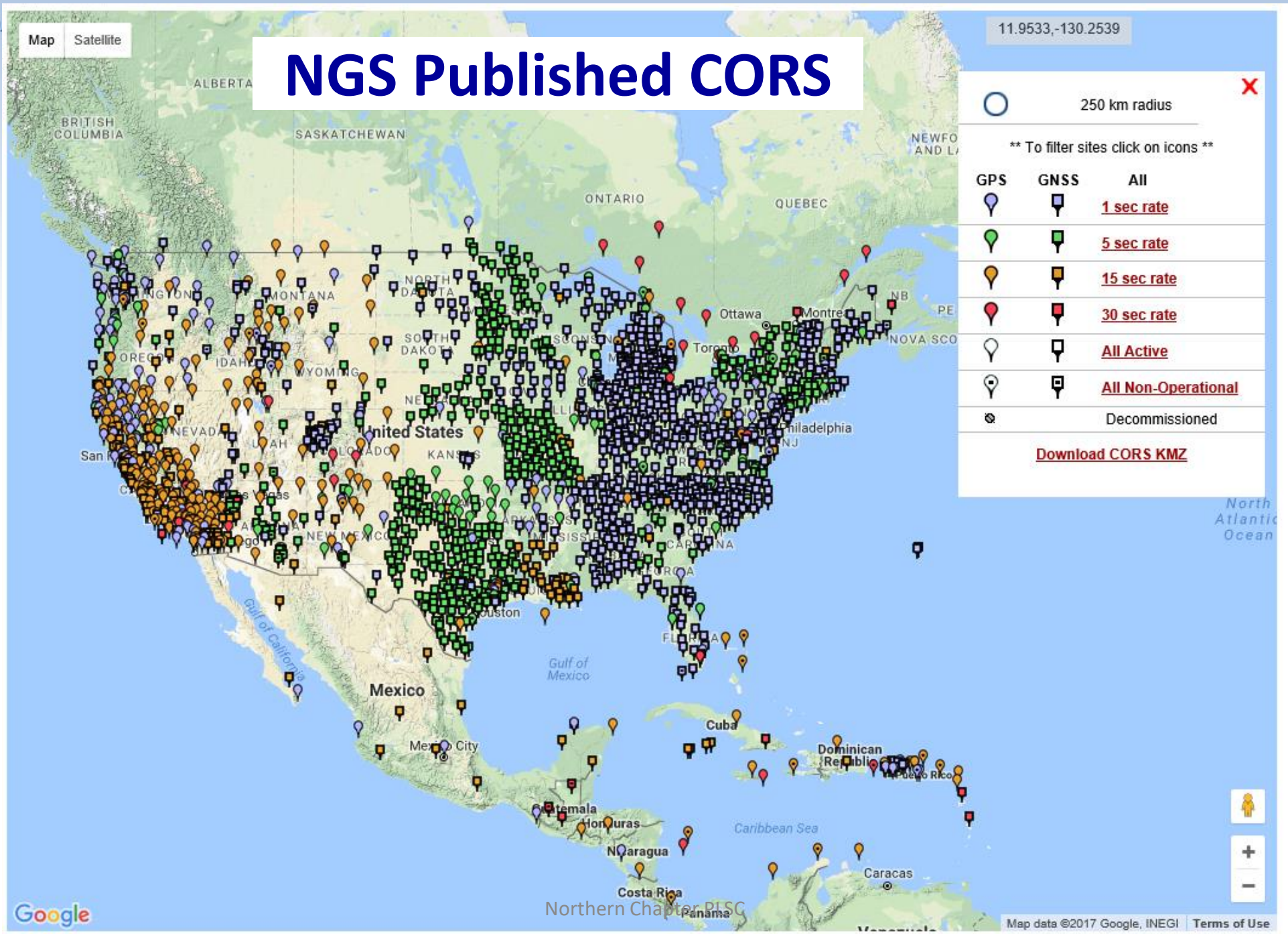
NETWORK	TIME SPAN	NETWORK ACCURACY	METHOD OF REFERENCE
NAD 27	1927-1986	10 meter	TERRESTRIAL BASED REFERENCE SYSTEM FOR NSRS
NAD83(86)	1986-1990	1 meter	
NAD83(199x)* HARN	1990-2007	0.1 meter	TERRESTRIAL BASED REFERENCED SYSTEM FOR NSRS
NAD83(2007) (CORS)	2007 - 2011	0.01 meter	SPACE BASED REFERENCE SYSTEM FOR NSRS
NAD83(2011) (CORS)	2011 - 2022	0.01 meter	

NSRS Reference Basis

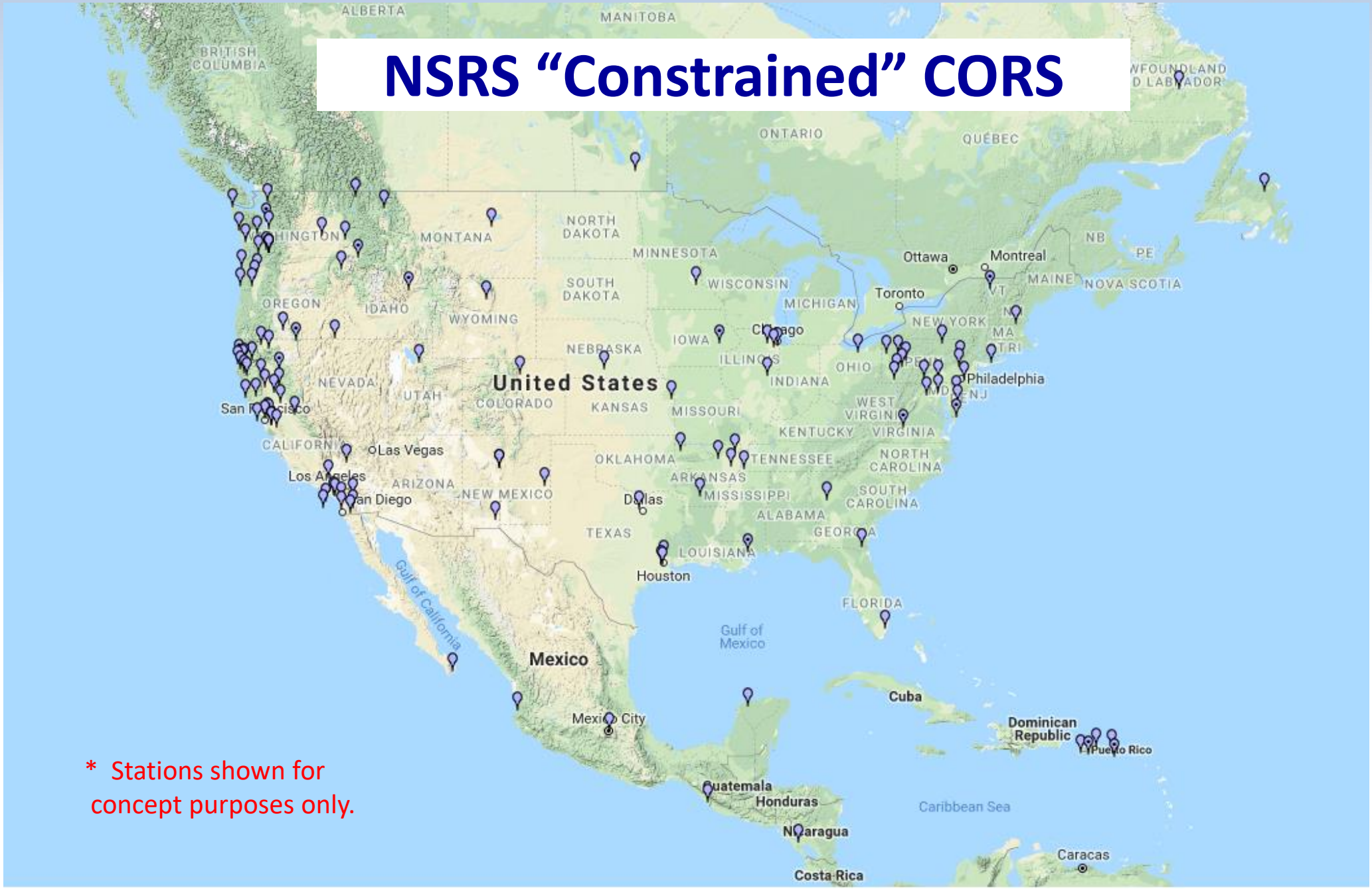
Old Method - Ground Marks (Terrestrial)

New Method - GNSS Stations (CORS)

NGS Published CORS



NSRS "Constrained" CORS



* Stations shown for concept purposes only.

Why Replace NAD83?

- **Datum based on best known information about the earth's size and shape from the early 1980's (≈34 years old), and the terrestrial survey data of the time.**
- **NAD83 is NON-geocentric & hence inconsistent w/GNSS (ITRF).**
- **Necessary for agreement with future ubiquitous positioning of GNSS capability.**

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

NOAA Technical Report NOS NGS 62

Blueprint for 2022, Part 1: Geometric Coordinates

Dru Smith
Dan Roman
Steve Hilla

April 21, 2017

National Oceanic and Atmospheric Administration • National Geodetic Survey

Future Geometric (3-D) Reference Frame

Blueprint for 2022: Part 1 – Geometric Datum

- CORS-based, accessed via GNSS observations.
- Coordinates & velocities in ITRF (IGS) & new US reference frame.
- Passive control tied to new reference frame (not a component).
- Transformation tools will relate NAD83 to new US reference frame (NCAT with 2022 transformation).

Datum Names

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)

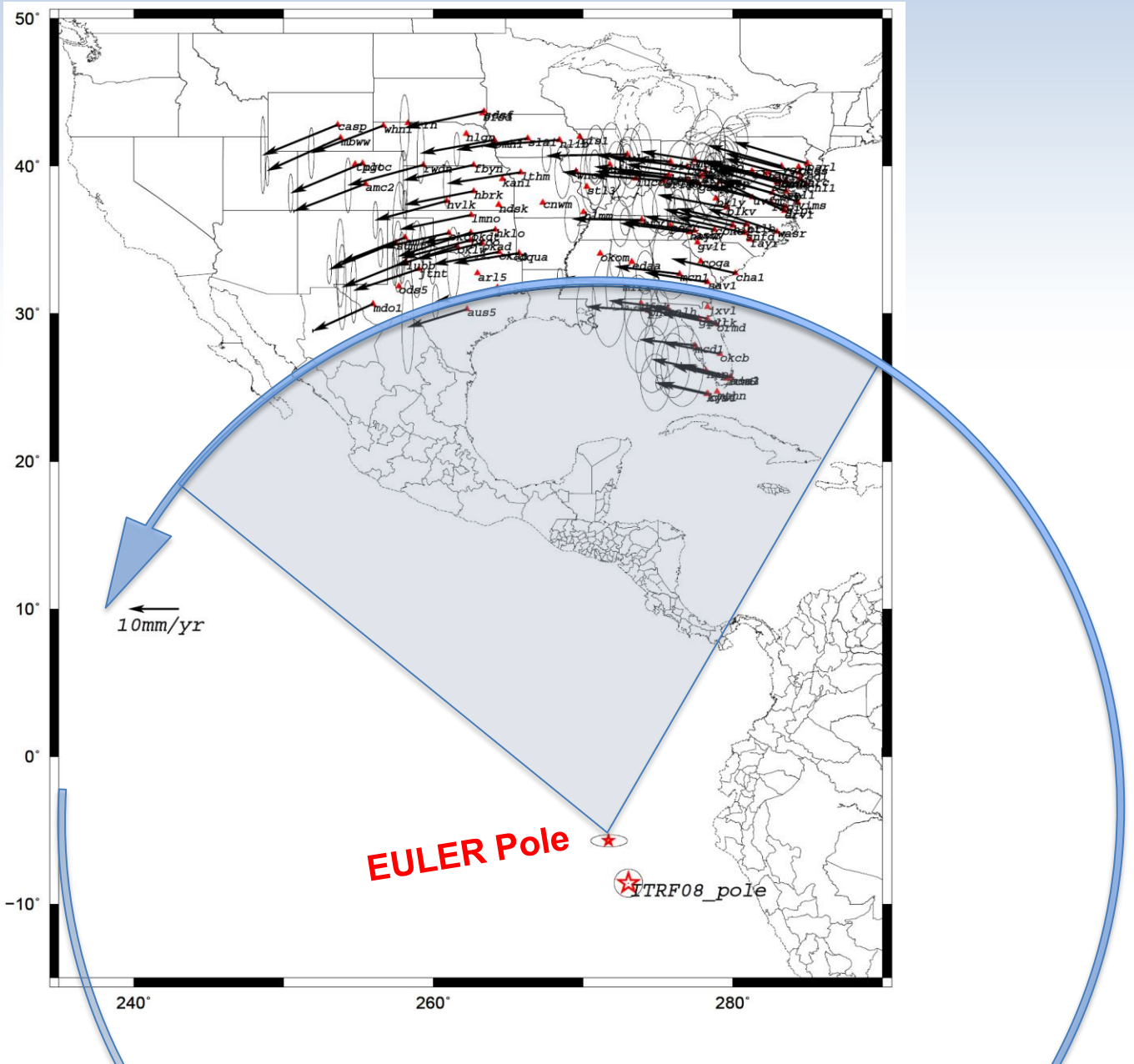
The Pacific Terrestrial Reference Frame of 2022 (PATRF2022)

The Mariana Terrestrial Reference Frame of 2022 (MATRF2022)

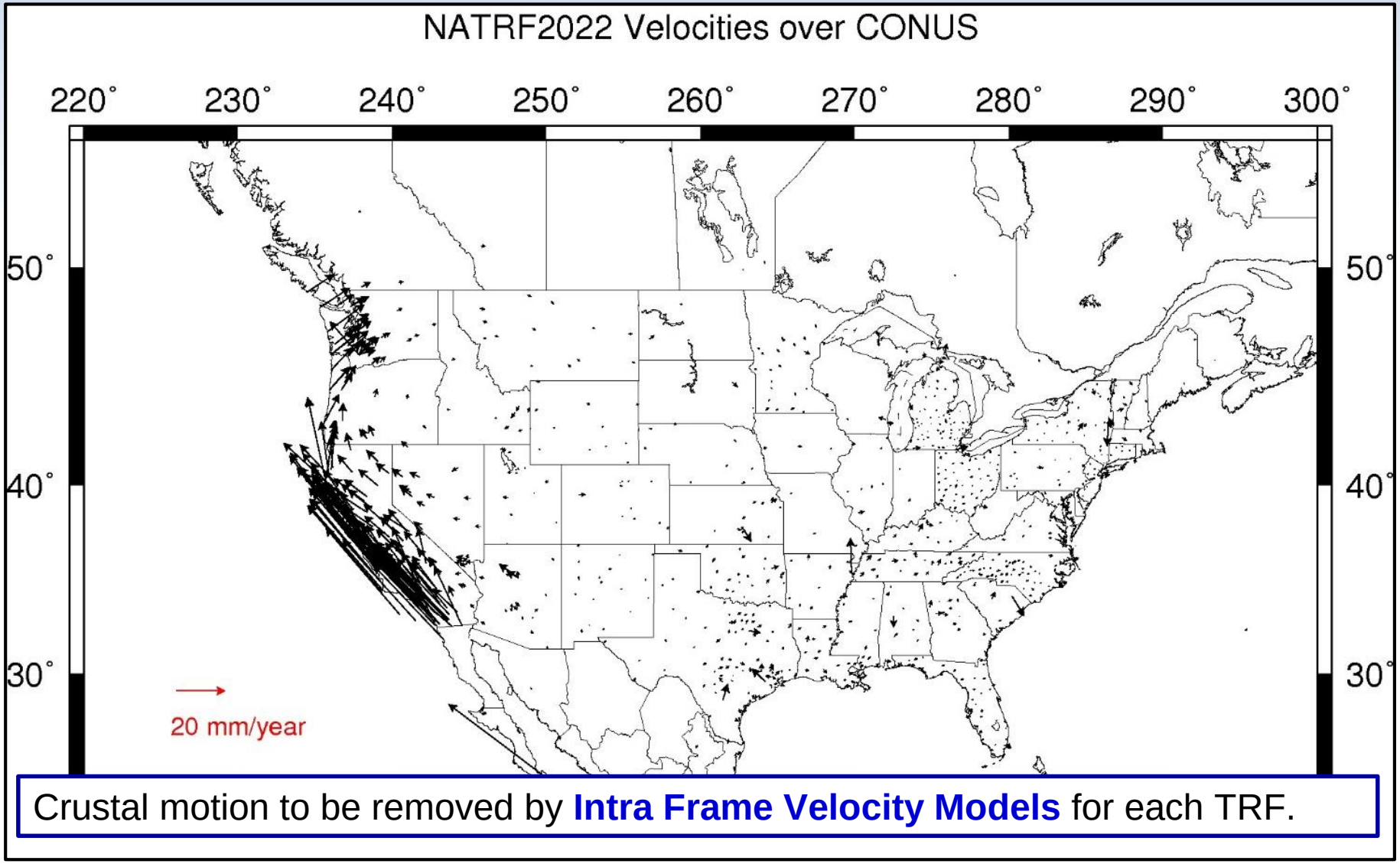
NSRS Plate Rotation Modeling

Each frame will get 3 parameters
- Euler Pole Latitude
- Euler Pole Longitude
- Rotation rate (radians / year)

This will be used to compute time-dependent TRF2022 coordinates from time-dependent IGS coordinates.

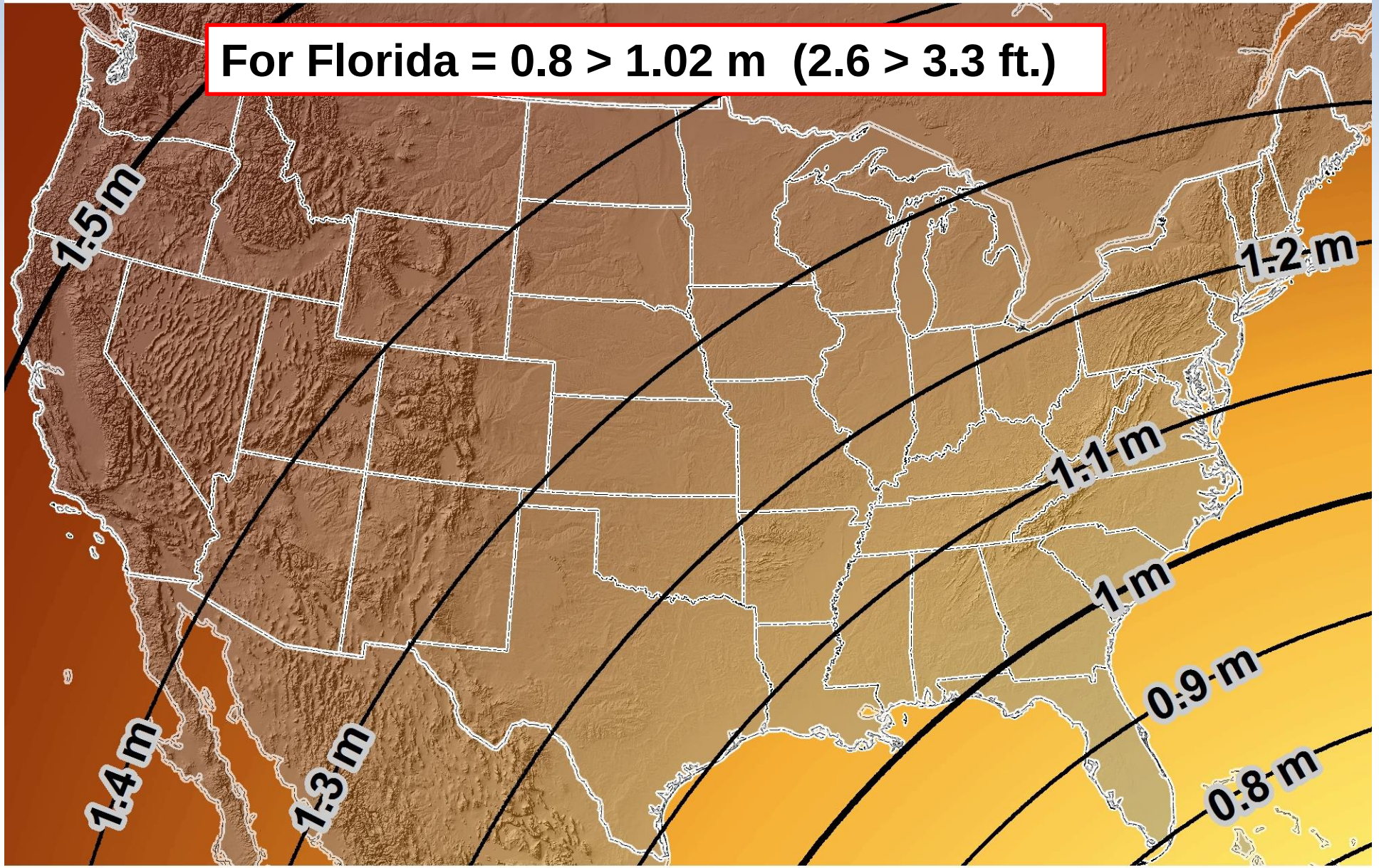


CORS Velocities – IGS08



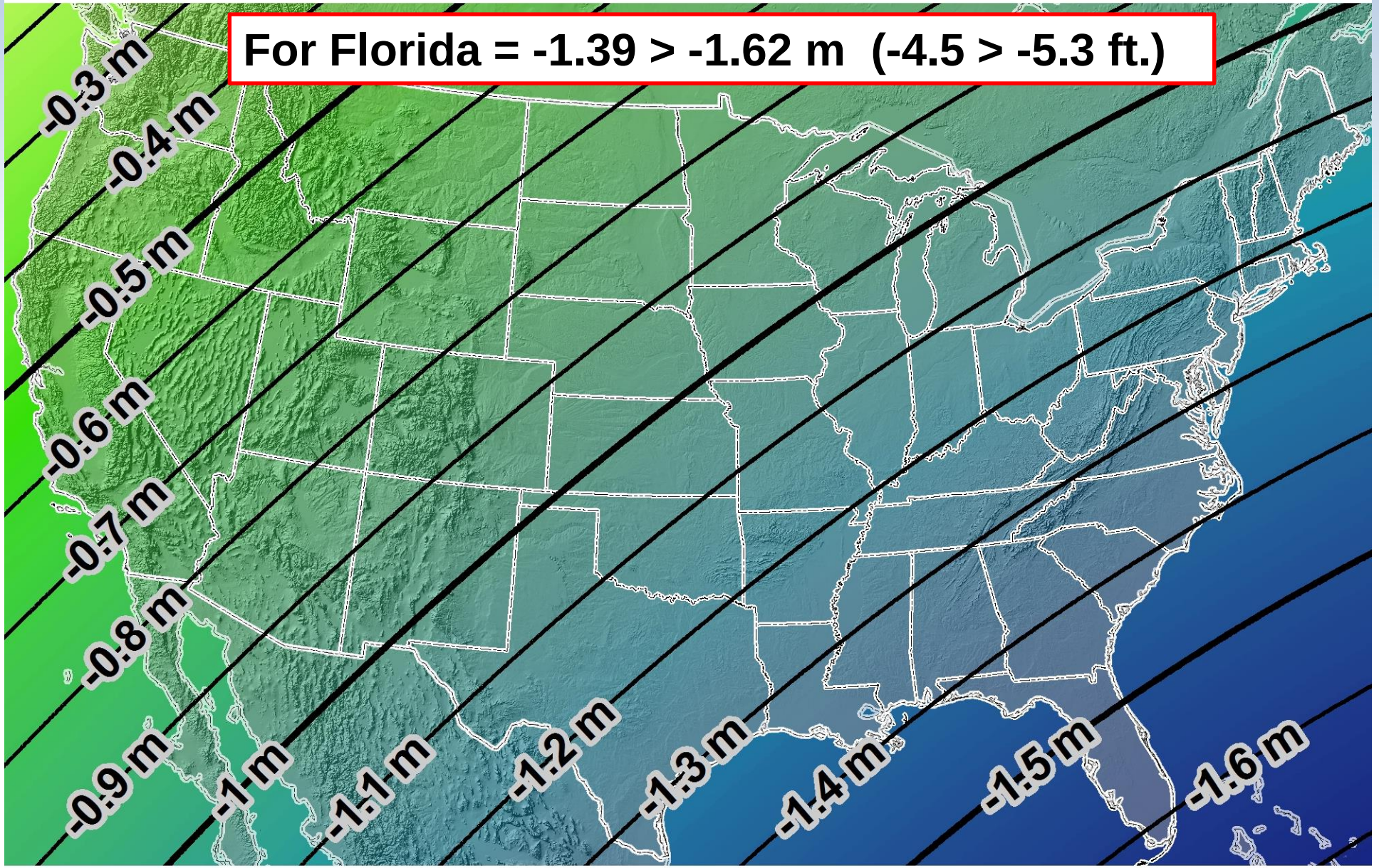
Crustal motion to be removed by **Intra Frame Velocity Models** for each TRF.

Estimated horizontal change from NAD 83 to NATRF2022



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

Estimated ellipsoid height change from NAD 83 to NATRF2022



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

Geometric Position Epochs

```
PROGRAM = datasheet95, VERSION = 8.12.1
1         National Geodetic Survey,    Retrieval Date = MAY  9, 2017
 BV0854 ***********************************************************************
 BV0854  DESIGNATION -  98 V 110
 BV0854  PID         -  BV0854
 BV0854  STATE/COUNTY-  MS/MARION
 BV0854  COUNTRY     -  US
 BV0854  USGS QUAD   -  COLUMBIA SOUTH (1982)
 BV0854
 BV0854                          *CURRENT SURVEY CONTROL
 BV0854
 BV0854* NAD 83(2011) POSITION- 31 14 16.29550(N) 089 49 13.85530(W)   ADJUSTED
 BV0854* NAD 83(2011) ELLIP HT      -14.558 (meters)          (06/27/12)   ADJUSTED
 BV0854* NAD 83(2011) EPOCH    -  2010.00
 BV0854* NAVD 88 ORTHO HEIGHT      44.754 (meters)       146.83   (feet) ADJUSTED
 BV0854* NAVD 88 EPOCH         -  2009.55
 BV0854  **This station is located in a suspected subsidence area (see below).
 BV0854
 BV0854  GEOID HEIGHT    -        -26.860 (meters)                       GEOID12B
 BV0854  NAD 83(2011) X  -     17,098.873 (meters)                       COMP
 BV0854  NAD 83(2011) Y  - -5,458,350.266 (meters)                       COMP
 BV0854  NAD 83(2011) Z  -  3,288,479.650 (meters)                       COMP
 BV0854  LAPLACE CORR    -         -0.44  (seconds)                      DEFLEC12B
 BV0854  DYNAMIC HEIGHT  -         44.698 (meters)       146.65   (feet) COMP
 BV0854  MODELED GRAVITY -    979,394.9   (mgal)                         NAVD 88
 BV0854
 BV0854  VERT ORDER      -  FIRST     CLASS II
 BV0854
 BV0854  Network accuracy estimates per FGDC Geospatial Positioning Accuracy
 BV0854  Standards:
 BV0854          FGDC (95% conf, cm)      Standard deviation (cm)      CorrNE
 BV0854             Horiz  Ellip           SD_N   SD_E   SD_h       (unitless)
 BV0854  ------------------------------------------------------------------------
 BV0854  NETWORK     1.28   1.59           0.58   0.44   0.81       0.15784404
 BV0854  ------------------------------------------------------------------------
 BV0854  Click here for local accuracies and other accuracy information.
 BV0854
 BV0854
 BV0854.The horizontal coordinates were established by GPS observations
 BV0854.and adjusted by the National Geodetic Survey in June 2012.
 BV0854
 BV0854.NAD 83(2011) refers to NAD 83 coordinates where the reference frame has
 BV0854.been affixed to the stable North American tectonic plate. See
 BV0854.NA2011 for more information.
 BV0854
 BV0854.The horizontal coordinates are valid at the epoch date displayed above
 BV0854.which is a decimal equivalence of Year/Month/Day.
```

Geometric Position Epochs

NGS OPUS SOLUTION REPORT

All computed coordinate accuracies are listed as peak-to-peak values.
For additional information: https://www.ngs.noaa.gov/OPUS/about.jsp#accuracy

USER: denis.riordan@noaa.gov DATE: October 16, 2018
RINEX FILE: 98v1273m.16o TIME: 20:58:47 UTC

SOFTWARE: page5 1603.24 master72.pl 160321 START: 2016/09/29 12:58:00
EPHEMERIS: igs19164.eph [precise] STOP: 2016/09/29 17:02:00
NAV FILE: brdc2730.16n OBS USED: 7726 / 8239 : 94%
ANT NAME: TRM41249.00 NONE # FIXED AMB: 37 / 41 : 90%
ARP HEIGHT: 2.001 OVERALL RMS: 0.020(m)

REF FRAME: NAD_83(2011)(EPOCH:2010.0000)			IGS08 (EPOCH:2016.7449)	
X:	17098.873(m)	0.013(m)	17098.067(m)	0.013(m)
Y:	-5458350.283(m)	0.003(m)	-5458348.799(m)	0.003(m)
Z:	3288479.671(m)	0.011(m)	3288479.501(m)	0.011(m)
LAT:	31 14 16.29578	0.008(m)	31 14 16.31612	0.008(m)
E LON:	270 10 46.14470	0.013(m)	270 10 46.11443	0.013(m)
W LON:	89 49 13.85530	0.013(m)	89 49 13.88557	0.013(m)
EL HGT:	17.914(m)	0.008(m)	16.555(m)	0.008(m)
ORTHO HGT:	44.774(m)	0.033(m)	[NAVD88 (Computed using GEOID12B)]	

	UTM COORDINATES UTM (Zone 16)	STATE PLANE COORDINATES SPC (2302 MS W)
Northing (Y) [meters]	3459394.081	192760.683
Easting (X) [meters]	231356.668	748852.175
Convergence [degrees]	-1.46357500	0.26595000
Point Scale	1.00049027	0.99997943
Combined Factor	1.00048746	0.99997662

US NATIONAL GRID DESIGNATOR: 16RBV3135659394(NAD 83)

BASE STATIONS USED

PID	DESIGNATION	LATITUDE	LONGITUDE	DISTANCE(m)
AJ7833	HAMM HAMMOND CORS ARP	N303047.051	W0902803.428	101420.0
DN7498	MSEV ELLISVILLE CORS ARP	N313542.081	W0891213.274	70769.2
DN8737	MSIN INFINITY CENTER CORS ARP	N301842.205	W0893615.507	104740.6

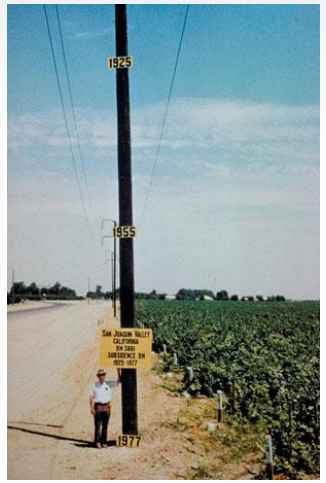
NEAREST NGS PUBLISHED CONTROL POINT

BV0854	98 V 110	N311416.295	W0894913.855	0.0

New U.S. Vertical Datum in 2022

Why isn't NAVD 88 good enough anymore?

* **NAVD 88 is a terrestrial based vertical datum that changes as the land changes.**



- **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
  - Were determined by leveling from a single point, allowing cross-country error build up

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

NOAA Technical Report NOS NGS 64

Blueprint for 2022, Part 2: Geopotential Coordinates

November 13, 2017

National Oceanic and Atmospheric Administration • National Geodetic Survey

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)

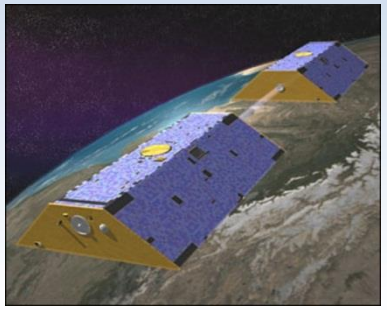
Names

	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

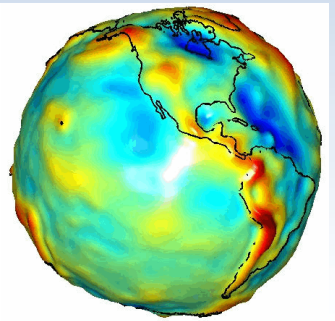
The New:

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

Building a Gravity Field



Long Wavelengths
(≥ 250 km)

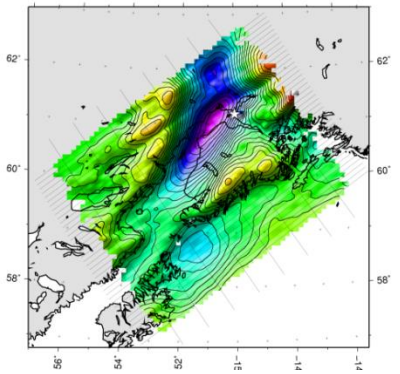


GRACE/GOCE/Satellite Altimetry

+

Airborne Measurement

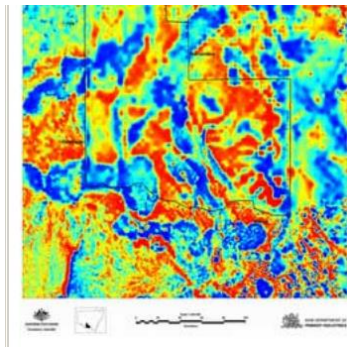
Intermediate Wavelengths
(500 km to 20 km)



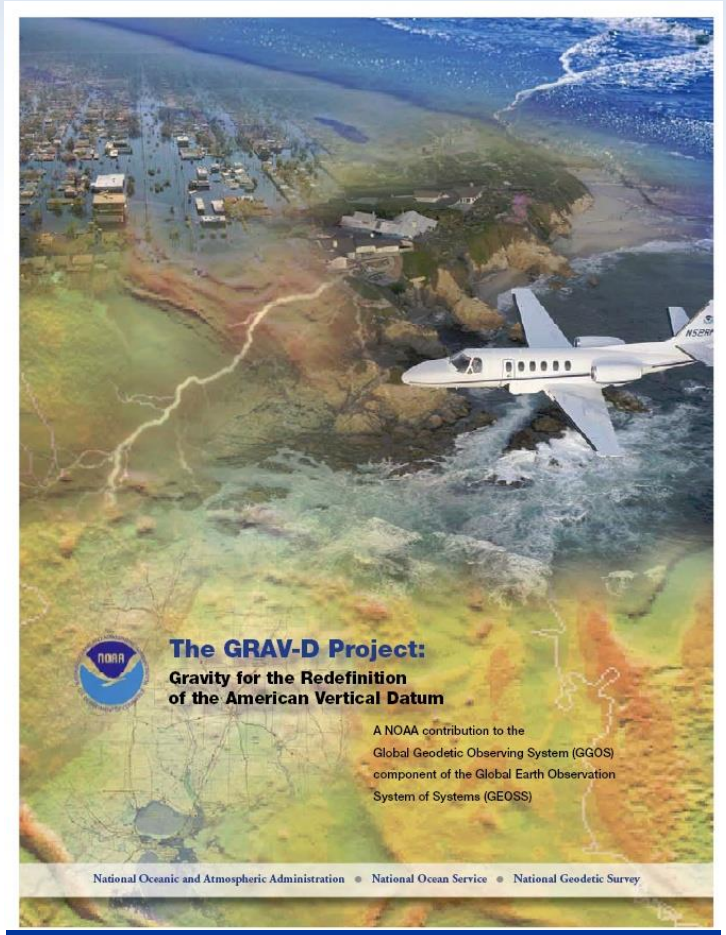
+

Surface Measurement and
Predicted Gravity from Topography

Short Wavelengths
(< 100 km)



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



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

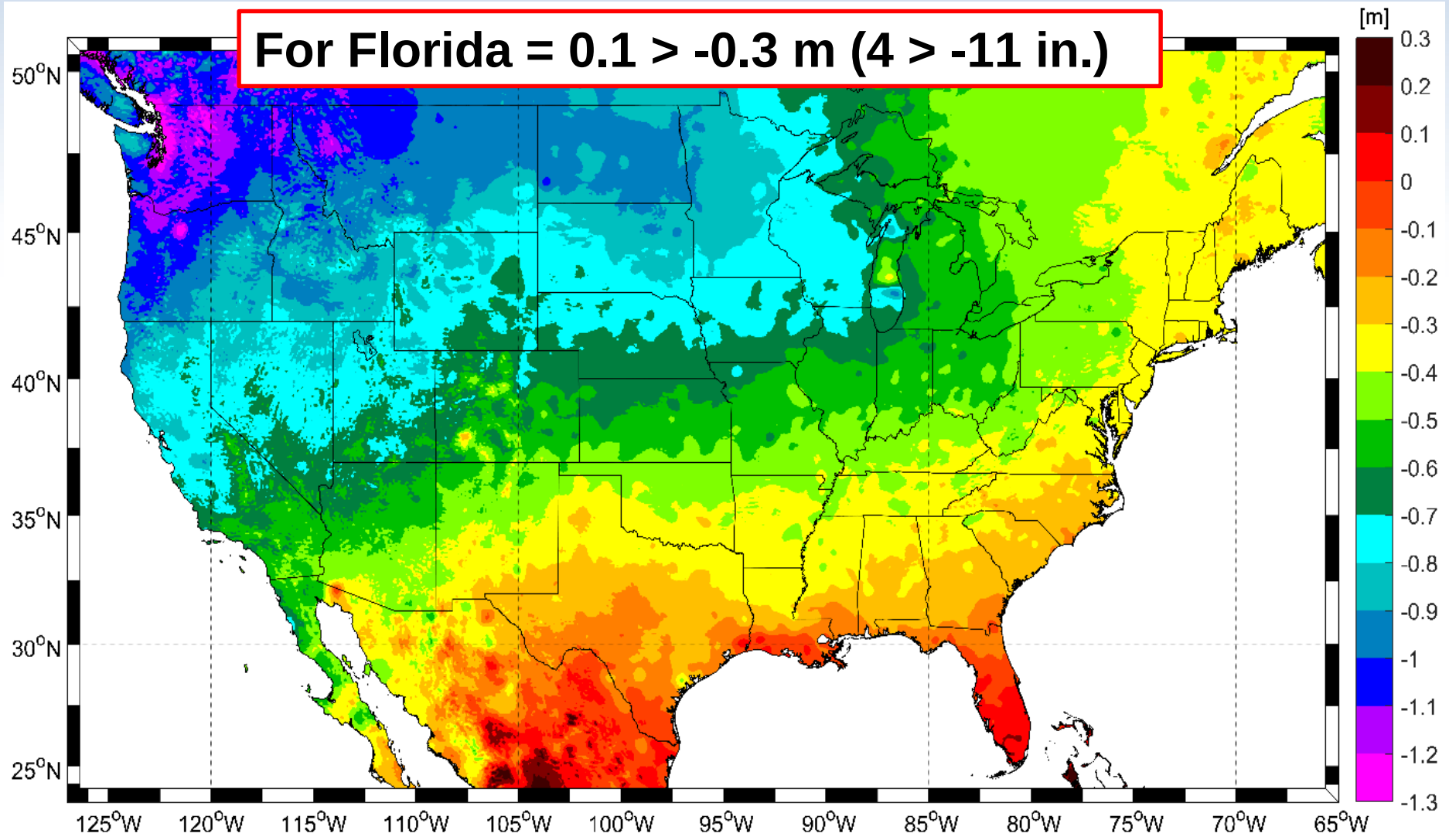
- Replace the Vertical Datum of the USA by 2022 (at today's funding)
- GRAV-D is:
  - An airborne gravity survey of the entire country and its holdings
  - A 2022 gravimetric geoid accurate to 1 cm
  - Long-term monitoring of geoid change over time
  - Partnership surveys
- Working to launch a collaborative effort with the USGS for simultaneous magnetic measurement
- Acting Manager: Monica Youngman
  Monica.Youngman@noaa.gov

Geoid Monitoring Service (GeMS)

- Goal: Track all changes to the geoid which would prevent 1 cm accuracy
- Aspects included:
  - Shape, Secular: e.g. Hudson Bay
  - Shape, Episodic: e.g. Massive Earthquakes
  - W0, Secular: Global Sea Level Change (see next slides)
- Examples of things excluded:
  - Size, Secular: Mass quantity of Earth is effectively static
  - Shape, Periodic: Seasonal glacier cycle

Extent of 2022 gravimetric geoid model used for NAPGD2022

Expected changes to orthometric heights – **NAVD88 to NAPGD2022**



NGS Products Update

GEOID 18 – Last NGS "Hybrid" Geoid Model`

National Geodetic Survey

Positioning America for the Future

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Geoid Quick Links

- NGS Geoid Home Page
- NGS Geoid models
- Publications
- NGS Geoid Research Page
- Geophysics of the Geoid
- Geoid Slope Validation Survey of 2011
- Geoid Slope Validation Survey of 2014
- xGEOID Model

Have a geoid question?

- Contact the Geoid Team

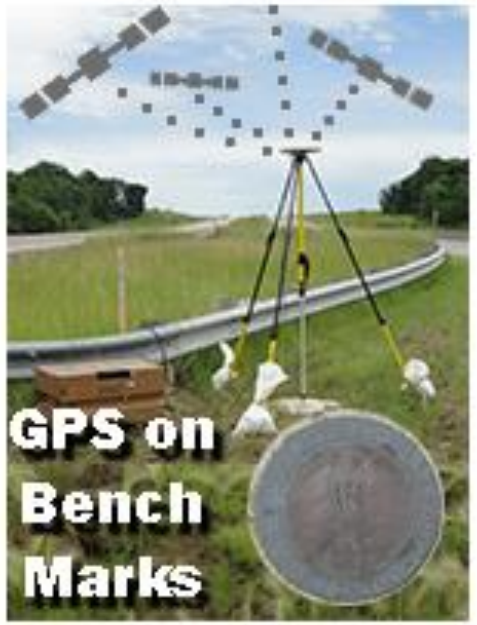
Geoid Models

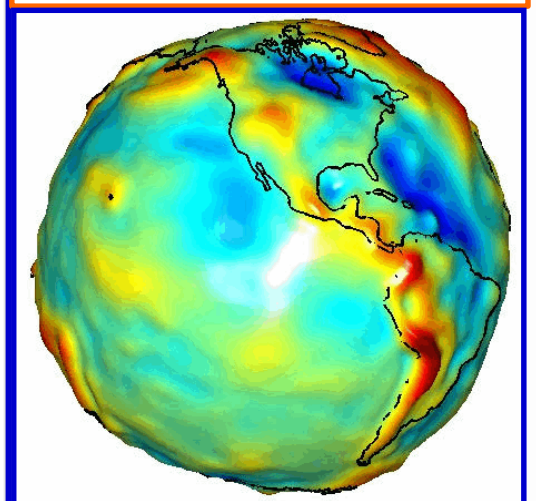
The National Geodetic Survey has released updated models for transforming heights between ellipsoidal coordinates and physical height systems that relate to water flow. These models cover regions including the conterminous United States (CONUS), Alaska, Hawaii, Puerto Rico, the Virgin Islands, Guam and the Commonwealth of the Northern Mariana Islands, and American Samoa. GEOID12B transforms to NAVD 88 in CONUS and Alaska and to the respective datums for all the other regions (each having its own datum point). Models for the Deflection of the Vertical have also been released for these same regions mainly for aid in navigation systems.

Hybrid Geoids

Converts heights from NAD 83 to regional Vertical datums (e.g., NAVD 88)

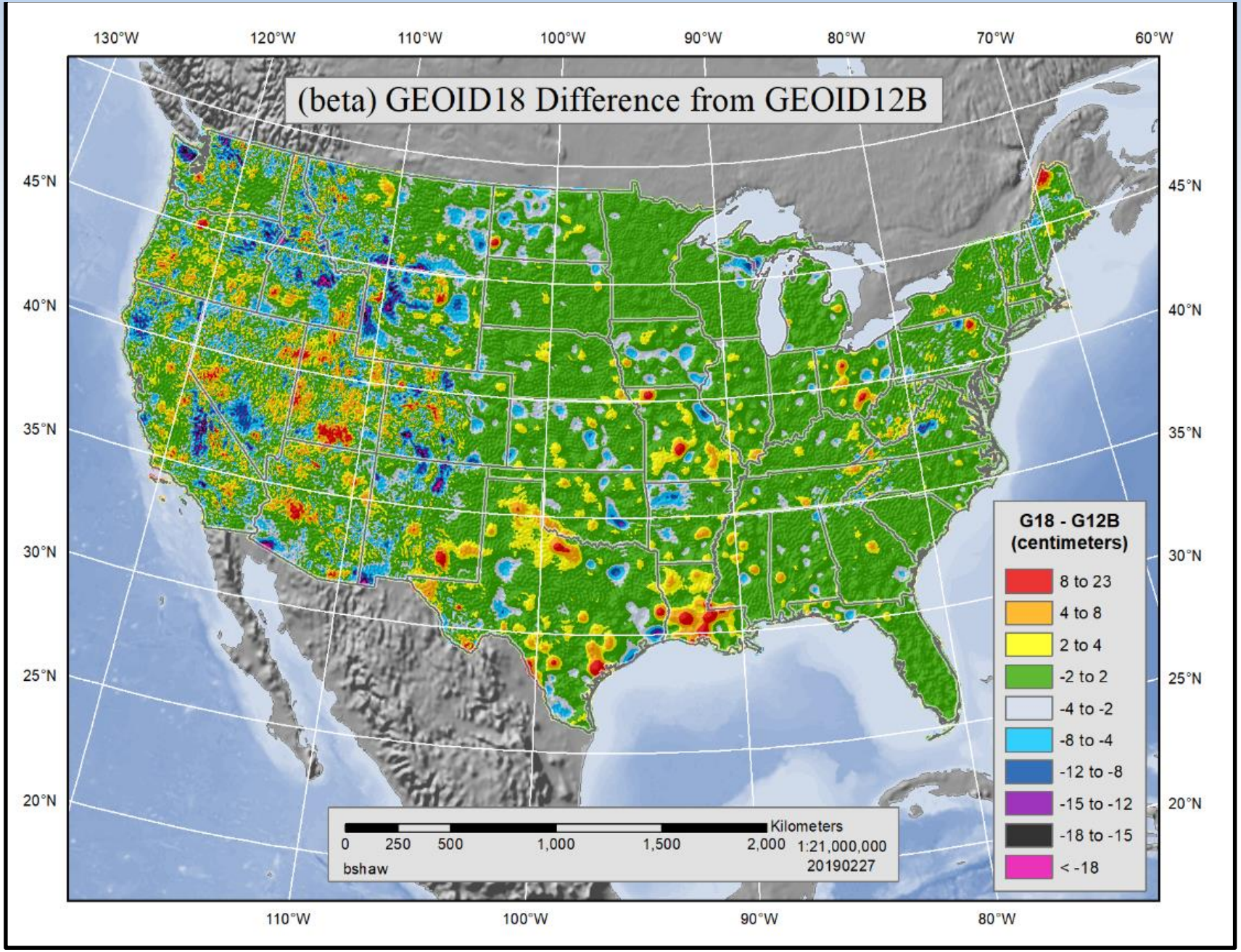
- **GEOID12B**
- **GEOID12A (replaced by GEOID12B)**
- **GEOID12 (replaced by GEOID12A)**
- **GEOID09**
- **GEOID03**
- **GEOID06**
- **GEOID99**
- **GEOID96**





Geoid 18 is being co-released with updated IGS14 positions on NGS published CORS

GEOID 18 – Last NGS "Hybrid" Geoid Model

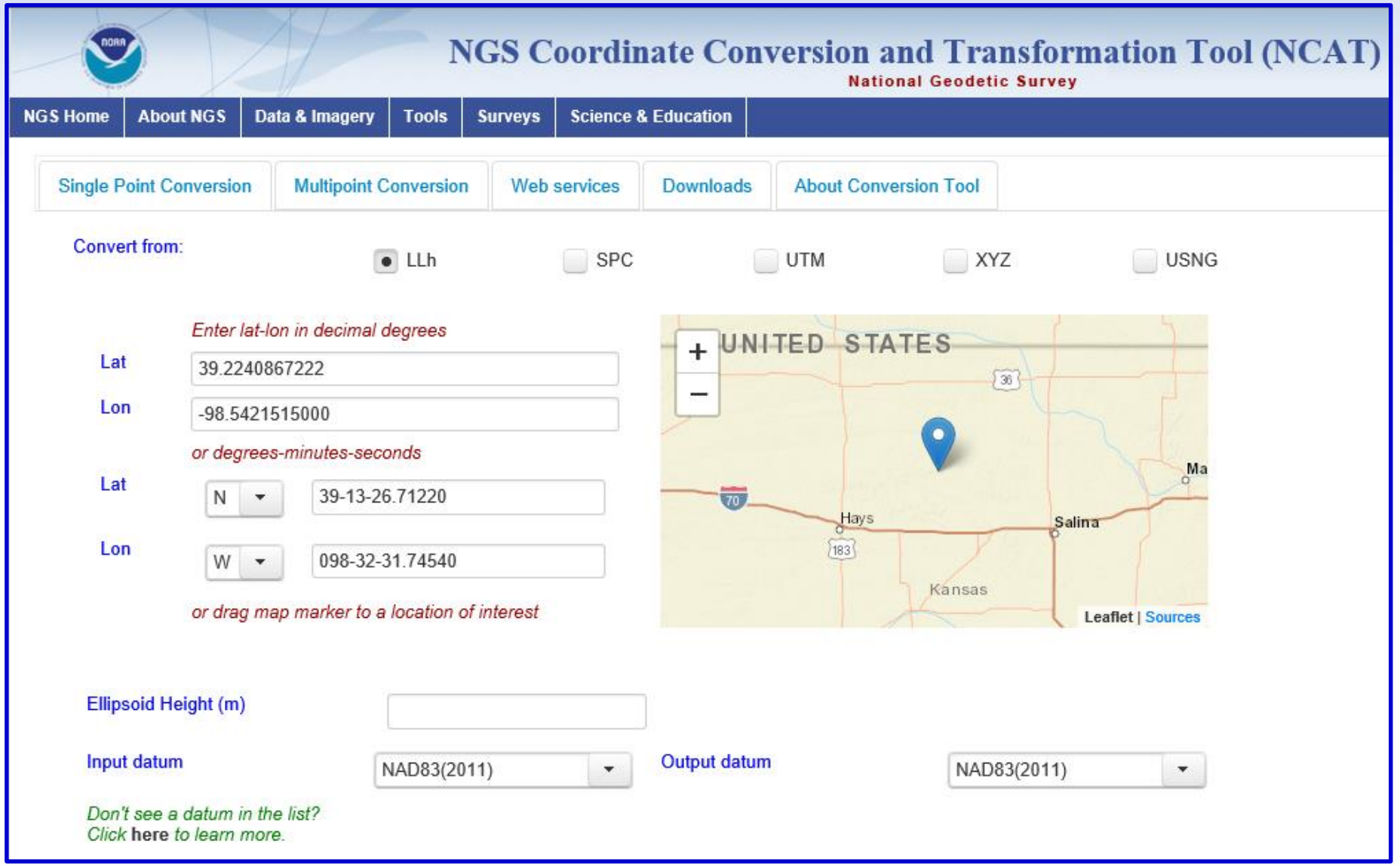


NGS Products Update

Coordinate Conversion and Transformation Tool – NCAT using NADCON v5.0

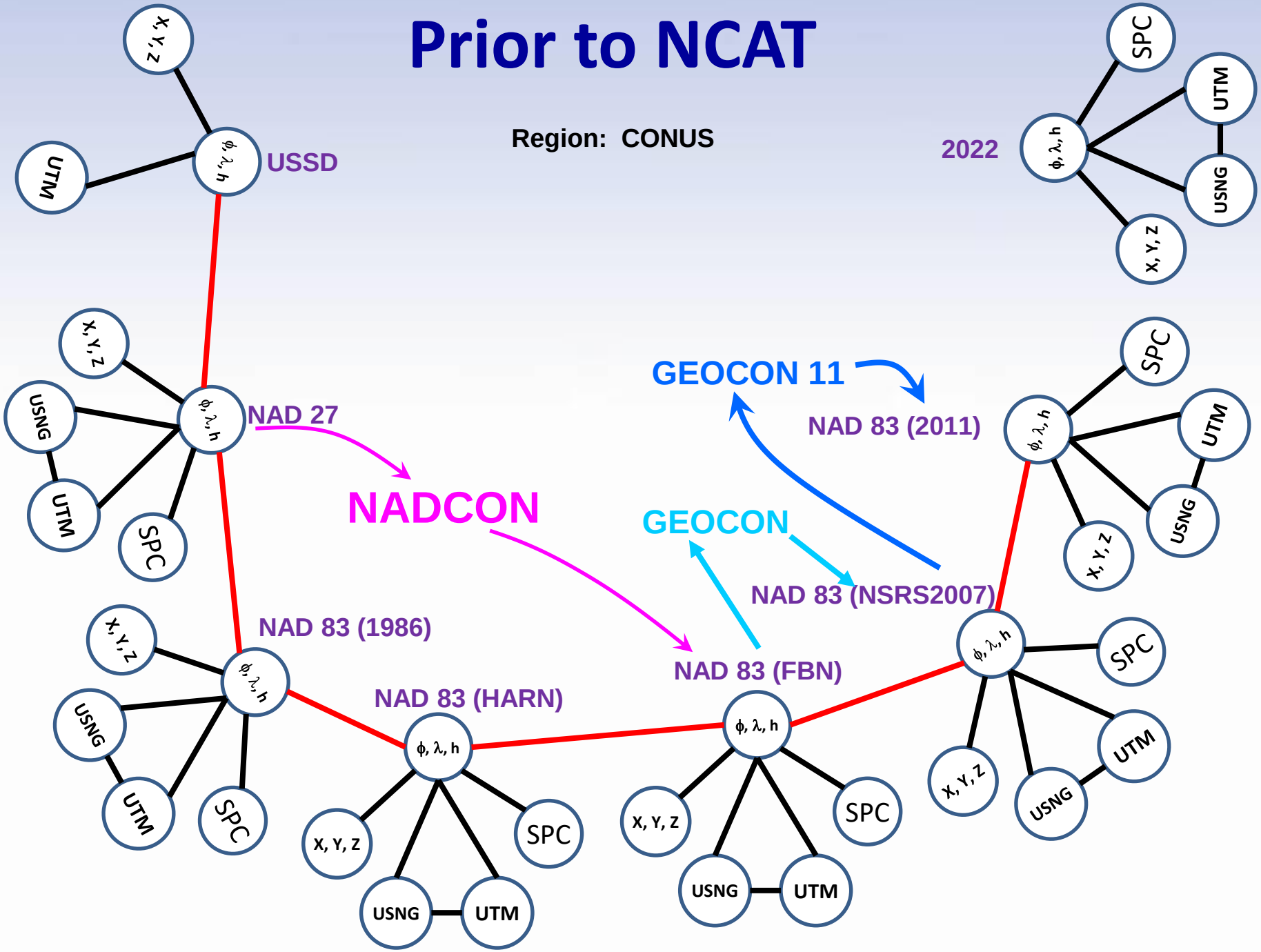
Other Updated NGS Products

NCAT - Updated coordinate transformation program.



Prior to NCAT

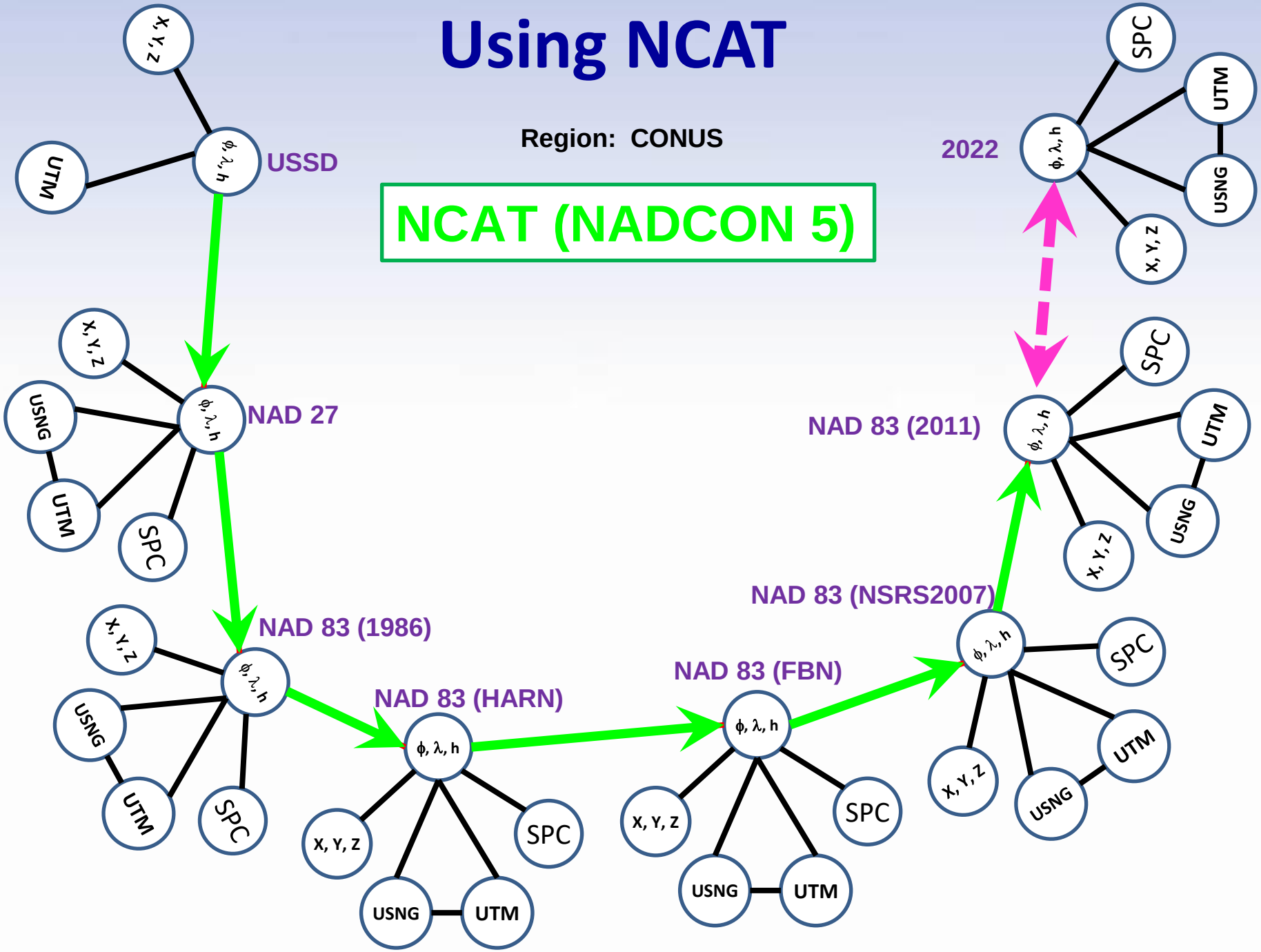
Region: CONUS



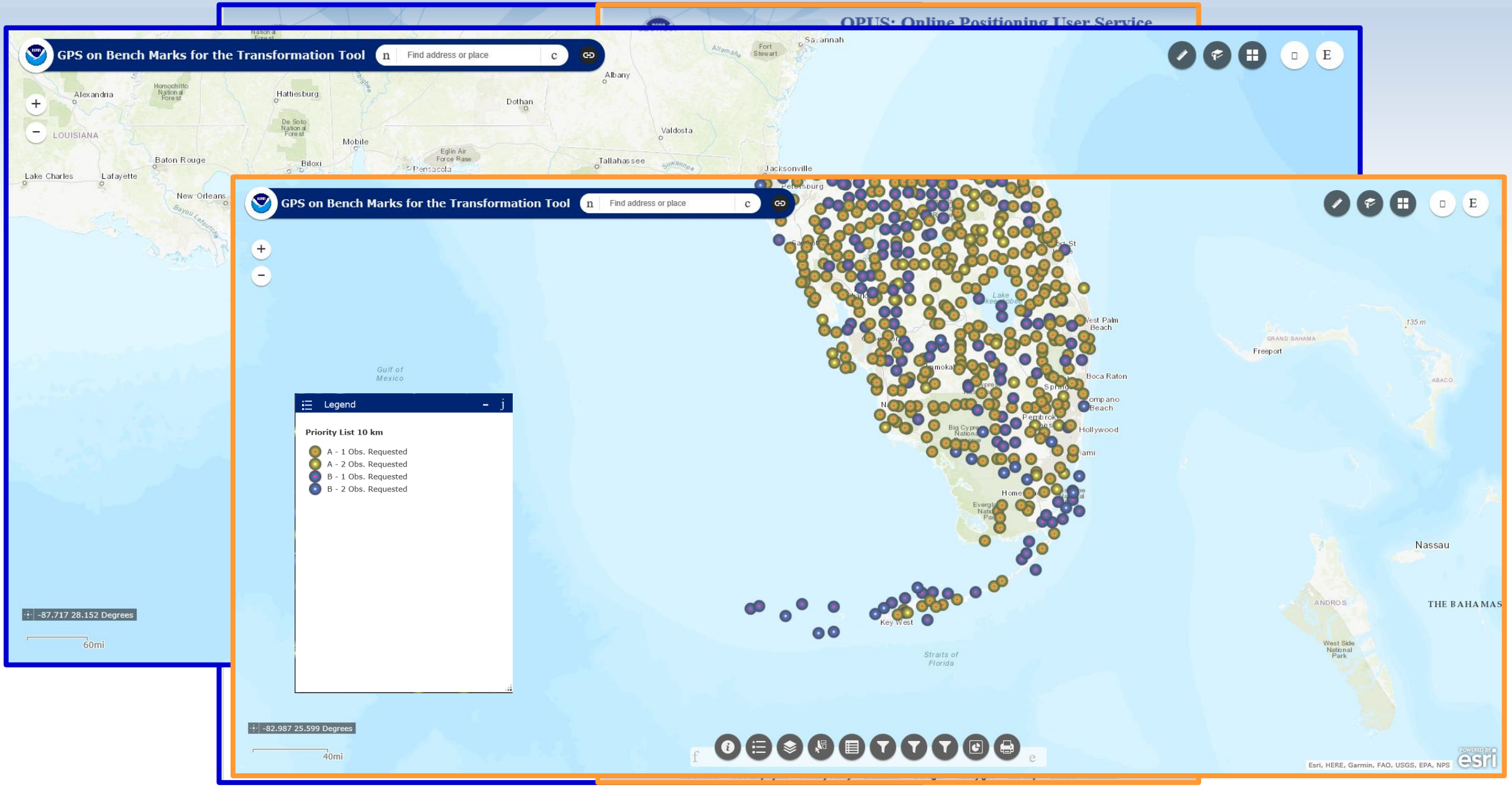
Using NCAT

Region: CONUS

NCAT (NADCON 5)



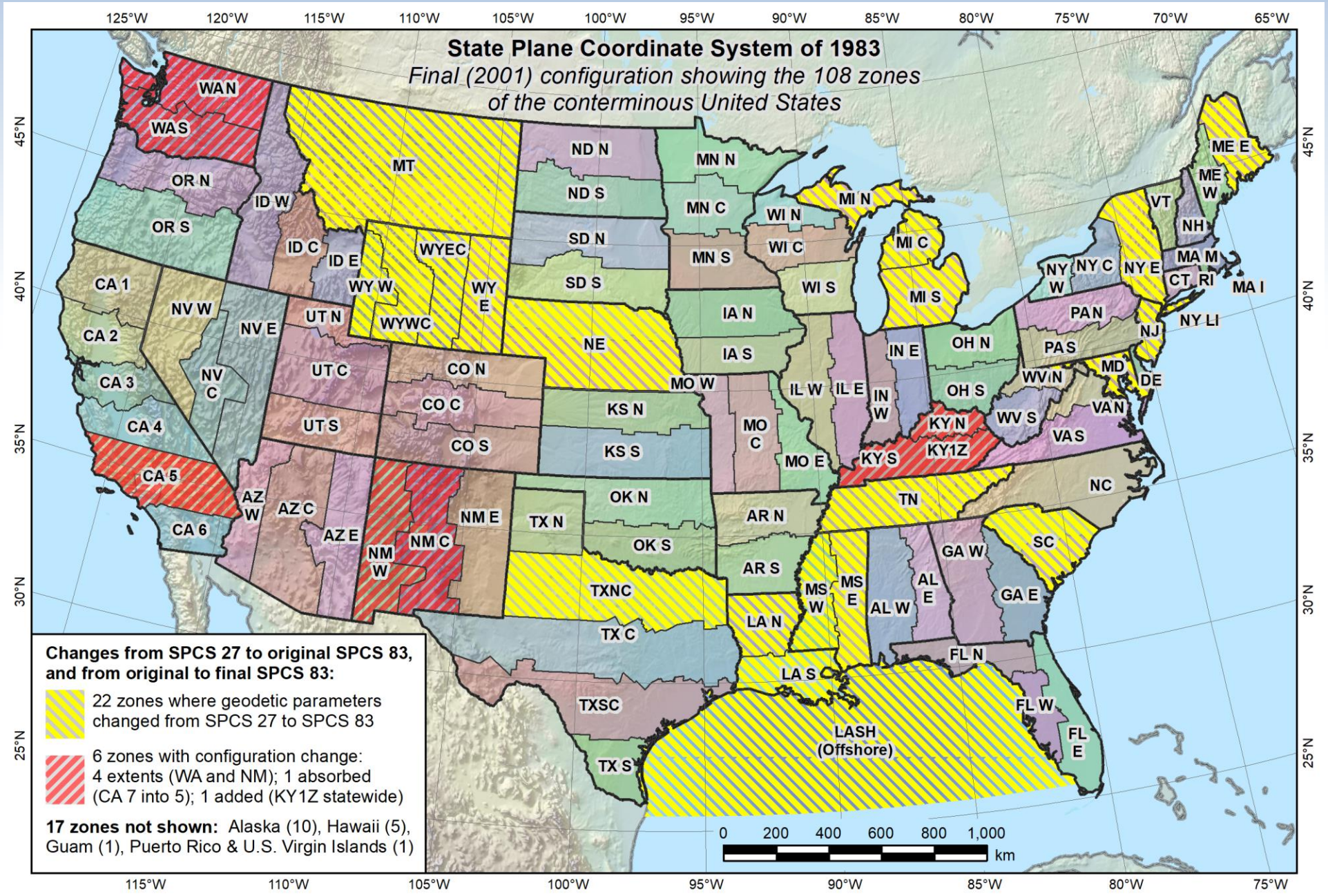
2022 Vertical Transformation Model – GPS on BM Project

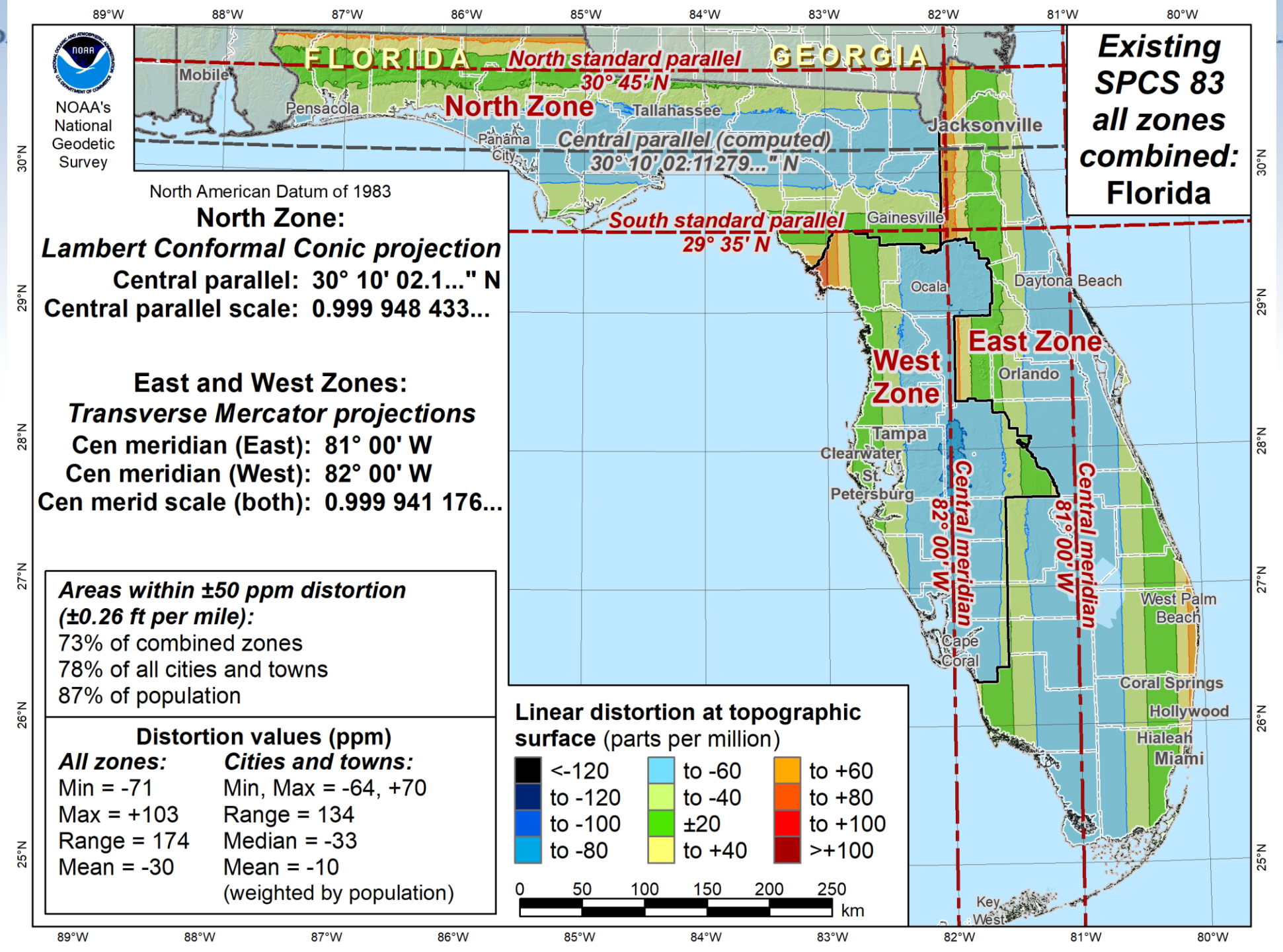


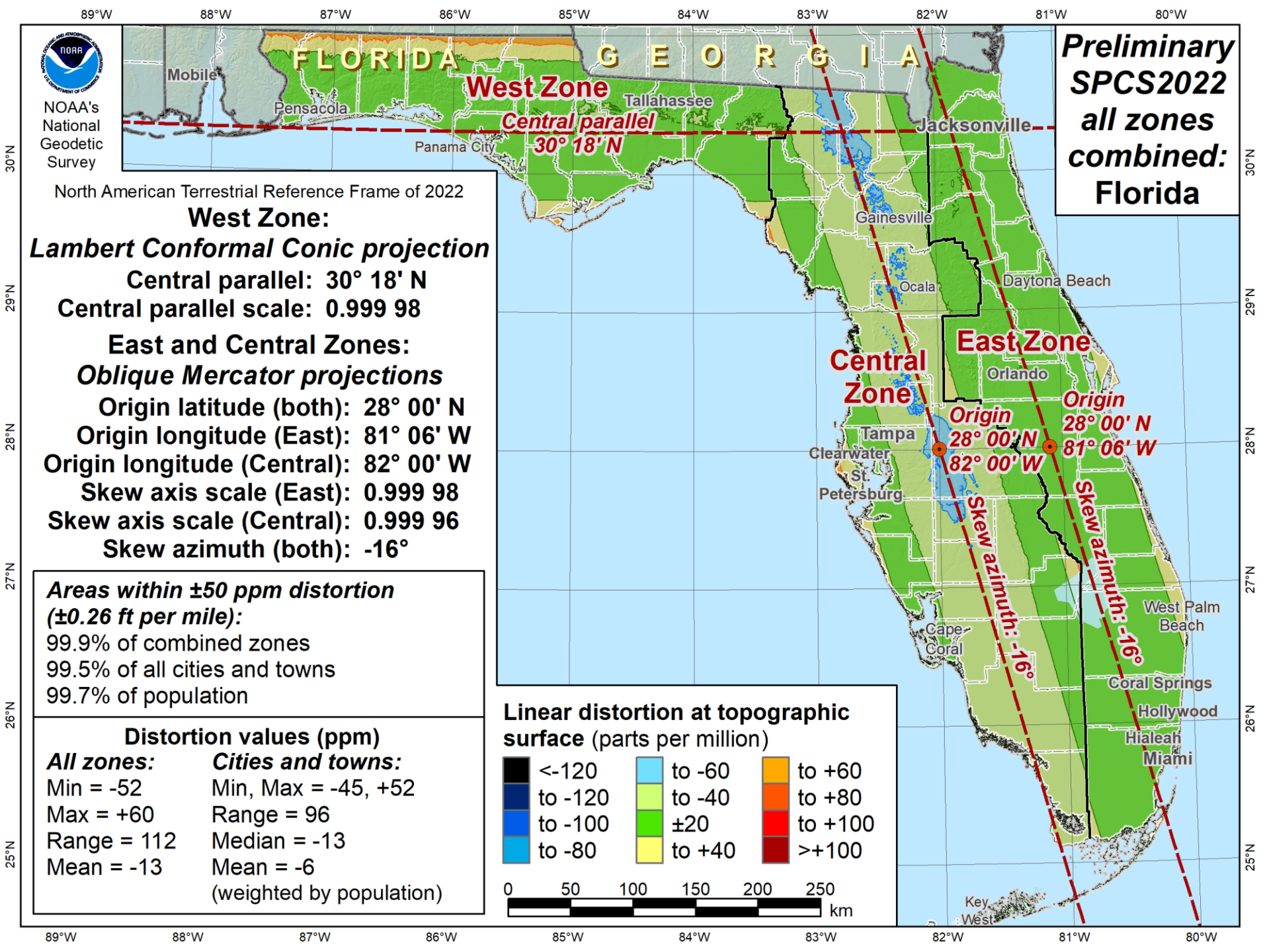
NGS Products Update

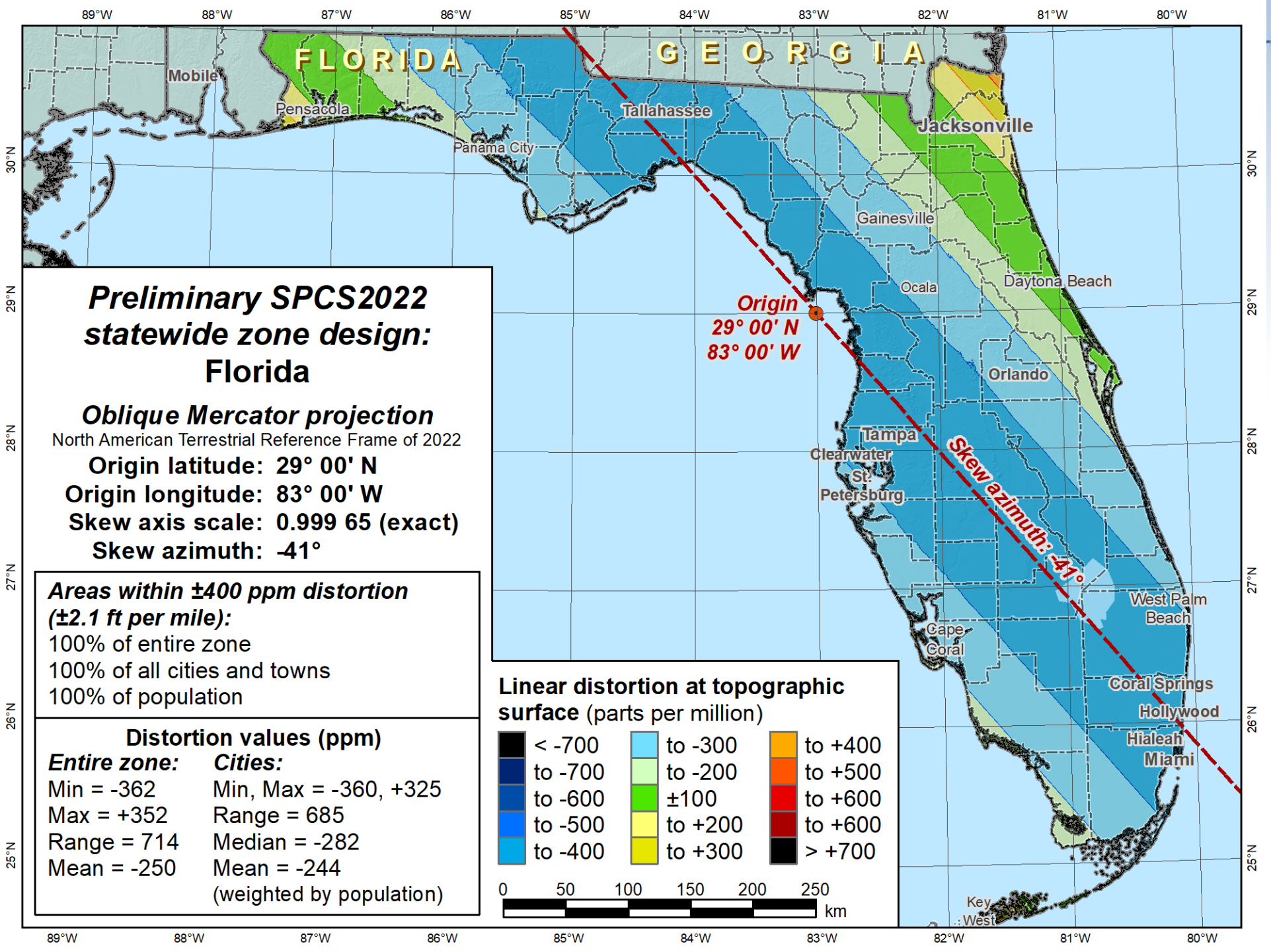
2022 State Plane Coordinate System Project

Final SPC 83 State Systems - 2001




NOAA's National Geodetic Survey
Existing SPCS 83 all zones combined: Florida
North American Datum of 1983
North Zone:
Lambert Conformal Conic projection
Central parallel: 30° 10' 02.1..." N
Central parallel scale: 0.999 948 433...
East and West Zones:
Transverse Mercator projections
Cen meridian (East): 81° 00' W
Cen meridian (West): 82° 00' W
Cen merid scale (both): 0.999 941 176...
FLORIDA
GEORGIA
North standard parallel 30° 45' N
North Zone
Central parallel (computed) 30° 10' 02.11279..." N
South standard parallel 29° 35' N
West Zone
East Zone
Central meridian 82° 00' W
Central meridian 81° 00' W
Mobile
Pensacola
Tallahassee
Panama City
Jacksonville
Gainesville
Ocala
Daytona Beach
Orlando
Tampa
Clearwater
St. Petersburg
Cape Coral
West Palm Beach
Coral Springs
Hollywood
Hialeah
Miami
Key West
Areas within ±50 ppm distortion (±0.26 ft per mile):
73% of combined zones
78% of all cities and towns
87% of population
Distortion values (ppm)
All zones:
Min = -71
Max = +103
Range = 174
Mean = -30
Cities and towns:
Min, Max = -64, +70
Range = 134
Median = -33
Mean = -10
(weighted by population)
Linear distortion at topographic surface (parts per million)
<-120
to -120
to -100
to -80
to -60
to -40
±20
to +40
to +60
to +80
to +100
>+100
0 50 100 150 200 250 km
89°W 88°W 87°W 86°W 85°W 84°W 83°W 82°W 81°W 80°W
30°N 29°N 28°N 27°N 26°N 25°N


NOAA's National Geodetic Survey
North American Terrestrial Reference Frame of 2022
West Zone:
Lambert Conformal Conic projection
Central parallel: 30° 18' N
Central parallel scale: 0.999 98
East and Central Zones:
Oblique Mercator projections
Origin latitude (both): 28° 00' N
Origin longitude (East): 81° 06' W
Origin longitude (Central): 82° 00' W
Skew axis scale (East): 0.999 98
Skew axis scale (Central): 0.999 96
Skew azimuth (both): -16°
Areas within ±50 ppm distortion (±0.26 ft per mile):
99.9% of combined zones
99.5% of all cities and towns
99.7% of population
Distortion values (ppm)
All zones:
Min = -52
Max = +60
Range = 112
Mean = -13
Cities and towns:
Min, Max = -45, +52
Range = 96
Median = -13
Mean = -6
(weighted by population)
Linear distortion at topographic surface (parts per million)
<-120
to -120
to -100
to -80
to -60
to -40
±20
to +40
to +60
to +80
to +100
>+100
0 50 100 150 200 250 km
Preliminary SPCS2022 all zones combined: Florida
FLORIDA
GEORGIA
West Zone
Central parallel 30° 18' N
Central Zone
East Zone
Origin 28° 00' N 82° 00' W
Origin 28° 00' N 81° 06' W
Skew azimuth: -16°
Skew azimuth: -16°
Mobile
Pensacola
Panama City
Tallahassee
Jacksonville
Gainesville
Ocala
Daytona Beach
Orlando
Tampa
Clearwater
St. Petersburg
Cape Coral
West Palm Beach
Coral Springs
Hollywood
Hialeah
Miami
Key West
89°W
88°W
87°W
86°W
85°W
84°W
83°W
82°W
81°W
80°W
30°N
29°N
28°N
27°N
26°N
25°N


FLORIDA
GEORGIA
Mobile
Pensacola
Tallahassee
Panama City
Jacksonville
Gainesville
Ocala
Daytona Beach
Origin
29° 00' N
83° 00' W
Orlando
Tampa
Clearwater
St. Petersburg
Skew azimuth: -41°
West Palm Beach
Cape Coral
Coral Springs
Hollywood
Hialeah
Miami
Key West
89°W
88°W
87°W
86°W
85°W
84°W
83°W
82°W
81°W
80°W
30°N
29°N
28°N
27°N
26°N
25°N
Preliminary SPCS2022 statewide zone design:
Florida
Oblique Mercator projection
North American Terrestrial Reference Frame of 2022
Origin latitude: 29° 00' N
Origin longitude: 83° 00' W
Skew axis scale: 0.999 65 (exact)
Skew azimuth: -41°
Areas within ±400 ppm distortion (±2.1 ft per mile):
100% of entire zone
100% of all cities and towns
100% of population
Distortion values (ppm)
Entire zone:
Min = -362
Max = +352
Range = 714
Mean = -250
Cities:
Min, Max = -360, +325
Range = 685
Median = -282
Mean = -244
(weighted by population)
Linear distortion at topographic surface (parts per million)
< -700
to -700
to -600
to -500
to -400
to -300
to -200
±100
to +200
to +300
to +400
to +500
to +600
to +600
> +700
0 50 100 150 200 250
km

? ? QUESTIONS ? ?

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Views expressed are those of the author and not necessarily those of NGS.