Correct Use of NAD 83 Realizations and GEOID Models

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I have been asked recently, "What geoid model should I use with which NAD 83 realization?" (Editor's Note: NGS uses the term *realization*. Locally, many use the term *adjustment*.)

Given the many geoid models and NAD 83 realizations that have become available over the past few years, it's not surprising that some surveyors are confused.

Here are the pairings that I recommend:

Datum/Realization	Geoid Model
NAD 83(1996)	GEOID03
NAD 83(NSRS2007)	GEOID09
NAD 83(2011)	GEOID12A

Now, for those of you who want to know why I recommend these pairings, I will explain the evolution of the datum realizations and companion geoid models.

What Is a Geoid Model?

As a general rule, a geoid model is simply a model of the separation between a chosen ellipsoid and the geoid. A geoid model is used to convert between ellipsoid heights and orthometric heights. This is because ellipsoid heights use the ellipsoid as a zero height surface and orthometric heights use the geoid as a zero height surface.

What Is a Regional Geoid Model?

Although the geoid is a global surface, models are often limited to regions of interest. For instance, the coterminous 48 United States have had successive geoid models computed by NGS since 1990. This is often done because (a) data that span the whole globe may not be available and/or (b) data within the region of interest may be higher quality or of a denser sampling rate, allowing for improved geoid detail within the region and/or (c) the computational burden of computing a geoid model for the entire globe may be prohibitive.

What Is a Global Geoid Model?

As might be expected, global geoid models are models of the geoid that span the entire globe. Global geoid models were historically computed only by those groups with access to global gravity data sets, even though these are not well-distributed over the Earth's surface and are of variable quality. Modern global geoid models have been improved by satellite missions dedicated exclusively to knowledge of the gravity field (GRACE, GOCE or CHAMP). In many places where terrestrial gravity data is well known, a global geoid model may be precise enough for surveyors to use in determining orthometric heights, but this is not the case in areas where gravity data are sparse or of questionable quality.

What Is a Hybrid Geoid Model?

A hybrid geoid model is a type of geoid model that has been purposefully distorted from "ideal" so that it is a useful converter between ellipsoid heights in the official "horizontal" datum (such as NAD 83) and orthometric heights in the official "vertical" datum (such as NAVD 88) for a region, such as the U.S. In Minnesota and other regions of the country, there are thousands of benchmarks that have orthometric heights (determined by differential leveling) and that also have ellipsoid heights determined by a GPS-based survey. The difference between the ellipsoid height and the orthometric height is a measurement of the hybrid geoid separation at that benchmark. Why isn't this just a measurement of the actual geoid separation at that benchmark? Because both NAD 83 and NAVD 88 contain systematic errors.

A well-spaced collection of these hybrid geoid separations can be used to constrain the regional geoid model in order to be a better fit to the more precise local measurements. The result is called a "hybrid geoid model" and has been given a name like GEOID12A.

Periodic Realizations

Historically, the National Geodetic Survey (NGS) has adjusted the data in its archive on an infrequent basis. Such adjustments are a simultaneous least squares analysis of the original measurements to create a set of latitude, longitude, and ellipsoid heights (for adjustments in the mid-1990s and later) for each point in the network. Obviously, as more data are added, or alternative sets of data are considered, the resulting adjustment will change. The result of each adjustment is a "realization" of NAD 83.

NAD 83(1986)

This is the original realization of NAD 83, built primarily from angle and distance measurements made throughout the preceding decades, with only a small amount of space geodetic techniques included (VLBI and Doppler). Its coordinates were computed nationwide in a single adjustment. As such, this realization is consistent across states.

NAD 83(1996) Realization for Minnesota

During the mid-1990s, many states were observing their individual High Accuracy Reference Network (HARN). Each state network was adjusted semi-independently of other state networks. In Minnesota, the state network realization was called NAD 83(1996), sometimes also called the HARN realization, and was a realization of ***only*** the Minnesota HARN observations constrained to a few of the CORS stations that existed at the time. The adjustment was "feathered" to match the neighboring states' HARN observations; small disparities in latitude, longitude, and ellipsoid heights remained near state boundaries. Note that in any given year, multiple state adjustments were performed, so, for instance, there is an NAD 83(1996) realization for Iowa, North Dakota, South Dakota and most of the New England states, but these are not the same "NAD 83(1996)" realization as in Minnesota. It was not until 2007 that a single adjustment was performed nationwide allowing state-by-state consistency in one realization (as per the 1986 realization).

A series of hybrid geoid models were developed to fit the published ellipsoid heights to the published orthometric heights. These geoid models were called GEOID96, GEOID99, and finally GEOID03. All were designed to convert the published ellipsoid heights to the published orthometric heights in the NGS database at the time of the geoid model creation.

The largest changes in hybrid geoid models came on a state-by-state basis, as new ellipsoid heights replaced older (or non-existent) ellipsoid heights. In states where ellipsoid heights didn't change, there were still changes to the hybrid geoid model, based on the new gravity information (either terrestrial or space borne). These several geoid models should be thought of as evolving (and converging) versions of a single truth. It would not actually be wrong to use GEOID96 or GEOID99, but they are simply not as accurate as the later GEOID03 model.

NAD 83(NSRS2007) Realization

Often colloquially shortened to "NAD 83(2007)", this was the first nationwide realization since NAD 83(1986). NGS had planned to incorporate the data from the independent state-by-state HARN surveys into a single nationwide adjustment, thereby eliminating the troublesome state-by-state biases.

NGS was also considering the possibility of analyzing the vast accumulation of data files of the expanding National CORS system with the goal of creating a master network adjustment of the CORS stations. This analysis would later be called the Multi-Year CORS Solution (MYCS). It was difficult to estimate the effort to perform the MYCS, so rather than wait for MYCS, NGS decided to proceed with the nationwide adjustment to eliminate the state-by-state biases.

The resulting adjustment, called NAD 83(NSRS2007), created an all-new set of ellipsoid heights in every state, some states being more affected than others. In Minnesota, there was a median 7 cm change in the southern part of the state, but only about 1 cm in the northern part of the state.

The network adjustment took place in February 2007, but the corresponding geoid model was not published until 2009 and was called GEOID09.

NAD 83(2011) Realization

The NAD 83(2011) realization was performed to incorporate the high level of consistency in both horizontal and vertical components made possible by the success of the MYCS. The latitude, longitude, and ellipsoid heights of the National CORS were used as the constraints for the NAD 83(2011) realization. Only small shifts in latitude, longitude, and ellipsoid heights occurred in this realization. In Minnesota, these shifts were about 2 cm in each component, varying slightly by region.

A geoid model was developed as a companion for the NAD 83(2011) realization and called GEOID12. After the release of GEOID12, a few mistakes were identified. Fixing the mistakes meant a new geoid model was needed, but the name had to be changed. Hence GEOID12A is the correct model to use with NAD 83(2011).

Why Do Realizations and Hybrid Geoid Models Exist as Pairs?

As explained, each successive realization altered the published ellipsoid height of marks in the database. A hybrid geoid model seeks to "convert" that ellipsoid height to an approximation of the orthometric height at that same location. Since the orthometric heights generally did ***not*** change at any time throughout the period from 1996 to 2011, every systematic change in the ellipsoid heights needed to be accompanied by a corresponding and compensating change in the hybrid geoid model.

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Why Would Someone Use the Wrong Hybrid Geoid Model?

Every ellipsoid height and every orthometric height is computed from surveying measurements that contain unavoidable errors. Every hybrid geoid model is computed by constraining the regional geoid model to fit the local measurements on benchmarks. Therefore, no single location can have a perfectly "correct" ellipsoid height, orthometric height, nor geoid-ellipsoid separation.

Since hybrid geoid models are computed to be a best-fit on a regional basis, there may be smaller sub-regions wherein a hybrid geoid model is not a perfect fit. Perhaps one could take an ellipsoid height at a particular location and by trial-and-error decide that one hybrid geoid model "fits" better in that locale than some other hybrid geoid model. One cannot generalize that such a goodness-of-fit extends across more than the local area.

In effect, this is an odd variation on the technique called "localization" or "site calibration".

What's the Correct Way to Use a Hybrid Geoid Model?

Modern surveyors should use the hybrid geoid model that is recommended (see above) as the compatible companion for the datum/realization in the survey. Then, "localize" to the orthometric heights in the area by occupying several benchmarks and comparing their published orthometric heights to their ellipsoid heights plus geoid-ellipsoid separations. The average discrepancy so determined represents the goodness-of-fit of the recommended hybrid geoid model. The discrepancy is then applied to the survey measurements.

Using the recommended hybrid geoid model ensures that any surveyor can use a single method of surveying in any location without resorting to trial-and-error techniques. It will be much easier to explain in the survey report what was done and why it was done if a standard method is used every time.

