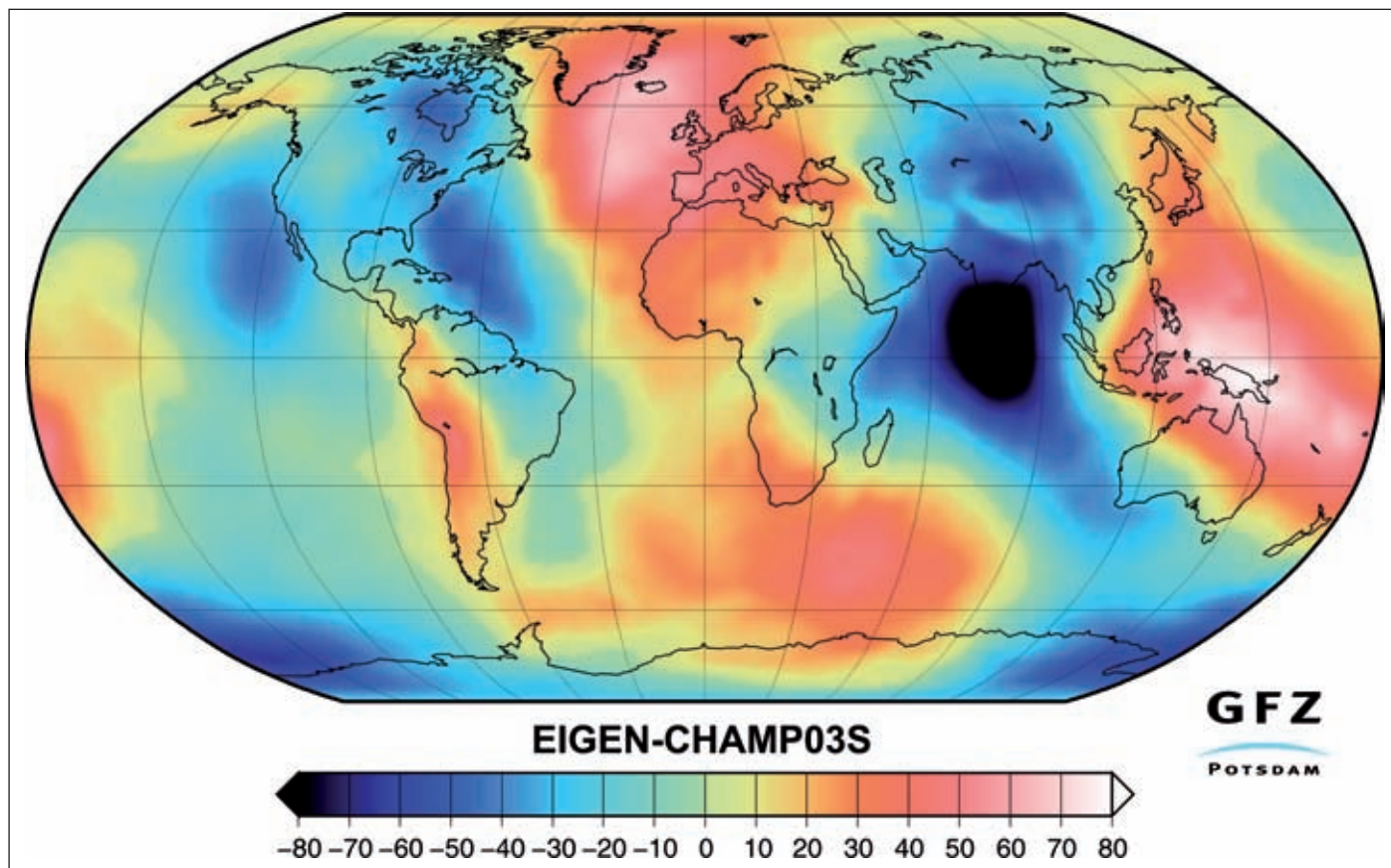


Part 3: The Geoid

Practical Geodesy



Worldwide geoid model (in meters) relative to the GRS80 ellipsoid. (source: www.gfz-potsdam.de)

In the previous articles we saw that the earth, considering its shape, could be compared to a potato or, more scientifically, the geoid. It was best approximated by the ellipsoid. But what is this geoid, the definition of which is: “The equipotential surface at mean sea level”?

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The definition says, in short, that if the sea were not influenced by the tides, wind and waves, and if the entire earth were covered with it, its level would represent the geoid. At a smaller scale we can imagine this as the surface of a small, sheltered lake; the water will distribute itself over the lake and, as such, form a level that corresponds to the local gravity.

Gravity Potential

The important part of the geoid definition deals with the gravity potential. Most of us will have learned at some time in our

academic career that the average gravitational acceleration equals roughly 10 m/s^2 .

The actual gravitational pull, however, depends on both the masses and the distance between two objects. A larger distance will thus result in gravity being less. On top of a mountain the gravity will thus be slightly lower than at sea level.

Another aspect is the mass of the earth: the more mass between the object and the center of the earth, the higher the gravity. In general, water has a lower density than rock and therefore less effect on gravity. But different types of rock have different impacts

on local gravity. We should therefore distinguish between the density, which influences gravity, and the actual shape of the earth.

Impact of the Geoid on Geodesy

Since the geoid equals the local gravity field, and this in turn depends on local circumstances, it does not form a mathematical surface but instead changes from location to location. In the previous article we saw that there are many ellipsoids (or, better, horizontal datums), but there is only one geoid.

When we measure height with a GPS receiver we always obtain height relative to the

ellipsoid. If we use a level instrument to determine height (differences), these are always related to the geoid (orthometric height). Therefore, if we want to integrate or compare GPS and leveled heights, we need to know the local difference between the ellipsoid and the geoid.

Geoid Models

The ellipsoid is a mathematical surface the size and shape of which can be determined with relative ease. Since the geoid varies with local circumstances, gravity measurements need to be taken for an accurate determination. The determination of absolute gravity is very difficult. Determining gravity differences is less difficult but still not easy, especially at sea. A number of expeditions using submarines were undertaken between the 1920s and the 1940s, but the information they gathered was fragmented.

With the launch of Sputnik in 1957 this changed. Soon after the launch, scientists discovered small variations in its orbit which seemed to be correlated with the gravity field of the earth. The first, coarse models of the geoid were developed. The models were improved upon, but with the introduction of carrier phase GPS systems such as RTK dGPS, they were found to be not precise enough. For this reason, extensive gravity measurement campaigns have been carried out from the 1990s on.

In order to obtain a good understanding of the entire geoid, the Gravity Recovery and Climate Experiment, GRACE, was started in

2002. This project employs two satellites that travel the same trajectory with a small distance between them. They can determine the gravity field / geoid to within a centimeter.

Geoid Model and GPS

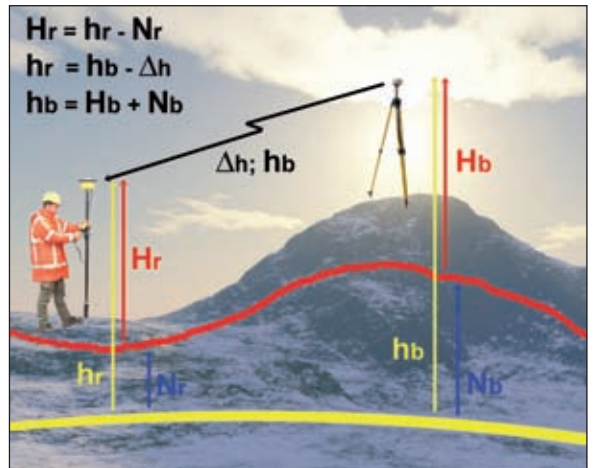
The geoid plays an important role in the accurate determination of height using GPS. Depending on the location in the world, the difference between the WGS84 ellipsoid and the geoid can amount to 100 meters. Differences regarding local ellipsoids are usually smaller, for example within the Netherlands the difference is at most approximately one meter.

Every GPS receiver has a coarse geoid model built into it, enabling it to calculate height relative to the geoid or mean sea level. This model is not precise enough, however, for accurate height determination.

With carrier-phase GPS it is not the absolute height that is important but the difference between two points: base and rover. The geoid difference between these two points depends on both the local geoid and the distance between the two points. The smaller the distance between base and rover, the smaller the potential error.

Practical Application of the Geoid Model

When using GPS for height determination, the geoid model needs to be taken into account. Usually the base station height is referenced to WGS84. The rover 'knows' the coordinates, and thus the height, of the base station. Based upon this knowledge the receiver can, using the geoid model, determine the difference between the geoid height at the base and rover positions. This difference is then applied to the WGS84 height as determined from the range measurements at the rover. The method used to correct for the geoid differs from receiver to receiver. For some countries a mathematical model describing the geoid-ellipsoid differences is available. Such a model will generally give the best results.

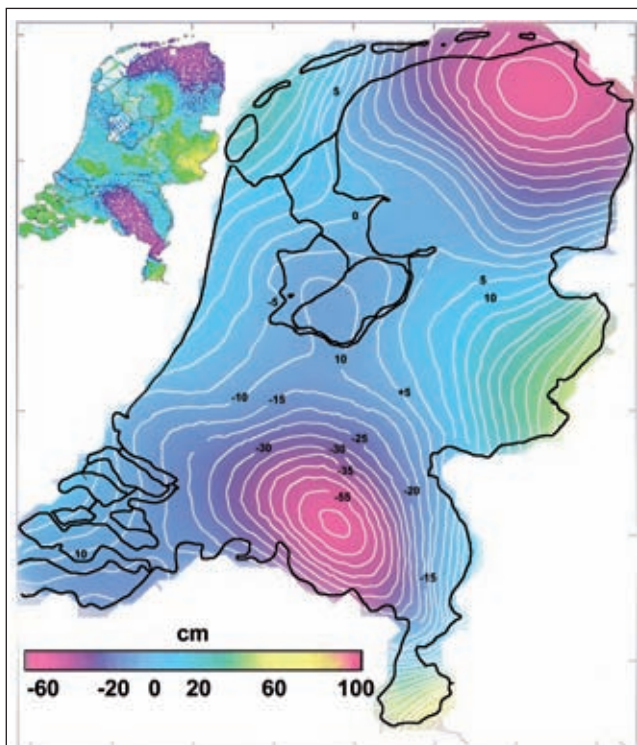


Relation between the geoid and the ellipsoid with GPS surveys.

H = orthometric (geoid) height; h = ellipsoid height; N = ellipsoid-geoid separation; h = ellipsoid height difference from GPS.
(source: staticfree.info - adapted)

A more common method is the calculation of a correction grid. The receiver then uses the positions of base and rover to determine into which grid cell they fall and applies the corresponding difference to the height. The accuracy of such a model depends on both the size of the grid cell used and the local variation of the geoid.

Another aspect is the mass of the earth: the more mass between the object and the center of the earth, the higher the gravity.



Dutch geoid model (De Min, 1996) relative to Bessel 1841 and the corresponding gravity measurements (source: www.rdnap.nl).

Conclusion

The geoid is, for many people, an abstract concept. When performing accurate carrier-phase GPS measurements, however, it is of the utmost importance to have a good grasp of the geoid. The main problem is that errors are relatively small and thus hard to detect in a practical situation.

A good method for checking for geoid errors is to begin each set of GPS measurements on a benchmark lying at a considerable distance from the base. Taking the degradation in precision into account, the average height of the benchmark should be found correctly. Any systematic error in the average height is an indication of either incorrect height of the GPS antenna or the geoid-ellipsoid separation.

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