Determining Positions After 2022

Institute of Navigation GNSS
Civil GPS Service Interface Committee Meeting
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Denis Riordan, PSM
NOAA, National Geodetic Survey
denis.riordan@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

**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

<table>
<thead>
<tr>
<th>NETWORK</th>
<th>TIME SPAN</th>
<th>NETWORK ACCURACY</th>
<th>METHOD OF REFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAD 27</td>
<td>1927-1986</td>
<td>10 meter</td>
<td>TERRESTRIAL BASED REFERENCE SYSTEM FOR NSRS</td>
</tr>
<tr>
<td>NAD83(86)</td>
<td>1986-1990</td>
<td>1 meter</td>
<td>TERRESTRIAL BASED REFERENCED SYSTEM FOR NSRS</td>
</tr>
<tr>
<td>NAD83(199x)*</td>
<td>1990-2007</td>
<td>0.1 meter</td>
<td>SPACE BASED REFERENCE SYSTEM FOR NSRS</td>
</tr>
<tr>
<td>HARN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NAD83(2007) (CORS)</td>
<td>2007 - 2011</td>
<td>0.01 meter</td>
<td></td>
</tr>
<tr>
<td>NAD83(2011) (CORS)</td>
<td>2011 - 2022</td>
<td>0.01 meter</td>
<td></td>
</tr>
</tbody>
</table>
NSRS Reference Basis

Old Method - Ground Marks (Terrestrial)

New Method - GNSS Stations (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.
NOAA Technical Report NOS NGS 62

Blueprint for 2022, Part 1: Geometric Coordinates

Dru Smith
Dan Roman
Steve Hilla

April 21, 2017
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(PAI11)
- NAD 83(MAI11)

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)
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

NATRF2022 Velocities over CONUS

Crustal motion to be removed by Intra Frame Velocity Models for each TRF.
New geometric datum minus NAD 83 (horizontal)

For Florida = 0.8 > 1.02 m (2.6 > 3.3 ft.)

Estimated horizontal change from NAD 83 to NATRF2022

Delta Horizontal = (ITRF 05) minus (NAD 83) at 2020.0
For Florida = -1.39 > -1.62 m (-4.5 > -5.3 ft.)
### Geometric Position Epochs

<table>
<thead>
<tr>
<th>PROGRAM</th>
<th>data sheet=55, VERSION = 8.12.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>National Geodetic Survey, Retrieval Date = MAY 8, 2017</td>
</tr>
<tr>
<td>BV0854</td>
<td><strong>CURRENT SURVEY CONTROL</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BV0854*</th>
<th>NAD 83(2011) POSITION</th>
<th>31 14 16.29550(M) 089 49 13.85530(W)</th>
<th>ADJUSTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>BV0854*</td>
<td>NAD 83(2011) EPOCH</td>
<td>-2020.00</td>
<td>ADJUSTED</td>
</tr>
<tr>
<td>BV0854*</td>
<td>NAVD 88 EPOCH</td>
<td>-2020.55</td>
<td></td>
</tr>
<tr>
<td>BV0854*</td>
<td>This station is located in a suspected subsidence area (see below).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BV0854</th>
<th>GEOD HEIGHT</th>
<th>-26.850 (meters)</th>
<th>GEOD12B</th>
</tr>
</thead>
<tbody>
<tr>
<td>BV0854</td>
<td>NAD 83(2011) X</td>
<td>-17,098,673 (meters)</td>
<td>COMP</td>
</tr>
<tr>
<td>BV0854</td>
<td>NAD 83(2011) Y</td>
<td>-5,458,380,266 (meters)</td>
<td>COMP</td>
</tr>
<tr>
<td>BV0854</td>
<td>NAD 83(2011) Z</td>
<td>3,288,479,650 (meters)</td>
<td>COMP</td>
</tr>
<tr>
<td>BV0854</td>
<td>LAIRACE CORR</td>
<td>-0.44 (seconds)</td>
<td>DEFLEC12B</td>
</tr>
<tr>
<td>BV0854</td>
<td>DYNAMIC HEIGHT</td>
<td>-41.689 (meters)</td>
<td>146.65 (feet)</td>
</tr>
<tr>
<td>BV0854</td>
<td>MODELED GRAVITY</td>
<td>979,394.9 (mau)</td>
<td>NAVD 88</td>
</tr>
<tr>
<td>BV0854</td>
<td>VERT ORDER</td>
<td>FIRST</td>
<td>CLASS II</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BV0854</th>
<th>Network accuracy estimates per FGDC Geospatial Positioning Accuracy Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>BV0854</td>
<td>FGDC (95% conf., cm) Standard deviation (cm) C8989</td>
</tr>
<tr>
<td>BV0854</td>
<td>Horiz. Ellip SD N SD E SD h (units)</td>
</tr>
<tr>
<td>BV0854</td>
<td>___________________________________________________________________________</td>
</tr>
<tr>
<td>BV0854</td>
<td>NETWORK</td>
</tr>
</tbody>
</table>

| BV0854 | Click here for local accuracies and other accuracy information. |

<table>
<thead>
<tr>
<th>BV0854</th>
<th>The horizontal coordinates were established by GPS observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>BV0854</td>
<td>and adjusted by the National Geodetic Survey in June 2012.</td>
</tr>
<tr>
<td>BV0854</td>
<td>NAD 83(2011) refers to NAD 83 coordinates where the reference frame has</td>
</tr>
<tr>
<td>BV0854</td>
<td>been affixed to the stable North American tectonic plate. See</td>
</tr>
<tr>
<td>BV0854</td>
<td>NAV2011 for more information.</td>
</tr>
<tr>
<td>BV0854</td>
<td>The horizontal coordinates are valid at the epoch date displayed above</td>
</tr>
<tr>
<td>BV0854</td>
<td>BV0854, which is a decimal equivalent of Year/Month/Day.</td>
</tr>
</tbody>
</table>
NGS OPUS SOLUTION REPORT

Geometric Position Epochs
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 use of bench marks 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
NOAA Technical Report NOS NGS 64

Blueprint for 2022, Part 2: Geopotential Coordinates

November 13, 2017
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:

- NAVD 88
- PRVD 02
- VIVD09
- ASVD02
- NMVD03
- GUVD04
- IGLD 85
- IGSN71
- GEOID12B
- DEFLEC12B

The New:

The North American-Pacific Geopotential Datum of 2022 (NAPGD2022)
Building a Gravity Field

Long Wavelengths
(≥ 250 km)

GRACE/GOCE/Satellite Altimetry +

Intermediate Wavelengths
(500 km to 20 km)

Airborne Measurement +

Short Wavelengths
(< 100 km)

Surface Measurement and Predicted Gravity from Topography
Gravity for the Redefinition of the American Vertical Datum (GRAV-D)

- 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

Gravity and Heights are inseparably connected
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

For Florida = 0.1 > -0.3 m (4 > -11 in.)
NGS Products Update
Geoid 18 is being co-released with updated IGS14 positions on NGS published CORS.

### Geoid Models

The National Geodetic Survey has released updated models for transforming heights between ellipsoidal coordinates and physical height systems that relate to wafer flow. These models cover regions including the contiguous 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 – Last NGS “Hybrid” Geoid Model
NGS Products Update

Coordinate Conversion and Transformation Tool – NCAT using NADCON v5.0
NCAT - Updated coordinate transformation program.

Other Updated NGS Products

NGS Coordinate Conversion and Transformation Tool (NCAT)
Prior to NCAT

Region: CONUS

NAD 27

NADCON

GEOCON 11

NAD 83 (2011)

NAD 83 (1986)

NAD 83 (HARN)

NAD 83 (FBN)

NAD 83 (NSRS2007)

NAD 83 (2011)

GEOCON

NADCON

NAD 27

NAD 83 (1986)

NAD 83 (HARN)

NAD 83 (FBN)

NAD 83 (NSRS2007)

NAD 83 (2011)
Using NCAT

Region: CONUS

NCAT (NADCON 5)
NGS Products Update

2022 State Plane Coordinate System Project
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...

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: Cities and towns:
Min = -71 Min, Max = -64, +70
Max = +103 Range = 134
Range = 174 Median = -33
Mean = -30 Mean = -10
(weighted by population)

Linear distortion at topographic surface (parts per million)
-120 to -60 to -40 to -20 to +20 to +40 to +80 to +100
0 50 100 150 200 250 km
Preliminary
SPCS2022
all zones
combined:
Florida

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)

<table>
<thead>
<tr>
<th>All zones:</th>
<th>Cities and towns:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min = -52</td>
<td>Min, Max = -45, +52</td>
</tr>
<tr>
<td>Max = +60</td>
<td>Range = 96</td>
</tr>
<tr>
<td>Range = 112</td>
<td>Median = -13</td>
</tr>
<tr>
<td>Mean = -13</td>
<td>Mean = -6</td>
</tr>
<tr>
<td>(weighted by population)</td>
<td></td>
</tr>
</tbody>
</table>
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: Cities:
Min = -362 Min, Max = -360, +325
Max = +352 Range = 685
Range = 714 Median = -282
Mean = -250 Mean = -244
(weighted by population)

Linear distortion at topographic surface (parts per million)
- < -700  - to -300  - to +300  - to +400
- to -700  - to -200  - to +200  - to +500
- to -600  - ±100  - to +600
- to -500  - to +100  - to +600
- to -500  - to +200
- to -400  - to +300
- to -400
- > +700
QUESTIONS

Denis Riordan, PSM
NOAA, National Geodetic Survey
Gulf Coast Regional Geodetic Advisor
Covering: AL, FL, LA, & MS
Jackson, MS
(240) 678 – 2107 (Cell.)
Denis.Riordan@noaa.gov

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