Development of a Seamless Vertical Reference System: Challenges and Opportunities

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Key words:

SUMMARY

Traditionally, bathymetric and topographic measurements have been collected independently to serve different purposes. As well, depth and height data were referred to different vertical datums, which created inconsistency across the land-sea interface. With the growing number of coastal applications, such as coastal zone management and marine boundary delimitation, it is necessary that a seamless vertical reference surface be established. The availability of such a reference surface is also necessary for the development of the three-dimensional ECDIS, which is expected to have significant economic and safety impacts. Unfortunately, however, establishing the relationships between the various vertical datums, and consequently the seamless vertical reference surface, is not an easy task. This is mainly due to the inconsistent datum distortion as well as the discrepancies in the subsequent measuring techniques.

To tackle this subject, the FIG Working Group 4.2 (WG 4.2), Vertical Reference Frame, was established. This paper summarizes the activities and findings of the Working Group.

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1. BACKGROUND

In the past, bathymetric and topographic measurements have been collected independently to serve different purposes. As well, depth and height data were referred to different vertical datums, which created inconsistency across the land-sea interface. With the growing number of coastal applications, such as coastal zone management and marine boundary delimitation, it is necessary that a seamless vertical reference surface be established. A seamless reference surface, as the name indicates, means continuous and time-invariance surface.

Various IAG and FIG working groups have been established since mid 80s to tackle the problem of establishing a seamless vertical datum (Wells et al., 1996). More recently a new FIG Working Group 4.2 (WG 4.2), Vertical Reference Frame, was established at the XXII FIG International Congress, which was held in Washington, C.D., USA. The working group will address a number of issues, including:

- Developing and promoting the understanding and realisation of a vertical reference frame;
- Examining the demand for a seamless vertical reference frame for use in hydrography, marine navigation, and coastal resource management;
- Developing an inventory of vertical reference surfaces used in various countries of the international community;
- Making some recommendations towards the establishment of a global seamless vertical datum.

2. WHAT IS A SEAMLESS DATUM?

The fact that the topographic surface of the earth is highly irregular makes it difficult for the geodetic calculations to be performed. To overcome this problem, geodesists adopted a smooth *mathematical* reference surface to approximate the irregular shape of the earth's surface (more precisely to approximate the *geoid* - the equipotential surface of the earth's gravity filed that best approximates the mean sea level on a global basis). For high accuracy positioning such as GPS positioning, the best mathematical surface to approximate the earth's surface and at the same time keeps the calculations as simple as possible was found to be the biaxial ellipsoid (Vanicek and Krakiwsky, 1986). The biaxial reference ellipsoid, or simply the reference ellipsoid, is obtained by rotating an ellipse around its minor axis (see Figure 1).

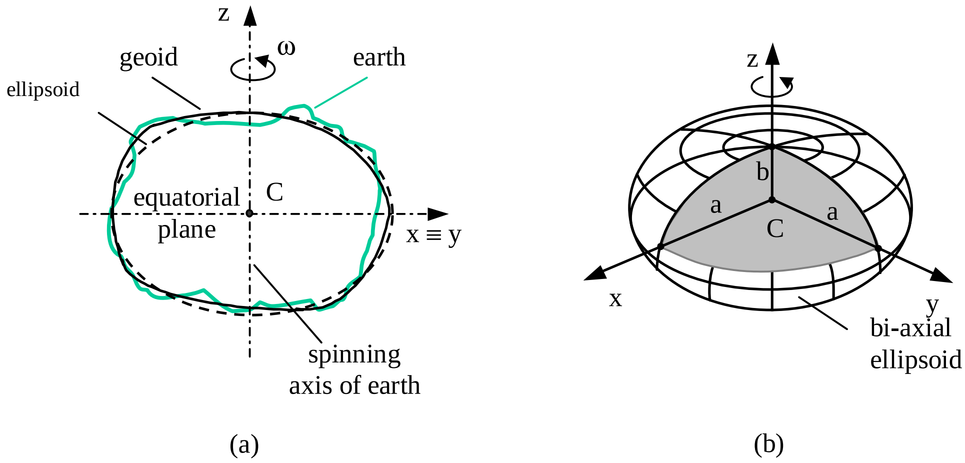

Figure 1. (a) Relationship between the physical surface of the earth, the geoid and the ellipsoid. (b) Ellipsoidal parameters.

An appropriately positioned reference ellipsoid is known as the geodetic (or horizontal) datum (Vanicek and Krakiwsky, 1986). In other words, a geodetic datum is a mathematical surface, or a reference ellipsoid, with a well-defined origin (center) and orientation. A geodetic datum is, therefore, uniquely determined by specifying 8 parameters: two parameters to define the dimension of the reference ellipsoid; three parameters to define the position of the origin with respect to the center of the earth; and three parameters to define the orientation of the three axes with respect to those of the earth. In the past, horizontal datums were non-geocentric and were selected to best fit the geoid at certain regions of the world. As such those datums were commonly called local datums. Over 150 local datums used by different countries of the world (El-Rabbany, 2002). With the advent of space geodetic positioning systems like GPS, it is now possible to determine global three dimension geocentric datums.

In addition to the geodetic datum, the vertical datum is also used in practice as a reference surface to which the heights (or depths) of points are referred. The vertical datum is often selected to be the geoid for topographic applications, while it is selected to be the Chart Datum for hydrographic applications. Therefore, heights presented on topographic maps are often referenced to the geoid, while depths presented on nautical charts are referenced to Chart Datums. As a result of the unavailability of accurate depth information as well as other factors, Chart Datums have traditionally been selected to represent near-worst-case vertical reference surfaces (Wells et al., 1996).

Chart Datums are site-specific surfaces that vary from one location to another, as they are established based on the water level measurements at discrete locations (Wells et al., 1996). In addition, at present, Chart Datums are defined differently among the various hydrographic offices. As such, Chart Datum is not a seamless reference surface [as mentioned above, a seamless reference surface means that the surface is continuous and time-invariance]. Geoid, on the other hand, is considered a seamless reference surface that could be used worldwide.

Unfortunately, however, the present geoidal accuracy varies from one location to another, with the accuracy at mountainous land areas and in open oceans being the worst. In addition, both Chart Datum and different (improved) geoid versions change over time, which creates a maintenance problem to the expected large volume of data. Consequently, the simplest reference surface that fulfils the requirements of a seamless reference surface is the reference ellipsoid (Wells et al., 1996). In addition to its suitability for being a global reference surface, the reference ellipsoid has a number of other advantages including its compatibility with RTK GNSS and consistency across the sea-land interface.

3. THE NEED FOR A SEAMLESS REFERENCE SURFACE

The development of a seamless datum would benefit a number of applications, such as coastal zone management and marine boundary delimitation. The availability of such a reference surface is also necessary for the development of the next generation three-dimensional ECDIS, which is expected to have significant economic and safety impacts. A summary of the primary applications, which would benefit from the development of a seamless datum, is given below.

3.1 Coastal Zone Monitoring

Coastal areas are known to change dynamically as a result of the environmental changes, urban growth and others. Monitoring such dynamic changes is important for many applications, including coastal resource management, erosion and accretion monitoring, flood monitoring and emergency response, and others. As pointed out by Gesch and Wilson (2002), coastal zone monitoring requires the availability of recent topographic and bathymetric data that refer to a seamless datum. Data from modern remote sensing technologies, such as InSAR and LIDAR, could be integrated with existing topographic and bathymetric data to help overcoming some consistency and accuracy problems (Figure 2).

3.2 Maritime Boundary Delimitation

Under the United Nations Convention on Law of the Sea (UNCLOS), a coastal state has various standard outer limits, which are measured seaward from the territorial sea baseline. The baseline separates the state’s internal waters and territorial sea, and comprises either the low-water line of the coastline as shown on large-scale nautical chart officially recognized by the coastal state or straight lines joining low-water points (IHO, 1993). The standard limits define the boundaries of specific maritime zones, namely the territorial sea, the Contiguous Zone, the Exclusive Economic Zone (EEZ) and, in some cases, the Continental Shelf (Figure 3). A coastal state has sovereignty rights over the seabed resources in these zones, provided that the boundary claims of adjacent and/or opposing states are taken into account. Clearly, unless the datum and uncertainty factors are considered, inaccurate determination of the state’s maritime outer limits would be expected, which in turn could lead to serious economic and sovereignty problems. Unless the neighbouring states adopt the same (hopefully seamless) geodetic datum as well as the same system of baselines for defining the equidistant line, i.e. the low-water line or a system of straight lines, technical problems could occur (Kapoor and Kerr, 1986).

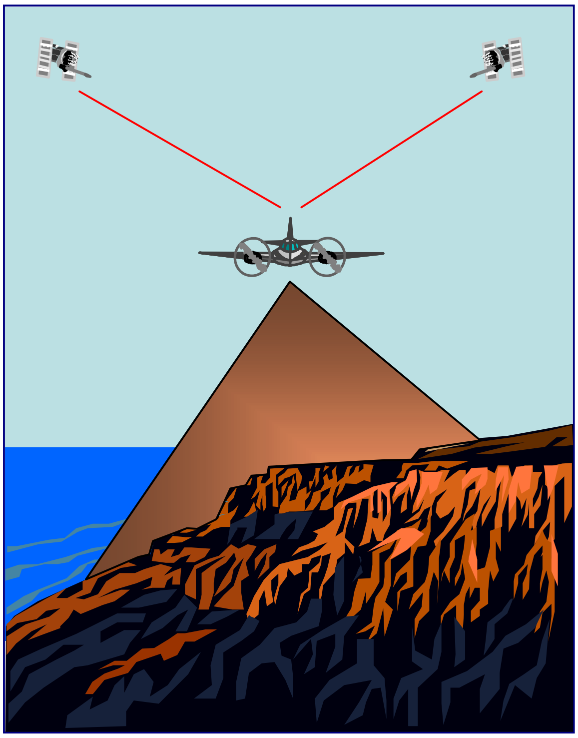

Figure 2. Coastal data collection using LIDAR system.

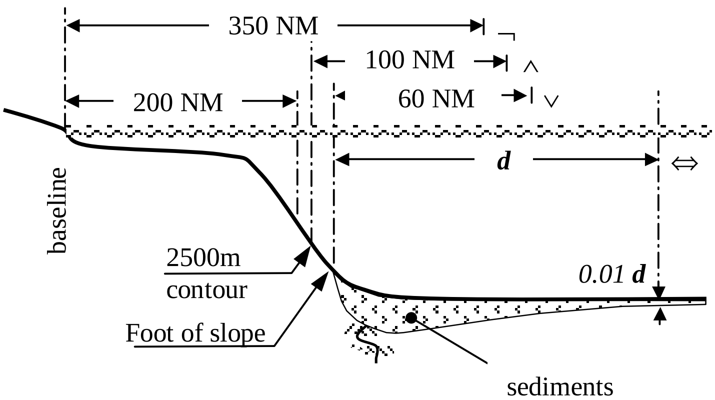

Figure 3. Possible Limits for the Continental Shelf.

3.3 Next Generation, Three-Ddimensional ECDIS

Accurate depth information is a key component for safe marine navigation. Presently, as a result of the unavailability of accurate depth information as well as other factors, nautical charts use near-worst-case vertical reference surfaces (i.e., Chart Datums), which provide conservative representations of the navigable water depths. This in turn led to reduction in the vessels loading, which is translated into a significant loss of profit per trip. With the increasing demands from the shipping industry to provide more realistic, yet reliable, keel-clearance information, there is an urgent need to develop the next-generation three-dimensional ECDIS. The 3D-ECDIS is expected to use digital bathymetric data referred to a seamless vertical datum. It is further expected to display depths below the instantaneous sea level, which is possible through the inclusion of time varying information such as tides (Figure 4). This would allow for the display of more realistic keel-clearance information, an important element for large vessels. As such, the development of a seamless vertical datum, and consequently the 3D-ECDIS, is expected to have significant economic and safety impacts.

4. THE CHALLENGES

The establishment of a seamless vertical datum could simply be carried out through the development of a transformation function between the present datums and the seamless datum. This, however, is accompanied by a number of challenges pertinent to the availability, volume and quality (i.e., uncertainty) of bathymetric and topographic data. Data availability addresses issues such as data coverage, both historic and recent. It is known that many regions of the world were either inadequately surveyed or had never been surveyed (see for example Barritt, 2001). As well, auxiliary data is needed so that the transformation function could be developed, e.g., the ellipsoidal heights (referred to seamless datum) at the Chart Datum points. Digital data volume is another challenging problem, which requires extensive study. As stated by Gesch and Wilson (2002), 50-gigabyte dataset was used for the development of a seamless model covering the Tampa Bay region.

Data uncertainty is attributed to various sources of errors, including geodetic measurements, hydrographic measurements, and Chart Datum determination. The uncertainties in the geodetic measurements originate mainly from the limitations in the employed geodetic technique, i.e. terrestrial or space. Such uncertainties would be propagated into the estimated positions. Old nautical charts and topographic maps were based on terrestrial techniques, which are far less accurate than modern space techniques. In addition, the distribution of the positioning uncertainty is not expected to follow a consistent pattern across the chart (map). This is mainly due to the inconsistent datum distortion as well as the discrepancies in the measuring techniques in the subsequent chart (map) versions. As well, the existing paper (and digitized) charts in some areas were based on old hydrographic surveying methods, for example the lead-line method, which are far less accurate than modern techniques such as multibeam echo-sounding method.

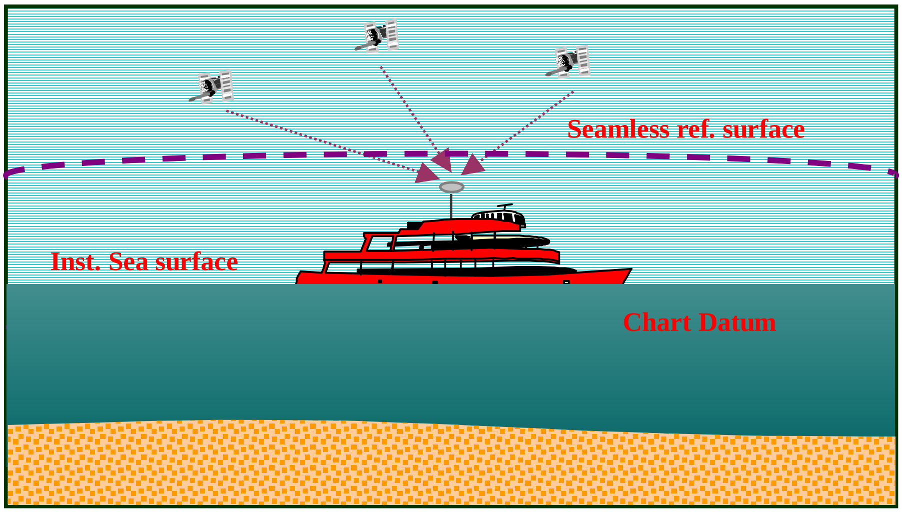

Figure 4. Relationship between CD, seamless datum and instantaneous sea surface.

As such, the associated uncertainty parameters must be considered when merging various sounding data sets. Furthermore, as stated above, Chart Datum is defined differently among the various hydrographic offices, which must be considered when merging data collected by various countries. Additionally, uncertainties in the tide measurements, tide prediction and spatial variations in Chart Datum must be considered in the development of the seamless reference surface.

5. SUMMARY

This paper summarizes the planned activities for the FIG WG 4.2 – vertical reference frame. It is shown that the development of a seamless vertical reference surface would benefit a number of applications, such as coastal zone management and marine boundary delimitation. The availability of such a reference surface is also necessary for the development of the next generation three-dimensional ECDIS, which is expected to have significant economic and safety impacts.

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