Preparing for Change: New Coordinates Coming in 2022

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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 briefly discuss the history of these datums, their relationship to other reference frames, the reasons for the change, and how it affects positioning professionals 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 users will access the new reference frames
  - New State Plane Coordinate Systems

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**

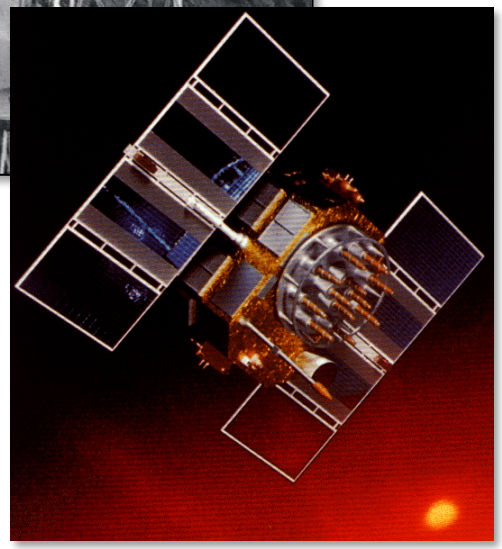
Consistent National Coordinate System

- Latitude/Northing
- Longitude/Easting
- Height
- Scale
- Gravity
- Orientation

& how these values change with time

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(9x-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 (19xx) - HARN
    - NAD 83 (1996) - FBN
    - 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)

ITRF2014

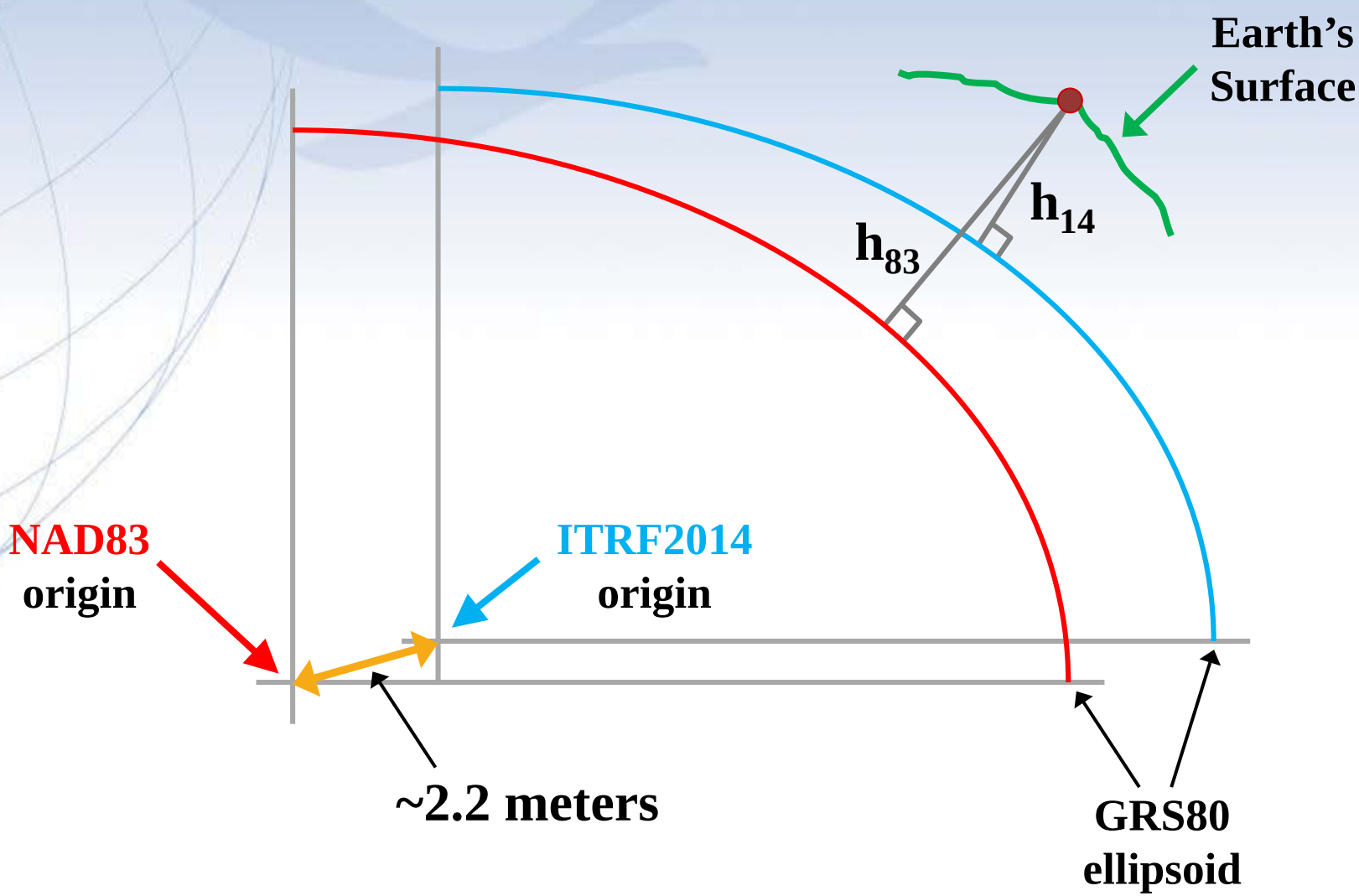
International Terrestrial Frame

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

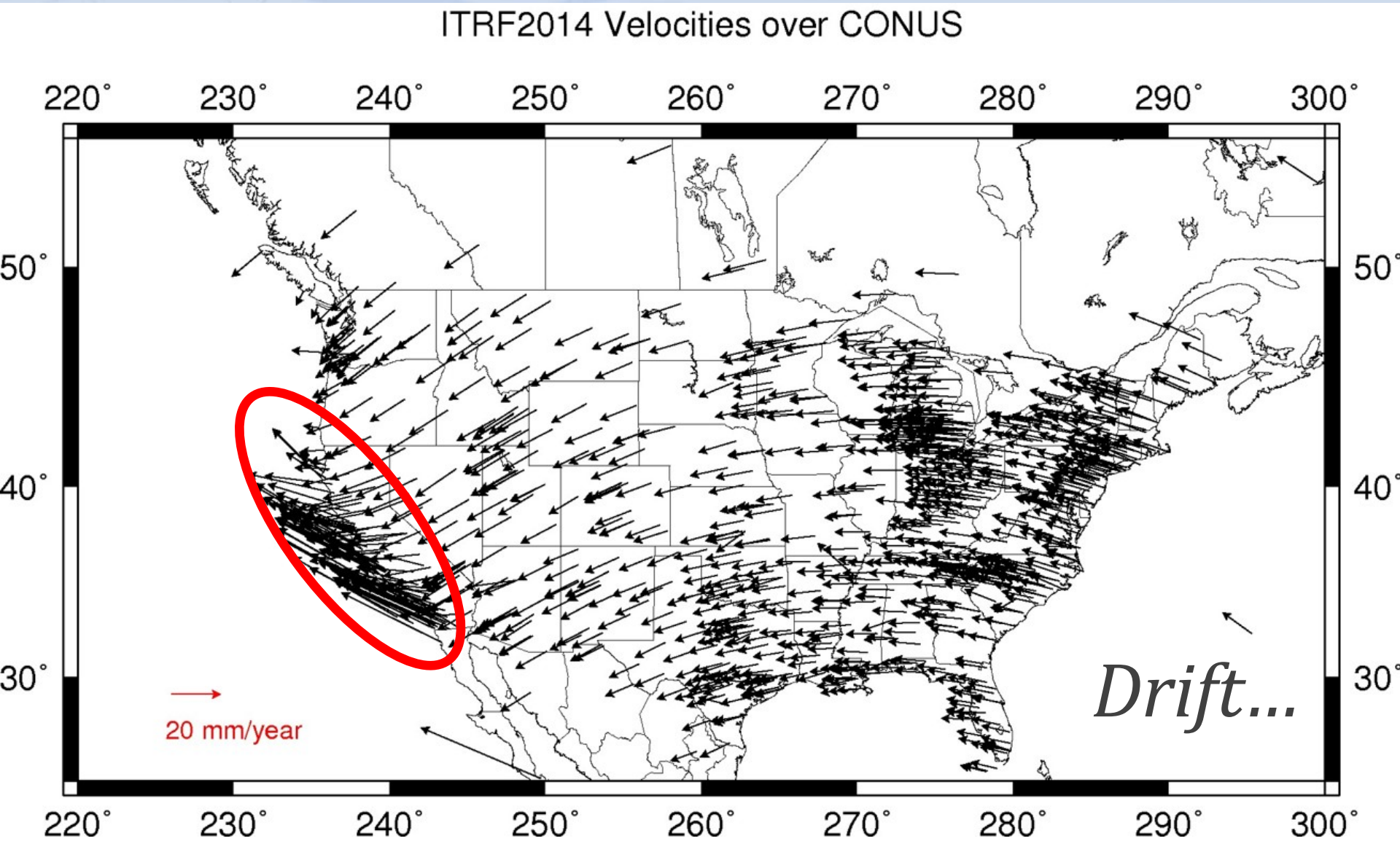
The global community adopted an updated expression for the reference frame, the ITRF2008.

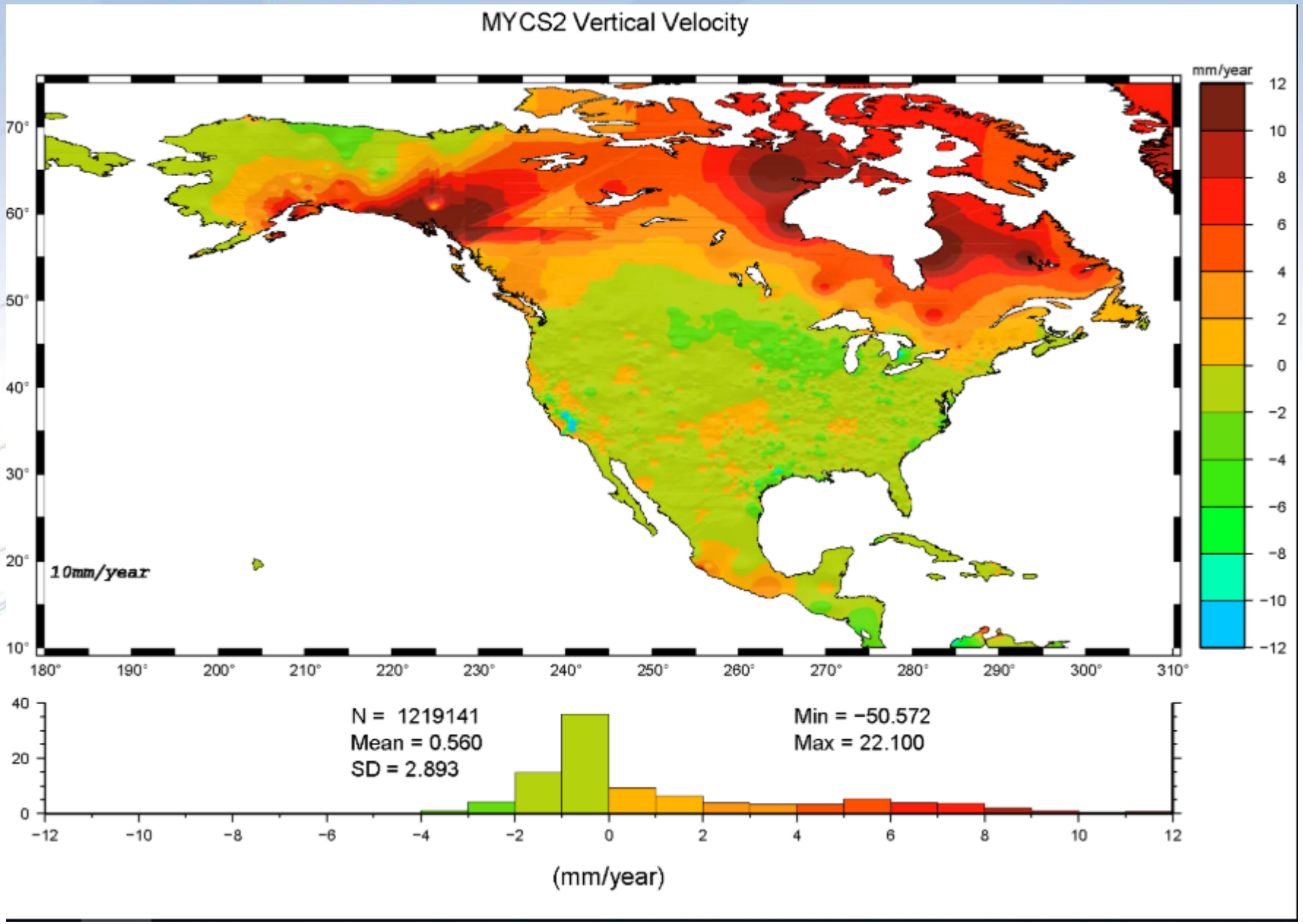
ITRF2014 was just released in the US

Non-geocentricity of NAD83



CORS Velocities in ITRF2014




MYCS2 Vertical Velocity
mm/year
12
10
8
6
4
2
0
−2
−4
−6
−8
−10
−12
70°
60°
50°
40°
30°
20°
10°
10mm/year
180°
190°
200°
210°
220°
230°
240°
250°
260°
270°
280°
290°
300°
310°
40
20
0
N = 1219141
Mean = 0.560
SD = 2.893
Min = −50.572
Max = 22.100
−12
−10
−8
−6
−4
−2
0
2
4
6
8
10
12
(mm/year)

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 Pedro
San Diego
Galveston
Biloxi
Pensacola
Fernandina Beach
Brunswick
St. Augustine
Cedar Keys
Norfolk
Old Point Comfort
Annapolis
Perth Amboy
Father's Point
Halifax
Yarmouth
Portland
Boston
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Image NASA
Image © 2008 TerraMetrics
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*

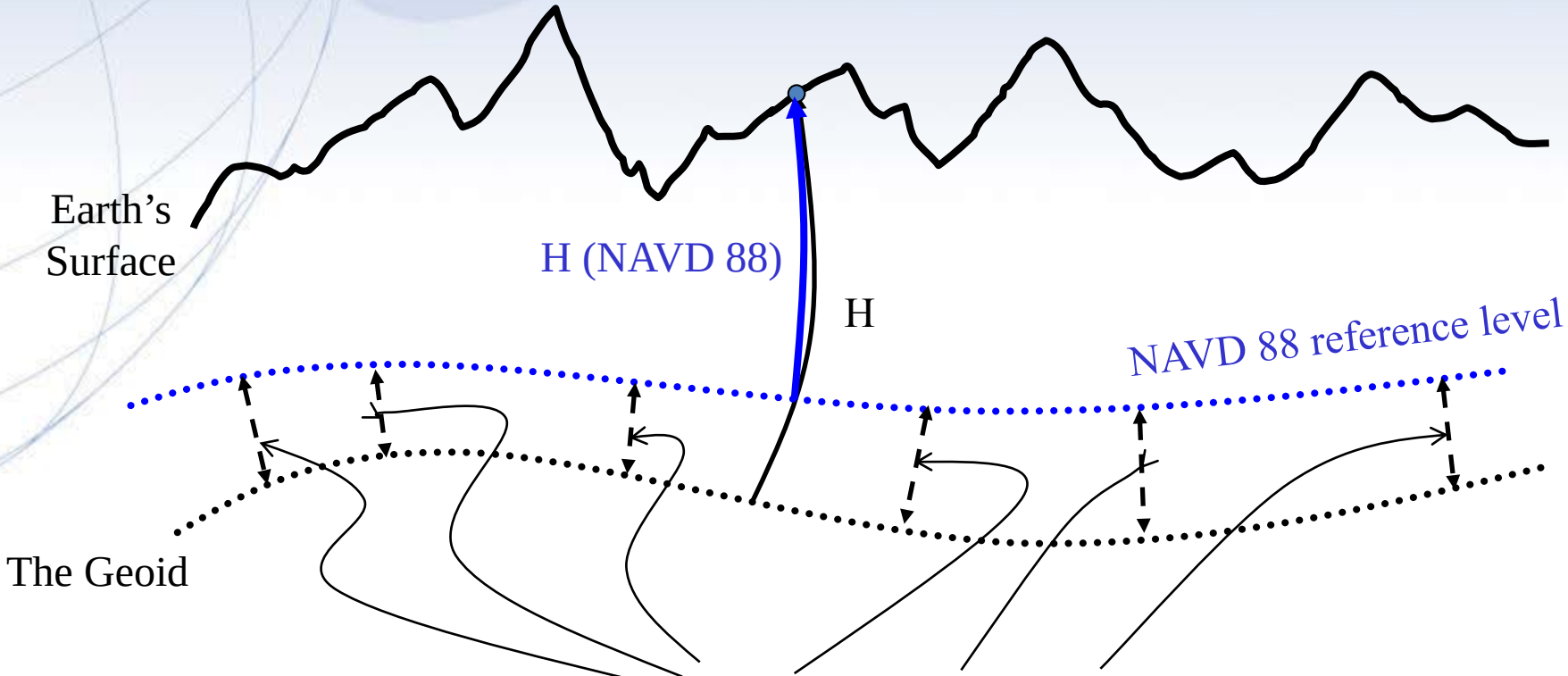
History of vertical datums in the USA

- **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)

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

Why isn't NAVD 88 good enough anymore?

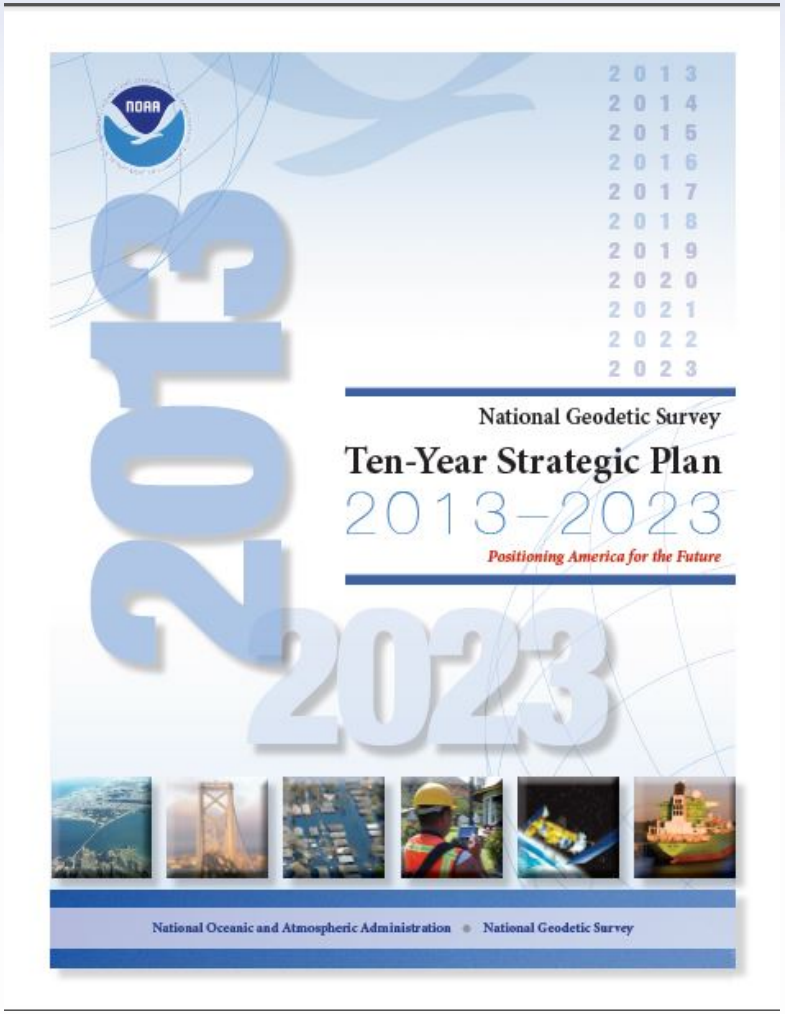


Errors in NAVD 88 : ~50 cm average,
100 cm CONUS tilt,
1-2 meters average in Alaska

The National Geodetic Survey 10 year plan
Mission, Vision and Strategy
2008 – 2018, 2013-2023

http://www.ngs.noaa.gov/INFO/NGS10yearplan.pdf

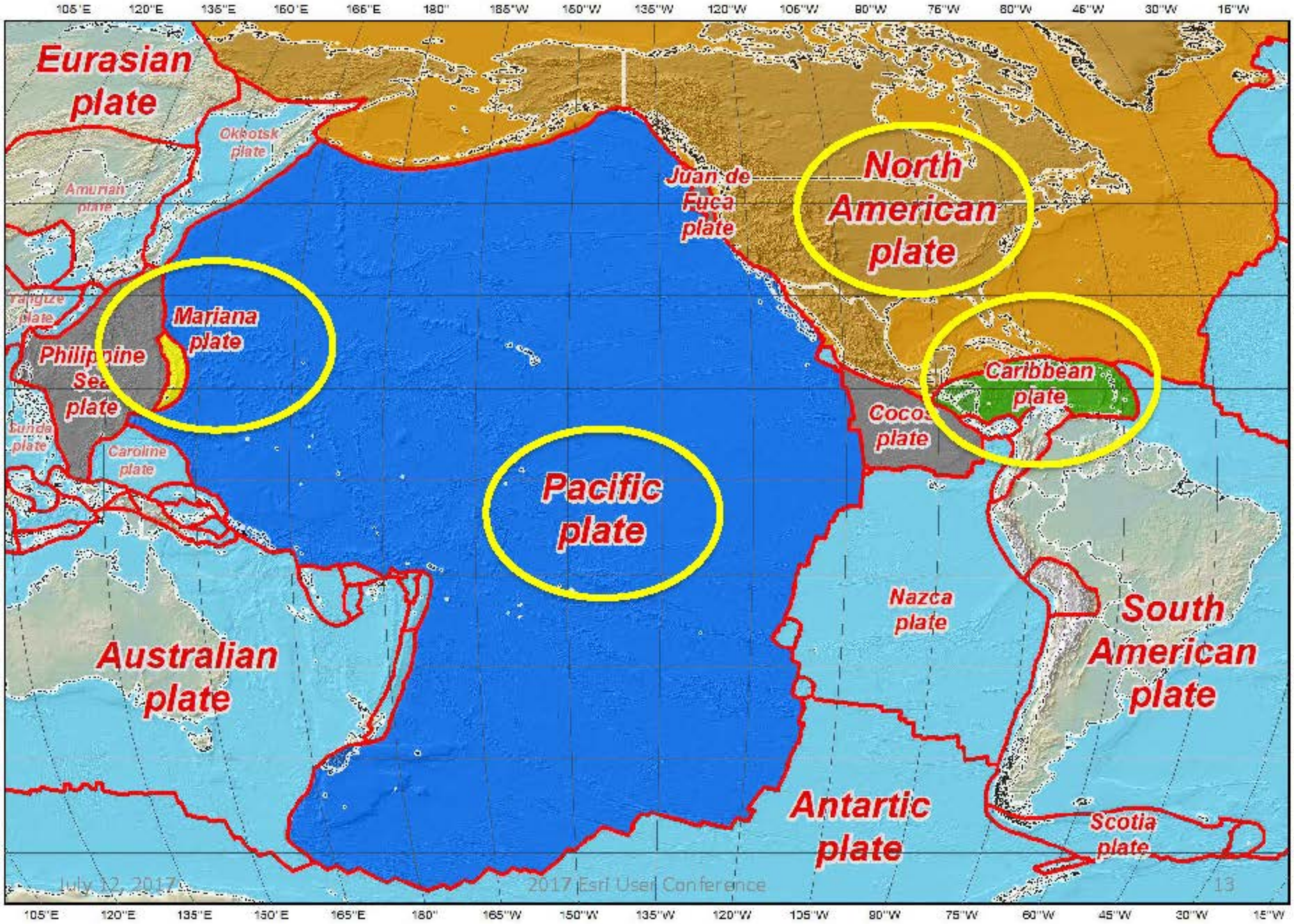
- *Official NGS policy as of Jan 9, 2008*
  - *Modernized agency*
  - *Attention to accuracy*
  - *Attention to time-changes*
  - *Improved products and services*
  - *Integration with other fed missions*
- *2022 Targets:*
  - *NAD 83 and NAVD 88 re-defined*
  - *Cm-accuracy access to all coordinates*
  - *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 ITRF and TRFs
    - ✓Plate Rotation Model for each plate
    - ✓Coordinates at survey epoch
  - ✓Intra-frame velocity model
    - ✓To compare coordinates surveyed at different epochs

The four tectonic plates "fixed" for the 2022 terrestrial reference frames



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)

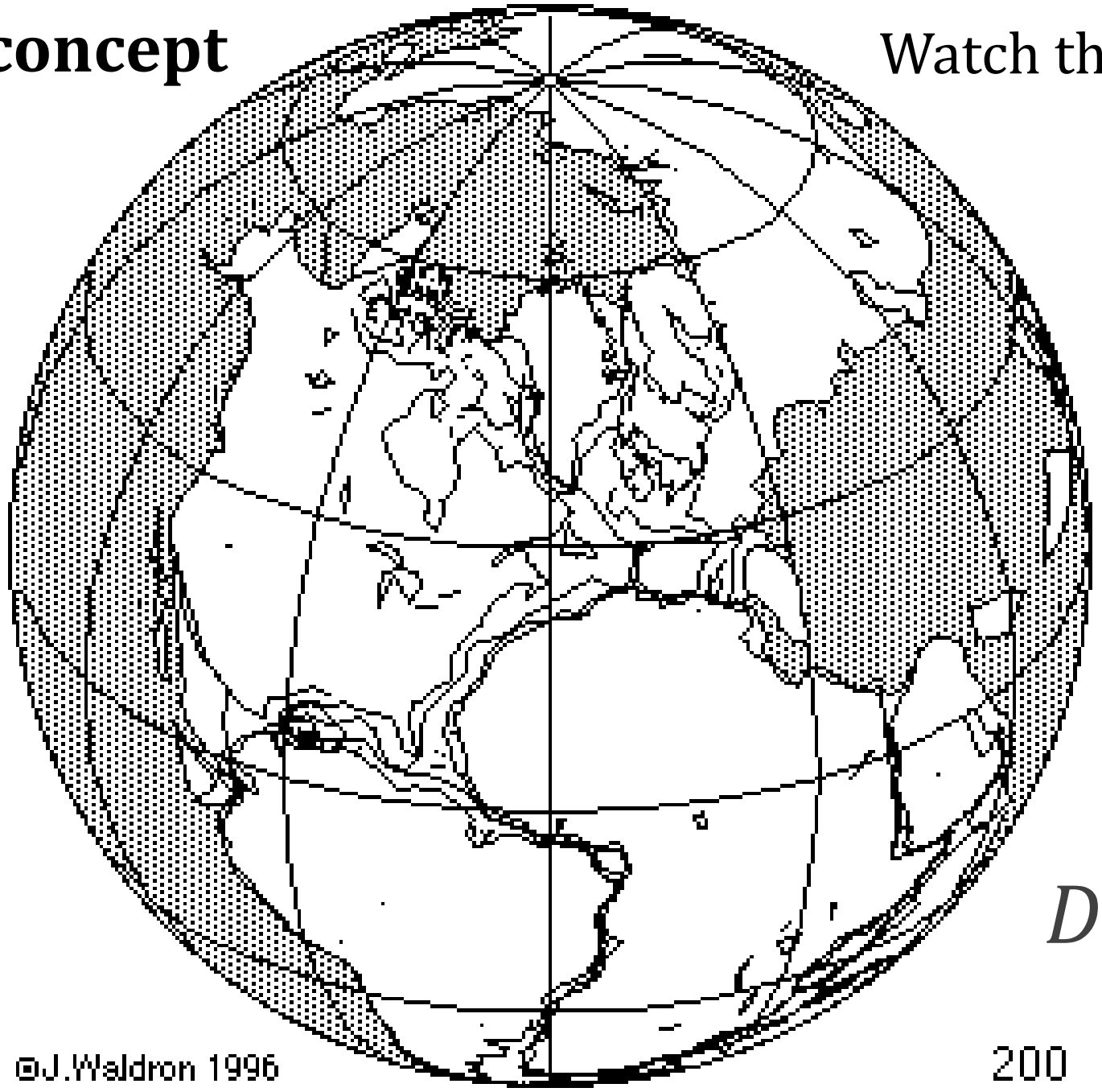
Replacing NAD83

1. develop four "plate-fixed" reference frames
2. remove non-geocentricity of NAD83
3. align to ITRF2014 at epoch 2020.00
4. **remove most of tectonic plate rotation from ITRF2014 via Euler Pole Parameters**
   (pronounced: "oiler")

Shift and Drift…

ITRF concept

Watch the grid!

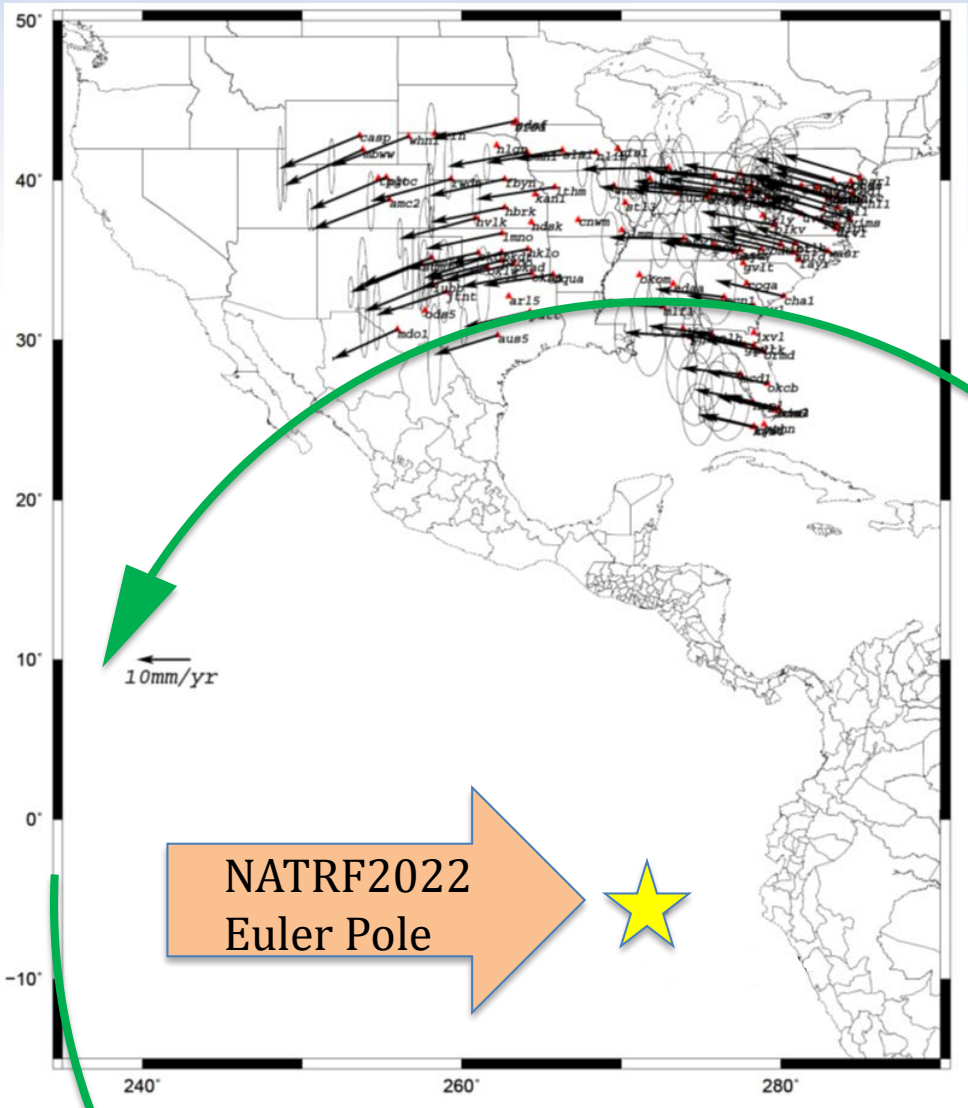


Drift…

Euler Poles and "Plate-Fixed"

- In the ITRF, many tectonic plates have a *dominant* motion: **rotation**

- **Euler Pole** - point about which a plate rotates (yellow star)



Euler Poles and "Plate-Fixed"

ITRF

Frame = constant

NA Plate = rotating

NATRF

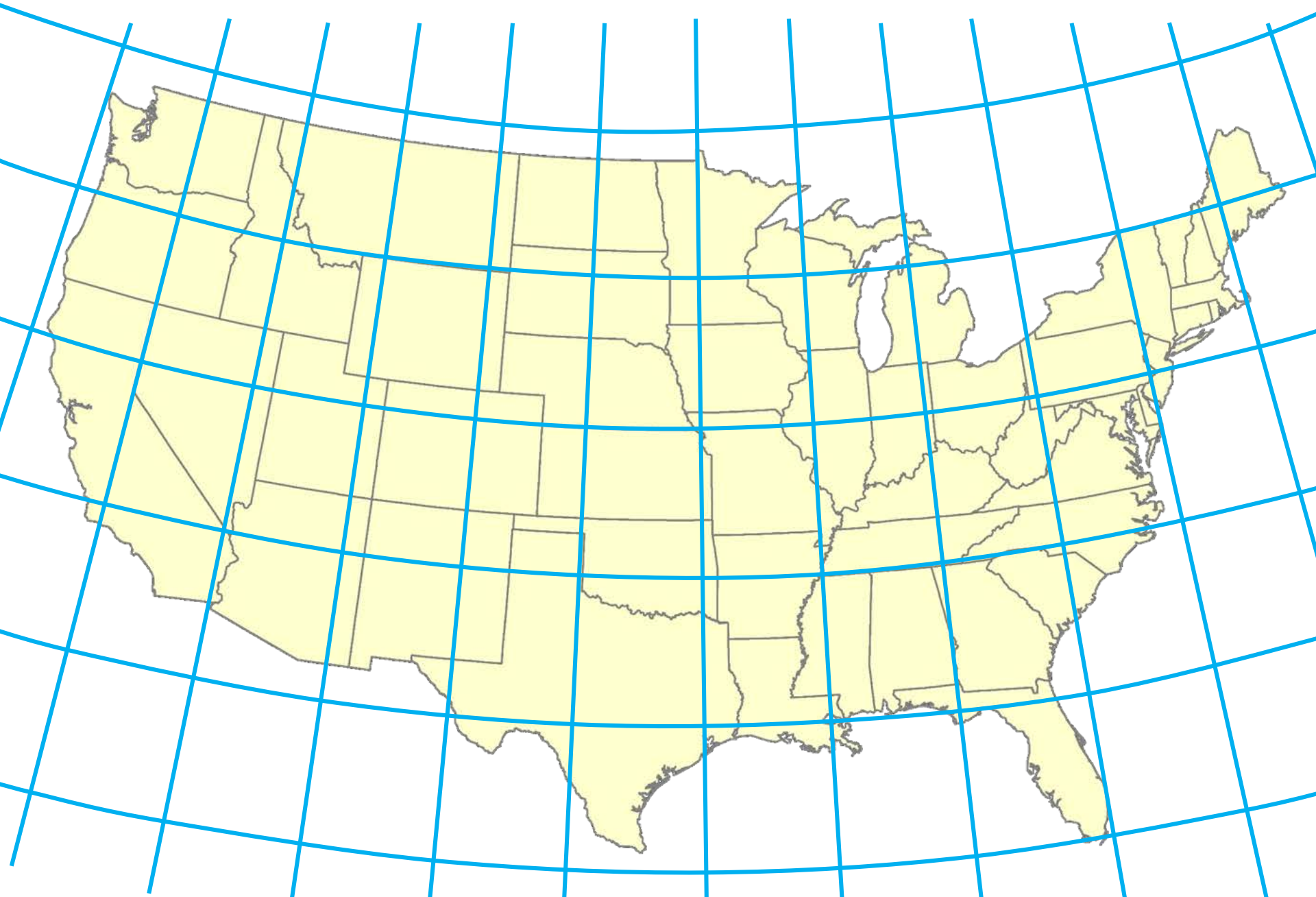
Frame = rotating

(*relative to ITRF*)

NA Plate = constant

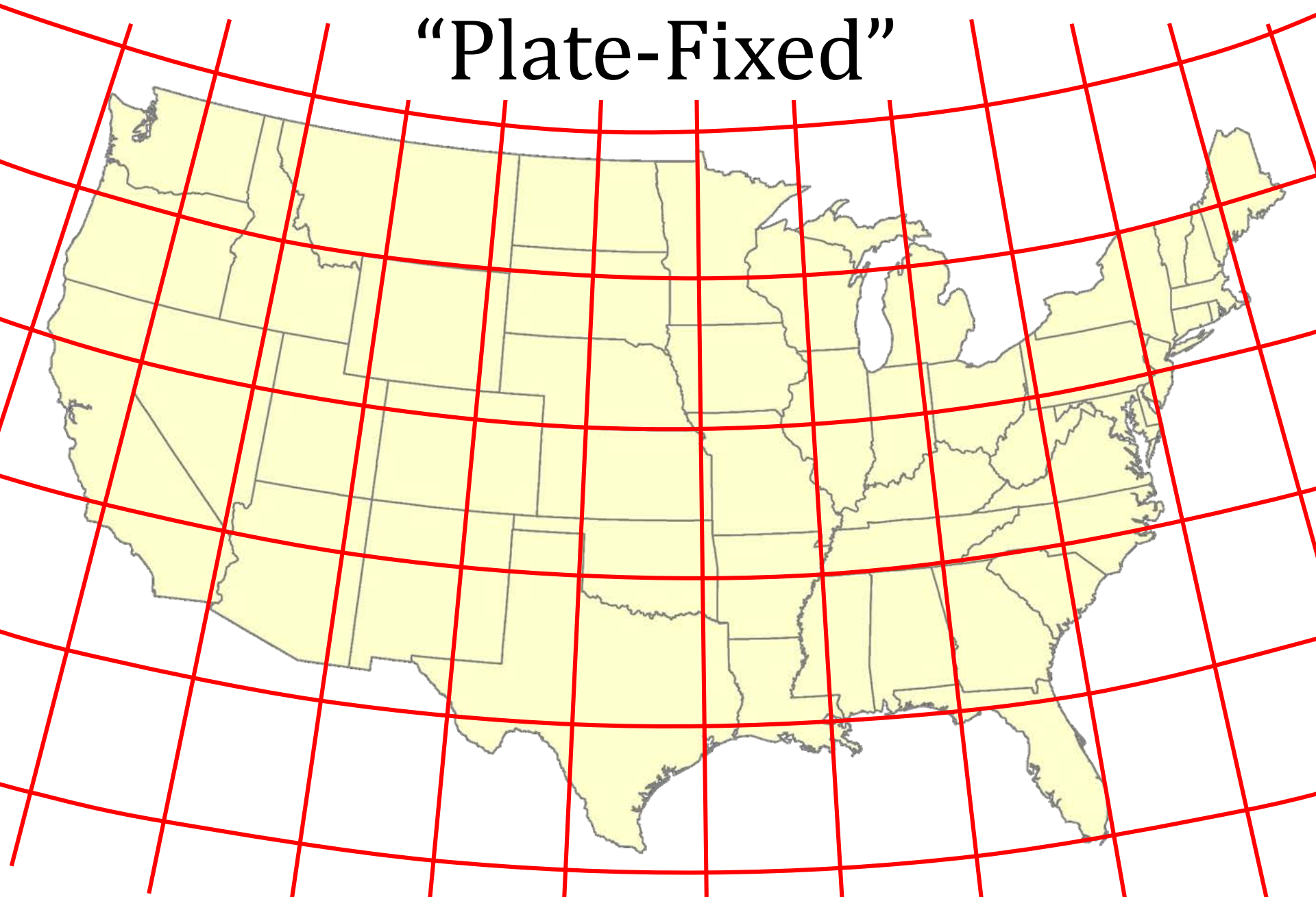
(*relative to NATRF2022*)

ITRF – constant frame, rotating plate

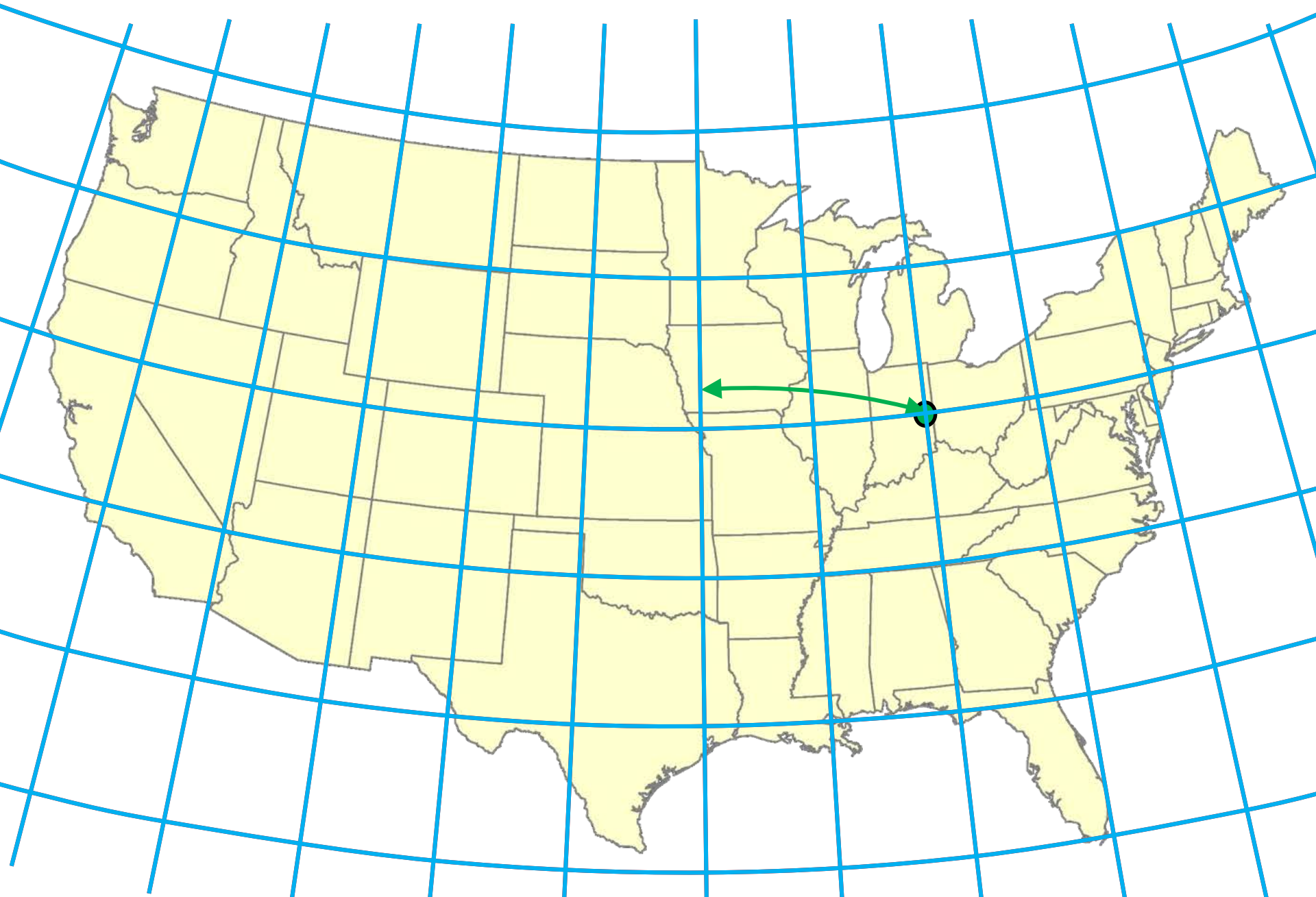


NATRF – rotating frame, constant with plate

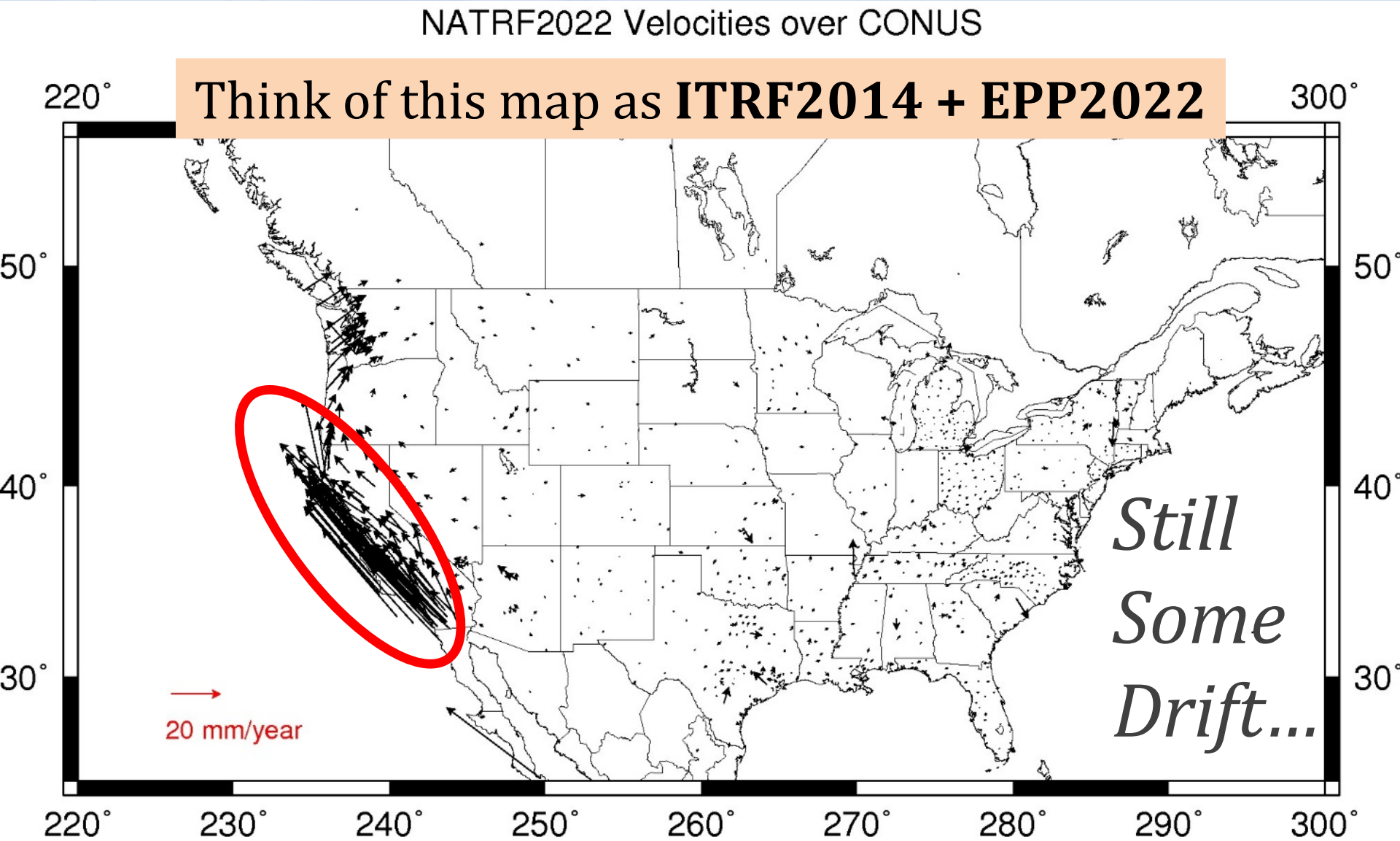
"Plate-Fixed"



ITRF or NATRF – your choice, just use EPP



CORS Velocities in NATRF2022



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)

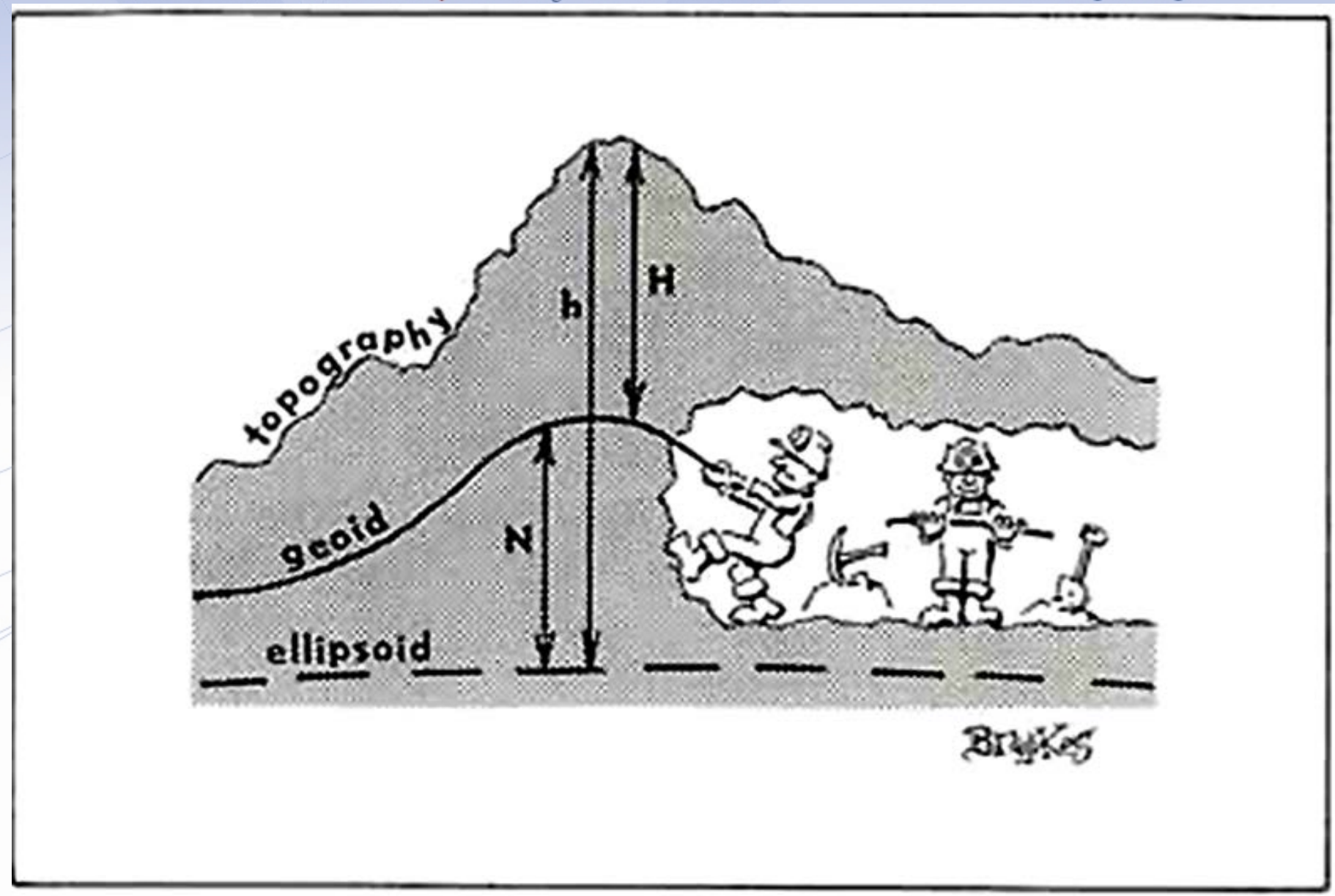
- Will include GEOID2022

Scientific Decisions!!

- Blueprint for 2022, Part 3: Working in a Modernized NSRS
  - ✓Terminology
  - ✓New types of coordinates
  - ✓New way of operating NOAA CORS Network
  - ✓New way to process GNSS and Leveling data
  - ✓New way for users to access data

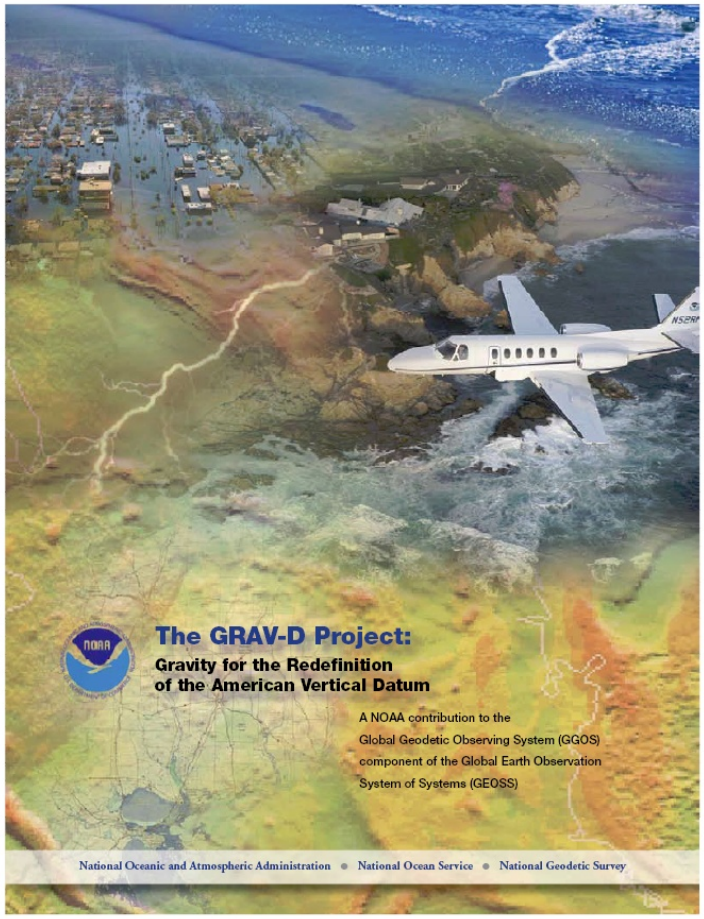
Why replace NAVD 88 and NAD 83?

- **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

Accessing the New Datums

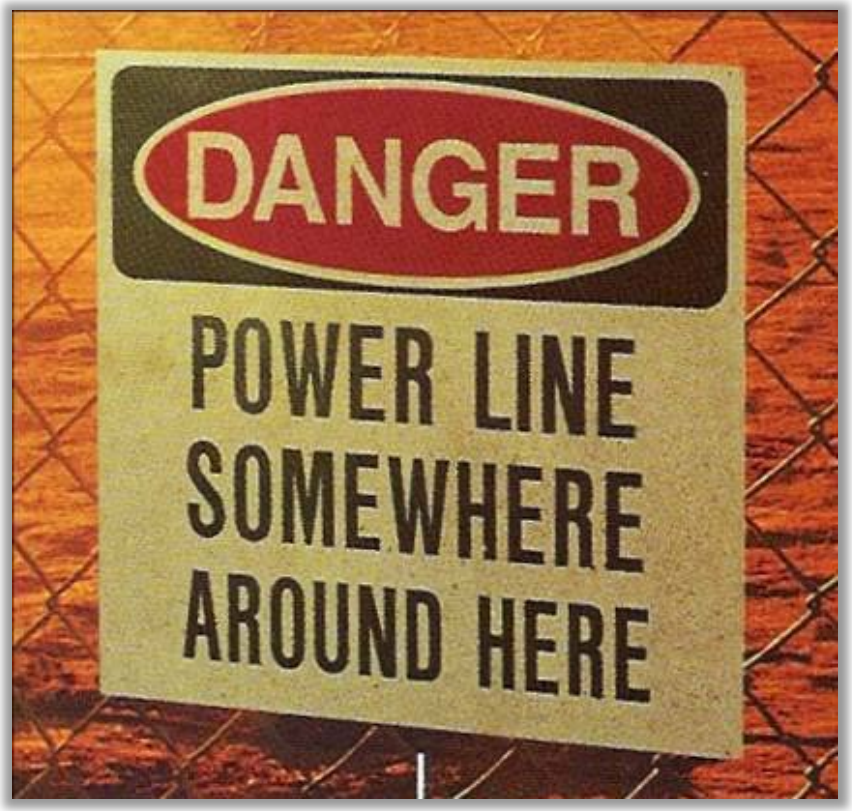
- **Primary access** (NGS mission)
  - Users with geodetic quality GNSS receivers will continue to use OPUS suite of tools
  - Ellipsoid heights computed, and then a gravimetric geoid removed to provide orthometric heights in the new datum
  - No passive marks needed
  - But, could be used to position 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

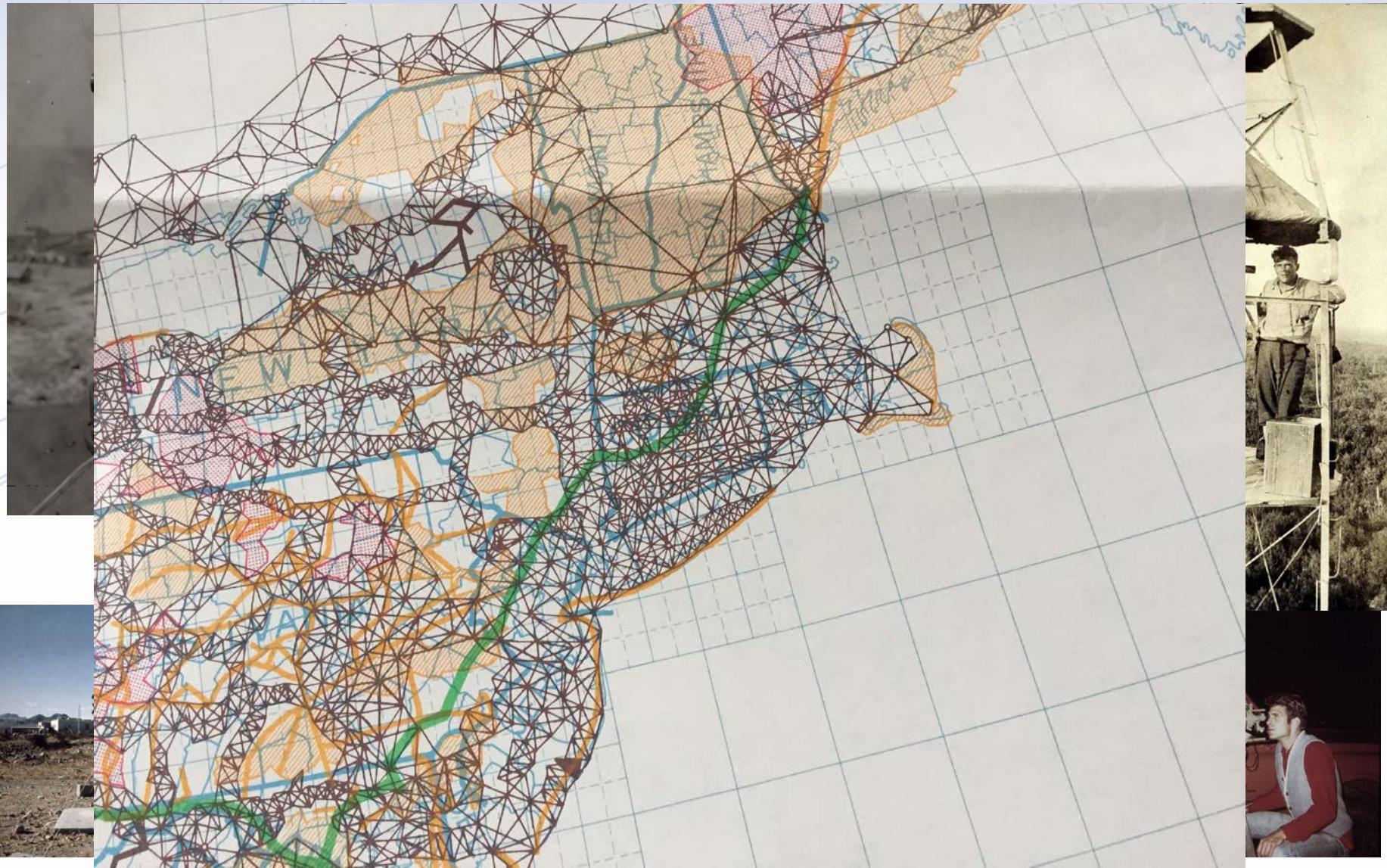
Why does all this stuff matter?

- Geospatial data is everywhere
- Usefulness diminished if stuff doesn't line up
- If problems easy to fix they already would be fixed



Courtesy of Michael Dennis

What does NAD 83(86) Imply?



Where on Earth is this Mark?

The NGS Data Sheet

See file dsdata.pdf for more information about the datasheet.

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1        National Geodetic Survey,   Retrieval Date = OCTOBER  2, 2018
 JU2981 ***********************************************************************
 JU2981  CBN         -  This is a Cooperative Base Network Control Station.
 JU2981  DESIGNATION -  BACARDI
 JU2981  PID         -  JU2981
 JU2981  STATE/COUNTY-  NJ/CUMBERLAND
 JU2981  COUNTRY     -  US
 JU2981  USGS QUAD   -  FIVE POINTS (1994)
 JU2981
 JU2981                        *CURRENT SURVEY CONTROL
 JU2981
 JU2981* NAD 83(2011) POSITION- 39 25 20.23060(N) 074 57 06.61866(W)   ADJUSTED
 JU2981* NAD 83(2011) ELLIP HT-    -1.723 (meters)        (06/27/12)   ADJUSTED
 JU2981* NAD 83(2011) EPOCH    -  2010.00
 JU2981* NAVD 88 ORTHO HEIGHT -    32.2   (meters)      106.    (feet) GPS OBS
 JU2981
 JU2981  NAVD 88 orthometric height was determined with an earlier geoid model
 JU2981  GEOID HEIGHT    -        -33.887 (meters)                    GEOID12B
 JU2981  NAD 83(2011) X  -  1,280,937.849 (meters)                    COMP
 JU2981  NAD 83(2011) Y  - -4,764,501.807 (meters)                    COMP
 JU2981  NAD 83(2011) Z  -  4,028,641.043 (meters)                    COMP
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```
 JU2981                         SUPERSEDED SURVEY CONTROL
 JU2981
 JU2981  NAD 83(2007)-  39 25 20.23105(N)    074 57 06.61947(W) AD(2002.00) 0
 JU2981  ELLIP H (02/10/07)   -1.713  (m)                       GP(2002.00)
 JU2981  ELLIP H (09/24/01)   -1.723  (m)                       GP(       ) 4 1
 JU2981  NAD 83(1996)-  39 25 20.23126(N)    074 57 06.61989(W) AD(       ) B
 JU2981  ELLIP H (07/24/97)   -1.709  (m)                       GP(       ) 3 2
 JU2981  ELLIP H (04/04/94)   -1.756  (m)                       GP(       ) 3 1
 JU2981  ELLIP H (12/31/92)   -1.756  (m)                       GP(       ) 4 1
 JU2981  NAD 83(1992)-  39 25 20.23029(N)    074 57 06.61961(W) AD(       ) B
 JU2981  ELLIP H (10/07/92)   -1.756  (m)                       GP(       ) 4 1
 JU2981  NAD 83(1991)-  39 25 20.22172(N)    074 57 06.61827(W) AD(       ) 1
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 JU2981  NAD 27      -  39 25 19.79900(N)    074 57 08.00000(W) AD(       ) 1
 JU2981  NAVD 88 (04/16/93)   32.2    (m)  GEOID93 model used   GPS OBS
 JU2981  NAVD 88 (03/31/93)   32.3    (m)  UNKNOWN model used   GPS OBS
 JU2981  NAVD 88 (12/31/92)   32.0    (m)  UNKNOWN model used   GPS OBS
 JU2981  NGVD 29 (06/12/91)   32.5    (m)  UNKNOWN model used   GPS OBS
 JU2981
 JU2981.Superseded values are not recommended for survey control.
 JU2981
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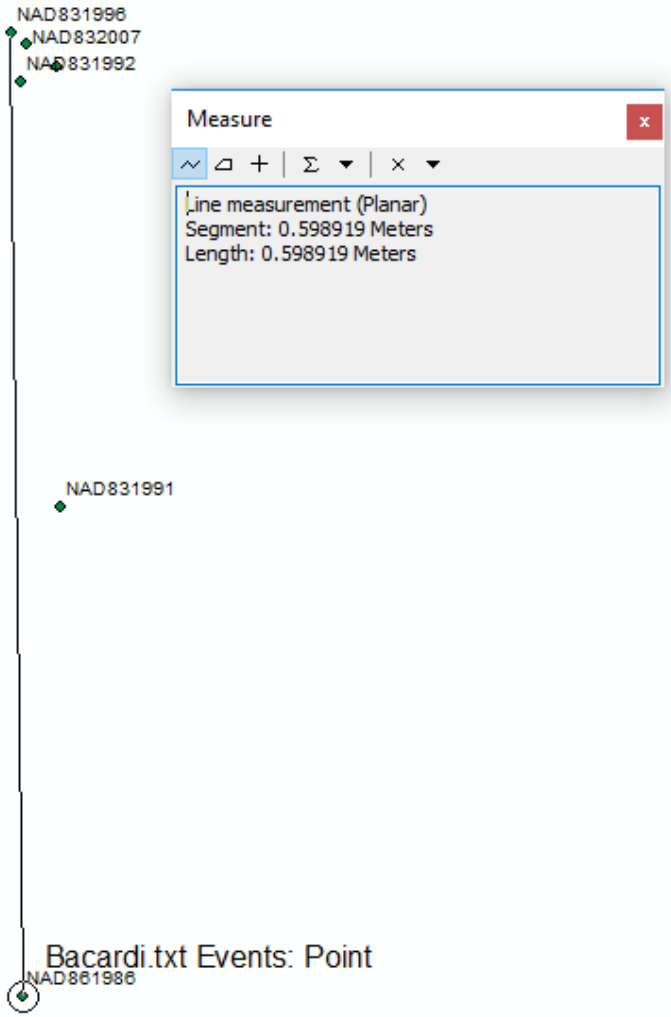
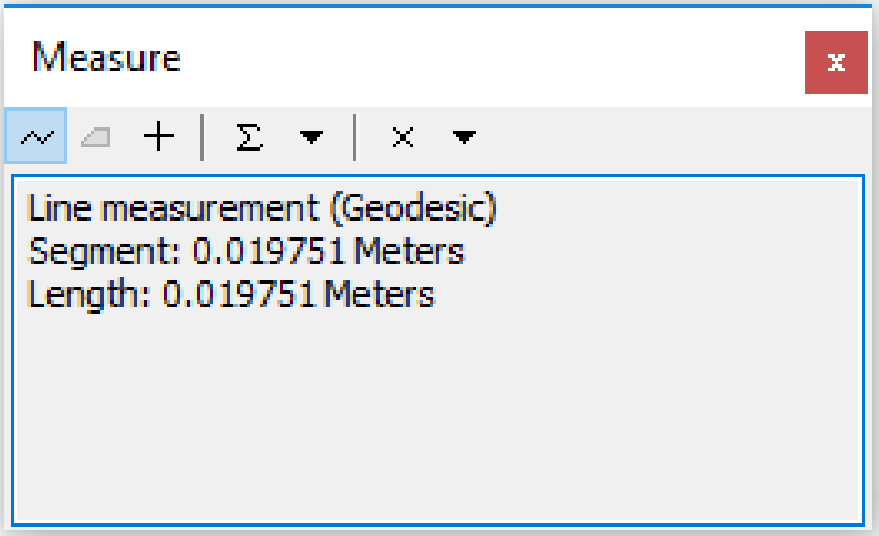
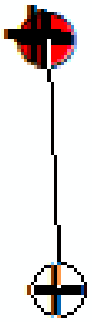


Transformations with NCAT

Actual NAD 83(2011) Position

\+ Transformed Positions Using NCAT





Bacardi - ncat.txt Events: Point

Questions to ask ***before*** performing a datum transformation

- What is the spatial accuracy?
- What is the datum (geographic coordinate system)?
  - Are you sure? How do you know?
- What datum do you want to convert to?
  - What method will you use?
  - What is the accuracy?
  - What if several to choose from?
- Are there temporal issues?
  - What is the input and output date (epoch)?
  - How do you know the epoch?
- Are you *really* sure you want to do this?

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

New Datums: What to do now

- Move to newest realizations.
  NAD 83(2011) epoch 2010.00
  USGG12 (gravimetric geoid) / GEOID12A (hybrid geoid)

- Obtain precise ellipsoid heights on NAVD 88 bench marks.
  (OPUS-DB, contact NGS Geodetic Advisor)
  Improves hybrid geoid models and provides "hard points" in new vertical datum.
  Follow new NGS Guidelines when released.

- Move from NGVD 29 to NAVD 88.
  Understand the accuracy of VERTCON in your area.

- Move away from passive marks to GNSS.
  Especially, move away from classical passive control.

- Require/provide complete metadata for all mapping contracts.
  How did they get the positions/heights? Document it!

geodesy.noaa.gov/SPCS/

geodesy.noaa.gov

National Geodetic Survey

Positioning America for the Future

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State Plane Coordinate System
- Home
- Maps
- Download Design Maps
- Convert Coordinates
- Current Policy
- 2022 Policy Changes
- Learn More

Have State Plane Questions?
- Contact Us

Preliminary Default SPCS2022 Design Maps

NGS is currently in the process of creating "default" preliminary designs for State Plane Coordinate System of 2022 (SPCS2022) zones. These preliminary designs will likely be very close to those eventually adopted by NGS, except in cases where U.S. state and territory stakeholders adopt approved alternative designs.

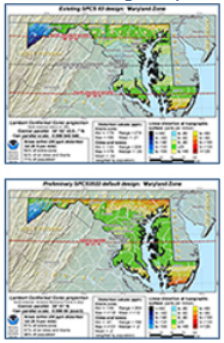
Download SPCS2022 Design Maps

A continuously updated set of **default SPCS2022 design maps** are available for download as .png image files.

The maps show linear distortion at the topographic surface for SPCS2022, along with existing State Plane and Universal Transverse Mercator (UTM) for comparison. Only projection parameters that affect linear distortion are given in the maps. Other parameters, such as false northing and easting, will be defined for the final SPCS2022 designs. Linear distortion rasters and other GIS feature datasets used to create the maps are **available for download**. If the state, territory, or subzone you require is not yet listed, please contact the **SPCS Team**.

Download
SPCS2022 Design Maps

Example of Downloaded Default Design Maps



Learn More

Documents

Related documents are listed below.

- **Policy on Changes to State Plane Coordinates** (PDF, 141 KB)
- **Policy of the National Geodetic Survey Concerning Units of Measure for the State Plane Coordinate System of 1983** (PDF, 136 KB)
- **NOAA Manual NOS NGS 5** (PDF, 2 MB)
- **NOAA Special Publication NOS NGS 13** (PDF, 7 MB)

Webinars

NGS has and will host various webinars about State Plane. These will be added to the following list as they are developed.

- **The State Plane Coordinate System: History, Policy, Future Directions (March 8, 2018)**
- **Building a State Plane Coordinate System for the Future (April 12, 2018)**

Website Owner: National Geodetic Survey / Last modified by **NGS Infocenter** Mar 08 2018

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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

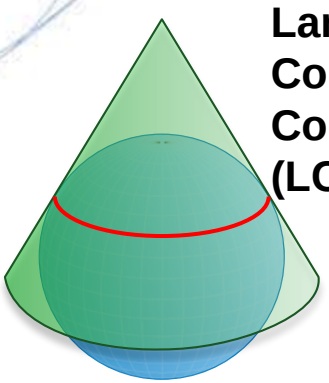
State stakeholders only!

SPCS2022 Procedures (draft)

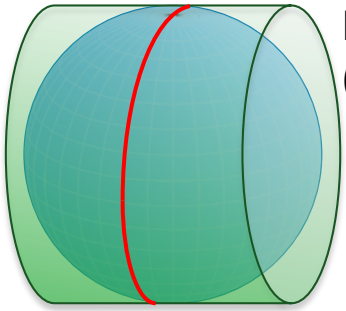
- **Consensus** input per SPCS2022 procedures
  - ***Requests*** for designs done by NGS
  - ***Proposals*** for designs by contributing partners
- Submittal of **approved** designs
  - Proposal must first be approved by NGS
  - Designs must be complete for NGS to review
- Later requests will be for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

A New State Plane Coordinate System

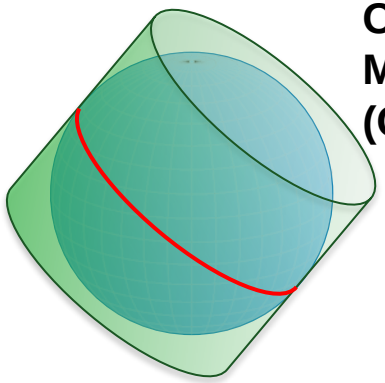
- **State Plane Coordinate System of 2022 (SPCS2022)**
  - Referenced to 2022 Terrestrial Reference Frames (TRFs)
  - Based on same reference ellipsoid as SPCS 83 (GRS 80)
  - Same 3 ***conformal*** projection types as SPCS 83 and 27:



Lambert Conformal Conic (LCC)



Transverse Mercator (TM)



Oblique Mercator (OM)

"Draft" SPCS2022 Policy & Procedures

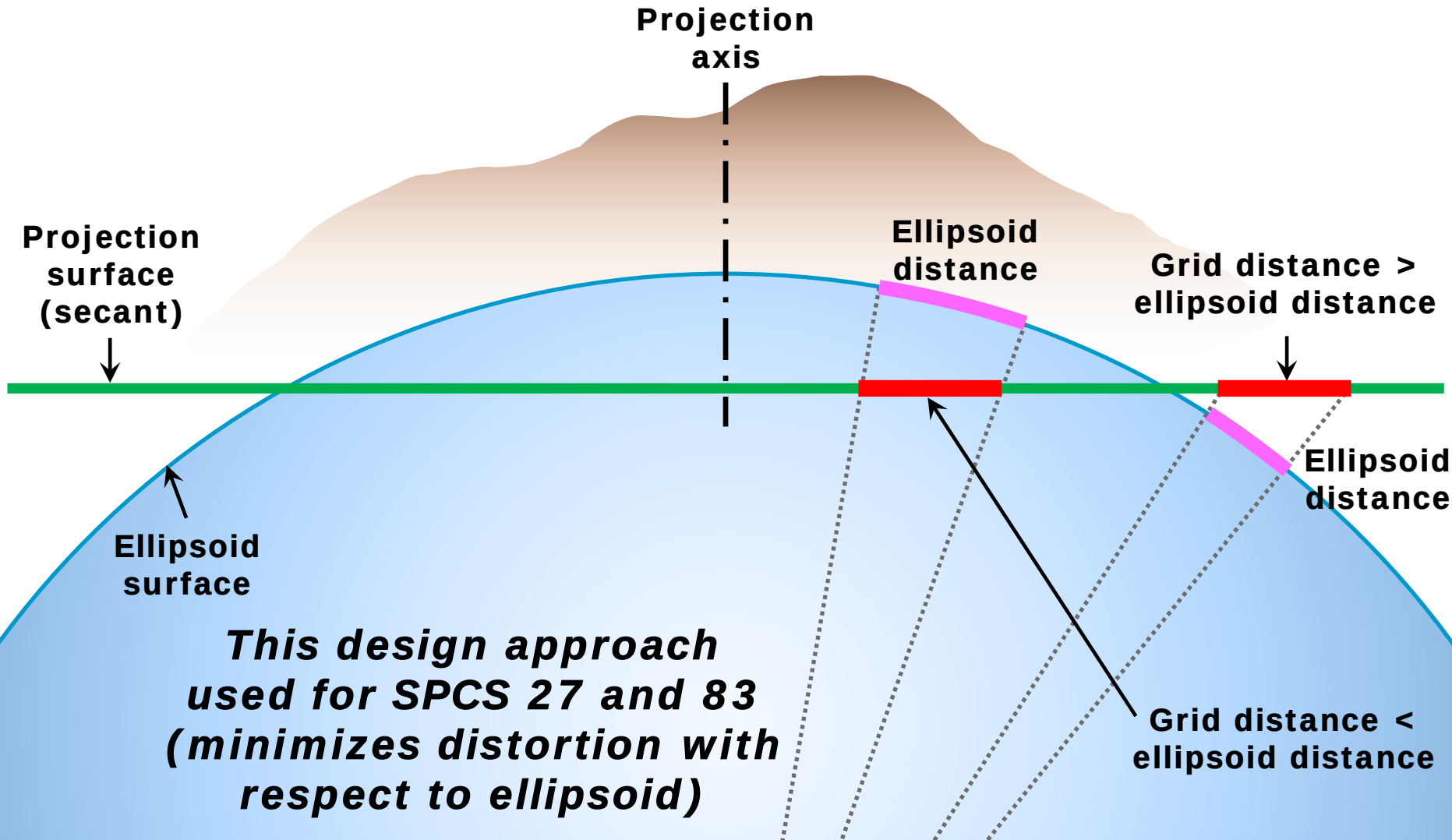
- **Policy**
  - Limited to LCC, TM, and OM projections
  - Zones designed to reduce distortion at ground
  - Default zones designed by NGS if no consensus input
  - Parameters in meters, but feet allowed for output
- **Procedures**
  - Stakeholders must submit requests/proposals
  - 1-parallel LCC and 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

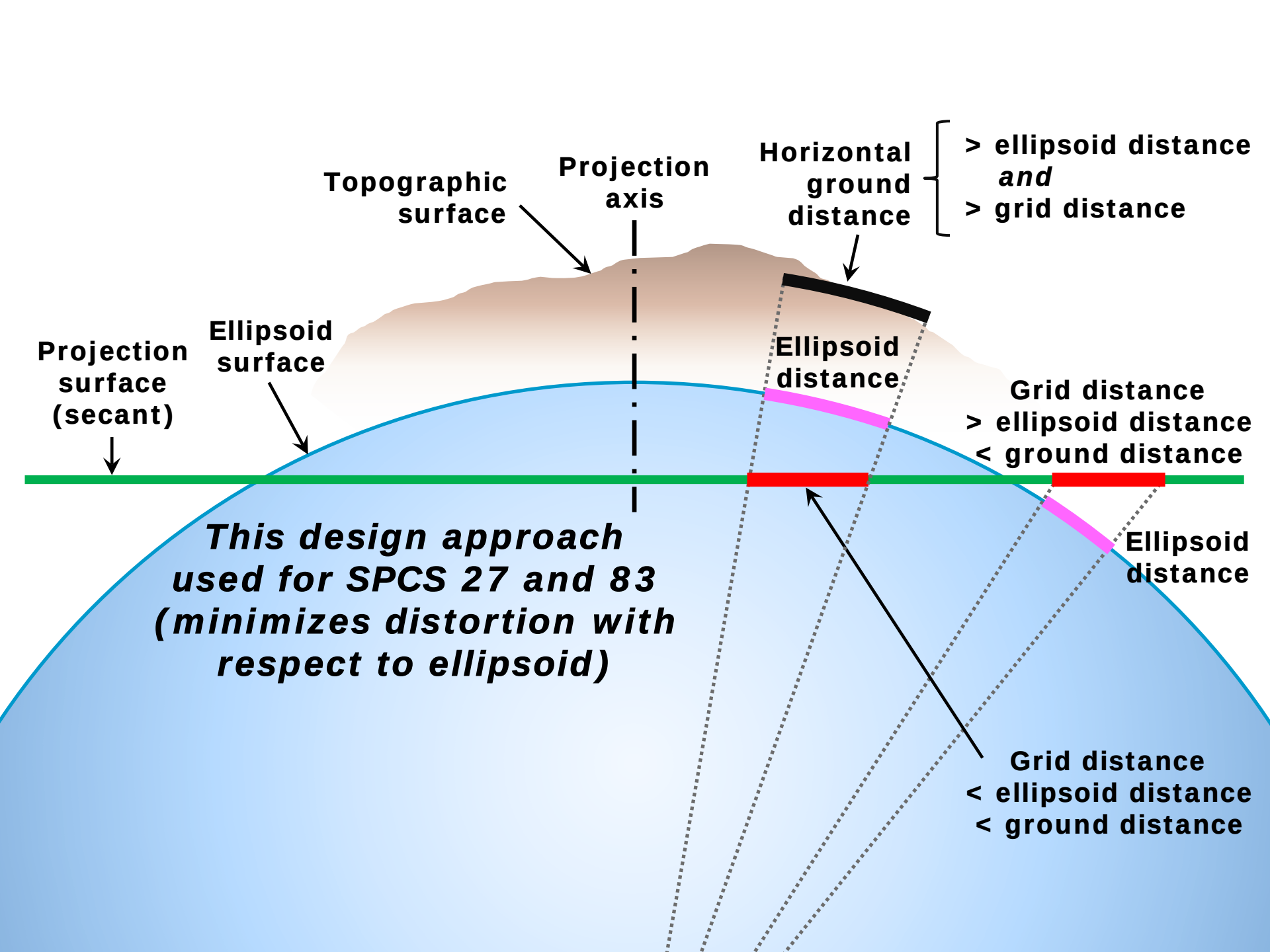
Changes to SPCS2022 Policies

Summary of main changes

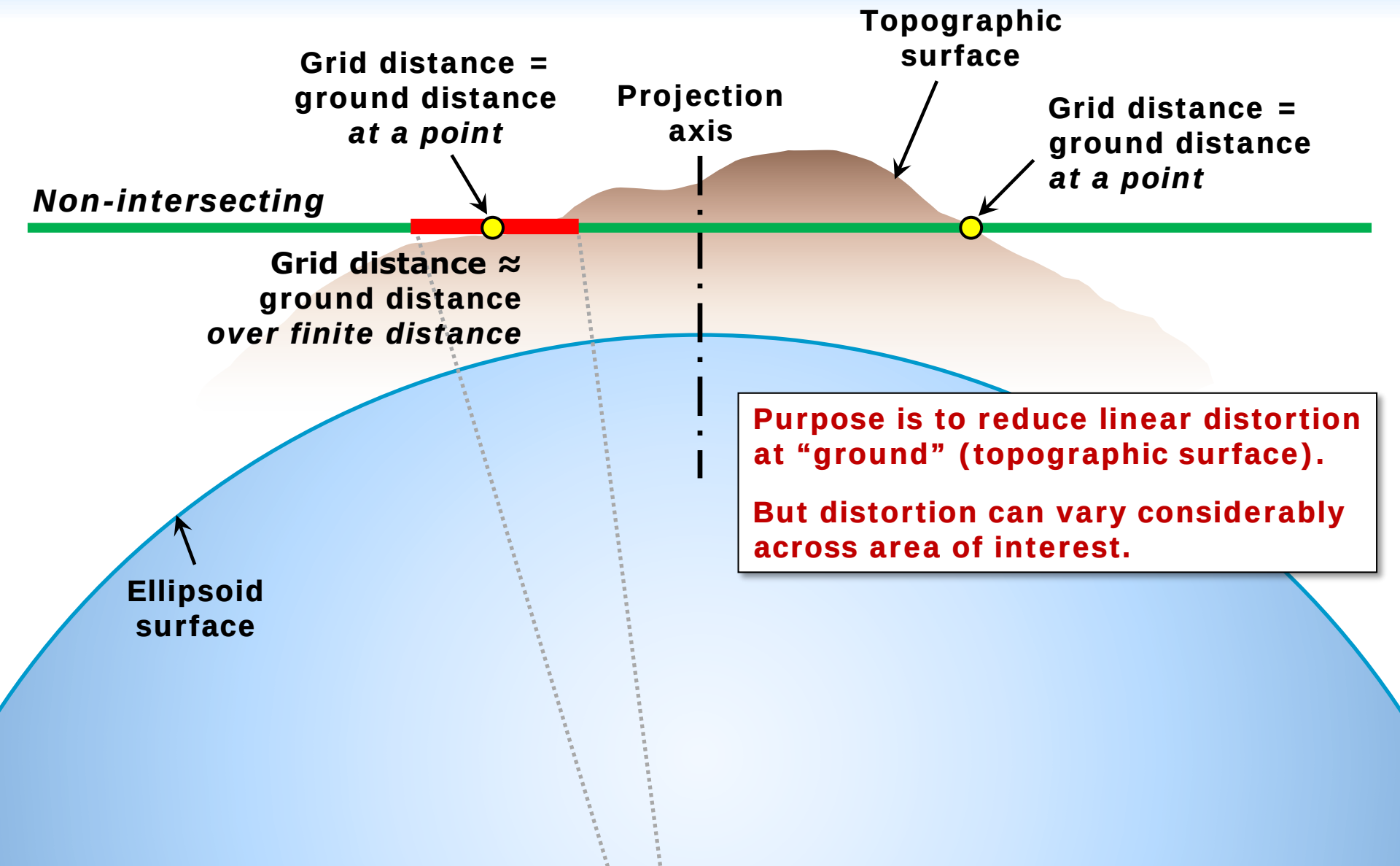
- Allow "special use" zones
  - But only for zone areas in more than 1 state
- NGS will design statewide zone for every state
  - Also will design default zones if no consensus request for something different from state stakeholders
- Allow max of 3 layers (1 statewide + 2 multi-zone)
  - But most states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

Linear distortion *with respect to ellipsoid*




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
This design approach used for SPCS 27 and 83 (minimizes distortion with respect to ellipsoid)
Ellipsoid distance
Grid distance
< ellipsoid distance
< ground distance

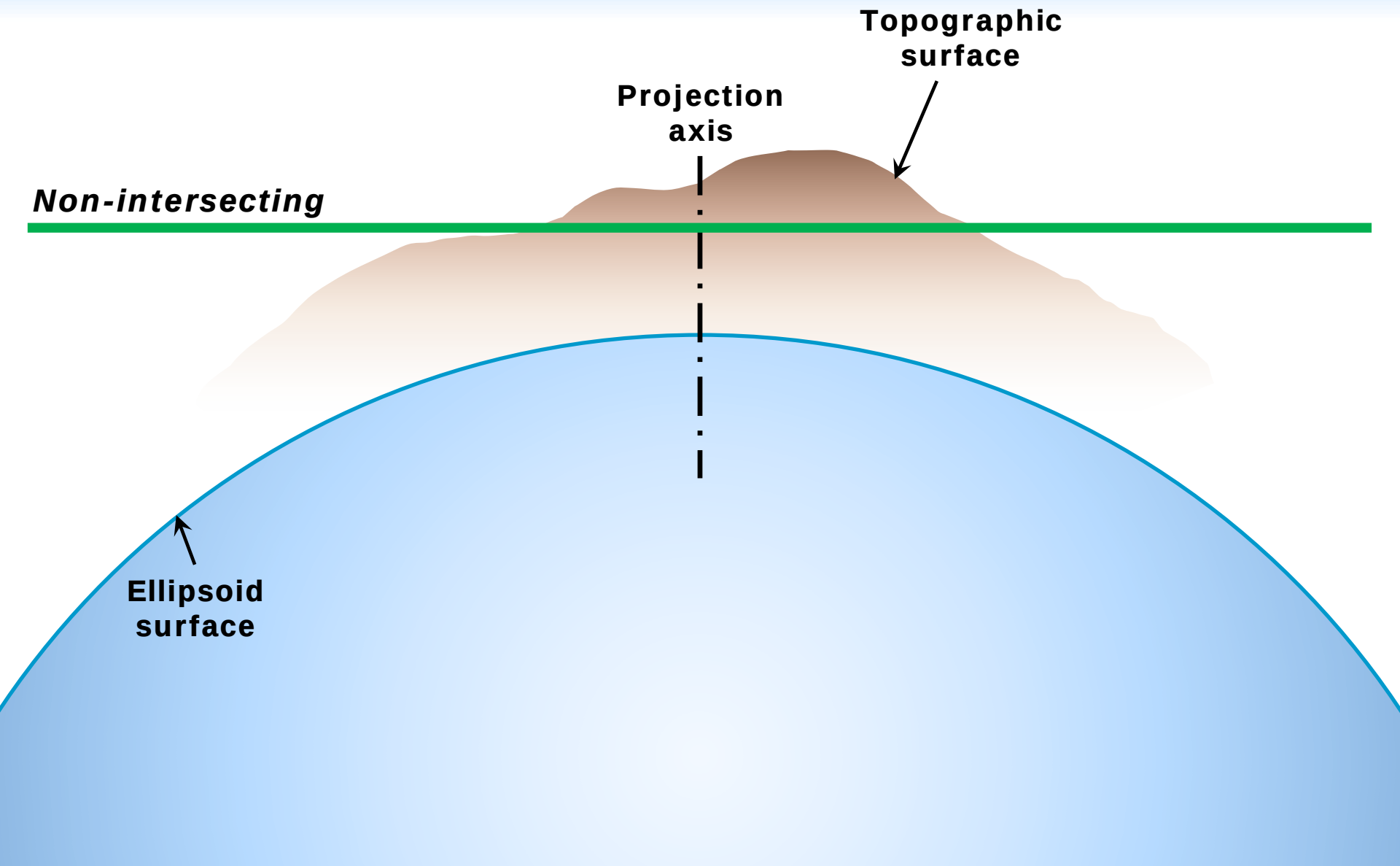
“Non-intersecting” conformal map projection



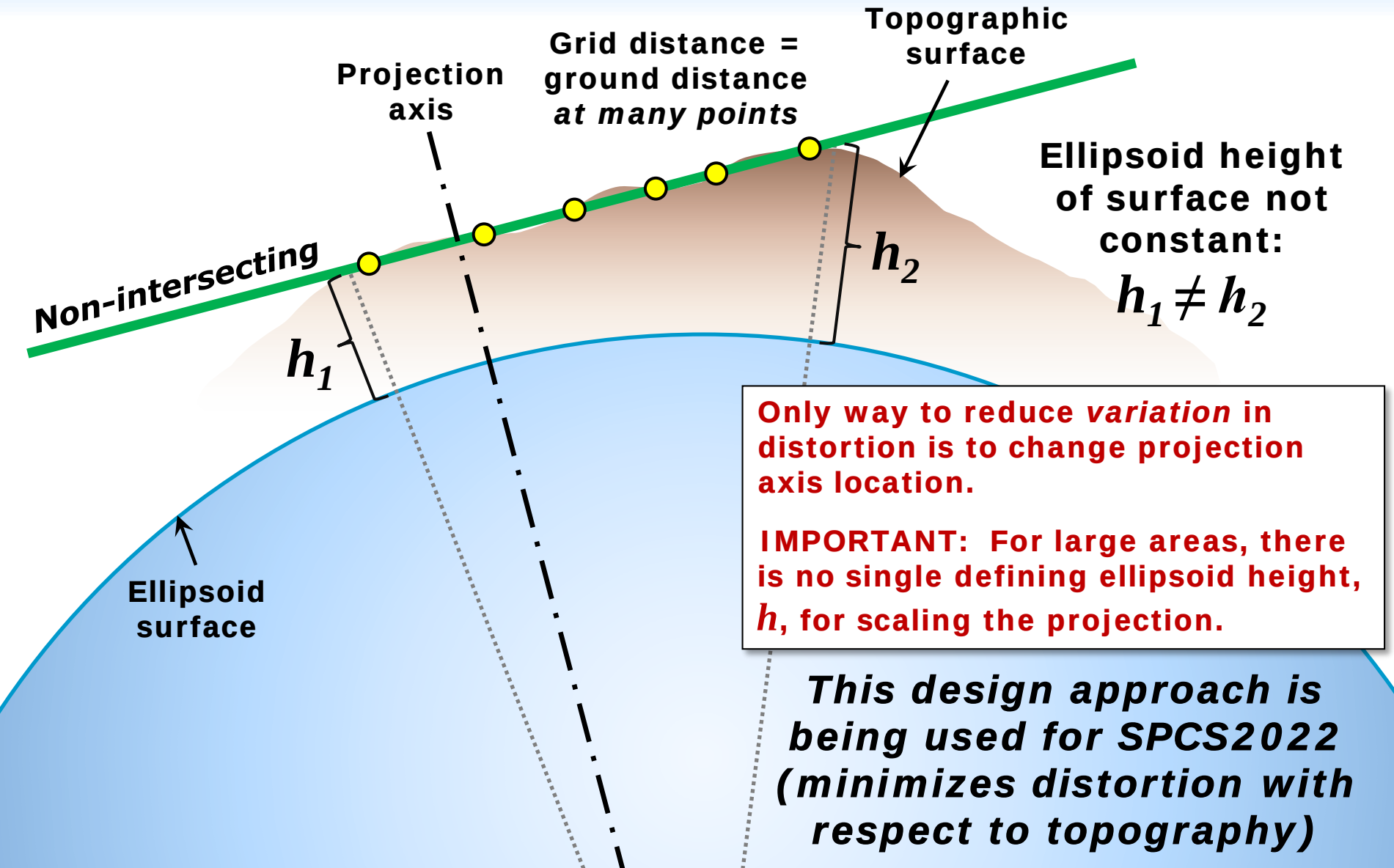
Purpose is to reduce linear distortion at “ground” (topographic surface).

But distortion can vary considerably across area of interest.

“Non-intersecting” conformal map projection



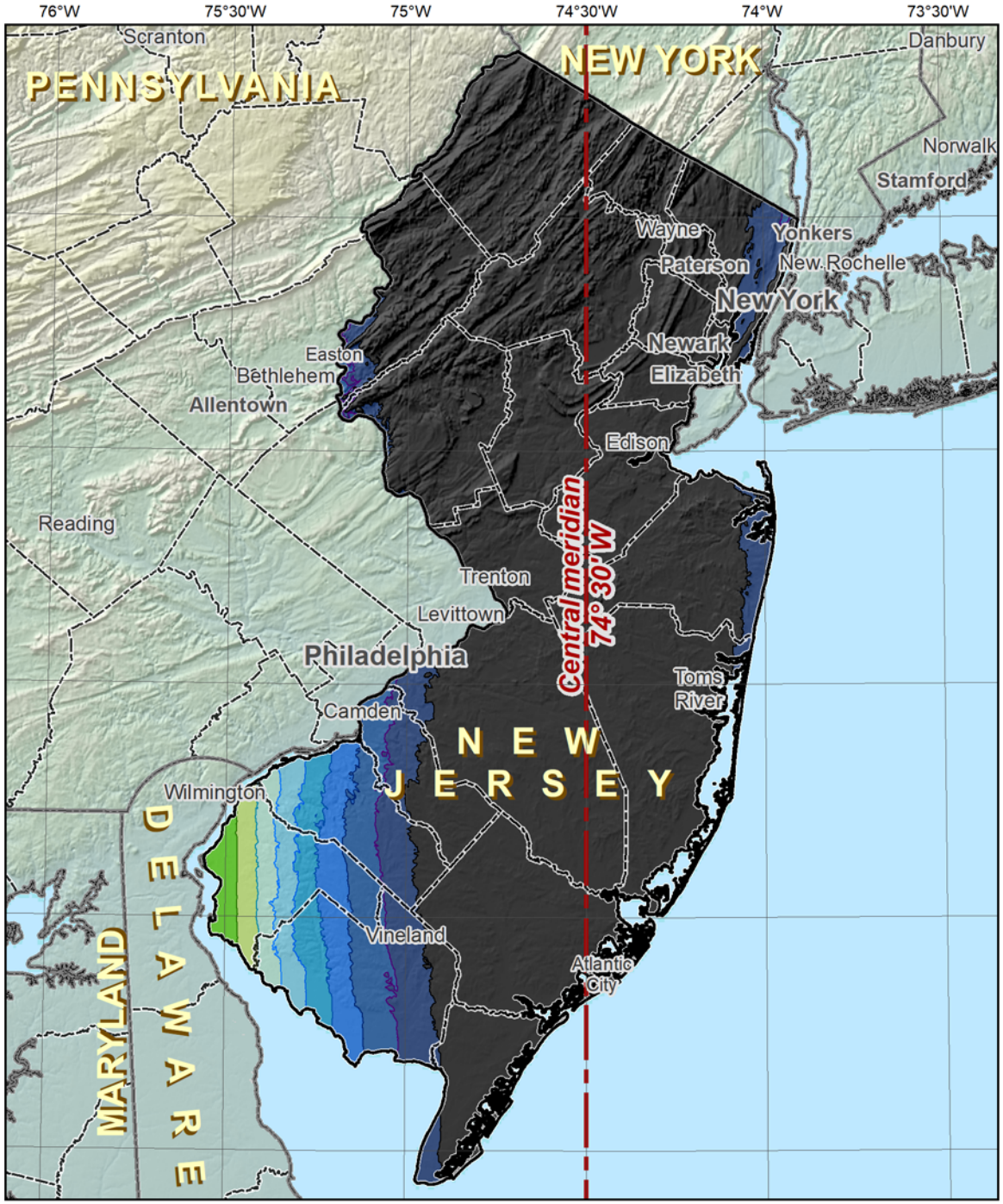
Changing projection axis to reduce distortion variation



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: New Jersey Zone

NOAA's National Geodetic Survey

Transverse Mercator projection

North American Datum of 1983

Central meridian: 74° 30' W
Cen merid scale: 0.999 9 (exact)

Areas within ±20 ppm distortion (1:50,000 = ±0.11 ft per mile):
0.6% of population
1.4% of all cities and towns
1.8% of entire zone area

Distortion values (ppm)

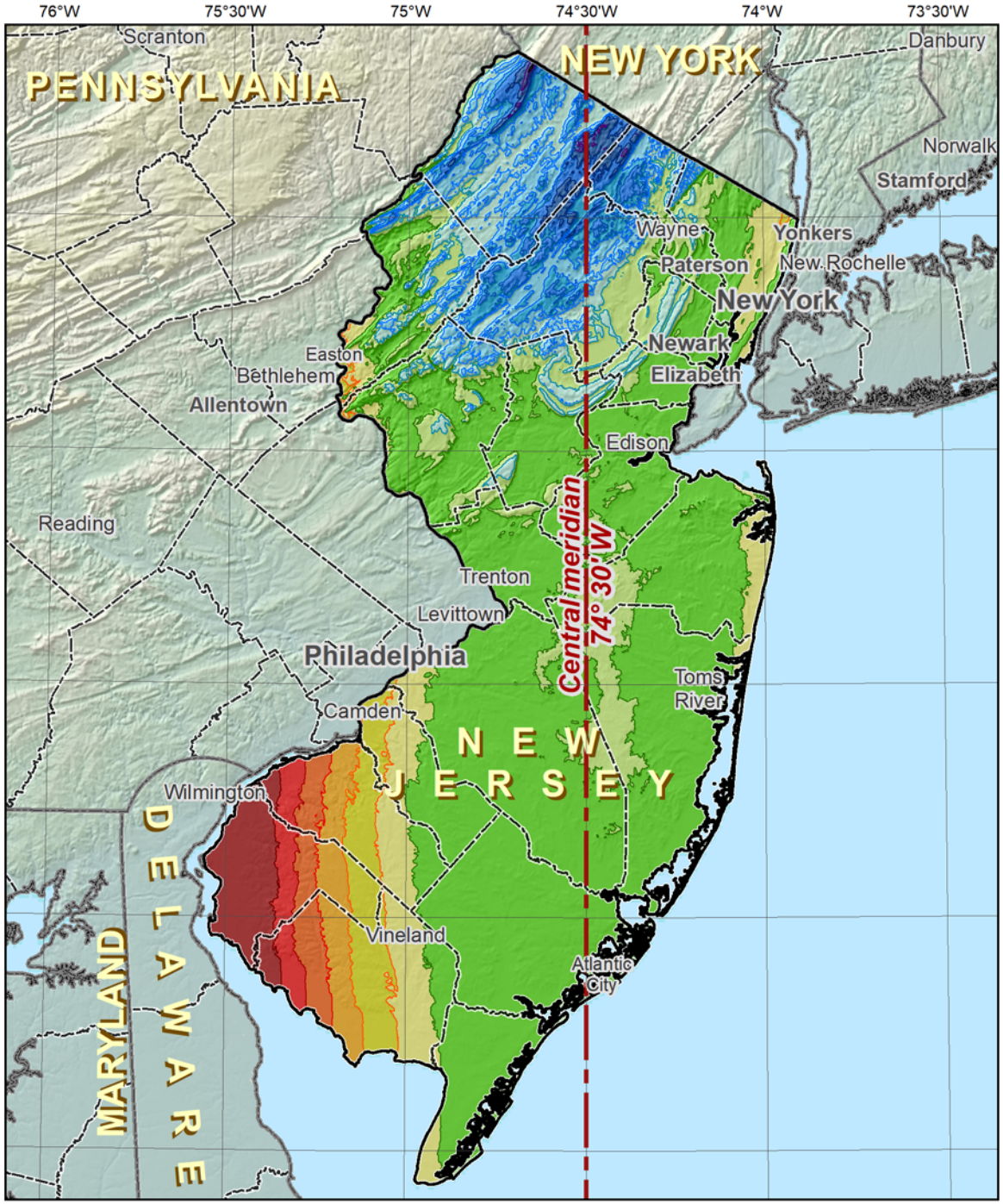
Entire zone:	***Cities and towns:***
Min = -175	Min, Max = -156, -2
Max = +7	Range = 155
Range = 182	Mean = -88
Mean = -92	(weighted by population)

Linear distortion at topographic surface (parts per million)

< -80	to -40	to +30
to -80	to -30	to +40
to -70	to -20	to +50
to -60	±10	to +60
to -50	to +20	> +60

0 25 50 75 100 km

Created 01/29/2019



Preliminary SPCS2022 default design: New Jersey Zone (alternative 4)

NOAA's National Geodetic Survey

Transverse Mercator projection

North American Terrestrial Reference Frame of 2022

Central meridian: 74° 30' W
Cen merid scale: 0.999 99 (exact)

Areas within ±20 ppm distortion (1:50,000 = ±0.11 ft per mile):
88% of population
77% of all cities and towns
71% of entire zone area

Distortion values (ppm)

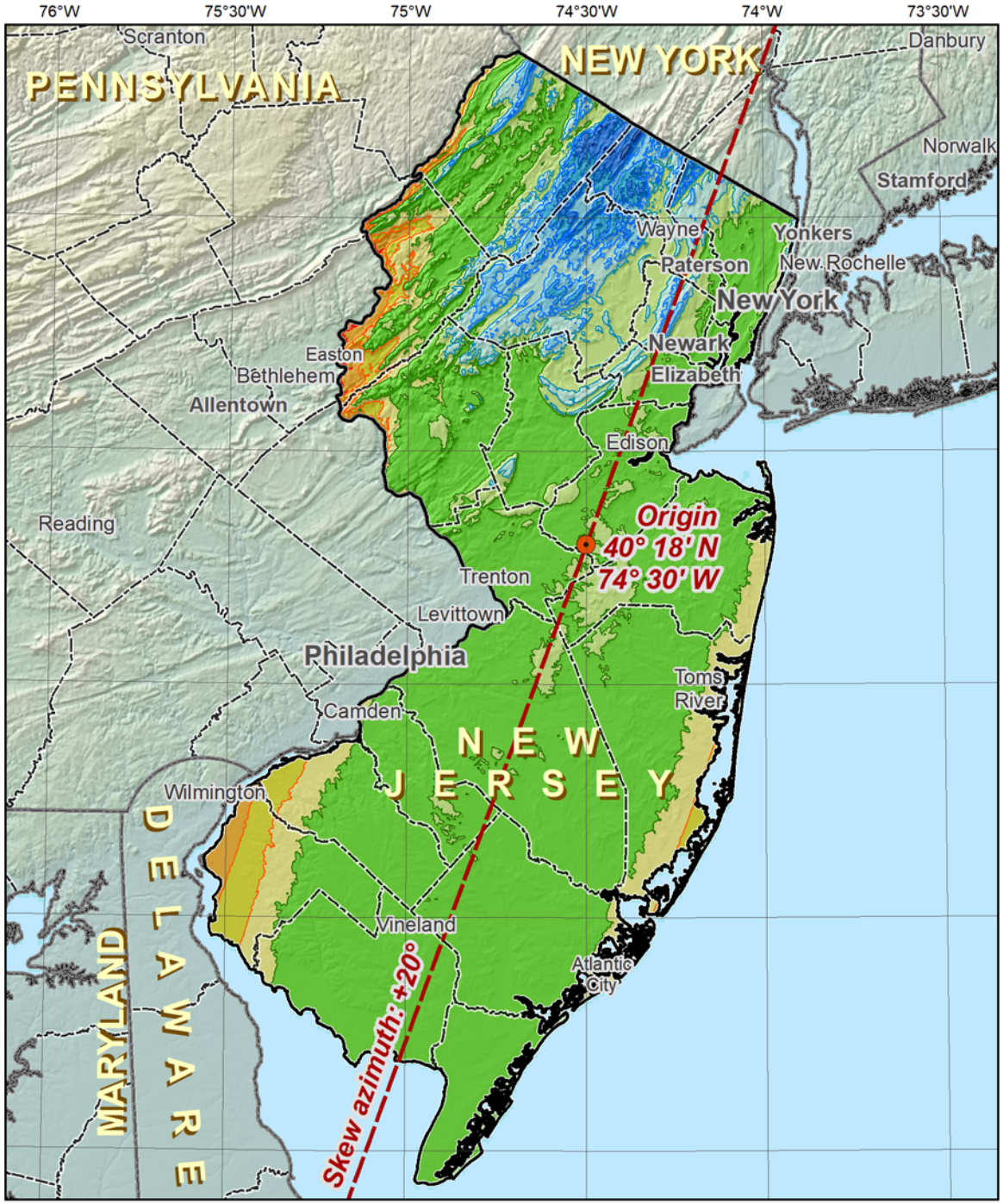
Entire zone:	***Cities and towns:***
Min = -85	Min, Max = -66, +88
Max = +97	Range = 155
Range = 182	Mean = +2
Mean = -2	(weighted by population)

Linear distortion at topographic surface (parts per million)

< -80	to -40	to +30
to -80	to -30	to +40
to -70	to -20	to +50
to -60	±10	to +60
to -50	to +20	> +60

0 25 50 75 100 km

Created 01/29/2019



Preliminary SPCS2022 default design:

New Jersey Zone

(alternative 1)

NOAA's National Geodetic Survey

Oblique Mercator projection

North American Terrestrial Reference Frame of 2022

Origin latitude: 40° 18' N
Origin longitude: 74° 30' W
Skew axis scale: 0.999 99 (exact)
Skew azimuth: +20°

Areas within ±20 ppm distortion (1:50,000 = ±0.11 ft per mile):

94% of population
85% of all cities and towns
85% of entire zone area

Distortion values (ppm)

Entire zone:	***Cities and towns:***
Min = -67	Min, Max = -55, +45
Max = +52	Range = 100
Range = 120	Mean = -5
Mean = -4	(weighted by population)

Linear distortion at topographic surface (parts per million)

< -80	to -40	to +30
to -80	to -30	to +40
to -70	to -20	to +50
to -60	±10	to +60
to -50	to +20	> +60

0 25 50 75 100 km

Created 01/29/2019

Questions?

Presentation available at:
https://www.ngs.noaa.gov/web/science_edu/presentations_library/

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