

IMPROVED TECHNIQUES FOR DEPTH QUALITY INFORMATION ON NAVIGATIONAL CHARTS

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Abstract

Navigational charts contain a combination of geospatial information of varying quality collected at different times using various techniques. Bathymetric data quality is mainly encoded in electronic charts with the Category of Zones of Confidence (CATZOC). CATZOC provides information about the horizontal and vertical uncertainty of depth information, as well as the seabed coverage and feature detection. It is visualized in Electronic Chart Display and Information Systems (ECDIS) as an additional layer with glyphs using a rating system of stars: six to two stars for the best to lowest quality data and “U” for unassessed data. The current symbology creates visual clutter which is worse in areas of high quality bathymetry. Furthermore, horizontal and vertical uncertainties may not be adequately assessed by the user. This paper presents a research program aimed at the development of a method for portraying bathymetric data quality and for integrating the quantified uncertainties in ECDIS.

Keywords: Spatial Data Visualization, Error-band geometry, Bathymetric Data Uncertainty, Electronic Navigational Charts ENC, Uncertainty Visualization, Visual Variables, Safety of Navigation

INTRODUCTION

Bathymetry shown on nautical charts is compiled from geospatial information of varying quality, collected at different times, using various techniques. The first systematic hydrographic surveys were conducted using hand deployed lead-lines and sextants. Improved techniques in the 20th century included single-beam echo-sounders, and most recently, high resolution bathymetry is collected using multi-beam echo-sounders and airborne lidar systems. At the same time, with the use of satellite positioning systems the positional accuracy of surveys has also considerably increased. Data quality of geospatial information plays an important role in decision making in maritime navigation, and failure to take it into account can be one of the factors leading to maritime accidents [see e.g., the cases of Nova Cura (DSB, 2017) and Pazifik (BSU, 2020)].

The hydrographic community has been concerned with informing mariners about the data quality on charts since the 1919 International Hydrographic Conference in London (HMSO, 1920). The first agreed approach was with a description in the title of the chart (Pielou, 1984), which with time took the form of a chart inset either with the use of the *source diagram* introduced by Beaton (1960) or with the more complex *reliability diagram*. The simplistic nature of the former made it obsolete as it could no longer meet the needs of maritime navigation at the end of the 20th century, whereas the complexity of the latter made it difficult for cartographers to construct and for the mariners to use (Roberts & Lewis, 1992 as cited in Johnson, 2004).

In an effort to fulfill the increasing needs of contemporary navigation, in the early 1990s, the hydrographic community introduced Zones of Confidence (ZOC) for use on paper and the newly introduced Electronic Navigational Charts (ENCs). The ZOC concept was developed to provide a simple and logical means of classifying all bathymetric data in terms of quality, and displaying the confidence that a national charting authority places in it (Johnson, 2004). The ZOC diagram has served nautical charting for about three decades and, with moderate enhancements, the concept will continue to exist in the new S-101 (IHO, 2018) transfer data standard for ENCs. However, the current symbology for displaying ZOC in the Electronic Chart Display and Information System (ECDIS) has shortcomings. The most important deficiencies are associated with the star glyphs coding scheme, and that the uncertainty values provided in the ZOC categories are not fully incorporated in ECDIS analysis in route planning and execution.

This work presents research on the development of new visualization and integration methods of data quality on charts in order to support decision making on board. In the following sections, we review the limitations of the current symbology, the recent research efforts for the development of improved visualization methods, the suitability of the available visual variables for the purpose, and, lastly, we discuss a potential solution under investigation.

ZONES OF CONFIDENCE AND QUALITY OF BATHYMETRIC DATA

The ZOC diagram formed a paradigm shift in the way the evaluation of data quality is performed by hydrographic offices in-house as part of the compilation process, replacing a system where the end-user was expected to perform the evaluation based on the provided quality indicators. For the ZOC diagram, the area of the chart is delineated into sectors (as with its predecessors) with each sector assigned one of the six ZOC categories shown in Table 1. The ZOC categories have a horizontal and vertical uncertainty associated with them, information about the seabed coverage and feature detection, as well as a short description of the typical survey characteristics [the detailed ZOC table can be found in IHO Special Publication 57 (IHO, 2014)]. With this information, mariners may more effectively interpret the seabed morphology, identify potential hazards for the vessel, and select routes that maintain under-keel clearance.

In ENCs, the ZOC categories are encoded in the attribute CATZOC (Category of ZOC) of the meta-object M_QUAL (quality of data) which also has a number of optional attributes, e.g., SOUACC (sounding accuracy) and POSACC (positional accuracy). Currently, CATZOC is portrayed in ECDIS as an additional layer with glyphs using a rating system of stars: six to two stars for the best to lowest quality data and “U” for unassessed data (see Table 1). The layer may be activated and de-activated by mariners.

Table 1: The six ZOC categories and the respective symbology, horizontal and vertical uncertainties, and achieved seabed coverage.

ZOC	Symbol	THU (m)	TVU (m)	Full Seabed Coverage
A1		5	0.5 + 1%	Yes
A2		20	1 + 2%	Yes
B		50	1 + 2%	No
C		500	2 + 5%	No
D		> 500	> 2 + 5%	No
U		U	U	U

As it can be seen in the examples of Figure 1, the current CATZOC symbology adds significant clutter on ECDIS screens, obscures high-quality more than low-quality data, may not be visible in small areas, is not intuitive, and dominates the screen, especially in dusk and night modes of ECDIS. Consequently, CATZOC is often not used and horizontal and vertical uncertainty may not be adequately assessed by the user, something that is confirmed by maritime accidents reports (e.g., DSB, 2017; BSU, 2020) and research (e.g., Harper et al., 2012; DQWG, 2016).

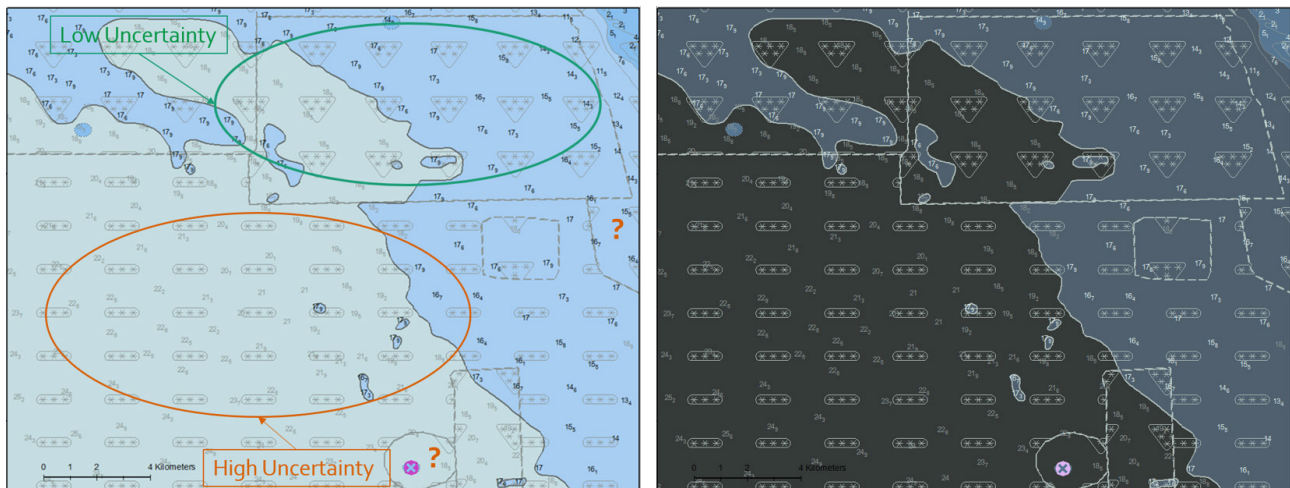


Figure 1: The visualization of CATZOC in Day (left) and Dusk (right) ECDIS modes (Kastrisios et al., 2020b)

For the S-101 standard, the CATZOC attribute is replaced by the Quality of Bathymetric Data (QoBD) in the form of a decision tree incorporated in ECDIS. The five categories of assessed data A1, A2, B, C, and D are renamed to 1, 2, 3, 4, and 5 respectively. One more category “O” (Oceanic) is provided for the areas where water depth is deeper than 200m (and, thus, does not pose a threat to surface navigation), and an attribute for the temporal variation of the seabed has been added (details in IHO S-101 Annex A). Other than that, the horizontal and vertical uncertainties and the seabed coverage criteria for each category remain unchanged. Due to the recognized deficiencies of the star symbols, the International Hydrographic Organization (IHO) Data Quality Working Group (DQWG) considers that “the current staggered pattern symbology of CATZOC should not be used in S-101” (DQWG, 2019a). The new visualization method for CATZOC and the S-101 QoBD in ECDIS has been a topic of research over the last decade, however it is yet to be selected.

PREVIOUS RESEARCH EFFORTS

Hare et al. (2011) used a continuous color scale to represent bathymetric uncertainty in their work on modelling of bathymetric uncertainty, a technique commonly used by hydrographers for the visualization of high resolution bathymetry and the associated depth uncertainty (e.g., Bathymetry Attributed Grids). With this they demonstrated the potential uses of the new IHO S-10X product specifications (e.g., S-102) while discussing under keel-clearance and the visualization of go / no-go areas with a red-green traffic-light display.

Two other visualization techniques were proposed by the IHO DQWG and Nautical Cartography Working Group (NCWG). In the work of the former, the quality levels are visualized with line textures of varying transparency. The work of the NCWG presented the use of four different coding schemes, i.e., a ring pattern of different hues (green, yellow, red, and white), single hue with variation in color value, and two with pie charts. However, both works targeted the four quality tiers that were under consideration at the time (i.e., good, fair, low-quality, and unassessed) (see e.g., DQWG, 2015) but officially abandoned in the 10th meeting of the DQWG (DQWG, 2016). As such, the proposals are not directly applicable to the six levels of CATZOC and QoBD (seven including the oceanic). Furthermore, the DQWG identified as primary drawbacks of the NCWG proposal the ambiguity of color value and the severe display clutter of pie charts (DQWG, 2016). Furthermore, the proposed ring patterns make use of color hues that are not recommended for the application (see DQWG, 2015) as they were intended for use in under-keel clearance, and dominate the screen view in most ECDIS modes.

The most comprehensive work on the visualization of data quality in ECDIS is that by Gladisch and Ruth (2016). Therein, the authors discuss common practices in the visualization of spatial data uncertainty, record the deficiencies of the current star symbology, review the previous research efforts, and investigate the use of noise, transparency, and textures for the visualization of data quality. The grid and hexagon textures they proposed are effective in all ECDIS modes. The main deficiencies of the method are the use of the same, very dense, texture for QoBD 5 and U, and, as the DQWG points out, that it is not intuitive and adds considerable clutter in ECDIS screen (DQWG, 2019b).

Lastly, in 2017 the DQWG proposed a method using color codes (DQWG, 2017). The main idea was to combine the safety contour, safety depth, and the four shades of blue used for the color coding of depth areas in ECDIS, with the populated QoBD values into a single view. This idea was presented at the 9th meeting of the Hydrographic Services and

Standards Committee (HSSC) but raised a few concerns, and the HSSC members decided that some issues remained to be addressed and that the possible options should first mature prior to an official proposal (HSSC, 2017).

STUDY AND PROPOSED SOLUTION

Ideally, symbology to display data quality on an ECDIS screen should:

1. Minimally interfere with the other charted information,
2. Unambiguously relate to the QoBD categories,
3. Emphasize the areas of greater uncertainty,
4. Be easy to remember, and
5. Be effective in all ECDIS modes (i.e., day bright, day whiteback, day blackback, dusk, and night).

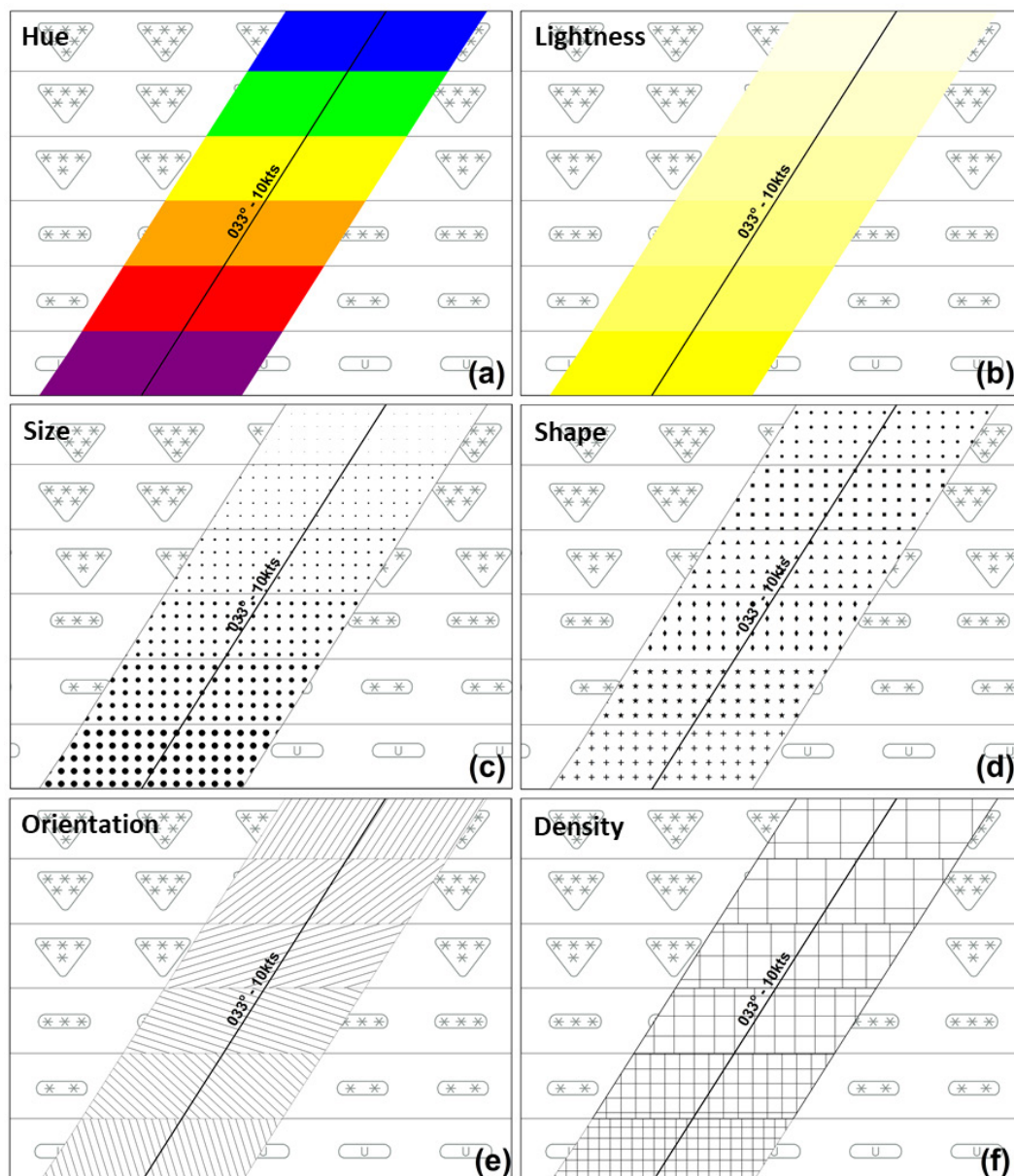


Figure 2: Examples of the utilization of the visual variables of hue (a), lightness (b), size (c), shape (d), orientation (e), and density (f) for the visualization of the six levels of ZOC on ENC's (Kastrisios et al., 2020a)

Most primary and secondary *color hues* (Figure 2a) are already reserved for other uses in the ENC/ECDIS or possibly not suitable for all ECDIS modes. In addition, the experimental results of MacEachren et al. (2012) have showed that

color hue has very low intuitiveness. *Color lightness/value* (Figure 2b) and *saturation* lead to visualizations that may obscure important underlying areal object on charts (e.g., the color coding of depth areas for shallow and deep waters). Furthermore, for all three dimensions of color the portrayed layer of data quality can become dominant in dusk and night modes. *Transparency* may alter user's perception of the color coding of the depth areas. The visual variable of *shapes* (Figure 2d) has no intuitiveness and the decoding of ZOC categories necessitates the use of a legend. With *size*, *orientation*, and *density/grain* (Figures 2c, 2e, and 2f, respectively), the identification of the different CATZOC levels becomes ambiguous whenever only a few of the levels are displayed.

Satisfying the set of requirements for ZOC visualization with a single visual variable can be challenging. The solution that seems most promising is to use a sequence of textures created by combining two or more visual variables. The advantages of textures are that they are minimally used in current ECDIS displays, and if they consist of open meshes they are expected to minimally interfere with other chart information (unlike, e.g., opaque colors or color transparency). Each texture must be designed to be clearly distinct from the previous one so that their values can be unambiguously perceived. Each texture should be visually denser than the last, with denser textures representing greater uncertainty. Furthermore, we are suggesting a boolean strategy for distinguishing between assessed (i.e., QoBD 1, 2, 3, 4, 5, and Oceanic) and unassessed (i.e., QoBD U) data.

Table 2 shows an example of a coding scheme with textures consisting of lines. The fundamental principle is that the number of lines represent the QoBD, e.g., one solid line for QoBD 1, three lines (one single and one double) for QoBD 3, and five lines (two double and one dash lines) for QoBD 5. Oblique lines are used for assessed data (i.e., QoBD 1, 2, 3, 4, and 5), whereas vertical-horizontal lines represent the unassessed data (i.e., quality "U"). Lastly, additional information is conveyed by the single and double lines (i.e., full vs not-full seafloor coverage has been achieved).

Table 2: A sample coding scheme of textures consisting of single, double, and dashed lines. Variation in transparency and orientation of lines is also used.

ZOC	QoBD	Symbol	Texture
A1	1		
A2	2		
B	3		
C	4		
D	5		
U	U		

Figure 3 shows an example of the textures of lines presented in Table 2 superimposed on a US ENC (US4NC15M, Cape Lookout to New River, North Carolina). The texture emphasizes uncertainty while reducing visual clutter (compared to star symbols) by varying density and transparency. Increasing density and opacity of lines indicate higher uncertainty values (lower quality data). An evaluation of the illustrated solution shows that it meets the criteria outlined previously with the primary advantage of being an intuitive representation of the different QoBD categories. This and other coding schemes based on the same principles that are under consideration, along with ideas by others (e.g., DQWG, 2019a) will be evaluated in the form an on-line questionnaire which will be distributed to the mariner community. This questionnaire is designed to evaluate a set of alternative coding schemes in terms of their ability to meet the requirement set in the first paragraph of the current section.

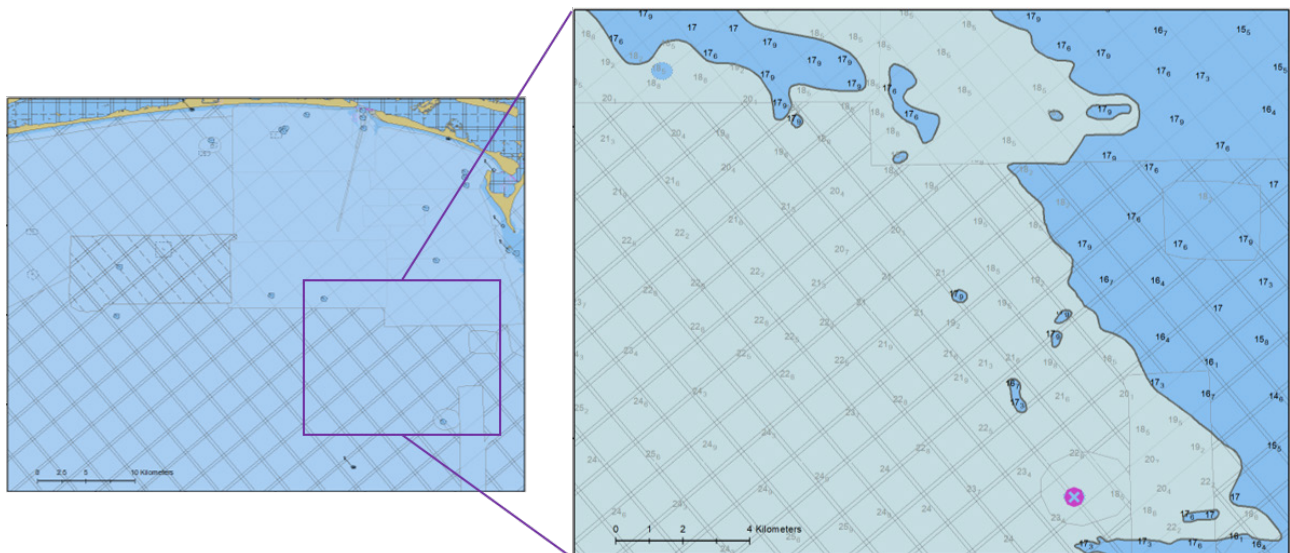


Figure 3: Visualization of ENC data quality using the textures of lines of table 2 (Kastrisios et al., 2020a)

A further aspect of the research project is the determination of the area to be visualized. Prior solutions use a layer that covers either the entire extent of the chart or a zone of fixed width around the plotted route. We are investigating the use of zone of variable width equal to the horizontal uncertainty in the area and its incorporation in the hazards appraisal performed by ECDIS. The advantage of this lies in the fact that shoals charted with high certainty (e.g., ZOC A1 / QoBD 1) not in the vicinity of the plotted route (which therefore do not pose a threat) will not be treated as a threat, but those with higher horizontal uncertainty would.

Besides the visualization of the CATZOC / QoBD sectors in ECDIS, we are also investigating the visualization of depth and positional uncertainty of individual bathymetric features (e.g., wrecks, underwater rocks, obstructions) and their incorporation in ECDIS analysis. The logical solution for their positional uncertainty is the use of an error-band geometry approach [e.g., Foy (2011)] that is already under consideration by the DQWG (2020). For the depth uncertainty, this can be incorporated in ECDIS for the adjustment of the charted depth and the consequent display of this depth value on ECDIS for the mariner's awareness whenever necessary. It is noted that the resulting error-band geometry and the depth uncertainty of features may be uniform or non-uniform in the same M_QUAL as other quality indicator may have been encoded, e.g., POSACC and SOUACC. Cases that require special treatment, such as features in navigable channels or near the boundaries of two areas with different QoBD categories, are under consideration. Other factors include the color (e.g., magenta, black), type of line (e.g., solid, dashed, or dotted), size of font and line, location of the displayed adjusted depth (e.g., over the hazard, on the outline of the circle), and minimum visible sizes.

CONCLUSION

This paper discusses the concept of CATZOC for bathymetric data quality in ENCs and its visualization and integration in ECDIS analysis in support of safe marine navigation. To overcome the deficiencies of the current star symbology it presents a research methodology for the development of a new coding scheme that includes the determination of application specific requirements and the evaluation of the visual variables for their suitability. It proposes the use of a sequence of textures created by combining two or more visual variables and presents an example consisting of lines with variation in the type (single, double, and dashed lines), the transparency, and the orientation of lines. The proposed solution is intuitive and unambiguous, emphasizes the areas of greater uncertainty, and is effective in all ECDIS modes. It also discusses the integration of bathymetric data uncertainty in ECDIS analysis with the use of a zone around the plotted route with width that is equal to the horizontal uncertainty encoded in CATZOC and error-band geometries around individual features. The advantage of the investigated approach is that features charted with high certainty not in the vicinity of the plotted course will not be treated as a threat (thus reducing useless alarms with a large user-defined zone width), whereas those with higher horizontal uncertainty are incorporated into the analysis (thus eliminating the risk of actual dangers that are overlooked due to a small user-defined zone width).

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REFERENCES

- Beaton, R.J. 1961. Can the mariner trust his chart ? The Intern. Hydrogr. Review, XXXVIII (2), July. IHB, Monaco.
- BSU. 2020. Investigation Report 241/18. Serious Marine Casualty. Grounding of the motor tanker PAZIFIK off Indonesia on 9 July 2018. Bundesstelle für Seeeunfalluntersuchung. 23 January 2020. Hamburg, Germany.
- DSB. 2017. Digital navigation: old skills in new technology. Lessons from the grounding of the Nova Cura. Dutch Safety Board. September 2017. The Hague. The Nederland.
- DQWG. 2015. New ways of representing quality of bathymetric data for surface navigation. Information paper for consideration by TSMAD, DIPWG, CSPCWG, TWLWG. Combined 29th TSMAD / 7th DIPWG Meeting and S-100WG-1 / ENCWG-1 Meeting. 2 – 6 February 2015, Ottawa, Canada.
- DQWG. 2016. Report from DQWG - NCWG2-04.6A. 2nd meeting of the Nautical Cartography Working Group (NCWG2). 26-29 April 2016, Monaco.
- DQWG. 2017. Proposal for Portrayal of bathymetry quality. Paper for consideration by HSSC9 - HSSC9-05.5C. 9th meeting of the Hydrographic Services and Standards Committee (HSSC9). 6-10 November 2017, Ottawa, Canada.
- DQWG. 2019a. Methodology for the display of quality information - DQWG14_08A. 14th meeting of the Data Quality Working Group (DQWG14). 5-8 February 2019. IHO Secretariat, Monaco.
- DQWG. 2019b. Final Minutes. 14th meeting of the Data Quality Working Group (DQWG14). 5-8 February 2019. IHO Secretariat, Monaco.
- DQWG. 2020. DQWG15_05.1A – Development of the conditional visualization methodology of quality of bathymetric data. 15th Data Quality Working Group (DQWG15) meeting. 4-7 February 2020. IHO Secretariat, Monaco.
- Foy, A. S.. “Making Sense Out of Uncertainty in Geospatial Data.” Ph.D. Diss., Virginia Polytechnic and State University, 2011.
- Gladisch, S. and T. Ruth. 2016. DQV - Data Quality Visualization Recommendations for Visualizing Uncertainty in Electronic Nautical Charts. Fraunhofer, Competence Center Maritime Graphics. Rostock, Germany.
- Harper, S., D. Wells, and K. Gunning. 2012. The Development of New Data Quality Visualisation Methods in Electronic Chart Information Systems and Investigation into Associated User Response. In Hydro12 - Taking care of the sea. 13 November 2012 - 15 November 2012, Rotterdam. <https://doi.org/10.3990/2.238>
- HMSO. 2019. International Hydrographic Conference. London 1919. Report of proceedings. His Majesty's Stationery Office. London. Available at <https://babel.hathitrust.org/cgi/pt?id=umn.31951002346858v&view=1up&seq=10>.
- HSSC. 2017. Final Minutes. 9th meeting of the Hydrographic Services and Standards Committee (HSSC9). 6-10 November 2017, Ottawa, Canada.
- IHO. 2014. IHO Transfer Standard for Digital Hydrographic Data. Publication S-57. Supplementary Information for the Encoding of S-57 Edition 3.1. ENC Data. Monaco: International Hydrographic Bureau.
- IHO. 2018. IHO Electronic Navigational Chart Product Specification. IHO Publication S-101. Ed. 1.0.0. Monaco: International Hydrographic Organization.
- Johnson, P. 2004. ZOCman Cometh' or 'On the Application of Category of Zone of Confidence in the Australian Hydrographic Service. International Hydrographic Review. Vol. 5 No.3. IHB. Monaco.
- Kastrisios, C., C. Ware, B.R. Calder, T. Butkiewicz, L. Alexander, and O. Hauser. 2020. “Nautical chart data uncertainty visualization as the means for integrating bathymetric, meteorological, and oceanographic information in support of coastal navigation.” 100th American Meteorological Society Meeting, 18th Symposium on Coastal Environment, 11-17 January 2020, Boston, MA, USA.
- Kastrisios, C., C. Ware, B.R. Calder, T. Butkiewicz, and L. Alexander. 2020. “An Alternative Methodology (to the Star Symbols).” IHO Data Quality Working Group, 4-7 February 2020, Monaco.
- MacEachren, A., R. Roth, J. O'Brien, B. Li, D. Swingley, and M. Gahegan. “Visual Semiotics & Uncertainty Visualization: An Empirical Study”. In: Visualization and Computer Graphics, IEEE Transactions on 18.12 (Dec. 2012), pp. 2496–2505.
- Pielou, F.A.. 1984. Source data diagrams and their use on British Admiralty charts. International Hydrographic Review. IHB. Monaco.
- Roberts, C. and R. Lewis. 1992. Report of the Reliability Diagrams on RAN Charts, Australian Hydrographic Service.

BIOGRAPHIES

Christos Kastrisios graduated from the Hellenic Naval Academy (HNA) in 2001 with a B.Sc. in Naval Science. After his graduation he served aboard frigate HS Aegean and submarines HS Protefs and HS Poseidon, mostly as the navigator and sonar officer, and participated in several deployments at sea. In 2008 he was appointed to the Hellenic Navy Hydrographic Service where he served in various positions and represented his country at international committees and working groups. He holds a Pg.Dip. from the Hellenic Naval War College, a M.P.S. in GIS from the University of Maryland at College Park, and a Ph.D. in Cartography from the National Technical University of Athens (NTUA). He has worked as a part-time lecturer in GIS and Cartography at the HNA and NTUA. His research work at the Center focuses on data generalization, visualization, and topology on nautical charts.

Colin Ware is a member of the Center for Coastal and Ocean Mapping and Director of the Data Visualization Research Lab. Dr. Ware's position is split between the Ocean Engineering and Computer Science Departments. Dr. Ware has a background in human/computer interaction (HCI) and has been instrumental in developing a number of innovative approaches to the interactive 3-D visualization of large data sets. As a founding member of the University of New Brunswick Ocean Mapping Group, Dr. Ware designed many of the algorithms and interactive techniques that were that were incorporated into Fledermaus, a 3D visualization package and into CARIS HIPS, the most commonly used commercial hydrographic processing package.

Brian Calder graduated with an M.Eng (Merit) and Ph.D in Electrical and Electronic Engineering in 1994 and 1997 respectively, from Heriot-Watt University, Scotland. His doctoral research was in Bayesian statistical methods applied to processing of sidescan sonar and other data sources. He joined the Center for Coastal and Ocean Mapping & NOAA-UNH Joint Hydrographic Center at the University of New Hampshire as a founding member in 2000, where his research has focused mainly on understanding, utilizing and portraying the uncertainty inherent in bathymetric (and other) data, and in efficient semi-automatic processing of high density multibeam echosounder data, and associated technologies. He is a Research Professor, Associate Director of CCOM, the Chair of the Open Navigation Surface Working Group, and a past Associate Editor of IEEE Journal of Oceanic Engineering.

Thomas Butkiewicz is an Assistant Research Professor at The Center for Coastal and Ocean Mapping at The University of New Hampshire. He received a Ph.D. in computer science from The University of North Carolina at Charlotte, where he designed and developed new interactive geospatial data visualization techniques. After a year as a research scientist at The Charlotte Visualization Center, he joined CCOM in 2011. Dr. Butkiewicz specializes in creating highly interactive visualizations that allow users to perform complex visual analysis on geospatial data sets through unique, intuitive, exploratory techniques and interfaces, including the use of multi-touch and natural interfaces, virtual reality, stereoscopic displays, and image processing/computer vision.

Lee Alexander is a Research Associate Professor Emeritus at the Center for Coastal and Ocean Mapping at the University of New Hampshire where he conducts applied research, development, test and evaluation on electronic chart and e-Navigation related technologies. Previously a Research Scientist with the US Coast Guard and a Visiting Scientist with the Canadian Hydrographic Service, he served on a number of international committees dealing with maritime navigation standards. He has published over 200 papers and reports on maritime navigation systems/services, and was a co-author of a textbook on Electronic Charting. Alexander received his Ph.D. from Yale University and is retired U.S. Navy Captain.

Rogier Broekman graduated from the Amsterdam University of Applied Science in 1994 with a B.Sc. in Hydrographic Surveying. He started his career as a navigator onboard seismic survey vessels at Schlumberger Inc. In 2001 he joined Quality Positioning Services, a Dutch company in maritime geomatics software and services, as a support engineer. In 2007 he moved to the Dutch Ministry of Infrastructure and Water where he started as hydrographic advisor, supporting the maintenance of the national coordinate reference systems and participated as national representative to the European INSPIRE Technical Working Group for Elevation. In 2014 he moved to his current position within the Royal Netherlands Navy – Hydrographic Service as lead of the Geodesy & Tides department. In 2017 he was elected Chair of the IHO Data Quality Working Group.