HTDP User Guide
(Software Version 3.6.0)
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Web: https://geodesy.noaa.gov/TOOLS/Htdp/Htdp.shtml
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1. Introduction

HTDP (Horizontal Time-Dependent Positioning) is a software application that allows users to transform positional coordinates across time and between spatial reference frames. HTDP enables users to perform each of the following functions:

- Estimate horizontal crustal velocities.
- Estimate crustal displacements between two specified dates.
- Update (or backdate) positional coordinates from one date to another.
- Transform coordinates from one reference frame to another and/or from one date to another.
- Transform certain types of geodetic observations from one reference frame to another and/or from one date to another.
- Transform crustal velocities from one reference frame to another.

The program supports the above functions for all three frames of the North American Datum of 1983 (NAD 83) referenced to the North America, Pacific, and Mariana tectonic plates. HTDP also supports all official realizations of the International Terrestrial Reference System (ITRS) (Petit and Luzum 2010), as well as all official realizations of the World Geodetic System 1984 (WGS 84) (National Geospatial-Intelligence Agency (NGA) 2014, True 2004).

HTDP can be run interactively online at https://geodesy.noaa.gov/TOOLS/Htdp/Htdp.shtml. The PC executable htdp.exe and all source code files can also be downloaded from this web site, and from the GitHub site at https://github.com/noaa-ngs/HTDP. The source code is in Fortran 90 and consists of the main program htdp.f, plus four subprograms (initbd.f, initeq.f, initps.f, and initvl.f) containing crustal motion and earthquake model datasets that are integrated into htdp.exe when the program is compiled. The htdp.exe file can be run directly on a PC through a Microsoft Windows command interface (cmd.exe).

The HTDP and GitHub web sites also contain:

- The latest version of this HTDP User Guide, including instructional exercises.
- Sample data files for use with the instructional exercises.
- A log file summarizing revisions to HTDP in reverse chronological order.
- Several crustal motion maps.
- GIS dataset (shapefile) of tectonic plate polygons used in HTDP.
- A link to relevant publications.

2. Estimating Horizontal Crustal Velocities

HTDP quantifies crustal motion in terms of:

- Constant interseismic horizontal velocities.
- Coseismic motion, i.e., abrupt changes in positional coordinates, each of which happens within a few minutes of an earthquake.

- Postseismic motion, i.e., the transient motion following an earthquake which—depending on the earthquake's magnitude—may remain geodetically measurable from as short as a few days to as long as several decades.

Other types of crustal motion—such as periodic motion—exist, but the current version of HTDP does not address these other types.

To quantify constant interseismic velocities, HTDP incorporates two types of regions. For the first type, HTDP employs a 2D rectangular grid (in latitude and longitude) spanning an area for which velocities at the grid nodes have been previously determined from geodetic and geophysical data. With this type of region, HTDP uses bilinear interpolation to compute the 2D velocity at a user-specified location by using the stored 2D velocities for the grid nodes, in particular, the four grid nodes at the corners of the 2D grid cell containing this location. Table 1 lists the ten regions of this type and provides pertinent information about these regions. The locations of these velocity grids are shown in Figure 1 (note that the St. Elias, Alaska, region is defined by a polygon that excludes the northwest portion of the rectangular envelope given in Table 1). The complete set of polygon vertices for all velocity grids (and tectonic plates) is given in file initbd.f included with the HTDP source code available for download. All velocity grids in HTDP currently give horizontal velocities only, with respect to ITRF2008.

If a point falls outside all of the velocity grids, HTDP uses the second type of region. This type consists of rigid tectonic plate models that cover the entire Earth and are used to estimate horizontal velocities via the equations

$$
\begin{aligned}
V_x &= \dot{T}_x + \dot{R}_y\, z - \dot{R}_z\, y \\
V_y &= \dot{T}_y + \dot{R}_z\, x - \dot{R}_x\, z \\
V_z &= \dot{T}_z + \dot{R}_x\, y - \dot{R}_y\, x\ . \qquad (2.1)
\end{aligned}
$$

Here (x, y, z) denote Earth-centered, Earth-fixed (ECEF) Cartesian coordinates for a user-specified location; (V_x, V_y, V_z) denote the ECEF velocity components at this location; $(\dot{R}_x, \dot{R}_y, \dot{R}_z)$ denote the rotation rates about the x-axis, the y-axis, and the z-axis, respectively; and $(\dot{T}_x, \dot{T}_y, \dot{T}_z)$ denote the translation rates along these three axes (which are usually zero). When the coordinates are expressed in meters and the rotation rates in radians per year, then the computed velocities will be expressed in meters per year. Note that vertical velocities equal zero for locations within this type of region. Table 2 lists the 52 tectonic plates as currently defined in HTDP, their rotation rates, and the sources for the rotation rates (the rotation rates given are the exact values used by HTDP, to 5 decimal places in nanoradians per year). Non-zero translation rates are only used for the first three plates listed, as indicated in the table for the North America, Pacific, and Caribbean plates (the translation rates for these plates are given in the Table 2 footnotes).

The first four plates in Table 2 encompass nearly the entire National Spatial Reference System (NSRS). All but one (the Caribbean plate) are also used as plate-fixed references for the three NAD 83 frames (the Caribbean plate will also be a plate-fixed reference for the Modernized NSRS; see NGS 2021). The definitions of these four plates have not been updated in the current version of HTDP, to maintain consistency with earlier versions of HTDP. These four plates (plus others) have been defined in previous versions of HTDP. Most of the other plates were added in HTDP v3.4.0 to achieve global coverage.

Three of the plates that were in HTDP prior to v3.3.0 had their rotation rates updated to ITRF2014, but they cover only offshore areas (the Cocos, Juan de Fuca, and Philippine Sea plates).

Table 1. The ten velocity grids defined in the current version of HTDP.

Region	HTDP region number	Latitude range	Longitude range	Node spacing (minutes)	Reference
San Andreas	1	35.8°N - 36.79N	120.51°W - 121.8°W	0.60	Pearson and Snay (2013) for horizontal velocities; vertical velocities have been set equal to 0.0 mm/yr relative to ITRF2008.
Southern California	2	31°N - 36°N	114°W - 121°W	3.75	
Northern California	3	36°N - 40°N	119°W - 125°W	3.75	
Pacific Northwest	4	40°N - 49°N	122°W - 125°W	3.75	
Western CONUS	5	31°N - 49°N	107°W - 125°W	15.0	
Eastern CONUS	6	24°N - 50°N	66°W - 110°W	30.0	Snay et al. (2013) for horizontal velocities; vertical velocities have been set equal to 0.0 mm/yr relative to ITRF2008.
St. Elias, Alaska [a]	7	56.5°N - 63°N	140°W - 148°W	15.0	
South-central Alaska	8	53.25°N - 65.75°N	143.25° - 162°W	15.0	
Southeast Alaska	9	54°N - 63°N	130°W - 142°W	15.0	
All mainland Alaska	10	56°N - 73°N	130°W - 170°W	15.0	

[a] St. Elias grid is defined by a polygon the excludes the northwest portion of the rectangular envelope (see Figure 1).

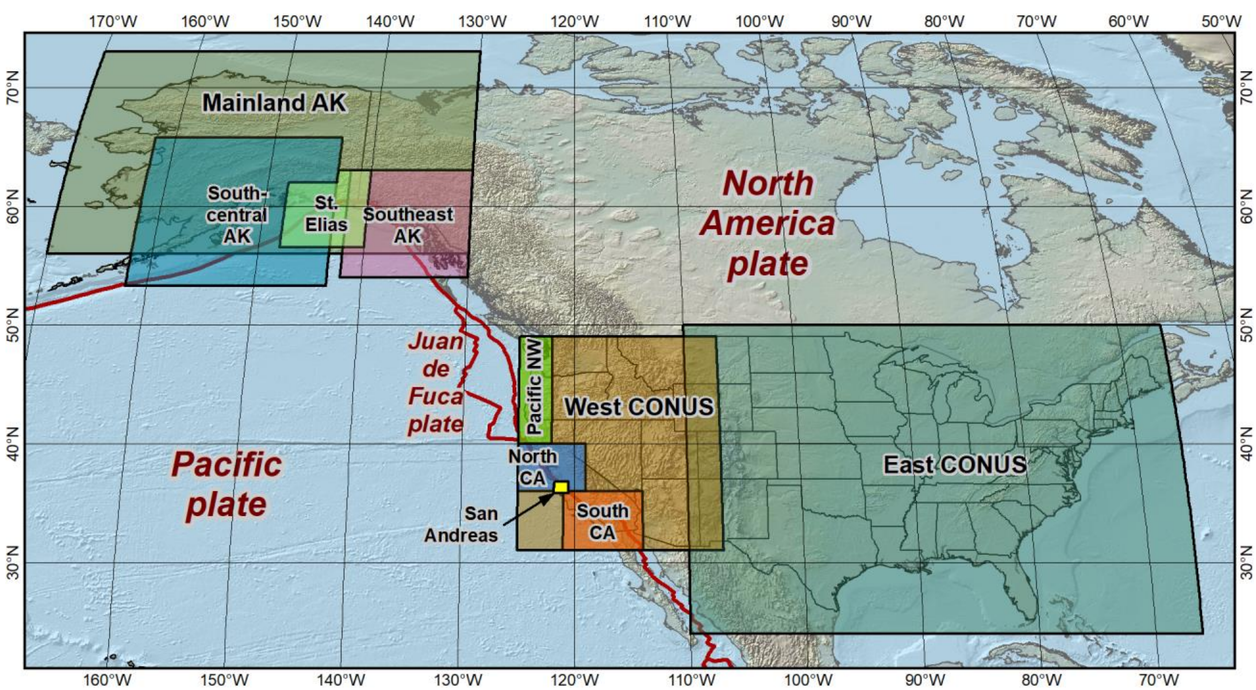

Figure 1. Extents of the ten velocity grids encoded in HTDP, along with tectonic plates.

Most plate rotation rates in HTDP are with respect to ITRF2014, except for the Mariana plate (ITRF2000) and the first three plates referenced to ITRF2008. Rates that are defined with respect to frames other than ITRF2008 are converted to ITRF2008 velocities within HTDP. This conversion is done to maintain consistency with the ITRF2008 velocity grids.

Plates added to or redefined in HTDP v3.4.0 are sorted alphabetically in Table 2 by name within the plate type groupings of primary, secondary, and tertiary (sometimes called “major”, “minor”, and “micro”). There is not complete agreement among researchers on the plate types, or even their names, much less their number and extent. So the plate types assigned here are interpretations of classifications by others, although no single source was used for assigning types. The tectonic plate names and polygons used in HTDP are based on those of Bird (2003), as provided by Ahlenius (2014). Minor topological corrections were made to the polygons to eliminate gaps and overlaps, as well as duplicated and superfluous vertices. Figure 2 is a map showing the plates currently encoded in HTDP. Figure 3 is a larger scale map of the southwest Pacific region, which has many small plates. A file of the plate polygons is available for download, in shapefile format.

The gridded regions and tectonic plates are ordered by region number shown in Tables 1 and 2 (regions 11-13 are omitted because they are placeholders for future velocity grids). Velocity grids all precede the tectonic plates (i.e., have a smaller region number). When a user specifies a location, HTDP steps through the regions sequentially until it finds the first region that contains the specified location. It then uses the model for this region to estimate the velocity at the location. Thus HTDP will only use a rigid tectonic plate model at locations where velocity grids do not exist.

When using HTDP to estimate velocities at a collection of locations, users can interactively provide coordinates for the locations one at a time, or they can submit them in an ASCII file. The types of coordinates and formats accepted by HTDP are described during the execution of the HTDP utility (and later in this document, as well as in the example exercises). Users can also specify a 2D grid in latitude and longitude and ask HTDP to estimate velocities at the nodes of this grid. In addition, users can define a line (actually a geodesic on an ellipsoidal representation of the Earth) and ask HTDP to estimate velocities at equally spaced locations along this line (geodesic).

The reference frame must be specified when providing positional coordinates to HTDP. The HTDP-estimated velocities will then also be referred to this frame. Section 7 of this document describes how to use HTDP to transform an estimated velocity to a different reference frame.

3. Estimating Crustal Displacements

HTDP can be used to estimate the crustal displacement at a specified location from time t_1 to time t_2. The estimated displacement equals the velocity at this location multiplied by the time difference ($t_2 - t_1$) plus all coseismic and postseismic motion that has occurred between these two times. Users can opt to allow HTDP to estimate the velocity used in this procedure, or they may interactively supply the velocity.

Table 2. Tectonic plates and their motion rates encoded in HTDP. Rotation rates are positive counterclockwise, in nanoradians per year (nrad/yr).

Tectonic plate name	Plate type	Percent Earth area	HTDP region num	Reference frame [a]	Plate rotation rates (nrad/yr) $\dot{R}_x$	$\dot{R}_y$	$\dot{R}_z$	Source for rotation rates
North America [b]	Primary	10.867%	14	ITRF2008	0.17000	-3.20900	-0.48500	Altamimi et al. 2012
Pacific [b]	Primary	20.506%	15	ITRF2008	-1.99300	5.02300	-10.50100	Altamimi et al. 2012
Caribbean [b]	Secondary	0.581%	16	ITRF2008	0.23800	-5.27500	3.21900	Altamimi et al. 2012
Mariana	Tertiary	0.083%	17	ITRF2000	-0.09700	0.50900	-1.68200	Snay 2003a
Most of the following plate definitions were added to HTDP v3.4.0. All that were included prior to HTDP v3.3.0 had their rates updated to ITRF2014.								
Africa (Nubia)	Primary	11.464%	18	ITRF2014	0.47997	-2.97676	3.55368	Altamimi et al. 2017
Antarctica	Primary	11.401%	19	ITRF2014	-1.20234	-1.57080	3.27249	Altamimi et al. 2017
Australia	Primary	9.016%	20	ITRF2014	7.32069	5.73050	5.89049	Altamimi et al. 2017
Eurasia	Primary	9.520%	21	ITRF2014	-0.41209	-2.57436	3.73307	Altamimi et al. 2017
South America	Primary	8.200%	22	ITRF2014	-1.30900	-1.45929	-0.67874	Altamimi et al. 2017
Amur	Secondary	1.040%	23	ITRF2014	-0.68964	-2.18428	4.19822	Kreemer et al. 2014 [c]
Arabia	Secondary	0.961%	24	ITRF2014	5.59475	-0.65935	7.00071	Altamimi et al. 2017
Cocos	Secondary	0.575%	25	ITRF2014	-10.38028	-14.90060	9.13337	DeMets et al. 2010 [c]
India	Secondary	2.438%	26	ITRF2014	5.59475	-0.02424	7.04919	Altamimi et al. 2017
Juan de Fuca	Secondary	0.050%	27	ITRF2014	6.63589	11.76141	-10.62984	DeMets et al. 2010 [c]
Nazca	Secondary	3.157%	28	ITRF2014	-1.61443	-7.48552	7.86853	Altamimi et al. 2017
Philippine Sea	Secondary	1.067%	29	ITRF2014	9.22141	-4.96294	-11.55438	Kreemer et al. 2014 [c]
Scotia	Secondary	0.333%	30	ITRF2014	-0.52297	-1.79239	0.63488	DeMets et al. 2010 [c]
Somalia	Secondary	3.755%	31	ITRF2014	-0.58662	-3.84942	4.28575	Altamimi et al. 2017
Sunda	Secondary	1.748%	32	ITRF2014	-0.34003	-3.69407	4.56571	Kreemer et al. 2014 [c]
Aegean Sea	Tertiary	0.063%	33	ITRF2014	1.26854	2.71543	3.07496	Kreemer et al. 2014 [c]
Altiplano	Tertiary	0.163%	34	ITRF2014	0.05864	-8.07657	-1.65936	Lamb 2000 (in Bird 2003) [c]
Anatolia	Tertiary	0.113%	35	ITRF2014	13.71303	7.54290	13.29303	McClusky et al. 2000 (in Bird 2003) [c]
Balmoral Reef	Tertiary	0.038%	36	ITRF2014	-2.85343	2.80815	-8.00888	Bird 2003 [c]
Banda Sea	Tertiary	0.136%	37	ITRF2014	-21.10731	35.16250	-0.28835	Rangin et al. 1999 (in Bird 2003) [c]
Birds Head	Tertiary	0.103%	38	ITRF2014	-1.79893	10.23283	-9.36606	Bird 2003 [c]
Burma	Tertiary	0.101%	39	ITRF2014	9.52310	-39.44962	-3.31898	Circum-Pacific Map Project 1986 (in Bird 2003) [c]
Caroline	Tertiary	0.300%	40	ITRF2014	1.73361	1.28481	-9.56706	Seno et al. 1993 (in Bird 2003) [c]
Conway Reef	Tertiary	0.028%	41	ITRF2014	-63.15807	10.29152	-24.27100	Bird 2003 [c]

Table 2. *(continued)*

Tectonic plate name	Plate type	Percent Earth area	HTDP region num	Reference frame [a]	Plate rotation rates (nrad/yr) $\dot{R}_x$	$\dot{R}_y$	$\dot{R}_z$	Source for rotation rates
Easter	Tertiary	0.033%	42	ITRF2014	68.15282	165.61029	83.81255	Engeln and Stein 1984 (in Bird 2003) [c]
Futuna	Tertiary	0.006%	43	ITRF2014	-85.23370	2.61244	-25.43833	Bird 2003 [c]
Galapagos	Tertiary	0.003%	44	ITRF2014	14.27334	94.43957	4.51959	Lonsdale 1988 (in Bird 2003) [c]
Juan Fernandez	Tertiary	0.019%	45	ITRF2014	106.03040	304.53677	220.01253	Anderson-Fontana et al. 1986 (in Bird 2003) [c]
Kermadec	Tertiary	0.099%	46	ITRF2014	31.33555	3.26279	25.92570	Bird 2003 [c]
Manus	Tertiary	0.002%	47	ITRF2014	-779.82645	445.94761	-57.95220	Martinez and Taylor 1996 (in Bird 2003) [c]
Maoke	Tertiary	0.023%	48	ITRF2014	-0.46179	12.81479	2.92132	Bird 2003 [c]
Molucca Sea	Tertiary	0.082%	49	ITRF2014	36.24013	-53.21492	3.16382	Rangin et al. 1999 (in Bird 2003) [c]
New Hebrides	Tertiary	0.126%	50	ITRF2014	42.92984	-4.47050	0.08496	Bird 2003 [c]
Niuafo'ou	Tertiary	0.024%	51	ITRF2014	-57.32448	-5.81369	-3.72208	Zellmer and Taylor 2001 (in Bird 2003) [c]
North Andes	Tertiary	0.191%	52	ITRF2014	-1.96421	-1.51836	0.40012	Mora-Páez et al. 2018 [d]
North Bismarck	Tertiary	0.076%	53	ITRF2014	-13.09213	12.88081	-10.73837	Kreemer et al. 2014 [c]
Okhotsk	Tertiary	0.595%	54	ITRF2014	-0.27495	-3.05687	1.56236	Kreemer et al. 2014 [c]
Okinawa	Tertiary	0.064%	55	ITRF2014	-15.50125	10.47202	14.79722	Kreemer et al. 2014 [c]
Panama	Tertiary	0.054%	56	ITRF2014	2.08835	-23.03737	6.72874	Kreemer et al. 2014 [c]
Rivera	Tertiary	0.020%	57	ITRF2014	-21.93297	-70.43203	27.07095	DeMets et al. 2010 [c]
Sandwich	Tertiary	0.036%	58	ITRF2014	16.58716	-11.88078	-12.18588	DeMets et al. 2010 [c]
Shetland	Tertiary	0.014%	59	ITRF2014	-8.64703	8.85561	27.07392	Kreemer et al. 2014 [c]
Solomon Sea	Tertiary	0.025%	60	ITRF2014	-19.17916	22.26207	-1.89243	Bird 2003 [c]
South Bismarck	Tertiary	0.061%	61	ITRF2014	97.26078	-61.73877	13.80350	Kreemer et al. 2014 [c]
Timor	Tertiary	0.069%	62	ITRF2014	-11.38292	28.13885	-1.68457	Bird 2003 [c]
Tonga	Tertiary	0.050%	63	ITRF2014	137.84116	10.44750	68.45806	Kreemer et al. 2014 [c]
Woodlark	Tertiary	0.089%	64	ITRF2014	-22.45705	26.05666	-1.16558	Kreemer et al. 2014 [c]
Yangtze	Tertiary	0.432%	65	ITRF2014	-1.01317	-2.26006	5.04044	Kreemer et al. 2014 [c]

[a] Motion rates relative to frames other than ITRF2008 are converted to ITRF2008 rates by HTDP.

[b] ITRF2008 translation rates of $\dot{T}_x$ = 0.41, $\dot{T}_y$ = 0.22, and $\dot{T}_z$ = 0.41 mm/yr are also applied, per Altamimi et al. (2012).

[c] Rotation rates relative to Pacific plate converted to ITRF2014 using rates for Pacific plate relative to ITRF2014 from Altamimi et al. (2017).

[d] Rotation rates relative to South America plate converted to ITRF2014 using rates for South America plate relative to ITRF2014 from Altamimi et al. (2017).

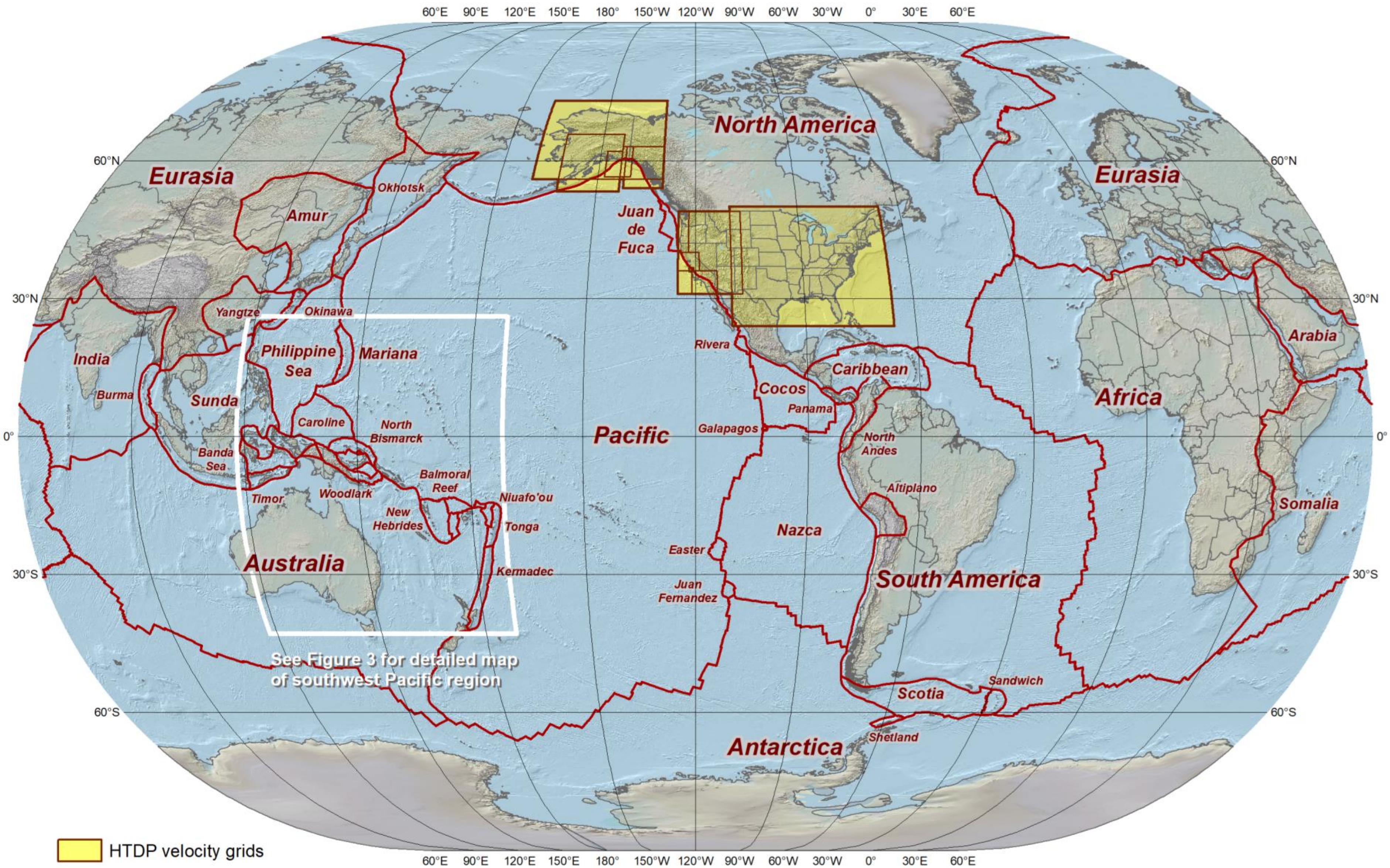

Figure 2. The 52 global tectonic plates modeled in HTDP, along with the velocity grids (see Figure 3 for a detailed map of the southwest Pacific region).

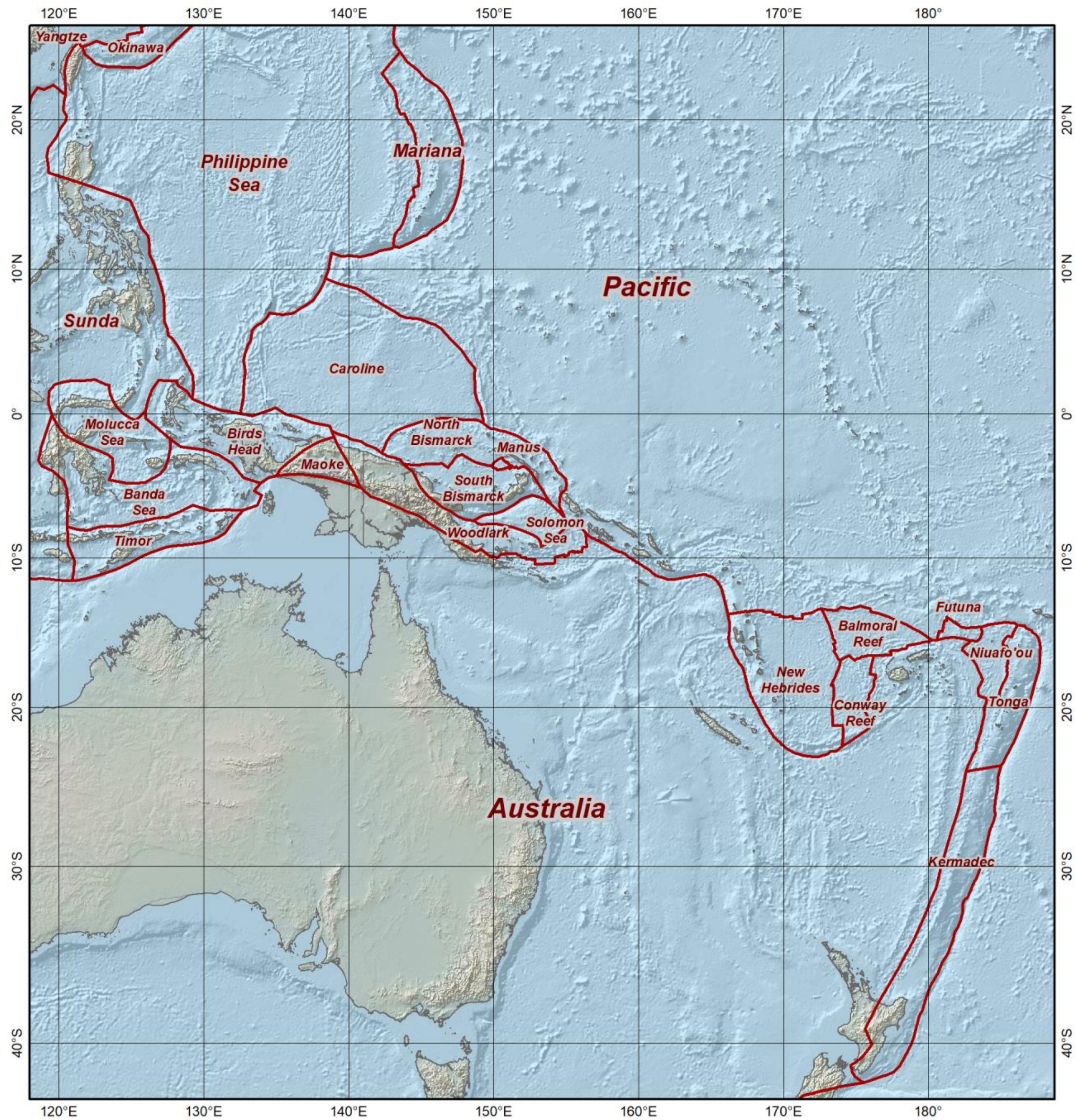

Figure 3. Tectonic plates of southwest Pacific as defined in HTDP (see Figure 2 for map of all plates).

Coseismic motion due to earthquakes is modeled in HTDP using the equations of dislocation theory (Okada 1985). Most of the major earthquakes that have occurred in and around the United States since 1934 are included. HTDP will not return results prior to 1907, because it does not include a model of the Great San Francisco Earthquake of April 18, 1906. Note that most of the earthquake models can cause a vertical change in coordinates.

Table 3 lists the earthquakes that have dislocation models encoded into the current version of HTDP. The locations of the earthquake epicenters are shown in Figure 4, with earthquakes of magnitude greater than 7 labeled. The radius of influence for each earthquake is shown by a circle centered on the epicenter. Beyond this radius, the modeled coseismic displacement is zero. Although the displacement generally decreases with distance from the epicenter, the maximum surface displacement may not occur at the epicenter.

For postseismic displacements, HTDP uses the equations

$$D_{i,j}(\varphi, \lambda, t) = A_{i,j}(\varphi, \lambda) - (1 - \exp[-(t - \tau_i) / \vartheta_i]) \qquad \text{if } \tau_i < t$$
$$D_{i,j}(\varphi, \lambda, t) = 0 \qquad \text{if } t \le \tau_i \qquad (3.1)$$

to model the cumulative motion $D_{i,j}(\varphi, \lambda, t)$ from time τ_i to time t, which is associated with earthquake i and dimension j (j = north, east, or up) and which occurred at the location with latitude φ and longitude λ. Here $A_{i,j}(\varphi, \lambda)$ equals the amplitude (in meters) associated with earthquake i and dimension j at the location with latitude φ and longitude λ; τ_i equals the time of occurrence of earthquake i; and ϑ_i equals the relaxation constant associated with earthquake i. The current version of HTDP contains a postseismic motion model for only the magnitude 7.9 Denali earthquake that occurred in central Alaska on November 3, 2002, as shown in Figure 4. This model was developed by Dr. Jeffery Freymueller of the University of Alaska, Fairbanks (Snay et al. 2013). It provides amplitudes $A_{i,j}(\varphi, \lambda)$ at the nodes of a 2D rectangular grid in latitude and longitude. HTDP uses bilinear interpolation to estimate corresponding amplitudes at other geographic locations within the grid's span. For other earthquakes, their postseismic motion has been neglected or incorporated into corresponding models for coseismic motion. For a discussion of the latter, see Pearson and Snay (2007). As with most of the coseismic models, the postseismic grid in HTDP includes a vertical displacement component.

When computing displacements, the reference frame of the positional coordinates must be specified. The displacements estimated by HTDP will be referred to this frame.

4. Updating Positional Coordinates

Within the context of HTDP, positional coordinates for a location are assumed to vary with time. Thus when specifying positional coordinates, it is necessary to also specify the time to which they refer. This time is called the *reference epoch* or *reference date*.

When updating (or backdating) positional coordinates with HTDP, the user must specify the:

- Reference frame.
- Starting positional coordinates and their reference epoch t_1.
- Reference epoch t_2 for the updated coordinates.

HTDP computes the displacement vector from t_1 to t_2 and adds this vector to the starting positional coordinates to obtain the corresponding positional coordinates at time t_2. When updating a collection of positional coordinates, the coordinates may be entered interactively one at a time, or the coordinates may be entered collectively in an ASCII file. The accepted formats are described during the execution of the HTDP utility and in the instructional exercises.

Table 3. Coseismic earthquake dislocation models incorporated into HTDP, in chronological order by region (California, Alaska, and Mexico).

Date (UTC)	Name	Mag-nitude	Epicenter location Latitude	Longitude	Influence radius (km)	Source of model
California						
6/8/1934	Parkfield	6.0	35°48'00"N	120°19'59"W	200	Segall and Du 1993
5/19/1940	El Centro	6.9	32°43'59"N	115°30'00"W	200	Snay and Herbrectsmeier 1994
10/21/1942	San Jacinto	6.6	32°58'01"N	116°00'00"W	200	Snay and Herbrectsmeier 1994
7/21/1952	Kern County	7.5	35°00'00"N	119°10'01"W	400	Snay and Herbrectsmeier 1994
3/19/1954	San Jacinto	6.4	33°16'59"N	116°10'59"W	200	Snay and Herbrectsmeier 1994
6/28/1966	Parkfield	5.6	35°54'57"N	120°32'00"W	200	Segall and Du 1993
4/9/1968	Borrego Mtn.	6.5	33°11'24"N	116°07'43"W	200	Snay and Herbrectsmeier 1994
2/9/1971	San Fernando	6.6	34°24'40"N	118°24'02"W	200	Snay and Herbrectsmeier 1994
3/15/1979	Homestead Valley	5.6	34°19'48"N	116°26'24"W	100	Stein and Lisowski 1983
8/6/1979	Coyote Lake	5.9	37°02'19"N	121°30'02"W	200	Snay and Herbrectsmeier 1994
10/15/1979	Imperial Valley	6.4	32°36'49"N	115°19'05"W	200	Snay and Herbrectsmeier 1994
5/2/1983	Coalinga	6.4	36°13'16"N	120°09'00"W	200	Stein and Ekstrom 1992
4/24/1984	Morgan Hill	6.2	37°12'11"N	121°36'29"W	200	Snay and Herbrectsmeier 1994
8/4/1985	Kettleman Hill	6.1	36°07'05"N	120°09'00"W	200	Ekstrom et al. 1992
7/8/1986	N. Palm Springs	5.6	33°56'24"N	116°38'24"W	200	Savage et al. 1993
7/21/1986	Chalfant Valley	6.2	37°35'00"N	118°25'00"W	200	Savage and Gross 1995
10/1/1987	Whittier Narrow	5.9	34°01'48"N	118°03'00"W	200	Lin and Stein 1989
11/24/1987	Superstition Hill	6.6, 6.2	33°00'00"N	115°45'00"W	200	Larsen et al. 1992
10/18/1989	Loma Prieta	7.1	37°04'49"N	121°52'00"W	200	Lisowski et al. 1990
4/22/1992	Joshua Tree	6.1	34°00'00"N	116°19'48"W	200	Bennett et al. 1995
4/25/1992	Cape Mendocino	7.1	40°22'18"N	124°24'02"W	200	Oppenheimer et al. 1993
6/28/1992	Landers/Big Bear	7.5, 6.6	34°13'12"N	116°25'48"W	500	Hudnut et al. 1994
1/17/1994	Northridge	6.7	34°24'34"N	118°33'39"W	200	Hudnut et al. 1996
10/16/1999	Hector Mine	7.1	34°33'33"N	116°19'19"W	500	Peltzer et al. 2001
12/22/2003	San Simeon	6.5	35°42'22"N	121°06'07"W	200	Johanson 2006
10/28/2004	Parkfield	6.0	35°48'54"N	120°22'26"W	200	Johanson et al. 2006
7/6/2019	Ridgecrest	6.4, 7.1	35°30'00"N	117°30'00"W	300	Jin and Fialko 2020
Alaska						
3/28/1964	Prince William Sound	9.2	60°00'00"N	150°00'00"W	1500	Holdahl and Sauber 1994
11/3/2002	Denali	7.9	63°31'12"N	147°31'48"W	2000	Elliott et al. 2007
1/23/2018	Kodiak	7.9	56°00'14"N	149°09'58"W	500	Ruppert et al. 2018
11/30/2018	Anchorage	7.1	61°20'46"N	149°57'18"W	200	He et al. 2020
Mexico						
4/4/2010	El Mayor/Cucapah	7.2	32°07'48"N	115°18'00"W	500	Fialko 2010 (personal comm)

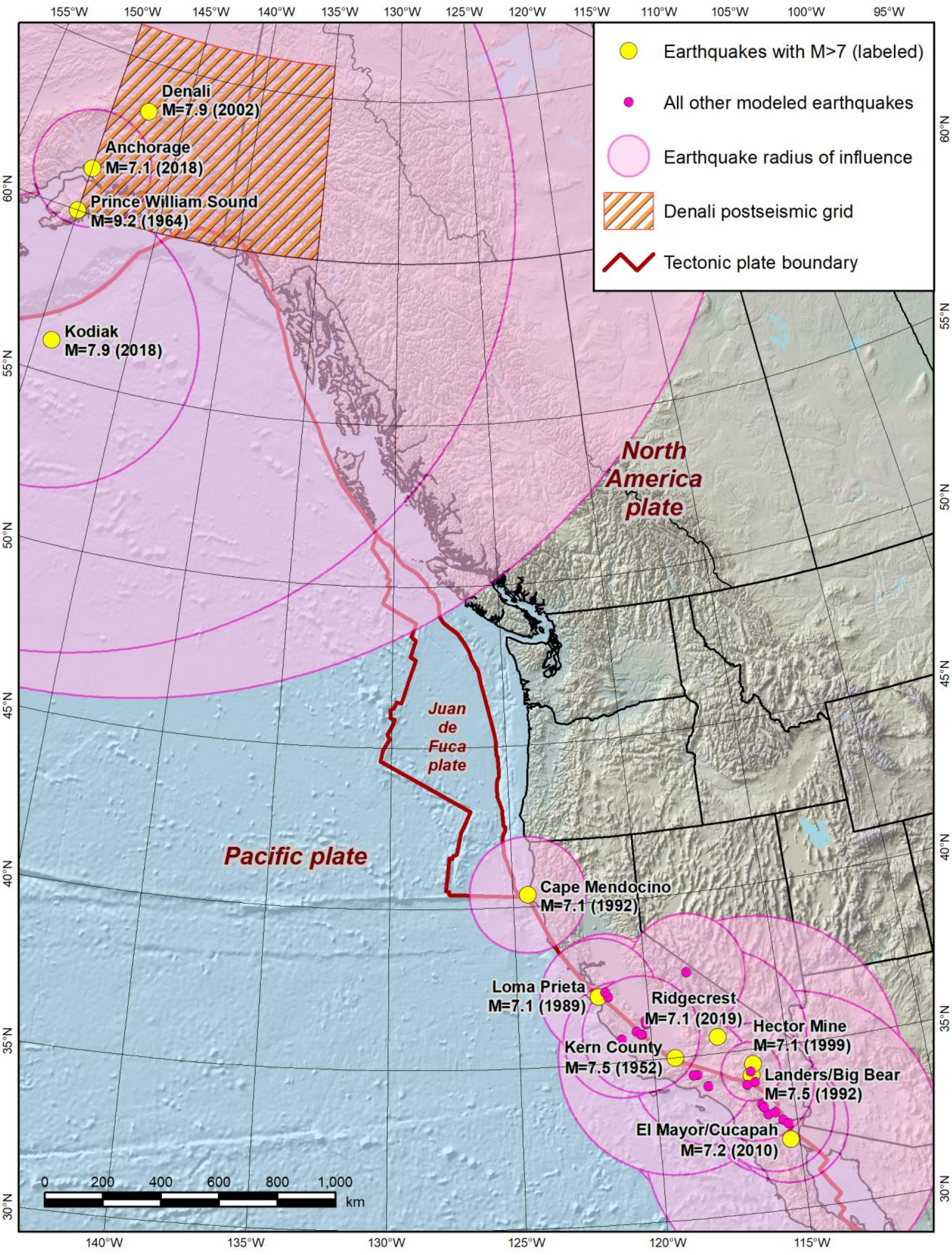

Figure 4. Coseismic earthquake dislocation models and postseismic motion grid encoded in HTDP.

5. Transforming Positional Coordinates

When transforming positional coordinates from one reference frame to another, the user must specify the:

- Starting (source) reference frame and the starting positional coordinates.
- Source reference epoch t_1 of the starting coordinates.
- Target reference frame for the transformed coordinates.
- Target reference epoch t_2 of the transformed coordinates.

Transforming positional coordinates from one reference frame to another and from one reference epoch to another may be considered a two-step process:

1. Use velocity and crustal displacement models to update the coordinates from time t_1 to time t_2 in the source reference frame.
2. Perform a 14-parameter Helmert transformation to update coordinates at time t_2 from the source reference frame to the desired target reference frame.

Section 4 described how HTDP performs the first step. The second step is addressed in this section.

Let $x(t)_A$, $y(t)_A$, and $z(t)_A$ denote the positional coordinates of a location at time t referred to source reference frame A in an ECEF Cartesian coordinate system. These coordinates are expressed as a function of time. Similarly, let $x(t)_B$, $y(t)_B$, and $z(t)_B$ denote the positional ECEF coordinates of this same location at time t referred to target reference frame B. Within HTDP, the coordinates in source frame A are approximately related to those in target frame B via the following equations of a 14-parameter Helmert transformation:

$$\begin{aligned}
x(t)_B &= T_x(t) + [1 + s(t)]\, x(t)_A + R_z(t)\, y(t)_A - R_y(t)\, z(t)_A \\
y(t)_B &= T_y(t) - R_z(t)\, x(t)_A + [1 + s(t)]\, y(t)_A + R_x(t)\, z(t)_A \\
z(t)_B &= T_z(t) + R_y(t)\, x(t)_A - R_x(t)\, y(t)_A + [1 + s(t)]\, z(t)_A\,. \qquad (5.1)
\end{aligned}$$

Here $T_x(t)$, $T_y(t)$, and $T_z(t)$ are translations along the x-, y- and z-axis, respectively; $R_x(t)$, $R_y(t)$, and $R_z(t)$ are counterclockwise rotations about these same three axes; and $s(t)$ is the differential scale between reference frames A and B. These approximate equations suffice because the three rotations have very small magnitudes (much less than 1 arcsecond, even for time spans exceeding a century). Note that each of the seven quantities is represented as a function of time because modern geodetic technology has enabled scientists to detect their time-related variations. HTDP treats these time-related variations as linear, so that each of the seven parameters P may be expressed by an equation of the form:

$$P(t) = P(\tau) + \dot{P}(t - \tau) \qquad (5.2)$$

Where τ denotes a prespecified reference epoch (or date), and the two quantities $P(\tau)$ and $\dot{P}$ are constants representing the parameter values at τ and their rates of change, respectively. Thus, the seven quantities give rise to 14 parameters, and the values of seven of these parameters depend on the value chosen for τ.

For illustrative purposes, consider a transformation of coordinates from the North America NAD 83 frame to ITRF96 coordinates. The NAD 83 velocity of a point is expressed as if the "stable" interior of the North America tectonic plate does not move on average. Its ITRF96 velocity, on the other hand, is expressed as if the major tectonic plates move according to the no-net-rotation NUVEL-1A model of DeMets et al. (1994). According to this model, the North America plate is rotating counterclockwise at a constant rate about an axis that passes through both the Earth's center of mass (i.e., the geocenter) and a point on the Earth's surface slightly west of Ecuador (this point is often called an Euler pole). The ITRF96 frame is thus rotating relative to the NAD 83 frame and *vice versa*. This relative motion may be quantified by specifying appropriate values for the three rotation rates $\dot{R}_x$, $\dot{R}_y$, and $\dot{R}_z$. The remaining four rates are not required to quantify this motion.

When transforming coordinates from ITRF96 to NAD 83, the current version of HTDP uses the following equations adopted by the U.S. National Geodetic Survey and Canada's Geodetic Survey Division (Craymer et al. 2000):

$$T_x(t) = 0.9910 \text{ m} + 0.0 \text{ m/yr} \times (t - 1997.00) \text{ yr} = 0.9910 \text{ m}$$
$$T_y(t) = -1.9072 \text{ m} + 0.0 \text{ m/yr} \times (t - 1997.00) \text{ yr} = -1.9072 \text{ m}$$
$$T_z(t) = -0.5129 \text{ m} + 0.0 \text{ m/yr} \times (t - 1997.00) \text{ yr} = -0.5129 \text{ m}$$
$$R_x(t) = 25.79 \text{ mas} + 0.0532 \text{ mas/yr} \times (t - 1997.00) \text{ yr}$$
$$R_y(t) = 9.65 \text{ mas} - 0.7423 \text{ mas/yr} \times (t - 1997.00) \text{ yr}$$
$$R_z(t) = 11.66 \text{ mas} - 0.0316 \text{ mas/yr} \times (t - 1997.00) \text{ yr}$$
$$s(t) = [0.0 + 0.0/\text{yr} \times (t - 1997.00) \text{ yr}] \times 10^{-9} = 0.0 \text{ (unitless)}, \qquad (5.3)$$

where mas is milliarcseconds. In these equations, τ is 1997.00, which is the reference epoch for this set of transformation parameters (corresponding to January 1, 1997), and t is some time of interest, also in decimal years (note that only the three rotation terms vary with time; all other terms are constant). These equations give the fundamental defining relationship between NAD 83 for North America and the ITRS, as represented by ITRF96, and the exact values of the parameters and rates in equations (5.3) are encoded in HTDP. This relationship has also been adopted as official NGS policy (NGS 2000), although it is represented differently. In NGS (2000), the relationship is given with respect to ITRF97 rather than ITRF96, and the parameters differ from those in equations (5.3). The reason for this difference is explained in Section 9.

Adopting the relationship represented by equations (5.3) significantly changed the definition of NAD 83. It was originally aligned with the Bureau International de l'Heure (BIH) Terrestrial Reference System at epoch 1984.0 (BTS 84) through transformation of Doppler-derived (Transit) coordinates (Schwarz 1989). The same approach was used to align the original realization of WGS 84 (McCarthy 1992), and it is why these two frames have historically been treated as equivalent. But with the change to the ITRF96 definition for NAD 83 in HTDP, it is no longer treated as equivalent to original WGS 84.

The importance of ITRF96 in defining the modern NAD 83 frame made it convenient to use equations (5.3) as the basis for all transformations in HTDP. In addition, ITRF96 is considered identical to ITRF94, so the two frames can be used interchangeably. Because ITRF94 was already encoded in HTDP when NAD 83 was redefined, ITRF94 is used as its proxy for ITRF96. That is, every transformation in HTDP is computed with respect ITRF94 (and thus ITRF96 by identity).

More than two dozen reference frames are available in HTDP. Transformations between these frames are each stored as a set of 14 parameters (plus the reference epoch, τ), for a total of 15 values per set (all with respect to ITRF94). For this number of frames, several hundred permutations are possible for performing transformations between them. Rather than store the 15 values needed for each possible combination of two frames, HTDP uses mathematical approximations to reduce the number of parameter sets stored. In particular, because all rotation angles are small, each of the 14 parameters for the transformation from frame *A* to frame *C* approximately equals the sum of its corresponding parameter from frame *A* to frame *B* and its corresponding parameter from frame *B* to frame *C* (if all three transformations employ the same value of τ). This relationship may be represented by the symbolic equation

$$(A \rightarrow C) \approx (A \rightarrow B) + (B \rightarrow C) \qquad (5.4)$$

where $(A \rightarrow C)$ represents the transformation from frame *A* to frame *C*. It is also the case that

$$(A \rightarrow B) \approx -(B \rightarrow A). \qquad (5.5)$$

That is, each of the 14 parameters for the transformation from frame *B* to frame *A* equals its corresponding parameter for the transformation from frame *A* to frame *B* multiplied by –1.

As a result of equations (5.4) and (5.5), HTDP stores only the 14 parameter values and one reference epoch needed for transforming from ITRF94 to the other reference frames. Thus, for transforming coordinates from frame *A* to frame *B*, HTDP uses the symbolic relationship

$$(A \rightarrow B) \approx -(\text{ITRF94} \rightarrow A) + (\text{ITRF94} \rightarrow B) = (A \rightarrow \text{ITRF94}) + (\text{ITRF94} \rightarrow B). \qquad (5.6)$$

The number of parameter sets is further reduced by treating some frames as equivalent to one another, as discussed in Section 8.

6. Transforming Observations

When transforming an observation, such as a measured distance between two locations, the user must specify the:

- Type of observation.
- Observed value.
- Date on which the observation was measured.
- Positional coordinates of the associated locations.
- Reference frame and the reference epoch of the provided coordinates.
- Date to which the transformed observation will correspond.

To transform a collection of observations, the user must supply the first four types of information (observation type, observed value, observation date, and the positional coordinates of the associated locations) via “Bluebook” files (NGS 2020). HTDP will then create new Bluebook files in which the observational records from the input Bluebook files have been replaced with corresponding records that contain updated values for the observed quantities. These coordinates must all refer to the same reference frame (denoted *F0*) and the same reference epoch (denoted t_0), both of which the user will be asked to supply during the execution of HTDP.

HTDP can update various types of observational records contained in a Bluebook file, including those for distances, azimuths, horizontal directions, horizontal angles, and 3D interstation vectors derived from GNSS data. The Bluebook files must contain positional coordinates for all of the stations associated with the observations to be transformed. The user may or may not need to specify the starting and ending reference frames, because some observations (like chord distances) are invariant with respect to reference frame choice whereas other observations (like 3D interstation vectors derived from GNSS data collected simultaneously at pairs of locations) do depend on the reference frame. An example of each possibility is presented below.

Let $C(t_1)$ represent an observed chord distance between locations A and B at time t_1. To estimate the corresponding distance $C(t_2)$ that would have been measured at time t_2, the software will first retrieve positional coordinates for A and B from the positional records of the Bluebook file. These coordinates are referred to frame $F0$ at time t_0. HTDP will update them to corresponding coordinates for A and B in frame $F0$ at time t_1 and then use these updated coordinates to compute the theoretical distance $\hat{C}(t_1)$ between A and B at time t_1. Similarly, HTDP will update the starting coordinates for A and B to corresponding coordinates in frame $F0$ at time t_2 and compute the theoretical distance $\hat{C}(t_2)$ at time t_2. The theoretical distance $\hat{C}(t_1)$ can differ from the observed distance $C(t_1)$ for several reasons. First, $C(t_1)$ contains some amount of observational error that is not considered in computing $\hat{C}(t_1)$. Second, the positional coordinates for A and B given in the Bluebook file might differ from the actual coordinates of A and B at time t_0. And third, any inaccuracy in the encoded crustal motion models will bias the value of $\hat{C}(t_1)$. For these same reasons, $\hat{C}(t_2)$ will differ from $C(t_2)$, but the difference $C(t_1) - \hat{C}(t_2)$ should approximate the difference $C(t_1) - \hat{C}(t_1)$ in value as both differences involve essentially the same errors. Consequently, the expression

$$C(t_1) + \hat{C}(t_2) - \hat{C}(t_1) \tag{6.1}$$

approximates $C(t_2)$. Hence, HTDP sets $C(t_2)$ to the value of this expression. The utility updates other types of observations that are reference-frame invariant in a similar manner.

Now let $(D_x(t_1)_{F1}, D_y(t_1)_{F1}, D_z(t_1)_{F1})$ denote a 3D-differential vector between locations A and B at time t_1 and referred to reference frame $F1$. To transform this vector to its corresponding vector at time t_2 and referred to frame $F2$, HTDP employs a three-step process:

- Transform the starting (source) 3D-difference vector from $F1$ to $F0$ at time t_1.
- Update the resulting vector from time t_1 to time t_2 in frame $F0$.
- Transform the resulting (target) vector from $F0$ to $F2$ at time t_2.

For the first step, HTDP uses the following equations to scale and rotate the vector components:

$$\begin{aligned} D_x(t_1)_{F0} &= [1 + s(t_1)]\, D_x(t_1)_{F1} + R_z(t_1)\, D_y(t_1)_{F1} - R_y(t_1)\, D_z(t_1)_{F1} \\ D_y(t_1)_{F0} &= -R_z(t_1)\, D_x(t_1)_{F1} + [1 + s(t_1)]\, D_y(t_1)_{F1} + R_x(t_1)\, D_z(t_1)_{F1} \\ D_z(t_1)_{F0} &= R_y(t_1)\, D_x(t_1)_{F1} - R_x(t_1)\, D_y(t_1)_{F1} + [1 + s(t_1)]\, D_z(t_1)_{F1} \end{aligned} \tag{6.2}$$

where $R_x(t_1)$, $R_y(t_1)$, and $R_z(t_1)$ are the three rotations from $F1$ to $F0$ at time t_1 and $s(t_1)$ is the differential scale change from $F1$ to $F0$ at time t_1.

For the second step, HTDP retrieves the positional coordinates for locations *A* and *B* from the Bluebook file. HTDP then updates these coordinates in frame *F0* from time t_0 to corresponding coordinates at time t_1, and also to the corresponding coordinates in frame *F0* at time t_2. HTDP then uses the equation

$$D_x(t_2)_{F0} = D_x(t_1)_{F0} + [x_B(t_2) - x_A(t_2)] - [x_B(t_1) - x_A(t_1)] \quad (6.3)$$

to compute the *x*-component of the 3D-difference vector at time t_2 as referred to *F0*. Here $x_i(t_j)$ refers to the *x*-component of the 3D-ECEF Cartesian coordinates of location *i* at time t_j as referred to *F0*. HTDP uses similar equations to compute $D_y(t_2)_{F0}$ and $D_z(t_2)_{F0}$.

For the third step, HTDP uses an equations similar to equations (6.2) to scale and rotate the vector components to the final desired frame *F2* at time t_2.

7. Transforming Velocity Vectors

When transforming a velocity vector at location *C* from reference frame *A* to reference frame *B*, the user must specify the:

- Velocity vector in frame *A*.
- Coordinates of location *C* in frame *A*.

Epochs are not needed because the velocities are treated as constant. HTDP then transforms the input velocities $(V_x)_A$, $(V_y)_A$, and $(V_z)_A$ in frame *A* to corresponding velocities in frame *B* via the equations:

$$
\begin{aligned}
(V_x)_B &= (V_x)_A + \dot{T}_x + \dot{s}\, x + \dot{R}_z\, y - \dot{R}_y\, z \\
(V_y)_B &= (V_y)_A + \dot{T}_y - \dot{R}_z\, x + \dot{s}\, y + \dot{R}_x\, z \\
(V_z)_B &= (V_z)_A + \dot{T}_z + \dot{R}_y\, x - \dot{R}_x\, y + \dot{s}\, z \quad (7.1)
\end{aligned}
$$

Here (x, y, z) denote the 3D-ECEF Cartesian coordinates of location *C* referred to frame *A*; $(\dot{T}_x, \dot{T}_y, \dot{T}_z)$ denote the three translation rates of frame *B* relative to frame *A*; $(\dot{R}_x, \dot{R}_y, \dot{R}_z)$ denote the three rotation rates of frame *B* relative to frame *A*; and $\dot{s}$ denotes the rate of differential scale change of frame *B* relative to frame *A*.

When using HTDP to transform a collection of velocity vectors from one frame to another, users may interactively provide the required information one location at a time or they may submit an ASCII file that contains the required information for all locations. The format of this file is described during the execution of the HTDP utility.

8. Reference Frames Supported in HTDP

Table 4 shows the reference frames currently supported in HTDP, along with other relevant information. They are listed in the order of their HTDP key, which is the number used by HTDP to identify each frame and its associated transformation parameters. Some reference frames share the same key.

Table 4. Reference frames recognized by HTDP. Domains (areas of usage) for NAD 83 frames are given in the table; all other frames are global. Includes ISO Geodetic Registry (ISOGR) and EPSG Geodetic Parameter Dataset codes for 3D geodetic coordinate reference systems.

Reference frame	Nominal realization reference epoch	Responsible agencies	HTDP key	References and additional information	ISOGR codes $(x, y, z), (\varphi, \lambda, h)$	EPSG codes $(x, y, z), (\varphi, \lambda, h)$
NAD 83 referenced to the North America plate. Includes only the (2011/CORS96/2007) realizations corresponding to specific reference epochs, per NGS (2000). Domain is CONUS, Alaska, Puerto Rico, U.S. Virgin Islands.	2010.00 for NAD 83 (2011); 2007.00 for NAD 83 (2007) in AK, AZ, CA, NV, OR, WA (2002.00 otherwise); 2003.00 for NAD 83 (CORS96) in AK (2002.00 otherwise)	NGS	1	Dennis (2020) for NAD 83 (2011) Pursell and Potterfield (2008) for NAD 83(2007/NSRS2007) Soler and Snay (2004) and NGS (2000) for NAD 83 (CORS96)	NAD 83 (2011): 239, 252 NAD 83 (2007): —, 397 NAD 83 (CORS96): 294, 354	NAD 83 (2011): 6317, 6319 NAD 83 (2007): 4892, 4893 NAD 83 (CORS96): 6781, 6782
NAD 83 referenced to the Pacific plate. Includes NAD 83 (PA11/PACP00). Domain is U.S. islands on Pacific plate.	2010.00 for NAD 83 (PA11); 1993.62 for NAD 83 (PACP00)	NGS	2	Dennis (2020) for NAD 83 (PA11) Snay (2003a) for NAD 83 (PACP00)	PA11: 449, 445 PACP00: 315, 455	PA11: 6320, 6321 PACP00: 9073, 9074
NAD 83 referenced to the Mariana plate. Includes NAD 83 (MA11/MARP00). Domain is U.S. islands on Mariana plate.	2010.00 for NAD 83 (MA11); 1993.62 for NAD 83 (MARP00)	NGS	3	Dennis (2020) for NAD 83 (MA11) Snay (2003a) for NAD 83 (MARP00)	MA11: 379, 231 MARP00: 408, 305	MA11: 6323, 6324 MARP00: 9070, 9071
WGS 72	1988.00	NGA	4	McCarthy (1992)	—, —	4984, 4985
WGS 84 original (Transit)	1984.00	NGA	5	NGA (2014) ≈ *BTS 84*	272, 342	7815, 7816
WGS 84 (G730)	1994.00	NGA	6	NGA (2014) ≈ *ITRF91*	314, 458	7656, 7657
WGS 84 (G873)	1997.00	NGA	7	NGA (2014) ≈ *ITRF94*	325, 344	7658, 7659
WGS 84 (G1150) [a]	2001.00	NGA	8	NGA (2014); *biased wrt ITRF2000*	210, 414	7660, 7661
WGS 84 (G1674) [a]	2005.00	NGA	9	NGA (2014); *biased wrt ITRF2008*	334, 216	7662, 7663
WGS 84 (G1762) [b]	2005.00	NGA	10	NGA (2014) ≈ *ITRF2008*	215, 405	7664, 7665
WGS 84 (G2139)	2016.00	NGA	11	NGA (2021) ≈ *ITRF2014*	796, 797	9753, 9754
WGS 84 (G2296)	2024.00	NGA	12	NGA (2023) ≈ *ITRF2020*	1255, 1256	10604, 10605
ITRF88	1988.00	IERS	13	IERS (1989)	439, 400	4910, 7900
ITRF89	1988.00	IERS	14	IERS Tech. Note 6 (1991) [c, d]	387, 361	4911, 7901
ITRF90 (or PNEOS 90, NEOS 90)	1988.00	IERS	15	IERS Tech. Note 9 (1991) [c, d]	301, 282	4912, 7902

Table 4. *(continued)*

Reference frame	Nominal realization reference epoch	Responsible agencies	HTDP key	References and additional information	ISOGR codes $(x, y, z), (\varphi, \lambda, h)$	EPSG codes $(x, y, z), (\varphi, \lambda, h)$
ITRF91 (or SIO/MIT 92)	1988.00	IERS	16	IERS Tech. Note 12 (1992) [c, d]	258, 241	4913, 7903
ITRF92	1994.00	IERS	17	IERS Tech. Note 15 (1993) [c, d]	261, 286	4914, 7904
ITRF93	1995.00	IERS	18	IERS Tech. Note 18 (1994) [c]	263, 227	4915, 7905
ITRF94 (= ITRF96 = ITRF97)	1996.00	IERS	19	IERS Tech. Note 20 (1996) [c]	352, 264	4916, 7906
ITRF96 (= ITRF94 = ITRF97)	1997.00	IERS	20	IERS Tech. Note 24 (1998) [c]	275, 233	4917, 7907
ITRF97 (= ITRF94 = ITRF96) [e]	1997.00	IERS	21	IERS Tech. Note 27 (1999) [c]	349, 388	4918, 7908
ITRF2000; IGS00; IGb00	1997.00	IERS; IGS	22	Altamimi et al. (2002); IERS Tech. Note 31 (2009) [a]; Kouba (2009); IGS (2017)	ITRF2000: 419, 355 IGS00: 289, 459 IGb00: 309, 420	ITRF2000: 4919, 7909 IGS00: 9004, 9005 IGb00: 9007, 9008
ITRF2005; IGS05	2000.00	IERS; IGS	23	Altamimi et al. (2007); IERS Tech. Note 35 (2004) [a]; Kouba (2009); IGS (2017)	ITRF2005: 269, 209 IGS05: 310, 453	ITRF2005: 4896, 7910 IGS05: 9010, 9011
ITRF2008; IGS08; IGb08	2005.00	IERS; IGS	24	Altamimi et al. (2011); IERS Tech. Note 37 (2012) [a]; Rebischung et al. (2011); IGS (2017)	ITRF2008: 242, 277 IGS08: 417, 205 IGb08: 382, 402	ITRF2008: 5332, 7911 IGS08: 6934, 9013 IGb08: 9015, 9016
ITRF2014; IGS14; IGb14	2010.00	IERS; IGS	25	Altamimi et al. (2016); IERS Tech. Note 38 (2017) [a]; IGS (2017)	ITRF2014: 425, 226 IGS14: 370, 299 IGb14: 727, 726	ITRF2014: 7789, 7912 IGS14: 8227, 9018 IGb14: 9378, 9379
ITRF2020; IGS20; IGb20; ITRF20200-u2023	2015.00	IERS; IGS	26	Altamimi et al. (2023); IGS (2022, 2024); IGN (2024)	ITRF2020: 802, 803 IGS20: 980, 981 IGb20: —, — ITRF2020-u2023: —, —	ITRF2020: 9988, 9989 IGS20: 10176, 10177 IGb20: 10783, 10784 ITRF2020-u2023: 10779, 10780

Table 4 footnotes are given on the following page.

Table 4 footnotes

[a] Intended to align WGS 84 (G1150) and (G1674) with ITRF2000 and ITRF2008, respectively, but both biased; see NGA (2014) Table 2.5 and Kelly and Dennis (2022).

[b] WGS 84 (G1762' "prime") is not included in HTDP because it is not considered an official realization of WGS 84; see Kelly and Dennis (2022).

[c] IERS Technical Notes are not given in the References section but all are available at https://www.iers.org/IERS/EN/Publications/TechnicalNotes/TechnicalNotes.html.

[d] This IERS Technical Note gives a transformation to the previous ITRF that has been superseded by the IERS in IGN (2022); see Kelly and Dennis (2022), Table S1.

[e] IGS97 is not included in HTDP because the IERS convention ITRF96 = ITRF97 is in conflict with the IGS convention ITRF96 ≠ ITRF97. The only role of the IGS convention in HTDP is for transformations involving NAD 83 (North America), which is handled internally. See Section 9 of this document for more information.

The supported frames include the three defined for NAD 83 (referenced to the North America, Pacific, and Mariana plates); WGS72 (added back in v3.6.0 with revised transformation parameters, having been removed in v3.2.1); all official realizations of WGS 84; and all International Terrestrial Reference Frame (ITRF) realizations of the ITRS, including the recent "updated" version of ITRF2020, called ITRF2020-u2023, which is considered identical to original ITRF2020 (IGN 2025). Also included are International GNSS Service (IGS) frames, each aligned with a specific ITRF, as shown in the table. Because each IGS frame is aligned with an ITRF, HTDP uses the same key (and hence the same transformation parameters) as its associated ITRF. Each WGS 84 realization is also nominally aligned with an ITRF, except for original WGS 84—also referred to as WGS 84 (Transit)—which was aligned with BTS 84 (NGA 2014). Its transformation parameters were determined by the International Earth Rotation and Reference Frame Service (IERS) with respect to ITRF90 (McCarthy 1992, Table 3.1). Although the intent of NGA was to align the WGS 84 (G1150) and (G1674) realizations with ITRF2000 and ITRF2008, respectively, it was later found that the realizations are biased with respect to these frames. The biases are fairly small but are larger than the estimated accuracies of the realizations themselves. Because of that, the biases are considered significant and were adopted in HTDP v3.5.0. The bias values used in HTDP are given in Table 2.5 of NGA (2014) and by Kelly and Dennis (2022). Both references give the reasons for the G1674 bias, and the G1150 bias is discussed in Kelly and Dennis (2022). Versions of HTDP prior to 3.5.0 treat G1150 as identical to ITRF2000 and G1674 as identical to ITRF2008 and WGS 84 (G1762). Although four WGS 84 realizations are treated as identical to a specific ITRF, all realizations get a unique key to aid HTDP users in identifying and selecting them.

The ITRF transformation parameters used in HTDP are given by the Institut Géographique National (IGN) 2022. Some of these parameters have been updated since they were originally published in IERS Technical Notes. The Technical Notes cited in Table 4 are not listed in the references but all are available at https://www.iers.org/IERS/EN/Publications/TechnicalNotes/TechnicalNotes.html.

Table 4 lists the recent realizations of the NAD 83 frame referenced to the North America tectonic plate that are consistent with the transformation performed by HTDP. These are the 2011, CORS96, and 2007/NSRS2007 realizations, and all have explicitly defined epochs. Although HTDP is consistent with these realizations, HTDP contains only *one* definition of NAD 83 for the North America plate, and that is the one given by equations (5.3) in this document, based on ITRF94/ITRF96. The NAD 83 relationship to all later ITRFs is based on IERS- or IGS-defined transformations between ITRFs, including the ITRF97 definition given in NGS policy (NGS 2000). Likewise, there is only *one* definition in HTDP for the NAD 83 PA11/PACP00 Pacific plate frame, and only *one* for the MA11/MARP00 Mariana plate frame. Section 9 gives more details about these NAD 83 relationships as implemented in HTDP.

Because HTDP contains only a single definition for each of the three NAD 83 frames, it is impossible for it to correctly perform transformations between realizations within these frames. For example, HTDP should not be used to perform transformations between the NAD 83 North America 2011, 2007, FBN, HARN, or original (1986) realizations. Moreover, HTDP is not entirely consistent with realizations completed prior to the relationships adopted in 2000 (Craymer et al. 2000, NGS 2000). The inconsistencies increase with the age of the realization, and most of those do not have explicitly defined epochs. For these reasons, HTDP should *never* be used to transform between NAD 83 realizations (although it can be used to transform between the three NAD 83 frames, each referenced to the North America, Pacific, and Mariana plates). To perform transformations between NAD 83 realizations within each of these frames, the NGS Coordinate Conversion and Transformation Tool (NCAT) should be used instead, available at https://geodesy.noaa.gov/NCAT/.

While it is true that HTDP should not be used to transform between NAD 83 realizations, it is appropriate to consider HTDP as being most consistent with the most recent realizations of the three NAD 83 frames: 2011, PA11, and MA11, at epoch 2010.00. The reason is that the accuracy and precision of the relationships between these NAD 83 frames and the ITRS improves with each subsequent realization and each reprocessing of the NOAA CORS Network. In addition, the velocity grids and tectonic plate models in HTDP improve over time, with the latest ones usually based on the most recent ITRFs.

Although all official WGS 84 realizations are included in HTDP, users should be aware that NGS cannot provide authoritative transformations, since WGS 84 is a product of NGA within the Department of Defense. NGS is only responsible for the civilian National Spatial Reference System (NSRS), not the U.S. military systems, so WGS 84 is outside NGS purview. Although NGS strives to use the most complete and correct transformations for WGS 84, we have no access to the information used to define the WGS 84 realizations or their actual relationships to the various ITRFs. Therefore transformations in HTDP involving WGS 84 should be considered approximate and used with caution.

Table 4 includes unique numeric identification codes from two well-known digital datasets, the International Standards Organization Geodetic Registry (ISOGR) at https://geodetic.isotc211.org/, and the European Petroleum Survey Group (EPSG) Geodetic Parameter Dataset at https://epsg.org/home.html. Both of these datasets are publicly available and widely referenced in commercial geospatial software. The codes given in Table 4 are for 3D geodetic coordinate reference systems that correspond to the frames included in HTDP; codes for 2D (φ, λ) systems are not included. For each HTDP-supported frame, the first code listed is for the ECEF (x, y, z) definition (if available), and the second is for the geodetic latitude, longitude, and ellipsoid height (φ, λ, h) definition. The version of the ISOGR used for Table 4 was last updated on November 28, 2022, and the EPSG Dataset version used was 10.077 released November 29, 2022.

9. Helmert Transformation Parameters Used in HTDP

As mentioned in Section 5, all transformations parameters in HTDP are defined as being from ITRF94 to various target reference frames. A total of 40 sets of these ITRF94-based transformations are used to handle all the frames listed in Table 4, each consisting of 14 Helmert parameters plus a reference epoch. These are actually encoded as two sets of 20 transformations, where each of the 20 transformations is represented twice.

The reason that the 20 transformations are represented twice is because of how NAD 83 referenced to the North America plate was redefined. When the current defining relationship between NAD 83 and ITRF94/ITRF96 was adopted (as discussed in Section 5), a joint decision was made by the U.S. and Canada to use the relationship between ITRF96 and ITRF97 as determined by IGS, rather than that determined by IERS. Based on multiple space-geodetic techniques (including GPS), IERS concluded that ITRF96 and ITRF97 are identical. In contrast, IGS concluded that ITRF96 and ITRF97 are not identical, based on GPS observations only. Because most of the geodetic control in the U.S. and Canada was established using GPS, it was decided to adopt the IGS convention (see Soler and Snay, 2004, for details). Adopting the IGS convention that ITRF96 ≠ ITRF97 is why the parameters and rates in equations (5.3) do not equal those published in NGS (2000). Had the IERS convention of ITRF96 = ITRF97 been adopted instead, equations (5.3) and NGS (2000) would be identical. Note that this difference only exists for NAD 83 referenced to the North America tectonic plate; HTDP uses the IERS convention for NAD 83 referenced to the Pacific and Mariana plates. For more information on the realization and evolution of the three NAD 83 frames, see Snay (2012).

Because NAD 83 (North America) uses the IGS convention that ITRF96 ≠ ITRF97, transformations in which this NAD 83 frame participates must use different parameters in HTDP than those that do not include it. Specifically, this affects all transformations after ITRF96, which includes those involving the Pacific and Mariana NAD 83 frames (since they are based on ITRF2000), for a current total of 10 additional sets of transformations. HTDP has 20 transformations for the case corresponding to the IERS convention (ITRF96 = ITRF97), of which 19 are unique because ITRF96 = ITRF97. There an additional 10 unique transformations to handle the IGS convention after ITRF96, for a total of 29 unique sets of transformation parameters. The reason HTDP has a total of 40 parameter sets is because it was easier to encode two complete groups of all 20 sets, even though 10 are duplicated (NAD 83 (North America), WGS 72, WGS 84 original (Transit), and ITRF88 through ITRF96).

It is possible to recast all the transformations in HTDP to a total of 18 unique parameter sets, while at the same time accounting for the IGS convention of ITRF96 ≠ ITRF97 that is specific to NAD 83 (North America). For example, all parameters can be computed with respect to ITRF2020, using equation (5.6). In addition, all parameters can be changed to a common epoch using equation (5.2). This has been done in Table 5, which is a list of every unique transformation in HTDP with respect to ITRF2020 at epoch 2010.0. Thus the 40 parameter sets in HTDP (with 29 unique) can be reduced to 18 unique sets (plus one set of "corrections" to account for the ITRF96 ≠ ITRF97 convention used by NAD 83 for North America). Although such an approach has not been implemented in HTDP, the parameters in Table 5 exactly reproduce the transformations as performed by HTDP.

Table 5. Transformations defined in HTDP, computed with respect to ITRF2020 [a] at epoch 2010.0 (rotations are counterclockwise positive). Includes valid ISO Geodetic Registry and EPSG Geodetic Parameter Dataset codes for transformations that are consistent with HTDP.

Transformation parameters ***Parameter rates (velocities)***	T_X mm *mm/yr*	T_Y mm *mm/yr*	T_Z mm *mm/yr*	R_X mas *mas/yr*	R_Y mas *mas/yr*	R_Z mas *mas/yr*	S ppb *ppb/yr*	**ISO Geodetic Registry codes for transformations consistent with HTDP**	**EPSG Dataset codes for transformations consistent with HTDP**
NAD 83 (2011/CORS96/2007) North America plate fixed [b]	1003.90 *0.79*	-1909.61 *-0.70*	-541.17 *-1.24*	26.78138 *0.06667*	-0.42027 *-0.75744*	10.93206 *-0.05133*	-0.05109 *-0.07201*	518, 524, 566, 604	6864, 6865, 6866, 7807, 8970
NAD 83 (PA11/PACP00) Pacific plate fixed	909.5 *0.1*	-2013.3 *0.0*	-585.9 *-1.7*	22.749 *-0.384*	26.560 *1.007*	-25.706 *-2.186*	1.70 *0.11*	565, 739	7808, 9077
NAD 83 (MA11/MARP00) Mariana plate fixed	909.5 *0.1*	-2013.3 *0.0*	-585.9 *-1.7*	28.711 *-0.020*	11.785 *0.105*	4.417 *-0.347*	1.70 *0.11*	738	7809, 9078
ITRF88	24.0 *0.1*	-0.9 *-0.6*	-154.4 *-3.1*	-0.10 *0.00*	0.00 *0.00*	-0.26 *-0.02*	10.87 *0.12*	550, 595, 603	6281, 6291, 8069
ITRF89	29.0 *0.1*	35.1 *-0.6*	-130.4 *-3.1*	0.00 *0.00*	0.00 *0.00*	-0.26 *-0.02*	7.77 *0.12*	461, 607, 662, 673	6292, 7814, 8070
ITRF90 [PNEOS90; NEOS90]	24.0 *0.1*	11.1 *-0.6*	-92.4 *-3.1*	0.00 *0.00*	0.00 *0.00*	-0.26 *-0.02*	4.37 *0.12*	499, 627, 645	6283, 6293, 8071
ITRF91 [WGS 84 (G730); SIO/MIT 92]	26.0 *0.1*	15.1 *-0.6*	-76.4 *-3.1*	0.00 *0.00*	0.00 *0.00*	-0.26 *-0.02*	4.07 *0.12*	494, 653, 665	6284, 6294, 8072, 9961
ITRF92	14.0 *0.1*	1.1 *-0.6*	-70.4 *-3.1*	0.00 *0.00*	0.00 *0.00*	-0.26 *-0.02*	2.67 *0.12*	507, 540, 548, 593	6285, 6295, 8073, 9024
ITRF93	-51.8 *-2.8*	2.9 *-0.2*	-59.8 *-2.3*	2.81 *0.11*	3.38 *0.19*	-0.40 *-0.07*	3.87 *0.12*	526, 533, 544	6286, 6296, 8074
ITRF94 = ITRF96 = ITRF97 [WGS 84 (G873)]	6.0 *0.1*	-0.9 *-0.6*	-62.4 *-3.1*	0.00 *0.00*	0.00 *0.00*	-0.26 *-0.02*	3.38 *0.12*	468, 553, 578, 600, 623, 646, 660, 680, 685, 691, 712, 715	6287-6289, 6297-6299, 8075-8077, 9026-9028, 9076

Table 5. *(continued)*

Transformation parameters / ***Parameter rates (velocities)***	T_X mm / *mm/yr*	T_Y mm / *mm/yr*	T_Z mm / *mm/yr*	R_X mas / *mas/yr*	R_Y mas / *mas/yr*	R_Z mas / *mas/yr*	S ppb / *ppb/yr*	**ISO Geodetic Registry codes for transformations consistent with HTDP**	**EPSG Dataset codes for transformations consistent with HTDP**
ITRF2000 [IGS00; IGb00]	-0.7	0.8	-25.7	0.00	0.00	0.00	1.70	475, 591, 602, 639, 641, 690, 720	6300, 6302, 8078, 9029, 9034
	0.1	*0.0*	*-1.7*	*0.00*	*0.00*	*0.00*	*0.11*		
ITRF2005 [IGS05]	1.2	0.6	-1.9	0.00	0.00	0.00	0.50	552, 614, 670	6389, 8079, 9030
	0.3	*-0.1*	*0.1*	*0.00*	*0.00*	*0.00*	*0.03*		
ITRF2008 [IGS08; IGb08; WGS 84 (G1762)]	0.2	1.5	2.8	0.00	0.00	0.00	-0.44	491, 602, 611, 708, 709	7666, 7669, 7790, 9031, 9037, 9038
	0.0	*-0.1*	*0.1*	*0.00*	*0.00*	*0.00*	*0.03*		
ITRF2014 [IGS14; IGb14; WGS 84 (G2139)]	-1.4	-0.4	0.4	0.00	0.00	0.00	-0.42	557, 728, 805-817	9032, 9381, 9382, 9757, 9991-9999, 10100, 10103-10105
	0.0	*-0.1*	*0.2*	*0.00*	*0.00*	*0.00*	*0.00*		
WGS 72 [c]	84.0	-505.9	-4815.4	-18.30	0.30	546.74	-226.63	—	1237 [d], 1238 [e]
	0.1	*-0.6*	*-3.1*	*0.00*	*0.00*	*-0.02*	*0.12*		
WGS 84 original (Transit)	84.0	-505.9	-315.4	-18.30	0.30	-7.26	-6.63	772	9145, 9960
	0.1	*-0.6*	*-3.1*	*0.00*	*0.00*	*-0.02*	*0.12*		
WGS 84 (G1150) [biased with respect to ITRF2000]	7.1	-2.6	-33.4	0.00	0.00	0.00	4.78	577	7668, 9962, 9963
	0.1	*0.0*	*-1.7*	*0.00*	*0.00*	*0.00*	*0.11*		
WGS 84 (G1674) [biased with respect to ITRF2008]	4.2	-1.5	-1.2	-0.27	0.27	-0.38	6.46	492	7667
	0.0	*-0.1*	*0.1*	*0.00*	*0.00*	*0.00*	*0.03*		

[a] Four frames are considered equivalent to ITRF2020: IGS20 (IGS 2022), WGS 84(G2296) (NGA 2023), IGb20 (IGS 2025), and ITRF2020-u2023 (IGN 2025).
[b] Based on IGS convention ITRF96 ≠ ITRF97; NAD 83 transformations for the Pacific and Mariana plates based on IERS convention ITRF96 = ITRF97.
[c] Based on IERS-published transformation from ITRF90 in Table 3.1 of McCarthy (1992).
[d] EPSG transformation 1237 (WGS 72 to WGS 84 original) very close to HTDP; only difference is that scale change is greater than HTDP by 6.3 ppb.
[e] EPSG transformation 1238 (WGS 72 to WGS 84 original) very close to HTDP; only difference is that scale change is less than HTDP by 1 ppb.

To facilitate cross-referencing of the parameters used in HTDP with those provided by the ISOGR and EPSG, their numeric identifiers are given in Table 5 for transformations that match the output of HTDP. Note that the values of parameters themselves may differ from those in Table 5, for example if they are based on a different reference epoch, use clockwise positive rotations, or specify a different source or target frame.

It is important to understand that the ISOGR and EPSG transformations in Table 5 will give results that are consistent with HTDP *only* if the source and target epochs are the same. If these epochs are not equal, all of these transformations will generally differ with HTDP, often significantly. This occurs because Helmert transformations by themselves do not account for differential crustal motion modeled in HTDP, such as that between different tectonic plates, near deforming plate boundaries, and due to modeled earthquakes.

Some of the HTDP Helmert transformations do not agree with those obtained from the ISOGR, EPSG, or other sources, including various publications (some of which are indicated in the Table 4 footnotes). It is not possible for HTDP to agree with all ISOGR and EPSG transformations while at the same time be internally consistent, because some of the ISOGR and EPSG transformations themselves are inconsistent. See the supplemental materials of Kelly and Dennis (2022) for more details on such conflicting transformations, including those in the ISOGR and IERS Technical Notes (and other publications). Although those supplemental materials do not include EPSG codes, most ISOGR codes have an exact match to a corresponding "alias" EPSG code.

10. Software Characteristics

HTDP can be run interactively online at https://geodesy.noaa.gov/TOOLS/Htdp/Htdp.shtml or on a PC by downloading the executable file, htdp.exe. The htdp.exe file is run through a Windows command interface (cmd.exe). The source code is also available from the same web site, or from the GitHub site (https://github.com/noaa-ngs/HTDP). If desired, the source code can be compiled and linked to create an executable file. The source code is written in Fortran 90 and consists of the main program, htdp.f, plus four sub-programs: initbd.f, initeq.f, initps.f, and initvl.f. These subprograms contain crustal motion model polygon boundaries, coseismic earthquake model data, postseismic earthquake model parameters, and 2D velocity grid values, respectively. The subprograms are integrated into htdp.exe when the program is compiled. The HTDP executable available for download was created using the current version of the MinGW (http://www.mingw.org/) gfortran compiler in the MSYS2 software distribution and building platform for Windows (https://www.msys2.org/).

The PC version of HTDP is menu-driven and most information is entered interactively. Users may also enter certain information in batch files if they wish to process data for multiple locations, for example, to transform coordinates for multiple locations across time and/or between reference frames. HTDP accepts batch files in three different formats. One is the so-called "Bluebook" format for horizontal control data (NGS 2020).

The second format for batch entry is an ASCII file with several records where (for transforming coordinates) each record has the format:

LAT, LON, EHT, TEXT

where

LAT = latitude in degrees (positive north)
LON = longitude in degrees (positive west)
EHT = ellipsoid height in meters
TEXT = descriptive text (maximum of 24 characters)

EXAMPLES:

40.731671553,112.212671753,34.241,Salt Air *[comma delimited]*
40.731671553 112.212671753 34.241 Salt Air *[space delimited]*

The individual fields in each record may be separated by commas or blanks. The format is slightly different for estimating displacements between two dates (LAT, LON, TEXT) and for transforming velocities between reference frames (LAT, LON, VN, VE, VU, TEXT), where VN, VE, and VU are the north, east, and up velocity components, in mm/yr.

The third format for batch entry involves a file with several records where (for transforming coordinates) each record has the format:

X, Y, Z, TEXT

where X, Y, and Z are ECEF Cartesian coordinates expressed in meters and TEXT is descriptive text (maximum of 24 characters).

Besides estimating displacements or velocities for individual locations, or for locations specified in a batch file, the software also has two other methods for output of multiple results. One will generate a set of points for a specified 2-dimensional grid on the Earth's surface, and the other will define an equally spaced set of points along a geodesic curve on the GRS 80 ellipsoid, as an approximation of the Earth's surface. In all cases the output is written to a user-specified file.

The software also has the capability to update positional coordinates and/or geodetic observations to a specified date. For such an application, the user must specify the horizontal coordinates (latitudes and longitudes) and/or the observed values for one date, and the software will predict corresponding values for another user-specified date. The software can update various observational types, all of which may be encoded in the Bluebook formats. In particular, the software accepts direction observations, angle observations, distance observations, azimuth observations, and interstation GNSS vector observations.

11. Auxiliary Information

This User Guide contains a set of seven exercises to familiarize HTDP users with some of the applications of this software. Also, Snay (1999) discusses the HTDP utility and its applications in considerable detail. Additional material on HTDP has been published by Snay (2003b), Pearson and Snay (2007), Pearson et al. (2010), Snay and Pearson (2010), Pearson and Snay (2013), and Snay et al. (2013). Moreover, the National Geodetic Survey maintains a log that summarizes modifications to HTDP in reverse chronological order (at https://geodesy.noaa.gov/TOOLS/Htdp/HTDP-log.pdf).

12. Disclaimer

The HTDP utility and supporting information is furnished by the Government of the United States of America, and is accepted/used by the recipient with the understanding that the U.S. Government makes no warranties, expressed or implied, concerning the accuracy, completeness, reliability, or suitability of this software, of its constituent parts, or of any supporting data.

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13. References

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14. HTDP Exercises

The following set of exercises is designed to familiarize the user with several capabilities of the HTDP utility. Angular brackets identify text that the user should type into the computer. For example, in response to the instruction “enter < abc >”, the user should type “abc” and then hit the ENTER key.

To open the Command Prompt in Microsoft Windows, open File Explorer and navigate to where the HTDP executable is located, then type “CMD” in the File Explorer address bar. A Command Prompt window will open with a path to that folder (any input files needed must be in the same location as the executable). Typing “htdp” on the command line will open HTDP and display the following window:

```
C:\Execute\NGS\HTDP\Workspace\htdp.exe
********************************************************
   HTDP (Horizontal Time-Dependent Positioning)
   SOFTWARE VERSION: 3.6.0
   VERSION DATE:     April 7, 2025

   AUTHORS: Michael Dennis, Jarir Saleh, Richard Snay,
            and Chris Pearson

   Web: https://geodesy.noaa.gov/TOOLS/Htdp/Htdp.shtml
   Email: ngs.cors.htdp@noaa.gov
********************************************************
 This software incorporates numerical models that
 characterize continuous crustal motion as well as
 the episodic motion associated with earthquakes.

 The User Guide contains additional information and a set
 of exercises to familiarize users with the software.
********************************************************
 MAIN MENU:
    0... Exit software.
    1... Estimate horizontal displacements between two dates.
    2... Estimate horizontal velocities.
    3... Transform observations to a specified reference frame and/or date.
    4... Transform positions between reference frames and/or dates.
    5... Transform velocities between reference frames.
```

Alternatively, the Command Prompt can be opened by typing “cmd” in the Windows search box. But that requires navigating to the HTDP executable location using command line instructions.

All input and output files in the examples are in the “HTDP-download.zip” file available on the HTDP web page at https://geodesy.noaa.gov/TOOLS/Htdp/Htdp.shtml. Although these examples are written for running HTDP on a PC, they can also be used via the interactive web-based version located on the same web page. Note that there may occasionally be very small numeric differences in the output from the PC version and the web version, due to slightly different rounding.

Exercise 1. *Estimating displacements at individual points*

1.1 Enter < htdp > to start the program. This will display some introductory information along with the MAIN MENU.

1.2 From the MAIN MENU enter < 1 > to estimate displacements between two dates

1.3 Enter < 2 > to indicate that time T1 will be entered in decimal year format.

1.4 Enter < 2010 > to indicate epoch 2010.00 (January 1, 2010).

1.5 Enter < 2 > to indicate that time T2 will be entered in decimal year format..

1.6 Enter < 2020 > to indicate that the second date is January 1, 2020.

1.7 Enter < Ex1_disp1.out > for the name of the output file to contain the estimated displacements.

1.8 Enter < 1 > to specify that positions and velocities will be expressed in the NAD_83(2011/CORS96/2007) reference frame.

1.9 Enter < 1 > to indicate that you will enter individual points interactively.

1.10 Enter < Ridgecrest > for the name of the point where the displacement from January 1, 2010 to January 1, 2020 will be estimated.

1.11 Enter < 1 > to specify that you will provide the point's latitude and longitude.

1.12 Enter < 35 43 36 > for a latitude of 35°43'36.0" N (note that commas can be used rather than spaces to separate degrees, minutes, and seconds).

1.13 Enter < 117 34 31 > for a longitude of 117°34'31.0" W (positive west).

1.14 Enter < 0 > for the ellipsoid height.

1.15 Enter < 0 > to indicate that the software will estimate the velocity used in calculating the displacement. The screen will display the following information:

```
*****************************************
Northward displacement =   3.275 meters
Eastward displacement  =  -2.146 meters
Upward displacement    =  -0.369 meters
*****************************************
```

1.16 Enter < 0 > to return to the main menu. This will also write following results to output file "Ex1_disp1.out":

```
 HTDP OUTPUT, VERSION 3.6.0

 DISPLACEMENTS IN METERS RELATIVE TO NAD_83(2011/CORS96/2007)
 FROM 01-01-2010 TO 01-01-2020 (month-day-year)
 FROM 2010.000 TO 2020.000 (decimal years)

NAME OF SITE              LATITUDE          LONGITUDE            NORTH    EAST    UP
Ridgecrest                35 43 36.00000 N  117 34 31.00000 W    3.275  -2.146  -0.369
```

Exercise 2 gives a constant northward velocity for RC1 of 10.55 mm/yr. Based on that velocity, RC should move 0.1055 m north in 10 years (from January 1, 2010 to January 1, 2020). The reason the movement is so much greater in this example is that HTDP adds displacements associated with major earthquakes. Point RC1 is located in an area that was greatly impacted by the 2019 Ridgecrest earthquake (note that HTDP models this earthquake by combining the July 5 magnitude 6.4 and July 6 magnitude 7.1 earthquakes as a single event). Thus it can be inferred that point RC1 moved 3.275 – 0.105 = 3.170 m during the Ridgecrest earthquake. To show this, the displacement at RC1 due only to the Ridgecrest earthquake will be estimated in the following steps of this exercise.

1.17 Enter < 1 > to estimate displacements, as before.

1.18 Enter < 1 > to indicate that time T1 will be entered in month-day-year format.

1.19 Enter < 7 5 2019 > for the first date of July 5, 2019 (commas can be used instead of spaces).

1.20 Enter < 1 > to indicate that time T2 will be entered in month-day-year format.

1.21 Enter < 7 7 2019 > for the second date is July 7, 2019.

1.22 Enter < Ex1_disp2.out > to name the output file that is to contain the estimated displacements.

1.23 Enter < 1 > to specify that positions and displacements will be expressed in the NAD_83(2011/CORS96/2007) reference frame.

1.24 Enter < 1 > to indicate that you will specify individual points interactively.

1.25 Enter < Ridgecrest > for the name of the point.

1.26 Enter < 1 > to specify that you will provide the point's latitude and longitude.

1.27 Enter < 35 43 36 > for the latitude.

1.28 Enter < 117 34 31 > for the longitude.

1.29 Enter < 0 > for the ellipsoid height.

1.30 Enter < 0 > to indicate that the software will estimate the velocity used in calculating the displacement. The screen will display the following information:

```
*****************************************
Northward displacement =   3.170 meters
Eastward displacement  =  -2.088 meters
Upward displacement    =  -0.357 meters
*****************************************
```

1.31 Enter < 0 > to return to the main menu and write following results to output file "Ex1_disp2.out":

```
 HTDP OUTPUT, VERSION 3.6.0

 DISPLACEMENTS IN METERS RELATIVE TO NAD_83(2011/CORS96/2007)
 FROM 07-05-2019 TO 07-07-2019 (month-day-year)
 FROM 2019.507 TO 2019.512 (decimal years)

NAME OF SITE             LATITUDE          LONGITUDE            NORTH    EAST     UP
Ridgecrest               35 43 36.00000 N  117 34 31.00000 W    3.170  -2.088  -0.357
```

The northward displacement due to the coseismic motion of the earthquake is 3.170 m, as expected. Note that most of the 0.357 m downward displacement (vs. 0.369 m for the 10-year time difference) is also due to the earthquake. The difference of 0.012 m (corresponding to an up velocity of -1.2 mm/yr) is an artefact of the transformation of the velocity grid from ITRF2008 to NAD 83. This will be discussed in Exercises 2 and 3.

This concludes Exercise 1.

Exercise 2. *Estimating horizontal velocities at individual points*

2.1 Enter < htdp > to start the program (if not already running) and obtain the MAIN MENU.

2.2 Enter < 2 > to indicate that you will be estimating velocities.

2.3 Enter < Ex2_vel.out > as the name for the file that will contain the estimated velocities.

2.4 Enter < 1 > to indicate that velocities will be estimated relative to the NAD_83(2011/CORS96/2007) reference frame.

2.5 Enter < 1 > to indicate that you will be entering coordinates for individual points interactively.

2.6 Enter < Ridgecrest > for the name of the first point where the velocity will be estimated (same as used in Exercise 1).

2.7 Enter < 1 > to specify that you will provide the point's latitude and longitude.

2.8 Enter < 35 43 36 > for a latitude of 35°43'36.0" N

2.9 Enter < 117 34 31 > for a longitude of 117°34'31.0" W

2.10 Enter < 0 > to denote that the ellipsoid height is 0.0 meter. The screen will display the following information:

```
*************************************
Northward velocity =  10.55 mm/yr
Eastward velocity  =  -5.84 mm/yr
Upward velocity    =  -1.26 mm/yr

X-dim. velocity    =  -1.85 mm/yr
Y-dim. velocity    =   9.07 mm/yr
Z-dim. velocity    =   7.83 mm/yr
*************************************
```

1.32 Enter < 0 > to return to the main menu and write following results to output file "Ex2_vel.out":

```
 HTDP OUTPUT, VERSION 3.6.0

VELOCITIES IN MM/YR RELATIVE TO NAD_83(2011/CORS96/2007)

Ridgecrest
LATITUDE   =  35 43 36.00000 N  NORTH VELOCITY =  10.55 mm/yr
LONGITUDE  = 117 34 31.00000 W  EAST VELOCITY  =  -5.84 mm/yr
ELLIPS. HT. =      0.000 m      UP VELOCITY    =  -1.26 mm/yr
X = -2399636.104 m              X VELOCITY     =  -1.85 mm/yr
Y = -4594908.344 m              Y VELOCITY     =   9.07 mm/yr
Z =  3703613.298 m              Z VELOCITY     =   7.83 mm/yr
```

Note that the up velocity of -1.26 mm/yr is an artefact of the transformation of the velocity grid from ITRF2008 to NAD 83, as mentioned at the end of Exercise 1. Up velocities are set to zero for the velocity grids, all of which are defined in ITRF2008. If this example instead specified ITRF2008 as the frame, the up velocities would be zero. This is shown in Exercise 3.

This concludes Exercise 2.

Exercise 3. *Estimating displacements and velocities for sets of points*

For estimating displacements between two dates and velocities, the latitudes and longitudes of the points may be entered in several ways in addition to entering individual points interactively. The options available are to specify:

(a) A grid of points
(b) The name of a file that contains the positional information in “Bluebook” format
(c) A sequence of points on a line (or more precisely, a geodesic curve on Earth's surface)
(d) The name of a file where each record in the file is of the format: LAT, LON, TEXT, where:

LAT = latitude in decimal degrees (positive north)
LON = longitude in decimal degrees (positive west)
TEXT = descriptive text (maximum of 24 characters)

The fields in each record may be separated by commas or blanks, for example:
40.731671553,112.21267153,Salt Air
40.713671553 112.21267153 Salt Air

The option for computing velocities on a specified grid is demonstrated below, in the vicinity of the Ridgecrest earthquake.

3.1 If needed, enter < htdp > to start the program and obtain the MAIN MENU.

3.2 Starting from the MAIN MENU, enter < 2 > to estimate horizontal velocities.

3.3 Enter < Ex3_vel_grid.out > for the name of the output file that is to contain the estimated velocities.

3.4 Enter < 24 > to estimate velocities relative to the ITRF2008 reference frame.

3.5 Enter < 2 > to indicate that the points form a regularly spaced two-dimensional grid on the Earth's surface.

3.6 Enter “grid1” name to identify the grid (maximum of 10 characters).

3.7 Enter < 35 0 0 > to indicate that the minimum latitude is 35°00’00” N.

3.8 Enter < 36 0 0 > to indicate that the maximum latitude is 36°00’00” N.

3.9 Enter < 600 > to indicate that the latitude spacing is 600 seconds (equals 10 arc-minutes).

3.10 Enter < 117 0 0 > to indicate that the minimum longitude is 117°00’00” W (positive west).

3.11 Enter < 118 0 0 > to indicate that the maximum longitude is 118°00’00” W.

3.12 Enter < 600 > to indicate that the longitude spacing is also 600 seconds.

3.13 Enter < 0 > to indicate that velocities will not be estimated for any other points. This will write final results to the output file “Ex3_vel_grid.out”, which contains estimated velocities for a grid of 49 points. The first five and last five points in the file are shown below (arranged from southeast corner to northwest corner):

```
 HTDP OUTPUT, VERSION 3.6.0

VELOCITIES IN MM/YR RELATIVE TO ITRF2008 or IGS08/IGb08
NAME OF SITE            LATITUDE          LONGITUDE           NORTH    EAST    UP

grid1        0   0       35  0  0.00000 N  117  0  0.00000 W    -0.07  -20.48    0.00
grid1        0   1       35  0  0.00000 N  117 10  0.00000 W     1.63  -21.45    0.00
grid1        0   2       35  0  0.00000 N  117 20  0.00000 W     2.43  -21.87    0.00
grid1        0   3       35  0  0.00000 N  117 30  0.00000 W     2.87  -22.05    0.00
grid1        0   4       35  0  0.00000 N  117 40  0.00000 W     3.17  -22.13    0.00
.
.
.
grid1        6   2       36  0  0.00000 N  117 20  0.00000 W    -3.49  -17.79    0.00
grid1        6   3       36  0  0.00000 N  117 30  0.00000 W    -2.83  -18.57    0.00
grid1        6   4       36  0  0.00000 N  117 40  0.00000 W    -2.54  -19.17    0.00
grid1        6   5       36  0  0.00000 N  117 50  0.00000 W     0.36  -21.46    0.00
grid1        6   6       36  0  0.00000 N  118  0  0.00000 W     0.21  -21.62    0.00
```

The horizontal velocities are quite variable for such a small area, ranging from a minimum 17.53 mm/yr for the 43rd point to a maximum of 22.54 mm/yr for the 7th point (the north velocities are particularly variable, ranging from -6.03 to +3.58 mm/yr). All up velocities are exactly zero because the ITRF2008 frame was used, which is the frame of the velocity grids, and the up velocities for these grids are set to zero. If a frame other than ITRF2008 (or its equivalents) is specified, the up velocities will differ slightly from zero because they are transformed from ITRF2008. Note also that these grids are only for constant velocities and do not include the effects of earthquake displacement. Those displacements are added to displacement due to constant velocities. This is shown in the next part of this exercise.

In the following steps, displacements are estimated for a sequence of points that lie along a line that forms a geodesic curve on the Earth's surface. This line goes from the west to east edge of the grid in the first part of this exercise, crossing rupture zones of the Ridgecrest earthquake.

3.14 In the MAIN MENU, enter < 1 > to estimate displacements.

3.15 Enter < 2 > to indicate that time T1 will be entered in decimal year format.

3.16 Enter < 2010 > to indicate epoch 2010.00 (January 1, 2010).

3.17 Enter < 2 > to indicate that time T2 will be entered in decimal year format.

3.18 Enter < 2020 > to indicate that the second date is January 1, 2020.

3.19 Enter < Ex3_disp_line.out > for the name of the output file that will contain the estimated displacements.

3.20 Enter < 24 > to estimate displacements relative to the ITRF2008 reference frame.

3.21 Enter < 4 > to indicate that the points lie on a line.

3.22 Enter name "line1" to identify the line (maximum of 10 characters).

3.23 Enter < 35 44 0 > to specify the latitude of a point through which the line is to pass. This point is the origin of the line.

3.24 Enter < 117 35 0 > to specify the longitude of the origin.

3.25 Enter < 90 > to specify that the line is to have an azimuth of 90 degrees (clockwise from north) when it passes through the origin (due east).

3.26 Enter < -25000 50000 > to specify that velocities will be estimated for points located between 25,000 meters before (west of) the origin and 50,000 meters after (east of) the origin.

3.27 Enter < 5000 > to specify that the spacing between the points will be 5000 meters.

3.28 Enter < 0 > to return to the main menu, and to write the estimated velocities for the points on the line to “Ex3_disp_line.out” (shown below for the 16 points 5000 m apart along the line, from west to east):

```
 HTDP OUTPUT, VERSION 3.6.0

 DISPLACEMENTS IN METERS RELATIVE TO ITRF2008 or IGS08/IGb08
 FROM 01-01-2010 TO 01-01-2020 (month-day-year)
 FROM 2010.000 TO 2020.000 (decimal years)

NAME OF SITE             LATITUDE          LONGITUDE            NORTH    EAST    UP
line1        0           35 43 58.85759 N  117 51 34.84345 W    0.030  -0.484  -0.019
line1        1           35 43 59.26886 N  117 48 15.87552 W    0.049  -0.546  -0.011
line1        2           35 43 59.58873 N  117 44 56.90708 W    0.102  -0.609   0.002
line1        3           35 43 59.81721 N  117 41 37.93826 W    0.287  -0.690   0.013
line1        4           35 43 59.95430 N  117 38 18.96920 W    0.728  -0.933   0.008
line1        5           35 44  0.00000 N  117 35  0.00000 W    2.627  -2.164  -0.106
line1        6           35 43 59.95430 N  117 31 41.03080 W   -0.762   0.731   0.107
line1        7           35 43 59.81721 N  117 28 22.06174 W   -0.531   0.505   0.042
line1        8           35 43 59.58873 N  117 25  3.09292 W   -0.275   0.387   0.032
line1        9           35 43 59.26886 N  117 21 44.12448 W   -0.156   0.229  -0.005
line1       10           35 43 58.85759 N  117 18 25.15655 W   -0.088   0.131  -0.021
line1       11           35 43 58.35493 N  117 15  6.18925 W   -0.056   0.065  -0.027
line1       12           35 43 57.76089 N  117 11 47.22271 W   -0.044   0.017  -0.028
line1       13           35 43 57.07545 N  117  8 28.25705 W   -0.042  -0.019  -0.027
line1       14           35 43 56.29862 N  117  5  9.29240 W   -0.046  -0.045  -0.025
line1       15           35 43 55.43041 N  117  1 50.32889 W   -0.051  -0.064  -0.022
```

The 6th of these points (#5) is at the origin. Note that the origin has the highest latitude of all the points because the line forms a geodesic curve whose azimuth is 90 degrees when passing through the origin. The maximum displacement also occurs at the origin, with the direction of displacement switching from northwest to southeast as the line crosses a major rupture zone immediately east of the origin. The magnitude of displacement generally decreases with distance from the origin. The maximum horizontal movement for the points on this line is 3.404 m (at the origin), which is much greater than the 0.225 m based on the maximum velocity of the previously computed grid for the 10-year time span. Note also that none of the up displacements are zero along the line, meaning that all vertical motion is due to the earthquake.

This concludes Exercise 3.

Exercise 4. *Updating vector components in a GPS observation file (G-file)*

The purpose of this exercise is to transform the GPS vector components to a different reference frame and date, but not the horizontal coordinates associated with the vectors (this is explained in the exercise). The files of input coordinates (B-file) and GPS vectors (G-file) are provided. These are so-called “Bluebook” files, and their format is described in NGS (2020). The files are from a January 2021 GPS project in Washington state.

4.1 If needed, enter < htdp > to start the program and obtain the MAIN MENU.

4.2 Enter < 3 > for the option to transform observations to a specified reference frame and/or date.

4.3 Enter < 2 > to indicate that the following time will be entered in decimal year format.

4.4 Enter < 2010 > to indicate that the updated observations will correspond to epoch 2010.00 (January 1, 2010).

4.5 Enter < 1 > to specify that the input positions are in the NAD 83(2011/CORS96/2007) reference frame.

4.6 Enter < 4 > to specify that both coordinates and observations are to be updated (note that options 2 and 3 allow the user to update one without updating the other).

4.7 Enter < 1 > to indicate a standard Bluebook file will be used.

4.8 Enter < Ex4_bfile > to indicate the input Bluebook B-file that contains the original coordinates.

4.9 Enter < Ex4_bfile.out > for the name of the B-file file that will contain the updated coordinates.

4.10 Enter < 2 > to indicate that the following time will be entered in decimal year format.

4.11 Enter < 2010 > to specify that input coordinates correspond to the epoch 2010.00 (January 1, 2010). Note that for updating the observation (vectors) in the G-file, HTDP uses the date that the observation were performed as the starting date. The date of observation is given in the beginning of the B record for each session in the G-file (January 20-22, 2021, in this exercise).

4.12 Enter < y > to indicate the existence of a file that contains the GPS observations (G-file).

4.13 Enter < Ex4_gfile > to specify the input G-file containing GPS observational records.

4.14 Enter < Ex4_gfile.out > to specify that name of the output G-file that will contain the updated GPS records.

4.15 Enter < 1 > to indicate that the GPS vectors will be transformed to the NAD_83(2011/CORS96/2007) reference frame. The original vectors are in the IGb14 frame (indicated by code 37 in columns 52-53 of the B record).

In B-files, the latitude and longitude are given on the *80* records, and the heights are given on the *86* records. These records occur as pairs, below the occupation and equipment records. The first *80* and *86* records are for station PNNL BASE ARP. Note that none of the coordinates have been updated in “Ex4_bfile.out”, since the input and output epochs are the same. That was done because the intent of this exercise was to update the G-file, for use in a least-squares adjustment with current NAD 83 epoch 2010.00 coordinates as constraints. Had the input and output epoch been different from one another, the horizontal B-file coordinates would what have been updated, but not the ellipsoid heights. Because the reference frame of the B-file cannot be updated using the option in this exercise, the option for transforming positions between reference frames and/or dates should be used instead, as described in Exercise 6 for a file of input points (with the B-file as the input file).

The three following lines of header text have been added to the beginning of file "Ex4_bfile.out" to caution users that any coordinates in that file have been updated to their estimated value on January 1, 2010 (however, as mentioned above, there is no change in coordinates for this case since the input epoch is the same):

```
***CAUTION: This file was processed using HTDP version 3.6.0   ***
***CAUTION: Coordinates in this file are in NAD_83(2011/CORS96/2007)***
***CAUTION: Coordinates in this file have been updated to  1-01-2010 = (2010.000) ***
```

Although the B-file was not updated, the G-file was transformed to a different reference frame and epoch, resulting in a change in the GPS vector components. The vector components are given on the C records (or on F records for vectors with components of 1000 km or greater). The first vector of the input G-file has an ECEF *x*-component of 13,755.5815 m, which has been transformed to 13,755.5868 m in "Ex4_gfile.out", a change of only 0.53 cm. The change is small because the vector component is short; the change for the *x*-component of the longer 5^{th} vector is 1.98 cm.

Also in "Ex4_gfile.out", columns 52-53 of all B records should read "34" to indicate that the updated GPS interstation vector has been transformed to the NAD_83(2011/CORS96/2007) reference frame.

The following three lines of header text have been added to the beginning of "Ex4_gfile.out" to caution users that the observations in this file have been updated to January 1, 2010 and that these observations have been converted to the NAD_83(2011/CORS96/2007) reference frame.

```
***CAUTION: Observations in this file have been updated to  1-01-2010 = (2010.000) ***
***CAUTION: All GPS interstation vectors have been transformed to NAD_83(2011/CORS96/2007) ***
***CAUTION: Observations were transformed using HTDP version 3.6.0    ***
```

It may be necessary to remove the caution header lines of text in these output files before processing them with software that expects standard Bluebook files as input.

In addition, when HTDP transforms a G-file, it writes "ZT" in columns 79-80 of the "A" record (immediately below the header "caution" message). HTDP will not transform a G-file with the ZT code, since it has already been transformed.

This concludes exercise 4.

Exercise 5. *Transforming positions between reference frames and/or dates*

5.1 If needed, enter < htdp > to start the program and obtain the MAIN MENU.

5.2 Enter < 4 > to specify that positional coordinates will be transformed between reference frames.

5.3 Enter < Ex5_trans.out > for the name of the output file that will contain the transformed coordinates.

5.4 Enter < 1 > to specify that the input coordinates are referenced to NAD_83(2011/CORS96/2007).

5.5 Enter < 26 > to specify that the output coordinates will refer to ITRF2020 or IGS20/IGb20.

5.6 Enter < 2 > to indicate that the following date is to be entered in decimal year format.

5.7 Enter < 2010 > to specify that the input coordinates refer to the location of the point on January 1, 2010.

5.8 Enter < 2 > to indicate that the following date is to be entered in decimal year format.

5.9 Enter < 2020 > to specify that the output coordinates will refer to the location of the point on January 1, 2020.

5.10 Enter < 1 > to indicate that you will transform coordinates for individual points entered interactively.

5.11 Enter < Kansas > for the name of the point (near the center of CONUS).

5.12 Enter < 1 > to indicate that you will specify the point’s latitude and longitude.

5.13 Enter < 39 0 0 > to specify that the NAD 83 latitude of the point on January 1, 2010 is 39°00’00.0” N.

5.14 Enter < 98 0 0 > to specify that the NAD 83 longitude of the point on January 1, 2010 is 98°00’00.0” W.

5.15 Enter < 370 > to specify a NAD 83 ellipsoid height of 370 meters.

5.16 Enter < 0 > to indicate that HTDP will estimate the velocity to be used in transforming the coordinates from NAD_83(2011/CORS962007) at January 1, 2010 to ITRF2020 at January 1, 2020. The will display the following information:

```
****************************************
 New latitude   =  39  0  0.02173 N
 New longitude  =  98  0  0.04468 W
 New Ellip. Ht. =      368.974 meters
 New X          =  -690802.570 meters
 New Y          = -4915307.967 meters
 New Z          =  3992549.746 meters
 ****************************************
```

5.17 Enter < n > to indicate that you will not transform coordinates at additional points. This will write the following information to the output file “Ex5_trans.out”:

```
HTDP OUTPUT, VERSION 3.6.0

TRANSFORMING POSITIONS FROM NAD_83(2011/CORS96/2007) (EPOCH = 01-01-2010 (2010.0000))
                         TO ITRF2020 or IGS20/IGb20  (EPOCH = 01-01-2020 (2020.0000))

Kansas
 LATITUDE     39 00  0.00000 N     39 00  0.02173 N        0.78 mm/yr  north
 LONGITUDE    98 00  0.00000 W     98 00  0.04468 W        2.21 mm/yr  east
 ELLIP. HT.            370.000              368.974 m     -1.10 mm/yr  up
 X                 -690801.675          -690802.570 m      2.38 mm/yr
 Y                -4915309.324         -4915307.967 m      1.02 mm/yr
 Z                 3992549.871          3992549.746 m     -0.09 mm/yr
```

Note that the velocities are for the input (source) reference frame. In this example, these are the NAD_83(2011/CORS96/2007) velocities that were used to transform NAD 83 coordinates from January 1, 2010 to January 1, 2020. These coordinates were than transformed from NAD 83 to ITRF2020 at epoch 2020.00. If the direction of the transformation was reversed, the velocities would be with respect to ITRF2020 (and with greater horizontal magnitudes).

This concludes Exercise 5.

Exercise 6. *Transforming positions between reference frames and/or dates for a set of points*

For this exercise, the input file "Ex6_NAmerica.txt" is provided, which is a comma-delimited ASCII file of points with latitude and longitude values in decimal degrees (with longitudes positive west), ellipsoid heights in meters, and a descriptive name for each point (the state or territory of the point location).

6.1 If needed, enter < htdp > to start the program and obtain the MAIN MENU.

6.2 Enter < 4 > to specify that positional coordinates will be transformed between reference frames.

6.3 Enter < Ex6_NAmerica.out > for the name of the output file to contain the transformed coordinates.

6.4 Enter < 1 > to specify that the input coordinates are referred to NAD_83(2011/CORS96/2007).

6.5 Enter < 26 > to specify that output coordinates are to be referred to ITRF2020 or IGS20/IGb20.

6.6 Enter < 2 > to indicate that the following date is to be entered in decimal year format.

6.7 Enter < 2010 > to specify that the input coordinates refer to point locations on January 1, 2010.

6.8 Enter < 2 > to indicate that the following date is to be entered in decimal year format.

6.9 Enter < 2020 > to specify that the output coordinates refer to point locations on January 1, 2020.

6.10 Enter < 3 > to specify that a file with multiple points as latitude, longitude, and ellipsoid height will be used for input (note that option 2 allows input of Bluebook B-files, as discussed in Exercise 4).

6.11 Enter < Ex6_NAmerica.txt > for the name of the input file. This file contains input point coordinates at locations that are referenced to NAD_83(2011/CORS96/2007). The contents of output file "Ex6_NAmerica.out" are shown below (note that the output for point Kansas is the same as in Exercise 5, except that latitude and longitude are in decimal degrees):

```
HTDP OUTPUT, VERSION 3.6.0

TRANSFORMING POSITIONS FROM NAD_83(2011/CORS96/2007) (EPOCH = 01-01-2010 (2010.0000))
                         TO ITRF2020 or IGS20/IGb20  (EPOCH = 01-01-2020 (2020.0000))

***CAUTION: This file was processed using HTDP version 3.6.0   ***
***CAUTION: Coordinates in this file are in ITRF2020 or IGS20/IGb20 ***
***CAUTION: Coordinates in this file have been updated to  1-01-2020=(2020.000) ***

  39.0000060350   98.0000124108   368.974    Kansas
  37.0000054840  122.0000193357    29.452    California
  48.0000034451  124.0000184305   549.713    Washington
  45.0000107414   69.0000048816    68.862    Maine
  28.0000058185   81.0000058833   -11.555    Florida
  64.9999966298  152.0000304458   120.482    Alaska
  18.2000050183   66.4999985027   888.122    Puerto Rico
```

There are also two other input files. "Ex6_Pacific.txt" is for two locations that would typically be referenced to the NAD 83 (PA11/PACP00) frame (in Hawaii and American Samoa). "Ex6_Mariana.txt" is for two locations that would typically be referenced to the NAD 83 (MA11/MARP00) frame (Guam and Saipan). The ITRF2020 epoch 2020.00 output files for both of these files are also provided ("Ex6_Pacific.out" and "Ex6_Mariana.out").

This concludes Exercise 6.

Exercise 7. *Transforming velocities between reference frames*

7.1 If needed, enter < htdp > to start the program and obtain the MAIN MENU.

7.2 Enter < 5 > to specify transformation of velocities between reference frames.

7.3 Enter < Ex7_vel_trans.out > for the name of the output file to contain the transformed velocities.

7.4 Enter < 1 > to specify that the input velocities are referred to NAD 83(2011/CORS96/2007).

7.5 Enter < 24 > to specify that output velocities will be referred to ITRF2008.

7.6 Enter < 1 > to specify that velocities for individual points will be entered interactively.

7.7 Enter < Kansas > as the name of the point that will have its velocity transformed from NAD 83(2011/CORS96/2007) to ITRF2008 velocity (this is the same Kansas point as used in Exercises 5 and 6).

7.8 Enter < 1 > to specify that you will provide the point's latitude, longitude, and ellipsoid height.

7.9 Enter < 39 0 0 > to denote the input NAD 83 latitude of 39°00'00.0" N.

7.10 Enter < 98 0 0 > to denote the input NAD 83 longitude of 98°00'00.0" W.

7.11 Enter < 370 > to denote the input NAD 83 ellipsoid height in meters (this height is not used in the computations).

7.12 Enter < 1 > to indicate that the north, east, and up components of the velocity will be entered (as given in the output of Exercise 5).

7.13 Enter < 0.78 > to specify the northward component of the NAD 83 velocity in mm/yr.

7.14 Enter < 2.21 > to specify the eastward component of the NAD 83 velocity in mm/yr.

7.15 Enter < -1.10 > to specify the upward component of the NAD 83 velocity in mm/yr. The screen will display the following information:

```
************************************************
New northward velocity =    -3.17 mm/yr
New eastward velocity  =   -14.23 mm/yr
New upward velocity    =    -0.00 mm/yr
New x velocity         =   -14.37 mm/yr
New y velocity         =     0.01 mm/yr
New z velocity         =    -2.46 mm/yr
************************************************
```

Note that the horizontal velocities in ITRF2008 increased (since NAD 83 coordinates are nominally fixed to the stable part of the North America tectonic plate). The upward velocity also became zero, as expected since the ITRF2008 velocity grids have vertical velocities of zero.

In the second part of this Exercise, the same point in California that was used in Exercise 6 will be added, to show the velocities in a much more tectonically active area (the input velocities were obtained separately using HTDP).

7.16 Enter < 1 > to add another point interactively.

7.17 Enter < California > for the name of the second point.

7.18 Enter < 1 > to specify that you will provide the point's latitude, longitude, and ellipsoid height.

7.19 Enter < 37 0 0 > to denote the input NAD 83 latitude of 37°00'00.0" N.

7.20 Enter < 122 0 0 > to denote the input NAD 83 longitude of 122°00'00.0" W.

7.21 Enter < 30 > to denote the input NAD 83 ellipsoid height in meters.

7.22 Enter < 1 > to indicate that the north, east, and up components of the velocity will be entered.

7.23 Enter < 36.08 > to specify the northward component of the NAD 83 velocity in mm/yr.

7.24 Enter < -24.88 > to specify the eastward component of the NAD 83 velocity in mm/yr.

7.25 Enter < -1.34 > to specify the upward component of the NAD 83 velocity in mm/yr. The screen will display the following information:

```
************************************************
New northward velocity =    23.06 mm/yr
New eastward velocity  =   -38.37 mm/yr
New upward velocity    =    -0.00 mm/yr
New x velocity         =   -25.19 mm/yr
New y velocity         =    32.10 mm/yr
New z velocity         =    18.42 mm/yr
************************************************
```

7.26 Enter < 0 > to return to the MAIN MENU and write the results to output file "Ex7_vel_trans.out":

```
HTDP OUTPUT, VERSION 3.6.0

TRANSFORMING VELOCITIES FROM NAD_83(2011/CORS96/2007) TO ITRF2008 or IGS08/IGb08

                INPUT VELOCITIES      OUTPUT VELOCITIES

Kansas
latitude =   39.000000000  longitude =   98.000000000
    northward velocity     0.78          -3.17 mm/yr
    eastward velocity      2.21         -14.23 mm/yr
    upward velocity       -1.10          -0.00 mm/yr
    x velocity             2.38         -14.37 mm/yr
    y velocity             1.03           0.01 mm/yr
    z velocity            -0.09          -2.46 mm/yr

California
latitude =   37.000000000  longitude =  122.000000000
    northward velocity    36.08          23.06 mm/yr
    eastward velocity    -24.88         -38.37 mm/yr
    upward velocity       -1.34          -0.00 mm/yr
    x velocity            -9.03         -25.19 mm/yr
    y velocity            32.51          32.10 mm/yr
    z velocity            28.01          18.42 mm/yr
```

For the California point, the horizontal velocity magnitude remained nearly the same (about 44 mm/yr in both cases), but the direction changed. The change occurred because the input velocity is with respect to the North America plate, but the point is in an actively deforming area in the boundary region between it and the Pacific plate. As with the Kansas point, the ITRF2008 upward velocity is zero.

This concludes Exercise 7.