Seamless Digital Data and Vertical Datums

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Key words: seamless data, vertical datums, Chart Datum, digital data, UKHO.

SUMMARY

The creation of accurate seamless digital data requires an awareness of many issues. These include, but are not limited to, datums (both horizontal and vertical), projections, the temporal nature of data, accuracy, scale and generalisation. This paper will highlight these concerns, but will then focus on how the United Kingdom Hydrographic Office (UKHO) is aiming to resolve the difficulty of assimilating geospatial data referred to different vertical surfaces. It will investigate the particular challenge of working with Chart Datum. The paper will use examples from the Integrated Coastal Zone Mapping project which is a tri-organisation project between the Ordnance Survey (GB), British Geological Society and the UKHO.

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1. INTRODUCTION

Mariners have long wanted seamless geospatial data. Long before the advent of digital data, cartographers strove to assimilate differing data types and sources to create one seamless product for their end users. Now, with the digital era well and truly upon us, this requirement from the user is stronger than ever. No longer are users content to ‘cut and paste’ analogue products, or switch between differing digital datasets on screen. Mariners, understandably, want to use geospatial data effortlessly, without breaks for datum, scale or other such changes.

At the United Kingdom Hydrographic Office (UKHO) safety is our prime concern, although user requirements obviously have a high impact on how products are produced. We supply a plethora of geospatial information to our customers worldwide, both civilian and military. These customers rely on us for accurate and reliable data. Their desire is for seamless geospatial digital data which can provide the backdrop to their needs; be this navigation, warfare, fishing, mineral exploration, leisure or a multitude of other activities.

2. TECHNICAL ARENA

The provision of this data requires the resolution of some quite basic technical issues. The creation of seamless data is, understandably, far more than just joining more than one digital dataset together. Issues such as horizontal datum, projection, temporal changes, error budgets (including accuracy, scale and generalisation) and vertical datums must be considered. Vertical datums are particularly relevant to the UKHO data sources and will be explored in depth in this paper. Ignoring these technical concerns will cause datasets of geospatial information to end up as meaningless and unreliable information.

3. HORIZONTAL DATUM

Horizontal datums are a key issue in the fusion of data. UKHO products use over 70 different horizontal datums, although this figures is gradually reducing as products move to WGS84 Datum, where possible. Figure 1 shows an example of horizontal datum shift in the Maldives. The difference between the original astro graticule and WGS84 Datum is over 3 miles. The largest known shift between WGS84 Datum and any charted feature is in the region of 7 miles. This is fortunately rare – but obviously very significant to navigation.

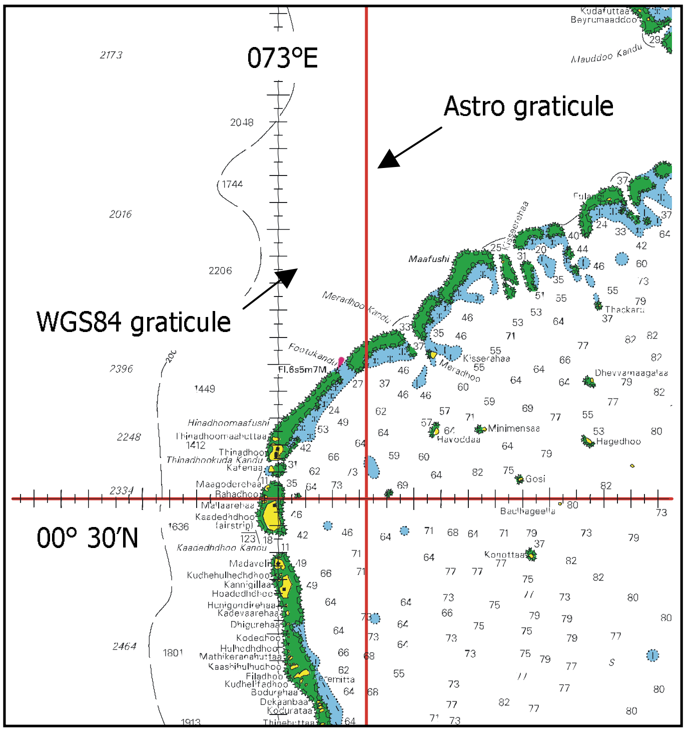


Figure 1: Portion of BA 1101 - Maldives

Closer to home, Figure 2 shows an example of a horizontal datum shift in the River Thames. The portion of chart on the left is referred to OSGB36 Datum whereas the one on the right is ETRS89 Datum (compatible with WGS84 Datum). This Figure shows the difference in position with respect to the Thames Barrier for two vessels which have identical coordinates. If the ship on the left went through the lowest barrier and passed their position to the ship on the right without qualifying which horizontal datum they were using there could easily be a grounding.

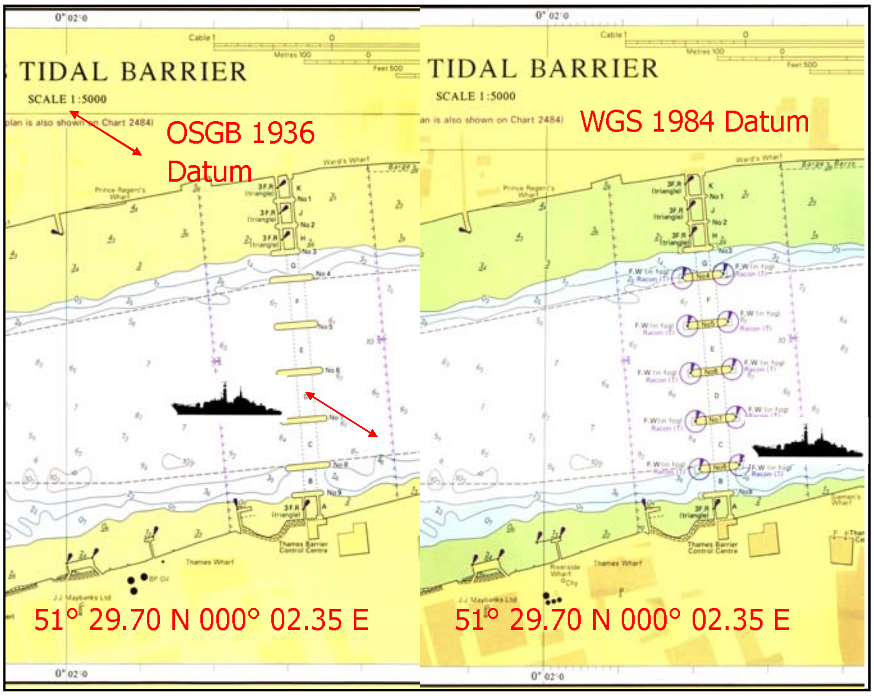


Figure 2: Portions of BA 3337 (previous and current edition)

3.1 Relating Charts to WGS84 Datum

The solution to the seamless problem for horizontal datums would be simply to refer everything to WGS84 Datum. Unfortunately about 30% of UKHO charts are not related to WGS84 Datum. This is due to the following reasons:

- The horizontal datum of the chart is not known (for example in many parts of the South China Sea, West Africa, Antarctica, central America).
- The horizontal datum of the chart is known, but the relationship to WGS84 Datum is not (for example Sao Tomé).
- The horizontal datum of the chart is known, but the uncertainty in the datum shift required to refer it to WGS84 Datum is too great. Hence the error in the shift is plottable at the scale of the product.
- There are internal inconsistencies in the charts (particularly for charts yet to be metricated).

When the relevant information is known, horizontal datums are not a problem – it is a straightforward computation to transform from one datum to another. But where there is a lack of data, for any of the above reasons, the data cannot be referred to WGS84 Datum.

4. PROJECTIONS

Projections can sometimes cause problems although these are usually easily surmountable. If a source is being scanned and its projection constants are not known then this can cause difficulties with geo-referencing. There can also be difficulties with scanned documents being displayed on a different projection to that which they were captured on. In such circumstances distortions can occur to the extent that legends become unreadable.

5. TEMPORAL ISSUES

It is not possible to simultaneously survey the oceans and therefore time gaps appear in the data. For rocky and/or deep areas these gaps may not be important, as the seabed morphology remains static. However, in areas of shifting sandbanks, such as the English Channel, surveys of different dates provide different results.

Around 1996 a vessel grounded on a 2m shoal in the Clyde which was actually charted as 10m. Subsequently a survey was carried out and Figure 3 shows the results of this survey. It is apparent that the data is not seamless. The Source Data Diagram for this chart is at Figure 4. The area in the west, area ‘a’, is the newly surveyed area, surveyed in 1997. In the east is the area ‘e’ which was last surveyed in the 1940s. Time has caused a considerable difference in the bathymetry here.

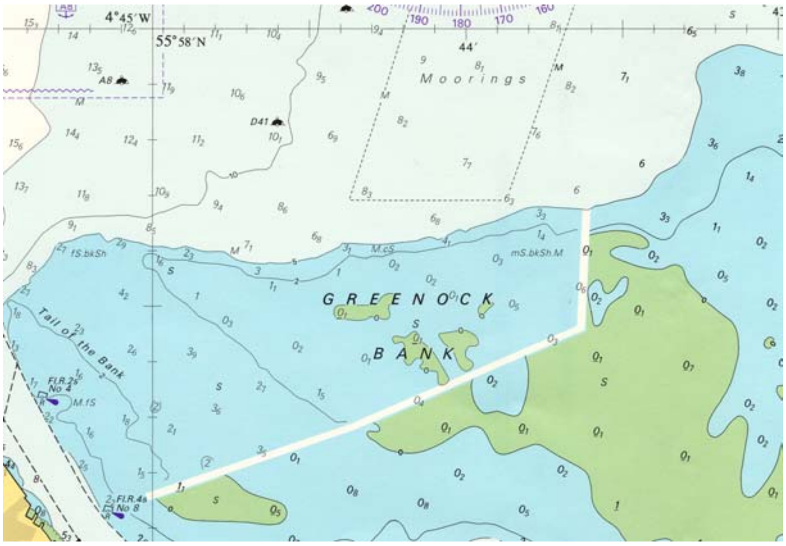


Figure 3: Portion of BA 1994 – Greenock Bank.

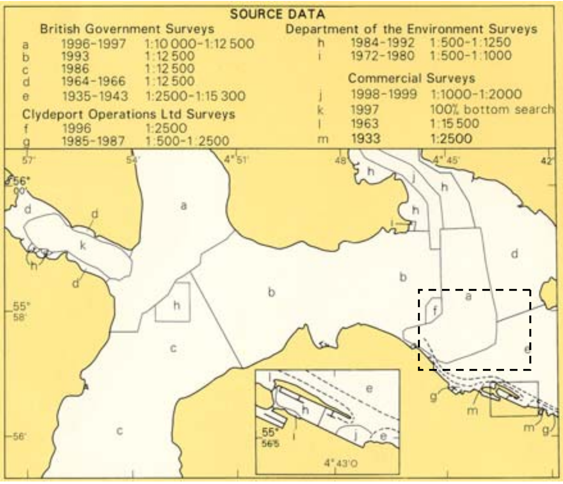


Figure 4: Source Data Diagram for BA 1994.

Temporal mismatch is also caused by the improvement of survey equipment over time. Features which were once ‘hidden’ from surveyors using old hydrographic methodology, such as leadline surveying, can be discovered with modern equipment. In such cases, the seabed morphology may have been stable, but improved survey methods have delineated more than was previously known to exist.

Unfortunately hydrographic surveying is extremely time consuming, and consequently expensive, compared with land surveying and this situation of mismatch of data due to time is likely to continue for some years to come.

6. ERROR BUDGETS

All data contains errors. This in itself is not a problem, but to maintain data integrity both the data provider and data user need to be aware of the data accuracy issue. There is unfortunately an all too common misunderstanding that because data is digital then it is perfect: it is not. Good quality metadata is an essential element of digital data – especially when data sources of differing accuracy, age and quality are being combined. Without this additional information the user has limited knowledge of the strengths, or weaknesses, of the data.

The final accuracy of one’s product depends in part on the following variables:

- Data acquisition errors
- Resolution of scanning and dimensional stability of original source material
- Datum shift inaccuracies
- Scaling differences – (eg small scale source enlarged for larger scale product)
- Positioning errors
- Cartographic generalisation

This paper won't go into much detail on the above, but included here are a few graphics to illustrate some of the problems encountered with trying to assimilate different types of source data. These graphics all originate from the Integrated Coastal Zone Mapping (ICZMap®) project.

Figure 5 contains an example of a mismatch of data due to different scales of compilation. The detailed coastline is from large scale Ordnance Survey (OS) data – probably compiled at 1:2 500. The polygons are from UKHO data compiled at a far smaller scale than the OS data. It is easy to see the gaps and areas of overlap that the generalisation of the chart compilation has produced.

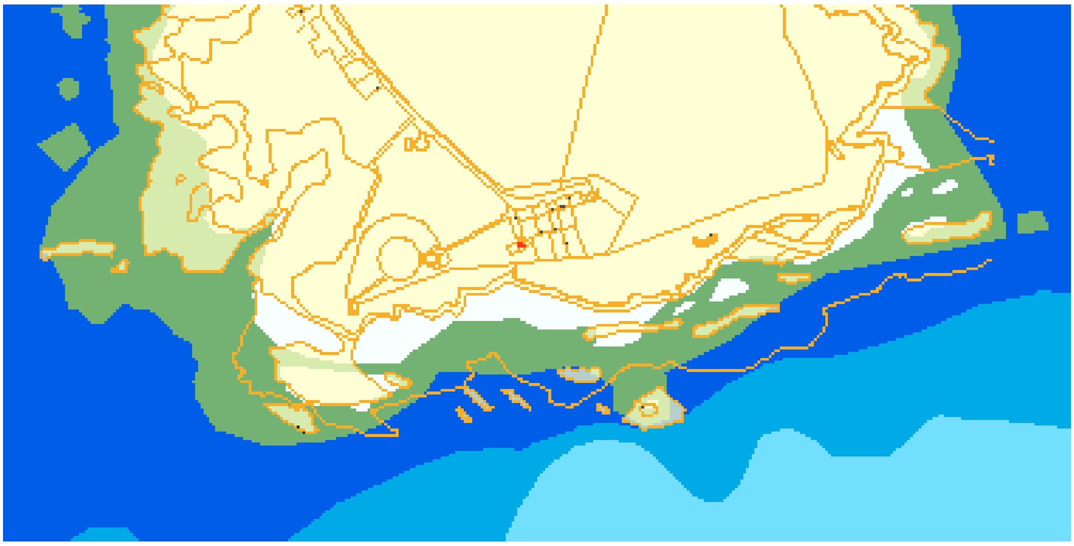


Figure 5: Overlap and missing data due to differences in compilation scale.

Figure 6 shows an example of misaligned data and Figure 7 shows contradictory data. In each case, which is the correct dataset?

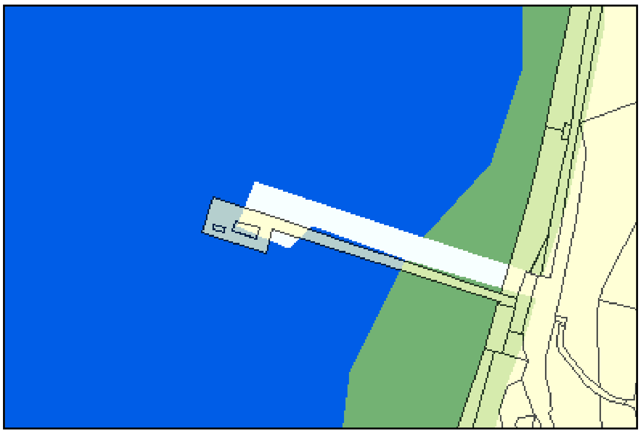


Figure 6: Misaligned data.

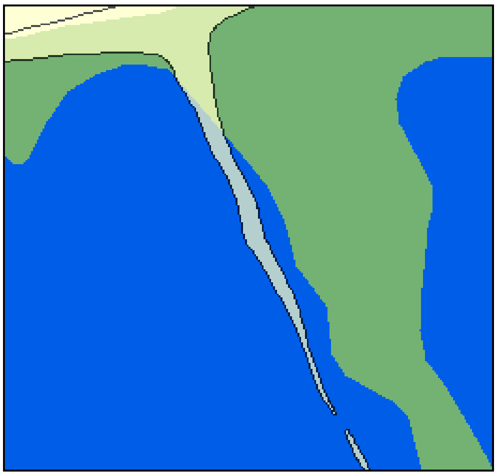


Figure 7: Contradictory data.

The user must also be aware that whatever quality of digital data is used, there will be error in their own location (no method of positioning is perfect) and this must be taken into account when assessing the final accuracy of their position with respect to the digital data.

7. VERTICAL DATUM

Vertical datums are a considerable challenge for cartographers in the marine world. Ultimately all datasets should refer all depths to WGS84 Datum (or equivalent) to create a seamless database. It is relatively straightforward for land data as geoidal models can be used to derive the separation between local land datum and a global reference surface. However, Chart Datum, to which all soundings are referred, is not a coherent surface. It is certainly not easy to model.

Figure 8 shows the different types of vertical datum used in the UKHO. The key surface is Chart Datum (CD), which approximates to Lowest Astronomical Tide (LAT). Off this hang the other datums such as Mean Sea Level, Mean High Water Springs (which is used for the coastline and above which heights ashore are charted), Mean Low Water Springs etc.

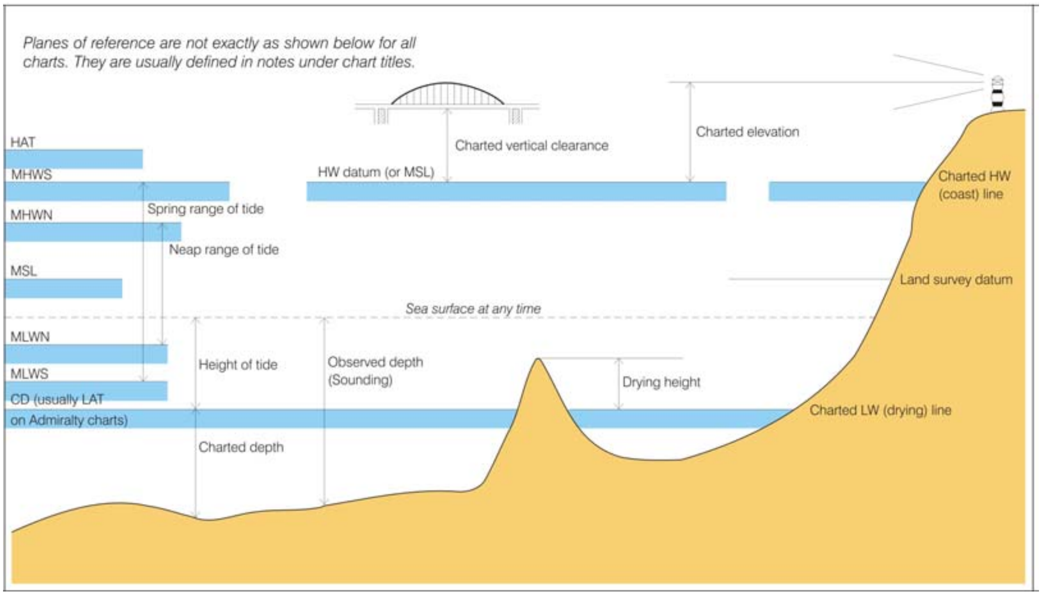


Figure 8: Relationship between different vertical datums.

Chart Datum varies around the UK and, indeed, the world. For example, around UK waters the following examples of differences exist between Chart Datum and Ordnance Datum Newlyn (the national land mapping datum):

-2.80m at Torquay
-1.50m at Lowestoft
-6.10m at Barry
+0.60m at Barnstaple

7.1 ICZMap® Project – Chart Datum Modelling

The ICZMap® project has investigated modelling Chart Datum with respect to Ordnance Survey vertical datum in Home Waters. This is to allow the integration of OS height data with UKHO depth data.

The differences between Chart Datum and the OS vertical datum are published in the Admiralty Tide Tables. Great Britain uses Ordnance Datum Newlyn, Northern Ireland uses Belfast Datum, Ireland uses Dublin Datum, also known as Poolbeg Datum, and some specific Islands around the coast have individual vertical datums. The differences between Chart Datum and OS vertical datum are only defined at specific coastal locations, usually where tidal observations have been obtained. The challenge is how to extrapolate the differences seaward.

7.1.1 Co-tidal Values

Co-tidal values have long been used to model the relationship between Chart Datum and a 'home port' offshore. Co-tidals are used to relate tidal range at a particular point offshore with a tidal station onshore. They consist of lines of equal tidal range (in metres, to the nearest decimetre) and of equal time of High and Low Water (in hours, to the nearest 10 minutes, depending on the scale of the co-tidal chart). In general, the further offshore one is, the less the tidal range is (except in the vicinity of a degenerate amphidrome when the converse is true). In effect, this means that Chart Datum slopes up towards the geoid as one travels offshore.

Co-tidal factors are used to reduce soundings when surveying. They are also used by navigators to determine the depth of water beneath the keel. They were created graphically some years ago by the UKHO and are only guaranteed to be accurate in the vertical dimension to ±0.5m.

7.1.2 Developing the Model

The ICZMap® project has developed a non-navigational model out to 20km offshore (Whitfield and Pepper, 2003).

By relating the co-tidal value offshore to the nearest appropriate port and using an equation developed by the Tidal Branch at the UKHO, an offshore value for the height correction relative to the OS height datum can be obtained. Interpolation techniques can then be employed to grid the derived values around the UK. The production of the geo-referenced grid provides a means for applying a correction to the observed UKHO soundings relative to OS height datum. The resulting dataset can be used to re-contour the bathymetric depths and hence produce, on the same vertical datum, an integrated terrestrial and marine geographic model for the UK. This derived model is a graphical representation and is not suitable for navigation.

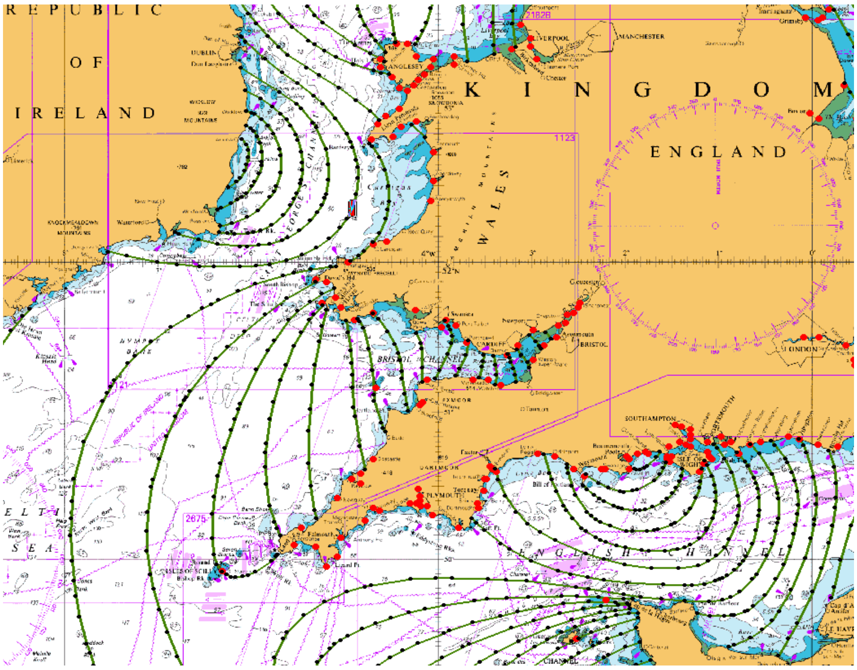
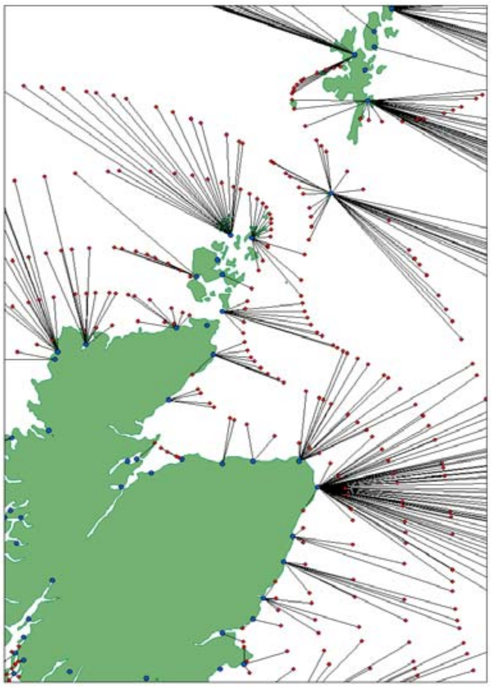


Figure 9: Co-tidal points, lines and ports.

To date, the separation value of Chart Datum (CD) to the OS vertical datum has been derived via the following process

1. Input CD to OS vertical datum values for tidal stations around the UK
2. itise co-tidal charts
3. reak up vector co-tidals to obtain point positions offshore (Figure 9)
4. For each point select nearest tidal station (Figure 10)
5. Compute the CD to OS vertical datum value at these points using co-tidal formula based on the nearest tidal station obtained in 4.
6. Model this separation to create continuous separation surface (Figure 11)

When this separation surface is applied to bathymetric data it will result in a consistent height model both onshore and offshore (see Figure 11).



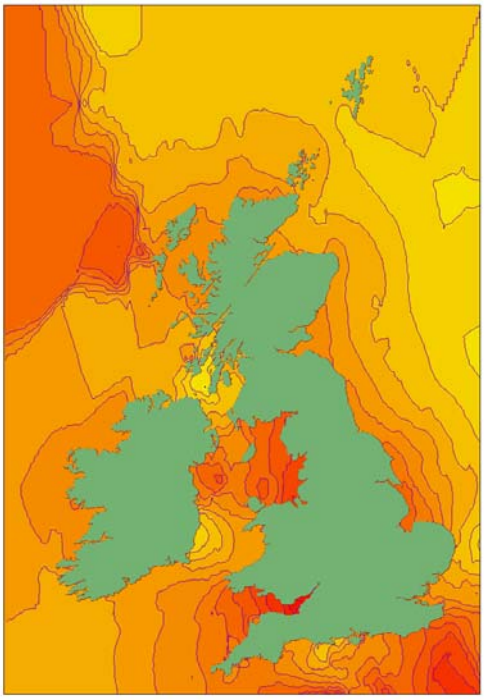


Figure 10: Co-tidal point related to nearest port

Figure 11: Contoured grid – red is 6m and yellow is 0m with 0.5m interval

7.2 Taking this Model Further

This model has been created as a non-navigational product for use by the ICZMap® product. However, to extend this model further for accurate reduction of survey data to Chart Datum a more detailed approach is necessary.

The Canadian Hydrographic Service has been working on a solution to this for a number of years (O'Reilly, Parsons and Langelier, 1996). A GPS campaign was carried out in selected areas to define the relationship between Chart Datum and WGS84 Datum. From this a separation surface was derived enabling the Canadian Hydrographic Service to handle data referred to a variety of vertical datums. It is hoped that this approach will be suitable for UKHO use – our investigations continue.

At some stage in the future, the UKHO is going to start receiving depth information with respect to a global reference frame, such as ETRS89. In Home Waters it is easy to obtain an accurate separation value for the difference between ETRS89 and the geoid by using the latest OS model, OSGM02 (Forsberg et al, 2002). But it is the accurate link onwards to Chart Datum which is still the unknown. Without this link it will not be easy to handle ETRS89 depths in the UKHO.

7.3 Use of Satellite Altimetry

One of the major concerns with the current derivation of the Chart Datum separation model is the reliance on the co-tidals, which are known to be only accurate to ±0.5m.

Satellite Altimetry measures mean sea surface height. It could possibly be used to derive co-tidal information if the mean sea surface height was combined with a tidal model. This would 'strip' out the tidal information so that the relationship between Chart Datum and a reference ellipsoid could be seen. This is only conjecture at the moment and, again, investigations continue in this area.

8. CONCLUSION

The provision of seamless data to customers is possible – but there are various technical challenges to overcome. Most are surmountable with sufficient information, but it is the lack of sometimes key data (such as horizontal datum information) which will continue to cause difficulties in this provision.

The UKHO is investigating the whole issue of modelling Chart Datum. The creation and maintenance of a separation model between Chart Datum and another stable reference surface is key to the future ability to be able to handle bathymetric data referred to various vertical datums.

Good quality metadata is an essential element of digital data – especially when data sources of differing accuracy, age and quality are being combined. It is essential that the user is made aware of the quality of their data. Seamless data <u>is</u> achievable, but it must be created and used with wisdom.

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BIOGRAPHICAL NOTES

Ruth Adams works for the UK Hydrographic Office based in Taunton heading up the Geodesy, Photogrammetry and Remote Sensing sections. During her career she has worked closely with the Royal Navy hydrographic surveyors and has had periods of detached duty at sea. Her geodetic expertise is a particular strength. Other career postings have included Project Management and charting for the Fleet Air Arm.

She has a degree in Surveying Sciences from the University of Newcastle upon Tyne and is a chartered surveyor with the RICS. She is the RICS UK delegate for FIG Commission 4, Hydrography.

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