



JOE SASS

GPS Elevations—Staying Out of Trouble

Part 1: Managing the Geoid

The Machine Control industry has invested billions of dollars outfitting heavy equipment with GPS and software primarily for the purpose of moving dirt. The efficiencies that can be gained through this automated approach have been proven repeatedly so we are witnessing an explosion of this technology adoption. Due to the expense of moving huge quantities of dirt, machine control operators expect and need their equipment to perform at certain levels. When the concern is only about horizontal measurements, these expectations are generally met. When speaking about the vertical component of these measurements however, more considerations must be taken into account and understood. Part 1 of this article will attempt to explain the differences between GNSS derived “ellipsoid” elevations and the more useable elevations we typically call “sea level.” In a subsequent article we will examine the other influences that must be considered when seeking high accuracy vertical results with GPS.

The basis for deriving horizontal values on the ground from GNSS measurements is purely mathematical. There is a one-to-one relationship between the horizontal measurement and the mapping plane onto which the measurement is placed. However, elevations are more complex to apply and to this day, still not completely understood. What would you

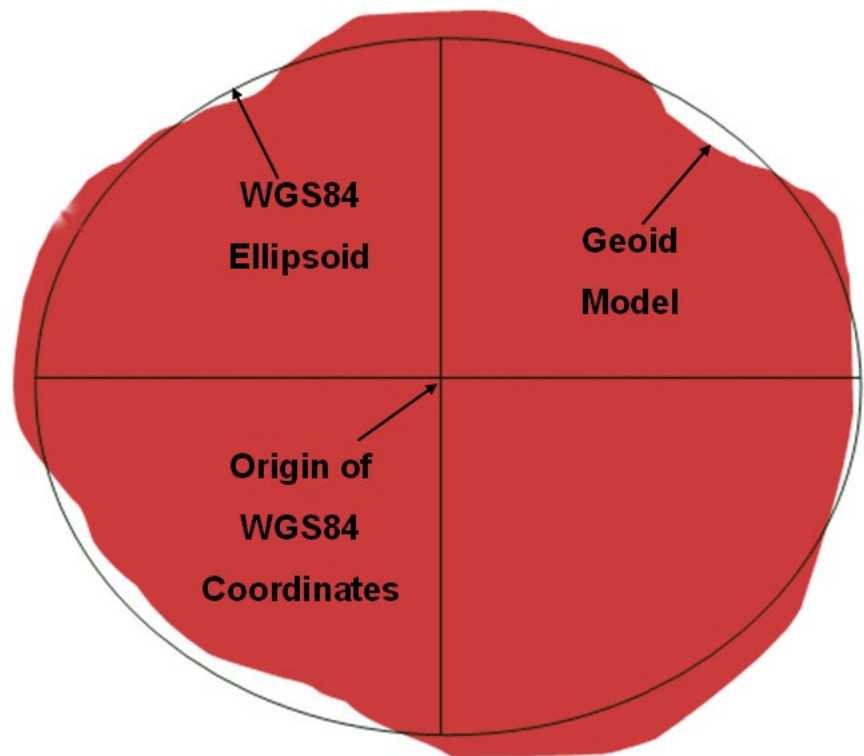


Figure 1 This article will explain the differences between GNSS derived “ellipsoid” elevations and the more useable elevations we typically call “sea level.”

say if you were told that the Pacific Ocean is about ten feet lower in elevation than the Atlantic Ocean? It sounds incredible but in some ways is true.

The historical technique and to a lesser extent, the same technique that is often used today for deriving elevations is to use an optical level and two identical rods scribed with ruler marks. These two rods are separated by

a distance usually less than two hundred feet and an optical level that can rotate on its standing axis is placed between the two rods. Let’s imagine that the instrument operator looks through the level’s optical sight at one of the rods which is setting on a known benchmark and the crosshairs fall exactly on the 5 foot mark. Then the instrument operator rotates the level, sights the second rod and

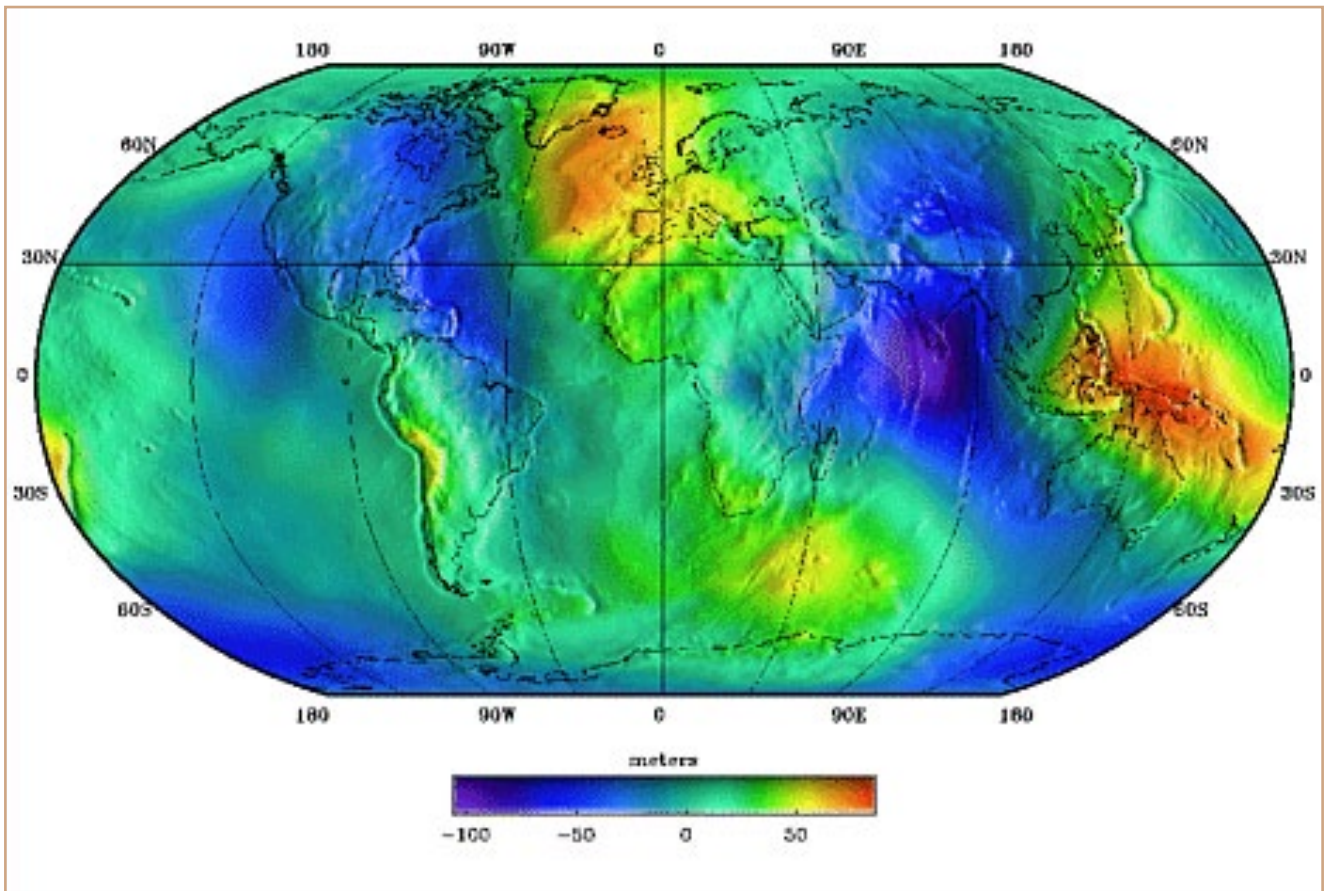


Figure 2 In the same way that the planet has topographical undulations in the form of mountains and valleys, the earth's gravity field undulates and causes variations in measured elevations as illustrated in this geoid model (EGM96).

the crosshairs fall exactly on the 6 foot mark. We now know that there is exactly 1 foot of elevation difference between these two rods and the surveyor records the result. Then, depending upon the direction of the leveling run, one of the rod-men will move forward, the instrument operator will once again place himself between the two rods and the process is repeated again and again and again. Dating back to colonial times in the United States, leveling benchmarks were propagated throughout the land and eventually a circuit was developed that spanned from the Atlantic Ocean to the Pacific Ocean.

There was a problem though. It had been previously assumed that both oceans would be at the same elevation and yet the actual measurements did not agree with this. The measurements themselves were proven to be correct by closing the level loops and getting the same elevations on previously surveyed points. So now there was the issue of how to deal with the variation. Should the Pacific Ocean actually be considered as 10 feet below sea level? Or should some portion of this "error" be assigned to each state along the way from east to west? This anomaly was a piece of the puzzle that helped lead to the determination

that elevations are influenced by gravity. Scientists are still learning how the mechanics fit together and have developed several techniques for measuring these gravitational undulations.

GPS measurements are calculated from the center of a theoretical spheroid that is a best fit for the shape of the earth (**Figure 1**). There have been several models such as the Clark Ellipsoid of 1866, the Geodetic Reference System of 1980 and the current World Geodetic System of 1984 (WGS1984). As mentioned, these models are a best fit for the earth and more specifically, a best fit for the United States since GPS is funded by

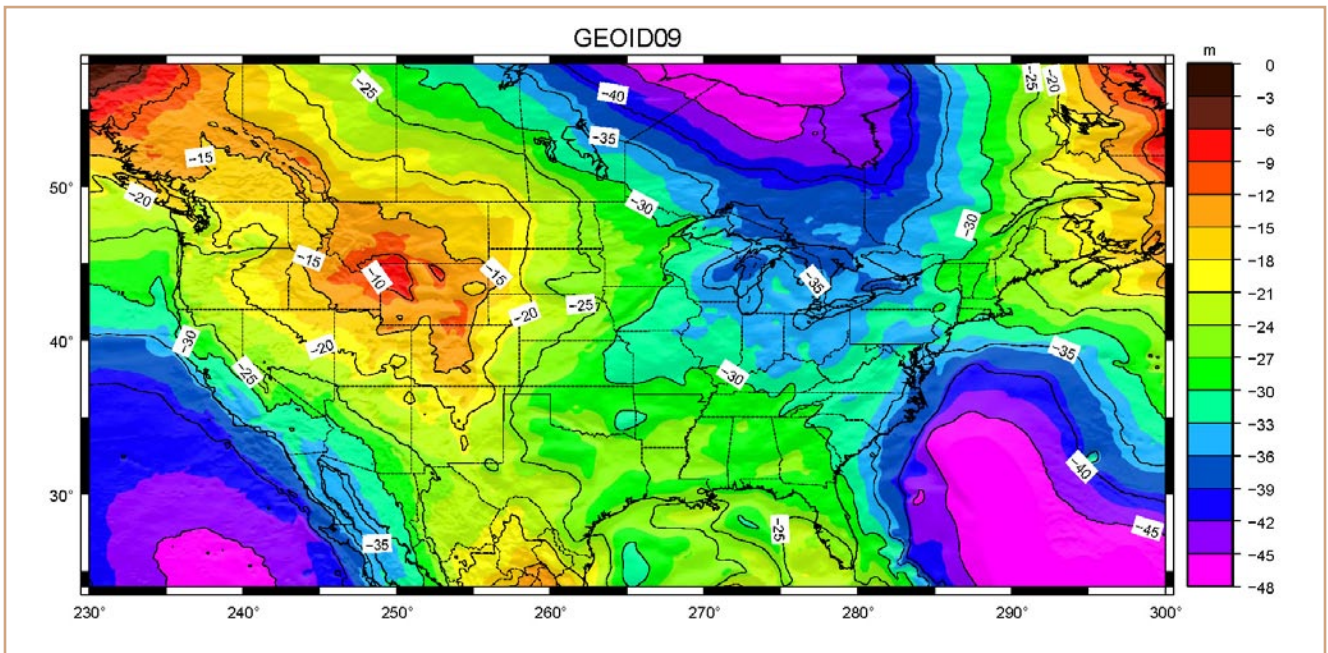


Figure 3 Geoid 09 is the most recent model for the United States for describing the differences between GPS elevations and “sea level” elevations.

the United States. This ellipsoid though is perfect in shape and does not account for variations in the land surfaces or the gravitational influences that we have discovered affect elevations. This research

This represents an early attempt to harmonize the entire planet with all the known gravitational information from various disciplines. With this information, it becomes possible to compute the

achieve elevation results that can be used on a job site unless specific vertical localization techniques are employed. There are now many geoid models available. Most of them are specific to a region or country such as GEOID09 (Figure 3) that covers the United States and its territories or CARIB97 (Figure 4) which covers the Caribbean Islands. The most current models possess the latest refinements in both an application of the technology that produces the models as well as in the precision of calculating the separations.

On most construction sites, this aspect of the GPS measurements is invisible; the software being used manages the separation values or a site localization has been performed by trained personnel. But it must be a consideration. If not, just imagine a construction site that is a one mile square. A base station is setup on a point of convenience and the

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about the effects of gravity on “sea level” or “orthometric” elevations has led to the creation of “geoid” models.

One of the most common geoid models in use today is the Earth Gravitational Model of 1996 (Figure 2).

elevation differences (called the geoid separation) between the perfect WGS84 ellipsoid and the irregularly shaped and gravitationally undulating planet. It is this difference that must be known and applied to every GPS measurement to

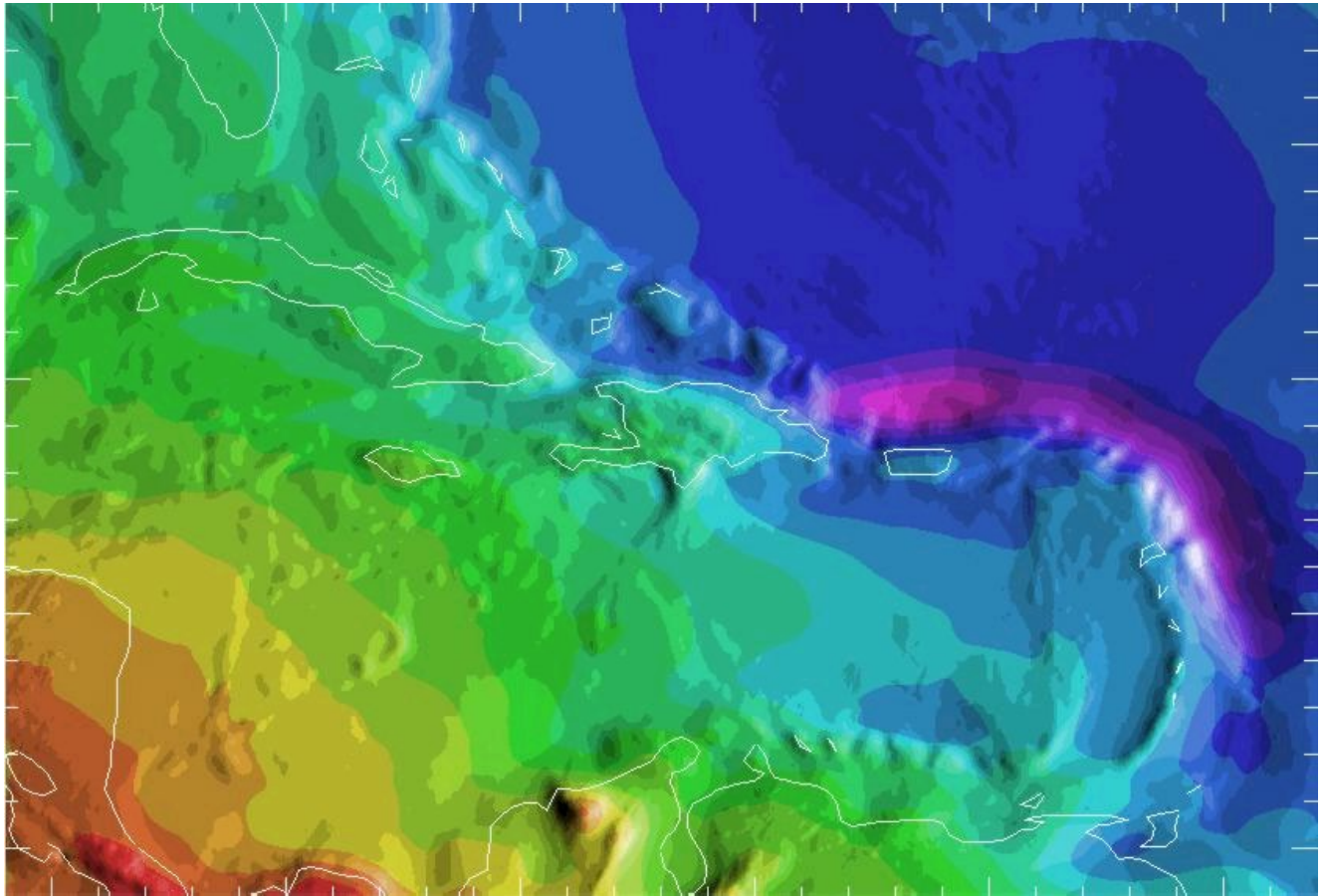


Figure 4 Carib 97 geoid model covering the Caribbean Islands.

rover operator goes out and performs a one-point localization on a known benchmark that happens to be in the northeast corner of the property. He does not apply any geoid model to the project inside the software. There is now a risk that as the operations move towards the south or west on the job site, the elevations will begin to miss. It will be just a little at first. 5/100th of a foot is still within the vertical specification. Then it becomes a 1/10th of a foot. By the time the southwest corner of the property is reached, it could be more. Now, imagine a corridor type project where lengths are measured in tens or even hundreds of

miles. What is happening with the geoid undulation? A look at the state of Kansas reveals that the difference in the effects of gravity between the western and eastern borders is about 29 feet. Geoid separation must be taken into account and all modern machine control software should possess the ability to manage this.

Do you know if the software you're using models the correct antenna definition for your GPS rover? What antenna is being used at the base station? Does it matter? Is your goal to be precise or accurate? What time of day are you making your critical measurements? These are other considerations

that must be taken into account when relying on good vertical results. In Part 2 of this article, we will explore how these issues can affect your work. Success using these tools relies on execution which in turn is a function of using the tools properly. GNSS and the software that drive these systems are complex. MachineControlOnline.com is committed to keeping you informed and educated about the technologies and methods to help you succeed. ☐

Joe Sass has more than 14 years experience in GNSS and is Technical Support Manager for Ashtech, in charge of technical support and training throughout the Americas.