

# **HTDP User's Guide**

## **(Software Version 3.2.7)**

### **October 17, 2018**

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## **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 positional 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 in most of the recent realizations of the North American Datum of 1983 (NAD 83), as well as in 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.

People may run the latest version of HTDP interactively on the world-wide-web at <http://www.ngs.noaa.gov/TOOLS/Htdp/Htdp.shtml>. They may also download the file, **HTDP.for**, from this web site. This file contains “Fortran-90” source code for HTDP. A user will need to compile and link this source code to create executable code that can be run directly on his/her computer. The 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

- 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  $\geq 6.0$ ) 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 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

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

to model the cumulative postseismic motion  $D_{ij}(\varphi, \lambda, t)$  from time  $\tau_i$  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  $\varphi$  and longitude  $\lambda$ . Here  $A_{ij}(\varphi, \lambda)$  equals the amplitude (in meters) associated with earthquake  $i$  and dimension  $j$  at the location with latitude  $\varphi$  and longitude  $\lambda$ ,  $\tau_i$  equals the time of occurrence of earthquake  $i$ , and  $\vartheta_i$  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  $A_{ij}(\varphi, \lambda)$  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  $\tau$  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  $\tau$ .

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,  $\tau = 1997.00$  which corresponds to January 1, 1997.

Presently, HTDP needs to deal with more than a 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  $\tau$ ). 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

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

## 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 (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:

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

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

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

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	<a href="http://www.geodesy.noaa.gov/CORS/coords.shtml">www.geodesy.noaa.gov/CORS/coords.shtml</a>
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 the Pacific plate	1993.62	NGS	2	Snay, 2003a
NAD 83(MARP00)	U.S. islands on the 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
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
ITRF2014 or IGS14	Global	2010.0	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 <http://www.ngs.noaa.gov/TOOLS/Htdp/Htdp.shtml>. Users may also download the file, HTDP.for, from this web site to obtain a copy of the HTDP source code. The user will need to compile and link this source code to create executable code that is compatible with the operating system on his/her computer. This source code is written in FORTRAN-90.

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

Here,

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

40.731671553 112.212671753 34.241 Salt Air

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

Here, 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.

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## HTDP EXERCISES

July 16, 2012

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.

%%%%%%%%%

### EXERCISE 1. Estimating velocities at individual points

1.1 Enter <HTDP.exe> 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 a name for the file that will contain the estimated velocities (for example, vfile.txt).

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.

1.9 Enter <122,56,7.80> 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. meters.

The screen should now be displaying the following information:

Northward velocity = 37.19 mm/yr.

Eastward velocity = -23.78 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 be displaying 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 now be displaying 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 = 29.00 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.

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. If you have a windowing capability, then you may open another window to read this file. Otherwise, enter <0> to exit the HTDP software so that you may read this file. Note that this file contains all the information pertinent to the velocities that were estimated.

This concludes Exercise 1.

%%%%%%%%%

## EXERCISE 2. Estimating displacements at individual points.

2.1 If needed, enter <HTDP.exe> to start the program. Then hit the ENTER key to obtain the MAIN MENU.

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

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

2.4 Enter <1,1,1985> to indicate that the first date is January 1, 1985.

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

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

2.7 Enter <dfile1.txt> 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 now be displaying 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.

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.

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.txt> 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 now be displaying 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. You may find it instructive to inspect the output files, dfile1.txt and dfile2.txt, at this time.

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.exe> 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.txt> 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 (or equivalently, 5 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 (or equivalently, 10 minutes).

The screen should now be displaying the menu for specifying additional points at which velocities are to be estimated. Estimated velocities for the grid are contained in vfile1.txt. To examine this file, enter <0> to return to the main menu (and if you do not have a windowing capability, enter <0> to exit the HTDP software).

In vfile1.txt, the first point (the southeast corner of the grid) should have the northward velocity of 29.66 mm/yr and the eastward velocity of -24.84 mm/yr and the upward velocity of -1.23 mm/yr. The last point (the northwest corner) should have the northward velocity of 20.42 mm/yr and the eastward velocity of -14.51 mm/yr and the 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. (Note that the file, wa.bfile.txt, is available for download from the HTDP web site.) 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, 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.

The screen should now be displaying the menu for specifying additional points at which velocities are to be estimated. Estimated velocities for the points in wa.bfile.txt are contained in the file, vfile2.txt.

3.16 To examine vfile2.txt, enter <0> to return to the main menu (and if you do not have a windowing capability, enter <0> to exit the HTDP software).

In vfile2.txt, the first point, SEDRO WOOLEY, should have a northward velocity of 4.90 mm/yr and an eastward velocity of 5.66 mm/yr.

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.txt, 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 now be displaying 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.txt.

3.25 To examine vfile3.txt, enter <0> to return to the main menu (and if you do not have a windowing capability, enter <0> to exit the HTDP software).

The first point in vfile3.txt should have a northward velocity of 32.80 mm/yr and an eastward velocity of -25.08 mm/yr and an upward velocity of -1.28 mm/yr. This file should contain estimated velocities for four points. 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. Updating positional coordinates at individual points.

4.1 If needed, enter <HTDP.exe> 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.txt> 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 <122,56,7.80> 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 now be displaying the following information:

Updated latitude	= 38 06 12.96502N
Updated longitude	= 122 56 7.80406W
Updated Ellip. Ht.	= -0.006 meters
Updated X	= -2732250.865 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.txt, at this time. Note that newfile.txt contains both the old and the new coordinates. Also newfile.txt contains the velocities and the (total) displacements applied to update the positional coordinates.

This concludes Exercise 4.

%%%%%%%%%

Exercise 5. Update positional coordinates for points in a BlueBook file and update the corresponding

observations.

5.1 If needed, enter <HTDP.exe> 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 <1> to indicate that the following time is to be entered in the month-day-year format.

5.4 Enter <1,1,2010> to indicate that the updated coordinates and observations are to 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 the original coordinates and the non-GPS observations are contained in the file called wa.bfile.txt.

5.9 Enter <newbf.txt> for the name of the blue-book file that will contain the updated coordinates and the updated non-GPS observations.

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. (Note that wa.gfile.txt is available for download from the HTDP web site.)

5.14 Enter <newgf.txt> to specify that the updated GPS records will be contained in the file called newgf.txt.

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, newbf.txt and newgf.txt, at this time. In newbf.txt, the first \*80\* record is for station SEDRO WOOLEY. The new latitude for SEDRO WOOLEY should equal 48° 31' 17.59511" N. In newgf, 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 newgf.txt, columns 52-53 of the first B record should read "02" to indicate that the updated GPS interstation vector has been transformed to the original WGS\_84 reference frame (also called WGS\_84(transit)) which is equivalent to the NAD\_83(2011/CORS96/2007) reference frame. (Note that post-1994 realizations of WGS\_84 are



not equivalent to NAD\_83.) Note also that a line of text has been added to the beginning of newbf.txt to caution users that any coordinates in newbf.txt have been updated to their estimated value on January 1, 2010. Also two lines of text have been added to the beginning of newgf.txt 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. Users may need to remove these lines of text in newbf.txt and newgf.txt before processing these files with software that expects standard BlueBook files as input.

This concludes exercise 5.

%%

**EXERCISE 6.** Transforming positional coordinates across time and/or between reference frames for a few points.

6.1 If needed, enter <HTDP.exe> 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.txt> for the name of the output file that will contain the transformed coordinates.

6.4 Enter <21> to specify that the input positional coordinates are referred to ITRF2000.

6.5 Enter <1> to specify that the output coordinates are to be referred to NAD\_83(2011/CORS96/2007).

6.6 Enter <1> to indicate that the following date is to be entered in the month-day-year format.

6.7 Enter <1,1,1997> to specify that the input coordinates are referred to the point's location on January 1, 1997.

6.8 Enter <1> to indicate that the following date is to be entered in the month-day-year format.

6.9 Enter <1,1,2002> to specify that the output coordinates are to be referred to the point's location on January 1, 2002.

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

6.11 Enter <gamma> 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 <43,5,17.34261> to specify that the ITRF2000 latitude of gamma on January 1, 1997 is 43° 5' 17.34261" N.

6.14 Enter <118,45,36.30295> to specify that the ITRF2000 longitude of gamma on January 1, 1997 is 118° 45' 36.30295" W.

6.15 Enter <36.421> to specify that the ITRF2000 ellipsoid height of gamma on January 1, 1997 is 36.421 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	= 43° 5' 17.32260" N
New longitude	= 118° 45' 36.25474" W
New ellip. ht.	= 36.931 meters
New X	= -2244674.061 meters
New Y	= -4089795.698 meters
New Z	= 4334683.529 meters

6.17 Enter <n> to indicate that you will not be transforming coordinates at additional points.

You may find it instructive to inspect the output file, tfile1.txt, at this time. Note that this file provides the ITRF2000 velocities that were used to transform velocities from January 1, 1997 to January 1, 2002.

This concludes Exercise 6.

%%%%%%%%%

**EXERCISE 7.** Transforming positional coordinates across time and/or between reference frames for several points whose coordinates will be entered via a batch file.

7.1 If needed, enter <HTDP.exe> 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 <tfile2.txt> for the name of the output file that will contain the transformed coordinates.

7.4 Enter <8> to specify that the input coordinates are referred to WGS\_84(G1150).

7.5 Enter <1> to specify that output coordinates are to be referred to NAD\_83(2011/CORS96/2007).

7.6 Enter <1> to indicate that the following date is to be entered in the month-day-year format.

7.7 Enter <10,18,2010> to specify that the input coordinates are referred to the locations of the points on October 18, 2010.

7.8 Enter <1> to indicate that the following date is to be entered in the month-day-year format.

7.9 Enter <1,1,2010> to specify that the output coordinates are to be referred to the locations of the points on January 1, 2010.

7.10 Enter <3> to specify that that you will be submitting a file with multiple points.

7.11 Enter <infile2.txt> for the name of the input file. (Note that this file is available for download from the HTDP website. For instructional purposes, you may want to view the contents of this file.)

7.12 Enter <0> to return to the MAIN MENU.

Examine the output file, tfile2.txt, at this time. Its content should match the following text.

```
HTDP (VERSION v3.2.5      ) OUTPUT

TRANSFORMING POSITIONS FROM WGS_84(G1150)          (EPOCH = 10-18-2010 (2010.795))
                        TO NAD_83(2011/CORS96/2007) (EPOCH = 01-01-2010
                        (2010.000))

***CAUTION: This file was processed using HTDP version v3.2.5      ***
***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) ***

40.22999636    120.41998439    0.528    SALT AIR
34.99999669    120.99998506    3.814    test
```

This concludes Exercise 7.

%%%%%%%%%

Exercise 8. Transforming velocities between reference frames.

8.1 If needed, enter <HTDP.exe> 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 <vfile.txt> 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 <38,6,12.96> to denote that the ITRF2000 latitude of gamma is 38° 06' 12.96" N.

8.10 Enter <122,56,7.80> to denote that the ITRF2000 longitude of gamma is 122° 56' 7.80" 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 <-12.5> to specify that the northward component of gamma's ITRF2000 velocity is -12.5 mm/yr.

8.14 Enter <-9.6> to specify that the eastward component of gamma's ITRF2000 velocity is -9.6 mm/yr.

8.15 Enter <2.4> to specify that the upward component of gamma's ITRF2000 velocity is 2.4 mm/yr.

The screen should now be displaying the following information:

New northward velocity=	2.18 mm/yr
New eastward velocity =	3.99 mm/yr
New upward velocity =	1.74 mm/yr
New x velocity =	3.33 mm/yr
New y velocity =	-2.19 mm/yr
New z velocity =	2.79 mm/yr

8.16 The screen should also be displaying the menu for continuing. Enter <0> to return to the MAIN MENU.

At this point, it is instructive to inspect the output file, vfile.txt. This is the file whose name was specified in Step 8.3.

This concludes Exercise 8.