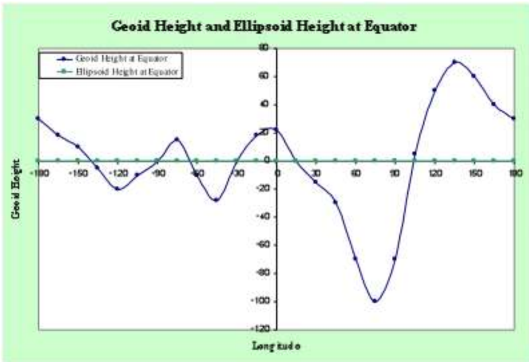
Tutorial: The Geoid and Receiver Measurements

The Geoid and Receiver Measurements

We have learned that the GPS receiver uses a map of sea level called a reference ellipsoid to calculate elevation. If you haven't learned this, and you want to, please go to the Elevation Correction and the Geoid (/education/resources/educational-resources/tutorial/elevation-and-geoid.html) page. We have also learned that the reference ellipsoid isn't a map of the exact shape of sea level, because it is too much to store inside the GPS receiver. Now we have to talk about the problems of some models.

We know that many models work very well. Maps tell you how to get from one place to another. But what if the map showed your street in the wrong place? People would be able to get to every other place in your town just by using the map, but how would somebody find your house?

The GPS receiver uses the reference ellipsoid Model of sea level, and so the number you see on the screen is the elevation above the Model and not the real sea level. The shape of the ellipsoid is a smooth squished sphere, but the shape of real sea level is actually pretty bumpy. If you looked at both the real sea level and the reference ellipsoid from the side they would look like this:



The blue line is the true sea level (also called the geoid) and the green line is the reference ellipsoid. The plot above goes all the way around the world at the equator (zero degrees latitude). As you can see, there are many places along the equator where the GPS receiver Model is not the same as the real sea level. Only the places where the two lines cross are an exact match! This means everywhere else, the GPS receiver is putting sea level in the wrong place!

What Does the Real Sea Level Look Like: The Geoid Model

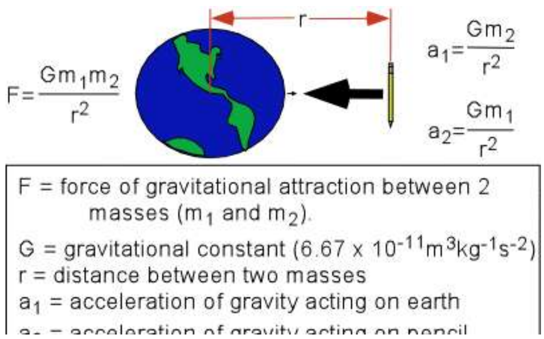
Let's review what we know so far:

1. We know that the Earth is shaped like an ellipsoid.
2. We know that the GPS receiver uses a map of sea level to calculate elevation.
3. We know that the map is called a reference ellipsoid, and more specifically the WGS-84 Reference Ellipsoid.
4. We know that the reference ellipsoid does not always match every point on the real sea level, just as any Model is a simplification of a real world situation.

Now what we need to know is, what is the real shape of sea level? It is very complex because the Earth has mountains and valleys on the surface which influence the shape. This influence is because of gravity. You can observe gravity all the time. Without gravity, if you held a pencil in the air and let go, it would just float (like it does for astronauts in the space shuttle). With gravity, if you hold up your pencil and then let go it falls to the ground. Why is this?

Gravity is an attraction between objects that causes them to accelerate towards one another. Now you might think, "I have never seen the ground move towards my pencil when I drop it!" That is because the Earth is much bigger and more massive than your pencil. The effect of gravity is much greater for a massive object than for a small one. Because the earth is SO MUCH BIGGER than everything on it, we can't really detect the earth moving towards things when we drop them.

Below is a cartoon that depicts a pencil accelerating towards the center of the Earth and the Earth accelerating towards the pencil (MUCH LESS). The equation for gravitational force can be used to calculate the gravitational attraction between the Earth (m1 = 5.97 x 10^24 kg) and the pencil (m2 = 0.001 kg) for more advanced students. Assume the distance from the surface of the earth to the center of the earth is approximately 6,360,000 meters, and that your hand is roughly 1 meter above that surface! You can also calculate the acceleration of gravity of the earth towards the pencil and the pencil towards the earth. Which one is bigger? (click here (/education/resources/educational-resources/tutorial/answer.html) for the answer).



a_2 – acceleration of gravity acting on pencil

As we said before, the shape of sea level is influenced by gravity. Without gravity the water on Earth would float around in the air. Gravity causes water to be attracted to the center of the earth. Because gravity is related to the mass of an object, a large object like a mountain attracts the water around it to the center of the mountain's mass as well as the center of the earth. As you can imagine, this makes the real surface of sea level much more bumpy and complex than the smooth reference ellipsoid. Below is an image of what the real sea level looks like for the entire world. The purple spots are depressions in the sea level, while the red areas are high points:

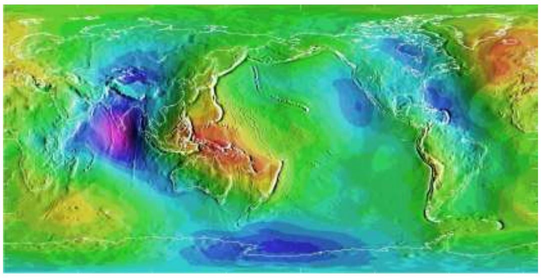


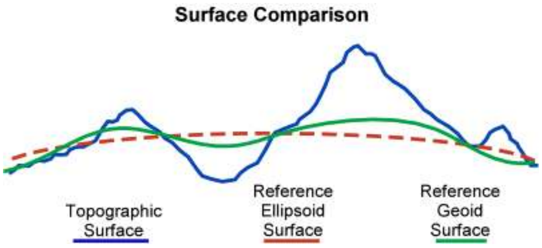
image source is National Geodetic Survey's webpage at http://www.ngs.noaa.gov/images/ngs/jpeg-geo/ww15mgh.jpg

This image is a picture of what we call a reference geoid. There are many different reference geoids for different areas of the world. This global version is called the WGS-84/EGM96 reference geoid.

Fixing a GPS Elevation

The last thing we need to talk about is how all of these things are related to one another. There are three parts of this puzzle that we need to fit together.

1. The reference ellipsoid surface (a map of average sea level).
2. The reference geoid surface (a true sea level surface).
3. The real surface of the Earth (the ground) also called the topographic surface.



The reference ellipsoid part, called the "ellipsoidal height", is easy. This is the elevation you measured with your GPS receiver.

The reference geoid part, called the "geoid height", comes from a geoid like the WGS-84/EGM96 reference geoid. You can find this value using UNAVCO's Geoid HeightCalculator (/software/geodetic-utilities/geoid-height-calculator/geoid-height-calculator.html) .

The topographic surface is the number we want to find. We know the elevation above the reference ellipsoid and we know the value of the reference geoid at our latitude and longitude from a sea level map like the WGS-84/EGM96 Geoid. Now we need to know how the true height above sea level can be found. The relationship is very simple:

Topographic Height	=	Ellipsoidal Height	–	Geoid Height

In other words, this means that your real height above sea level is equal to the difference between the height above the reference ellipsoid MODEL and the height of the reference geoid at that point on the Earth.

Example

1. Sally took 15 readings of her position with a GPS receiver and then calculated the average of these readings, which she wrote down.

   Latitude = 40 degrees 2.08 minutes North
   Longitude = 104 degrees 14.25 minutes West
   Elevation = 1602 meters (ellipsoidal height)

2. Next Sally visited our on-line geoid height calculation website. She entered her latitude and longitude where indicated and got a geoid height of -15.9 meters.

   Geoid Height = -15.9 meters

3. Finally, Sally used these numbers to calculate her topographic height.

Topographic Height	=	Ellipsoidal Height	–	Geoid Height
Topographic Height	=	1602 meters	–	-15.9 meters
Topographic Height	=	1617.9 meters		

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