Integration of Geoidal Models into PointMan

Altitude Referencing

Synopsis of Issue

The survey and engineering worlds have various methods of determining the height of a point on the ground surface. In the same manner as horizontal coordinates having different datums so do vertical coordinates. There are three surfaces we are concerned with in this case (**Figure 1**) Topographic surfaces are what we ordinarily see as the ground and it is that surface that wish to have the elevation of a point on. The two others (Geoid and Ellipsoid) are the base or the datum from which we are measuring the height from. We need a consistent and industry standard way of referencing the topographic height value. To that we need to be able to have as our datum the surface shown as the ***Geoid,*** an elevation measured from this geoid datum or surface is also known as the **Orthometric** height or Mean Sea Level (MSL). Technically there are many different Geoid surfaces, the Geoid surface we are interested in is defined by actual sea level stations, survey level stations and more predominantly gravity measurements. These inputs are combined and adjusted to create a **Geoid** surface. This **Geoid** surface is not static, as better gravity measurements arise, the **Geoid** surface is updated This is done by government agencies; in the US case by US National Geodetic Survey (NGS); but it is usually several years between updates to the surfaces, The **Geoid** surface is also called a geoidal model as it is not truly a physical surface all the time, MSL means something physical on the coast but it varies physically from the actual mean sea level in the mountains where gravity measurements vary. Several presently used geoid models are called **Geoid12**, **Geoid18**, and **EGM96**, the number indicates the year that it was finalized and published by the relevant agencies.

Technical Description

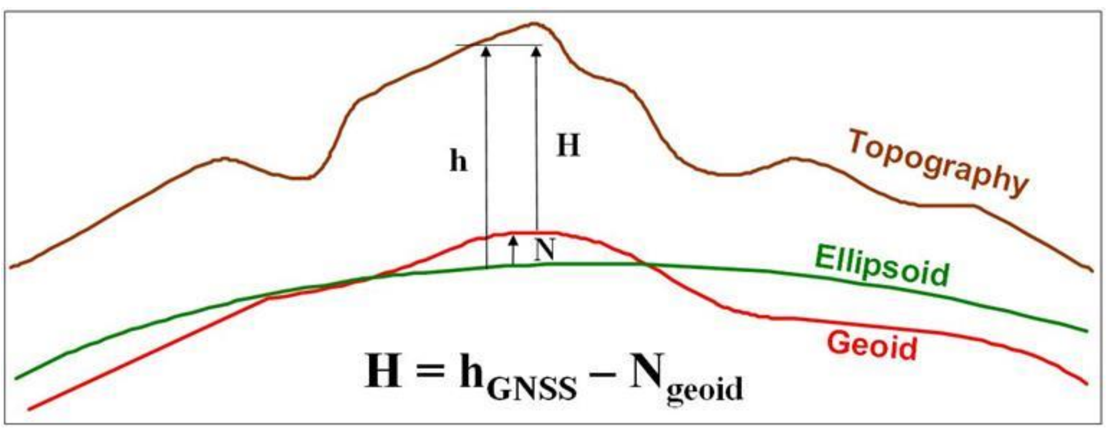

Figure 1: The ellipsoidal height (h), orthometric height (H) and geoid height (N)

Reference : Natural Resources Canada - Retrieved Sept 30, 2019

Orthometric height (H), often referred as Mean Sea Level Height, can be obtained by subtracting the geoid height (N) which we obtained from the Geoid model (i.e. Geoid18) from the GNSS ellipsoidal height (h): H = h – N. A geoid height (N) is positive (+) when the geoid is above the ellipsoid and negative (-) when it is below (as shown on the right and left sides of Figure 1)

Hybrid geoid models such as **Geoid12b/18, EGM96** etc. are created by constraining a gravimetric geoid model to published heights which used GNSS observations on leveled benchmarks. The **Geoid 12b,** and **Geoid18** hybrid models are used in the US, the **CGVD28, CGVD2013, CGVD2013a** model are used in Canada and a model called EGM96 is used as a global reference if the localized models are unavailable.

The North American-Pacific Geopotential Datum of 2022 (NAPGD2022) is scheduled to replace both the Canadian and US models in 2022 which will replace all existing US and Canadian geoid models at that time

The relationship between horizontal and vertical GNSS parameters is that WGS84 parameters approximate the Earth by an ellipsoid, basically a flattened deformed sphere. EGM96 is a complex model based on the gravitational force of the Earth (which is not constant) that defines what "sea level" or up and down means, this is a smooth but irregular shape called the "**geoid**". WGS84 is the ellipsoid that best fits that EGM96 **geoid**, and this fit has been updated as more accurate measurements of the geoid have been carried out over the years. It is the EGM geoid that has re/defined the WGS84 ellipsoid over the years. In a similar manner the local to North America NAD83 parameters are used in conjunction with the localized Geoid12b,18, CGVDxxxx Geoid models. To get the correct geoidal undulation values from the various Geoid models you must have the horizontal coordinates in the correct NAD83 datum. The correct horizontal datum coordinates are required as the geoidal model files are gridded in those specific horizontal datums.

GEOID18 is intended for use with coordinates in the North American Datum of 1983 (2011). NAD 83 (2011) is from epoch 2010.00. It provides orthometric heights consistent with the North American Vertical Datum of 1988 (NAVD 88).

The Canadian models can be referenced to NAD83(CSRS) epochs (1997.0, 2002.0, 2010.0), depending on which Geoidal model you use. Even though the CGVD2013a geoid model is now associated to an epoch (2011.0), Natural Resources Canada (NRCan) considered the current geoid model as static**.** The epoch of 2011.0 is selected as it represents approximately the middle of the gravity measurements time span used in CGG2013a.

The use of epochs is done to ensure that tectonic plate movements and similar temporal displacements are accounted for. If needed to ensure very high precision measurements that are between epochs a velocity grid is available. This is needed to ensure the correct horizontal position and epoch to get correct highly precise geoid model. In most cases unless a very high accuracy is need the use of standard NAD83 (CSRS) for Canada, NAD83 (2011) for US or WGS84 for EGM96 are enough.

Proposed Solutions

PointMan uses the output CGGA portion of NMEA string (NMEA-0183 messages: Overview) as the data input, in that data string there are two height values, one is the orthometric height (H) and the other is the Geoidal height (N), while this may seem to solve our problem - finding the orthometric height, the problem lies in that this orthometric height is not generally based on an accurate geoidal model. In the Bluestar GPS the geoidal height and thus the orthometric height is based on a generic inclined plane, essentially a low resolution approximation that is of limited use for surveying. The correct procedure is to revert that NMEA orthometric height to the GNSS Ellipsoidal height (h) by adding the NMEA geoidal height (N) to the NMEA orthometric height. This results in an Ellipsoidal height; from this point we subtract the correct accurate geoidal height (N) that we derive from one of the appropriate hybrid geoidal surfaces (i.e. Geoid18) to get a final accurate Orthometric height (H).

The essential problem is to find the **Geoidal height (N)** from the appropriate Geoidal model. The geoidal models are freely available from the various government agencies (links below). There are various formats and some files are available from proprietary sources (Trimble GGF files). In all cases the solution is to convert to a common format (BIN from the Geoid18 models) and load this surface in the program. We may need to subdivide the Geoidal grid if it becomes too unwieldy to load and search the full set. The next process is to convert the GPS (from NMEA string) horizontal coordinates to the appropriate horizontal datum temporarily (see explanation above) and search with the hybrid geoid model at those horizontal coordinates for the corresponding geoidal height (N). This is the value we are looking for.

The problem arises in that the hybrid geoidal model is not a continuous surface, it only has values at regular grid points, these points can be spaced up to 100 km apart in the case of the EGM96 model. An interpolation scheme must be used to get the correct geoidal value, something like a bi or tri-cubic interpolation is normally used. Other schemes that may need to be considered in future work would be to use the GDAL libraries to rasterize the Geoidal surfaces, that way a continuous surface is created which solves the interpolation problem. This also transfers the processing needed for interpolation to a one-time process done on the initial back end load off of the local computer.

Links

Further Explanation – Geoid models

https://geodesy.noaa.gov/GEOID/

United States Geoid Models (Geoid18)

https://www.ngs.noaa.gov/GEOID/GEOID18/geoid18_tech_details.shtml

Canadian Geoid Models

https://webapp.geod.nrcan.gc.ca/geod/data-donnees/geoid.php?locale=en

EGM 96 models

https://earth-info.nga.mil/GandG/wgs84/gravitymod/egm96/egm96.html

EGM 96 and EGM 2008

https://www.usna.edu/Users/oceano/pguth/md_help/html/egm96.htm

Proprietary Geoid Models – useful for Second phase loading of GGF Models

https://www.trimble.com/globalTRLTAB.asp?Nav=Collection-71

Link to test results for Canadian Geoid models

http://webapp.geod.nrcan.gc.ca/geod/tools-outils/gpsh.php?locale=en