The Development of a Vertical Reference Surface and Model for Hydrography – a Guide

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SUMMARY

Those working in the maritime arena have long been aware that relating depths to a stable reference surface is not easy. The need to do this, however, increases year on year as satellite positioning enables measurement of a vessel's position (in all 3 dimensions) to accuracies never known before. There is increasing pressure from all areas of the consumer sector to marry maritime and land datasets – environmentalists, planners, leisure users, the military, lawyers etc all see a need to join up data to create seamless land/sea products.

Historically depth data has been collected to a tidal datum that, although of benefit to the Mariner, means that depths remain referred to 'local' vertical reference surfaces rather than something more coherent and stable. FIG Working Group 4.2 (WG4.2) Vertical Reference Frame has been exploring this issue and has recently published a flyer on this subject. Papers have been presented at FIG meetings in Paris (2003), Athens (2004) and Cairo (2005) that should all be read to provide background information to this subject. A handbook has been developed to help those entering this subject know where to go for more information. It does not cover all modelling techniques currently in use but will provide a basis from which future work can grow.

1. BACKGROUND

It has long been realised that maritime users face a challenge in relating depths to topographical heights due to the different vertical datums used. Land heights are invariably related to a local land height system which reflects the geoid. Increasingly land heighting is becoming referenced to global reference systems such as WGS84 Datum. Depths, however, are related to tidal datums, the most common of which approximates to Lowest Astronomical Tide (LAT). There is little information on the relationship between LAT and local land datums, let alone global reference systems.

To research this and provide more information Working Group 4.2 of Commission 4 (Hydrography) was set up in 2002. WG4.2 "Vertical Reference Frame" is a joint working group with Commission 5 (Positioning and Measurement).

It aimed to:

- Develop and promote the understanding and realisation of a vertical reference frame for use in hydrography.
- Examine the demand for a seamless vertical reference frame for use in hydrography and marine navigation.
- Develop an inventory of vertical reference surfaces used in hydrography in various countries of the international community.

And the agreed outputs were:

- To produce a white paper on current understanding of what is meant by a Vertical Reference Frame and how this relates to Hydrography and Navigation.
- To work with Commission 5 and sister organisations to increase awareness and knowledge of the use of a vertical reference frame.
- To collect information from the international communities on the activities related to the vertical reference surfaces in hydrography. Previous efforts by FIG, IHO and IAG shall be considered.

1.1. Working Group 4.2 Output 2002-2006

Throughout the 4 year tenure of this Working Group various papers have been presented at FIG conferences demonstrating progress in this (Adams, 2003; El-Rabbany, 2003; Adams and El-Rabbany, 2004; Adams, 2005; El-Rabbany, 2005).

The culmination of this work is delivery of a flyer and a guide on the 'vertical reference surface for hydrography'.

2. VERTICAL REFERENCE SURFACE FOR HYDROGRAPHY - FLYER

The flyer was produced in 2006, providing a quick reference to the issue of a vertical reference surface for hydrography; in particular introducing the concept of a vertical separation model. The leaflet is not aimed to be a detailed document but a high level overview of some of the concepts involved. It ensures that issues such as cost, resource, accuracy and time are considered. The flyer is available from FIG and on www.fig.net.

3. VERTICAL REFERENCE SURFACE FOR HYDROGRAPHY – GUIDE

The FIG guide, 'The Development of a Vertical Reference Surface' was written by members of the Commission 4 Working Group 4.2 - Vertical Reference Frame (A Joint Working Group with Commission 5).

It is not meant to be an authoritative handbook on vertical datums, but is designed to be a guide and resource to those who wish to develop a separation model. The guide contains numerous references and links that it is hoped the reader will follow through to gain a greater understanding of this complex subject.

The guide is split into the following sections, each of which will be covered briefly in this paper. Obviously more detail will be found in the guide (available from FIG):

- Overview
- Definitions
- Definition/creation of a transformation model
- Surveying without directly measuring tides
- Case studies
- Glossary
- References
- Further reading

4. THE GUIDE - OVERVIEW

The overview of the guide has been directly copied from the recently published FIG flyer "development of a vertical reference surface for hydrography" mentioned in section 2.

> A Vertical Reference Surface for Hydrography (VRSH) is one that does not vary either over time or area. Development of a stable surface is a vital step in being able to handle modern bathymetric depth data and use it to its fullest.

(Adams and El-Rabbany, 2004)

And this will allow for:
- Depth data to be more easily merged with land data.
- Increased efficiencies in hydrographic surveying.
- Easier merging of different databases such as realtime tides, surge monitoring, flood prediction.

The possibility of having data which can easily be output on different vertical datums is not to be understated.

Chart Datum is the traditional surface to refer depths to. However Chart Datum is not a seamless reference surface as it varies from location to location. Chart Datum is established based on local water level measurements at discrete locations.

There are various methods which can be employed to develop a vertical reference surface model. The chosen method will depend on existing information, available resources, hydrographic capacity and the extent of the area of coverage. Section 3 of The Guide, Definition/creation of a transformation model, covers this in more detail.

5. THE GUIDE - DEFINITIONS

This section of The Guide provides an overview of geodetic concepts for those without a strong geodetic background.

It is essential that the developer of a vertical separation model has, at the very least, a basic grasp of geodesy and geodetic concepts. A good starting place is a publication called "Geodesy for the Layman". It is published by NGA, National Geospatial-Intelligence Agency, and although not currently available in hard copy can be found at http://earth-info.nga.mil/GandG/publications/geolay/toc.html. (NGA, 2005). The IHO, International Hydrographic Organisation, Manual of Hydrography (M13) chapter 2 also explains these concepts well (IHO, 2006).

5.1. Geodetic Datums

The Guide explains that all three dimensional positions have, by definition, to be related to a three dimensional surface. It provides definitions and information on the geoid and the difference between this and the reference ellipsoid, including diagrams. Definition of the reference ellipsoid is provided along with a definition of geodetic datum.

5.2. What is a Global Reference Frame?

The subject of a 'global reference frame' is covered. Prior to the advent of space based measurements geodetic datums were locally defined and were sufficient for surveyors' needs. Satellite positioning systems, however, need a single, global geodetic datum.

An important underlying concept is that reference system definitions are purely definitions and must be *realised* through some defined process. Three particularly relevant realisations are WGS84 as used for GPS, PZ90 for GLONASS and the International Terrestrial Reference Frame (ITRF). (Cross et al, 2000).

5.3. WGS84

Details on WGS84, World Geodetic System 1984, are provided including references to its definition and a FIG publication on how to work with it (Appendix 1, Cross et al, 2000). The 1980 Geodetic Reference System (GRS80) spheroid is defined. It is essentially the basis for geodetic positioning by the Global Positioning System and is thus in extremely widespread use.

Further information on WGS84 can be found at the National Geospatial-Intelligence Agency website in particular TR8350.2. (NGA, 2000)

5.4. The Difference between ITRS and IRTF

The International Terrestrial Reference Frame (ITRF) and the International Terrestrial Reference Surface (ITRS) are often used interchangeably (and incorrectly) by non-geodesists. The Guide explains the difference between the conceptual system and how it is realised into a frame.

Realisations of ITRS are ITRF89, ITRF90, ITRF91, ITRF92, ITRF93, ITRF94, ITRF95, ITRF96, ITRF97, ITRF2000, ITRF2005.

There are also many regional variations based on ITRS such as ETRF89 (European Terrestrial Reference Frame 1989), GDA94 (Geodetic Datum of Australia 94), JGD2000 (Japanese Geodetic Datum 2000), AFREF (African Geodetic Reference Frame) etc.

Information on reference frames in practice can be found on the FIG Commission 5 website http://www.fig.net/commission5/wgroups/wg5_2.htm and also on the International Association of Geodesy website (Subcommission 1.2, Global Reference Frames) at http://iag.dgfi.badw.de/index.php?id=36

5.5. Global Vertical Reference Frames

Detail on global vertical reference frames is provided including the work of the IAG (International Association of Geodesy) and its working groups.

5.6. Tidal Datums for Depths

Lowest Astronomical Tide (LAT) is the tidal datum most commonly used to reference depths. Technical Resolution A2.5 of the IHO resolves that LAT shall be adopted as Chart Datum where tides have an appreciable effect on the water level.

Most nations, if not already using approximate LAT, are moving towards its use. There are some exceptions such as:
– Finland – the tide is practically unobservable
– Greece – minimal tide, MLLW used for Chart Datum

– USA – use MLLW
– Japan – use Nearly Lowest Low Water

6. THE GUIDE - DEFINITION/CREATION OF A TRANSFORMATION MODEL

This section provides details on the development of a separation model. It is does not cover it in minute detail, but provides sufficient information and references to provide the reader with links to provide greater depth in this subject.

The creation of a vertical surface separation model (from herein called a 'separation model') can range in difficultly from very simple to extremely complex. A low accuracy, low resolution model can be easily derived using global tidal and geoid models.

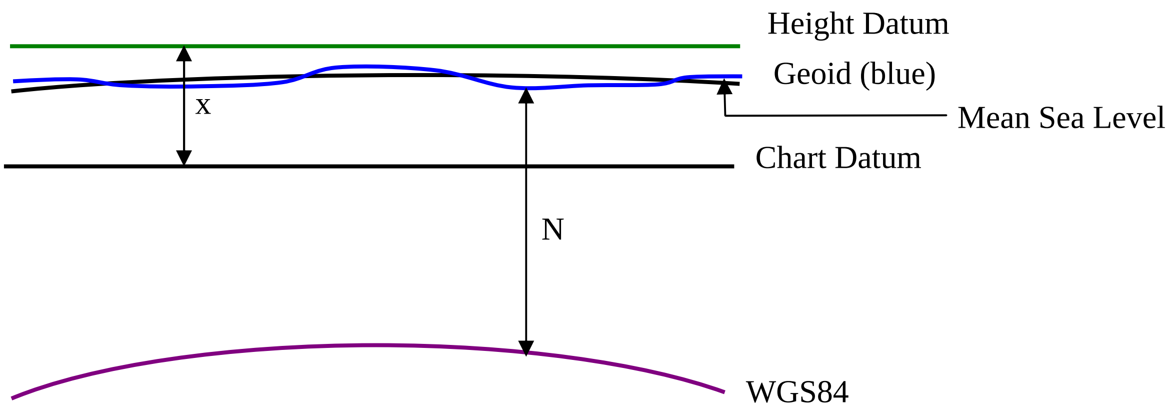
The section concentrates on the development of a separation model between Chart Datum and a global geodetic datum (for ease of reference WGS84 is used). However the principles can apply to any tidal datum, geodetic datum or, indeed, other vertical surface.

There are two main steps to the development of a separation model
– Derivation of the difference between Chart Datum and WGS84 at discrete points (usually tide stations)
– Extrapolation of the difference offshore.

6.1. Derivation of the Difference between Chart Datum and WGS84 at Discrete Points

The Guide provides a flowchart describing the steps to take for this process.

Figure 1 describes the relationship between the vertical surfaces.



Where
x = height datum/Chart Datum separation
N = geoid/spheroid separation

Figure 1 – Relationship between geoid, spheroid and Chart Datum

Other separation values may be known and can be used with the above diagram.

6.2. Extrapolation of the Differences Offshore

Once the differences between Chart Datum and WGS84 have been found this separation can be extended offshore. It is obvious that the separation will not be constant and will need modelling. The Guide provides a few examples of techniques to investigate.

6.3. Issues with the Development of a Separation Model

The key issue that should always be kept in mind is

What is the separation model going to be used for?

The answer to this question will vary the approach needed and the resources spent in achieving the aim. There is obviously no point using a lot of time and expense defining a sub-centimetre separation model when, for example, the user only needs decimetre accuracy.

The Guide details the issues surround the development of a separation model:

6.3.1. Accuracy
6.3.2. Resolution
6.3.3. Coverage
6.3.4. Resource availability
6.3.5. GPS network/measurements
6.3.6. Other extant data sets
6.3.7. Storage
6.3.8. Maintenance

7. SURVEYING WITHOUT DIRECTLY MEASURING TIDES

As a key benefit of the development of a separation model, a section of The Guide has been devoted to this.

Hydrographic surveying without directly measuring tides is one of the many benefits a separation model can bring.

In traditional hydrographic surveying sounding depth is the measured depth from the vessel plus heave minus the tide (left hand equation in figure 2). Using GPS, such as RTK (real time kinematic), sounding depth can be obtained by subtracting the height of the vessel's antenna above the WGS84 spheroid and the geoid/chart datum separation value from the height of the antenna above the seabed (right hand equation in figure 2). Tide and, theoretically, heave/squat do not need to be measured.

Therefore, assuming that the surveyor can obtain their depth with respect to WGS84 accurately enough, including squat, use of the separation model negates the need to measure tides.

It is clear that surveying without measuring tides is impossible without a separation model.

There is much research into this topic and papers are continually being written on this subject.

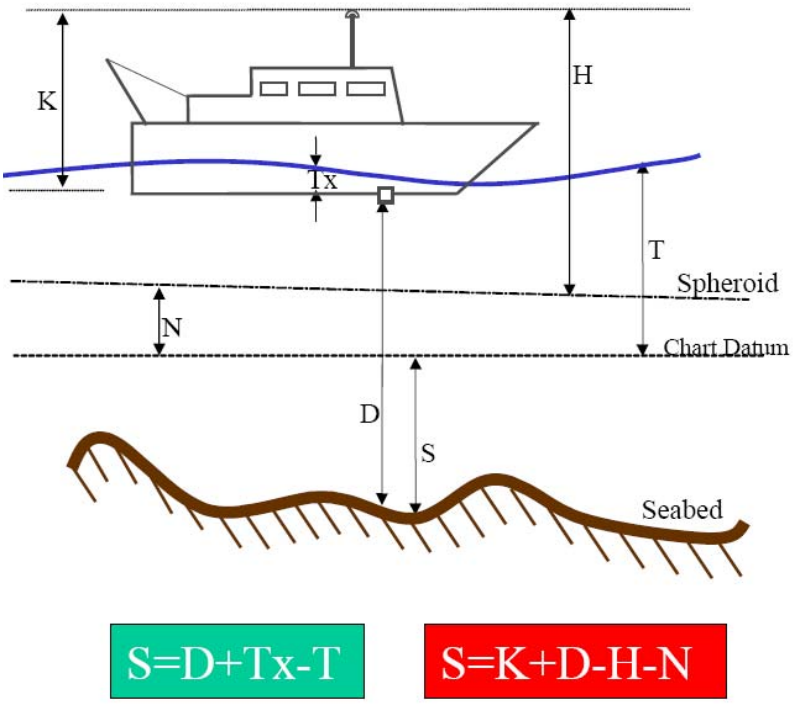


Figure 2 – Surveying formulae for traditional and non-tide measurement surveying (with thanks to Steve Shipman, IHB)

8. CASE STUDIES

The Guide details case studies from four countries. Many more nations have developed or are in the process of developing separation models.

8.1. Australia

Australia has developed the AUSHYDROID for Queensland waters (Martin and Broadbent, 2004). AUSHYDROID is a model of the height of chart datum relative to the WGS84 ellipsoid, akin to the AUSGEOID. The separation model has been developed using the known height of the AUSHYDROID at tidal stations and the interpolation of tide offshore has been done using the zoning process.

8.2. Canada

Canada have been a lead nation in the development of separation models. In the absence of a geoid which could be used to define the separation model at the shore tide stations, Canada revisited many tide stations with GPS to calculate the separation value. Then, using hydrodynamic modelling and satellite altimetry data, the tide/water level variation off shore was developed (O'Reilly et al, 1996).

8.3. United Kingdom

The UK are developing a separation model for UK Waters called VORF (Vertical Offshore Reference Frame). Its development is nearing completion and further information will be available in due course from the United Kingdom Hydrographic Office www.ukho.gov.uk.

VORF has been developed using known shore station separation values (determined via the UK geoid model) and then realising the separation offshore using a combination of hydrodynamic models and satellite altimetry data (Adams, 2003).

8.4. United States of America

For many years the United States has been developing its VDatum capability. VDatum is the tool by which users can transform between 28 tidal, orthometric and ellipsoidal vertical datums (Myers et al, 2005).

The United States' National Oceanic and Atmospheric Administration (NOAA) developed a Chart Datum model in Tampa Bay and Delaware Bays using a hydrodynamic tidal model and a known relationship to NAD83 (Parker, 2002, Hess et al, 2003, Gesch, 2002). NOAA is now using this methodology to extend it further round the coast of Continental US (Parker et al, 2003). VDatum applications currently exist in Tampa Bay, Los Angeles, New York Bight, Delaware Bay, Puget Sound and California (Myers et al, 2005).

Further details and figures are contained in The Guide.

It is well known that other nations have developed or are developing separation models for their area of interest. This is a key research and developmental area.

9. CONCLUSION

The work of Working Group 4.2 has successfully concluded after 4 years with the publication of both a flyer and guide on the "Vertical Reference Surface for Hydrography". It has researched the area of separation models for use in hydrography and has provided guidance to the mariner (and non mariner) on how these can be developed.

It has published a flyer providing a high level overview of the concept and benefits of a separation model.

The Working Group has provided a basic guide to geodesy, covered the elements of developing a separation model, described the particular use of a separation model in hydrographic surveying and provided some case studies from around the world.

The papers produced from 2002-2006 provide excellent background reading to this subject and the reader would also be wise to follow up some of the 'background reading' provided at the end of this paper. As ever, this whole subject will continue to develop over the months and years. FIG Commission 4 will continue to monitor this subject and update developments.

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BIOGRAPHICAL NOTES

Ruth Adams works for the UK Hydrographic Office based in Taunton, United Kingdom. She is currently a programme manager for the Maritime Systems section responsible for the delivery of projects to meet the needs of the Mariner. Previously to this she was Head of Additional Military Layers, Staff Officer to Director of Operations and Head of Geodesy and Imagery. During her career she has worked closely with the Royal Navy hydrographic surveyors and has had periods of detached duty at sea. Her geodetic and imagery expertise are particular strengths.

She has a first class degree in Surveying Sciences from the University of Newcastle upon Tyne and is a fellow chartered surveyor of the RICS. She is the RICS UK delegate for FIG Commission 4, Hydrography and co-chair of WG4.2. She is vice-chair of the RICS

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