The Navigation Surface: A New Database Approach to Creating Multiple Products from High-density Surveys

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High-resolution bathymetric surveys are revolutionising hydrographic surveying. In addition to safety-of-navigation, there are a host of other uses for high-resolution bathymetry, including habitat mapping, hydrologic modelling, marine archaeology, and marine environmental protection. However, at present, there is no suitable method that can be used to produce multiple products that meet the needs of both navigation customers and other users.
A research project conducted at the University of New Hampshire developed a model of the seafloor that is optimised for safety-of-navigation. This new technique bypasses the rather subjective, 'selected soundings' approach. Instead, a statistical model is created directly from the cleaned and processed data. The model – called a 'navigation surface' – consists of a high-resolution bathymetric grid with an uncertainty value assigned to each node on the grid. The model is then optimised to preserve the least depths over significant features. For each node an uncertainty value is computed which becomes an integral part of the model. The distribution of the points around the mean is combined with the predicted uncertainty of each measurement to form an overall uncertainty model. For low-density single-beam and lead-line surveys, the area between measurements is modelled based on a triangular irregular network (TIN). The uncertainty model then incorporates the distance from the measurement, as well as the uncertainty of the measurement itself.

Using a navigation surface as a database, a variety of products (contours, selected soundings, depth areas, DTMs, etc.) can be produced or extracted. A central challenge of creating an ENC is to generalise the available source data to a level of detail appropriate for the intended use. This is directly related to the desired scale of the product (navigational purpose) and the assignment of an uncertainty value. One technique is to defocus the model first to account for horizontal uncertainty, and then to generalise to the intended scale of the ENC. An example of an ENC that was created from a navigation surface is discussed.

Background

The methodology used by hydrographic offices to produce a nautical chart from processed bathymetry has not fundamentally changed since lead-line days.

Currently, a large number of soundings that are considered acceptable form the pool from which shoal-biased selected soundings are chosen and plotted on a sounding plot. These selected soundings become the basis upon which a nautical chart is built. The overriding concern addressed by this procedure is to ensure that the shoalest measured depth is charted. All accepted soundings are treated equally, and multiple measurements of the same portion of the seafloor are not integrated together in the final product. However, there are two main problems with this approach. First, all noise in the measurements is preserved in the final product. Second, there is an inherent scale in the survey smooth sheet that is driven by the intended navigation use, and not by the information collected in the survey. The result is that small features cannot be portrayed in the survey product.

A workshop was held by NOAA's Office of Coast Survey at the University of New Hampshire Joint Hydrographic Center/Center for Coastal Ocean Mapping in January 2001 to discuss the possibility of using the full resolution of the survey to create depth areas at frequent depth intervals to support a next-generation ENC. Also, the digital database produced could become a record of the survey, replacing the need for a CAD smooth sheet. For either one of these purposes, there would necessarily be thousands of depth areas in a survey area, and they could no longer be hand edited.

The automated contour generation process was examined, which raised an important question:
What type of digital terrain model (DTM) should be used for making cartographic products suitable for navigation safety, particularly the ENC?

Unfortunately, there was not an obvious answer. Typically, contours produced from a triangular irregular network (TIN) tend to be very noisy and jagged, and contain a large number of small closed contours on either side of a main contour. On the other hand, contours produced from a mean gridded surface do not respect shoal features. Any consideration of high-density contours to support a high-resolution ENC would require a carefully constructed DTM.

The logical extension of this concept is that if there is a DTM that respects the needs of safe navigation, the DTM itself could become the product of the survey. In this paper, we propose to produce a DTM rather than a smooth sheet, and to manipulate the DTM prior to producing contours using a set of objective rules. The time-consuming and subjective cartographic contouring process would be completely eliminated.
If this concept is extended from the survey level to the regional level, a database of depth and uncertainty information is created at the highest resolution. Key benefits of this database include:

- It is a flexible and robust framework for using bathymetry information from non-traditional sources
- It can rigorously handle the full resolution of the survey
- It can be used to produce a variety of navigation and non-navigation chart-related products
- It can be updated/improved by adding new data sets

The Canadian Hydrographic Service conducted a research and development project through the 1990s concentrating on modelling sparse single-beam surveys to create a 'Third Generation Electronic Chart' (Kielland et al, 1996). Kielland proposes a new chart format, which provides a gridded model of the depth and uncertainty of the seafloor to the user for display and manipulation in real time. The surface is interpolated using a program called 'Hydrostat', which uses a kriging algorithm that honours the measurements and estimates the interpolation error based on the local seafloor roughness and the direction of characteristic features.

This paper expands and generalises these ideas to include multi-beam and side scan sonar surveys. It also describes a path from this model into first generation (paper and raster) and second generation (vector ENC) charts while laying the groundwork for third-generation navigation products, and making the highest resolution data available for military, academic and resource management users.

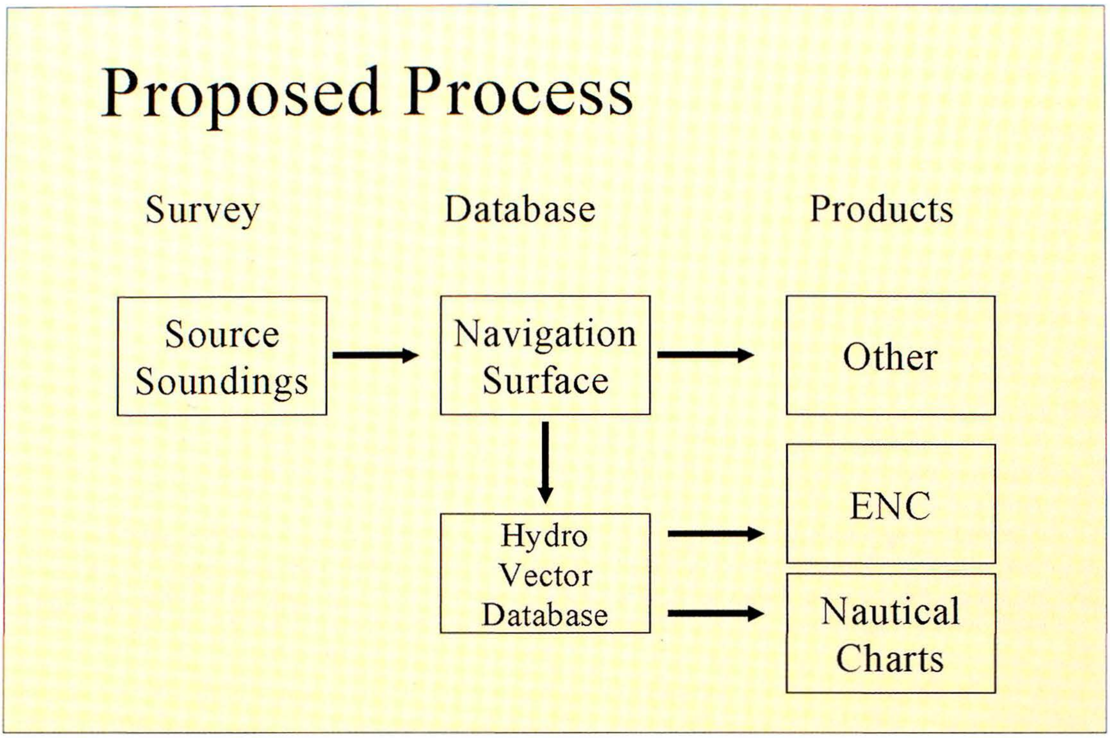

Figure 1: Like most hydrographic offices, NOAA is envisioning a move to an underlying vector database to support multiple navigation products (ENC and Paper/Raster Charts). We propose that the master database reside not at the cartographic level but at the model level (e.g., a Navigation Surface Database).
Some people might be alarmed by the proposed shift from a sounding-based approach to a model-based approach. However, this is not really such a drastic change. Whenever a Hydrographic Office puts a depth curve on the chart, it becomes, in fact, an implied model. The truth is, we are already modelling the seafloor. We just need to find a better way to do it

Creation of a Navigation Surface Database

Overview

Currently, NOAA does not have a comprehensive database of best available depth information distinct from compiled paper nautical charts. Consequently, no new navigation products can be produced without using either new higher resolution survey data or performing a painstaking reconciliation of a wide variety of historic source documents. In addition, the survey smooth sheet (a CAD drawing of the survey) that is currently produced to support existing chart products contains only those depth curves that are relevant to those charts. In the US, this is a major impediment to implementing metric charts.

Australia is one of the first to use a hydrographic vector database as a collection of cartographic objects to support multiple navigation products (Hudson 2000). Similarly, *CARIS* (Fredericton, NB) offers a comprehensive database solution called HPD (Hydrographic Product Database), which holds the promise of supporting streamlined product creation and maintenance (CARIS Web-site). However, both of these approaches share the limitation that they are essentially a database of cartographic objects.

The navigation surface approach attempts to step further back by creating an underlying high-resolution model of the seafloor from which cartographic objects can be extracted. Using this approach, the seafloor surface model (in itself) would be certified as suitable for navigation. Similarly, any derivative cartographic objects would carry the same certification. The highest resolution model is still preserved and non-navigation products can be derived from it that will meet the needs of other customers (See Figure 1).

Populating the Navigation Surface DB

The Navigation Surface database is populated with the highest resolution reconciled surface model that the source measurements can support. For complete coverage multi-beam surveys, this resolution is approximately the footprint size of the sonar. For example, a 1.5 degree sonar has a footprint size of about 1 metre in 20 metres of water. The methodology initially used for the basic DTM generation was the footprint and grazing angle weighted mean grid as implemented by *CARIS HIPS*. The specific methodology that is used is not critical to the process, except that it must be a most probable surface, not a shoal-biased binned surface. Clearly, footprint size varies both across track and as a function of depth. For simplicity and to fit existing data structures, a regular grid was used that approximated a nominal footprint size. Future implementations may incorporate variable grid node spacing.
In any surveyed area, there may be instances where the most probable surface is not adequate for navigation. In this case, the DTM node at the location of interest is changed to the new value. Other considerations include:

1. Features of critical navigational significance (e.g., a rock near a navigation channel) - the least measured depth must be used
2. Cultural items with fine features, (e.g., wrecks and obstructions) where a modelled depth is unlikely to adequately represent the feature (i.e., the least measured depth) must be used
3. Measurements of high certainty (e.g., a definitive measurement made by a diver on the top of a feature) - must be used

On US coasts, the proportion of navigationally significant seabed that has been mapped with high-resolution systems is very small. Consequently, any method that proposes to change the chart production process must be compatible with historical sparse data sets. This is discussed in the next section.

Uncertainty Modelling

Traditionally, the measurement error of a given sounding is the value reported as the uncertainty of the depth. In other words: *How good was that measurement?* However, the question that mariners usually want answered is: *How well do we know the depth at this location?* In fact, they probably think they are getting the answer to the second question when they are actually getting the answer to the first.
So, how well do we know the depth at a particular location? Uncertainty modelling can be broken down into three basic methodologies:

Forward Error Modelling

Using this method applied to dense multi-beam bathymetry, each sounding is assigned a predicted error based on the systems used to collect it, and the environmental conditions at the time of the survey. The assignment of predicted error based on system and environmental parameters is discussed in a CHS report (Accuracy estimation of Canadian Swath and Sweep systems – Hare, Godin and Mayer). A procedure for incorporation of this model into an automated process of creating both depth and uncertainty models from uncleaned multi-beam data (CUBE-Combined Uncertainty and Bathymetry Estimation) has been developed by Dr. Brian Calder at UNH CCOM (Calder, Shallow Survey 2001). Where multiple soundings exist on the same area of seafloor, the predicted error can be reduced around the mean of the measurements.
It should be noted that it is appropriate to reduce the uncertainty for multiple measurements of the same parameter (e.g., reduced depth) only if each of the measurements are completely independent. In the case of a collection of multi-beam soundings, they can only be considered partially independent since multiple soundings use the same sound velocity cast, tide measurements, draft measurements and sys-

tem calibration constants. For our study, we placed a minimum value on predicted node uncertainty of 0.2m that was intended to account for the commonly applied values. The complexity of tracking the interdependence of multiple measurements was beyond the scope of this effort. We also used a simplified error model where all soundings were assumed to have the same error out to +/- 60 degrees. The forward error model in this case becomes a function of the number of soundings near the node.

Backward Error

A second method is to use the standard error of the measurements around the weighted mean. Numerous Commercial-Off-The Shelf (COTS) packages have employed this method for years. The common problem with this approach is that it is impossible to distinguish between areas of high slope or high seafloor irregularity and areas of high error. This is because horizontal errors on slopes cannot be distinguished from depth errors.

Uncertainty for Interpolated Areas

Only a small portion of the US coasts have been surveyed with 100 per cent coverage multi-beam, and it will be many decades before we have full multi-beam coverage. Even in the areas where multi-beam surveys have been conducted, it is not always possible to achieve full coverage. In shallow areas, many modern surveys utilise side-scan sonar to make certain that there are no obstructions between sounding lines. In these cases, there are often gaps between multi-beam sounding lines.

The uncertainty computation for these interpolated areas has been investigated by the CHS (Kielland et al, 1996). In their approach, they used kriging to simultaneously interpolate a DTM and compute the uncertainty associated with it. The uncertainty algorithm had the following properties:

- Is set to the measurement uncertainty at a node where a measurement was made
- Increases as a function of the distance from the nearest measurement
- Increases faster on a more irregular seafloor

For this project, we tried to replicate the CHS results, but found that our sample dataset did not lend itself to kriging for two reasons. First, the kriging routine we used applied a variogram computed over the entire survey area, so the uncertainty estimation was unresponsive to local changes in seafloor roughness. This was simply a limitation to our tools. Second and more fundamental, the point spacing in the survey was not uniform and was dependent on seafloor roughness, since the hydrographers who conducted the survey split lines in areas where the broad line spacing detected irregularities. This leads to cases where very interesting seafloor bathymetry is mathematically constructed based on only a few points.

In order to simplify the interpretation of our results, our approach was to use a linear triangular irregular network to interpolate between sounding lines, then grid the interpolated section to merge with the portions modelled by a weighted mean grid. A new algorithm was constructed which had the same properties of kriging listed above. For areas surveyed with side-scan sonar between sounding lines, the uncertainty was capped at the largest size of an insignificant contact (e.g., 1m). See Figure 2.

This approach allows us to create a comprehensive database of the best available bathymetric information, even in areas where there is no modern full seafloor coverage.

Time Dependent Uncertainty

Some areas of seafloor are dynamic and may change on time scales of days to tens of years. For these types of areas, the navigation surface database model can be used to assign a changeability coefficient to every node. In computing the uncertainty for a portion of seafloor, the changeability coefficient is mul-

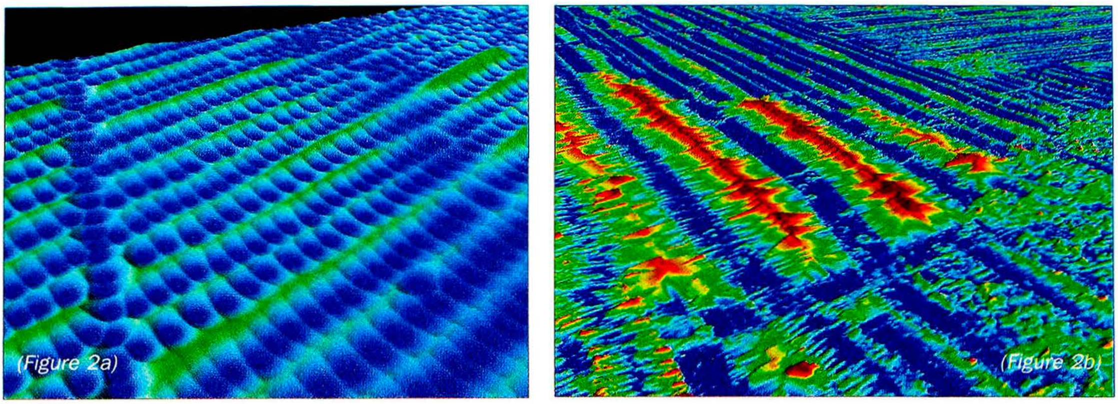

Figure 2: Uncertainty surfaces for interpolated models from sparse single-beam data (Figure 2a) and from multi-beam run without full coverage (Figure 2b). The vertical axis of the three-dimensional figure is the estimated uncertainty. The node uncertainty is set to the measurement uncertainty at the nodes that correspond to a measurement. For interpolated nodes, uncertainty is a function of distance from the closest measured node and the local variability of the seafloor. In the Figure 2a, the maximum uncertainty is between sounding lines, and the higher values occur when sounding lines are furthest apart. For the case of discontinuous multi-beam, the area between the lines is treated in the same way as the single-beam case

tiplied by the age of the survey and added to the original uncertainty. The time dependent uncertainty is then capped at some reasonable value. In addition, if a subsequent event (earthquake, storm, breakwater installation) creates a suspicion of possible change in an area, an additional uncertainty may be applied to the affected area. Depending on the navigation use of the area, the total uncertainty corrected for survey age may become inadequate.

Superseding Data

In order to be both efficient and accurate, the database must have inconsistent information reconciled. With a navigation surface database, superseding old data with new can be done by using rigorously applied rules. Some examples of potential decisions might include:

- A model node with lower uncertainty supersedes a node with greater uncertainty
- A newer node always supersedes an older node, particularly when the old data is known to be inadequate
- A shoaler node supersedes a deeper node (for numerous poor quality surveys)

Ideally, a hydrographic office will establish a hierarchy for applying these and other rules for superseding that can be followed in a rigorous and repeatable way.

Application to Charting

Once the full-resolution depth surfaces and their companion uncertainties have been compiled, stored, and reconciled, the database can be used to create multiple products. For most hydrographic offices, the most important product is the nautical chart.

The basic task in creating paper charts (and ENCs) is to generalise high-resolution data to make it appropriate for display at a desired scale for a particular navigation purpose. For bathymetric data, this process has traditionally occurred at the cartographic level. A subset of soundings are selected from the smooth sheet and depth curves are further generalised by hand to produce a product that is uncluttered, yet clearly presents the safe and unsafe water. Any discrepancy that occurs between the soundings and the depth curves must be reconciled by hand. Reconciliation between adjacent data sources is also done by hand by making depth curves meet at the junction.

We propose a process of generalisation at the model level rather than at the cartographic level. The generalised model can then be used to create cartographic objects for a particular product. The underlying principle in the cartographic process is to portray what we know and how well we know it.

Defocusing

The first step in the cartographic extraction process is to apply the horizontal uncertainty of the model nodes to the model. In effect, this should prevent any cartographic object from being created that would give the impression of safe water within the horizontal error of a sounding on a shoal. For each node in the model, adjacent nodes are adjusted in the shoal direction if they are deeper and fall within the horizontal error circle of the node. For modern surveys collected with DGPS where the horizontal error is close to the footprint size, this step has little effect on the surface. However, for older data survey where the horizontal error might be >20m, this step is important. The key is to be sure not to misrepresent the quality of the data in the final products.

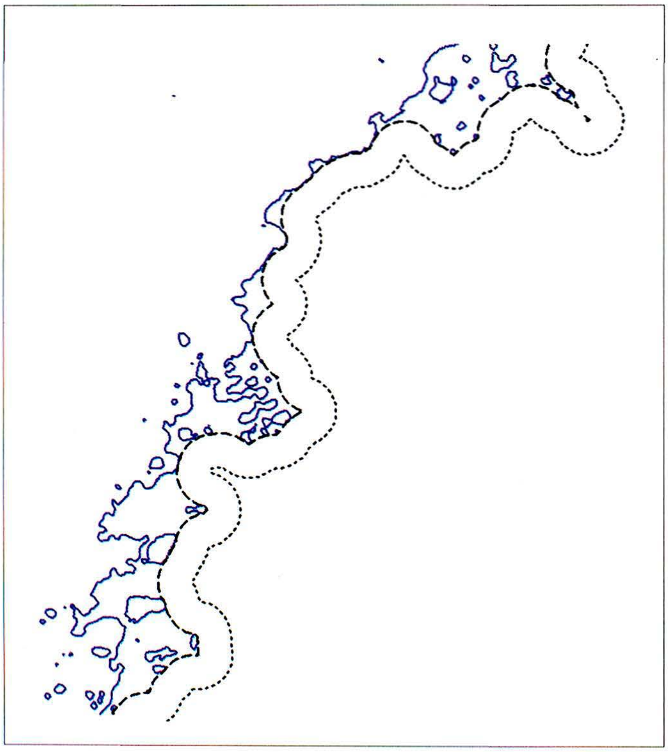

Figure 3: Double buffering for generalisation. The original (solid) contour was buffered using a 1,000m radius to the outer (dotted) line. This new line was then buffered back using the same radius to create the generalised (dashed) line. Note that the generalised line honours the seaward extent of the contour and honours the charting definition of a depth curve. This is the basic methodology of the three-dimensional double buffering used in the second stage defocusing for scale of product

The second step is to defocus for the purpose of the product to be produced. The algorithm used in defocusing for horizontal uncertainty is inappropriate for scale generalisation because it tends to move the depth curves offshore. A better approach is three-dimensional double buffering.

Buffering is a common GIS function, whereby a new line is created that is a distance from the nearest point on the original line (or polygon). If that new line is then buffered back in the opposite direction, a generalised version of the original line is created that conforms to one edge (in this case the seaward edge) of the original line (See Figure 3). Three-dimensional double buffering is an extension of this concept to three dimensions. A new surface is created that is a specified distance up from the nearest point on the original surface. Then this new surface is used to buffer back toward the original surface. The net effect is to honour the shoal features, but smooth over small, regular depressions (such as the troughs between sand waves).

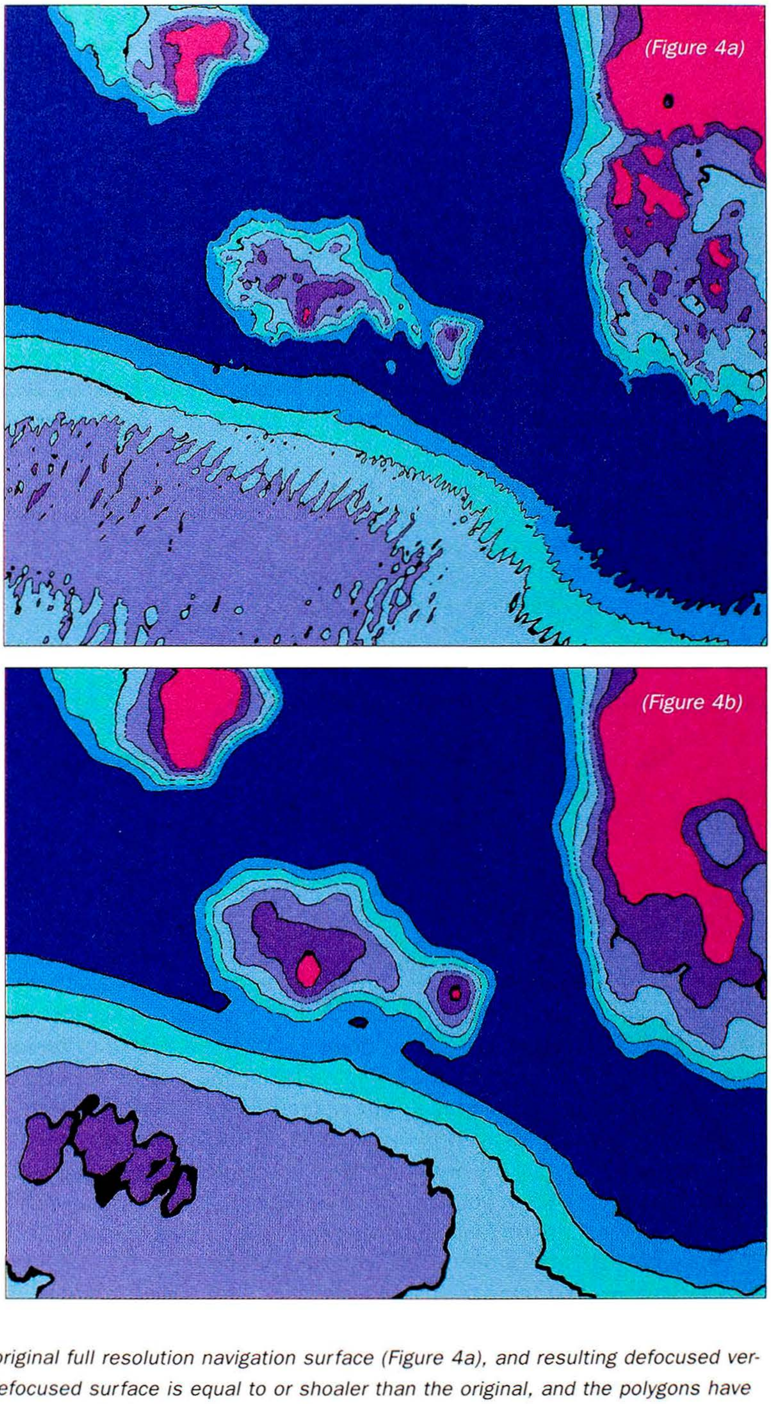

Figure 4: Colour-filled contours of original full resolution navigation surface (Figure 4a), and resulting defocused version (Figure 4b). In all cases the defocused surface is equal to or shoaler than the original, and the polygons have a simpler geometry. Note that the narrower channel to the south of the rock is connected to the southern bank at this scale of representation. A larger scale product might show this channel as passable at this depth. This sort of scale-dependent representation is typical of traditionally derived navigational products as well

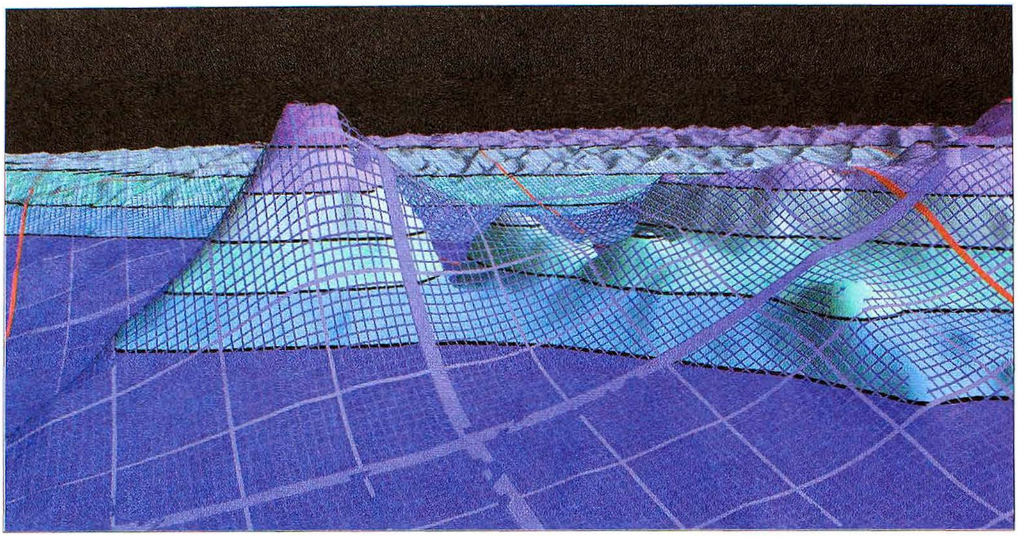

Figure 5: Defocused model over original DTM. Note that the peak of the rock matches precisely in the defocused and original models

By varying the radius of the buffering, different levels of defocusing can be achieved for different products. (See Figures 4 and 5). The shoal features are preserved through the defocusing process, and the resulting surface can be used to create linework that meets the definition of a depth curve (i.e., a line which encloses all soundings of a certain depth).

Extract Cartographic Objects for an ENC

Following the completion of the generalisation of the product model, contours, depth areas, and selected soundings can be extracted directly from the model. All the types of cartographic objects are inherently free from conflict because they come from exactly the same source.

Product Uncertainty

Current navigation products do not provide the structure to report high-resolution, uncertainty information. The paper nautical chart has a source diagram which shows the age of surveys in parts of the chart. Although S-57 ENC objects can be attributed with an estimated error, the meaning of a vertical error of a depth area is not clear since the depth area is defined by a variety of measurements and areas that were interpolated without measurement. One approach would be to declare that the bathymetric portions of an individual ENC must have uniform reported error. In this case, areas of the navigation surface that exceed the reported error could be classified as 'unsurveyed', be assigned a lower CATZOC value, or otherwise adjusted to match the product error. The navigation surface concept offers much more flexibility in dealing with these issues than measurement-only sounding products

Applications and Implications

High-data volume

When processing high-density depth data, the current approach used calls for every measurement to be flagged as being good or bad. The overall process is often called 'cleaning'. Of all 'cleaned' soundings, the shoalest one is selected for a particular geographic area. Depending on the type of survey conducted, the ratio of selected soundings to all soundings can vary widely. In leadline surveys, this ratio might have been as little as 1:2. However, for modern multi-beam surveys, this ratio might be as much as 1:20,000.

The result of this high ratio is that the smooth sheet soundings become biased toward individual measurements containing the greatest error. A recent multi-beam survey conducted in the Piscataqua River in Portsmouth, New Hampshire provides a typical example. The density of soundings shown on a smooth sheet was significantly reduced when using a traditional shoal-biasing algorithm on the recorded beams. The distribution of beams preserved on the smooth sheet is shown in Figure 6. In this example, the two outermost beams on either side were rejected. However, the outermost accepted beams on each side are disproportionately represented in the final smooth plot, and these are precisely the beams that are prone to the largest errors.

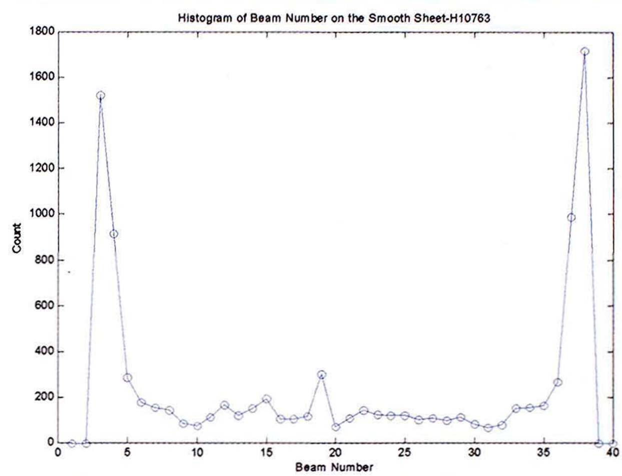

Figure 6: Histogram of the source beam number for each selected sounding on the smooth sheet. The outermost accepted beams, with the highest error, are disproportionately represented. Shoal features are equally likely to occur anywhere in the swath, assuming that swath-to-swath overlap counteracts the increasing beam spacing in outer beams. Note that the outer two beams on each side are systematically rejected

If a more statistical approach is adopted, it is possible to predict the expected error due to shoal biasing in flat areas. For example, consider a particular survey system that has a 95 per cent measurement error of 0.3m under certain conditions. If we assume a normal distribution, this implies a 0.15m standard distribution and a cumulative distribution curve as seen in Figure 7.

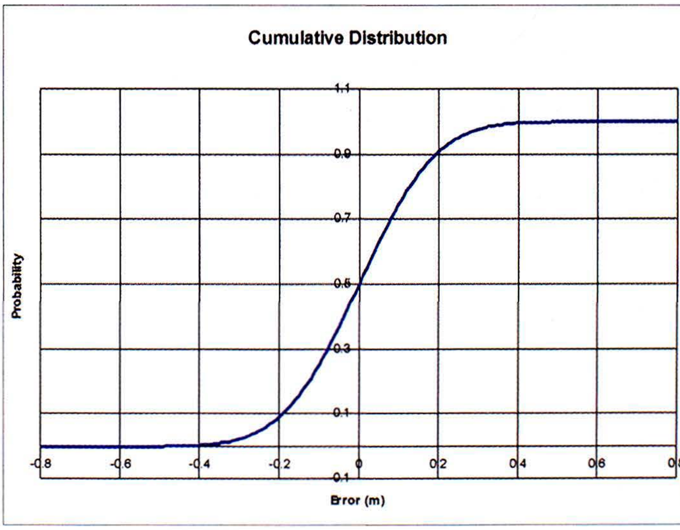

Figure 7: Cumulative distribution of a normally distributed error for a standard deviation of 0.15m. The line represents the proportion of measurements that lie below the specified error value. For example, approximately 2.5 per cent of measurements fall below 0.3m error

Assume that a high-density multi-beam survey is conducted over a flat seafloor. For a given site, the same seafloor is measured 8000 times. At the scale of the representation, one sounding is chosen to represent this area. If we choose the shoalest sounding, this sounding would be, on average, 0.55m shoaler than the mean measurement. With shoal-biasing, every sounding that is selected for the smooth sheet would exceed the IHO error limit for the survey [IHO S44 ed 4]. This type of analysis means that treating high-density multi-beam is not only statistically justified, it may also be required in order to meet IHO standards for hydrographic surveying. Using the navigation surface approach, the most probable depth is retained while the noise in the final product is reduced.

Other Users of Bathymetric Data

Currently, surveys are conducted for a specific purpose (e.g., navigation safety), and produce a product that is focused directly on the nautical charting process, as it exists today. However, many users of marine bathymetric data have requirements that are different from those of the nautical charting process, including:

- High spatial resolution
- Less concern about absolute depth with respect to datum than internal consistency
- Gridded form
- Less concern with small wrecks and obstructions

Increasingly this type of data is used for:

- Coastal Zone Management
- Marine Geology
- Fisheries Habitat/Management
- Hydrodynamic Modelling
- Ocean Engineering
- Military Operations (e.g., Additional Military Layers or AMLs)

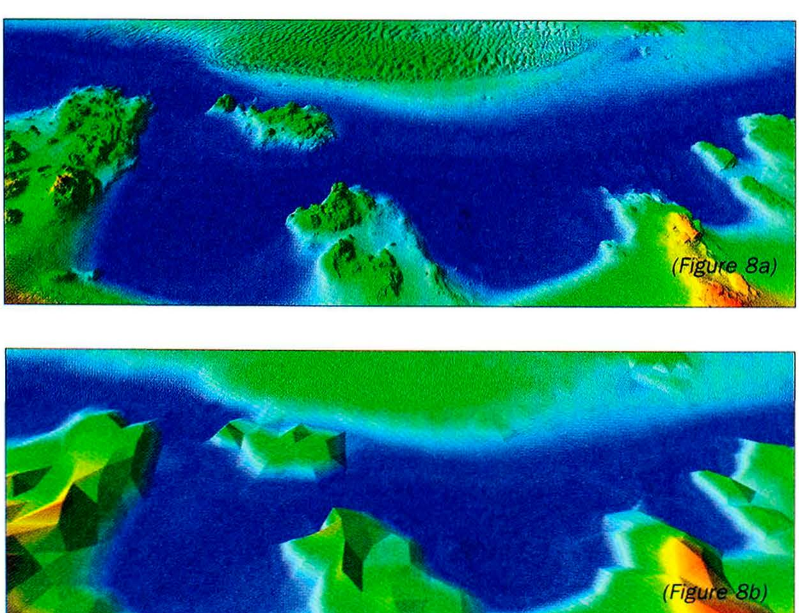

Figure 8: Figure 8a is the 0.5m weighted mean grid, which represents the full resolution of the sonar. Figure 8b is derived from the smooth sheet soundings used for chart compilation. The bottom model was created using a Triangular Irregular Network (TIN) model, which was then supersampled to a regular grid for display

Using traditional methods, the shoal-biasing and sounding suppression processes reduce the value of the data for these other purposes. For instance, the smooth sheet produced for nautical charting has data density as seen in Figure 8b. While least depths are perfectly preserved, none of the underlying, highly-detailed bathymetry is retained. Detailed DTMs are often produced as part of the survey process for quality assurance. However, no regular program exists to create DTMs to a particular standard, or to preserve the ability to create them in the future. As such, much of the detailed bathymetry is lost and not available to the scientific, military and resource management communities that may need this data.

Non-traditional Sources of Bathymetric Data

Many federal, state, commercial and academic institutions are collecting high-quality bathymetric data. While it may be the best data available for a given area, it is usually not acquired and processed to national hydrographic office standards. HOs need to develop a process whereby this data can be used for charting purposes. However, before doing so, the accuracy of the data should be assessed. The approach outlined in this paper provides a methodology for systematically tracking survey accuracy. For some data sources, the accuracy may have to be coarsely applied. For example, if tide information was not applied, uncertainty could be increased to encompass the tidal range in the area. However, if the resulting depth and uncertainty is adequate for the intended navigational purpose, and its accuracy is assessed and maintained as part of a master database, then there should be little impediment to its use for navigation.

Prioritisation of Survey Effort

Survey effort is prioritised to address areas where the current level of uncertainty in incompatible with current or proposed use. Currently, we have no systematic way of doing this. Using the proposed navigation surface database, surveys can be systematically prioritised in areas with:

- Low under-keel clearances
- High uncertainty of depth estimates
- Older data in areas with dynamic seabed
- Known inconsistencies and large numbers of unresolved reported items

Field Quality Control

Using an uncertainty surface, hydrographers can optimise their time in the field by tuning their acquisition needs to meet the assigned standards. Currently, many hydrographers systematically remove the

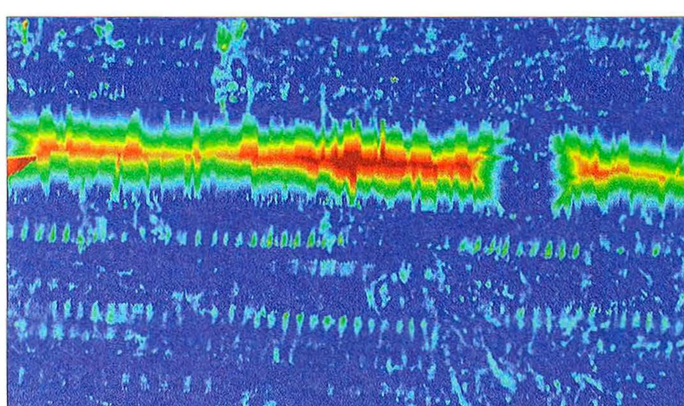

Figure 9: Uncertainty during the survey can be used to meet a pre-defined standard. In this case, any area that is red has an uncertainty greater than 0.3m and needs further work. The residual roll artifacts in green have a magnitude of less than 0.2m, and do not require further work

outer beams of wide-swath multi-beam systems, in many cases narrowing the width of the swath by half. This practice is based on a worst-case scenario for accuracy of those outer beams. If the hydrographer instead tracked the uncertainty both of the measurement and the derived surface, it would be possible to use a larger swath during optimal conditions. See Figure 9.

Electronic Navigational Chart (ENC)

The transition from the paper nautical chart to Electronic Navigational Chart (ENC) makes it possible to deliver more detailed chart-related products to the mariner. The ENC, in particular, contains a variety of objects that contain depth information. These include: selected soundings (SOUNDG), depth curves (DEPCNT), depth areas (DEPARE), and rocks, wrecks, and obstructions (UWTROC, WRECKS, OBSTRN).

It is generally agreed that the most effective way to present more detailed bathymetric data in an ENC is to include more depth areas and contours (Hudson, 2000). However, more selected soundings only adds further clutter on a display that already contains a wide variety of information. Furthermore, the use of selected display based on scale (SCAMIN) as a means of reducing the density of soundings when the display is shown at a smaller scale has both display and database implications. In practice, it does little to aid real-time decision support.

For so-called tide-aware ENCs, the vertical resolution of the depth areas must be much finer than the tidal range. In most areas, this means the ENC must have depth areas at sub-meter intervals (i.e. decimetres). As discussed earlier, the defocusing procedure will allow a surface to be created that can automatically produce contour intervals or depth areas that are appropriate for any scale of chart. Current procedures for creating depth curves for charts are too manual and labor-intensive to be easily scaled to the thousands of curves that need to be produced for sub-meter contours. As such, some automated process should be established. However, this problem is complicated by the need to have different generalised contours that are applicable to different scales of ENC. Furthermore, to maintain the internal consistency of the ENC, all selected soundings contained in the ENC must fall within the depth range of the depth area that contains them. The key property of a navigation surface model for charting is that it can be used to *create contours and depth areas at any intervals in any unit, and at any scale.*

Implications for ECDIS

The transition from paper nautical charts to ECDIS is causing a fundamental change in the way mariners use chart-related information. Contrary to popular belief, ECDIS is not just a replacement for the paper chart. Instead, it is a real-time navigation system that integrates a variety of information to be displayed and interpreted. However, to reach full potential, ECDIS requires ENC data containing more information than what is available from a static, two-dimensional paper nautical chart. In the near future, mariners will expect ECDIS to deal with 'Z' (i.e., height and depth) and time dimensions. The Navigation Surface Database provides an important element of the 'next generation' ENC. We now have the ability to use high-density hydrographic surveys to produce ENCs with decimetre contour intervals or depth areas. However for full benefit, this ENC should also incorporate time-variant water levels and current flow information so it can be used in ECDIS to precisely determine planned & alternative routes, time-of-arrival, and under-keel clearance.

Although the navigation surface offers a means to produce better ENC data, there are some additional considerations regarding where it should be applied, how it will be used, and what are the benefits.

1. When using high-density hydrographic survey data for ENC production, key areas are major shipping routes (e.g., approaches and channels). With increasingly larger, deeper draft vessels, decisions on loading and under-keel clearance are becoming more critical. Decimetre depth information (i.e., contour intervals or depth areas) within the shipping channel will be particularly far more useful to many commercial vessels than high-density soundings of the surrounding area.

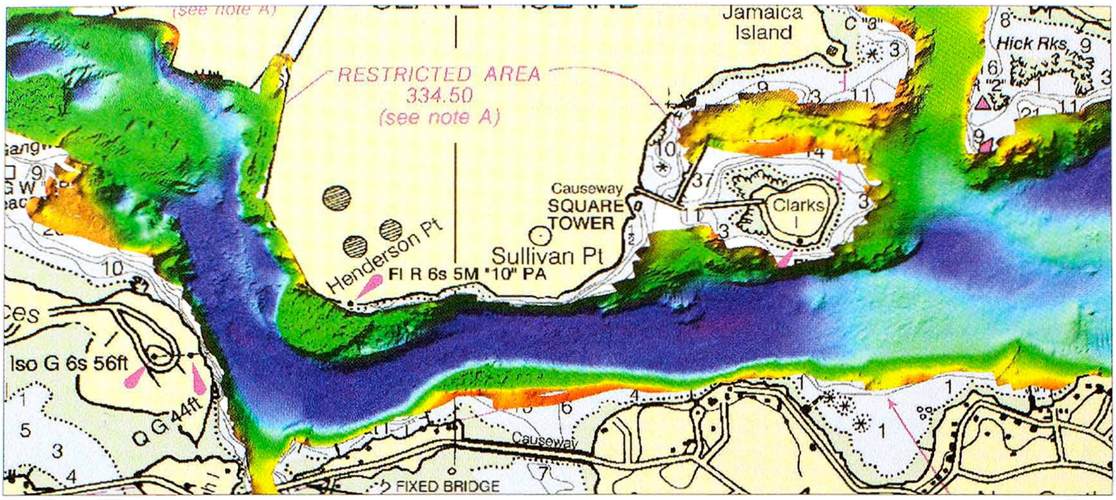

Figure 10: High Resolution bathymetry with the nautical chart. Portsmouth Harbour, NH

2. Collecting data to support digital terrain models (DTM) is important for some mapping and GIS applications (e.g., oceanography, mineral exploration or marine environmental protection). However, a DTM-based vessel navigation system is presently of limited use to the commercial shipping industry. Most commercial vessels will have an ECDIS installed that requires the use of ENC data. While the next generation of shipboard navigation systems may include DTMs, this is not possible using currently available shipboard equipment (e.g. type-approved ECDIS).
3. When used in ECDIS, an ENC should be regarded as baseline data upon which additional navigation-related information will be added. In particular, forecast and real-time information on water levels and current flow will be important for the timing of vessel transits or the amount of cargo loading for deep draft vessels. However, producing ENC data that is 'tide-aware' or capable of providing 'dynamic current-flow' will require changes to be made in the next Edition of IHO S-57.

Summary

The proposed navigation surface approach would change the way charts are currently created and maintained. The product of a survey becomes a model at the full horizontal resolution of the survey. This model is reconciled with existing source data and merged into a master model (Navigation Surface Database). Cartographic products, including paper charts and ENCs could use the NSDB as the source of cartographic objects for periodic updates. In addition, other products, such as essential fish habitat maps, geologic maps, and additional military layers (AMLs), can be derived from the same database.

Acknowledgements

Dr. Larry Mayer and Dr. Brian Calder at the University of New Hampshire have served as continual sounding boards for ideas. The NOAA Ship *Whiting*, participating in the common data set collection for Shallow Survey 2001 provided much of the data used in the study.

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