# DIFFERENT CHART FORMATS: SOME MYTHS AND MYSTERIES

Electronic navigation systems are coming of age. An enormous amount of work has been invested in digitising chart data and developing display systems. But there is still some way to go and, in particular, there are some unresolved and often inaccurately reported issues concerning the relative merits of the raster and vector chart formats. Both formats have limitations which we - and no doubt many other developers - have encountered through working with them. But these limitations are not always well understood.

This paper considers some aspects of creating and using digital charts. It suggests some areas where further discussion and development are indicated. Along the way it also attempts to clarify for the navigator and software engineer alike some of the ways in which different chart formats can be misinterpreted.

## What is raster and vector?

We see a lot of nonsense written about chart data formats. For example vector is no more 'intelligent' than raster; they are both just dumb data formats. It is what the computer can usefully do with the data that matters. The key difference between raster and vector charts is in the way in which they are rendered, where rendering is process of translating the chart data into an image which can then be displayed on the screen. The screen is *always* raster display, that is, it is made up of dots. So:

> A raster chart is ***early rendered***. The source data is analysed by a hydrographic office and the chart is drawn by a cartographer. The final image is decided by a cartographer and this image is captured for display on a computer screen.
>
> A vector chart by contrast is ***late rendered***. In this case the hydrographic office collates a set of (vector) data which can be used to generate a chart image. However, the image is drawn by the computer and this is not actually done until just before it is displayed on the screen.

Ultimately, therefore, all chart displays are raster. But in addition to the distinction in terms of rendering, there are also differences in functionality between raster and vector charts and these form the subject of much debate.

## A standard for many purposes

So what are the practical differences? Well, this depends a lot on what you intend to do and here the Electronic Chart Display and Information System (ECDIS – IEC 61174) standard can be a little schizophrenic. On the one hand it describes a system to be used for navigating a vessel; on the other it describes a system for passage planning. Intuitively these two activities seem closely related. In practice they can be very different. A system to help in actually navigating a passage will sit at the front of the bridge and in many ways behave like the radar. Specifically it should be a virtually hands-free operation. The screen should show the mariner exactly what they need to know automatically. There will be very few controls. A passage planning system is a very different proposition. There is no real-time imperative but there is a lot of disparate information to assess and collate. This will be a highly interactive system allowing the navigator to explore many possibilities and consider many factors.

ECDIS also has an underlying tendency (or some would say even an agenda) to attempt to de-skill bridge operations. Nominally, the purpose of ECDIS is to improve the information available on the bridge. Is it the role of the computer also to make decisions about how the vessel should be navigated? This seems unlikely but then what is the purpose of route checking alarms, for example? SOLAS vessels are not navigated like dodgem cars and the navigator should be carefully inspecting the planned route. How far do we rely on the computer to tell us whether a passage will be safe?

In our view, there are other areas where the ECDIS standard in its current form is someway short of being truly fit for purpose and some of these problems are touched on below. The evolution of the standard could no doubt improve the situation, but it is important to understand that there are standard-related issues, as well as those related to programming or navigation.

## From paper to pixels

We believe the original paper charts are often very difficult to improve in key respects. They are created to the best scale, cover the best area, display just the right amount of data, with just the right level of detail and so on. We can make this claim because they have been refined over many years (sometimes 200 years) to give the mariner exactly what they need for certain purposes. Because of this, raster charts, which are facsimiles of the original charts, should make a good choice for a navigation system. Without any user intervention they display navigational information with just the right level of consistent detail. Ideal for real navigation. They are also familiar, a factor which should not be underestimated. Familiarity helps enormously with ease of use and also has significant safety implications - although it seems likely that new and younger mariners less steeped in grand traditions may be less affected by this.

Consequently one might consider that vector charts would be better suited for planning purposes because they offer so much more control over display properties. However, interestingly a company called AtoBviaC Ltd are just embarking on a large project to create distance tables for the world. This is effectively a massive passage planning operation using a team of master mariners. They have expressed a strong preference to use official raster charts exclusively. To understand why is to understand more clearly some of the problems involved in vector charting.

At the UK Hydrographic Office, and many other national Hydrographic Offices, vector data (ENC) is created by tracing over the raster data. ***The significance of this cannot be overstated***. The best quality image possible from this data can only ever approach the original raster image. When the electronic navigation chart (ENC) is displayed, with all possible display options enabled, the total amount of display information will still only approximate to that available from the raster image.

So a reasonable way to consider the difference between vector and raster without getting embroiled in technical computer discussions is to consider the consequences of early and late rendering.

## Rendering

Early rendering means basically letting the cartographer do his job. This work is not only highly skilled but also time consuming. It is not unknown for a cartographer to literally spend all day looking at a new edition of a chart just to make sure that the layout and labelling and detail and myriad other factors are all just so; just right to make the chart clear, concise, uncluttered and useful for the navigator. Another critical stage in raster chart production is anti-aliasing. This is a data manipulation technique that allows raster display device, such as a computer screen, to display a much better representation of certain types of image. For example, in Figure 1 below, the sharpness and clarity of the image is significantly degraded without anti-aliasing.

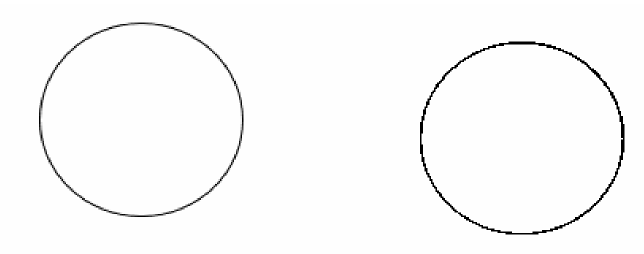

**Figure 1: The left hand image is anti-aliased to create a visually smoother line**

With late rendering the computer has to attempt to duplicate this production process in a small fraction of the time. If the system is to sensibly support scrolling and zooming then a full screen of chart needs to be rendered in a few tens of milliseconds. Even on the fastest of computers this is only possible so long as the system restricts itself to just few simple rules. For the developer, this is a significant problem. We think our vector display systems are quite fast but it has been an immense task to get to that position.

In principle, a sophisticated program could attempt the sort of complex layout used on a paper chart. This involves curved labels, many different fonts, moving labels around to avoid certain features or each other and so on. In practise, and for the time being at least, this level of computing intelligence is impossible in the available time. Furthermore, the ECDIS standard would need a substantial re-write to support such a process. Both of these problems could be solved with better technology and the further evolution of ECDIS. But we do not recommend that you start holding your breath in anticipation of an early and significant improvement.

So certain degrees of complexity are beyond us for the moment - which means keeping things simple. And the trouble with simple rules is just that, they are simple. Possibly too simple. It becomes very easy to display an image with too much or too little detail, both important safety issues. Clutter can obscure important features and lack of detail may omit critical features altogether. Anti-aliasing is not (currently) a realistic proposition and this is what causes the typically harsh and bitty appearance of vector charts. Dynamic positioning of labels combined with the myriad of display options such as depth shading means that a portion of chart can be displayed in many different ways. Sometimes even scrolling a small distance can be enough to change the basic look and feel of the displayed chart. Recently we encountered a complaint: “some of the symbols are following my ship!” This was actually perfectly correct ECDIS behaviour and simply a consequence of the dynamic nature of area centred symbols.

## Layering and Display Scales

Vector systems allow chart detail to be added or removed. This is advertised as a good thing and it has uses in certain specific areas. For example with the use of Additional Military Layers (AML) it may be desirable to display multiple views of the same area with different views focusing on different types of military information, as well as a separate view for navigation. This is of course outside the remit of ECDIS. For SOLAS type use it is hard to argue that any feature should be optional. Either the navigator needs to be aware of an item on the chart or they do not. However, in practice, vector systems need to have options to control detail level because otherwise the display suffers badly from either clutter or scarcity. This is a direct consequence of the simple rules that need to be used by the computer to design the layout. The mariner now needs to understand the display options from a cartographic point of view so that they can make additional decisions to configure the display. There are a lot of options. Are you really sure that the chart is showing you everything you need to know?

Each feature in a vector chart can have a minimum display scale associated with it. The intention of this is that the feature should not be displayed at chart scales below this. It is a simple mechanism to help de-clutter images that cover a large area. Unfortunately is it rarely used in commercial ENC data. The reason is simple; the producing Hydrographic Office has to consider each feature and decide whether or not it should be displayed at a particular scale. This is a remarkably onerous and difficult job. It cannot be automated – if it could then we could replace the value with a rule and let the computer decide. So unfortunately the value cannot be relied on and so is of limited use. The images become more susceptible to clutter and the user is forced to play with the display settings to get a useful chart image. Achieving an uncluttered display is of little consolation after a collision.

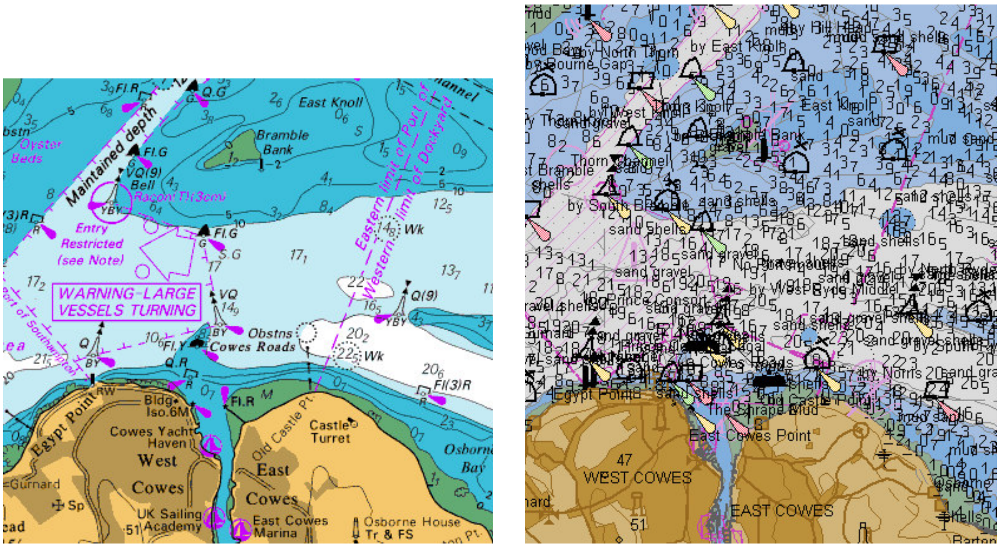


**Figure 2: Comparison of Raster and Vector images**

Overall, the effect of late rendering is one of uncertainty. Features can come and go depending on display scale and a myriad of settings. Simplified symbols may be in use to reduce clutter. Annotations can occupy changeable positions in relationship to the features they are labelling. Features can be displayed in different ways. The whole chart can be rotated. Stability in the chart display should be paramount. A navigator needs to be able to easily and quickly orientate themselves on a chart. This task is significantly harder on an ENC. If an incident happened there is no way that an accident investigator could confidently determine exactly what the navigator was seeing on the chart. But there are other problems with vector charts, of which the four below have entertained us from time to time.

## Updating Charts

Updating paper charts is tedious and time consuming. But it has one big advantage – the user is focused on the changes. Even afterwards, other people can see where the changes have been made as they admire the handwriting and glue smears. Updating ARCS is fast and easy. It is also very easy to spot where updates have been applied. See figure 3. Updating ENCs is similarly fast and easy but the results are far less clear. If the update is a visible difference then you need to make sure that the scale and display options are correctly set so as to make the feature visible. If the change is to an attribute which does not contribute to the appearance of an object then the change will be very difficult to find. There are various schemes which attempt to highlight changes but these can only indicate an area – where there may be many objects. The update in figure 4 is not visible at any larger scales.

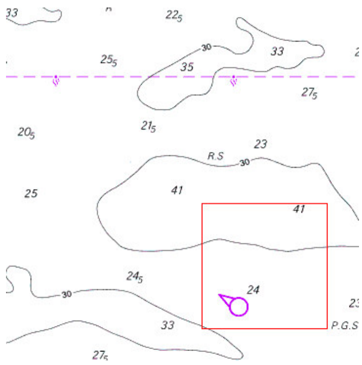


**Figure 3: The location of an update is indicated by a border**

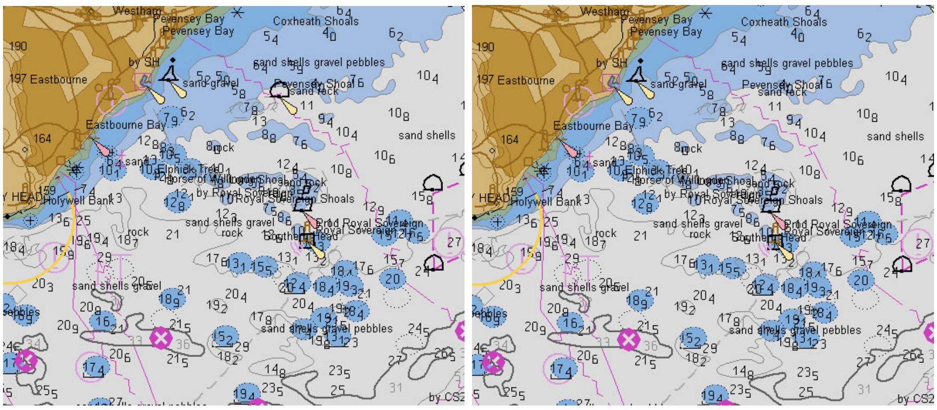


**Figure 4: Two ENC views – spot the update**

## Zooming, magnifying and changing scale

The ability to arbitrarily zoom a chart display is often cited as being an advantage of vector data over raster, but the truth is less clear cut. For a start arbitrary zoom levels can be confusing. Working with well defined and regular scales (eg 1:200,000, 1:50,000, etc) is generally less likely to cause disorientation. However, the real problem is one of detail levels. How much detail should be displayed at any particular scale? Cartographers have solved this problem. They have picked certain display scales to work with and they have tailored the amount of detail to be appropriate. Over time the charts have been improved and refined. With late rendering the computer has to make it up as it goes along and this inevitably and commonly leads to a scarcity or over abundance of features.

But what does it actually mean to 'zoom' a chart? For a vector chart it means changing the display scale. For a raster chart it also means changing the scale. However it is sometimes erroneously taken to mean magnifying the screen image. This is comparing apples with oranges. If a portion of vector chart is magnified (electronically or by putting a magnifying glass in front of the screen) it shows just the same heavy pixilation, and distortion that would affect any image including raster charts (Figure 5). If we change the display scale in a raster chart system it means we load a new chart of a different scale. This looks fine. In fact it usually looks better than the vector image of the same area. The number of display scales is limited because they have been determined during the early rendering process. As discussed above it is probably safer to limit display scales to a few common values so this is not necessarily a bad thing.

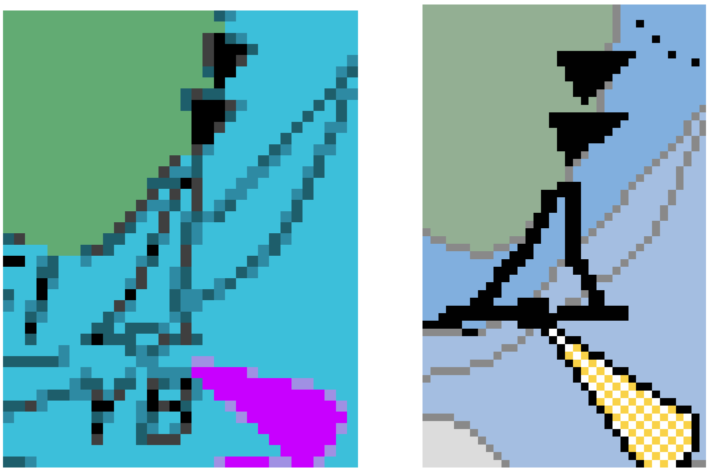

**Figure 5: Magnifying raster or vector causes the same problems**

Display scale and clutter are related. In general if a vector chart display is cluttered then this can be reduced by zooming in. It means there are fewer objects to display on the same portion of screen. In practise zooming is essential to vector systems as a mechanism for controlling clutter. But it can also be very dangerous. A raster chart should be displayed at its intended scale. Using magnification in a bridge situation is probably a bad thing to do. Since the chart is displayed as intended the size of certain features will be displayed in way consistent with their accuracy. For example, the edge of a pier will be known to within the width of the line used to draw the edge of the pier. A vector chart of a similar scale will generally draw the pier edge in a similar way. This is all fine until the vector system is used to zoom in on the pier. If the image is zoomed ten times then the uncertainty about the exact position of the edge as displayed on the screen has increased ten times. However the system will draw this edge with exactly the same line. There is no clear indicator that the line should really be ten times thicker because at this scale it cannot genuinely be represented any more accurately. This has happened. In a recent incident involving a 60m positioning error it turned out that the chart being used was over zoomed. The system showed an over-scale warning in the correct way but none the less the navigator believed what the chart on the screen was showing him.

So, zooming is not an advantage of vector charts over raster charts. It is simply a prerequisite for usable vector charts.

This incident also highlights another important aspect of computer assisted disasters which is the tendency for over optimistic belief in the information displayed by a computer. In any system that is converting paper charts to ENC the data quality cannot be improved. Under some circumstances it can actually be degraded because of the way that paper charts were never really intended to be absolutely accurate in a universal frame of reference: they were really only designed to be consistent within the chart and suitable for relative navigation. Publishing this information as 'state-of-the-art' ENC data can easily create an illusion that the data is actually of better quality than it really is. ENC charts do not contain a Source Data Diagram. It is hard to determine whether or not the chart data you are using originated with the HMS Beagle. ENC does contain a data quality indicator but this is, at best, a poor substitute.

**The projection myth……**

The ENC product specification (4.3) specifies that no projection is used. This causes a problem when considering what is meant by a straight line. That is - what is the path to follow between two points? The question is not significant for points close together (less than about 6 km) however if the two points are several hundreds of miles apart then there is a big problem.

A simple and common definition of a straight line is that it is the shortest distance between two points. For navigating around the earth, that would mean a Great Circle. But that does not seem to be what is intended with ENC. In practice, the nature of a straight line is actually determined by the manufacturer - hardly what Euclid had in mind. Specifically, it is what appears to be the shortest distance between two points *when they are projected onto a plane surface*. This means that there is an implicit projection. It means that to qualify the data fully we need to know the projection that was used to create the chart in the first place. A further clue can be found in the co-ordinate system. Geodetic latitude and longitude are well suited for describing a flat, square surface but cause problems (singularities) when applied to an oblate spheroid. Putting these two points together we guess (we have not enquired) that the originators of the ECDIS standard considered the starting point for generating vector data to be a Mercator chart and that a straight line is actually a Rhumb line.

Why does this matter? Well the straight line problem has several ramifications. The centre point of a long (6km or greater) line will only be in the correct place if the chart manufacturer and the display manufacturer have agreed on the projection to use (and 'correct place' here means within the smallest resolution of a computer screen – which is a pixel).

Further, Rhumb lines get very tricky at high latitudes. If you were 100m from the South Pole and you followed a rhumb line at 90 degrees then you would walk round in a circle of 100m radius. This is not a good definition of a straight line. Real route legs would need to be constructed of many short lines in the world as it is according to S57 and the ECDIS standard.

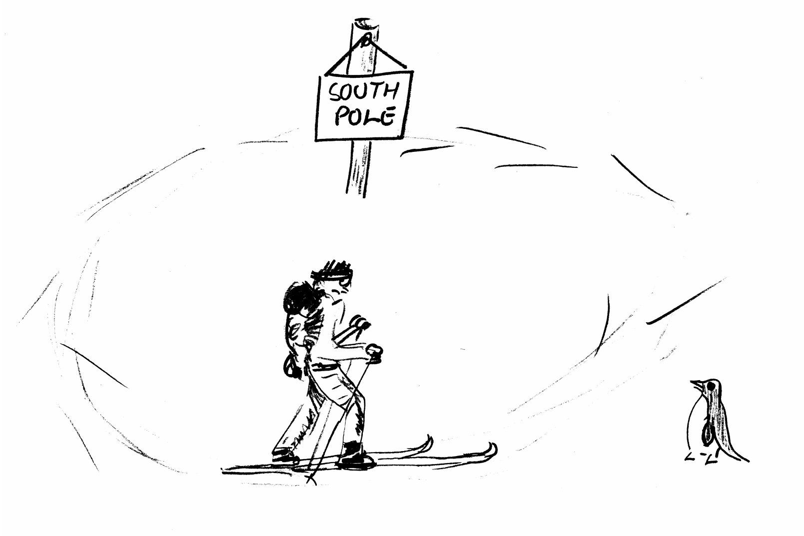


**Figure 6: Not a good definition of a straight line**

At the moment most S57 viewers use a simple cylindrical projection because this is computationally the quickest way to convert geodetic coordinates into pixel coordinates. However a cylindrical projection is a pretty limited view of the world and is next to useless for high latitude visualisations; just what is the longitude of the North Pole? Even at moderate latitudes severe distortions can be introduced. Incidentally the current raster (ARCS) specifications cannot support polar mapping either.

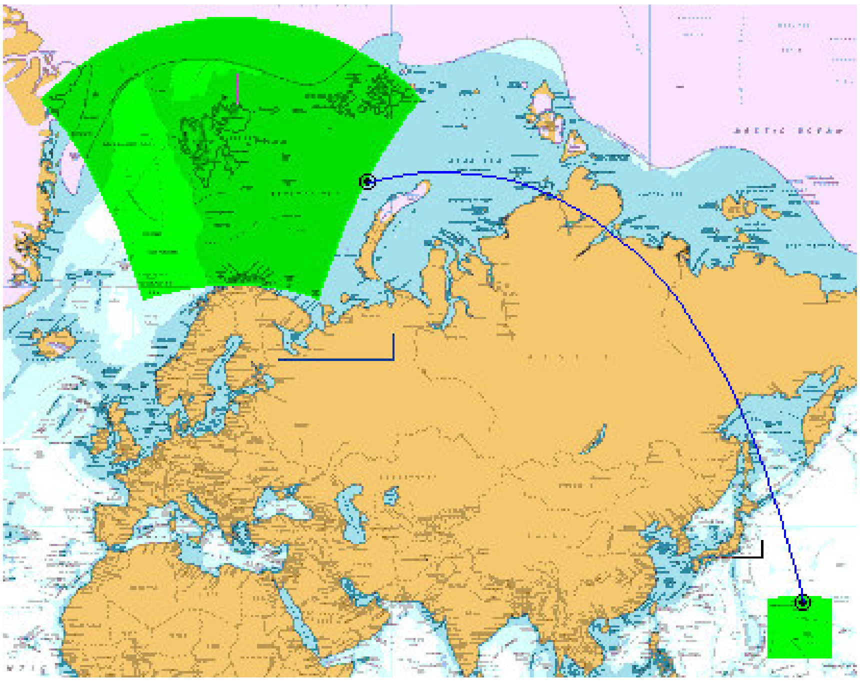

**Figure 7: Two equal sized areas joined by a (shortest) straight line.**

## ……And the way ahead

When working with bits of paper we learn to put up with this stuff. Paper charts require precise projections so that accurate bearings and distances can be plotted using a pencil and simple instruments (dividers, protractors and parallel rule). Not so the computer displayed chart – the calculation of accurate bearings and distances can be handled entirely separately from the display of the chart. The display of the chart should focus on speed and being reasonably distortion free. Why should we expect shapes to be more or less distorted because of their latitude? If we clear our minds of historical chart clutter and consider the world in its full 3 dimensional glory then it becomes apparent that a 3D coordinate system is going to be much more appropriate, Projection issues now genuinely vanish because the data will now describe a the surface of the planet directly rather than describing a 3D surface one it has been flattened to a 2D surface. The flattening (projection) can come later as was apparently the intent with S57. Recall that this is a late rendered system; the projection can even be changed dynamically even as the chart is scrolled. This is all starting to sound complex so to jump to the conclusion: if 3D data is used then an intuitively simple bird's eye view (technically a tangential projection) would be readily feasible. A tangential projection is way we naturally see the world. It limits distortion and does not have any problems with high latitudes. This is of course possible now but involves an awful lot of pre-processing of the data.

## Datums

Local Horizontal Datums are something many mariners wish would go away but unfortunately, we cannot ignore them. Local datums are important; much of the local advice and knowledge will be using the local datum. Positions may need to be transferred between local charts and the ECDIS. Differences between the local datum and WGS84 can introduce shifts of up to a kilometre. ENC make no concession to local datums at all. This means that all local positions have to be converted to WGS84 externally to the ECDIS.

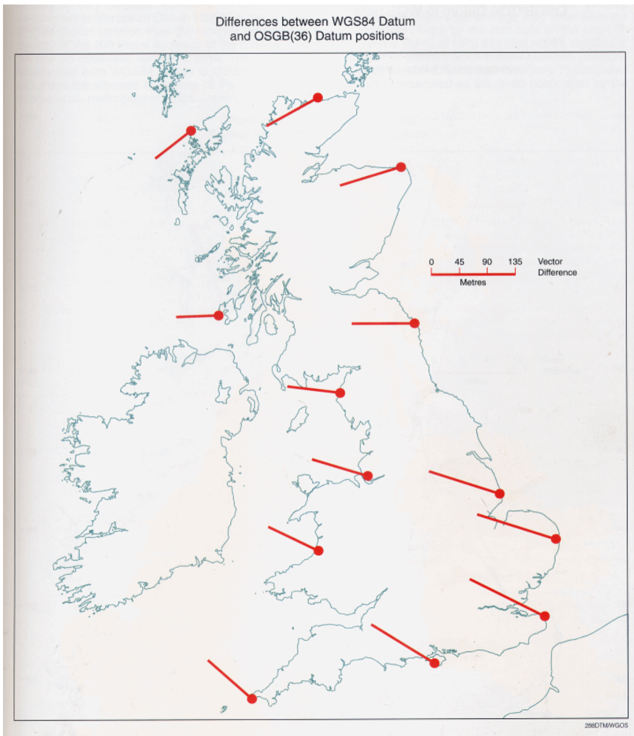


**Figure 8: Non-linear nature of local datum shifts.
Reproduced from NP288 by permission of UKHO**

ARCS charts contain local datum transformation information (fifth order polynomial) which allows the local datum to be used as easily and accurately as WGS84. Doing the conversion externally may not be very precise. A contemporary GPS can give a very accurate WGS84 position however converting this to and from local can be awkward. The GPS will often be able to do the conversion; it could also be done manually or with a computer program. However these will typically only ever use a simple fixed offset (linear shift) for the whole extent of the datum. As figure 8 shows this can be an oversimplification. To do an accurate conversion really needs chart specific information.

In April this year Primar recommended that unofficial vector data should be preferred by navigators over raster data where ENC coverage was not available. Much of this un-official vector data is traced from paper charts. Less than 40% of the UKHO chart portfolio (6,550+ plans) is referenced to WGS84 and approximately 30% of the portfolio cannot be related to any known datum at all. The UKHO position on this is that without WGS84 referencing there can be no official ENC chart. You can purchase unofficial vector charts for pretty much anywhere. Guess how unofficial vector providers deal with chart data of no known datum? Guess how many mariners using high-tech computer navigation systems actually understand how woefully inaccurate some of this third hand chart data is.

**Conclusion**

We know that there may be other points of view on the raster-vector debate. We know that many people are working hard at vector charting - and so are we. We also know that the construction and maintenance of an international standard such as ECDIS is complex, tortuous and - let us be honest - often plagued by political or commercial concerns. But in the ten years during which we have been working with electronic navigation software it is striking to see the extent to which there are still such wide differences of opinion on some issues.

If we were being uncharitable we would say that there has been some muddling thinking at times. But whether or not that is the case it is clear that the both the technology and the market environment for electronic charting is still relatively immature. We can surely expect continued development of both in coming years and this may lead to better solutions to some of the problems we have highlighted.

But for that process to go forwards as quickly as it can the debate about some of the issues needs to be very clear. All too often, as we hope we have illustrated here, it is not. After all, safety, as ever, is paramount. Indeed, it is a central reason behind the difference between vector charts and raster charts in terms of acknowledged parity with paper charts. The newcomer to the field would conclude from this that vector charts were the safer option. As the zooming issue alone shows, it is far from obvious that this is the case.

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