

HTDP User's Guide

(Software Version 3.2.9)

May 17, 2020

Richard Snay, Chris Pearson, Jarir Saleh, and Michael Dennis
Email: ngs.cors.htdp@noaa.gov

1. Introduction

HTDP is a utility that allows users to transform positional coordinates across time and between spatial reference frames. HTDP, which is an acronym for “Horizontal Time-Dependent Positioning”, 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), as well as all official realizations of the International Terrestrial Reference System (ITRS) (Altamimi et al. 2011), including ITRF2014, and all official realizations of the World Geodetic Reference System of 1984 (WGS 84) (True, 2004) including G1762.

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 the HTDP User's 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 17 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.

Table 1. Velocity grids used in HTDP

Region	Latitude Range	Longitude Range	Node Spacing (minutes)	Reference
San Andreas	35.8°N – 36.79°N	120.51°W – 121.8°W	0.6	Pearson and Snay (2013) for horizontal velocities; vertical velocities have been set equal to 0.0 mm/yr relative to ITRF2008.
Southern California	31°N - 36°N	114°W - 121°W	3.75	
Northern California	36°N - 40°N	119°W - 125°W	3.75	
Pacific Northwest	40°N - 49°N	122°W - 125°W	3.75	
Western CONUS	31°N - 49°N	107°W - 125°W	15.0	
Eastern CONUS	24°N - 50°N	66°W - 107°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	56.5°N - 63°N	140°W - 148°W	15.0	
South-Central Alaska	53.25°N – 65.75°N	143.25° - 162°W	15.0	
Southeast Alaska	54°N - 63°N	130°W - 142°W	15.0	
Mainland Alaska	56°N - 73°N	130°W - 170°W	15.0	

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

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

Here (x, y, z) denote Earth-centered, Earth-fixed Cartesian (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 seven regions of this type and provides some pertinent information about these regions.

Table 2. Plate motion rates encoded into HTDP (positive rotation rates are counterclockwise).

Tectonic Plate	Frame	\dot{T}_x mm/yr	\dot{T}_y mm/yr	\dot{T}_z mm/yr	\dot{R}_x nrad/yr	\dot{R}_y nrad/yr	\dot{R}_z nrad/yr	Reference
North America	ITRF2008	0.41	0.22	0.41	0.170	-3.209	-0.485	Altamimi et al. (2012)
Caribbean	ITRF2008	0.41	0.22	0.41	0.238	-5.275	3.219	Altamimi et al. (2012)
Pacific	ITRF2008	0.41	0.22	0.41	-1.993	5.023	-10.501	Altamimi et al. (2012)
Juan de Fuca	ITRF2008	0.41	0.22	0.41	6.626	11.708	-10.615	DeMets et al. (2010)*
Cocos	ITRF2008	0.41	0.22	0.41	-10.390	-14.954	9.148	DeMets et al. (2010)*
Mariana	ITRF2000	0.00	0.00	0.00	-0.097	0.509	-1.682	Snay (2003)
Philippine Sea	ITRF2008	0.41	0.22	0.41	-0.841	3.989	-10.626	DeMets et al (2010)*

* DeMets et al. (2010) provides the rotation rates of this plate relative to the Pacific plate. For each of the three rotation rates (estimated by DeMets et al.), its value has been added to the corresponding ITRF2008 rotation rate of the Pacific plate (as estimated by Altamimi et al.(2012)) to obtain the corresponding ITRF2008 rotation rate for the plate.

When a user specifies a location, HTDP will step through the 17 regions in a specific order until this utility finds the first region that contains the specified location. It will then use the model for this region to estimate the 3D velocity at this location. Gridded regions all precede the tectonic plates. The gridded regions are ordered as they appear in Table 1, from top to bottom. The tectonic plates are ordered as they appear in Table 2, from top to bottom. If the specified location is not contained in any of the 17 regions, then HTDP outputs a message to the effect that it is unable to estimate the velocity for this location.

When using HTDP to estimate velocities at a collection of locations, a user may interactively provide positional coordinates for the locations one at a time or he/she may submit an ASCII file that provides positional coordinates for all of the locations in the collection. HTDP accepts two different file formats, each of which is described during the execution of the HTDP utility. Also, a user can specify a 2D grid in latitude and longitude and ask HTDP to estimate velocities at the nodes of this grid. In addition, a user may specify a line (actually a geodesic on an ellipsoidal representation of Earth) and ask HTDP to estimate velocities at equally spaced locations along this line (geodesic).

A user must specify the reference frame in which he/she is providing the 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 may 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. The user may opt to allow HTDP estimate the 3D velocity to be used in this procedure, or he/she may interactively supply the velocity to be used.

HTDP uses the equations of dislocation theory (Okada 1985) to quantify coseismic motion for most of the major (magnitude ≥ 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 Herbrechtsmeier, 1994
10-21-1942 San Jacinto (M=6.6)	Snay and Herbrechtsmeier, 1994
07-21-1952 Kern County (M=7.5)	Snay and Herbrechtsmeier, 1994
03-19-1954 San Jacinto (M=6.4)	Snay and Herbrechtsmeier, 1994
06-26-1966 Parkfield (M=5.6)	Segall and Du, 1993
04-09-1968 Borrego Mtn. (M=6.5)	Snay and Herbrechtsmeier, 1994
02-09-1971 San Fernando (M=6.6)	Snay and Herbrechtsmeier, 1994
03-15-1979 Homestead Valley (M=5.6)	Stein and Lisowski, 1983
08-06-1979 Coyote Lake (M=5.9)	Snay and Herbrechtsmeier, 1994
10-15-1979 Imperial Valley (M=6.4)	Snay and Herbrechtsmeier, 1994
05-02-1983 Coalinga (M=6.4)	Stein and Ekstrom, 1992
04-24-1984 Morgan Hill (M=6.2)	Snay and Herbrechtsmeier, 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

$$\begin{aligned}
 D_{i,j}(\varphi, \lambda, t) &= A_{i,j}(\varphi, \lambda) \cdot [1.0 - \exp(-(t - \tau_i)/g_i)] && \text{if } \tau_i < t \\
 D_{i,j}(\varphi, \lambda, t) &= 0 && \text{if } t \leq \tau_i
 \end{aligned} \tag{3.1}$$

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). This model 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 using HTDP to estimate displacements at a collection of locations, a user may interactively provide positional coordinates for the locations one at a time or he/she may submit an ASCII file that provides positional coordinates for all of the locations in the collection. HTDP accepts two different file formats, each of which is described during the execution of the HTDP utility. Also, a user can specify a 2D grid in latitude and longitude and ask HTDP to estimate displacements at all of the grid nodes. In addition, a user may specify a line (actually a geodesic on an ellipsoidal representation of Earth) and ask HTDP to estimate displacements at equally spaced locations along this line (geodesic).

A HTDP user must specify the reference frame in which he/she is providing the positional coordinates to HTDP. The estimated displacements will also be referred to this reference 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.

Then 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. HTDP accepts two different file formats, each of which is 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:

- update the coordinates from time t_1 to time t_2 in the starting reference frame, and
- transform the updated coordinates at time t_2 from the starting reference frame to the desired reference frame.

Section 4 describes how HTDP performs the first step, thus this section addresses only the second step.

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 transformation:

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

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 with some degree of accuracy. 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:

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

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 from NAD 83(CORS96) coordinates to ITRF96 coordinates. A point's NAD 83(CORS96) velocity is expressed as if the "stable" interior of the North American 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(CORS96) 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(CORS96), 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):

$$\begin{aligned}
 T_x(t) &= 0.9910 + 0.0(t - 1997.00) \text{ meters} \\
 T_y(t) &= -1.9072 + 0.0(t - 1997.00) \text{ meters} \\
 T_z(t) &= -0.5129 + 0.0(t - 1997.00) \text{ meters} \\
 R_x(t) &= [125.033 + 0.258(t - 1997.00)] \cdot (10^{-9}) \text{ radians} \\
 R_y(t) &= [46.785 - 3.599(t - 1997.00)] \cdot (10^{-9}) \text{ radians} \\
 R_z(t) &= [56.529 - 0.153(t - 1997.00)] \cdot (10^{-9}) \text{ radians} \\
 s(t) &= 0.0 + 0.0(t - 1997.00) \text{ (unitless)} .
 \end{aligned} \tag{5.3}$$

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

$$(A \rightarrow C) \approx (A \rightarrow B) + (B \rightarrow C) \tag{5.4}$$

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

$$(A \rightarrow B) \approx - (B \rightarrow A) . \tag{5.5}$$

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

$$(A \rightarrow B) \approx -(ITRF94 \rightarrow A) + (ITRF94 \rightarrow B) . \tag{5.6}$$

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 (Federal Geodetic Control Subcommittee 2000). 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 $C^*(t_1)$ 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 $C^*(t_2)$ at time t_2 . The theoretical distance $C^*(t_1)$ 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 $C^*(t_1)$. 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 $C^*(t_1)$. For these same reasons, $C^*(t_2)$ will differ from $C(t_2)$, but the difference $C(t_2) - C^*(t_2)$ should approximate the difference $C(t_1) - C^*(t_1)$ in value as both differences involve essentially the same errors. Consequently, the expression

$$C(t_1) + C^*(t_2) - C^*(t_1)$$

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:

$$\begin{aligned}
 D_x(t_1)_{F0} &= [I + s(t_1)] \cdot D_x(t_1)_{F1} + R_z(t_1) \cdot D_y(t_1)_{F1} - R_y(t_1) \cdot D_z(t_1)_{F1} \\
 D_y(t_1)_{F0} &= -R_z(t_1) \cdot D_x(t_1)_{F1} + [I + s(t_1)] \cdot D_y(t_1)_{F1} + R_x(t_1) \cdot D_z(t_1)_{F1} \\
 D_z(t_1)_{F0} &= R_y(t_1) \cdot D_x(t_1)_{F1} - R_x(t_1) \cdot D_y(t_1)_{F1} + [I + s(t_1)] \cdot D_z(t_1)_{F1}
 \end{aligned} \tag{6.1}$$

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

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

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:

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

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, the user may interactively provide the required information one location at a time or he/she 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. Information about reference frames recognized by HTDP

Reference Frame	Domain	Default Reference Epoch [*]	Responsible Agency	Key ^{**}	More Information
NAD 83(2011)	CONUS, Alaska, Puerto Rico, U.S. Virgin Is.	2010.00	NGS	1	https://geodesy.noaa.gov/CORS/coords.shtml#TABLE2
NAD 83(PA11)	U.S. islands on Pacific plate	2010.00	NGS	2	
NAD 83(MA11)	U.S. islands on Mariana plate	2010.00	NGS	3	
NAD 83(NSRS2007) or NAD 83(2007)	CONUS, Alaska, Puerto Rico, U.S. Virgin Islands	2007.00 in California, Oregon, Washington, Nevada, and Arizona; 2002.00 otherwise	NGS	1	Pursell and Potterfield, 2008
NAD 83(CORS96)	CONUS, Alaska, Puerto Rico, U.S. Virgin Is.	2003.00 in Alaska, 2002.00 otherwise	NGS	1	Soler and Snay, 2004
NAD 83(PACP00)	U.S. islands on Pacific plate	1993.62	NGS	2	Snay, 2003a
NAD 83(MARP00)	U.S. islands on Mariana plate	1993.62	NGS	3	Snay, 2003a
WGS 84(TRANSIT)	Global	Date of observation	DoD	5	True, 2004
WGS 84(G730)	Global	1994.00	DoD	6	True, 2004
WGS 84(G873)	Global	1997.00	DoD	7	True, 2004
WGS 84(G1150)	Global	2001.00	DoD	8	True, 2004
WGS 84(G1674)	Global	2005.00	DoD	9	
WGS 84(G1762)	Global	2005.00	DoD	10	
PNEOS 90 & NEOS 90	Global	1988.00		14	
SIO/MIT 92	Global	1992.57		11	
ITRF88	Global	1988.00	IERS	12	IERS Ann. Rep. for 1988
ITRF89	Global	1988.00	IERS	13	IERS Tech. Note No. 6
ITRF90	Global	1988.00	IERS	14	IERS Tech. Note No. 9
ITRF91	Global	1988.00	IERS	15	IERS Tech. Note No. 12
ITRF92	Global	1994.00	IERS	16	IERS Tech. Note No. 15
ITRF93	Global	1995.00	IERS	17	IERS Tech. Note No. 18
ITRF94	Global	1996.00	IERS	18	IERS Tech. Note No. 20
ITRF96	Global	1997.00	IERS	19	IERS Tech. Note No. 24
ITRF97	Global	1997.00	IERS	20	IERS Tech. Note No. 27
ITRF2000	Global	1997.00	IERS	21	IERS Tech. Note No. 31
ITRF2005	Global	2000.00	IERS	22	Altamimi et al., 2007
ITRF2008	Global	2005.00	IERS	23	Altamimi et al., 2011

Reference Frame	Domain	Default Reference Epoch [*]	Responsible Agency	Key ^{**}	More Information
ITRF2014	Global	2010.00	IERS	24	Altamimi et al., 2016
IGS97	Global	1997.00	IGS	20	Kouba, 2009
IGS00 or IGb00	Global	1998.00	IGS	21	Kouba, 2009
IGS05	Global	2000.00	IGS	22	Kouba, 2009
IGS08 or IGb08	Global	2005.00	IGS	23	Rebischung et al., 2011
IGS14 or IGb08	Global	2010.00	IERS, IGS	24	Altamimi et al., 2016

^{*} When a user enters positional coordinates into HTDP, he/she will need to provide the epoch (or date) to which these coordinates correspond. If the user is uncertain as to the correct epoch, then he/she may enter either (1) the date on which the observations—used for determining the coordinates—were performed or (2) the *default reference epoch* associated with the reference frame to which the coordinates are referred.

^{**} The *key* is the number that the HTDP software uses to identify a particular reference frame. Note that some reference frames share the same key. This key is only important to people who develop software and/or applications that will directly invoke the HTDP software.

9. Software Characteristics

Users may run the latest version of HTDP interactively on the World Wide Web at <https://geodesy.noaa.gov/TOOLS/Htdp/Htdp.shtml>. Users may 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 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. 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 very different formats. One is the so-called "Bluebook" format for horizontal control data [see Federal Geodetic Control Subcommittee, 2000]. 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 a 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, and again the format is slightly different for transforming velocities between reference frames.

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 will estimate these quantities for a set of points which defines a 2-dimensional grid on the Earth's surface or which defines an equally spaced 1-dimensional array 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 user-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.

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.

The Government of the United States of America shall be under no liability whatsoever resulting from the use of this software. This software should not be relied upon as the sole basis for solving a problem

whose incorrect solution could result in injury to person or property.

This software is the property of the Government of the United States of America. Therefore, the recipient further agrees not to assert proprietary rights therein and not to represent this software to anyone as being other than U.S. Government software.

12. References

- Altamimi Z, Collilieux X, Legrand J, Garayt B, and Boucher C (2007) ITRF2005: A new release of the International Terrestrial Reference Frame based on time series of station positions and Earth Orientation Parameters. *J Geophys Res*, 112, B09401, doi:10.1029/2007/JB004949
- Altamimi Z, Collilieux X, Metivier L (2011) ITRF2008: an improved solution of the international terrestrial reference frame. *J. Geodesy*, doi: 10.1007/s00190-011-0444-4
- Altamimi Z, Metivier L, and Collilieux X (2012) ITRF2008 plate motion model. *J Geophys Res*, doi:10.1029/2011JB008930
- Altamimi Z, Rebischung P, Metivier L, and Collilieux X (2016) ITRF2014: A new release of the International Terrestrial Reference Frame modeling nonlinear station motions. *J Geophys Res*, doi:10.1002/2016JB013098
- Bennett RA, Reilinger RE, Rodi W, Li Y, Toksoz MN, Hudnut K (1995) Coseismic fault slip associated with the 1992 M_w 6.1 Joshua Tree, California, earthquake: Implications for the Joshua Tree- Landers earthquake sequence. *J Geophys Res* 100:6443-6461
- DeMets C, Gordon RG, Argus DF (2010) Geologically current plate motions, *Geophys J Int*, 181:1-80, doi: 10.1111/j.1365-246X.2009.04491.
- Dixon TH, et al. (2002) Seismic cycle and rheological effects on estimation of present-day slip rates for the Agua Blanca and San Miguel-Vallecitos faults, northern Baja California, Mexico. *J Geophys Res*, 107(B10), 2226, doi:10/1029/2000JB000099
- Ekstrom E, Stein RS, Eaton JP, Eberhart-Phillips D (1992) Seismicity and geometry of a 110-km-long blind thrust fault, 1, the 1985 Kettleman Hills, California, earthquake. *J Geophys Res* 97:4843-4864
- Elliot JL, Freymueller JT, Rabus B (2007) Coseismic deformation of the 2002 Denali fault earthquake : contributions from synthetic aperture radar range offsets. *J Geophys Res*, 112, B06431, doi:10.1029/2006JB004428
- Federal Geodetic Control Subcommittee (2000) Input formats and specifications of the National Geodetic Survey data base: Volume I. Horizontal control data. National Geodetic Information Branch, NOAA, Silver Spring, Maryland, 20910 (<http://www.ngs.noaa.gov/FGCS/BlueBook/>)
- Hammond WC and Thatcher W (2004) Contemporary tectonic deformation of the Basin and Range province, western United States: 10 years of observation with the Global Positioning System. *J Geophys Res*, 109, B088403, doi:10.1029/2003JB002746
- Hammond WC, and Thatcher W (2005) Northwest Basin and Range tectonic deformation observed with the Global Positioning System. *J Geophys Res*, 110, B10405, doi:10.1029/2005JB003678
- Holdahl SR, Sauber J (1994) Coseismic Slip in the 1964 Prince William Sound Earthquake: A New Geodetic Inversion. *Pure and Applied Geophys* 142:55-82
- Hudnut KW and 16 others (1994) Co-seismic displacements of the 1992 Landers earthquake sequence. *Bull Seismol Soc Am* 84:625-645
- Hudnut KW and 10 others (1995) Co-seismic displacements of the 1994 Northridge, California, Earthquake, *Bull Seismol Soc Am* 86:S19-S36

- Hurst KJ, Argus DF, Donnellan A, Heflin MB, Jefferson DC, Lyzenga GA, Parker JW, Smith M, Webb FH, and Zumberge, JF (2000) The coseismic geodetic signature of the 1999 Hector Mine Earthquake. *Geophys Res Letters* 27:2733-2736. See also <http://milhouse.jpl.nasa.gov/hector/hectormine3.model>.
- Johanson, IA (2006) Slip characteristics of San Andreas fault transition zone segments, Ph.D. Dissertation, Univ. of California, Berkeley, 117 pp
- Johanson, IA, Fielding RJ, Rolandone F, and Burgmann R (2006) Coseismic and postseismic Slip of the 2004 Parkfield earthquake, *Bull.Seismol. Soc. Am.*, 96, S269-S282
- Kouba J (2009) A guide to using International GNSS Service (IGS) products. igsb.jpl.nasa.gov/igsb/resource/pubs/UsingIGSProductsVer21.pdf (Accessed Dec. 12, 2011)
- Larsen S, Reilinger R, Neugebauer H, Strange W (1992) Global Positioning System measurements of deformations associated with the 1987 Superstition Hills earthquake: evidence for conjugate faulting. *J Geophys Res* 97:4885-4902
- Lin J, Stein RS (1989) Coseismic folding, earthquake recurrence, and the 1987 source mechanism at Whittier Narrows, Los Angeles Basin, California. *J Geophys Res* 94:9614-9632
- Lisowski M, Prescott WH, Savage JC, Johnston MJ (1990) Geodetic estimate of coseismic slip during the Loma Prieta, California, earthquake. *Geophys Res Lett* 17:1437-1441
- Marquez-Azua B, DeMets C (2003) Crustal velocity field of Mexico from continuous GPS measurements, 1993 to June 2001 : Implications for the neotectonics of Mexico. *J Geophys Res*, 108, doi: 10.1029/2002JB002241
- McCaffrey R (2005) Block kinematics of the Pacific – North America plate boundary in the southwestern US from inversion of GPS, seismological, and geologic data. *J Geophys Res*, 111, B07401, doi:10.1029/2004JB003307
- McCaffrey R, Qamar AI, King RW, Wells R, Ning Z, Williams CA, Stevens CW, Vollick JJ, and Zwick PC (2007) Plate locking, block rotation and crustal deformation in the Pacific Northwest, *Geophys J Int*, doi:10.1111/j.1365-246X.2007.03371.
- McCarthy DD (1996) IERS Conventions (1996). *IERS Technical Note 21*, Observatoire de Paris Okada Y (1985) Surface deformation due to shear and tensile faults in a half-space. *Bull Seismol Soc Amer* 75:1135-1154
- Oppenheimer D and 19 others (1993) The Cape Mendocino, California earthquake sequence of April, 1992: Subduction at the triple junction. *Science* 261:433-438
- Payne SJ, McCaffrey R, and King RW (2008) Strain rates and contemporary deformation in the Snake River Plain and surrounding Basin and Range from GPS and seismicity. *Geology* 36:647-650
- Pearson C, and Snay R (2008) Updating HTDP for two recent earthquakes in California. *Surveying and Land Information Science* 67:149-158
- Pearson C, McCaffrey R, Elliott JL, and Snay R (2010) HTDP 3.0: Software for coping with the coordinate changes associated with crustal motion. *J Surv Eng*, doi:10.1061/(ASCE)SU.1943-5428.0000013
- Pearson C, Snay R (2013) Introducing HTDP 3.1 to transform coordinates across time and spatial reference frames. *GPS Solutions*, doi:10.1007/s10291-012-0255-y
- Peltzer G, Crampe, F, and Rosen P (2001) The Mw 7.1, Hector Mine, California earthquake: surface rupture, surface displacement field, and fault slip solution from ERS SAR data. *C. R. Acad. Sci. Paris*, 333:545-555 (<http://www-radar.jpl.nasa.gov/insar4crust/HME/>)
- Pursell DG, Potterfield M (2008) NAD 83 (NSRS2007) National Readjustment Final Report, NOAA Technical Report NOS NGS 60,

- (https://geodesy.noaa.gov/library/pdfs/NOAA_TR_NOS_NGS_0060.pdf)
- Reischung P, Griffiths J, Ray J, Schmid R, Collilieux X, Garayt B (2011) IGS08: The IGS realization of ITRF2008. *GPS Solut*, doi: 10.1007/s10291-011-0248-2
- Savage JC, Gross WK (1995) Revised dislocation model of the 1986 Chalfant Valley earthquake, eastern California. *Bull Seismol Soc Am* 85:629-631
- Savage JC, Lisowski M, and Murray M (1993) Deformation from 1973 through 1991 in the epicentral area of the 1992 Landers, California, earthquake ($M_s = 7.5$). *J Geophys Res* 98:19951-19958
- Segall P, Du Y (1993) How similar were the 1934 and 1966 Parkfield earthquakes?, *J Geophys Res* 98:4527-4538
- Snay RA (1999) Using the HTDP software to transform spatial coordinates across time and between reference frames, *Surveying and Land Information Systems*, 59:15-25
- Snay RA (2003a) Introducing two spatial reference frames for regions of the Pacific Ocean. *Surveying and Land Information Science*, 63(1):5-12
- Snay R (2003b) Horizontal time-dependent positioning. *The Professional Surveyor Magazine*, November 2003
- Snay RA, Herbrechtsmeier E (1994) The TDP-H91-CA model for historical horizontal deformation in California. *Manuscripta Geodaetica* 19:180-198
- Snay RA, Cline MW, Philipp CR, Jackson DD, Feng Y, Shen ZK, Lisowski M (1996) Crustal velocity field near the big bend of California's San Andreas fault. *J Geophys Res* 101:3173-3185
- Snay R, Pearson C (2010) Coping with tectonic motion, *The American Surveyor*, vol 7, No. 9
- Snay RA, Freymueller JT, Pearson C (2013) Crustal motion models developed for version 3.2 of the Horizontal Time-Dependent Positioning utility, *J. Appl. Geod.*, 7:173-190, doi: 10.1515/jag-2013-0005
- Soler T, Snay RA (2004) Transforming positions and velocities between the International Terrestrial Frame of 2000 and the North American Datum of 1983. *J of Surveying Engineering*, doi: 10.1061/(ASCE)0733-9453(2004)130:2(49)
- Stein RS, Ekstrom G (1992) Seismicity and geometry of a 110-km-long blind thrust fault, 2, synthesis of the 1982-1985 California earthquake sequence. *J Geophys Res* 97:4865-4884
- Stein RS, Lisowski M (1983) The 1979 Homestead Valley earthquake sequence, California: Control of aftershocks and postseismic deformation. *J Geophys Res* 88:6477-6490
- True SA (2004) Planning the future of the World Geodetic System 1984. Presented at the IEEE Position Location and Navigation Symposium 2004, 26-29 April 2004, Monterey, California
- Williams TB, Kelsey HM, and Freymueller JT (2006) GPS-derived strain in northwestern California: Termination of the San Andreas fault system and convergence of the Sierra Nevada – Great Valley block contribute to southern Cascadia forearc contraction. *Tectonophysics*, 413, 171-184

HTDP EXERCISES

May 17, 2020

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. Hit the ENTER key to obtain 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 3.2.9

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. Then hit the ENTER key to 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 month-day-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 User's Guide Exercises

HTDP OUTPUT, VERSION 3.2.9

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 User's Guide Exercises

HTDP OUTPUT, VERSION 3.2.9

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. Then hit the ENTER key to 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	FORTTRAN 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. Estimated following velocities for the points in wa.bfile.txt are in vfile2.out:

HTDP OUTPUT, VERSION 3.2.9

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.

The screen should display the menu for specifying additional points at which the velocities are to be estimated. Estimated velocities for the points on the line are contained in the file, vfile3.out.

- 3.25 To examine vfile3.txt, enter <0> to return to the main menu, and to write the following estimated velocities for the points on the line are contained to vfile3.out:

HTDP OUTPUT, VERSION 3.2.9

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. Then hit the ENTER key to 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 User's Guide Exercises

HTDP OUTPUT, VERSION 3.2.9

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. Then hit the ENTER key to 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° 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.

HTDP User's Guide Exercises

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 3.2.9 ***
***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 3.2.9 ***
```

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, then hit the ENTER key to 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 test1 on 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 ITRF2000 at January 1, 1997 to NAD_83(2011/CORS962007) at January 1, 2002. 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 3.2.9

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.

It is important to understand that for transformations where the input and output dates (epochs) differ, HTDP will only give results for points located within areas where crustal motion is modeled. These areas are within the following seven tectonic plates: North America, Pacific, Mariana, Caribbean, Juan de Fuca, Cocos, and Philippine Sea. For points located outside these plates, HTDP will not give output results and will instead give the message that the point “is outside of the modeled region.”

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

This behavior for the three NAD 83 frames is illustrated with the input files test_NAmerica.txt, test_NAmerica_alt.txt, test_Pacific.txt, and test_Mariana.txt, and their corresponding output files (same name with extension “out”). File test_NAmerica_alt.out is for the case where the input and output epochs are the same. Note that it gives output for the unmodeled location (on equator near Africa). All of these files are included in the downloadable file set on the HTDP web page.

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, then hit the ENTER key to 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). It also includes ones point in an unmodeled region (on the equator off the west coast of Africa).
- 7.12 Enter <0> to return to the MAIN MENU.

Examine the output file, test_NAmerica.out. Its content should match the following text.

HTDP OUTPUT, VERSION 3.2.9

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 3.2.9 ***

***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
18.2000050384	66.4999985203	-1.879	Puerto Rico
64.9999966235	152.0000304343	0.483	Alaska

Unmodeled location (near Africa) is outside of the modeled region.

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). All of the files include the same point in an unmodeled region (on the equator off the west coast of Africa).

This concludes Exercise 7.

EXERCISE 8. Transforming velocities between reference frames.

- 8.1 If needed, enter <htdp> to start the program. Then hit the ENTER key to 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 <21> to specify that the input velocities are referred to ITRF2000.
- 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 ITRF2000 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 ITRF2000 latitude of gamma is 38° 00' 00.0" N.
- 8.10 Enter <123 0 0> to denote that the ITRF2000 longitude of gamma is 123° 00' 00.00" W.
- 8.11 Enter <0> to denote that the ITRF2000 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 ITRF2000 velocity of gamma.
- 8.13 Enter <-12> to specify that the northward component of gamma's ITRF2000 velocity is -12 mm/yr.
- 8.14 Enter <-10> to specify that the eastward component of gamma's ITRF2000 velocity is -10 mm/yr.
- 8.15 Enter <2> to specify that the upward component of gamma's ITRF2000 velocity is 2 mm/yr. The screen should now be displaying the following information:

```
*****
New northward velocity =    2.70 mm/yr
New eastward velocity  =    3.55 mm/yr
New upward velocity    =    1.34 mm/yr
New x velocity         =    3.31 mm/yr
New y velocity         =   -1.42 mm/yr
New z velocity         =    2.95 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.