# *Case Study of USA*
# *Session 4, 1700, 01 MAY 2016*

Dr. Daniel R. Roman

Chief, SRSD, NGS

GRAV-D P.I.

Sponsors: Land Information New Zealand *Toitū te whenua* Leica *Geosystems* Trimble.
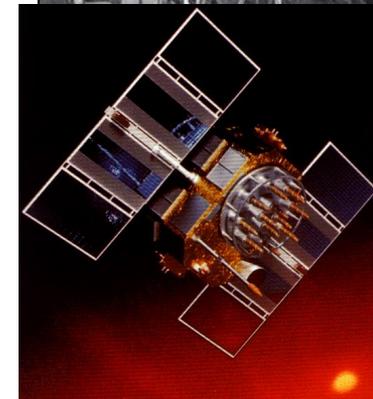
# Topics

- *Current horizontal and vertical datums in USA*
  - *North American Datum of 1983 (NAD 83)*
  - *North American Vertical Datum of 1988 (NAVD 88)*

- *Geodetic Reference Datum of 2022*
  - *Replaces both NAD 83 and NAVD 88*
  - *Geometric component based on IGS 14 or follow on model*
  - *Geopotential component based on EGM and aerogravity*
  - *GRAV-D project for a centimeter geoid*

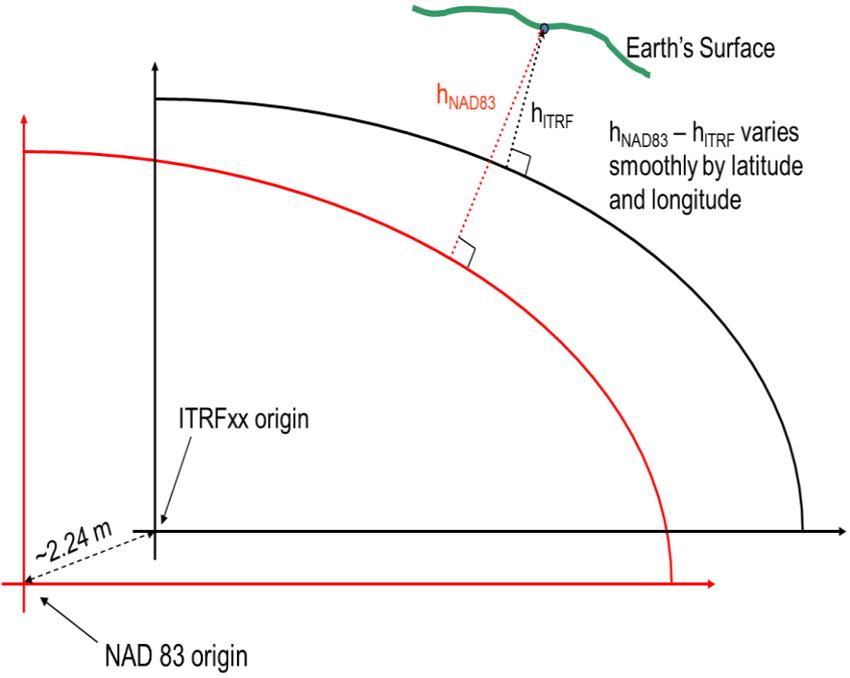- *How will heights be determined in 2022*

# A 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
  - GNSS based, with classical obs. incl. in adjustments
  - Did NOT use CORS as constraints
- National Re-Adjustment of 2007
  - NAD 83(CORS96) and (NSRS2007)
  - Simultaneous nationwide adjustment (GNSS only)
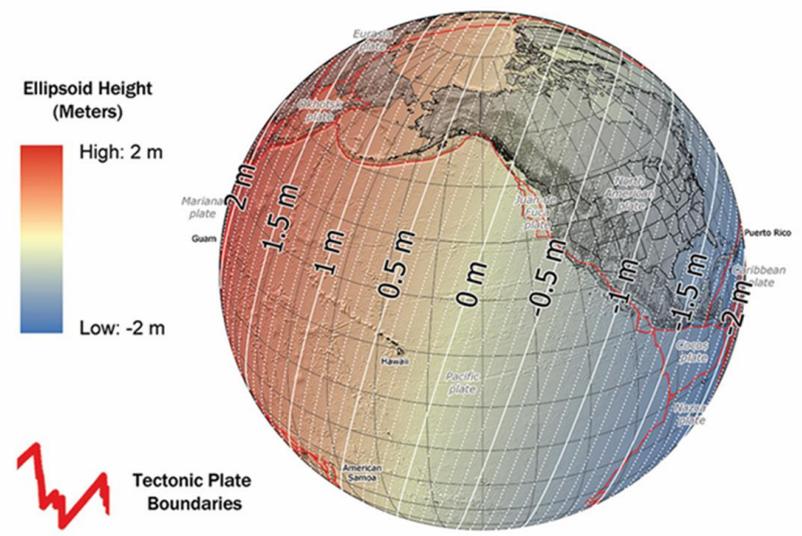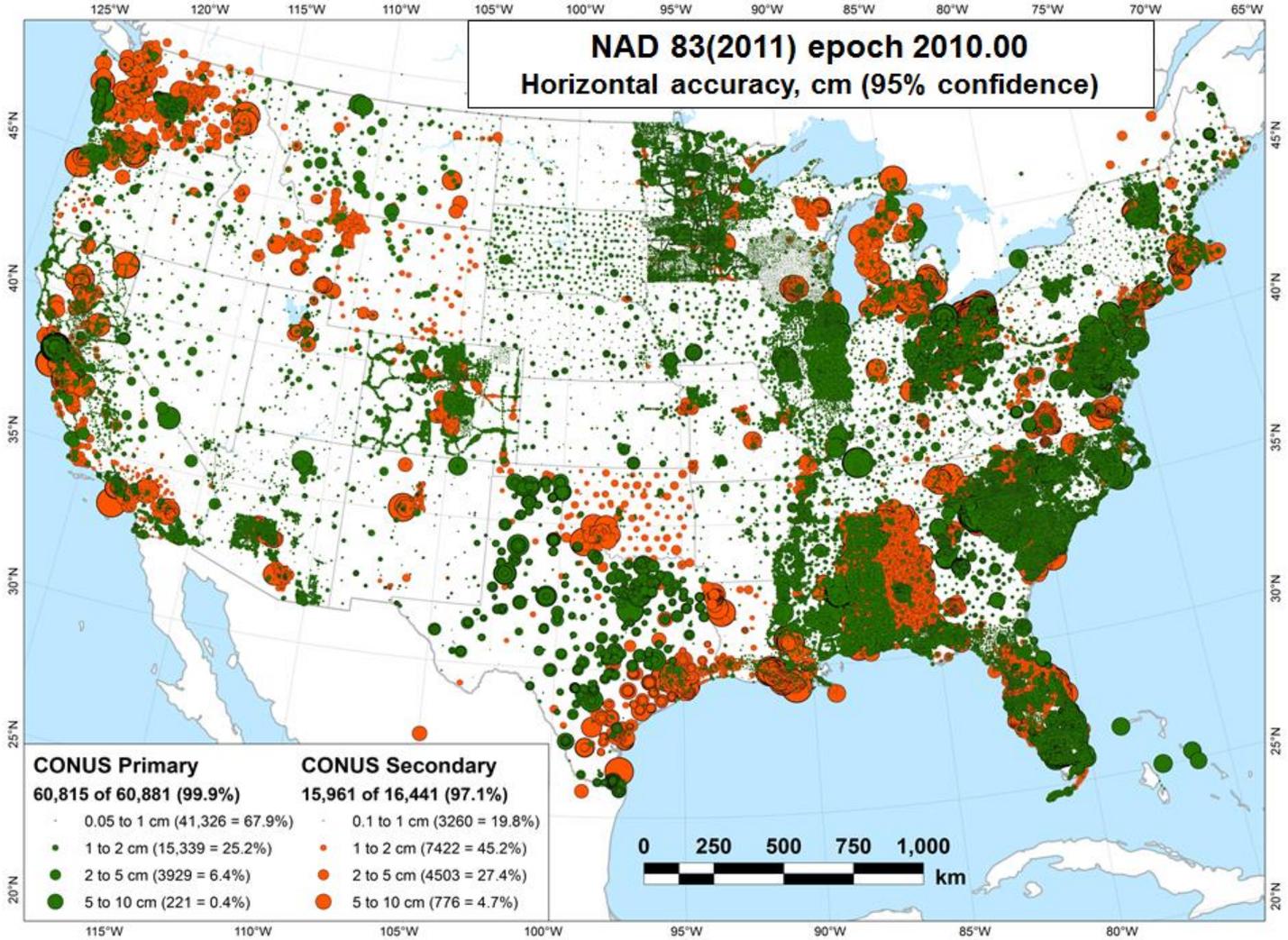- *New realization: NAD 83(2011) epoch 2010.00*

# Datum Defect in NAD 83



Simplified Concept of NAD 83 vs. ITRF

Earth's Surface

$h_{NAD83} - h_{ITRF}$ varies smoothly by latitude and longitude

ITRFxx origin

~2.24 m

NAD 83 origin



Approximate Ellipsoid Height Change

Ellipsoid Height (Meters)

High: 2 m
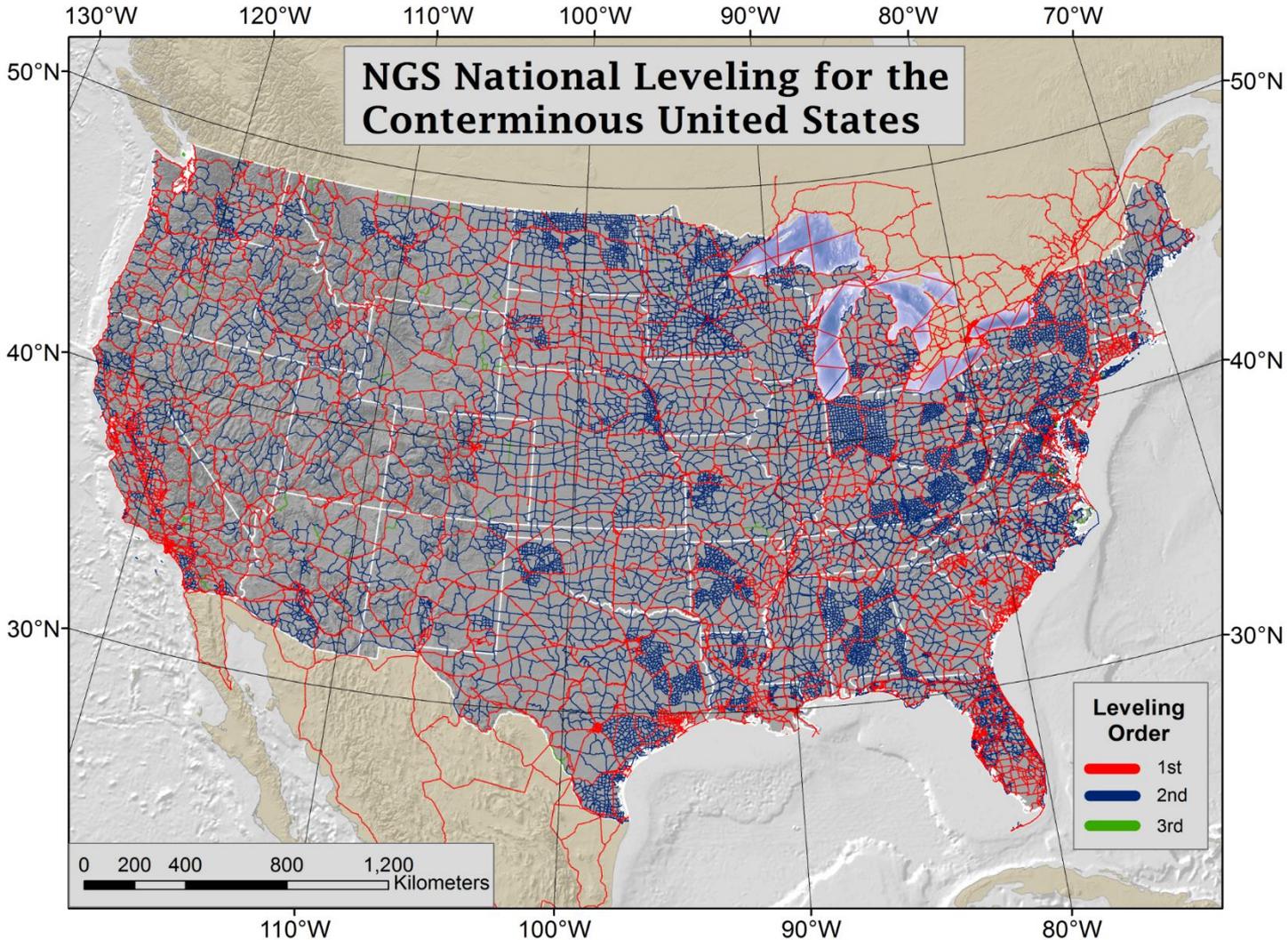
Low: -2 m

Tectonic Plate Boundaries
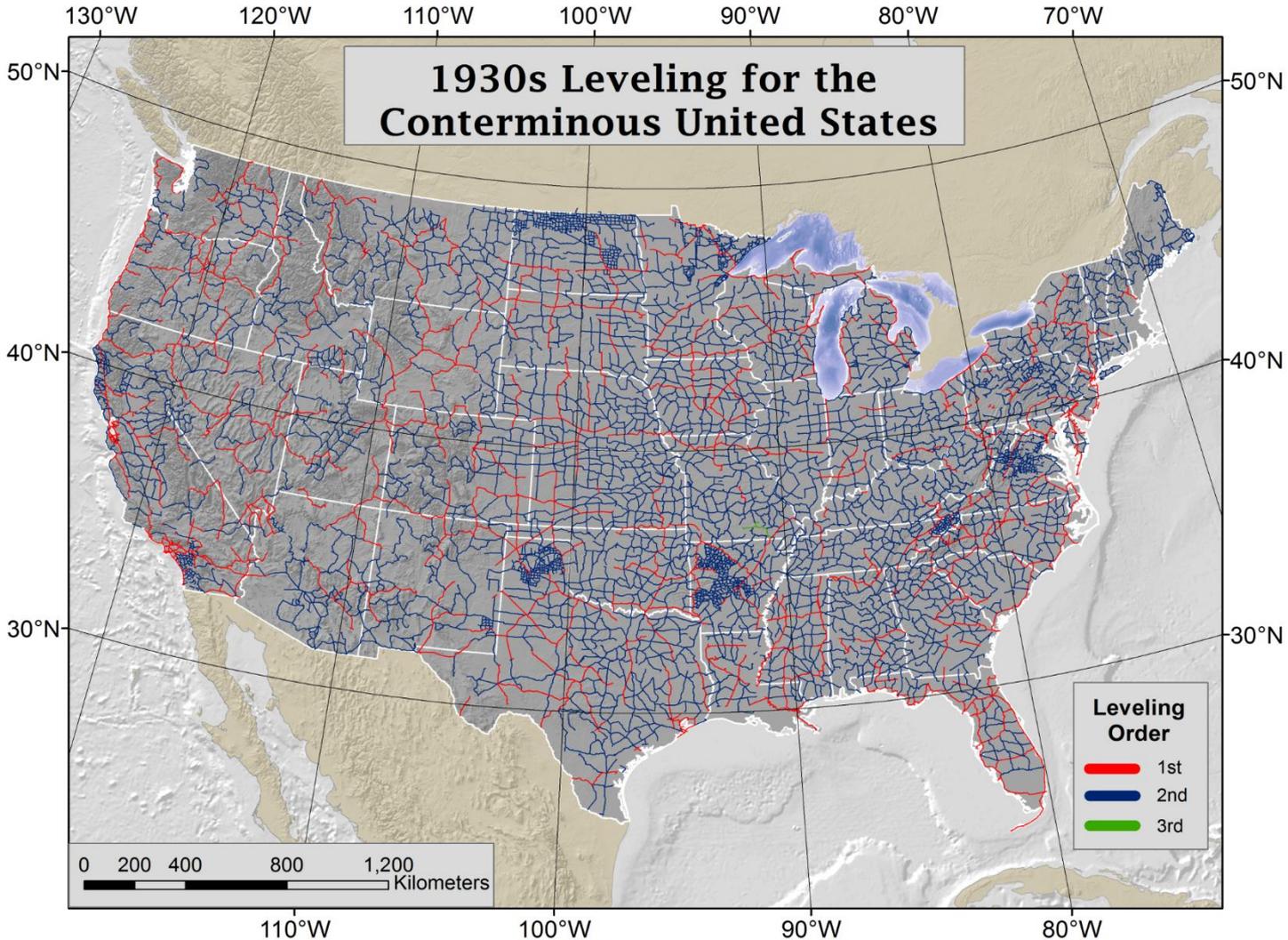
Sponsors:

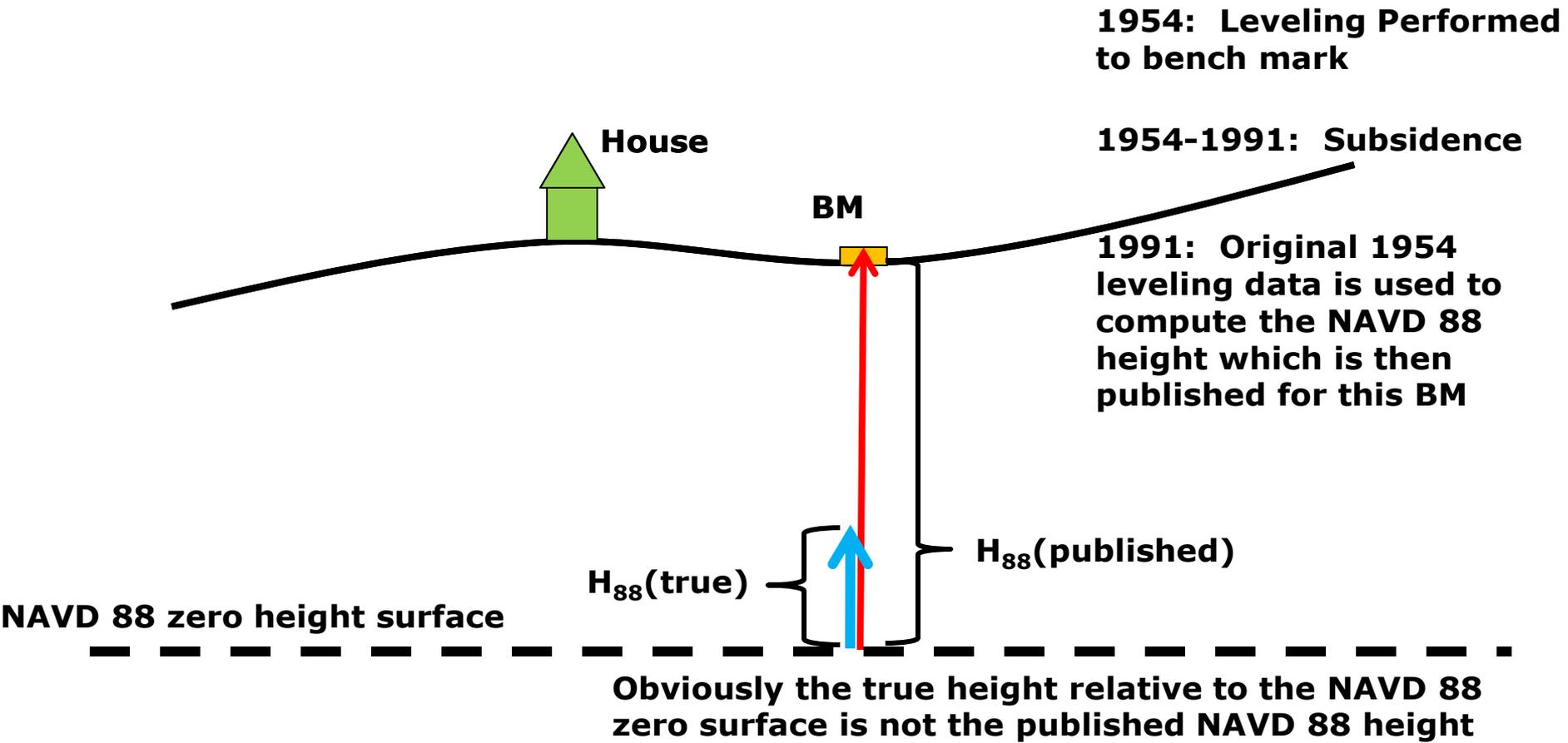# Current Vertical Datum in the USA



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

NGS National Leveling for the Conterminous United States

Leveling Order
- 1st
- 2nd
- 3rd

1930s Leveling for the Conterminous United States

Sponsors:

# Subsidence and Bench Mark Height



1954:  Leveling Performed to bench mark

1954-1991:  Subsidence

House

BM

1991:  Original 1954 leveling data is used to compute the NAVD 88 height which is then published for this BM

$H_{88}$(published)

$H_{88}$(true)

NAVD 88 zero height surface

Obviously the true height relative to the NAVD 88 zero surface is not the published NAVD 88 height

# Bench marks

- **NAVD 88 uses bench marks that:**
  - Are rarely re-checked for movement
  - Disappear by the thousands every year
  - Are not funded for replacement
  - Are not necessarily in convenient places, particularly for GPS measurements
  - Don't exist in most of Alaska
  - Weren't adopted in Canada
  - Were determined by leveling from a single point, allowing cross-country error build up
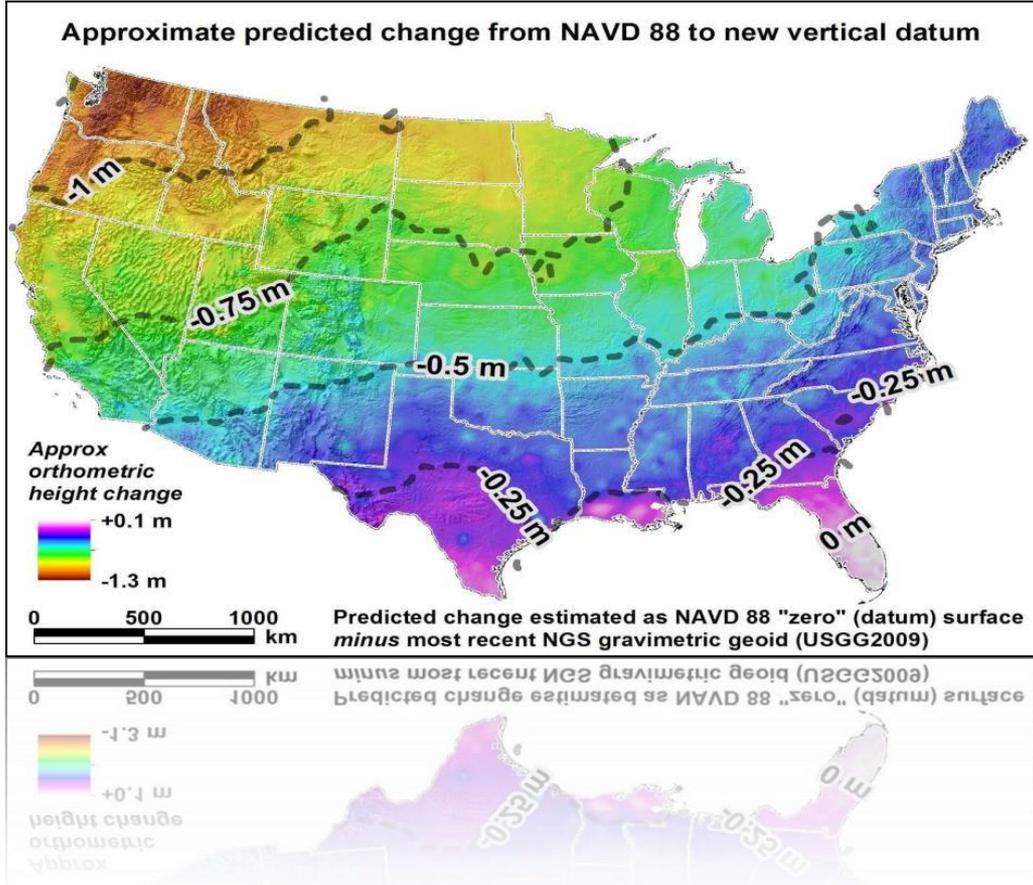
PID: EZ0840

Earth's Surface

H (NAVD 88)

H

NAVD 88 reference level

The Geoid
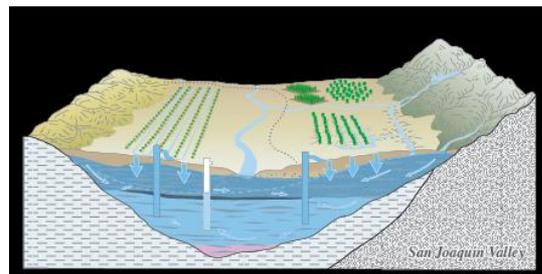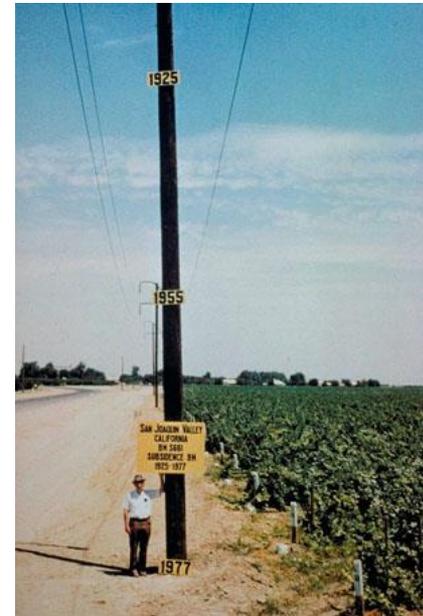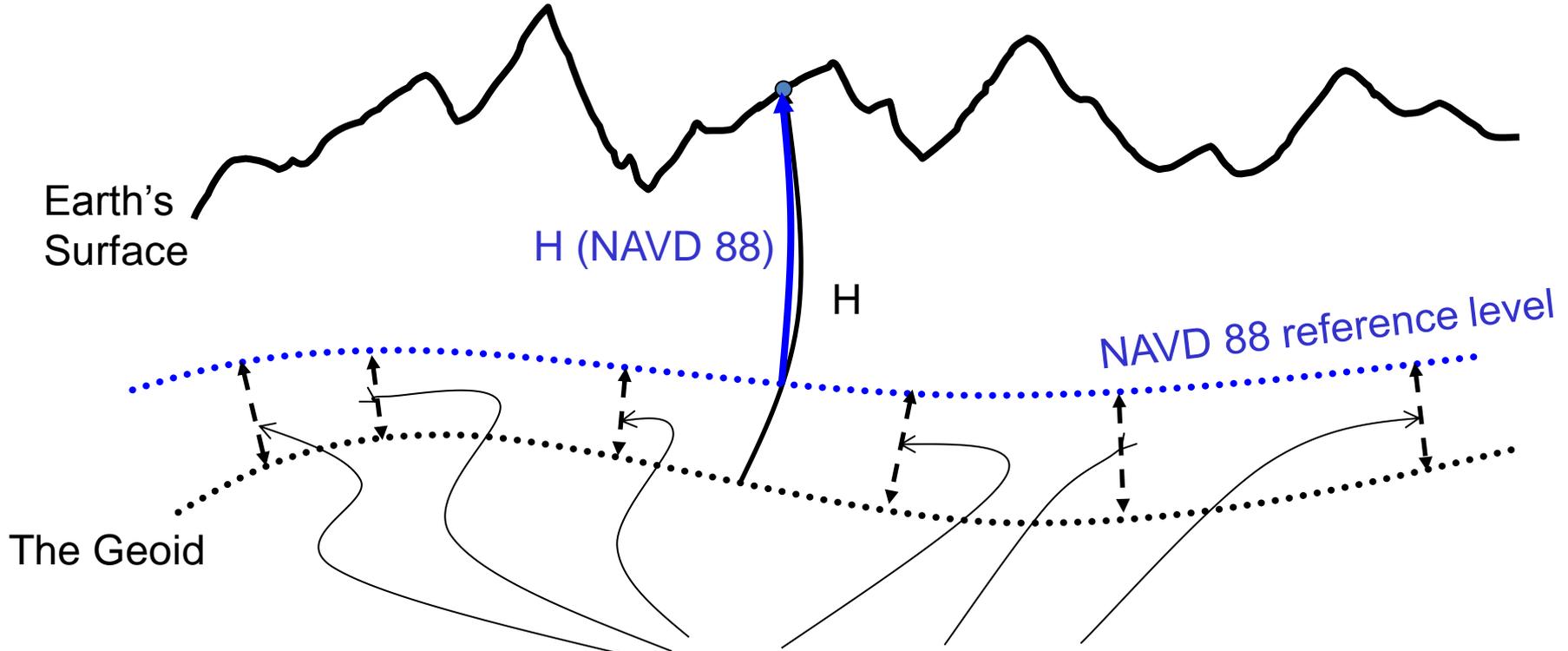
**Errors in NAVD 88 : ~50 cm average,
100 cm CONUS tilt,
1-2 meters average in Alaska
NO tracking**

# How will the new datums affect you?

- The new geometric datum will change latitude, longitude, and ellipsoid height by between 1 and 2 meters.

- The new vertical datum will change heights on average 50 cm (20"), with a1 meter (39") tilt towards the Pacific Northwest.



Approximate predicted change from NAVD 88 to new vertical datum

Approx orthometric height change
+0.1 m
-1.3 m

Predicted change estimated as NAVD 88 "zero" (datum) surface *minus* most recent NGS gravimetric geoid (USGG2009)

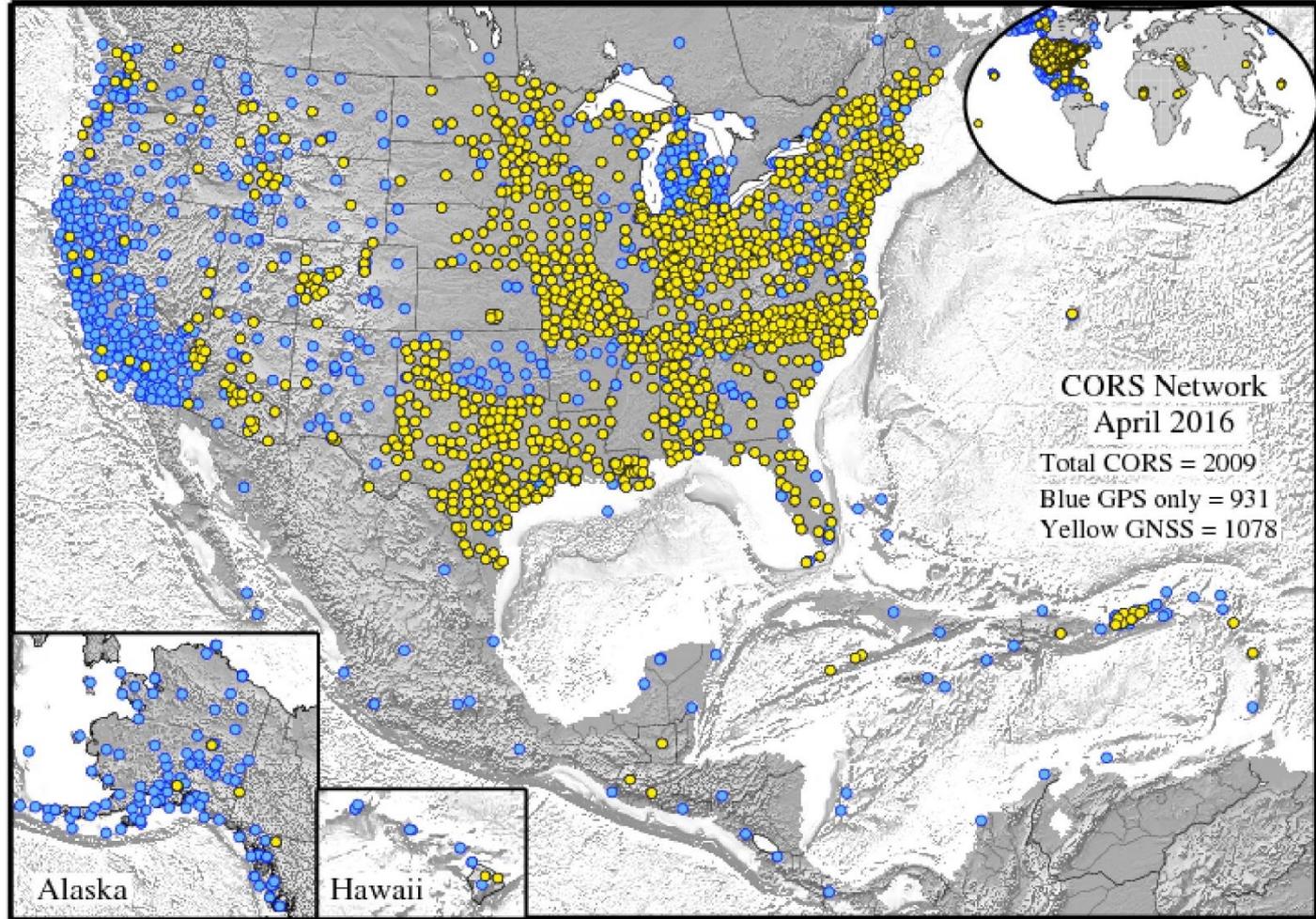# Geodetic Reference Datum of 2022 (tentative)

- Replaces both NAD 83 and NAVD 88
  - Resulting datum is combined
  - Will also include update to IGLD 85, which was based on NAVD 88

- Geometric component
  - Based on IGS 14 or follow on model to define reference frame
  - CORS will be used to augment velocities to better access NSDI
  - Provides consistent coordinates over time referenced to common epoch

- Geopotential component based on EGM and aerogravity
  - Satellite data provides long wavelengths (GRACE, GOCE, CHAMP)
  - GRAV-D project for a centimeter geoid improves mid-wavelengths
  - Terrestrial data provides shortest wavelengths

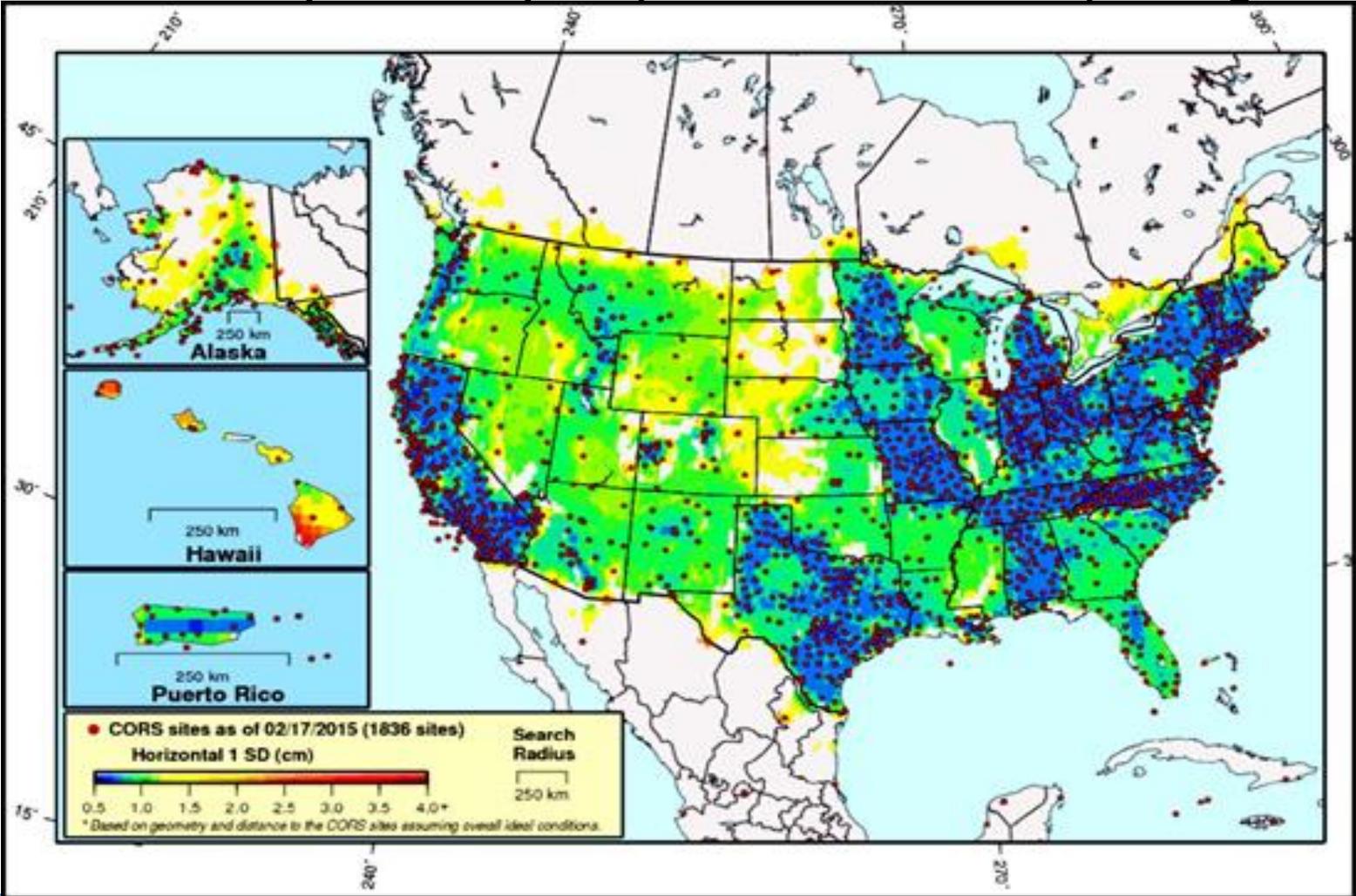- GSVS lines, TBM's and other data used to validate

# Implementation

- Foundation CORS tied to IGS solutions

- Reprocessing yields consistent CORS coordinates and velocities

- Bench Marks are then adjusted to fit CORS control

- GNSS/OPUS coordinates supersede bench mark values

- Velocities applied to revert back to datum epoch (2022.0)

- Effectively provides "fixed" plate & state plane coordinates

- Permits use for RTK positioning at current epoch

Sponsors:

# CORS Network



CORS Network
April 2016
Total CORS = 2009
Blue GPS only = 931
Yellow GNSS = 1078

Alaska          Hawaii

# OPUS-RS Quality Directly Depends on CORS Spacing

# What will a future geopotential frame look like?

- Scientific basis that can be modeled & updated
  - Tied to global MSL, geoid change, MSL rise, local effects

- Built from multiple data sets:
  - Long wavelength (400+ km scale) from satellite (GRACE, GOCE, Champ)
  - Middle wavelengths (40-400 km) GRAV-D aerogravity
  - Short wavelength (40- km) terrestrial gravity and DTM's

- More consistency in heights across the region
  - cm=-level agreement at all scales

- Better ties between geoid (MSL), TBM's (LMSL) & MODT
  - Geoid (MSL) = LMSL - MODT

- Applicable to all countries in the regions (U.S., Canada, etc.)

- Better basis for comparisons with SIRGAS

# A Geopotential Model has Infinite Layers
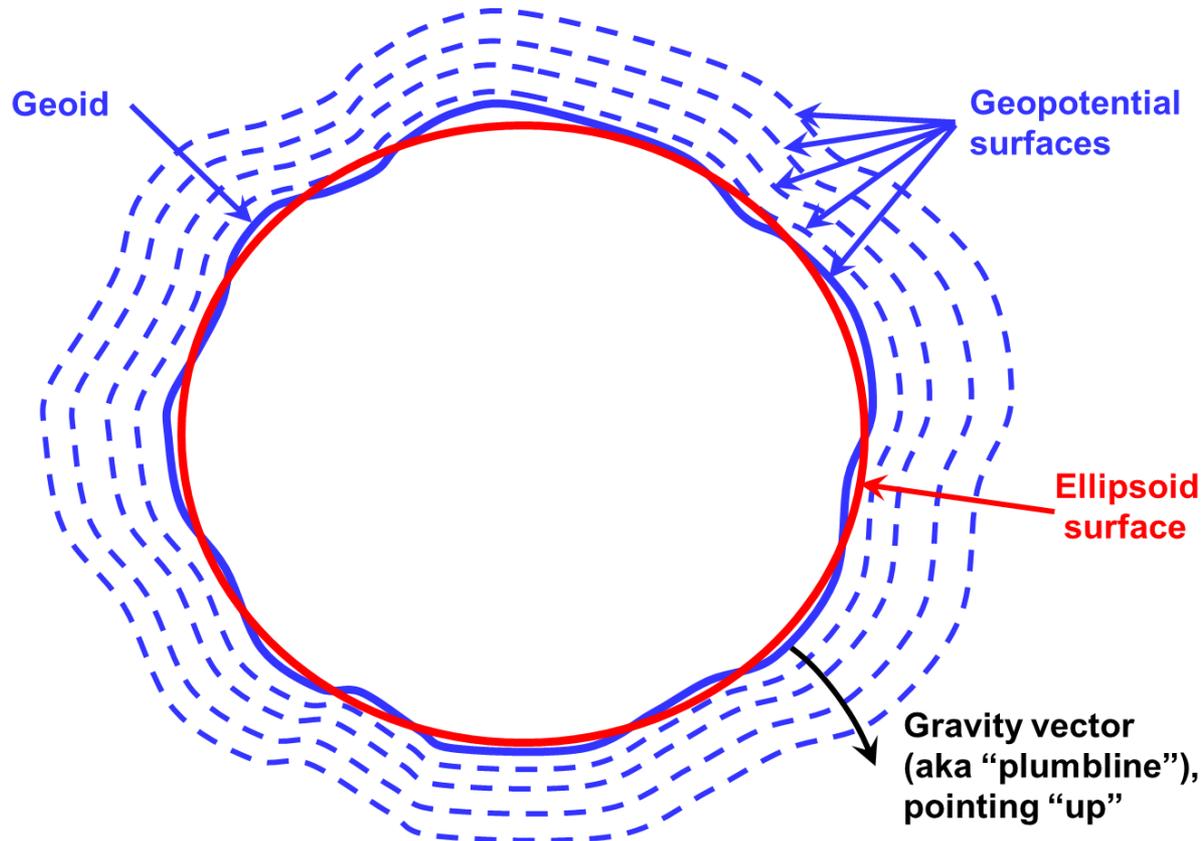


The relationships between the ellipsoid surface (solid red), various geopotential surfaces (dashed blue), and the geoid (solid blue).  The geoid exists approximately at mean sea level (MSL).  Not shown is the actual surface of the earth, which coincides with MSL but is generally above the geoid.

# Which geopotential to pick for datum level or $W_0$?



#pts=188
Mean=56.00
STD=1.429

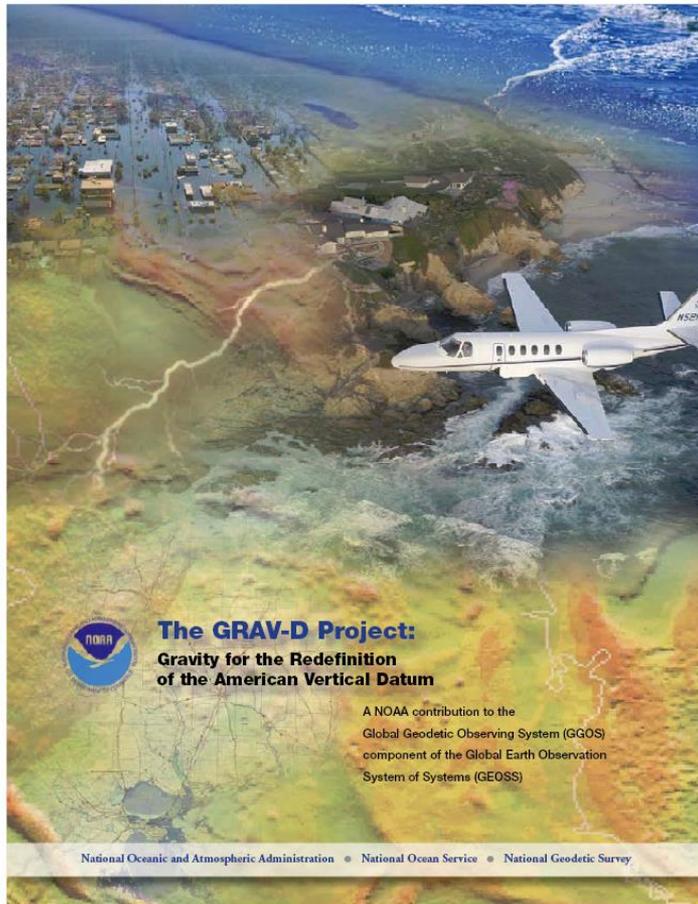W0−62,636,800 at TGs − SST  (m²/s²)

Sponsors:
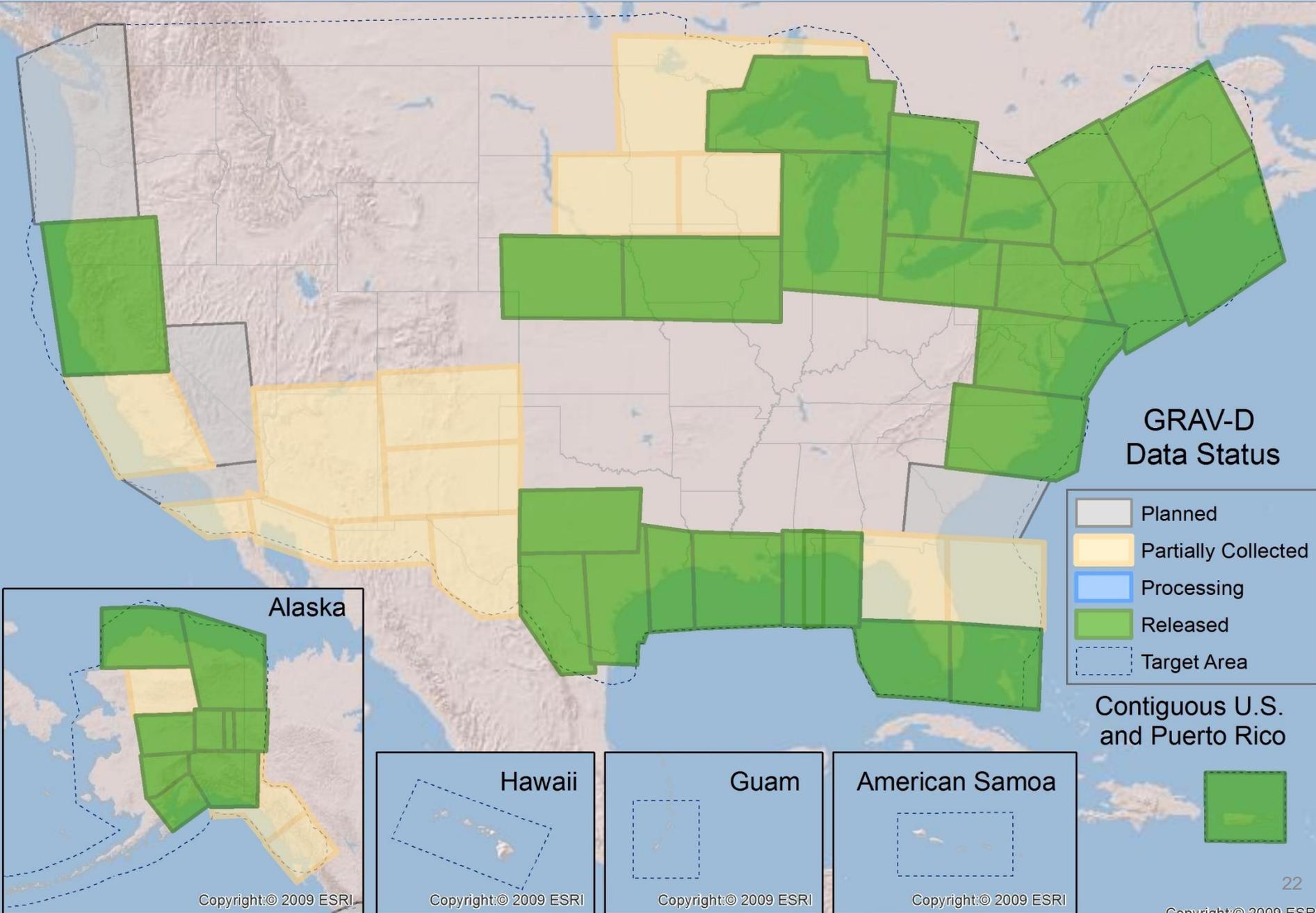
19
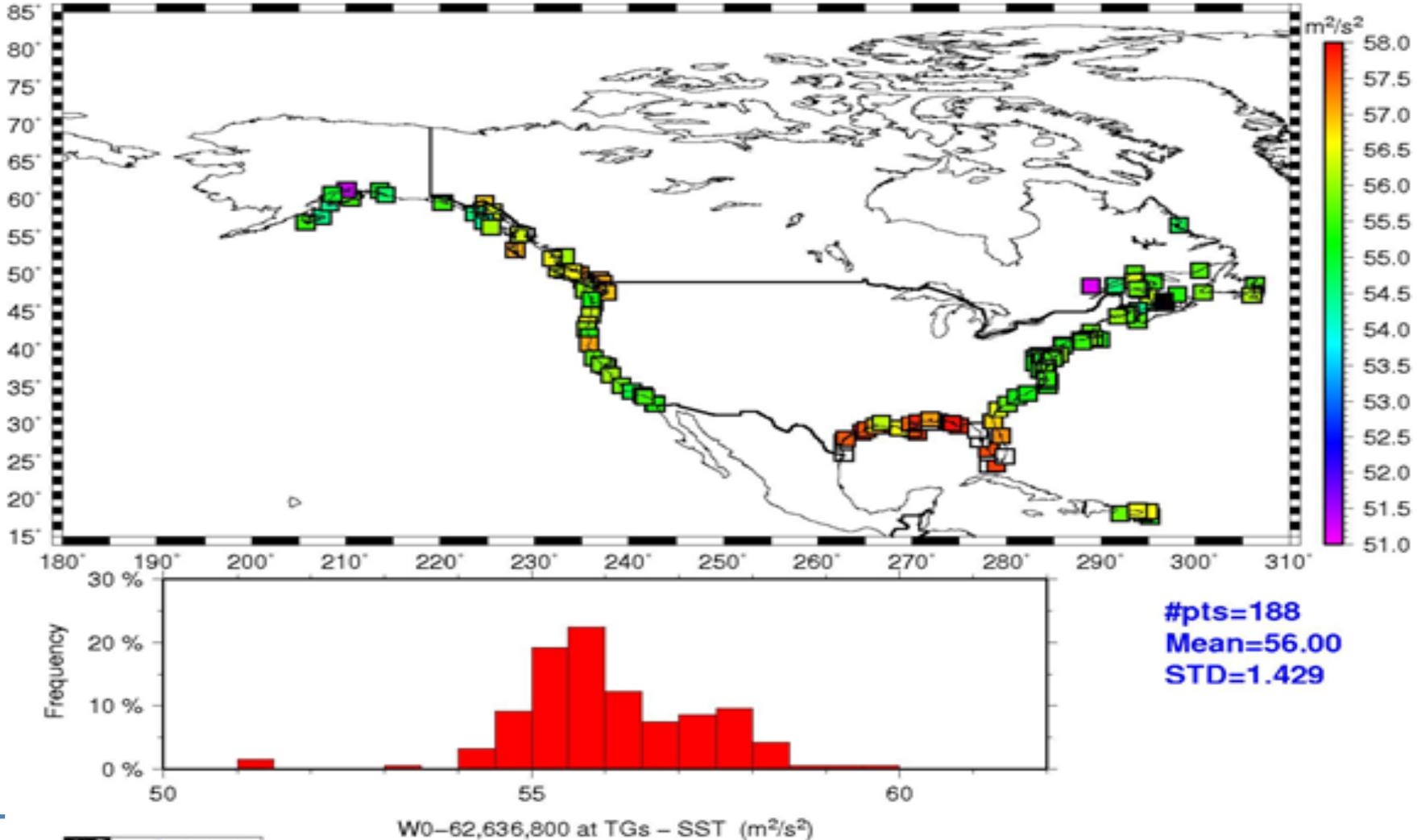
# Gravity Field Power Spectrum
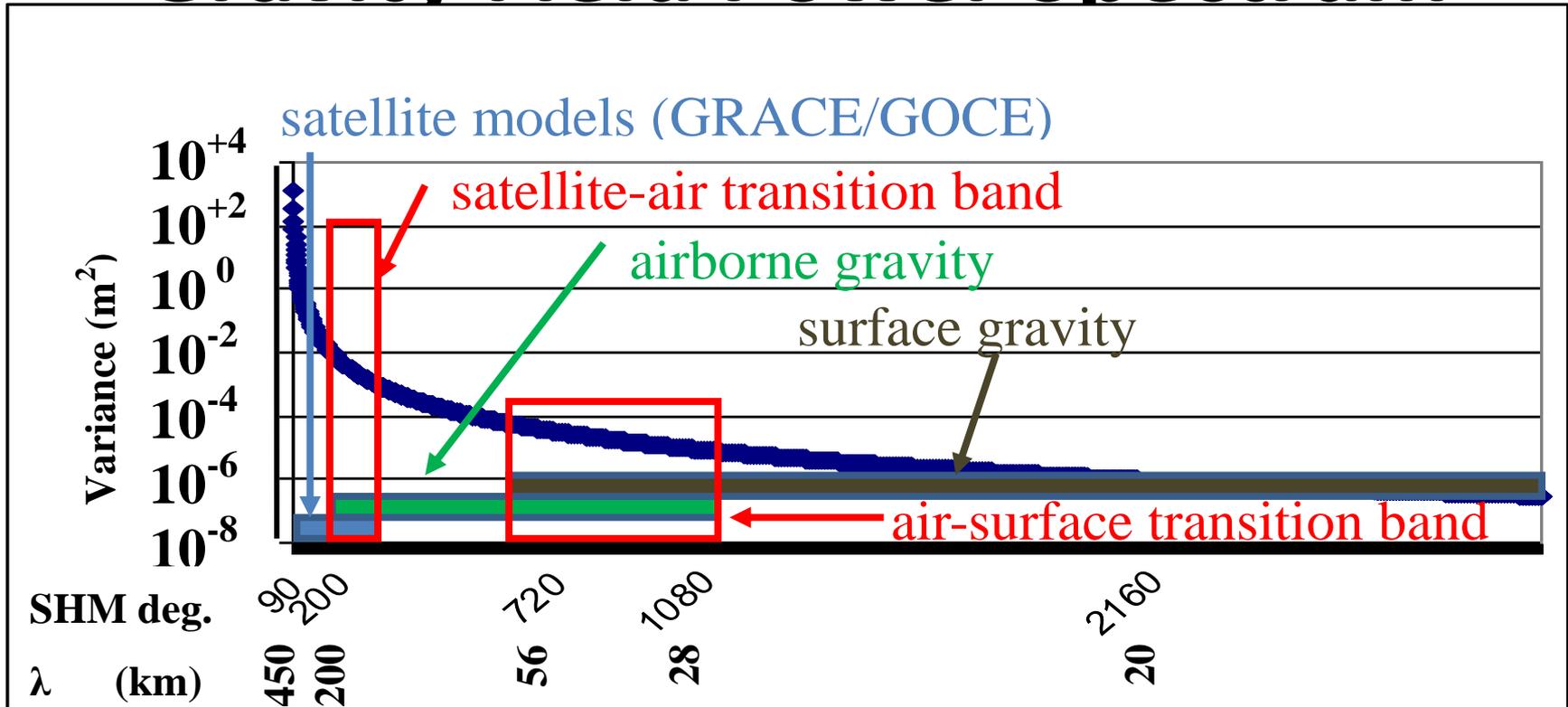


**Power Spectrum plot of gravity field (blue line). Most power is at longest wavelengths (λ) at left on the lowest degree harmonics, where satellite (light blue bar) data dominate. Surface data (brown bar) contain the shortest to the right. Aerogravity (green bar) overlaps both parts of spectrum (red boxes).**

Sponsors: Land Information New Zealand — Toitū te whenua    Leica Geosystems    Trimble.

# GRAV-D Project Overview



The GRAV-D Project:
Gravity for the Redefinition
of the American Vertical Datum

A NOAA contribution to the
Global Geodetic Observing System (GGOS)
component of the Global Earth Observation
System of Systems (GEOSS)

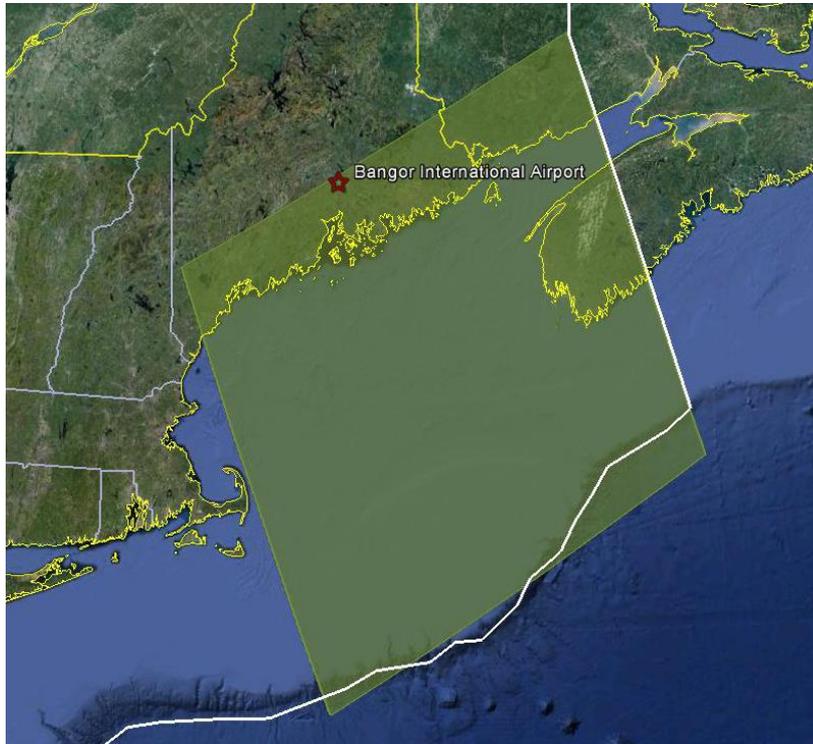National Oceanic and Atmospheric Administration • National Ocean Service • National Geodetic Survey

- **Overall Target**: orthometric heights accurate to 2 cm from GNSS and a geoid model

- **GRAV-D Objective**: Create gravimetric geoid accurate to 1 cm where possible using airborne gravity data

- **GRAV-D**: two phases
  - Airborne gravity survey of entire country and its holdings
  - Long-term monitoring of geoid change

GRAV-D
Data Status

| | Planned |
| | Partially Collected |
| | Processing |
| | Released |
| | Target Area |

Contiguous U.S.
and Puerto Rico
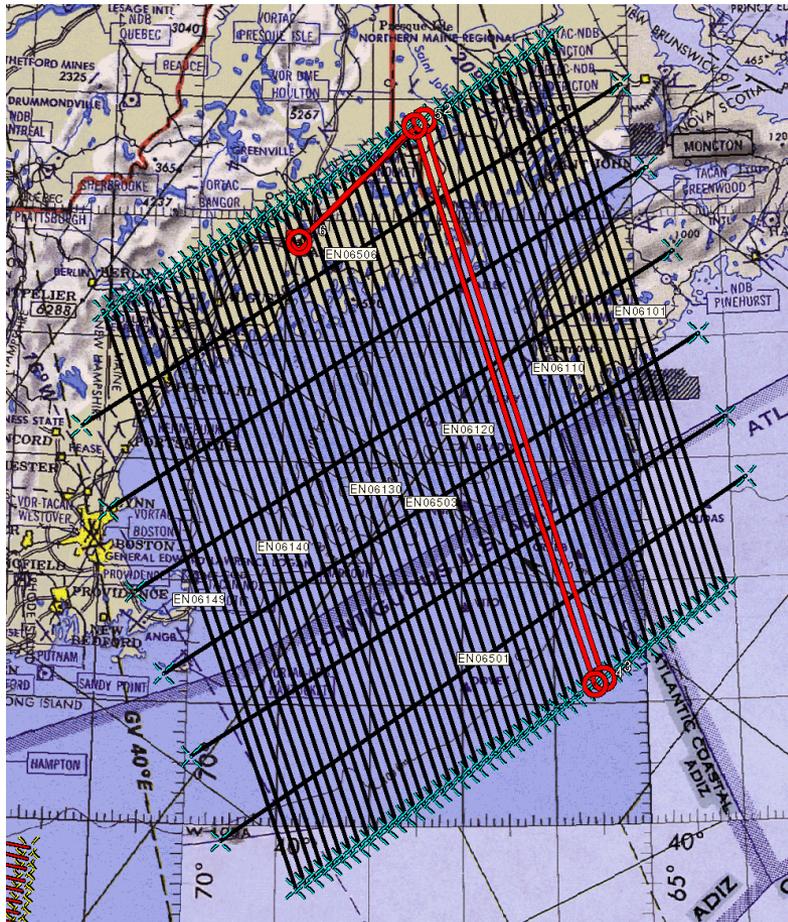
Alaska

Hawaii

Guam

American Samoa

# Survey and Block Plans



- Layout rectangular survey 400 x 500 km

- Extends beyond the shelf break

- Block size will be limited to the endurance of the aircraft or areas remaining to be collected

# Survey and Block Plans



- Data lines spaced 10 km apart

- Cross lines spaced 60-80 km apart

- Flight altitude 20,000 ft

- Nominal speed 220-250 kts

# Experimental Geoids

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

- Methods for blending will be tested to prepare for 2022

- Available on the Website



http://beta.ngs.noaa.gov/GEOID/xGEOID/
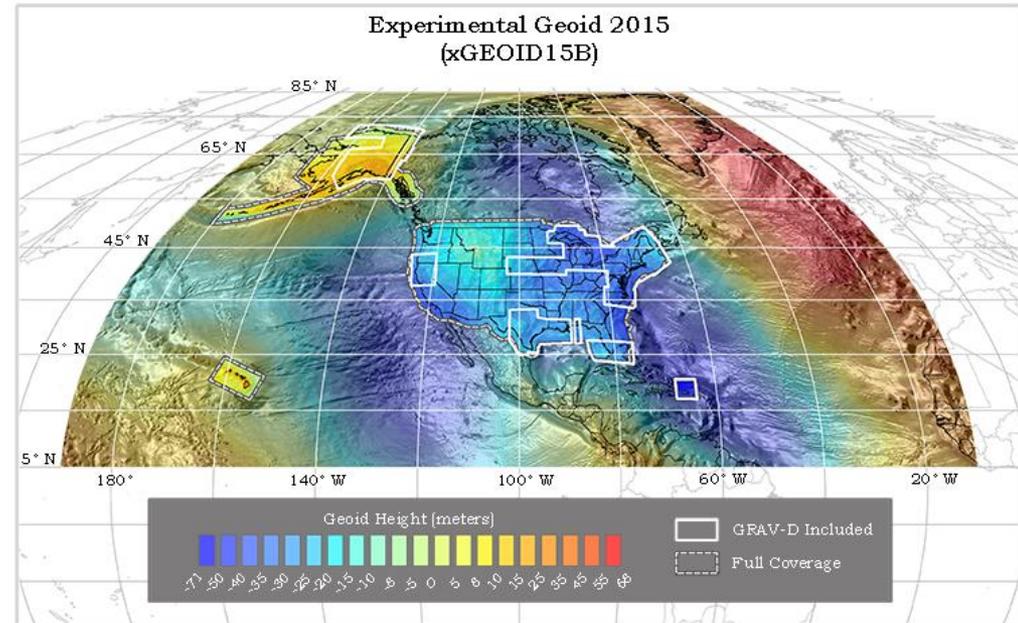
# Summary

- Existing datums have known meter level errors

- New datum will combine geometric and geophysical datums

- Geometric coordinates from 15 minutes GNSS data at cm-level

- Requires significant improvements to existing infrastructure

- Possibly achieved using OPUS-RS or similar product

- Geometric coordinates access the geopotential model

- Determines orthometric heights for leveling base stations

- RTN/RTK provides potential extender but is not a part of NSRS

# Questions?

Daniel R. Roman Ph.D.

+1-301-713-3200

Dan.roman@noaa.gov