Modernization of the National Spatial Reference System

New York State Association of Professional Land Surveyors
Verona
January 20, 2011

Dave Doyle
NGS Chief Geodetic Surveyor
dave.doyle@noaa.gov
301-713-3178
ftp://ftp.ngs.noaa.gov/dist/DaveD/NYSAPLS

Mission and Vision of NGS

- To define, maintain and provide access to the National Spatial Reference System to meet our nation’s economic, social, and environmental needs

"Maintain the NSRS" means "NGS must track all of the temporal changes to the defining points of the NSRS in such a way as to always maintain the accuracy in the NSRS definition."

- Vision - Modernize the Geopotential ("Vertical") and Geometric ("Horizontal") datums

Problems with NAD 83 and NAVD 88

- NAD 83 is not as geocentric as it could be (approx. 2 m)
- Surveyors don’t see this - Yet

- NAD 83 is not well defined with positional velocities

- NAVD 88 is realized by passive control (bench marks) most of which have not been releveled in at least 40 years.

- NAVD 88 does not account for local vertical velocities (subsidence and uplift)
- Post glacial isostatic readjustment
- Subsurface fluid withdrawal
- Sediment loading
- Sea level rise
- Montauk – 2.8 mm/yr (0.01 ft/yr) Since 1947
- Port Jefferson – 2.4 mm/yr (0.01 ft/yr) Since 1937
- Long Island – 2.4 mm/yr (0.01 ft/yr) Since 1933
- The Battery – 2.8 mm/yr (0.01 ft/yr) Since 1854
- Sandy Hook, NJ – 3.9 mm/yr (0.01 ft/yr) Since 1932
GLOBAL POSITIONING SYSTEM

- 1978 1st NAVSTAR Satellite Launched (October 22, 1978)
- 1995 Fully Operational
- 2000 Selective Availability turned off (May 1, 2000)
- 2005 Additional Band L2C
- 2010 Additional Frequency L5 added (May 28, 2010)
- 2020? 10-50 cm real-time accuracy?


- Three positioning and navigation systems
  - Navstar/GPS – US (Currently 31)
  - GLONASS – Russia (Currently 24)
    - December 5 (3 satellites lost at launch)
    - December 7 (First GLONASS-M launch)
  - GALILEO – EU (Currently 2)
  - BEIDOU (Compass) – China (Complete by 2020?)
- All satellites available for positioning purposes.

The National Geodetic Survey 10 year plan
Mission, Vision and Strategy
2008 – 2018
http://www.ngs.noaa.gov/INFO/NGS10yearplan.pdf

- Official NGS policy as of Jan 9, 2008
  - Modernized agency
  - Attention to accuracy
  - Attention to time changes
  - Improved products and services
  - Integration with other fed missions
- NGS Targets:
  - NAD 83 and NAVD 88 re-defined
  - Cm-accuracy access to all coordinates
  - Customer-focused agency
  - Global scientific leadership
1807
President Thomas Jefferson signs legislation establishing the Survey of the Coast

Ferdinand Hassler (1770-1843)

1984
An End of an Era
Global Satellite Triangulation Network 1964-1973

ECHO/PAGEOS Balloon Satellite
Type of satellite photographed by BC-4

BC-4 camera photograph
Stars in circular pattern
Satellite is a series of dots in straight line.
US Navy Transit Satellite
1964 (Military), 1967 (Civilian)

DOPPLER and VLBI

National Shoreline
- Consistent, accurate, and up-to-date
- Networks of geodetic control points
  - Permanently marked passive survey monuments

NSRS COMPONENTS
- National CORS Network
  - A network of GPS Continuously Operating Reference Stations
- Tools
  - Models of geophysical effects on spatial measurements
  - e.g., NADCON, INVERSE, SPCS83, UTMS, FORWARD
The NSRS has evolved

- 1 Million Monuments (Horizontal and Vertical Systems)
- Passive Marks (Limited Knowledge of Stability)
- 70,000 Passive Marks (3-Dimensional)
- 1,400 GPS CORS (Time Dependent System Possible; 4-Dimensional)

GPS CORS → GNSS CORS

GEODE蒂C DATUMS

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

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

GEOMETRIC
3 D (Latitude, Longitude, and Ellipsoid Height)
Fixed and Stable - Coordinates seldom change
(e.g. NAD 83 (1996), NAD 83 (2007), NAD 83 (CORS96))
also
4 D (Latitude, Longitude, Ellipsoid Height, Velocities) Coordinates change with time
(e.g. ITRF00, ITRF08)

Tectonic Motions

National Geographic Survey
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 Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS).

ITRF89, ITRF90, ITRF91, ITRF92, ITRF93, ITRF94, ITRF95, ITRF96, ITRF97, ITRF2000, ITRF2005, ITRF2008
International Terrestrial Reference Frame
4 Global Independent Positioning Technologies

International Global Navigation Satellite Systems Service (IGS)
International Laser Ranging Service (ILRS)
International Very Long Baseline Service (IVS)
International DORIS Service (IDS)

Simplified Concept of NAD 83 vs. ITRF00

Identically shaped ellipsoids (GRS-80)
a = 6,378,137.000 meters (semi-major axis)
1/f = 298.25722210088 (flattening)

History of vertical datums in the USA

• Pre-National Geodetic Vertical Datum of 1929 (NGVD 29)
  - The first geodetic leveling project in the United States was surveyed by the Coast Survey from 1856 to 1857.
  - Transcontinental leveling commenced from Hagerstown, MD in 1877.
  - General Adjustments of leveling data yielded datums in 1900, 1903, 1907, and 1912. (Sometimes referenced as the Sandy Hook Datum)
  - NGS does not offer a utility which transforms from these older datums into newer ones (though some users still work in them!)
History of vertical datums in the USA

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

- **NAVD 88**
  - North American Vertical Datum of 1988
  - One height held fixed at "Father Point" (Rimouski, Canada)
  - ...height chosen was to minimize 1929/1988 differences on USGS topo maps in the eastern U.S.
  - Thus, the “zero height surface” of NAVD 88 wasn’t chosen for its closeness to the geoid (but it was close...few decimeters)
History of vertical datums in the USA

- **NAVD 88** (continued)
  - Use of one fixed height removed local sea level variation problem of NGVD 29
  - Use of one fixed height did open the possibility of unconstrained cross-continent error build up
  - But the H=0 surface of NAVD 88 was supposed to be parallel to the geoid...(close again)
Problems using traditional leveling (to define a National Vertical Datum)

- Leveling the country can not be done again
  - Too costly in time and money (Estimated ~ $1B)
- Leveling yields cross-country error build-up; problems in the mountains
- Leveling requires leaving behind passive marks
  - Bulldozers and crustal motion do their worst

Why isn’t NAVD 88 good enough anymore

- 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
  - Weren’t adopted in Canada
  - Were determined by leveling from a single point, allowing cross-country error build up

Why isn’t NAVD 88 good enough anymore?

- NAVD 88 suffers from:
  - A zero height surface that:
    - Has been proven to be ~50 cm biased from the latest, best geoid models (GRACE satellite)
    - Has been proven to be ~ 1 meter tilted across CONUS (again, based on the independently computed geoid from the GRACE satellite)
1. Using GNSS is cheaper, easier than leveling
2. To use GNSS we need a good geoid model

Why isn’t NAVD 88 good enough anymore?

Errors in NAVD 88: ~50 cm average, 100 cm CONUS tilt, 1-2 meters average in Alaska

GRACE — Gravity Recovery and Climate Experiment
Approximate level of geoid mismatch known to exist in the NAVD 88 zero

Why isn’t NAVD 88 good enough anymore?

• Relative (local) accuracy in ellipsoid heights between adjacent points can be better than 2 cm, at 95% confidence level
• Network accuracy (relative to NSRS) in ellipsoid heights can be better than 5 cm, at 95% confidence level
• Accuracy of orthometric height is dependent on accuracy of the geoid model — Currently NGS is improving the geoid model with more data, i.e. Gravity and GPS observations on leveled bench marks from Height Mod projects
• Geoid09 can have an uncertainty in the 2-5 cm range.

How accurate is a GPS-derived Orthometric Height?

• Gravimetric (or Gravity) Geoid Height Models
  – Defined by gravity data crossing the geoid
  – Refined by terrain models (DEM’s)
  – Scientific and engineering applications
• Composite (or Hybrid) Geoid Height Models
  – Gravimetric geoid defines most regions
  – Warped to fit available GPSBM control data
  – Defined by legislated ellipsoid (NAD 83) and local vertical datum (NAVD 88, PRVD02, etc.)
  – May be statutory for some surveying & mapping applications

Types and Uses of Geoid Height Models
GGPSBM2003: 14,185 total 579 Canada STDEV 4.8 cm (2σ)
GGPSBM1999: 6,169 total 0 Canada STDEV 9.2 cm (2σ)

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 2018
(2022 more likely due to funding issues)
What is GRAV-D?

• National Scale Part 1
  - Predominantly through airborne gravity
  - With Absolute Gravity for ties and checks
  - Relative Gravity for expanding local regions where airborne shows significant mismatch with existing terrestrial

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

1500+ Installed and Operated by various Federal-State-local Agencies

- NOAA/National Geodetic Survey
- NOAA/OAR Global Systems Division
- U.S. Coast Guard - DGPS/NDGPS
- Corps of Engineers - DGPS
- FAA - WAAS/LAAS
- State DOTs
- County and City
- Academia
- Private Companies

REGIONAL CORS NETWORK
Antenna Reference Point (ARP): MOHAWK VALLEY COOP CORS ARP

ITRF00 POSITION (EPOCH 1997.0)
Computed in January 2005 using 11 days of data
X = 1190490.159 m
Y = -4511732.966 m
Z = 4333943.156 m
Ellipsoid height = 158.203 m

ITRF00 VELOCITY
Predicted with HTDP version 2.7 January 2005
VX = -0.0175 m/yr
VY = -0.0018 m/yr
VZ = 0.0032 m/yr

NAD_83 (CORS96) POSITION (EPOCH 2002.0)
Transformed from ITRF00 (epoch 1997.0) position in Jan. 2005.
X = 1190490.704 m
Y = -4511734.393 m
Z = 4333943.259 m
Ellipsoid height = 159.382 m

NAD_83 (CORS96) VELOCITY
Transformed from ITRF00 velocity in Jan. 2005.
VX = 0.0000 m/yr
VY = 0.0000 m/yr
VZ = 0.0000 m/yr

OPUS-DB
SS Receivers
4 Hours of data
Results shared

OPUS-RS
SS Receivers
15 Minutes of data
Results not shared

OPUS-S
SS Receivers
2 Hours of data
Results not shared

OPUS-Projects
SS Receivers
2-4 Hours of data
Multiple Receivers
Network Solution
Results shared or not

LOCUS
Leveling On Line Computing Service
Integration with GPS?
Results shared or not

FLAVORS OF OPUS

OPUS-DB
Simple
Shared Data
NGS Archived

OPUS-RS

OPUS-S

OPUS-Projects

LOCUS

ITRF00 - NAD 83 (CORS96)
Delta = 1.179 m
**Ten-Year Milestones (2018)**

1) NGS will compute a pole-to-equator, Alaska-to-Newfoundland geoid model, preferably in conjunction with Mexico and Canada as well as other interested governments, with an accuracy of 1 cm in as many locations as possible

2) NGS redefines the vertical datum based on GNSS and a gravimetric geoid

3) NGS redefines the national horizontal datum to remove disagreements with the ITRF

---

**Predicted Positional Changes in 2022**

**Vicinity of Verona, NY.**

(Computed for station Z 465, pid O1E1692)

**HORIZONTAL** = 1.15 m (3.8 ft)

**ELLIPSOID HEIGHT** = -1.19 m (-3.9 ft)

Predicted with HTDP

**ORTHOMETRIC HEIGHT** = -0.39 m (-1.3 ft)

Predicted with HTDP and USGG2009

---

**Calendrier of Upcoming Classes**

---
GOOD COORDINATION BEGINS WITH GOOD COORDINATES

GEOGRAPHY WITHOUT GEODESY IS A FELONY