Mapping Matters

Your Questions Answered
The layman's perspective on technical theory and practical applications of mapping and GIS

By Qassim A. Abdullah, Ph.D., PLS, CP**

Question: We have been using two datums (horizontal and vertical) separately for topographical mapping. Why can't we use the geoid itself as horizontal and vertical datum in topographic mapping since the recent advancements enabled us to define the geoid very accurately?

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Dr. Abdullah: Your concern about the concept of using two different datums to represent the horizontal and vertical position and height is valid, and using a single datum for both horizontal and vertical coordinates sounds like a good idea. A single datum representing horizontal coordinates and height is possible and may be used for certain applications. Unfortunately it is not practical for many of us in the mapping industry.

The orthometric height, which is derived from the geoid model that is modeled through gravity measurements, has a physical meaning and is considered to be the natural definition of heights as gravity is what causes water to flow down hill.

The World Geodetic Systems of 1984 (WGS84) and the International Terrestrial Reference System (ITRS) are examples of such three-dimensional systems. WGS84 and ITRS provide users with unique position and height values based on the three-dimensional Cartesian system. The Cartesian system, when associated with a geo-centric system (in which the center of the system's ellipsoid coincides with or near the mass center of Earth), is known as Earth Centered, Earth Fixed (ECEF). Therefore, position and height of a point near or on the surface of the Earth as defined by ECEF systems are referenced to the mass center of the Earth (or near it). GPS provides global positions (X,Y,Z) in WGS84-based ECEF systems. To many users, expressing coordinates in ECEF is not practical as positions are referenced to the mass center of the Earth.

The following values are the three-dimensional coordinates for the CORS station AMC2 located in Colorado Springs, Colorado, USA based on ITRF2000 ECEF:

X = -1248596.072 m
Y = -4819428.218 m
Z = 3976506.023 m

The above coordinates are also published in geographic representation as follows:

latitude = 38° 48' 11.249150" N
longitude = 104° 31' 28.53276" W
ellipsoid height = 1911.393m

Examining the above coordinates one can easily realize that the height value of 3,976,506.023m is too large to deal with or to interpret. In addition, the geo-centric derived height, or Z, is not practical from the operational sense as it represents the perpendicular distance between the reference point and the plane of the equator and not the distance from the reference point to the local geoid as users are accustomed to. There are other reasons that have prevented users from using the three-dimensional ECEF for day-to-day operations, but there is no room in this column to discuss those.

The latest advancements achieved in determining and modeling the geoid will not negate the need for a positional system or datum to define the geoid elevation at a certain place in the world.

While using heights based on ellipsoidal, such GPS-derived heights based on WGS84, may serve the field commanders of the armed forces, it does not serve the needs of the larger community of users who are conducting accurate engineering operations for dams, sewers and pipelines, and tunnels. The previous operations require topographic details that reflect and explain the actual direction of water flow as influenced by gravity. Also, aircraft navigation databases need to provide pilots with accurate ground elevation to maintain constant altitude above the actual surface of the Earth. These are just examples on the reasons behind

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GPS-derived heights or elevations based on gravity modeling such as orthometric or dynamic heights are obtained by converting the WGS84-based ellipsoidal heights using an accurate gravity-based geoid model.

the development of the geoid models. The ellipsoid height of a point* is based on a geometrical (mathematical) definition without any consideration given to the Earth's gravity field. The orthometric height**, which is derived from the geoid model that is modeled through gravity measurements, has a physical meaning and is considered to be the natural definition of heights as gravity is what causes water to flow down hill. If we submit to such reality, then we are accepting the fact that height values derived from geocentric system, such as WGS84, are not practical to represent land elevation for many people in the engineering and navigation industries. However, user defined or local systems based on the datum of these geo-centric systems such as WGS84 or ITRS can resolve many of the users concerns.

Based on the above discussions, I would like to address why the geoid itself can't be used to reference positions or locations. In reality, the geoid is nothing but an imaginary surface modeled through measurements of the acceleration of gravity near the Earth's surface at different locations on the Earth. The word "locations" in the previous term, "different locations", dictates that a reference system should be used to define the position at which such gravity reading is measured and recorded. The gravity reading can not be used to reference the location as it is merely a measurement of the gravitational force of the Earth at that location in the world. When dealing with elevation data, position on the Earth is defined through latitude and longitude or Easting and Northing. This position is used to derive geoid elevation. The geoid elevations, the geoid heights, or geoid-ellipsoid separation are always derived for a certain position and that position is based on a reference coordinate system such as UTM and a datum such as WGS84. GPS-derived heights or elevations based on gravity modeling such as orthometric or dynamic heights*** are obtained by converting the WGS84-based ellipsoidal heights using an accurate gravity-based geoid model. When you deal with a coordinate's database, a location must be provided in terms of latitude and longitude in order to derive a geoid-based height that corresponds to that location on the Earth. I believe that having the derived height accompanied by horizontal coordinates is the reason behind the belief that the geoid provides a three-dimensional system. It may appear as one system but in reality it is two different datums, a horizontal datum for the Easting and Northing (such as WGS84) and a vertical datum (such as the global EGM08 or the American NAVD88) for the orthometric heights. In conclusion, the latest advancements achieved in determining and modeling the geoid will not negate the need for a positional system or datum to define the geoid elevation at a certain place in the world.

To many users, expressing coordinates in ECEF is not practical as positions are referenced to the mass center of the Earth.

* **Ellipsoidal height**: is the distance from a point on the surface of the Earth to the reference ellipsoid measured along a perpendicular line to the ellipsoid.

** **Orthometric height**: is the distance from a point on the surface of the Earth to the geoid measured along a perpendicular line to the geoid (plump line).

*** **Dynamic height**: is a height measure that is more sensitive than orthometric height in representing and modeling water flow. The International Great Lakes Datum of 1985 (IGLD85) is an example on this system.

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