Another Coordinate System
This Time Without Survey Marks

The National Geodetic Survey Federal Geospatial Summit was held in Silver Spring, MD on May 11–12, 2010 to introduce recommended replacements for the North American Datum of 1983 (NAD 83) and the North American Vertical Datum of 1988 (NAVD 88). The National Geodetic Survey (NGS) introduced to interested federal agencies a concept for the replacement of the two national datums which NGS believes are nearing obsolescence in terms of absolute accuracy of the approximately 1,000,000 geodetic control monuments and increasingly better technology based on Global Navigation Satellite Systems, or GNSS. (GNSS differs from the Global Positioning System (GPS) because it makes use of other navigation satellite systems such as the GLONASS Russian, Galileo European, and COMPASS Chinese navigation satellite systems.) The basis for this decision is contained in the White Paper authored by Dr. Dru Smith, Chief Geodesist for the NGS found at: http://www.ngs.noaa.gov/2010Summit/Improving_the_NSRS.pdf.

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**Background**

A geometric datum can be defined mathematically by eight unique parameters and realized in practice by the coordinates of a select set of points on the Earth. These parameters are referred to as a geodetic reference *system* and its realization referred to as a geodetic reference *frame*. The system is unique and exact while the frame is only as accurate as the data used to realize coordinates of the selected points on the Earth.

The present reference frame for North America is NAD 83, officially adopted by the United States in 1986. NAD 83 was the first North American datum based on an Earth-Centered-Earth-Fixed (ECEF) coordinate system (latitude, longitude and ellipsoid height) based upon the recently accepted internationally defined system, Geodetic Reference System 1980 (another realization is the World Geodetic System, or WGS84).

The definition of NAD 83 is a set of eight parameters, but the reference frame was originally realized by a network of approximately 250,000 geodetic control points and a sparsely spaced network of TRANSIT satellite positions across North America. The relative accuracy of the original realization was 1:100,000 between directly connected points and one meter in absolute accuracy (positional accuracy). This first realization was named NAD 83 (86) in recognition of the epoch date for the national adjustment. NAD 83 went through a series of readjustments making the realization more accurate using GPS surveying technology along with the creation of a network of approximately 1,450 Continuously Operating Reference Stations (CORS). The latest realization has an epoch date of 2007. As NAD 83 progressed through various realizations so did the ITRF and WGS84. Due to different methods and distribution of observations, the latter two realizations have an ECEF origin which is different from NAD 83 by about two meters. A goal for a new North American Datum would be to eliminate difference in ECEF origins.

NAD 83 defines a geometric coordinate system where height is measured from a reference ellipsoid surface. Heights in this system are known as *ellipsoid heights*. Heights used for surveying and mapping are referred to an equipotential (gravimetric) surface and are known as *orthometric heights*. A geoid model can be used to transform ellipsoid heights into orthometric heights. GNSS surveying technology can be used to determine accurate ellipsoid heights transformable into orthometric heights when used with a geoid model. In response to the requirement to relate a gravimetric-based vertical reference surface that would also be compatible with NAD 83 ellipsoid heights, the NGS implemented the North American *Vertical Datum of 1988* (NAVD 88) as the most accurate realization for orthometric heights across North America.

To minimize any impact to the contours on paper maps, such as the USGS 7.5-minute topographic maps, an origin for NAVD 88 was chosen in Quebec. The choice of origin and uncompensated errors caused by the imperfect model for the distribution of mass in the

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Lew Lapine (left) and Tom Hall, SCGS Senior Geodetic Technician, discuss site location for an NGS Height Modernization passive station. *Photo by Julie J. Prickett.*

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Rocky Mountains created a slope to the equipotential surface amounting to nearly two meters in the northwestern coastal region of the United States. NGS uses the above pair of two meter discrepancies to make a compelling rationale for replacing NAD 83 and NAVD 88 with the National Spatial Reference System aligned to an internationally accepted reference frame, the ITRF, and relying upon a gravimetric geoid model for ellipsoid-to-orthometric height conversions.

**Next Step**
NGS discussed two possible reference frames resulting for introducing a new geocentric and gravimetric datum for North America as follows:

1. A reference frame that exactly matches ITRF including the accommodation of crustal motion velocities for the realization of coordinates for the United States.

2. A hybrid reference frame that both exactly matches ITRF including the use of crustal motion velocities for the United States and that can be exactly transformable to a fixed North American Plate without crustal motion velocities.

In both cases, NGS stated that the primary method of defining and accessing the new system would be through CORS and a gravimetric geoid model. Passive control will not define the reference frame but will still be tied to the NSRS and serve as access to the new frame. This does not relieve the user of verifying the accuracy of control points. However, NGS encourages its users to use control that has been “recently” tied to the NSRS through GNSS and CORS.

**Potential Issues**

1. Realization of both proposed reference frames would change the future support for the approximately 1,000,000 passive geodetic control monuments, requiring NGS to provide a suite of online tools and databases to support user surveys on those monuments they desired.

2. Either of the above realizations would introduce sufficiently large changes to the present realization requiring all users to eventually transition off of NAD 83 and NAVD 88 as their needs for increased accuracies dictate. The author suspects that much like the transition from NGVD 29 to NAVD 88 and NAD 27 to NAD 83, users will likely take a decade or more to make this transition.

Thankfully, NGS explicitly stated that there will be a transformation algorithm to convert NAD 83 and NAVD 88 coordinates to the new realization that preserves as much as possible the geometric properties of the coordinates.

North America has always had separate (time invariant) horizontal and vertical datums. NGS is proposing a unique single datum that provides centimeter accuracy for the three-dimensional coordinates of latitude, longitude and orthometric heights (understanding that ellipsoid heights would also be available as part of the geometric portion of the datum) as the ultimate goal. This datum would be a mix of gravimetric and geometric qualities with time-dependent coordinates. NGS made it clear that certain time dependencies (such as the effect of plate rotation) would be transparently removable for users who preferred a plate-fixed approach to horizontal coordinates, while other time dependencies such as subsidence of bench marks would be purposefully spotlighted, to ensure that users of those heights understand the impact they may have on life and property.
NGS was, and always will be a world leader in geodesy. To maintain its leadership role and prepare the Nation for future improvements in positioning technology, adoption of a new datum based on the ITRF definition is necessary. Implementing proposal #1 above, with just the ITRF concept being realized, it is hard to imagine a requirement to transform terabytes of geospatial data every time it is used, or the difficulty of using continually changing coordinates during the completion of a large geodetic control project requiring several months to complete, especially considering most users are on the stable North American Plate. These geodetic surveys would be tied to the active network only.

Implementing the hybrid proposal #2 above might be “best” for the majority of users because it can accommodate crustal motion for the most accurate scientific work and at the same time be accurately transformed to realize coordinates on the stable North American Plate. Such a combination would benefit 90% of the states that are located on the North American Plate and provide the luxury of long-term consistency as well as economy of use.

Another alternative that might be “most acceptable” to the largest number of users would be to implement an ITRF datum with time dependent coordinates, readjust all passive control points established by GNSS technology and submitted to NGS for inclusion in the National Spatial Reference System (NSRS), and produce a transformation from ITRF that would yield North American Plate fixed coordinates for the passive stations included in the readjustment. However, it would require NGS to develop a countrywide three dimensional crustal velocity model (replacing the two-dimensional HTDP model now in use).

**View from a User’s Perspective**

NGS believes that a sparsely populated network of continuously operating GNSS reference stations, an Active Geodetic Network, should be used to define, and be the primary method of accessing a new datum. At the present time, NGS operates a network of 1463 CORS that are not equally distributed across the Nation. Currently, NGS owns only 30 CORS; while 1433 CORS are built and operated by other government and private sector participants. There is no guarantee at this time (or in the future) that the majority of the CORS will continue to be maintained or ever become more equally spaced across the Nation. For this reason NGS should be encouraged to move forward with their proposal for a “Foundation CORS” project (see the NGS 10-year plan), where CORS are to be equally distributed, NGS-owned, or sites of the highest standards.

Twenty years ago, few surveyors and geodesists were capable of establishing control points that met the NGS standard. As a result, NGS had a large field force operating nationwide to establish passive geodetic control points for its users. Passive monuments are the very fabric of surveying, engineering and mapping to this day. Passive monuments will be required for a long time to come and must become an integral part of any new realization. The surveyor and geodesist must be capable of returning to the same point for various reasons including: temporal changes, sea level rise or studies that require repeat observations. Passive monuments are required to tie various data sets together collected over long periods of time. NGS believes the use of a passive network which has not been regularly checked through GNSS technology has limited usefulness. It is always recommended that any monument used in a survey be verified by connecting it the active network.

Many states are creating a real-time network (RTN). Like the national CORS, these RTNs are composed of continuously operating GNSS stations, but are more densely spaced. Most RTNs are tuned to NAD 83 and realize centimeter-level relative accuracy to the existing passive geodetic control monuments and thus have no requirement for improved accuracy. The already proven economic benefits of RTNs will drive more states to build their own RTNs. Although the RTNs are generally tied to the CORS, the coordinates based on the sparse population of CORS has not proven to be sufficiently accurate for use in an RTN. Should NGS choose to pursue only the ITRF Option, what compelling reason would there be for the states to adopt an ITRF realization?

The Director of NGS has assured the author that NGS is not considering converting the CORS into an RTN despite the fact that such activities have been suggested in the past.

**Summary**

The National Geodetic Survey’s Federal Geospatial Summit provided federal users of the NSRS several interesting concepts for developing one new datum to replace both NAD 83 and NAVD 88. There are many compelling reasons based on accuracy and future technology that may force a change to a new datum. The best case made for a change to NAVD 88 was made at the Summit and as was pointed out in the NGS White Paper. The case for replacing NAD 83 with an ITRF-aligned datum is logical and necessary in order to bring the United States in sync with the rest of the world. After all, GNSS is a worldwide system. The realization of ITRF should be studied carefully with input from users outside of the Federal government. ITRF realized by a sparse network of CORS heavily dependent on CORS built and operated by other entities while changing the role of the traditional passive network had its risks and may not be readily acceptable to the greatest number of users, particularly with the advent of RTNs which is clearly outside the NGS Mission.