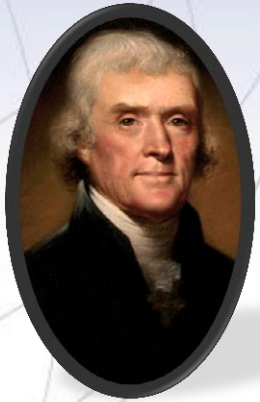
# How to Connect GNSS CORS to ITRF and Geospatial Datasets

**Edward E. Carlson**

**NOAA, National Geodetic Survey**
**Pacific Region Geodetic Advisor**
**ed.carlson@noaa.gov**

# The National Geodetic Survey (NGS)

## Our Nation's first science agency

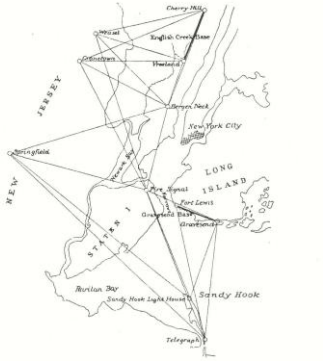


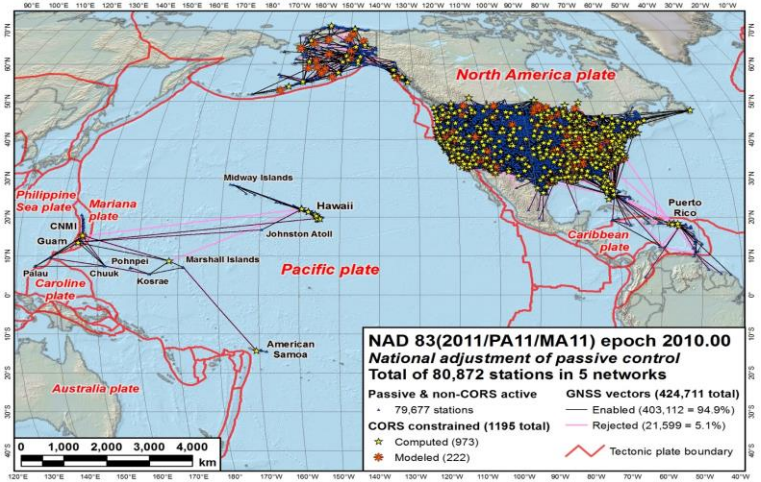
**1807**
**Thomas Jefferson**
**Survey of the Coast**

**1807**
**Ferdinand R. Hassler**
**First Superintendent**

**1878**
**U.S. Coast and Geodetic Survey**

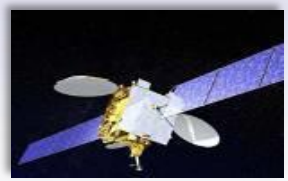
**1970**
**NOAA is established**



# NGS Provides the Geospatial Infrastructure Critical to Our Economy through the NSRS





Satellite Operations




Personal Navigation






Survey Marks

# NGS Programs

## Modernizing the NSRS

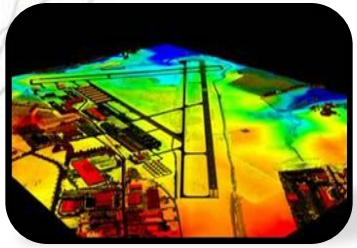
CORS

Height Modernization

GRAV-D

Ecosystem and Climate Operation

## NGS Products and Services

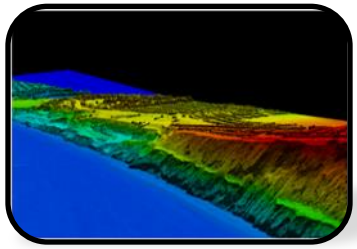


Airport Surveys

OPUS

VDatum

GPS Satellite Orbits



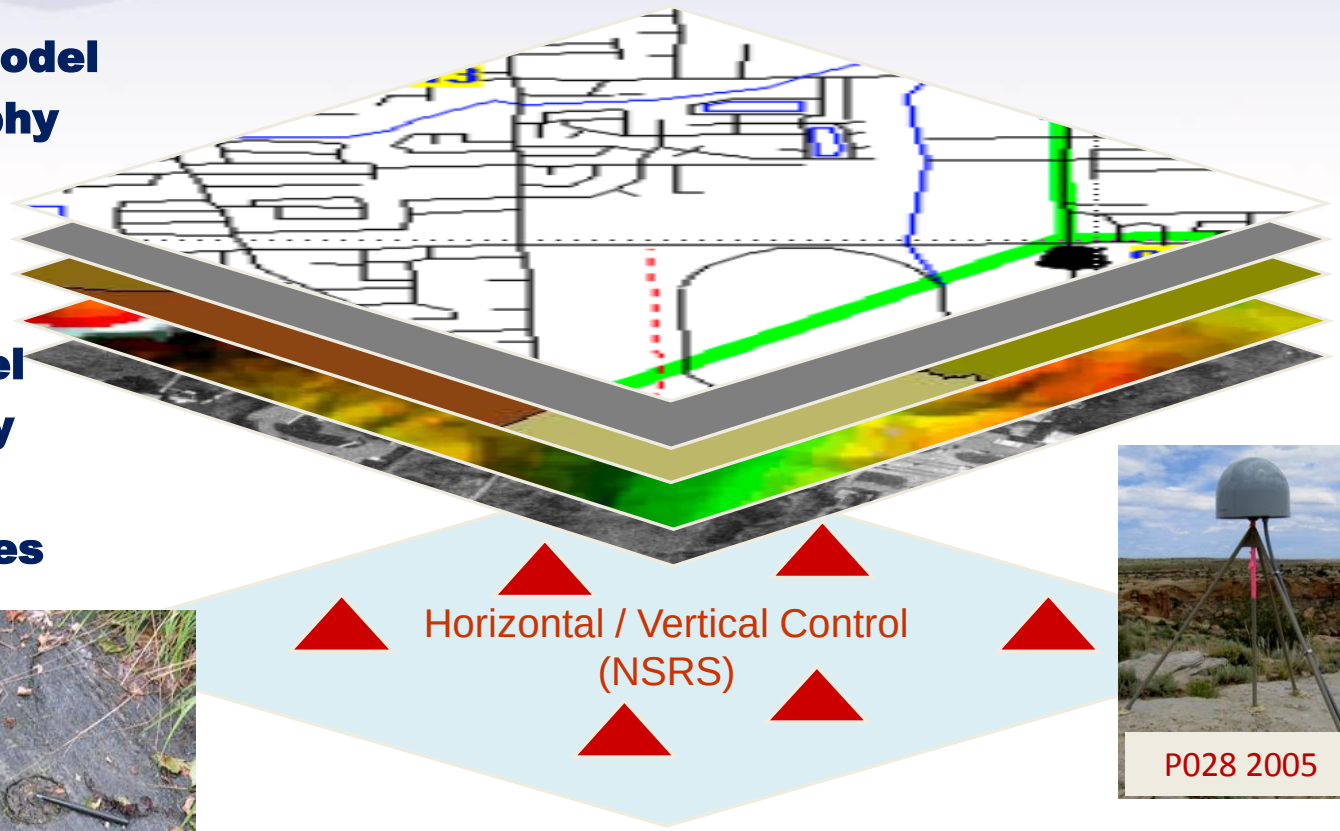
Coastal Mapping


Regional Advisor Program

Emergency Response Imagery

# National Spatial Reference System
## Ties It All Together

- LiDAR
- Digital Terrain Model
- Aerial Photography
- Cartography
- Parcels
- Engineering
- Laser Scan Model
- Satellite Imagery
- Hydrography
- Natural Resources

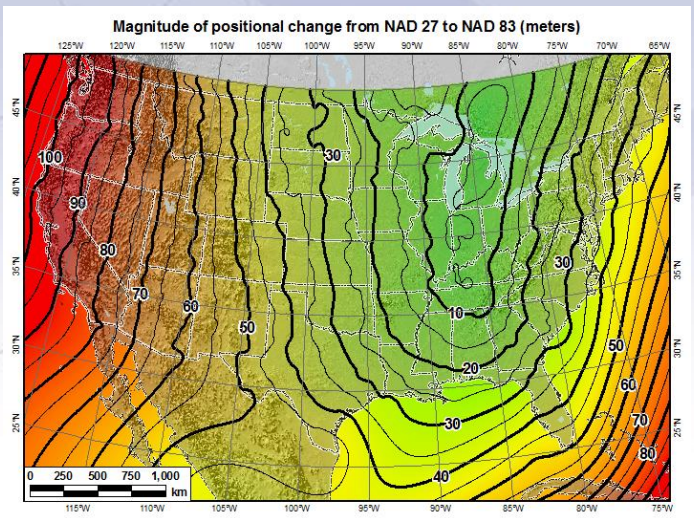



BUTTERMILK 1833



P028 2005

# NSRS - Evolved Over Time





U.S. Standard Datum

NAD27

NAD83 (1986)

NAD83 (HARN /199X)

NAD83 (2007)

**NAD83 (2011)**

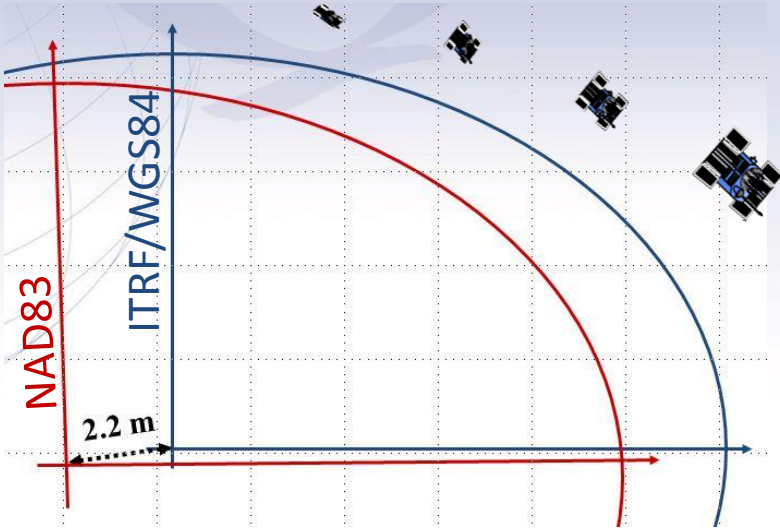
time

< 10m | ~ 10m | 1m | 0.1m | 0.01m | 0.01m

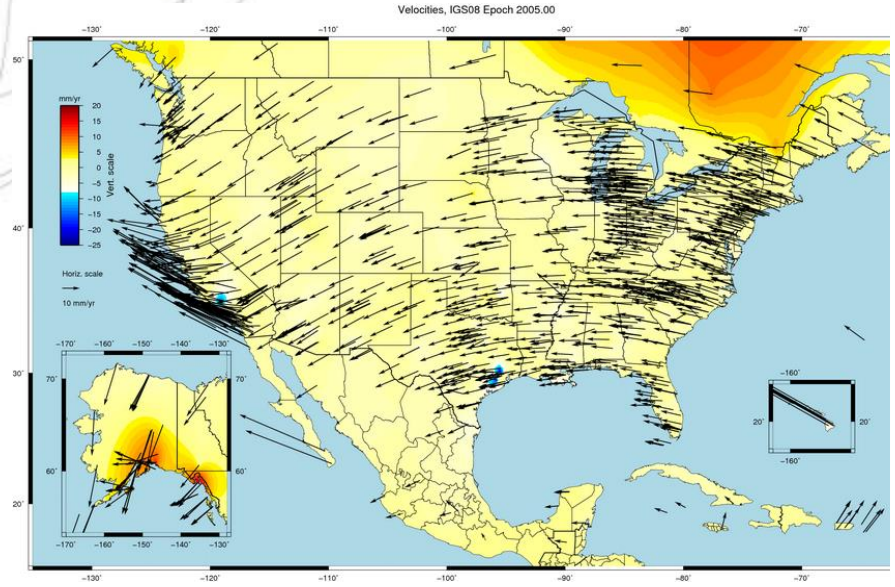
Network Accuracy

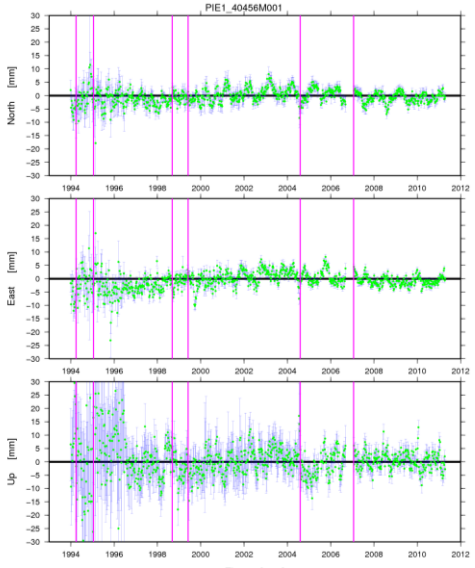
# NAD83 Shortcomings

- 2.2 m offset – NAD83 vs.
- International Terrestrial Reference Frame (ITRF) [~ International GNSS Service (IGS)]
- World Geodetic System 1984 (WGS84)

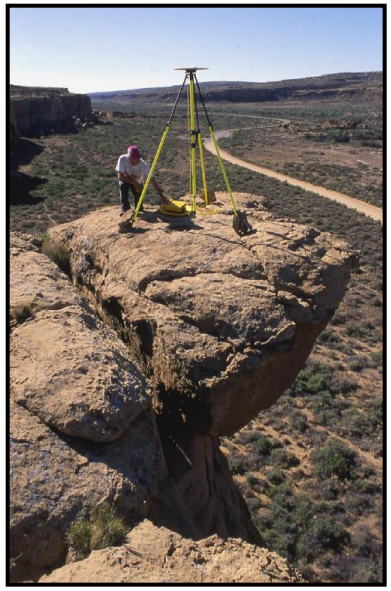



- CORS <> passive network "disconnect"




vs.



# Why replace NAD 83 & Vertical Datums?

- **Main driver:** ***Global Navigation Satellite System (GNSS)***
- **ACCESS!**
  - GNSS equipment is fast, inexpensive, reliable (and improving)
  - Reduces reliance on finding survey control ("bench marks")
- **ACCURACY!**
  - Insensitive to distance-dependent errors; reliable
  - Immune to bench mark instability (referenced to CORS)
- **CONSISTENCY!**
  - Eliminates systematic errors in current datums
  - Aligned with global reference frames
  - Integrated system for both positions and heights ("elevations")

# The National Geodetic Survey Ten-Year Plan

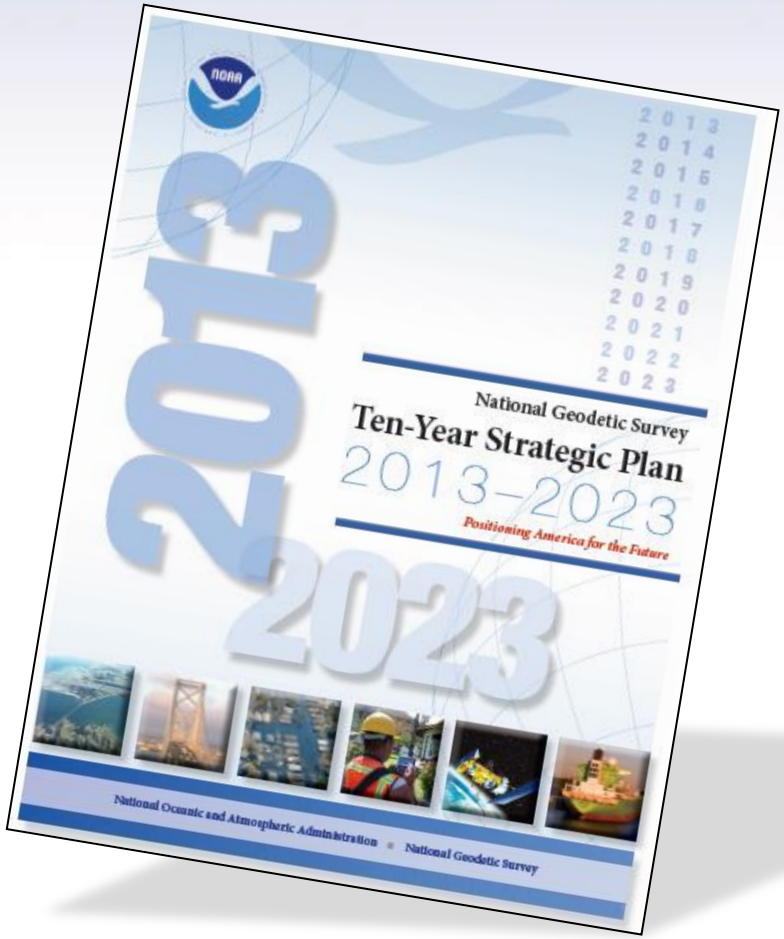
**Support the users** of the National Spatial Reference System.

**Modernize and improve** the National Spatial Reference System.
***( i.e., Replace NAD83 & NAVD88 )***

**Expand** the National Spatial Reference System stakeholder base through partnerships, education, and outreach.

**Develop and enable** a workforce with a supportive environment.

**Improve** organizational and administrative functionality.



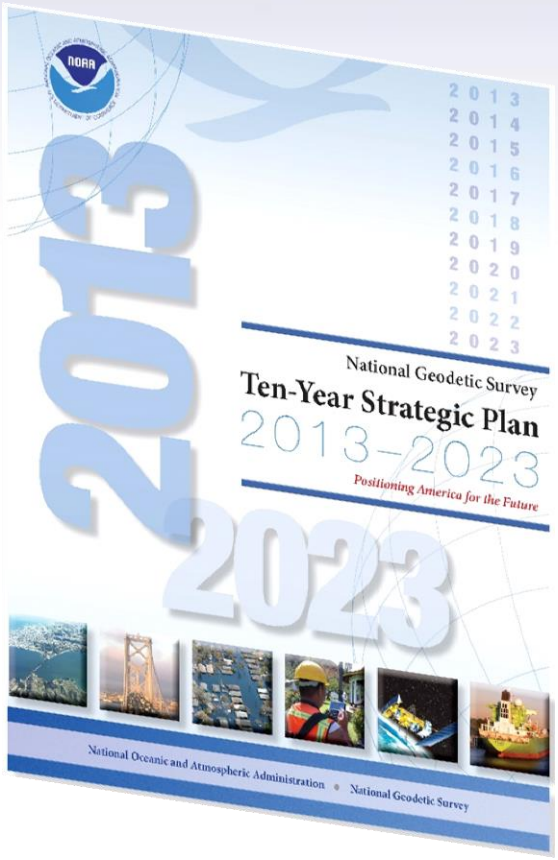

**http://www.ngs.noaa.gov/web/news/Ten_Year_Plan_2013-2023.pdf**

# 2022 Datums Goals

- **"Replace NAD83"** - By 2022, reduce all definitional & access-related errors in geometric reference frame to 1 cm when using ~15 min of GNSS data

- **"Replace NAVD88"** - By 2022, reduce all definitional & access-related errors in orthometric heights, relative to sea level, in geopotential datum to 2 cm when using ~15 min of GNSS data

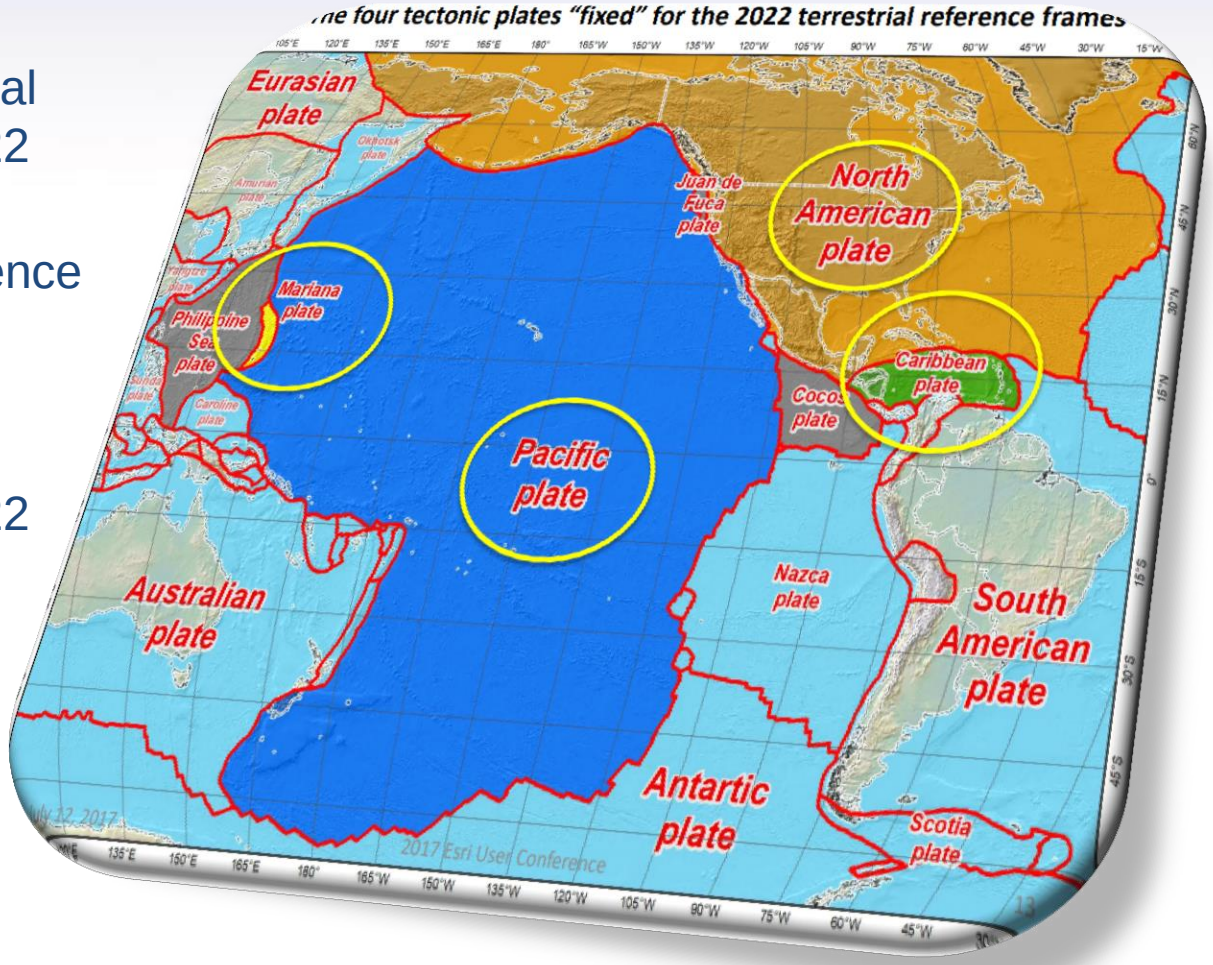
- Provide tools to easily transform between new old datums



# Four Tectonic Plates NGS Monitors

**In 2022, the entire National Spatial Reference System (NSRS) will be modernized and will contain four new reference frames:**

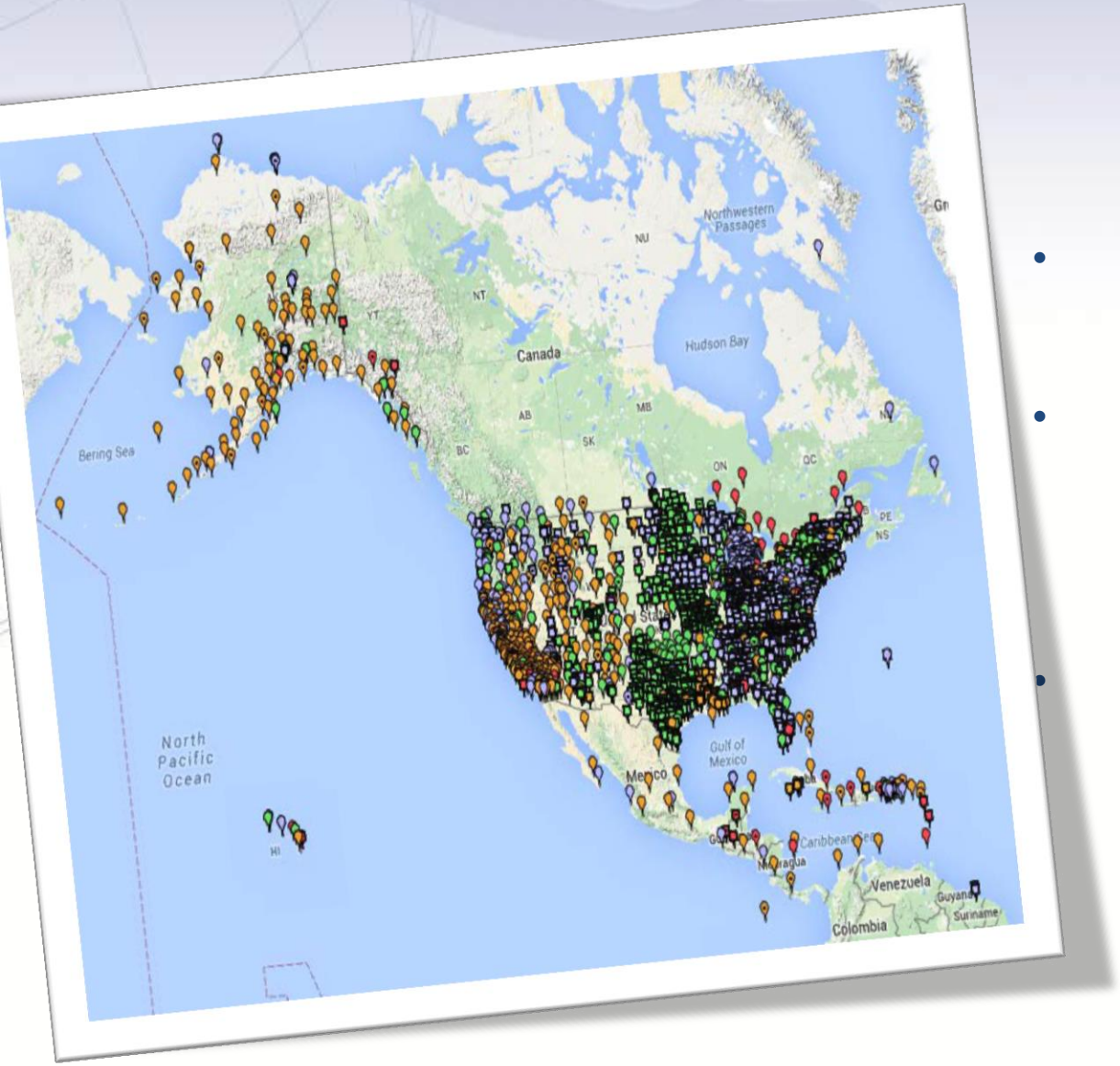
- ✓ North American Terrestrial Reference Frame of 2022 **(NATRF2022)**
- ✓ Pacific Terrestrial Reference Frame of 2022 **(PATRF2022)**
- ✓ Caribbean Terrestrial Reference Frame of 2022 **(CATRF2022)**
- ✓ Mariana Terrestrial Reference Frame of **(MATRF2022)**



# Guiding Principals

- By 2022, the National Spatial Reference System (NSRS) will be modernized with CORS becoming a more foundational component.
- The International Earth Rotation and Reference Systems Service (IERS) International Terrestrial Reference System (ITRF) will continue to be the worldwide standard reference system.
- NGS will continue to support the ITRF through International GNSS Service (IGS) reference sites.
- The NSRS will continue to be defined in relation to the ITRF.

# Current Continuously Operating Reference Stations (CORS)




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

# Foundation CORS Requirements

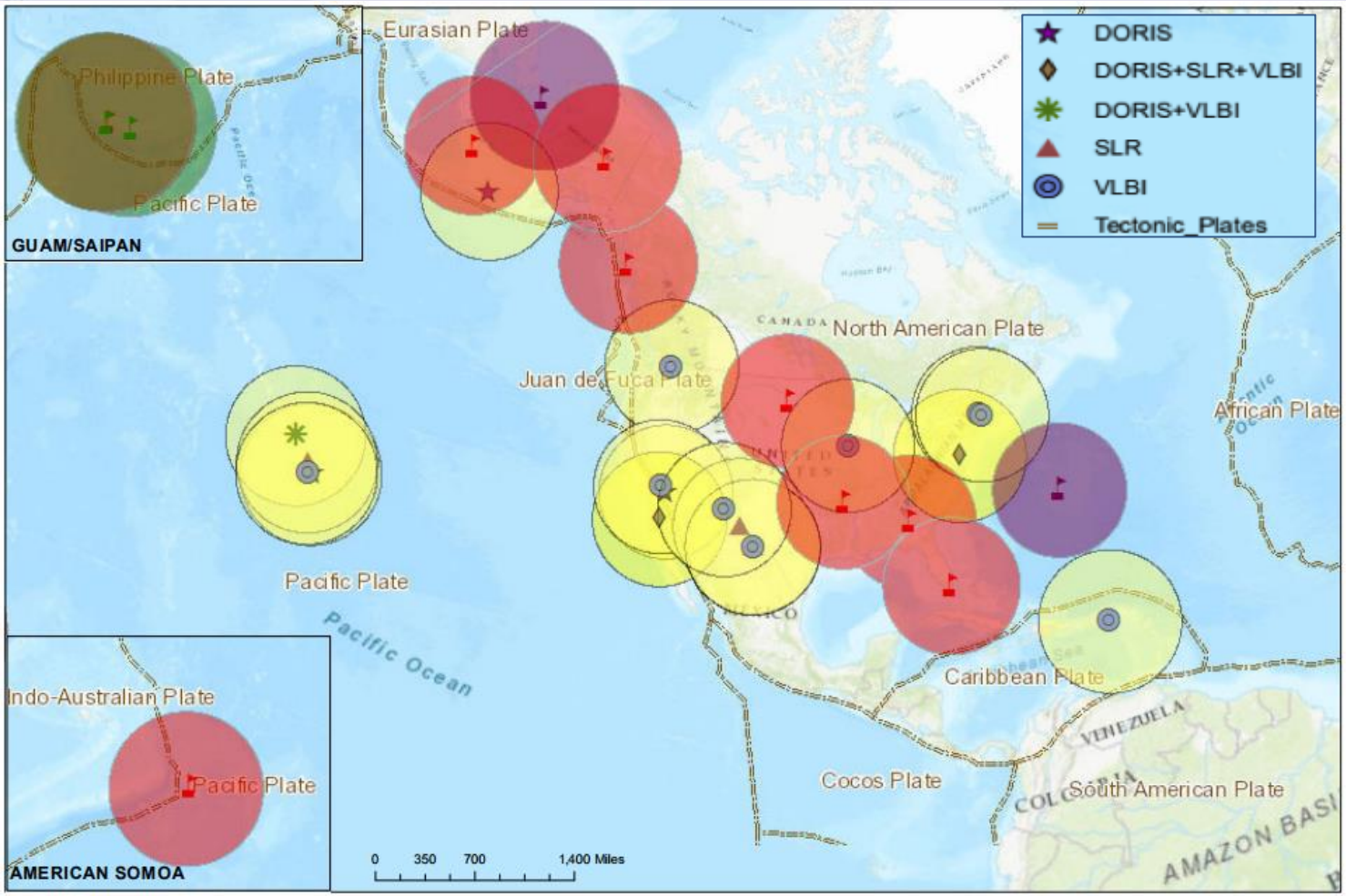
- **Baseline Foundation CORS Network:**
  - **COLLOCATE - All Sites** within the Foundation CORS target area of the United States, that have an existing space geodetic techniques **(SLR, VLBI or DORIS)** will have a collocated Foundation CORS

- **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.

# Foundation CORS tentative target

Criteria

1. Co-located with space-based technology
2. Density
3. Euler pole
4. Additional site (Bermuda)

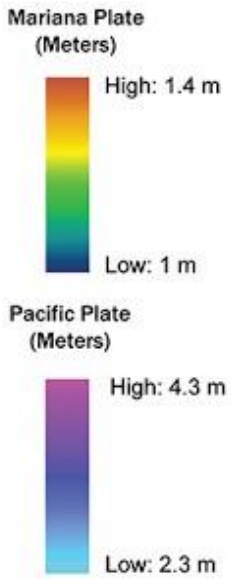


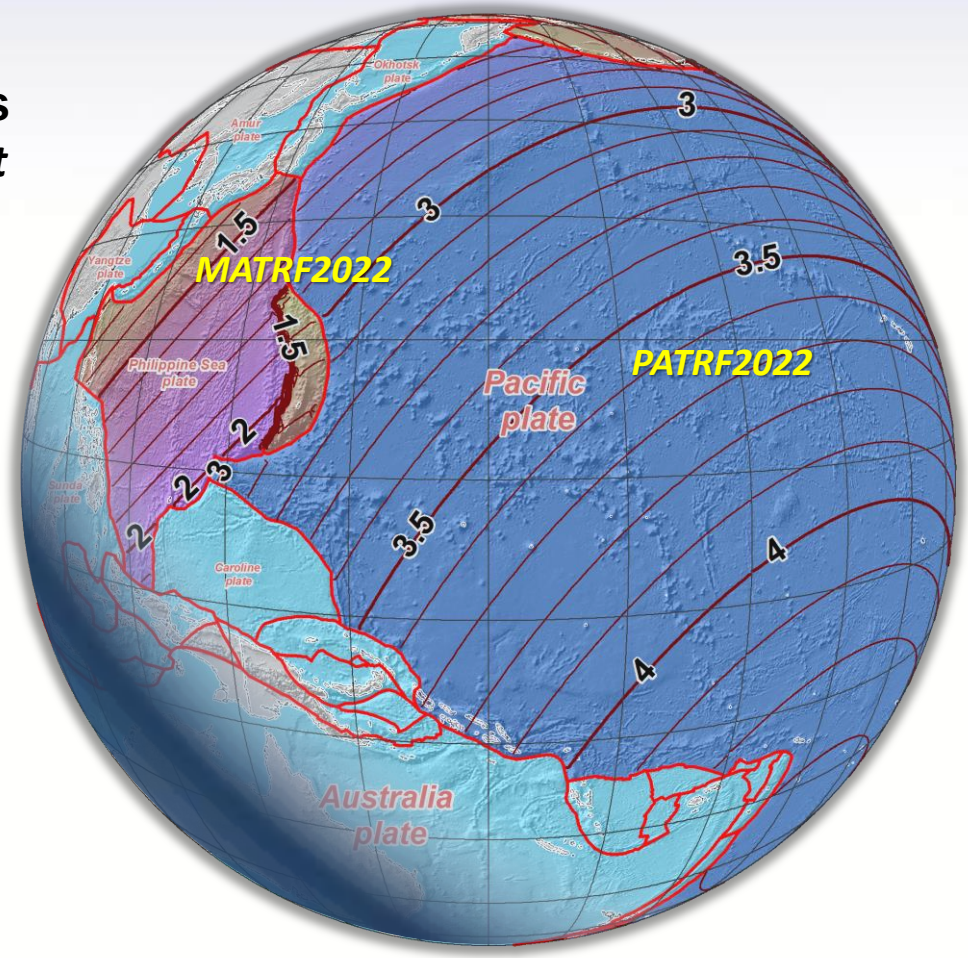
# Approximate Horizontal Change

**NAD 83 (2011/PA11/MA11) epoch 2010.00 → 2022 Terrestrial Reference Frames**

***Horizontal change at epoch 2022.00***

***(contours in meters)***

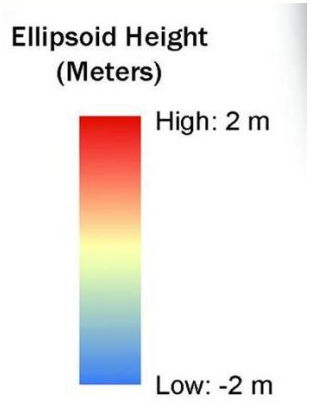


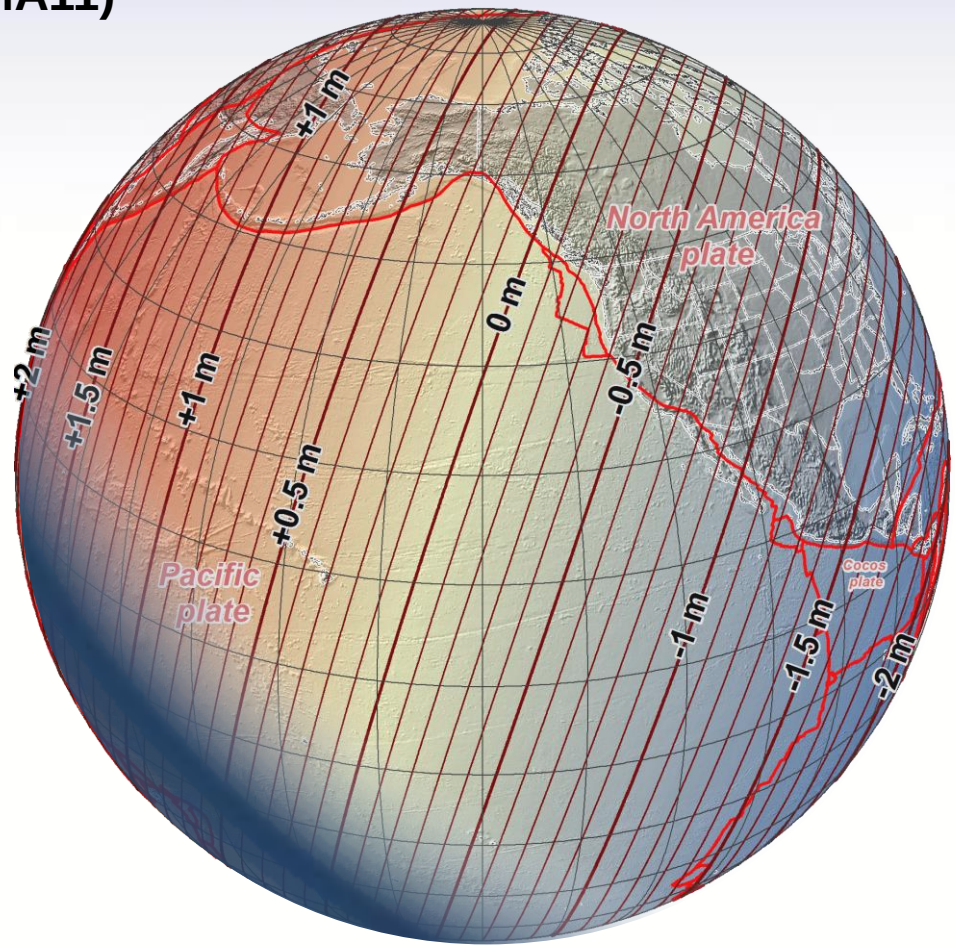



# Approximate Ellipsoid Height Change

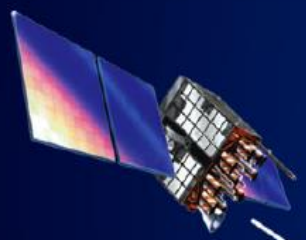
**NAD 83 (2011/PA11/MA11) epoch 2010.00 → 2022 Terrestrial Reference Frames**

***Change in ellipsoid heights at epoch 2022.00***
***(contours in meters)***



# How Geodesists View the World



Earth's Surface

Sea Level (geoid)

Ellipsoid

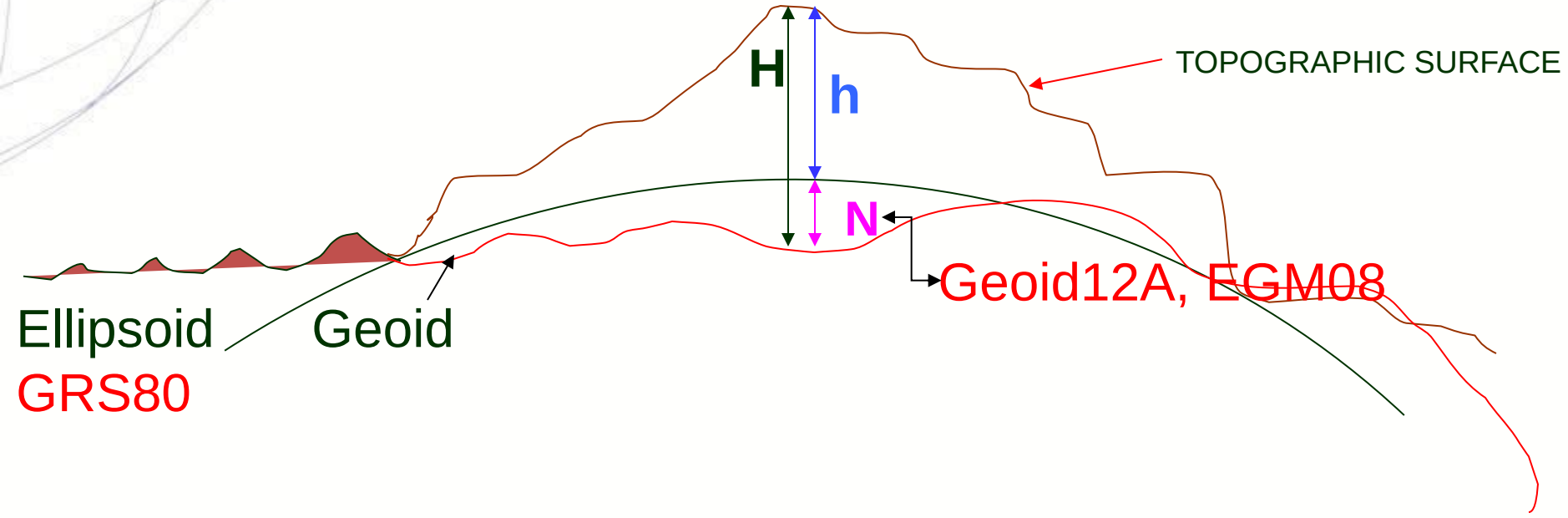
# ELLIPSOID - GEOID RELATIONSHIP

**H = Orthometric Height (Mean Sea Level)**

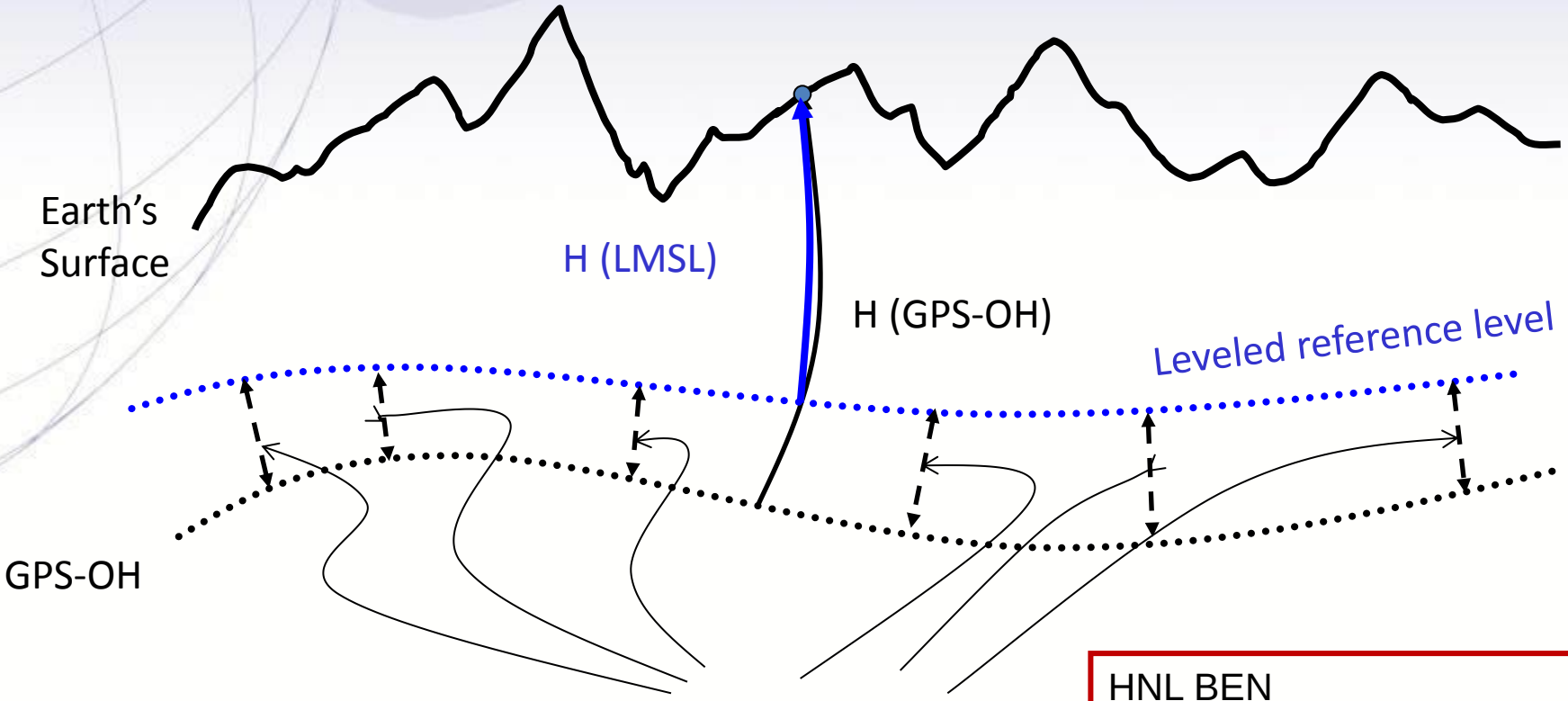
**h = Ellipsoidal Height (NAD 83)**

**N = Geoid Height (GEOID12A, EGM08)**

$$H = h - N$$



# Problems in NAVD88



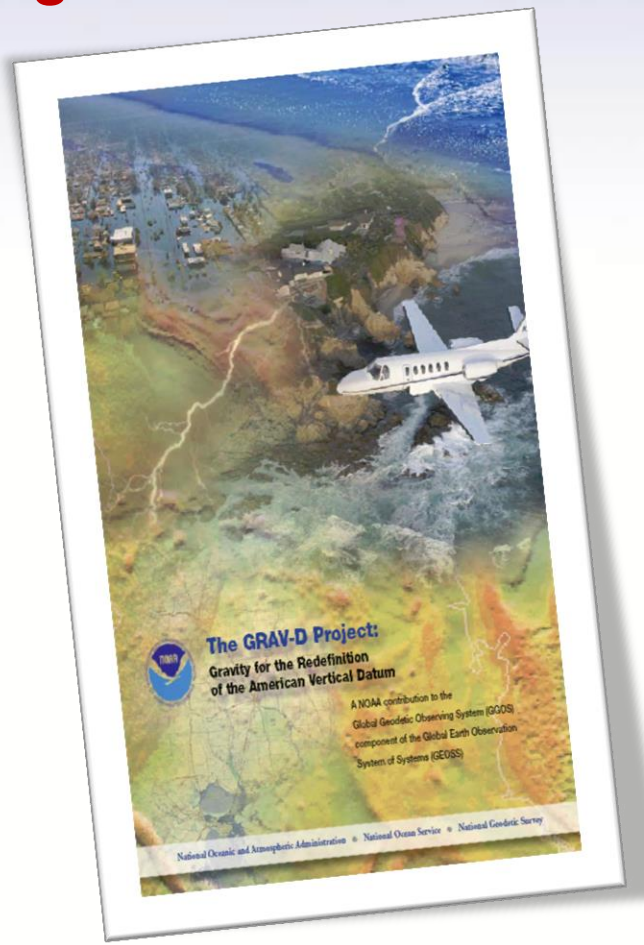

**Errors : ~50 cm average,**
**100 cm CONUS tilt,**
**50/70 cm in Hawaii**
**1-2 meters average in Alaska**

HNL BEN
Geoid12A
5.894 = 21.090 – (+15.196)m
5.894 = 5.320m (LMSL)
Difference ~ 0.574m or 1.87ft

# 2022 Vertical Datum

- Changing from a ***leveling-based*** to a **geoid/GNSS-based** vertical datum

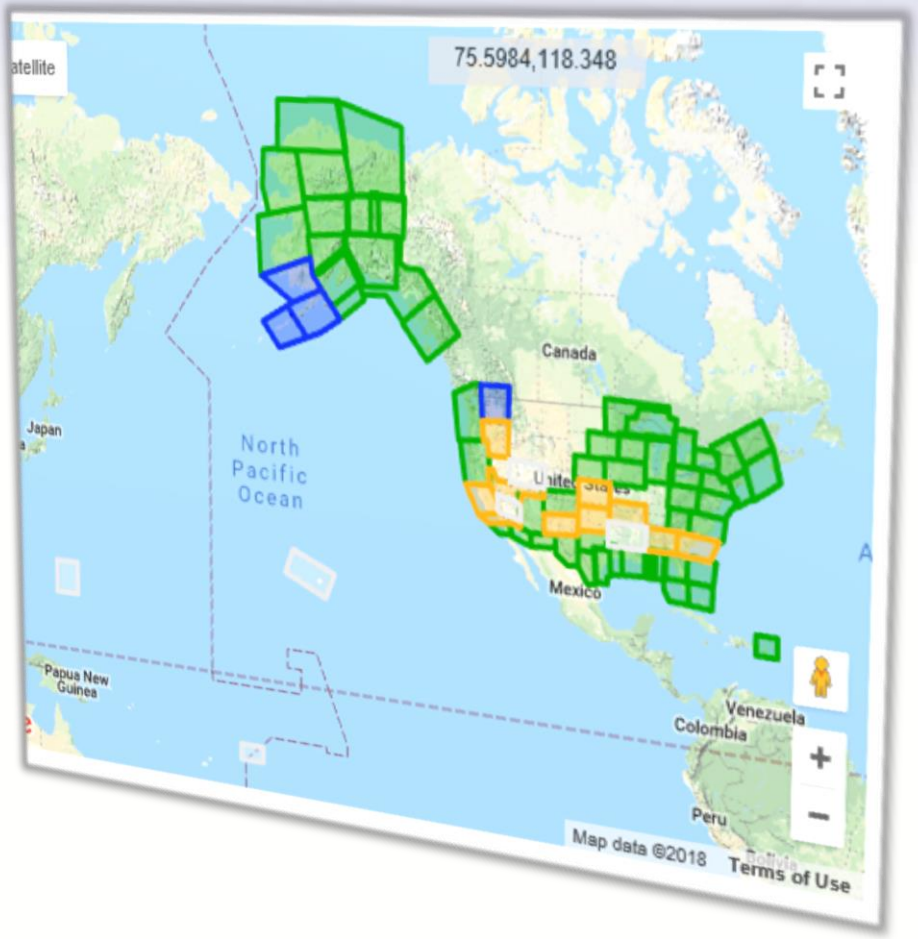
- Biggest requirement: An updated, accurate, nationwide gravity survey
  - Airborne
  - GRAV-D!
    - **G**ravity for the **R**edefinition of the **A**merican **V**ertical **D**atum




http://www.ngs.noaa.gov/GRAV-D/pubs/GRAV-D_v2007_12_19.pdf

# GRAV-D

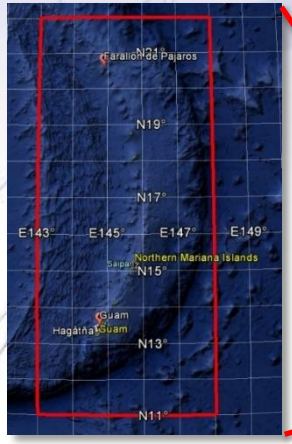
- Two aircrafts at a time
  - Occasionally three
- Mix of **Government and Private** Industry Flights
- Experiments with G4
  - Were successful, begin using G4 to collect Pacific states and territories as early 2019.



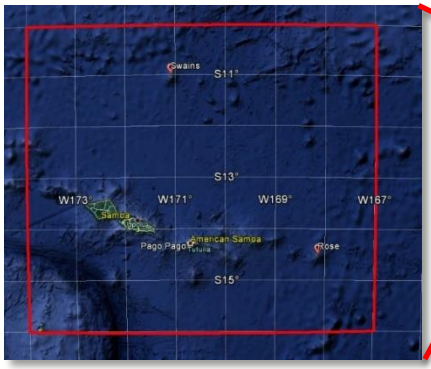

**100% BY 2022**

# Extent of Gravimetric Geoid Model NAPGD2022

Guam and Northern Marianas Islands




American Samoa




# International Coordination

- IAG (Comm. 1 & 2)
  - ITRF/IHRF
  - SIRGAS
  - APREF
- UN-GGIM
  - UN-GGRF
  - UN-GGIM-Americas
  - UN-GGIM- AP
- FIG et al.
- ISO – TC 211, TC 172
- GLCC – IGLD update

# Positioning With 2022 Datum

# Four Frames/Plates in 2022

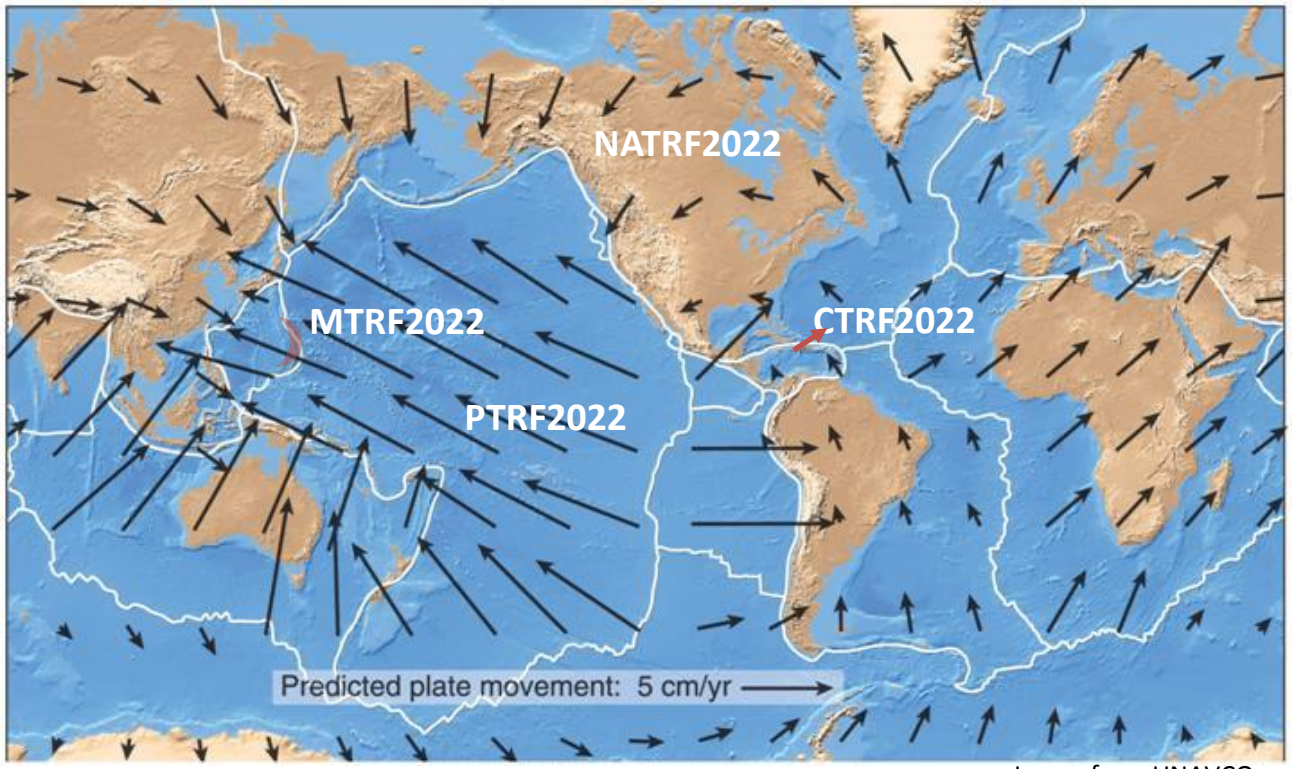


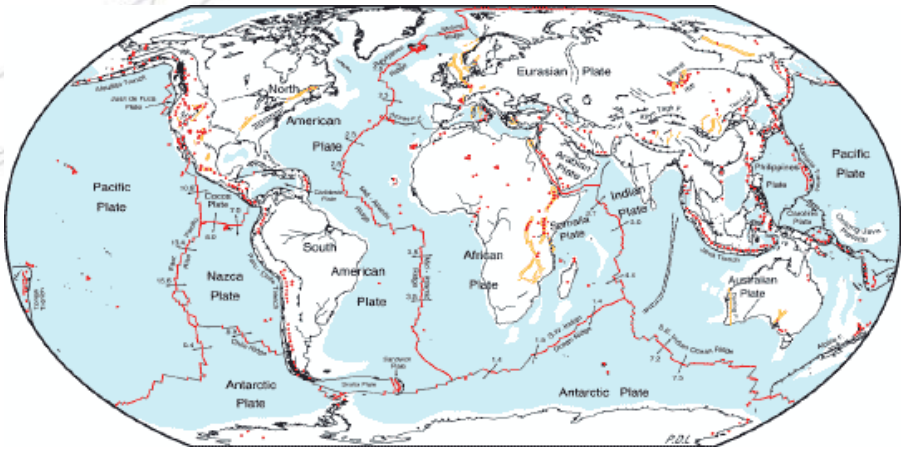

Image from UNAVCO

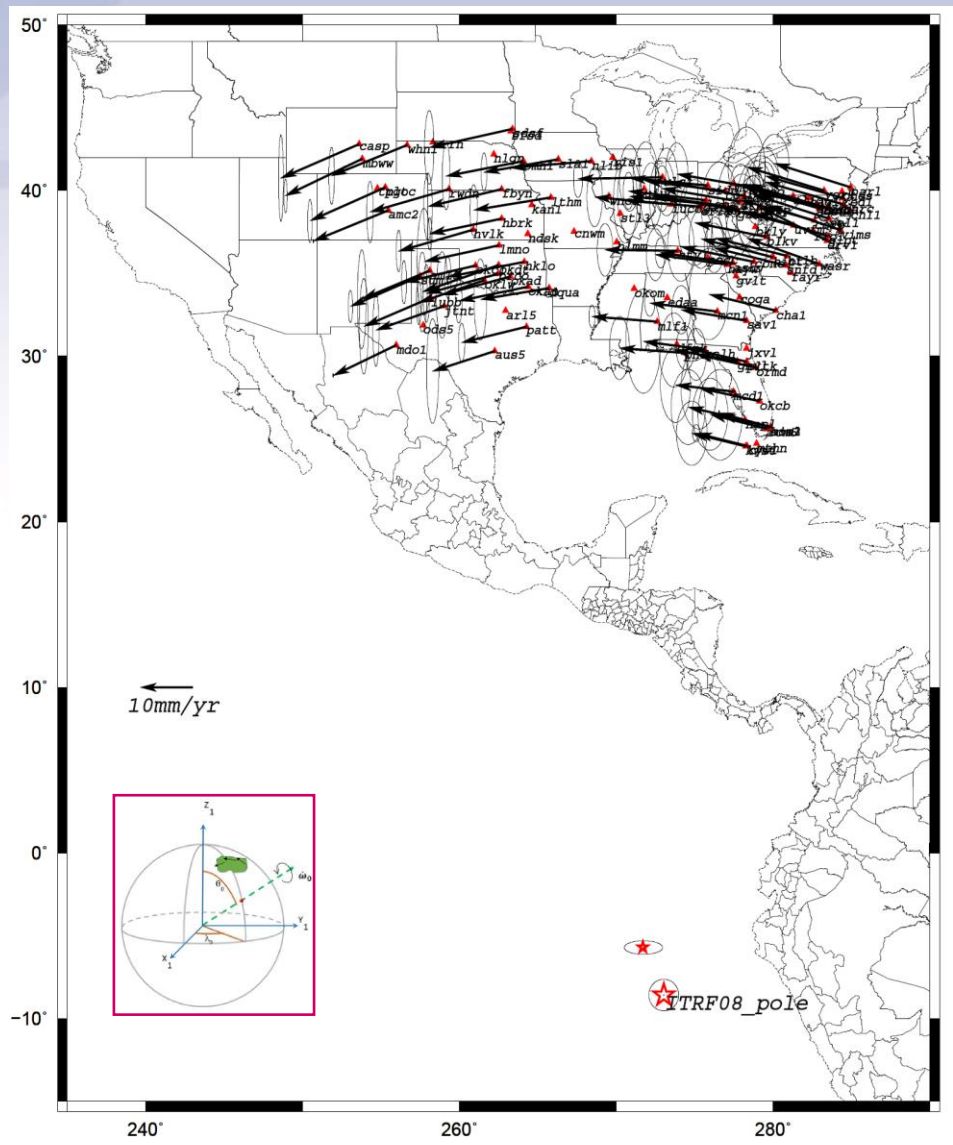
# Euler Pole

Each reference frame will get:

- Euler Pole Latitude/Longitude
- Rotation rate (radians/year)

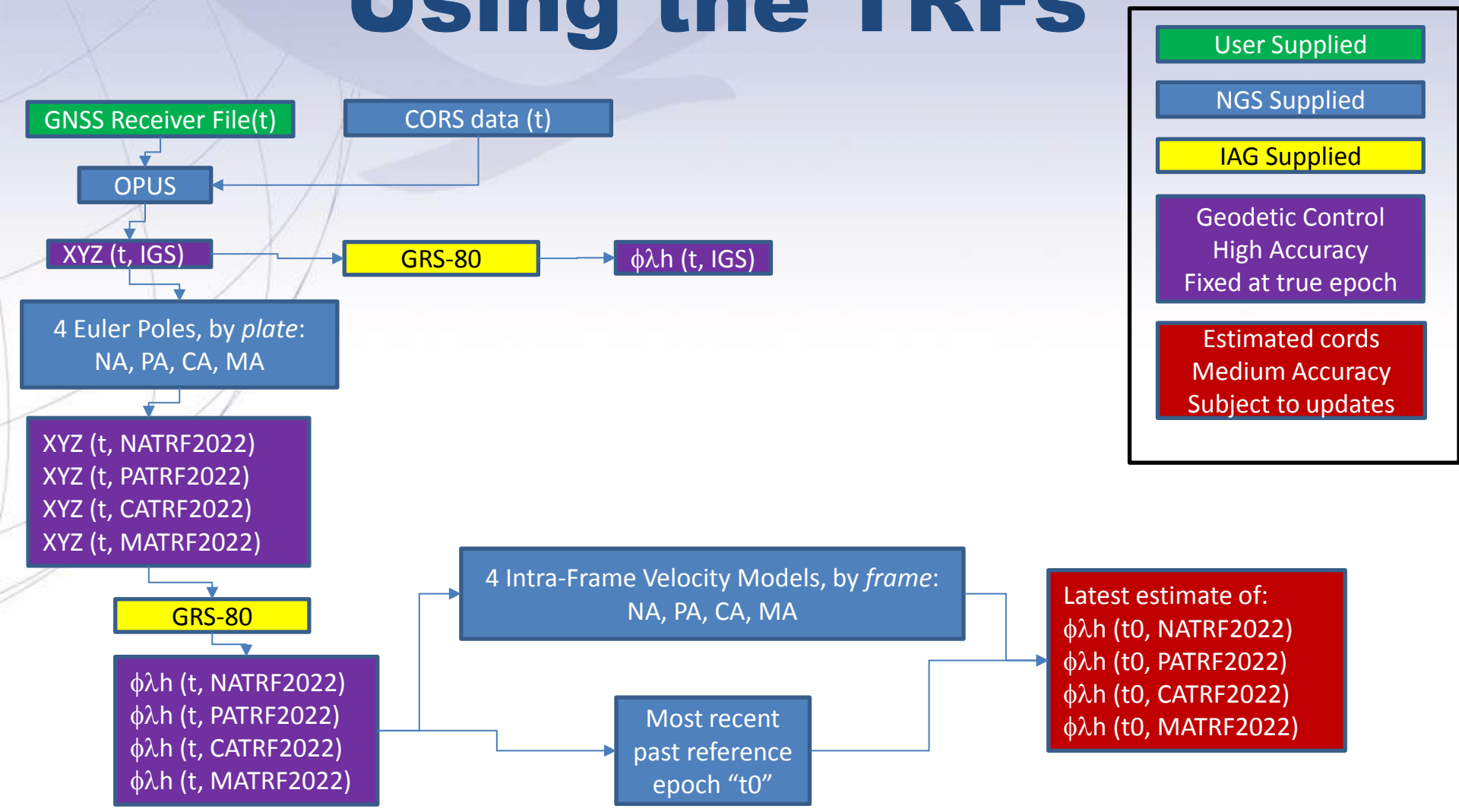
Used to compute time-dependent TRF2022 coordinates from time-dependent global (IGS) coordinates



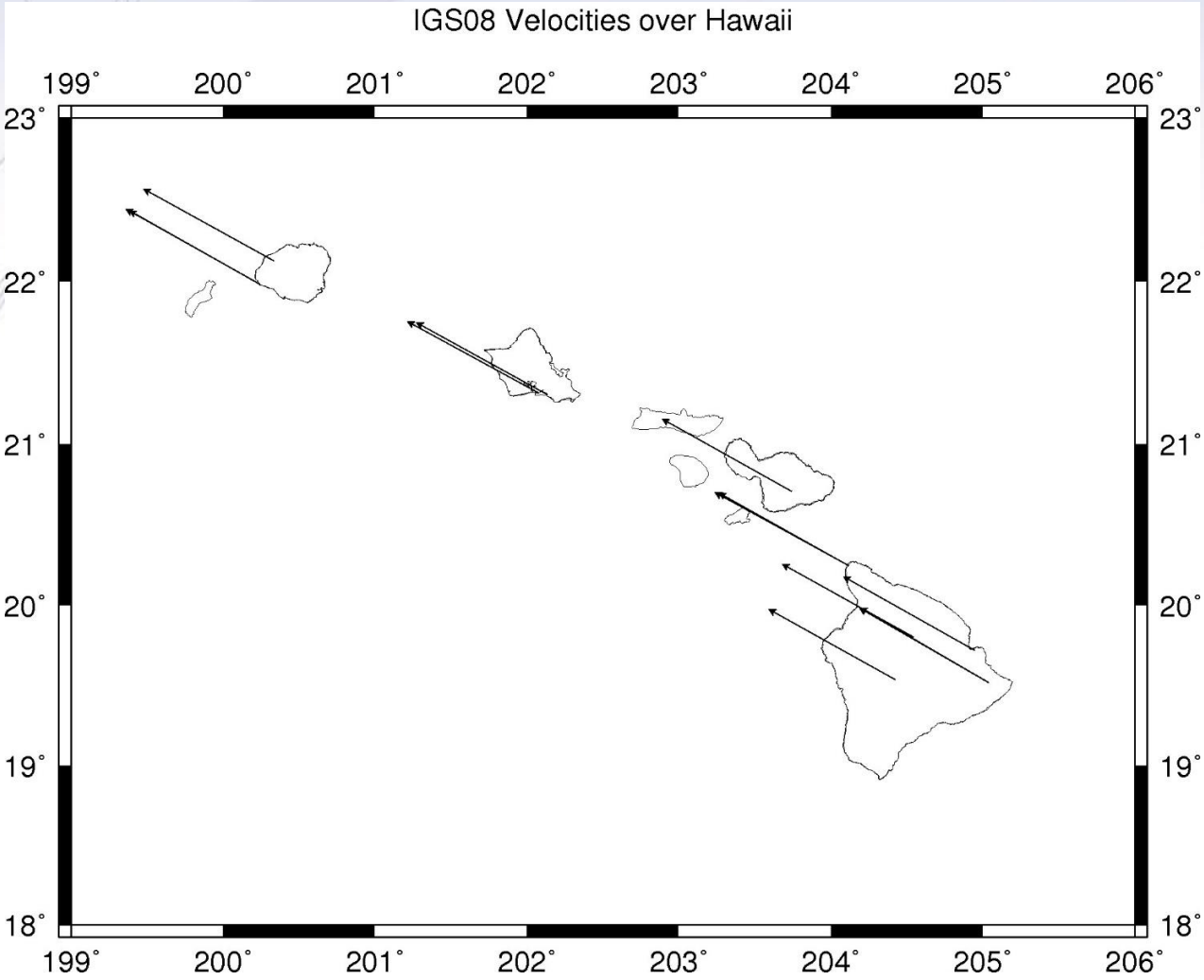

Euler's fixed point theorem states: any motion of a rigid body on the surface of a sphere may be represented as a rotation about an appropriately chosen rotation pole ("Euler Pole")

# Using the TRFs

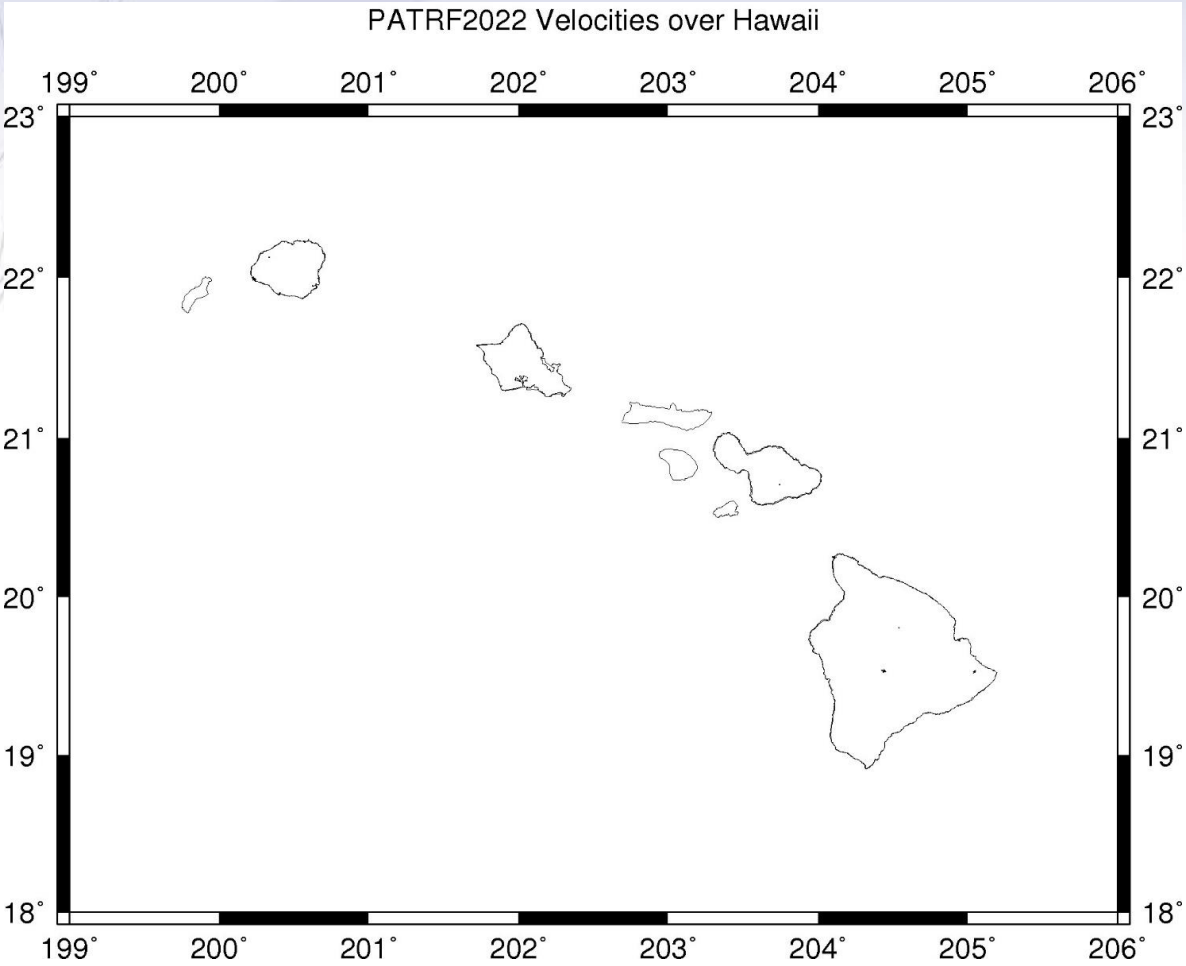



**Blueprint for 2022, Part 1: Geometric Coordinates**

# CORS Velocities Hawaii IGS08

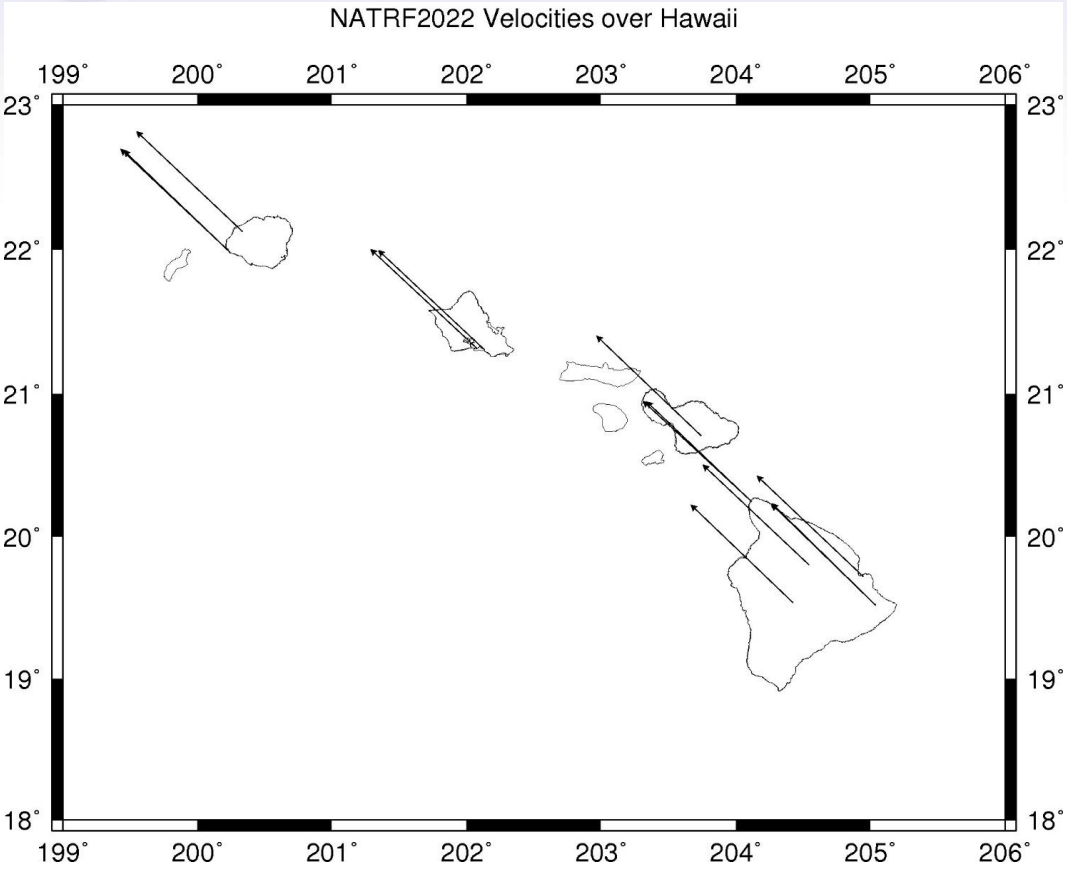


# CORS Velocities Hawaii PATRF2022



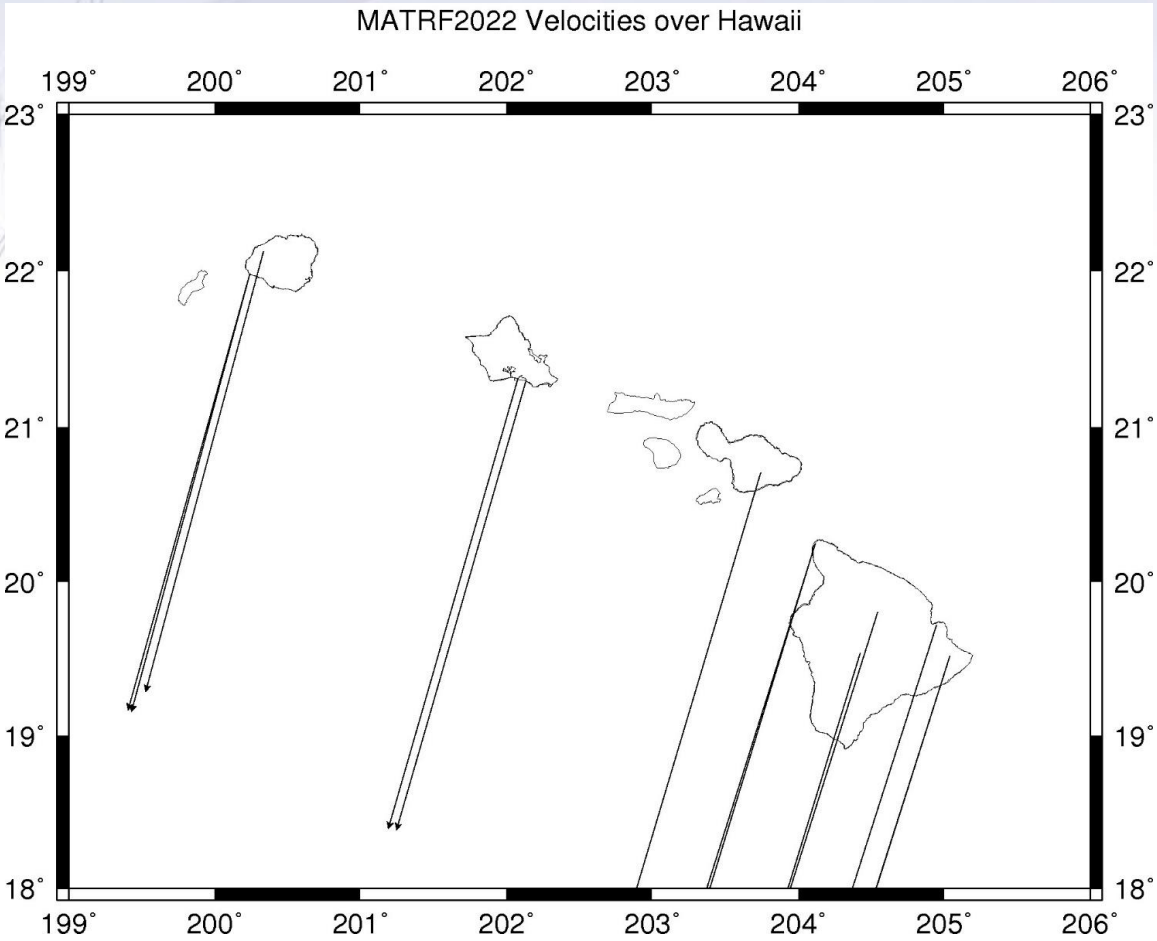

After Euler Pole Correction Applied for Pacific Terrestrial Reference

# CORS Velocities Hawaii NATRF2022



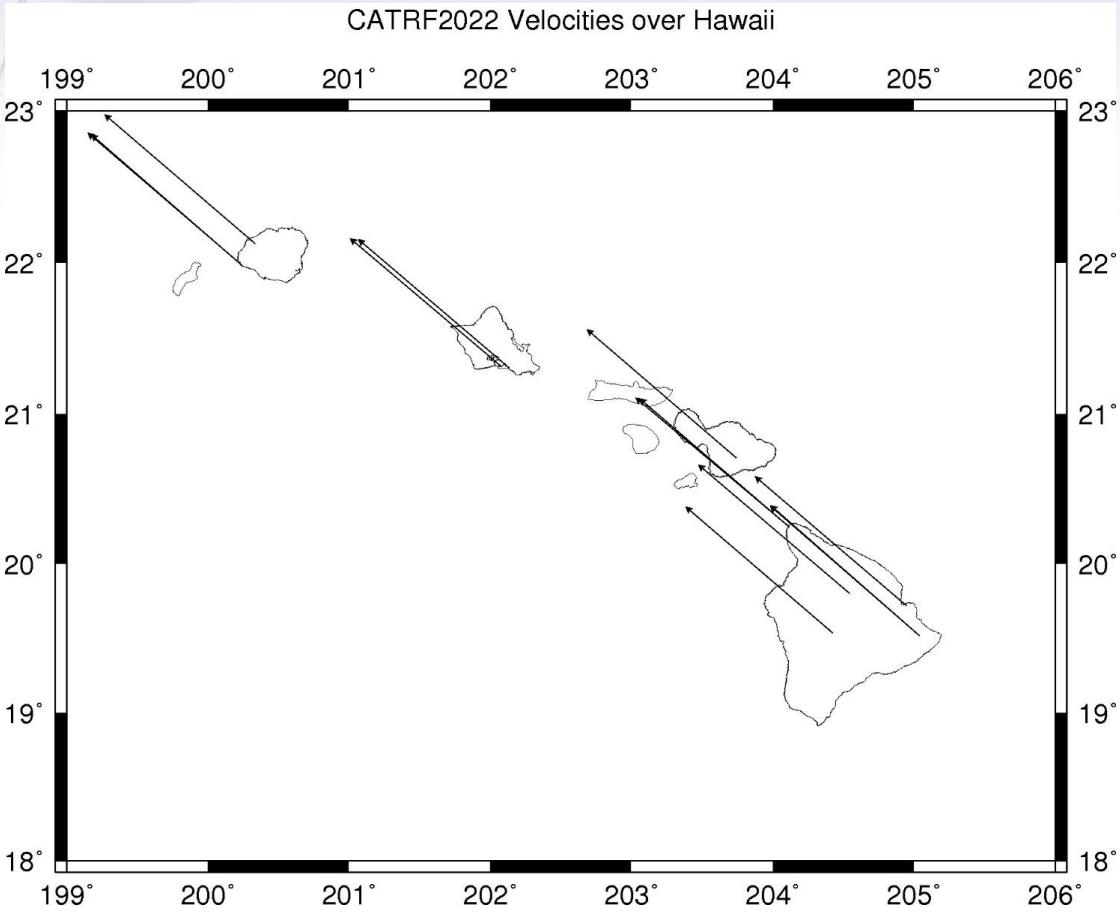

After Euler Pole Correction Applied for North American Terrestrial Reference

# CORS Velocities Hawaii MATRF2022



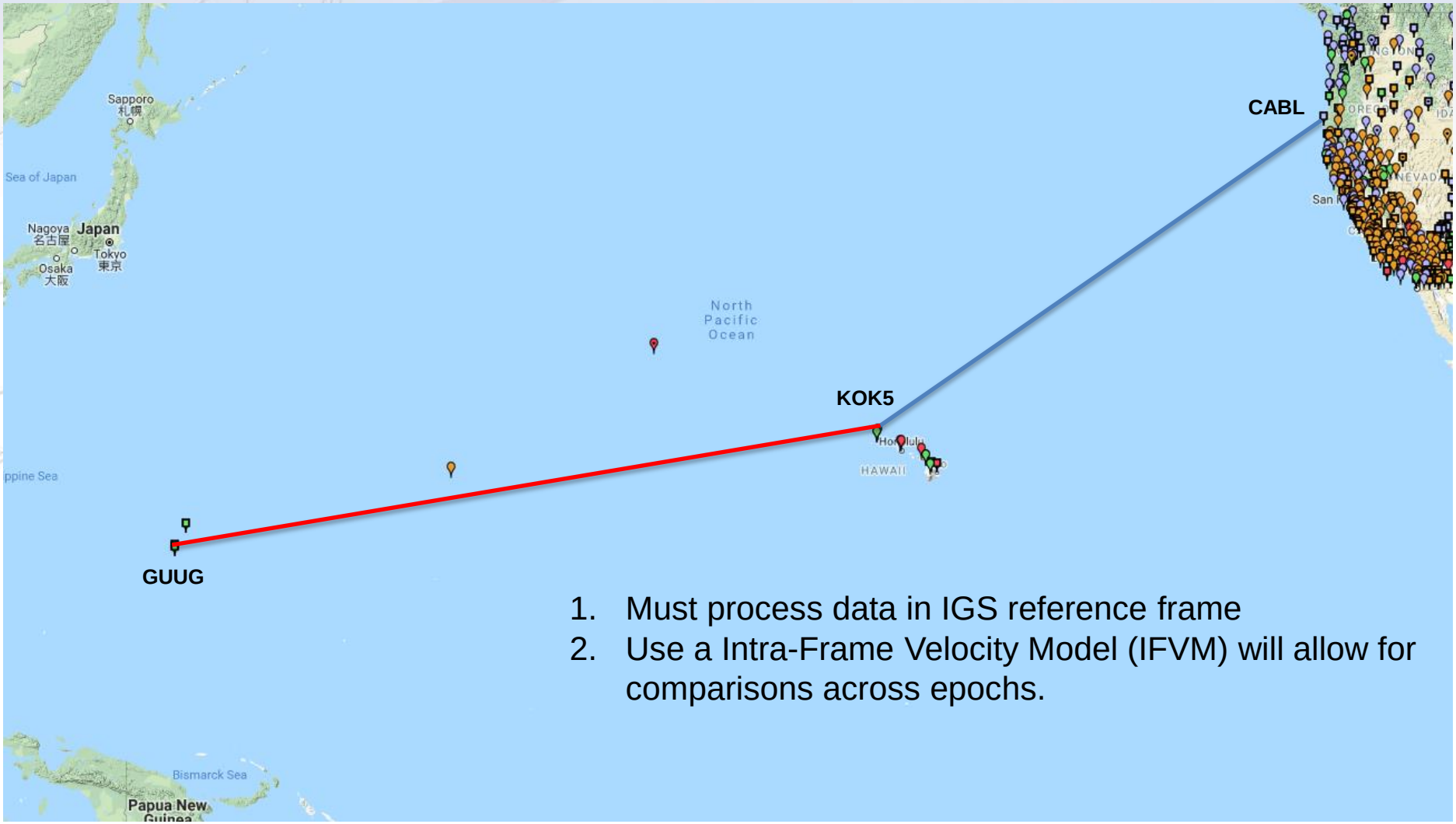

After Euler Pole Correction Applied for Marianas Terrestrial Reference

# CORS Velocities Hawaii – CATRF2022



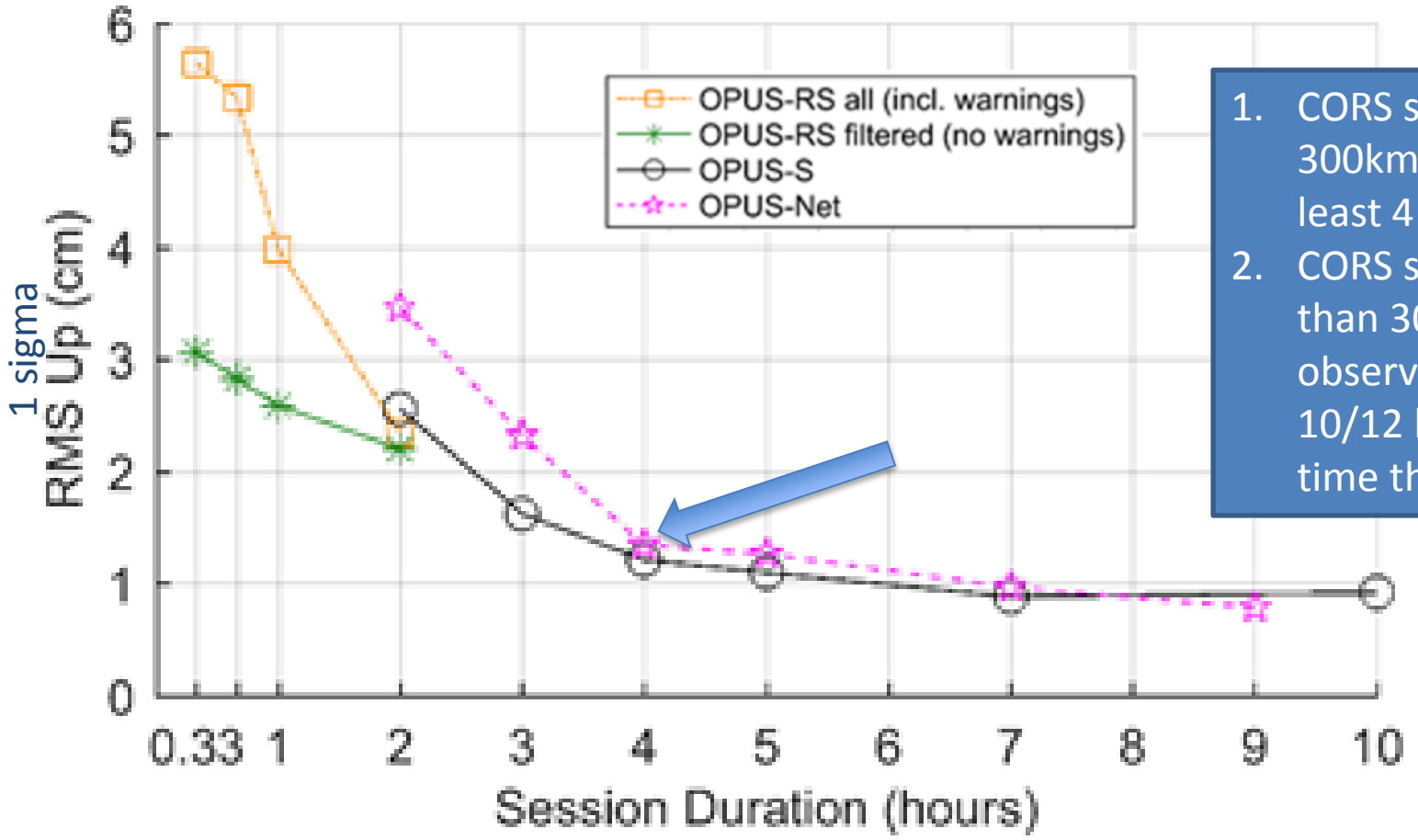

After Euler Pole Correction Applied for Caribbean Terrestrial Reference

# Observations Across Plates




1. Must process data in IGS reference frame
2. Use a Intra-Frame Velocity Model (IFVM) will allow for comparisons across epochs.

# Observation Times




1. CORS sites within 300km observe at least 4 hours
2. CORS sites greater than 300km observe at least 10/12 hours. More time the better.

Graph Courtesy of Dr. Daniel Gillins

# Leveling With 2022 Datum

# Accuracy of Leveling

# Leveling after 2022

1. Begin by establishing vertical control with GNSS and GEOID2022

$$H = h - N$$

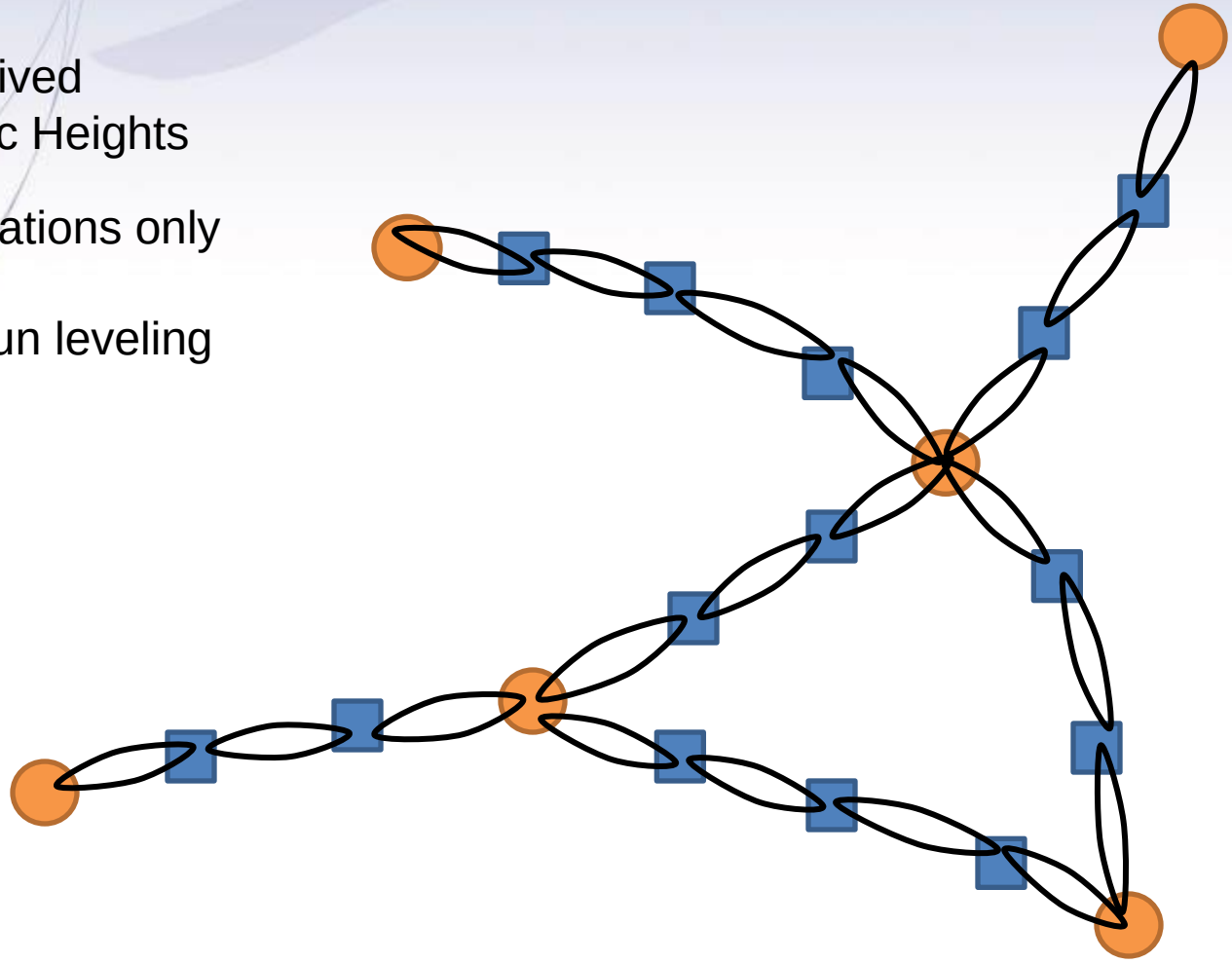
2. Estimate the error in *H* of the vertical control
3. Establish a leveling network and tie the control to other desired marks
4. Perform a least squares adjustment of the leveling network while holding *H* with stochastic constraints

# GNSS + Leveling Surveys Post 2022

GNSS-Derived Orthometric Heights

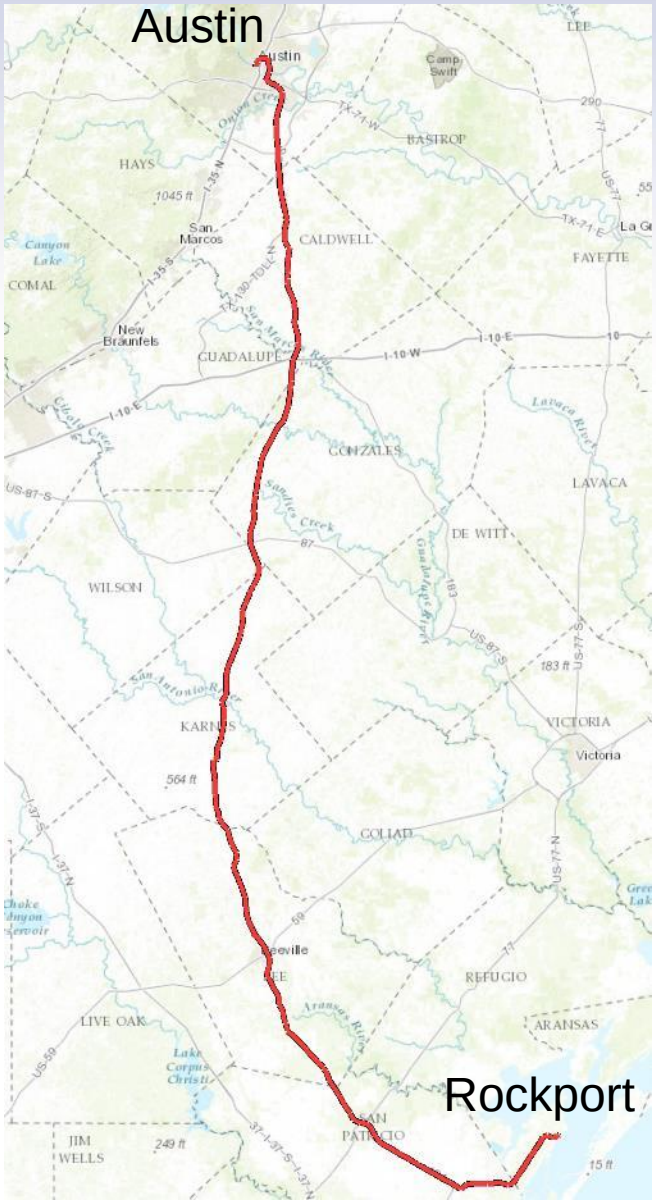
Leveling stations only

Double-run leveling



# Case Study: GSVS11

- 325 km line from Austin to Rockport, TX
- Static GPS collected on 218 stations (48-h sessions)
- First-order Class 2 geodetic leveling
- Surface gravimetry



# Test Adjustment Results

| BM | Input H (m) | Output H (m) | Input Sigma (cm) | Output Sigma (cm) | $H_{in} - H_{out}$ (cm) |
|---|---|---|---|---|---|
| 2003 | 159.828 | 159.851 | ±3.5 | ±2.7 | -2.3 |
| 3006 | 1.430 | 1.401 | ±4.0 | ±2.8 | +2.9 |
| | $\Delta H_{GNSS+L}$ | 158.450 | | | |
| | $\Delta H_{leveling}$ | 158.454 | | | |
| | *Difference* | -0.004 | | | |

BETA
This is a BETA Release Site

# NGS Coordinate Conversion and Transformation Tool (NCAT)

National Geodetic Survey

NGS Home | About NGS | Data & Imagery | Tools | Surveys | Science & Education | Search

Single Point Conversion | Multipoint Conversion | Web services | Downloads | About Conversion Tool

Convert from: ● LLh ○ SPC ○ UTM ○ XYZ ○ USNG

*Enter lat-lon in decimal degrees*

Lat 39.2240867222

Lon -98.5421515000

*or degrees-minutes-seconds*

Lat N 39-13-26.71220

Lon W 098-32-31.74540

*or drag map marker to a location of interest*


Ellipsoid Height (m)

Input datum NAD83(2011)

Output datum USSD

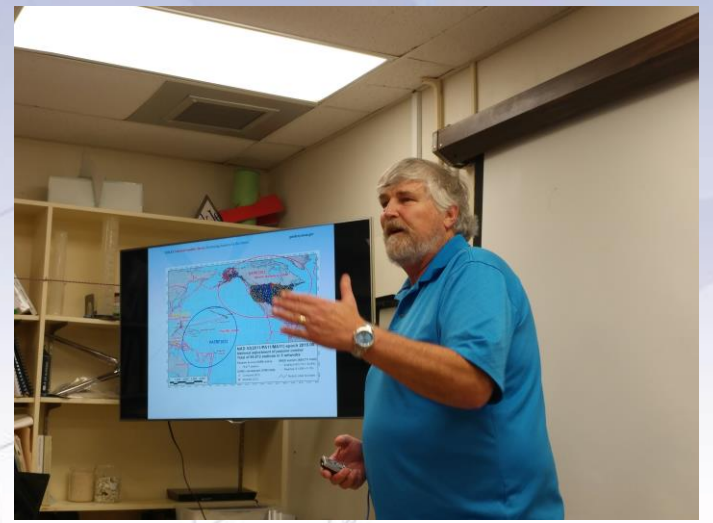
NAD83(2011)
NAD83(NSRS2007)
NAD83(FBN)
NAD83(HARN)
NAD83(1986)
NAD27
USSD

*Converted coordinates will be in outp*

**Convert**

*Export Results to* PDF

| LLh | | SPC | | | XYZ (m) | USNG |
|---|---|---|---|---|---|---|
| SrcLat | 39.2240867222 N391326.71220 | | N/A | Northing | 4,341,535.046 | X N/A | 14SNJ3955141535 |
| DestLat | 39.2240802426 N391326.68887 | Northing (m) | N/A | Easting | 539,551.389 | Y N/A | |
| Siglat (arcsec) | ±0.004065 | Northing (usft) | N/A | Convergence (dms) | 00 17 23.08 | Z N/A | |
| SrcLon | -98.5421515000 W0983231.74540 | Northing (ift) | N/A | Scale factor | 0.99961926 | | |
| DestLon | -98.5418070317 W0983230.50531 | Easting (m) | N/A | Combined factor | N/A | | |
| Siglon (arcsec) | ±0.007567 | Easting (usft) | N/A | | | | |
| SrcEht | N/A | Easting (ift) | N/A | | | | |
| DestEht | N/A | Convergence (dms) | N/A | | | | |
| sigeht | ±N/A | Scale factor | N/A | | | | |
| | | Combined factor | N/A | | | | |



# Mahalo
# Questions ????

**Contact Information:**

**Edward E. Carlson**

**Pacific Regional Geodetic Advisor**

**National Geodetic Survey**

**Phone: (808) 725-5255**

**email: ed.carlson@noaa.gov**