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# NAVSTAR GPS - CHARTING ASPECTS

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## Abstract

The historical development of positioning in relation to the nautical chart is very briefly described. Present nautical charts are largely based on geodetic surveys which date from the 19th and early 20th century. This gave rise to the use of many local datums and there has been a need to provide the mariner with information to enable him to transfer his position from one chart to an adjacent one on a different datum. The sizes of discrepancies in position between various datums are given. The availability of the Global Positioning System (GPS) and the World Geodetic System 1984 (WGS 84) datum enables positioning on a single worldwide datum to become a reality. The important factors affecting the adoption of WGS 84 as the datum for nautical charts, namely data availability and the practical and political considerations, are discussed. The importance of the proper consideration of datum in relation to new developments in the use of nautical charts is also mentioned.


## 1. INTRODUCTION

The availability of GPS to the worldwide community will potentially revolutionize the positioning accuracy achievable in the marine environment. This will inevitably have a significant effect on many of those working at sea and also on those ashore who are supporting the maritime activities. Hydrographic charts are essential aids to navigation and they are not immune to the changes being caused by GPS. In order to appreciate why changes to nautical charts are necessary it is useful to understand how the positioning aspects of them have developed with time.

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## 2. BACKGROUND

Geodetic surveys provide the framework for the positioning of hydrographic detail on nautical charts. These surveys date mainly from the 19th and early 20th century and were carried out by national and colonial survey organizations for their own local needs. The methods of surveying were classical; mainly astronomical observations and triangulation. This resulted in more than 100 horizontal charting datums being developed throughout the world. The horizontal charting datum is equivalent to the geodetic datum and this can be described simply as a reference system for latitudes and longitudes of points on the Earth's curved surface.

The large number of local datums was rationalized after World War II. More powerful computers became available and national datums could be adjusted properly. These could then be linked together into more extensive regional datums. Since the introduction of satellite-based navigational systems, the Doppler Navy Navigation Satellite System, Transit, and more recently NAVSTAR GPS, the opportunity to have a worldwide datum has become a reality. We initially had World Geodetic system 1972 datum (WGS 72) and now we have World Geodetic System 1984 datum (WGS 84).

## 3. NAUTICAL CHARTS AND GPS

Today we find that, of the many datums that have been established around the world, nautical charts are published on sixty-five of them. It is estimated that a similar number of datums are in use for land maps. The sixty-five geodetic datums on which UK Hydrographic Office (HO) charts are published are listed in Table I. By far the most significant aspect of the list is that over half of the chart panels (a basic chart can consist either of just one panel or many panels if it consists of a sheet of plans) are on unknown datums.

**Table I**
**Geodetic datums on which HO charts are published**

| Number of chart panels on each horizontal datum | |
|---|---|
| Abidjan | 4 |
| Arc (1950) | 12 |
| Arc (1960) | 1 |
| Australian Geodetic | 292 |
| Batavia, Java, Jakarta | 5 |
| Bathurst Base East End, Gambia | 2 |
| Bissau Base North-west End Pillar | 5 |
| Bogota | 1 |
| Bukit Rimpah | 4 |
| Cape Datum, South Africa | 3 |
| Castania | 5 |
| Castelo di Sao Jorge (Lisboa) (Bessel) | 1 |

| Number of chart panels on each horizontal datum | |
|---|---|
| Corrego Alegre | 42 |
| European (1950) (ED 50) | 822 |
| Falkland Islands (1943) | 44 |
| Fiji (1986) | 2 |
| Fiji (1956) | 21 |
| Finnish (Helsinki) | 10 |
| Geodetic Datum (1949) | 70 |
| Goenoeng Segara (1933) | 1 |
| GUX I Astro | 30 |
| Hermanskogel (Vienna) | 24 |
| Hito XVIII Astro, Chile | 1 |
| Hjorsey | 5 |
| Hong Kong (1963) | 13 |
| IGN (North Block, Bellevue) | 20 |
| IGN (South Block, Tanna) | 9 |
| Indian (Survey of India) | 63 |
| Itarare N Base, Itajuba-Santa Catarina | 2 |
| Kandawala (1933) | 12 |
| Revised Kertau | 39 |
| Le Pouce | 6 |
| Lisboa (Sao Jorge) (Int) | 11 |
| Luzon (1911) | 6 |
| Merchich | 15 |
| Monte Mario (1940) | 126 |
| Revised Nahrwan | 42 |
| Nahrwan | 24 |
| Naparima (1955) | 11 |
| North American Datum (1927) (NAD 27) | 207 |
| North American Datum (1983) (NAD 83) | 34 |
| Nouméa, Nouvelle-Calédonie IGN (1972) | 3 |
| Old Hawaiian | 11 |
| Ordnance Survey of Great Britain (1936) | 642 |
| Ordnance Survey of Ireland | 136 |
| OGB & OSI | 11 |
| Panama Colon | 4 |
| Phare d'Ayabelle | 2 |
| Pico de la Nieves | 10 |
| New Porto Santo | 5 |
| Reykjavik | 1 |
| Provisional South American (1956) | 46 |
| South American (1969) | 2 |
| South East Island | 10 |
| SHOM 1984, Martinique | 8 |
| Sierra Leone (1960) | 6 |
| Swedish | 8 |
| Tete | 1 |
| Timbalai (1948) (Bessel) | 26 |
| Timbalai (1948) (Everest) | 3 |
| Tokyo | 185 |
| Viti Levu (1916) | 1 |
| WGS (1972) | 112 |
| WGS (1984) | 87 |
| Unknown | 3596 |
| Total | 6963 |
| (Total of 6963 panels on 3337 navigational charts) | |

The problem created by the use of this wide range of datums is that positional discrepancies are found where two datums abut. In 1922, HMS RALEIGH, a 10 000-tonne naval cruiser, was wrecked off the Labrador coast. At the subsequent court martial of her officers, differences between adjoining charts were claimed to have been a cause of the accident. Notes drawing attention to datum shifts have appeared on navigational charts ever since. A typical datum shift or 'Positions' note is shown in Fig. 1.

CHARTS 442 AND 2565 POSITIONS

To agree with charts 442 and 2565 which are referred to Ordnance Survey of Great Britain (1936) Datum, positions read from this chart should be moved 0-10 minutes SOUTHWARD and 0-02 minutes WESTWARD.

FIG. 1.- Positions note from chart 2644.

The use of a note such as this addresses the problem of relative positioning between adjacent and overlapping charts. This approach has been acceptable in the past as the mariner has used land-based navigational aids to fix his position. These navigational aids, which include buoys, beacons, lights and electronic position fixing systems such as Decca, are all shown referenced to the chart datum. With GPS the situation is somewhat different. Positions produced by GPS receivers are primarily related to WGS 84 datum. In 1980 'Satellite-Derived Positions' notes were introduced on charts to assist the mariner to relate the position generated by Transit to his position on the chart, and they have been included ever since. The current format of this note for large scale charts (i.e. scale greater than 1:50 000) is shown in Fig. 2.

SATELLITE-DERIVED POSITIONS

Positions obtained from satellite navigation systems are normally referred to WGS 84 Datum; such positions should be moved 0-XX minutes NORTHWARD (SOUTHWARD) and 0-XX minutes EASTWARD (WESTWARD) to agree with this chart).

FIG. 2.- Satellite-Derived Positions note for large-scale charts.

Initially these notes referred to WGS 72 datum. Whilst this is very similar to WGS 84 the positional shift between them can amount to 17 m at the equator and this can be significant on large-scale charts. Notes referring to WGS 72 datum are gradually being amended; on large-scale charts they are being amended to WGS 84 datum and on charts at a scale of 1:50 000 and smaller the year date (84) is being omitted. On charts on scales of 1:500 000 and smaller, shifts are only quoted to one decimal place of a minute.

It must be emphasized that these notes can only be included on charts where the relationship between chart datum and WGS 84 datum has been established. The Defense Mapping Agency of the United States (DMA) has published a Technical Report [1] identifying this relationship for a large number of datums. Similarly, the International Hydrographic Organization (IHO) has distributed details [2] of transformation parameters of particular interest to Hydrographic Offices. There are, however, many cases where the relationship between chart datum and WGS 84 datum has not yet been established, and in these cases the note shown in Fig. 3 is added to charts.

SATELLITE-DERIVED POSITIONS

Positions obtained from satellite navigation systems are normally referred to WGS Datum; adjustments for plotting such positions are not known for this chart, but it should not be assumed that they are negligible.

FIG. 3.- Satellite-Derived Positions note where shift to WGS 84 is unknown.

Until recently these notes have been added to new charts and new editions when they are published. Consequently, there are many charts (all those published before 1980) which do not yet contain these notes. The current state of notes on charts covering UK waters is shown in Fig. 4. Provisional Notices to Mariners (NMs 2854(P)/91, 2855(P)/91 and 2856(P)/91) have recently been issued which give the sizes of the shifts for those charts covering UK and Irish waters (at scales of 1:50 000 and greater) which do not currently carry this information. Whilst these are not chart-correcting NMs, the information is now available to the mariner should he want to make use of it. A gradual process of adding notes to all the other charts in our chart series will follow on from this.

Total number of charts 348

Charts at scales larger than 1:50 000
- (a) Number with WGS 84 note 60
- (b) Number with WGS 72 note 116
- (c) Number without a note 33

Charts at a scale of 1:50 000 or smaller
- (a) Number with WGS note (no year date) 46
- (b) Number with WGS 72/84 note 67
- (c) Number without a note 26

FIG. 4.- Status of Satellite-Derived Positions notes on charts covering UK waters.

To compute the datum shift, we need to use certain geodetic parameters. The detail provided by DMA and the IHO is used along with that included on foreign government charts and notices. Sometimes conflicting information is received and this has to be resolved before chart action can be taken.

The size of positional discrepancies between datums varies considerably. The size of shifts for the charted position of some islands in the Pacific Ocean to WGS 84 is in excess of 2 km. Shifts between datums in use in the area of the English Channel are much smaller than this but are still significant for charting purposes. Charts covering the UK coast are invariably on Ordnance Survey of Great Britain 1936 datum. (OSGB 36). European Datum 1950 is generally used for coastal charts of mainland Europe. If the satellite datums, WGS 72 and WGS 84, are added to this scenario we have the situation shown in Fig. 5.

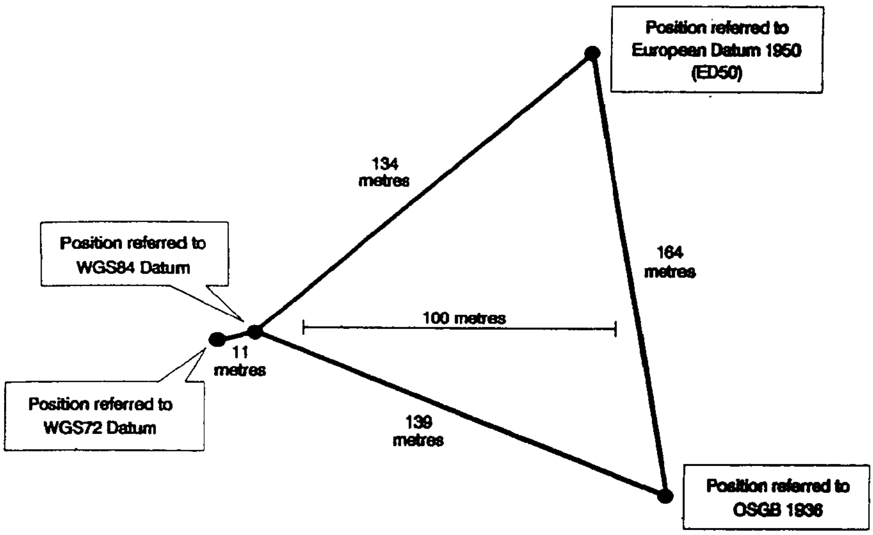


FIG. 5.- Horizontal datum discrepancies, Dover Strait.

Clearly we have to assist the mariner to use the satellite datum, and the inclusion of the shift notes on charts is one way of doing so. A further step is to adopt WGS 84 as the chart datum. There are many practical difficulties in this approach, but it is gradually being adopted. The areas where WGS 84 is currently being adopted are essentially self-contained islands or island groups such as Cyprus and the Azores. Contiguous stretches of coastline such as the North African coast between Egypt and Libya where there is no established charting authority can also be considered.

Other areas where we are planning to adopt WGS 84 are the Grenadines in the Windward Isles and Antigua. In many of these areas, we are the primary charting authority or there is no local Hydrographic Office producing charts in the area. Where a well-established mapping series exists on a local datum, it is likely that the local charts will be on the same datum. As close links exists between mapping and charting we have to establish very good reasons for moving away from the mapping datum for nautical charts. Even with all the necessary data and political will to adopt WGS 84, it will take many years to transfer all of our charts onto this datum. The ultimate aim must be to adopt WGS 84 for all our navigational charts. We have to progress slowly to ensure that WGS 84 is being implemented as safely as possible. It is feasible that the move to WGS 84 in the UK area will be when all the charting information is available in digital form and the conversion can then be completed at the 'push of a button'. Unfortunately, this is not likely to happen in the near future.

## 4. ACCURACY

No discussion of charts and GPS is complete without mention of positional accuracy. During the compilation of a chart the aim is to achieve a positional accuracy of ±0.3 mm at chart scale for all features critical to navigation such as fixed lights and radio beacons.

The accuracy of the coarse acquisition (C/A) signal of GPS is claimed by the US Department of Defense (DoD) to be 100 m 2DRMS at the 2-sigma level so that 95 percent of the positions will be within 100 m of their true position. Even without the controlled degradation of the signal to reduce accuracy to this level by the use of selective availability (S/A) the position calculated by the GPS receiver does contain errors.

The errors inherent within the GPS position come from three sources; the satellites themselves (there are errors in their clocks and stated positions), atmospheric effects (the ionosphere and troposphere both cause delay in the signal transmission) and at the receiver, both from noise within the receiver and from multipath effects. These errors are potentially always present and they can combine to degrade the positional accuracy by several metres.

Many GPS receivers have the facility to convert positions from WGS 84 datum to a number of other datums. If this facility is used, it is yet a further source of error; a simple transformation, one that is possibly used in GPS receivers, between WGS 84 and OSGB 36 is provided in the DMA publication referred to earlier. This uses a single transformation derived from averaged values across England, Scotland and Wales. If the shifts calculated using this transformation are compared with those calculated using a more accurate transformation derived within the HO, the positional discrepancies range from 13.6 m in the north of Scotland to virtually zero in the centre of the country and to 6.4 m at Lands End as shown in Fig. 6.

## 5. THE FUTURE

Many developments are currently taking place which all have requirements for more accurate positional information. The availability of GPS to many users at sea is just one of the factors in this situation. Positional information is required for many systems planned for use at sea which is, in some instances, an order of magnitude better than that included on printed charts. Electronic chart data for use in the Electronic Chart Display and Information System (ECDIS), will be referred to WGS 84 datum [3]. Other geographical information systems, naval command systems, the delimitation of international boundaries, territorial limits and fisheries

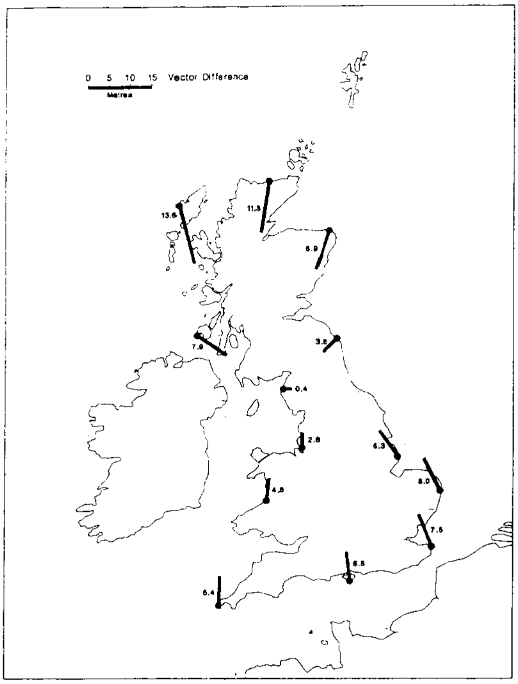


FIG. 6.- Vector showing differences between DMA and locally-derived datum transformations from OSGC 36 to WGS 84.

limits, all require positional information which is not subject to the same practical limitations as those printed on charts. Greater positional accuracy is now required with these new systems and consideration of horizontal datum becomes more important than it has been in the past. As with electronic chart data, many of these will adopt WGS 84 as their horizontal, or geodetic, reference datum as it is consistent on a worldwide basis.

## 6. CONCLUSION

The availability of GPS enables accurate positioning on a single worldwide datum to become a reality. The sizes of datum discrepancies between the many existing geodetic datums and WGS 84 vary considerably and cannot be ignored where precise work is being undertaken. The Hydrographic Office is attempting to provide mariners with the information that they need to enable them to navigate safely whilst using their GPS receivers. The adoption of WGS 84 datum for both nautical charts and land maps will take many years but it is likely that new products, many in digital form, will be referred to WGS 84 in the near future.

With the increasing use of GPS all users have to pay proper attention to possible sources of positional error to ensure that they do not place undue confidence in positions provided by GPS receivers.

## References

[1] Defense Mapping Agency of the United States of America. *Technical Report, DMA TR 8350-2, World Geodetic System 1984.*

[2] International Hydrographic Organization Circular *Letters 28/1988*, dated 15 July 1988; and *34/1989*, dated 26 June 1989, *Transformation Notes - WGS 84.*

[3] International Hydrographic Organization Special Publication No. 52, *Provisional Specifications for Chart Content And Display Aspects of ECDIS*, April 1991.