# Understanding the Evolution of WGS 84 and NAD 83

**October 10, 2016**

**Summary**
Both WGS 84, the datum used by GPS, and NAD 83, commonly used in North America, have been redefined several times since their beginning. Parallel to this, there have also been several realizations of the International Terrestrial Reference System (ITRS), referred to as ITRFxx, where ITRF stands for International Terrestrial Reference Frame and xx refers to the date. ITRF realizations are closely tied to developments both in WGS 84 and NAD 83.

The introduction of various realizations of reference frames has affected the methods used by Trimble MGIS processing software to transform from WGS 1984 to NAD 1983, as well as the methods used by field software to effect the same transformation. It has also given rise to much confusion regarding datum transformation methods and recommended practices.

You may want to ask what's the problem and why should we care? With the cost of high precision geospatial data collections declining, more people are looking to get submeter or subfoot accuracies. This is bringing about the need to have more reliability with data collection and datums. Some of the legacy and current geospatial base data is likely less accurate than what you are collecting with today.

With so many options available, how do we know which data is good? First off, you will need to understand the source or datum from which the data was collected in or referenced to. Most people want to compare their data to some sort of orthophotos, which is not the best way of seeing how accurate you data is. The best way to check the accuracy of your data is to compare it to a survey marker or benchmark. To learn how to do this, please see out support note on GPS Data Not Lining Up With GIS Data.

This paper will briefly cover the history of WGS 1984 and NAD 1983, then discuss in practical terms how users of Trimble MGIS software and ESRI's ArcPad mobile GIS software are affected by these issues.

**The Evolution of NAD 83**
There have been at least six realizations of NAD 83 in the United States. These changes have come as a result of maturing GPS and other geodetic technologies that have allowed for more precise measurements of the earth's center of mass, and other elements that define a reference system (the location of the North Pole, or International Reference Pole, and the location of zero longitude at the equator, used in defining the alignment of the cartesian axes; and the realization of the unit of length (what constitutes the physical measurement of the meter) or "scale.").

The original NAD 83 (referred to as NAD 83 (1986) by the National Geodetic Survey) was developed using the best technology available at the time. However, the geocenter, cartesian axes, and scale were all somewhat imprecise.

Starting in 1989, each state - in conjunction with NGS and various other state institutions – used GPS to establish regional reference frames that were to be consistent with NAD 83. These networks of GPS control points were originally called High Precision Geodetic Networks (HPGN), and currently are referred to as High Accuracy Reference Networks (HARN). This collection of regional realizations referred to as NAD 83 (HPGN) or NAD 83 (HARN) is the second realization of NAD 83.

Beginning in late 1994, NGS introduced further realizations of NAD 83 when the agency organized a ne work of continuously operating reference stations (CORS). These realizations are the result of transforming then-current


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ITRFxx positional coordinates of a subset of CORS stations in the United States, and in its last realization, in the US and Canada, to NAD 83. These realizations are referred to as NAD 83 (CORS93), NAD 83 (CORS94), and NAD83 (CORS96). Since 2002, all CORS sites (except those in the Pacific islands and some in Alaska) have had their coordinates referenced to NAD83 (CORS96), more specifically, to the 2002 'epoch,' or the NAD83 coordinate as it was on January 1, 2002. These coordinates are referred to as NAD83 (2002.00). Coordinates of CORS stations in the Pacific islands are referenced to NAD83 (PACP00) or NAD83 (MARP00) (fixed Pacific plate and fixed Mariana plate respectively). CORS stations in Alaska are referenced to NAD83 (2003.00) due to the Denali earthquake in 2002.

The NGS completed a national readjustment of NAD 83 on February 10, 2007 which is being referred to as NAD83 (NSRS2007) or simply NAD83 (2007). More than 70,000 passive geodetic control monuments are now referenced to this realization. However, CORS stations are not referenced to NAD83 (NSRS2007), since their location was held constant for the adjustment. Hence, the corrections supplied by NGS CORS stations is still referenced to NAD 83 (CORS96), either 2002.00 or 2003.00 epoch. Also, since the difference between NAD 83 (HARN) and NAD83 (NSRS2007) is in the 1-3 cm range, no transformation has been or will be produced by the NGS for converting to NAD83 (NSRS2007). For more information, please see the NGS Website.

It should be noted that the NAD 83 (HARN) latitude and/or longitude of a given control point may differ by up to a meter from its corresponding NAD 83 (1986) coordinate. Fortunately, the horizontal discrepancy between the NAD 83 (CORS93) and NAD 83 (HARN) positions for a control point is almost always less than 10 cm, and the horizontal discrepancy between any two NAD 83 (CORSxx) positions for a control point is almost always less than 2 cm.

The NGS recently completed a national readjustment of NAD 83 on June 30, 2012 which is being referenced as NAD 83 (2011/PA11/MA11) epoch 2010.00. This project adjusted the NGS "passive" control, physical marks that can be occupied with survey equipment, positioned using Global Navigation Satellite System (GNSS) technology. The adjustment was constrained to current NAD 83 latitude, longitude, and ellipsoid heights of NGS CORS network. Constraining the adjustment to the CORS optimally aligned the GNSS passive control with the active control, providing a unified reference frame to serve the nation's geometric positioning needs. For more information, please see the NGS Website on the 2011 project.

**The Evolution of WGS 84**

The DoD (Department of Defense) established the original WGS 84 reference frame in 1987. As GPS was in its infancy, GPS was not used to establish this original WGS 84. The original WGS 84 realization essentially agrees with NAD 83 (1986). It is generally assumed, and this assumption is substantiated by the National Geodetic Survey, that WGS 84 (original) is identical to NAD 83 (1986).

In 1994, DoD introduced a realization of WGS 84 that was based completely on GPS observations. This new realization is officially known as WGS 84 (G730) where the letter G stands for "GPS" and "730" denotes the GPS week number (starting at 0h UTC, 2 January 1994). This realization is generally assumed to be identical to ITRF92.

A third realization of WGS 84, also based completely on GPS observations, was introduced 29 September 1996, and adopted by the GPS Operational Control Segment on 29 January 1997. This realization is termed WGS 84 (G873), and is generally assumed to be identical to ITRF96.
The latest realization is termed WGS 84 (G1150) and is generally assumed to be identical to ITRF00. This


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realization was adopted 20 January 2002.
A GPS position calculated in one realization of WGS 84, when converted to another realization of WGS 84, will differ at most by only a few centimeters.

**The Impact of Evolution**
What does all this mean?GIS data that is referenced to NAD 83 and was created by GPS input is actually referenced to an epoch or realization of NAD 83, such as NAD 83 (1986). Therefore, it is important to understand that different datum transformations from WGS 84 to NAD 83 exist, and their use assumes a certain input reference frame and specifies a certain output reference frame.

In GPS positioning as it applies to Trimble Mapping systems and software, the input reference frame or 'input datum' can vary depending on DGPS source, field software datum transformation settings (in the case of ArcPad), and post-processed differential correction settings. These will affect the output reference frame or 'output datum,' as will other processing software settings, such as Export settings.

These facts are in conflict with many long-standing assumptions for some users, which can lead to confusion and unsatisfactory positioning results, especially when using H-Star receivers such as the GeoXH and ProXH, which are capable of sub-8" accuracy using a Zephyr antenna.

**Input Datum – Field Software**
It has long been assumed that GNSS data collected with a Trimble Mapping system is always reference to WGS 84. It is absolutely true that the GNSS coordinates calculated by the receiver are always referenced to WGS 84. However, the data that is collected by software such as TerraSync, ArcPad or ArcGIS Mobile can actually be referenced to a different spatial reference.

TerraSync theoretically collects all data referenced to WGS 84. However, if a real-time correction source such as a VRS or single base is used and attention is not paid to the TerraSync real-time settings to account for the real-time datum, then data can actually be referenced to some version of NAD 83 depending on the datum of the real-time source. For detailed information on the best practices for dealing with datums in TerraSync, refer to our support note on Non-WGS 84 Datums in Trimble TerraSync and Pathfinder Office.

ArcPad with Trimble Positions will convert GNSS data on the fly into the coordinate system and datum specified in the map. Care must be taken in the project setup, ArcPad settings, and check-in with Trimble Positions to ensure that the map datum, real-time datum, and GNSS datum are all accounted for. For details on this process, refer to out support note on Non-WGS 84 Datums in ESRI ArcPad and Trimble Positions.

ArcGIS for Windows Mobile with Trimble Positions will convert GNSS data on the fly into the coordinate system and datum specified in the Mobile Project. It is very important that real-time settings and workflows account for the different datums being consumed. For details on how to deal with datums in ArcGIS for Windows Mobile, refer to our support note on Non-WGS 84 Datums in ESRI ArcGIS for Windows Mobile and Trimble Positions.


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**Conclusion**

As spatial references continue to evolve, it is important to understand how such evolution affects the Mapping software that we use for collecting and processing GPS data. Options in both field and office software can change the spatial reference of the GPS data that we collect. Knowing how these changes occur can eliminate much confusion and lead to satisfactory positioning results.

**More information**

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