Wisconsin
State Cartographer's Office

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UNIVERSITY OF WISCONSIN–MADISON

Your resource for mapping and geographic information in the state of Wisconsin *January 2012*

Understanding Elevation

Introduction

Growing up, most of us were taught that a sign reading "Timms Hill - Elevation 1,951 feet" means the highest point on Timms Hill is 1,951 feet above sea level. Sea level is a simple way to describe elevations on the Earth's surface in a way that is widely understood by the general public.

However, as geospatial professionals, we need a deeper understanding of how elevations are defined and derived. With the continued growth of the Global Positioning System (GPS), a solid grasp of the fundamentals is critical to avoid confusion and possible erroneous data collection.

It all begins at zero… but where is zero?

Elevation points on the Earth's surface must be measured from a recognized and standardized point of zero elevation. In simple terms, a vertical datum is how we define the zero point from which all other elevation measurements are made.

The most common vertical datum used in the U.S. for over 50 years was the National Geodetic Vertical Datum of 1929 (NGVD 29). Originally established by the U.S. Coast and Geodetic Survey as the "Sea Level Datum of 1929" (and later renamed), NGVD 29 was determined by continuously measuring the rise and fall of the ocean at 26 tide gage stations along the U.S. and Canadian coastlines. This tidal information, together with a national network of "level lines," formed the basis for NGVD 29.

By the 1980s, thousands of in-ground monuments (bench marks) across the nation were damaged or destroyed, thousands of new bench marks were added, and many existing bench marks had moved due to the effects of crustal motion, post-glacial rebound, subsidence, or frost.

To correct errors resulting from these changes, the National Geodetic Survey (NGS) established a new vertical datum called the North American Vertical Datum of 1988 (NAVD 88). NAVD 88 has largely replaced the use of NGVD 29 in most areas of the country. In Wisconsin, the difference between NGVD 29 and NAVD 88 is negligible for many mapping applications, typically less than approximately one quarter of a foot. See the Wisconsin Coordinate Reference Systems handbook[1], published by the State Cartographer's Office in 2009, for more information on vertical datums.

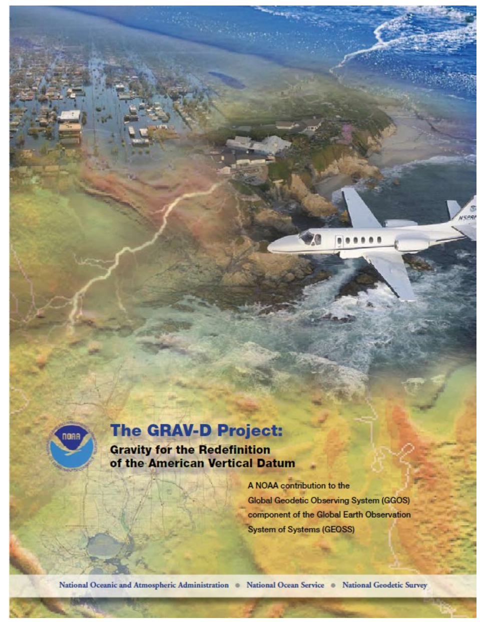
Elevations and GPS

Prior to the arrival of GPS technology, land surveyors conducted elevation surveys by creating line-of-sight level lines from known elevation points in a geodetic network. Unfortunately, elevations could only be determined with high precision through differential leveling, which is very costly (in terms of both time and money) compared to the relatively low cost of GPS.

Today, with inexpensive GPS receivers, a user can easily collect x, y and z (height) values in the field. This ease of use, however, can lead to confusion if the user doesn't understand the three different types of heights used in geodetic systems: ellipsoid, geoid, and orthometric (see Figure 1).

The ellipsoid

Mathematically modeling the exact shape of the Earth's surface is impractical. Therefore, we need a practical way to describe the approximate shape of the Earth. A reference ellipsoid is a 3-dimensional mathematical surface that generally fits the shape of the Earth. The GRS 80 ellipsoid is the most common reference ellipsoid in use today.



For many novice GPS users, the distinction between the different types of heights can be very confusing. An ellipsoid height is the perpendicular distance of a point above the reference ellipsoid. In contrast, an elevation (also called an orthometric height), is the distance above or below a vertical datum. In Wisconsin, an ellipsoid height incorrectly assumed to be an elevation would be approximately 27 to 37 meters lower than its elevation.

While it's true that most GPS receivers can output elevation values calculated during

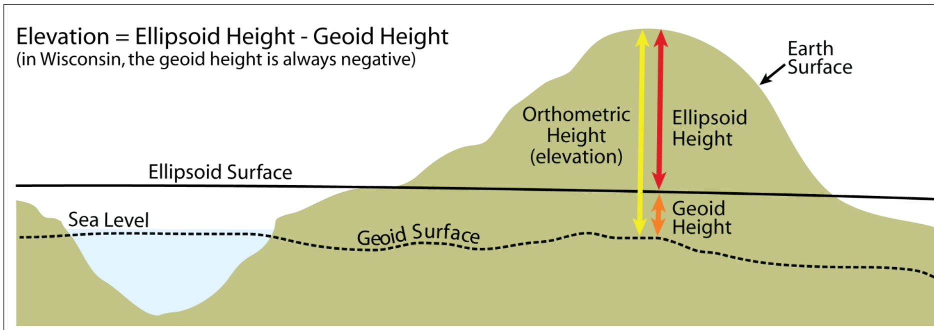


Figure 1 — Relationship of the "heights" (geoid, ellipsoid, orthometric.) Exaggerated for clarity.

data collection, in reality GPS receivers only measure ellipsoid heights. Accurately computing elevations from ellipsoid heights involves another Earth model— the geoid.

The geoid

The geoid[2] is an undulating surface that mirrors the Earth's irregular gravity field, and best approximates the global equivalent of mean sea level. A simple way to express the geoid is through geoid heights. At any given point, the geoid height is the distance between the geoid and the ellipsoid (see Figure 1). In Wisconsin, the geoid lies between approximately 27 and 37 meters below the GRS 80 ellipsoid, resulting in negative geoid heights throughout the entire state (See Figure 2).

It is important to understand that most GPS units internally combine ellipsoid heights with a built-in geoid model, and output a computed elevation value. The geoid is the key in deriving elevations from GPS measurements.

The distinction between ellipsoid heights and elevation is important because ellipsoid heights alone cannot be used to determine how water will flow. Elevations, since they are based on the direction of gravity, are much more useful in applications such as floodplain mapping, storm water modeling, and engineering design.

The NGS GRAV-D project

One of the main limiting factors in obtaining high-accuracy elevation measurements from a GPS receiver is the accuracy of the geoid model used for ellipsoid height to elevation conversions. By improving the underlying geoid model, elevation values derived from GPS measurements can also be improved.

With an estimated completion in 2018, the NGS GRAV-D project[3] is a $39 million effort to define a new vertical datum and improve the geoid model used in the United States. The fundamental goal of GRAV-D is to facilitate fast, accurate elevation determinations from GPS receivers. NGS expects the new vertical datum developed through GRAV-D will support elevation computations that are accurate to 2 centimeters.

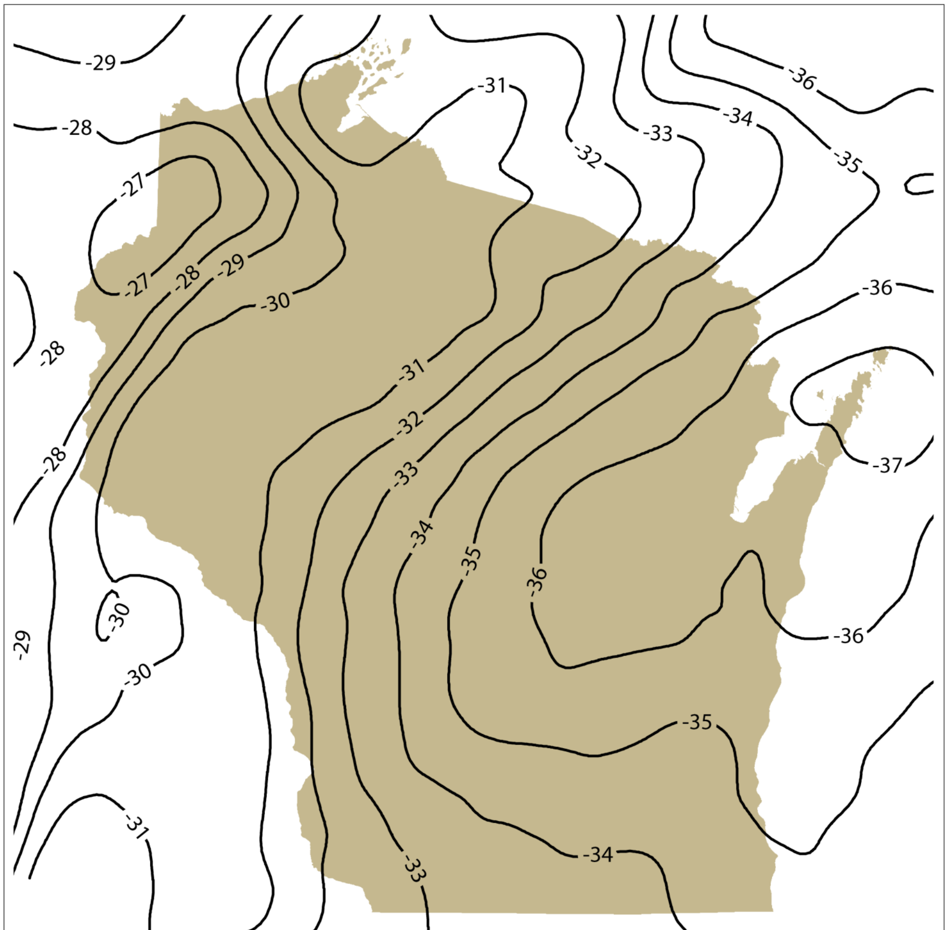


Figure 2 — Geoidal Separation. In Wisconsin, the geoid generally lies between 27 and 37 meters below the GRS 80 reference ellipsoid.

The GRAV-D project will result not only in a high-resolution "snapshot" of gravity in the U.S., but also an ongoing temporal picture of gravity changes. GRAV-D measurements will replace gravity data collected by NGS in the 1950s through 1970s.

In addition, the vertical accuracies enabled through the GRAV-D project, combined with national efforts to establish Continuously Operating Reference Stations (CORS)[4], will significantly change the way in which elevations are monitored and determined in the future. In their ambitious 10-year strategic plan[5], NGS predicts the necessity for "passive marks" (bench marks placed in the ground) will decrease by 2018. For further reading, including more details on vertical datums, visit the NGS index of online geodetic publications.[6]

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Wisconsin State Cartographer's Office

The Wisconsin State Cartographer's Office provides a wide range of services to the state's geospatial community, including educational workshops and presentations, technical consulting, print and online publications, web-based mapping applications, and information about events, jobs and emerging trends. We collaborate with state and national associations to promote effective utilization of geospatial technology, and serve as a liaison between geospatial data producers and consumers in Wisconsin to help coordinate the needs of these groups. The office also assists the public with map-related inquiries. The State Cartographer's Office has operated from the University of Wisconsin-Madison since 1974.

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