New Datums – What you need to know with only two years to go!

New York State Association of Professional Land Surveyors
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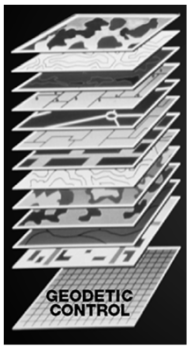
National Spatial Reference System (NSRS)

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

& how these values change with time



GEODETIC 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) NAD 83 (2011))

also

4 D (Latitude, Longitude, Ellipsoid Height, Velocities) Coordinates change with time
(e.g. ITRF00, ITRF08)

A (very) brief history of NAD 83

- Original realization completed in 1986
  - Consisted (almost) entirely of classical (optical) observations
- "High Precision Geodetic Network" (HPGN) and "High Accuracy Reference Network" (HARN) realizations
  - Most done in 1990s, essentially state-by-state
  - Based on GNSS but classical stations included in adjustments
- National Re-Adjustment of 2007
  - NAD 83(CORS96) and (NSRS2007)
  - Simultaneous nationwide adjustment (GNSS only)
- ***New realization: NAD 83(2011) epoch 2010.00***

Why change datums/Realizations

- NAD27 based on old observations and old system
- NAD83(86) based on old observations and new system
- NAD83(96) based on new and old observations and same system (HARN)
- NAD83(NSRS2007) based on new observations and same system. Removed regional distortions and made consistent with CORS
- NAD83(2011) based on new observations and same system. Kept consistent with CORS

National Spatial Reference System (NSRS) Improvements over time

NETWORK	TIME SPAN	NETWORK ACCURACY	LOCAL ACCURACY	SHIFT
NAD 27	1927-1986	10 meters	(1:100,000)	10-200 m
NAD83(86)	1986-1990	1 meter	(1:100,000)	0.3-1.0 m
NAD83(199x)* "HARN", "FBN"	1990-2007	0.1 meter	(1:1 million) (1:10 million)	0.05 m
NAD83(NSRS2007)	2007-2011	0.01 meter	0.01 meter	0.03 m
NAD83(2011)	2011-	0.01 meter	0.01 meter	0.01 m

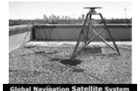
Horizontal Datums/Coordinates…What do we (you) use in your state?

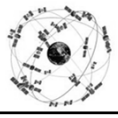
- NAD 27
- NAD 83 (Lat-Lon) SPC
  - Which one???
    - NAD 83 (1986)
    - NAD 83 (19xx) - HARN
    - NAD 83 (1996) - FBN
    - NAD 83 CORS96(2002)
    - NAD 83 (NSRS2007)
    - NAD 83 (2011) epoch 2010.00
- WGS 84
  - Which one???
    - WGS 84 (1987)
    - WGS 84 (G730)
    - WGS 84 (G873)
    - WGS 84 (G1150)
    - WGS 84 (G1674)
    - WGS 84 (G1762)
- ITRFxx (epoch xxxx)
- IGSxx (epoch xxxx)

The NSRS has evolved

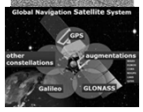
1 Million Monuments (Separate Horizontal and Vertical Systems) → 70,000 Passive Marks (3-Dimensional)

Passive Marks (Limited Knowledge of Stability) → ≈ 2,000 GPS CORS (Time Dependent System Possible; 4-Dimensional)





GPS CORS → GNSS CORS



Multi-Year CORS Solution (MYCS)

In 2011,NGS used its contribution to the IGS08 plus the additional CORS to produce improved IGS08 coordinates and velocities for the CORS network. From this, improved CORS coordinates and velocities in the NAD 83 frame were defined.

To distinguish this from earlier realizations, this reference frame is called the NAD 83 (2011). This is *not* a new datum: the origin, scale and orientation are the same as in the previous realization.

In September 2011, NGS formally released IGS08 and NAD 83 (2011) coordinates and velocities for the CORS. Information about the IGS08 and NAD 83 (2011) can be found at geodesy.noaa.gov/CORS/coords.shtml.

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Introducing…
NAD 83(2011) epoch 2010.00

- **Multi-Year CORS Solution (MYCS)**
  - Continuously Operating Reference Stations
  - Reprocessed all CORS GPS data Jan 1994-Apr 2011
  - 2264 CORS & global stations
  - NAD 83 computed by *transformation* from IGS08
- **2011 national adjustment of passive control**
  - New adjustment of GNSS passive control
  - GNSS vectors tied (and constrained) to CORS NAD 83(2011) epoch 2010.00
  - Over 80,000 stations and 400,000 GNSS vectors
- **Realization SAME for CORS *and* passive marks**
- **This is *NOT* a new datum! (still NAD 83)**

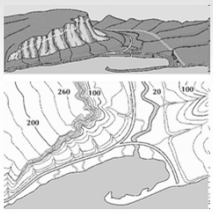
Why a new NAD 83 realization?

- Multi-Year CORS Solution
  - Previous NAD 83 CORS realization needed many improvements
  - Consistent coordinates *and* velocities from global solution
  - Aligned with most recent realization of global frame (IGS 08)
  - Major processing, modeling, and metadata improvements
    - Including new ***absolute phase center antenna calibrations***
- National adjustment of passive control
  - Optimally align passive control with "active" CORS control
    - ***Because CORS provide the geometric foundation of the NSRS***
  - Incorporate new data, compute accuracies on all stations
  - Better results in tectonically active areas
- ***Bottom line***
  - **Must meet needs of users for highly accurate *and* consistent coordinates (*and* velocities) using *B*est *A*vailable *M*ethods**

NOAA's **National Geodetic Survey** Positioning America for the Future www.ngs.noaa.gov

What is a Vertical Datum?

- Strictly speaking, a vertical datum is a ***surface*** representing zero elevation
- Traditionally, a vertical datum is a ***system*** for the determination of heights above a zero elevation surface
- Vertical datum comprised of:
  - Its ***definition:*** Parameters and other descriptors
  - Its ***realization:*** Its physical method of accessibility



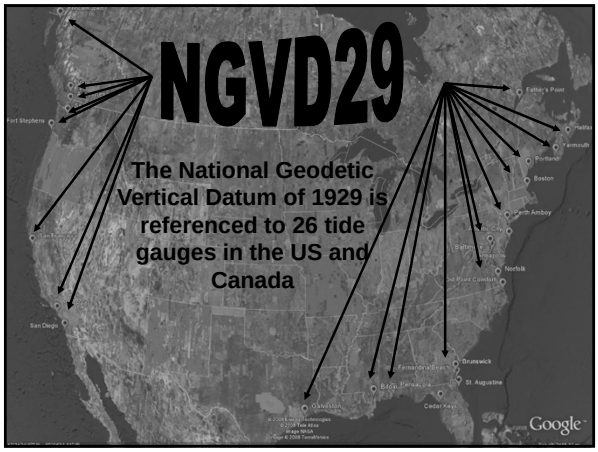
"*topographic map.*" Online Art. Britannica Student Encyclopædia. 17 Dec. 2008 <http://student.britannica.com/ebi/art-53199>

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



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Current Vertical Datum in the USA

Father Point
Lighthouse, Quebec

- **NAVD 88**: North American Vertical Datum of 1988
- ***Definition:*** The surface of equal gravity potential to which orthometric heights shall refer in North America*, and which is 6.271 meters (along the plumb line) below the geodetic mark at "Father Point/Rimouski" (NGSIDB PID TY5255).
- ***Realization:*** Over 500,000 geodetic marks across North America with published Helmert orthometric heights, most of which were originally computed from a minimally constrained adjustment of leveling and gravity data, holding the geopotential value at "Father Point/Rimouski" fixed.

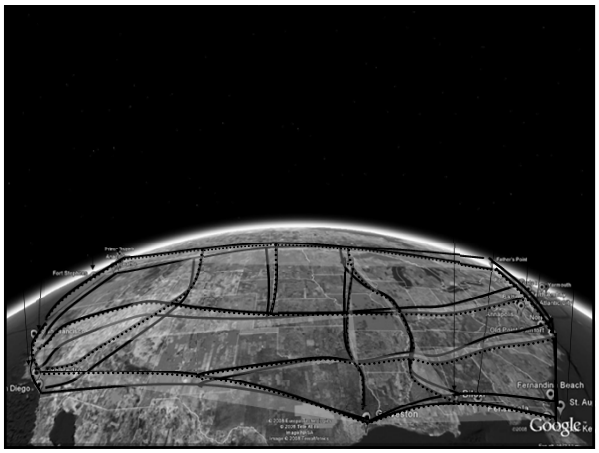
**Not adopted in Canada*

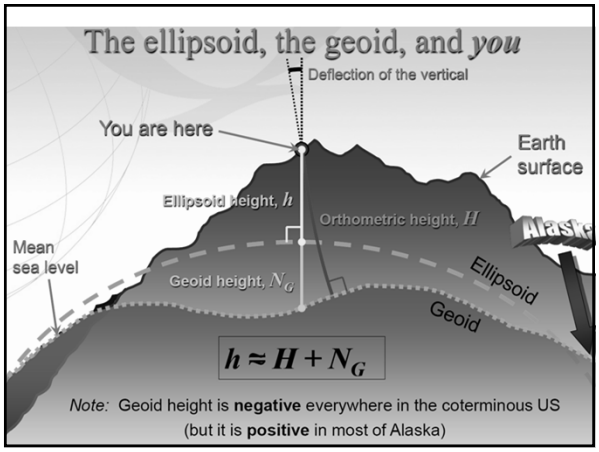
History of vertical datums in the USA

- **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

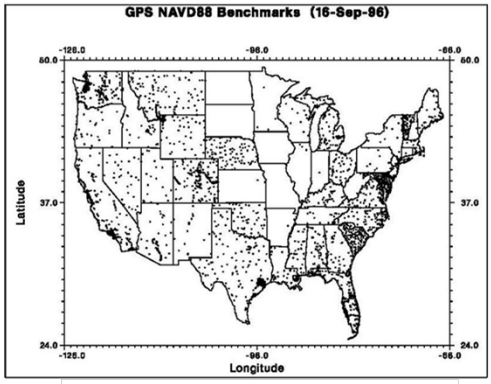
- **NAVD 88** (continued)
  - Use of one fixed height removed local sea level variation problem of NGVD 29
  - Use of one fixed height did open the possibility of unconstrained cross-continent error build up
  - H=0 surface of NAVD 88 was supposed to be parallel to the geoid…(close again)



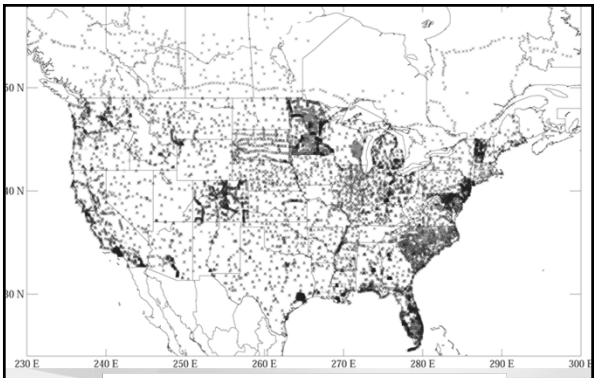


Types Uses and History of Geoid Height Models

- 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

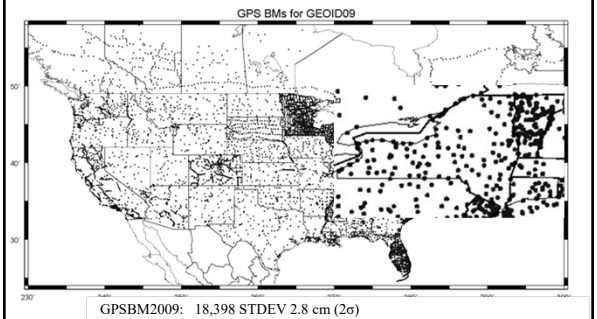


GPSBM1996: 2,951total 0 Canada STDEV ≈ 5 cm (2σ)

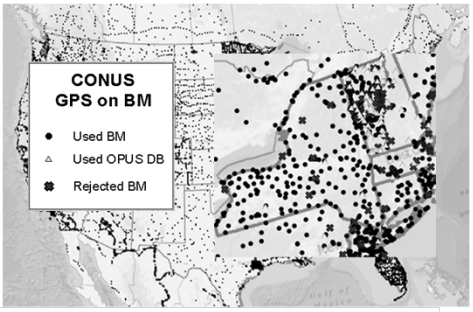


GPSBM1999: 6,169 total 0 Canada STDEV 9.2 cm (2σ)

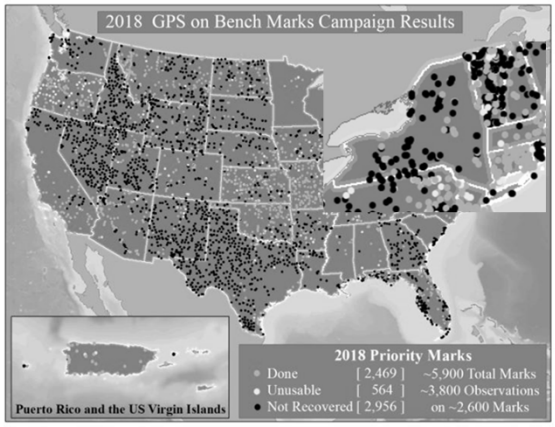
GPSBM2003: 14,185 total 579 Canada STDEV 4.8 cm (2 σ)

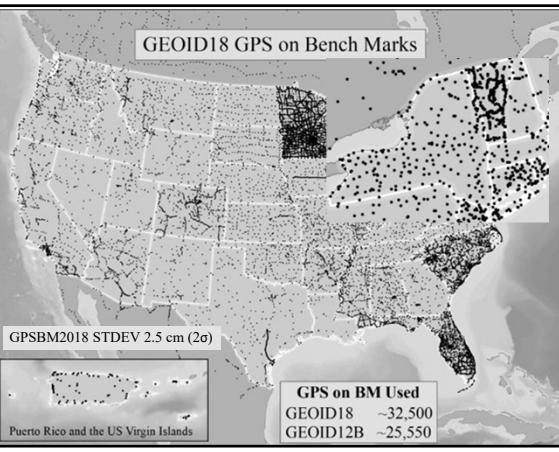


GPSBM2009: 18,398 STDEV 2.8 cm (2σ)



GPSBM2012B: 23,961 (CONUS)
499 (OPUS on BM)
574 (Canada)
177 (Mexico)



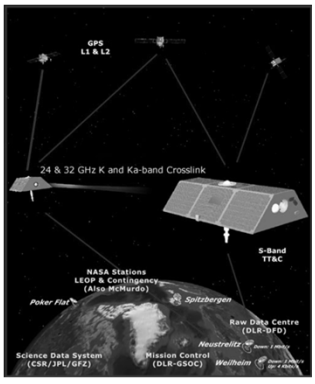


Which Geoid for Which NAD 83?

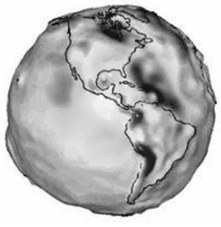
• NAD 83(2011)	• Geoid18 • Geoid12A/12B
• NAD 83(2007)	• Geoid09 • Geoid06 (AK only)
• NAD 83(1996) & CORS96	• Geoid03 • Geoid99 • Geoid96

Problems with NAD 83 and NAVD 88

- **NAD 83** is not as geocentric as it could be (approx. 2 m)
  - Positioning Professionals 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 re-leveled in at least 40 years.
- **NAVD 88** does not account for local vertical velocities (subsidence and uplift)
  - Post glacial isostatic readjustment (uplift)
  - Subsurface fluid withdrawal (subsidence)
  - Sediment loading (subsidence)
  - Sea level rise (Up to 1.34 ft per 100 years)
    - **Montauk, NY 3.32 mm/yr (0.010 ft/yr) 1947-2018**
    - **Sandy Hook, NJ 4.09 mm/yr (0.013 ft/yr) 1932-2018**



GRACE – Gravity Recovery and Climate Experiment



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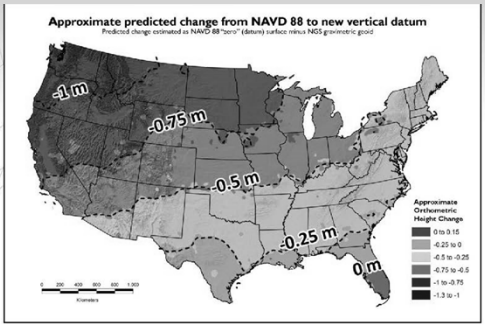
NAVD 88 is tilted and biased



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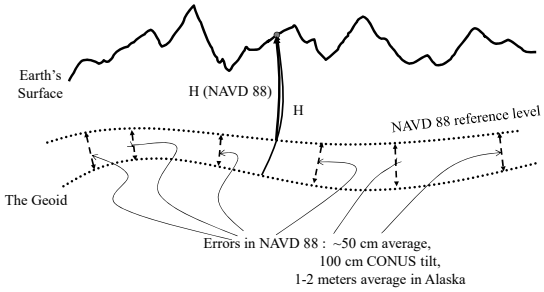
Why isn't NAVD 88 good enough anymore?



Why replace NAVD 88 and NAD 83?

- **ACCESS!**
  - easier to find the sky than a 60-year-old bench mark
  - GNSS equipment is cheap and fast
- **ACCURACY!**
  - easier to trust the sky than a 60-year old bench mark
  - immune to passive mark instability
- **GLOBAL STANDARDS!**
  - systematic errors of many meters across the US
  - aligns with GPS, international efforts
  - aligns with Canada, Mexico

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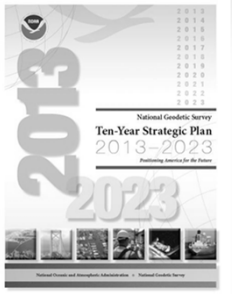
The National Geodetic Survey 10 year plan
Mission, Vision and Strategy
2008 – 2018, 2013-2023

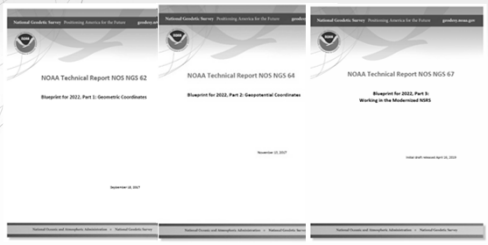
http://www.ngs.noaa.gov/INFO/NGS10yearplan.pdf

- *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*
- *2022 Targets:*
  - *NAD 83 and NAVD 88 re-defined*
  - *Cm-accuracy access to all coordinates*
  - *Customer-focused agency*
  - *Global scientific leadership*



Modernizing the NSRS

The "blueprint" documents: Your best source for information



Geometric: Sep 2017

Geopotential: Nov 2017

Working in the modernized NSRS: April 2019

Scientific Decisions

- Blueprint for 2022, Part 1: Geometric
  - ✓Four plate-fixed Terrestrial Reference Frames
    - ✓And what "plate fixed" means
  - ✓Mathematical equation between IGS and TRFs
    - ✓Plate Rotation Model for each plate
    - ✓Coordinates at survey epoch
  - ✓Intra-frame velocity model
    - ✓To compare coordinates surveyed at different epochs

Replacing the NAD 83's

- Three plate-(*pseudo*)fixed frames will be replaced with four *plate-fixed* reference frames
  - N. Amer., Pacific, Mariana, Caribbean(new!)
- Remove long-standing non-geocentricity of NAD 83 frames
- All four : identical to IGSxx at a TBD epoch
  - 2020.00?
- All four : differ from IGSxx by plate rotation only
  - Updated Euler Pole determination for rigid plate only

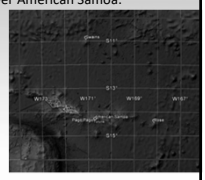
Names

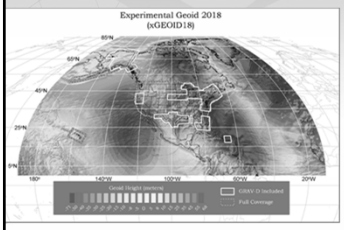
The Old:	The New:
NAD 83(2011)	The North American Terrestrial Reference Frame of 2022 (NATRF2022)
NAD 83(PA11)	The Caribbean Terrestrial Reference Frame of 2022 (CTRF2022)
NAD 83(MA11)	The Pacific Terrestrial Reference Frame of 2022 (PTRF2022)
	The Mariana Terrestrial Reference Frame of 2022 (MTRF2022)

Scientific Decisions!!

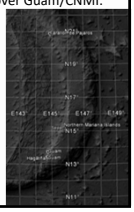
- Blueprint for 2022, Part 2: Geopotential
  - ✓Global 3-D Geopotential Model (GGM)
    - ✓Will contain all GRAV-D data
    - ✓Able to yield any physical value on/above surface
  - ✓Special high-resolution geoid, DoV and surface gravity products consistent with GGM
    - ✓Not global: NA/Pacific, American Samoa, Guam/CNMI
  - ✓Time-Dependencies
    - ✓Geoid monitoring service
      - ✓Impacts of deglaciation, sea level rise, earthquakes, etc

GEOID2022 (et al) over American Samoa:
-16 to -10, 186-193





GEOID2022 (et al) over Guam/CNMI:
11-22, 143-148



GEOID2022 (et al) over the North America/Pacific/Caribbean/Central America/Greenland region will range from 0 to 90 latitude and from 170 to 350 longitude.

Names

The Old:

Orthometric Heights
- NAVD 88

Normal Orthometric Heights
- PRVD 02
- VIVD09
- ASVD02
- NMVD03
- GUVD04

Dynamic Heights
- ICLD S

Gravity
- IGSN

Geoid Undulations
- GEOID12B

Deflections of the Vertical
- DEFLEC12B

The New:

The N… American … Geopotential Datum … 2022 (NAPGD2022)

… include GEOID2022

one vertical datum
pole-to-equator

Before today had you already heard that NAD83 and NAVD88 are scheduled to be replaced?

Who's nervous?

Who's ready?

Who's already working in ITRF?

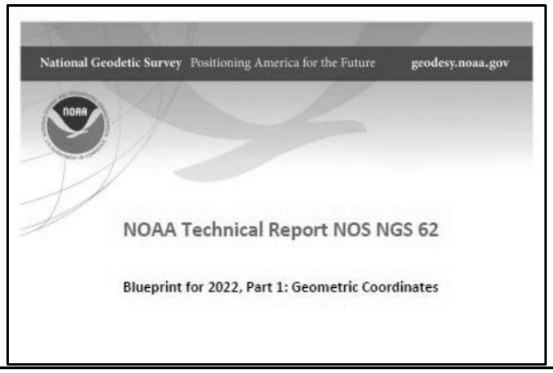
The wrong question, circa 2022:

"What's the position of that point?"

The right question, circa 2022:

"What's the position of that point, **on some specific date**?"

Drift…



North American Terrestrial Reference Frame of 2022

NATRF2022

(pronounced: nat-ref)

Reference Frame ≈ Datum

- Reference Frame is a more *scientifically appropriate* way of saying "datum"
- could be debated that "datum" was misused
- you will continue to see NGS use the phrase "New Datums" for 2022

Reference Frame Defined

A point of view or a 'frame of reference'.

If your reference frame is North America, you are standing somewhere within North America, **seeing how other places move** from your point of view.

Replacing NAD83

1. develop four "plate-fixed" reference frames
2. remove non-geocentricity of NAD83
3. align to ITRF2014 at epoch 2020.00
4. remove most of tectonic plate rotation from ITRF2014 via Euler Pole Parameters
   (pronounced: "oiler")

Shift and Drift…

Replacing NAD83

1. **develop <u>four "plate-fixed" reference frames</u>**
2. remove <u>non-geocentricity of NAD83</u>
3. align to <u>ITRF2014 at epoch 2020.00</u>
4. remove most of tectonic plate rotation from ITRF2014 via <u>Euler Pole Parameters</u>
   (pronounced: "oiler")

Shift and Drift…

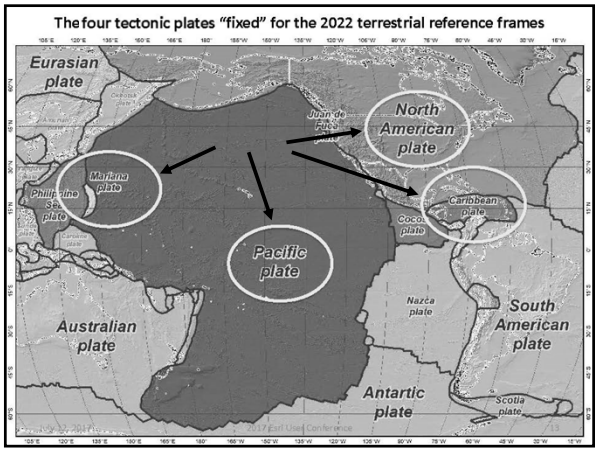
Four "Plate-Fixed" Reference Frames

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 2022 (MATRF2022)



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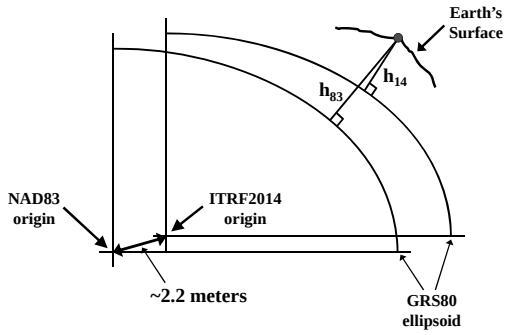
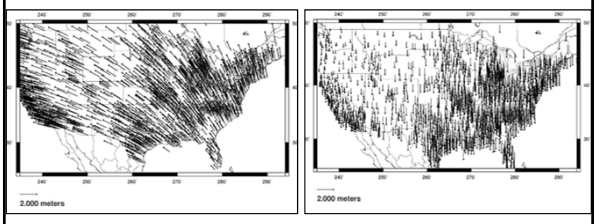
Shift and Drift…

Non-geocentricity of NAD83



Geometric change due to ellipsoid non-geocentricity



Horizontal (Lat, Lon) Ellipsoidal (h)

Shift…

Replacing NAD83

1. develop four "plate-fixed" reference frames
2. remove non-geocentricity of NAD83
3. **align to ITRF2014 at epoch 2020.00**
4. remove most of tectonic plate rotation from ITRF2014 via Euler Pole Parameters
   (pronounced: "oiler")

Shift and Drift…

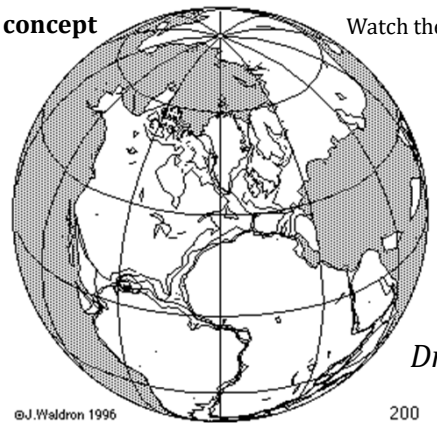
International Terrestrial Reference Frame (ITRF)

International Earth Rotation and Reference Systems Service (IERS)

International Union of Geodesy and Geophysics (IUGG)

ITRF concept

Watch the grid!



Drift…

Replacing NAD83

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   (pronounced: "oiler")

Shift and Drift…

Two types of drift

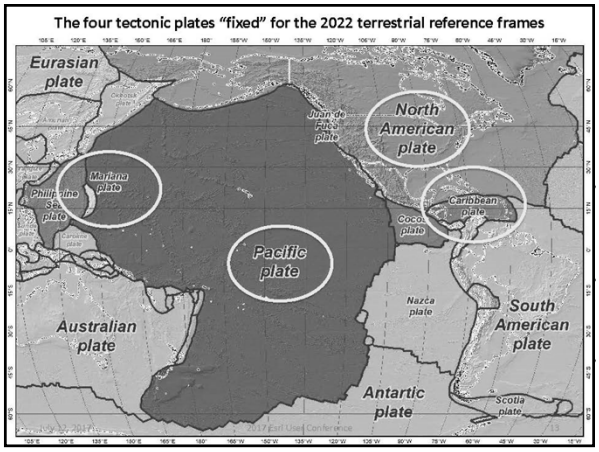
Tectonic Plate Rotation
- horizontal *simple to model*

Everything Else
- residual motions left after rotation
- regional linear motions
- localized subsidence or uplift *complex*

Tectonic Plate Rotation
- horizontal *simple to model*

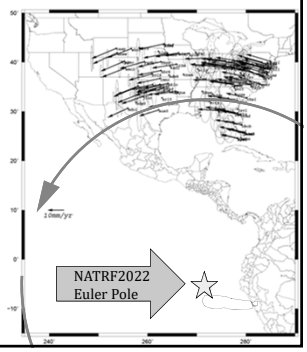
Euler Pole Parameters of 2022

EPP2022



Euler Poles and "Plate-Fixed"

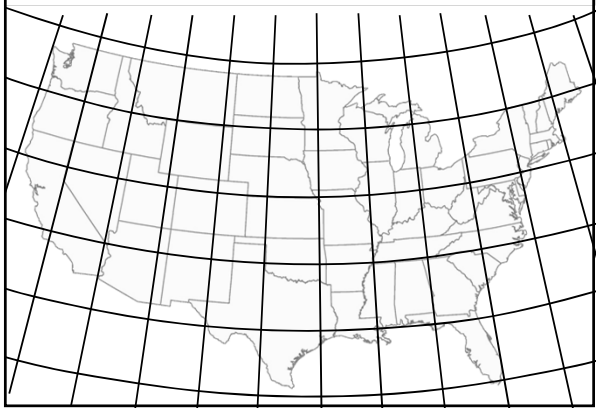
- In the ITRF, many tectonic plates have a *dominant* motion: **rotation**
- **Euler Pole** - point about which a plate rotates (yellow star)



Euler Poles and "Plate-Fixed"

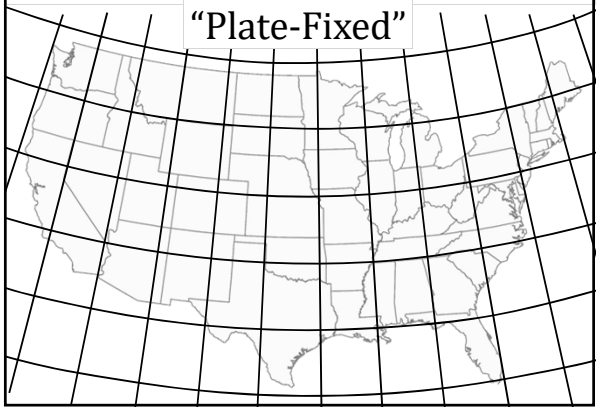
ITRF	**NATRF**
Frame = constant	Frame = rotating (*relative to ITRF*)
NA Plate = rotating	NA Plate = constant (*relative to NATRF2022*)

ITRF – constant frame, rotating plate

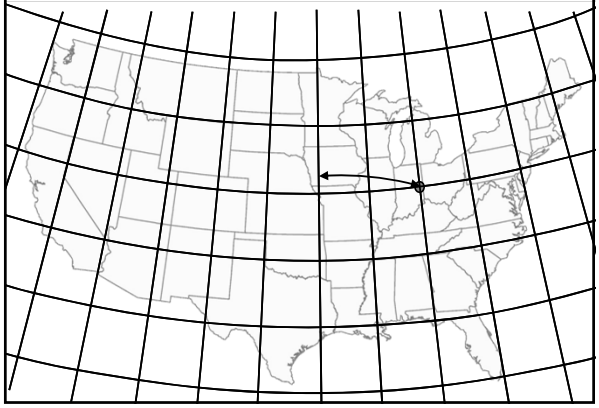


NATRF – rotating frame, constant with plate

"Plate-Fixed"



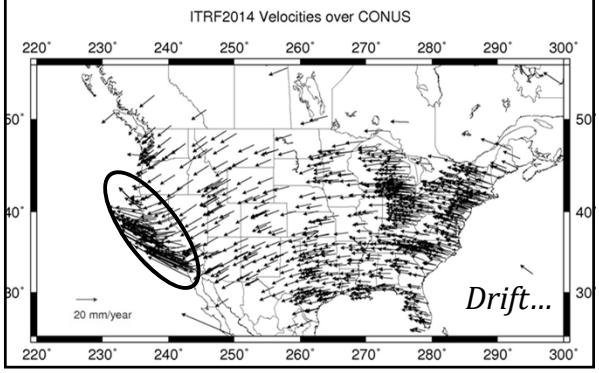
ITRF or **NATRF** – your choice, just use EPP



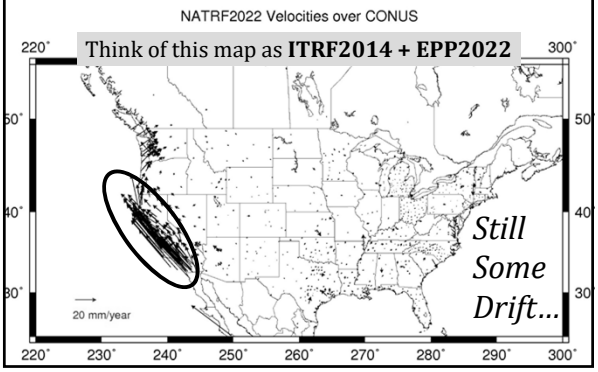
EPP – Euler Pole Parameters

Latitude
Longitude } yellow star off west coast of S. America
Rotation Speed

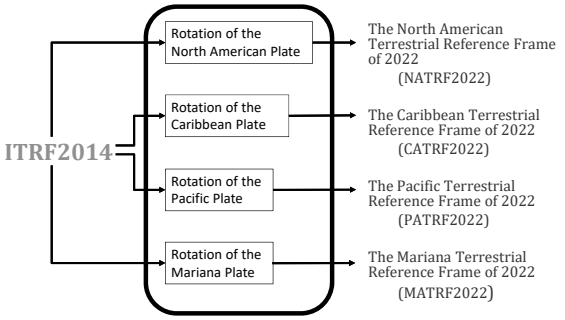
CORS Velocities in ITRF2014



CORS Velocities in NATRF2022



ITRF2014 + **EPP2022** = --TRF2022



Two types of drift

Tectonic Plate Rotation
- horizontal *simple to model*

Everything Else
- residual motions left after rotation
- regional linear motions
- localized subsidence or uplift

complex

Still Some Drift…

Everything Else

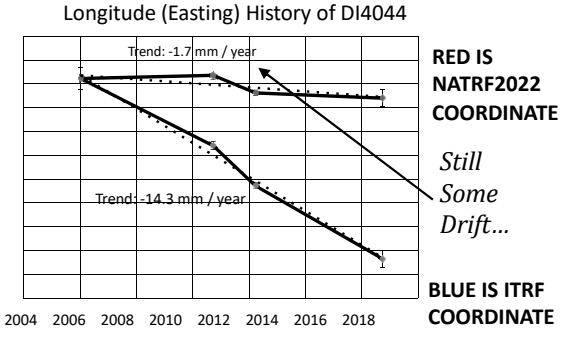
- residual motions left after rotation
- regional linear motions
- localized subsidence or uplift

complex

Intra-Frame Velocity Model of 2022

IFVM2022

Concept of goal of IFVM



Still Some Drift…

- **Everything** in the world moves
- Coordinates will be associated with the actual date when the data was collected!
- Velocities at all marks can be *estimated* using this Intra-Frame Velocity Model
- IFVM goal is to move collected data thru time to Reference Epochs for coordinate comparisons/analysis

Intra-Frame Velocity Model

- A model of all residual velocities, *after removal of tectonic rotation via EPP*:
  - Horizontal residual motion
  - Total vertical motion (ellipsoid heights)
  - Replaces / Improves upon HTDP
- Given t_1 and t_2, compute Df, Dl, Dh at any point, accounting for all motions (drifts, earthquakes, GIA, etc.)
- Likely be built upon CORS data, geodynamic models and InSAR

EPP2022 – Euler Pole Parameters – Simple Rotation

- Three parameters: lat, lon, rotation speed
- Horizontal *only*: just latitude and longitude
- Changes the *frame*: ITRF2014 + EPP2022 = NATRF2022
- Does **not** change the *epoch*

IFVM2022 – Intra-Frame Velocity Model - Complex

- Complex set of parameters
- *Residual* horizontal motion: all the motion leftover after Euler Pole rotation
- *All* vertical motion: localized subsidence or uplift
- Changes the *epoch*
- Does **not** change the *frame*: "intra" = on the inside; within

EPP2022
IFVM2022

Two new tools that will make time dependent geodetic control practical

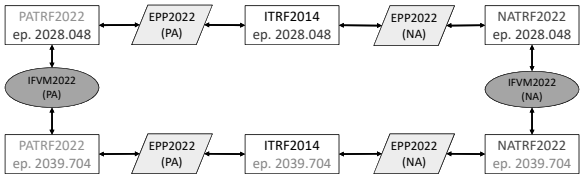
They work together to account for the Drift…

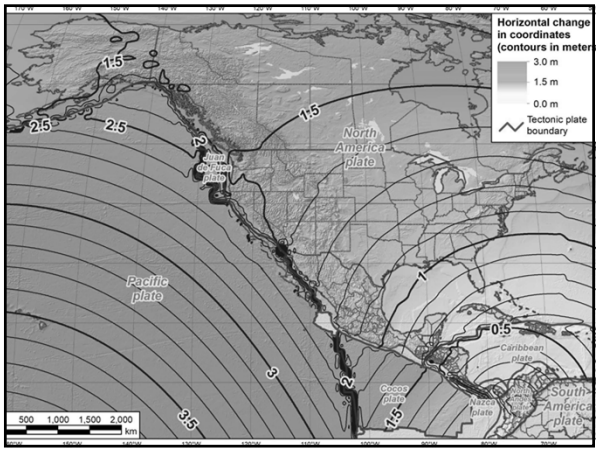
Example of application of EPP and IFVM

- It's 2039 and you are working in San Diego using NATRF2022
- And you need to compare your work to another survey from 2028

Important: This slide only covers *geometric* coordinates.

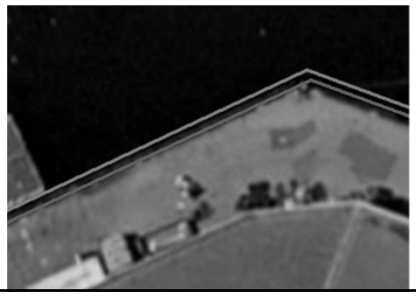
…the catch is, that survey was done in PATRF2022





What's that going to look like?

PHOTO = NAD83
RED = NAD83 shoreline data
GREEN = shoreline transformed to NATRF2022



North American-Pacific Geopotential Datum of 2022

NAPGD2022

(pronounced: nap-jee-dee)

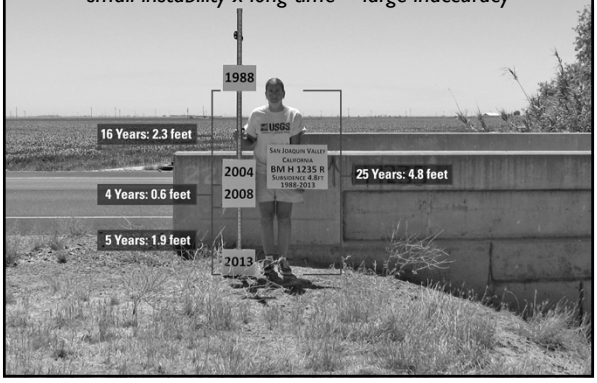
Overview NAPGD2022

- primary access via GNSS and geoid (think OPUS)
- accurate continental **gravimetric** geoid
- aligned with:
  1) --TRF2022
  2) **global** mean sea level (GMSL)
- monitor time-varying nature of gravity
  - via the Geoid Monitoring Service (GeMS)

Why Replace NAVD88?

Passive marks may lie still… but they still may lie!

small instability x long time = large inaccuracy



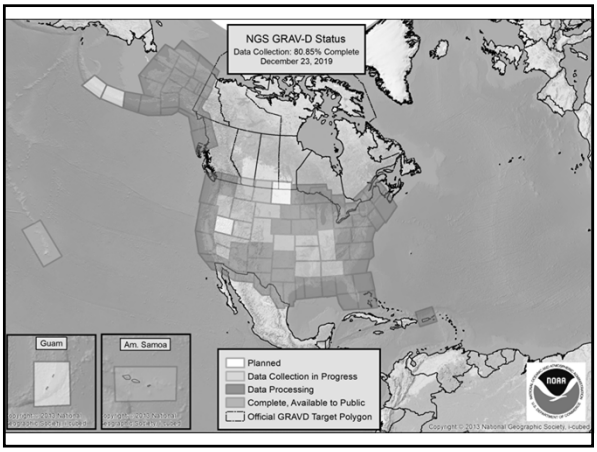
Gravity for the Redefinition of the American Vertical Datum

- **2022 Goal**: 2 cm accurate ortho heights (H)
  - GNSS plus geoid model
- **GRAV-D Goal**: Gravimetric geoid (N_g) accurate to 1 cm where possible using airborne gravity data
- Leverage partnerships to improve and validate gravity data
  - State-based gravity programs?

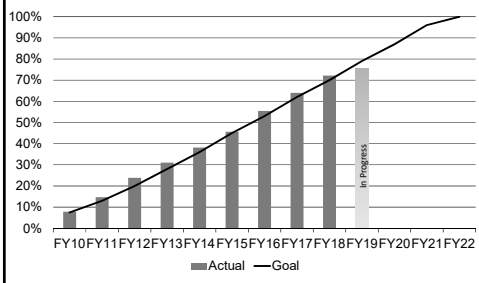
Gravity for the Redefinition of the American Vertical Datum

There are two major campaigns within GRAV-D

1. High-resolution snapshot of gravity
   - primarily airborne observations, all **relative gravity**, covering the US and Territories at an estimated cost of ~$39 million
2. Low-resolution "movie" of gravity changes
   - primarily terrestrial, episodic observations of **absolute gravity** sites to monitor long-term change



GRAV-D Performance Metric

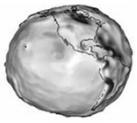


Year	Goal
FY10	7.5%
FY11	13%
FY12	20%
FY13	28%
FY14	36%
FY15	45%
FY16	53%
FY17	62%
FY18	70%
FY19	79%
FY20	87%
FY21	96%
FY22	100%

Building a Geopotential Field Model

GRACE/GOCE/Satellite Altimetry

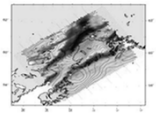
Long Wavelengths (> 250 km)



+

Airborne Observations

Intermediate Wavelengths (20km to 300 km)



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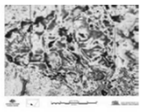
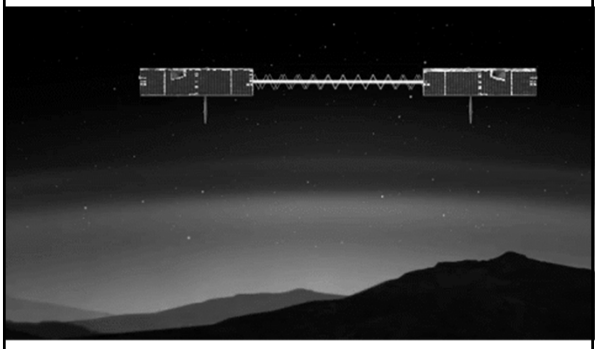
Short Wavelengths (< 100 km)



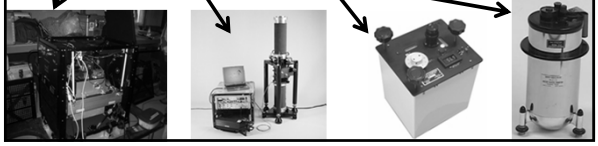
Terrestrial/Surface Observations and Predicted Gravity from Topography

GRACE – satellite observations



Gravity Survey Plan

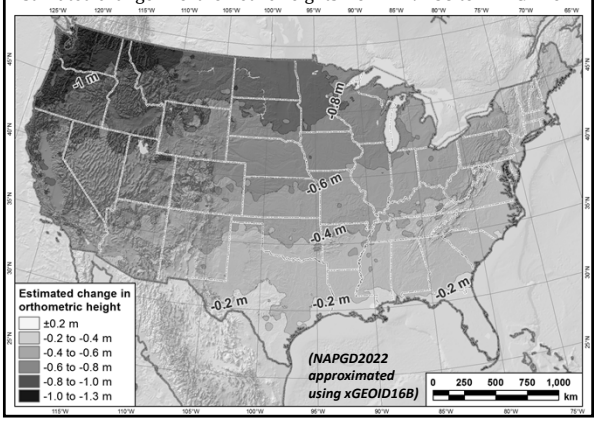
- National Scale Part 1
  - Predominantly through airborne gravity
  - With Absolute Gravity for ties and checks
  - Relative Gravity for expanding local regions where airborne shows significant mismatch with existing terrestrial



Individual Components of NAPGD2022

- global model of the geopotential field
  - **GM2022**
- geoid undulation models by region
  - **GEOID2022** aka "0 elevation"
- deflection of the vertical (DoV) models by region
  - **DEFLEC2022**
- surface gravity models by region
  - **GRAV2022**
    - static – SGRAV2022
    - dynamic – DGRAV2022

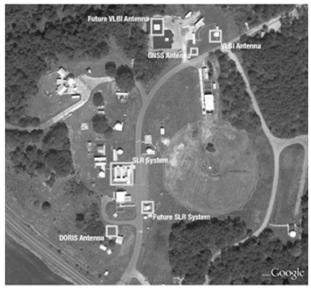
Estimated change in orthometric heights from NAVD88 to **NAPGD2022**



Science!

Co-location Site

NASA Goddard Space Flight Center, Greenbelt MD, USA



- GNSS, SLR, VLBI, DORIS

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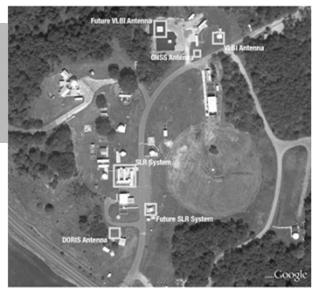

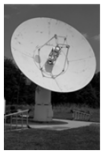

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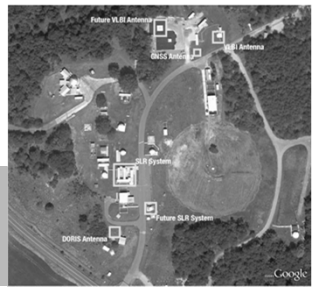
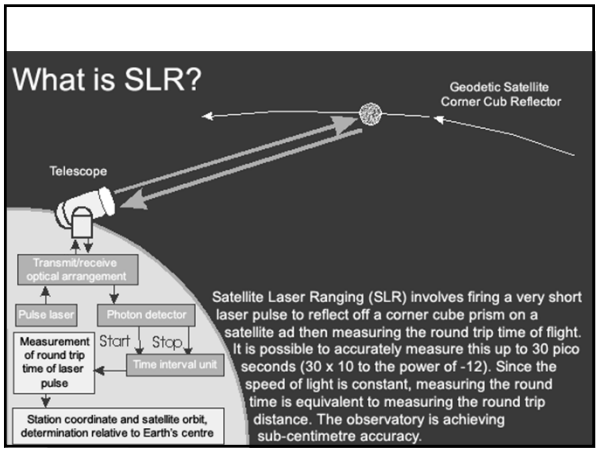


- GNSS, SLR, VLBI, DORIS

SLR

Satellite **L**aser **R**anging



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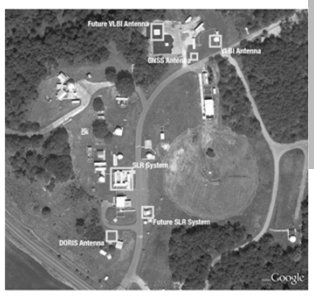
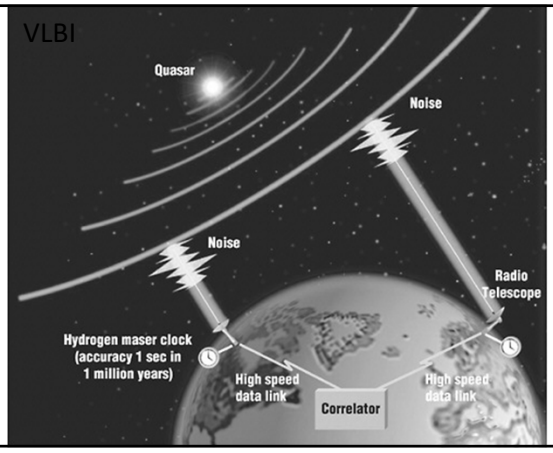


- GNSS, SLR, VLBI, DORIS

VLBI

Very **L**ong
Baseline
Interferometry

VLBI



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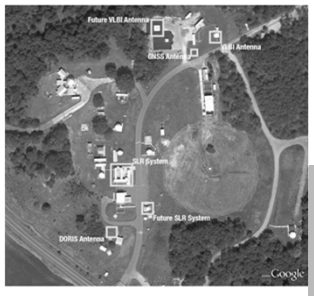
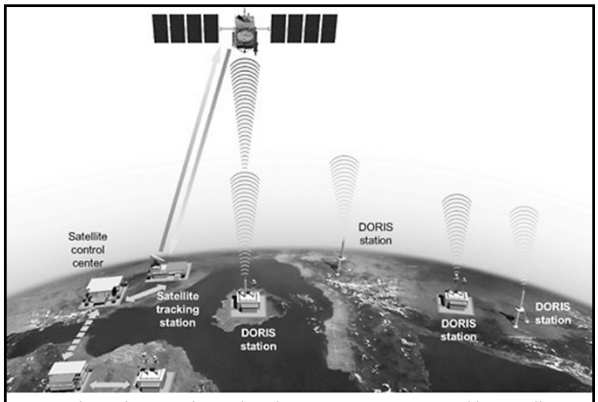


- GNSS, SLR, VLBI, DORIS

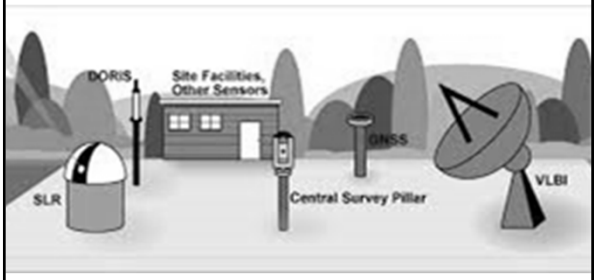
DORIS

Doppler **O**rbitography and **R**adiopositioning **I**ntegrated by **S**atellite

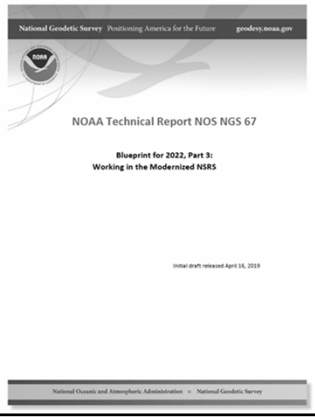


Doppler **O**rbitography and **R**adiopositioning **I**ntegrated by **S**atellite

Space Geodesy Co-location Diagram



Generic concept of "co-location survey", typically more complex.



Outline

- What is Blueprint for 2022, Part 3 (*BP3*)?
- Terminology
- New types of coordinates
- New way of operating the NOAA CORS Network (*NCN*)
- New way for *USERS* to process GNSS projects
- New way of processing leveling projects
- New way for *NGS* to process and store GNSS data
  - ***Final Discrete*** Coordinates (*FDCs*)
- New way for *NGS* to process and store GNSS data
  - ***Reference Epoch*** Coordinates (*RECs*)
- Miscellaneous / TBD

What is BP3?

- BP3 is a companion to BP1 (geometric) and BP2 (geopotential), both released in 2017
  - It is about "re-inventing bluebooking"
  - It's about how NGS will provide the frames/datum in the future
  - It's about how YOU will use the frames/datum in BP1 and BP2

Terminology

- The following terms (and more) are defined meticulously in BP3 in a coordinated effort within NGS and with the IERS:
  - Point, Mark, Station, Site, ARP, GRP, Site Marker, CORS, the NOAA CORS Network
    - GRP = Geometric Reference Point – the official point on a station to which all coordinates refer
- As a direct fallout: NGS will no longer provide CORS coordinates at an *ARP*, only to a *GRP*
  - An ***antenna*** has an ARP.
    - A CORS only ***sometimes*** has an antenna.
      - Therefore a CORS only ***sometimes*** has an ARP.
      - But it ***always*** has a GRP.
        - » The ARP and GRP are only ***sometimes*** coincident in space when the antenna is mounted at a CORS
  - The GRP gets a Permanent Identifier (PID)

Terminology

- "CORS" is an acronym
  - It is *singular* (S means "Station", not "Stations")
  - It will no longer be used to describe the *network* of all such stations
    - That will, for now, be called **the NOAA CORS Network, or NCN**
      - Which has a subset of stations called **the NOAA Foundation CORS Network, or NFCN**
  - Its plural form is **CORSs**
    - **No apostrophe, No "es" and no skipping the "s"**
    - GODE is a CORS
      - Not "a CORS site"
        - » And ***definitely*** NOT "a CORS Station"
          - That's like "an ATM machine"
    - GODE and 1LSU are CORSs
    - GODE and 1LSU belong to the NOAA CORS Network
    - TMG2 is a NOAA Foundation CORS
    - TMG2 and FLF1 are NOAA Foundation CORSs
    - TMG2 and FLF1 belong to the NOAA Foundation CORS Network

Terminology

- "OPUS"
  - Online Positioning User Service
  - Adopted as the general term for all of our online positioning software
    - Rather than "-Projects" , "-S" , etc
    - Basically "**do it with OPUS**" should be applicable to a wide variety of tasks
      - Recon, Mark Recovery, GPS, Leveling, Gravity, Classical

Terminology

- "GPS Month"
  - A span of four consecutive GPS weeks, where the first GPS week in the GPS month is an integer multiple of 4
  - GPS Month 0 = GPS weeks 0, 1, 2 and 3
  - GPS Month 1 = GPS weeks 4, 5, 6 and 7
  - Etc.

New Types of Coordinates

New Types of Coordinates

- **Reported**
  - *"These are from any source where the coordinate is directly reported to NGS without the data necessary for NGS to replicate the coordinate."*
    - Scaled
    - From NCAT or Vdatum
      - NGS Coordinate Conversion and Transformation Tool (NCAT)
    - Hand Held / Smartphone
    - Reported directly from an RTK rover without data files

Reported Coordinates

New Types of Coordinates

- **Preliminary**
  - *"These are coordinates at survey epoch that have been computed from OPUS, but not yet quality checked and loaded into the National Spatial Reference System Database (NSRS DB)."*
    - *User-computed* values, such as they might get today from either OPUS-S or OPUS-Projects
    - "Preliminary" coordinates are the ***only*** coordinates a user will get directly from OPUS

New Types of Coordinates

- **Reference Epoch**
  - *"These are coordinates which have been estimated by NGS, from time-dependent (final discrete and final running) coordinates, at an Official NSRS Reference Epoch (ONRE)"*
    - NAD 83(2011) epoch 2010.00 (sort of) would've fallen under this category
    - These will be computed by NGS every 5 years
      - On a schedule 2-3 years past ONRE
        - » 2020.00 coordinates will be computed in CY 2022
        - » 2025.00 coordinates will be computed in CY 2027

New Types of Coordinates

- **Final Discrete**
  - *"These are coordinates computed by NGS using submitted data and metadata, checked and adjusted and referenced to one survey epoch."*
    - These represent the best estimates NGS has of the time-dependent coordinates at any mark
    - Could be a:
      - Daily solution on one CORS
      - The single adjusted value coming from one or more occupations on a passive mark within **1 GPS Month***

*More on that in a moment…

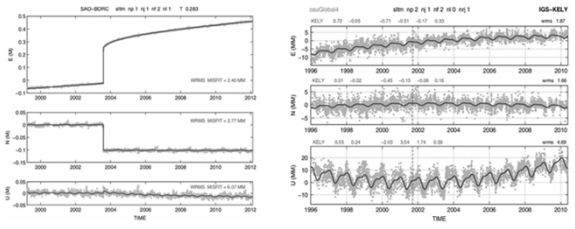
New Types of Coordinates

- **Final Running**
  - *"Of all types of coordinates on a mark, these are the only ones which will have a coordinate at any time."*
    - At a CORS GRP, they will be the coordinate function
      - Which will be generated by a "fit" to regularly computed Final Discrete Coordinates (FDCs) on a TBD basis, perhaps daily, perhaps weekly
    - On a passive mark, they will come from a mixture of Final Discrete Coordinates (FDCs) and the Intra-Frame Velocity Model (IFVM2022)
      - And possibly the time-dependent geoid, DGEOID2022

New Way of Operating the NOAA CORS Network (NCN)

- Each CORS will get a coordinate function
  - Actually three functions, X(t), Y(t), Z(t), in the ITRF2014 frame
  - In the strict mathematical definition of "function"
    - For any given "t", there is one and only one X , Y and Z
    - We actually do this today, just that the functions are piecewise linear
  - We are NOT limiting our "modernized NSRS" discussions of CORS coordinate functions to linear functions only!
    - But have made no further decisions yet

Examples of what non-linear CORS coordinate functions look like



New Way of Operating the NOAA CORS Network (NCN)

- Philosophy:
  - The NOAA CORS Network (NCN) will be self-consistent, meaning:
    - The impact of a user's CORS choices within their project will not exceed a small, statistically acceptable value:
      - Horizontal < 5 mm, Vertical < 10 mm
  - On a daily basis NGS must be able to detect, and react to, *persistent disagreement* between daily solutions and the current "coordinate function" assigned to any CORS in the NOAA CORS Network (NCN)

Persistent Disagreement

- The point:
  - It's not enough to say "each CORS is good to 1 cm in ellipsoid height".
    - That phrase is vague, lacking what it means to be "good to 1 cm".
  - NGS will define and publish "persistent disagreement"
    - Possible component: A persistent non-zero average disagreement
    - Possible component: A persistently deviating disagreement
  - And NGS will define what happens when a CORS exhibits "persistent disagreement"

New Way for *USERS* to Process GNSS Projects…

- GNSS projects have no time limit.
  - (Leveling does. More on that later)
  - But they will be processed by NGS in GPS Months*

GNSS: Processing *by users* in OPUS

- GNSS projects, processed by users using OPUS, must always be processed by GPS month as a first step
  - Multiple occupations on a point within a GPS month will be adjusted together
  - Coordinate functions from the IGS network or the NOAA CORS Network are the only allowable control
  - These are effectively the identical steps NGS will use in-house to compute Final Discrete Coordinates (FDCs) from your data
    - Except NGS will merge your data with all other data in the nation during each GPS month
  - This process will be built into OPUS as the default, making it easy for users to quickly perform the adjustment
  - Afterwards, users may move on to a second step…

GNSS: Processing by users in OPUS

- As a second step, a user may do many alternative things…
  - Adjust to some epoch that is convenient to them…
  - Hold any CORSs or passive control as constraints…
- This two-step approach is a form of sequential adjustments and allows a win-win:
  - NGS gets to see the user-computed time-dependent "preliminary" coordinates, which have been computed by GPS Month
    - Which will be checked against "final discrete" coordinates computed by NGS
  - The user gets whatever adjustment and/or coordinates fulfill their contractual needs
  - Redundancy checks can occur both *within* a GPS month (at step 1, if multiple occupations occur in 1 GPS month) and *across* GPS months (at step 2, if occupations occur in different GPS months)

New Way of Processing Leveling Projects

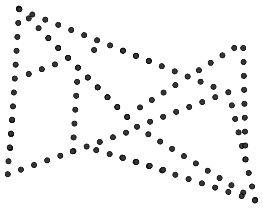
Leveling: Time Span…

- Leveling projects must not exceed 12 sequential months
  - Longer projects must be broken into sub-projects each spanning less than 12 sequential months
- A compromise between:
  - Treating "1 GPS Month" as "simultaneous" in the GNSS arena, and
  - Acknowledging that leveling surveys often take weeks to months to conduct
- Mixed with the reality that:
  - You can't solve for time-dependent orthometric heights in most leveling projects

Leveling: GNSS required

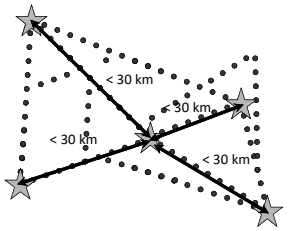
- For the immediate years following 2022, NGS will require that all leveling projects turned in have GNSS on primary control
  - Minimum of 3 points
  - Maximum spacing of 30 km
  - At least two occupations:
    - +/- 14 days of beginning of leveling
      - But also within the same GPS month
    - +/- 14 days of ending leveling
      - But also within the same GPS month
  - If leveling exceeds 6 months, must have a 3rd, middle occupation
- A GNSS "occupation" can mean "RTK/N"!

Leveling: Step 1
Identify project marks



Leveling: Step 2
Identify primary control marks (PCM)

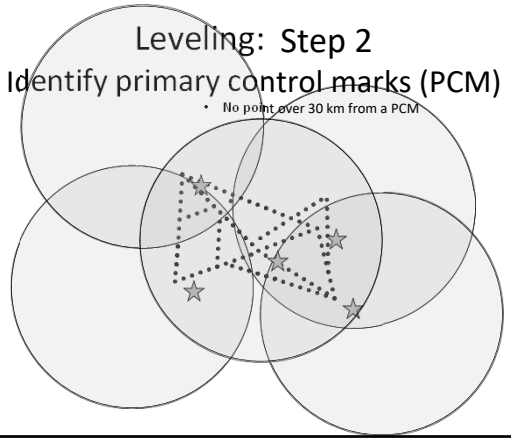
- Each PCM is within 30 km of at least one other PCM



Leveling: Step 2

Identify primary control marks (PCM)

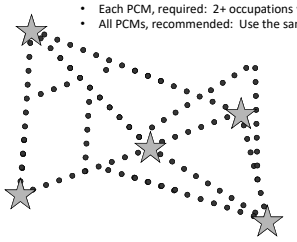
- No point over 30 km from a PCM



Leveling: Step 3

Initial GNSS on all PCMs

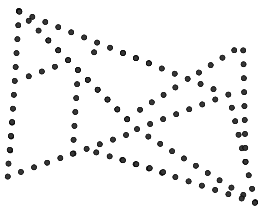
- All PCMs, required: within +/- 2 weeks of the start of leveling
- Each PCM, required: 2+ occupations within the same GPS month
- All PCMs, recommended: Use the same GPS month



Leveling: Step 4

Leveling

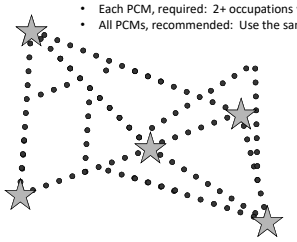
- Finished in under 12 months
- If greater than 6 months, need a mid-project GNSS set on PCMs



Leveling: Step 5 (if 6-12 months)

Mid-project GNSS on all PCMs

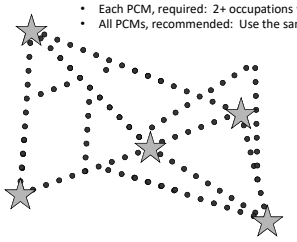
- All PCMs, recommended: Near midpoint of project
- Each PCM, required: 2+ occupations within the same GPS month
- All PCMs, recommended: Use the same GPS month



Leveling: Step 6

Final GNSS on all PCMs

- All PCMs, required: within +/- 2 weeks of the end of leveling
- Each PCM, required: 2+ occupations within the same GPS month
- All PCMs, recommended: Use the same GPS month



Leveling: Processing

- All GNSS data processed into GPS months, as per normal processing
- These are then adjusted to a mean epoch of the entire leveling survey to yield “representative” orthometric heights that serve as control over the entire leveling project
- Stochastic but no time dependency

Leveling: Processing

- The pre-computed GNSS-based orthometric heights are held as stochastic constraints in the adjustment of leveling data
- Use math model from NOAA TM NOS NGS 74
- Separates out errors in GNSS from Leveling:
  - *Absolute* heights will have standard deviations that are "at GNSS accuracy levels"
  - *Differential* heights will have standard deviations that are "at leveling accuracy levels"

Leveling: Absolute errors

- Consider this quote from a concerned user:
  - "In the old NSRS, I could pull the datasheet for a point in California and see that NGS trusted the NAVD 88 height to 1 millimeter. Now, you're telling me to use RTN to establish orthometric heights in the same area, and I'm getting heights with 4 cm standard deviations! Why are your heights less accurate today than in the past?"

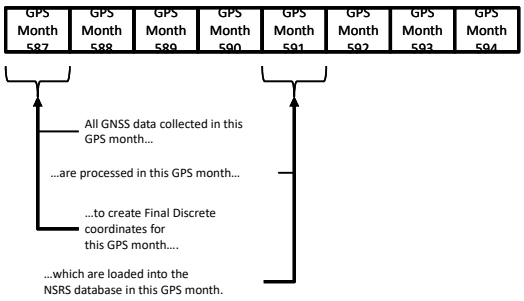
New Way for *NGS* to Process and store GNSS Data:

Final Discrete Coordinates (*FDCs*)

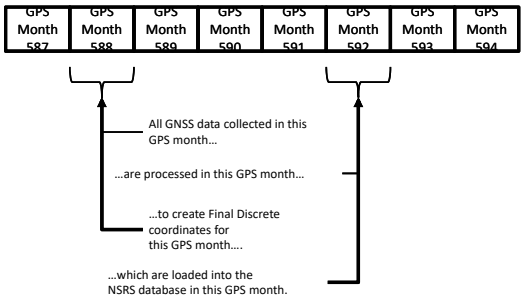
GNSS: Monthly workflow…

- Every **GPS month** (say the first Monday of that GPS month), NGS will "process the GPS month of 12-16 weeks ago" by doing the following:
  - Ensure that the "final" IGS orbits for the GPS month that spans 12-16 weeks prior are available
    - If not, hold off on this until they are
  - Create an in-house project named for that prior GPS month
  - Farm all data (collected during that GPS month) from all projects submitted to NGS, and put them all into the in-house project

Processing by GPS Month…



Processing by GPS Month…



GNSS: Monthly workflow…

- Adjust all that data together
- Take the results of this adjustment and load them into the NSRS database as “final discrete” coordinates

GNSS: Monthly workflow…

- Q: What about users’ projects that span more than 12-16 weeks?
- A: NGS will provide a way for a user to “allow NGS to farm my data as it is loaded to my ongoing project”
  - Thus NGS needn’t wait for them to finish their project and click “submit”.
  - Will require some sort of metadata validity statement from the user for each data file uploaded

GNSS: Monthly workflow…

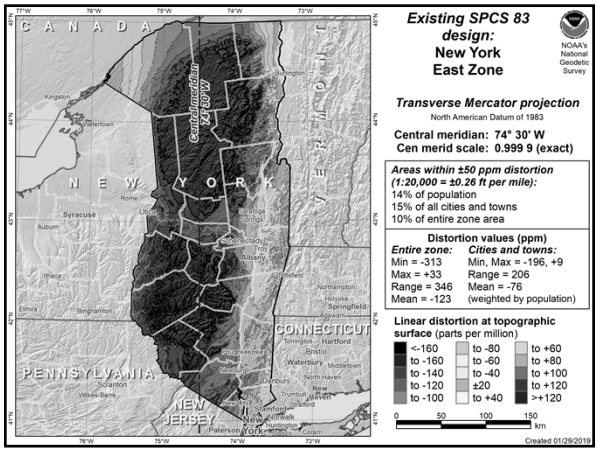
- Q: What if a user turns in data more than 12-16 weeks after it was collected?
- A: NGS will have a “holding bin” for such data. Occasionally, but not more than 1/year, NGS will sweep up all data in the holding bin, and put that data into the proper in-house GPS-month-based projects, depending on the GPS month of that data.
  - Since those in-house projects have already been adjusted once before using data that WAS submitted within the 12-16 week limit, and “final discrete” coordinates were computed on those early-submitted data, NGS will hold the “final discrete” coordinates on that early-submitted data as “fixed”, and adjust the later-submitted data only.

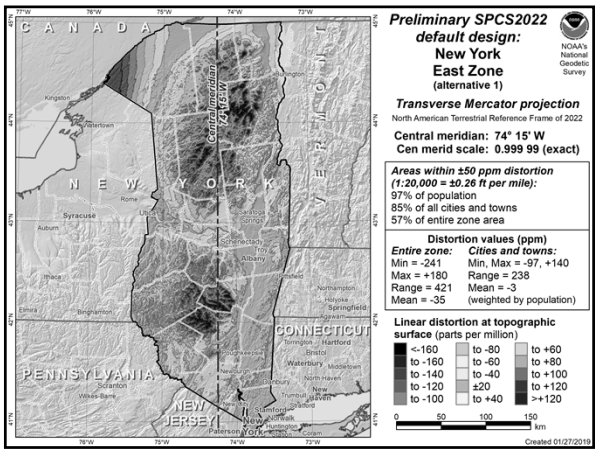
New Way for *NGS* to Process and store GNSS Data:

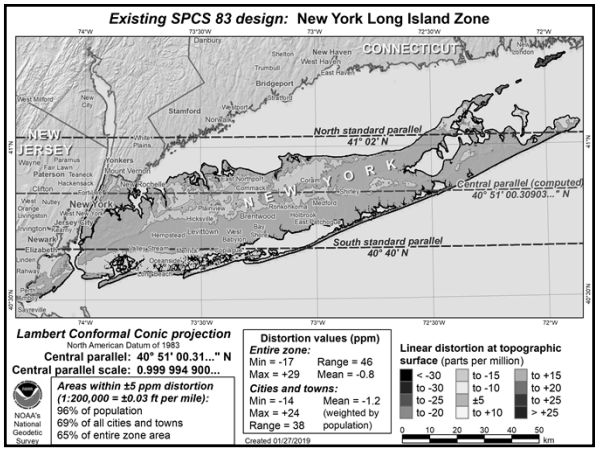
Reference Epoch Coordinates (*RECs*)

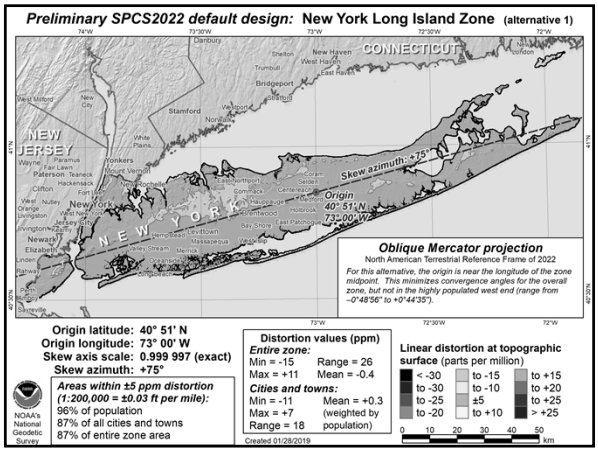
GNSS: Every five years…

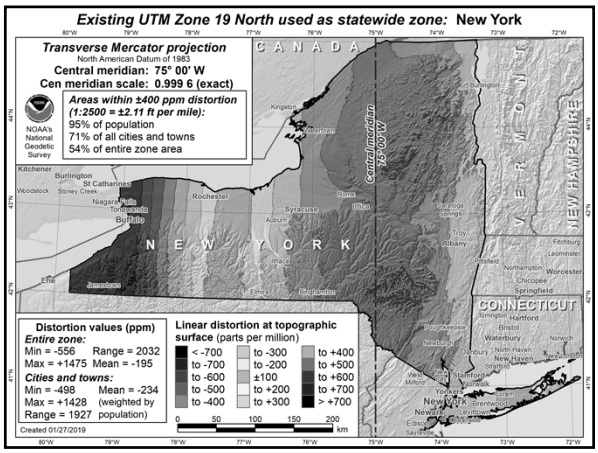
- Official NSRS Reference Epochs (*ONREs*) will happen every five years, beginning with 2020.00.
- Every ONRE will have a project associated with it
  - To estimate the Reference Epoch Coordinates (RECs) at each ONRE
  - That project will begin 2 years after the ONRE and will end 3 years after it
    - Thus the project to create 2020.00 RECs will run January 1-December 31, 2022
    - Using data collected through the end of 2021
- Error estimates in RECs will grow larger every five years for those points which are not regularly observed
- Once computed, the REC at an ONRE for a point will stand forever, unless corrected for a blunder

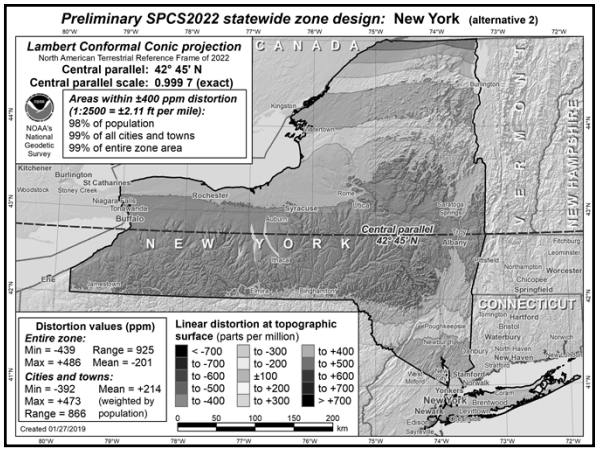



Preliminary SPCS2022 default design:
New York East Zone
(alternative 1)
NOAA's National Geodetic Survey
Transverse Mercator projection
North American Terrestrial Reference Frame of 2022
Central meridian: 74° 15' W
Cen merid scale: 0.999 99 (exact)
Areas within ±50 ppm distortion (1:20,000 = ±0.26 ft per mile):
97% of population
85% of all cities and towns
57% of entire zone area
Distortion values (ppm)
Entire zone:
Min = -241
Max = +180
Range = 421
Mean = -35
Cities and towns:
Min, Max = -97, +140
Range = 238
Mean = -3
(weighted by population)
Linear distortion at topographic surface (parts per million)
<-160
to -160
to -140
to -120
to -100
to -80
to -60
to -40
±20
to +40
to +60
to +80
to +100
to +120
>+120
0 50 100 150 km
Created 01/27/2019
CANADA
NEW YORK
CONNECTICUT
PENNSYLVANIA
NEW JERSEY
Central meridian 74°15' W


Existing SPCS 83 design: New York Long Island Zone
North standard parallel
41° 02' N
Central parallel (computed)
40° 51' 00.30903... " N
South standard parallel
40° 40' N
Lambert Conformal Conic projection
North American Datum of 1983
Central parallel: 40° 51' 00.31..." N
Central parallel scale: 0.999 994 900...
Areas within ±5 ppm distortion (1:200,000 = ±0.03 ft per mile):
96% of population
69% of all cities and towns
65% of entire zone area
Distortion values (ppm)
Entire zone:
Min = -17
Max = +29
Range = 46
Mean = -0.8
Cities and towns:
Min = -14
Max = +24
Range = 38
Mean = -1.2
(weighted by population)
Linear distortion at topographic surface (parts per million)
< -30
to -30
to -25
to -20
to -15
to -10
±5
to +10
to +15
to +20
to +25
> +25
0 10 20 30 40 50 km
Created 01/27/2019
CONNECTICUT
NEW JERSEY
NEW YORK


Preliminary SPCS2022 default design: New York Long Island Zone (alternative 1)
Skew azimuth: +75°
Origin
40° 51' N
73° 00' W
Oblique Mercator projection
North American Terrestrial Reference Frame of 2022
For this alternative, the origin is near the longitude of the zone midpoint. This minimizes convergence angles for the overall zone, but not in the highly populated west end (range from −0°48'56" to +0°44'35").
Origin latitude: 40° 51' N
Origin longitude: 73° 00' W
Skew axis scale: 0.999 997 (exact)
Skew azimuth: +75°
Areas within ±5 ppm distortion (1:200,000 = ±0.03 ft per mile):
96% of population
87% of all cities and towns
87% of entire zone area
Distortion values (ppm)
Entire zone:
Min = -15
Max = +11
Range = 26
Mean = -0.4
Cities and towns:
Min = -11
Max = +7
Range = 18
Mean = +0.3
(weighted by population)
Linear distortion at topographic surface (parts per million)
< -30
to -30
to -25
to -20
to -15
to -10
±5
to +10
to +15
to +20
to +25
> +25
0 10 20 30 40 50 km
Created 01/28/2019
CONNECTICUT
NEW JERSEY
NEW YORK


Existing UTM Zone 19 North used as statewide zone: New York
Transverse Mercator projection
North American Datum of 1983
Central meridian: 75° 00' W
Cen meridian scale: 0.999 6 (exact)
Areas within ±400 ppm distortion (1:2500 = ±2.11 ft per mile):
95% of population
71% of all cities and towns
54% of entire zone area
NOAA's National Geodetic Survey
Central meridian 75° 00' W
CANADA
NEW YORK
VERMONT
NEW HAMPSHIRE
CONNECTICUT
Distortion values (ppm)
Entire zone:
Min = -556 Range = 2032
Max = +1475 Mean = -195
Cities and towns:
Min = -498 Mean = -234
Max = +1428 (weighted by
Range = 1927 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 +700
> +700
0 50 100 150 200 km
Created 01/27/2019


Preliminary SPCS2022 statewide zone design: New York (alternative 2)
Lambert Conformal Conic projection
North American Terrestrial Reference Frame of 2022
Central parallel: 42° 45' N
Central parallel scale: 0.999 7 (exact)
Areas within ±400 ppm distortion (1:2500 = ±2.11 ft per mile):
98% of population
99% of all cities and towns
99% of entire zone area
NOAA's National Geodetic Survey
Central parallel 42° 45' N
CANADA
NEW YORK
VERMONT
NEW HAMPSHIRE
CONNECTICUT
Distortion values (ppm)
Entire zone:
Min = -439 Range = 925
Max = +486 Mean = -201
Cities and towns:
Min = -392 Mean = +214
Max = +473 (weighted by
Range = 866 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 +700
> +700
0 50 100 150 200 km
Created 01/27/2019