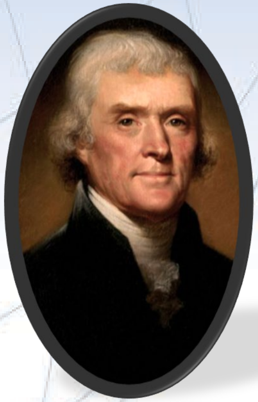
Transitioning to the United States 2022 National Coordinate System Without Getting Left Behind

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

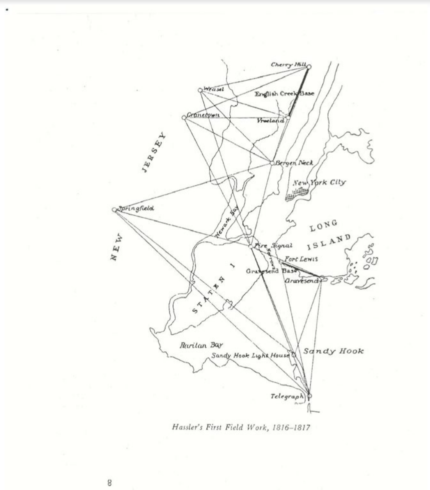


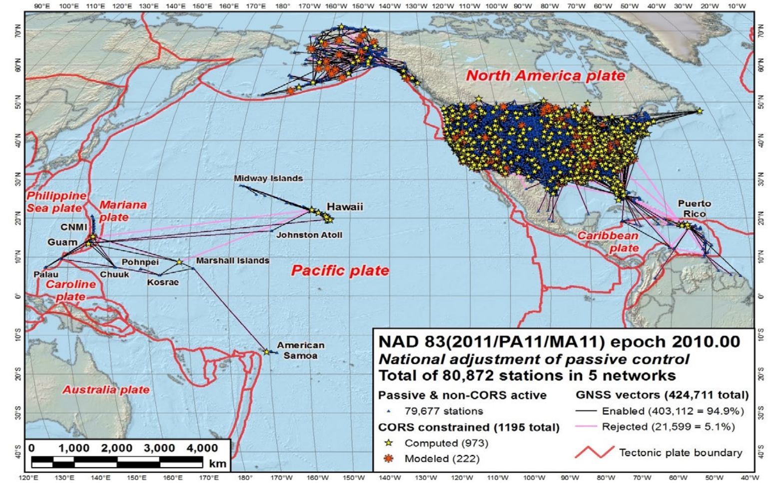
1807
Thomas Jefferson
Survey of the Coast

1807
Ferdinand R. Hassler
First Superintendent

1878
U.S. Coast and
Geodetic Survey

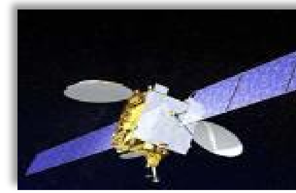
1970
NOAA is
established





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

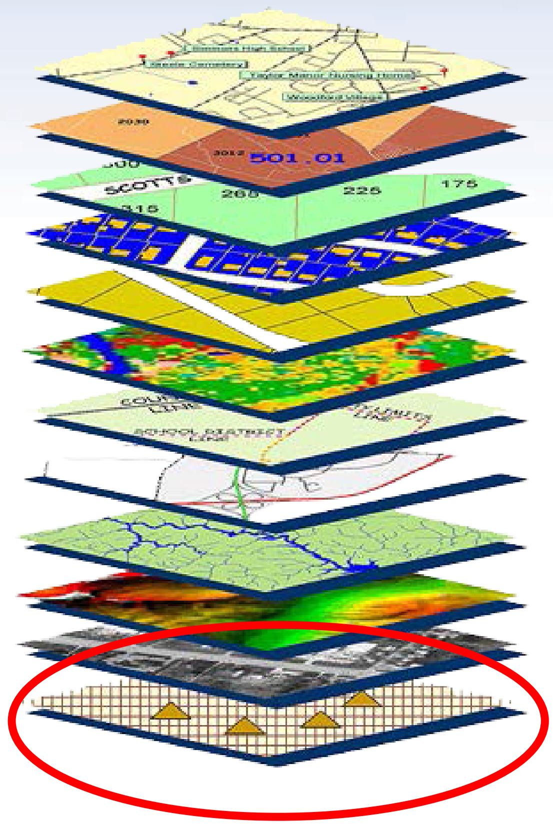
Mission: To define, maintain & provide access to the ***National Spatial Reference System (NSRS)*** to meet our Nation's economic, social & environmental needs



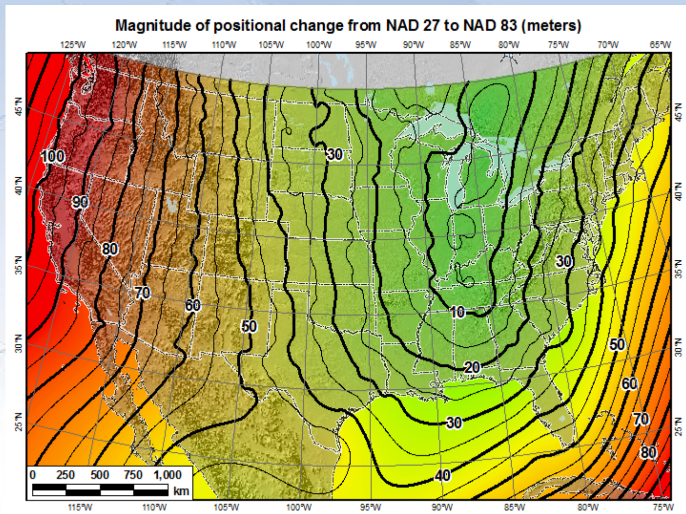
Satellite Operations

Role of National Spatial Reference System

- The **NSRS** is the official coordinate system for all geospatial work done by the U.S. *non-military federal government*. (Latitudes, Longitudes, Heights)
- A geodetic **datum** is an abstract coordinate system with a reference surface (such as NAD83(2011) or GUVD04) that serves to provide known locations to begin surveys and create maps.
- **Geodetic control** provides a common reference system for establishing coordinates for all geographic data on geodetic datum.
- All **National Spatial Data Infrastructure framework data** and users' applications data require geodetic control to accurately register spatial data.



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

These *are* part of the NSRS*

Horizontal Datums and Geometric Reference Frames	Vertical Datums	Great Lakes Datums	Geoid Models	Transformations and Conversions
USSD	NGVD 29	IGLD55	GEOID90	NADCON
NAD 27	NAVD 88	IGLD85	GEOID93	VERTCON
NAD 83	PRVD02		ALASKA94	
	ASVD02		GEOID96	SPCS 27
	NMVD03		GEOID99	SPCS 83
	GUVD04		GEOID03	UTMs
	VIVD09		GEOID06	
			GEOID09	
			GEOID12(A,B)	

*This not a complete list.

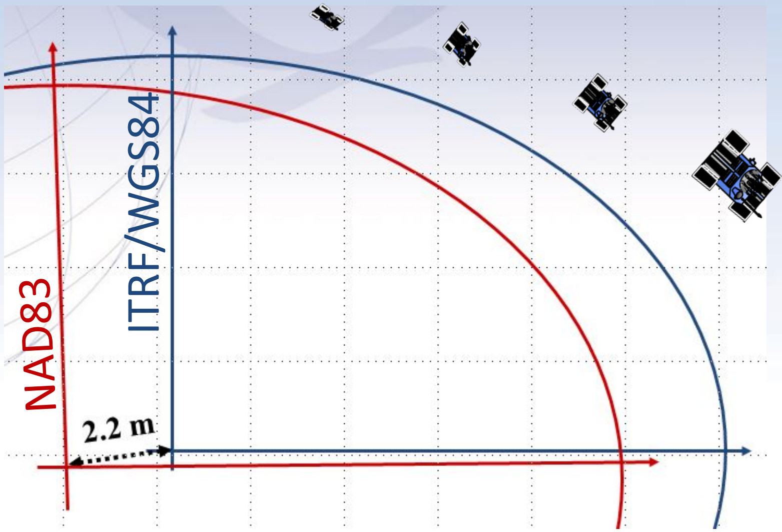
These are *not* part of the NSRS*

Horizontal Datums and Geometric Reference Frames	Vertical Datums	Great Lakes Datums	Geoid Models	Transformations and Conversions
WGS 84	IHRS		OSU91A	CORPSCON
ITRF			EGM96	Appendix B.6 of DMA TR 8350.2 (WGS 84)
IGS			EGM2008	Oregon Coordinate Reference System
				The Kansas Regional Coordinate System

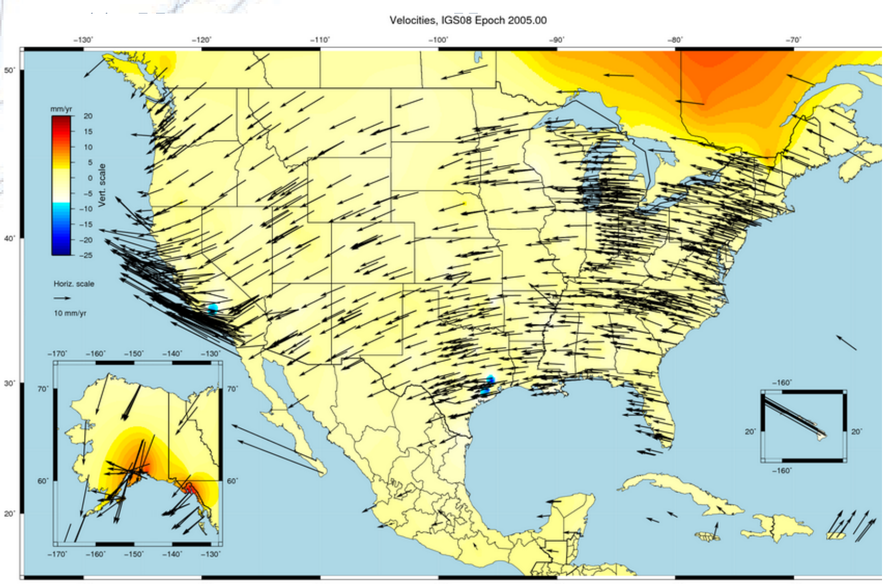
*This is not a complete list.

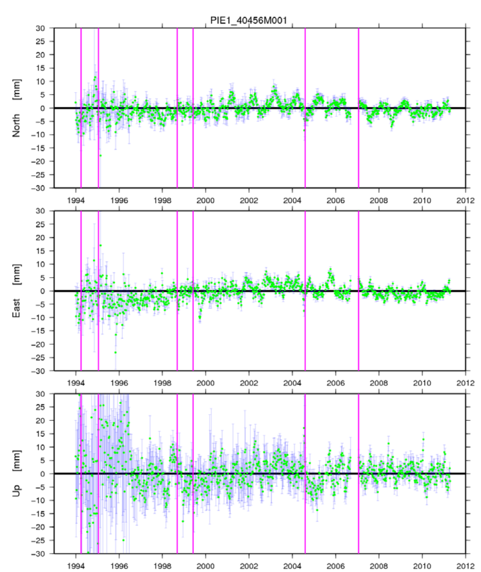
NAD83 Shortcomings

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

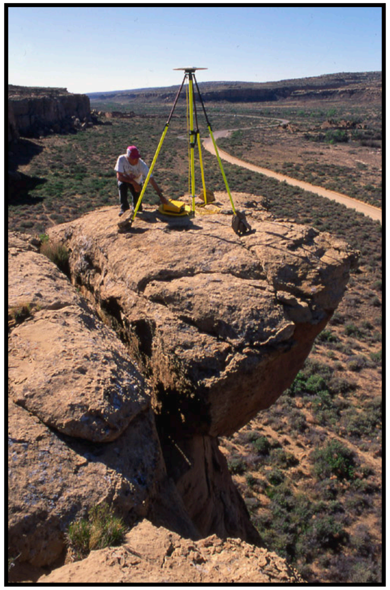


- ○ CORS <> passive network





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

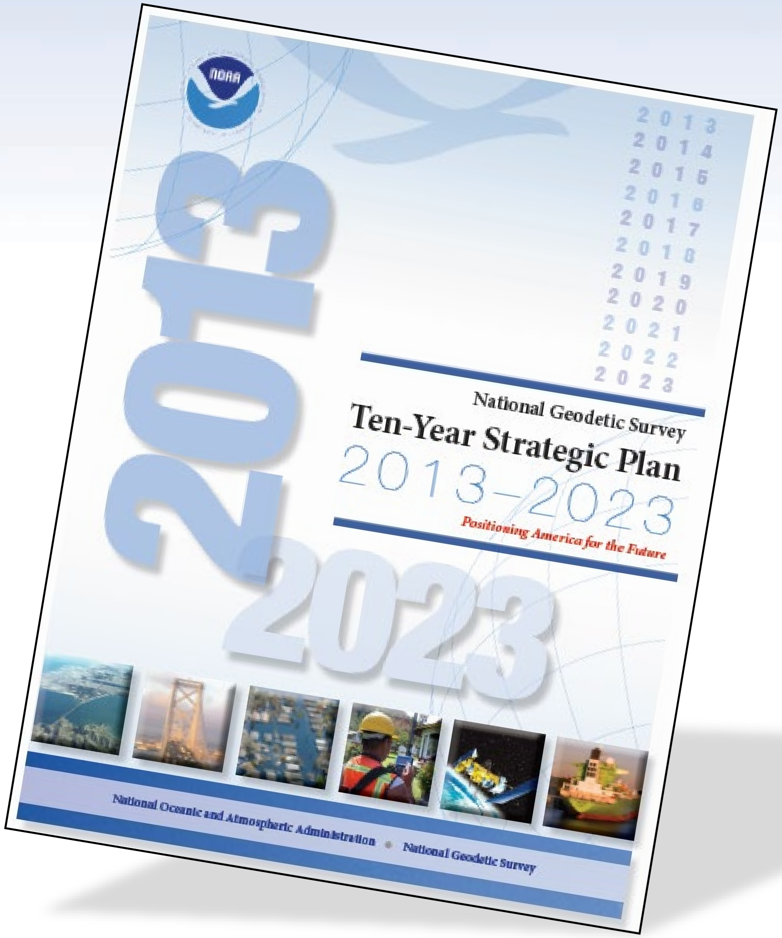
Support the users of the National Spatial Reference System.

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.

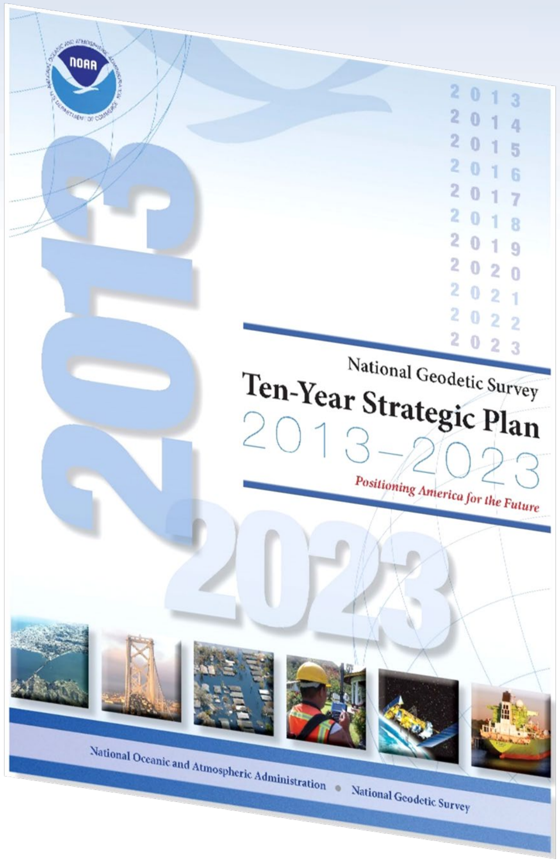
Develop and enable a workforce with a supportive environment.

Improve organizational and administrative functionality.



2022 Datums Goals

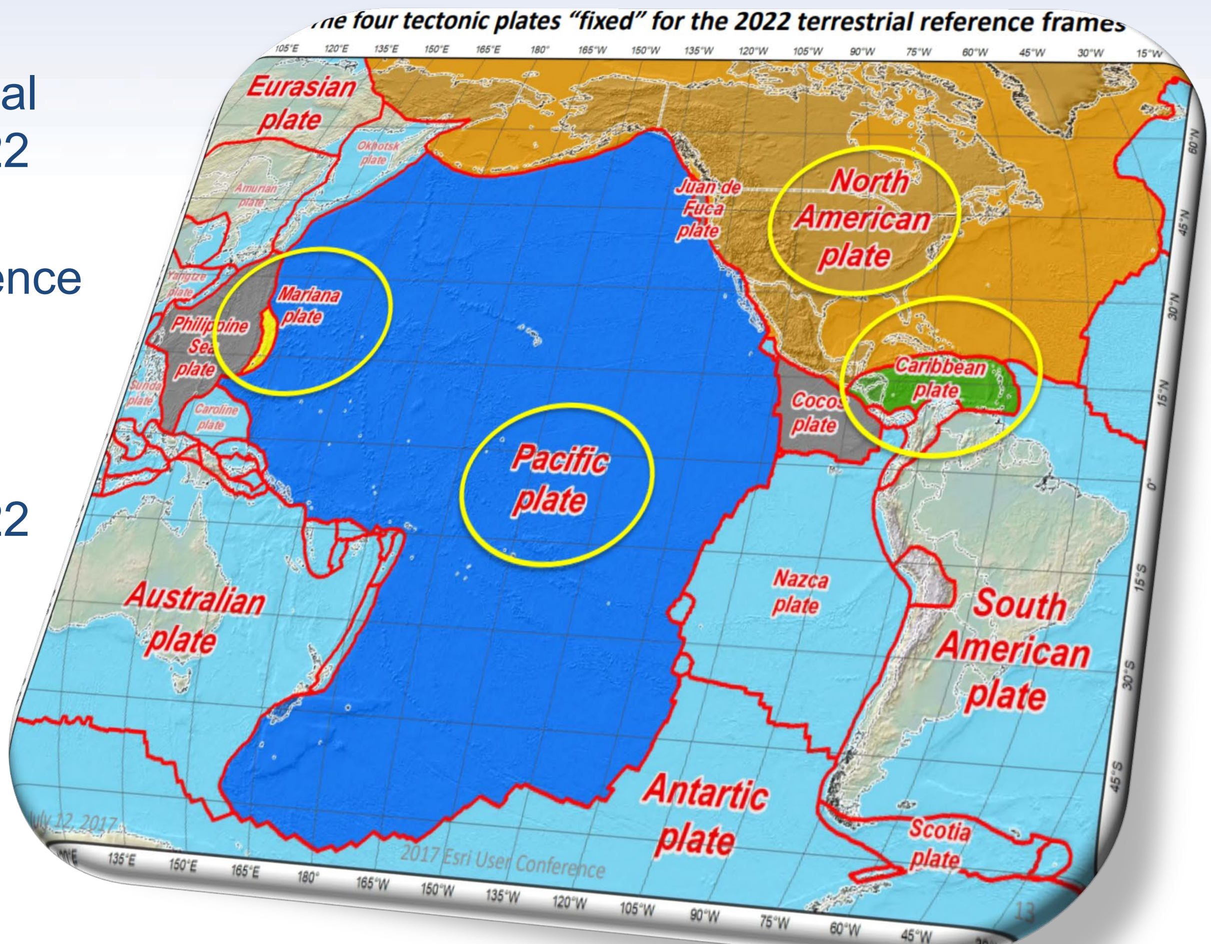
- **"Replace NAD83"** - By 2022, reduce all definitional & access-related errors in geometric reference frame to 1 cm when using ≤30 min of GNSS data
- **"Replace NAVD88"** - By 2022, reduce all definitional & access-related errors in orthometric heights, relative to sea level, in geopotential datum to 2 cm when using ≤30 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)**



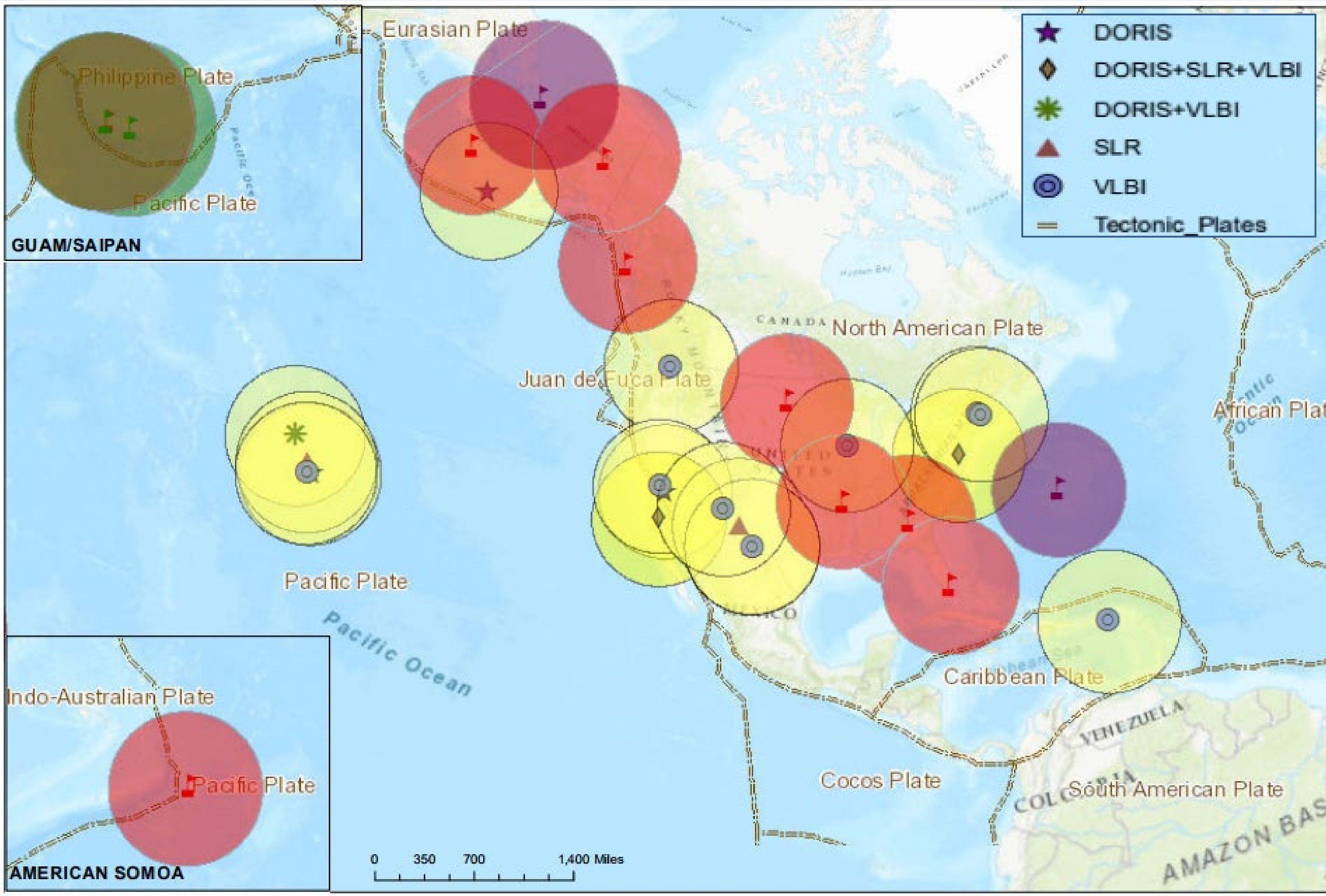
Guiding Principles

- The 2022 Datum will be modernized with Continuously Operating Reference Station (CORS) becoming the 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.

Foundation CORS tentative target

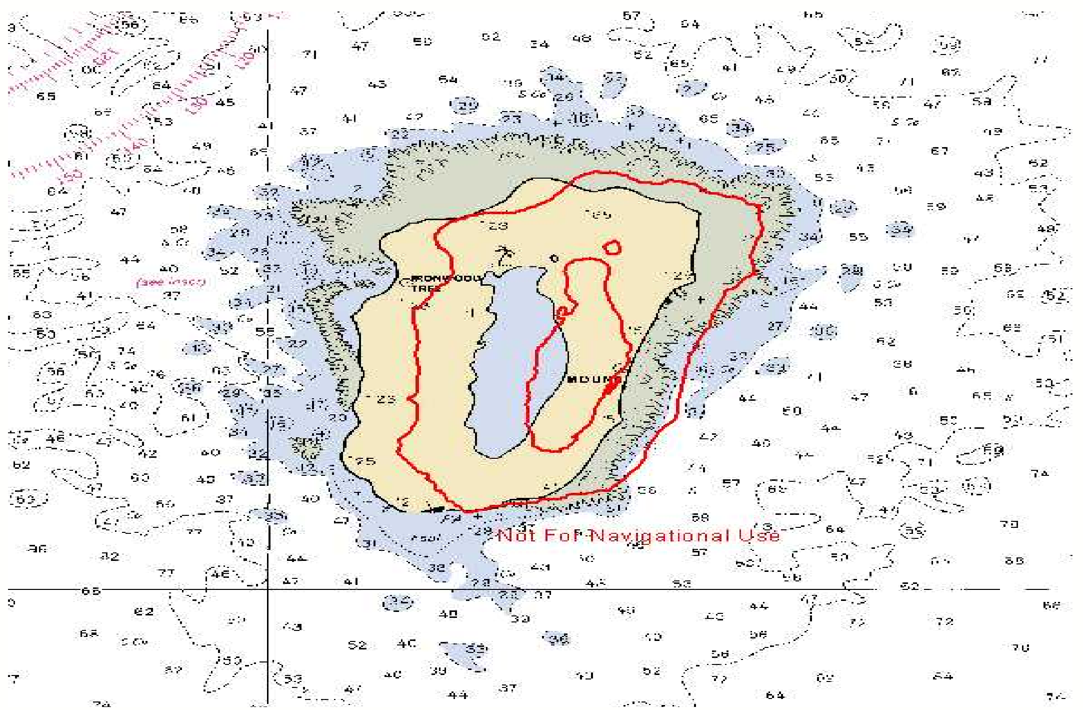
Criteria

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



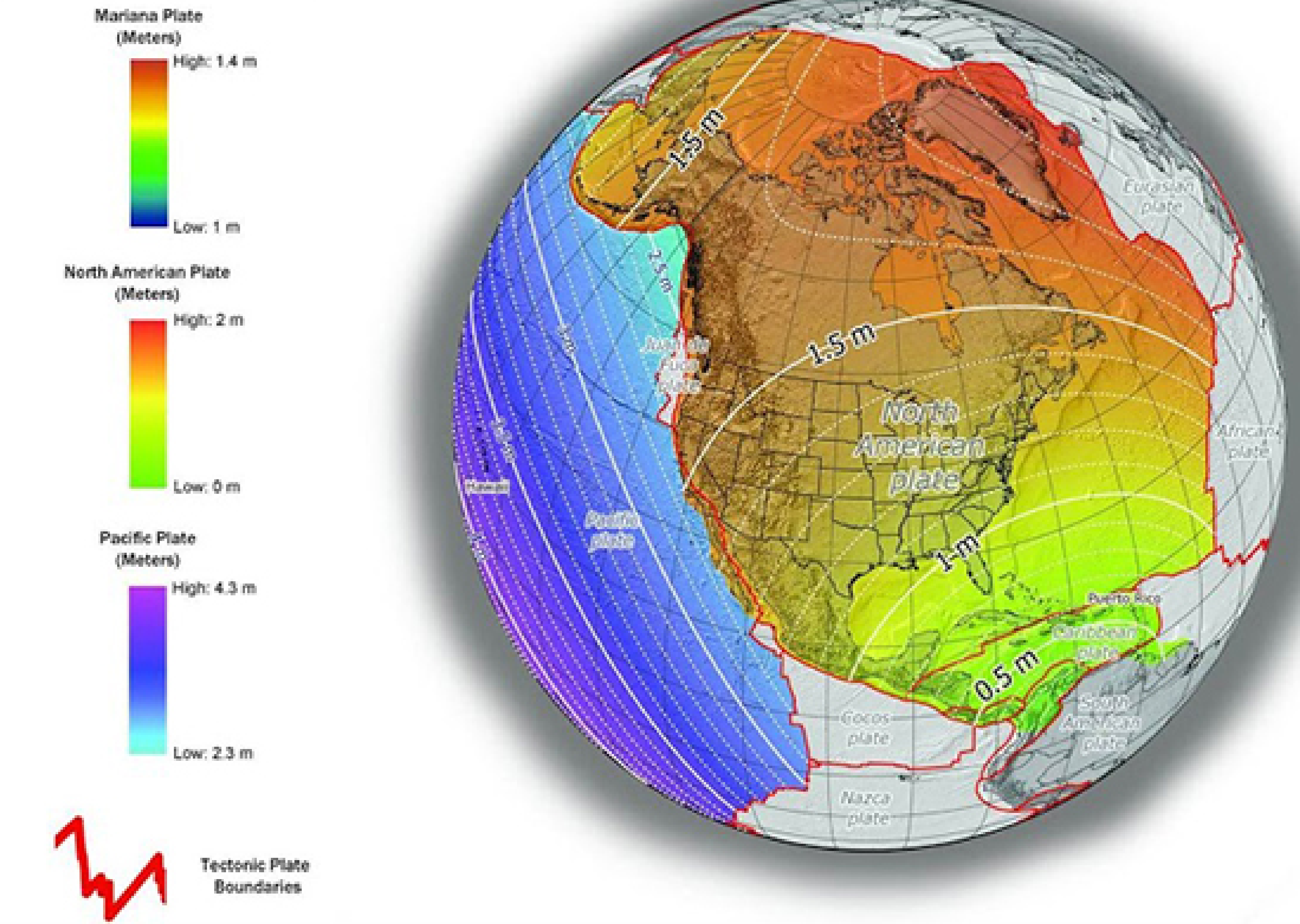
Density Buffer 800km	
Euler Buffer 800km	
Additional Buffer 800km	
SBT Buffer 800km	
Tectonic_Plates	

All coordinates and heights will change!

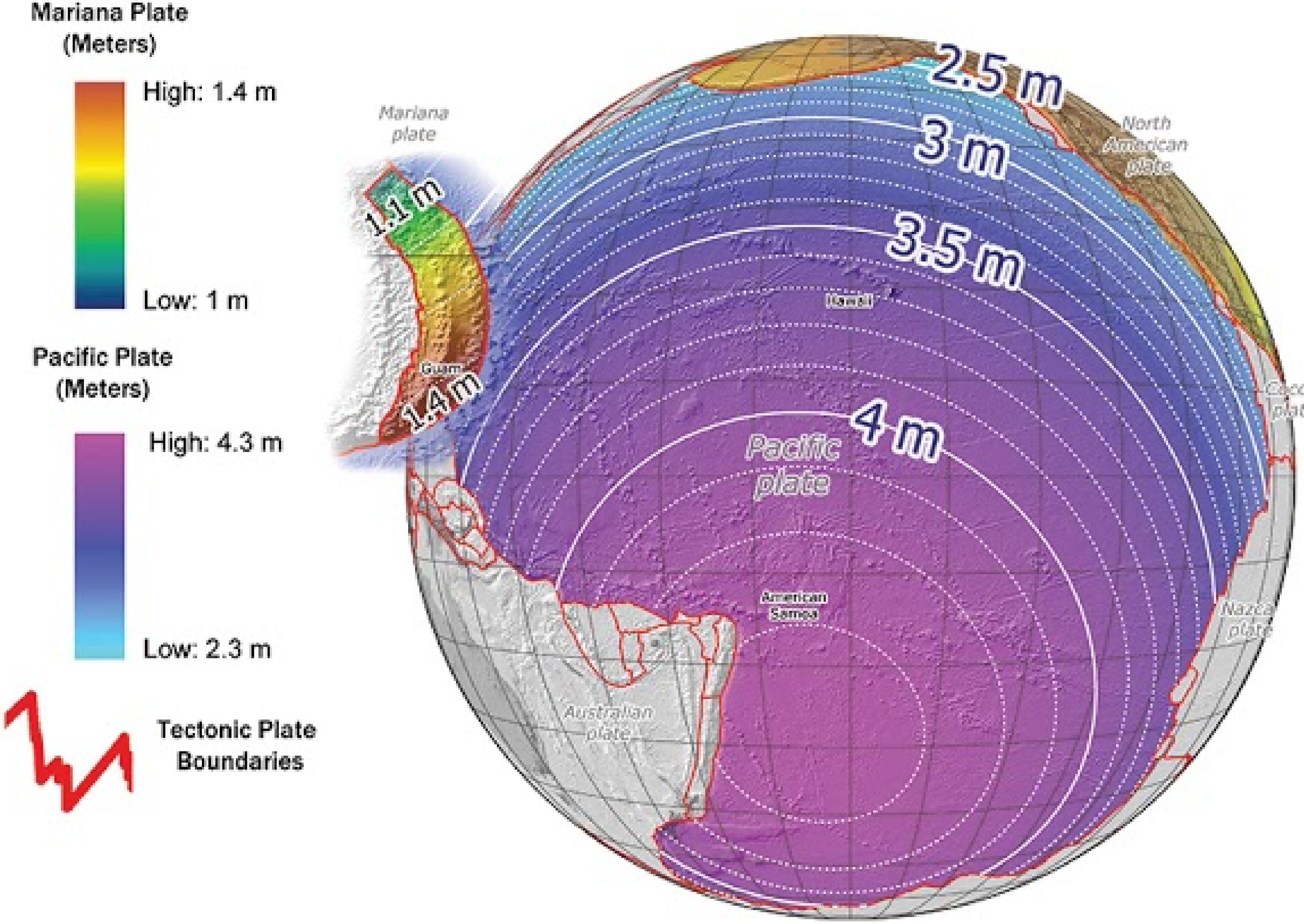


Approximate Horizontal Change

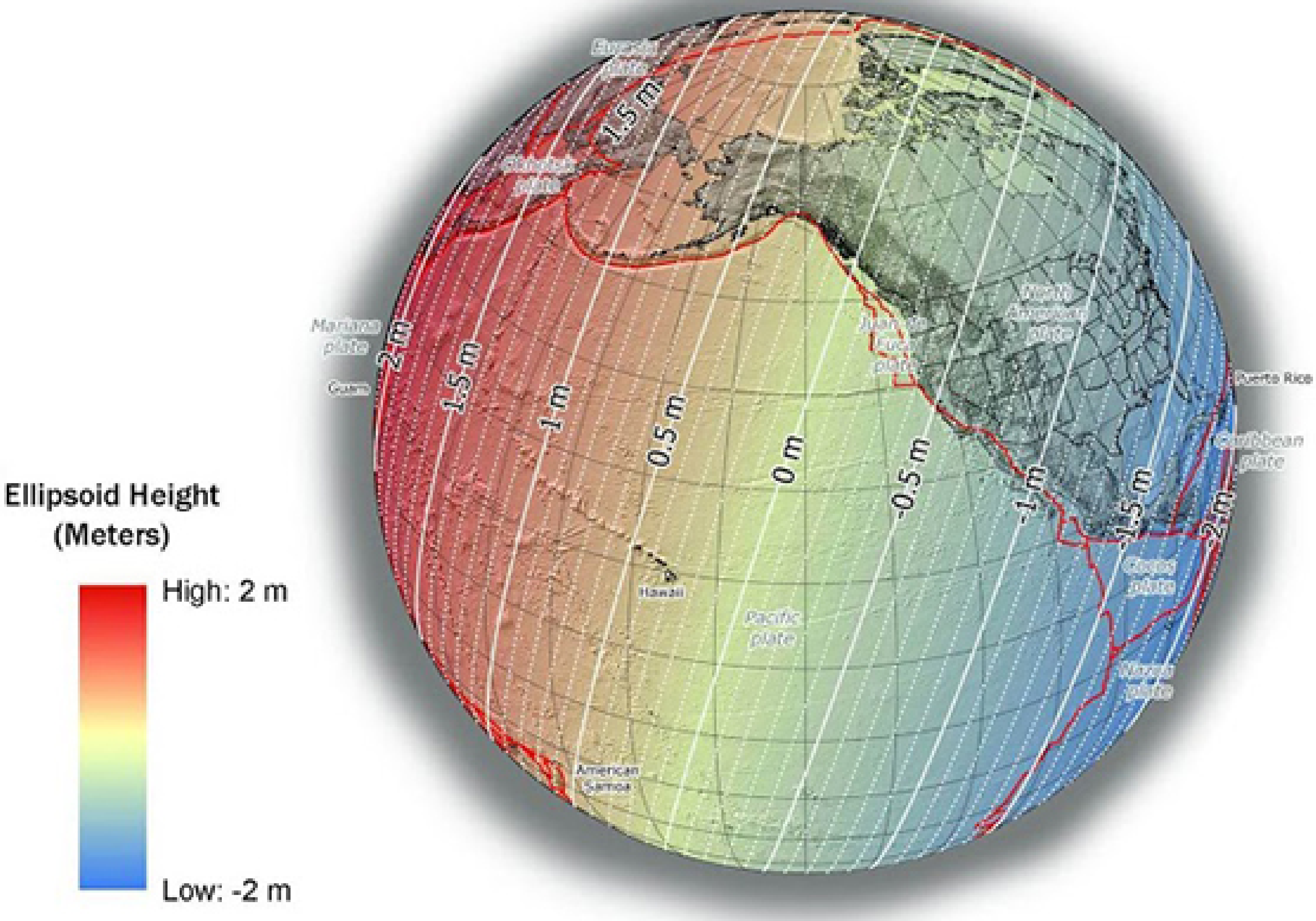
Approximate Horizontal Change North American Plate



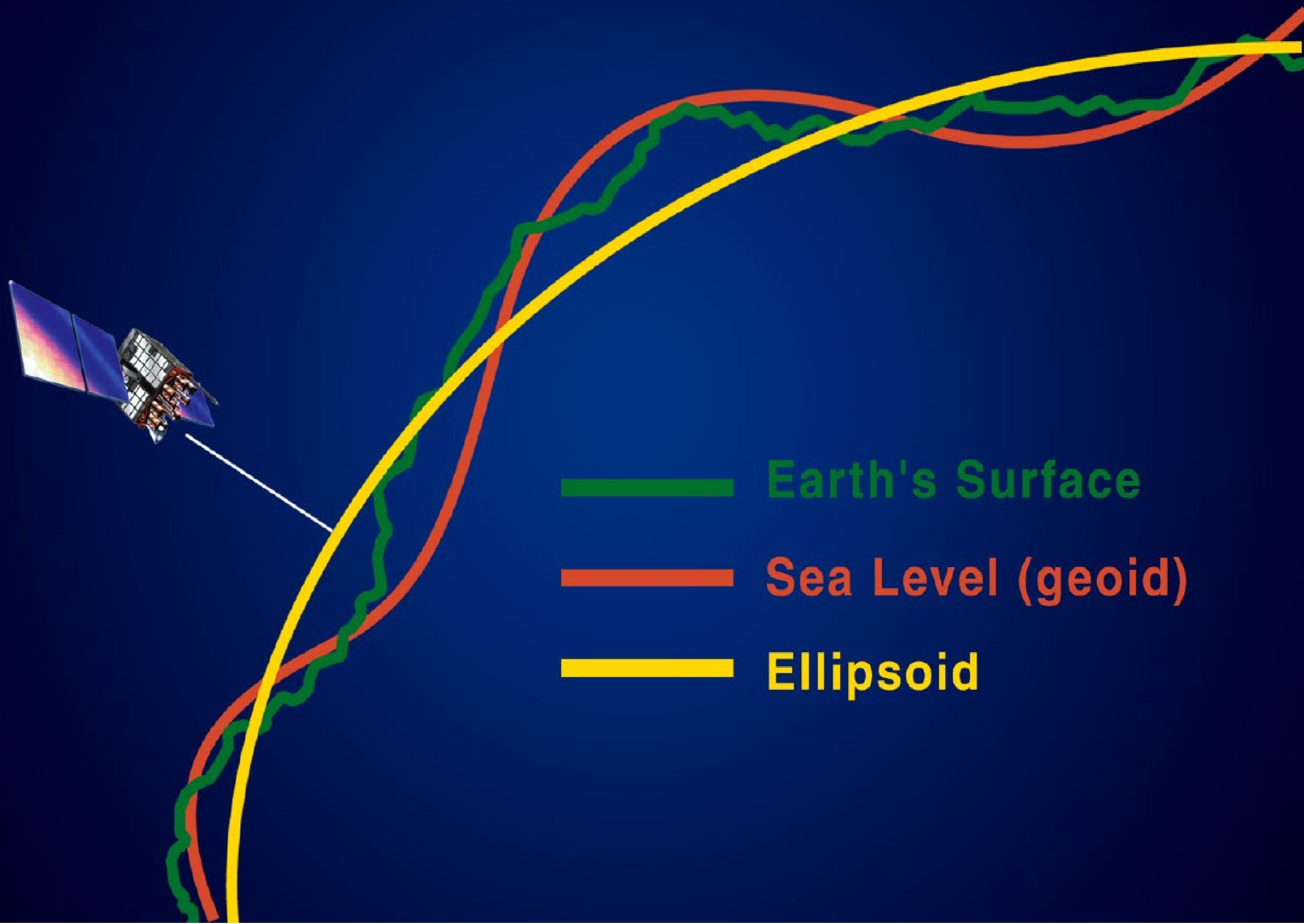
Approxmate Horizontal Change Pacific Plate



Approximate Ellipsoid Height Change



How Geodesists View the World



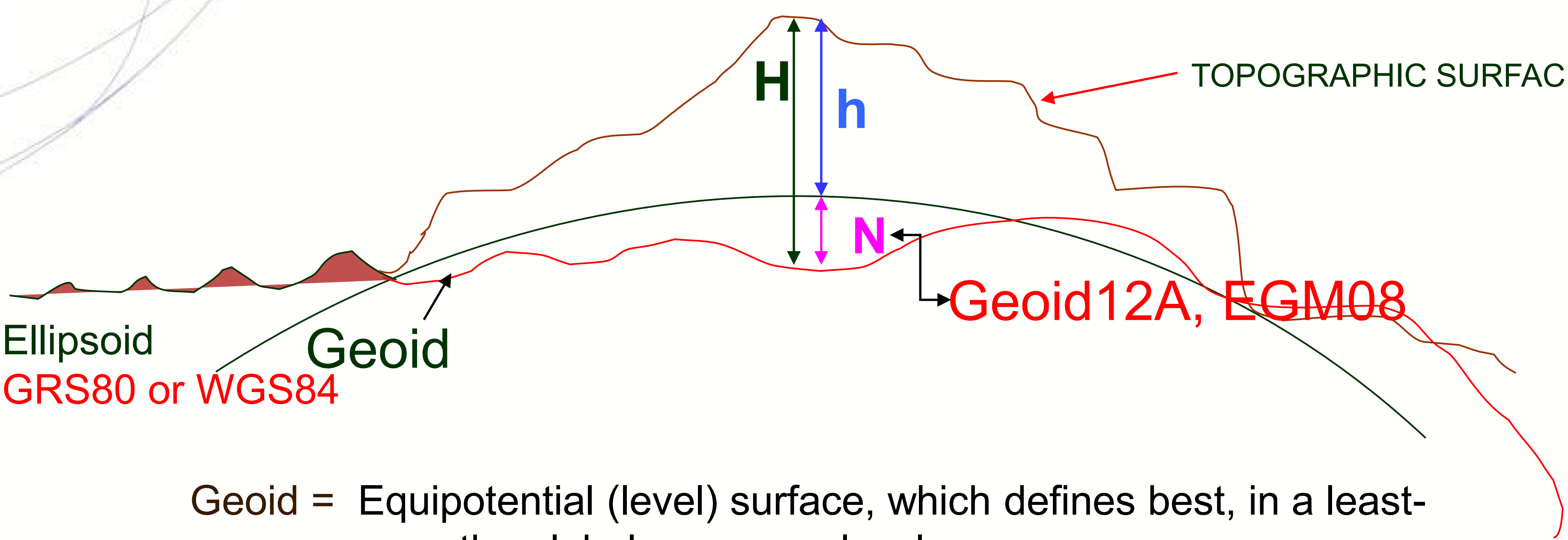
ELLIPSOID - GEOID RELATIONSHIP

H = Orthometric Height (NAVD88 or Local Mean Sea Level)

h = Ellipsoidal Height (NAD 83)

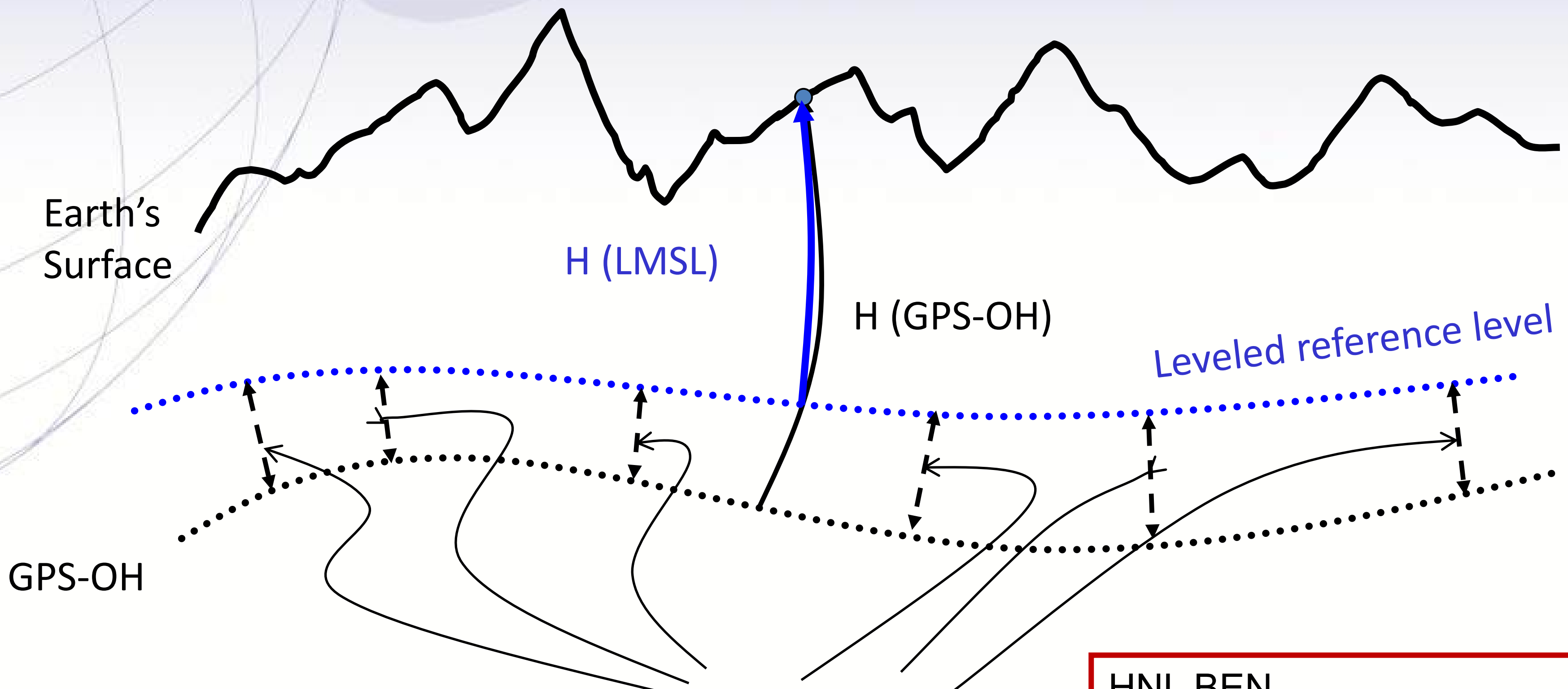
N = Geoid Height (GEOID12A, EGM08)

$$H = h - N$$



Geoid = Equipotential (level) surface, which defines best, in a least-square sense, the global mean sea level.

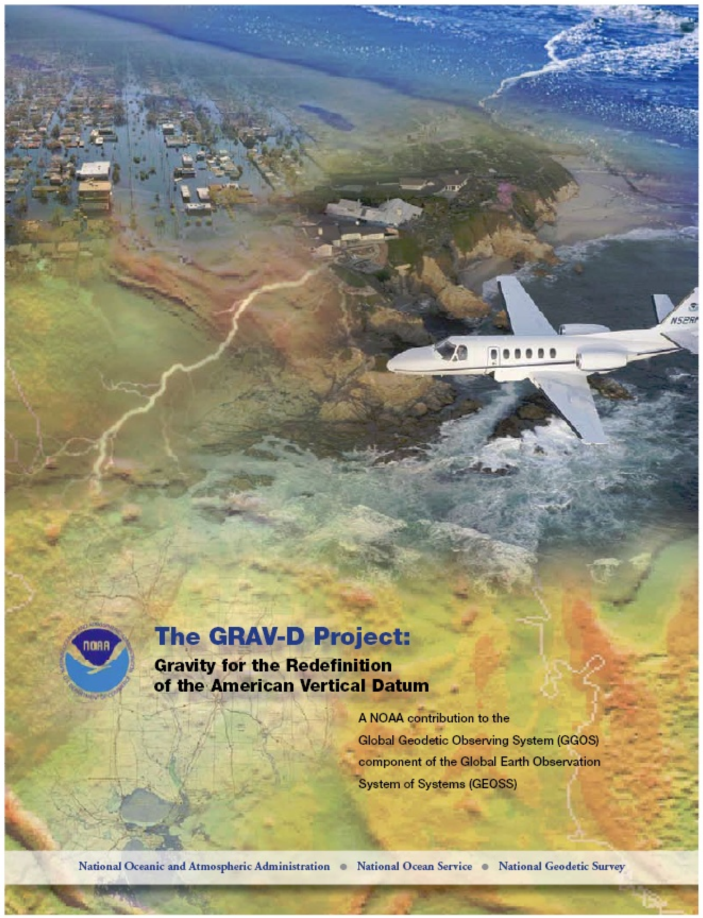
Problems in Different Vertical Datums



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

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

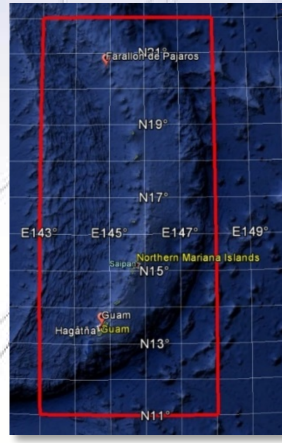


Gravity *and* ***Heights*** *are inseparably connected*

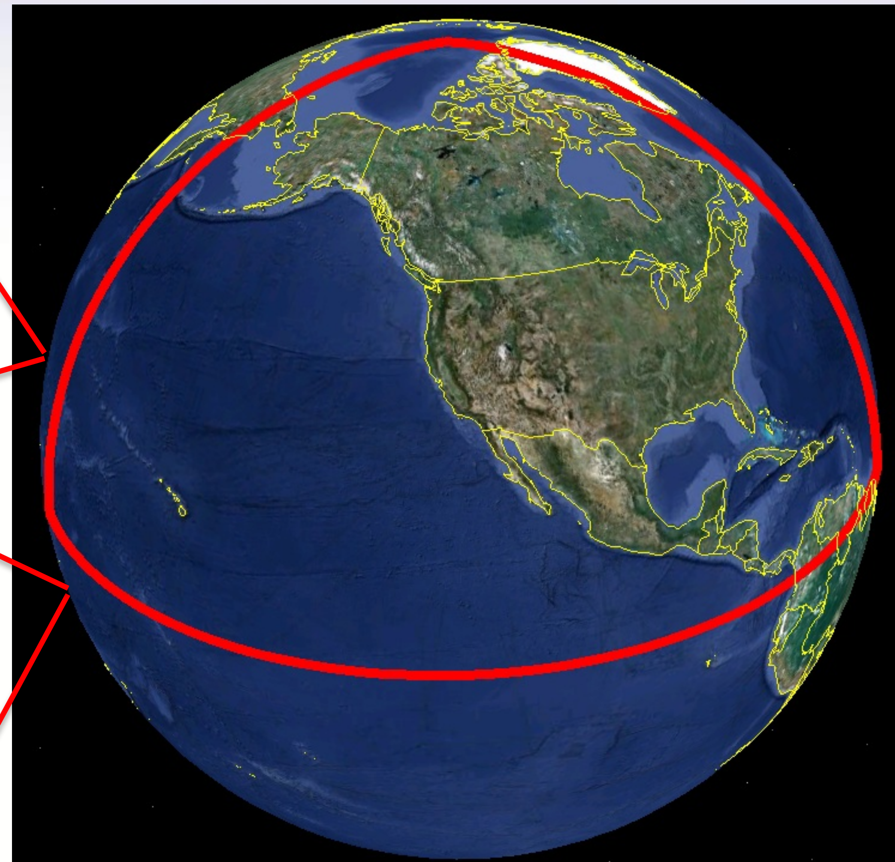
- Changing from a leveling-based to a geoid/GNSS-based (gravimetric) vertical datum
- Orthometric heights accessed via GNSS accurate to 2 cm
- Three thrusts of project:
  - Airborne gravity survey of entire country and its holdings
  - Long-term monitoring of geoid change
  - Partnership surveys
- Working to launch a collaborative effort with the USGS for simultaneous magnetic measurement

Extent of Gravimetric Geoid Model NAPGD2022

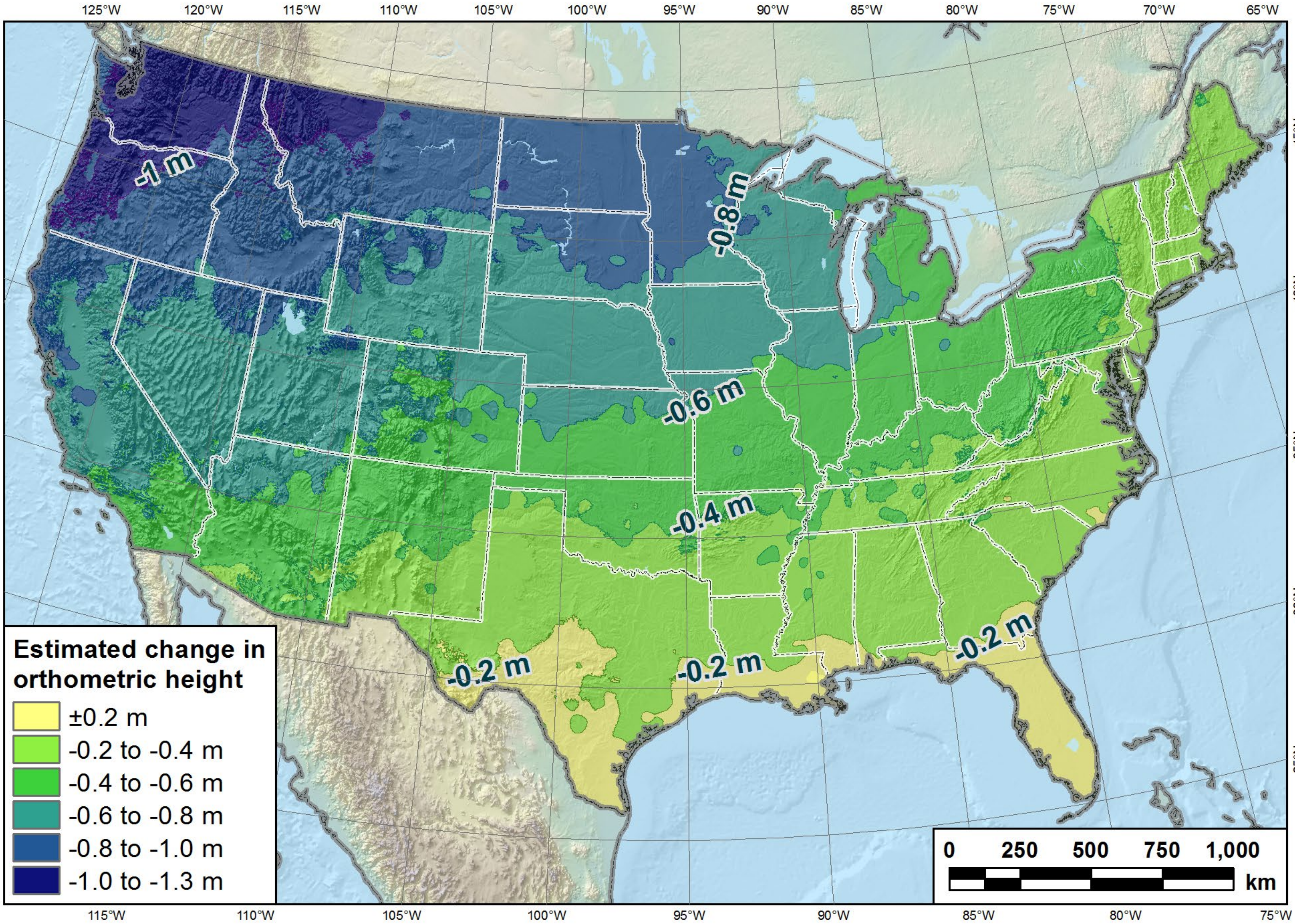
Guam and Northern Marianas Islands



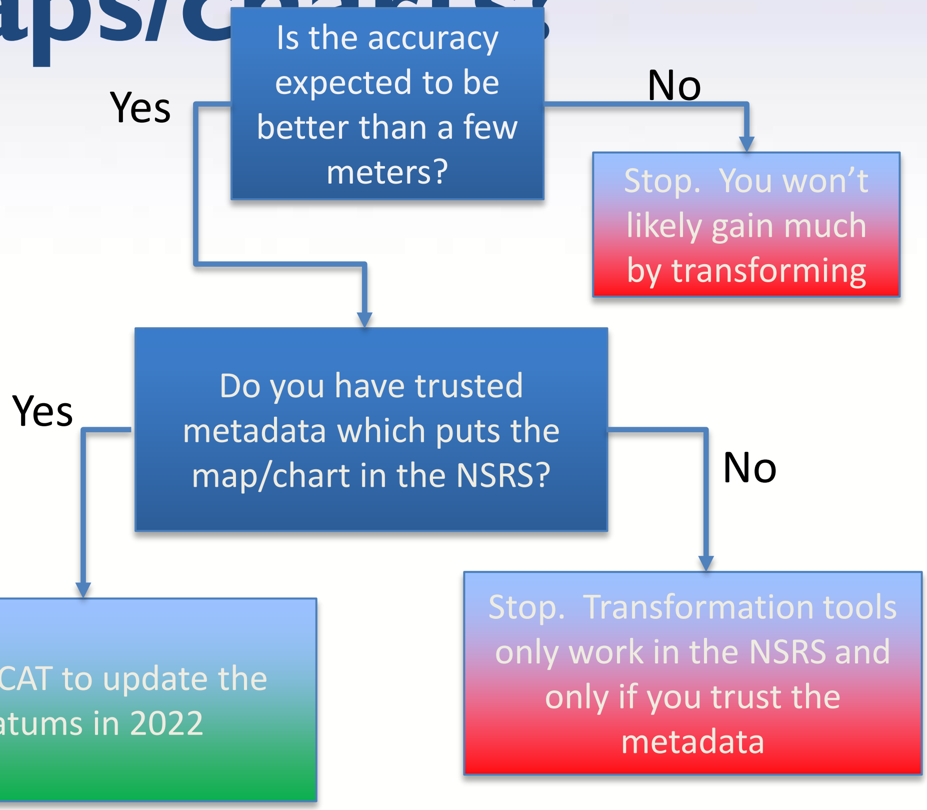
American Samoa



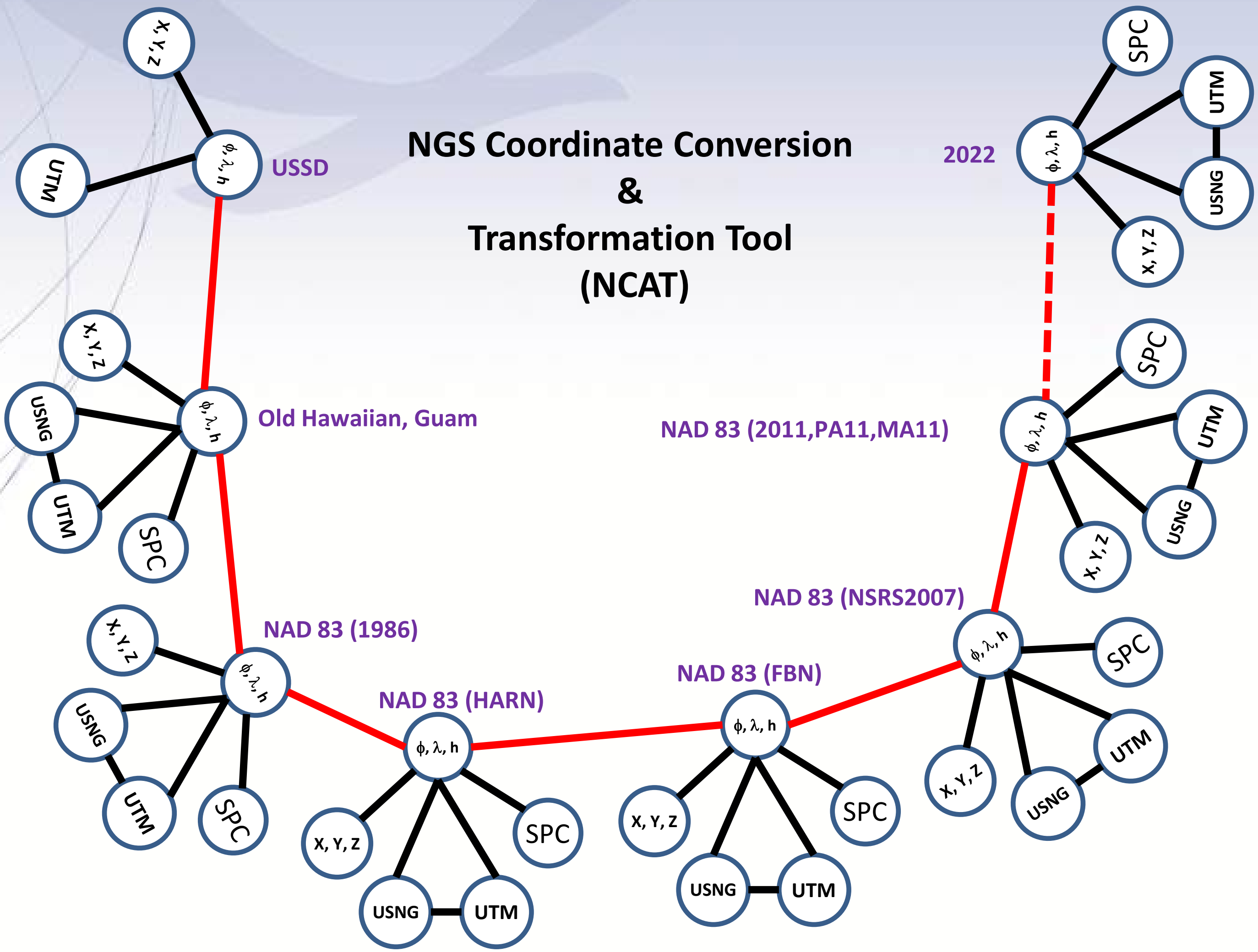
Estimated change in orthometric heights from NAVD 88 to *NAPGD2022*



What to do with historic maps/charts?



NGS Coordinate Conversion & Transformation Tool (NCAT)



NOAA's **National Geodetic Survey** Positioning America for the Future — geodesy.noaa.gov

ngs.noaa.gov/NCAT/

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

Convert/Transform from: (•) Horizontal ( ) Horizontal+height ( ) XYZ

Select the type of horizontal coordinate: (•) Geodetic lat-long ( ) SPC ( ) UTM ( ) USNG

Enter lat-lon in decimal degrees

Lat: 21.2874716056

Lon: -157.8510607139

or degrees-minutes-seconds

Lat: N 21-17-14.89778

Lon: W 157-51-03.81857

or drag map marker to a location of interest

Input reference frame (historically called 'horizontal datum'): NAD83(PA11)

- NAD83(PA11)
- NAD83(1993)
- NAD83(1986)
- OHD

Don't see a reference frame in the list? Click **here** *to learn more.*

SPC zone: HI 3-5103

Output reference frame (historically called 'horizontal datum'): OHD

- NAD83(PA11)
- NAD83(1993)
- NAD83(1986)
- OHD

Submit

Export Results to PDF | XLS | CSV | XML

Click blue bar(s) to expand/collapse

Click blue bar(s) to expand/collapse

Transformed Coordinate

Input Coordinate		Output Coordinate		Total Change + Uncertainty	
Latitude	N21° 17′ 14.89778" N211714.89778 21.2874716056	Latitude	N21° 17′ 03.56082" N211703.56082 21.2843224502	Latitude	-11.33696" ±0.005410" (-348.677 m ±0.1664 m)*
Longitude	E202° 08′ 56.18143" W1575103.81857 -157.8510607139	Longitude	E202° 09′ 6.06204" W1575053.93796 -157.8483160994	Longitude	9.88061" ±0.002206" (284.812 m ±0.0636 m)*
Ellipsoid Height (m)	Not given	Ellipsoid Height (m)	Not given	Ellipsoid Height	Not given
				Orthometric Height	Not given

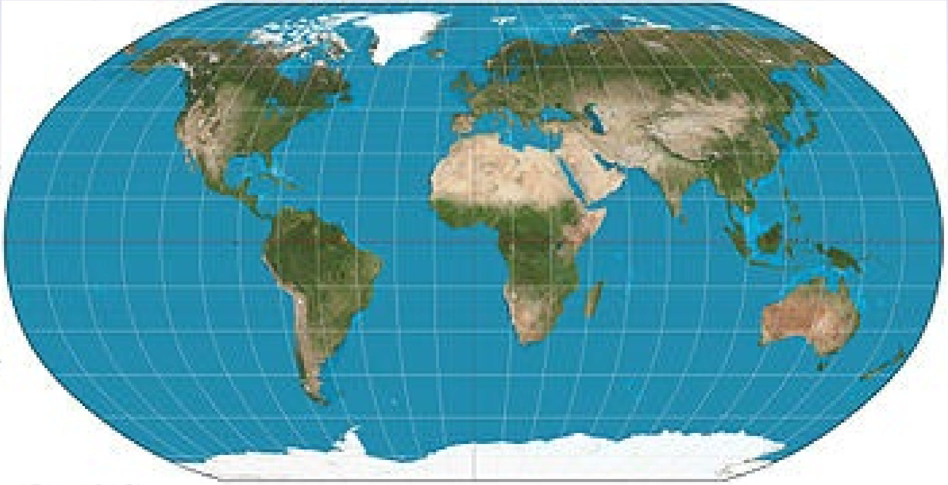
Converted Coordinate

Reference Frame:NAD83(PA11)

Lat-Lon-Height		SPC		UTM/USNG		XYZ (m)	
Latitude	N21° 17′ 03.56082" N211703.56082 21.2843224502	Zone	HI 3-5103	Zone	4	X	N/A
Longitude	E202° 09′ 6.06204" W1575053.93796 -157.8483160994	Northing	13,034.278 (m) 42,763.293 (usft) 42,763.379 (ift)	Northing (m)	2,354,050.809	Y	N/A
Ellipsoid Height (m)	Not given	Easting	515,740.433 (m) 1,692,058.405 (usft) 1,692,061.789 (ift)	Easting (m)	619,470.970	Z	N/A
		Convergence (dms)	00 03 18.22	Convergence (dms)	00 25 05.18		
		Scale factor	0.99999306	Scale factor	0.99977638		
		Combined factor	N/A	Combined factor	N/A		
				USNG	4QFJ1947054050		

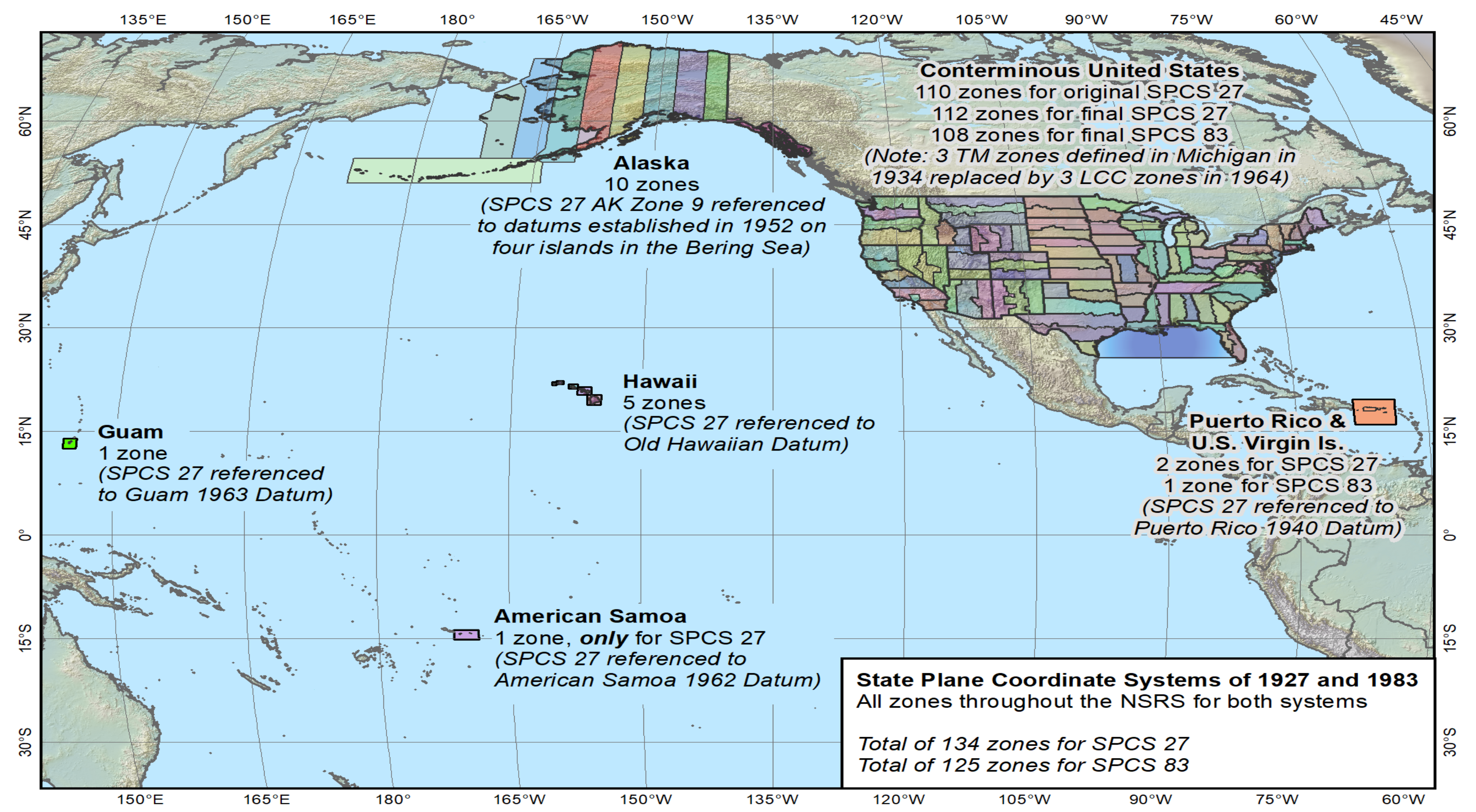
You may change the default UTM zone. The change is processed interactively once a lat-long is converted; DO NOT click the Submit button.

Map Projections

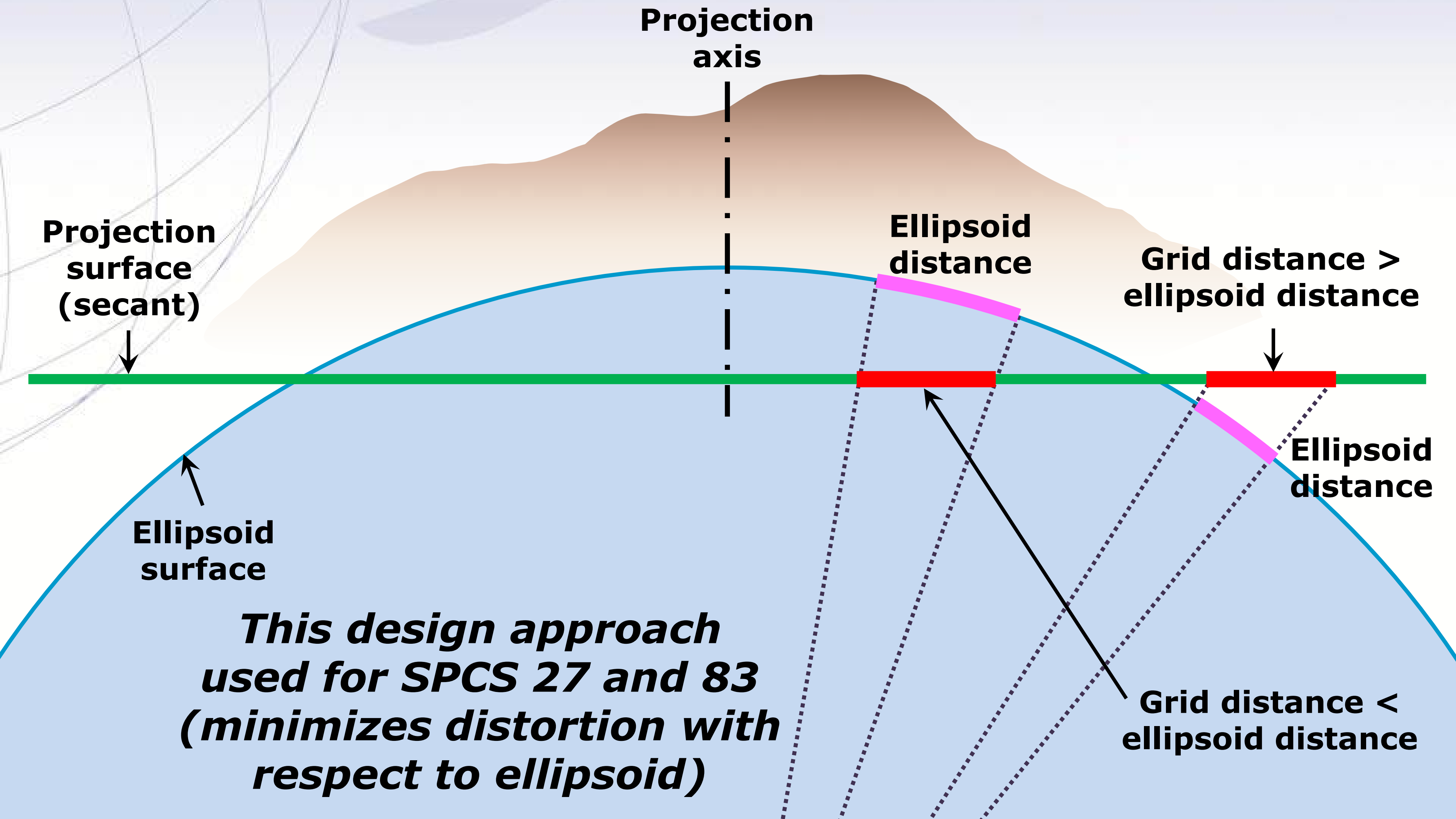


History and Future of State Plane

- SPCS created 85 years ago
  - **SPCS 27:** 1933 – 1986 (53 years, with some changes)
  - **SPCS 83:** 1986 – 2022 (36 years, with some changes)



Linear distortion *with respect to ellipsoid*

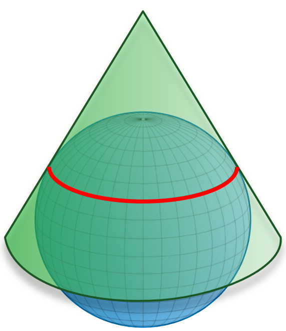


This design approach used for SPCS 27 and 83 (minimizes distortion with respect to ellipsoid)

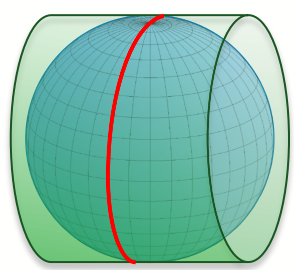
A New State Plane for 2022

- 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:

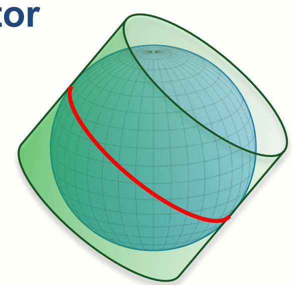
Lambert Conformal Conic (LCC)



Transverse Mercator (TM)



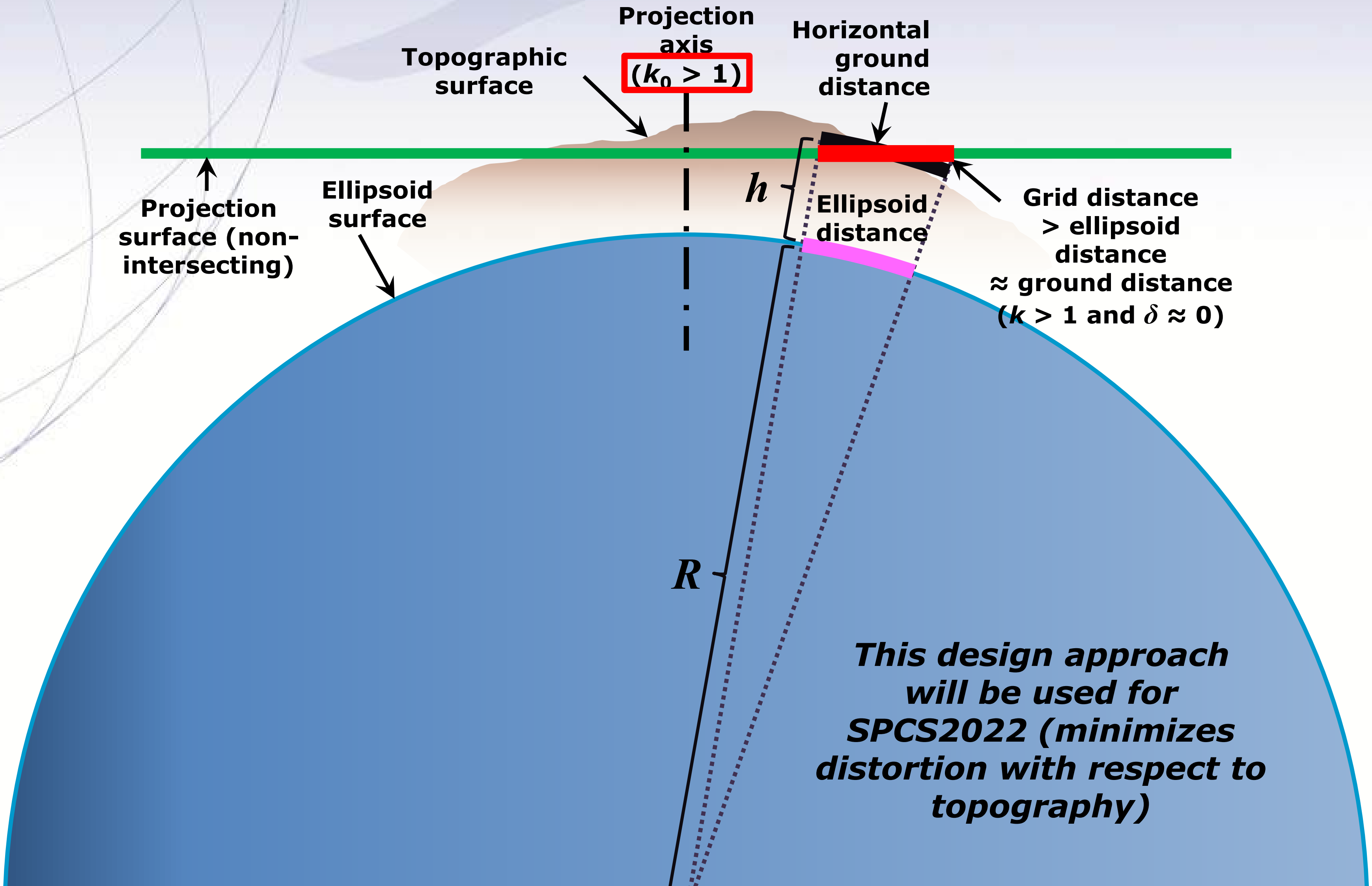
Oblique Mercator (OM)



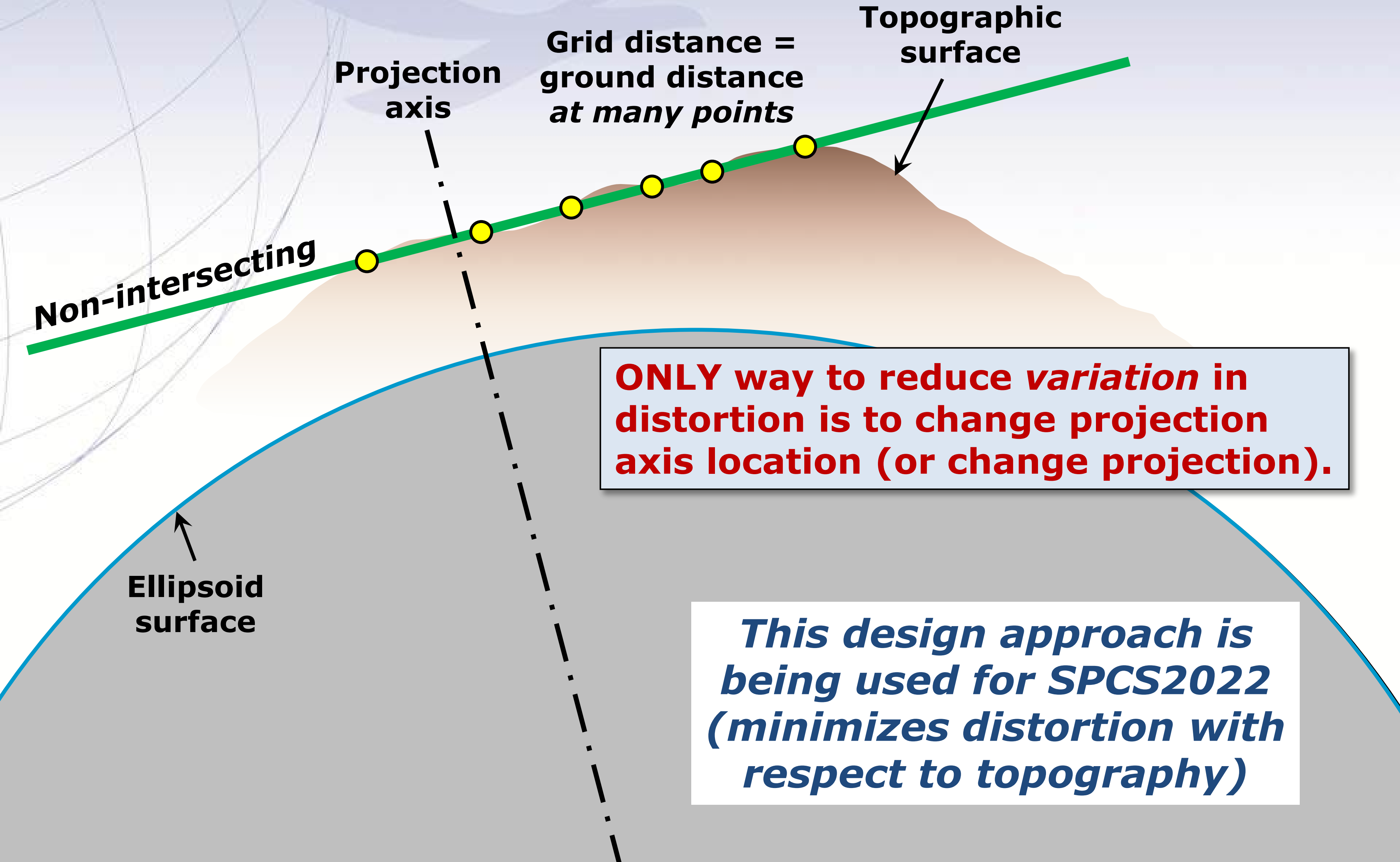
Getting Acquainted with SPCS2022

- Distortion design requirements
  - ***Minimize distortion*** at topographic surface (*not* at ellipsoid surface)
  - ***Purpose:*** to reduce difference between and projected "grid" and actual "ground" distances

Linear distortion *with respect to topographic surface*



Changing projection axis to reduce distortion variation



ONLY way to reduce *variation* in distortion is to change projection axis location (or change projection).

This design approach is being used for SPCS2022 (minimizes distortion with respect to topography)

More About SPCS2022

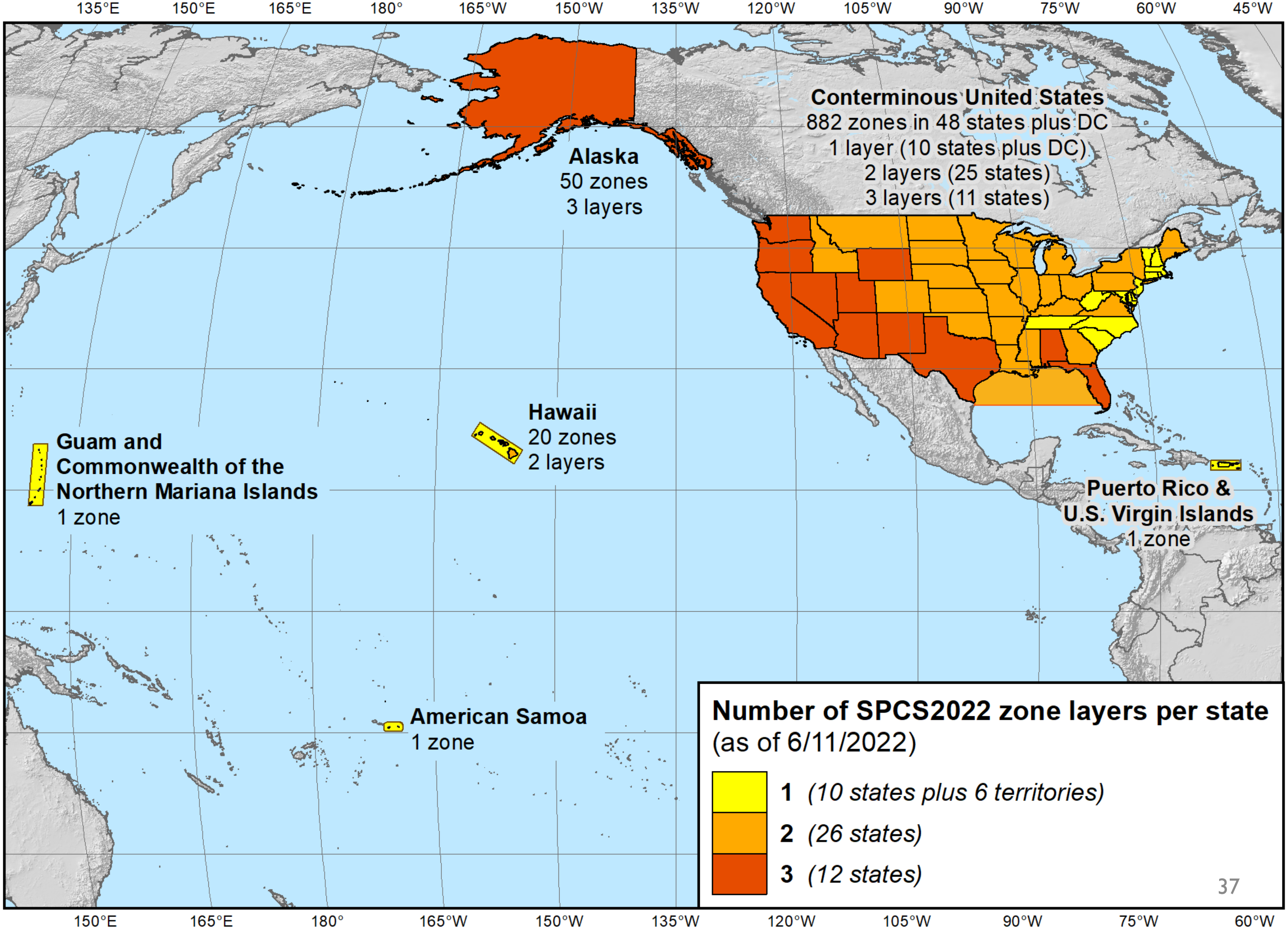
- **Statewide zones** created for ***all*** states
- **Default zones** created as necessary
  - To ensure ***all*** states and territories covered
  - Modify existing zones to meet policy

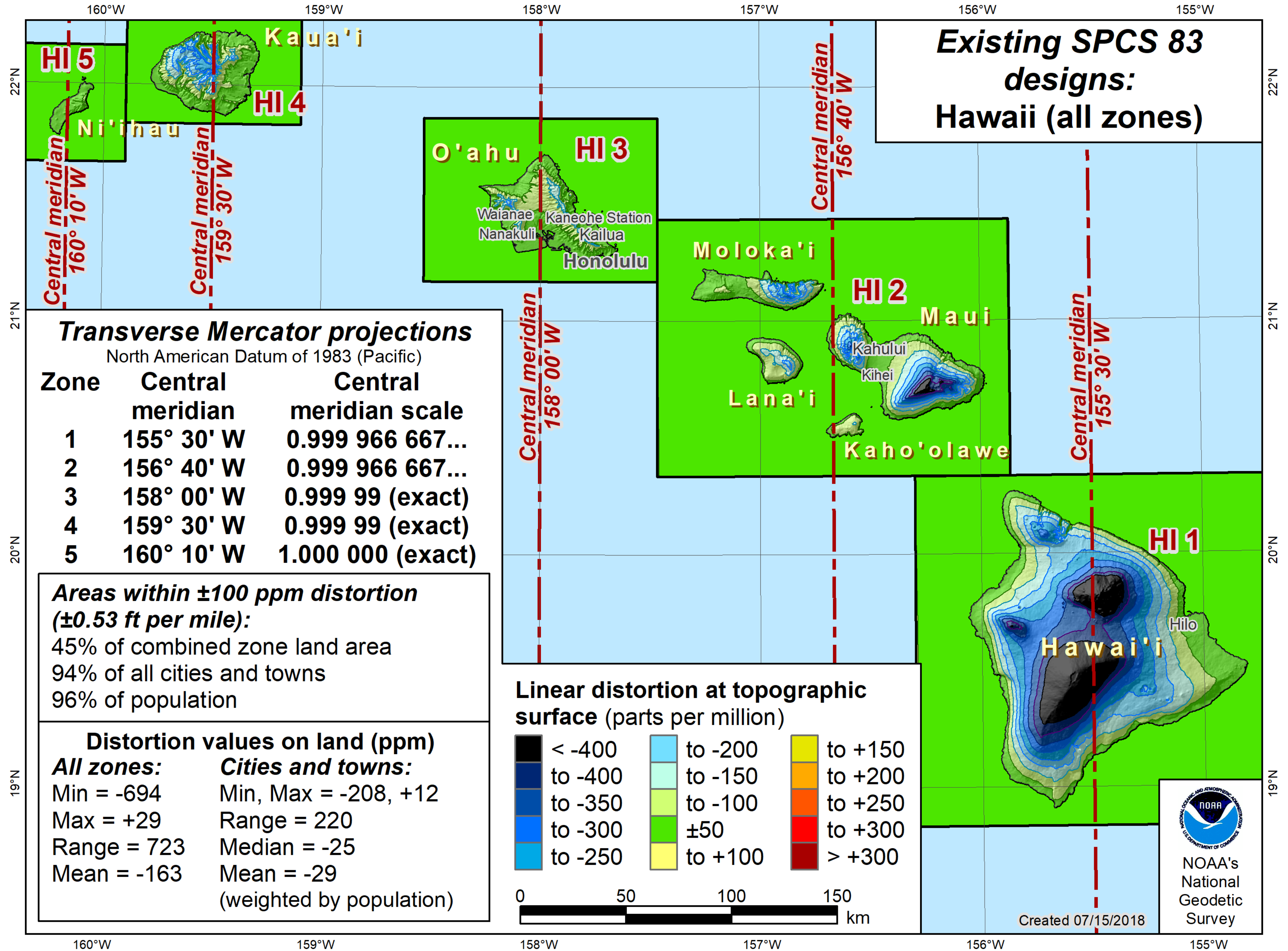
States often want statewide ***and*** small zones

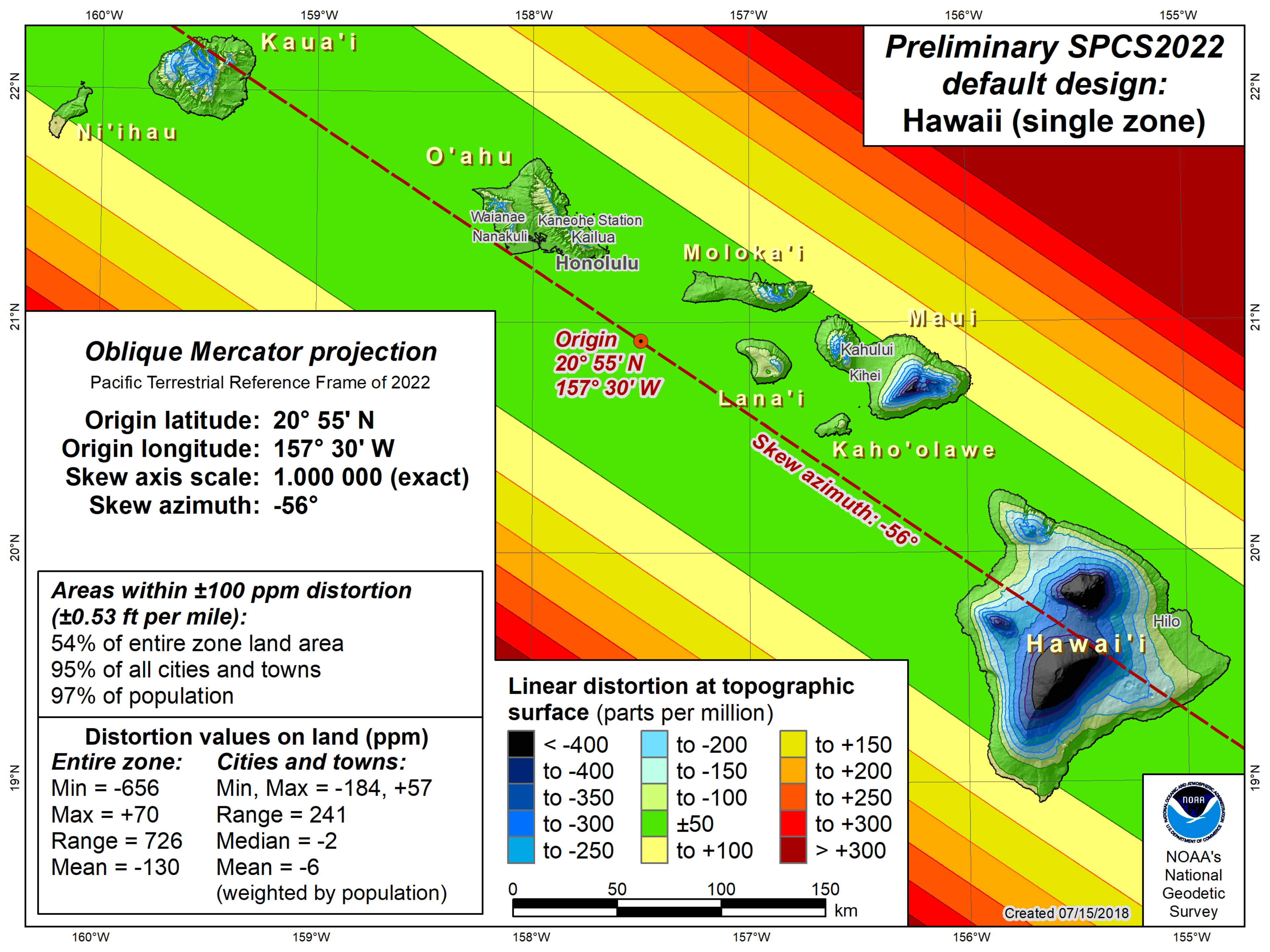
Statewide: Single geometry required for state GIS

Sub-zones: Lower distortion for surveying/engineering

State Plane Coordinate System of 2022 (955 zones in 56 states and territories)




Existing SPCS 83 designs:
Hawaii (all zones)
Transverse Mercator projections
North American Datum of 1983 (Pacific)
Zone | Central meridian | Central meridian scale
1 | 155° 30' W | 0.999 966 667...
2 | 156° 40' W | 0.999 966 667...
3 | 158° 00' W | 0.999 99 (exact)
4 | 159° 30' W | 0.999 99 (exact)
5 | 160° 10' W | 1.000 000 (exact)
Areas within ±100 ppm distortion (±0.53 ft per mile):
45% of combined zone land area
94% of all cities and towns
96% of population
Distortion values on land (ppm)
All zones:
Min = -694
Max = +29
Range = 723
Mean = -163
Cities and towns:
Min, Max = -208, +12
Range = 220
Median = -25
Mean = -29
(weighted by population)
Linear distortion at topographic surface (parts per million)
< -400
to -400
to -350
to -300
to -250
to -200
to -150
to -100
±50
to +100
to +150
to +200
to +250
to +300
> +300
0
50
100
150
km
HI 1
HI 2
HI 3
HI 4
HI 5
Kaua'i
Ni'ihau
O'ahu
Moloka'i
Lana'i
Maui
Kaho'olawe
Hawai'i
Waianae
Nanakuli
Kaneohe Station
Kailua
Honolulu
Kahului
Kihei
Hilo
Central meridian 160° 10' W
Central meridian 159° 30' W
Central meridian 158° 00' W
Central meridian 156° 40' W
Central meridian 155° 30' W
160°W
159°W
158°W
157°W
156°W
155°W
22°N
21°N
20°N
19°N
NOAA's National Geodetic Survey
Created 07/15/2018


Preliminary SPCS2022 default design: Hawaii (single zone)
Oblique Mercator projection
Pacific Terrestrial Reference Frame of 2022
Origin latitude: 20° 55' N
Origin longitude: 157° 30' W
Skew axis scale: 1.000 000 (exact)
Skew azimuth: -56°
Areas within ±100 ppm distortion (±0.53 ft per mile):
54% of entire zone land area
95% of all cities and towns
97% of population
Distortion values on land (ppm)
Entire zone:
Min = -656
Max = +70
Range = 726
Mean = -130
Cities and towns:
Min, Max = -184, +57
Range = 241
Median = -2
Mean = -6
(weighted by population)
Linear distortion at topographic surface (parts per million)
< -400
to -400
to -350
to -300
to -250
to -200
to -150
to -100
±50
to +100
to +150
to +200
to +250
to +300
> +300
0
50
100
150
km
Kaua'i
Ni'ihau
O'ahu
Waianae
Nanakuli
Kaneohe Station
Kailua
Honolulu
Moloka'i
Maui
Kahului
Kihei
Lana'i
Kaho'olawe
Hawai'i
Hilo
Origin
20° 55' N
157° 30' W
Skew azimuth: -56°
160°W
159°W
158°W
157°W
156°W
155°W
22°N
21°N
20°N
19°N
Created 07/15/2018
NOAA
NOAA's
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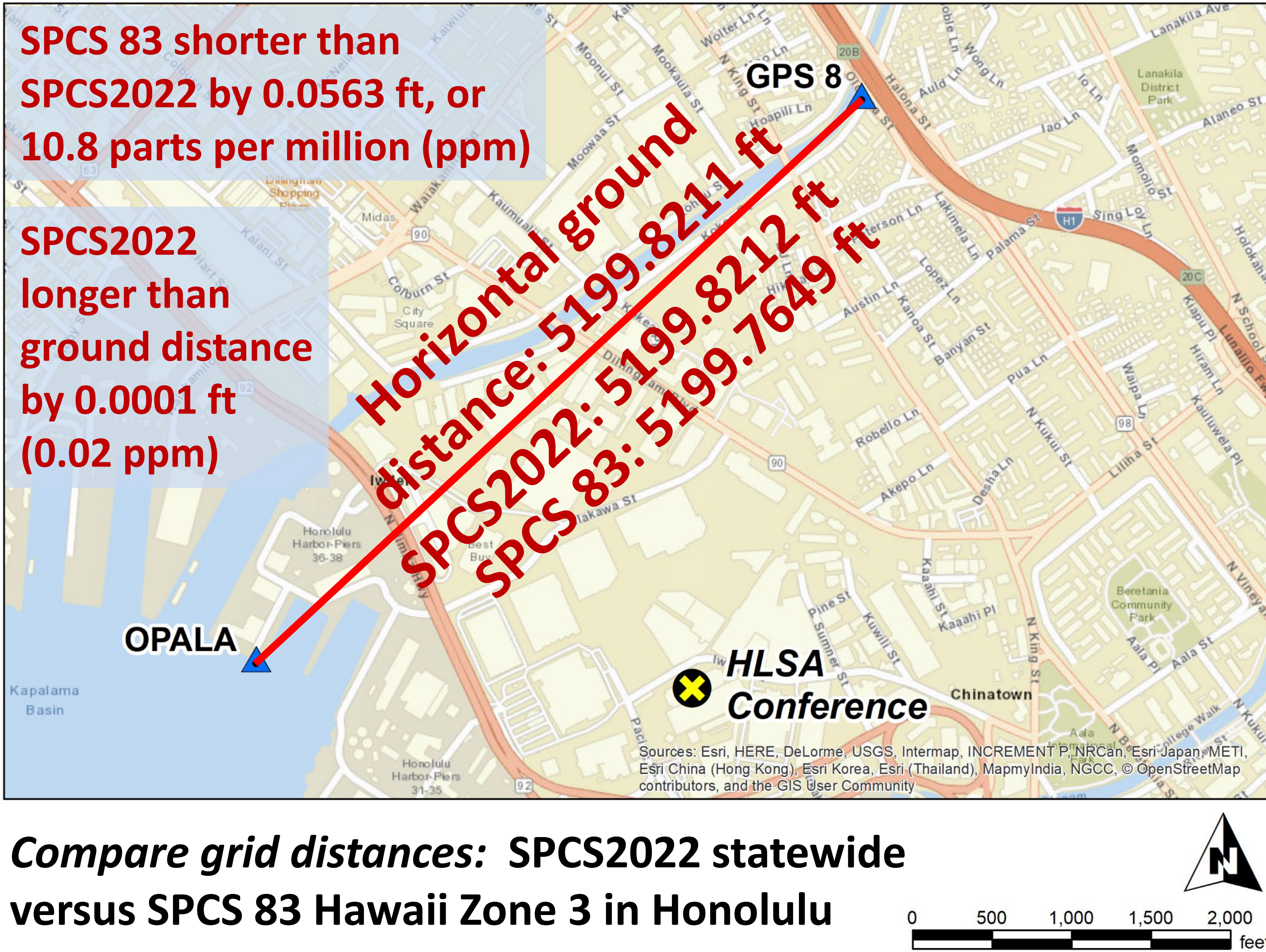
Survey



Compare grid distances: **SPCS2022 statewide versus SPCS 83 Hawaii Zone 3 in Honolulu**

And now for something completely different...

A tale of two feet

Two versions of "foot" in current use:

"Old" U.S. survey foot → "New" international foot

1 ft = 0.3048006096… m

1 ft = 0.3048 m *exactly*

differ by
2 parts per million
(ppm) or ~0.01 ft/mile

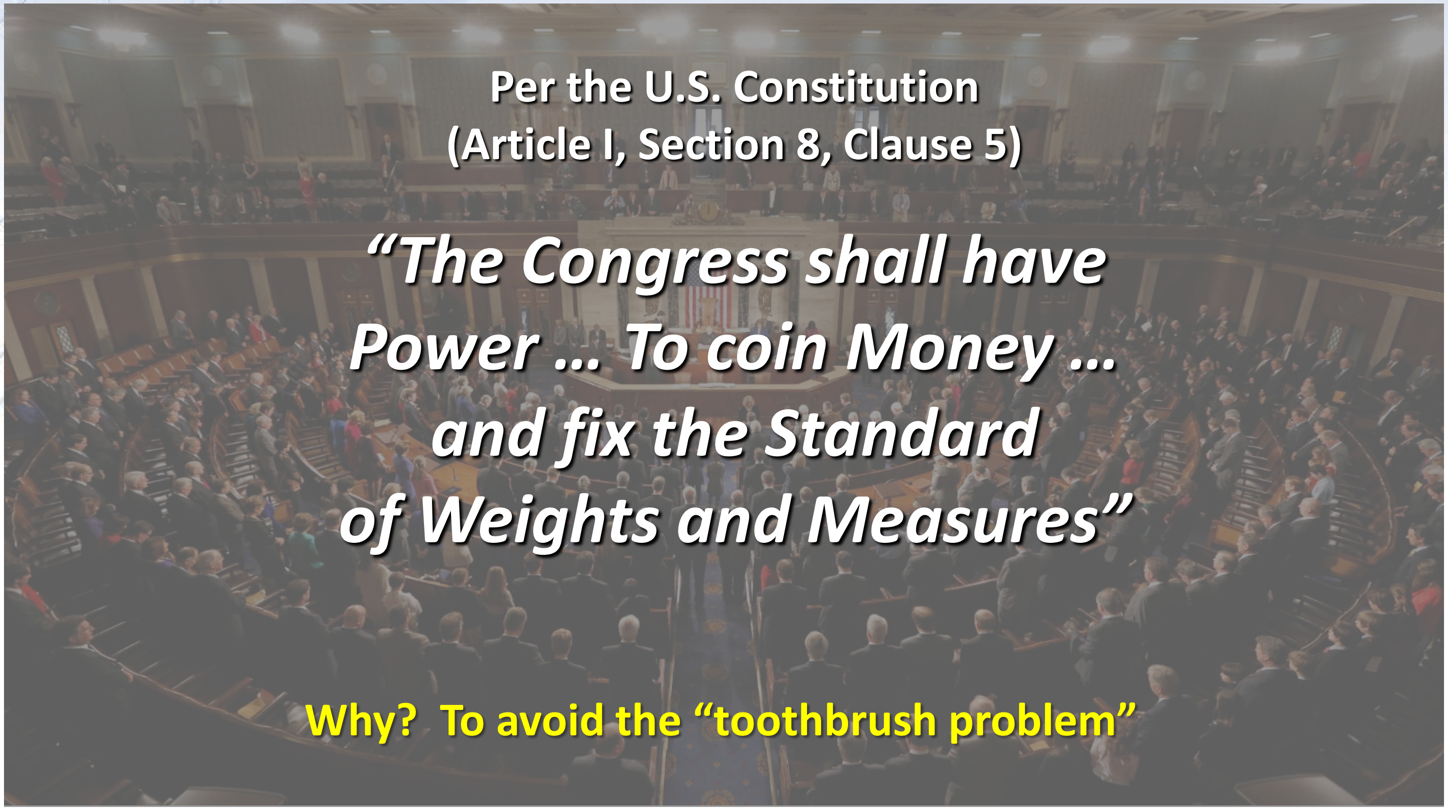
A ***real*** problem with ***real*** costs

Who is responsible for standards?

Today:

National Institute of Standards and Technology

Congress is the Authority

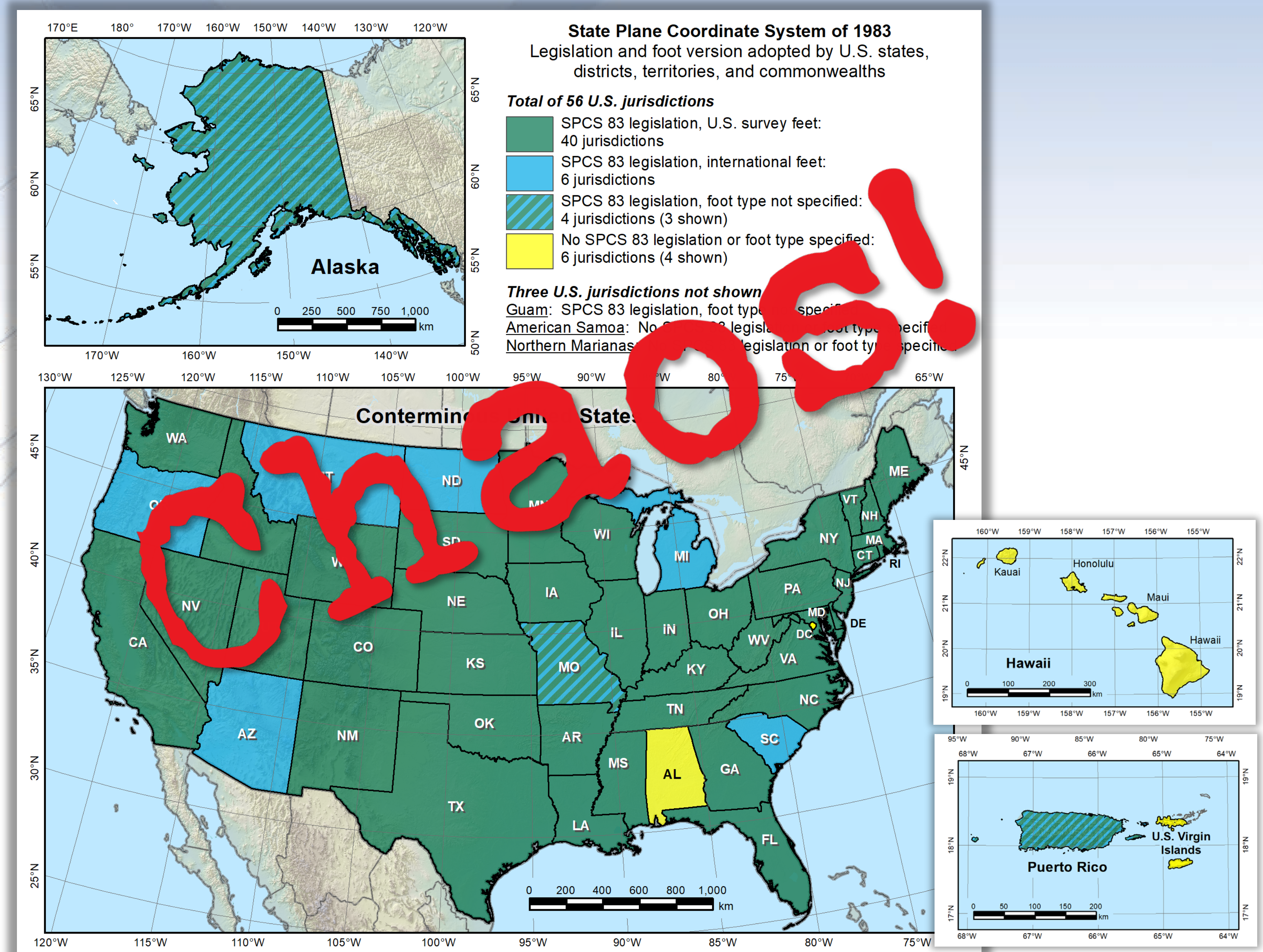


The trouble with standards…

Image from beyondplm.com

Why make the change?

- That was original intent (*60 years ago!*)
- Two "feet" is inefficient and causes confusion
  - Leads to errors that cost money
  - Absurd to have "same" unit that differs by 2 ppm
  - Defeats purpose of having a length standard
- Only recognized in ***part*** of U.S.
- NGS software can support backward-compatibility
- ***Now is the time***
  - Many changes already being made for 2022
  - Change in foot trivial compared to other changes
  - U.S. survey foot problems will never go way if not addressed


State Plane Coordinate System of 1983
Legislation and foot version adopted by U.S. states, districts, territories, and commonwealths
Total of 56 U.S. jurisdictions
SPCS 83 legislation, U.S. survey feet: 40 jurisdictions
SPCS 83 legislation, international feet: 6 jurisdictions
SPCS 83 legislation, foot type not specified: 4 jurisdictions (3 shown)
No SPCS 83 legislation or foot type specified: 6 jurisdictions (4 shown)
Three U.S. jurisdictions not shown
Guam: SPCS 83 legislation, foot typ
American Samoa: No
Northern Marianas
Alaska
Conterminous United States
Hawaii
Kauai
Honolulu
Maui
Puerto Rico
U.S. Virgin Islands
chaos!

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Converted coordinates will be in output datum.

Convert

Export Results to PDF CSV XML

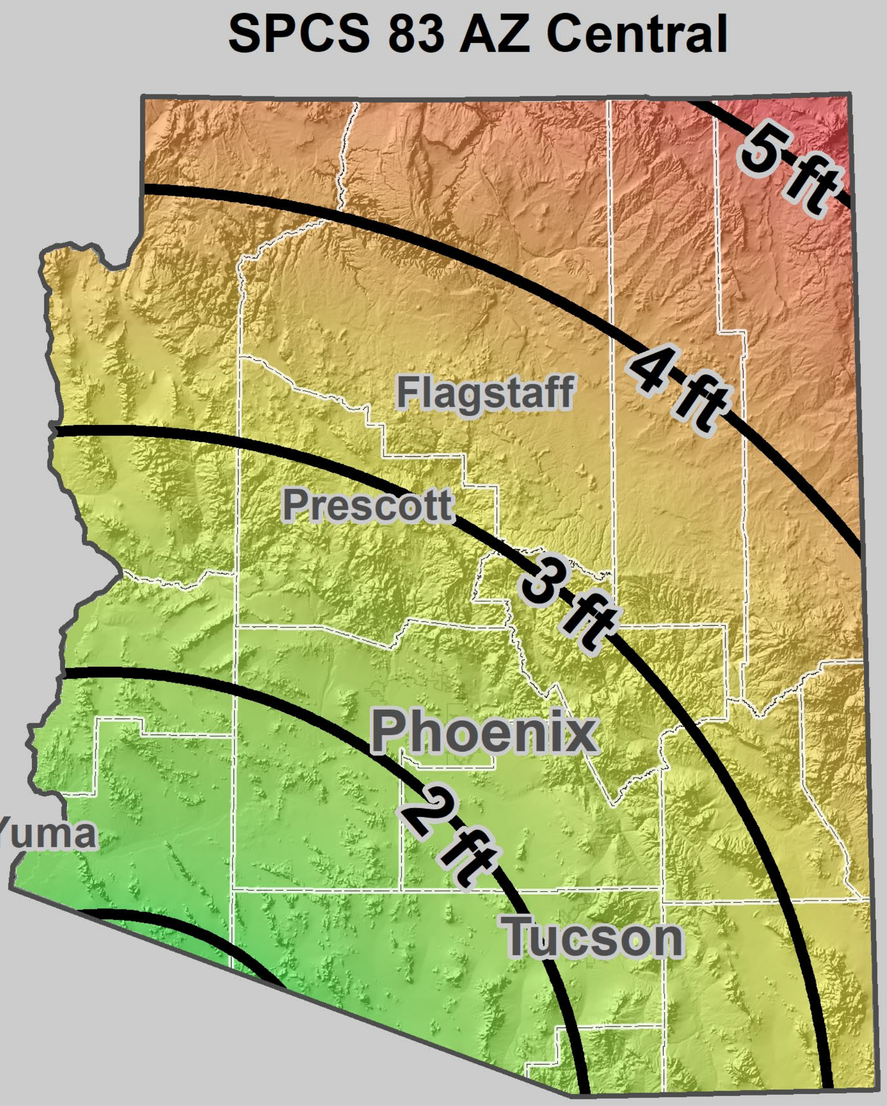
LLh		SPC		UTM (m)		XYZ (m)		USNG
SrcLat	21.2874716056 N211714.89778	Zone	HI 3-5103	Zone	4	X	N/A	4QFJ1947054050
DestLat	21.2843224502 N211703.56082	Northing (m)	13,034.278	Northing	2,354,050.809	Y	N/A	
Siglat (arcsec)	±0.005410	Northing (usft)	42,763.293	Easting	619,470.972	Z	N/A	
SrcLon	-157.8510606972 W1575103.81851	Northing (ift)	42,763.379	Convergence (dms)	00 25 05.18			
DestLon	-157.8483160827 W1575053.93790	Easting (m)	515,740.435	Scale factor	0.99977638			
Siglon (arcsec)	±0.002206	Easting (usft)	1,692,058.410	Combined factor	N/A			
SrcEht (m)	N/A	Easting (ift)	1,692,061.794					
DestEht (m)	N/A	Convergence (dms)	00 03 18.22					
sigeht (m)	±N/A	Scale factor	0.99999306					
		Combined factor	N/A					

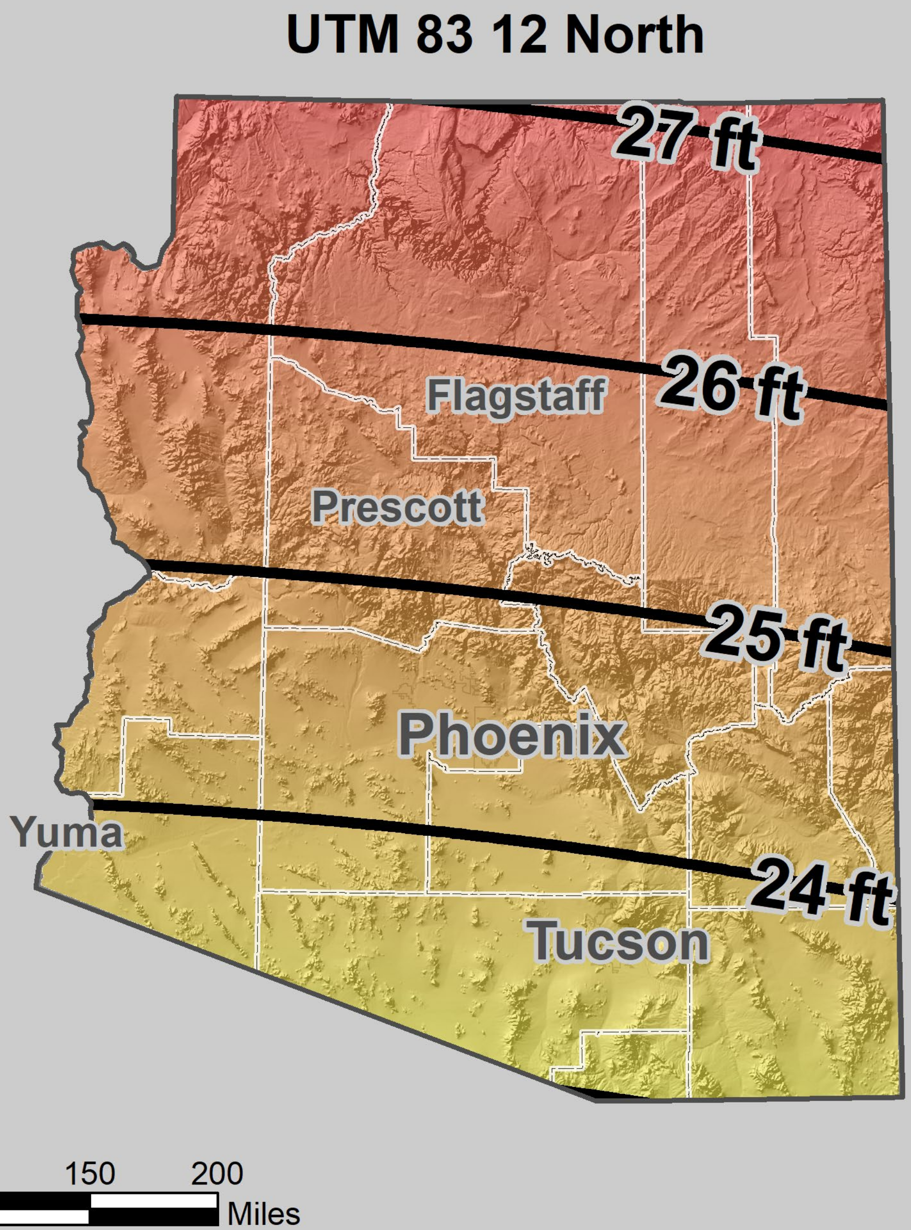
0.08ft

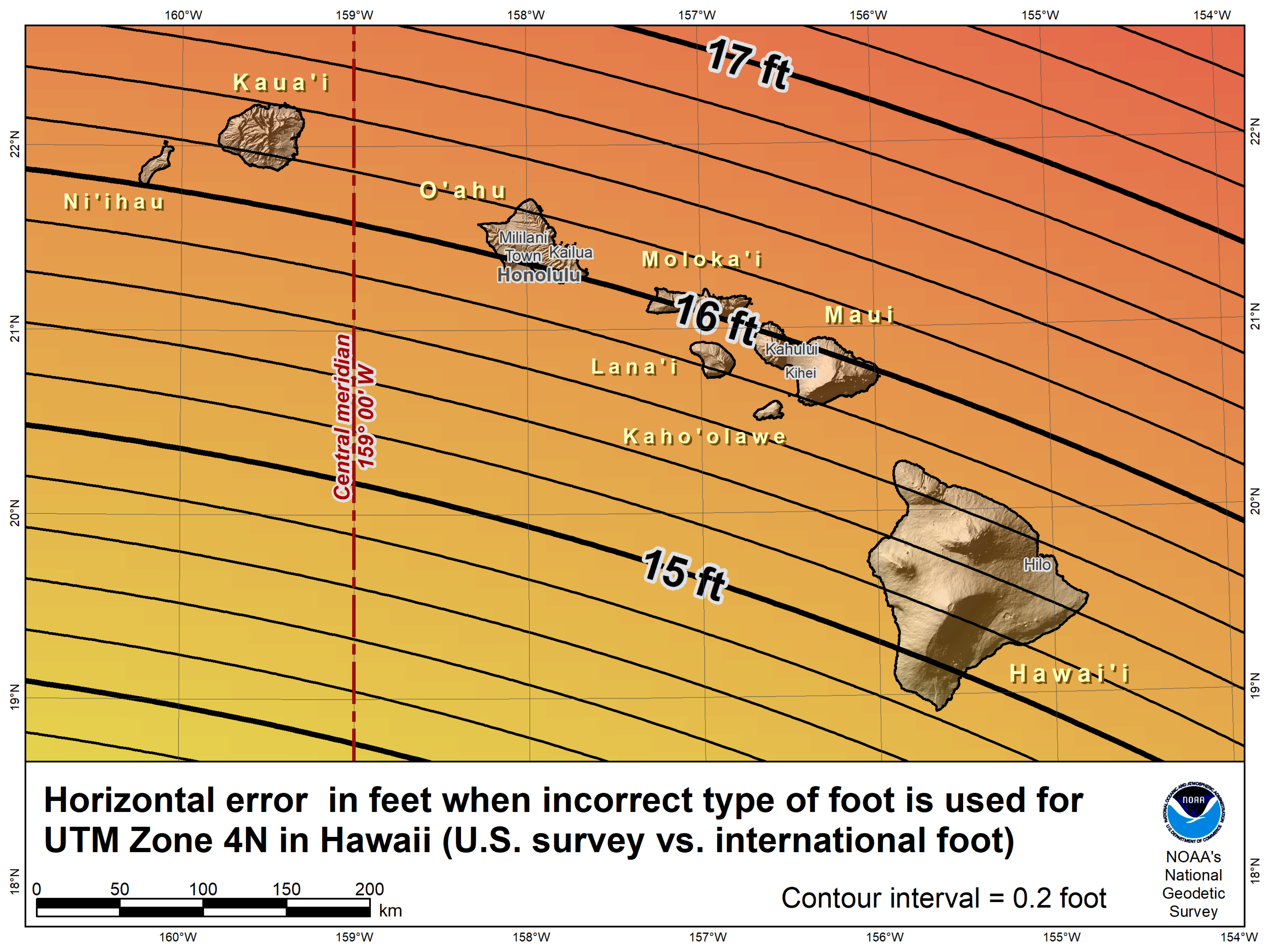
3.39ft

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.

Horizontal difference in coordinates due to difference between international and US survey foot







Horizontal error in feet when incorrect type of foot is used for UTM Zone 4N in Hawaii (U.S. survey vs. international foot)

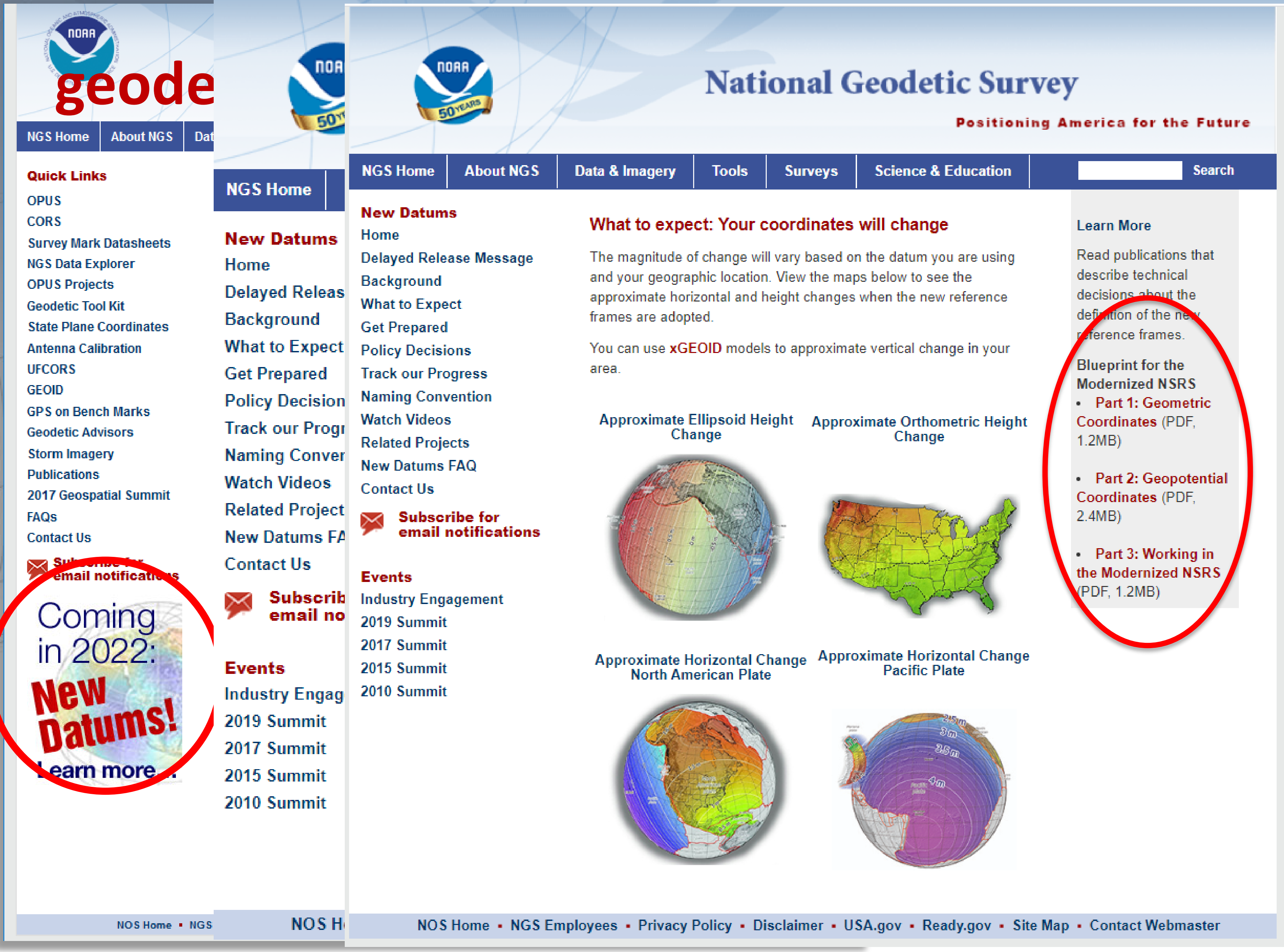
How can you prepare for 2022 Datum?

Procedures and Workflows:

- Analyze current procedures and workflows
- Create plans for adjusting future data collection, including contract language

Data:

- Maintain raw data collected today for transformations to the new datums in the future
- Ensure ***proper metadata for current data*** and planned data collection to ensure the proper transformations will be used in the future (datum, foot)
- Share information with NGS so we can understand agency challenges in converting current data to new datums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2017 Summit
2015 Summit
2010 Summit
What to expect: Your coordinates will change
The magnitude of change will vary based on the datum you are using and your geographic location. View the maps below to see the approximate horizontal and height changes when the new reference frames are adopted.
You can use xGEOID models to approximate vertical change in your area.
Approximate Ellipsoid Height Change
Approximate Orthometric Height Change
Approximate Horizontal Change North American Plate
Approximate Horizontal Change Pacific Plate
Learn More
Read publications that describe technical decisions about the definition of the new reference frames.
Blueprint for the Modernized NSRS
Part 1: Geometric Coordinates (PDF, 1.2MB)
Part 2: Geopotential Coordinates (PDF, 2.4MB)
Part 3: Working in the Modernized NSRS (PDF, 1.2MB)
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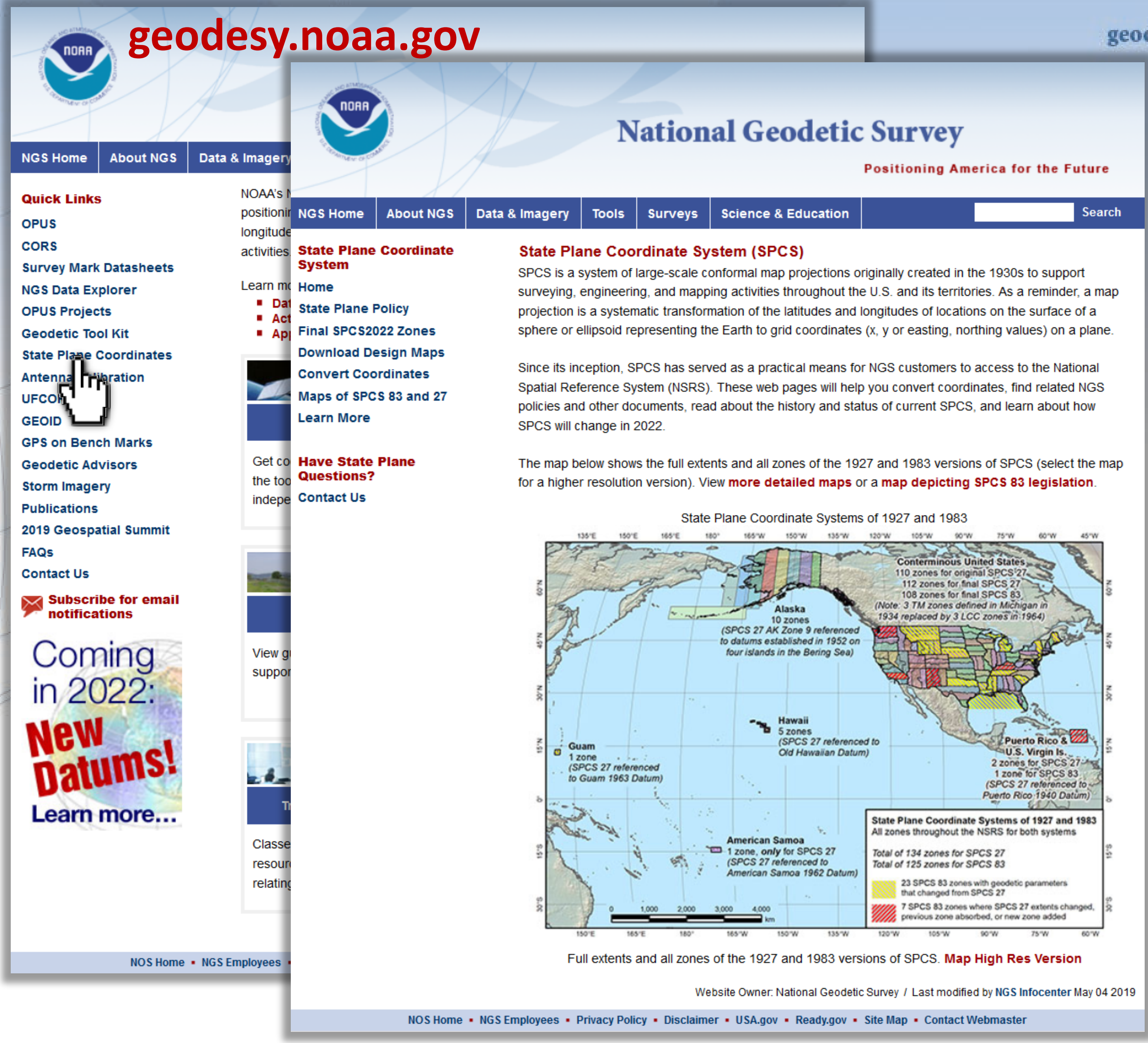
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State Plane Coordinate System (SPCS)
SPCS is a system of large-scale conformal map projections originally created in the 1930s to support surveying, engineering, and mapping activities throughout the U.S. and its territories. As a reminder, a map projection is a systematic transformation of the latitudes and longitudes of locations on the surface of a sphere or ellipsoid representing the Earth to grid coordinates (x, y or easting, northing values) on a plane.
Since its inception, SPCS has served as a practical means for NGS customers to access to the National Spatial Reference System (NSRS). These web pages will help you convert coordinates, find related NGS policies and other documents, read about the history and status of current SPCS, and learn about how SPCS will change in 2022.
The map below shows the full extents and all zones of the 1927 and 1983 versions of SPCS (select the map for a higher resolution version). View more detailed maps or a map depicting SPCS 83 legislation.
State Plane Coordinate Systems of 1927 and 1983
Conterminous United States
110 zones for original SPCS 27
112 zones for final SPCS 27
108 zones for final SPCS 83
(Note: 3 TM zones defined in Michigan in 1934 replaced by 3 LCC zones in 1964)
Alaska
10 zones
(SPCS 27 AK Zone 9 referenced to datums established in 1952 on four islands in the Bering Sea)
Hawaii
5 zones
(SPCS 27 referenced to Old Hawaiian Datum)
Guam
1 zone
(SPCS 27 referenced to Guam 1963 Datum)
Puerto Rico & U.S. Virgin Is.
2 zones for SPCS 27
1 zone for SPCS 83
(SPCS 27 referenced to Puerto Rico 1940 Datum)
American Samoa
1 zone, only for SPCS 27
(SPCS 27 referenced to American Samoa 1962 Datum)
State Plane Coordinate Systems of 1927 and 1983
All zones throughout the NSRS for both systems
Total of 134 zones for SPCS 27
Total of 125 zones for SPCS 83
23 SPCS 83 zones with geodetic parameters that changed from SPCS 27
7 SPCS 83 zones where SPCS 27 extents changed, previous zone absorbed, or new zone added
0 1,000 2,000 3,000 4,000 km
Full extents and all zones of the 1927 and 1983 versions of SPCS. Map High Res Version
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Issue 20, June 2020

NSRS Modernization News

For all issues of **NSRS Modernization News**, visit:
geodesy.noaa.gov/datums/newdatums/TrackOurProgress.shtml

Delayed Release of the Modernized NSRS

NOAA's National Geodetic Survey (NGS) is announcing a delay in the release of the modernized National Spatial Reference System (NSRS).

In 2007, NGS began planning for the modernized NSRS, acquiring its first airborne gravimeter, creating and initiating the Gravity for the Redefinition of the American Vertical Datum (GRAV-D) project and by 2008 had codified its modernization plans into a Ten Year Plan. At that time, the target completion date was 2018. By 2013, that date seemed unlikely, due to both the broadening of the GRAV-D project coverage area and the experience of five years of operational planning and execution.

In 2013, NGS revised its 2007 Strategic Plan, and targeted 2022 as the date of the release of the modernized NSRS. This date was reinforced with a 2018 Strategic Plan revision. By 2017, confidence in hitting the 2022 target was high enough to reach final agreement with Canada and Mexico on a naming convention for certain components, to include "2022" in their names.

Since 2017, operational, workforce, and other issues have arisen and compounded, causing NGS to recently re-evaluate whether a successful roll-out by 2022 is possible. The most significant impacts have been in workforce hiring and retention, and in meeting GRAV-D data collection milestones, which underpin the NSRS modernization efforts.

NGS is currently conducting a comprehensive analysis of ongoing projects, programs, and resources required to complete NSRS modernization and will continue to provide regular updates on our progress. To get the latest news on NSRS modernization and track our progress, subscribe to NGS News or visit our "New Datums" web pages.

Here are brief answers to some expected questions:

Q) How long will the delay be?

A) We don't know. At best, it now looks like the 2024–2025 timeframe.

Q) Will the names stay the same?

A) Yes, terms containing "2022" such as "GEOID2022" and "NATRF2022" will remain the same.

Q) How will this affect deadlines, such as for SPCS and GPS on BM data submittals?

A) Those deadlines will not be changed.

Further details, and more answers are available on this FAQ.

Summary or Bottom Line

If you do geospatial work in the United States and its territories, and you work in the National Spatial Reference System, then every product you've ever made…

- **every survey**
- **every map**
- **every lidar point cloud**
- **every image**
- **every DEM**

… WILL have *NEW* coordinates in 4/5 years.

Mahalo
Questions ????

Edward E. Carlson
Pacific Regional Geodetic Advisor
National Geodetic Survey
email: ed.carlson@noaa.gov

Michael L. Dennis
State Plane Coordinate System 2022 Project Manager
National Geodetic Survey
email: Michael.dennis@noaa.gov