Mapping Matters

By Qassim A. Abdullah, Ph.D., PLS, CP**

Your Questions Answered

The layman's perspective on technical theory and practical applications of mapping and GIS

Question: Due to plate tectonics, the Earth's crust is moving at a rate of 5cm per year. What impact does this have on our GPS solutions and the accuracy of jobs that requires very high coordinate measurements?

Sean Atkinson, Frederick, Maryland - USA

Dr. Abdullah: The answer to the question, yes the Earth's crustal movement is physical movement and unless a measured position is corrected overtime, such position will drift farther and farther from its accurate value. Over the past several decades, tremendous effort has been spent monitoring the crustal and rotational motions of planet Earth by the International Earth Rotation and Reference Systems Service (IERS). As part of their work, the IERS has introduced an ideal geocentric reference system called the International Terrestrial Reference System (ITRS), which is realized by a set of three-dimensional Cartesian coordinates defined as the International Terrestrial Reference Frame (ITRF). It is through periodic modifications to the ITRF that surveyors ensure crustal movements are addressed in measured positions. Every year or so since introducing the initial ITRS realization during 1988 (which is referred to as ITRF88), the IERS has published a new ITRS realization (ITRF89, ITRF90, ITRF97,…, ITRF00, ITRF05). With each new realization, the IERS publishes revised positions and velocities for a worldwide network of several hundreds stations. In addition, each new realization not only incorporates at least an additional year of data, but also the most current understanding of Earth's dynamic. This is also why it is important to specify the epoch date (the date to which the coordinates correspond) for the ITRS realization used in certain surveying work. Every well defined reference frame, such as the ITRF, must specify a velocity for each point to transform its positional coordinates from epoch t0 to any other arbitrary epoch t. To compute a certain position at another time, t, one can use the following formula:

$X(t) = X(1997.0) + Vx(t - 1997.0)$. Similar formulas are used for $Y(t)$ and $Z(t)$, where,

$X(t)$ denotes the point's X-coordinate at time t, $X(1997.0)$ denotes the point's X-coordinate on 1 January 1997, and Vx denotes the X-component of the point's velocity.

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In an effort to keep up with the continuous advancements in technology and computational procedures, the U.S. National Geodetic Survey updated the NAD83 and published few modernized and more accurate realizations for the datum. Most notably in 1997, the Natural Resources Canada (NRC) and the NGS jointly developed a transformation to convert the ITRF96 positional coordinates into their corresponding NAD 83 coordinates for all CORS sites to establish a new "realization" of NAD 83 later referred to as NAD 83 (CORS96). In December 2001, the NRC and the NGS jointly adopted another transformation for converting positional coordinates and velocities between the International Terrestrial Reference Frame of 2000 (ITRF00) and NAD 83. Later on, another multiple realization based on a state-by-state basis was published under the acronym HARN, which stands for High Accuracy Reference Network. A few years later, the NGS undertook a readjustment of all the GPS survey control in the United States to resolve inconsistencies between existing statewide HARN adjustments and the nationwide CORS system, as well as between states. This latest adjustment was completed in February 2007, and is now known as the NAD 83(NSRS2007). For all states located on the stable North American Plate (all states except Arizona, California, Oregon, Washington, Nevada, and Alaska), the control for the NAD 83(NSRS2007) adjustment was provided by the CORS stations epoch date of 2002.0. For all stations on the stable North American plate, no epoch date will be shown as is currently the practice. For the other states, an epoch date such as 2007.0 will be shown. It is worth noting here that states like California and Alaska, which have relatively high crustal motion and earth quick activities, require more frequent realizations of the reference frame for precise surveying work. Likewise, more stable states can safely rely on older epoch dates, such as in the case of using an epoch dated 2002.0 in adjusting NAD 83(NSRS2007).

The introduction of GPS makes it possible to monitor Earth's crustal motion for any location around the world with unprecedented precision. The latest advancement in GPS technology and methods has reached the point that, with little effort, relative positioning of stations with respect to the national CORS sites can be accomplished with an accuracy of a few centimeters and therefore any crustal motion can be determined accurately through the correction for the estimated velocities associated with the control station. Ground surveying activities in areas situated on unstable tectonic plates requires extra attention and continuous updating of the datum in order to keep up with the plate activities. The state of California greatly exemplifies the delicate situation of the unstable datum and its effect on surveying work. The state territories are located on the San Andreas Fault, which separates the stable North American plate and the less stable Pacific plate. Due to the dynamic environment mentioned above, the state maintains within its territories a dense network of approximately 765 CORS stations. All of these stations participate in forming the California Spatial Reference System (CSRS), which is maintained by the California Spatial Reference Center (CSRC). CSRS operates a positioning service similar to OPUS known as SCOUT (Scripps Coordinate Update Tool) which produces ITRF2005 coordinates at the date of observation. In addition to ITRF2005, the Center has published several updated products, including a CSRS epoch 2007.0 set of coordinates, and a CSRS epoch 2009.0. This latter set is consistent with the NAD 83(NSRS2007) coordinates for the rest of the CONUS at the epoch of 2009.0 (i.e., January 1, 2009).

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To illustrate the severity of crustal movement on surveying work in areas over a relatively high-dynamic tectonic plate, I would like to present the metrics from two California CORS stations — NSSS, located near Tijuana at the southern end of the state, and P786, located near the northern edge of the state — that were submitted to OPUS. The following 2002.0 positions (OPUS default) were returned and compared against the 2009.0 positions. As is evidenced, there is a significant shift in position that has taken place over the 7-year difference in epochs between the 2002.0 epoch used by OPUS and

Table 1

Station	Epoch	Latitude	Longitude
NSSS(OPUS)	2002.0	32 34 45.51492	-116 58 21.60034
NSSS(CSRC)	2009.0	32 34 45.521687	-116 58 21.607636
		Difference Δ	0.28 m

Table 2

Station	Epoch	Latitude	Longitude
P786 (OPUS)	2002.0	41 50 43.72805	-123 58 50.78583
P786 (CSRC)	2009.0	41 50 43.731149	-123 58 50.785683
		Difference Δ	0.10 m

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the latest epoch of 2009.0 published by CSRS (Tables 1 and 2).

As for the annual crustal movement, represented by estimating the different velocities with respect to NAD 83(NSRS2007) in meters per year, I took the example of two of California GPS stations located at the extreme ends of the state -- P473, which is situated near San Diego, and P316, which is situated near Crescent City. Table 3 quantifies the velocities of such motion.

Table 3

Station	Velocity in Easting (meter/year)	Velocity in Northing (meter/year)
P473	-0.0273 m	+0.0127 m
P316	+0.0014 m	-0.0005 m

Station P473, which is located over the unstable Pacific plate, shows a maximum velocity along the Easting of 2.7cm/year.

In conclusion, the issues of datum changes over time should be taken seriously and great consideration should be taken in planning and executing survey work over unstable tectonic plates. Even over the stable North American plate, careful consideration should be exercised when deciding on the compatibility between the versions of datum used in the adjustment of the coordinates and the date of survey. To avoid many uncertainties, seek coordinates computed with the latest realization of ITRS, WGS84, or NAD83. Furthermore, if you are using an older ground control set for a current project, ask the surveying contractors for a new adjustment of the old data compatible with the realization of the datum that will be used to compute the new project data, such as the airborne GPS.

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