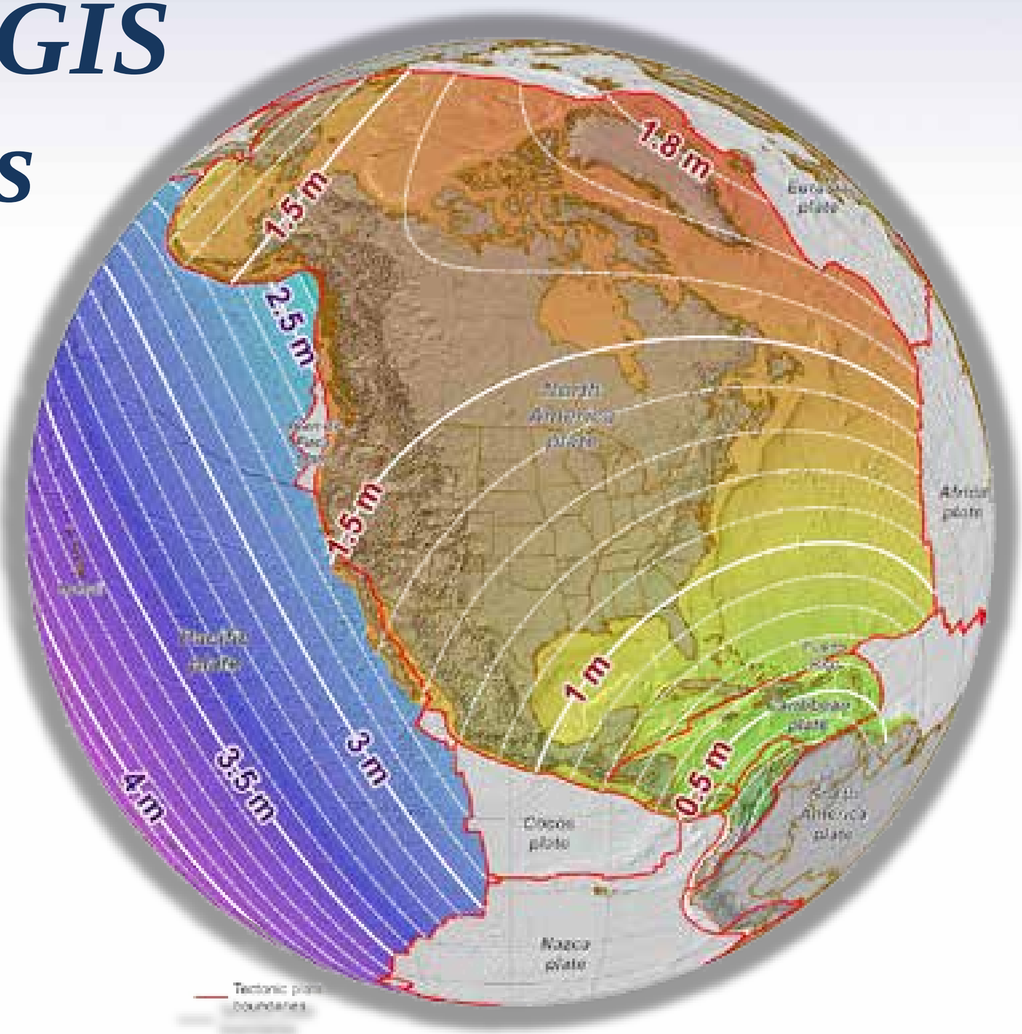
An NGS Illustrated Guide to Geodesy for GIS Professionals



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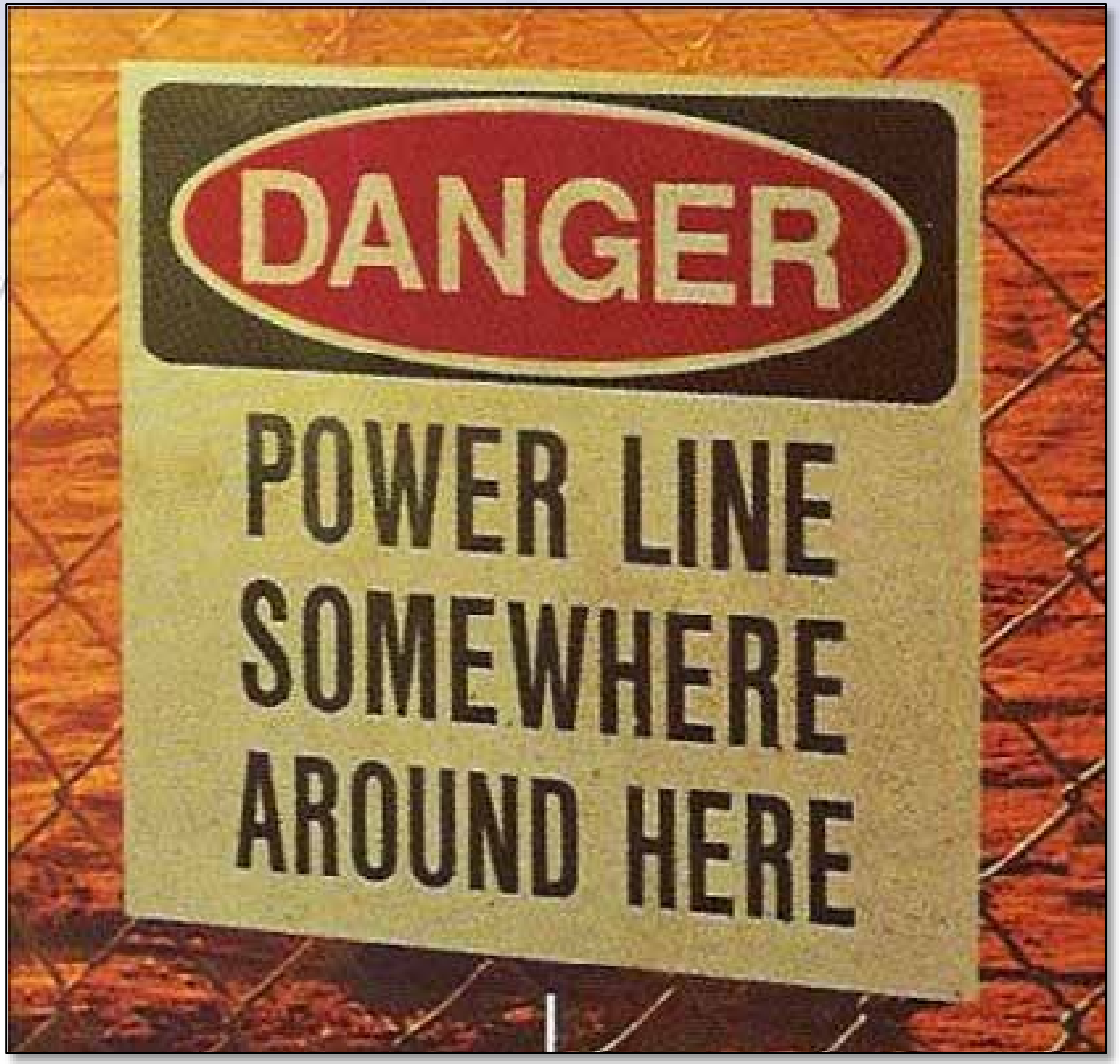
Esri User Conference
San Diego Convention Center
July 14-18, 2014 • San Diego, CA

Why should we care about ***geodesy?***



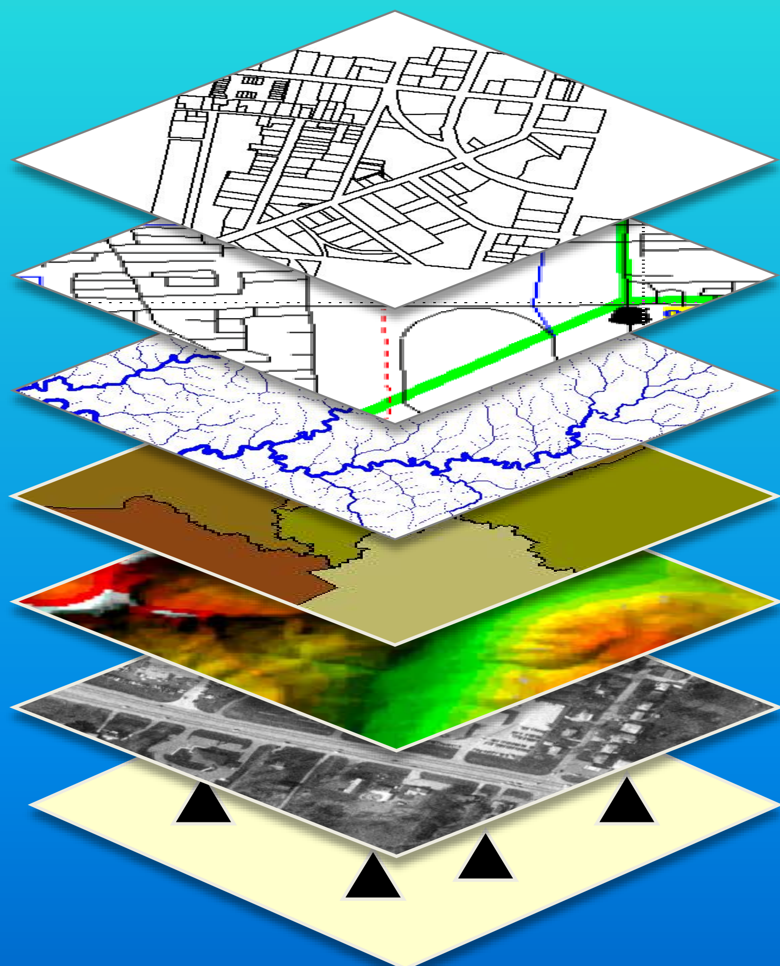
The Plan

- Introducing the ***National Geodetic Survey***
- GIS and the ***National Spatial Reference System (NSRS)***
- Geodetic concepts – *illustrated!*
- Focus today is on geometric ("horizontal") datums
  - Connecting data to the Earth: *Datums*
  - A complicated topic: *Datum transformations*
  - Nothing is constant except change: *Time dependence*
  - Specific example: **"WGS 84" ß à "NAD 83"**
- Other topics of Great Interest but not enough time to pursue
  - How data are displayed and analyzed: *Map projections*
  - How high? How deep? Where will water go? *Heights*
  - How good is it? How do you know? *Accuracy vs. Precision*

NGS: Who we are is where you are

- **Been around a long time** (*since 1807*)
  - Became **National Geodetic Survey** in 1970 (when NOAA created)
- **Keepers of the *National Spatial Reference System* (NSRS)**
  - Define, maintain, provide access for US and territories
  - Position, height, scale, gravity, orientation
  - ***...and how they change with time***
- **Products & Services**
  - Geodetic control (active and passive)
  - Data, models, and imagery (gravity, geoid, aerial imagery)
  - Tools and services (online and desktop software and services)
  - Standards, specifications, guidelines, and education

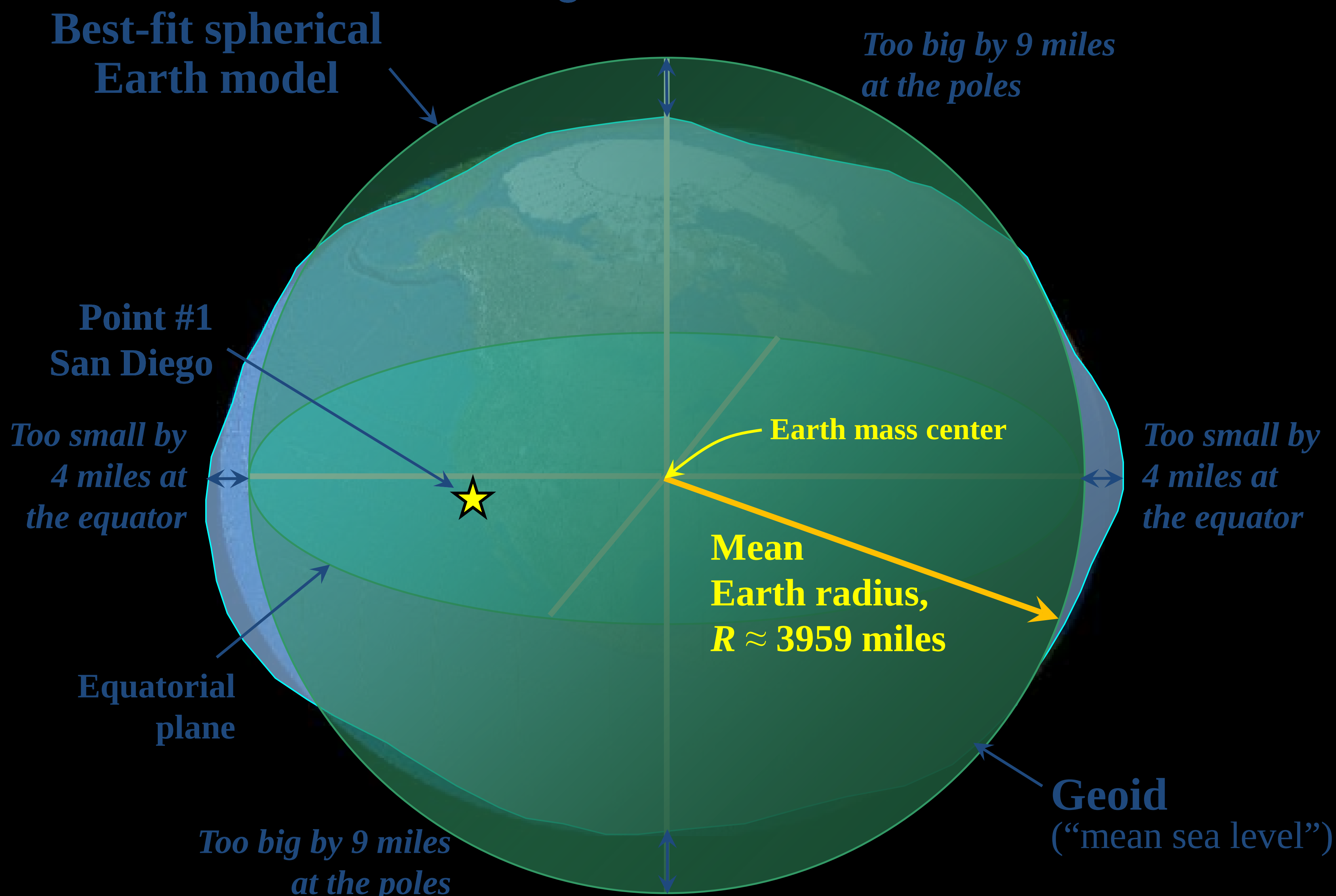
The NSRS is the foundation for GIS



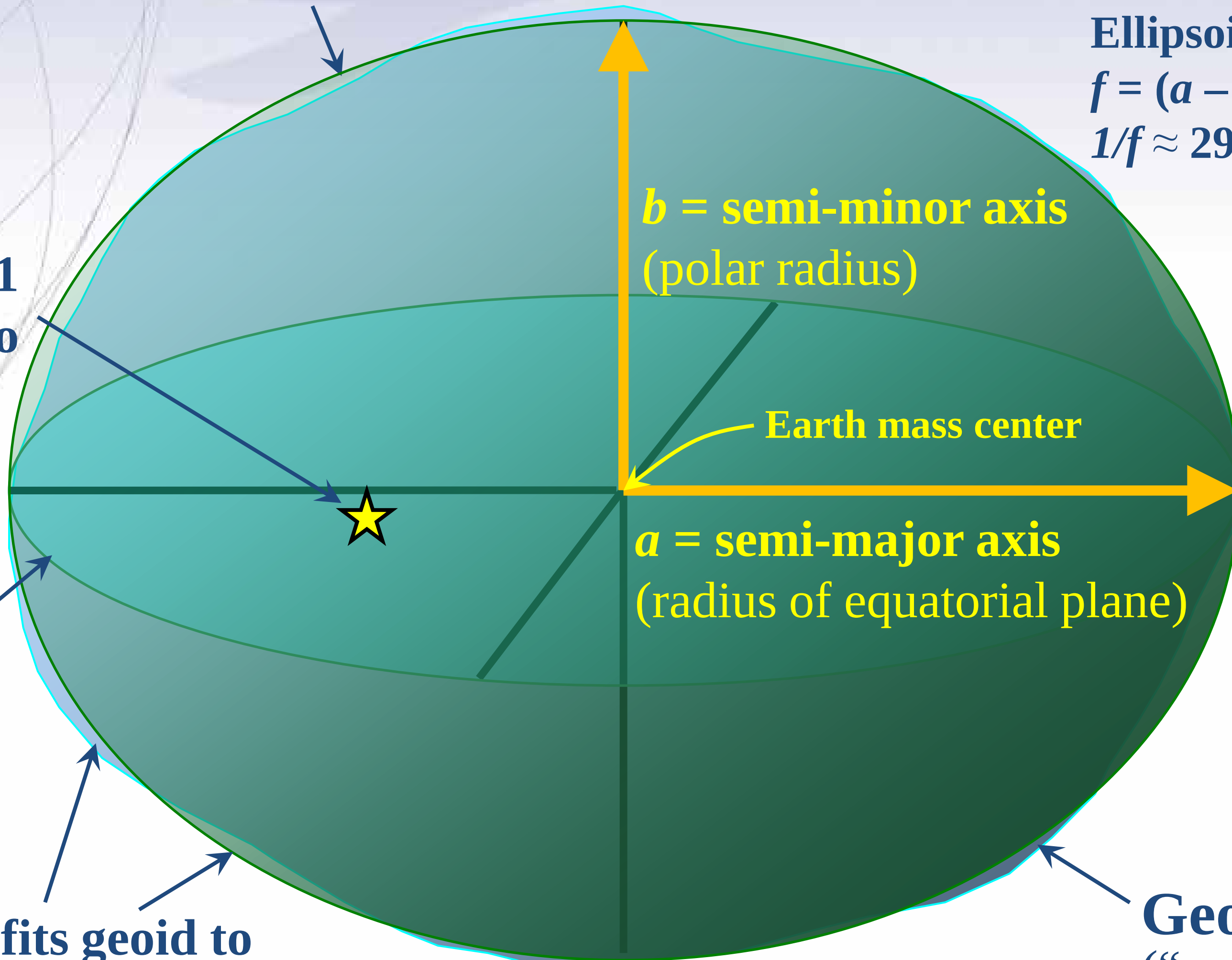
What is a (geometric) "datum"?

- Geometric ("horizontal") datums
  - a.k.a. "geographic coordinate systems"
  - Basis for determining positions on the Earth
  - Modern ones are 4-D (time is 4th dimension)
    - Lat, lon, height (or Earth-Centered, Earth-Fixed XYZ), velocities
  - Ellipsoid ("spheroid") by itself is ***NOT*** a datum
    - ~Same ellipsoid for NAD 83 and WGS 84, but differ by ~2 m
- Includes "local" and "global" datums
  - "Local" (regional) datums (e.g., NAD 83)
  - "Global" datums (e.g., WGS 84)
- Vertical datums another topic for another time…

"The Figure of the Earth"



Earth model: Ellipsoid of revolution



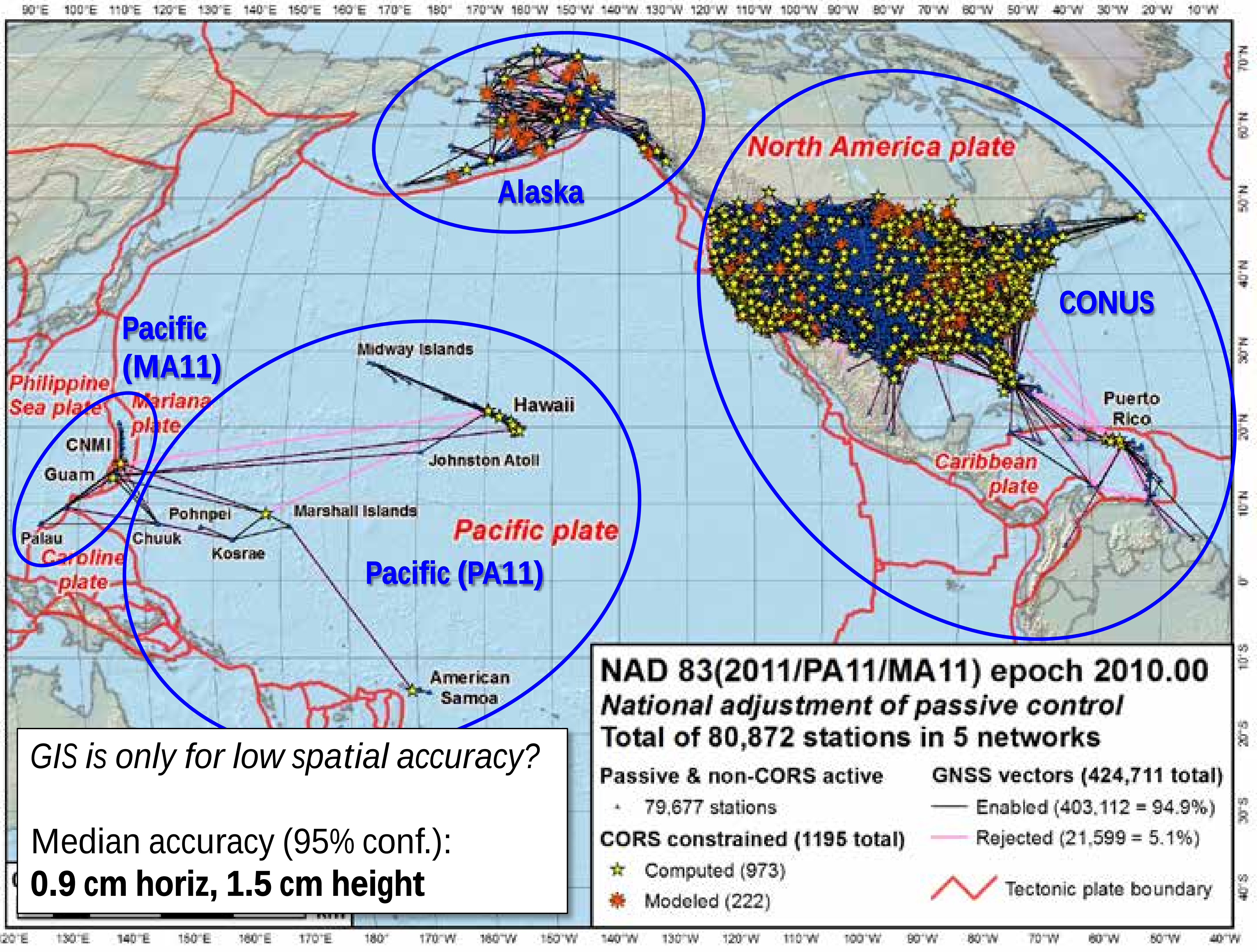
Geospatial Codependence

the first step is admitting you have a problem

- Datums must be "realized"
  - Connected to Earth by observations (e.g., GNSS)
  - New realizations improve accuracy of coordinates
  - A single datum can have multiple realizations
- Interrelationships given by "datum transformations"
  - Mathematical methods for converting between datums
  - Needed if combining data based on different datums
  - There are many different kinds and they can vary greatly
- ***Modern datum definitions are accurate but complex***
  - Will focus on two here: **NAD 83** and **WGS 84**.

A (very) brief history of NAD 83 datum

- Original realization completed in 1986
  - Almost entirely classical (optical) observations
- "High Accuracy Reference Network" (HARN) realizations (1990s)
  - Done essentially state-by-state
  - Based on GNSS but classical stations included
- National Re-Adjustment of 2007
  - NAD 83(NSRS2007/CORS96) epoch 2002.00
  - Nationwide adjustment (GNSS only)
- ***NAD 83 (2011/PA11/MA11) epoch 2010.00***
  - Also nationwide GNSS-only adjustment
  - **This is *NOT* a new datum! (still NAD 83)**

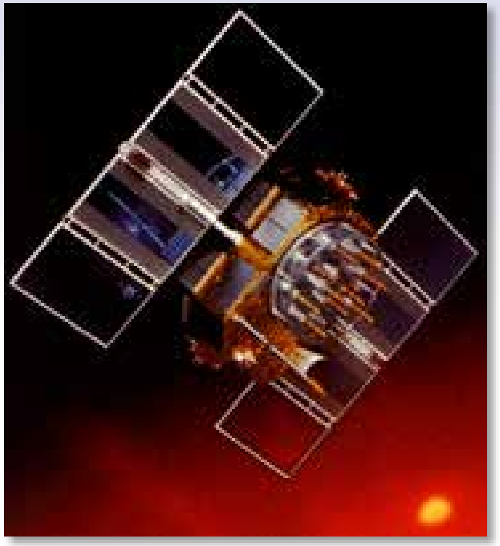


GIS is only for low spatial accuracy?

Median accuracy (95% conf.):

0.9 cm horiz, 1.5 cm height

A (very) brief history of WGS 84 datum

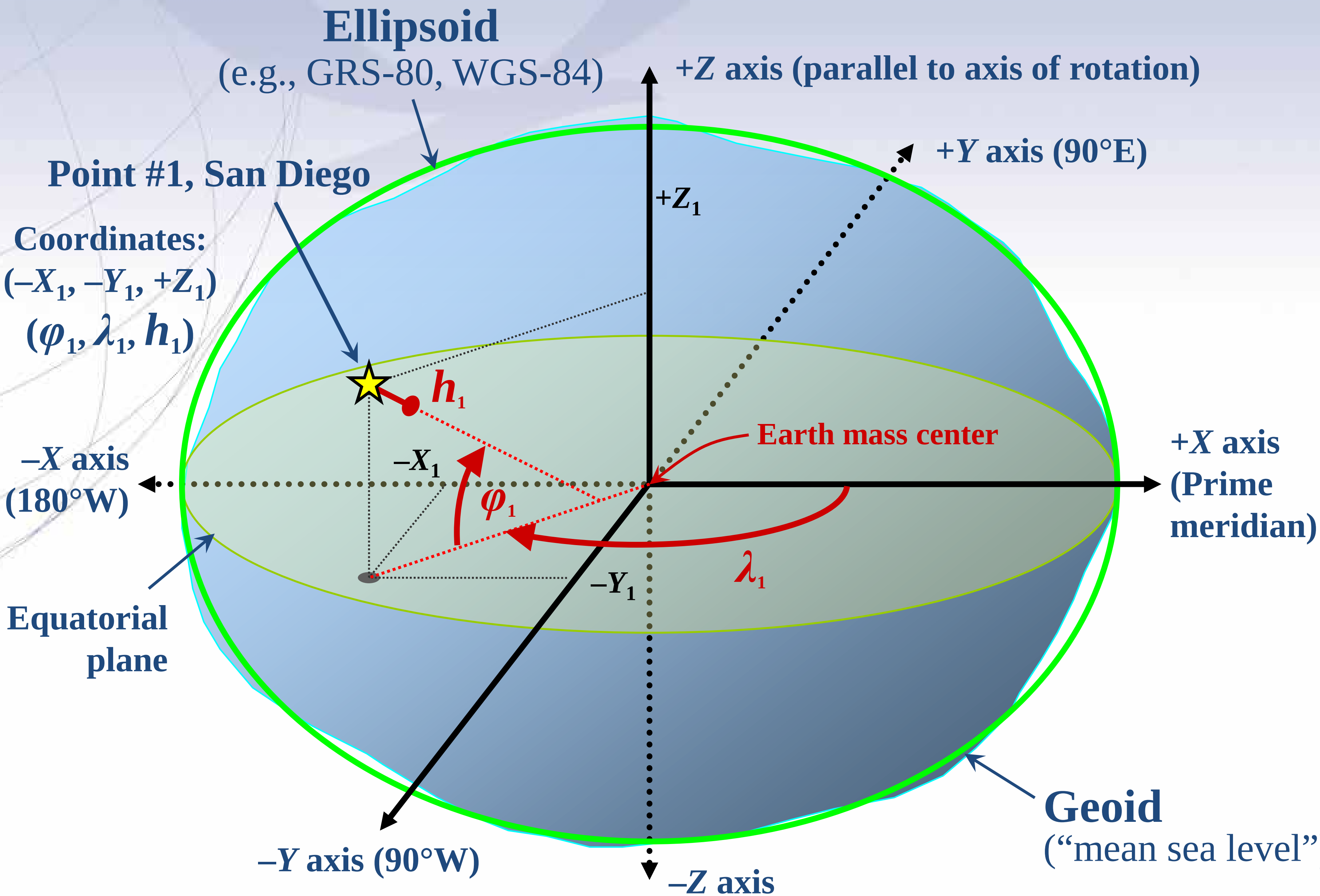


- Original realization completed in 1987
  - "Same" as original NAD 83 (***to within ±1-2 m***)
- WGS 84 (G730) — adopted Jan 2, 1994
  - Aligned with ITRF91
- WGS 84 (G873) — adopted Sep 29, 1996
  - Aligned with ITRF94
- WGS 84 (G1150) — adopted Jan 20, 2002
  - Aligned with ITRF2000 (at epoch 2001.00)
- WGS 84 (G1674) — adopted Feb 5, 2012
  - Aligned with ITRF2008 (at epoch 2005.00)
- ***WGS 84 (G1762) — adopted Mar 1, 2014***
  - Also aligned with ITRF2008 (at epoch 2005.00)
  - ***Note that current NAD 83 is epoch 2010.00***

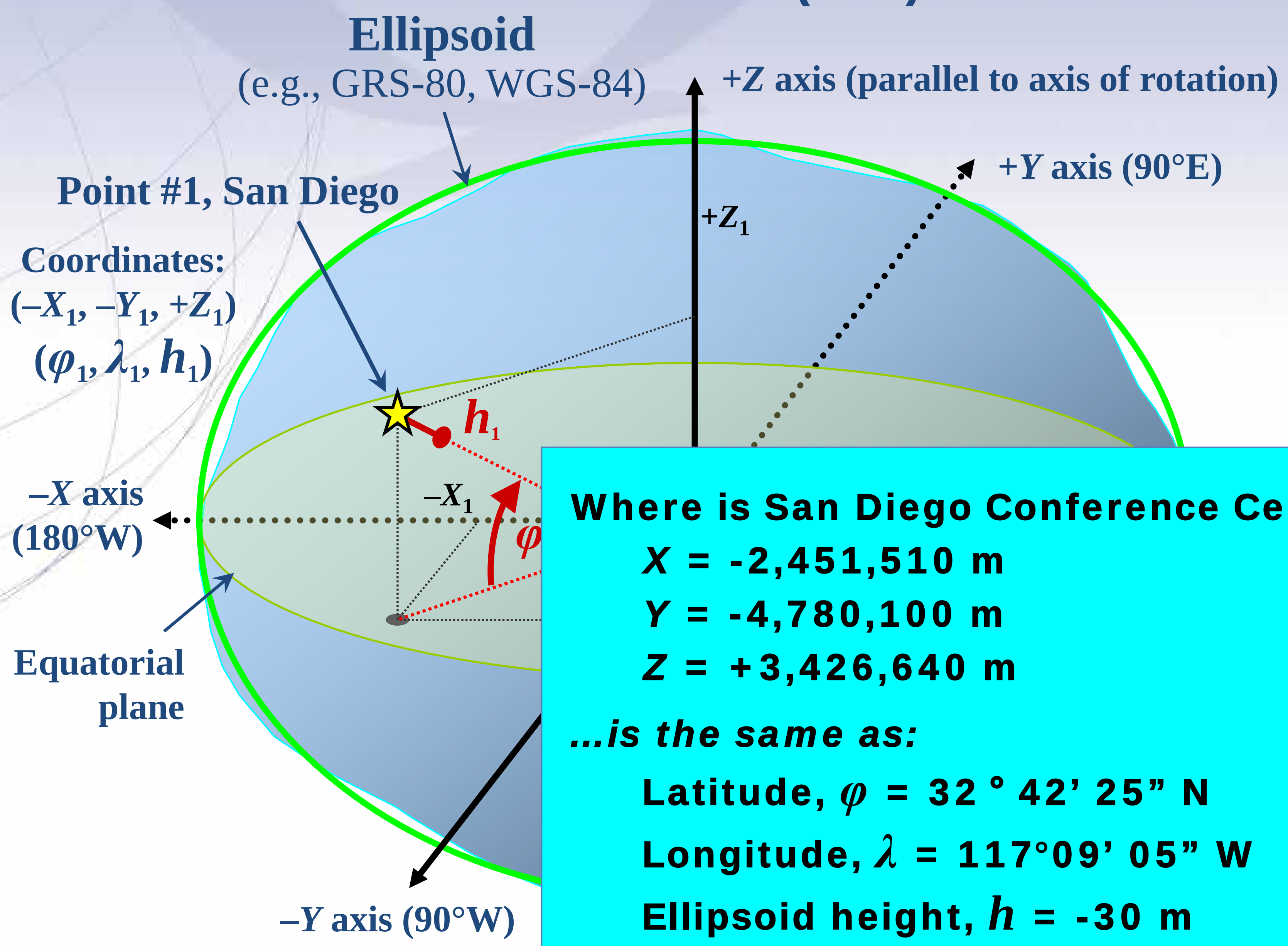
Understanding geodetic coordinates

- Positions for entire Earth (or large part of Earth)
  - For modern datums these are 3-D
    - With velocities they are 4-D
  - Here concerned with *geometric coordinates*
- Two main types:
  - Latitude, longitude, and ellipsoid height: φ, λ, h
  - Earth-Centered, Earth Fixed (ECEF) Cartesian: X, Y, Z
    - Used for many types of geodetic computations
  - Can covert between both types without error

Earth-Centered Earth-Fixed (ECEF) coordinates



Earth-Centered Earth-Fixed (ECEF) coordinates



Where is San Diego Conference Center?

X = -2,451,510 m

Y = -4,780,100 m

Z = +3,426,640 m

…is the same as:

Latitude, φ = 32 ° 42' 25" N

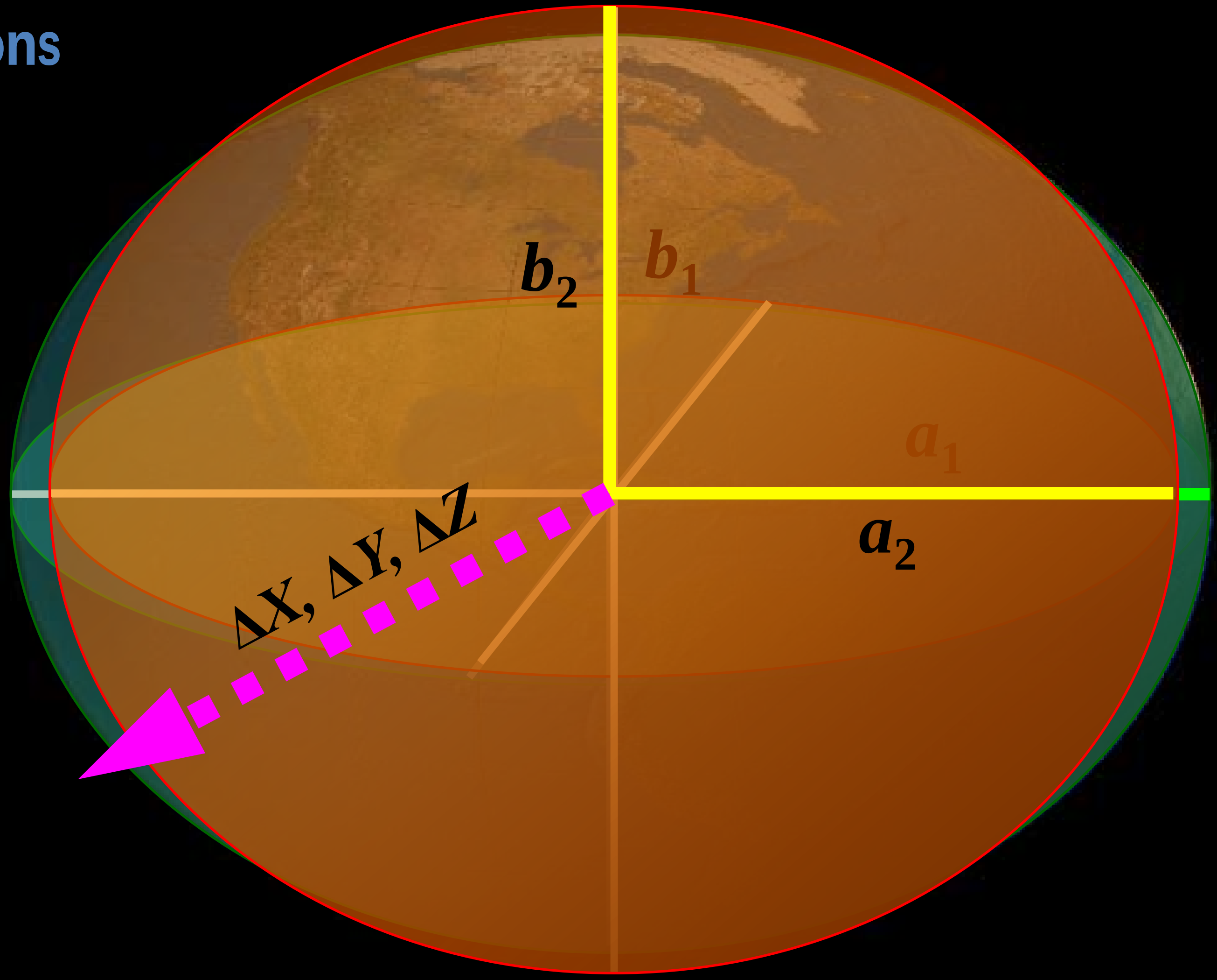
Longitude, λ = 117°09' 05" W

Ellipsoid height, h = -30 m

Datum transformations

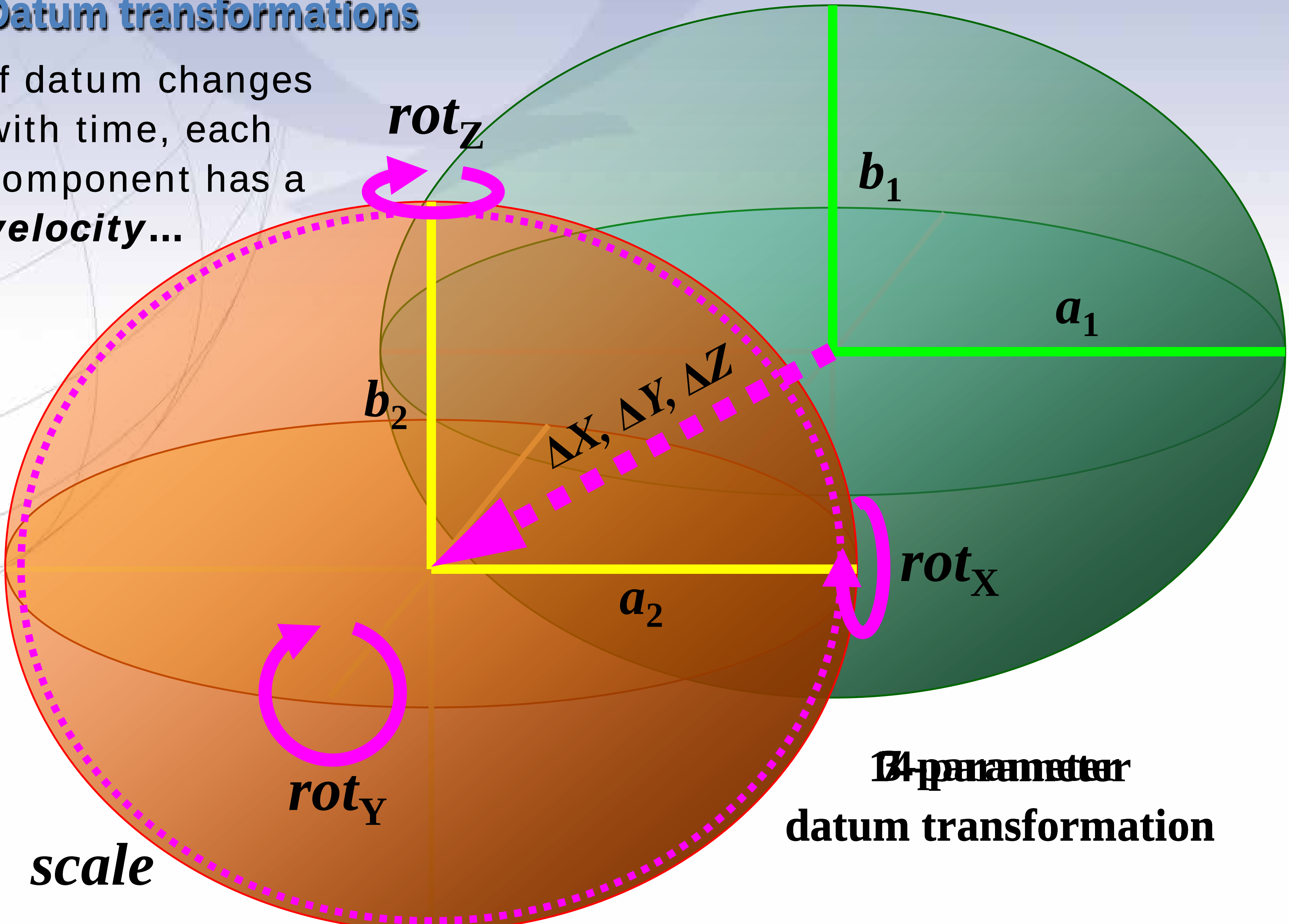
- **Typical datum transformations**
  - **3-parameter:** 3-dimensional translation of origin as ΔX, ΔY, ΔZ
  - **7-parameter:** 3 translations *plus* 3 rotations (one about each of the axes) *plus* a scale
  - **14-parameter:** A 7-parameter where each parameter changes with time (each has a *velocity*)
  - Transformations that model tectonic displacement and other distortion (e.g., NGS models in HTDP, GEOCON, and NADCON)
- **Vertical datum transformations**
  - Can be simple shift or complex operation that models distortion (e.g., GEOCON, VERTCON)

Datum transformations



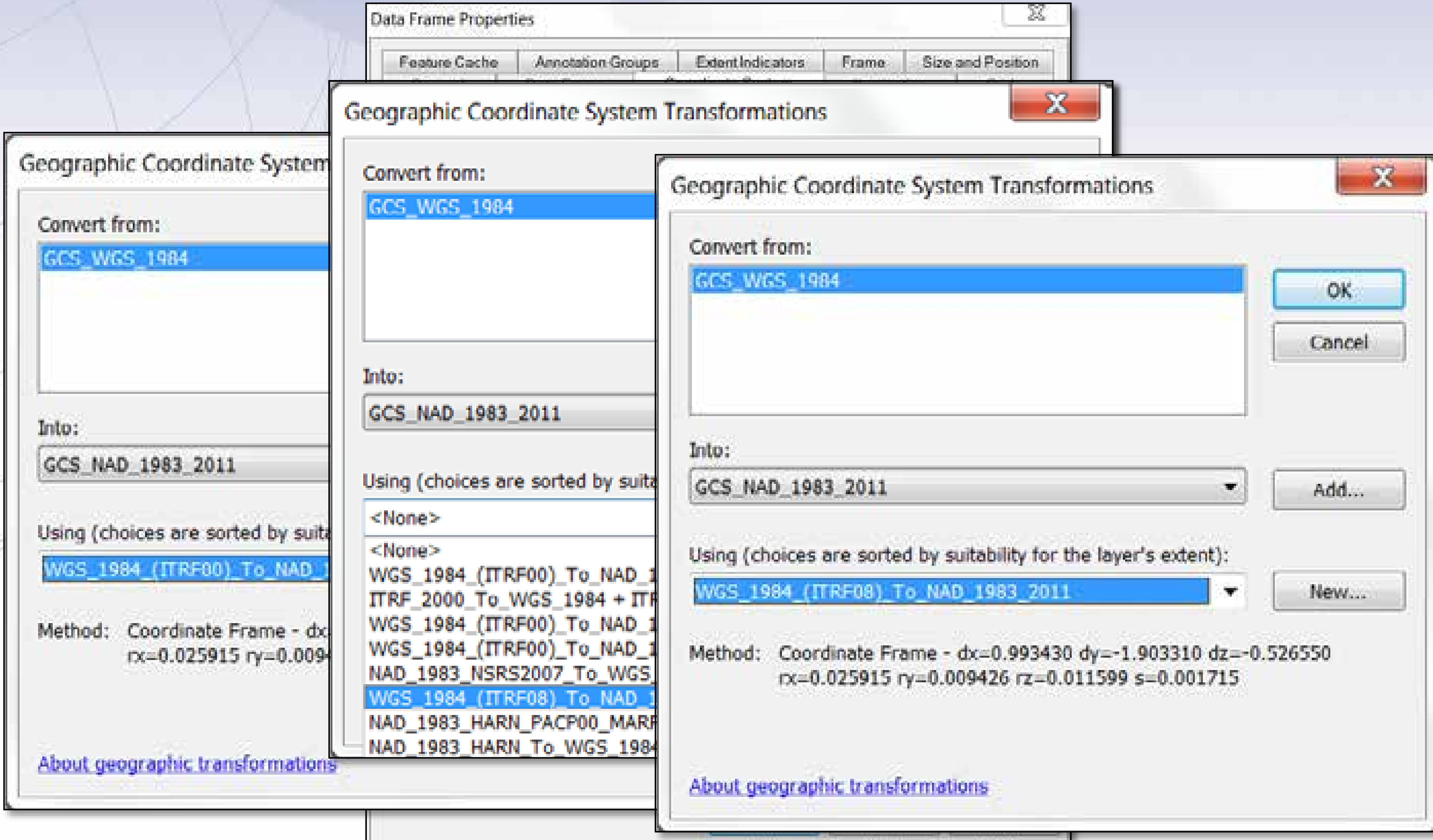
Datum transformations

If datum changes with time, each component has a ***velocity*...**

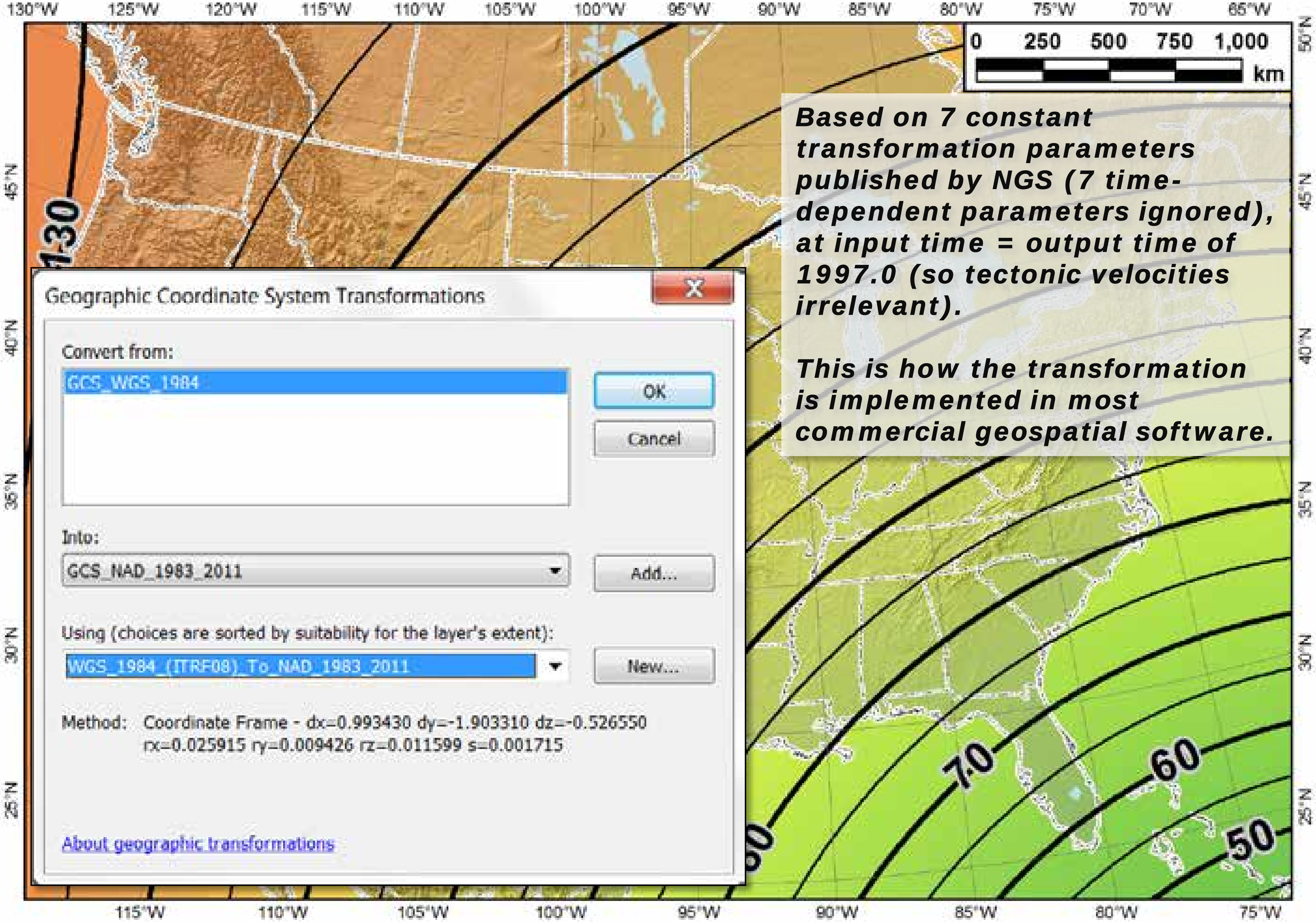


14-parameter
datum transformation

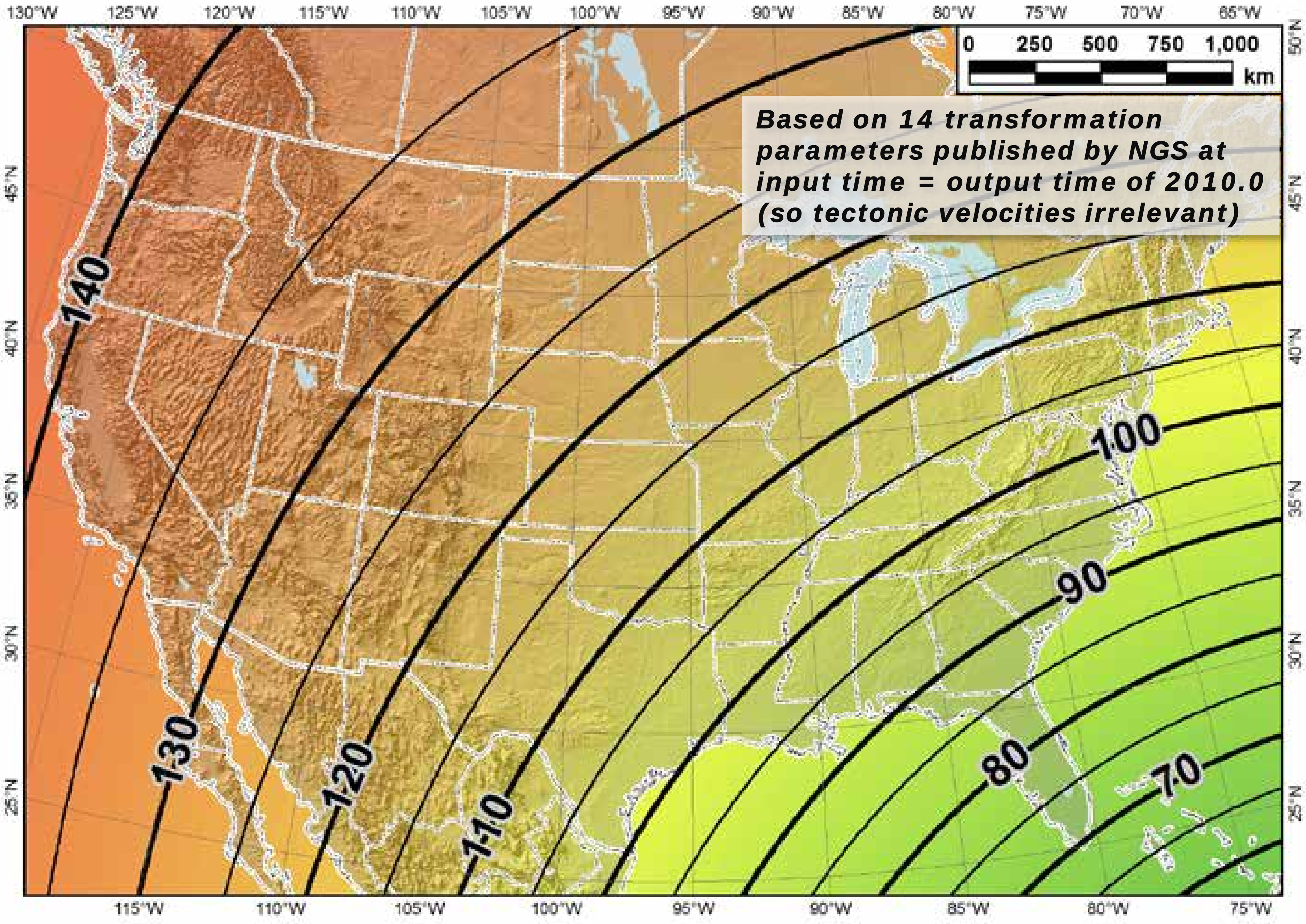
What to do...?


Data Frame Properties
Feature Cache
Annotation Groups
Extent Indicators
Frame
Size and Position
Geographic Coordinate System Transformations
Convert from:
GCS_WGS_1984
Into:
GCS_NAD_1983_2011
Using (choices are sorted by suitability for the layer's extent):
WGS_1984_(ITRF08)_To_NAD_1983_2011
<None>
Method: Coordinate Frame - dx=0.993430 dy=-1.903310 dz=-0.526550
rx=0.025915 ry=0.009426 rz=0.011599 s=0.001715
OK
Cancel
Add...
New...
About geographic transformations

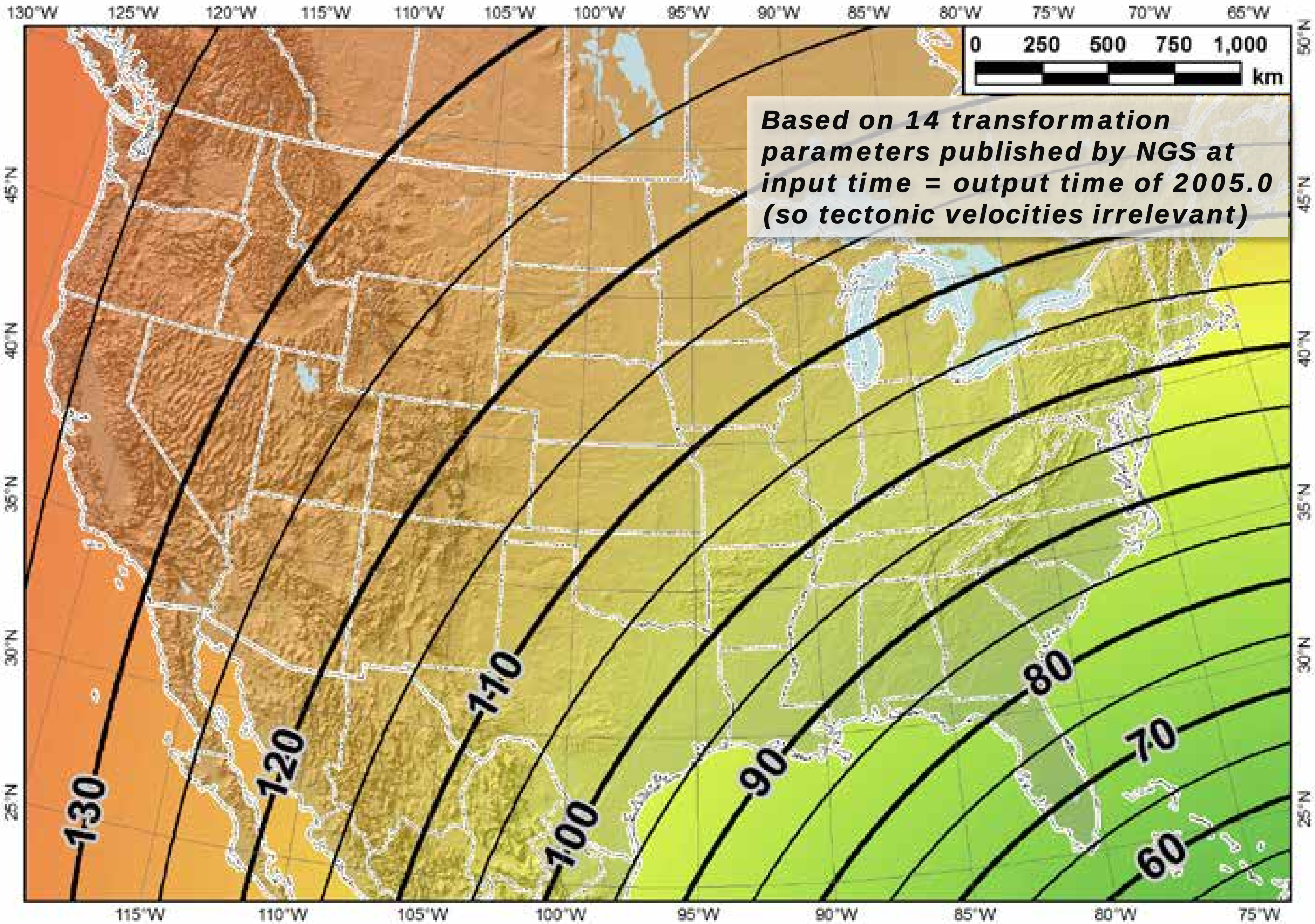
Horizontal shift from WGS 84 (G1762) epoch 1997.00 to NAD 83(2011) epoch 1997.00 (cm)



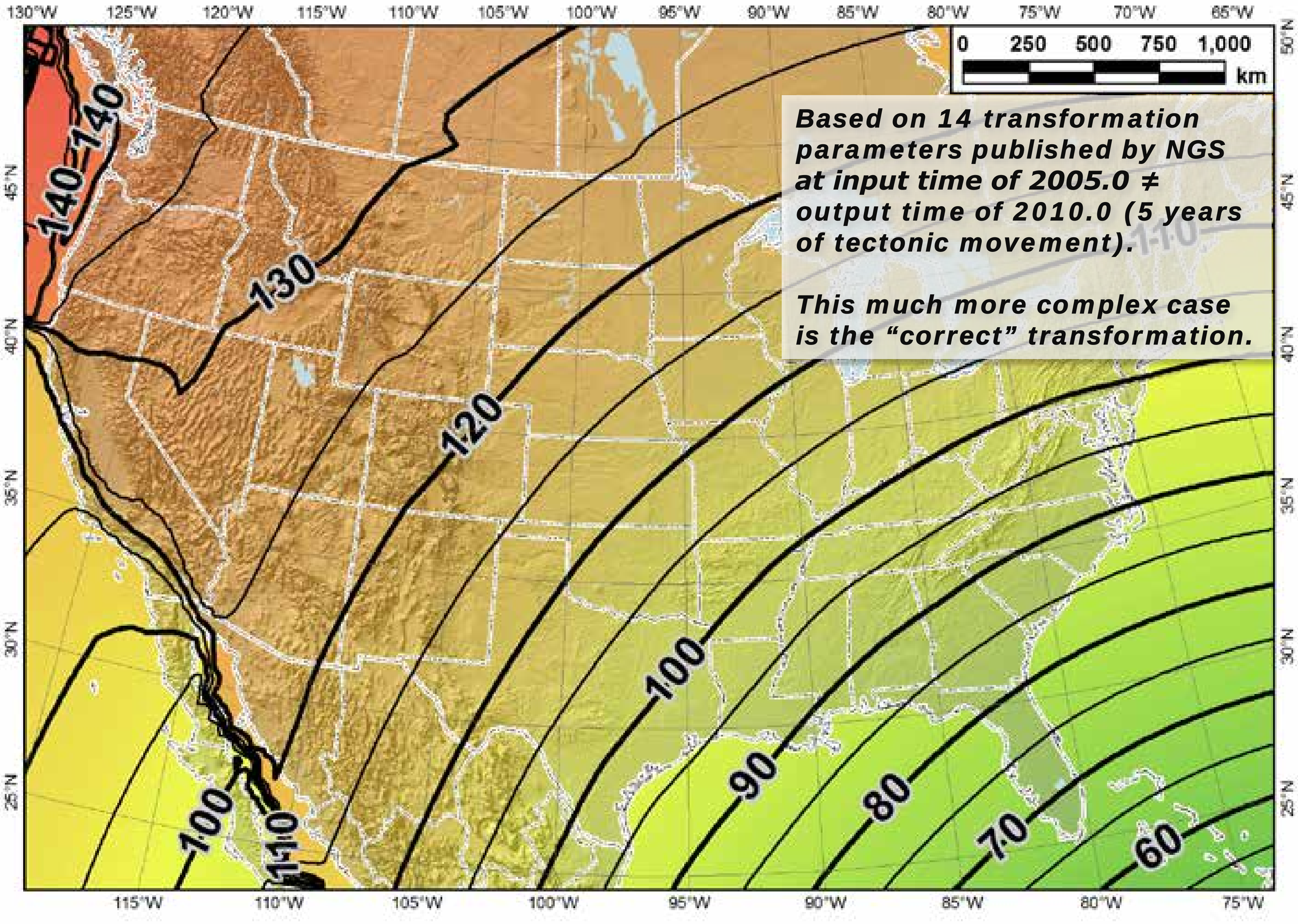
Horizontal shift from WGS 84 (G1762) epoch 2010.00 to NAD 83(2011) epoch 2010.00 (cm)



Horizontal shift from WGS 84 (G1762) epoch 2005.00 to NAD 83(2011) epoch 2005.00 (cm)

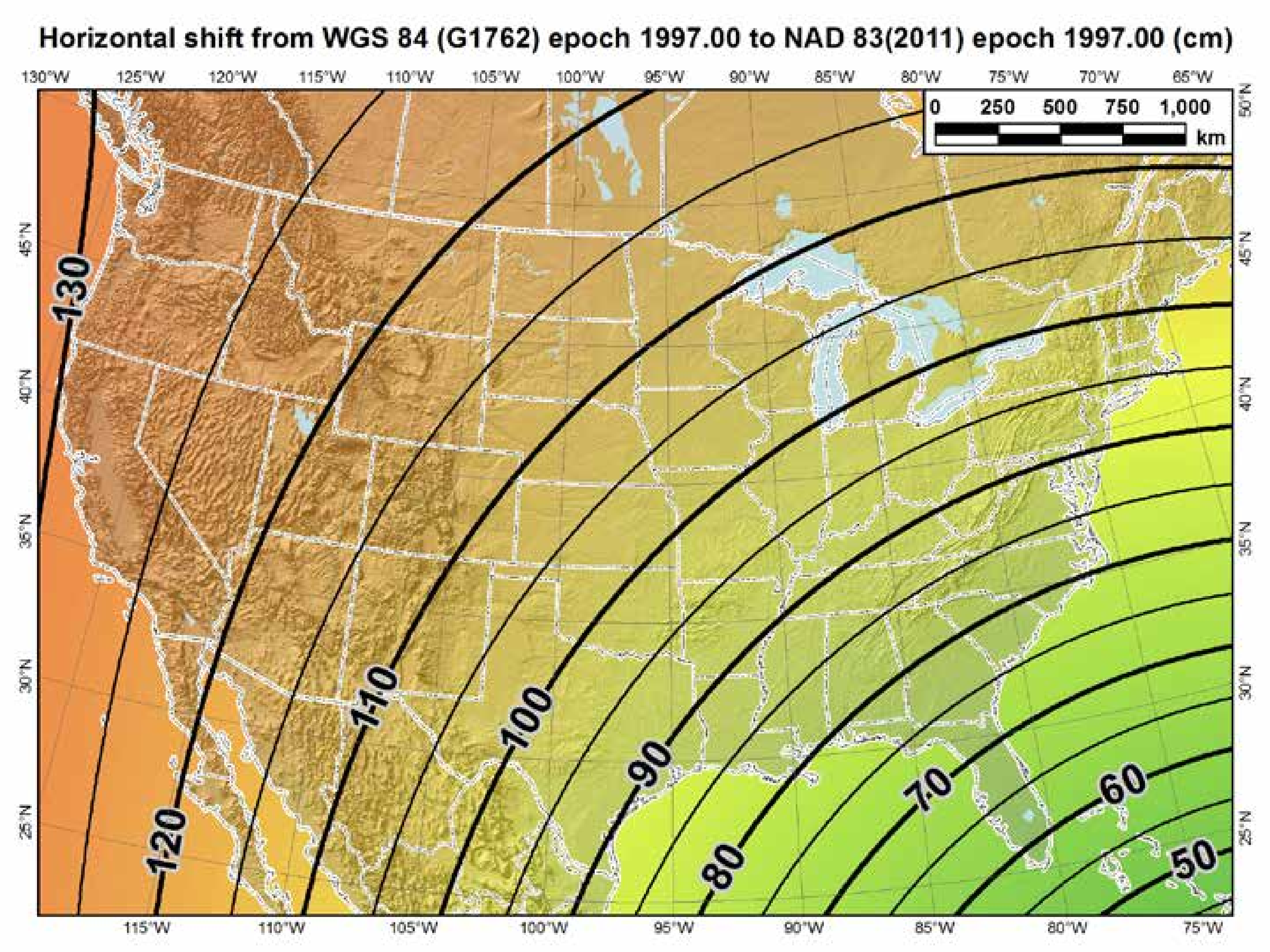


Horizontal shift from WGS 84 (G1762) epoch 2005.00 to NAD 83(2011) epoch 2010.00 (cm)



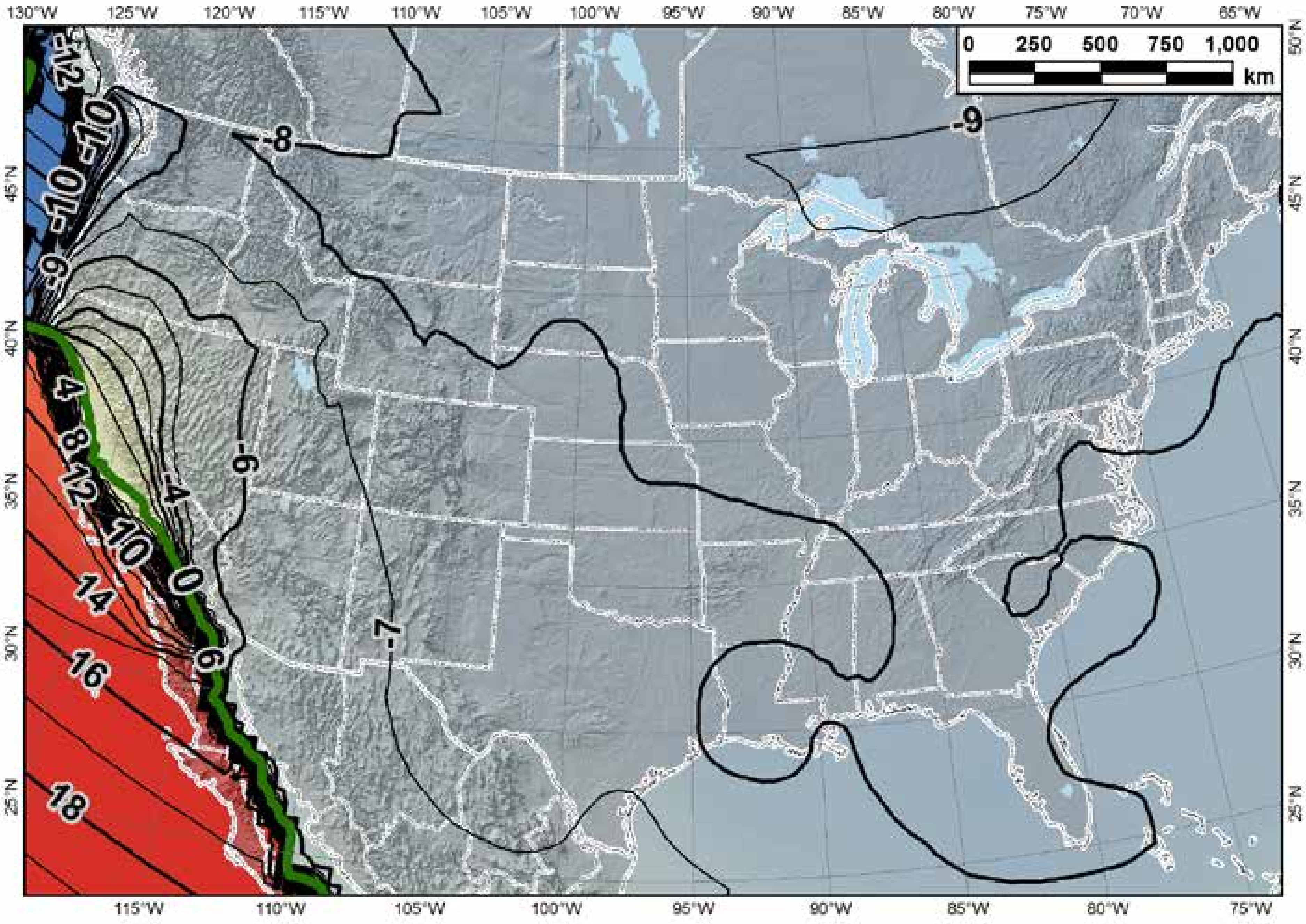
Based on 14 transformation parameters published by NGS at input time of 2005.0 ≠ output time of 2010.0 (5 years of tectonic movement).

This much more complex case is the "correct" transformation.

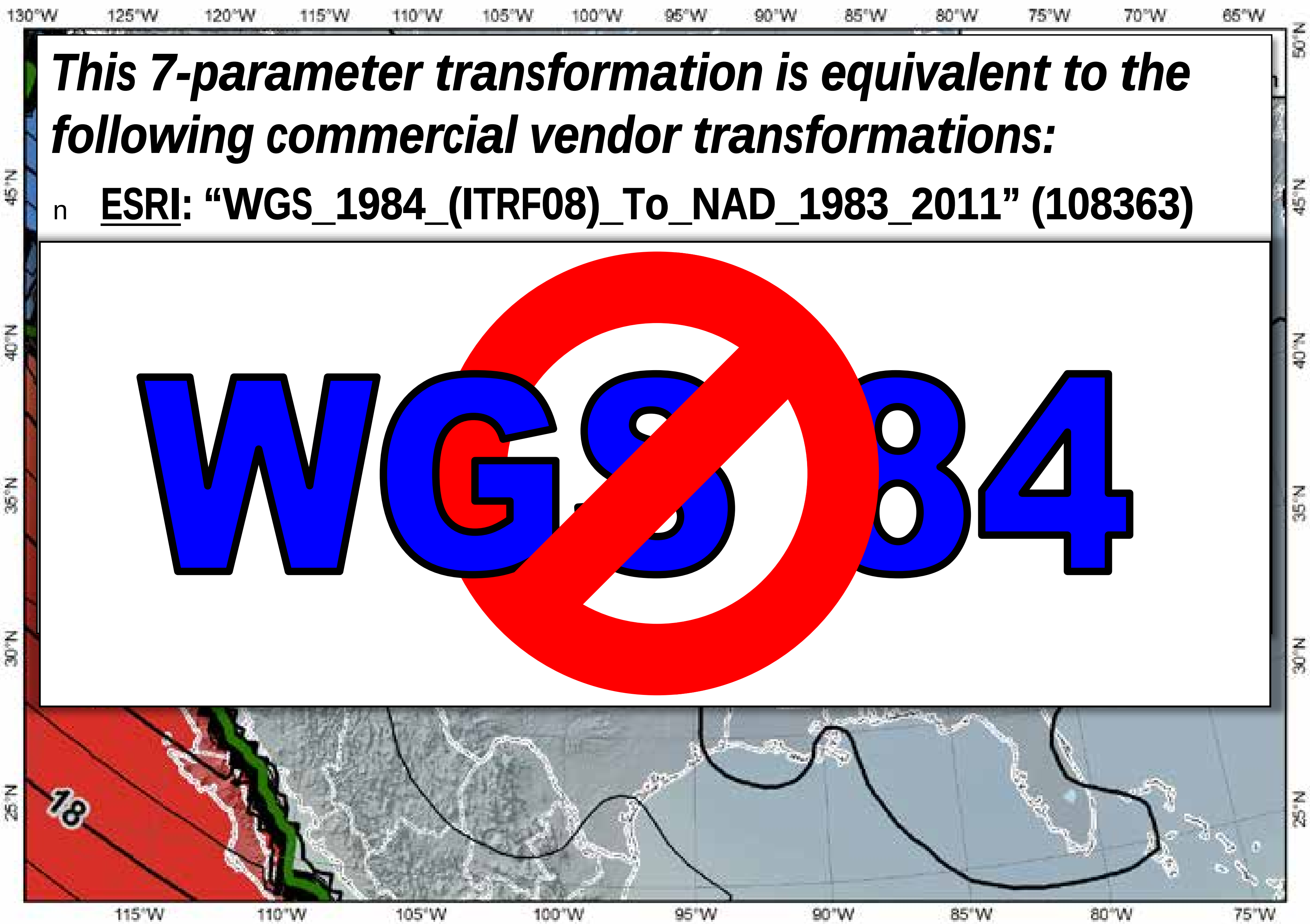


Horizontal shift from WGS 84 (G1762) epoch 1997.00 to NAD 83(2011) epoch 1997.00 (cm)
130°W
125°W
120°W
115°W
110°W
105°W
100°W
95°W
90°W
85°W
80°W
75°W
70°W
65°W
0
250
500
750
1,000
km
50°N
45°N
40°N
35°N
30°N
25°N
130
120
110
100
90
80
70
60
50
115°W
110°W
105°W
100°W
95°W
90°W
85°W
80°W
75°W

Horizontal error of 7-parameter WGS 84 to NAD 83(2011) transformation (cm)



Horizontal error of 7-parameter WGS 84 to NAD 83(2011) transformation (cm)



This 7-parameter transformation is equivalent to the following commercial vendor transformations:

- **<u>ESRI</u>: “WGS_1984_(ITRF08)_To_NAD_1983_2011” (108363)**

WGS 84

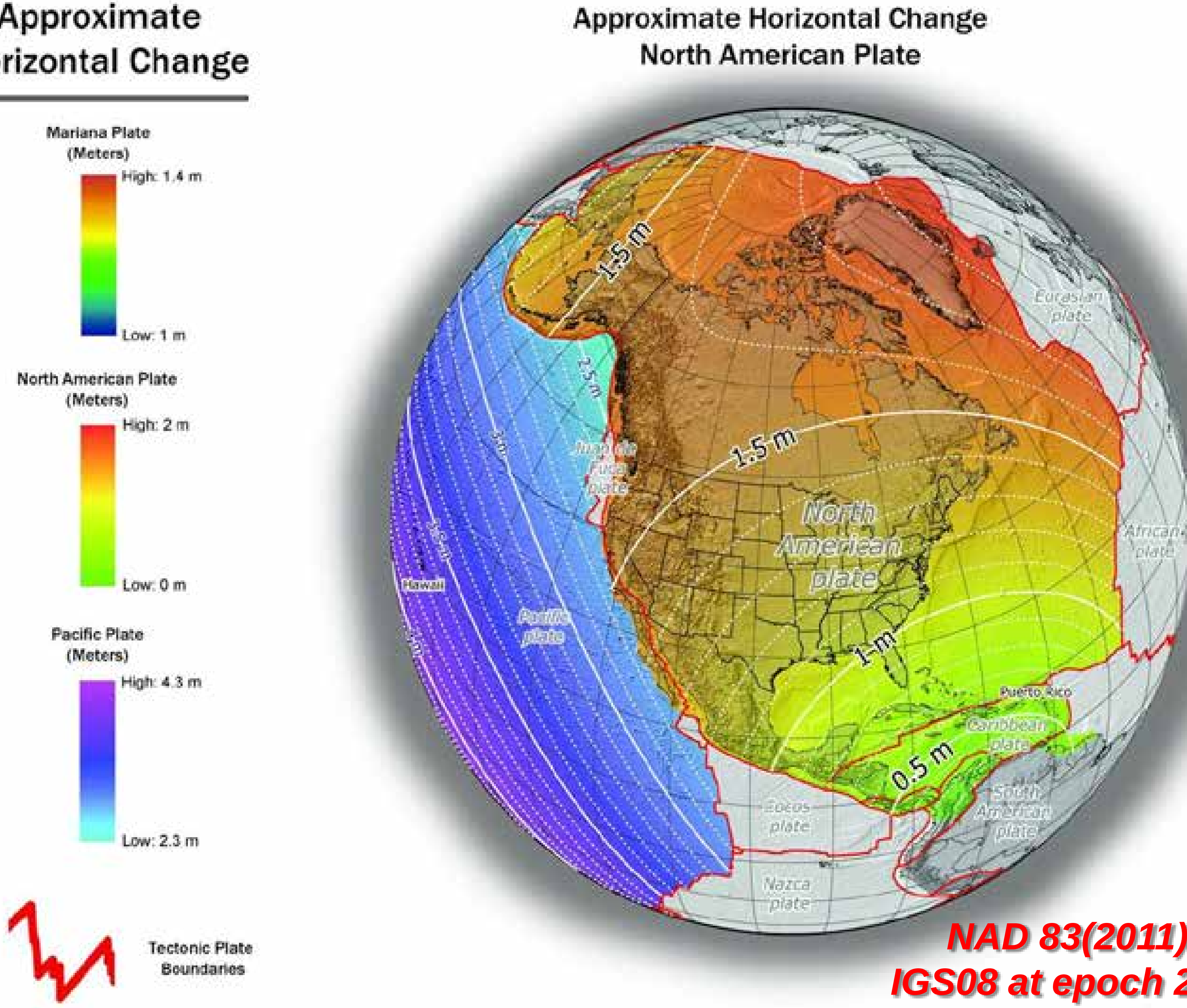
Does this stuff really matter?

- Significant for accuracies better than ~1-2 m
  - Can be problem for combining accurate datasets
  - Requires understanding of modern datums
  - Be careful when using "WGS 84"
    - Which realization? At what epoch? At what level of accuracy?
- Things are moving, and it can make a difference
  - e.g., San Diego moving **4.0 cm/yr NW** w.r.t. Phoenix, AZ
- Modern GNSS becoming more ***precise***
  - Autonomous positions soon better than 1-2 m
  - But ***accuracy*** another issue… with respect to what?

New Datums for the U.S.

- Planned release in 2022
  - Geometric datum: Aligned with ITRF/WGS 84
  - Vertical datum: Based on gravimetric geoid
- How much will NSRS coordinates change?
  - North America plate (CONUS and AK): Approx 0.8 to 1.6 m
  - Pacific plate: Approx 3.4 (Midway) to 4.3 m (American Samoa)
  - Mariana plate: Approx 1.1 to 1.4 m
- How much will NSRS ellipsoid height change?
  - Approx -1.9 m (Puerto Rico) to +2.0 m (Guam)
- How much will NSRS CONUS orthometric height change?
  - Approx +0.1 m (Florida) to -1.3 m (Washington)

Approximate Horizontal Change



NAD 83(2011) to IGS08 at epoch 2022.0

Approximate Horizontal Change

Mariana Plate (Meters)

High: 1.4 m

Low: 1 m

North American Plate (Meters)

High: 2 m

Low: 0 m

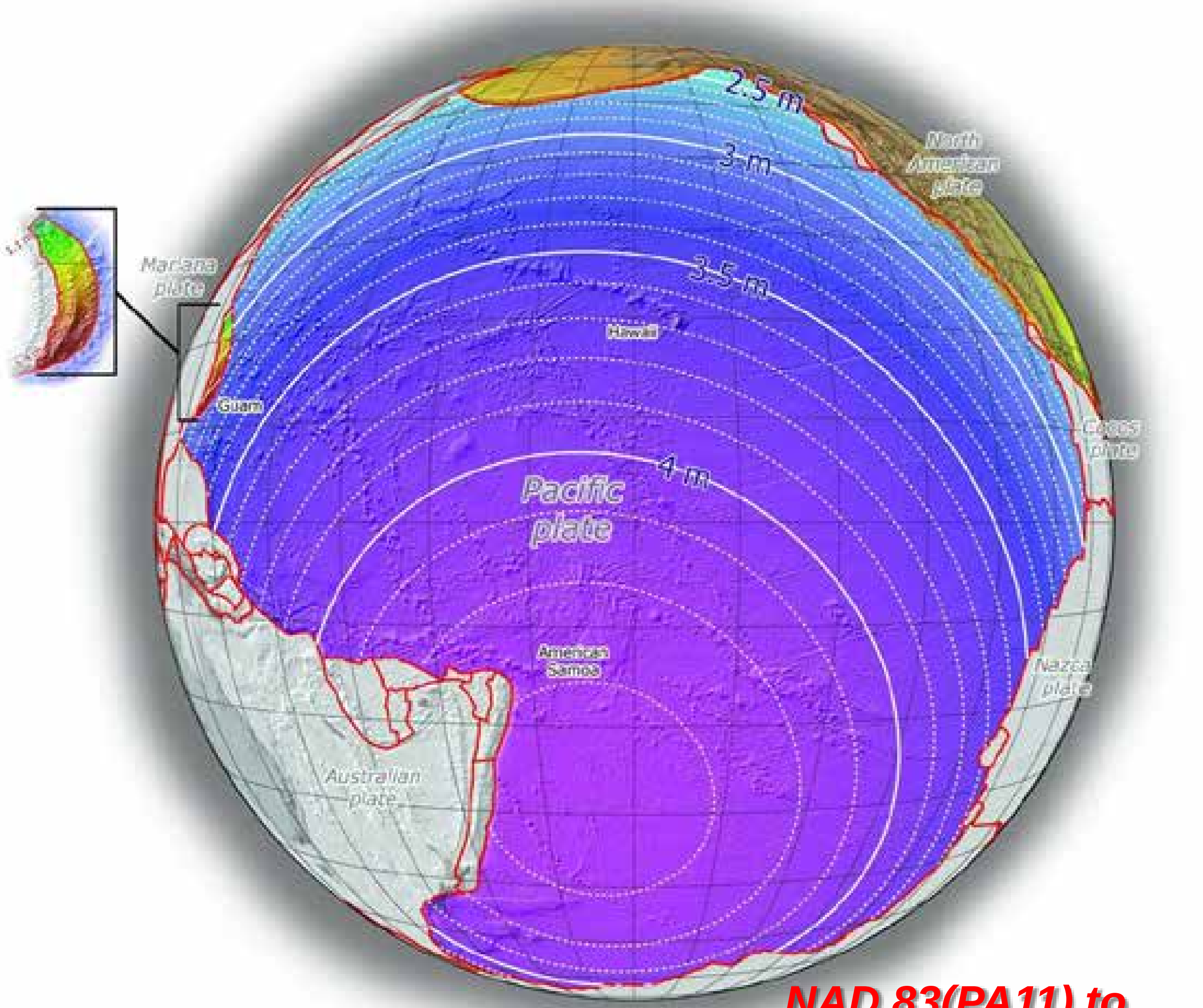
Pacific Plate (Meters)

High: 4.3 m

Low: 2.3 m

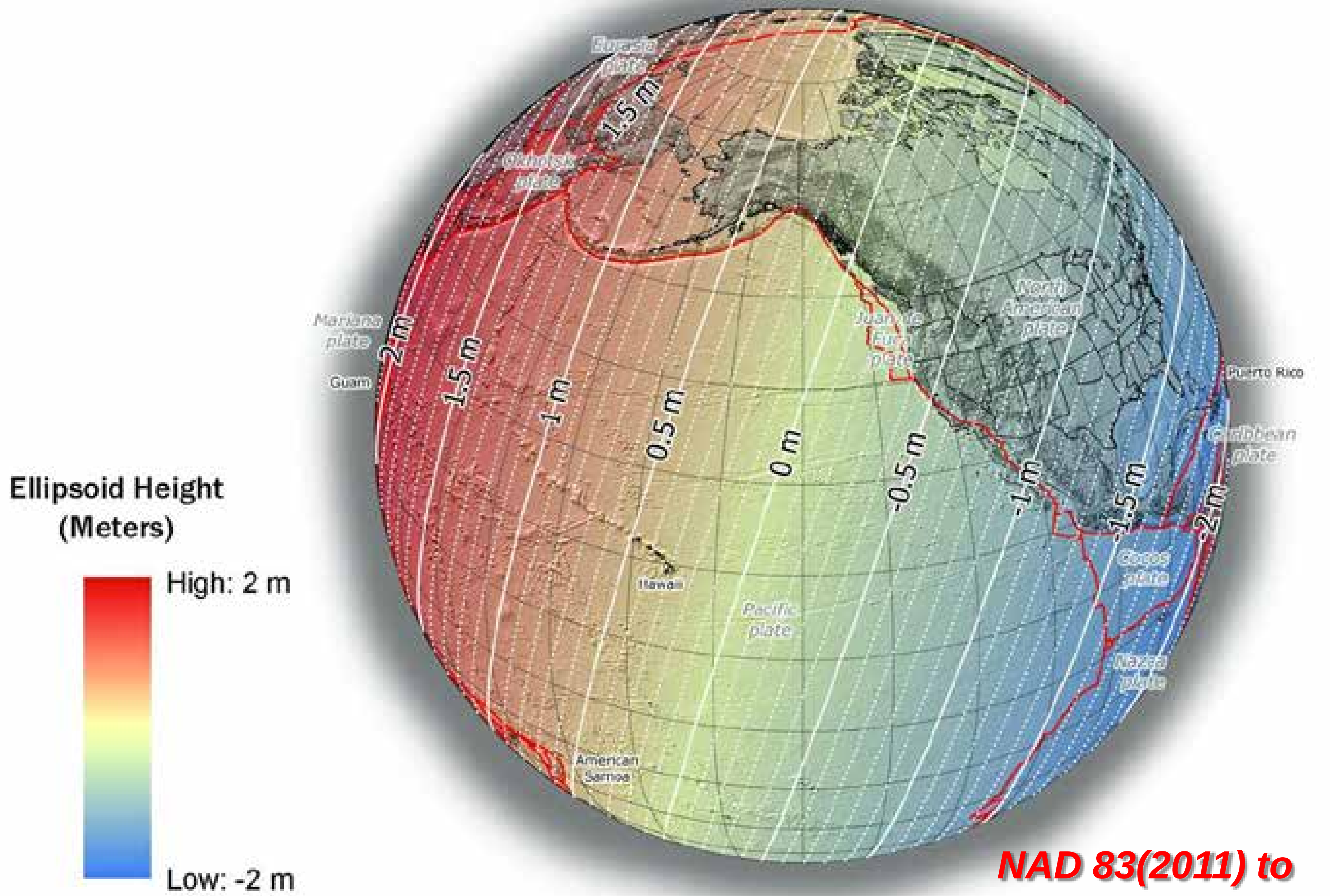
Tectonic Plate Boundaries

Approximate Horizontal Change Pacific Plate

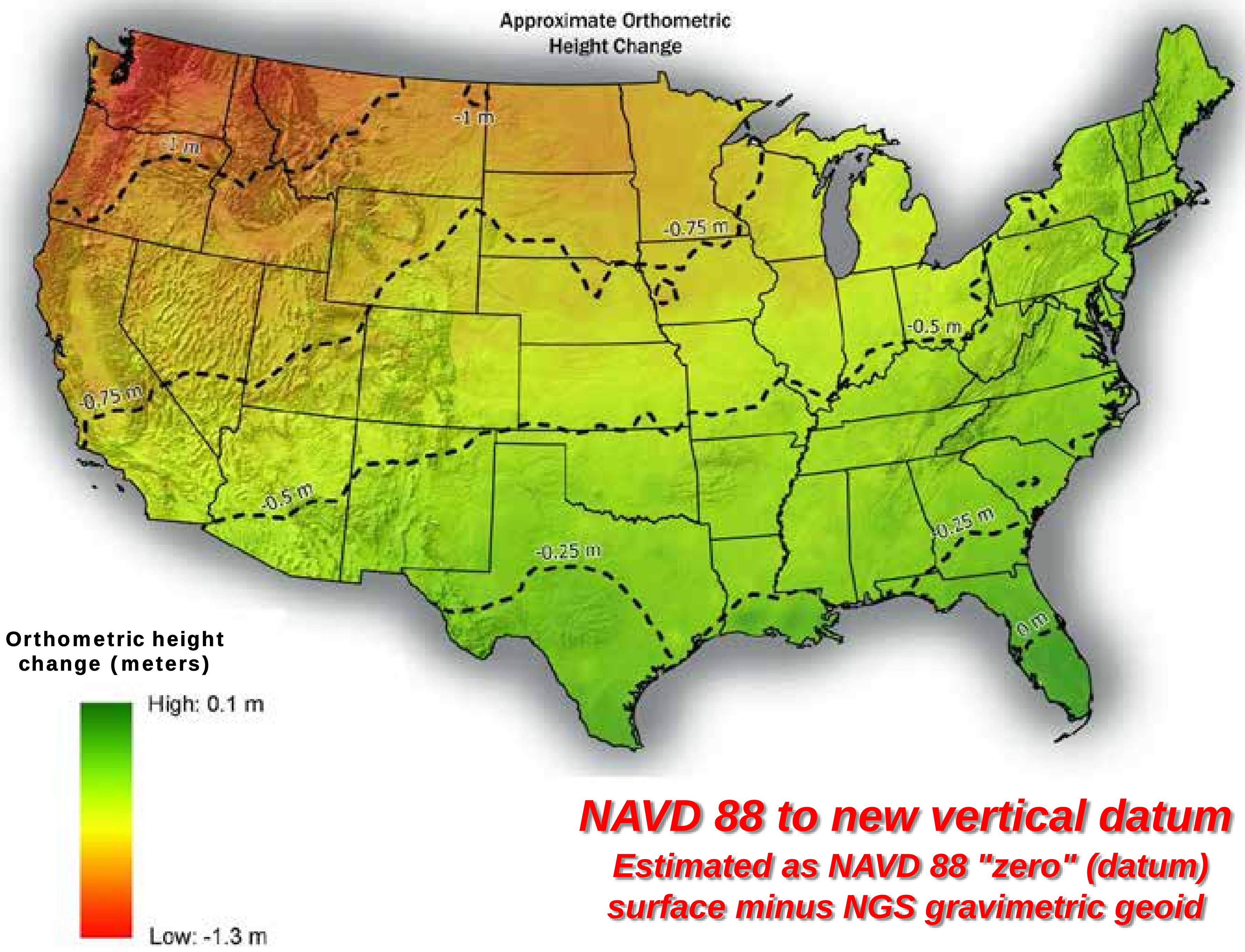


NAD 83(PA11) to IGS08 at epoch 2022.0

Approximate Ellipsoid Height Change



NAD 83(2011) to IGS08 at epoch 2022.0



NAVD 88 to new vertical datum

Estimated as NAVD 88 "zero" (datum) surface minus NGS gravimetric geoid

Conclusions

- Geodesy knowledge needed for correct georeferencing
  - Becomes more important as spatial accuracy increases
  - Driven by high precision and low cost of GNSS (a geodetic tool)
- High-accuracy geodetic transformations are complicated
  - Time-dependence especially complex for differential tectonic motion
  - Datasets representing different times difficult to spatially align
- Metadata (documentation) is ***essential***
  - Improves reliability and accuracy of data
  - Increases value and usefulness of spatial data
  - Needed all geospatial data (GIS, surveying, engineering, etc.)

More information...

geodesy.noaa.gov

National Geodetic Survey

Positioning America for the Future

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Announcements: NGS Completes Vertical Datum for Puerto Rico

June 27, 2014

Notices

June 30, 2014: The National Geodetic Survey (NGS) Releases new Beta experimental geoid height model “xGEOID14B,” spanning one-quarter of Earth's surface 06.27.2014

June 26, 2014: NGS Webinar Presentation "A Conversation with the National Geodetic Survey" 06.06.2014

NGS Hosts the North American Comparison of Absolute Gravimeters(NACAG14), September 13-21, 2014 05.15.2014

Heartbleed Vulnerability Notice 05.02.2014

Popular GPS Positioning Service Is Enhanced: OPUS Projects 01.28.2014

In The News

06/26/2014 - NGS Serves Key Role at International GNSS Service Workshop

National Geodetic Survey (NGS) staff presented at the International GNSS Service (IGS) Workshop in Pasadena, California, June 23 to 27. The IGS sets

Most Popular

- Antenna Calibration
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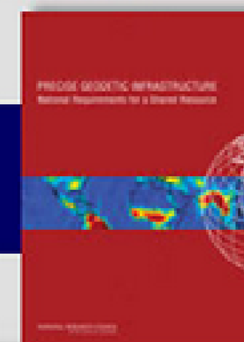
- CORS
- Geodetic Advisors
- Geodetic Tool Kit
- LOCUS
- NAD 83(2011) epoch 2010.00
- NGS Data Explorer
- OPUS
- Publications
- Storm Imagery
- Survey Mark Datasheets

Looking for Bench Marks?

NRC Highlights Importance of NGS Products...



Federal Geodetic Control Subcommittee

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Questions?