# New Datums Are Coming in 2022

## Connecticut GIS Network Spring Meeting

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# Session description and objectives

- In 2022, the National Geodetic Survey will be replacing the U.S. horizontal and vertical datums (NAD 83 and NAVD 88). We will discuss the history of these datums, their relationship to other reference frames, the reasons for the change, and how it affects surveyors and their access to these datums.
- Objective…gain a fundamental understanding of:
  - How and why our datums/reference frames have changed over time
  - The need to further modernize the US reference frames
  - How NGS will define new reference frames
  - How users will access the new reference frames

# U.S. Department of Commerce
# National Oceanic & Atmospheric Administration
# **National Geodetic Survey**

*Mission*: To define, maintain & provide access to the
***National Spatial Reference System (NSRS)***
to meet our Nation's economic, social & environmental needs

National Spatial Reference System

- Latitude
- Longitude
- Height
- Scale
- Gravity
- Orientation

*& their time variations*

# 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)

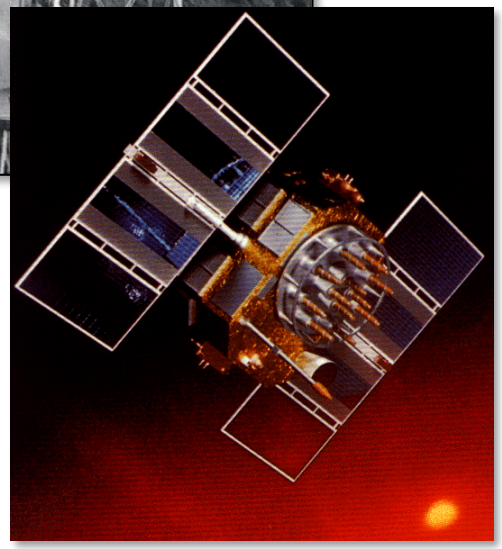
Fixed and Stable - Coordinates seldom change
(e.g. NAD 83 (1996), NAD 83 (2007), NAD 83 (CORS96) NAD 83 (2011))

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(92, 96) based on new and old observations and same system (HARN/FBN)
- 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?

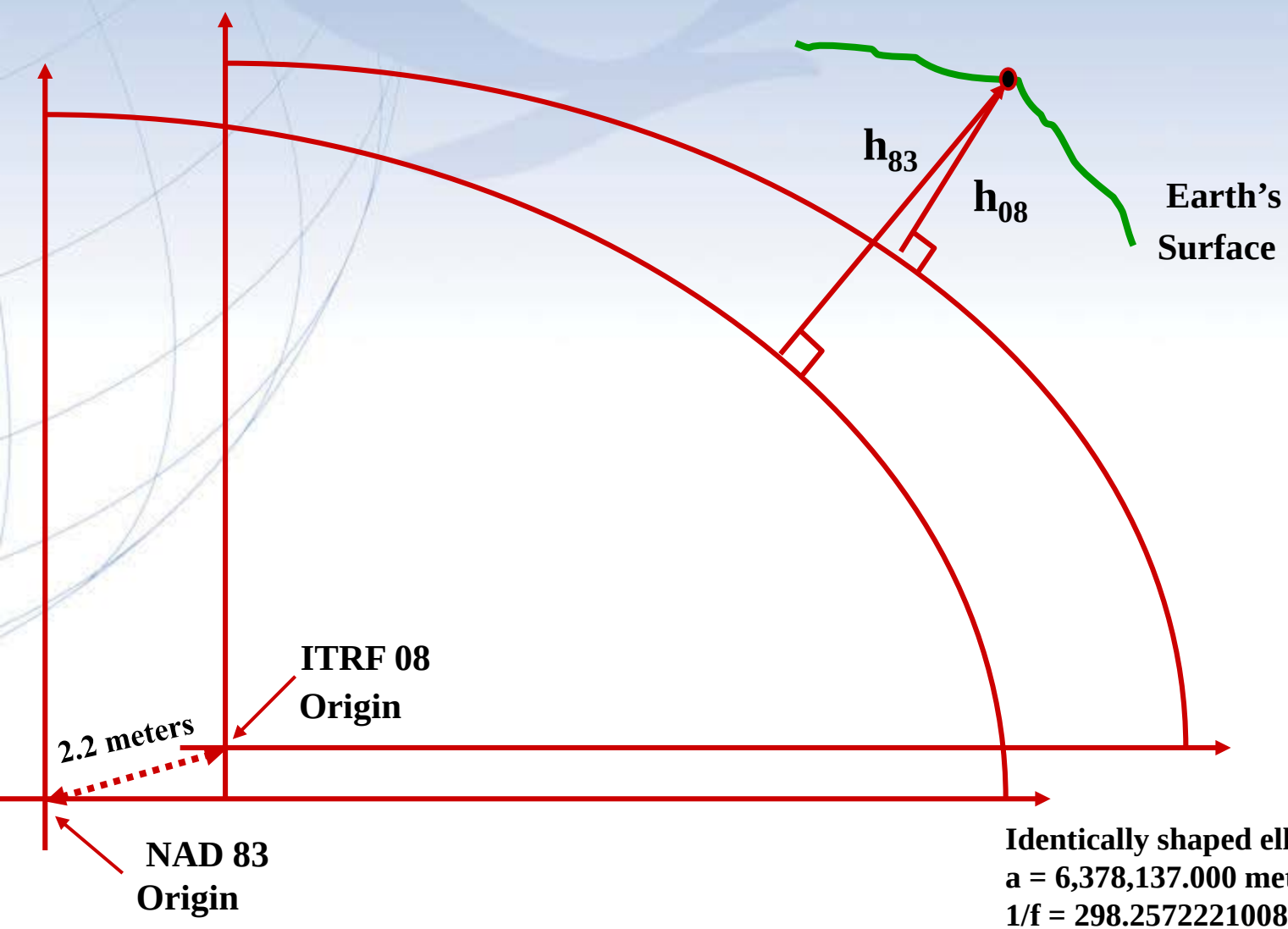
- NAD 27
- NAD 83 (Lat-Lon) SPC
  - Which one???
    - NAD 83 (1986)
    - NAD 83 (1992)
    - NAD 83 (1996)
    - NAD 83 CORS96(2002)
    - NAD 83 (NSRS2007)
    - NAD 83 (2011) epoch 2010.00
- WGS 84
  - Which one???
    - WGS 84 (1987)
    - WGS 84 (G730)
    - WGS 84 (G873)
    - WGS 84 (G1150)
    - WGS 84 (G1674)
    - WGS 84 (G1762)
- ITRFxx (epoch xxxx)
- IGSxx (epoch xxxx)

# ITRF2008

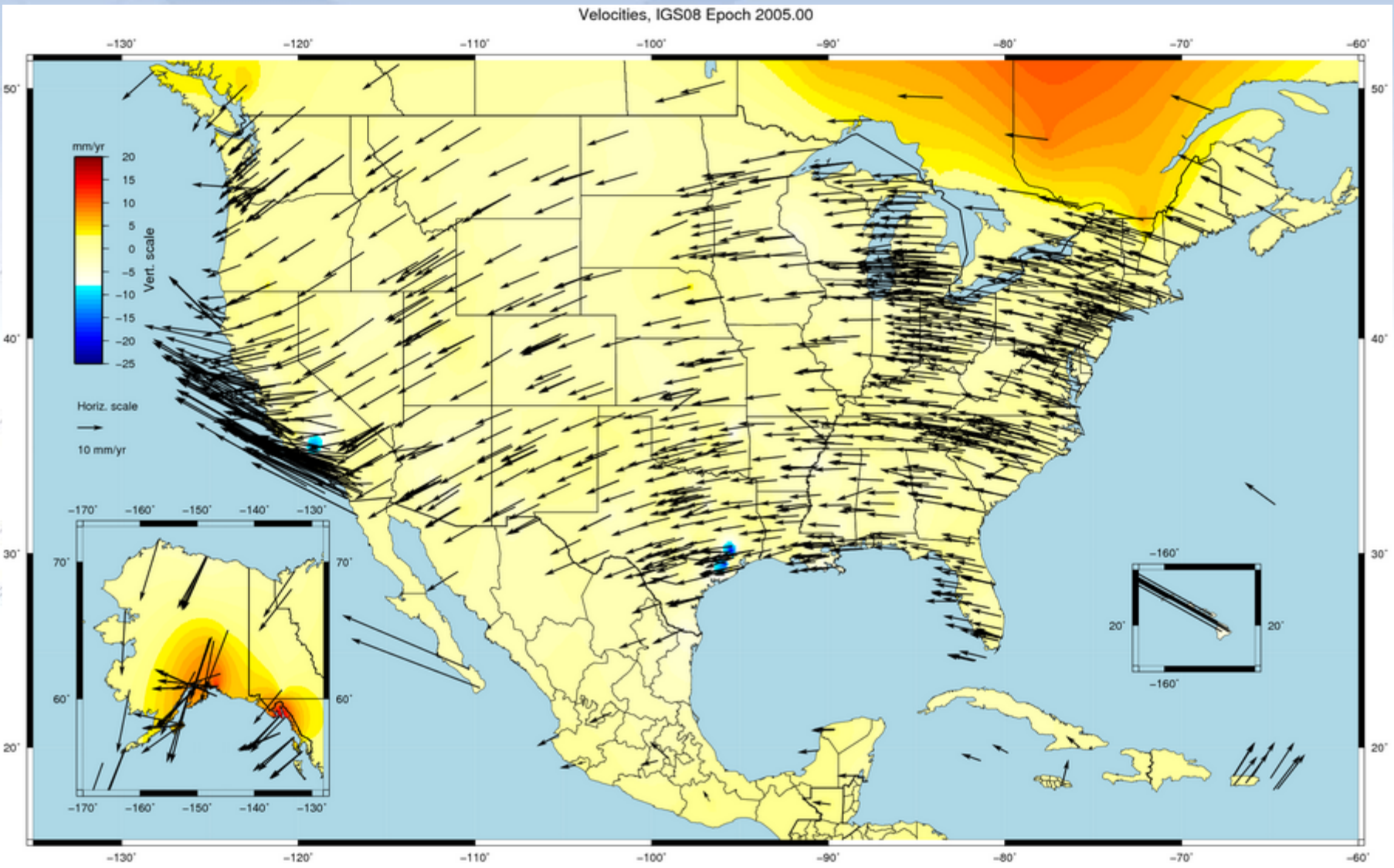
For the geodesy, geophysics and surveying communities, the best International Terrestrial Reference Frame is the "gold standard."

The global community adopted an updated expression for the reference frame, the ITRF2008.

# Simplified Concept of NAD 83 vs. ITRF08




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


Velocities, IGS08 Epoch 2005.00
mm/yr
20
15
10
5
0
−5
−10
−15
−20
−25
Vert. scale
Horiz. scale
10 mm/yr
−130°
−120°
−110°
−100°
−90°
−80°
−70°
−60°
50°
40°
30°
20°
−170°
−160°
−150°
−140°
−130°
70°
60°

# 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


NGVD29
The National Geodetic Vertical Datum of 1929 is referenced to 26 tide gauges in the US and Canada
Prince Rupert
Fort Stephens
San Francisco
San Diego
Galveston
Biloxi
Pensacola
Cedar Keys
Fernandina Beach
Brunswick
St. Augustine
Norfolk
Perth Amboy
Boston
Portland
Yarmouth
Halifax
Father's Point
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Google

# Current Vertical Datum in the USA

Father Point
Lighthouse, Quebec

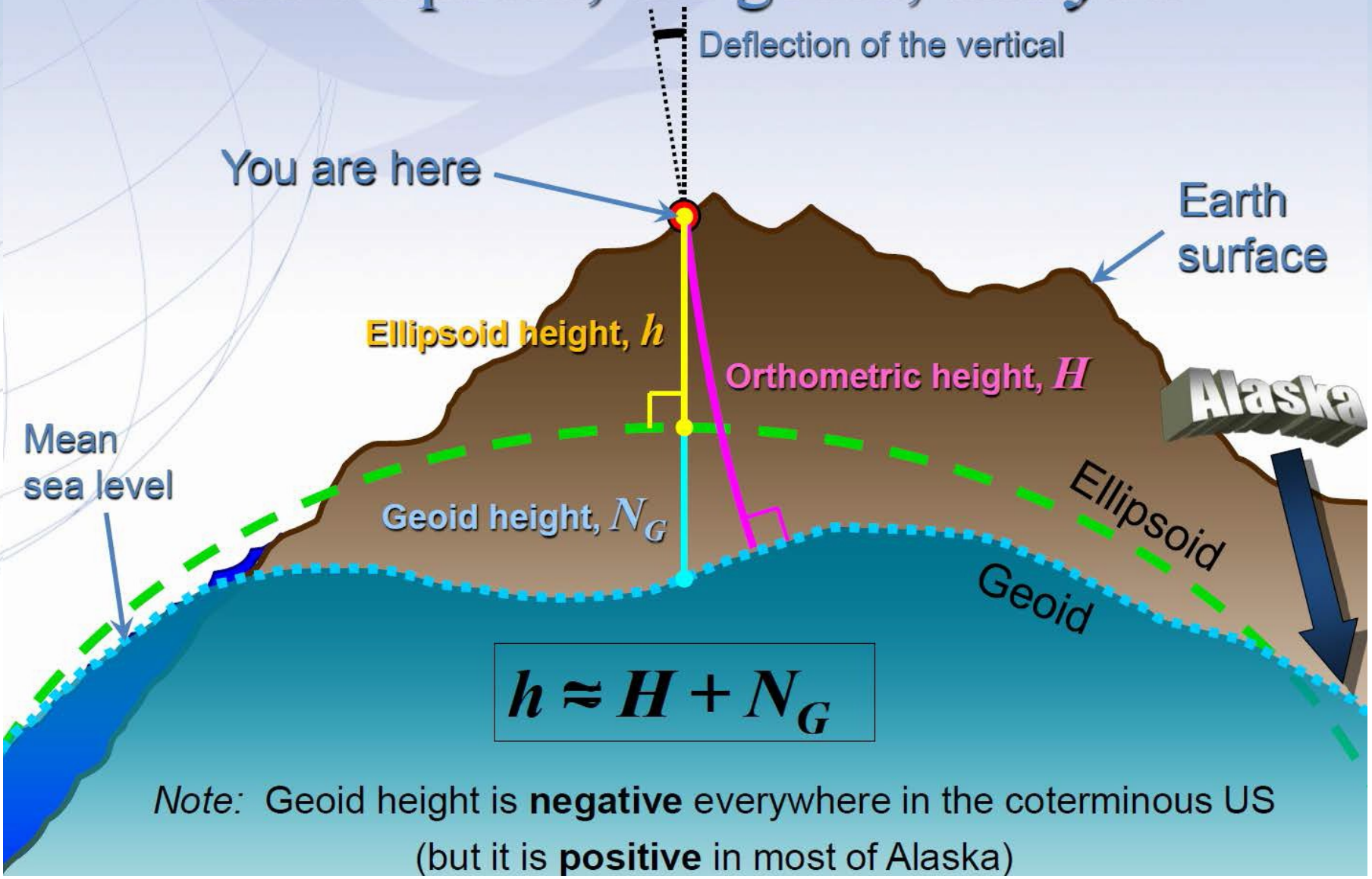
- **NAVD 88**: North American Vertical Datum of 1988
- ***Definition:*** The surface of equal gravity potential to which orthometric heights shall refer in North America*, and which is 6.271 meters (along the plumb line) below the geodetic mark at "Father Point/Rimouski" (NGSIDB PID TY5255).
- ***Realization:*** 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** (continued)
  - Use of one fixed height removed local sea level variation problem of NGVD 29
  - Use of one fixed height did open the possibility of unconstrained cross-continent error build up
  - But the H=0 surface of NAVD 88 was supposed to be parallel to the geoid…(close again)

# The ellipsoid, the geoid, and *you*




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

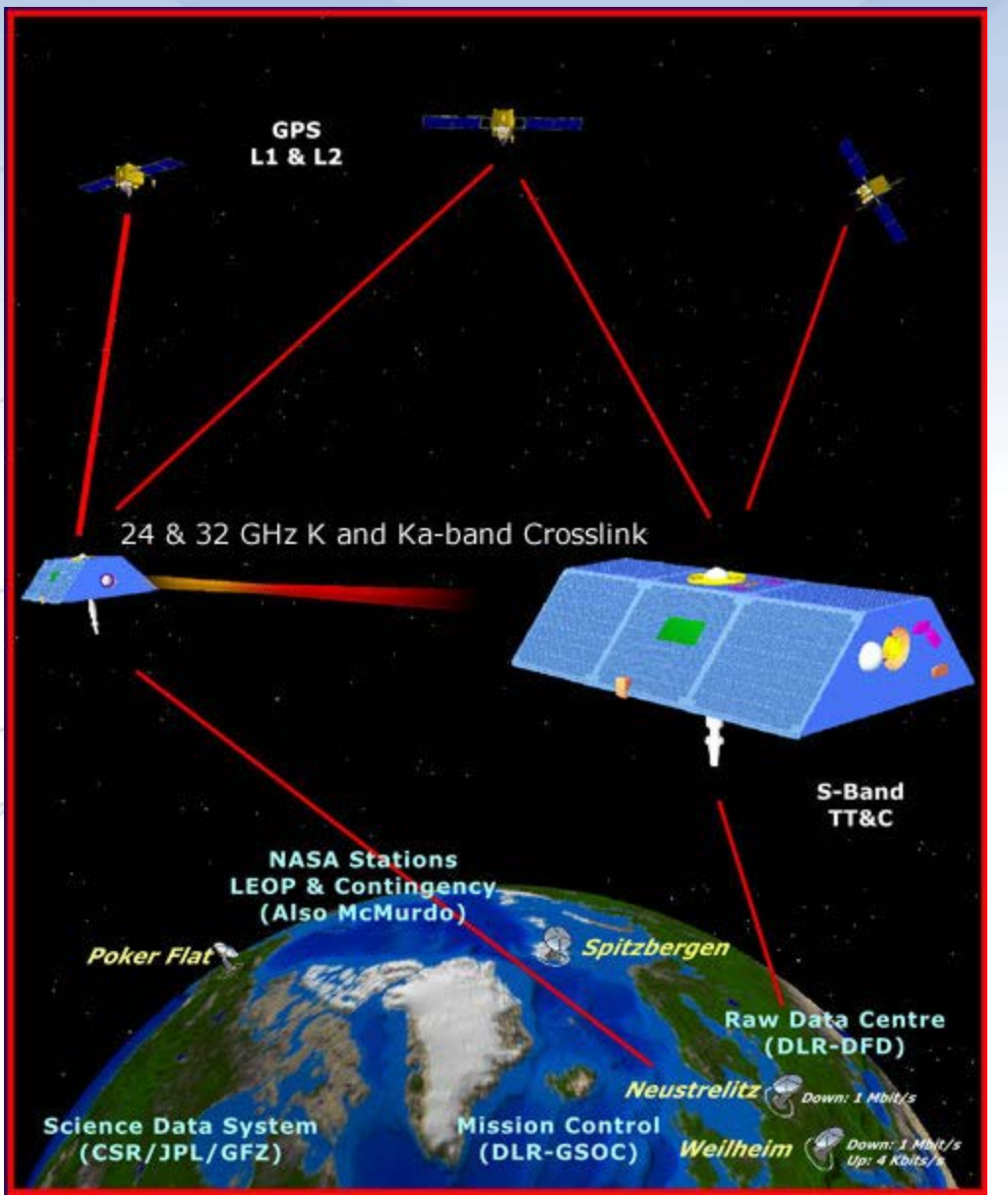
# Which Geoid for Which NAD 83?

- NAD 83(2011)
- NAD 83(2007)
- NAD 83(1996) & CORS96

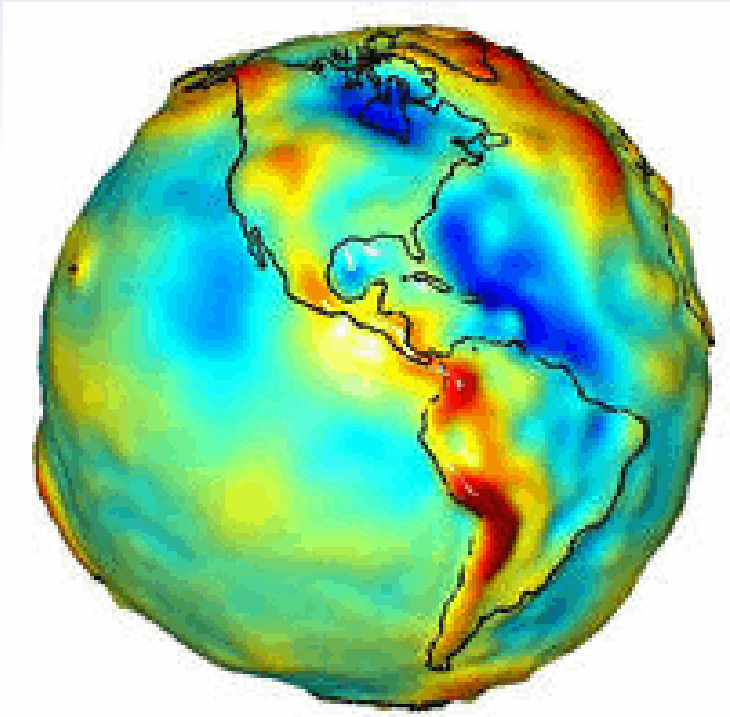
- Geoid12A/12B
- Geoid09
- Geoid06 (AK only)
- Geoid03
- Geoid99
- Geoid96

# Problems with NAD 83 and NAVD 88

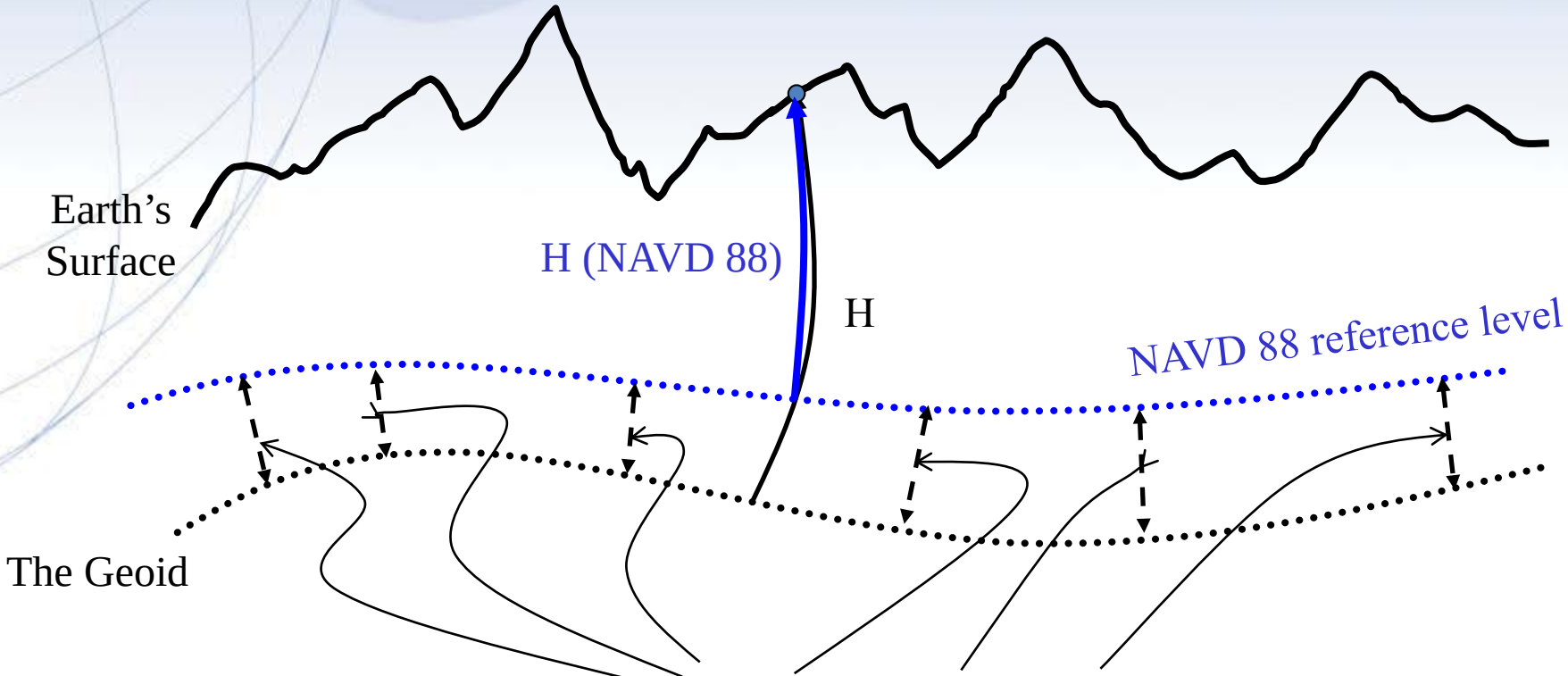
- **NAD 83** is not as geocentric as it could be (approx. 2 m)
  - Positioning Professionals don't see this - **Yet**
- **NAD 83** is not well defined with positional velocities
- **NAVD 88** is realized by passive control (bench marks) most of which have not been re-leveled in at least 40 years.
- **NAVD 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




# GRACE – Gravity Recovery and Climate Experiment



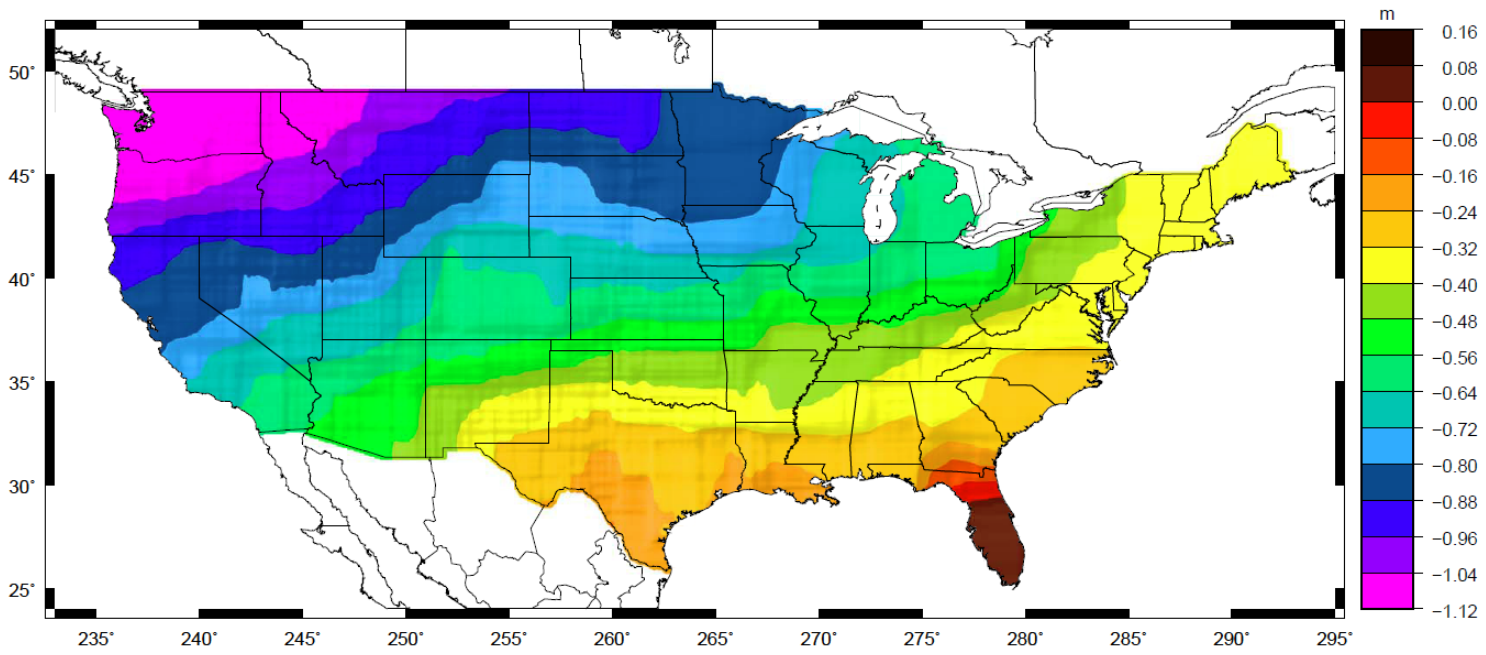
# Why isn't NAVD 88 good enough anymore?




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

# Why isn't NAVD 88 good enough anymore?

- **Approximate level of geoid mismatch known to exist in the NAVD 88 zero surface:**



# Height-Mod means More Marks?

# Height Modernization

***Height Modernization***

-faster

-cheaper

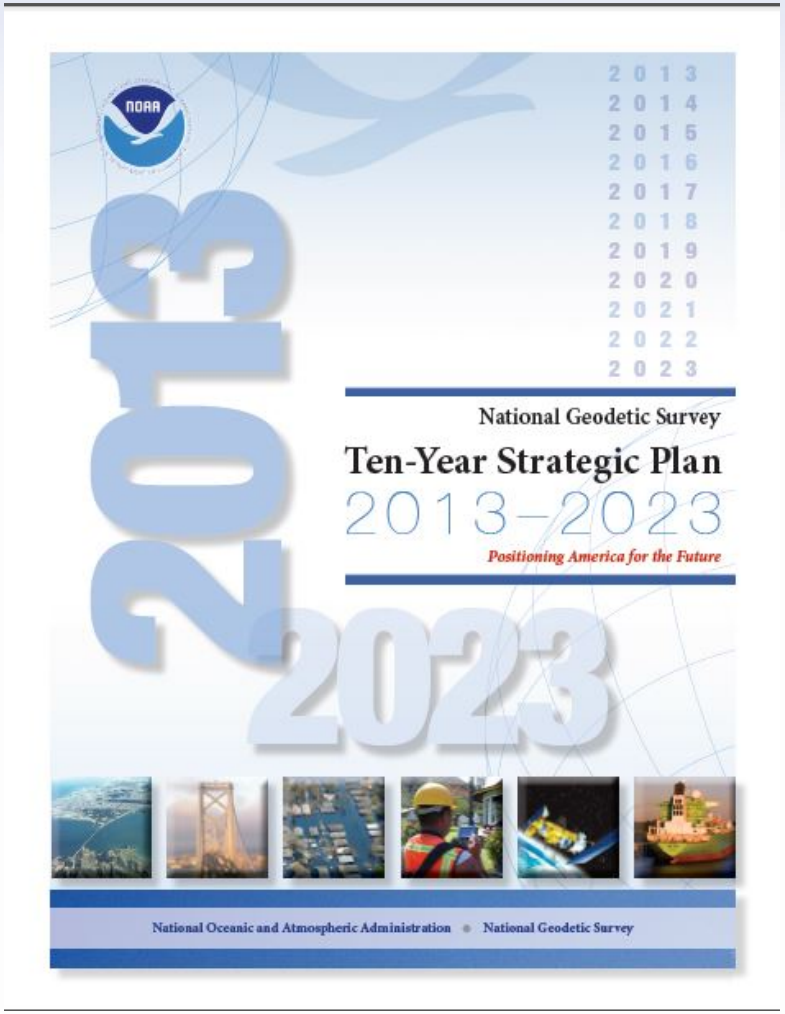
**Differential Leveling**

**GNSS + …**

# 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*



# 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

# 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)

# Future Geometric Reference Frame

- CORS-based, via GNSS
- coordinates & velocities in ITRF and official US datum
- Identical to the latest IGS reference frame (as available in 2022) at an epoch to be determined
- replace NAD 83 with new geometric reference frame – by 2022
- passive control tied to new datum; not a component of new datum
- address user needs of datum coordinate *constancy vs. accuracy*
- lat / long / ellipsoid height of defining points accurate to 1 mm, anytime
- CORS coordinates computed / published daily; track changes
- support development of real-time networks

# 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

# 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)

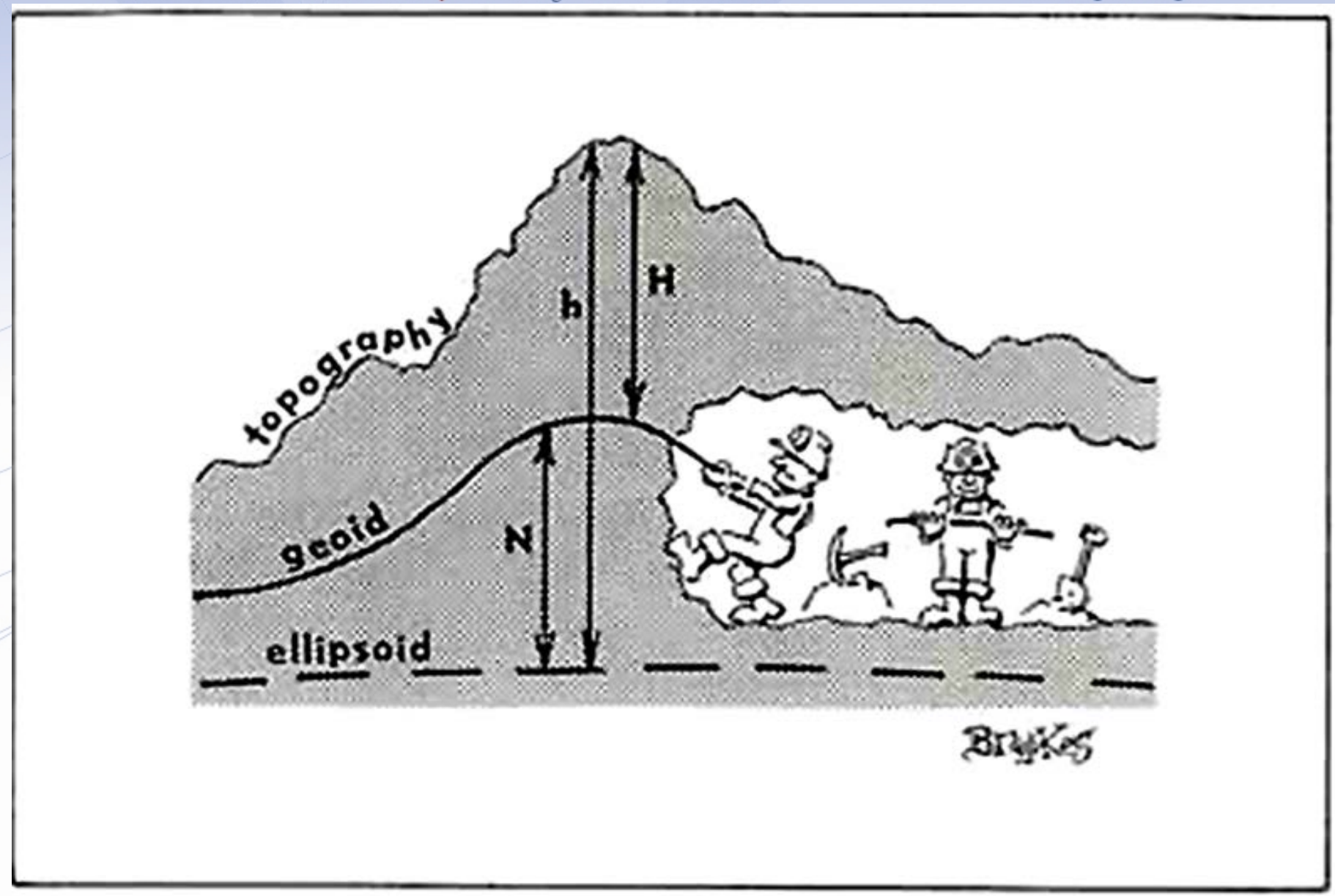
- Will include GEOID2022

# Future Geopotential Reference Frame

- replace NAVD88 with new geopotential reference frame – by 2022
- gravimetric geoid-based, in combination with GNSS
- monitor time-varying nature of gravity field
- develop transformation tools to relate to NAVD88
- build most accurate ever continental gravimetric geoid model (GRAV-D)
- determine gravity with accuracy of 10 microGals, anytime
- support both orthometric and dynamic heights
- Height Modernization is fully supported

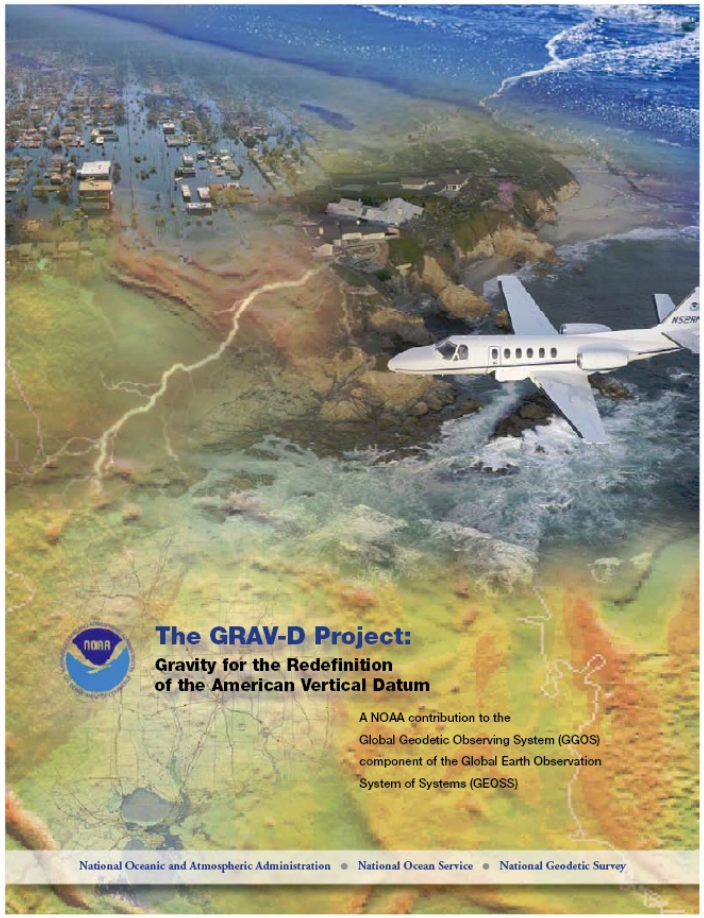
# Why replace NAVD 88 and NAD 83?

- **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




In Search of the Geoid

# 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

# What is GRAV-D?

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

# Accessing the New Datums

- **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 Datums

- **NAD 83 conversion to new datum**
  - A transformation will be provided
- **NAVD 88 conversion to new datum**
  - A transformation will be provided (VERTCON)
    - Only where recent GNSS ellipsoid heights exist to provide modern heights in the new datum

# Predicted Positional Changes in 2022
# Vicinity of New Britain,CT

(Computed for station W 91, pid LX3162)

**HORIZONTAL = 1.20 m (3.9 ft)**
**ELLIPSOID HEIGHT = - 1.23 m (- 4.0 ft)**
**Predicted with HTDP**

**ORTHOMETRIC HEIGHT = - 0.32 m (- 1.1 ft)**
**Predicted with HTDP and xGEOID16B**

**HTDP**
"Coping with Tectonic Motion"
R. Snay & C. Pearson
American Surveyor Magazine, December 2010
www.Ameriserv.com

# metadata to the rescue

- your positional metadata should include:
  - datum
  - epoch
  - source
- these will facilitate transforming from current to new datum
- maintaining your original survey data will provide more accurate results

# Questions?