Modern Terrestrial Reference Systems—Part 4: Practical Considerations for Accurate Positioning

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Prior to the space-age, people primarily used terrestrial techniques like triangulation and/or trilateration to position points. In those days, they had essentially only one choice for a nationwide reference frame; namely, NAD 27. To position new points, a person would measure distances and angles that related the unknown positional coordinates of the new points to the known coordinates of some pre-existing terrestrial control points. More often than not, these known coordinates were referred to NAD 27. Hence, calculated positions for the new points were automatically referred to NAD 27.

In the 1970s, people started using Earth-orbiting satellites for positioning points. In particular, before GPS became operational, a number of people used the Doppler satellite system, known as TRANSIT, to position points with an accuracy of several meters relative to the geocenter. Now people use GPS to position points even more accurately. Hence, satellites have become flying control points whose time-dependent positions are well known thanks to diligent work by several institutions. Currently, GPS satellite orbits are available in appropriate realizations of both WGS 84 and ITRS, but not in any NAD 83 realization.

Confusion Can Be Introduced

Techniques that position new points by using only satellites as control automatically yield positional coordinates that are referred to the same reference frame as that used for the orbits, either some realization of WGS 84 or some realization of ITRS. Satellite-only positioning techniques, however, do not currently enable the centimeter-level positioning accuracy that is possible with techniques, like the static differential carrier phase GPS technique, that involve using both satellite and pre-existing terrestrial points as control. The use of an integrated approach, however, introduces confusion when the satellite orbits are referred to one reference frame and the terrestrial control points are referred to another, as the newly computed positions will be referred to some ambiguous hybrid reference frame. Although this hybrid reference frame will approximate the reference frame of the terrestrial control points, the error of this approximation at a given point depends on many factors including the distances and directions from this point to the various terrestrial control points being used as well as the magnitude and orientation of the vector connecting the origins of the two reference frames. For the case of a single terrestrial control point referred to NAD 83 with the GPS orbits referred to ITRF96, the error of this approximation at a point will grow less than 1 cm for every 100 km of distance to the terrestrial control point. Hence, for accurate positioning, people should use the same reference frame for both the orbits and the terrestrial control points, especially if the distance to the nearest terrestrial control point is large. If for some reason the available orbits are expressed in one reference frame while the terrestrial control is expressed in another, then the positions of the terrestrial control points should ideally be transformed into the given reference frame of the orbits, as may be accomplished, for example, by using the HTDP software. Alternatively, one could transform the orbits to the reference frame of the terrestrial control points, but this option is likely to involve more computations. Moreover, the software being used to process GPS data may require the orbits to be expressed in a realization of a specific reference system. Thus, it is usually better to transform the terrestrial control points rather than to transform the orbits.

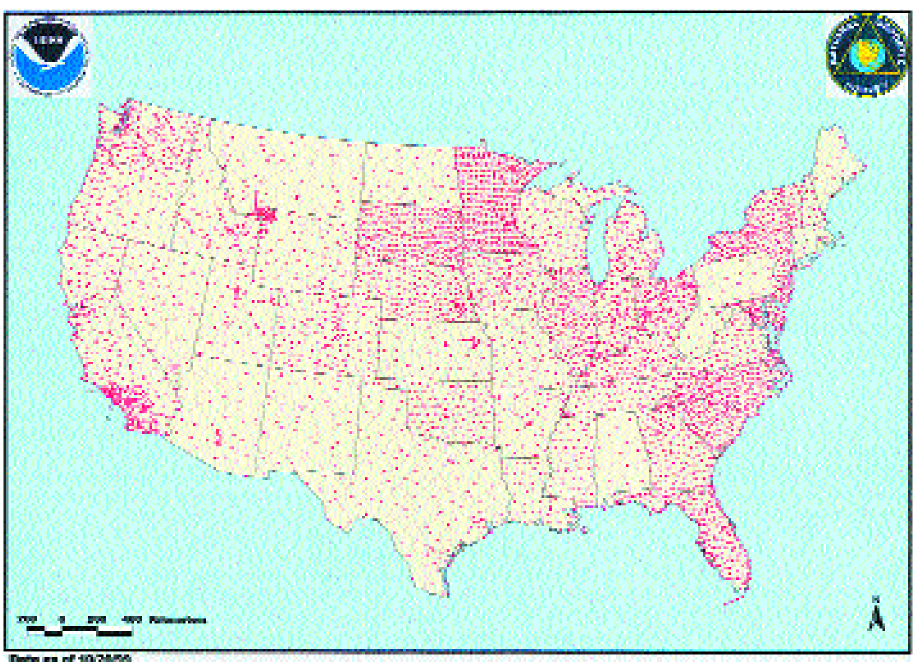

Figure 5: GPS stations defining the National Spatial Reference System: NAD 83 (NSRS)

Now, once the orbits and the terrestrial control are expressed in a common reference frame, the computed coordinates of the newly positioned points will also be referred to this reference frame. Hence, if people need these positional coordinates to be expressed relative to some other reference frame, then they will need to transform these coordinates. Again, the HTDP software will serve this purpose.

For rigorous computations, the epoch date of the positional coordinates of the terrestrial control should agree with the date that the GPS observations were performed. This agreement is especially important when computations are performed in an ITRS realization because terrestrial points are moving relative to this reference system. As previously mentioned, ITRF96 velocities have magnitudes ranging between 10 and 20 mm/yr in the coterminous United States, and these magnitudes are even higher in Alaska and Hawaii. If velocities at the control points are known, then equation (2) may be applied to convert the positional coordinates of these points from their given epoch date to the date that the GPS observations were performed. If velocities of these control points are unknown, then these velocities may be predicted using the HTDP software.

Use of Precise Orbits Recommended

As previously implied, we are recommending the use of highly precise postfit GPS orbits expressed in ITRS coordinates for accurate GPS positioning. The International GPS Service (IGS) freely distributes such orbits through their website *http://igscb.jpl.nasa.gov/*. The IGS orbits are the result of computational efforts involving seven different institutions located in four different countries: Canada, Germany, Switzerland, and the United States. Three of these seven institutions are U.S. based: the Jet Propulsion Laboratory, Scripps Institute of Oceanography, and NGS. Each of the seven institutions computes GPS orbits essentially independently, and then IGS rigorously combines the seven solutions to produce the orbits that they distribute. Also, the NGS-derived postfit orbits are available at *www.ngs.noaa.gov/GPS/GPS.html*

Finally for accurate positioning, sites from the National CORS system provide good terrestrial control. These CORS sites have been positioned with great accuracy, as they form the foundation of the National Spatial Reference System. Each site contains a geodetic-quality GPS receiver whose carrier phase and code range measurements are transmitted to NGS headquarters in Maryland. NGS then makes these data freely available via the Internet. In particular, people may download CORS data either via anonymous FTP (file transfer protocol) using the address *ftp://www.ngs.noaa.gov/cors/* or through the World Wide Web using the address *http://www.ngs.noaa.gov/CORS/*. Furthermore, people may pose CORS-related questions to NGS via the email address *cors@ngs.noaa.gov*. Whether using CORS or other sites as terrestrial control, it is usually best to include several points for the sake of redundancy and to suppress those systematic errors that grow as a function of distance.

The Species of "Origins"

In 1859, Charles Darwin published his revolutionary book, *The Origin of Species*, in which he documented evidence for the theory of how various forms of life evolve to better adapt to their environment. Inasmuch as this theory of evolution applies to humans, it may also apply to the products that humans develop. In particular, the theory of evolution may apply in large measure to terrestrial reference systems, as these human artifacts evolve to adapt to our knowledge of our environment and to become commensurate with our ability to position points with ever increasing accuracy.

In this series of articles, we have discussed how three particular species of reference systems—NAD 83, WGS 84, and ITRS—have evolved over the past couple of decades. Surely, they will continue to evolve into the future. Indeed, U.S. and Canadian representatives are already planning to introduce a new realization of NAD 83. The U.S. geospatial community will come to know this new realization as NAD 83 (NSRS) where NSRS is an acronym for National Spatial Reference System. NAD 83 (NSRS) will serve to supercede the conglomeration of regional reference frames that comprise NAD 83 (HARN). In particular, NAD 83 (NSRS) will incorporate newly computed positional coordinates for all HARN control points, as well as other control points, so that these new positions will be consistent with adopted CORS positions (Figure 5). Currently, horizontal discrepancies as large as 7 cm exist between NAD 83 (HARN) positions of control points and their idealized NAD 83 (CORS96) positions. Significantly greater discrepancies exist in the vertical dimension, because the accuracy of ellipsoidal heights measured during the earlier HARN surveys compares poorly relative to today's height-measuring capability. Consequently to obtain more accurate heights, NGS is cooperating with several organizations to resurvey the HARN in each State. These HARN resurveys reflect NGS's Height Modernization Initiative to support the public's growing use of GPS to measure accurate heights. NGS expects to complete the HARN resurveys around 2002. Moreover, NGS will wait until these resurveys have been completed before releasing NAD 83 (NSRS), as this agency plans to combine these new observations rigorously with existing observations to compute accurate ellipsoidal heights that are consistent across the country. NGS is also developing more and more accurate geoid models to convert such ellipsoidal heights to appropriate orthometric heights. Additional details about this forthcoming NAD 83 realization may be found at the Internet address: *http://www.ngs.noaa.gov/initiatives/new_reference.shtml.*

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Transformation Parameters from ITRF96 to NAD83 (CORS96)

In the summer of 1998, NGS and Canada's Geodetic Survey Division adopted the following parameters for transforming positions in North America from ITRF96 to NAD 83 (CORS96) via equation (1) :

For the three shifts:

Tx = 0.9910 m
Ty = -1.9072 m
Tz = -0.5129 m.

For the scale factor:

s = 0.0 (unitless).

For the three rotations (counterclockwise sense positive):

Rx = [25.79 + 0.0532 • (t - 1997.0)]• mr radians
Ry = [9.65 - 0.7423 • (t -1997.0)]• mr radians
Rz = [11.66 - 0.0316 • (t - 1997.0)]• mr radians.

In the above equations, mr = 4848.13681• (10**-12) is the conversion factor from milli-arcseconds to radians; t is the "epoch date" in years (e.g., 1999.3096 0h UTC, 23 April 1999). Recall that the epoch date is the date to which the given positions correspond. Note that the rotations, Rx, Ry, and Rz, are time dependent because the North American tectonic plate moves relative to ITRF96 while this plate is essentially stable relative to NAD 83 (CORS96).

Because ITRF94 and ITRF97 have the same origin, orientation, and scale as ITRF96, these same parameters are applicable for transforming these other two ITRS realizations to NAD83 (CORS96). On the other hand, these parameters are not applicable for transforming ITRF93 and earlier ITRS realizations to NAD 83 (CORS96).