HTDP User Guide
(Software Version 3.3.0)
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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 utility that allows users to transform positional coordinates across time and between spatial reference frames. HTDP enables users to perform each of the following six 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.

HTDP 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).

The latest version of HTDP can be run interactively on the world-wide-web at https://geodesy.noaa.gov/TOOLS/Htdp/Htdp.shtml. The PC executable **htdp.exe** and source code can also be downloaded from this web site. HTDP source code is in Fortran 90 and consists of the main program **htdp.f**, plus four sub-programs (initbd.f, initeq.f, initps.f, and initvl.f) containing crustal motion model block 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 Windows command interface (cmd.exe).

The HTDP web site also contains:

- The latest version of this HTDP User Guide, containing instructional exercises.
- Sample data files for use with the instructional exercises.
- A log file summarizing revisions to HTDP in reverse chronological order.
- Copies of relevant publications.
- Several crustal motion maps.

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 27 regions, with each region being one of two types. With the first type, HTDP employs a 2D rectangular grid (in latitude and longitude) spanning a region 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 the velocity grids are shown in the map of Figure 1. Note that the St. Elias, Alaska, region is defined by a polygon the 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.

Table 1. The ten velocity grids defined in 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).

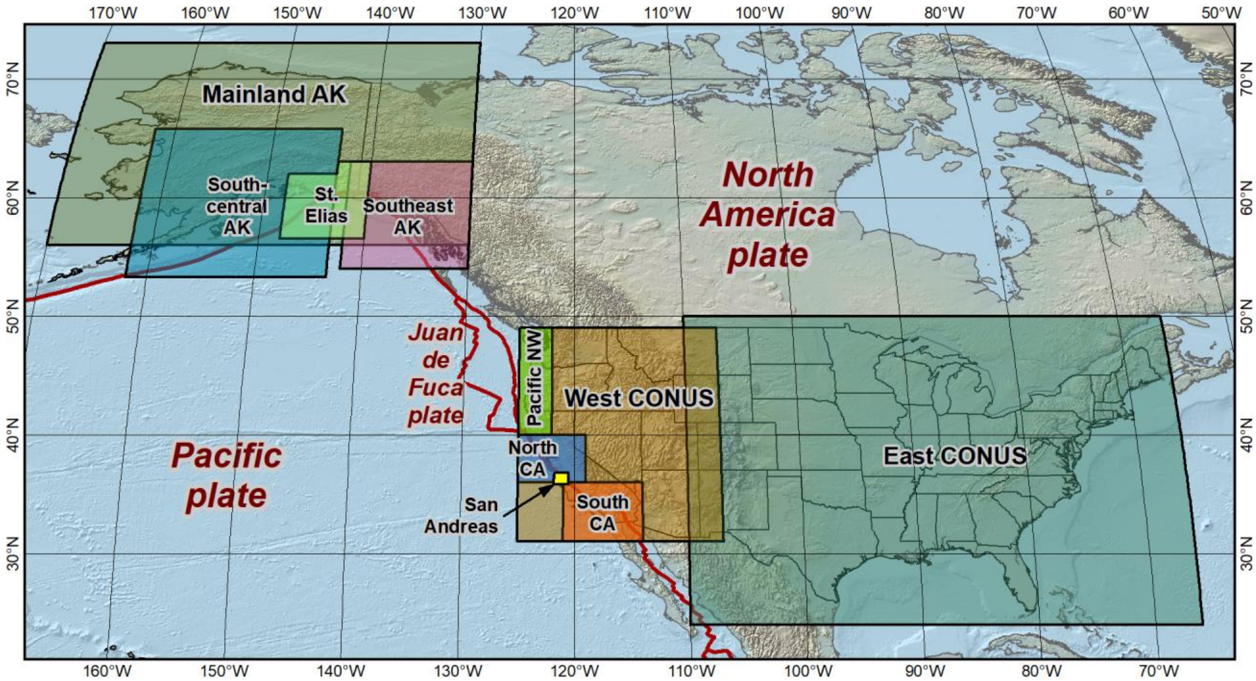

Figure 1. Extents of the ten velocity grids in the current version of HTDP, along with tectonic plates.

With the second type of region, HTDP uses rigid tectonic plate models to estimate horizontal velocities via the equations

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

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 3D velocity 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. When the coordinates are expressed in meters and the rotation rates in radians/year, then the computed velocities will be expressed in meters/year. Note that vertical velocities equal zero for locations within this type of region. Table 2 lists the 17 tectonic plates regions currently defined in HTDP and the sources for the translation and rotation rates. All plate motions in HTDP are computed with respect to ITRF2008. Rates defined in other frames are converted to ITRF2008 within the current version of HTDP. The following plates have rates referenced to other frames in Table 2: the Mariana plate (ITRF2000) and the ten plates added in HTDP v3.3.0 (ITRF2014).

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 by NGS in December 2020 to eliminate gaps, overlaps, duplicates, and superfluous vertices. Figure 2 is a map showing the plates currently encoded in HTDP.

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

Tectonic plate name	**HTDP region number**	**Reference frame** [a]	**Translation rates (mm/yr)**			**Rotation rates (nrad/yr)**			**Source for motion rates**
			$\dot{T}_X$	$\dot{T}_Y$	$\dot{T}_Z$	$\dot{R}_X$	$\dot{R}_Y$	$\dot{R}_Z$	
North America	14	ITRF2008	0.41	0.22	0.41	0.170	-3.209	-0.485	Altamimi et al. (2012)
Caribbean	15	ITRF2008	0.41	0.22	0.41	0.238	-5.275	3.219	Altamimi et al. (2012)
Pacific	16	ITRF2008	0.41	0.22	0.41	-1.993	5.023	-10.501	Altamimi et al. (2012)
Juan de Fuca	17	ITRF2008	0.41	0.22	0.41	6.626	11.708	-10.615	DeMets et al. (2010) [b]
Cocos	18	ITRF2008	0.41	0.22	0.41	-10.390	-14.954	9.148	DeMets et al. (2010) [b]
Mariana	19	ITRF2000	0.00	0.00	0.00	-0.097	0.509	-1.682	Snay (2003a)
Philippine Sea	20	ITRF2008	0.41	0.22	0.41	-0.841	3.989	-10.626	DeMets et al (2010) [b]
The following ten plates were added to HTDP v3.3.0 using motion rates relative to ITRF2014									
South America	21	ITRF2014	0.00	0.00	0.00	-1.309	-1.459	-0.679	Altamimi et al. (2017)
Nazca	22	ITRF2014	0.00	0.00	0.00	-1.614	-7.486	7.869	Altamimi et al. (2017)
Panama	23	ITRF2014	0.00	0.00	0.00	2.088	-23.037	6.729	Kreemer et al. (2014)
North Andes	24	ITRF2014	0.00	0.00	0.00	-1.964	-1.518	0.400	Mora-Páez et al. (2018) [c]
Africa [d]	25	ITRF2014	0.00	0.00	0.00	0.480	-2.977	3.554	Altamimi et al. (2017)
Eurasia	26	ITRF2014	0.00	0.00	0.00	-0.412	-2.574	3.733	Altamimi et al. (2017)
Rivera	27	ITRF2014	0.00	0.00	0.00	-21.933	-70.432	27.071	DeMets et al. (2010) [b]
Galapagos	28	ITRF2014	0.00	0.00	0.00	14.273	94.440	4.520	Bird (2003) [b]
Tonga	29	ITRF2014	0.00	0.00	0.00	137.841	10.447	68.458	Kreemer et al. (2014)
Niuafo'ou	30	ITRF2014	0.00	0.00	0.00	-57.324	-5.814	-3.722	Bird (2003) [b]

[a] Motion rates relative to frames other than ITRF2008 are converted to ITRF2008 rates by HTDP for the following plates: Mariana (ITRF2000) and all ten plates (region numbers 21-30) added to HTDP v3.3.0 (ITRF2014).

[b] Rotation rates were provided relative to the Pacific plate. Those rates were converted to rates relative to ITRF2008 or ITRF2014, as indicated, using rates for the Pacific plate relative to ITRF2008 from Altamimi et al. (2012) or to ITRF2014 from Altamimi et al. (2017), respectively.

[c] Rotation rates were provided relative to the South America plate and were converted to ITRF2014 using rates for the South America plate relative to ITRF2014 from Altamimi et al. (2017).

[d] Referred to as Nubia plate in Altamimi et al. (2012 and 2017) and DeMets et al. (2010).

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 placeholder numbers for future velocity grids). Velocity grids all precede the tectonic plates and are contained entirely within the area defined by the tectonic plates. When a user specifies a location, HTDP steps through the 27 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.

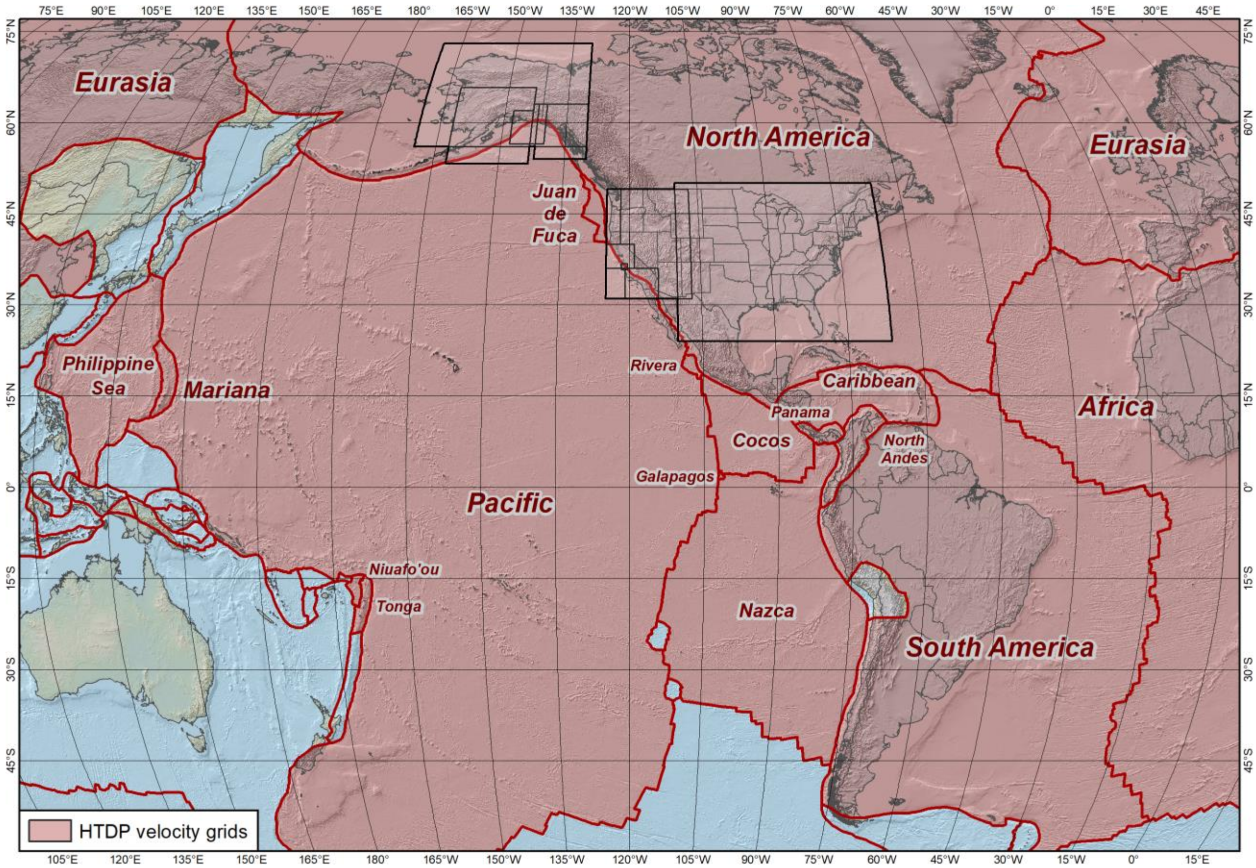

Figure 2. The 17 tectonic plates currently encoded in HTDP (labeled and shaded red). Plate polygons are based on Bird (2003). HTDP velocity grids are also shown.

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, and 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.

The 17 plates defined in HTDP were selected to provide coverage where NGS products and services require velocity or time-dependent computations. If the specified location is not contained within the tectonic plate polygons shown in Figure 2 (which includes all the velocity grids), HTDP is unable to compute velocities, displacements, or reference frame transformations where the input and output dates (epochs) differ. When this occurs, HTDP generates a message that the locations are "outside of the modeled region." However, HTDP can compute a frame transformation anywhere on Earth when the input and output epochs are the same (although such results may be of limited use).

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 may opt to allow HTDP to estimate the 3D velocity used in this procedure, or they may interactively supply the velocity.

HTDP uses the equations of dislocation theory (Okada 1985) to quantify coseismic motion for most of the major (magnitude $\geq$ 6.0) earthquakes that have occurred in and around the United States and/or its territories since 1934. Table 3 lists the earthquakes whose dislocation models are encoded into the current version of HTDP.

Table 3. Earthquake dislocation models incorporated into HTDP.

Date (month-day-year), Earthquake (magnitude)	Source of model
CALIFORNIA	
06-07-1934 Parkfield (M=6.0)	Segall and Du, 1993
05-17-1940 El Centro (M=6.9)	Snay and Herbrectsmeier, 1994
10-21-1942 San Jacinto (M=6.6)	Snay and Herbrectsmeier, 1994
07-21-1952 Kern County (M=7.5)	Snay and Herbrectsmeier, 1994
03-19-1954 San Jacinto (M=6.4)	Snay and Herbrectsmeier, 1994
06-26-1966 Parkfield (M=5.6)	Segall and Du, 1993
04-09-1968 Borrego Mtn. (M=6.5)	Snay and Herbrectsmeier, 1994
02-09-1971 San Fernando (M=6.6)	Snay and Herbrectsmeier, 1994
03-15-1979 Homestead Valley (M=5.6)	Stein and Lisowski, 1983
08-06-1979 Coyote Lake (M=5.9)	Snay and Herbrectsmeier, 1994
10-15-1979 Imperial Valley (M=6.4)	Snay and Herbrectsmeier, 1994
05-02-1983 Coalinga (M=6.4)	Stein and Ekstrom, 1992
04-24-1984 Morgan Hill (M=6.2)	Snay and Herbrectsmeier, 1994
08-04-1985 Kettleman Hill (M=6.1)	Ekstrom et al., 1992
07-08-1986 N. Palm Springs (M=5.6)	Savage et al., 1993
07-21-1986 Chalfant Valley (M=6.2)	Savage and Gross, 1995
10-01-1987 Whittier Narrow (M=5.9)	Lin and Stein, 1989
11-24-1987 Superstition Hill (M=6.6,6.2)	Larsen et al., 1992
10-17-1989 Loma Prieta (M=7.1)	Lisowski et al., 1990
04-22-1992 Joshua Tree (M=6.1)	Bennett et al., 1995
04-25-1992 Cape Mendocino (M=7.1)	Oppenheimer et al., 1993
06-29-1992 Landers/Big Bear (M=7.5,6.6)	Hudnut et al., 1994
01-17-1994 Northridge (M=6.7)	Hudnut et al., 1996
10-16-1999 Hector Mine (M=7.1)	Peltzer, Crampe, & Rosen, 2001
12-22-2003 San Simeon (M=6.5)	Johanson, 2006
10-28-2004 Parkfield (M=6.0)	Johanson et al., 2006
ALASKA	
03-28-1964 Prince William Sound (M=9.2)	Holdahl and Sauber, 1994
11-03-2002 Denali (M=7.9)	Elliott et al., 2007
MEXICO	
04-04-2010 El Mayor – Cucapah (M=7.2)	Fialko, personal communication, 2010

HTDP uses the equation

$$D_{i,j}(\varphi,\lambda,t) = A_{i,j}(\varphi,\lambda) \cdot [1.0 - exp(-(t - \tau_i)/\vartheta_i)] \qquad \text{if } \tau_i < t$$

$$D_{i,j}(\varphi,\lambda,t) = 0 \qquad \text{if } t \leq \tau_i \qquad (3.1)$$

to model the cumulative postseismic 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 M7.9 Denali earthquake that occurred in central Alaska on November 3, 2002. 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).

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,
- the starting positional coordinates and their reference epoch t_1, and
- the 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.

5. Transforming Positional Coordinates

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

- the starting reference frame and the starting positional coordinates,
- the reference epoch t_1 of the starting coordinates,
- the reference frame for the transformed coordinates, and
- the 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 a velocity model to update the coordinates from time t_1 to time t_2 in the starting reference frame.
2. Perform a Helmert 14-parameter transformation to update coordinates at time t_2 from the starting reference frame to the desired reference frame.

Section 4 describes how HTDP performs the first step. The second step is addressed in this section, as follows.

Let $x(t)_A$, $y(t)_A$, and $z(t)_A$ denote the positional coordinates of a location at time t referred to reference frame A in a 3D Earth-centered, Earth-Fixed (ECEF) Cartesian coordinate system. These coordinates are expressed as a function of time to reflect the reality of crustal motion. Similarly, let $x(t)_B$, $y(t)_B$, and $z(t)_B$ denote the positional coordinates of this same location at time t referred to reference frame B also in a 3D-ECEF Cartesian coordinate system. Within HTDP, the coordinates in frame A are approximately related to those in frame B via the following equations of a 14-parameter Helmert transformation:

$$x(t)_B = T_x(t) + [1 + s(t)]\, x(t)_A + R_z(t)\, y(t)_A - R_y(t)\, z(t)_A$$

$$y(t)_B = T_y(t) - R_z(t)\, x(t)_A + [1 + s(t)]\, y(t)_A + R_x(t)\, z(t)_A$$

$$z(t)_B = T_z(t) + R_y(t)\, x(t)_A - R_x(t)\, y(t)_A + [1 + s(t)]\, z(t)_A \quad . \qquad (5.1)$$

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 frame A and reference frame B. These approximate equations suffice because the three rotations have relatively small magnitudes. 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. In HTDP, these time-related variations are assumed to be linear, so that each of the seven quantities 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 time of reference and the two quantities, $P(\tau)$ and $\dot{P}$, are constants. Thus, the seven quantities give rise to 14 parameters, but note that 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. A point's NAD 83 velocity 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 American 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. 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 1999):

$$T_x(t) = 0.9910 + 0.0\ (t - 1997.00) = 0.9910 \text{ meters}$$

$$T_y(t) = -1.9072 + 0.0\ (t - 1997.00) = -1.9072 \text{ meters}$$

$$T_z(t) = -0.5129 + 0.0\ (t - 1997.00) = -0.5129 \text{ meters}$$

$$R_x(t) = [125.033 + 0.258\ (t - 1997.00)] \times 10^{-9} \text{ radians}$$

$$R_y(t) = [46.785 - 3.599\ (t - 1997.00)] \times 10^{-9} \text{ radians}$$

$$R_z(t) = [56.529 - 0.153\ (t - 1997.00)] \times 10^{-9} \text{ radians}$$

$$s(t) = 0.0 + 0.0\ (t - 1997.00) = 0.0 \text{ (unitless).} \quad (5.3)$$

In these equations, τ is 1997.00, which corresponds to January 1, 1997.

Presently, HTDP needs to deal with more than a two dozen reference frames. Rather than store the 14 parameters for each possible combination of two reference frames, HTDP uses two mathematical approximations to reduce its storage requirement. In particular, because all rotation angles are relatively 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

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

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

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

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 –1.0.

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

$$(A \rightarrow B) \approx -(ITRF94 \rightarrow A) + (ITRF94 \rightarrow B). \quad (5.6)$$

6. Transforming Observations

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

- the type of observation,
- the observed value,
- the date on which the observation was measured,
- the positional coordinates of the associated locations,

- the reference frame and the reference epoch of the provided coordinates, and
- the date to which the transformed observation is to 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 a Bluebook file (NGS 2020). HTDP will then create a new Bluebook file in which the observational records from the input Bluebook file have been replaced with corresponding records that contain updated values for the observed quantities. These coordinates must all be referred 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 GPS data). The Bluebook file 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 GPS data collected simultaneously at pairs of locations) do depend on reference frame choice. An example of each possibility is presented in the remaining paragraphs of this section.

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 $C(t_2) - \hat{C}(t_2)$ should approximate the difference $C(t_1) - \hat{C}(t_1)$ in value as both differences involve essentially the same errors. Consequently, the expression

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

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-difference vector between locations *A* and *B* at time t_1 as referred to reference frame *F1*. To transform this vector to its corresponding vector at time t_2 and referred to frame *F2*, HTDP will employ a three-step process:

- transform the starting 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*, and
- transform the resulting vector from *F0 to F2* at time t_2.

For the first step, HTDP uses the equations:

$$D_x(t_1)_{F0} = [1 + s(t_1)]\, D_x(t_1)_{F1} + R_z(t_1)\, D_y(t_1)_{F1} – R_y(t_1)\, D_z(t_1)_{F1}$$

$$D_y(t_1)_{F0} = - R_z(t_1)\, D_x(t_1)_{F1} + [1 + s(t_1)]\, D_y(t_1)_{F1} + R_x(t_1)\, D_z(t_1)_{F1}$$

$$D_z(t_1)_{F0} = R_y(t_1)\, D_x(t_1)_{F1} – R_x(t_1)\, D_y(t_1)_{F1} + [1 + s(t_1)]\, D_z(t_1)_{F1} \qquad (6.1)$$

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 corresponding coordinates at time t_2. HTDP then uses the equation

$$D_x(t_2)_{F0} = D_x(t_1)_{F0} + [x_B(t_2) – x_A(t_2)] – [x_B(t_1) – x_A(t_1)] \qquad (6.2)$$

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 equation similar to equation (6.1).

7. Transforming Velocity Vectors

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

- the velocity vector in frame *A*, and
- the coordinates of location *C* in frame *A*.

HTDP then transforms the input velocity $((V_x)_A, (V_y)_A, (V_z)_A)$ in frame *A* to corresponding velocities in frame *B* via the equations:

$$(V_x)_B = (V_x)_A + \dot{T}_x + \dot{s}\, x + \dot{R}_z\, y – \dot{R}_y\, z$$

$$(V_y)_B = (V_y)_A + \dot{T}_y – \dot{R}_z\, x + \dot{s}\, y + \dot{R}_x\, z$$

$$(V_z)_B = (V_z)_A + \dot{T}_z + \dot{R}_y\, x – \dot{R}_x\, y + \dot{s}\, z \qquad (7.1)$$

Here (x, y, z) denotes the 3D-ECEF Cartesian coordinates of location *C* referred to frame *A*; $(\dot{T}_x, \dot{T}_y, \dot{T}_z)$ denotes the three translation rates of frame *B* relative to frame *A*; $(\dot{R}_x, \dot{R}_y, \dot{R}_z)$ denotes 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 recognized by HTDP

Table 4 shows the 23 reference frames currently supported in HTDP, along with other relevant information and references. 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. Note that some reference frames share the same key. Key 4 is not listed because it was used for WGS 72, and HTDP stopped supporting that frame in v3.2.1, because WGS72 uses a different ellipsoid than the other reference frames defined in HTDP.

The supported frames include all three realizations of NAD 83 (referenced to the North America, Pacific, and Mariana plates); all official realizations of WGS 84; and all International Terrestrial Reference Frame (ITRF) realizations of the ITRS. Also included are all of the 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 WGS 84 (original)—also referred to as WGS 84 (Transit)—which is assumed as equivalent to NAD 83 referenced to the North America plate. However, the WGS 84 frames each 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) 2020. Some of these parameters have been updated since they were originally published in International Earth Rotation and Reference Frame Service (IERS) Technical Notes. The IERS 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 NAD 83 referenced to the North America tectonic plate that have explicitly defined epochs. However, it is important to understand that HTDP should not be used to transform between the various NAD 83 realizations. Only a single definition for NAD 83 referenced to the North America plate exists in HTDP, and that is the one defined by equation (5.3) in this document. Because of this, it is impossible for HTDP to correctly transform between NAD 83 realizations (e.g., 2011, NSRS2007, CORS96, HARN, FBN, etc.). To perform such transformations between NAD 83 realizations, the NGS Coordinate Conversion and Transformation Tool (NCAT) should be used instead, available at https://geodesy.noaa.gov/NCAT/. The same is true for the NAD 83 frames referenced to the Pacific and Mariana plates. Only a single definition for each exists in HTDP, and so NCAT should be used for transforming between NAD 83 realizations in these areas as well.

Although all the 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. Reference frames recognized by HTDP. Domains (areas of usage) for NAD 83 frames are given in the table; all other frames are global.

Reference frame	Default reference epoch [a]	Responsible agencies	HTDP key	References and additional information
NAD 83 referenced to the North America plate. Includes all realizations of NAD 83 but reference epochs only specifically defined for (2011/2007/ NSRS2007/CORS96). 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) for NAD 83 (CORS96)
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)
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)
WGS 84 (original)	1984.00	NGA	5	NIMA (2004) ≈ *NAD 83(2011)*
WGS 84 (G730)	1994.00	NGA	6	NGA (2014) ≈ *ITRF91*
WGS 84 (G873)	1997.00	NGA	7	NGA (2014) ≈ *ITRF94*
WGS 84 (G1150)	2001.00	NGA	8	NGA (2014) ≈ *ITRF2000*
WGS 84 (G1674)	2005.00	NGA	9	NGA (2014) ≈ *ITRF2005*
WGS 84 (G1762)	2005.00	NGA	10	NGA (2014) ≈ *ITRF2005*
SIO/MIT 92	1992.57		11	*(aligned with ITRF91)*
PNEOS 90 & NEOS 90	1988.00		14	*(aligned with ITRF90)*
ITRF88	1988.00	IERS	12	IERS Ann. Rep. for 1988 [b]
ITRF89	1988.00	IERS	13	IERS Tech. Note 6 [b]
ITRF90	1988.00	IERS	14	IERS Tech. Note 9 [b]
ITRF91	1988.00	IERS	15	IERS Tech. Note 12 [b]
ITRF92	1994.00	IERS	16	IERS Tech. Note 15 [b]
ITRF93	1995.00	IERS	17	IERS Tech. Note 18 [b]
ITRF94	1996.00	IERS	18	IERS Tech. Note 20 [b]
ITRF96	1997.00	IERS	19	IERS Tech. Note 24 [b]
ITRF97; IGS97	1997.00	IERS; IGS	20	IERS Tech. Note 27 [b]
ITRF2000; IGS00; IGb00	1997.00	IERS; IGS	21	IERS Tech. Note 31 [b]; Kouba (2009)
ITRF2005; IGS05	2000.00	IERS; IGS	22	Altamimi et al. (2007) [b]; Kouba (2009)
ITRF2008; IGS08; IGb08	2005.00	IERS; IGS	23	Altamimi et al. (2011) [b]; Rebischung et al. (2011)
ITRF2014; IGS14; IGb14	2010.00	IERS; IGS	24	Altamimi et al. (2016) [b]; IGS (2017)

[a] The *default reference epoch* is typically the date to which coordinates refer when a frame is realized. If an HTDP user is uncertain as to the correct epoch, either this epoch or the date of the observations used for determining the coordinates can be used.

[b] Not all of the IERS Technical Notes for the ITRFs give the current accepted transformation parameters between ITRFs. A complete set of the official transformation parameters used in HTDP is given by IGN (2020).

9. Software Characteristics

Users can run the latest version of HTDP interactively online at https://geodesy.noaa.gov/TOOLS/Htdp/Htdp.shtml. Users can also download the executable file, htdp.exe, or the source code from this web site. The htdp.exe file can be run directly on a PC through a Windows command interface (cmd.exe). The source code is written in Fortran 90 and consists if the main program, htdp.f, plus four sub-programs (initbd.f, initeq.f, initps.f, and initvl.f) containing crustal motion model block datasets that are integrated into htdp.exe when the program is compiled. If desired, the source code can be compiled and linked to create an executable file. 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 HTDP software 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). For example, if requested, the software will estimate displacements and/or velocities for all locations having an *80* record in an existing Bluebook file. The second format for batch entry involves 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). The format is also slightly different 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 Earth-centered, Earth-fixed Cartesian coordinates expressed in meters and TEXT = descriptive text (maximum of 24 characters).

Besides estimating displacements and/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 an ellipsoid that approximates 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 format. In particular, the software accepts direction observations, angle observations, distance observations, azimuth observations, and interstation GPS vector observations (also known as GPS baselines).

10. Auxiliary Information

This User's Guide contains a set of eight 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 (2008), Pearson et al. (2010), Snay and Pearson (2011), 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).

11. 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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HTDP EXERCISES

January 8, 2021

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.

All input and output files in the examples are in the “HTDP-download.zip” file available on the HTDP web page (https://geodesy.noaa.gov/TOOLS/Htdp/Htdp.shtml).

EXERCISE 1. Estimating velocities at individual points.

1.1 Enter <htdp> to start the program. Some introductory information should now be displayed on the computer's screen along with the "MAIN MENU."

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

1.3 Enter <vfile.out> as the name for the file that will contain the estimated velocities.

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

1.5 Enter <1> to indicate that you will be entering positional coordinates for individual points in an interactive manner.

1.6 Enter <alpha> for the name of the first point whose velocity will be estimated.

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

1.8 Enter <38,6,12.96> to denote that the latitude of alpha is 38° 06' 12.96" N (note that a space can be used rather than a comma to separate degrees, minutes, and seconds).

1.9 Enter <122,56,7.8> to denote that the longitude of alpha is 122° 56' 7.80" W.

1.10 Enter <0> to denote that the ellipsoid height of alpha is 0.0 meters. The screen should display the following information:

```
 **************************************
 Northward velocity =  37.19 mm/yr
 Eastward velocity  = -23.79 mm/yr
 Upward velocity    =  -1.37 mm/yr

 X-dim. velocity    =  -6.90 mm/yr
 Y-dim. velocity    =  33.10 mm/yr
 Z-dim. velocity    =  28.42 mm/yr
 **************************************
```

1.11 The screen should also display the menu for continuing. Enter <1> to estimate the velocity for another point.

1.12 Enter <beta> for the name of this second point.

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

1.14 Enter <36,40,11.28> to specify the latitude of beta.

1.15 Enter <121,46,19.92> to specify the longitude of beta.

1.16 Enter <0> to specify the ellipsoid height of beta. The screen should display the following information:

```
**************************************
 Northward velocity =  37.15 mm/yr
 Eastward velocity  = -25.83 mm/yr
 Upward velocity    =  -1.33 mm/yr

 X-dim. velocity    =  -9.71 mm/yr
 Y-dim. velocity    =  33.37 mm/yr
 Z-dim. velocity    =  29.01 mm/yr
 **************************************
```

1.17 If you wish to estimate velocities for additional points, then you may enter <1> and proceed as before. Otherwise, enter <0> to return to the main menu (the results will not be written to the output file until <0> is entered).

At this time, it is instructive to inspect the output file that contains the predicted velocities. This is the file whose name was specified in Step 1.3. Note that this file contains all the following information pertinent to the velocities that were estimated:

```
HTDP OUTPUT, VERSION 3.3.0

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

alpha
LATITUDE   =  38  6 12.96000 N  NORTH VELOCITY =  37.19 mm/yr
LONGITUDE  = 122 56  7.80000 W  EAST VELOCITY  = -23.79 mm/yr
ELLIPS. HT. =      0.000 m      UP VELOCITY    =  -1.37 mm/yr
X = -2732250.837 m              X VELOCITY     =  -6.90 mm/yr
Y = -4217684.424 m              Y VELOCITY     =  33.10 mm/yr
Z =  3914499.164 m              Z VELOCITY     =  28.42 mm/yr

beta
LATITUDE   =  36 40 11.28000 N  NORTH VELOCITY =  37.15 mm/yr
LONGITUDE  = 121 46 19.92000 W  EAST VELOCITY  = -25.83 mm/yr
ELLIPS. HT. =      0.000 m      UP VELOCITY    =  -1.33 mm/yr
X = -2696934.816 m              X VELOCITY     =  -9.71 mm/yr
Y = -4354426.684 m              Y VELOCITY     =  33.37 mm/yr
Z =  3788064.740 m              Z VELOCITY     =  29.01 mm/yr
```

This concludes Exercise 1.

EXERCISE 2. Estimating displacements at individual points.

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

2.2 From the MAIN MENU enter <1> to select option for estimating displacements between two dates.

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

2.4 Enter <1985> to indicate epoch 1985.00 (January 1, 1985).

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

2.6 Enter <1995> to indicate that the second date is January 1, 1995.

2.7 Enter <dfile1.out> for the name of the output file that is to contain the estimated displacements.

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

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

2.10 Enter <beta> for the name of the first point whose displacement from January 1, 1985 to January 1, 1995 is to be estimated.

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

2.12 Enter <36 40 11.28> for the latitude of beta.

2.13 Enter <121 46 19.92> for the longitude of beta.

2.14 Enter <0> for the ellipsoid height of beta.

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

```
****************************************
Northward displacement =   0.445 meters
Eastward displacement  =  -0.259 meters
Upward displacement    =  -0.018 meters
****************************************
```

Recall from Exercise 1 that the northward velocity of beta is 37.15 mm/yr. Thus in 10 years, beta moved 0.3715 meters northward as a result of its velocity. To this displacement, the HTDP software adds those displacements associated with major earthquakes. For example, the point beta moved northward 0.074 meters during the Loma Prieta earthquake (M=7.1) of October 18, 1989. The sum of 0.3715 meters and 0.074 meters equals the total estimated displacement of 0.445 meters (with 0.001 meter rounding error) for the 10-year period from January 1, 1985 to January 1, 1995. In the following steps, the displacement that occurred at beta during the Loma Prieta earthquake will be estimated.

2.16 Enter <0> to return to the main menu. This will also write following results to output file dfile1.out:

```
 HTDP OUTPUT, VERSION 3.3.0

 DISPLACEMENTS IN METERS RELATIVE TO NAD_83(2011/CORS96/2007)
 FROM 01-01-1985 TO 01-01-1995 (month-day-year)
 FROM 1985.000 TO 1995.000 (decimal years)

NAME OF SITE              LATITUDE          LONGITUDE            NORTH    EAST    UP
beta                      36 40 11.28000 N  121 46 19.92000 W    0.445  -0.259  -0.018
```

2.17 Enter <1> to estimate displacements.

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

2.19 Enter <10 16 1989> to indicate that the first date is October 16, 1989 (spaces can be used in place of commas, if preferred).

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

2.21 Enter <10 18 1989> to indicate that the second date is October 18, 1989.

2.22 Enter <dfile2.out> to name the output file that is to contain the estimated displacements.

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

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

2.25 Enter <beta> for the point's name.

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

2.27 Enter <36 40 11.28> for the latitude of beta.

2.28 Enter <121 46 19.92> for the longitude of beta.

2.29 Enter <0> for the ellipsoid height of beta.

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

```
*****************************************
Northward displacement =   0.074 meters
Eastward displacement  =  -0.001 meters
Upward displacement    =  -0.004 meters
*****************************************
```

Displacements associated with the Loma Prieta earthquake can now be estimated for other locations by entering <1> and responding to the prompts. When finished, enter <0> to return to the main menu and write following results to output file dfile2.out:

```
 HTDP OUTPUT, VERSION 3.3.0

 DISPLACEMENTS IN METERS RELATIVE TO NAD_83(2011/CORS96/2007)
 FROM 10-16-1989 TO 10-18-1989 (month-day-year)
 FROM 1989.789 TO 1989.795 (decimal years)

NAME OF SITE             LATITUDE          LONGITUDE            NORTH    EAST     UP
beta                     36 40 11.28000 N  121 46 19.92000 W    0.074  -0.001  -0.004
```

This concludes Exercise 2.

EXERCISE 3. Estimating velocities for sets of points.

For estimating velocities, the latitudes and longitudes of the points may be entered in several ways in addition to entering individual points interactively. The options include:

(a) specifying a grid of points,
(b) specifying the name of a file that contains the positional information in the Bluebook format,
(c) specifying a sequence of points on a line (or more precisely, a geodesic curve on Earth's surface), and
(d) specifying 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)

Examples:

40.731671553,112.21267153,Salt Air
40.713671553 112.21267153 Salt Air

The fields in each record may be separated by commas or blanks.

These same four options are available for specifying the latitudes and longitudes of points where displacements between two dates are to be estimated.

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 velocities.

3.3 Enter <vfile1.out> for the name of the output file that is to contain the estimated velocities.

3.4 Enter <1> to estimate velocities relative to the NAD_83(2011/CORS96/2007) reference frame.

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

3.6 Enter a name to identify the grid (for example, grid1).

3.7 Enter <34 0 0> to indicate that the minimum latitude is 34° 00' 00" N.

3.8 Enter <35 0 0> to indicate that the maximum latitude is 35° 00' 00" N.

3.9 Enter <300> to indicate that the latitude spacing is 300 seconds (equals 5 arc-minutes).

3.10 Enter <118 30 0> to indicate that the minimum longitude is 118° 30' 00" W.

3.11 Enter <119 10 0> to indicate that the maximum longitude is 119° 10' 00" W.

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

The screen should display the menu for specifying additional points at which velocities are to be estimated. Estimated velocities for the grid are contained in vfile1.out. To examine this file, enter <0> to return to the main menu (this will write final results to the output file).

In vfile1.out, the first point (the southeast corner of the grid) should have northward velocity of 29.66 mm/yr, eastward velocity of -24.84 mm/yr, and upward velocity of -1.23 mm/yr. The last point (the northwest corner) should have northward velocity of 20.42 mm/yr, eastward velocity of -14.51 mm/yr, and upward velocity of -1.26 mm/yr.

In the following steps, velocities will be estimated for a set of points in the file wa.bfile.txt which contains data for selected reference stations located in Washington state. This file is in the Bluebook format which is the format adopted by the Federal Geodetic Control Subcommittee for transferring geodetic data. For estimating velocities, the HTDP software uses only the Bluebook records that have *80* in columns 7 through 10. Furthermore, the program reads only the following fields on these records.

Columns	Content	FORTRAN format
15-44	name of point	A30
45-55	latitude (deg-min-sec)	I2,I2,F7.5
56	N or S latitude	A1
57-68	longitude (deg-min-sec)	I3,I2,F7.5
69	W or E longitude	A1

Before estimating velocities for the points in wa.bfile.txt, it may be instructive to examine the contents of this file, especially the *80* records.

3.13 Follow Steps 3.1 through 3.4 as before except use the name, vfile2.out, for the output file that will contain the estimated velocities.

3.14 Enter <3> to indicate that the points are in a Bluebook file.

3.15 Enter <wa.bfile.txt> to specify the name of the Bluebook file.

3.16 To examine vfile2.out, enter <0> to return to the main menu. The estimated velocities for the points in wa.bfile.txt are in vfile2.out (shown below):

```
HTDP OUTPUT, VERSION 3.3.0

VELOCITIES IN MM/YR RELATIVE TO NAD_83(2011/CORS96/2007)
NAME OF SITE              LATITUDE          LONGITUDE           NORTH    EAST    UP

SEDRO WOOLEY DNR CORS AR 48 31 17.59215 N  122 13 25.78964 W     4.90    5.66   -1.55
GP 29020 9               48 30 27.21580 N  122 13 40.82432 W     4.91    5.67   -1.55
POT TXY 3                48 28 14.93084 N  122 25 49.90300 W     5.16    5.92   -1.55
BVS A                    48 27 45.70456 N  122 25 33.86127 W     5.16    5.92   -1.55
```

In the following steps, we will estimate velocities for a sequence of points that lie along a line that forms a geodesic curve on Earth's surface.

3.17 Follow Steps 3.1 through 3.4 as before except use the name, vfile3.out, for the output file that will contain the estimated velocities.

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

3.19 Enter a name to identify the line (for example, “line1”).

3.20 Enter <35 17 28.3> to specify the latitude of a point through which the line is to pass. We will refer to this point as the origin.

3.21 Enter <120 15 35.431> to specify the longitude of the origin.

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

3.23 Enter <-5000 10000> to specify that velocities will be estimated for points located between 5000 meters before the origin and 10000 meters after the origin.

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

3.25 The screen should display the menu for specifying additional points at which the velocities are to be estimated. Enter <0> to return to the main menu, and to write the estimated velocities for the points on the line to vfile3.out (shown below):

```
HTDP OUTPUT, VERSION 3.3.0

VELOCITIES IN MM/YR RELATIVE TO NAD_83(2011/CORS96/2007)
NAME OF LINE      LATITUDE          LONGITUDE           NORTH    EAST    UP

line1        0   35 17 28.25504 N  120 18 53.31236 W    32.80  -25.08   -1.28
line1        1   35 17 28.30000 N  120 15 35.43100 W    32.25  -24.70   -1.28
line1        2   35 17 28.25504 N  120 12 17.54964 W    31.66  -24.28   -1.28
line1        3   35 17 28.12016 N  120  8 59.66841 W    31.00  -23.82   -1.28
```

The second of these points should correspond to the origin. Note that the origin has the highest latitude of the four points because the line forms a geodesic curve whose azimuth is 90 degrees when passing through the origin.

This concludes Exercise 3.

EXERCISE 4. Transform observations to a specified reference frame and/or date.

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

4.2 Enter <3> to specify that positions will be updated.

4.3 Enter <1> to indicate that the following time will be entered in the month-day-year format.

4.4 Enter <7 4 1995> to specify that the new coordinates are to correspond to the position of the point on July 4, 1995.

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

4.6 Enter <1> to specify that individual points will be entered interactively.

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

4.8 Enter <1991.345> to specify that the input coordinates are to correspond to the position of the point at the beginning of the day on May 7, 1991.

4.9 Enter <newfile.out> for the name of the output file that will contain the updated coordinates.

4.10 Enter <alpha> for the name of the point whose positional coordinates will be updated.

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

4.12 Enter <38 6 12.96> for the latitude of alpha on May 7, 1991.

4.13 Enter <122 56 7.8> for the longitude of alpha on May 7, 1991.

4.14 Enter <0> for the ellipsoid height of alpha on May 7, 1991.

4.15 Enter <0> to indicate that the software will estimate the velocity to be used in updating the position. The screen should display the following information:

```
****************************************
Updated latitude   =  38  6 12.96502 N
Updated longitude  = 122 56  7.80406 W
Updated Ellip. Ht. =       -0.006 meters
Updated X          = -2732250.866 meters
Updated Y          = -4217684.286 meters
Updated Z          =  3914499.282 meters
****************************************
```

4.16 Enter <n> to indicate that no more coordinates are to be updated at this time.

Examine the file, newfile.out, at this time, which are shown below. Note that it contains both the old and the new coordinates. It also contains the velocities and the (total) displacements applied to update the positional coordinates.

```
HTDP OUTPUT, VERSION 3.3.0

UPDATED POSITIONS IN NAD_83(2011/CORS96/2007)
FROM  5-06-1991 TO  7-04-1995 (month-day-year)
FROM 1991.345 TO 1995.504 (decimal years)

               OLD COORDINATE    NEW COORDINATE    VELOCITY      DISPLACEMENT

alpha
LATITUDE     38 06 12.96000 N   38 06 12.96502 N   37.19 mm/yr   0.155 m north
LONGITUDE   122 56  7.80000 W  122 56  7.80406 W  -23.79 mm/yr  -0.099 m east
ELLIP. HT.            0.000             -0.006   -1.37 mm/yr  -0.006 m up
X               -2732250.837       -2732250.866   -6.90 mm/yr  -0.029 m
Y               -4217684.424       -4217684.286   33.10 mm/yr   0.138 m
Z                3914499.164        3914499.282   28.42 mm/yr   0.118 m
```

This concludes Exercise 4.

EXERCISE 5. Update positional coordinates for points in a Bluebook file and update the corresponding observations (menu option "Transform observations to a specified reference frame and/or date.")

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

5.2 Enter <3> to indicate that coordinates and observations will be updated.

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

5.4 Enter <2010> to indicate that the updated coordinates and observations will correspond to January 1, 2010.

5.5 Enter <1> to specify that positions will be expressed in the NAD 83(2011/CORS96/2007) reference frame.

5.6 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).

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

5.8 Enter <wa.bfile.txt> to indicate that file that contains the original coordinates.

5.9 Enter <wa.bfile.out> for the name of the blue-book file that will contain the updated coordinates.

5.10 Enter <1> to indicate that the following time will be entered in the month-day-year format.

5.11 Enter <5 7 1991> to specify that input coordinates correspond to the positions on May 7, 1991. For updating an observation, HTDP uses the date that this observation was performed as the starting date. The date of observation is specified within the Bluebook file as part of the corresponding observational record.

5.12 Enter <y> to indicate the existence of a file that contains the GPS observations.

5.13 Enter <wa.gfile.txt> to specify that the GPS observational records are contained in the file called wa.gfile.txt.

5.14 Enter <wa.gfile.out> to specify that name of the output file that will contain the updated GPS records.

5.15 Enter <1> to indicate that the GPS vectors are to be transformed to the NAD_83(2011/CORS96/2007) reference frame.

The screen should now be displaying the main menu. You may wish to examine the files, wa.bfile.out and wa.gfile.out, at this time. In wa.bfile.out, the first *80* record is for station SEDRO WOOLEY. The new latitude for SEDRO WOOLEY should equal 48^o 31' 17.59511" N. In wa.gfile.out, the first C record is for a GPS observation involving the station whose ID is 0002 and the station whose ID is 0006. The updated values for this observation should be -15242.9845 meters in X.

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

Note also that the three following lines of text have been added to the beginning of file wa.bfile.out to caution users that any coordinates in wa.bfile.out have been updated to their estimated value on January 1, 2010:

```
***CAUTION: This file was processed using HTDP version 3.3.0   ***
***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) ***
```

Also, the following three lines of text have been added to the beginning of wa.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 3.3.0    ***
```

Users may need to remove these lines of text in wa.bfile.out and wa.gfile.out before processing these files with software that expects standard BlueBook files as input.

This concludes exercise 5.

EXERCISE 6. Transform positions between reference frames and/or dates.

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 <tfile1.out> for the name of the output file that will contain the transformed coordinates.

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

6.5 Enter <24> to specify that the output coordinates will refer to ITRF2014 or IGS14/IGb14.

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 are referred to the point's location 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 will refer to the point's location on January 1, 2020.

6.10 Enter <1> to indicate that you will be transforming coordinates for individual points entered interactively.

6.11 Enter <test1> for the name of the point.

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

6.13 Enter <40 0 0> to specify that the NAD 83 latitude of test1 on January 1, 2010 is 40° 00' 00.00000" N.

6.14 Enter <100 0 0> to specify that the MAD 83 longitude of test1 on January 1, 2010 is 100° 00' 00.00000" W.

6.15 Enter <0> to specify that the NAD 83 ellipsoid height of test1on January 1, 2010 is 0.0 meters.

6.16 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 ITRF2014 at January 1, 2020. The screen should now be displaying the following information:

```
****************************************
New latitude   =  40  0  0.02126 N
New longitude  = 100  0  0.04746 W
New Ellip. Ht. =        -0.965 meters
New X          =  -849610.666 meters
New Y          = -4818375.039 meters
New Z          =  4077985.454 meters
****************************************
```

6.17 Enter <n> to indicate that you will not be transforming coordinates at additional points. This will write the following information to the output file, tfile1.out:

```
HTDP OUTPUT, VERSION 3.3.0

TRANSFORMING POSITIONS FROM NAD_83(2011/CORS96/2007) (EPOCH = 01-01-2010 (2010.0000))
                         TO ITRF2014 or IGS14/IGb14  (EPOCH = 01-01-2020 (2020.0000))

test1
 LATITUDE     40 00  0.00000 N     40 00  0.02126 N        0.81 mm/yr  north
 LONGITUDE   100 00  0.00000 W    100 00  0.04746 W        1.88 mm/yr  east
 ELLIP. HT.               0.000                -0.965 m    -1.14 mm/yr  up
 X                  -849609.759          -849610.666 m      2.09 mm/yr
 Y                 -4818376.378         -4818375.039 m      1.05 mm/yr
 Z                  4077985.572          4077985.454 m     -0.11 mm/yr
```

Note that this file provides the NAD_83(2011/CORS96/2007) velocities that were used to transform velocities from January 1, 2010 to January 1, 2020.

However, if the input and output epochs are the same, HTDP will perform transformations anywhere on Earth, for all frames defined in HTDP.

This concludes Exercise 6.

EXERCISE 7. Transform positions between reference frames and/or dates for several points whose coordinates will be entered via a batch file.

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

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

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

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

7.5 Enter <24> to specify that output coordinates are to be referred to ITRF2014 or IGS14/IGb14.

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

7.7 Enter <2010> to specify that the input coordinates are referred to the locations of the points on January 1, 2010.

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

7.9 Enter <2020> to specify that the output coordinates are to be referred to the locations of the points on January 1, 2020.

7.10 Enter <3> to specify that that you will be submitting a file with multiple points as latitude, longitude, and ellipsoid height.

7.11 Enter <test_NAmerica.txt> for the name of the input file. This file contains points at locations where that are referenced to NAD_83(2011/CORS96/2007). Note that the points have positive west longitude. The contents of output file test_NAmerica.out are shown below.

```
HTDP OUTPUT, VERSION 3.3.0

TRANSFORMING POSITIONS FROM NAD_83(2011/CORS96/2007) (EPOCH = 01-01-2010 (2010.0000))
                         TO ITRF2014 or IGS14/IGb14  (EPOCH = 01-01-2020 (2020.0000))

***CAUTION: This file was processed using HTDP version 3.3.0   ***
***CAUTION: Coordinates in this file are in ITRF2014 or IGS14/IGb14 ***
***CAUTION: Coordinates in this file have been updated to  1-01-2020=(2020.000) ***

  40.0000059056  100.0000131843    -0.965    Kansas
  37.0000054908  122.0000193408    -0.548    California
  48.0000034473  124.0000184377    -0.286    Washington
  45.0000107518   69.0000049046    -1.138    Maine
  28.0000058327   81.0000058995    -1.556    Florida
  64.9999966235  152.0000304343     0.483    Alaska
  18.2000050384   66.4999985203    -1.879    Puerto Rico
```

There are also two other input files, one for locations referenced to the NAD 83 (PA11/PACP00) frame (test_Pacific.txt), and the other for locations referenced to the NAD 83 (MA11/MARP00) frame (test_Mariana.txt).

This concludes Exercise 7.

EXERCISE 8. Transforming velocities between reference frames.

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

8.2 Enter <5> to specify that you will be transforming velocities between reference frames.

8.3 Enter <tvfile.out> for the name of the output file that will contain the transformed velocities.

8.4 Enter <24> to specify that the input velocities are referred to ITRF2014.

8.5 Enter <1> to specify that output velocities are to be referred to NAD 83(2011/CORS96/2007).

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

8.7 Enter <gamma> as the name of the point whose ITRF2014 velocity is to be transformed to its corresponding NAD 83(2011/CORS96/2007) velocity.

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

8.9 Enter <38 0 0> to denote that the ITRF2014 latitude of gamma is 38° 00' 00.0" N.

8.10 Enter <123 0 0> to denote that the ITRF2014 longitude of gamma is 123° 00' 00.00" W.

8.11 Enter <0> to denote that the ITRF2014 ellipsoid height of gamma is zero meters.

8.12 Enter <1> to indicate that you will specify the north, east, and up components of the ITRF2014 velocity of gamma.

8.13 Enter <25> to specify that the northward component of gamma's ITRFF2014 velocity is 25 mm/yr.

8.14 Enter <-38> to specify that the eastward component of gamma's ITRF2014 velocity is -38 mm/yr.

8.15 Enter <1> to specify that the upward component of gamma's ITRF2014 velocity is 1 mm/yr. The screen should now be displaying the following information:

```
************************************************
New northward velocity =    38.29 mm/yr
New eastward velocity  =   -24.42 mm/yr
New upward velocity    =    -0.24 mm/yr
New x velocity         =    -7.54 mm/yr
New y velocity         =    33.23 mm/yr
New z velocity         =    30.02 mm/yr
************************************************
```

8.16 The screen should also be displaying the menu for continuing. Enter <0> to return to the MAIN MENU and write results to the output file, tvfile.out.

This concludes Exercise 8.