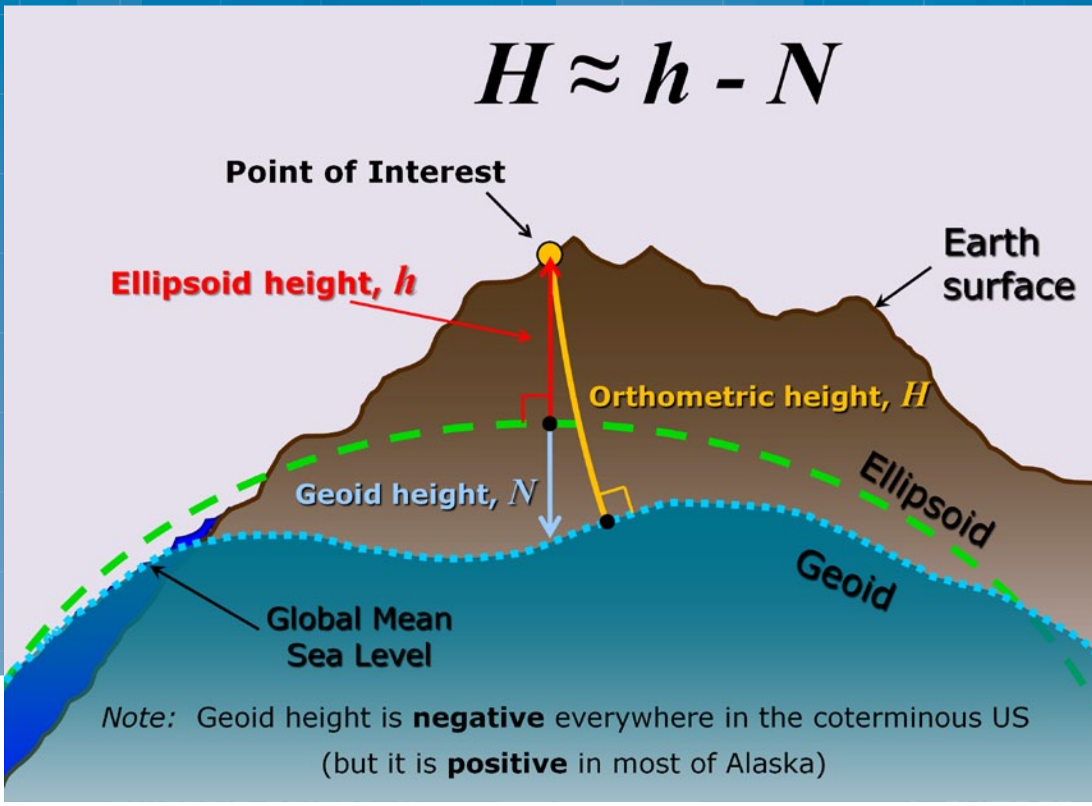

Figure 5. The relationship between orthometric height (H), ellipsoid height (h), and geoid height (N). Note that the geoid is below the reference ellipsoid in the coterminous US, hence the geoid height is negative (i.e., H > h). Both ellipsoid and geoid heights are determined from the ellipsoid; the orthometric height is determined from the geoid.

Frames for the Future

New Datum Definitions for Modernization of the U.S. National Spatial Reference System

Replacing NAVD 88—The Role of Geoid Models (Part 2 of 4)

Background

Assuming funding allows the planned schedule, a new gravity geopotential-based vertical datum to replace NAVD 88 could be defined and nationally adopted by 2022 (since this is highly dependent on funding availability, the reader should consider this date somewhat tentative). This datum will reference a purely gravimetric geoid model, rather than a hybrid geoid model like GEOID09 and its precursors (this difference is discussed later). Like NAVD 88, the heights will be orthometric heights but, unlike NAVD 88, leveling data and other data on passive marks (such as gravity observations) will not be the primary observational data set used to define the datum. In fact, the role of leveling in defining the new datum has not yet been fully determined (Smith, 2011). The relationship between orthometric height, ellipsoid height, and geoid height is shown in **Figure 5.**

Strictly speaking, the reader should note that NAVD 88 is not purely an orthometric height system. The primary parameters, determined when NAVD 88 was first defined, were geopotential numbers determined from leveling and the nationwide NAVD 88 surface gravity model (derived from surface gravity measurements). For NAVD 88, a specific approximation to true orthometric heights, known as "Helmert orthometric heights" were computed from the geopotential numbers and the NAVD 88 surface gravity model (dynamic heights were also computed from the geopotential numbers, and required no surface gravity). Although NAVD 88 is based on geopotential numbers which can in turn be used to compute other types of heights (such as dynamic heights), it is common to equate NAVD 88 with orthometric heights, and that typical usage will be followed for the remainder of this paper.

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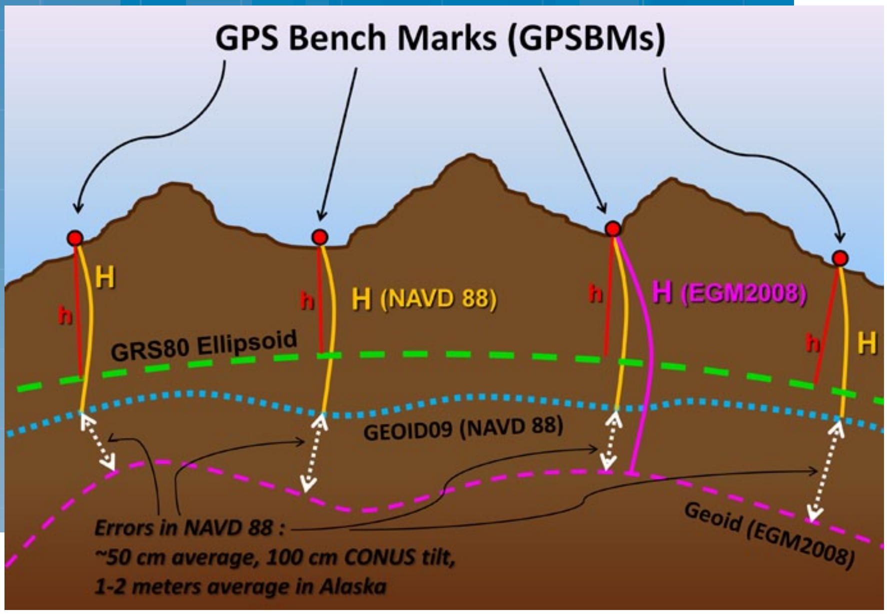

Figure 6. Illustrates the use of GNSS bench marks to create a hybrid geoid model (GEOID09) from a purely gravimetric geoid model. While GEOID09 is actually based on the gravimetric model USGG09, EGM2008 is shown in the figure since the "errors" in NAVD 88 are with respect to EGM2008. USGG09 is a refinement of EGM2008 specifically for the United States. "CONUS" refers to the Continental U.S.

Note: for ease of reading, for the remainder of this paper the new datums will be called the National Geometric Datum (NGD) and the National Vertical Datum (NVD). However, please note that the names of the new datums have not yet been determined.

The intent of the new NVD is to allow the conversion of ellipsoid heights–determined by GNSS observations referenced to the new NGD–to orthometric heights with an accuracy of 2 cm (at 95% confidence). This accuracy statement incorporates both the expected 2022 geoid model and GNSS-based ellipsoid height accuracies of 1–2 cm, for a total combined accuracy of approximately 2 cm for orthometric heights. To achieve this will require a geoid model accuracy approaching 1 cm, which likely will only be achievable in coastal, eastern, and mid-western portions of the United States. Expected accuracies are still being evaluated for the geoid model in the mountainous western states, Alaska, Hawaii, and U.S. possessions.

Hybrid Geoid Models

A hybrid geoid model is a product developed by NGS in 1996 specifically designed to convert ellipsoid heights in NAD 83 to orthometric heights in NAVD 88. It differs from a gravimetric geoid in that it incorporates the systematic errors of the official datums of the Unite States, NAD 83 and NAVD 88. The two primary systematic errors are the lack of geocentricity of NAD 83 and the approximately one-meter "slope" of NAVD 88 across the country; both issues will be discussed later.

In short, a hybrid geoid model is constructed by taking a gravimetric geoid model and "adjusting" it to best fit the surface of orthometric heights in NAVD 88 that also have accurate NAD 83 ellipsoid heights. As shown in **Figure 6,** the resultant surface is the hybrid geoid model (e.g., GEOID09; see Roman, et al., 2010b). GEOID09 was created from the gravimetric geoid model USGG2009 (U.S. Gravimetric Geoid of 2009; see Roman, et al., 2010a), which was derived in part from EGM2008 (Earth Gravitational Model 2008; see Pavlis, et al., 2008). Generating the hybrid model introduces additional uncertainty on the resultant orthometric heights and, therefore, diminishes the accuracy and efficiency of GNSS in determining orthometric heights.

By defining a geometric datum that is truly geocentric and a vertical datum based on a purely gravimetric geoid model, the need for a hybrid model will no longer exist. The resultant GNSS-derived orthometric heights will be more accurate on a national basis with respect to mean sea level (as represented by the gravimetric geoid). One of the main reasons for this improved nationwide accuracy is that the new vertical datum will not be defined by differential leveling, and so the datum definition will not be subjected to the systematic errors that accumulate in large (continental) scale leveling. Note that this new approach requires consistent, modern, high-accuracy gravity observations along with other high-quality geospatial data (e.g. high-resolution terrain models) not available until recently. The NVD will be determined by high-resolution airborne gravity data collected across the U.S. and its possessions. Flights, to date, have been performed in Alaska, the U.S. Virgin Islands, Puerto Rico, the Great Lakes, and portions of the Gulf Coast, Texas, and California. This program is called GRAV-D (Gravity for the Redefinition of the American Vertical Datum). GRAV-D is expected to require twelve years to yield the data needed to completely redefine the U.S. vertical datum. More information on the GRAV-D project is provided in NGS (2007) and at www.geodesy.noaa.gov/grav-d.

In the meantime, NGS expects to continue to define hybrid geoid models on an as-needed cycle until NVD is defined and adopted. Note that NVD will not be released until a complete (full U.S. coverage) system is defined. Therefore, the continued acquisition of GNSS observations on leveled NAVD 88 bench marks, resulting in so-called GPSBMs (Global Positioning System Bench Marks) is encouraged, especially in areas with sparse distribution of GPSBMs. Additional GPSBMs will improve the reliability of subsequent hybrid geoid models, thereby providing more accurate conversion of NAD 83 ellipsoid heights to NAVD 88 orthometric heights.

References for this four-part series are available in the Exclusive Online-only Content area of amerisurv.com

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