SupportBulletin

Understanding the Evolution of WGS 84 and NAD 83

December 29, 2008 MAPPING & GIS

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.

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 network of continuously operating reference stations (CORS). These realizations are the result of transforming then-current 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

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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 recently completed a national readjustment of NAD 83 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 at http://www.ngs.noaa.gov/NationalReadjustment/.

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 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 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

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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 GPS data collected with a Trimble Mapping system is always referenced to WGS 84. It is absolutely true that the GPS coordinates calculated by the Trimble GPS receiver are always referenced to WGS 84. However, the data that is collected by software such as TerraSync or ArcPad can actually be referenced to a different spatial reference.

For Trimble Mapping software, such as TerraSync (or now discontinued software such as Asset Surveyor), theoretically all data collected will be referenced to WGS 84. Coordinate System and datum settings in the software are display-only; data stored in WGS 84 is converted to the spatial reference of your choice for map display and measurement.

When NDGPS (USCG Beacon) corrections or Omnistar VBS corrections are used in real-time, the spatial reference of TerraSync data is changed to NAD 83 (CORS96). This is because USCG Beacon and Omnistar VBS corrections are referenced to NAD 83 (CORS96), being based on the NGS CORS network. The datum of the real-time correction source can be taken into account in more recent field software (such as TerraSync 3.20 or greater), or subsequent processing in office must take this fact into account. For example, if beacon-corrected data is downloaded to Pathfinder Office and exported without differential correction, care must be taken not to apply a NAD 83 (CORS96) datum transformation again during Export, since it has already been effected in the field by the DGPS source.

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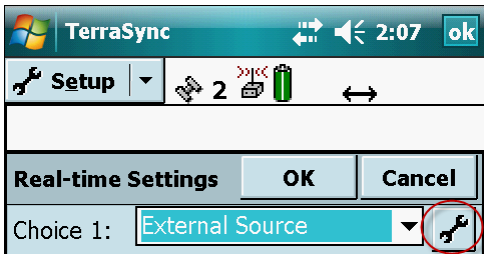
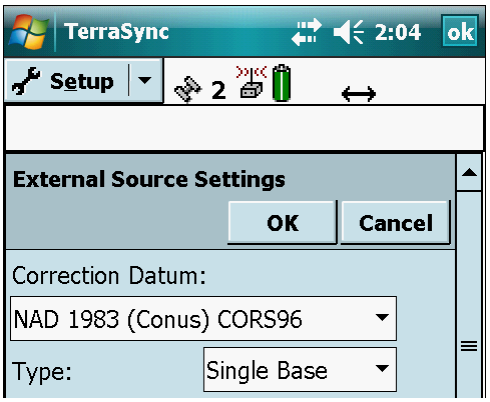
TerraSync Software

In TerraSync 3.20 or greater, real-time settings include specifying the datum of the correction source. These settings are available if a real-time choice is 'External Source,' 'Integrated Beacon,' or 'Integrated Satellite' by pressing the Settings button.



For beacon or Omnistar VBS service, choose NAD83 (Conus) CORS96. Real-time corrected data will have a datum transformation applied so that it is still referenced to WGS84.



ArcPad Software

ESRI ArcPad software records data in shapefiles that can be referenced to any supported projected coordinate system and datum. To accurately transform incoming GPS coordinates, ArcPad therefore needs to know three things – the input GPS datum (assumed to be WGS 84), the output datum (e.g. NAD 83 (CORS96)), and datum transformation parameters.

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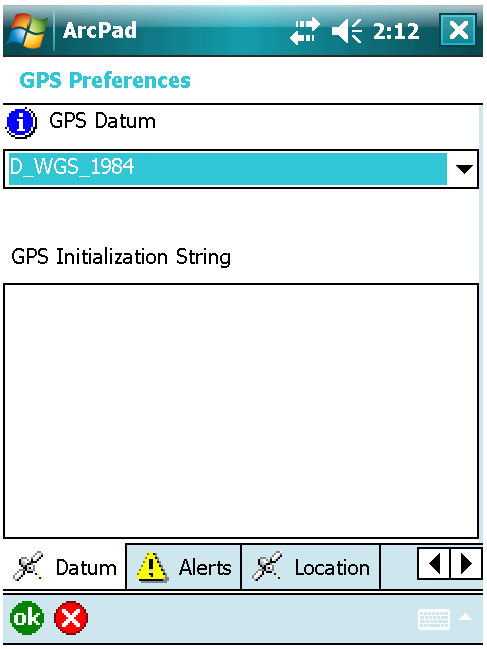
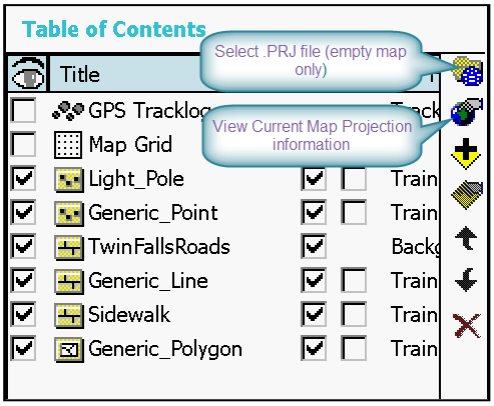
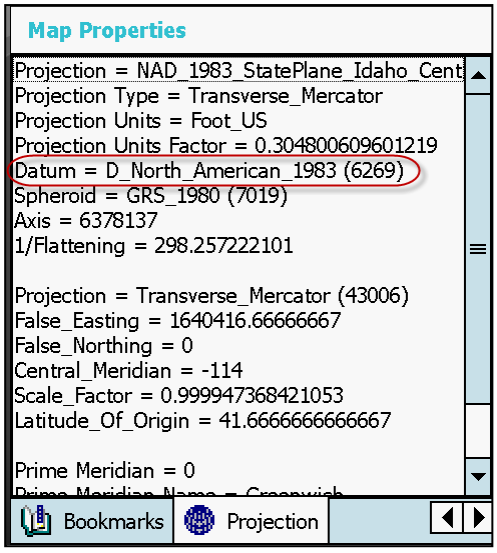
The input GPS datum in ArcPad is selected from the GPS Datum drop-down list found in GPS Preferences > Datum tab (above left). The default is D_WGS_1984.



The output datum is specified in the .prj file used by ArcPad to set the Map Projection. The .prj file used will be that .prj associated with the first layer loaded in the current map, the ArcPad.prj file found in \My Documents (if present), or the .prj file chosen in the Table of Contents. Press the 'Map Properties' button to view current map projection information (last page), including the datum being used in the map.





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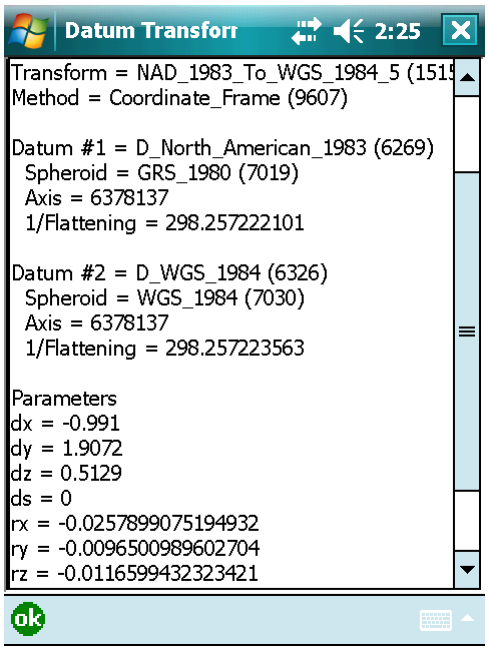
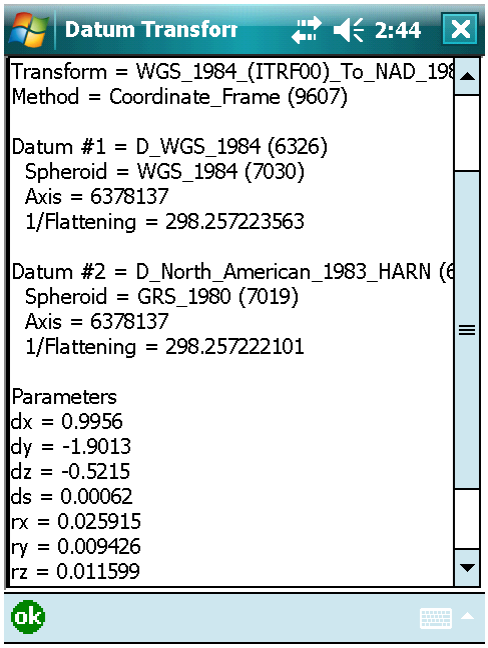
The datum transformation parameters can be verified after a map projection is set by pressing the button on the Datum tab. In ArcPad 7.0.1 and newer, the default datum transformation parameters from WGS 84 to NAD 83 are for ITRF 96 (essentially WGS 84 (G873)) to NAD 83 (CORS96) (see below left).





Since this is not an ITRF 00 to NAD 83 (CORS96) transformation, it could introduce 5-7cm of error.

However, the default transformation between WGS84 and NAD83 (HARN) is consistent with ITRF00 to NAD83 (HARN) (see above right).

In ArcPad 7.0 and 6.0.x the default transformation between WGS 84 and NAD 83 is a 'zero' datum transformation. This could lead to 1 meter horizontal errors when compared with NAD 83 (CORS96) control.

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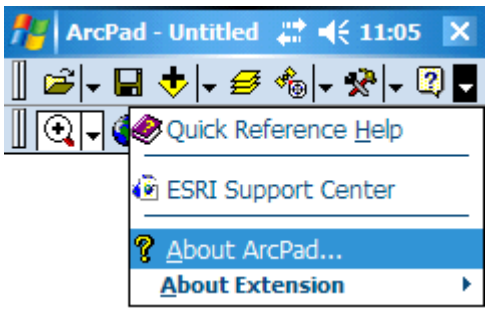
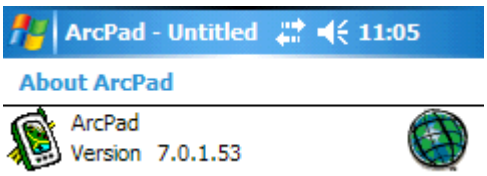
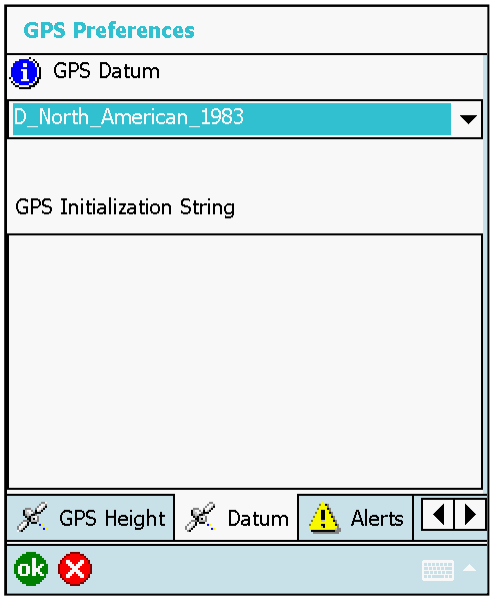
To find out which version of ArcPad you have, go to the Help drop-down, and select About ArcPad…





As noted above, when using a Trimble Mapping receiver, the input GPS datum will always be WGS 84 unless using USCG Beacon corrections, in which case the input GPS datum will be NAD 83 (CORS96). It would be necessary to change the GPS Datum to D_North_American_1983, particularly in ArcPad 7.0.1. Otherwise, a datum transformation from WGS 84 to NAD 83 (CORS96) could be applied twice – once by the USCG Beacon correction, and a second time by ArcPad.



Note: In ArcPad 6.0.x or 7.0, if the GPS Datum is left at the default D_WGS_1984, no datum transformation will be applied anyway, since the default transformation in these versions between WGS 84 and NAD 83 is a 'zero' datum transformation. Therefore, input = output, e.g., NAD 83 (CORS96) input > 'zero' datum transformation > NAD 83 (CORS96) output.

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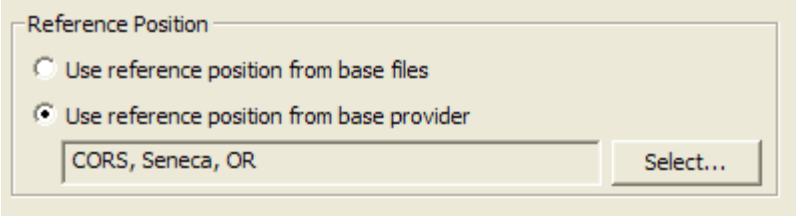
Office Software

Whether using Pathfinder Office or GPS Analyst software, there are several places where datum transformation can take place during processing.

Pathfinder Office

The spatial reference of GPS data can be changed from WGS 84 to a realization of NAD 83 during Differential Correction as well as during Export.

During Differential Correction, the user is presented with a choice regarding the base station reference position. Essentially, the choice is to use the reference position contained in Trimble's base station list, or to use the reference position from the base files themselves. The default choice is to use the reference position contained in Trimble's base station list, which has been compiled from details submitted by base station operators and is presented in terms of ITRF00. This is the option selected below, in the Pathfinder Office Differential Correction Wizard (v3.1 and newer).



Since the release of Pathfinder Office 3.0, all reference positions contained in Trimble's base station list have been put in terms of ITRF00 (essentially WGS 84 (G1150)). The reliability of the assumption that all of these reference positions are in terms of ITRF00 depends upon the coordinate supplied by the base provider; and if the reference position was originally referenced to a NAD 83 realization, whether the correct realization could be determined when converting to ITRF00. Particularly with CORS stations, data sheets exist that document clearly which NAD 83 realization the reference position is referenced to, whereas with private base stations, that is not always so easily determined. This could introduce positional errors. For example, if a base station reference position were actually referenced to NAD 83 (1986) but it was assumed that it was referenced to NAD 83 (CORS96) when the reference position contained in Trimble's base station list was converted to ITRF00, there could be 1 meter horizontal errors introduced by what amounts to an 'incorrect' reference position.

The other option, 'Use reference position from base files' or 'Set From Base File…,' will use whatever reference position is supplied by the base station operator in whatever datum it has been established. In the case of CORS stations, that would be NAD 83 (CORS96) (2002.00 or 2003.00 epoch), NAD83 (PACP00), or NAD83 (MARP00). Therefore, if this option is selected, GPS data will actually be transformed to the datum of the base station reference position, in this case NAD 83 (CORS96), NAD83 (PACP00), or NAD83 (MARP00). Care would have to be taken that a datum transformation from WGS 84 to NAD 83 (CORS96) was not applied again during Export.

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The 'Use reference position from base files' option will transform data to whatever spatial reference is used by the base station reference position. In the case of non-CORS stations, there may be confusion regarding what that spatial reference is. In reality, it could be WGS 84 or any realization of NAD 83. This could cause positional errors, since the input datum may not be known accurately.

It should be noted that if USCG Beacon-corrected data is differentially corrected, *the raw GPS information (referenced to WGS84) that is recorded in parallel to the DGPS positions is what is post-processed.*

In Pathfinder Office, the final place where spatial reference can be changed for data collected with TerraSync or other Trimble Mapping software is during Export. This is specified in Export Setup Properties on the Coordinate System tab.

In Pathfinder Office 3.0 and older, the NAD 1983 datum choices were all "zero" datum transformations, based on the old assumption that WGS 84 (original) = NAD 83 (1986). As these spatial references evolved and the demand for greater accuracy increased, the need for a more accurate transformation to NAD 83 was recognized.

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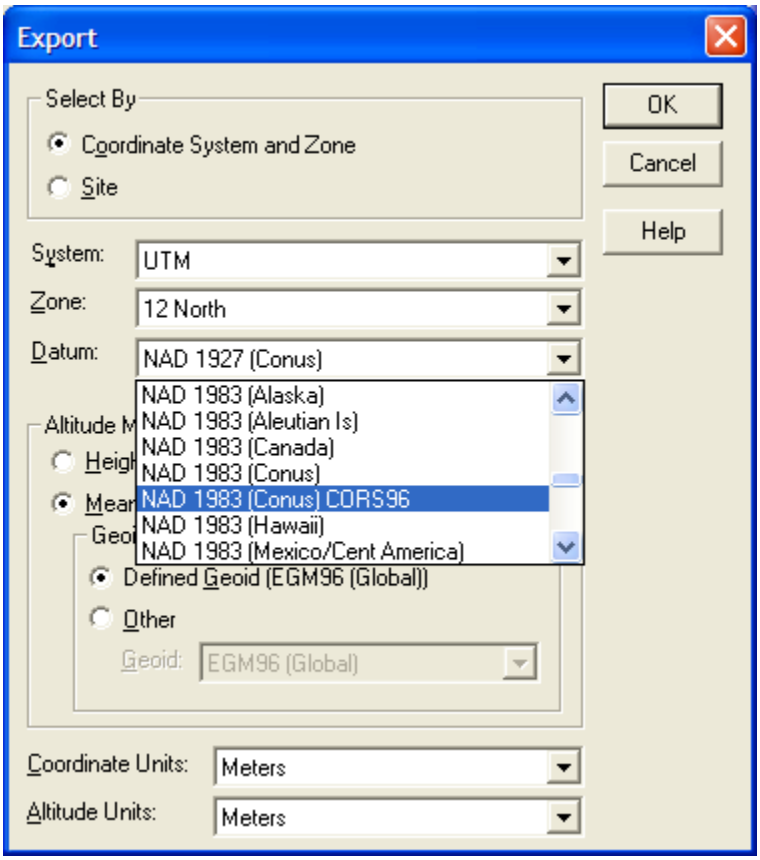
In Pathfinder Office 3.1, a new datum choice, NAD 1983 (Conus) CORS96, was introduced.



For those who are still using Pathfinder Office 3.0 or earlier, a Support Note is available specifying how to add this datum transformation into the Coordinate System Database. For more information, click here: http://trl.trimble.com/dscgi/ds.py/Get/File-170369/SprtNote_PFO-GPSA_NAD83Datum.pdf.

Note: In the case of USCG Beacon-corrected data that is not differentially corrected, and is therefore still referenced to NAD 83 (CORS96), or in the case of data that has been differentially corrected against CORS base stations with the Reference Position option 'Use reference position from base files' and is therefore referenced to NAD 83 (CORS96) one would want to select the NAD 1983 (Conus) datum choice (a "zero" datum shift) to avoid applying a datum transformation twice.

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GPS Analyst

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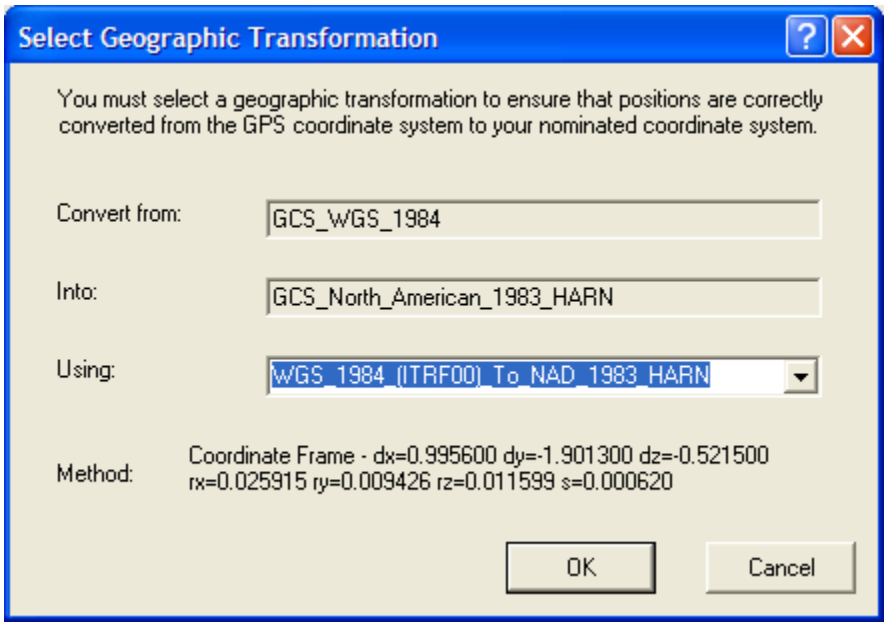
When a geodatabase is GPS-enabled, you are prompted to specify a datum transformation if your geodatabase is referenced to something other than WGS 84. For WGS 84 to NAD 83 transformation, the choices are:

NAD_1983_To_WGS_1984_1	NAD 83 (1996) - "zero" datum shift
NAD_1983_To_WGS_1984_2	Alaska Aleutians
NAD_1983_To_WGS_1984_3	Hawaii
NAD_1983_To_WGS_1984_4	United States - ITRF94
NAD_1983_To_WGS_1984_5	United States - ITRF96
NAD_1983_To_WGS_1984_6	Canada Quebec
NAD_1983_To_WGS_1984_7	Canada Saskatchewan
NAD_1983_To_WGS_1984_8	Canada Alberta

Specify the _5 transformation for NAD83 (CORS96).

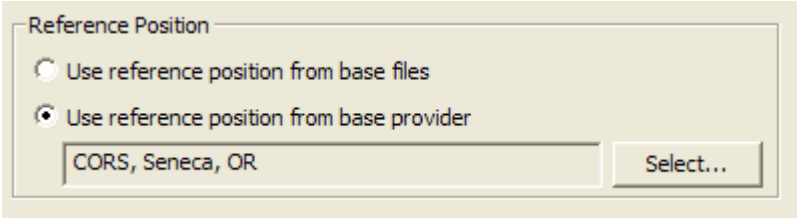
Note: This is a transformation between NAD 83 (CORS 96) and ITRF96, which is only a few centimeters different from ITRF00.

To effect an ITRF00 transformation, set the spatial reference of the geodatabase to NAD83 (HARN). Then, set the Geographic Transformation to WGS_1984_(ITRF00)_To_NAD_1983_HARN.



When doing differential correction in GPS Analyst, you are again prompted to select the source of base station Reference Position. If you have selected a non-zero geographic

transformation (such as the _5 transformation), use the default option to avoid applying a transformation twice.



Alternatively, if you select an _1 datum transformation ("zero" datum transformation) when GPS-enabling a geodatabase, you could choose the option to 'Use reference position from base files' with CORS base stations, which would effectively transform to NAD83 (CORS96).

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

Snay, Dr. Richard A. and Dr. Tomas Soler, "Modern Terrestrial Reference Systems (Part 1-4)," [online], http://www.ngs.noaa.gov/CORS/Articles/Reference-Systems-Part-1.pdf, http://www.ngs.noaa.gov/CORS/Articles/Reference-Systems-Part-2.pdf, http://www.ngs.noaa.gov/CORS/Articles/Reference-Systems-Part-3.pdf, http://www.ngs.noaa.gov/CORS/Articles/Reference-Systems-Part-4.pdf

Trimble, "GPS Pathfinder Office Software or the GPS Analyst Extension: Resolving the NAD 83 Datum Transformation Issue," [online], http://trl.trimble.com/docushare/dsweb/Get/Document-170369/SprtNote_PFO-GPSA_NAD83Datum.pdf, 5 May 2005

Dr. Richard Snay is Manager of the National Continuously Operating Reference Station (CORS) program and a geodesist with the National Geodetic Survey. Dr. Tomas Soler is Chief, Global Positioning System Branch, Spatial Reference Systems Division, National Geodetic Survey.

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