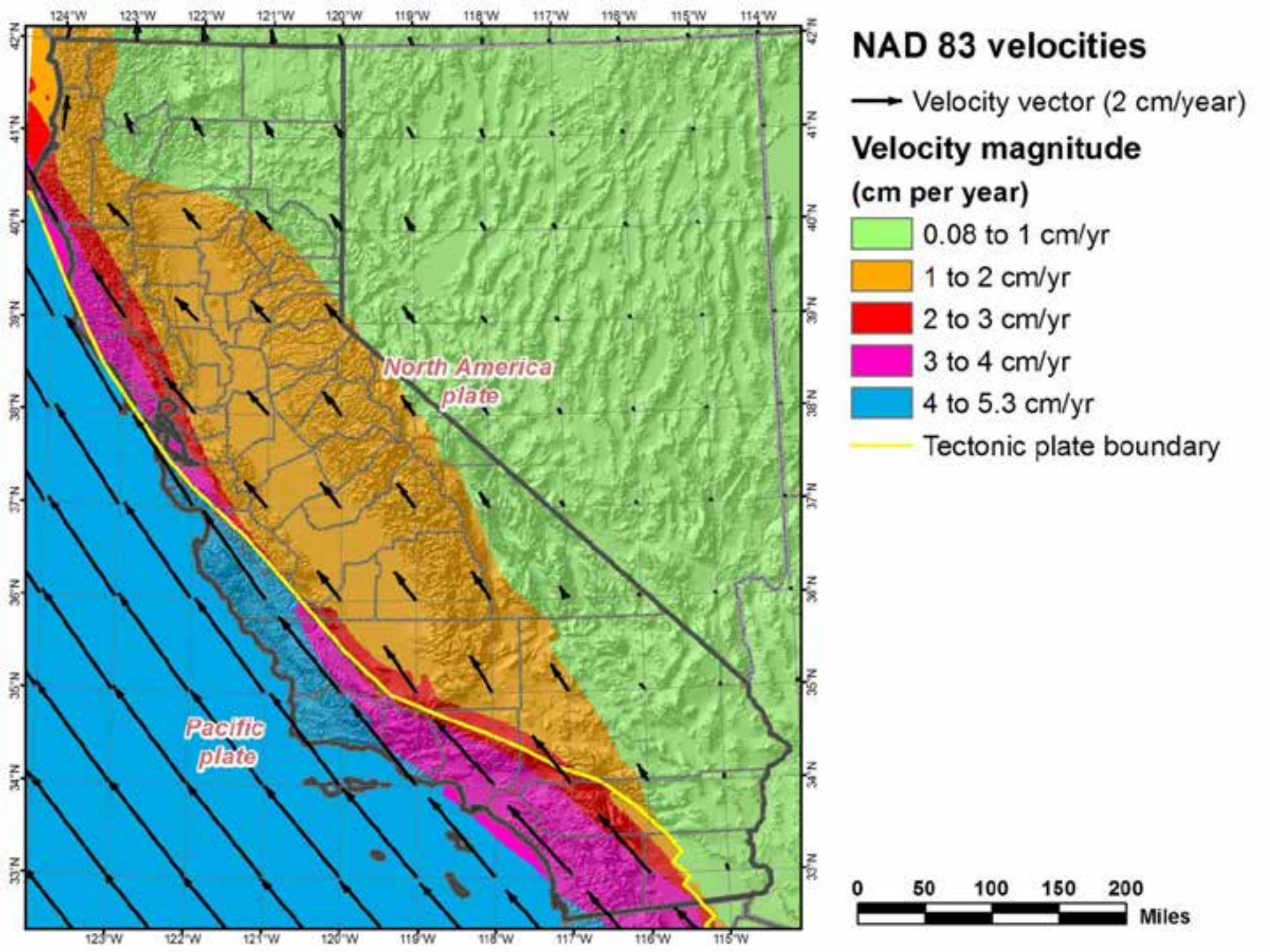
Space, Time, and Datum Forensics

Aligning GIS Data on a Dynamic Earth

Michael L. Dennis, RLS, PE

Projections are easy
Datums are hard


NAD 83 velocities
Velocity vector (2 cm/year)
Velocity magnitude
(cm per year)
0.08 to 1 cm/yr
1 to 2 cm/yr
2 to 3 cm/yr
3 to 4 cm/yr
4 to 5.3 cm/yr
Tectonic plate boundary
North America plate
Pacific plate
0 50 100 150 200
Miles

Speaking the same language

- Coordinate system MUST have a “datum”
- Coordinate system MAY have a “map projection”
- “Datum” for this discussion…
  - = “Geographic coordinate system”
  - = “Geometric reference frame”
  - Modern ones 4-dimensional (3-D position PLUS time)
- “Map projection”
  - Curved geographic à planar projected (*x, y* or *east, north*)
  - Horizontal ONLY
- Vertical datums (coordinate systems)
  - An even more complex topic for another time…

Projections are easy.
Datums are hard.

- Aligning data REQUIRES consistent datums
  - The map projection does NOT matter
- Datum (geographic) transformation
  - Method for converting between datums
- Datums can have multiple “realizations”
  - Definition is same but coordinates change
- NAD 83 has at least FOUR historic realizations
  - Three current realizations based on location (epoch 2010.0)
- WGS 84 has SIX realizations

Our good friends

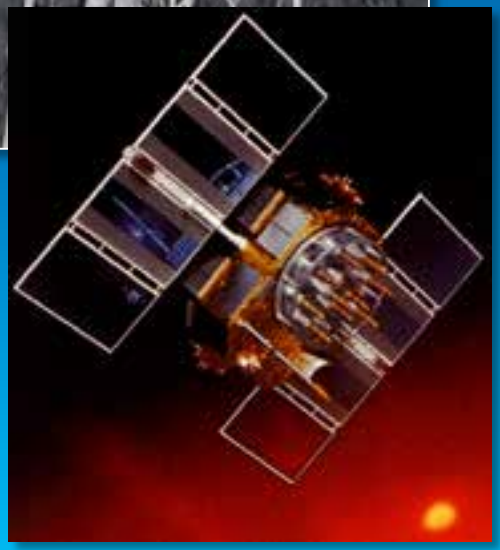
WGS 1984

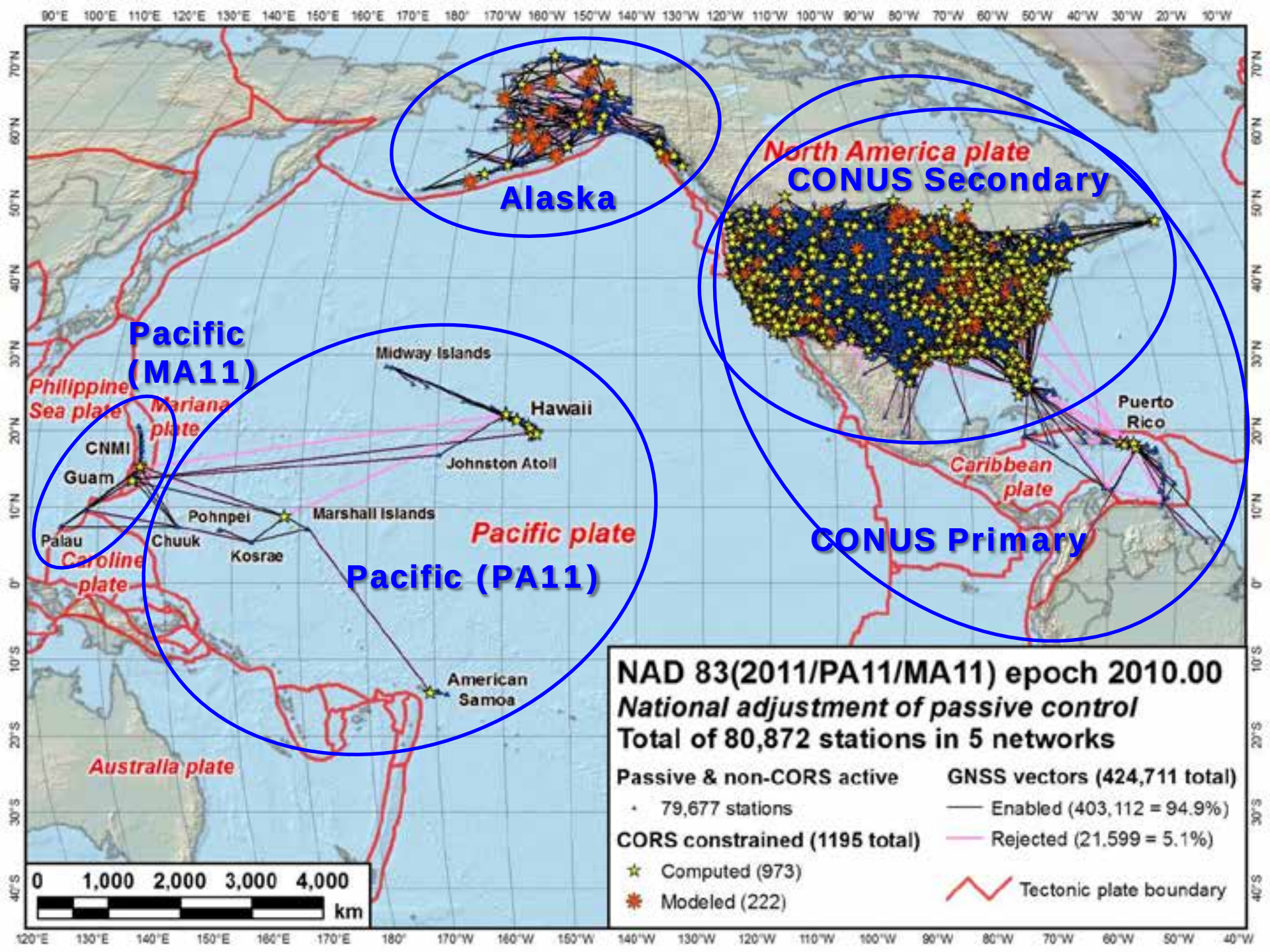
and

NAD 1983

A (very) brief history of NAD 83

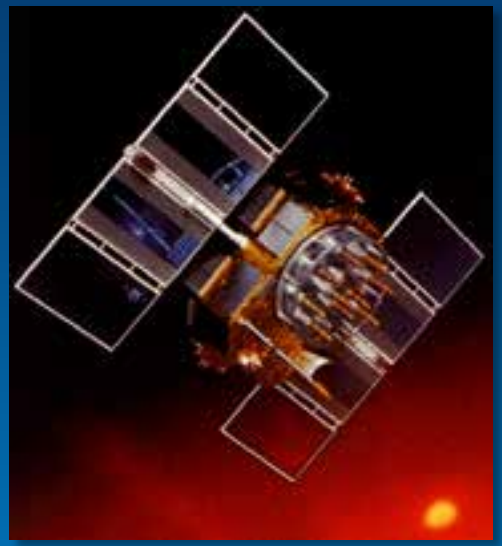
- **Original realization completed in 1986**
  - **Consisted (almost) entirely of classical (optical) observations**
- **"High Precision Geodetic Network" (HPGN) and "High Accuracy Reference Network" (HARN) realizations**
  - **Most done in 1990s, essentially state-by-state**
  - **Based on GNSS but 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/PA11/MA11) epoch 2010.00***




Alaska
North America plate
CONUS Secondary
Pacific (MA11)
Philippine Sea plate
Mariana plate
CNMI
Guam
Palau
Chuuk
Pohnpei
Kosrae
Marshall Islands
Midway Islands
Hawaii
Johnston Atoll
Pacific plate
Pacific (PA11)
Caroline plate
American Samoa
Australia plate
Puerto Rico
Caribbean plate
CONUS Primary
NAD 83(2011/PA11/MA11) epoch 2010.00
National adjustment of passive control
Total of 80,872 stations in 5 networks
Passive & non-CORS active
79,677 stations
CORS constrained (1195 total)
Computed (973)
Modeled (222)
GNSS vectors (424,711 total)
Enabled (403,112 = 94.9%)
Rejected (21,599 = 5.1%)
Tectonic plate boundary
0 1,000 2,000 3,000 4,000
km

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 1994**
  - **Aligned with ITRF91**
- **WGS 84 (G873) — adopted Sep 1996**
  - **Aligned with ITRF94**
- **WGS 84 (G1150) — adopted Jan 2002**
  - **Aligned with ITRF2000 (at epoch 2001.00)**
- **WGS 84 (G1674) — adopted Feb 2012**
  - **Aligned with ITRF2008 (at epoch 2005.00)**
- ***WGS 84 (G1762) — adopted Oct 2013***
  - **Also aligned with ITRF2008 (at epoch 2005.00)**
  - ***Note that current NAD 83 is epoch 2010.00***



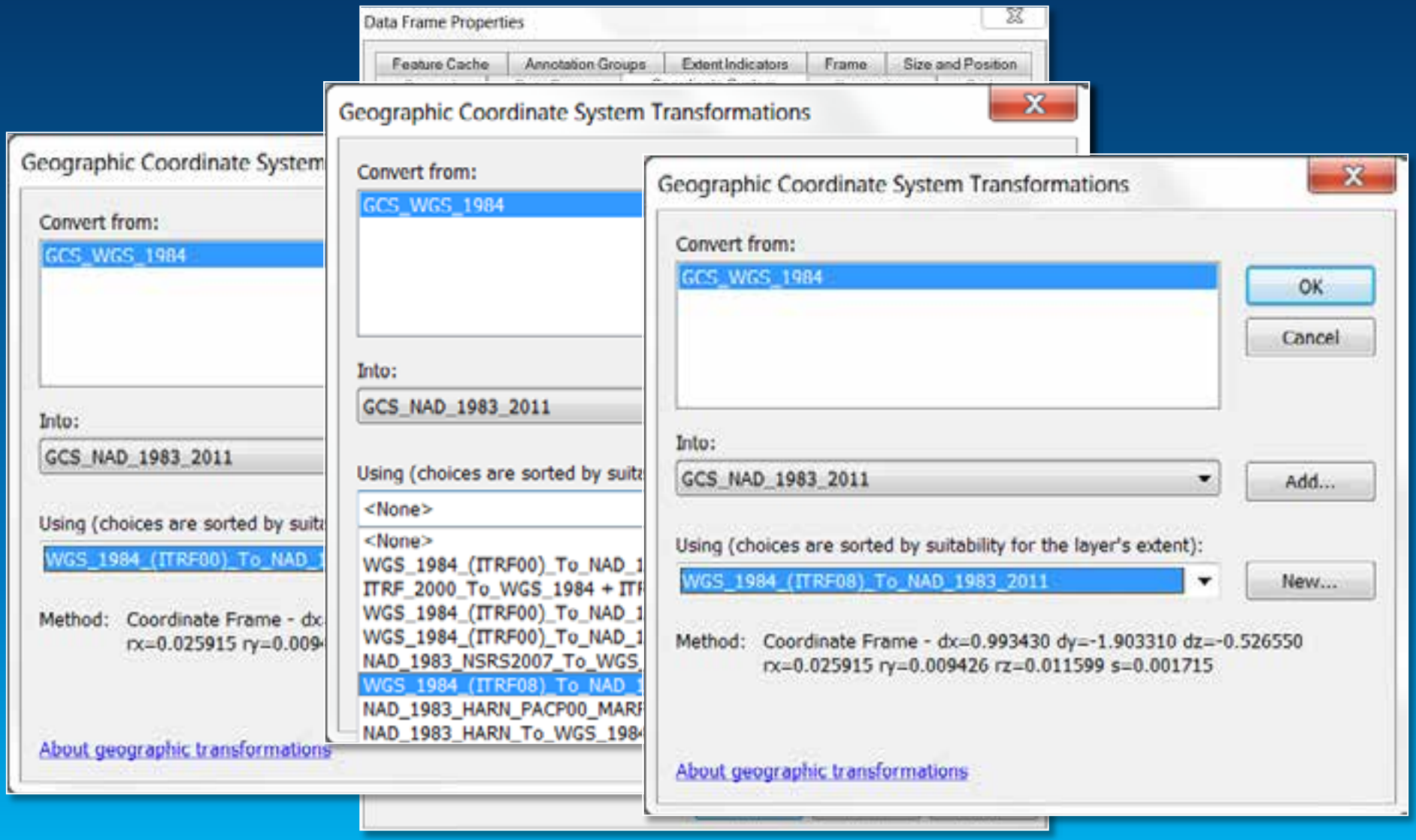
How do you get WGS 84 coordinates?

- Only true access: Broadcast orbits
  - Accuracy ~3 to 5 meters horizontal
- Can assume equal to civilian global frames
  - International Terrestrial Reference Frame (ITRF)
  - International GNSS Service (IGS) frame
- Sources:
  - Satellite Based Augmentation Systems (SBAS)
    - E.g., WAAS, OmniSTAR
  - Various positioning services
    - E.g., OPUS, AUSPOS,

So, you think you have WGS 84 coordinates…

- If accuracy worse (larger) than ~3 m
  - Can consider same as “generic” NAD 83
  - Don’t need realization or epoch date
  - No need to transform to NAD 83
- If (stated) accuracy better (smaller) than ~3 m:
  - Must include realization (e.g., G1762)
  - Must include epoch date (e.g., 2005.00)
  - Otherwise can NOT be at accuracy stated
  - May not be able to accurately transform to NAD 83

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
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

Datum (geographic) transformations in Esri software

ArcGIS 10.3.1 documentation (for 10.1, dated Mar 2012)

- **1368 datum (geographic) transformations**
  - **886 involve “WGS 84”**
  - **115 involve “NAD 83”**
  - **26 between “NAD 83” and “WGS 84”**
  - ***And transformations can be combined for even more!***

Where is the Esri documentation?

- **C:\Program Files (x86)\ArcGIS\Desktop10.3\Documentation**
  - **“geographic_coordinate_systems.pdf”**
  - **“geographic_transformations.pdf”**

Back to our good friends “WGS 84” and “NAD 83”

- Geospatially empower yourself!
  - You are not helpless!
  - You are not a victim!
- You CAN check the transformations
  - NAD 83 is defined by NGS
  - NAD 83 formally related to IGS08 (= “current” WGS 84)
  - Current WGS 84 defined as equivalent to ITRF2008
  - IGS08 functionally equivalent to ITRF2008
- Can use NGS control to check transformation

How to check “WGS 84” ß à “NAD 83”
Consider NGS CORS “POINT LOMA 5” (PLO5)

- NGS Datasheets
  - Gives NAD 83 (2011) epoch 2010.00
  - Use HTDP to transform to WGS 84/ITRF2008/IGS08
- NGS CORS
  - Gives NAD 83 (2011) epoch 2010.00
  - Gives IGS08 = ITRF2008 = WGS 84 (G1674/G1762) at epoch 2005.00
- NGS OPUS
  - Gives NAD 83 (2011) epoch 2010.00
  - Gives IGS08 = ITRF2008 = WGS 84 (G1674/G1762) at current epoch

geodesy.noaa.gov

National Geodetic Survey

Positioning America for the Future

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

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

Looking for Bench Marks?

NRC Highlights Importance of NGS Products...

Federal Geodetic Control Subcommittee

Most Popular

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

The NGS Datasheet

```
DI0894  CORS         -  This is a GPS Continuously Operating Reference Station.
DI0894  DESIGNATION -  POINT LOMA 5 CORS ARP
DI0894  CORS_ID      -  PLO5
DI0894  PID          -  DI0894
DI0894  STATE/COUNTY-  CA/SAN DIEGO
DI0894  COUNTRY      -  US
DI0894  USGS QUAD    -  POINT LOMA (1994)
DI0894
DI0894                        *CURRENT SURVEY CONTROL
DI0894  ___________________________________________________________________
DI0894* NAD 83(2011) POSITION- 32 39 55.50397(N) 117 14 34.85949(W)   ADJUSTED
DI0894* NAD 83(2011) ELLIP HT-   -21.774 (meters)        (08/??/11)   ADJUSTED
DI0894* NAD 83(2011) EPOCH   -  2010.00
DI0894* NAVD 88 ORTHO HEIGHT -          **(meters)           **(feet)
DI0894  ___________________________________________________________________
DI0894  NAD 83(2011) X  - -2,460,295.155 (meters)                     COMP
DI0894  NAD 83(2011) Y  - -4,778,388.922 (meters)                     COMP
DI0894  NAD 83(2011) Z  -  3,422,768.630 (meters)                     COMP
DI0894  GEOID HEIGHT    -        -35.51  (meters)                     GEOID12B
DI0894
DI0894  Network accuracy estimates per FGDC Geospatial Positioning Accuracy
DI0894  Standards:
DI0894         FGDC (95% conf, cm)     Standard deviation (cm)     CorrNE
DI0894            Horiz  Ellip           SD_N   SD_E   SD_h      (unitless)
DI0894  ------------------------------------------------------------------
DI0894  NETWORK    0.95   3.23           0.41   0.37   1.65      0.00694412
DI0894  ------------------------------------------------------------------
```

CORS coordinate sheet

```
|          Antenna Reference Point(ARP): POINT LOMA 5 CORS ARP                |
|          ---------------------------------------------------                |
|                              PID = DI0894                                   |
|                                                                             |
| IGS08 POSITION (EPOCH 2005.0)                                               |
| Computed in Aug 2011 using data through gpswk 1631.                         |
|     X =  -2460295.762 m      latitude    =  32 39 55.51335 N                |
|     Y =  -4778387.728 m      longitude   = 117 14 34.90119 W                |
|     Z =   3422768.470 m      ellipsoid height =  -22.520   m                |
|                                                                             |
| IGS08 VELOCITY                                                              |
| Computed in Aug 2011 using data through gpswk 1631.                         |
|     VX =  -0.0299 m/yr       northward =   0.0193 m/yr                      |
|     VY =   0.0287 m/yr       eastward  =  -0.0397 m/yr                      |
|     VZ =   0.0154 m/yr       upward    =  -0.0016 m/yr                      |
|                                                                             |
| NAD_83 (2011) POSITION (EPOCH 2010.0)                                       |
| Transformed from IGS08 (epoch 2005.0) position in Aug 2011.                 |
|     X =  -2460295.155 m      latitude    =  32 39 55.50397 N                |
|     Y =  -4778388.922 m      longitude   = 117 14 34.85949 W                |
|     Z =   3422768.630 m      ellipsoid height =  -21.774   m                |
|                                                                             |
| NAD_83 (2011) VELOCITY                                                      |
| Transformed from IGS08 velocity in Aug 2011.                                |
|     VX =  -0.0151 m/yr       northward =   0.0307 m/yr                      |
|     VY =   0.0291 m/yr       eastward  =  -0.0267 m/yr                      |
|     VZ =   0.0243 m/yr       upward    =  -0.0028 m/yr                      |
```

Online Positioning User Service Solution

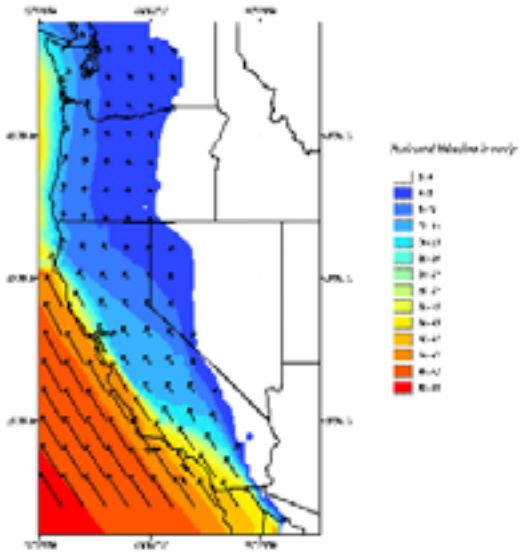
```
                    NGS OPUS SOLUTION REPORT
                    ========================

All computed coordinate accuracies are listed as peak-to-peak values.
For additional information: http://www.ngs.noaa.gov/OPUS/about.jsp#accuracy


      USER: mld@geodetic.xyz                          DATE: July 03, 2015
RINEX FILE: plo5152a.15o                              TIME: 16:37:34 UTC

  SOFTWARE: page5  1209.04 master53.pl 022814       START: 2015/06/01  00:00:00
 EPHEMERIS: igs18471.eph [precise]                   STOP: 2015/06/01  08:00:00
  NAV FILE: brdc1520.15n                         OBS USED: 19863 / 20594   :  96%
  ANT NAME: TRM41249USCG    SCIT              # FIXED AMB:    82 /    89   :  92%
ARP HEIGHT: 0.000                               OVERALL RMS: 0.009(m)

 REF FRAME: NAD_83(2011)(EPOCH:2010.0000)          IGS08 (EPOCH:2015.4142)

         X:     -2460295.149(m)   0.011(m)        -2460296.081(m)   0.011(m)
         Y:     -4778388.929(m)   0.002(m)        -4778387.433(m)   0.002(m)
         Z:      3422768.628(m)   0.011(m)         3422768.633(m)   0.011(m)

       LAT:   32 39 55.50387      0.008(m)       32 39 55.51983      0.008(m)
     E LON:  242 45 25.14083      0.010(m)      242 45 25.08274      0.010(m)
     W LON:  117 14 34.85917      0.010(m)      117 14 34.91726      0.010(m)
    EL HGT:          -21.772(m)   0.009(m)             -22.530(m)   0.009(m)
 ORTHO HGT:           13.733(m)   0.027(m) [NAVD88 (Computed using GEOID12B)]
```

The NGS Geodetic Toolkit

Horizontal Time Dependent Positioning

Geodetic Toolkit: HTDP

HTDP - Horizontal Time Dependent Positioning



Horizontal velocities across the western United States. Colors specify speed in mm/yr and arrows specify corresponding directions of motion relative to the North American Datum of 1983.

The HTDP software enables users to predict horizontal displacements and/or horizontal velocities related to crustal motion in the United States and its territories. The software also enables users to update positional coordinates and/or geodetic observations to a user-specified date. HTDP supports these activities for coordinates in the North American Datum of 1983 (NAD_83) as well as in all official realizations of the International Terrestrial Reference System (ITRS),and all official realizations of the World Geodetic System of 1984 (WGS_84). Hence this software may be used to transform geodetic coordinates between any pair of these reference frames in a manner that rigorously addresses differences among the definitions of their respective velocity fields.

Geodetic Toolkit: HTDP

HTDP - Horizontal Time-Dependent Positioning

HTDP is a utility that allows users to transform positional coordinates across time and between spatial reference frames.

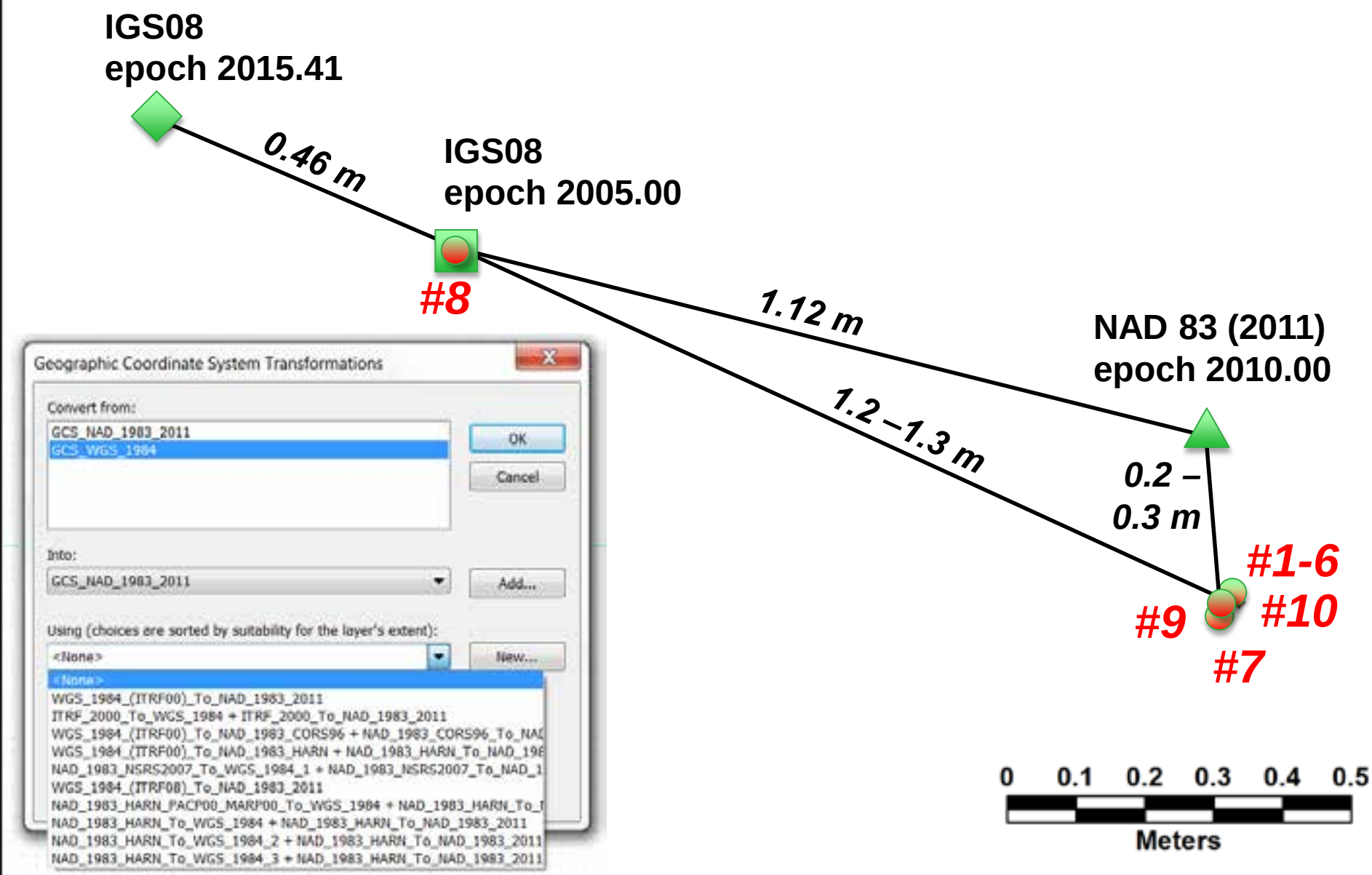
Interactive Computations (using HTDP version 3.2.3):

- Interactively estimate horizontal velocities.
- Interactively estimate horizontal displacements between two dates.
- Interactively update positions and/or observations to a specified date.
- Interactively transform positions between reference frames and/or dates.
- Interactively transform velocities between reference frames.

More Info:

- View User's Guide [**pdf format**] and/or Revision Log [**pdf format**]
- Download a Zip'ed (md5 813d003503a5dc680c9b2483576fd2b7) archive of the HTDP Fortran-90 source code, the User's Guide, Revision Log, and some sample data files
- This archive also contains the HTDP executable code, which should work on most computers having a recent Windows operating system.
- Relevant publications

Transformations from “WGS 84” à “NAD 83”
Station “POINT LOMA 5”



Where can you find these transformations?

www.geodesy.noaa.gov/CORS/coords.shtml

IGS08 --> NAD 83 (2011)
[12 common points]
$t_0 = 1997.0$

$T_x(t_0) = 0.99343$ m; $T_y(t_0) = -1.90331$m; $T_z(t_0) = -0.52655$ m
$\varepsilon_x(t_0) = 25.91467$ mas; $\varepsilon_y(t_0) = 9.42645$ mas; $\varepsilon_z(t_0) = 11.59935$ mas
$s(t_0) = 1.71504 \cdot 10^{-9}$ (unitless)
$\dot{T}_x = 0.00079$ m · year^{-1}; $\dot{T}_y = -0.00060$ m · year^{-1}; $\dot{T}_z = -0.00134$ m · year^{-1}
$\dot{\varepsilon}_x = 0.06667$ mas · year^{-1}; $\dot{\varepsilon}_y = -0.75744$ mas · year^{-1}; $\dot{\varepsilon}_z = -0.05133$ mas · year^{-1}
$\dot{s} = -0.10201 \cdot 10^{-9}$ year^{-1}

IGS08 --> NAD 83 (PA11)
$t_0 = 1997.0$

$T_x(t_0) = 0.9080$ m; $T_y(t_0) = -2.0161$ m; $T_z(t_0) = -0.5653$ m
$\varepsilon_x(t_0) = 27.741$ mas; $\varepsilon_y(t_0) = 13.469$ mas; $\varepsilon_z(t_0) = 2.712$ mas
$s(t_0) = 1.10 \cdot 10^{-9}$ (unitless)
$\dot{T}_x = 0.0001$ m · year^{-1}; $\dot{T}_y = 0.0001$ m · year^{-1}; $\dot{T}_z = -0.0018$ m · year^{-1}
$\dot{\varepsilon}_x = -0.384$ mas · year^{-1}; $\dot{\varepsilon}_y = 1.007$ mas · year^{-1}; $\dot{\varepsilon}_z = -2.186$ mas · year^{-1}
$\dot{s} = 0.08 \cdot 10^{-9}$ year^{-1}

IGS08 --> NAD 83 (MA11)
$t_0 = 1997.0$

$T_x(t_0) = 0.9080$ m; $T_y(t_0) = -2.0161$ m; $T_z(t_0) = -0.5653$ m
$\varepsilon_x(t_0) = 28.971$ mas; $\varepsilon_y(t_0) = 10.420$ mas; $\varepsilon_z(t_0) = 8.928$ mas
$s(t_0) = 1.10 \cdot 10^{-9}$ (unitless)
$\dot{T}_x = 0.0001$ m · year^{-1}; $\dot{T}_y = -0.0001$ m · year^{-1}; $\dot{T}_z = -0.0018$ m · year^{-1}
$\dot{\varepsilon}_x = -0.020$ mas · year^{-1}; $\dot{\varepsilon}_y = 0.105$ mas · year^{-1}; $\dot{\varepsilon}_z = -0.347$ mas · year^{-1}
$\dot{s} = 0.08 \cdot 10^{-9}$ year^{-1}

Read the bottom of the webpage!

Transformation Parameters are applied using the equations shown below to transform from IGS08 to the various NAD 83

WARNING and RECOMMENDATION:

Because the Earth's crust does not behave as a perfect rigid body, e.g earthquakes, models for crustal deformation are needed, especially in California and Alaska. Therefore the equations written below DO NOT account for a rigorous transformation. NGS **strongly recommends** that to obtain an accurate transformation between frames users use **HTDP software** which combines the transformation parameters and deformation models.

$$x_{NAD\,83}(t) = T_x(t) + [1+s(t)] \cdot x_{IGS08}(t) + \omega_z(t) \cdot y_{IGS08}(t) - \omega_y(t) \cdot z_{IGS08}(t)$$
$$y_{NAD\,83}(t) = T_y(t) - \omega_z(t) \cdot x_{IGS08}(t) + [1+s(t)] \cdot y_{IGS08}(t) + \omega_x(t) \cdot z_{IGS08}(t)$$
$$z_{NAD\,83}(t) = T_z(t) + \omega_y(t) \cdot x_{IGS08}(t) - \omega_x(t) \cdot y_{IGS08}(t) + [1+s(t)] \cdot z_{IGS08}(t)$$

$$T_x(t) = T_x(t_0) + \dot{T}_x \cdot (t-t_0)$$
$$T_y(t) = T_y(t_0) + \dot{T}_y \cdot (t-t_0)$$
$$T_z(t) = T_z(t_0) + \dot{T}_z \cdot (t-t_0)$$
$$\omega_x(t) = [\varepsilon_x(t_0) + \dot{\varepsilon}_x \cdot (t-t_0)] \cdot m_r$$
$$\omega_y(t) = [\varepsilon_y(t_0) + \dot{\varepsilon}_y \cdot (t-t_0)] \cdot m_r$$
$$\omega_z(t) = [\varepsilon_z(t_0) + \dot{\varepsilon}_z \cdot (t-t_0)] \cdot m_r$$
$$s(t) = s(t_0) + \dot{s} \cdot (t-t_0)$$

$m_r = 4.84813681 \times 10^{-9}$, conversion factor from milli-arcseconds (mas) to radians

$\varepsilon_x(t_0)$, $\varepsilon_y(t_0)$, and $\varepsilon_z(t_0)$ are differential rotations about the x_{IGS08}, y_{IGS08}, and z_{IGS08} axes respectively.

The sense of the rotations is counterclockwise (anticlockwise) positive.

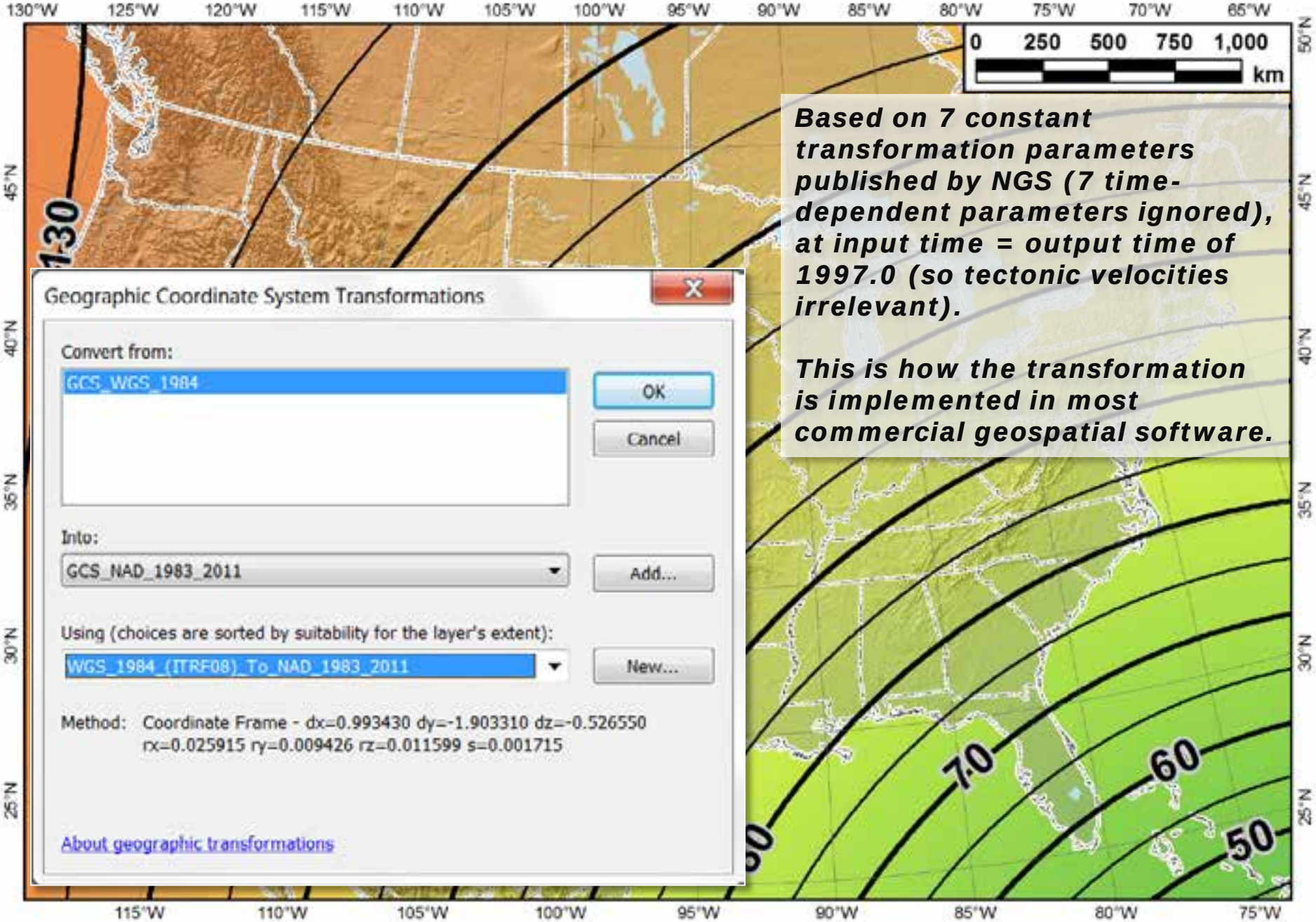
t_0 is the epoch at which the 7 transformation parameters are given.

Note.- The equations given above serve to transform IGS08 positional coordinates (x_{IGS08}, y_{IGS08}, z_{IGS08}) whose epoch date is at time t to NAD 83 positional coordinates ($x_{NAD\,83}$, $y_{NAD\,83}$, $z_{NAD\,83}$) for this same epoch date.

Positional coordinates for a different epoch date (and for a particular reference frame) can only be obtained by knowing the velocity of the point in this reference frame.

For example, if the IGS positional coordinates are given at a different epoch t' ≠ t, their positions should be updated to epoch t using the HTDP software. For more information about the implementation of these equations consult the following article Soler and Snay, 2004.

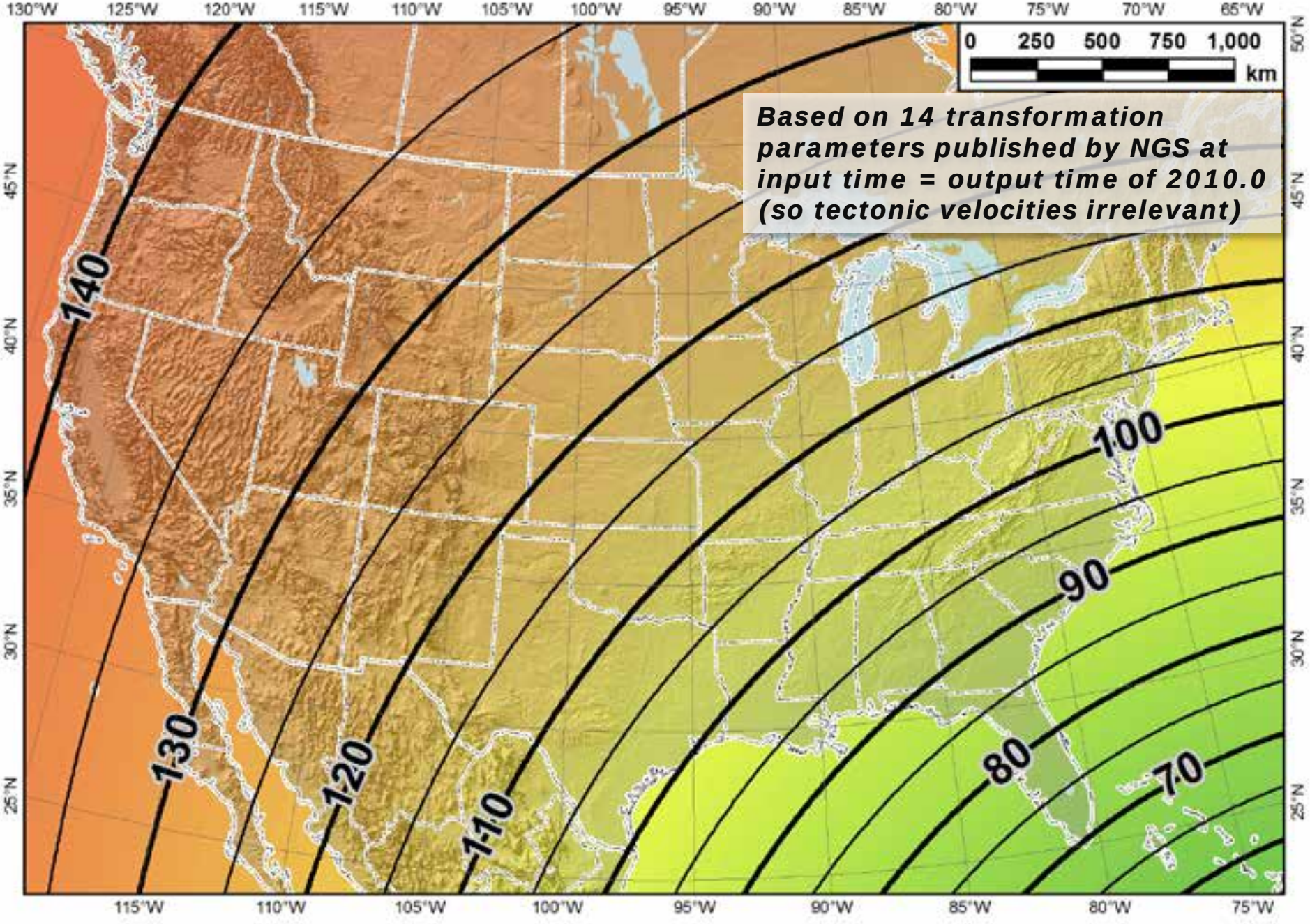
Horizontal shift from WGS 84 (G1762) epoch 1997.00 to NAD 83(2011) epoch 1997.00 (cm)



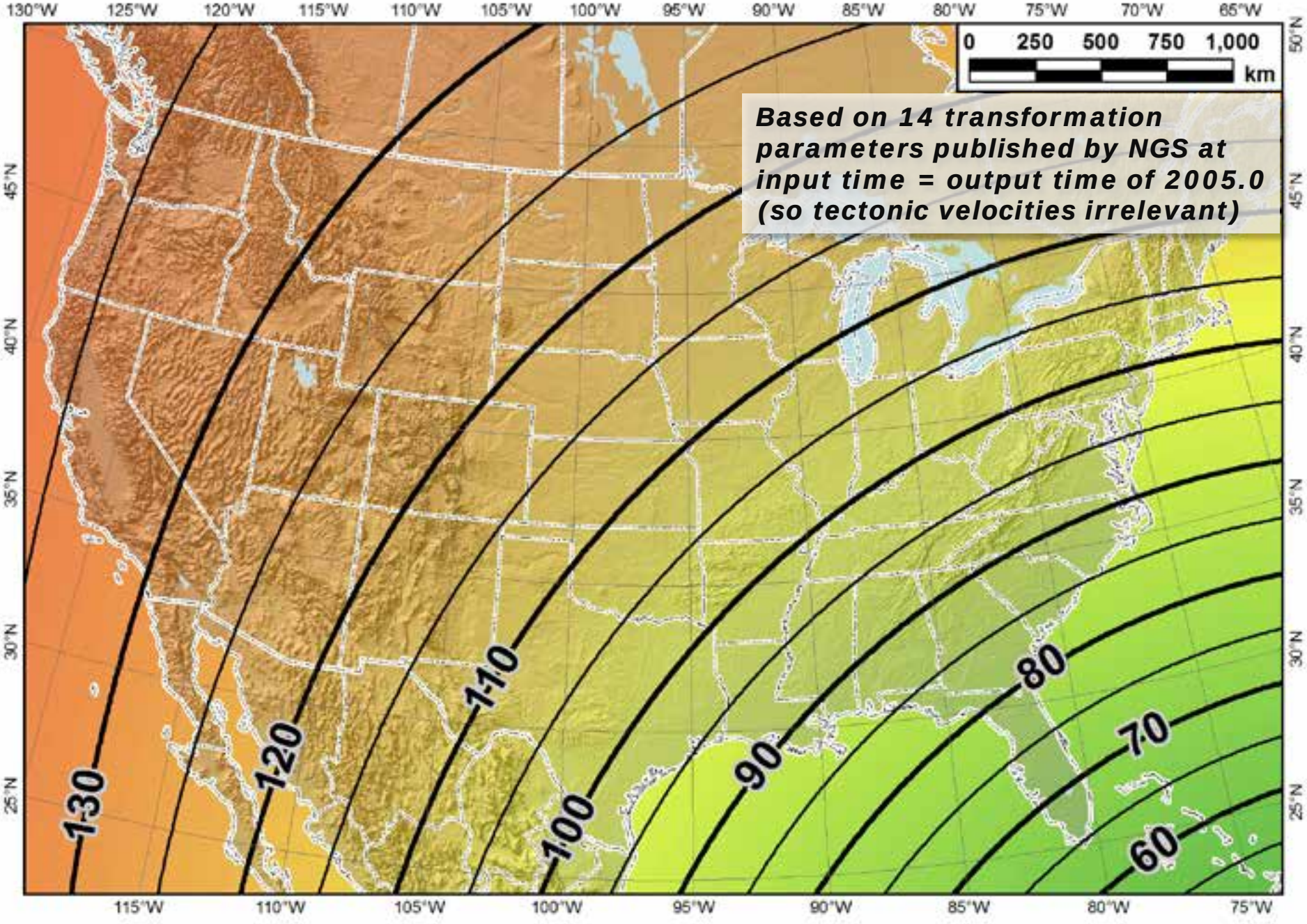
Based on 7 constant transformation parameters published by NGS (7 time-dependent parameters ignored), at input time = output time of 1997.0 (so tectonic velocities irrelevant).

This is how the transformation is implemented in most commercial geospatial software.

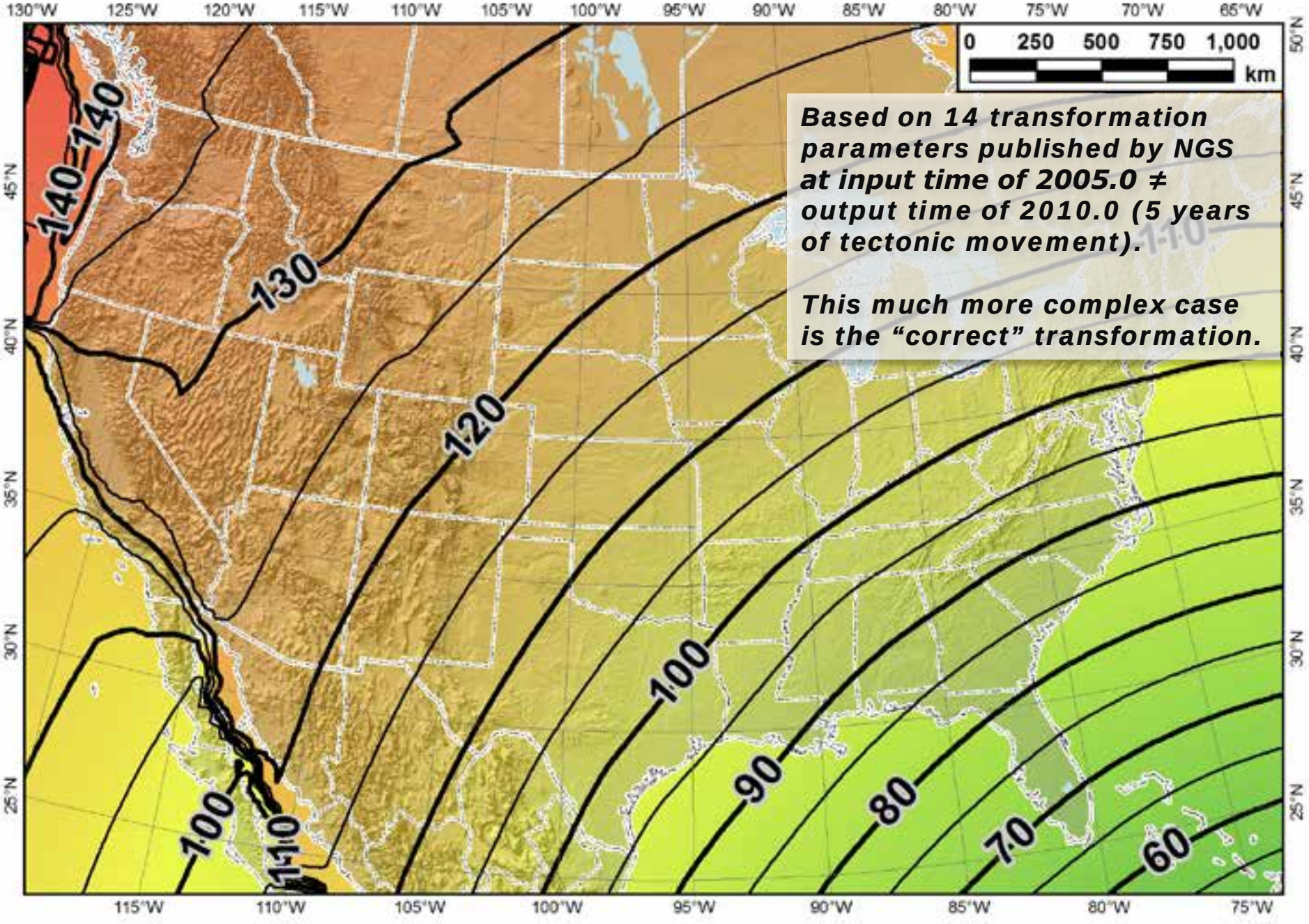
Horizontal shift from WGS 84 (G1762) epoch 2010.00 to NAD 83(2011) epoch 2010.00 (cm)



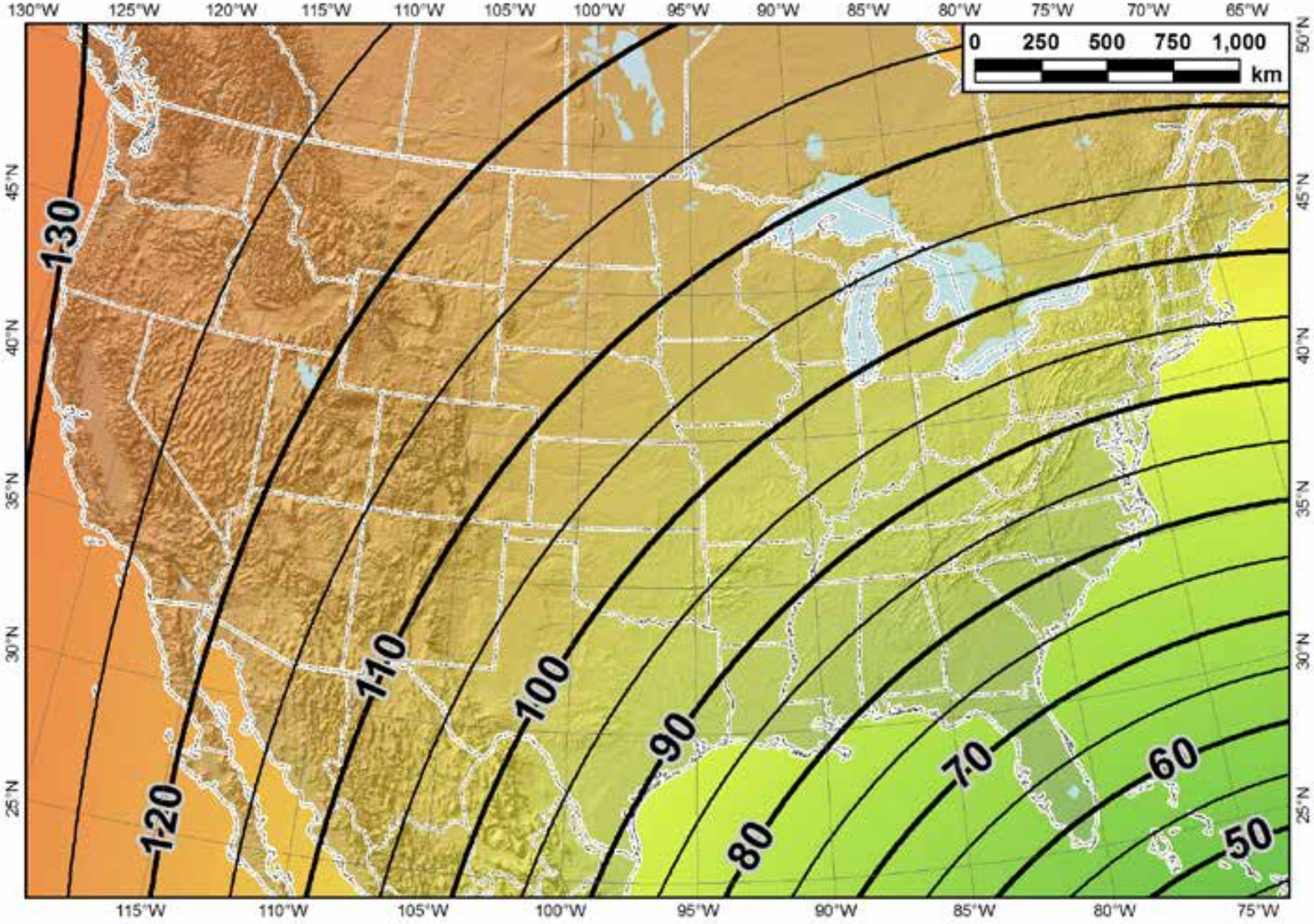
Horizontal shift from WGS 84 (G1762) epoch 2005.00 to NAD 83(2011) epoch 2005.00 (cm)



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

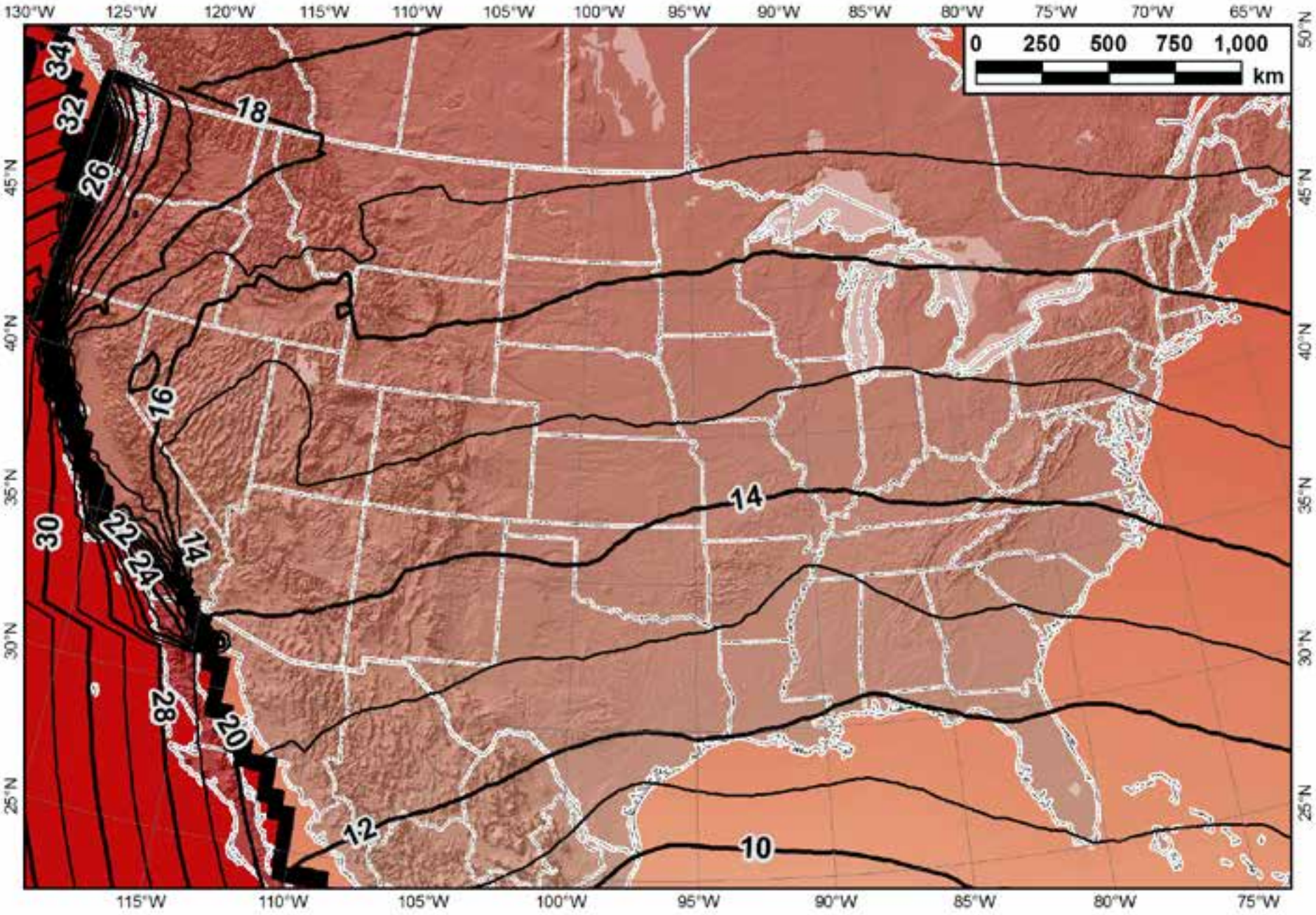


Horizontal shift from WGS 84 (G1762) epoch 1997.00 to NAD 83(2011) epoch 1997.00 (cm)



Horizontal error (cm) of IGS08 to NAD 83 (2011) transformation if epoch 1997.00 used for both frames

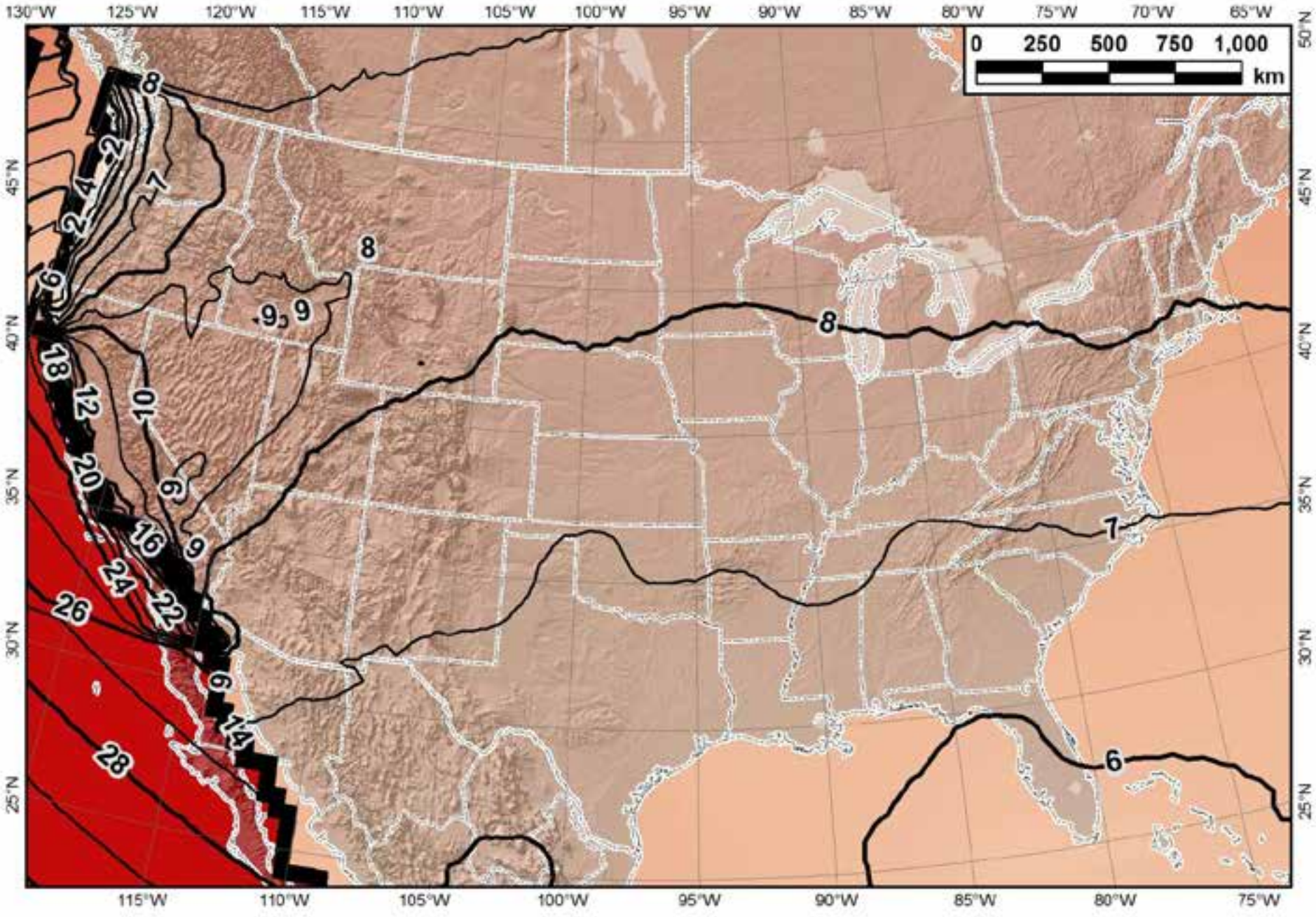
with respect to the transformation IGS08 epoch 2005.00 to NAD 83 (2011) epoch 2010.00 (per HTDP v3.2.3)



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

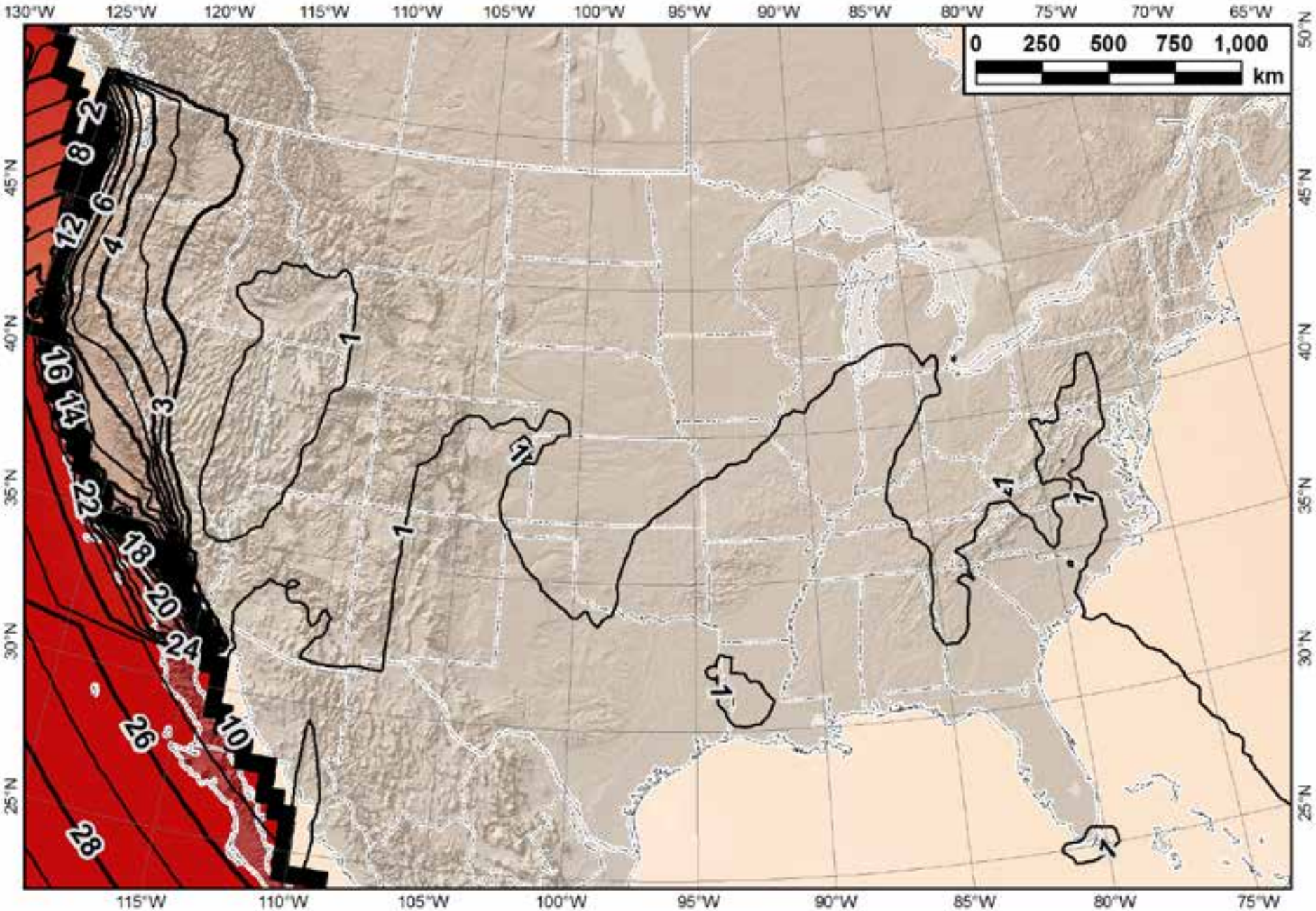
- **<u>Esri</u>: "WGS_1984_(ITRF08)_To_NAD_1983_2011" (WKID 108363)**
  - *NOT* "WGS_1984_(ITRF00)_To_NAD_1983_2011", or the 25 other NAD 83 ß à WGS 84 transformations in ArcGIS 10.x
- **Trimble: "ITRF to NAD 1983 (2011)"**

Horizontal error (cm) of IGS08 to NAD 83 (2011) transformation if epoch 2010.00 used for both frames
with respect to the transformation IGS08 epoch 2005.00 to NAD 83 (2011) epoch 2010.00 (per HTDP v3.2.3)



Horizontal error (cm) of IGS08 to NAD 83 (2011) transformation if epoch 2005.00 used for both frames

with respect to the transformation IGS08 epoch 2005.00 to NAD 83 (2011) epoch 2010.00 (per HTDP v3.2.3)



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 transformation method will you use?
  - What is the accuracy of the transformation?
  - What if there are several to choose from?
- Are there temporal issues?
  - What is the date (epoch) of the input and output data?
  - How do you know the epoch?
- Are you *really* sure you want to do this?

Does this stuff really matter?

- Significant for accuracies better than ~2 m
  - Requires understanding of modern datums
- Be careful when using “WGS 84”
  - Which realization? At what epoch? At what accuracy?
  - Just because it comes from GPS does *NOT* mean it’s “WGS 84”
- Things are moving, and it can make a difference
  - e.g., San Diego moving 4.0 cm/yr NW w.r.t. Phoenix, AZ
- What if the US Supreme Court said the data was in WGS 84?

Where do we go from here?

- Modern GNSS becoming more *precise*
  - Autonomous positions soon better than 1 m
  - Many position services now at cm precision
- But *accuracy* another issue…
  - With respect to what? And at what point in time?
- Standardization is needed
  - Solutions are regional (e.g., HTDP is for US only)
  - No agreement yet on global models

Conclusions

- **Be VERY careful with datum transformations**
  - **Know what you have first**
  - **Understand limitations**
  - **Metadata may not be correct**
  - **Check if at all possible**
  - **Avoid if you can**
- **Your data likely NOT "WGS 84" at cm accuracy**
  - **GPS source does NOT mean it's WGS 84**
  - **Date of data may not equal epoch of data**
- **"Precision" may NOT equal "accuracy"**
  - **What good is cm precision if offset from other data by 2 m?**
  - **Transformations can degrade accuracy**