Counting Down to 2022

Vermont Society of Land Surveyors
April 12, 2019

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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
  - What Progress has been made?
  - What related projects are underway?
    - SPCS2022
    - New horizontal and vertical transformation tool

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

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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)

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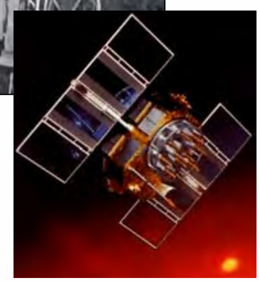
A (very) brief history of NAD 83

- 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***



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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

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

- NAD 27
- NAD 83 (Lat-Lon) SPC
  - Which one???
    - NAD 83 (1986)
    - NAD 83 (1992)
    - NAD 83 (1996)
    - NAD 83 CORS96(2002)
    - NAD 83 (NSRS2007)
    - NAD 83 (2011)
- 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)

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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

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

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ITRF2014, IGS14 AND NAD 83(2011)

ITRF2014

For the geodesy, geophysics and surveying communities, the best International Terrestrial Reference Frame is the "gold standard."

The global community recently adopted an updated expression for the reference frame, the ITRF2014.

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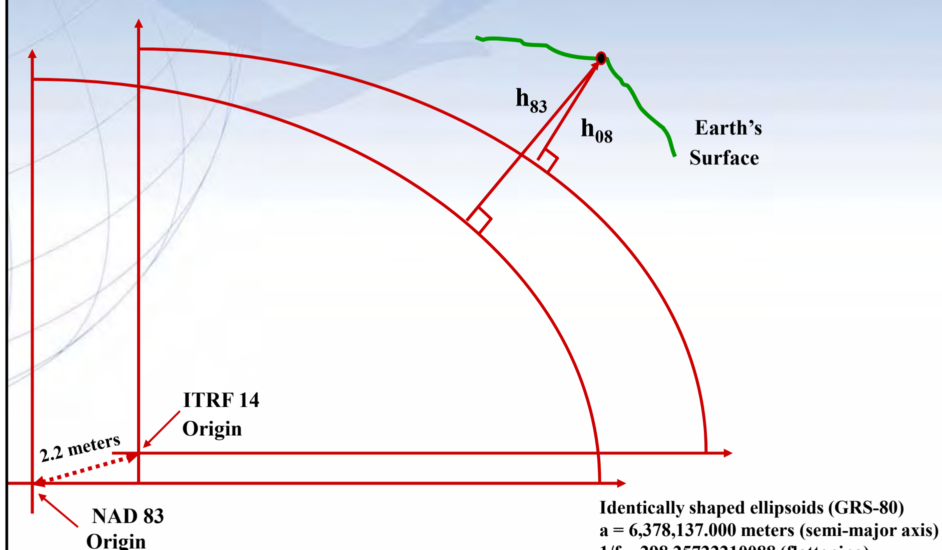
Simplified Concept of NAD 83 vs. ITRF14



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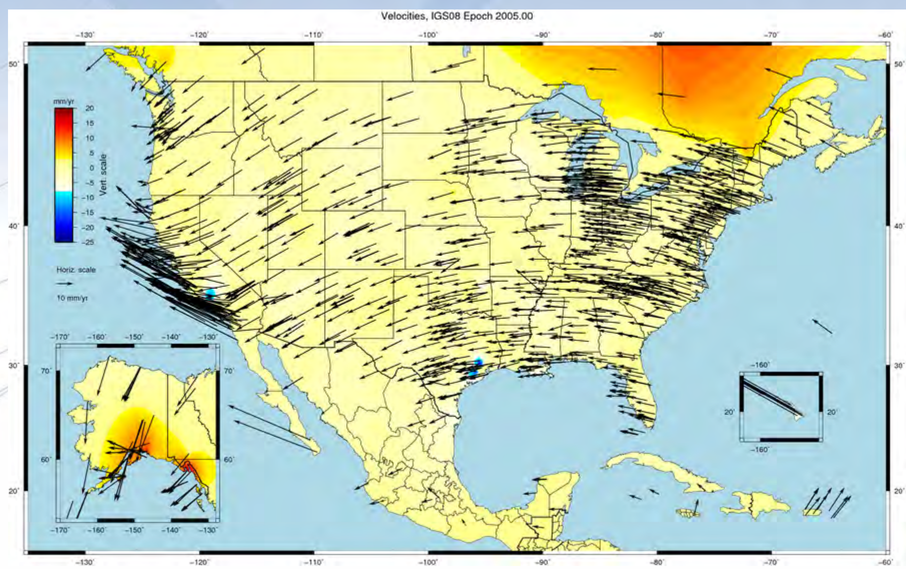

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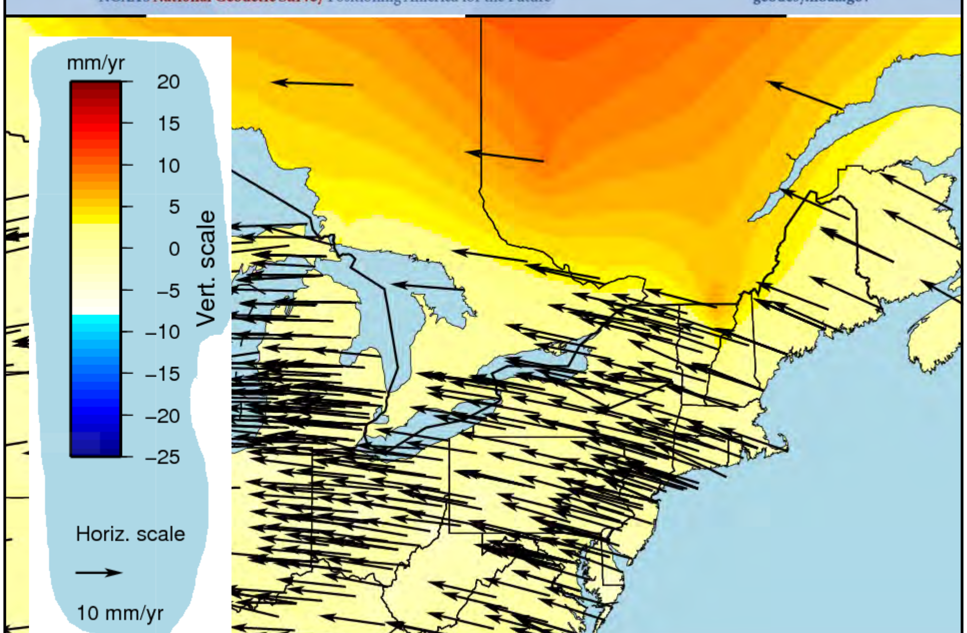

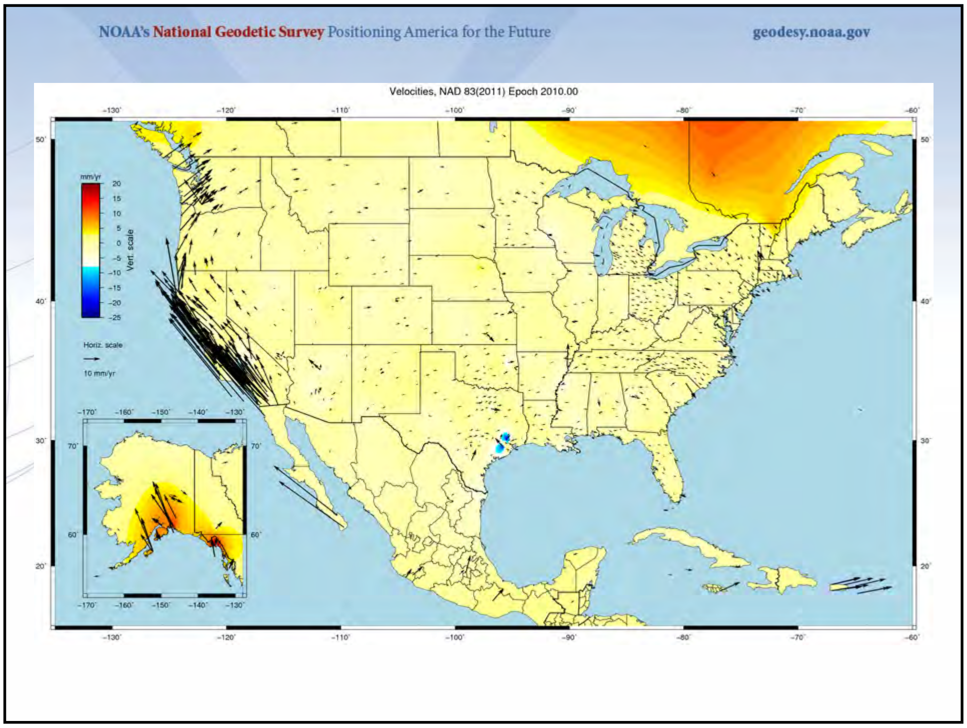
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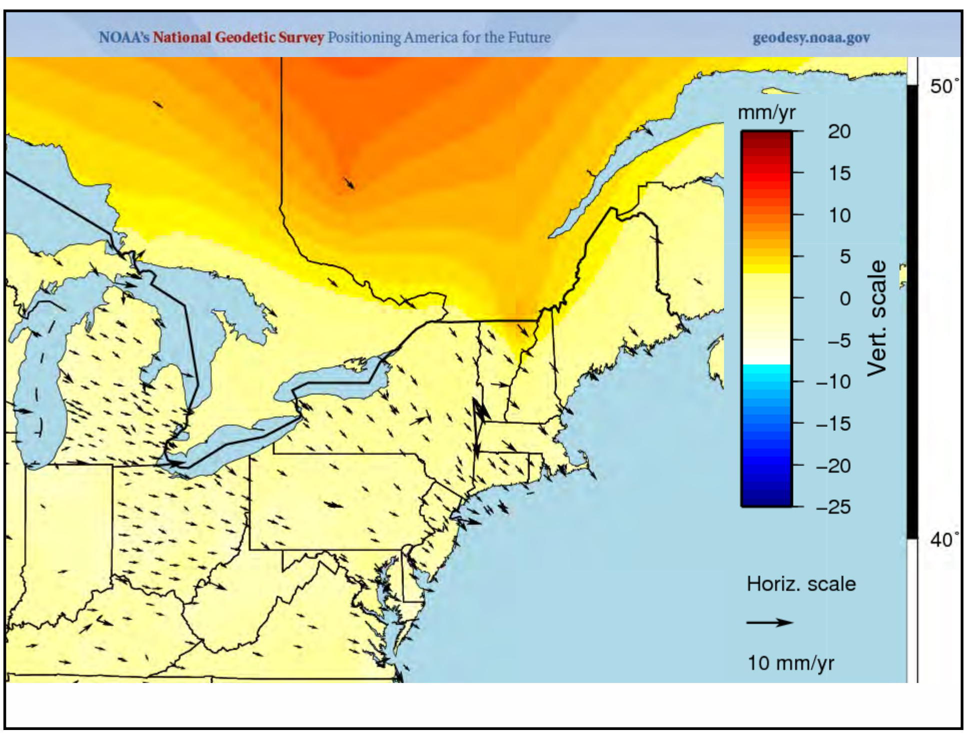
Velocities, NAD 83(2011) Epoch 2010.00
mm/yr
Vert. scale
Horiz. scale
10 mm/yr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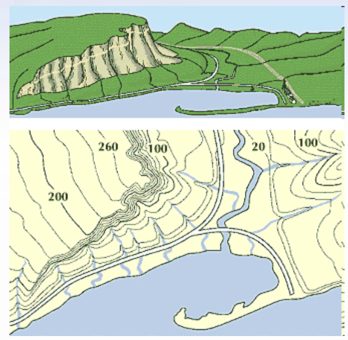
mm/yr
20
15
10
5
0
−5
−10
−15
−20
−25
Vert. scale
Horiz. scale
10 mm/yr
50˚
40˚

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!)

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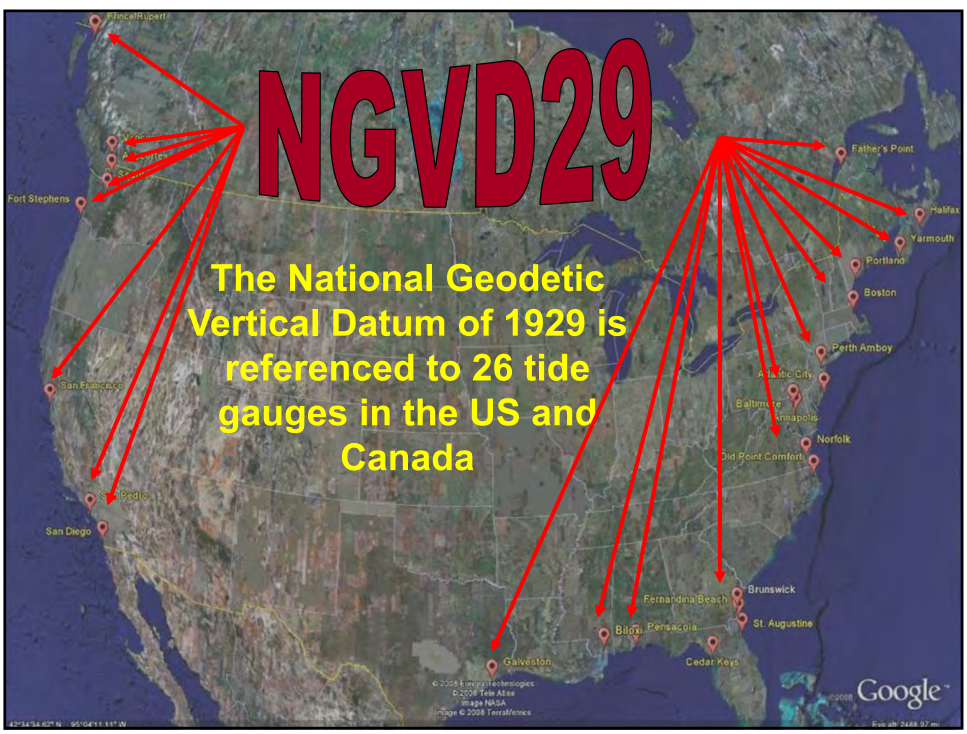
History of vertical datums in the USA

- **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



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.

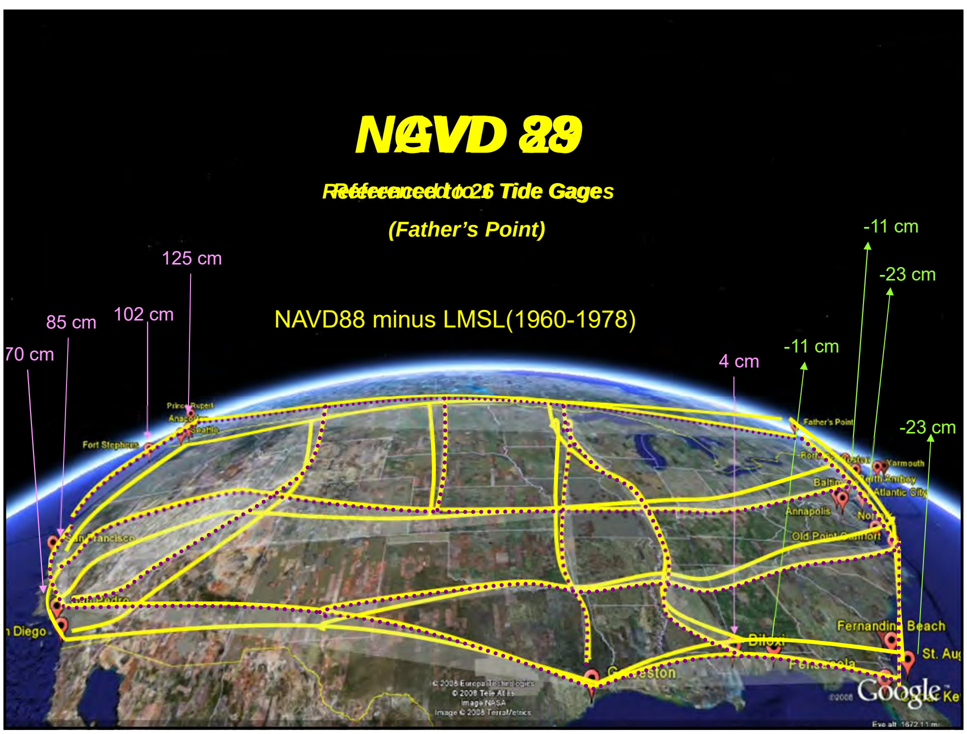
**Not adopted in Canada*

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)

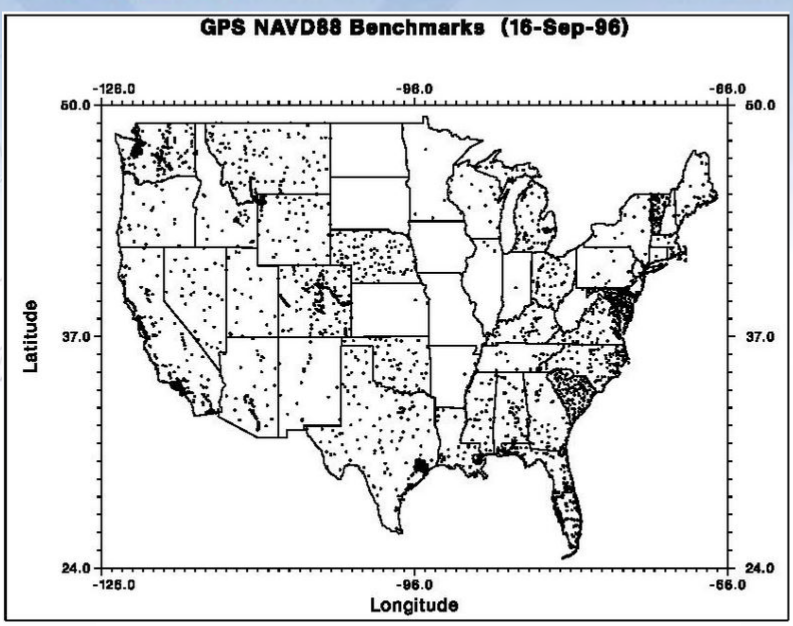
History of vertical datums in the USA

- **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)

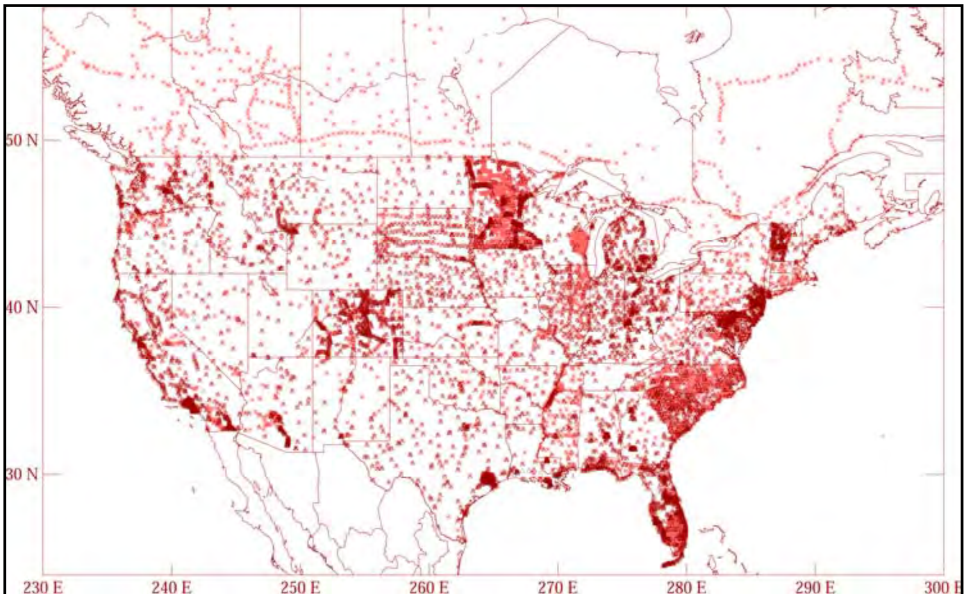


Types Uses and History of Geoid Height Models

- 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)

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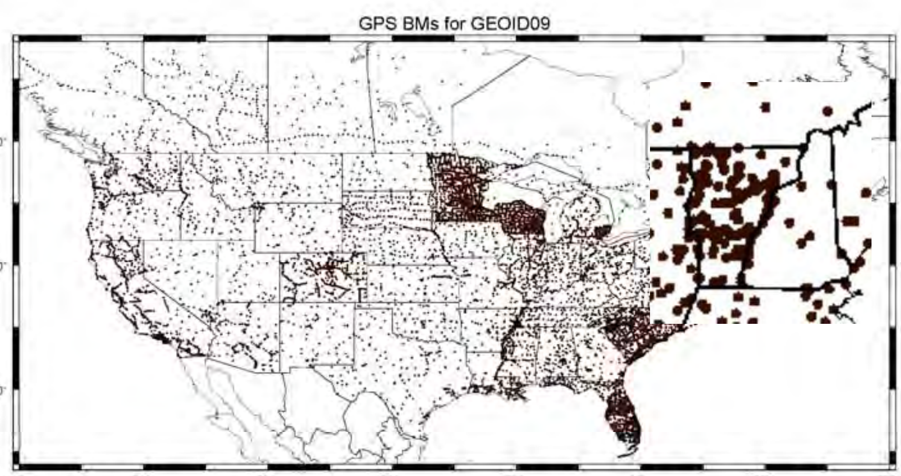
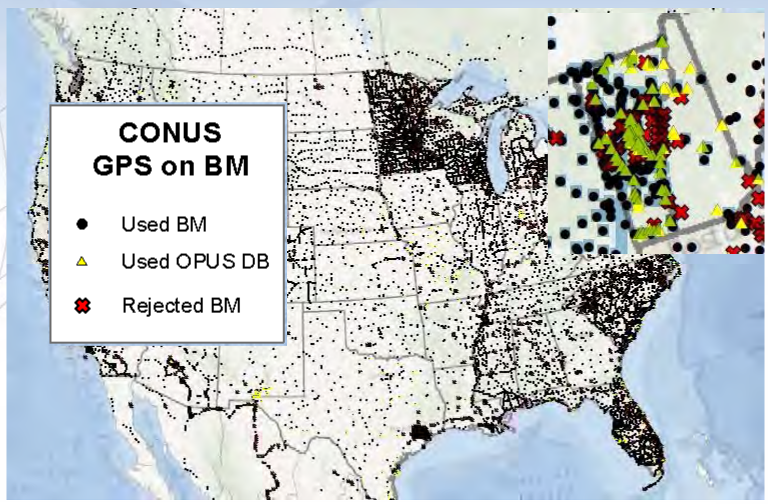
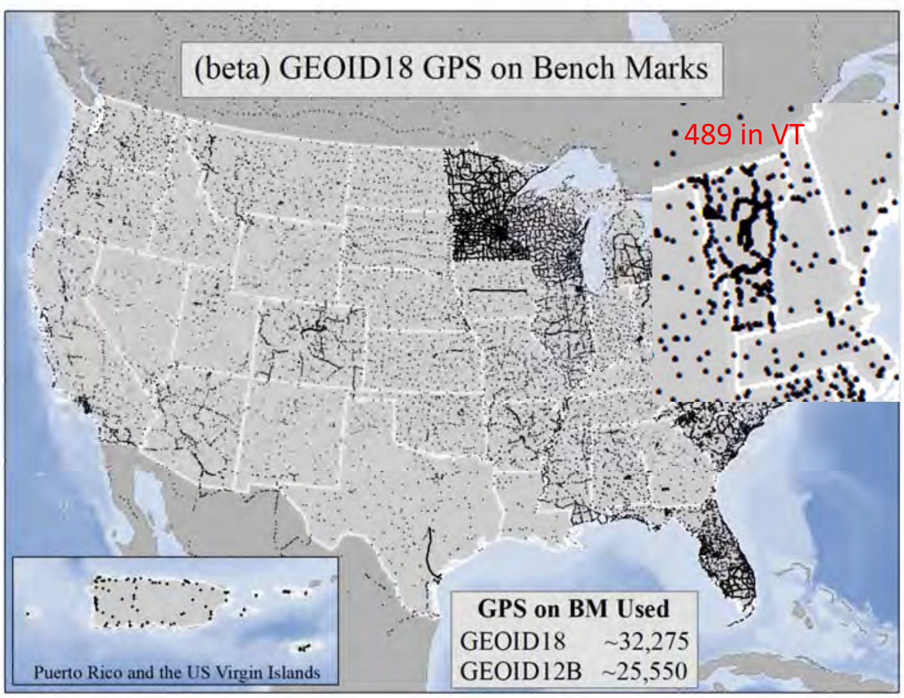
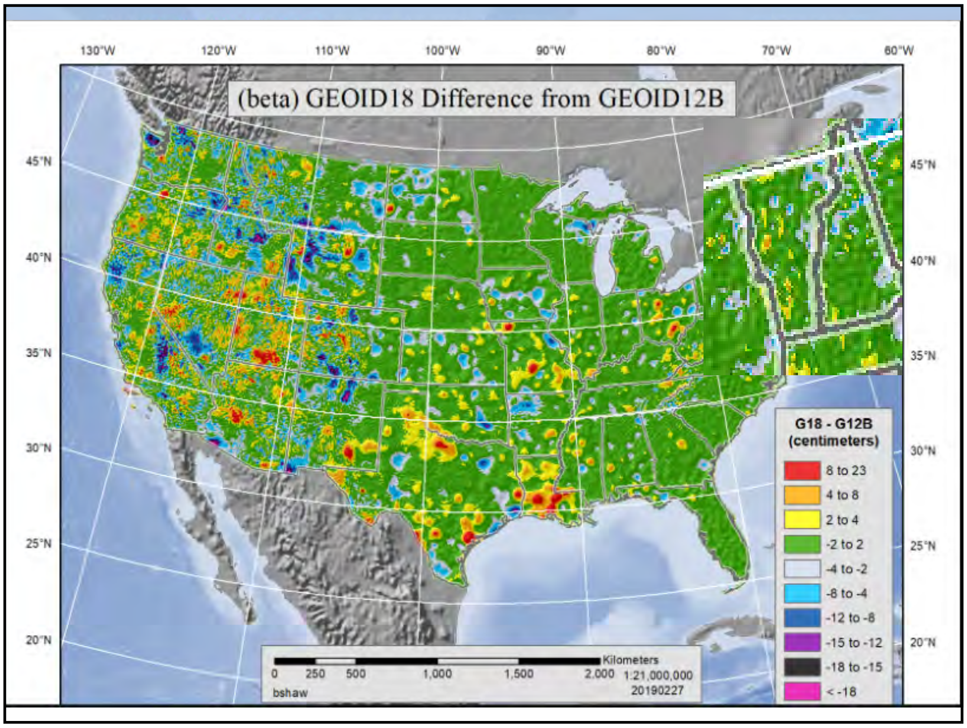


GPSBM2009: 18,398 STDEV 2.8 cm (2σ)



GGPSBM2012A: 23,961 (CONUS) STDEV 3.4 cm (2σ)
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

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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 in CT (0.84 ft – 0.92 ft per 100 years)
    - **Bridgeport, CT 2.88 mm/yr (0.009 ft/yr) 1964-2015**
    - **New London, CT 2.55 mm/yr (0.008 ft/yr) 1938-2015**

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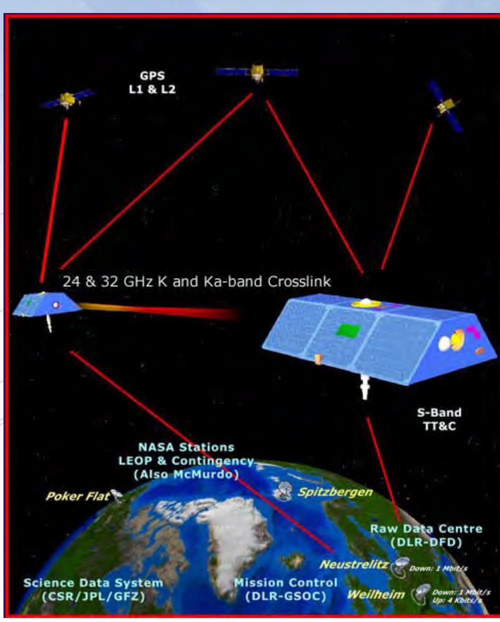
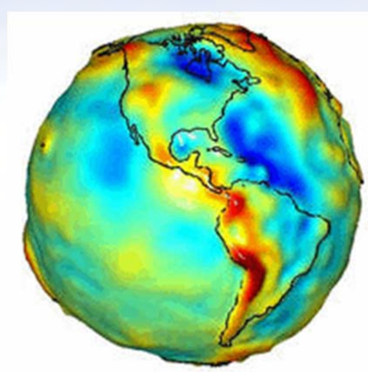
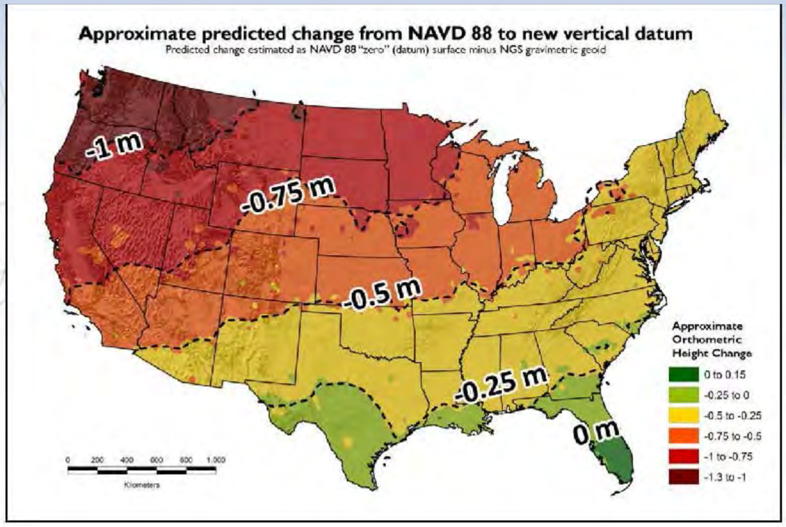


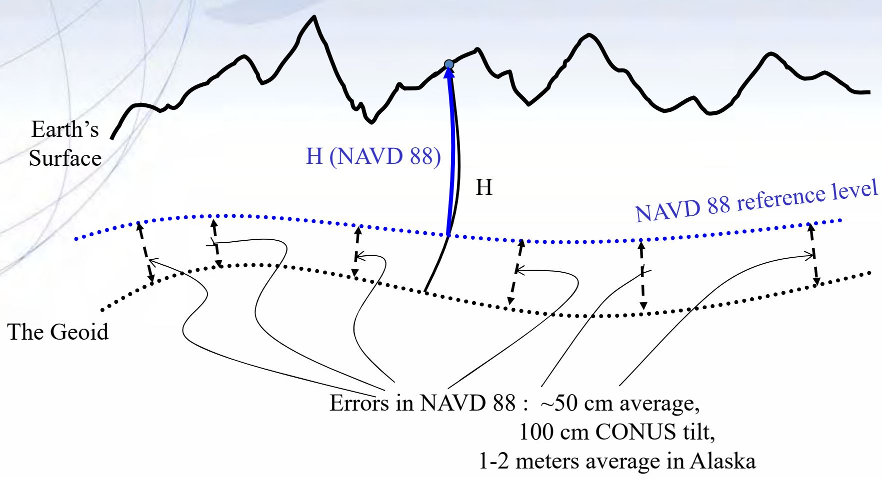
GRACE – Gravity Recovery and Climate Experiment



NAVD 88 is tilted and biased



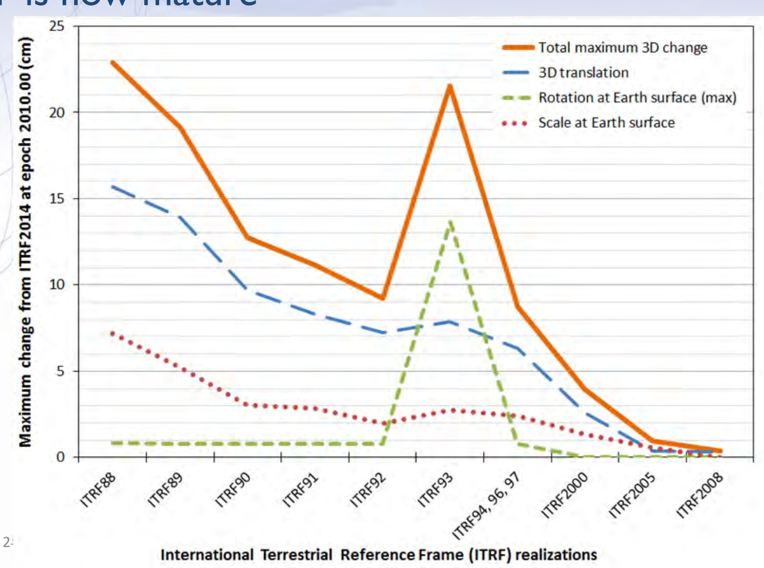
Why isn't NAVD 88 good enough anymore?



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

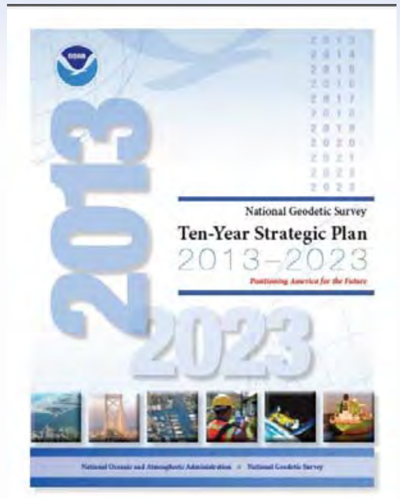
ITRF is now mature



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*



GEOMeet

Locating love for those who love location

Introducing Global Mapper GEOMeet:
The Dating Extension for Geographers

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

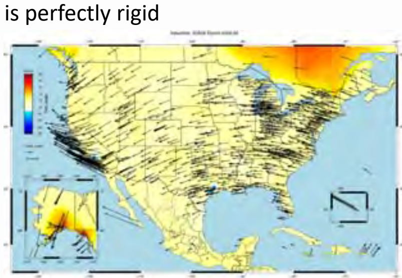
- Three plate-(*pseudo*)fixed frames will be replaced with four *plate-fixed* reference frames
  - N. Amer., Pacific, Mariana, Caribbean(new!)
- Remove long-standing non-geocentricity of NAD 83 frames
- All four : identical to IGSxx at a TBD epoch
  - 2020.00?
- All four : differ from IGSxx by plate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

NAD 83 is not ITRF

- GPS & WAAS navigation uses WGS84, aligned to ITRF
- satellite orbits and other geospatial datasets use global frames

- our TRFs will agree with ITRF (specifically, IGSyy) at the initial epoch
- our TRFs will diverge from ITRF by a few cm each year to stay "plate-fixed"
  – difference is a simple Euler plate rotation
  – many areas will diverge further, as no plate is perfectly rigid

- plate-fixed **or** ITRF-fixed; can't have both



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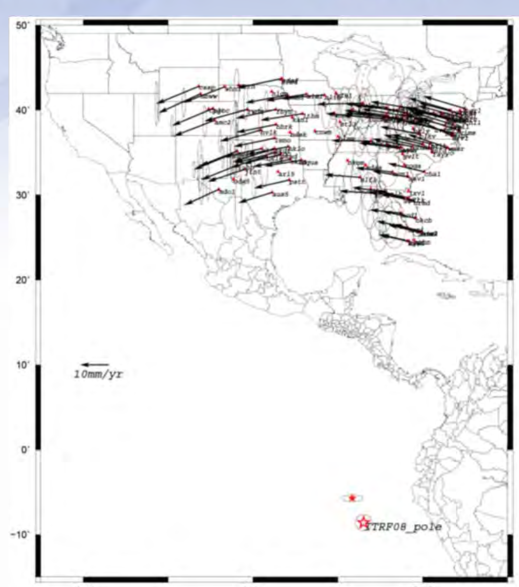
Each frame will get 3 parameters
- Euler Pole Latitude
- Euler Pole Longitude
- Rotation rate (radians / year)

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



Names

The Old:

NAD 83(2011)

NAD 83(PA11)

NAD 83(MA11)

The New:

The North American Terrestrial Reference Frame of 2022 (NATRF2022)

The Caribbean Terrestrial Reference Frame of 2022 (CTRF2022)

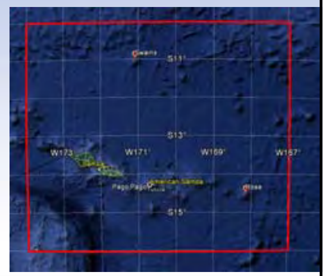
The Pacific Terrestrial Reference Frame of 2022 (PTRF2022)

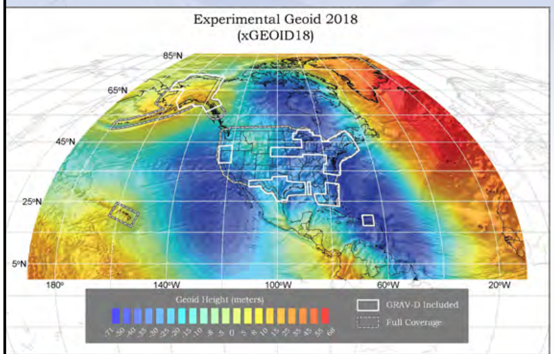
The Mariana Terrestrial Reference Frame of 2022 (MTRF2022)

Scientific Decisions!!

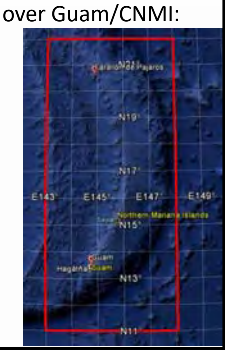
- Blueprint for 2022, Part 2: Geopotential
  - ✓Global 3-D Geopotential Model (GGM)
    - ✓Will contain all GRAV-D data
    - ✓Able to yield any physical value on/above surface
  - ✓Special high-resolution geoid, DoV and surface gravity products consistent with GGM
    - ✓Not global: NA/Pacific, American 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	IGLD 85
Gravity	IGSN71
Geoid Undulations	GEOID12B
Deflections of the Vertical	DEFLEC12B

The New:

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

- Will include GEOID2022

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NAVD 88 is not alone

- NAVD 88 North American Vertical Datum of 1988
- PRVD02 Puerto Rico Vertical Datum of 2002
- ASVD02 American Samoa Vertical Datum of 2002
- NMVD03 Northern Marianas Vertical Datum of 2003, [illegible] each
- GUVD04 Guam Vertical Datum of 2004
- VIVD09 Virgin Islands Vertical Datum of 2009, 3 each
- Hawaii … Hawaiian Islands Vertical Datum (coming soon)
- various local datums, as national datum is inaccessible
- IGLD 85 International Great Lakes Datum of 1985
- IGSN71 gravity dataset
- GEOID12B geoid undulations
- DEFLEC12B deflection of the vertical

one vertical datum
pole-to-equator

April 24, 2017 2017 Geospatial Summit 49

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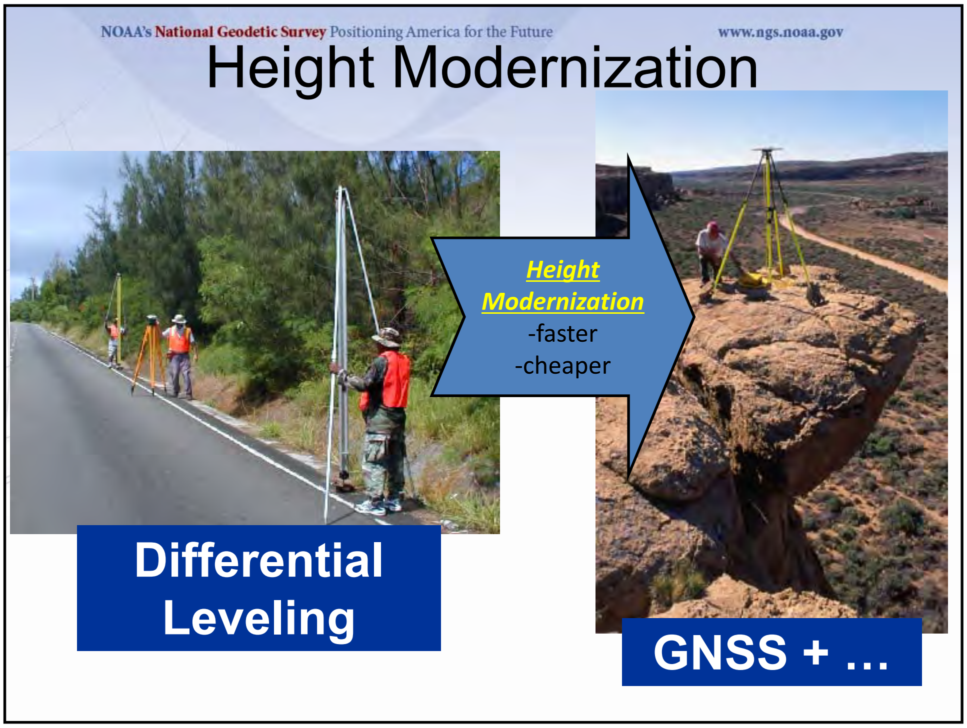
Height-Mod means More Marks?



How accurate is a GPS-derived Orthometric Height?

- 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
- Geoid12a can have an uncertainty in the 2-5 cm range.

National Geodetic Survey

How Good Can I Do With OPUS Static?

OPUS Static reliably addresses the more historically conventional requirements for GPS data processing. It typically yields accuracies of:

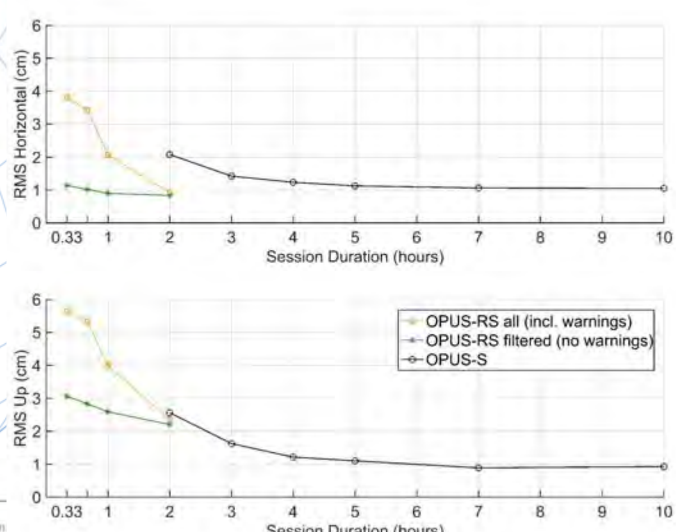
1 – 2 cm horizontally
2 – 4 cm vertically

- 4-7 mm differential ellipsoid height accuracy in GSVS11
- New ellipsoid height accuracy estimates will be included in a planned update to HTMOD guidelines for a number of GNSS techniques.

National Oceanic and Atmospheric Administration 53

National Geodetic Survey

RMSE of OPUS-S, OPUS-RS



Gillins (2019)

GNSS vs Leveling

- Using GNSS can be:
  - Faster
  - Cheaper
  - More accurate?
- To use GNSS, we need a good geoid model

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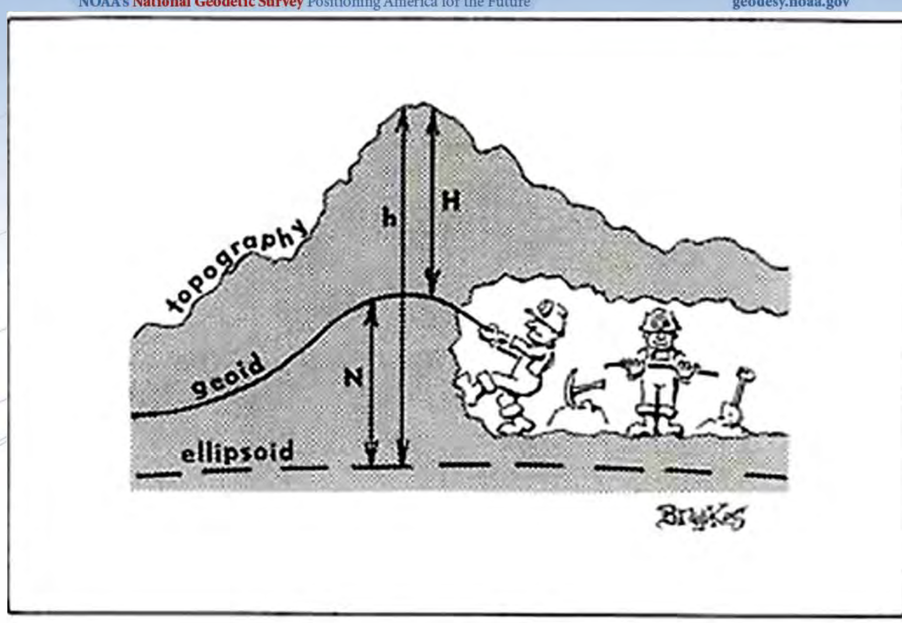
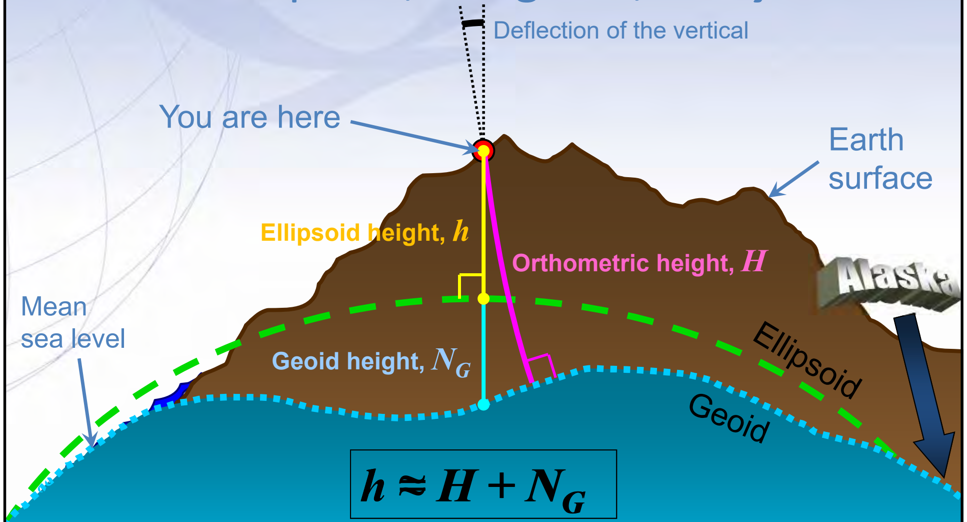


In Search of the Geoid

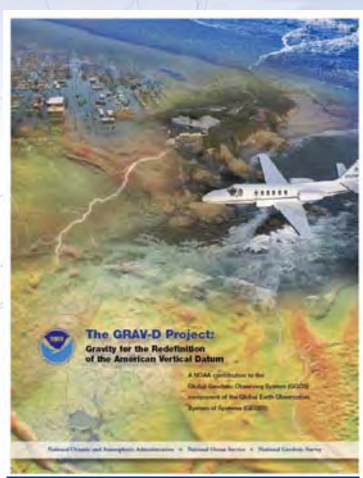
The ellipsoid, the geoid, and *you*



$$h \approx H + N_G$$

Note: Geoid height is **negative** everywhere in the coterminous US (but it is **positive** in most of Alaska)

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

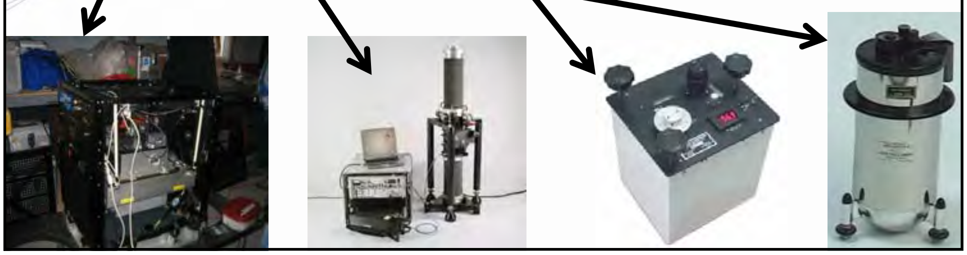


Gravity *and* ***Heights*** *are inseparably connected*

- Replace the Vertical Datum of the USA by 2022 (at today's funding) with a **gravimetric geoid accurate to 1 cm**
- Orthometric heights accessed via GNSS accurate to 2 cm
- Three thrusts of project:
  - Airborne gravity survey of entire country and its holdings
  - Long-term monitoring of geoid change
  - Partnership surveys
- Working to launch a collaborative effort with the USGS for simultaneous magnetic measurement

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



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Airborne Gravity Current Coverage

Data Block Status
- Complete
- Processing
- Collecting
- Planned

As of Oct 2018

http://www.ngs.noaa.gov/GRAV-D/data_products.shtml

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Performance Metric

For Airborne Surveys

FY09 Baseline	Targets vs Actual											
	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
6.14%	7.5%	12%	20%	28%	36%	45%	53%	62%	70%	79%	87%	96%	100% and Implement
6.14	8%	15%	24%	31%	38%	45%	55%	64%	72%				

- **Measure**: Percentage of the U.S. and its territories with GRAV-D data available to support a 1 cm geoid supporting 2 cm orthometric heights.

October 27, 2017

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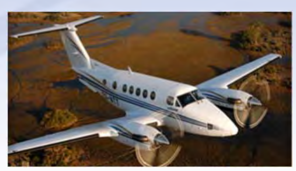
GRAV-D Aircraft

Bureau of Land Management
Pilatus PC-12



Dynamic Aviation King Air 200T

Fugro King Air E-90A

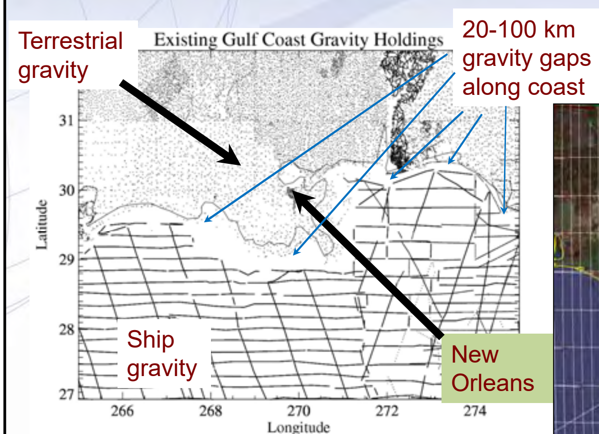
Naval Research Laboratory
King Air RC-12

Aurora Flight Sciences Centaur
Optionally Piloted Aircraft

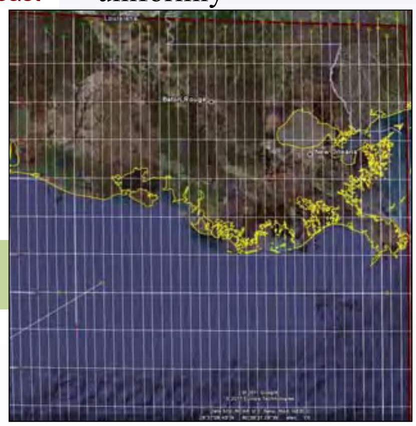
NOAA P-3 (background)
NOAA Turbo Commander (foreground)

Fugro Cessna Conquest

Problems with Gravity Holdings



- Field is not sampled uniformly



Validating Geoid Accuracy

- NGS planed 3 surveys to validate the accuracy of the gravimetric geoid model
  - GSVS11
    - 2011; Low/Flat/Simple: **Texas**; Done; Success!
  - GSVS14
    - 2014; High/Flat/Complicated: **Iowa**; Field work Complete
  - GSVS17
    - 2016 - 2017; High/Rugged/Complicated: **Colorado**

Objective of the GSVSs

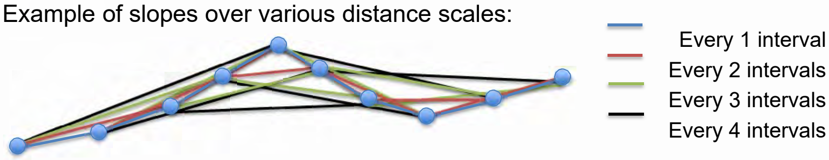
- How do we know that GRAV-D is working?
- The Geoid Slope Validation Surveys (GSVSs) use high precision, high resolution (~1.5km spacing), ground-based survey techniques to determine the **shape** of the geoid consistently along a large (~300km) distance.
- This allows for the direct comparison of the geoid shape predicted by various, gravity-based geoid models.
- This **also** allows for a quantification of the airborne gravity's contribution to the improvement of these models.

Objective of the GSVSs (cont.)

Why compare the **shape** of the models?

Rather than using "absolute" values of the geoid at specific locations to compare models, it is actually more useful to look at the changes in the shape of the geoid over various distance scales (i.e. looking at the **slope** between various pairs of survey points separated by 1, 2, 5, 10, 20, 50, 100, 200 km, etc.) . Hence the name…

Example of slopes over various distance scales:



Choosing the Place and Time for a New Survey

- Criteria:
  - Significantly exceed 100 km
  - Under existing GRAV-D data
  - Avoid trees and woods
  - Along major roads
  - Cloud-free nights
  - No major bridges along the route
  - Low elevations
  - Significant geoid slope
  - Inexpensive travel costs

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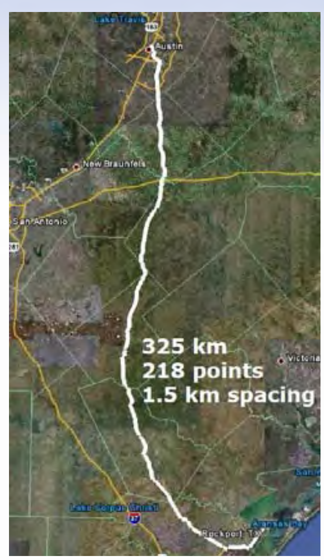
GSVS Survey Techniques

- Survey techniques employed:
  - Bechmarks installed ~1.5km
  - Leveling
  - Absolute/Relative Gravity
    - Vertical Gravity Gradient
  - Long-session GPS
  - Deflection of Vertical



Leveling and Gravity

- The entire line was leveled (double-run). Geodetic heights provided at each benchmark.
- Leveling and gravity are both needed for orthometric height determination. Usually gravity is modeled, but in this case was actually measured at every point.
  - Relative gravity and vertical gravity gradient at every benchmark
  - Absolute gravity (A10 and/or FG5) at ~every 10th benchmark

Long Period GPS

- Calibrated, fixed-height antennas, all identical models
- In Texas 2011:
  - 20 complete sets of equipment (2 parties, 10 sets each)
  - Each party observed 10 new stations each day
  - 20 hours of observation each day
  - Project processed with OPUS Projects

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Campaign GPS

- Full antenna recalibration check before survey
- Each fixed height tripod height measured before and after
- 20 complete sets of equipment - 2 parties (10 sets each)
- Each party observe 5 new and 5 repeat stations each day
- 30 observation days
- Project processed with OP

ID	before	after	a - b	avg.
A	2.0028	2.0029	0.0001	2.0029
B	2.0019	2.0018	-0.0001	2.0018
C	2.0005	2.0002	-0.0003	2.0004
D	2.0079	2.0079	0.0000	2.0079
E	2.0011	2.0010	-0.0001	2.0010
F	1.9999	1.9998	-0.0001	1.9998
G	2.0006	2.0009	0.0003	2.0008
H	2.0016	2.0017	0.0001	2.0017
I	2.0020	2.0020	0.0000	2.0020
J	2.0041	2.0041	0.0000	2.0041
K	2.0003	2.0004	0.0001	2.0003
L	2.0010	2.0007	-0.0003	2.0008
M	2.0000	2.0002	0.0002	2.0001
N	1.9964	1.9963	-0.0001	1.9963
O	2.0005	2.0005	0.0000	2.0005
P	2.0003	2.0002	-0.0001	2.0002
Q	2.0024	2.0029	0.0005	2.0027
R	1.9999	1.9999	0.0000	1.9999
S	2.0052	2.0052	0.0000	2.0052
T	2.0026	2.0023	-0.0003	2.0024
U	2.0031	2.0031	0.0000	2.0031
V	1.9995	1.9995	0.0000	1.9995
W	2.0002	2.0003	0.0001	2.0003
X	2.0020	2.0022	0.0002	2.0021
Y	2.0053	2.0053	0.0000	2.0053
Z	2.0016	2.0014	-0.0002	2.0015

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The "Dimple-ometer"

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Deflection of the Vertical (DoV)

- Measure the slope of the geoid directly!
- Precision tilt meters provide alignment "level" to the geoid.
- Celestial almanacs provide predicted alignment with star field (relative to ellipsoid).
- The difference between the two vectors (broken into orthogonal components) are the Deflections of the Vertical (or "slopes").
- In Iowa 2014:
  - 228 stations (204 official points, 11 redundant observations, 3 reobservations)
  - 31 nights
  - 7 stations/night
  - Observing with Swiss CODIAC (COmpact DIgital Astrometric Camera)

GSVS11, South Texas

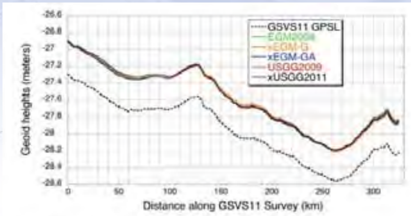


Fig. 11 Geoid profiles along the GSVS11 survey line

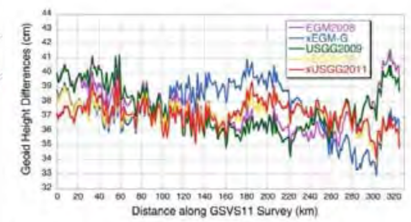


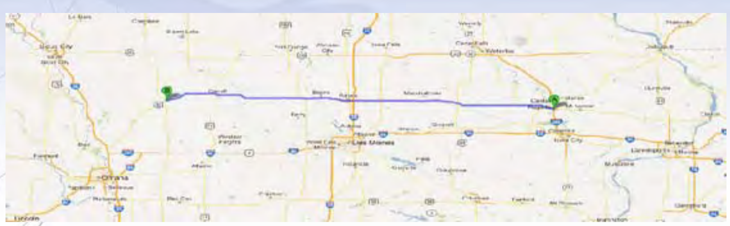
Fig. 12 Differences (cm) between Gravimetric Geoid Models and GPS/leveling along GSVS11

- The first survey was performed in south Texas in 2011
- Low (close to the geoid) and flat.

Results were excellent!

"Confirming regional 1 cm differential geoid accuracy from airborne gravimetry: the Geoid Slope Validation Survey of 2011", Smith *et al.*, Journal of Geodesy, 2013.

GSVS14 Line



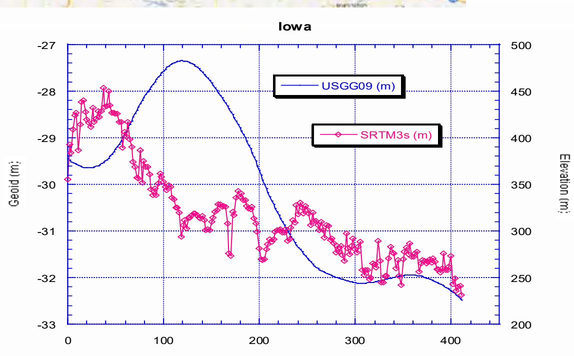
Goal: Same as GSVS11

Region: Moderate terrain
More complex gravity

Data: Same as GSVS11

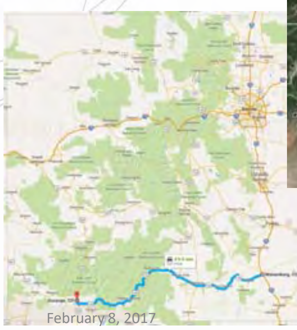
Timeline: Fiscal year 2014 field season

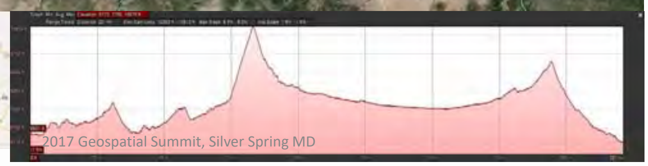
IA (Cedar Rapids to Denison)



GSVS17 Colorado

- The third (and likely final) GSVS will take place along US160, from Durango to Walsenburg, in southern Colorado.
- High elevation and rugged topography. "Worst case" for geoid modeling.
- Variation from 6,000' (MSL) to 11,000', over two passes.





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Differences with GSVS17

- Numerous "extra" bench marks had to be installed for leveling accuracy purposes (very steep terrain in some sections).
- Absolute gravity (A10) and quadratic (3 tier) gravity gradients will be measured at all benchmarks.
- Topographic corrections are being developed to aid in field DoV quality control as well as post-survey geoid modeling.

Accessing the New Vertical Datum

- **Primary access** (NGS mission)
  - Users with geodetic quality GNSS receivers will continue to use OPUS suite of tools
  - Ellipsoid heights computed, and then a gravimetric geoid removed to provide orthometric heights in the new datum
  - No passive marks needed
  - But, could be used to position a passive mark
- **Secondary access** (Use at own risk)
  - Passive marks that have been tied to the new vertical datum
  - NGS will provide a "data sharing" service for these points, but their accuracy (due to either the quality of the survey or the age of the data) will not be a responsibility of NGS

Continuously Operating Reference Station

Accessing the New Vertical Datum

- **NAVD 88 conversion to new datum**
  - A conversion will be provided between NAVD 88 and the new datum
    - Only where recent GNSS ellipsoid heights exist to provide modern heights in the new datum

Predicted Changes in 2022
Vicinity of Montpelier, VT

(Computed for station VCAP, pid AF9563)

```
Note: The GRS80 ellipsoid is used for both NAD83 and IGS08.

Your i
Latitu
44 15

Your R
Latitu
44 15 43.14337   72 34 56.57788    159.392

The geoid height of GEOID12B (with respect to NAD83):          -27.661 m
The orthometric height in NAVD88 (based on GEOID12B):          188.200 m

Estimated orthometric height in North American-Pacific Geopotential Datum of 2022 (NAPGD2022)
based on different geoid models (all heights in meters):

Geoid Model          Geoid Height          Ortho Height          Ortho(model)-NAVD88(GEOID12B)
USGG2012                 -28.435               187.827                    -0.372
xGEOID18A                -28.459               187.851                    -0.349
xGEOID18B                -28.440               187.832                    -0.368
---------------------------------------------------------------------------------------------
```

HORIZONTAL = 1.25 m (4.1 ft)
ELLIPSOID HEIGHT = - 1.15 m (- 3.8 ft)
Predicted with HTDP

-0.368m (-1.21ft)

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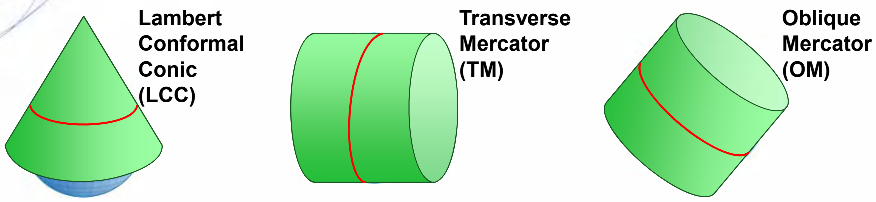
metadata to the rescue

- your positional metadata should include:
  - Datum, epoch, projection/zone, source, method, accuracy estimate, date of observation, geoid model, UNITS!!
- these will facilitate transforming from current to new datum
- maintaining your original survey data will provide more accurate results

A New State Plane Coordinate System

- **State Plane Coordinate System of 2022 (SPCS2022)**
  - Referenced to 2022 Terrestrial Reference Frames (TRFs)
  - Based on same reference ellipsoid as SPCS 83 (GRS 80)
  - Same 3 ***conformal*** projection types as SPCS 83 and 27:



83

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Deadlines for SPCS2022 input

NGS.Feedback@noaa.gov
by **August 31, 2018**

Anyone can comment!

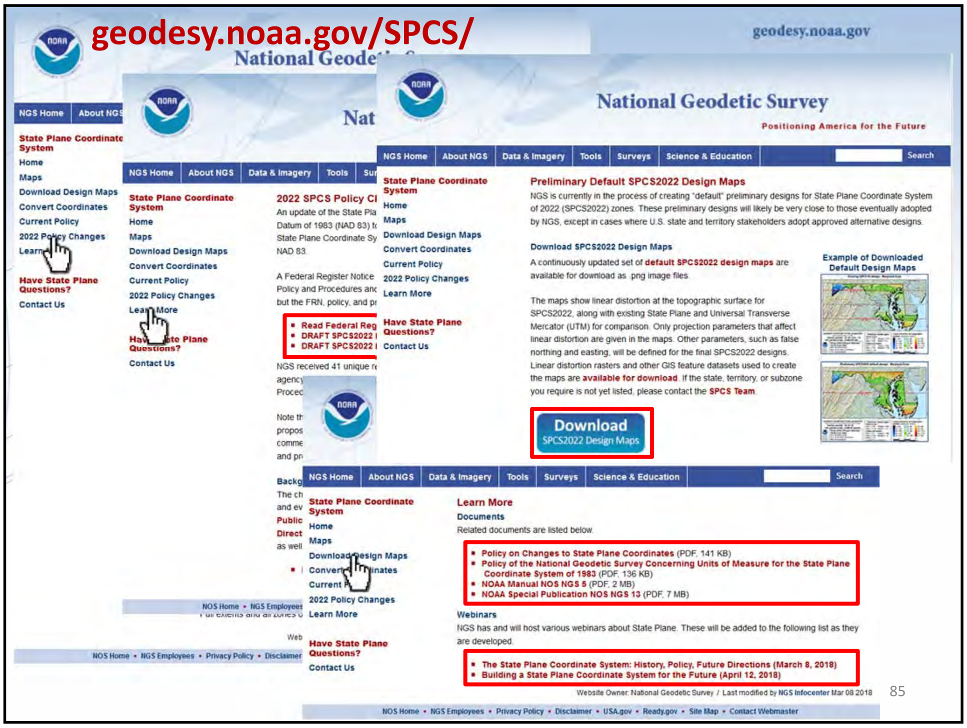
Federal Register Notice (FRN)
- Announcement and public comments
  - On draft **SPCS2022 policy & procedures**
  - On **"special purpose"** zones

NGS.SPCS@noaa.gov
by **March 31, 2020** for ***requests*** and ***proposals***

by **March 31, 2021** for ***submittal*** of ***approved*** designs

State stakeholders only!

SPCS2022 Procedures (draft)
- **Consensus** input per SPCS2022 procedures
  - ***Requests*** for designs done by NGS
  - ***Proposals*** for designs by contributing partners
- Submittal of **approved** designs
  - Proposal must first be approved by NGS
  - Designs must be complete for NGS to review
- Later requests will be for ***changes*** *to* SPCS2022



SPCS2022 Policy & Procedures

Summary of main things that did* NOT *change

- **Policy**
  - Limited to LCC, TM, and OM projections
  - Zones designed to reduce distortion at ground
  - Default zones designed by NGS if no consensus input
  - Parameters in meters, but feet allowed for output
- **Procedures**
  - Stakeholders must submit requests/proposals
  - 1-parallel LCC and local OM projection definitions
  - Specified a linear distortion design criterion
  - Limit NGS designs to minimum of ±50 ppm
  - 50 km min zone size for height range of 250 m or less

86

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Changes to SPCS2022 Policies

Summary of main changes

- Allow "special use" zones
  - But only for zone areas in more than 1 state
- NGS will design statewide zone for every state
  - Also will design default zones if no consensus request for something different from state stakeholders
- Allow max of 3 layers (1 statewide + 2 multi-zone)
  - But most states will have 1 or 2 layers
- Added requirement that all zones be unique
- Require positive east longitudes

87

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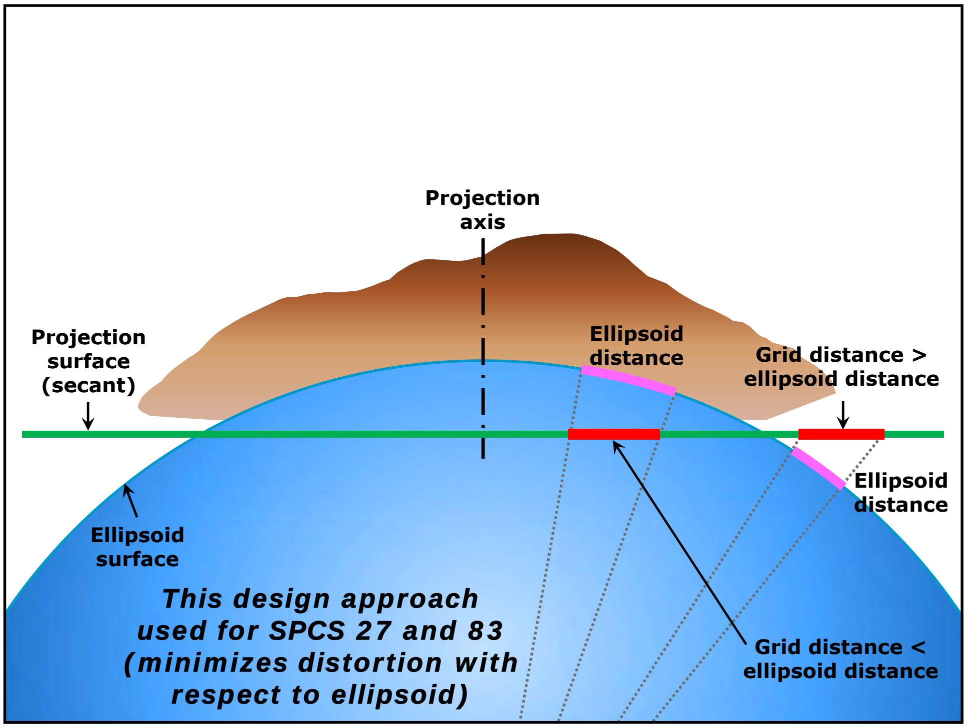
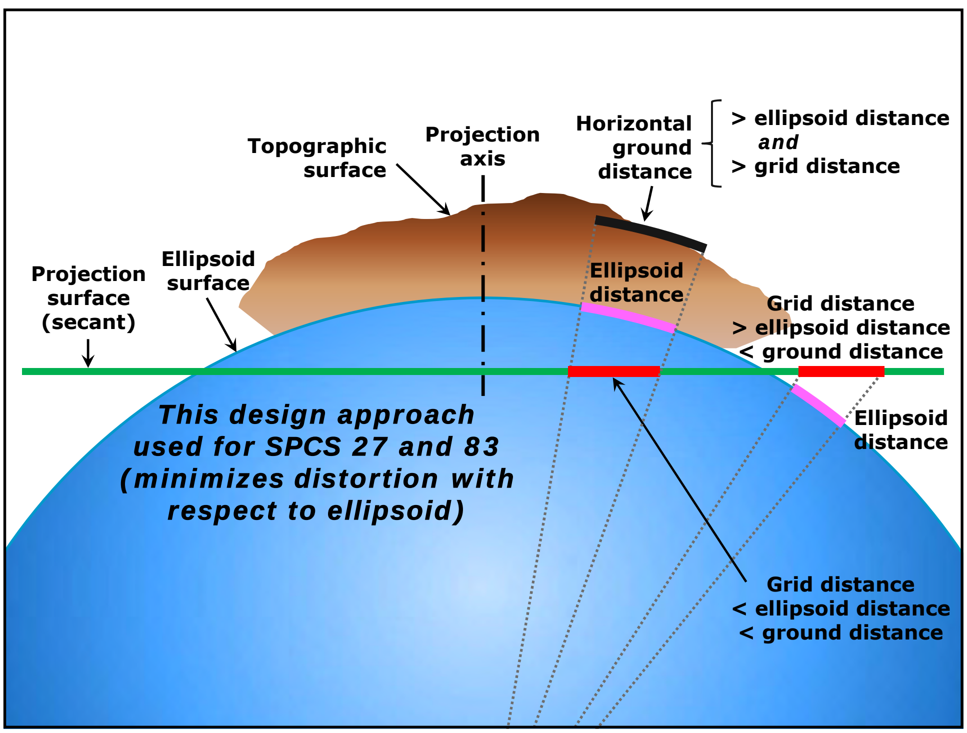
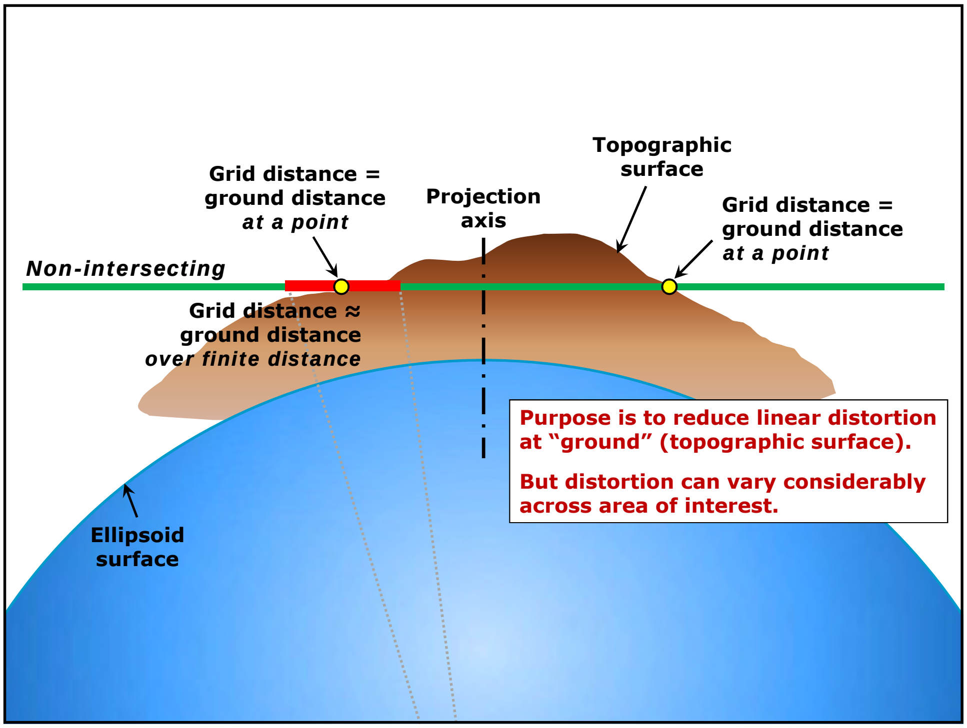
SPCS2022 stakeholders

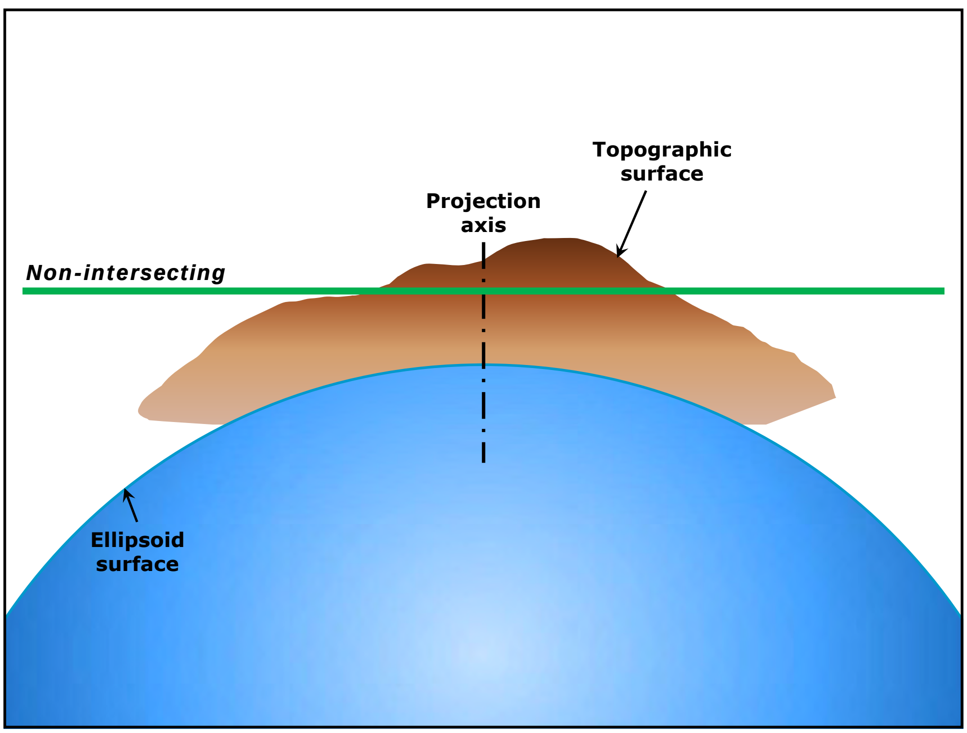
- **State *groups*** that formally interface with NGS
  - Departments of transportation
  - Cartographer/GIS office
  - Professional surveying, engineering, GIS societies
  - Colleges/universities with geospatial curriculum
- Can submit ***requests*** and ***proposals*** for designs
  - ***Requests*** are for designs by NGS
  - ***Proposals*** are designs by stakeholders
- Stakeholder input must be ***unanimous***

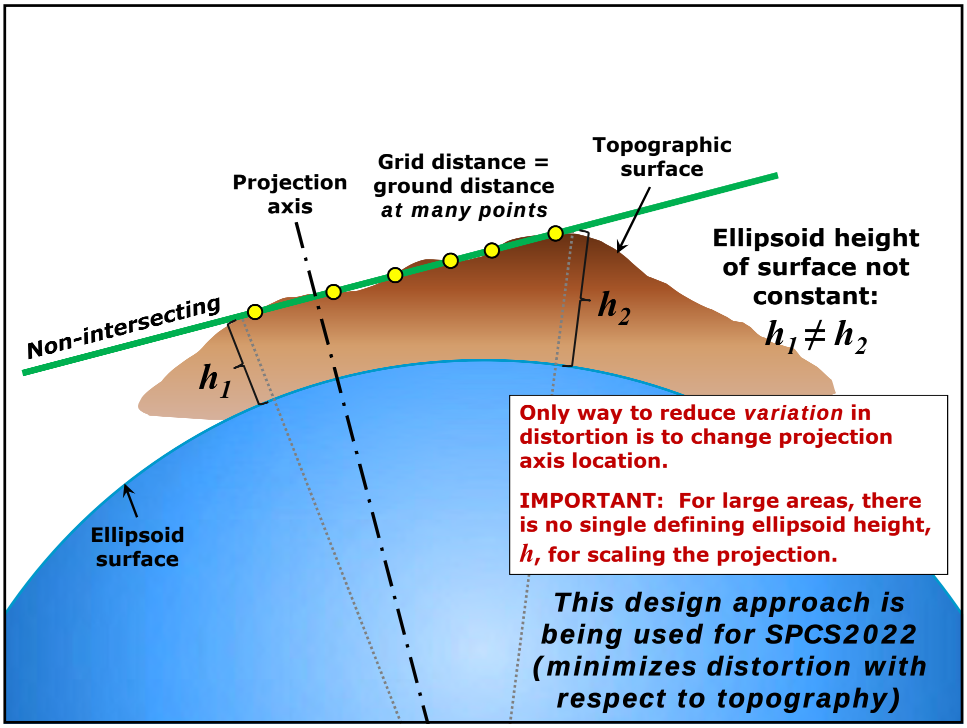
88

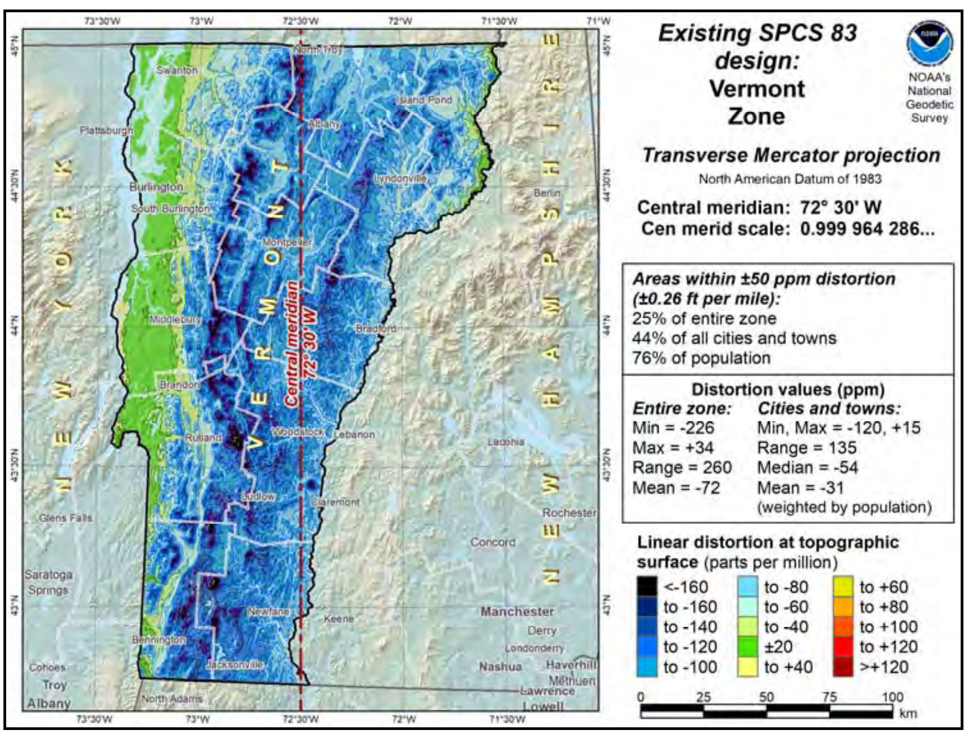

Projection axis
Projection surface (secant)
Ellipsoid distance
Grid distance > ellipsoid distance
Ellipsoid distance
Ellipsoid surface
This design approach used for SPCS 27 and 83 (minimizes distortion with respect to ellipsoid)
Grid distance < ellipsoid distance

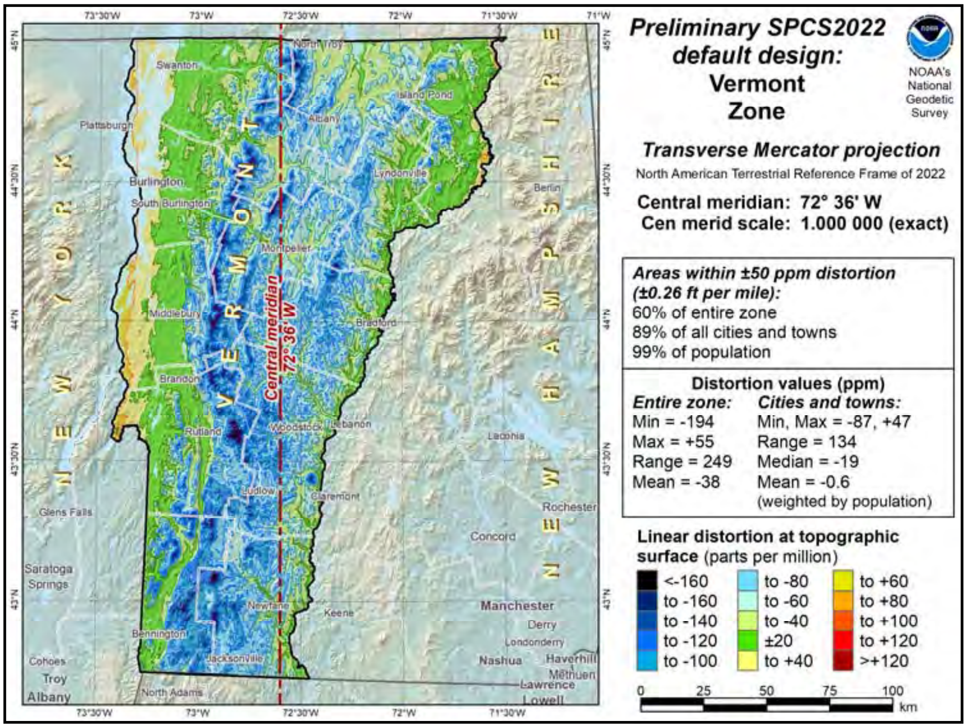

Topographic surface
Projection axis
Horizontal ground distance
> ellipsoid distance
and
> grid distance
Projection surface (secant)
Ellipsoid surface
Ellipsoid distance
Grid distance
> ellipsoid distance
< ground distance
Ellipsoid distance
This design approach used for SPCS 27 and 83 (minimizes distortion with respect to ellipsoid)
Grid distance
< ellipsoid distance
< ground distance


Topographic surface
Grid distance = ground distance at a point
Projection axis
Grid distance = ground distance at a point
Non-intersecting
Grid distance ≈ ground distance over finite distance
Purpose is to reduce linear distortion at "ground" (topographic surface).
But distortion can vary considerably across area of interest.
Ellipsoid surface


Topographic surface
Projection axis
Non-intersecting
Ellipsoid surface


Topographic surface
Grid distance = ground distance at many points
Projection axis
Non-intersecting
Ellipsoid height of surface not constant:
$h_1 \neq h_2$
h_1
h_2
Ellipsoid surface
Only way to reduce variation in distortion is to change projection axis location.
IMPORTANT: For large areas, there is no single defining ellipsoid height, h, for scaling the projection.
This design approach is being used for SPCS2022 (minimizes distortion with respect to topography)


Existing SPCS 83 design: Vermont Zone
NOAA's National Geodetic Survey
Transverse Mercator projection
North American Datum of 1983
Central meridian: 72° 30' W
Cen merid scale: 0.999 964 286...
Areas within ±50 ppm distortion (±0.26 ft per mile):
25% of entire zone
44% of all cities and towns
76% of population
Distortion values (ppm)
Entire zone:
Min = -226
Max = +34
Range = 260
Mean = -72
Cities and towns:
Min, Max = -120, +15
Range = 135
Median = -54
Mean = -31
(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 25 50 75 100 km
Central meridian 72° 30' W
VERMONT
NEW YORK
NEW HAMPSHIRE
Burlington
Montpelier
Rutland
Bennington
Manchester
Concord
Nashua



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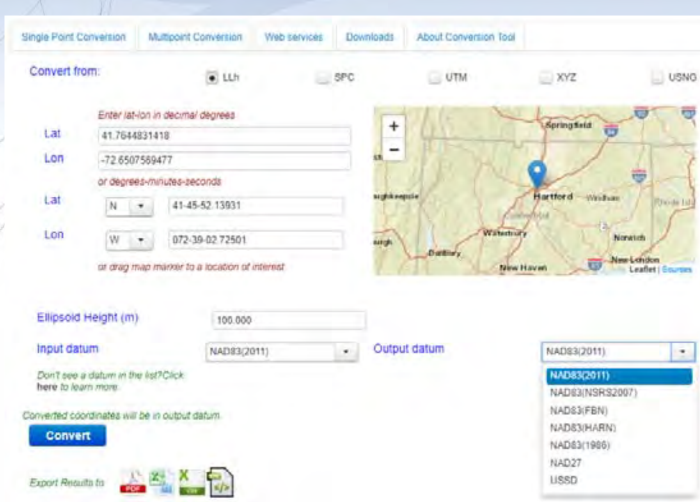
NGS Coordinate Conversion and Transformation Tool (NCAT)



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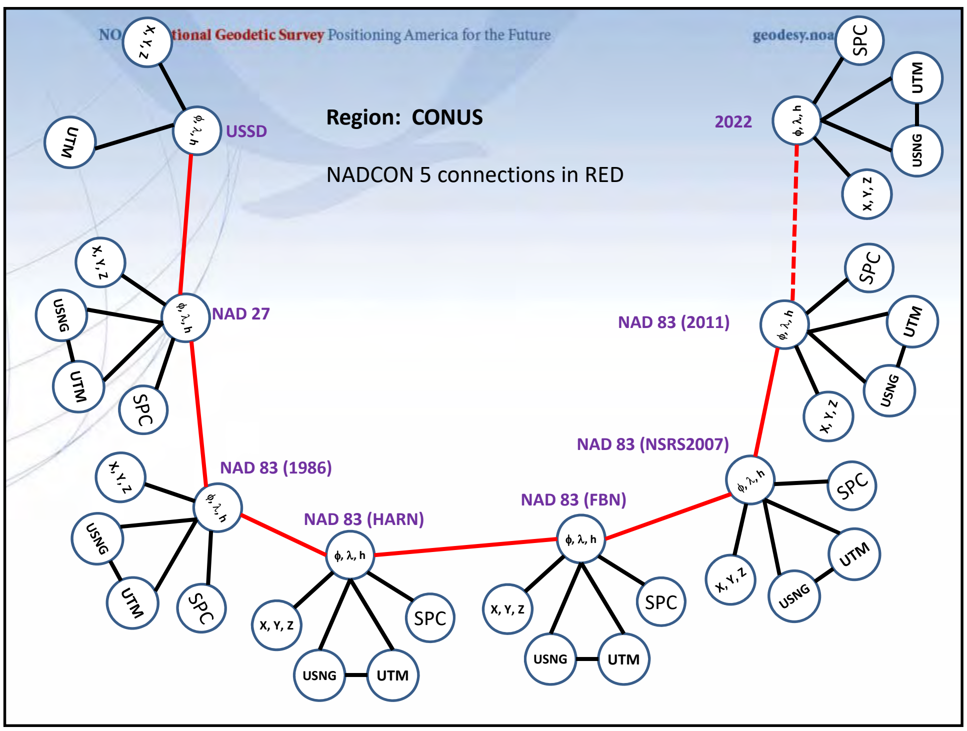
NCAT Output

LLh		SPC		UTM (m)		XYZ (m)		USNG
SrcLat	41.7644831418 N414552.13931	Zone	CT-0600	Zone	18	X	1,420,762.820	18TXM9528026294
DestLat	41.7644831407 N414552.13931	Northing (m)	255,818.505	Northing	4,626,294.971	Y	-4,547,774.146	
Siglat (arcsec)	±0.000053	Northing (usft)	839,297.880	Easting	695,280.741	Z	4,226,194.529	
SrcLon	-72.6507569477 W0723902.72501	Northing (ift)	839,299.558	Convergence (dms)	01 33 54.92			
DestLon	-72.6507571320 W0723902.72568	Easting (m)	313,053.132	Scale factor	1.00006929			
Siglon (arcsec)	±0.000103	Easting (usft)	1,027,075.151	Combined factor	1.00005360			
SrcEht (m)	100.000	Easting (ift)	1,027,077.205					
DestEht (m)	100.001	Convergence (dms)	00 03 56.89					
sigeht (m)	±0.002	Scale factor	0.99999124					
		Combined factor	0.99997556					

You may change the default UTM and SPC zones, where applicable. The change is processed interactively once a lat-long is converted; DO NOT click the Convert button.

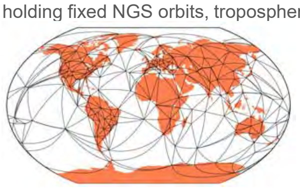


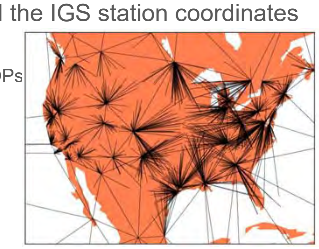
NGS' 2nd Reprocessing Campaign

- IGS08 coordinates and velocities were released in 2011 through the first reprocessing campaign
- Need for the new coordinates and velocities due to:
  - The geophysical activities (earthquakes) in some area,
  - The equipment changes,
  - New CORS stations and 6 more years of data since 2011, and
  - New frame released (IGS14)
- Model update since Repro1 campaign
  - IGb08 reference frame model
  - Updated IGS08 absolute antenna calibration
  - Generally implement IERS 2010 convention

Processing

- Data span 1994 to 2016 (23 years)
  - 3050 stations including decommissioned
  - ~25 TB of data volume
- 15 iterations for the rigorous quality control and discontinuity checking
- To be released in September 2018
- Global processing to solve for orbits and the IGS station coordinates
- Tie remaining CORS to backbone sites
  - holding fixed NGS orbits, troposphere and EOPs





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Modernized Database

- Foundation for all NGS data of the future
  - Spatial Database
  - Hold all data from existing Integrated DataBase
  - Hold all future data generated by and for NGS
  - Capable of representing everything in 4-D
  - Be easily loadable by NGS personnel
  - Be easily retrievable by NGS and the public
  - Capable of permanently storing all of NGS survey data (future and historic)
  - Capable of tracking all changes to the data

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Data Delivery System (DDS)

(Working Group)

- More than just new "datasheets"
- Ability to deliver dynamic data
- Ability to generate time-based data
- Ability for user to customize output

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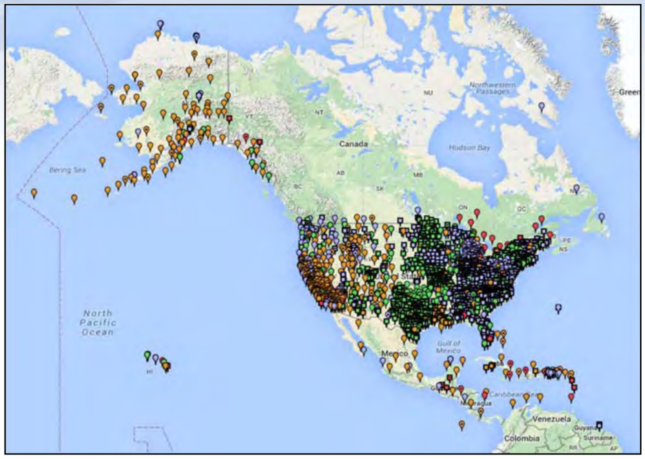
Current Partnership Network

- Consists of ~**2000 Continuously Operating Reference Stations (CORS)**
- Run by more than **200 organizations** (various government, academic, and private organizations)
- Provides access to the U.S. National Spatial Reference System (NSRS)



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Foundation CORS Requirements

Baseline Foundation CORS Network:

- **COLLOCATE - All Sites** within the Foundation CORS target area of the United States that have **existing space based geodetic techniques (SLR, VLBI or DORIS)** will have a **collocated Foundation CORS.**

Additional Desired Foundation CORS Network Requirements:

- **DENSITY** – Install or adopt new stations within the Foundation CORS target area of the United States to **fulfill the spacing criteria of 800 km** within the Foundation CORS target area, after the above criteria are met.
- **EULER** – Install or adopt new stations within the Foundation CORS target area of the United States to raise the minimum number of Foundation CORS to **3 on each of the 4 plates of interest**, once the above criteria are met.
- **ADDITIONAL (Gap Filling)** – Install or adopt new stations, on a case-by-case basis, once the above criteria is met.

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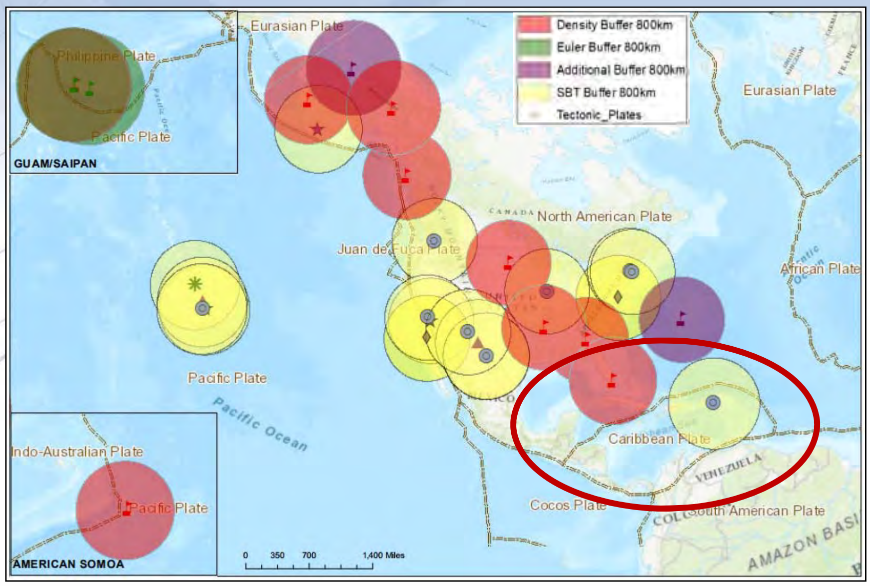
Future "Foundation CORS" Network



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Project Implementation

- **Phase 1** – **Incorporate ~28 existing partner and NGS CORS** into Foundation CORS network
- **Phase 2** – **Upgrade ~7 existing CORS to GNSS** to meet Foundation CORS requirements
- **Phase 3** – **Construct ~8 new Foundation CORS**

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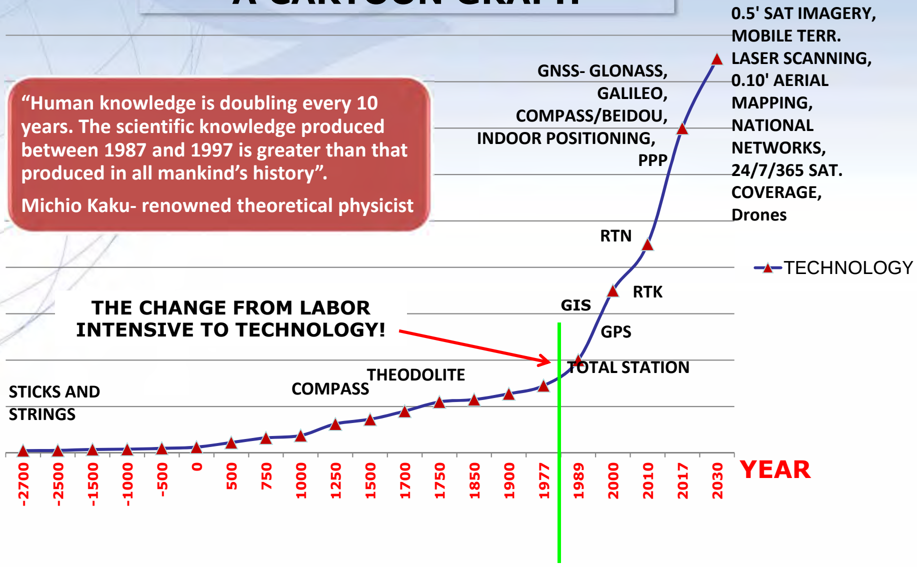
POSITIONING TECHNOLOGY- A CARTOON GRAPH



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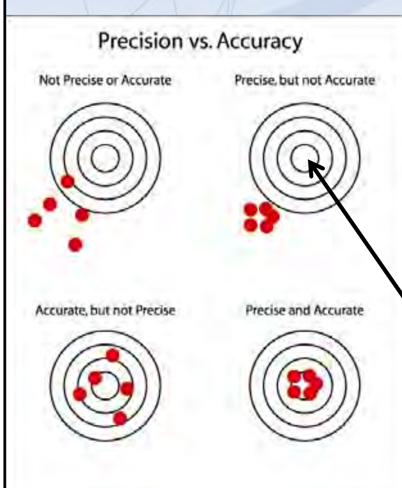
Precision vs. Accuracy measurement from RTN correctors

More questions?



- Is there systematic bias, multipath, and atmospheric errors to overcome? Always some!
- How is the accepted true (accurate) position determined?

Accurate - Accepted truth

Courtesy www.calguns.net

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RTN Measurement Precision

Typical (normal) RTN precisions at the 95% confidence level:

- horizontal 2-3 cm
- vertical (ellipsoid height) 3-5 cm
- orthometric heights 5-7 cm (typical-using the NGS hybrid geoid model)

Exceptional RTN derived precisions at the 95% confidence level at the limit of RT technology:

- horizontal: ≤ 1 cm
- vertical (ellipsoid height) ≤ 1 cm
- orthometric heights ≤ 2 cm

http://www.geodesy.noaa.gov/PUBS_LIB/NGS.RTN.Public.v2.0.pdf

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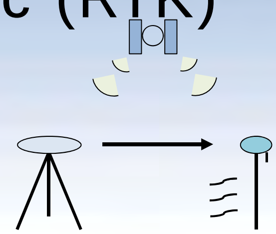
Real-Time Kinematic (RTK) Surveying



Conventional RTK

- Stationary single "base" station
- Transmits precise coordinates and GNSS observables to moving "rover"
- < 10-20 km baseline length

Applications

- Survey engineering
- Mobile mapping
- Precision agriculture
- Mining
- Construction

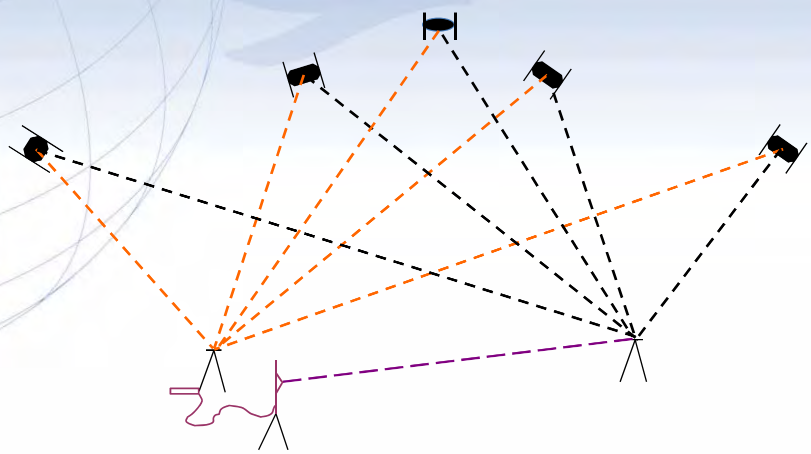

www.alberding.eu


www.gcfarm.com


www.steckbeck.net

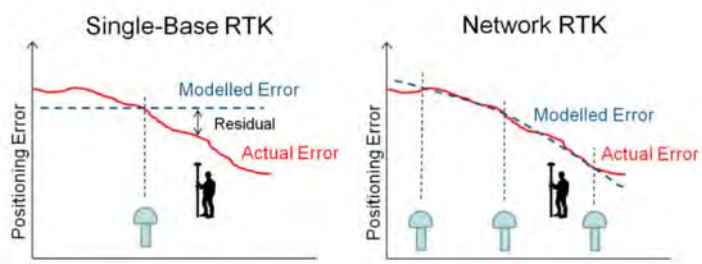

www.positionpartners.com.au

RTK



Real-Time Networks

- Network of GNSS base stations
  - < 70 km spacing between base stations
  - < 40 km maximum baseline length
- Atmospheric and orbital corrections are transmitted to rover via mobile data link

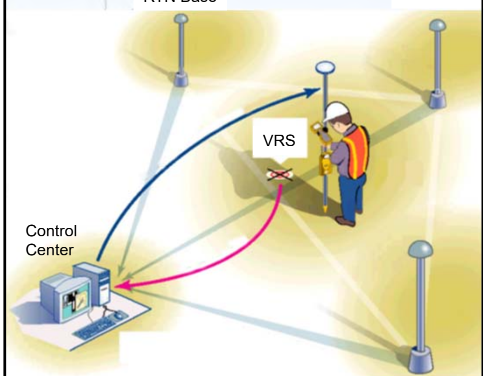


(Janssen and Haasdyk 2011)

RTN Corrections

Virtual Reference Stations (VRS)

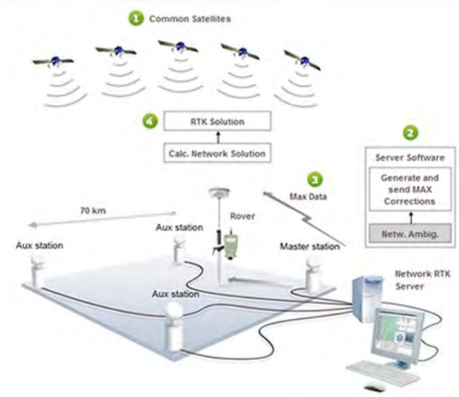
- Vector "tails" referenced to virtual base station
- Base station position is variable



(Landau et al. 2002)

Master-Auxiliary Concept (MAC)

- Vector "tails" connected to physical base station
- Base station position is fixed



(Leica 2005)

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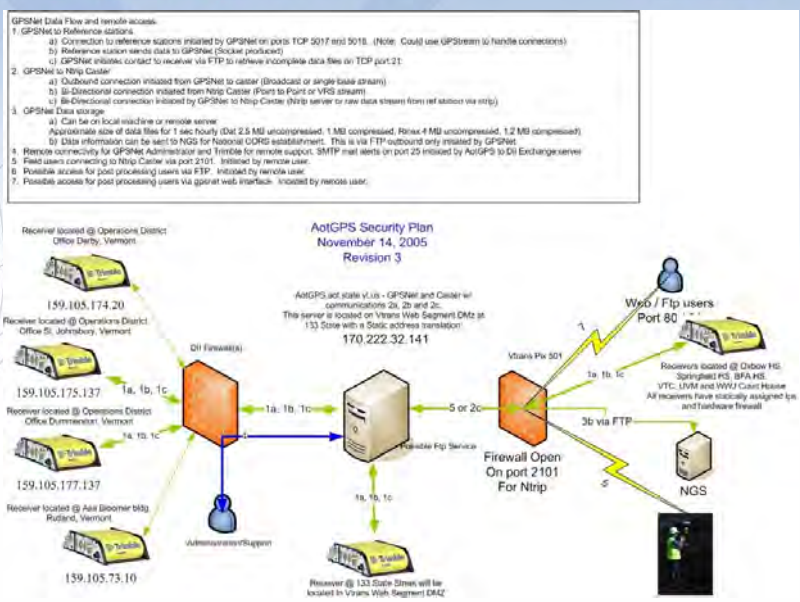
GNSS Signals

Bluetooth connection

Internal Cell Modem Connected to NTRIP Caster via internet



Pros and Cons of RTNs

Benefits	Concerns
FAST. Could reduce field observations from several hours to just a few minutes	RTN may not be aligned with the National Spatial Reference System
Can evaluate data quality in real time	Ideally, survey should be tied to CORS network
Easy to obtain additional observations	More prone to multipathing errors
Only a single receiver (i.e., rover) is needed during a session	Baselines must be kept short (i.e., < 40 km)

116

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Real Time Networks

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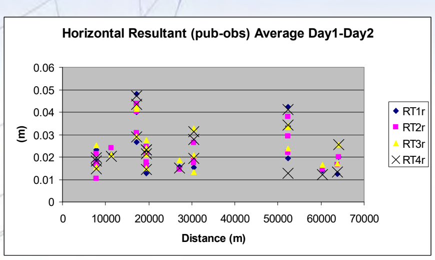
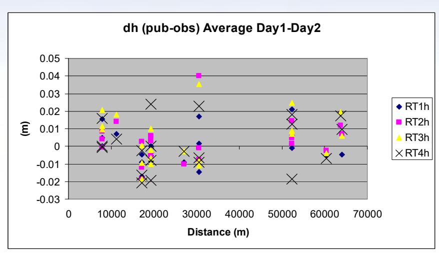
How does Precision translate to Accuracy

- NGS Accuracy Classes defined by 2d horizontal, 1d vertical precision (Repeatability) at 95% per redundant observation set





	2σ Horizontal	2σ Vertical
RT1	0.024663	0.020933
RT2	0.021754	0.023475
RT3	0.020684	0.027002
RT4	0.025223	0.027488

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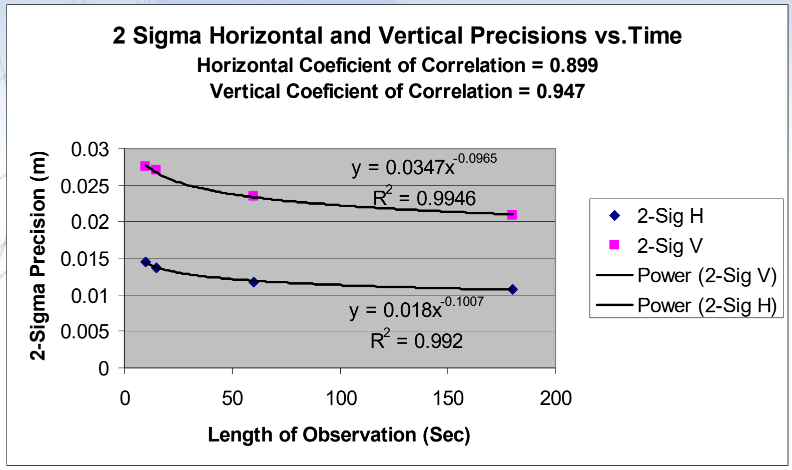

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Conclusions

(Based on this study only)

- Duration of observation only appears to improve field RMS – no apparent bearing on actual precision
- No apparent correlation between actual precision and:
  - Baseline Length
  - Number of SV's
  - RDOP
- Most important factor is achieving good initialization.
- Small increase in accuracy (vertical) with longer observations (based on 2σ error estimates of all observers' data)
- Horizontal and Vertical precisions can be about the same
- Good accuracy and precision is possible even with short occupations on long vectors

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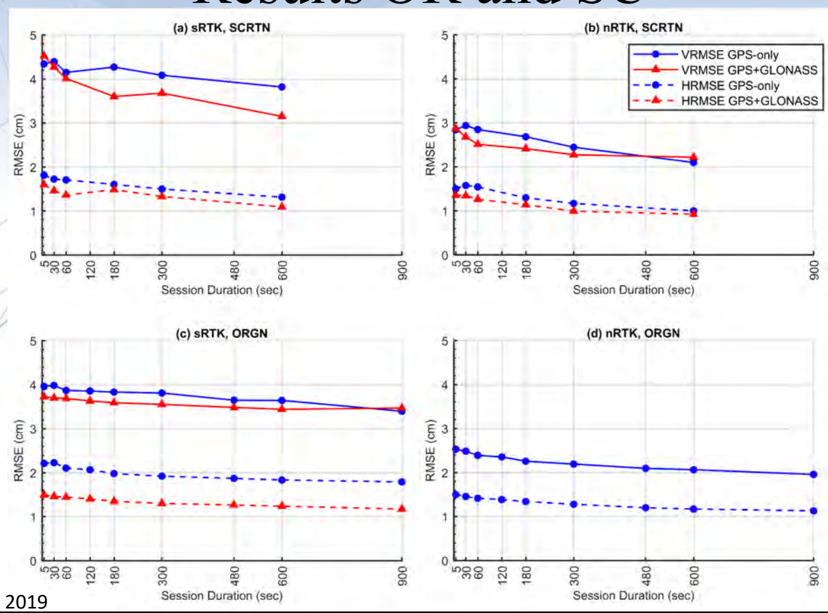
Results OR and SC



Gillins 2019

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Summary on the Accuracy of RTNs

- RTNs in Oregon and South Carolina produced similar results
- NRTK is more accurate than SRTK, especially vertically
  - HRMSE = 1.0 to 1.8 cm for ***both*** NRTK and SRTK
  - VRMSE = 3.1 to 4.7 cm for SRTK
  - VRMSE = 2.0 to 2.7 cm for NRTK
    - *VRMSE @ 95% = 3.9 to 5.3 cm*
- GPS+GLONASS is slightly more accurate than GPS-only
- Accuracy hardly improves with session duration, especially after 5 minutes
  - T = 3 to 5 minutes appears optimal

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What can we use it for?

- Topo
- Asset Management
- LiDAR/Photo Control/QA/QC
- Flood Plain Mapping
- AVL
- Stakeout
- Change Detection/Analysis
- Boundary??

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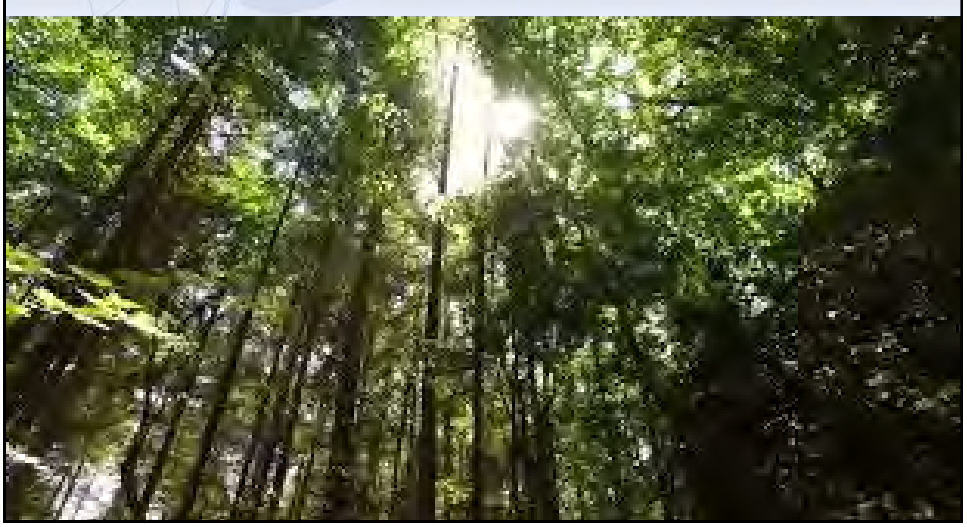
Not Here!!



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BEST METHODS FROM THE GUIDELINES: THE 7 "C's"

https://www.ngs.noaa.gov/PUBS_LIB/NGSRealTimeUserGuidelines.v2.1.pdf

- CHECK EQUIPMENT
- COMMUNICATION
- CONDITIONS
- CONSTRAINTS(OR NOT)
- COORDINATES
- COLLECTION
- CONFIDENCE

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Check Equipment

- Rover pole and Bubbles checked/adjusted
- Using bipod?
- Batteries
- Cables
- Phones, Modems, Antenna's

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Communications

- Are you going to have cell coverage/WiFi?
- Know before you go…Check http://Vector.Vermont.gov
- Make sure GSM/CDMA antenna attached!!!

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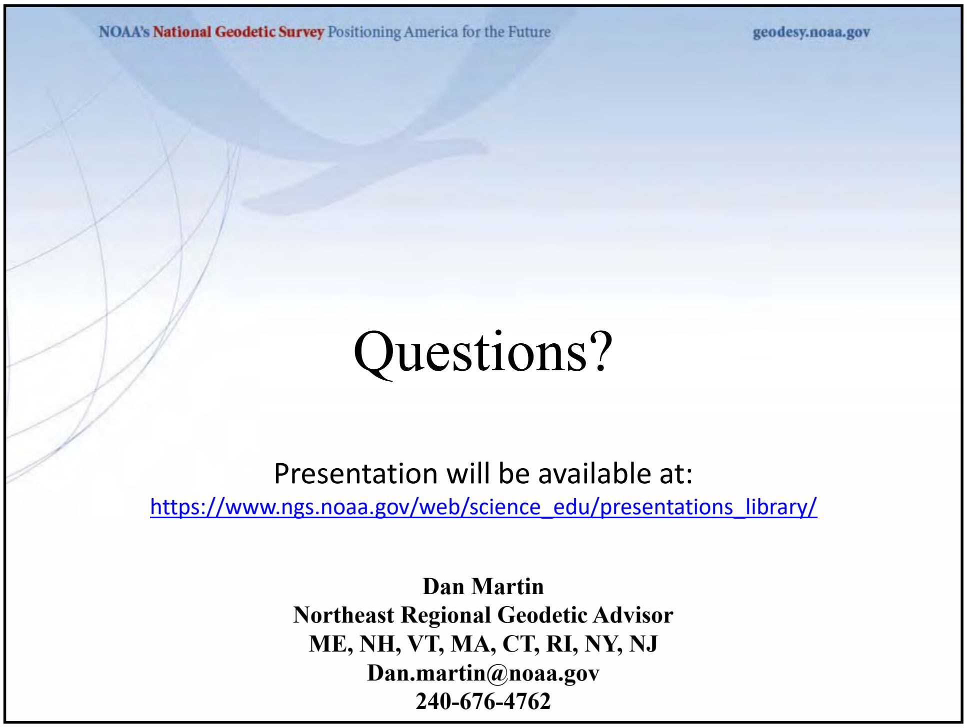
Collection

- Initialize in the open
  - Should be quick, RMS quick to stabilize
- Take observation
  - Recommend 1-3 minutes for “hard” points.
  - Reinitialize
    - Different Day/Time
    - Different Location?
    - Different HI?
  - Take redundant observation
    - Average position if spread is acceptable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Questions?
Presentation will be available at:
https://www.ngs.noaa.gov/web/science_edu/presentations_library/
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