NSRS Modernization Update

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Session description and objectives

• In 2022, the National Geodetic Survey will be replacing the U.S. horizontal and vertical datums (NAD 83 and NAVD 88). We will discuss the history of these datums, their relationship to other reference frames, the reasons for the change, and how it affects surveyors and their access to these datums.

• Objective…gain a fundamental understanding of:
  – How and why our datums/reference frames have changed over time
  – The need to further modernize the US reference frames
  – How NGS will define new reference frames
  – How users will access the new reference frames
New Datums are Coming in 2022!

-Where are we now?
-Where are we going?

(2022 will be here sooner than we think!)
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."
INTRODUCTION: THE NSRS
NGS Mission: To define, maintain & provide access to the *National Spatial Reference System (NSRS)* to meet our Nation’s economic, social & environmental needs.

Consistent National Coordinate System

- Latitude/Northing
- Longitude/Easting
- Height
- Scale
- Gravity
- Orientation

and how these values change with time.
Overview

• The National Spatial Reference System (NSRS) is the official coordinate system for all geospatial work done by the civilian federal government.

• Current datums:
  – NAD 83 (latitude, longitude, ellipsoid height)
  – NAVD 88 (orthometric height)
  – IGLD 85 (dynamic heights: predominantly on the Great Lakes)

• These datums are often adopted, even legislated, by states, counties and municipalities.
Why Modernize?

• Older Methodology
  – Terrestrial, pre-space-geodesy, line-of-sight observations
  – Easily destroyed, unmonitored *passive* control marks
Historical datums/Realizations

- NAD27 based on old observations and old datum
- NAD83(86) based on old observations and new datum
- NAD83(91) based on new and old observations and same datum (original HARN)
- NAD83(????) based on better observations and same datum (FBN)
- NAD83(NSRS2007) based on new observations and same datum. Removed regional distortions and made consistent with CORS
- NAD83(2011) based on new observations and same datum. **Consistent with new Multi Year CORS solution**
Global Positioning System

- February 22, 1978 - 1st NAVSTAR Satellite launched
- July 17, 1995 - System Fully Operational
- May 1, 2000 - Selective Availability turned off
- September 26, 2005 - L2C band added
- May 28, 2010 - First L5 Satellite added
  (12 L5 SVs launched to date)
- Mid 2017 – First Block III scheduled for launch?
- 2020? - 10-50 cm real-time accuracy! Maybe Sooner!

NO GROUND CONTROL
Global Navigation Satellite System

Four positioning and navigation systems

- **NAVSTAR/GPS** – US (Currently 33)
- **GLONASS** – Russia (Currently 24)
- **GALILEO** – EU (Currently 18, 30 by 2019)
- **BEIDOU/COMPASS** – China (30+ by 2020?)
The NSRS has evolved

1 Million Monuments
(Separate Horizontal and Vertical Systems)

70,000 Passive Marks
(3-Dimensional)

Passive Marks
(Limited Knowledge of Stability)

≈ 2,000 GPS CORS
(Time Dependent System Possible; 4-Dimensional)

GPS CORS → GNSS CORS
Historical Vertical Datums

- Sea Level Datum of 1929
- NGVD29 National Geodetic Vertical Datum of 1929
- NAVD88 North American Vertical Datum of 1988
- PRVD02 Puerto Rico Vertical Datum
- ASVD02 American Samoa Vertical Datum
- NMVD03 Northern Marianas Vertical Datum
- VIVD09 Virgin Islands Vertical Datum
When was the passive mark last leveled?

1957
1991

When was the passive mark last leveled?

1957
1991

Due to land subsidence, the elevation of this spot near Luke Air Force Base in Maricopa County has dropped by more than 18 feet over a 34-year period. Knowledge of subsidence areas is a fundamental requirement for planning infrastructure such as pipelines, canals, and power plants.

Approximate levels of subsidence. The signs show the position of land surface in 1925, 1955, and 1977. Although the rate of subsidence has decreased, the continued pumping of ground water has resulted in additional subsidence in the past 20 years.

*Figure 6: Subsidence in California’s Central Valley*
Why Modernize?

• Evidence of systematic errors
  – Decades of space geodetic observations
    • All of the datums contain systematic errors (decimeters to meters)
      – At scales larger than today’s accuracy capabilities (centimeters)
  – Origin (center of Earth) offset: 2+ meters
  – Zero elevation surface: 0.5 to 2+ meters
What’s Being Replaced?

**Horizontal**

- NAD 83(2011)
- NAD 83(PA11)
- NAD 83(MA11)

**Vertical**

- NAVD 88
- PRVD 02
- VIVD09
- ASVD02
- NMVD03
- GUVD04
- IGLD 85

Latitude
Longitude
Ellipsoid Height
State Plane Coordinates

Heights
The National Geodetic Survey 10 year plan

- Official NGS policy as of Jan 31, 2013
  - Updates 2008 plan
  - Modernized and improve NSRS
  - Attention to accuracy
  - Attention to time-changes
  - Improved products and services
  - Fully vetted by NSPS/AAGS

- 2022 Targets:
  - Replace NAD 83 and NAVD 88
  - Cm-accuracy access to all coordinates
NOMENCLATURE AND LEGISLATION
Nomenclature

• A chance to increase accuracy in **naming**!
  – “North American”?
    • Ignores Guam, Hawaii, American Samoa, Northern Mariana Islands
  – Datum vs. Reference Frame?
  – Plate-specific?
  – Vertical vs. Geopotential?

• 6/8/2016: NGS and the Canadian Geodetic Survey (CGS) negotiated a naming proposal
  – Approved by the NGS Executive Steering Committee
  – Approved by the CGS leadership (with minor reservations)

• Early 2017
  – Approved by the Mexico’s INEGI
(DRUM ROLL Please)
New Reference Frame Names

NAD 83 becomes:
• North American Terrestrial Reference Frame (NATRF2022)
• Caribbean Terrestrial Reference Frame (CATRF2022)
• Mariana Terrestrial Reference Frame (MATRF2022)
• Pacific Terrestrial Reference Frame (PATRF2022)

NAVD88 becomes:
• North American-Pacific Geopotential Datum of 2022 (NAPGD2022)

(Realized by GEOID2022)
Legislation

• When NAD 83 replaced NAD 27, the Federal NSRS users were required to switch to NAD 83

• Through the 1980s and 1990s NGS worked with the states to update their laws
  – To encourage use of the new system beyond the feds

• 48 states now have laws that refer to NAD 83 by name
  – A name which will be retired in 2022
Legislation

- In 2016, NSPS, AAGS, and NGS formed a committee to address this issue
  - The NSPS/AAGS/NGS Advisory Committee on National Spatial Reference System Legislation

- New Legislative Template completed June 2016
  - Generic terminology: “NSRS or its successor,” etc.
  - NSPS will work with the states to adopt the new template between 2017 and 2022
OBJECTIVE 1 OF 5: REPLACE NAD 83
Replace NAD 83

Simplified concept of NAD 83 vs. “2022”

all vary smoothly by latitude and longitude

Earth’s Surface

NAD 83 origin

“2022” origin

h_{NAD83} – h_{"2022"}

φ_{NAD83} – φ_{"2022"}

λ_{NAD83} – λ_{"2022"}

~2.24 m

9/25/2017
Horizontal Shifts

• Approximate
  – IGS08(GRS-80) minus NAD 83(2011)
Ellipsoid Height Shifts

- Approximate
  - IGS08(GRS-80) minus NAD 83(2011)
Replace NAD 83

Access and definition

• Primary: CORS
  – Continuous monitoring
  – IGS coordinates
    • Transformable to any national reference frame chosen for 2022
  – OPUS
  – Static Surveys
  – RTK/RTN
    • Validation service

• Secondary: Passive
  – Time-tagged coordinates
  – Will reflect each occupation of the mark
  – Will *generally* not be accepted as “fixed control” in surveys turned in to NGS
More on:
ITRF2008, IGS08
For the geodesy, geophysics and surveying communities, the best International Terrestrial Reference Frame is the “gold standard.”

The global community adopted an updated expression for the reference frame, the ITRF2008. *(actually ITRF2014 published as of Jan2016)*
The International Terrestrial Reference System (ITRS) constitutes a set of prescriptions and conventions together with the modeling required to define origin, scale, orientation and time evolution.

ITRS is realized by the International Terrestrial Reference Frame (ITRF) based upon estimated coordinates and velocities of a set of stations observed by:
- Very Long Baseline Interferometry (VLBI),
- Satellite Laser Ranging (SLR),
- Global Positioning System and GLONASS (GNSS), and

International Terrestrial Reference Frame

4 Global Independent Positioning Technologies
The IGS08

(ITRF- but GNSS only)

The IGS has densified reference frame with much larger, global subset of GNSS tracking sites thereby creating a GNSS-only expression of the ITRF2008 called the IGS08. All IGS products have been recreated so as to be consistent with the IGS08 including GNSS ephemerides and antenna models. Information about the IGS08 can be found at the IGS web sites: igscb.jpl.nasa.gov. I would suggest starting with IGSMAIL-6354, -6355 and -6356, all dated 2011-03-07.
Enough International,
Back to the New Datums
Definition of New Frames

“Plate fixed” … defined at an Epoch.

• Euler Pole Plate rotations will tie the new terrestrial reference frames of 2022 to the IGS frame

• Deformational velocities will be modeled separately
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")
Time Dependencies

Track CORS and always know where you are

• Surveying to CORS positions at survey epoch
  – If we track CORS, we can do this easily

• Plate rotations
  – Easily removed for a “good east of the Rockies” solution
    (Euler Pole Rotation for each plate’s reference frame)
    • Latitude/Longitude only

• Residual deformations
  – Can be modeled many ways and provided for cross-epoch checking between surveys
    (Inter-frame velocities models)
IGS Plate Velocities

IGS08 Velocities
Baltimore County CORS
BACO
N = + 0.0022 m/yr
E = - 0.0147 m/yr
U = - 0.0032 m/yr
OBJECTIVE 2 OF 5: REPLACE NAVD 88
Replace NAVD 88

Errors in NAVD 88: ~50 cm average, 100 cm CONUS tilt, 1-2 meters average in Alaska, NO tracking
Subsidence areas of the U.S.

Source: U.S. Geological Survey
Replace NAVD 88

• Changing from a leveling-based to a geoid/GNSS-based vertical datum

• Biggest requirement: An updated, accurate, nationwide gravity survey
  – Airborne
  – GRAV-D!
  • Gravity for the Redefinition of the American Vertical Datum
**ELLIPSOID – GEOID RELATIONSHIP**

\[ H = \text{Geopotential Height (NAVD88)} \]

\[ h = \text{Ellipsoid Height (NAD 83 (2011))} \]

\[ N = \text{Geoid Height (GEOID2022)} \]

\[ H = h - N \]

\[ H \approx h - N \]

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“Average Mean Sea Level”

or

NAVD 88 Surface
Transition to the Future – GRAV-D

Gravity for the Redefinition of the American Vertical Datum

- Official NGS policy as of Nov 14, 2007
  - $38.5M over 10 years
- Airborne Gravity Snapshot
- Absolute Gravity Tracking
- Re-define the Vertical Datum of the USA by 2022
GRAV-D Coverage

Alaska

“CONUS”

Guam/Northern Marianas

Hawaii

Puerto Rico/Virgin Islands

American Samoa
Parking spot ID

Micro-G A10 Absolute Gravity measurement

GPS Base Stations

Vertical gravity gradient
GRAV-D AIRCRAFT INSTRUMENTATION

- Both instruments include GNSS receivers
- SPAN system allows for tightly coupled GPS/IMU solutions
SURVEY AND BLOCK PLANS

- Layout rectangular survey 400 x 500 km
- Extends beyond the shelf break
- Block size will reflect the endurance of the aircraft
• Data lines spaced 10 km apart
• Cross lines spaced 60-80 km apart
• Flight altitude 20,000 ft
• Nominal speed 220-250 kts
Space-Base Gravity Observations

Gravity Recovery And Climate Experiment (GRACE)
Launched - 2002

Gravity field and steady state Ocean Circulation Explorer (GOCE)
Launched – 2009
Re-entered November, 2013
Building a model of the Earth’s Gravity Field

**Intermediate Wavelengths**
(500 km to 20 km)

**Long Wavelengths:**
(≥ 400 km)

**GRACE & GOCE Satellites**

**Intermediate Wavelengths**
(500 km to 20 km)

**Airborne Measurement**

**Short Wavelengths**
(< 200 km)

**Surface Measurement**

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The gravity data from satellites, airborne, corrected surface data, and terrain predictions will be blended into a gravity field.

Methods for blending will be tested to prepare for 2022.

Available on the Website:

http://beta.ngs.noaa.gov/GEOID/xGEOID/
GRAV-D Status
100% by 2022

• 50% mark hit in FY2016
  – FY2017 target: 62%
• Two planes at a time
  – Occasionally three
• Mix of government and private industry collection
Orthometric Heights

Approximate EXPECTED SHIFTS

• Approximate level of geoid mismatch known to exist in the NAVD 88 zero surface
• Does not include local subsidence issues
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
OBJECTIVE 3 OF 5: RE-INVENT BLUEBOOKING
Bluebooking

• Refers to the blue cover of *Input Formats and Specifications of the National Geodetic Survey Data Base*
  – The requirements for turning in a geodetic survey to NGS
  – Very DOS/FORTRAN heavy
  – Horizontal (angles, distances) vertical (leveling) and gravity
    • GPS surveys were force-fitted into the horizontal rules
• Reputation: “Cumbersome”
  – To be fair: All industry standards are cumbersome – it prevents chaos
OPUS-Projects

Or “bluebooking for the 21st century”

The 2013 Survey of the Washington Monument had GPS, leveling and traverse components.

An integrated OPUS-Projects might allow for easier processing and especially cross-processing.
OPUS-Projects

Or “bluebooking for the 21st century”
New Database
Replacing the NGS IDB

**NGS IDB**
- “Integrated Database”
- Current official repository of some (most?) NSRS data
- “Integrated”...2 old DBs:
  - Horizontal / Vertical
- Built for
  - Passive control
  - No time dependencies
  - Line of sight techniques
  - Points

**NSRS DB**
- Being built (target: 2020)
- “Spatial” database
- Time tags for everything
- Open design for any type of data
- Things that couldn’t go into the IDB, but can go in the NSRS DB:
  - Lines of airborne gravity
  - LIDAR clouds
  - CORS
  - Superconducting Gravimeter data
  - Etc.
OBJECTIVE 4 OF 5: IMPROVE THE TOOLKIT
NGS Toolkit

- A set of (mostly FORTRAN-based) geodetic tools
- Little integration
- Many with no online capability
- No web services
New Toolkit

http://beta.ngs.noaa.gov/gtkweb/

- Datum transformations
- Convert to/from latitude and longitude
  - State Plane Coordinates
  - UTM
  - US National Grid
- Upload file of points
- Web service
- Download and run offline
NADCON 5

- Replacing NADCON 4.2 and GEOCON 2.0
- Support for nearly all horizontal datums since 1897
  - Exceptions: Regional Alaska
- No “state by state” grids
- Fixing all existing bugs

- Web service
- Consistent
- Documented
- Rigorous location-dependent error estimates
- **Ready to support 2022**
The entire NGS Toolkit will be integrated eventually

- VERTCON 3.0
- HTDP
- VDatum
- All other tools
OBJECTIVE 5 OF 5: BETTER SURVEYING
Better Surveying

Overview

• A focus on updating technology and field procedures
• Field research
• New manuals
Summary

NSRS Modernization

- More than just replacing NAD 83 and NAVD 88
- Affects most tools, products and services of NGS
- Dozens of interdependent, multi-year projects ongoing
- Expect rollouts and announcements throughout the next 6 years!
To Learn More

Visit the New Datums web page

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.

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.

Specifically, NAD 83 is non-geocentric by about 2.2 meters. Secondly, NAVD 88 is both biased (by about one-half meter) and tilted (about 1 meter coast...
To Learn More

Geospatial Summit

On April 24-25, 2017 NGS hosted the 2017 Geospatial Summit at the Silver Spring Civic Building at 1 Veterans Pl, Silver Spring, MD 20910.


The Summit provided an opportunity for NGS to share updates and discuss the progress of projects related to NSRS Modernization. NGS also heard feedback and collected requirements from its stakeholders across the federal, public and private sectors. This event continued discussions from previous Geospatial Summits held in 2010 and 2015.

Additional information about the 2017 Geospatial Summit will be posted online. If you have questions or comments, contact us.

https://www.ngs.noaa.gov/geospatial-summit/index.shtml
Details: Blueprint documents

• Blueprint for 2022, Part 1: Geometric Coordinates
  – Time-dependency
  – Four terrestrial reference frames
  – Intra-frame velocity models

• Blueprint for 2022, Part 2: Geopotential Coordinates
  – A.K.A. *NOAA Technical Report NOS NGS 64* (September 2017 release)
  – Time-dependency
  – One geopotential datum
    • Interrelated global geopotential model, regional geoid grids, regional DoV grids, regional surface gravity grids

9/25/2017

80
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!!!!**
-Where are we now?
-Where are we going?

(2022 is already almost an hour closer!)

QUESTIONS?