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Contents

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Editorial

Welcome to the November 2021 edition of the International Hydrographic Review! I am excited to share the articles and notes of this edition with you. This will be my last IHR edition as the editor. The past two years have been very different than I expected when taking this position, but I have truly enjoyed the experience. The COVID pandemic impacted everyday life in so many ways: loss of friends and family, reduction in hydrographic surveys, travel restrictions, virtual conferences, establishment of remote work protocols, and so much more. Through it all, I was amazed by the resilience and ingenuity of the hydrographic community.

I want to thank the IHO for allowing me the privilege of serving as the IHR Editor - it has been my honor. I am proud of the work the entire IHR team accomplished these past two years: a new website, improved access to IHR archives and four great editions. I especially want to thank all the authors who contributed articles and notes - without your insight, dedication and commitment, the IHR would not be successful.

This edition starts off with a series of articles that look deep into subjects that are highly important to today's hydrographic offices. First up, three articles from Brazil beginning with a discussion of chart datums in areas of micro and meso tidal regimes. Closely following, but inherently related, is an article addressing the various components required to enable under keel clearance operations. Finally, Brazil has provided a detailed look at their testing of the IHO S-57 to S-101 converter to help improve the process and expand the greater community's knowledge. Next is an article from Toitū Te Whenua Land Information New Zealand discussing the challenges and methods available to conduct mapping and charting missions in remote locations, which is particularly applicable to island nations. The MACHC provides a comprehensive look at the status of ENCs in their region and the need to adopt regional standardization to ensure navigation safety.

Our notes begin with the Kenya National Hydrographic Office and Kenya Port Authority providing a very positive update of hydrographic services and hydrospatial data infrastructure in their country. This is followed by a description of the bathymetry compilation process used by the Canadian Hydrographic Service that is designed to improve quality and accelerate dissemination of products. Next, a note from members of the IHO's Crowdsourced Bathymetry (CSB) Working Group that provides both an update on current status of the working group and a reminder of the impact CSB can provide to the global community. Continuing in our effort to highlight Women in Hydrography, Ms. Jacinthe Cormier provides a fascinating look at her career in hydrography, culminating in her service as Director, Canadian Hydrographic Service (CHS) in Nova Scotia. The next note highlights the commitment of NOAA (USA) to engage stakeholders through the establishment of a NOAA Hydrographic Services Review Panel (HRSP) Federal Advisory Committee (FAC). Finally, a global Hydrospatial Movement Club and Community (HMCC) is reviewed with a collection of references that should prove useful to learn more about this concept.

Editorial

I hope you enjoy the articles and notes in this edition; the topics addressed are wide-ranging, relevant, and reflective of the ever-growing knowledge and skill in our hydrographic community. Don't forget to submit articles for the May 2022 by January 31, 2022. It's a great time to be a hydrographer!

Brian Connon
Editor

Articles

ESTIMATION OF NAUTICAL CHART DATUM BY THE STATISTICAL METHOD IN MICRO AND MESO TIDAL REGIME : AN ALTERNATIVE TO THE BALAY HARMONIC METHOD

By V. Fuchs, G.L. Galvão Teixeira, T. Das Neves Milisse Nzualo (Brazil)

Abstract

In coastal areas that have a great meteoceanographic influence in sea-level variability, the Chart Datum (CD) can be computed using the statistical method (SM), which considers the tidal and the non-tidal sea-level components. However, that method was not systematically evaluated along the Brazilian coast. In this work, the SM is compared with the harmonic method used to define the CD in Brazilian Nautical Charts. Both methods were applied in five tidal gauge stations, with simulations performed for different time range series. The results show that the method found a safe value in all the cases, being consistent even at microtidal regimen with significant meteorological influences.

Résumé

Dans les zones côtières où la variabilité du zéro hydrographique est fortement influencée par la météorologie, le zéro hydrographique (ZH) peut être calculé à l'aide de la méthode statistique (SM), qui tient compte des composantes de la marée et des composantes non soumises à la marée dans le niveau de la mer. Cependant, cette méthode n'a pas été systématiquement éprouvée le long de la côte brésilienne. Dans l'article qui suit, la méthode statistique est comparée à la méthode harmonique utilisée pour définir le ZH dans les cartes marines brésiliennes. Les deux méthodes ont été appliquées dans cinq observatoires de marées, avec des simulations effectuées pour différentes séries temporelles. Les résultats montrent que la méthode a trouvé une valeur sûre dans tous les cas, en étant cohérente même dans le cas d'un régime de micro-marée avec d'importantes influences météorologiques.

Resumen

En áreas costeras con gran influencia meteo-oceanográfica en la variabilidad del nivel del mar, se puede calcular el Cero Hidrográfico o Datum de la Carta (CD) mediante el método estadístico (SM), que considera los componentes de mareas y no de mareas en el nivel del mar. Sin embargo, ese método no se evaluó sistemáticamente en la costa de Brasil. En este trabajo se compara el SM con el método armónico usado para definir el CD en las Cartas Náuticas de Brasil. Se aplicaron los dos métodos en cinco estaciones de mareógrafos, y se realizaron simulaciones en diferentes series de abanicos de horas. Los resultados muestran que el método proporcionó un valor seguro en todos los casos, manteniéndose consistente incluso en régimen micromareal con influencias meteorológicas significativas.

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1. INTRODUCTION

The signatory countries to the SOLAS Convention (Safety of Life at Sea - International Maritime Organization) are committed to preparing and publishing documents and nautical charts to provide safe navigation. In order to fulfill this responsibility, member countries seek to follow the terms and guidelines of the International Hydrographic Organization (IHO), whose international standards are intended to reduce uncertainties that may result in accidents to navigation. The parameters used for hydrographic surveys, making nautical charts and other activities inherent to hydrography were then standardized to ensure that this uncertainty reached the acceptable value range, guaranteeing 95% reliability (SOLAS, 2014 and IHO, 2008).

Within this scope we have the Chart Datum (CD), also known in some literature as Water Level Datum or Sounding Datum, which is the reference plane used to reduce the depths represented on nautical charts (IHO, 2005). Although there are specifications for hydrographic surveys and for the various activities that involve this work, IHO has concluded that each Hydrographic Service in each country will have the responsibility to choose the methods and prepare their standards, as long as they are able to do so and fulfill the minimum requirements for Safety of Navigation (IHO, 2008). This means that there is not a single method used by Hydrographic Services in different countries for the hydrographic activities that are within the competence of each. This is true of the identification of CD, as each country uses a method that it considers appropriate.

In the case of Brazil, the Directorate of Hydrography and Navigation (DHN) chose to use the Balay method to determine CD, associated with the Courtier Criterion for tide classification (BALAY, 1952, COURTIER, 1939). However, this method is the result of the sum of the most significant components of the astronomical tide, which means that it does not consider the effect of noise and meteorological tide, the non-tidal components (FRANCO, 2009). This factor causes the method to deviate from the ideal in places with great influence of that component.

The Balay method is consolidated, and its use has allowed the DHN to make nautical charts that comply with the concept of safe navigation. Nevertheless, the method is a sum of harmonic constituents of the astronomical tide. The greater the influence from shallow water constituents or from the non-tidal component, the greater occurrence of sea-level heights observed below the CD.

For the first case, calculating the Lowest Astronomical Tide (LAT) from a harmonic forecast would be a solution that would allow the identification of a more accurate CD. For the second case, even a harmonic forecast can deviate from the desired value. For the case of a microtidal regime with great meteorological influence, as is the case in the south of Brazil, LAT can constantly present negative values for the height of the sea level. A statistical method allows the use of both the astronomical portion and the meteorological portion for the calculation of CD, being a solution for both cases.

During this study, the level of reduction was calculated using a statistical method, with the CD being calculated from Probability Density Functions (PDF) for the astronomical tide and non-tidal components of the sea-level, for different tide stations throughout the Brazilian territory. This calculation was carried out for the periods of 15 days, 30 days, 3 months, 6 months, 1 year and 5 years, being limited superiorly by the size of the existing sample for each of the stations. This result was then compared with those observed using the Balay Method to identify which would be more stable and which would be more secure.

Although the statistical method is relatively old, it has not been applied consistently along the Brazilian coast, nor considering the diversity of the types of tides and adverse meteoceanographic conditions. Also, this methodology might be implemented in areas where sea level records are scarce or poorly reliable. Thus, it may be valuable for planning and building port and coastal infrastructure, as well as for implementing risk reduction measures.

2. AREA OF STUDY

The present study looked for places with different tidal characteristics and meteorological influence throughout the Brazilian territory. The astronomical tide follows semidiurnal patterns, typically two high waters (HW) and two low waters (LW) are observed during a lunar day. This pattern can vary according to the region and according to the local geography or latitude, among other aspects that alter the harmonic constituents (PUGH and WOODWORTH, 2014).

In the extreme north of the country, the prevailing tide is macrotidal, with hipertidal being found in some cities. From 4ºS to 18.5ºS the mesotidal regimen prevails, and between 18.5ºS and 33ºS the microtidal regimen is predominant. Also, the semidiurnal tide pattern (SD) is observed from the extreme north to 22ºS, and between 22ºS and 30ºS, predominant tidal pattern is the semidiurnal tide with diurnal inequalities (SDI). From 30ºS to the extreme south of the Brazilian Coast the prevailing tidal patterns are mixed tide and diurnal tide (D) (VELLOZO and ALVES, 2005).

In order to cover those different tide patterns, the tide stations of Pecém Port, Recife Port, Shipyard Naval Base (EBN), Itajaí Port and the Southern Nautical Signaling Service (SSN-5) were selected, where simulations were carried out within the existing continuous data limit for each of the stations. All tide gauge stations in this study used a float operated shaft encoder, presenting discrete data with sampling rates between 5 minutes and 1 hour. The tide stations on the Brazilian coast can be seen in ***Figure 1.***

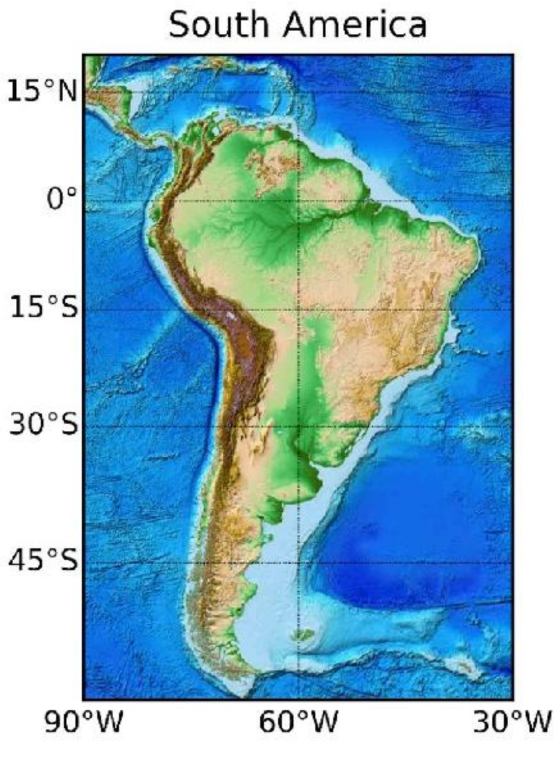

Figure 1. *At left, geographic location of South America. At right, geographic location of Brazil and the distribution of the tide gauge stations along the Brazilian continental margin. The red dots represent the location of the tide gauge. In 1 and 2 we observe mesotidal regimens and semidiurnal patterns. In 3 we observe mesotidal regimen and semidiurnal pattern tide with diurnal inequalities. In 4 and 5 we observe microtidal regimen, being semi-diurnal pattern tide with diurnal inequalities at Itajaí Port and mixed-tidal pattern at the SSN-5. Source: the authors.*

The tide datasets used at the Pecém Port station have a temporal resolution of 5 min, starting on November 12, 2016, at 00:00 and ending on February 02, 2017, at 23:55. This data set was the same processed by DHN for the calculation of the station's Mean Sea Level (MSL) and CD, and it was possible to use this result as a reference for the calculations performed. For the Recife Port, the data set had a sampling rate of 1 hour, starting on November 9, 1978, at 00:00, and ending on October 31, 1986, at 23:00. The tide dataset of the EBN station has a temporal resolution of 10 minutes, starting on May 24, 2014, at 00:00, and ending on May 24, 2015, at 22:00. For the port of Itajaí, the dataset has a temporal resolution of 1 hour, starting on March 31, 1960, at 00:00 and ending on March 22, 1961, at 23:00. Finally, the tide station of the SSN-5 has a dataset with a 5-minute temporal resolution, from January 1, 2015, at 00:00 until January 1, 2016, at 23:55, also being processed by DHN for calculating the station's MSL and CD.

3. METHODS

During this work, the Harmonic Method and the Statistical Method were applied in the tide datasets for the calculation of the CD, to compare the results obtained for the simulations carried out. At first, the consistency of the dataset was analyzed, looking for time series gaps, and checking whether the tidal curve and the MSL were consistent with what was expected at the site.

Both methods were initiated by carrying out the tide harmonic analysis, in order to identify the harmonic constituents. Those studies were made using the software PacMare, a package of tidal analysis and prediction based on frequency domain. The PacMare was developed by Franco (2009) according to the harmonic analysis method proposed by Franco and Rock (1971).

3.1 Harmonic Method

For the tide classification, the Courtier criterion, “C”, was used, which uses the harmonic constituents obtained by the harmonic analysis. For this, the method must be able to correctly identify the diurnal principal lunar (O1), diurnal principal lunar and solar (K1), semidiurnal principal lunar (M2) and semidiurnal principal solar (S2) constituents (PUGH and WOODWORTH, 2014), applying them in equation 3.1. The result obtained represents the tide class observed at the location, from the values present in ***Table 1***.

$$C = \frac{H(O_1) + H(K_1)}{H(M_2) + H(S_2)} \tag{3.1}$$

Table 1. *Tide classification as a function of C.*

Inequalities	Classification
$0 < C \leq 0.25$	Semidiurnal tide (2 HW and 2 LW per day)
$0.25 < C \leq 1.5$	Semidiurnal tide with diurnal inequalities (2 HW and two unequal LW)
$1.5 < C \leq 3$	Mixed tide
$C > 3$	Diurnal tide (1 HW and 1 LW per day)

For the case of the semidiurnal tide with diurnal inequalities, which is divided into three types, it is also necessary to verify the type of diurnal inequality, using equation 3.2 (BALAY, 1952). Then, the Balay method is used to calculate the distance between the MSL and the CD. It depends directly on the Courtier Criterion C and the diurnal inequality 2K, and the equations for calculating the level of reduction can be seen in ***Table 2***. During this work, all the CD calculated by the Balay Method will be called as BCD.

$$2K = g(M_2) - [g(O_1) + g(K_1)] \quad (3.2)$$

Table 2. *Equations for calculating the distance between the Mean Sea Level and the Chart Datum, depending on the values of C and 2K.*

C and 2K values	Vertical distance between the Mean Sea Level and the Chart Datum	Equation
$0<C\leq 0,25$	$Z_0=H(M_2)+H(S_2)+H(N_2)+H(K_2)$	(Eq.3)
$0,25<C\leq 1,5$ and $2K=0^\circ$	$Z_0=H(M_2)+H(S_2)+H(N_2)$	(Eq.4)
$0,25<C\leq 1,5$ and $2K=180^\circ$	$Z_0=H(M_2)+H(S_2)+H(N_2)+H(K_1)+H(O_1)$	(Eq.5)
$0,25<C\leq 1,5$ and $2K\neq 0^\circ$ or 180°	$Z_0=H(M_2)+H(S_2)+H(K_1)+H(O_1)+H(P_1)$	(Eq.6)
$1,5<C\leq 3$	$Z_0=H(M_2)+H(S_2)+H(K_1)+H(O_1)$	(Eq.7)
$C>3$	$Z_0=H(M_2)+H(S_2)+H(K_1)+H(O_1)+H(P_1)$	(Eq.8)

3.2 Statistical Method

For the calculation of CD using the Statistical Method (SCD), the probability distributions of the tidal and the non-tidal components of sea-level are considered separately (PUGH and VASSIE, 1978). Separating those tidal and the residual non-tidal components allows us to evaluate the influence of the observed residual component over the sea-level variations that were found at the astronomical tide (PUGH and VASSIE, 1978).

To separate the astronomical tide from the noise, the sea level must be considered as a function of time, containing 3 main components, as given by equation 3.9 :

$$\zeta_{obs}(\mathrm{t}) = \zeta_a(\mathrm{t}) + \zeta_s(\mathrm{t}) + S_0(\mathrm{t}) \qquad (3.9)$$

where $\zeta_{obs}(t)$ is the height of the tide referred to the zero of the tide gauges as a function of time,

$\zeta_a(t)$ is the astronomical component of the tide,

$\zeta_s(t)$ is the non-tidal component as a function of time and

$S_0(t)$ is the local MSL (FRANCO, 2009).

The astronomical tide is the sum of periodic constituents generated mainly by the Earth-Moon and Sun-Earth systems interaction, with their physical representation presented by equation 3.10.

$$\zeta_a(\mathrm{t}) = \sum_{n=1}^{N} \left(H_n . cos(\sigma_n t + v_n - g_n)\right) \qquad (3.10)$$

Since H_n is the amplitude of each of the harmonic constituents,

σ_n the angular velocity of each constituent,

v_n the equilibrium phase and

g_n the phase difference in relation to the equilibrium tide (PUGH and VASSIE, 1978).

The identification of the non-tidal component will depend directly on the size of the sample. This is because for a few days, such as 15 days or 1 month, few meteoceanographic phenomena generating significant anomalies at sea level may have occurred, making it difficult to differentiate between the first ones and the astronomical component. In addition, some important astronomical tidal constituents cannot be identified by the harmonic analysis, which means that the astronomical tide will not be completely reliable. In such cases, that will be shown at the non-tidal component.

In general, the non-tidal influence can be considered small, when compared with the astronomical tide (PUGH and VASSIE, 1978), which allows investigating the extent to which that component affects the reliability of the method for smaller samples.

An important observation to be made is that equation 3.9 considers that the components are independent of each other, due to the generating force of each one of them (PUGH and WOODWORTH, 2014). Thus, it is possible to consider that the astronomical and non-tidal components have their Probability Density Function (PDF), with zero covariance (PUGH and VASSIE, 1978).

From this concept, if ζ is a given tidal height, the probability of occurrence of ζ is equal to the sum of the probabilities of all products of the probabilities of the possible combinations of astronomical and non-tidal heights that result in ζ.

Thus, being $p_a(\zeta - y)$ the PDF for the astronomical component and the PDF $p_s(y)$ for the non-tidal component, the PDF for sea level $P(\zeta)$ is given by the convolution of the PDF's, resulting in equation 3.11 below.

$$\mathrm{P}(\zeta) = \int_{-\infty}^{\infty} p_a\,(\zeta - \mathrm{y}).\, p_s(\mathrm{y}).\,\mathrm{dy} \qquad (3.11)$$

Bearing in mind that the tide gauge data offers data in a discrete distribution, equation 3.11 can be rewritten in the form presented in equation 3.12. To calculate the probability associated with each height, 10 cm class intervals were used (FRANCO, 2009).

$$\mathrm{p}(\zeta) = \sum_{j=-M}^{M} p_a\,(\zeta - \mathrm{jh}).\, p_s(\mathrm{jh}) \qquad (3.12)$$

With the probabilities associated with each height ζ, it is possible to find the Cumulative Distribution Function (CDF) for any level η of interest, as can be seen in equations 3.13 and 3.14.

$$\mathrm{F}(\eta) = \sum_{\eta}^{\infty} p\,(\zeta) \qquad (3.13)$$

$$\mathrm{F}(\eta) = \sum_{-\infty}^{\eta} p\,(\zeta) \qquad (3.14)$$

Considering η the CD, the value of $F(\eta)$ found in equation 3.13 shows the probability of finding a safe level for navigation, that is, a level higher than that shown in the chart, while the value found by equation 3.14 presents a Complementary CDF, calculating the probability of being below the CD, that is, below η (PUGH and VASSIE, 1978).

With the CDF curve in hand, it is possible to identify the accumulated density for each value of η, or to identify an associated η value for each accumulated density. During this study, the probabilities of 0.5%, 1% and 5% were chosen as SCD in order to compare with the BCD.

With this method it is possible to make different combinations of the astronomical and non-tidal components. In this way, it will be possible to analyze a component of the astronomical tide resulting from an equinoctial spring tide combined with the largest surge observed. Although this simultaneous occurrence is rare, it still is possible, and that methodology includes such cases in the range of probabilities. (PUGH and VASSIE, 1978).

For the application of the statistical method, it was considered that the portion of the astronomical tide is equivalent to the predicted tidal curve from the harmonic constituents calculated for each of the sampled periods. The non-tidal component was calculated from equation 3.9. Although this approximation deviates from reality, the further away from the actual value the predicted tide height is, this error is inserted in the non-tidal values, and appears to maintain safe results during the simulations.

In order to verify the results obtained by the tide harmonic analysis carried out, it was necessary to use a low-pass filter, which would allow the identification of the daily variation of the sea level in each of the analyzed samples. A simplified application of the Godin filter was used for this operation (FRANCO, 2009). This filter methodology causes the first and last 36 hours to be lost, but it allows the results to be compared to those obtained by the main methodology.

The implementation of the statistical method and process automation was made in a Python environment. In addition to the CD values, the code aided the analysis with the comparative graphs of the observed tide, predicted tide and the non-tidal residual, in addition to histograms and graphs of the PDF calculated for each of the locations and periods, probability graphs for each of the classes of astronomical tide, noise and non-astronomical tide as a function of time, and the PDF values and the accumulated density for all possible tide heights found.

4. RESULTS AND DISCUSSIONS

In order to discuss whether the method currently used to define CD is superior to the statistical method, the tide data observed in some ports on the Brazilian coast were analyzed in the light of the literature, each of which was analyzed for periods of 15 days, 30 days, 3 months, 6 months, 1 year and 5 years, with the upper limit of the sample size provided by the DHN. The distance between the MSL and the CD (Z_0) values obtained from the methods is summarized in ***Table 3.***

Following the concept that the CD should be "a plane so low that the tide rarely drops below it" (FRANCO, 2009), among the results obtained, the calculated Statistical CD (SCD) of 0.5% proved to be the safest, as it has the lowest occurrence of negative heights. The exceptions occurred in the 3-month sample for the Port of Recife and in the 15-day sample for the EBN. Observing the variation of the SCD of 0.5% between the samples of 6 and 3 months, it is noticeable the reduction in the value of Z_0 calculated for the tide gauges of Port of Recife, Port of Itajaí and SSN-5. As the variation between the other samples presented a random profile, and due to the small number of repetitions, it is not possible to assess whether there is a trend. It is important to consider that, apart from the tide observed by the SSN-5 tide gauge, the results obtained in the tide forecasts were able to similarly represent the astronomical tides for the periods of 6 and 3 months, indicating that the variation present in the SCD of 0.5% resulted from extra-tidal effects, which, in turn, are predominantly random.

The forecast for the 15-day sample of EBN tide gauge data, in addition to the significant variation in the SCD, also showed a large variation in the calculated MSL. This joint variation may be due to the presence of a meteorological effect in the period, causing an increase in the local Sea Level during the period.

In all ports, the closest proximity between the Z_0 values calculated for the different simulations was observed in the calculated CD using the Balay Method (BCD), making it possible to consider this as the most stable method. In the SSN-5, for example, the difference between the highest and lowest BCD calculated was 1.87 cm, while the SCD 0.5% varied by 18 cm. This is already expected, considering that the statistical method uses the data present in the sample, and extremes do not occur very often, which is why years of observation are needed to identify tidal extremes (PUGH and VASSIE, 1978).

Table 3. *Distance between the Mean Sea Level and the Chart Datum calculated, in centimeters, separated by tide station and sample size.*

		15 days	30 days	3 months	6 months	1 year	5 years
Port of Pecém	0.5%	168	167	161	-	-	-
	1%	161	158	152	-	-	-
	5%	131	123	120	-	-	-
	BCD	156.54	155.38	155.21	-	-	-
	MSL	327.16	326.3	325.1	-	-	-
Port of Recife	0.5%	134	131	121	127	125	126
	1%	130	125	115	120	118	118
	5%	111	102	95	97	96	95
	BCD	128.07	127.94	126.68	119.69	122.05	124.33
	MSL	153.31	153.14	152.75	154.28	153.94	155.17
Shipyard Naval Base (EBN)	0.5%	83	104	100	99	100	-
	1%	78	95	91	91	91	-
	5%	62	70	67	67	66	-
	BCD	87.68	86.94	87.89	85.91	86.12	-
	MSL	296.24	289.36	280.76	279.34	281.37	-
Port of Itajaí	0.5%	66	64	68	75	73	-
	1%	62	59	62	68	66	-
	5%	49	46	45	50	49	-
	BCD	61.79	59.76	58.03	57.94	56.96	-
	MSL	141.12	144.58	142.67	139.33	136.99	-
Southern Nautical Signaling Service (SSN-5)	0.5%	42	48	50	56	60	-
	1%	39	45	44	50	54	-
	5%	29	35	31	33	39	-
	BCD	19.43	19.05	19.02	19.48	17.61	-
	MSL	260.94	258.94	246.98	244.39	255.38	-

Table with the results obtained from the carried simulations. For each station, the SCD of 0.5%, 1% and 5%, the BCD and the MSL are presented in centimeters, separated by the simulation sample size. “-” was used when there were no results obtained for one sample size.

On the other hand, as mentioned, the calculated value of Z_0 was much higher for the statistical method. Referring to the CD calculated from zero of the rulers, in the SSN-5, we have that the safest BCD was found for the 6-month sample (224.9 cm), while the less safe 0.5% SCD was found for the 15-day sample (218.9 cm), which was still 6 cm below the best BCD for the site. For the 6-month sample, the SCD of 0.5% was 188.4 cm, that is, 36.5 cm below the BCD calculated for the period. These results are shown in ***Figure 2***.

If we analyze each station individually, it is possible to observe that the value of Z_0 calculated by the Balay Method varied little depending on the size of the sample. The greatest variation was 8.4 cm, between samples of 6 months and 15 days for the Pecém Terminal. The MSL, however, changed more significantly, reaching 16.55 cm between samples of 6 months and 15 days for the SSN-5 station.

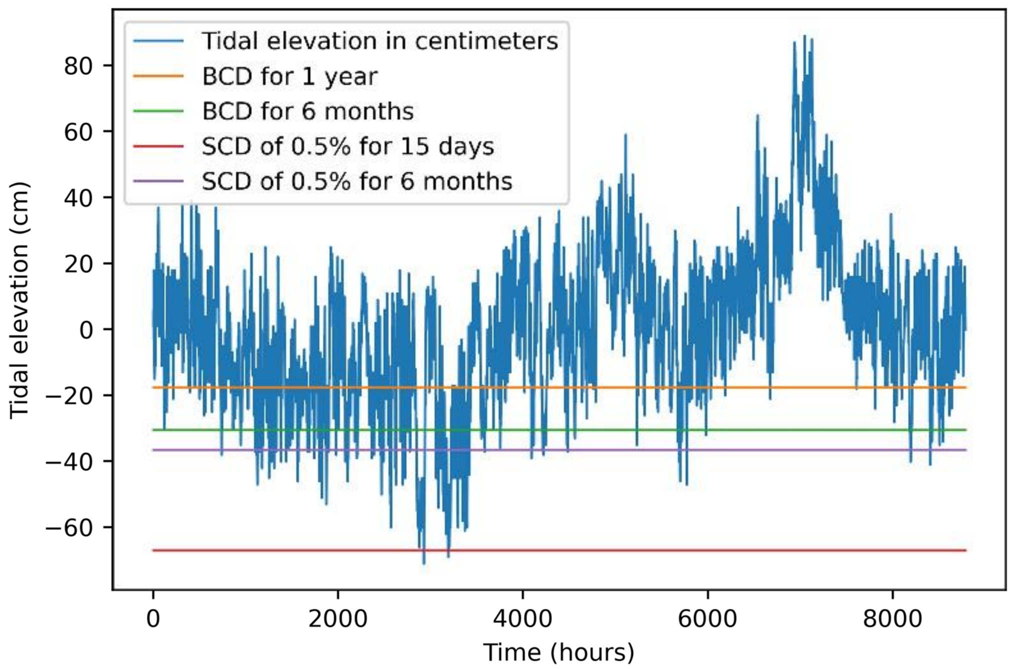

Figure 2*. Comparison between the most conservative BCD calculated (horizontal green line), the BCD calculated for the sample 1 year (horizontal orange line), the less conservative SCD of 0.5% (horizontal purple line) and the most conservative calculated SCD of 0.5% (horizontal red line). In blue, the tidal curve observed for the period of 1 year on SSN-5. All the CD were calculated for EBN.*

The large difference observed between the calculated BCD and SCD of 0.5% for the 6-month sample is indicative of the ability to more safely identify the CD using the statistical method, when the influence of the non-astronomical tide is higher than the astronomical tide of a location. From the data in ***Table 3***, we see that the BCD calculated for the SSN-5 from the data set with a period of 1 year was 237.77 cm in relation to the zero of the tide rulers, 6.62 cm above the MSL calculated for the 6-month period.

5. CONCLUSIONS AND FINAL CONSIDERATIONS

In this work, two methods for calculating CD were compared. The first was proposed by Balay (1952), whose principle is harmonic, and the second was implemented according to that indicated by Pugh and Vassie (1978), whose principle is statistical. Both methods were applied and analyzed for the five stations along the Brazilian coast.

Regarding the calculated Reduction Levels, it was possible to observe that in most of the simulations performed, the calculated SCD of 0.5% was below the BCD found for the same temporal sample. The exceptions were the 3-month sample for the Port of Recife, in which the SCD of 0.5% was 5.68 cm above, and the 15-day sample for the EBN, in which the 0.5% NRE was 4.68cm above.

One case that could not fail to be noticed was the CD calculated from the data from the SSN-5 tide gauge. When comparing the SCD and the BCD, it is possible to notice that, if the SCD were used for the location, the reference plane used would be 42.39 cm below the one currently used. In other words, just by inspecting the nautical chart of the place, the navigator cannot be sure if his vessel can navigate the area, which represents a risk to the safety of navigation.

It was also observed that the Z_0 calculated by the Balay Method proved to be very stable since they present slight variation in their value, when different sizes of time series are used, considering the MSL to be fixed. The most significant variation was 8.4 cm between the 6-month and 15-day samples from the Port of Recife. On the other hand, there was a remarkable variation in the values calculated by the statistical method, according to the size of the sample used. During the simulations, while the CD calculated by the statistical method varied with the sample size mainly due to the computed Z_0 value, the CD calculated by the Balay Method changed with the sample size primarily due to the calculated MSL.

It is important to note that CD is calculated as a function of both Z_0 and MSL calculated from the sample used. As shown in ***Table 3***, for the tide station of the SSN-5, when considering only the samples of six months and one year, it is possible to identify a difference of 10.99 cm. This significant variation reinforces the need for tide stations with an observation period longer than one year to reduce the seasonal influence in the calculation of MSL. Also, since there was a high frequency of negative tide heights for the CD currently used in SSN-5, it is considered extremely important to use other methods, such as the statistical method presented here, for locations with high influence of meteorological tide.

Those results show that the statistical method is feasible to be used to determine a safe CD, being a safe alternative for the Balay Method even when there are small time series or for data from tidal regimen such as those from the Brazilian south coast. Also, the statistical method was able to perform well for the four tidal patterns where the simulations were carried.

For future work, it is recommended to reproduce these simulations in others tide gauge stations to see if there are influences that this study cannot see for different tidal patterns. Also, another suggestion would be to carry those simulations in rivers, in order to find if the method should be able to offer a safe CD in those places.

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DYNAMIC DRAFT AND UNDER KEEL CLEARANCE : A HYDROGRAPHIC VIEW

By Lieutenant G.R. Catarino, Brazilian Navy

Abstract

The management of under keel clearance is becoming a reality in most of the ports around the world. As the demand for efficiency grows, it is important to have a decision support tool that fulfills this purpose keeping the requirements of navigation safety. The systematization of obtaining environmental and vessel parameters contributes to the increase of the efficiency of port maneuvers while acting positively for the safety of navigation. This paper brings a descriptive approach to the conceptualization of the dynamic draft, addressing the aspects of technical standardization and showing which factors are involved in the implementation and validation of the systems.

Résumé

La gestion de la profondeur d'eau sous quille devient une réelle nécessité dans la plupart des ports du monde. A mesure que les exigences d'efficacité augmentent, il est important de disposer d'un outil d'aide à la décision qui réponde à cet objectif tout en respectant les contraintes de sécurité de la navigation La systématisation de l'obtention de paramètres sur les conditions environnementales et sur les navires contribue à accroître l'efficacité des manœuvres portuaires tout en ayant une incidence positive sur la sécurité de la navigation. Cet article propose une approche descriptive de la conceptualisation du tirant d'eau dynamique, en abordant les aspects de la normalisation technique et en montrant quels facteurs sont impliqués dans la mise en œuvre et la validation des systèmes.

Resumen

La gestión del espacio libre bajo la quilla se está convirtiendo en realidad en la mayoría de puertos del mundo. Conforme aumenta la demanda de eficiencia, es importante disponer de una herramienta de apoyo a las decisiones que satisfagan este propósito manteniendo los requisitos de seguridad de la navegación. La sistematización de la obtención de parámetros del entorno y del buque contribuye al aumento de la eficiencia de las maniobras en puerto, teniendo a la vez un efecto positivo para la seguridad de la navegación. Este artículo aporta un enfoque descriptivo a la conceptualización del calado dinámico, atendiendo a los aspectos de normalización técnica y mostrando qué factores están involucrados en la aplicación y validación de estos sistemas.

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1. INTRODUCTION

The prosperity of civilizations that pioneered economic activity through trading between settlements on the Mediterranean Sea stands out in human history. From that time, knowing the benefit of efficient waterways for the transportation of goods, the improvement of navigation proved to be fundamental for the maintenance of great empires, territorial expansions and pursuit of goods that could only be transported by the sea.

Today it is no different. The capacity of a country to manage its production, receive tourists and explore its natural resources in its Jurisdictional Waters is closely related to the maritime port structure that this State possesses. So, it is vital, in order to contribute to increasing the national economic system, to find ways to optimize the aspects related to this structure and its proper use.

Regarding navigation, the draft of the ship, which is defined as the linear measurement of submerged portions of the hull, is directly linked to its ability to transport cargo. In port operations, it is generally seen that ships transport the maximum permissible load, therefore, having the maximum draft.

Considering that the concept of effectiveness is related to the achievement of a purpose and efficiency to the optimized use of the resources employed in that accomplishment, in the context of port operations, it is important to reduce the intervals of permanence of the ships to the exact loading and unloading times in the terminals. Those intervals, known as operational windows, when they occur mooring and unberthing maneuvers are limited by several parameters relating to the environment and vessels, their calculation is summarized in the under keel clearance (UKC) indicator.

In order to expand the operational window, when the UKC along the route is safe, two effective approaches are possible: acting in the environment in order to change it, especially by dredging the access channels, giving rise to the increase in UKC throughout the route of the maneuver or seek to operate in harmony with some environmental changes by gathering environmental and vessel information and using it in real time to safely and in detail predict the safety margin that is available. Both contribute to the purpose, however only the second has a focus on efficiency, in addition to not requiring the huge investments that are necessary for the first one.

Considering fluctuations in the value of the UKC is to consider subtle variations of the draft, in the face of changes in the environment along the route of the maneuver, as a function of those changes and the design of the vessel, thus having a value of draft with variable characteristics, the dynamic draft.

Expanding the operational window means rotating the operating cycle faster, reducing the idle time between maneuvers and thus saving unnecessary costs. Therefore, the issue that permeates this theme today is the comparison between the static depth, presented in the cartographic document and the instant depth, tuned to the characteristics of the ship and their comparison, which is aimed at checking the UKC repeatedly and can contribute to the expansion of the operational window in the port.

2. THE CONCEPT OF DYNAMIC DRAFT

Nautical cartography, in its development over the years, has made an effort to represent waterways in order to provide decision-making tools for planning and position monitoring with adequate safety margins at any time of the year and under diverse meteorological and oceanographic conditions.

However, in order to have the nautical chart statically represent the environment, which is eminently dynamic, it is necessary to use some approximations.

The definition of a nautical chart presented by the IHO Manual on Hydrography (C-13) is the following:

> **a graphic portrayal of the marine environment showing the nature and form of the coast, depths of the water and general character and configuration of the sea bottom, locations of dangers to navigation, rise and fall of the tides, cautions of manmade aids to navigation, and the characteristics of the Earth's magnetism. (IHO, 2011, p.7).**

From the definition cited and the one illustrated in the figure below, involving mainly measurements of tides, currents and waves, it is noted that using charts does not make it possible to find all the necessary information, in particular referring to those local dynamic factors, which influence the accuracy that the maneuver in port environments requires.

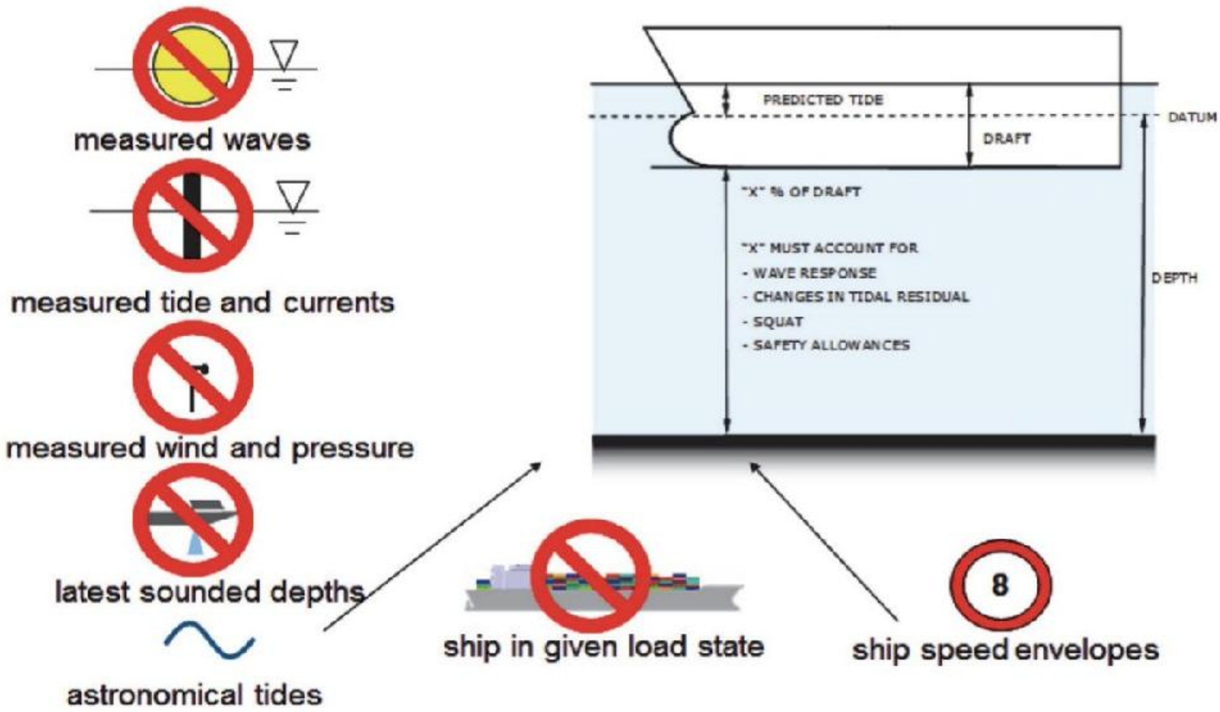

Figure 1: *Static determination of the UKC.*

Source: Pearce, 2012

The figure illustrates that from the mapped depth, referenced to a Datum, the safe UKC of operation is calculated, in percentage values of the draft, from data of the height of the astronomical tide of the variation of draft inherent to the inclination of the ship in its axes of freedom, the Squat Effect (depending on the speed of evolution) and the safety margin adopted by the navigator. However, each listed component presents an intrinsic and variable uncertainty according to the accuracy adopted in each situation, limiting the port authority in the adoption, through formal normative ways of an operational draft that exceeds the mapped depth.

It is evident that the greater the draft of a vessel sailing on a channel, the greater the amount of cargo carried on the same trip. Quantitatively, the appropriate way to measure such quantity is by means of the Tonnes Curve per centimeter of immersion (Fonseca, 2019) of each vessel. The order of magnitude for an ore cargo vessel or a containership indicated by an increase of 10 cm of operational draft, depending on the length of the vessel, is shown in the graphs below.

Having this notion of efficiency in maritime transport and the consequent economic advantage linked to navigation in restricted waters, it is noted that the instant combination of the appropriate variables to the static information of the cartographic document is fundamental for port operators.

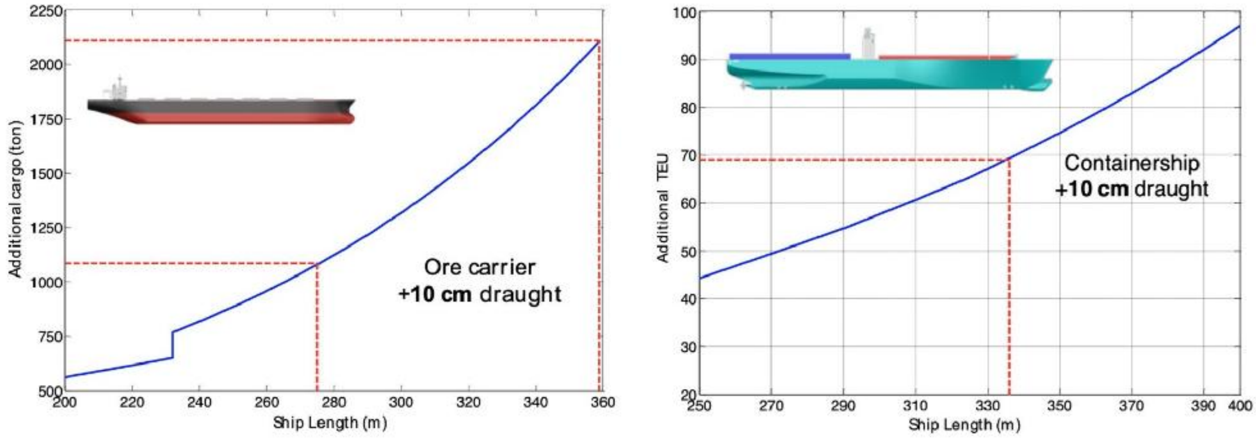

***Figure 2:** Additional cargo transported, depending on the length, with the implementation of 10 cm of draft for ore and container cargo ships.*

***Source:** Ruggeri et al, 2018*

The following figure illustrates the adoption of sensors that provide updated information on the parameters that influence the determination of the UKC, thereby reducing the uncertainties of the variables. By means of an appropriate mathematical modeling, the quotas corresponding to each parameter are then obtained, enabling the definition of the operational windows that dictate the safe interval that each vessel is able to navigate.

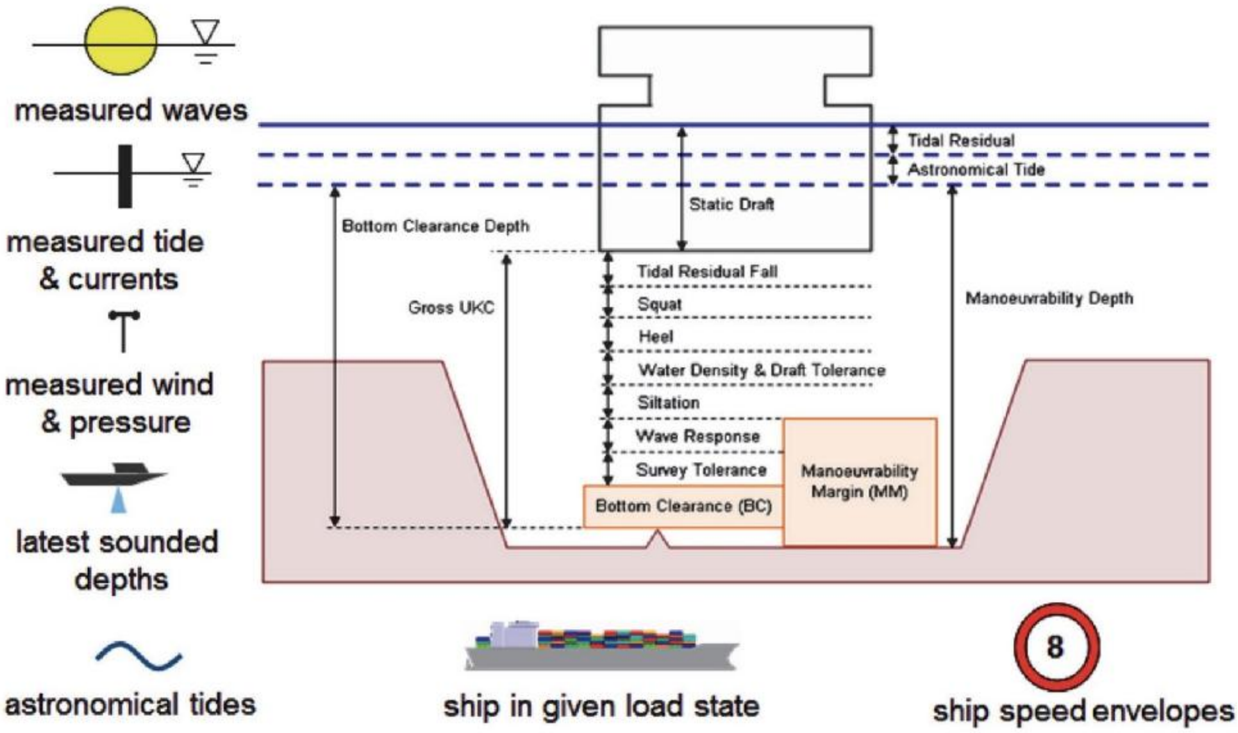

***Figure 3:** Dynamic determination of the UKC.*

***Source:** Pearce, 2012*

The World Association for Waterborn Transport Infrastructure (PIANC), in its Report No. 121-2014 (PIANC, 2014), determines the guidelines for the implementation of port channels and adopts a series of terms presented in the figure below that conceptualize the factors in determining depth on a waterway. Such concepts are divided into three categories of factors: those related to sea level, those related to the platform and those related to the bottom. The meaning of each parameter will be explained below.

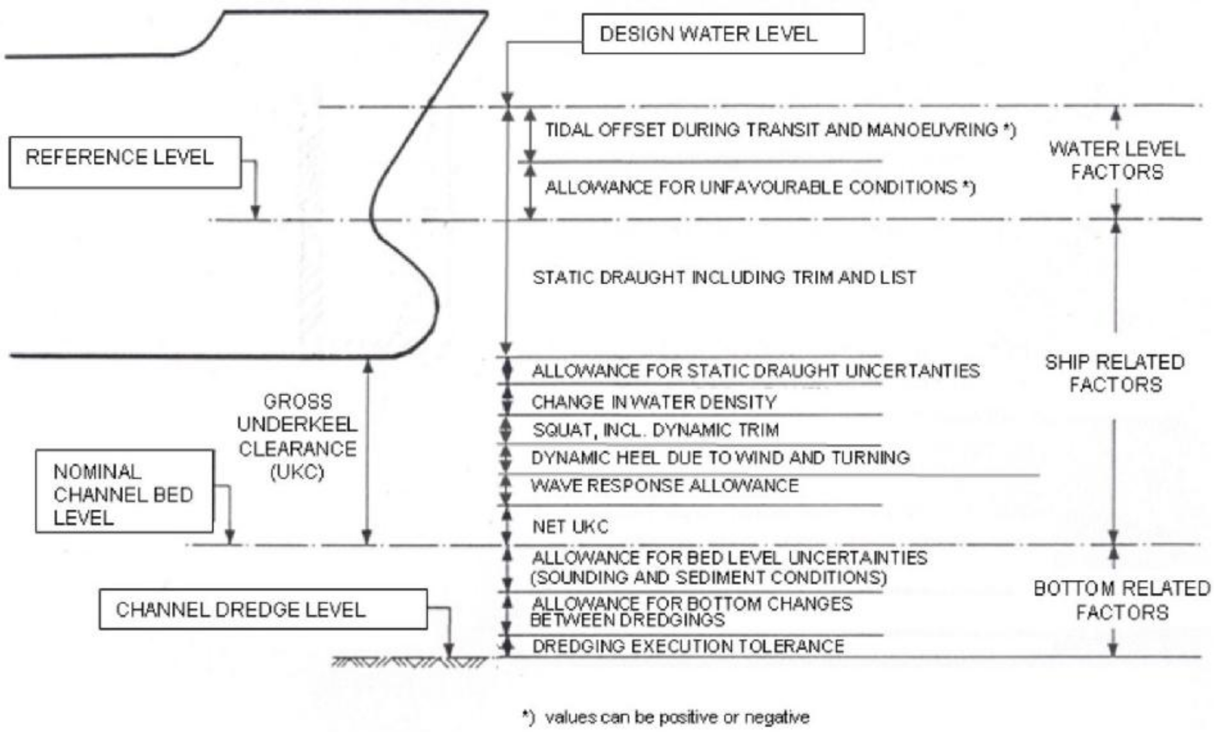

Figure 4: *Factors for determining the UKC.*

Source: *PIANC, 2014*

2.1 Factors related to Sea Level

According to Franco (2009), the periodic oscillation of the sea level occurs due to the action of astronomical forces, predominantly of the moon and the sun, in all the extension of the terrestrial globe. The tidal generating force, according to the theory of static tide, acts with different periods and intensities in each location, as it varies with the observer's latitude, declination and hourly angle of the moon, presenting harmonic components that oscillate in their time series in periods of up to approximately 18.7 years.

Associated with this phenomenon of global scale, in which the tide presents a wave behavior in shallow waters, there is also the action of local phenomena that distinguishes the amplitude of the theoretical tide from the real tide, they are: resonance, bottom friction and the increase in amplitude due to the reduction in the depth and geometry of the estuary (presence of accentuated channels and gradients).

As the prediction of the height of the tide must be carried out for each region, it is appropriate that the cartographic services use a local vertical datum to reference the mapped depths. In general, the Reduction Level is adopted as approximately the average of the low tides of syzygy, defined by means of the Harmonic Analysis of the tide components, assuring the navigator that the sea level, due to the astronomical effects, is very rarely found below the depth shown on the nautical chart.

Another more rigorous way is the adoption of the lowest historical level (Lowest Astronomical Tide - LAT) that the tide can assume in the syzygy due to the lower frequency harmonic constant (Franco, 2009). In this case, the nautical chart would guarantee that the real depth would never be less than the mapped (due only to astronomical effects), however the excess of rigor, when using as reference a level that appears only once in a cycle of approximately nineteen years, promotes a compromise in determining the operational draft when only this static information is considered in the calculation of the UKC.

For predicting the height of the tide at any given moment, the most used resource is the Tide Tables, which is published annually by Hydrographic Services, containing the forecast for the main ports, terminals, oceanic islands and anchorages. Tthe use of such a resource offers the navigator an estimate of the times of high tide and low tide, however in the intervals between such extremes, the table only allows interpolation where there are no considerable inequalities, which keeps the curve resulting from the pure sine wave away.

Thus, seeking to increase precision and accuracy, in addition to allowing computational integration with the other sensors eventually involved in real-time monitoring, it is important to use a digital tide gauge with electronically discretized data, linked to a mathematical model that includes the constants harmonics and the prediction of their respective periods, which becomes essential in the area of interest.

The second factor that must be considered, related to the variation in sea level, is the influence of meteorological conditions in the port region. The ocean-atmosphere interaction and the horizontal gradient of atmospheric pressure can cause both an increase in the level due to the stacking of water on the coast and a reduction in the level due to the withdrawal of water by local or synoptic phenomena.

According to Pugh (1987), the formation of waves, the third factor to consider occurs with the transfer of momentum from the winds to the sea surface, causing disturbances that intensify according to the continuous performance of this energy source and propagate with periods and well-defined amplitudes for kilometers beyond their generation area. When approaching the coast, these waves start to exhibit non-linear behaviors for the same reasons mentioned for tidal waves, plus refraction, diffraction and reflection, which in this case will be clearer because they are oscillations with short associated periods.

It is natural to assume that coastal engineering works are planned with a view to reducing the effects of the waves, in order to reduce their amplitude in the port areas, however in the interface that connects the access channel from the port to the sea, such interaction is inevitable and must be accompanied by means of sensors installed in buoys with the purpose of composing the desired precision in determining the UKC. It is worth mentioning that the data obtained can be correlated with the forecasts provided by the meteorological services, which provides essential elements for the safety of navigation.

While the effect of the direct incidence of waves on the coast causes the piling up of mass, raising the level and accentuating the amplitude of oscillation of the water column, on the other hand, the phenomenon of resurgence caused by Ekman Transport can occur. This effect of lowering the sea level is due to the fact that the superficial layer of water along the coast is displaced towards the deeper areas.

The study by Coelho et al. (2016) has showed that there is a significant contribution of Ekman Transport at the Reduction Level to the region where the research was carried out, where an average daily drop of 60 cm at sea level was found, bringing it to 20 cm below the Reduction Level. Although it offers risks to the safety of navigation, this phenomenon does not occur suddenly, as it depends on a geostrophic movement in which the Coriolis Force acts.

Therefore, the simplified formulation that governs sea level (μ) over time will be given by a Mean Sea Level (MSL), referenced to a local vertical datum, added to a time series (A) as a function of its decomposition harmonic governed by a deterministic pattern of oscillations under gravitational influences of the moon and sun, and a third term, determined by stochastic factors, which varies with the meteorological conditions (M) that can be inferred by numerical modeling fed by properly positioned sensors. Therefore, we have that:

$$\mu(t) = MSL + A(t) + M(t)$$

When planning a port operation, the variation in sea level due to the effects of the astronomical tide and the prevailing weather conditions must be taken into account during the entire transit and maneuvering of the ship, from entering the access channel to the berth mooring and to understand the entire time interval necessary for its completion.

Therefore, it is assumed that the variation in daytime, semi-daytime or mixed sea levels associated with interference resulting from the ocean-atmosphere interaction in the region will be one of the main parameters for the adequate and accurate determination of operational windows.

2.2 Factors related to the platform

Currently, the range of platforms with different characteristics, shapes, types and functionalities is enormous. In order to contemplate all of them, it is necessary to define which static and dynamic parameters must be considered when determining the under keel clearance. According to the illustration shown in figure 4, it can be seen that the PIANC divides these factors into two groups:

1) Static draft: level between the sea level (referenced to the Datum of the nautical chart) and the lowest level of the ship's keel.

2) Gross Under Keel Clearance: level between the ship's keel and the bottom corresponding to the nominal depth of the channel (mapped depth).

The first group as its name characterizes it is static and defined, in general, at the time of loading the vessel, varying according to the dimensions and the volume of cargo to be transported. The draft can have different dimensions along the longitudinal plane of the ship, resulting in an imbalance between the forward level and the aft level, called Trim. As a measure to prevent the ship from touching the bottom, the lowest draft of the hull is assumed as the vessel's draft.

The second group consists of six parameters, namely:

a) Tolerance due to uncertainties in the determination of the Static Draft: in the measurement of the forward and aft dimension there are several sources of uncertainty that must be considered to assume a nominal value. The draft scale at the side includes a measurement with limited accuracy in its reading, aggravated by the occurrence of ripples in the waterline and the possibility of the transverse inclination of the ship.

b) Variations in water density: most of the ports are located in estuarine regions, with the waters of the internal channels that house the berths highly influenced by the hydrological discharge. The access channel that connects the port to the sea has a higher salinity, consequently there is a variation in the density of water in the course of the ship.

The variation of this environmental parameter is related to the platform, and therefore to the geometry of its living works, as it acts directly on the submerged portion of the hull of the vessels, altering the resultant of the buoyant force that makes it possible to float, corroborating the Archimedes Principle. According to PIANC (2014), a ship that comes from the sea and enters a “fresh water” environment may present an increase in draft in the order of magnitude of 2 to 3%.

c) Squat effect: it is a hydrodynamic interaction, resulting from the Bernoulli effect and therefore also related to the geometry of living works, where the variation of the speed field along the vessel's hull influences the pressure field that the water exerts on the structure, conserving the balance between kinetic energy and flow potential. This phenomenon "(...) produces a downward vertical force (causing sinking, positive downward displacement) and a moment on the transverse axis (causing trim) that may result in different values in the bow and stern." (PIANC, 2014) being strongly accentuated in shallow waters and by the increase in the vessel's speed.

The difficulty in determining this parameter stems from the fact that it is specific to each hull shape and varies according to the constructive configuration of the channel, which is evidently not constant along its length. In this way, the modeling of Squat is done empirically, generating formulations that seek to determine its effect for ships and channel patterns of the same type.

Currently, the most accepted approach was proposed by Huuska (1976, apud Ruggeri, 2018, p. 9), which should be applied in each section of the channel, considering its bathymetric profile, and according to the block coefficient of the ship and its relative speed (vectorial sum of the speed of evolution with the speed of the current).

The following figure shows the bathymetric profile of several normal sections of the same channel, showing that the application of the approximations for the calculation of the quota that the Squat causes in each ship must be analyzed individually, in the field, along the entire extension of the area of interest and dynamically.

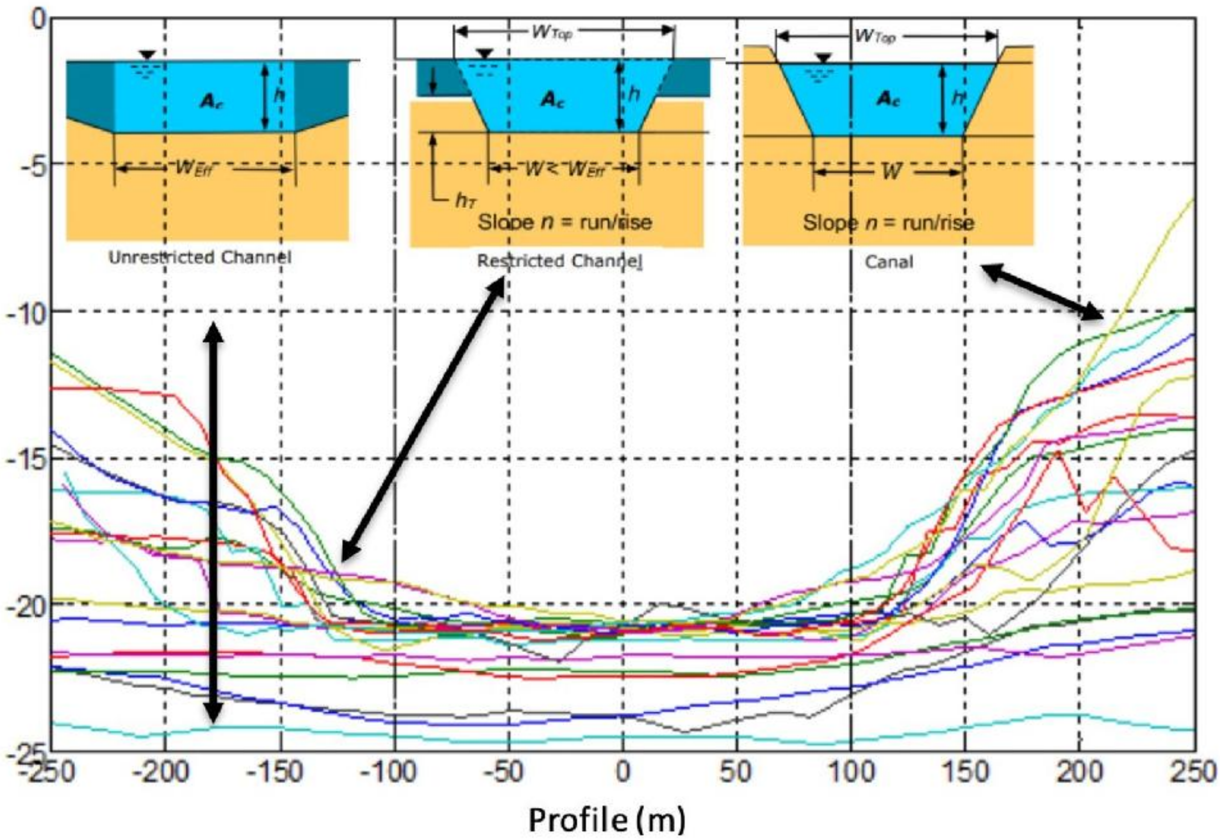

Figure 5: *Classification of normal sections of the same channel according to their bathymetric profile.*

Source: *Ruggeri, 2018*

The classification, proposed by PIANC (2014), divides a channel into three idealized categories: Unrestricted (navigation channel limited by a smooth gradient of the bottom in its margins), Restricted (presence of a lowering of the bottom that limits the margins of the channel) and Canal (limited by strictly solid margins). For each category, a correction is applied in the calculation, which includes the dimensions of the normal section: distance between vertical margins and depth.

d) Dynamic inclination due to yaw or wind: during the yaw of a vessel, the intensity of the transverse slope will depend on the speed of evolution, yaw rate, metacentric height and the forces applied by the cables connected to the port tugs, if applicable (PIANC, 2014). Additionally, the ship may suffer the influence of the wind, which will cause an angle of inclination, depending on the direction it falls in relation to the bow, increasing the influence according to the sailing area and the aerodynamic shape of the vessel's superstructure. Therefore, the dynamic inclination will increase the draft of the ship, since one of the edges will have its elevation increased, approaching the bottom.

e) Response movements to waves: the platform has six degrees of freedom (three of rotation [roll, pitch and yaw] and three of translation [heave, surge and sway], through which it moves under the influence of waves. This aspect is closely related to what was previously said about sea level variation for meteorological reasons, considering that the length of the waves is the same order of magnitude as the dimensions of the ships.

The situation that offers the greatest risk to navigation is when the resonance phenomenon occurs, which causes the amplification of the vessel's movements. Its predictive analysis is made in the frequency domain, in order to discriminate the incidence of oscillations, caused by waves, close to the ship's natural frequency in some of its degrees of freedom (roll, pitch and yaw) (RUGGERI, 2018).

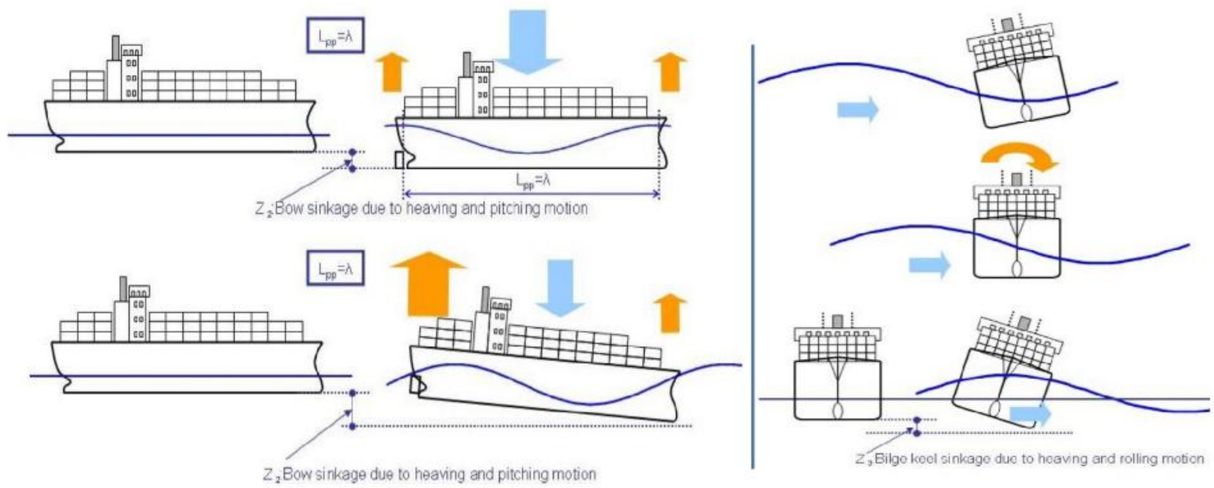

Figure 6: *Movements of the vessel due to the action of waves.*

Source: *MLIT, 2007, apud PIANC, 2014*

f) Net UKC: the last component of the gross UKC represents the shortest distance the keel of the ship can take in relation to the bottom, considering the nominal depth of the waterway. Therefore, it is determined through the integration of the other parameters addressed in their extreme situations.

According to Icorelis (1980, apud PIANC, 2014) the definition of this safety margin must be based on the type and size of the vessel, the cargo being transported (it is advisable to increase the quota for dangerous cargoes), the environmental consequences that an incident would cause in the traffic density, among other risk factors that are characteristic of each port operator. The author recommends a “net UKC of at least 0.5 m, which can be increased to 1.0 m where the consequences of touching the bottom are severe (eg, in channels with a rocky bottom)” (PIANC, 2014, p. 33). Thus, since such margin is arbitrated through experience and risk management for navigation in the region, the participation of Pilotage and the Maritime Authority in its proper determination is essential.

2.3 Factors related to the bottom

The last category of factors is directly related to the aspects of bathymetric survey, geology and the sedimentological nature of the waterway. The quota range covered by these factors varies from the nominal level adopted for the bottom, this being the value inserted in the nautical chart, up to the level of the dredging depth of the channel.

The terms are defined by PIANC (2014) as: allowance for bed level uncertainties (due to bathymetry); allowance for bottom changes between dredgings (due to bottom sedimentation);

and Dredging Execution Tolerance. So the uncertainties of the factors related to the bottom can be satisfactorily generalized, such as those resulting from the Hydrographic Survey, carried out conveniently after a situation of balance in the sedimentological erosion in the bottom, after the dredging works.

The IHO Standards for Hydrographic Surveys (S-44) (IHO, 2020) classifies the surveys and establishes uncertainty criteria that they must meet for each situation in which they must be performed.

Other factors related to the bottom but that will not be the scope of this research are related to the viscosity of the environment, in which the study of rheology defines parameters for the characterization of Fluid Mud in the seabed, allowing, with due management of the associated risk, the navigation of vessels touching the bottom.

3. TECHNICAL STANDARDIZATION

In the last decades, the maritime sector, following the global trend, has seen the development and improvement of several technologies. The massive digitalization and automation of equipment and sensors is increasingly present on board, from the construction to the operation of the ships. At the same time, as discussed in the previous section, the tonnage and the cargo capacity transported per trip have been presenting increasingly complex and refined operational requirements, since the economic interest dictates the mercantile rhythm of navigation.

In this context, the E-Navigation concept was presented by the International Maritime Organization (IMO) as a strategy to implement the integration of navigation tools, in order to improve navigation operation and safety. It is defined as: "the harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment." (IMO, 2020).

In this way, we can infer that E-Navigation is a concept that aims at the integration and harmonization of systems, including future systems and those already on board, with the exchange of useful data between ships and operators that provide ground support services in favor of security and operational simplification. The main objective is to develop a system that can adequately organize data from all sources in a given area, in order to expand and maintain a high level of security while also giving rise to increased situational awareness and supporting the operators decision-making.

The document NCSR 1/28 in its Annex 7 of the IMO Navigation, Communications and Search and Rescue Sub-Committee (NCSR), called "Draft E-Navigation Strategy Implementation Plan" (IMO, 2020) lists five solutions, in order of priority for the fulfillment of this system. They are:

- S1: improved, harmonized and user friendly bridge design;
- S2: means for standardized and automated reporting;
- S3: improved reliability, resilience and integrity of bridge equipment and navigation information;
- S4: integration and presentation of available information in graphical displays received via communications equipment; and
- S9: improved communication of VTS Service Portfolio.

This publication examines each solution individually and tries to standardize each of the procedures that must be adopted by users. In this standardization, S4 stands out, as it foresees the adoption of the International Hydrographic Organization's model S-100 for the presentation of the aforementioned relevant information and communication with other sources. ***Figure 7*** outlines the various standards and tools contained in this IHO framework, exemplifying the parameters that must be adopted worldwide to implement the E-Navigation concept.

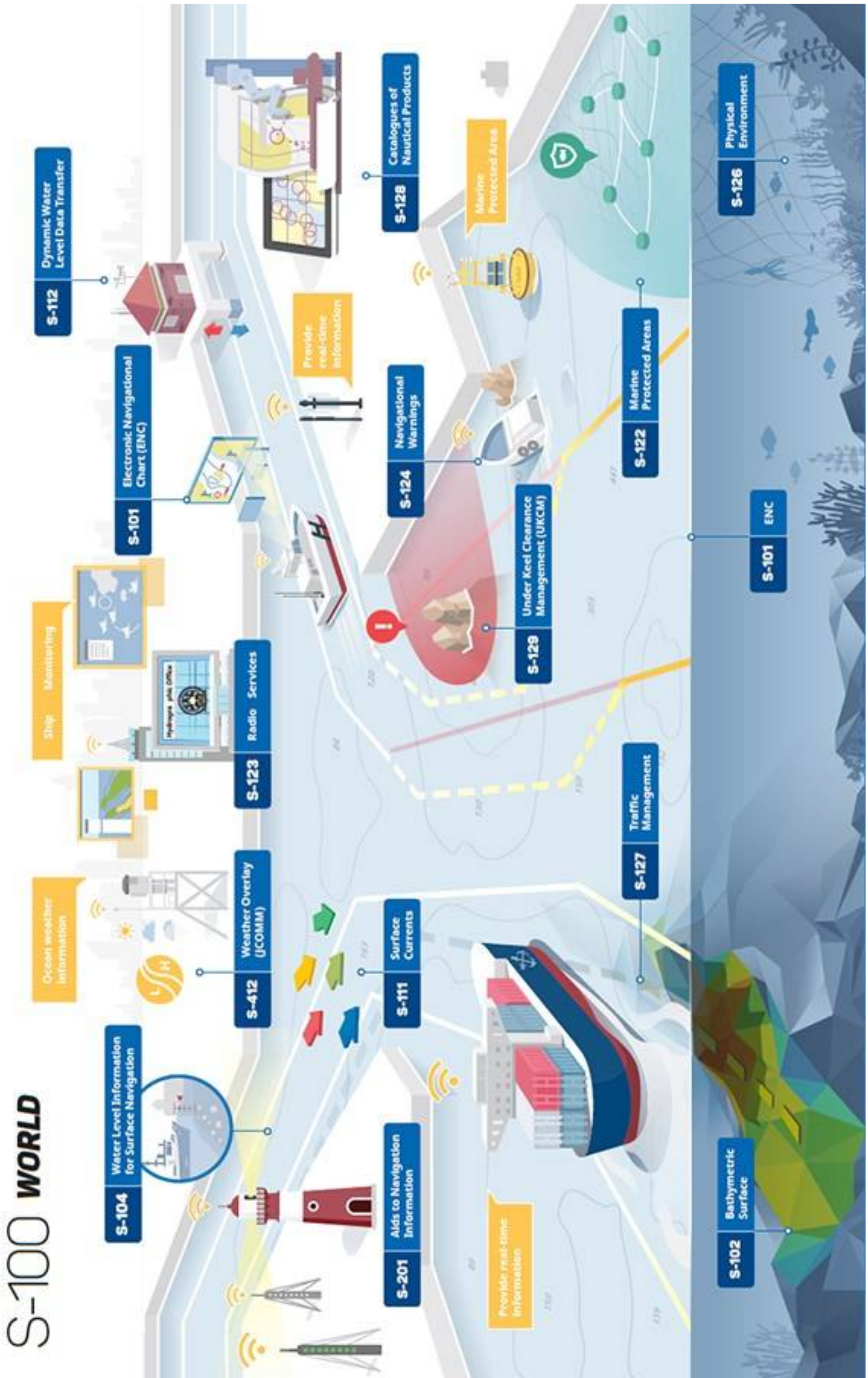

Figure 7: *Framework S-100.*
Source: *IHO, 2020*

Inserted in this list of products, there is the S-129: Management and Specifications of Under Keel Clearance Information (IHO, 2019), reinforcing the idea that the dynamic draft and its proper determination are relevant factors in the waterways. Thus, it can be considered that the main actor, with regard to the definition of technical goals for the determination of UKC systems, is the IHO.

The purpose of this publication is to define requirements for the production of a data layout that can be inserted and presented superimposed on the other information that make up an electronic navigation chart, provided for the S-100 framework (IHO, 2019).

Thus, information from a dynamic draft determination system can be used both in planning and during port maneuvers.

The operational dynamics, according to the S-129 (IHO, 2019), occur as follows:

a) Initial navigation planning: a ship that plans to call at a given port needs to determine the time intervals in which sea level conditions are suitable for sailing in that area. Based on static parameters, a series of possible windows is defined for a given ship, concluding a pre-plan with the intention of maneuver.

b) Adequacy of on-track planning with operational monitoring of the dynamic UKC: choosing the appropriate operational window for the ship, while it approaches the area covered by the dynamic draft determination system, the vessel's particular data (information about dimensions, stability, draft and so on). The system operator will identify you and establish a correspondence with a type ship pre-defined by the system, with the respective dynamic data provided. When integrating the data related to the ship with information on predicted and observed environmental conditions (wind, tide, current, etc.), a maneuver plan is defined.

This plan establishes directions, speed restrictions and non-navigable areas. In the planning phase, Control Points are inserted: waypoints associated with the time interval in which the ship will find a satisfactory Maneuverability Margin. The logistical aspect can also be favored by the precision of this planning that can be shared with other actors, such as the shipowners, the management company, the charterers or the ship's agent in the port, who will receive subsidies to contact the port authorities of interest for making the necessary reservations, such as the pilotage service or the availability of a berth.

The planning of the maneuver can be changed due to changes in the predicted weather forecasts, tide heights or damage and limitations of the ship. This update process allows the ship to manage its speed to meet the time window defined for navigation, reducing or eliminating the need for anchoring off the approach channel to await favorable conditions for entering the port.

c) Monitoring during the maneuver: since the product of the S-129 is a data layer applicable to electronic nautical charts, its display is liable to be displayed on the Electronic Chart Display System (ECDIS) equipment installed on the ships' passageways or, when applicable, at VTS stations operating on land controlling traffic in certain areas. Additionally, it is usual for information to be also displayed on mobile devices used by Pilots, called the Portable Pilot Unit (PPU), improving decision making during the maneuvers.

Dynamic draft determination systems provide real-time data to these display platforms, enabling the monitoring of the waterway and areas suitable for the passage of the ship, respecting the limitations imposed by the Port and Maritime Authorities. As the vessel progresses through the planned course, the factors related to sea level vary, the non-navigable areas are being updated and the time intervals of each waypoint are being monitored.

After docking and the ship's loading operation is completed, the new stability and draft parameters must be passed to the system operator who will determine, through the same operational dynamics, the safe window for the ship to leave the port.

The other technical aspects, data structuring diagrams, presentation requirements, standardized metadata formats, among other specifications imposed by IHO are described in that publication.

The following figure illustrates a representation of the symbology in the established pattern, exemplifying a route, the control points separating the kicks, the non-navigable areas in red and the non-navigable areas in yellow. It is observed that this information is superimposed on other layers of data available in the electronic nautical charts of the model S-100. Evidently, this is an example of the user's visualization (master, pilot and VTS), and the system may contain other layouts with additional useful information.

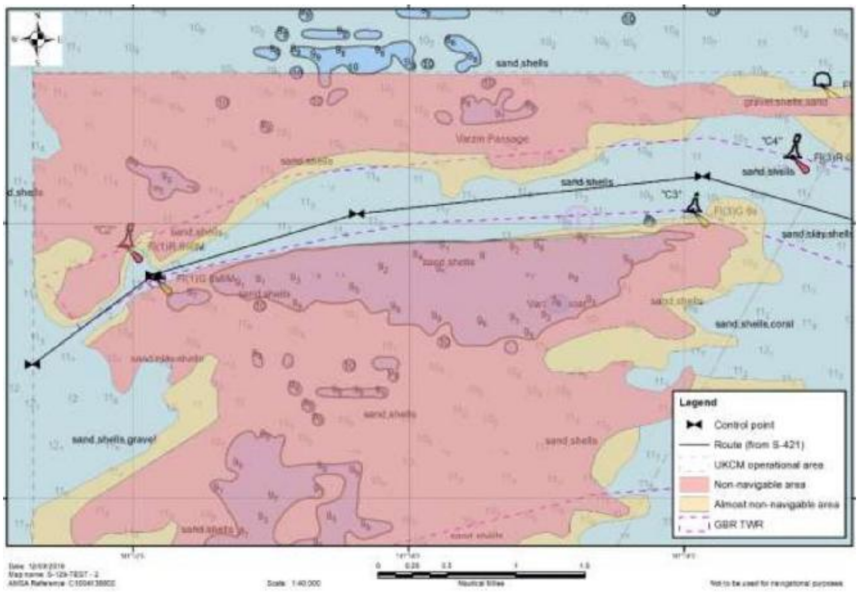

Figure 8: *Representation of the S-129 model for dynamic UKC management.*

Source: *IHO, 2019*

4. COMPUTER SYSTEMS

The range of systems in operation at ports around the world is enormous, but the principles of application and operation are similar. The implementation project must meet and contemplate the characteristics and peculiarities of each waterway, demanding a study of the dynamics of the area of interest, of the environmental and climatic factors involved, as exposed in the conceptualization of dynamic drafts, and of the type ships served by the information produced.

Meteorology and ceanographic aspects are implemented in two ways: observed data and forecasts. In general, to obtain real-time values of the elements of interest, remote monitoring is employed, in which the following sensors are conveniently positioned: tide gauges, indographs, anemometers and Acoustic Doppler Current Profiler (ADCP).

The application of the predictability aspect of these elements is carried out by means of hydrodynamic modeling, which tends to present good accuracy and precision, since its demand is in a short time scale and the aforementioned sensors feedback these models. It is also possible to associate the modeling with the forecasts coming from the meteorological services, with the proviso that the spatial scales employed must be adjusted.

A source of highly relevant data is the local bathymetry, respecting the sedimentary features and characteristics of the area of interest, which will dictate the necessary frequency of conducting new hydrographic surveys that update the system and enable the appropriate measurement of the UKC in each section of the site port canals. The uncertainties associated with this aspect are those related to the order of the survey defined by IHO and increase throughout time in accordance with the geological nature and the sedimentary dynamics of the region.

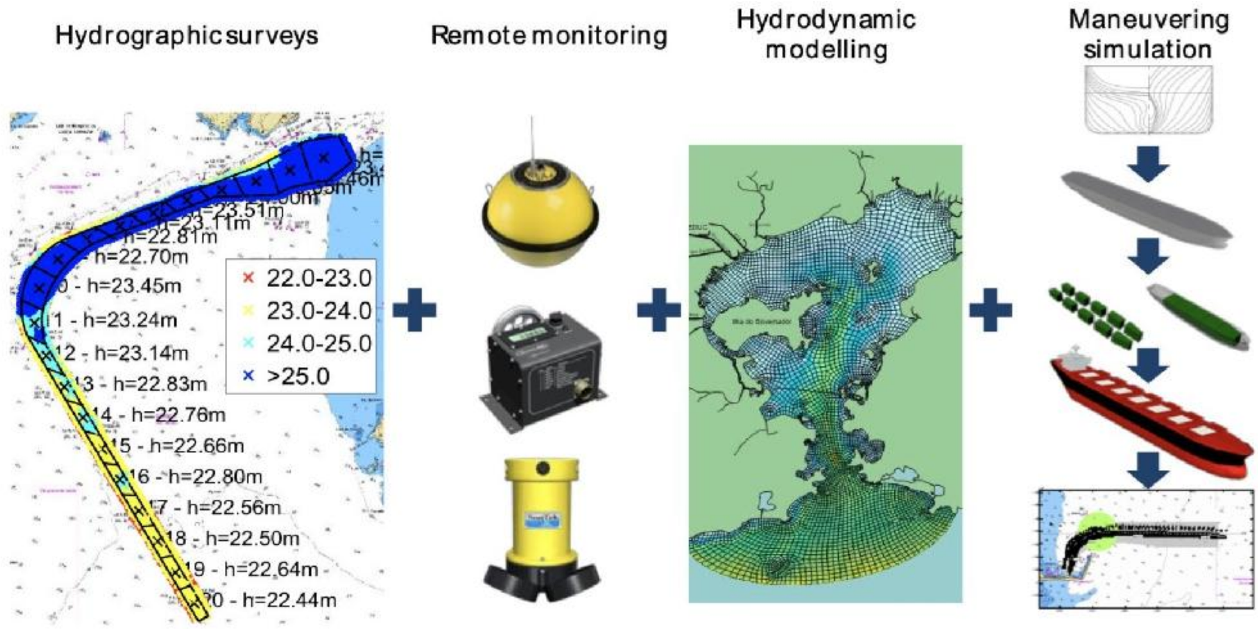

Figure 9: *Data sources for dynamic UKC management systems.*

Source: *Ruggeri et al, 2018*

Finally, the other data source used in the implementation of the dynamic UKC determination systems is related to the ship's maneuverability factors, in this case, model ships are established and modeled by the system developer and tested in tanks in order to determine the dynamic responses to fluids (water and air). Such simulations increase the accuracy of the vessel's behavior in various situations of yaw and speed on the waterway. Through computational resources, the coefficients that will be inserted in the systems are calculated, reducing the associated uncertainties.

After integrating these data, the systems use computational resources to operationalize their use and calculate the ideal intervals for each maneuver. “Nowadays, cloud computing offers great computational capacity and the data transfer from the monitoring system is very robust, with access to the internet on several platforms.” (Ruggeri et al, 2018, p.16)

In this way, in order to optimize the system, calculations are performed in the cloud and the output format and the respective computational platform can be customized according to the preferences of each user. Since different users may require different data, for example those required by the IHO S-129 model, a single database is managed in the cloud to provide each user with the required information.

The systems validation phase aims to determine the accuracy and precision in the determination of the elements that compose the calculation of the UKC, in addition to certifying that the decision support information extracted from them fulfills the requirements, ensuring that the system will provide a sufficient probability suitable for safe use by its users.

Meteoceanographic data, because they are obtained through on-site measurements, are susceptible only to the uncertainties of the sensors and will present results as satisfactory as the equipment specifications are. Therefore, in order to maintain the validity of these data, the maintainer of these systems must comply with the periodicity of calibration and replacement of components established by the manufacturer.

The uncertainties related to the hydrodynamic models are also measurable and usually associated with the interpolation factors used by the formation algorithm, however, as they have the possibility of feedback by the sensors, they tend to present an even more reliable performance.

Therefore, the greatest source of uncertainties in the validation of the systems is linked to the execution in the real environment of the simulations performed on the models created for the test tanks.

Therefore, for a system to be validated, it is necessary to carry out evaluation runs on standard ships for which the calculation of the dynamic draft is appropriate in that port. These tests will ensure that the sum of uncertainties, both in the data acquisition phase and in the calculations made by the software, will be lower than the safety margins used by the authorities in determining the Maneuverability Margin.

A methodology used in carrying out the evaluation runs consists of the disposition of DGPS receiving antennas at the bow, stern and at the ends of each edge. Through the obtained positioning data, it is possible to measure the rotation and translation responses of the platform on its axes of freedom, along the entire route traveled on the waterway. Therefore, once the parameters provided by the system are known and the quantities measured during the tests, it is possible to guarantee, by comparison, the accuracy of the data provided by the system and to evaluate the robustness of the parameters obtained in test tanks for each type-vessel.

5. CONCLUSION

The management of under keel clearance is becoming a reality in most of the ports around the world. As the demand for efficiency grows, it is important to have a decision support tool that fulfills this purpose keeping the requirements of navigation safety.

The methods for determining operational windows or non-navigable areas using only static factors are ways for decision-making tools that consider in particular the environmental factors, both those of the vessel and the structural characteristics of the channels.

The use of these systems allows accurate determination of the best times for entering and leaving ports by observing and forecasting environmental elements, thereby increasing the efficiency of port maneuvers. When it is integrated with the navigation systems, incorporating the E-Navigation concept, the determination of the under keel clearance allows commanders and pilots to manage speed variations, use of tugs and areas to be avoided during navigation in restricted waters having more accurate subsidies.

It was seen that the creation of standards, such as the S-129 framework by IHO, resulted from the perception of the diversity of actors that exchange information, in the operation of the computational systems that calculate and predict the UKC.

This research has identified the environmental and vessel parameters involved in the calculation and prediction of the dynamic draft, however it is assessed that the experience in the effective use of those draft systems is vital in increasing the accuracy of the responses, resulting in economic efficiency and respecting the security aspects. Besides, as it was previously mentioned, it is needed to adopt minimum parameters capable of being used as indicators, which will allow a quick and objective analysis by the Maritime Authority.

The economic advantages associated with the use of these systems are undeniable, keeping the security of port navigation. In addition, intangible and priceless gains are highlighted, such as the prevention of environmental disasters, reduction in the emission of polluting gases and consumption of fossil fuels per ton transported, greater speed of production flow, among other ones.

The improvement of equipment, hydrodynamic models and the computational technologies involved tend to increase the accuracy and precision of the factors predicted by the systems. The use of dynamic under keel clearance management tends to become a common and fundamental practice in the future of waterways. However, the navigator that uses this navigation aid is still likely to be analyzed in order to make the correct decision keeping the safety of navigation and the safety of life at sea, even having these robust and reliable tools.

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Articles

CONVERSION OF ELECTRONIC NAVIGATIONAL CHARTS FROM S-57 TO S-101 STANDARD FORMAT

By Lieutenant G. Neves Vieira, D.Sc. F. Mandarino (Brazil)

Abstract

With the advance of technology, the S-57 standard format has become rigid and inflexible, creating a need for a new standard of information exchange. The IHO published the S-100 standard which enables the exchange of information of various types, among them ENC S-101. Therefore, an update of the ENC from S-57 to S-101 will be necessary. In order to facilitate an efficient conversion, IHO, through ESRI, developed specialized conversion software. This article aims to test the converter provided by the IHO/ESRI/NOAA partnership and analyze the results, presenting possible causes of errors and solutions, through the use of a Brazilian sample of S-57 ENC.

Résumé

Avec les avancées technologiques, le format standard S-57 est devenu rigide et non flexible, rendant nécessaire une nouvelle norme d'information. L'OHI a ainsi publié le cadre S-100 qui permet l'échange d'informations de différents types, dont les ENC de la S-101. Une mise à jour des ENC de la S-57 sera donc nécessaire. Afin de faciliter ce travail, l'OHI, par le biais d'ESRI, a créé un logiciel de conversion. L'article qui suit vise à tester le convertisseur fourni par le partenariat OHI/ESRI/NOAA, et à analyser les résultats, en présentant les causes possibles d'erreurs et les solutions, en utilisant un échantillon brésilien des ENC de la S-57.

Resumen

Con el avance de la tecnología, el formato normalizado S-57 ha pasado a ser rígido e inflexible, y se necesita un nuevo estándar de información. Por eso la OHI publicó el marco S-100, que permite el intercambio de información de varios tipos, entre ellos las ENCs de la S-101. Por tanto, se necesitará una actualización de las ENCs de la S-57. Para hacer más fácil este trabajo, la OHI a través de ESRI ha creado un software de conversión. Este artículo pretende probar el convertidor proporcionado por IHO/ESRI/NOAA y analizar los resultados, presentando posibles causas de errores y soluciones, usando una muestra de S-57 ENC de Brasil.

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1. INTRODUCTION

Electronic navigation consists of defining the position and controlling the ship by any kind of electronic system or equipment (Miguens, 2019) on board of almost every ship, no matter their size or type. For such a task, there are many platforms that can integrate several systems with ship capabilities.

SOLAS (Safety of Life at Sea) vessels, such as merchant ships, use the ECDIS (Electronic Chart Display Information System), an electronic system that integrates information from various sensors, for navigation and visualization of nautical charts. ECDIS works with ENC (Electronic Navigational Charts), which are official nautical charts produced by Hydrographic Offices all around the globe, in accordance with the guidelines and technical specifications established by IHO (International Hydrographic Organization). ENCs are used globally and regulated to permit data transfer between Hydrographic Offices and sailors.

ENCs are databases which contain all information available on paper nautical charts and they can have additional data that might help navigators. ECDIS can interact with ENC features, allowing, inside rigid regulations, to customize the visualization of electronic chart features and also the querying of ENC details and features. Once ECDIS receives information from many sensors, such as the gyro, GNSS (Global Navigation Satellite System), radar, and so forth, all of these data are integrated and shown in a single console, which contributes to safety of navigation.

IHO, as regulator of hydrographic standards for safety of navigation, published the ENC standards. Today, the S-57 standard is the one authorized for use. This standard was developed in the 80's, and ENC production was gradually implemented over the last three decades. ENCs also meet the requirements of Rule 9, Chapter V, of the Safety of Life at Sea regulations.

Due to the progress of technology over the last decades and the establishment of geospatial data standards by the OGC (Open Geospatial Consortium) and ISO (International Organization for Standardization), S-57 standards have become outdated. Also, hydrographic data should be used not only for navigational purposes, but also to integrate other geospatial data. For that reason, IHO has recently published S-100 (IHO Universal Hydrographic Data Model), which will easily, simply and safely enable it to integrate data of several kinds, such as high-resolution bathymetry, meteorology, tides, and so on, aiming at navigation safety.

In parallel, the International Maritime Organization (IMO) has processed the concept of e-Navigation, which consists of "the harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment", as defined by IMO (2020). The concept of e-Navigation provides that, for the integration of information, S-100 products are used.

There is now then be a need to transition from the products and services currently made available to sailors to the new S-100 standard. This implies that hydrographic services will start making available the new S-100 products, according to a schedule to be set by IHO and other international associations, such as the World Meteorological Organization (WMO) and the International Association of Lighthouse Authorities (IALA). In the specific case of ENCs, it must be mandatory, according to the standard that specifies the new product, the ENC S-101 (ENC Product Specification).

As with any transition, it is necessary to provide and support for both, the new and the old product, concomitantly. As such, Hydrographic Services will have to produce the ENCs under their responsibility in accordance with both standards for a long period of time, until IHO and IMO define a deadline for the availability of all S-101 ENC and the installation of S-100 ECDIS compatible with new products and services, on all SOLAS vessels. The other organizations, such as WMO and IALA, will also be in line with these changes, setting deadlines within their competencies. In the case of ENCs, the need for production, updating and concomitant support for the two standards (S-57 and S-101) will require a major development and production effort for Hydrographic Services.

IHO, being aware of the effort needed for a change of this size, requested Environmental Systems Research Institute (ESRI) and the National Oceanic and Atmospheric Administration (NOAA) to develop a converter. This converter is intended to transform the data from the S-57 standard into the new S-101 standard. After the creation of this software, IHO itself has encouraged that it be tested, and it is currently distributed free of charge by ESRI.

Thus, this article aims to test the converter provided by IHO / ESRI / NOAA partnership, for the conversion of navigation charts in the S-57 standard into S-101. Due to the simple fact that the update of standards is complicated, it has been anticipated that some S-101 ENC features will not be perfectly contemplated by the conversion of the ENC S-57 features, which will require manual work of data coding and / or additional attributes.

2. LITERATURE REVIEW

The ENCs currently used follow the guidelines established in the S-57 standard, which have been used for a long time. Companies have manufactured and produced systems capable of interpreting and presenting the ENC S-57 data. These systems, called ECDIS, have been improved and updated, in order to currently achieve the most modern and technological level in terms of navigation, by integrating several systems and consoles in a single piece of equipment capable of managing all this information.

ECDIS are able to gather information from several sensors available in just one equipment, which, in turn, is able to gather all these data and present it to the navigator in accordance with the specific standards set by the International Electrotechnical Commission (IEC) and other organizations. ECDIS can also perform calculations and projections, make markings on the screen, alert the user of dangers through alarms, monitor contacts, present various information layers, such as radar and Automatic Identification System (AIS), among several other additional features, inherent to each equipment from each manufacturer.

The S-100 standard, in the scope of e-Navigation, comes in line with the thought of insertion capacity and presentation of layers made possible by the current ECDIS. The future S-100 ECDIS will have the ability to provide the user with the application and presentation of several layers, based on the ENC S-101. Beyond the S-101 ENC, it will be possible to use the other products of the S-100 family, such as Water Level Information for Surface Navigation (S-104), Surface Currents (S-111), Navigational Warnings (S-124), Under Keel Clearance Management (S-129), Weather Overlay (S-412), among others.

As for the development of new equipment and systems capable of working with the S-100 products, the Korean Hydrographic and Oceanographic Agency (KHOA) has been testing systems for visualization of the S-101 ENC together with other S-100 products, since 2017, in order to contribute to the development of standards for the use of S-100 products in future ECDIS.

According to the report issued by KHOA, the ECDIS prototype test was conducted by members of the hydrographic services of the United States of America, United Kingdom and Canada (Korean Hydrographic and Oceanographic Agency, 2017). Also, according to this report, the test was carried out between Busan and George Islands in the Republic of Korea, on board of the KHOA research ship called Hae Yang 2000 and tested ten[1] S-100 standard products.

As the main comments made by KHOA, it has emphasized that it is necessary to harmonize the presentation of data by the navigation system. They also warn that if the development and presentation of the products are done in isolation, there will be a lot of information on the screen, causing the need for collaboration between the working groups responsible for the development of the various S-100 products.

On the other hand, within the scope of the S-100 production, Teledyne Caris has published a new version of the Caris HPD 4.0 software that is capable of working with S-100 products. According to the company, the program is able to edit and work concurrently with the two information standards and create ENC of the S-57 and S-101 standard.

Although there is already a functional ECDIS prototype, many tests and developments are still necessary, mainly in the matter of data presentation, in order to be able to reach a safe and reliable level according to the established safety standards. Only in this way can the new S-100 standard be properly used.

Finally, this study meets the scope of the tests recommended by IHO, for the conversion of ENC S-57 into ENC S-101.

3. METHODOLOGY

In the development of this study, the converter developed by ESRI, version 1.0.0.20, will be used. It is expected that the program can convert most objects and attributes. However, as the software is not fully functional and not all S-57 data has a direct S-101 equivalent, there will be a need to analyze and process the converted data to verify the consistency and reliability of the conversion.

The conversion by the program generates log files with warnings, errors and information about the conversion process. ENC S-57 will be converted and subsequently analyzed, based on the records, to verify the errors that had occurred and possible causes and solutions, thus enabling full compatibility of the new ENC S-101.

The types and quantity of warnings, errors and other information will be taken into account so that they can be qualified and quantified. After that, causes will be analyzed so that changes can be suggested and the necessary corrections are made.

This study has been carried out in partnership with CHM (Brazilian Navy Hydrographic Center), which provided a sample of coastal, approach and port ENCs to be converted. The ENCs chosen cover the area between the Port of Santos, in the state of São Paulo, and Vitória / Tubarão, in the state of Espírito Santo, passing by the coast of Rio de Janeiro. Due to the scales of these ENCs, some have a wide scope and others have a great wealth of data depending on the geographic region. In addition, they represent an important area for maritime navigation and economic development in Brazil.

Table 1 lists the ENC that have been used and converted in the course of this study

[1] - S-101, S-102, S-104, S-111, S-122, S-123, S-124, S-127, S-129 e S-412.

Table 1 : ENC used.

ENC	Name
BR501401	Portos de Vitória e Tubarão
BR401410	Proximidades dos Portos de Vitória e Tubarão
BR401501	Baía de Guanabara
BR401506	Proximidades da Baía de Guanabara
BR501511	Barra do Rio de Janeiro
BR501512	Porto do Rio de Janeiro
BR401607	Baías da Ilha Grande e de Sepetiba
BR501621	Baía da Ilha Grande – parte leste (terminal da Ilha Guaíba)
BR401622	Baía de Sepetiba
BR501623	Porto de Itaguaí
BR501643	Canal de São Sebastião (parte norte)
BR501644	Canal de São Sebastião (parte sul)
BR401711	Proximidades do Porto de Santos
BR501712	Porto de Santos - parte norte
BR501713	Porto de Santos - parte sul
BR322900 (INT 2122)	De Vitória ao Cabo de São Tomé
BR323000 (INT 2123)	Do Cabo de São Tomé ao Rio de Janeiro
BR323100 (INT 2124)	Do Rio de Janeiro a Santos

4. IHO S-57 AND S-101 STANDARDS

This chapter will focus on briefly describing and outlining the structure of the S-57 data, in order to familiarize the reader with this type of data, and so allow a better understanding during the analysis of the results obtained in this study. It should be noted that, during the development of Chapter 4, all information will be based on the publications that govern the ENC S-57 and S-101 standards.

According to IHO, the S-57 standard has been developed in order to allow the transfer of data that describe the real world, in a simplified but very specific way (International Hydrographic Organization, 2000). Specificity is based on the need to keep the necessary data under control and to model only the information relevant to hydrography.

In order to model the real world, IHO defined two main types of data – objects and attributes. As defined by the IHO, objects are an identifiable set of information. Objects can have attributes and can be related to other objects. They were further divided into two types, "feature" and "spatial". The feature object contains the non-locational information. On the other hand, spatial objects can contain locational information about real world entities.

Although the new information standard S-101 maintains the same data structure of objects and attributes, the newer standard has a different approach in that S-101 attributes can be either simple or complex. ***Table 2*** lists the seven types of S-101 simple attributes.

Table 2 : Types of S-101 simple attributes.

Attribute	Definition
Boolean	the value is a logical value either 'True' or 'False'
Integer	the value is an integer number
Real	the value is a floating point number
Enumeration	the value is one of a list of predefined values
Text	the value is general text. This is also defined as CharacterString
Truncated Date	the value is a date according to the Gregorian calendar, and allows for partial dates to be provided
Time	the value is a 24 hour time, it may contain a time zone

Complex attributes are defined as an aggregate of simple and / or complex attributes. This junction occurs through links between the attributes.

Another major difference between the two patterns is the correlation between objects and attributes. Some correlations have remained the same, but others have been completely changed. In some cases, there is a need for total remapping of the object and its attributes and in other cases, the attributes have been remodeled.

As a semantic case, the new RESARE (Restricted Area) may or may not be linked to navigation. A good example is the case of restricted areas for activities related to navigation (Restricted Area Navigational) or for other activities, which do not directly interfere with navigation (Restricted Area Regulatory). Both are coded with the acronym RESARE.

For example, to define a prohibited fishing area in the S-57 standard, a RESARE – Restricted Area – must be defined and assigned to its RESTRN – Restriction attribute – the value "3-Fishing Prohibited". On the other hand, according to Annex A of S-101 (IHO, 2018), the S-101 Codification Guide (DCEG - Data Classification and Encoding Guide) – Annex A of S-101 Standard, a RESARE (Restricted Area Regulatory) must be defined and assigned to attribute RESTRN (Restriction) with the value "3-Fishing Prohibited".

In ENC S-57, RESARE is defined as an area designated by an appropriate authority within which navigation is restricted in accordance with certain specified conditions, that is, by definition this type of area is intended only for navigation restriction, although the attribute RESTRN make it possible to restrict a fishing area, for example. In this case, where the only restriction is fishing, ECDIS would treat the area in the same way as an area where navigation was restricted. On the other hand, in S-101 ENCs these codifications are separated and make it possible to treat areas restricted to navigation or restricted areas in different ways.

5. DISCUSSION OF S-57 AND S-101 ENCS COMPARATIVE STUDY

The standards established for the S-57 and S-101 ENCs, although they may seem very similar, have very significant differences, not only in terms of the structure of the data, but in terms of the metadata of each cell (ENC file). Since there are differences between these two standards, some changes should be made to all files, as described in the following items.

5.1 MAXIMUMDISPLAYSCALE AND MINIMUMDISPLAYSCALE

As a significant example, which should be carefully studied by the Hydrographic Services for the preparation of S-101 ENC, there is the attribute of minimum and maximum scale for the visualization of each cell.

Currently, in the S-57 standard, by the S-52 data visualization standard (International Hydrographic Organization, 2015), the visualization of the ENCs inside ECDIS obeys the purpose of use and the compilation scale of the cell, through the Compilation Scale (CSCL) metadata, which tells from which scale such a cell should not be used. Normally, the CSCL is the double of the ratio scale of the respective paper chart.

However, the S-101 requires that each dataset have the scale values individually configured, both for the maximum scale, corresponding to the old CSCL and the visualization scale from which ECDIS displays the overscale message, and for the minimum scale of display, from which the ENC starts to be visualized. This configuration is extremely important as it will guarantee the navigator the proper use of the S-101 ENC.

To better visualize the issue of the minimum and maximum scale, we have ***Figure 1*** (International Hydrographic Organization, 2018). There are three different cells with different maximum and minimum scales, described in the first line. The drawing order in ECDIS is from left to right, starting with ENC “X”, then “Y”, and finally “Z”. The expression “Mariners Selected Viewing Scale (MSVS)” refers to the navigator's viewing scale in ECDIS.

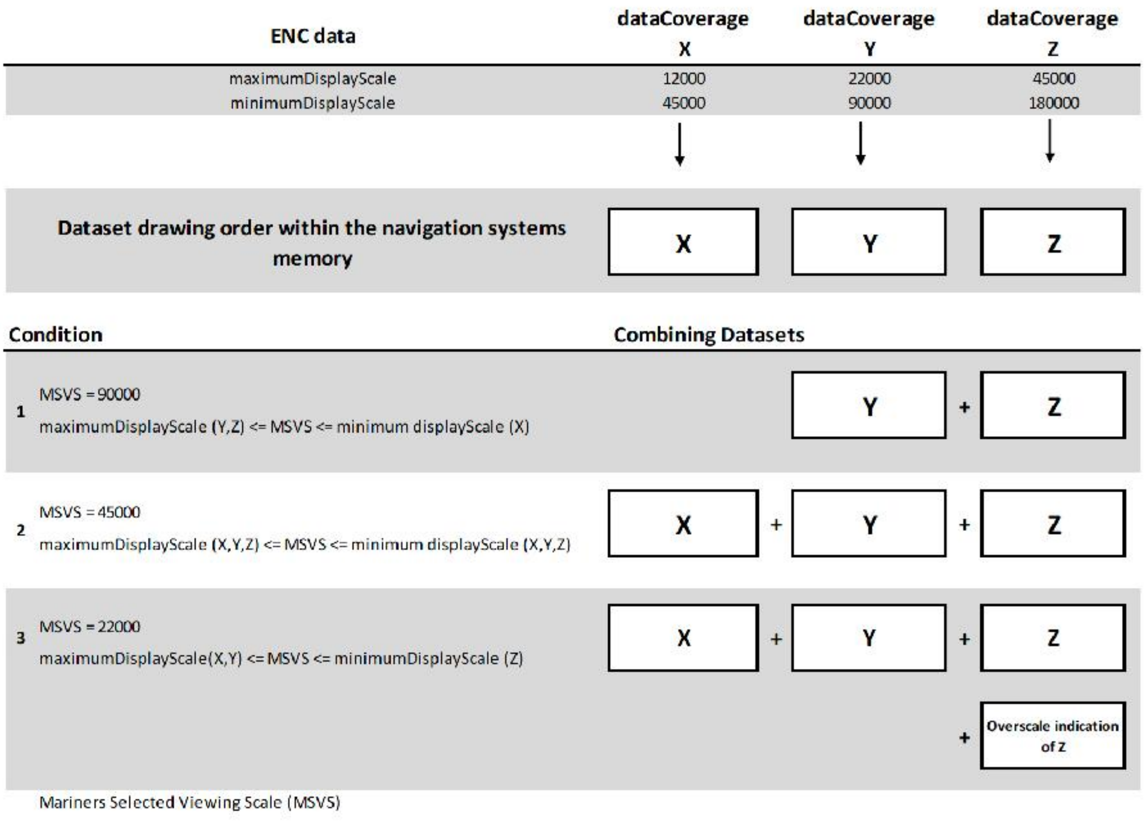

Figure 1 *: Data Loading Algorithm*

In the first condition, the MSVS is 90,000. As the minimunDisplayScale of ENC “X” is bigger than the MSVS it is not shown in this scale of visualization so it will not be presented to the navigator, but only the ENC “Y” and “Z”.

$$maximumDisplayScale(Y, Z) \leq MSVS \leq minimumDisplayScale(X)$$

Subsequently, in condition 2, the MSVS equals to 45,000:

$$maximumDisplayScale(X, Y, Z) \leq MSVS \leq minimumDisplayScale(X, Y, Z)$$

Thus, all cells will be displayed, with preference being given to "X", of a larger scale, then to "Y", and finally to "Z" of a smaller scale. In this last condition, where MSVS has a value of 22,000, we have:

$$maximumDisplayScale(X, Y) \leq MSVS \leq minimumDisplayScale(Z)$$

Thus, the datasets "X" and "Y" are displayed normally and "Z" will also be displayed but with an alert that it is over scaled. Finally, it is suggested that the Hydrographic Services conduct studies on board of ships, so they will be able to choose the best scale for each dataset.

5.2 NAMING THE DATASETS

Another difference is in the pattern of file names for each cell. According to IHO (International Hydrographic Organization, 2018) the name of each cell must comply with the following standard: 101CCCC0000000000.EEE as explained below.

The first three characters – "101" – are mandatory, demonstrating that the file is an ENC S-101. The next four characters – CCCC – refer to the issuing entity of that ENC, coded according to the producer code, which can be between 2 and 3 characters long in the current S-57 standard and the missing characters can be completed with "00" or "0". Then we have a sequence of zeros, which indicate a composition of at least 8 and at most 17 alphanumeric characters and / or the special character _ (underscore), in order to have a unique combination for each file. This opens up a range of new possibilities for existing encoding names.

Taking for example the Brazilian ENC 23100, which is currently named "BR323100.000", it could become "101BR0000023100.000". As a great possibility, it can be mentioned that the charts belonging to the waterways may carry their respective names or codes. For example, "101BR00AMnnnnnn.000", where "AM" would indicate Amazon River and "nnnnnn" the chart number. There may be several other possibilities and possible combinations.

Finally, ".EEE" indicates editions and / or updates, "000" for new datasets and new editions and updates, starting from 001 to a maximum of 999. This is a mandatory element in cell names. And the new aspect is the possibility of updating cancellations, that is, an update that cancels the previous version of ENC and publishes a new one, using the same name. For example, if a Hydrographic Service needs to publish a new version of an ENC, it will no longer be necessary to withdraw the old ENC from circulation and publish the new version by a new name, it will simply be possible to publish a new ENC of the same name, with the format ".000", which will then cancel the previous version and become the updated ENC, having the same name as the previous file.

Another difference is that in the new S-101 standard there will no longer be a need to include the purpose of use in the dataset nomenclature, so allowing hydrographic services more flexibility to name the cells.

So being, it is possible to verify some general changes that will affect the making of an ENC and its coding. As a result, all ENCs should be individually reassessed and studied for the change from standard S-57 into S-101.

5.3 CONVERSION RESULTS

Due to the results of the conversions, the program categorizes the errors into two types: "Warnings" and "Information". Both types of errors are dangerous, as ENCs may no longer have important information for the sailor and thus compromise the safety of navigation. Thus, this study will address a possible solution throughout the analysis of the results.

Below, you can see ***Table 3*** that relates each ENC with the types and number of errors present in each conversion.

Table 3 : Correlation between ENC and errors types

Cell	Info	Warning	Total
BR 3 22900	8	32	40
BR 3 23000	11	33	44
BR 3 23100	7	119	126
BR 4 01410	19	31	50
BR 4 01501	13	83	96
BR 4 01506	13	74	87
BR 4 01607	2	46	48
BR 4 01622	9	99	108
BR 4 01711	17	48	65
BR 5 01401	6	110	116
BR 5 01511	13	124	137
BR 5 01512	12	81	93
BR 5 01621	3	7	10
BR 5 01623	8	80	88
BR 5 01643	1	52	53
BR 5 01644	1	80	81
BR 5 01712	13	0	13
BR 5 01713	7	28	35
Total	**163**	**1,127**	**1,290**

By analyzing ***Table 3***, it can be quickly seen that there is no direct correlation between the total number of errors and the purpose of using each ENC. Another point that can be concluded is that the amount of "warning" is almost always higher than the amount of "info".

After the conversion, 1,290 errors were verified, of which 163 were of the “info” type and the other 1,127 were of the “warning” type. The errors were filtered and grouped by similarity, so being 63 different error groups were obtained, even though they could be regrouped. At the end of the filtering, it was found that as much as the number of "warnings" was higher, many errors were repeated and thus greatly simplifying the analysis and correction of the data. Finally, there were only 20 “warning” and 43 different “info” errors.

In the following items, the main errors (info and warning) have been separated and classified by types, in order to facilitate understanding and improve the organization of this study and data resulting from the conversion.

5.4 "INFO" TYPE ERRORS

In this item, the "info" errors present in the compilation of all log files generated during conversions will be shown. Then they will be aggregated by similarity and possible solutions for a better understanding will be proposed. The title of each subsection is the error itself, and the causes and solutions will be shown in its development.

5.4.1 Attribute EXPSOU for feature SOUNDG dropped from S-101 feature Sounding.

In this error, the attribute EXPSOU – Exposition of Sounding – has been removed from the SOUNDG - Sounding object. According to DCEG, the EXPSOU attribute indicates objects in which the sounding value is outside the depth range where it is located. The publication itself points out that this attribute indicates objects that could be potential hazards to navigation.

Although this security feature has been removed from surveys, IHO draws special attention to this detail. Thus, DCEG recommends caution when encoding soundings that are shallower than the area depth variation of the area, since sounding values will not always be shown, depending on the user's settings in ECDIS. This possibility is not exclusive to the S-101 and already existed on the S-57, however, as this attribute has been removed from the S-101, IHO has reinforced the importance of correctly coding, using other resources as available, the use of an obstruction area, which would not be hidden along with the sounding in the ECDIS configuration.

5.4.2 Attribute NATQUA for feature UWTROC dropped from S-101 feature UnderwaterAwashRock.

In this error, the NATQUA attribute – Nature of Surface-Qualifying Terms – has been removed from the UWTROC - Underwater / Awash Rock object. According to DCEG, the NATQUA attribute encodes the surface material in terms of its size, morphology and consistency. According to the decision of the S-101 Electronic Navigational Chart Project Team (S101PT), this attribute will no longer be necessary for the UWTROC object in ENC S-101.

5.4.3 Attribute QUASOU for feature SWPARE dropped from S-101 feature SweptArea.

For the SWPARE – Swept Area object – the QUASOU attribute – Quality of Vertical Measurement – has been removed. This attribute is about the reliability of a sounding value. According to IHO, this attribute will be inserted in the metadata M_QUAL – Quality of Bathymetric Data – which encodes the quality of bathymetric data for a given area (International Hydrographic Organization, 2019).

5.4.4 Attribute SCAMIN for feature BRIDGE dropped from S-101 feature SpanFixed.

This error occurred not only with the SpanFixed object, but also with the SpanOpening and COALNE – Coast Line object – and it means that the SCAMIN - Scale Minimum attribute has been removed from these objects.

According to IHO, the SCAMIN attribute defines the minimum scale that the referred object can be used (International Hydrographic Organization, 2018), as an example in the visualization through ECDIS.

Here is a brief explanation of how to code a bridge in the S-101 to better understand this error. According to IHO, when a bridge is coded on navigable water, the new standard must be made up from the BRIDGE – Bridge type object – together with other correlated objects (SpanFixed; SpanOpening; and PYLONS - Pylon / Bridge Support) through the association called "Bridge

Aggregation" (International Hydrographic Organization, 2018). The BRIDGE object by itself does not have a defined geometry, and its representation comes from geometry inherited from the objects present in its aggregation. In ***Figure 2***, it is possible to verify a coding scheme for an "Opening Bridge", that is, a bridge that is closed when it allows the traffic of cars and open to make maritime traffic possible.

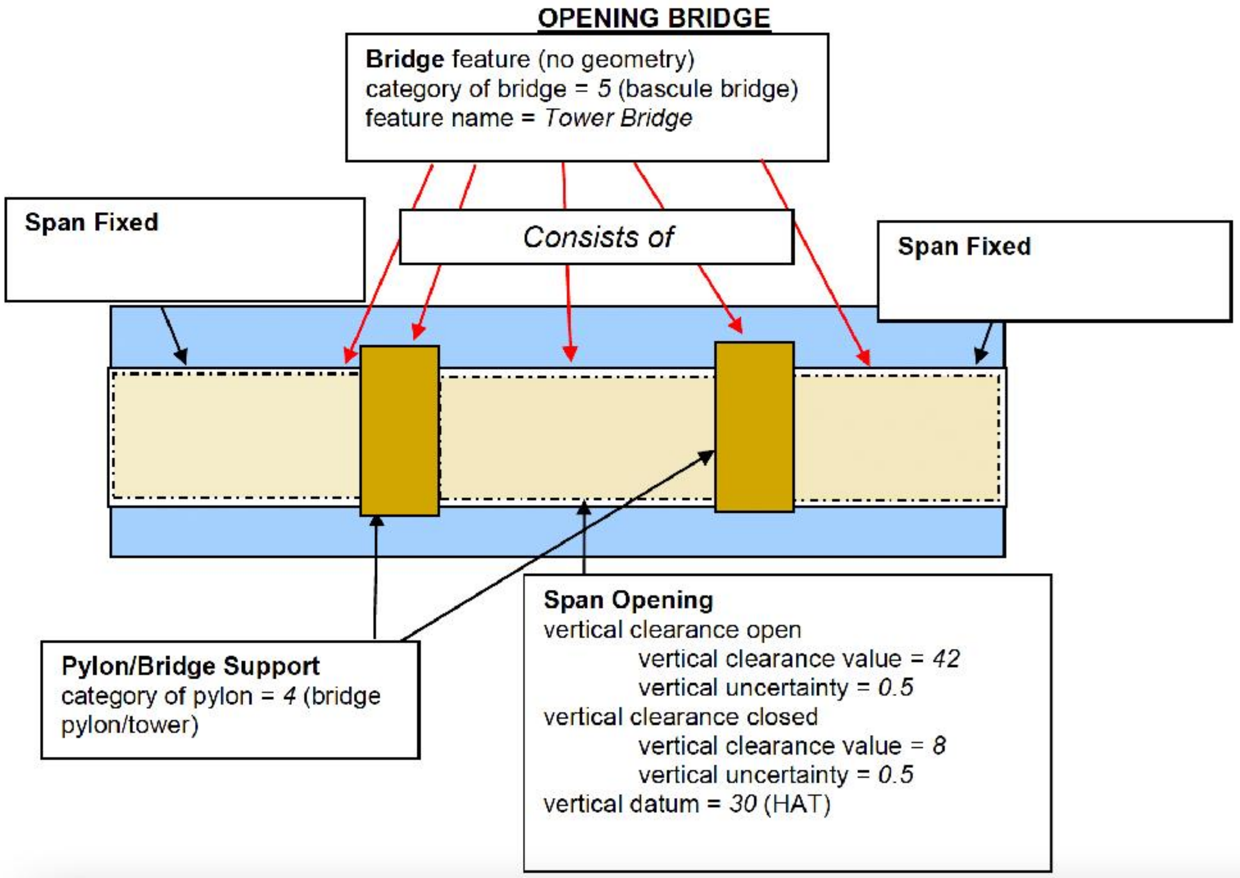

Figure 2 : *Opening Bridge Example*

Once the previous part of the process has been explained, the SCAMIN attribute will not be linked to each SpanFixed or SpanOpening object, but to the bridge as a whole encoded as BRIDGE – Bridge – and all of its pieces will be gathered through the configuration called "Bridge Aggregation".

The converter was able to perform the conversion correctly. The "Presidente Costa e Silva" Bridge (also known as "Rio-Niterói" bridge) was converted into an aggregation of objects, of which the main one was the BRIDGE type, with the correct value for the SCAMIN attribute, which can be seen in ***Figure 3***. The central span and lateral spans have been defined each as an object of the type "SpanFixed" with its respective attributes, and the rest of the bridge extension was divided into just two objects.

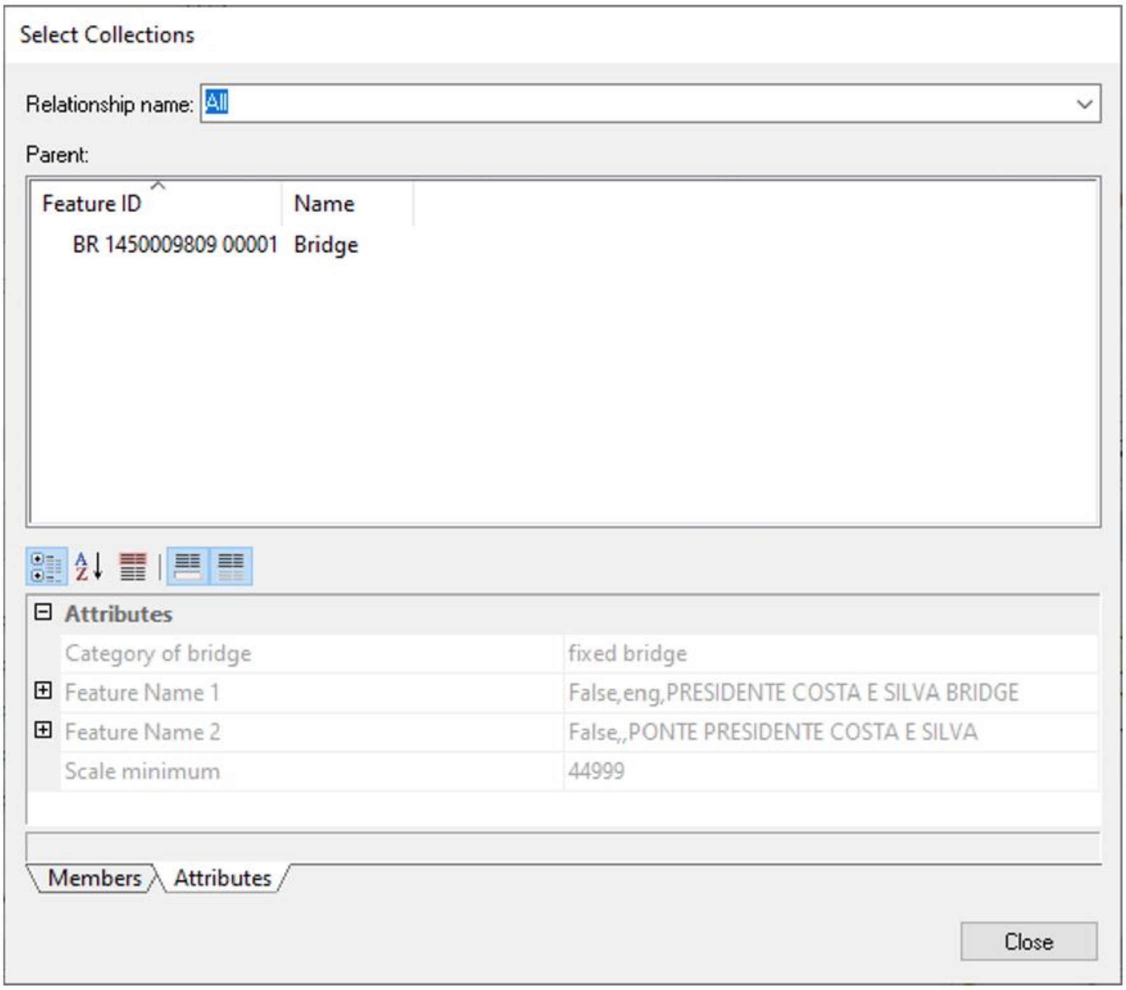

Figure 3 *-:SCAMIN attribute corrected assigned for BRIDGE object in ENC S-101*

In ***Figure 4,*** it can be seen that the "Bridge Aggregation" was correctly assigned to the "Rio-Niterói" Bridge. And finally, in Figure 5 it is possible to see some of the elements that compose the "Bridge Aggregation" of the "Rio-Niterói" Bridge in the converted ENC S-101.

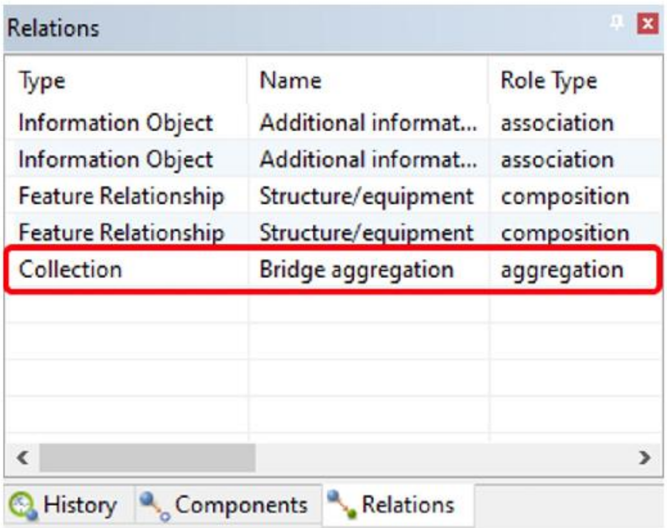

Figure 4 *: Bridge Aggregation - correctly assigned to « Presidente Costa e Silva » Bridge in ENC S-101*

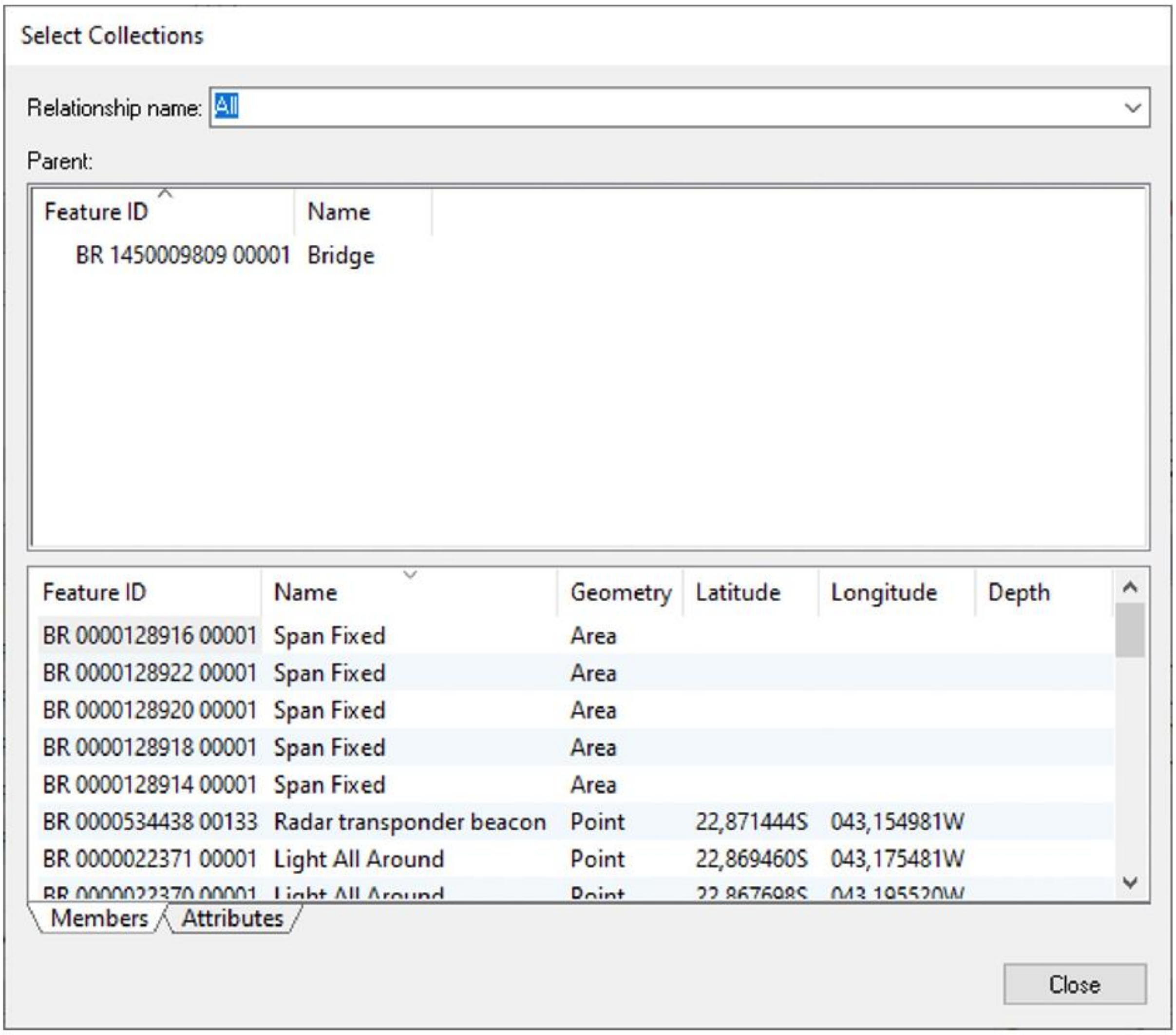

Figure 5 *: Elements of « Presidente Costa e Silva » Bridge Aggregation in ENC S-101*

5.4.5 Attribute SORDAT for feature ACHARE dropped from S-101 feature AnchorageArea.

The attribute SORDAT - Report Date - in general, indicates the date when a feature was observed, completed or investigated.

This error occurred for the following objects: ACHARE - Anchorage Area; ADMARE - Anchorage Area; BOYINB - Buoy Installation; BOYSPP - Buoy Special Purpose / General; BRIDGE - Bridge; DEPARE - Depth Area; DEPCNT - Depth Contour; DMPGRD - Dumping Ground; LIGHTS - Light All Around; and RESARE - Restricted Area Navigational. According to IHO in general, this attribute has been removed from the S-101 (International Hydrographic Organization, 2019), remaining only in some objects.

5.4.6 Attribute SORIND for feature ACHARE dropped from S-101 feature AnchorageArea.

Again, this error occurred for several objects, which are: ACHARE - Anchorage Area; ADMARE - Anchorage Area; BOYINB - Buoy Installation; BOYSPP - Buoy Special Purpose / General; BRIDGE - Bridge; BRIDGE - SpanOpening; CTNARE - Caution Area; DEPARE - Depth Area; DEPCNT - Depth Contour; DMPGRD - Dumping Ground; DRGARE - Dredged Area; HRBFAC - Harbor Facility; LIGHTS - Light All Around; MORFAC - Mooring / Warping Facility; OBSTRN -

Foul Ground; OBSTRN - Obstruction; PIPSOL - Pipeline Submarine / On Land; RESARE - Restricted Area Navigational; SLCONS - Shoreline Construction; SOUNDG - Sounding; and WRECKS- Wreck. According to a decision by S101PT, the SORIND attribute has been completely removed from the S-101. Therefore, this error does not generate any action necessary for its correction.

*5.4.7 Attribute TECSOU for feature the SWPARE dropped from S-101 feature Swept*Area.

The TECSOU - Technique of Vertical Measurement - attribute is no longer correlated with the SWPARE - Swept Area object. This attribute lists the possible survey methods that are used to obtain depth information. According to IHO, this attribute is no longer needed for the SWPARE - Swept Area object (International Hydrographic Organization, 2019).

5.4.8 Attribute VERCCL for feature BRIDGE dropped from S-101 feature Bridge.

Instead of what happened with the SCAMIN attribute on the BRIDGE object, the VERCCL attribute - Vertical Clearance -, which defines the vertical distance from the horizontal reference plane to the bottom of the feature in the real world, must be defined individually for each part of a bridge. Specifically, the VERCCL attribute must be encoded for each Span of a bridge. Thus, a thorough search should be made on all values for each span that composes a bridge for coding this attribute correctly.

This codification must be checked manually for each span of a bridge, since the ESRI converter may not correctly assign this attribute to each span individually.

5.4.9 Attribute VERCLR for the feature BRIDGE dropped from S-101 feature SpanOpening

This error is similar to the error in item 5.4.8. The VERCLR attribute – Vertical Clearance – is linked to the Span Fixed object, individually coded for each object of this type present on a bridge. The correction of this error is made the same way as in the previous item.

5.4.10 Attribute VERCOP for the feature BRIDGE dropped from S-101 feature Bridge

Exactly the same as the error in item 5.4.8, but with the VERCOP attribute – Vertical Clearance Open – which is linked to the vertical distance between the horizontal reference plane to the bottom of the feature when an “Opening Bridge” is open.

5.4.11 Enumeration code 9 (rock) dropped for attribute natureOfSurface for feature Under-waterAwashRock

This error indicates that the value “9-rock” of the attribute NATSUR – Nature of Surface – was removed for the object UWTROC - Underwater / Awash Rock. According to the decision by the S101PT, the NATSUR attribute no longer has the value “9-Rock” for this object on the S-101.

5.4.12 Feature CTRPNT dropped from S-101

The object CTRPNT – Control Point – was removed from the S-101. In the S-57 standard, the CTRPNT object is defined as a point on land at which the position, both horizontal and vertical, is known and used as the basis for a survey. In the S-101 standard, this object has been remodeled to LNDMRK – Landmark – and is defined as any prominent object in a fixed position on land that can be used to determine a location or direction. This definition is more comprehensive and allows other functions for each LNDMRK. Thus, each case must be studied individually to verify the correct suitability of the points.

5.5 “*Warning*” errors type

This item will have the same approach that was given to item 5.4 and its subitems. In general, this type of error is linked to the identification number (ID) of each object that generated the error message. Caris editors have a tool to select objects by their ID, so it is possible to generate a list of objects with their respective ID and select them directly on Caris and manually correction of each one, thus facilitating the work of correcting the objects errors.

5.5.1 Unable to copy support file "PRESIDENTE COSTA E SILVA BRIDGE" referenced in NTXTDS for feature FE0000000900. File not found at path "C:/Users/Guilherme/ Documents/ENC/ENC S-57/BR501511"

This error occurred with all external description files present in the ENC directories. The NTXTDS attribute – Textual Description in National Language – encodes the name of the file external to the cell that contains a description in the national language. It was not possible to verify the cause of the error, but possibly there was some kind of discrepancy between the name of the external files. Therefore, it will be necessary to encode and configure each external file, individually, in ENC S-101.

5.5.2 Unable to map attribute EXPSOU for OBSTRN to FoulGround. Alias value not found in Feature Catalog.

“Foul Ground” is a safe area to navigate, but it should be avoided for anchoring, taking the ground or ground fishing. The coding of this type of area has changed, now it must continue coding with the acronym OBSTRN – Foul Ground – but with the different attributes of an OBSTRN - Obstruction.

The converter should be able to make this change automatically. Apparently, due to an inconsistency in the database, this object cannot be converted correctly, and its information must be verified and encoded manually.

5.5.3 Unable to map attribute PILDST for PILBOP to PilotBoardingPlace. Alias value not found in Feature Catalog.

In addition to the PILDST - Pilot District - attribute, the same error occurred with the NPLDST - Pilot District in National Language attribute. The attributes PILDST and NPLDST have been remodeled to an attribute of the Pilotage District object, with no direct correlation with the PILBOP - Pilot Boarding Place object. Similarly to the error in item 5.5.2, the converter should have made this correlation automatically. Apparently, due to an inconsistency in its database, this conversion was not performed, so it had to be encoded manually.

5.5.4 Unable to map S-57 enumeration code 1 (circular (non-directional) marine or aero-marine radiobeacon) for attribute CATROS for feature RDOSTA (BR000021604200133) to S-101 attribute categoryOfRadioStation for feature RadioStation

The conversion software was unable to assign the value “1-circular (non-directional) marine or aero-marine radiobeacon” to the attribute CATROS - Category of Radio Station. According to a decision by S101PT, it will no longer be necessary to code this value for the category of “radio stations” for nautical charts. The corresponding value will simply no longer be needed, nor will it be possible to encode it. Therefore, this error can be ignored.

5.5.5 Unable to map S-57 enumeration code 1 (directional function) for attribute CATLIT for feature LIGHTS (BR000019482300001) to S-101 attribute categoryOfLight for feature LightSectored

The CATLIT attribute – Category of Light – no longer has the value “1-Directional Function”. In order to code this same object on the S-101, an LIGTHS type object – Light Sectored – must be created and the Directional Character complex attribute must be configured according to the specific characteristics of the object's light. It is suggested to read item 19.3 of the CDEG for a better understanding of the coding of a directional light.

5.5.6 Unable to map S-57 enumeration code 1 (permanent) for attribute STATUS for feature OBSTRN (CATOBS = 7) (BR000005256300001) to S-101 attribute status for feature FoulGround

Similarly to the error mentioned in item 5.5.2, in which the object OBSTRN was remodeled, in this error the object OBSTRN – Foul Ground – the attribute STATUS no longer has the value “1-Permanent”. Therefore, it is not possible to perform a direct correlation, and this value for this attribute will no longer appear on the S-101. So being, this error does not require additional actions by the encoder.

5.5.7 Unable to map S-57 enumeration code 3 (fishing prohibited) for attribute RESTRN for feature RESARE (BR000000062900001) to S-101 attribute restriction for feature RestrictedAreaNavigational

In the S-57 standard, the RESARE object – Restricted Area – had several values for the attribute RESTRN – Restriction –, which defines the types of restriction. In the S-101 standard, this object was remapped into two different objects, but with the same acronym of RESARE (RESARE – Restricted Area Navigational – and RESARE – Restricted Area Regulatory), so that the first encodes the areas of restriction to navigation and the former deals with areas with regulatory restrictions. By default, the software used converts S-57 RESARE objects to S-101 RESARE - Restricted Area Navigational. As the choice between an area restricted to navigation or regulation depends on the value of the RESTRN attribute, some values cannot be converted correctly.

For the reason explained above, the error described occurred not only with the value “3-Prohibited Fishing”, but also with the following values: “4-Restricted Fishing”; “5-Forbidden Trawling Fishing”; "11-Prohibited Diving"; and “24-Prohibited Dragging”. To correct these errors, it is necessary to correct the object for RESARE - Restricted Area Regulatory, so the RESTRN attribute and its values can be included.

5.5.8 Unable to map S-57 enumeration code 3 (sandy shore) for attribute CATCOA for feature COALNE (BR000003232600001) to S-101 attribute categoryOfCoastline for feature Coastline.

This was one of the mistakes that happened more often in all conversions. It reports that the value “3-Sandy Shore” for the attribute CATCOA – Category of Coastline – cannot be mapped on the S-101. This fact is due to the remodeling of the object COALNE – Coastline – on the S-101. In the new standard, the attribute NATSUR – Nature of Surface – was included in this object, which enumerates the type of the material which the land surface or the sea bed is composed. Along with the value already mentioned in the error, the value “4-Stony Shore” was also numerous. Thus, we can observe in the ***Figure 6 below*** a simplified scheme of this change and how the new encoding for these objects will be carried out.

It is worth mentioning that the COALNE object still has the CATCOA attribute, but with less possible values. This change allows for greater detail of the data in S-101 ENC, which must be encoded individually to correct this error.

In the figures below, the attributes of the same coastline in Caris HPD 4.0 for both ENC S-57 and ENC S-101 are listed. In ***Figure 7***, we can view the presentation of Caris HPD 4.0 for an ENC S-57, highlighting the ENC S-57 layer, the coastline, COALNE object and the CATCOA attribute with the value “Sandy shore”. In ***Figure 8***, the same presentation is shown, however for an ENC S -101, with the ENC S-101 layer highlighted, the coastline, COALNE object and the CATCOA and NATSUR attributes. Note that these attributes were not correctly filled in on the S-101, so requiring manual updating by the encoder. It is also possible to observe that the other fields were filled in correctly.

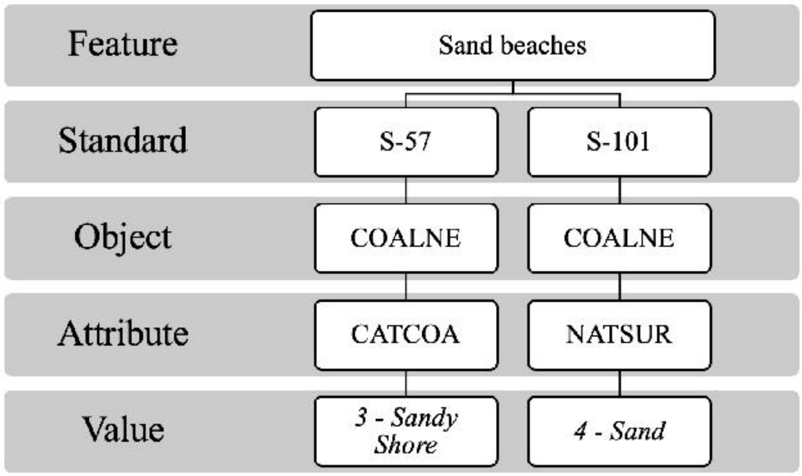

***Figure 6**.- S-57 x S-101 Encoding scheme - Example*

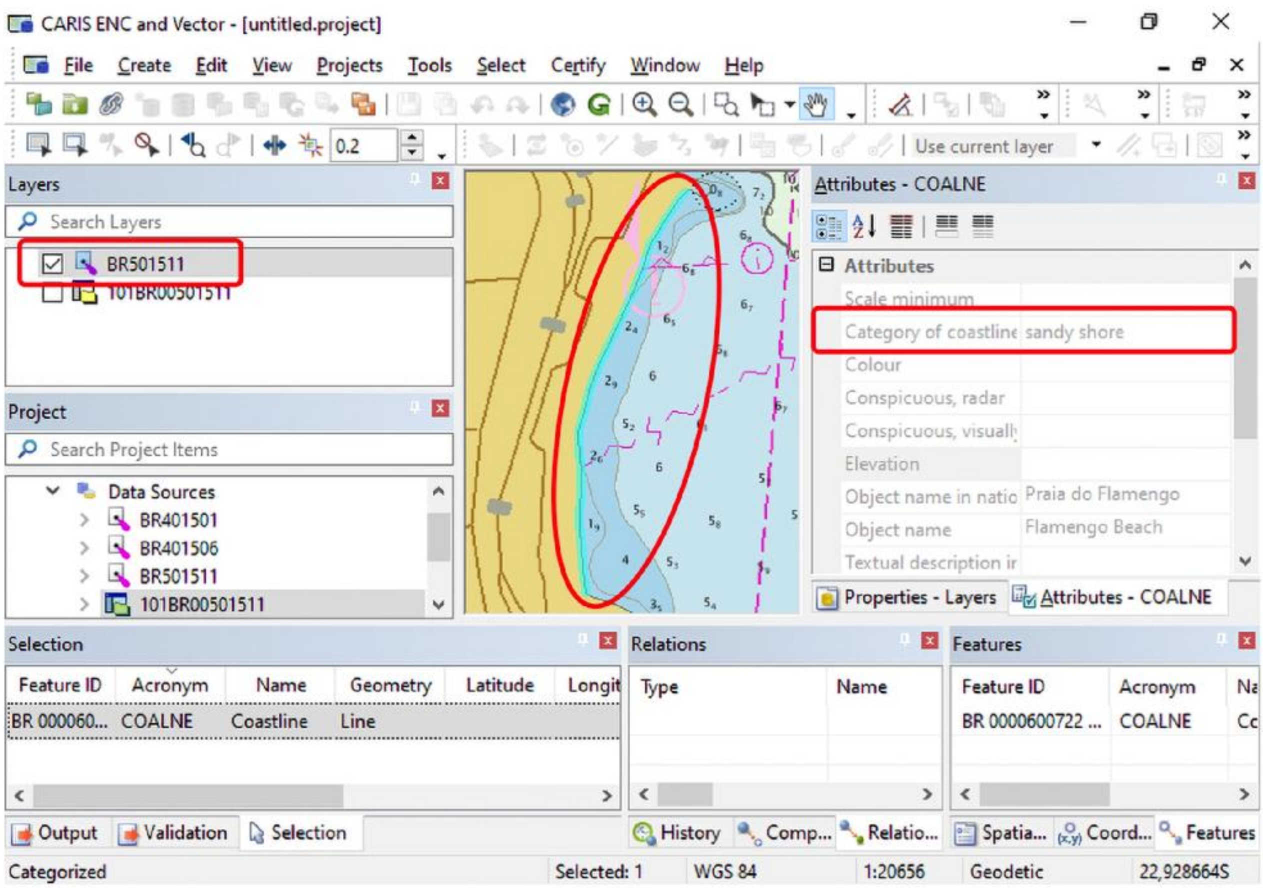

***Figure 7** - COALNE attribute of ENC S-57 in Caris HPD*

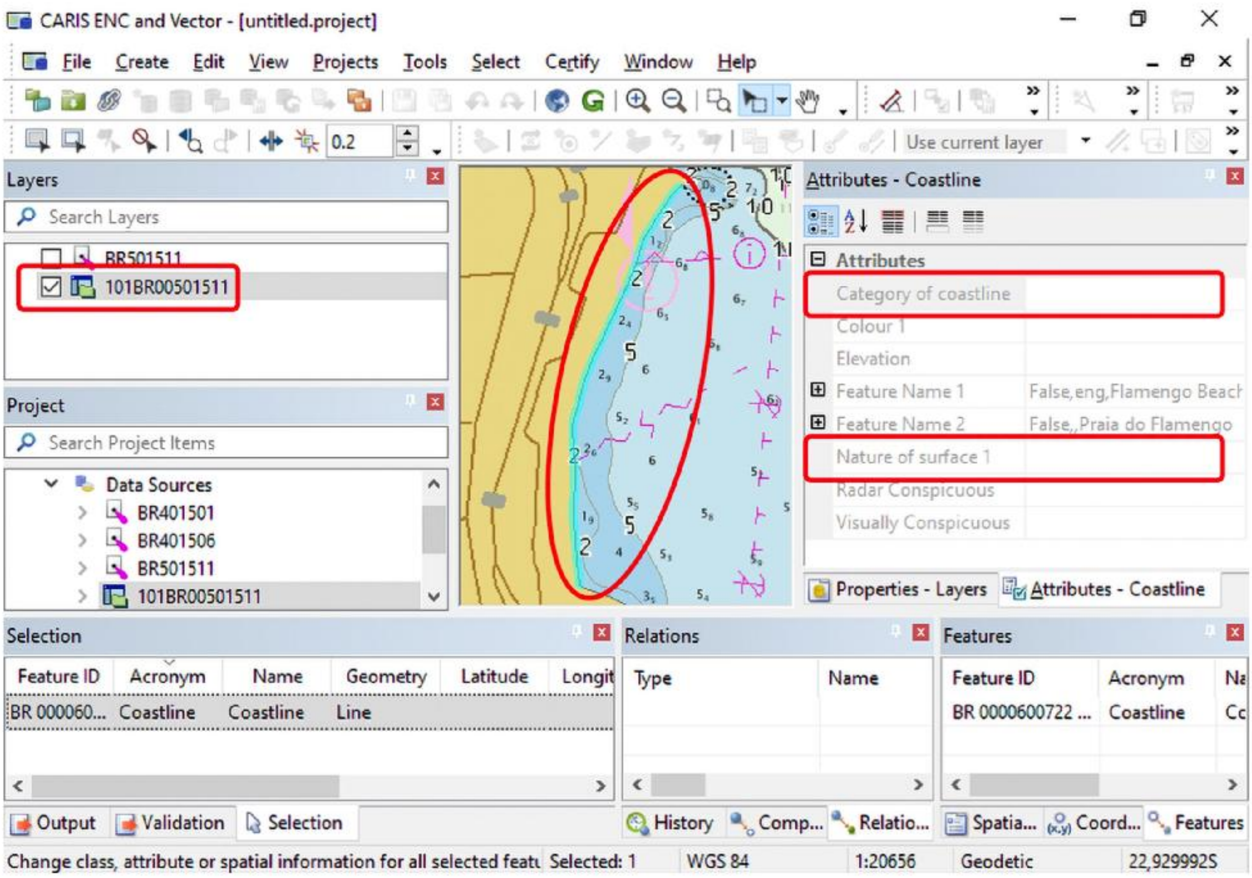

Figure 8 *- COALNE attribute of ENC S-101 in Caris HPD*

5.5.9 Unable to map S-57 enumeration code 3 (deeper than the range of depth of the surrounding depth area) for attribute EXPSOU for feature UWTROC (BR000000826300001) to S-101 attribute expositionOfSounding for feature UnderwaterAwashRock

In the message above, it can be noted that the encoding of the value “3-Deeper than the range of depth of the surrounding depth area” for the attribute EXPSOU - Exposition of Sounding - cannot be mapped in the UWTROC object. According to a decision by S101PT, this value is no longer needed for this attribute. Therefore, this error does not require additional actions.

5.5.10 Unable to map S-57 enumeration code 4 (lattice beacon) for attribute BCNSHP for feature BCNLAT (BR000002252600001) to S-101 attribute beaconShape for feature BeaconLateral.

An error identical to the one mentioned above happened to the BCNSPP object. According to the message, the BCNSHP attribute – Beacon Shape – no longer has the value “4-Lattice Beacon”. This data was remodeled to the NATCON attribute – Nature of Construction – with the value “11-Latticed”.

According to the explanation given by the S101PT, a lattice is not a format, but the type of construction, explaining the change. The S101PT emphasizes that the BCNSHP attribute is mandatory and suggests that it be coded with the value “5-Pile Beacon” or even “3-Beacon Tower”, depending on each case. Also, according to S101PT, ENC producers must confirm it on a case-by-case basis. This case can be extended to all types of beacons.

5.5.11 Unable to map S-57 enumeration code 4 (telephone) for attribute CATCBL for feature CBLSUB (BR000003933200001) to S-101 attribute categoryOfCable for feature CableSubmarine.

The attribute CATCBL – Category of Cable – of the object CBLSUB – Cable Submarine – has been remodeled and no longer has the value "4-Telephone". The S101PT explains that the "8-Fiber Optic Cable" value is more appropriate in terms of navigation. Therefore, the values of these errors must be changed manually to the new value "8-Fiber Optic Cable", since the converter does not make this correlation automatically.

5.5.12 Unable to map TOPMAR as an attribute to Landmark. Unable to bind attribute topmark/colour e Unable to map TOPMAR as an attribute to Landmark. Unable to bind attribute topmark/topmarkDaymarkShape

This error comes from the transformation from objects to attributes. In S-57 ENC the topmarks were categorized as objects, however in the S-101 the topmarks have been remodeled to complex attributes, containing the attributes of "color" and "topmark / daymark shape". However, as this error occurred in an object of the type "Landmark", this correlation no longer exists in the S -101, because that object no longer has the attribute "TOPMAR".

6. CONCLUSION

The need to update the ENC data structure is in evidence due to the technological improvements over the last 30 years. To meet this incredible speed of technological innovations, IHO has developed a new information standard called S-100, which encompasses several products, including the S-101 ENC. This innovation will change the way of encoding vector charts and creates the need to reassess all ENCs already produced.

This reassessment will demand great efforts from Hydrographic Services around the globe and, in order to assist and try to estimate the size of this demand, this work analyzed 18 ENCs. This sample included part of the coast of São Paulo state, Rio de Janeiro state and Espírito Santo state, thus covering an area of extreme importance for Brazilian maritime navigation. The chart samples used hereby encompassed the purposes of coastal use, approaching areas and port.

In order to achieve the objective of the work, a conversion software developed by ESRI was used, which transformed the ENC S-57 into S-101. After that, the results were analyzed and the causes and solutions for each type of error were defined. It was possible to verify and analyze the demand for work necessary to correct and update those ENC.

The conversion of the 18 ENCs generated more than 1,200 errors which were analyzed, grouped and separated by types. The two main errors observed were "warnings" and "information", each one having different causes and solutions, as presented in the course of the article. There were 12 categories of "info" and 13 "warning", with the majority, 1,127 of the 1,290 errors, being "warning".

After analyzing the errors, causes and solutions, it has been concluded that the change in the data structure, presented in the S-101, significantly modified some objects and attributes. On the other hand, several others have not gone through major changes. Thus, in the light of DCEG and IHO (2019), these changes were identified and described throughout Chapter 5 of this study.

Emphasis was placed on the description and explanation of the attributes and what each one encodes, thus demonstrating the causes of errors and, in the sequence, a possible solution for each one was described.

The complexity, ease of coding and correcting errors varies widely from error to error. For example, some can simply be ignored, as the object has been remodeled and no longer has an attribute it used to have. On the other hand, some errors require additional study and deeper analysis on the source data structure, for its correction. Thus, the attempt to quantify and qualify errors regarding the need for work necessary for their correction is neither easy nor simple, so each type of error should be treated as unique and analyzed individually.

Also, based on the results presented by the converter provided by IHO, in partnership with ESRI, it seems that not all conversions are accurate and complete.

Another important point is the metadata of each ENC, mainly the minimum display scales (minimumDisplayScale), which must be studied and tested on board.

This article was not intended and could not exhaust the subject, given the complexity and variety of objects and attributes present in the information standards S-57 and S-101, in addition to having adopted a sample of Brazilian ENC. It is encouraged that further studies on the subject are carried out so that they can, in the same way, assist the Hydrographic Services around the globe in the hard task of updating ENCs to the new S-101 ENC standard.

Finally, after all the results have been presented, with analysis to identify causes of error and their solutions, it is expected that the present study will contribute to Hydrographic Services' work. This also assists in the task of updating and making the two standards concomitant during the transition period to be defined by IHO.

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EFFECTIVELY MAPPING AND CHARTING OF REMOTE LOCATIONS WITH SATELLITES, LASERS AND ACOUSTICS

By B. Cooper (New Zealand - LINZ)

Abstract

In 2018, Toitū Te Whenua Land Information New Zealand (LINZ) commissioned hydrographic survey work in the Ha'apai island group in the Kingdom of Tonga to update the charts in the area to improve maritime safety. A combination of sensor technologies were used in the survey, comprising Satellite Derived Bathymetry (SDB), Airborne Laser Bathymetry (ALB) and Multibeam Echo Sounder (MBES). The novel approach allowed for efficient utilisation of resources during the data acquisition phase. Commencing with SDB, the subsequent ALB extents were refined after a review of the SDB coverage. Similarly, the MBES extents were reviewed based on the achieved ALB coverage. This ensured the efficient and effective use of each technology. Before incorporating the data into charts, each sensor dataset and combinations of datasets were analysed to assess data quality. This informed the decision on how best to portray the data and quality attributes on the charting products.

Résumé

En 2018, Toitū Te Whenua Land Information New Zealand (LINZ) a fait réaliser des levés hydrographiques dans l'archipel d'Ha'apai du Royaume de Tonga afin de mettre à jour les cartes marines de la région pour améliorer la sécurité maritime. Une combinaison de technologies de capteurs a été utilisée pour les levés, incluant la bathymétrie dérivée par satellite (SDB), la bathymétrie laser aéroportée (ALB) et les échosondeurs multifaisceaux (MBES). Cette nouvelle approche a permis d'utiliser efficacement les ressources pendant la phase d'acquisition des données. Après avoir commencé par la SDB, les balayages ultérieurs de l'ALB ont été peaufinés après un examen de la couverture de la SDB. De même, les balayages MBES ont été revus à partir de la couverture ALB obtenue. Cela a permis de garantir l'utilisation efficace et efficiente de chaque technologie. Avant d'incorporer les données dans les cartes marines, chaque jeu de données de capteurs et les combinaisons de jeux de données ont été analysés pour évaluer la qualité des données. Cela a permis de décider de la meilleure façon de représenter les données et les attributs de qualité sur les produits de cartographie marine.

Articles

Resumen

En 2018, Toitū Te Whenua Land Information New Zealand (LINZ) comisionó trabajos de levantamientos hidrográficos en el archipiélago Ha'apai en el Reino de Tonga para actualizar las cartas del área y mejorar la seguridad marítima. En este levantamiento se usó una combinación de tecnologías de sensores, incluyendo Batimetría Derivada por Satélite (SDB), Batimetría por Laser Aéreo (ALB) y Ecosonda Multihaz (MBES). Este nuevo enfoque permitió el uso eficiente de recursos durante la fase de adquisición de datos. Después de comenzar con SDB, los siguientes barridos ALB se afinaron después de una revisión de la cobertura SDB. De manera similar, los barridos MBES se revisaron basándose en la cobertura ALB alcanzada. Esto aseguró el uso eficiente y efectivo de cada tecnología. Antes de incorporar los datos en las cartas, se analizó el conjunto de datos de cada sensor y las combinaciones de los datos, para valorar la calidad de los datos. En esto se basó la decisión de cómo representar los datos y los atributos de calidad en los productos cartográficos.

1. INTRODUCTION

Traditional approaches to mapping remote, shallow waters are often expensive and challenging. In 2018 a combination of satellite, aircraft and vessel based sensors were used to survey and map the seafloor in the Ha'apai island group in the Kingdom of Tonga, an area last mapped in the late 1800's using leadline and sextant. The latest surveys were undertaken for Toitū Te Whenua Land Information New Zealand (LINZ) in partnership with New Zealand's Ministry of Foreign Affairs and Trade (MFAT) as part of the New Zealand Aid Programme Pacific Regional Navigation Initiative (PRNI). LINZ is the New Zealand agency responsible for producing and maintaining official nautical charts for New Zealand and a number of pacific island countries including Tonga, the Cook Islands, Niue, Samoa and Tokelau. LINZ contracted survey companies iXblue, Geomatics Data Solutions (now Woolpert Inc.) and EOMAP to undertake the work in Tonga.

Recent developments in Satellite-Derived Bathymetry (SDB) provided a way to map these remote shallow water areas with some confidence[1]. Combined with Airborne Laser Bathymetry (ALB) and multi-beam echo sounder (MBES) technology, it was possible to sequence data collection using SDB, ALB then MBES. This novel approach enabled LINZ and the contractors to review and refine the extent of subsequent data acquisition phases, ensuring greater efficiency and an effective survey campaign.

This article outlines the approach taken by LINZ and the contracted survey companies in conducting a successful multi-sensor survey. The article then looks at the ways the technologies were assessed and how datasets were combined for use in charting products. Finally, some recommendations are made on how the multi-sensor approach to survey can be improved.

2. SAFE SHIPPING IN THE SW PACIFIC

In 2012, in partnership with MFAT, LINZ completed a novel approach to hydrographic risk assessment[2] of the Tonga region. Using GIS to build a multi-layered risk model, the approach identified shipping routes at risk, in relation to traffic type, size, density as well as volume of passengers, and compared it against a number of consequence criteria. The resulting heat-maps indicate the location and level of risk. These were then used in 2016 as the basis of discussions with Tonga to identify and prioritise a hydrographic survey programme.

The Tonga archipelago comprises 169 islands scattered over an area of 700,000 km^2, stretching approximately 800km north to south. The region typically comprises clear water, fringing reefs and subsea volcanoes.

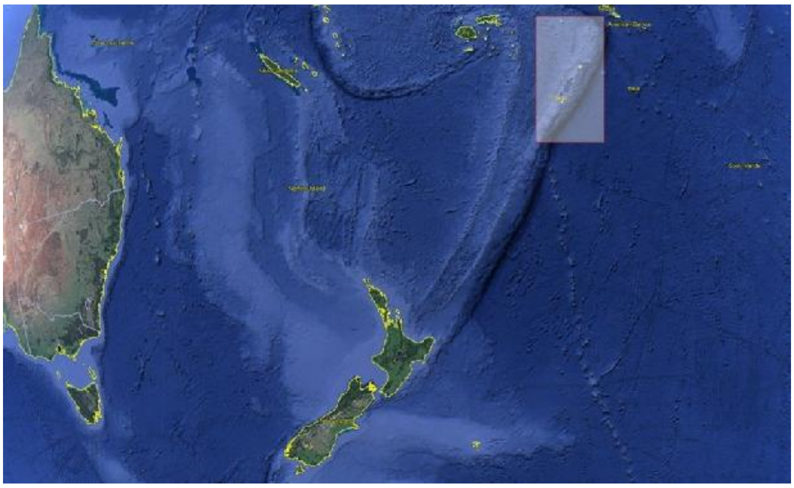


***Figure 1** : Location of Tonga archipelago in SW Pacific Ocean*

[1] EOMAP, Satellite Derived Bathymetry Survey Report, HYD2017/18-03 (HS60), Phase 2, 2018

[2] MFAT, LINZ, Marico Marine NZ Ltd, South West Pacific Regional Hydrography Programme, Tonga Risk Assessment, Report Number 14NZ262-TM (https://www.linz.govt.nz/sea/maritime-safety/improving-maritime-safety-pacific)

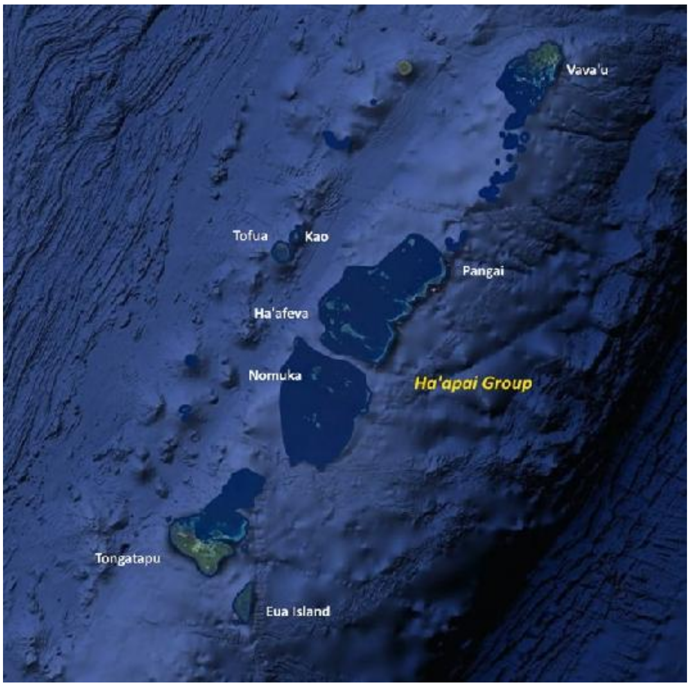


Figure 2 *; Ha'apai Island Group*

It is only relatively recently that some of the charts for Tonga have been modernised and produced in terms of WGS84 and depths in metres. A number of small scale charts were modernised in the early 1990's with a significant number of large scale charts remaining on undetermined datums. Even then, the charts that were modernised were compiled from previously published British Admiralty charts dating from the 1900's and incorporated 'new' surveys. Of particular note are the Ha'apai Group of islands that were charted in fathoms and on an undetermined datum.

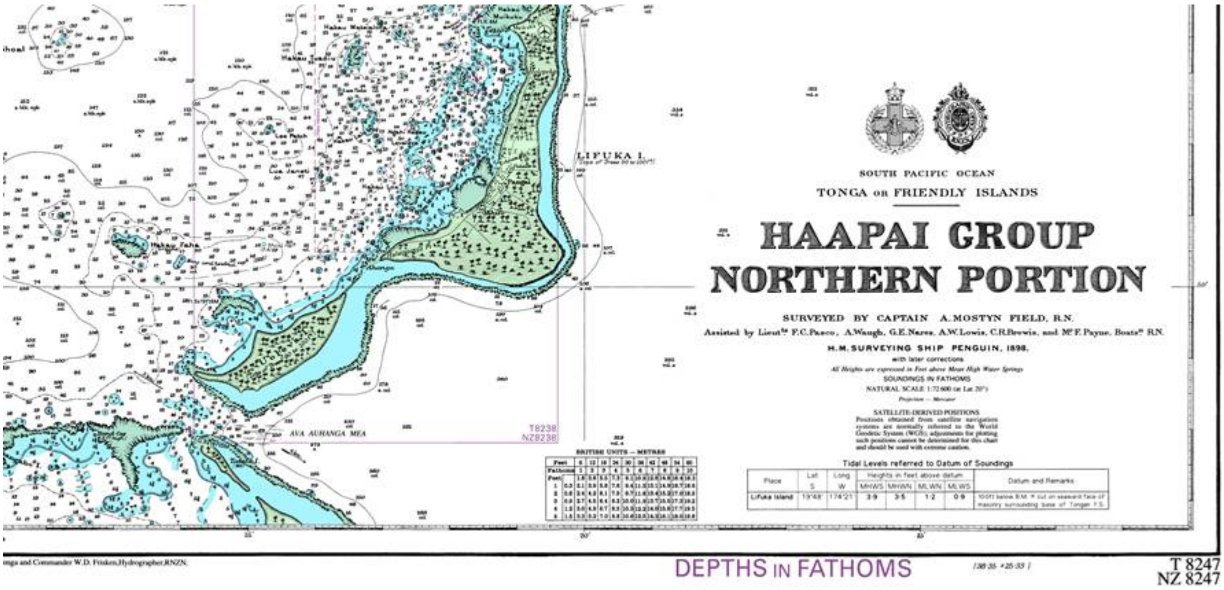


Figure 3 *: former fathoms chart of Ha'apai Group in Tonga*

Using satellite-based vessel traffic data (Automatic Identification System or S-AIS) the hydrographic risk assessment highlighted the risks to safe navigation using such charts. The images below show the tracks of domestic shipping and recreational yachts navigating in the Ha’apai islands.

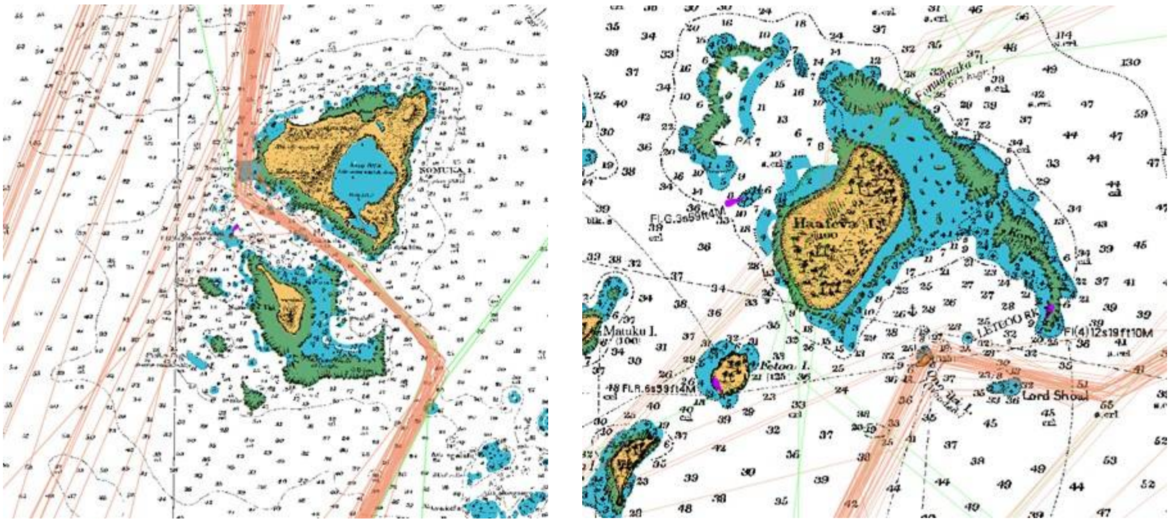


Figure 4 *:S-AIS ship traffic over former chart on an undetermined datum*

The remote location of Tonga together with the vast area of water surrounding the archipelago presented a challenge to map effectively and efficiently.

In response to this problem, LINZ took a phased approach by using SDB, ALB and MBES technologies. Specifications based on existing charts established the survey extents for each sensor. As some of the charts were on undetermined datums, LINZ understood there would be a need to adjust the survey extents to ensure data was collected in the right location. The SDB data was processed in early 2018; the ALB data was acquired mid-2018; and the MBES data was acquired in late-2018.

The first phase used SDB to provide coverage throughout the entire Tonga archipelago, to a water depth of approximately 15m with a 2m resolution bathymetric dataset. This resulted in approximately 6,000km^2 of the (often challenging) shallow zone being mapped. Using the SDB dataset the fathom charts were aligned so that the islands matched the observed drying line. For greater charting confidence in higher risk areas ALB and MBES survey areas were planned in the areas ‘Eua, Nomuka, Ha’afeva, Lifuka, Tofua and Kao islands. The SDB enabled LINZ and the contractors to adjust the initial flight plan for the ALB phase. This included moving flight lines from areas of deep water to cover previously uncharted isolated reef areas identified by the SDB, to fully delineate the feature with respect to least depth, position and extent. This approach was repeated to adjust the extent of the MBES survey, based on the ALB coverage. Similarly, a number of planned MBES lines were realigned to cover features identified in the ALB or just on the edge of the ALB coverage. At the MBES planning phase, coverage commenced at the 20m contour as defined in the ALB data. This decision was based on factors such as ALB system capabilities (maximum planned depth penetration), charting requirements and budget constraints.

The images below show the progression of assessing the coverage, aligning the chart to the SDB data, and the coverage achieved by the ALB and MBES. The final image shows the combined ALB and MBES coverage over and around Nomuka.

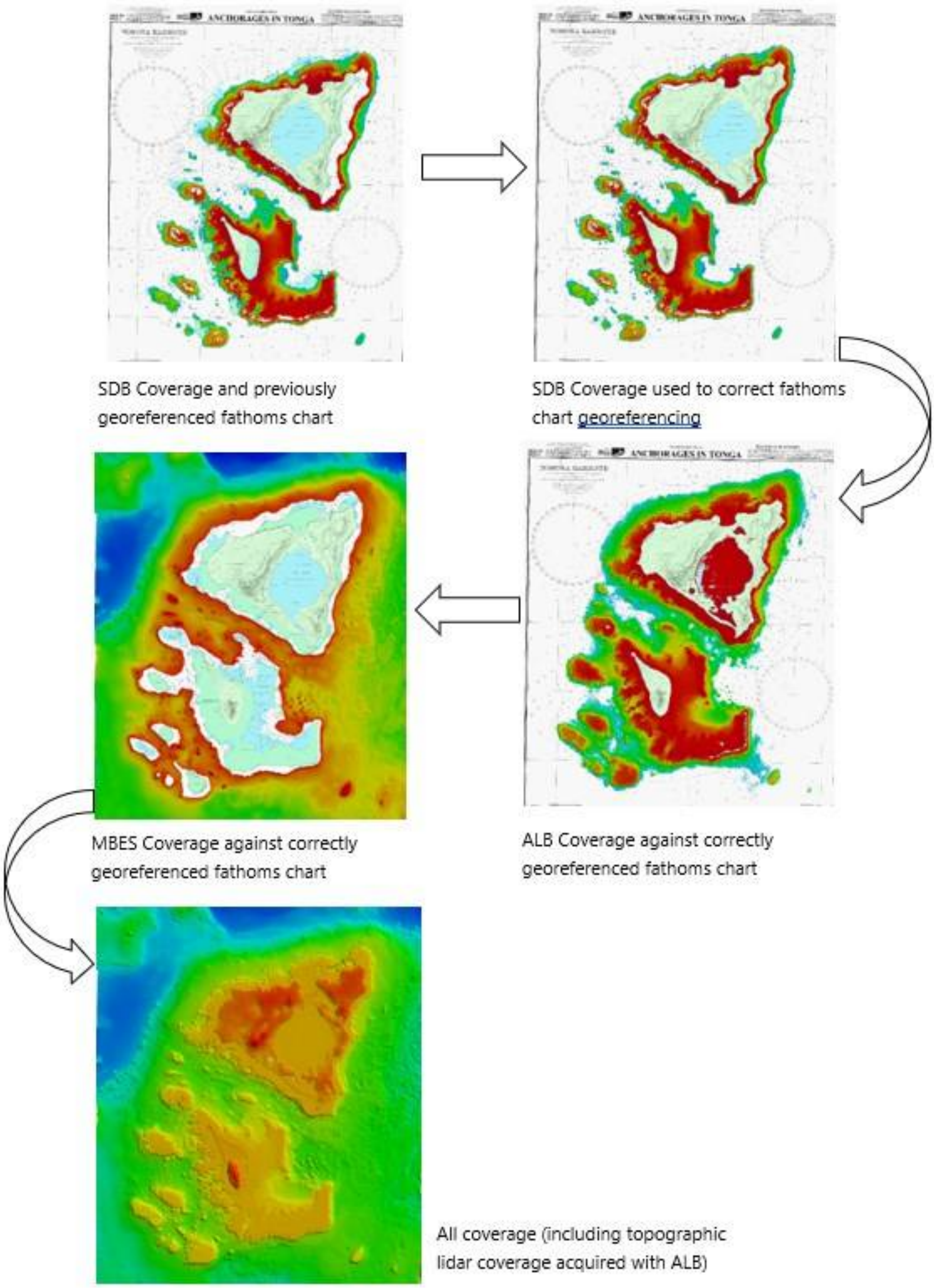


Figure 5 *: Progression of the multi sensor survey on the Nomuka dataset(s)*

In order for SDB and ALB to be accurately depicted on charting products the two respective technologies needed to be understood. Two crucial pieces of information were needed: how accurate was the data; and, what were the feature detection capabilities of each sensor. The overlap of the datasets from the different sensors provided a good opportunity to assess the different sensors on a very large scale. As the data was applied to a wide range of product scales a more “data centric” approach was used when assessing the data.

The ALB system used for this survey was the Leica Chiroptera 4X, a shallow water system with an elliptical scan pattern. As a shallow water system the ALB was planned to capture depths to a maximum of 20 m.

3. ASSESSMENT OF ALB

To assess the ALB datasets the MBES data was used as the “control” dataset. This was done as MBES has a proven track record for LINZ with its sources of error well understood and because the ALB data had been reduced to sounding datum utilising Geoid separation data, whereas the MBES used tide observations. The MBES data was gridded at a resolution of 0.5 m, this was then compared to the 0.5 m gridded ALB data. Both ALB and MBES datasets were gridded using the CUBE statistical algorithm which assisted comparison as limited bias had been applied in gridding. Although the ALB was specified to collect depths to 20 m, depths to 35 m are included in the comparisons.

As the table below indicates there is generally good vertical agreement between the ALB and MBES data. The mean difference of each dataset is within expected accuracy tolerances of the two methods and suggests that the reduction of soundings to datum is accurate. It can also be seen that the mean difference grows in areas of deeper water covered by the ALB. This is perhaps a reflection of the growing uncertainty with depth of each source dataset. In some areas the mean and standard deviation increases quickly with depth, this is particularly the case in Ha’afeva and Tofua and Kao Islands where the standard deviation doubles in the last two depth bands. The standard deviation and range of the difference is quite high, as the data was gridded at a very high resolution (0.5 m) it is unlikely this can be attributed to gridding.

Tables 1, 2 and 3 : Difference comparison statistics across the different depth bands for all survey areas

Area	*Nomuka*						*‘Eua*					
Depth Range (m)	*5-10*	*10-15*	*15-20*	*20-25*	*25-30*	*30-35*	*5-10*	*10-15*	*15-20*	*20-25*	*25-30*	*30-35*
Mean Diff (m)	-0.04	-0.01	0.01	0.07	0.12	0.18	0.01	0.02	0.13	0.19	0.21	0.22
StDev (m)	0.18	0.24	0.20	0.15	0.15	0.18	0.25	0.40	0.35	0.29	0.22	0.18
Max Diff (m)	3.96	5.06	6.23	8.08	5.39	4.42	3.60	5.87	7.20	5.51	4.72	2.64
Min Diff (m)	-3.15	-6.73	-8.33	-13.04	-8.32	-5.14	-2.19	-6.48	-7.32	-9.89	-8.63	-2.87

Area	*Ha’afeva*						*Lifuka*					
Depth Range (m)	*5-10*	*10-15*	*15-20*	*20-25*	*25-30*	*30-35*	*5-10*	*10-15*	*15-20*	*20-25*	*25-30*	*30-35*
Mean Diff (m)	-0.07	-0.02	0.09	0.16	0.24	0.27	0.03	-0.01	-0.02	0.04	0.11	0.19
StDev (m)	0.36	0.44	0.35	0.34	0.34	0.75	0.29	0.53	0.54	0.4	0.31	0.28
Max Diff (m)	10.36	9.47	8.04	5.38	5.05	2.87	7.27	9.93	8.5	10.87	7.16	5.57
Min Diff (m)	-4.39	-9.98	-14.33	-18.31	-27.74	-28.13	-7.45	-11.73	-17.59	-19.01	-20.56	-21

Area	Tofua and Kao					
Depth Range (m)	5-10	10-15	15-20	20-25	25-30	30-35
Mean Diff (m)	0.04	0	-0.03	-0.01	-0.01	-0.04
StDev (m)	0.35	0.33	0.32	0.35	0.64	1.35
Max Diff (m)	3.5	-10.11	-19.09	-24.51	-29.6	-33.56
Min Diff (m)	-4.18	15.52	12.29	8.05	5.62	4.59

It is likely the steep nature of the seabed and beam footprint size contribute to the high standard deviation and range of differences. This is supported when the assessment is repeated with high sloping areas removed, resulting in a reduction of the standard deviation and range of differences. This reduction is more pronounced in areas of steeper seabed slope such as Tofua and Kao islands

***Tables 4, 5 and 6** : Difference comparison statistics across the different depth bands for all survey areas, grids with slope greater than 15° excluded*

Area	Nomuka						'Eua					
Depth Range (m)	5-10	10-15	15-20	20-25	25-30	30-35	5-10	10-15	15-20	20-25	25-30	30-35
Mean Diff (m)	-0.02	0.02	0.02	0.06	0.11	0.18	0.02	0.05	0.12	0.15	0.19	0.21
StDev (m)	0.15	0.16	0.12	0.10	0.13	0.17	0.22	0.30	0.17	0.12	0.13	0.15
Max Diff	3.63	5.06	5.60	3.34	4.24	4.42	2.27	5.82	4.91	4.23	4.72	2.02
Min Diff	-2.88	-5.57	-7.49	-7.68	-4.55	-3.92	-2.02	-6.48	-7.32	-6.22	-7.48	-1.34

Area	Lifuka						Ha'afeva					
Depth Range (m)	5-10	10-15	15-20	20-25	25-30	30-35	5-10	10-15	15-20	20-25	25-30	30-35
Mean Diff (m)	0.06	0.06	0.03	0.06	0.10	0.18	0.00	0.05	0.12	0.18	0.24	0.30
StDev (m)	0.18	0.34	0.33	0.21	0.14	0.17	0.24	0.26	0.19	0.20	0.21	0.28
Max Diff (m)	5.87	8.25	6.38	4.55	5.25	2.56	8.09	9.47	3.70	2.88	3.70	2.87
Min Diff (m)	-7.14	-10.86	-16.09	-17.35	-20.56	-19.57	-4.39	-9.38	-14.33	-18.31	-27.74	-28.13

Area	Tofua and Kao					
Depth Range (m)	5-10	10-15	15-20	20-25	25-30	30-35
Mean Diff (m)	-0.03	-0.05	-0.05	-0.02	0.01	0.05
StDev (m)	0.21	0.21	0.2	0.16	0.34	0.36
Max Diff (m)	2.1	8.59	9.46	6.77	4.19	4.09
Min Diff (m)	-2.78	-10.11	-18.49	-20.19	-29.6	-27.47

Due to the growing differences observed with depth the decision was made to exclude depths greater than 30 m before merging the ALB data with the MBES data. Another consideration was the physical properties of the ALB system meant that seabed returns were intermittent beyond 30 m depth. Although the above numbers would suggest that across all depths MBES and ALB agree within respective tolerances, leaving some areas of deeper ALB data in the product would result in intermittent coverage and likely create issues with later sounding selection and contour creation. It is worth noting that the inclusion of this dataset to 30 m water depth exceeds the expectations of the planning phase where the ALB data was only supposed to be used in depths <20 m.

4. FEATURE DETECTION

ALB data has historically been quite sparse with point spacings approximately 0.5-5 m apart. The data density of the Leica Chiroptera 4X system (approx. 16pts per square metre) indicates that feature detection of a 2x2 m target should theoretically be possible. During the accuracy assessment it was shown that steep features were an issue, suggesting that footprint size was a limitation in the technology. To assess the ALB feature detection capability, data was viewed against MBES data on overlapping features. Feature detection is considered demonstrated if nine returns register on the target and the height from the surrounding seabed is similar between the MBES and ALB datasets, a definition that aligns with LINZ HYSPEC[3]. A selection of features at different depths were investigated to understand the difference between the two systems at defining features.

Across the areas investigated some features were detected whilst others were not, examples of these are contained in the ***following Figures***.

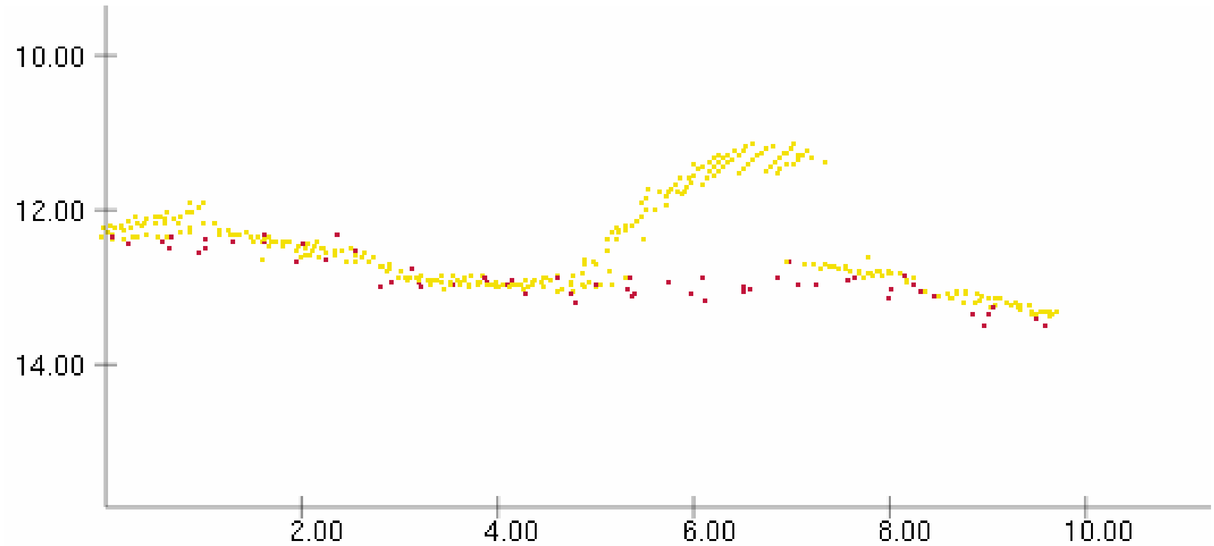


Figure 6 *: 2m subset slices showing the MBES data (in yellow) and ALB data (in maroon). Feature is detected in the MBES data but not in the ALB data.*

[3] *LINZ/NZHA, HYSPEC, Contract Specifications for Hydrographic Surveys Version 2.0 (https://www.linz.govt.nz/sea/charts/standards-and-technical-specifications-for-our-chart-and-hydrographic-work)*

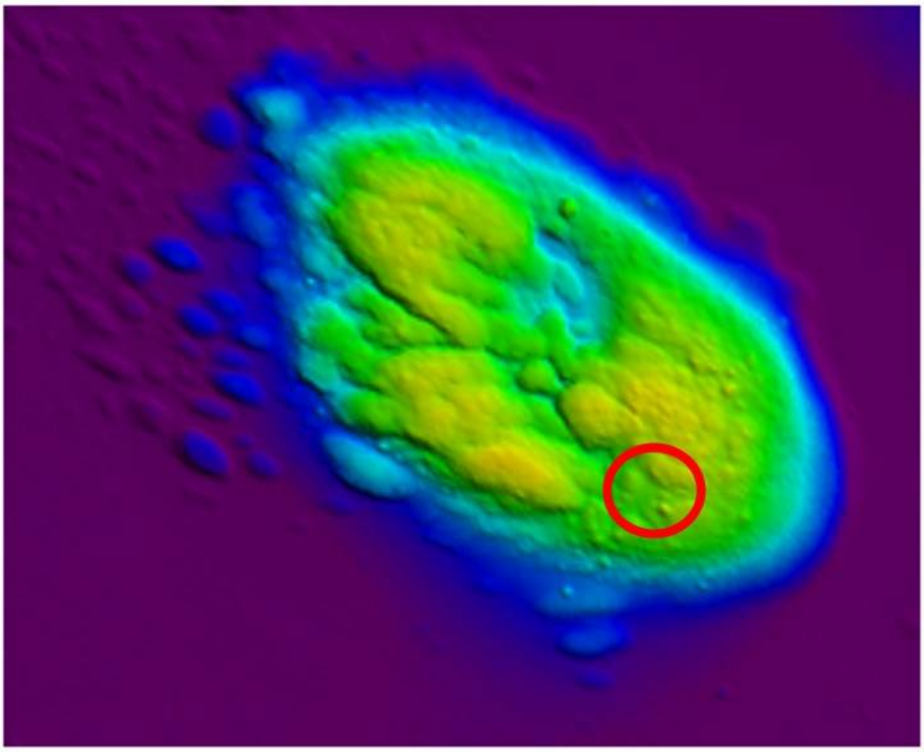


Figure 7 *: Plan view of the feature above in the combined ALB/MBES surface*

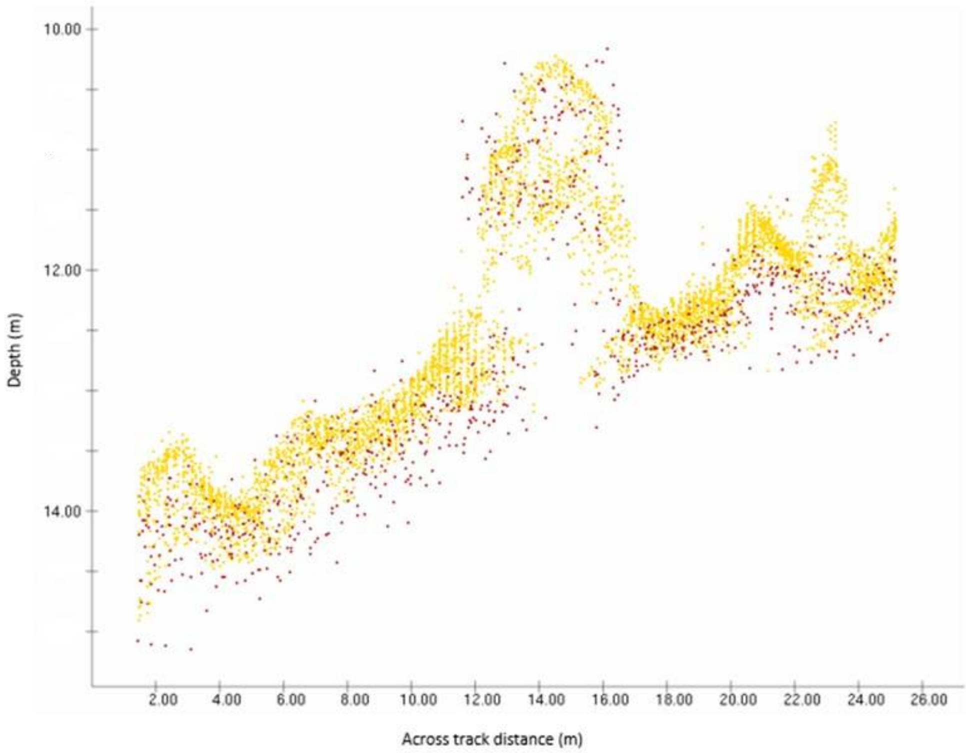


Figure 8 *: 2m subset slices showing the MBES data (in yellow) and ALB data (in maroon). Feature detection is similar (in terms of the relationship between seabed and least depth) between the two systems.*

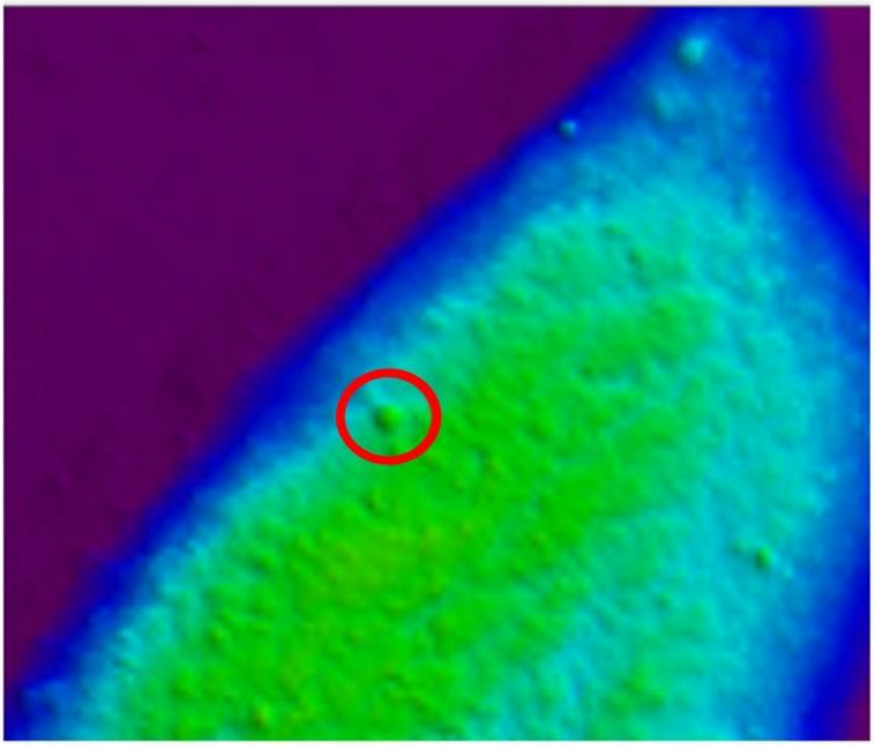


Figure 9 *: Plan view of the feature above in the combined ALB/MBES surface*

In some cases, the shape of the feature detected by the ALB is not as well defined as the same feature in the MBES data. More importantly the least depth is not comparable to the MBES data. This was generally observed on features in deeper water (approximately 20m).

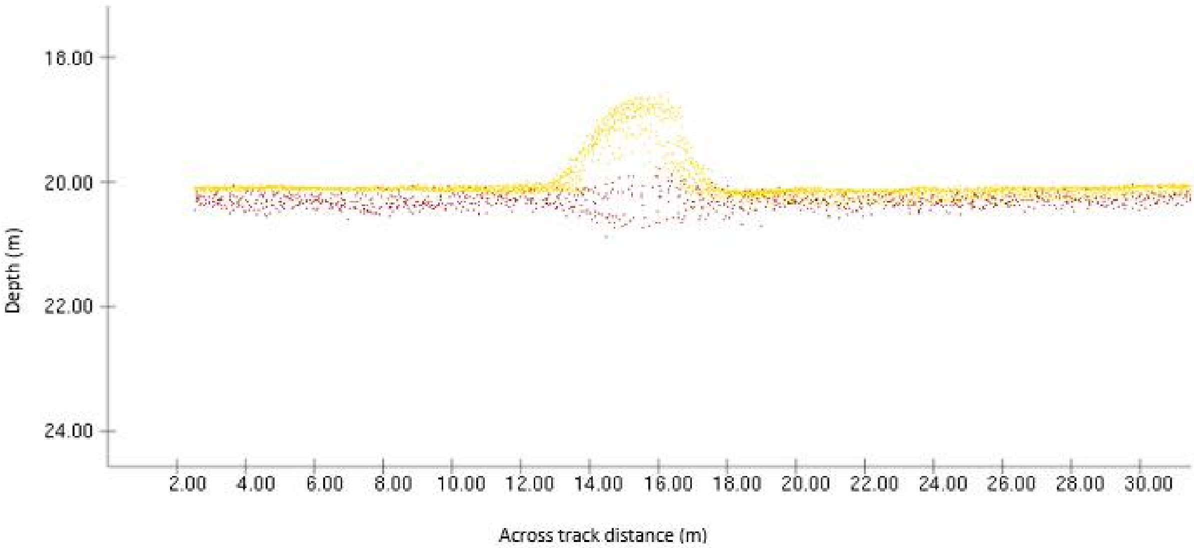


Figure 10 *: 2m subset slice showing the MBES data (in yellow) and ALB data (in maroon). The feature is rounded off in the ALB point cloud.*

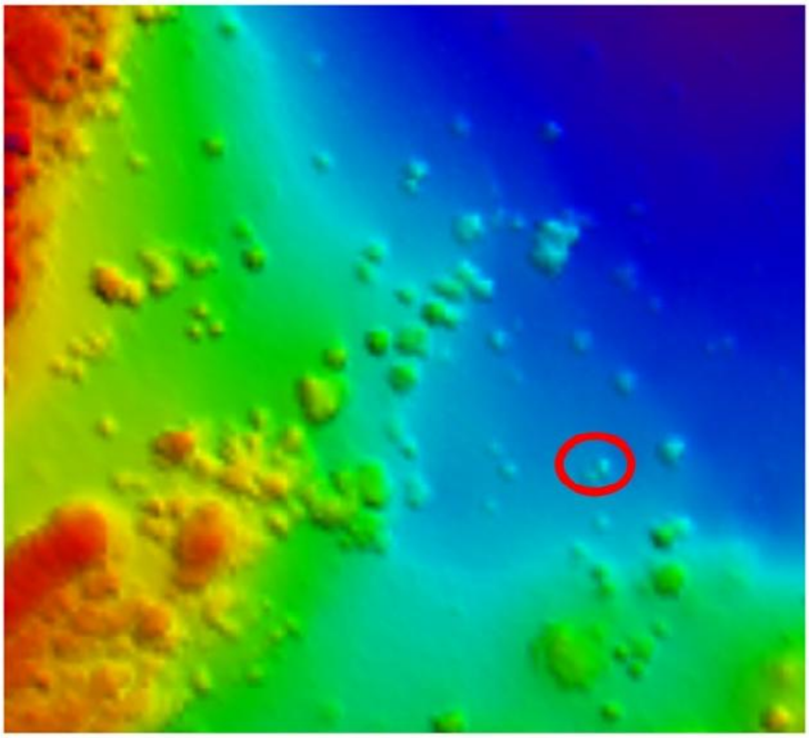


***Figure 11** : Plan view of the feature above in the combined ALB/MBES surface*

Viewing the data across the different areas it is noticed that feature detection varied in different areas. In one of the survey areas it is noticed that feature detection is similar between the MBES and ALB across all depths. This area was Tofua and Kao Islands, two volcanic islands where a band of higher intensity seafloor reflectance can be seen around both islands.

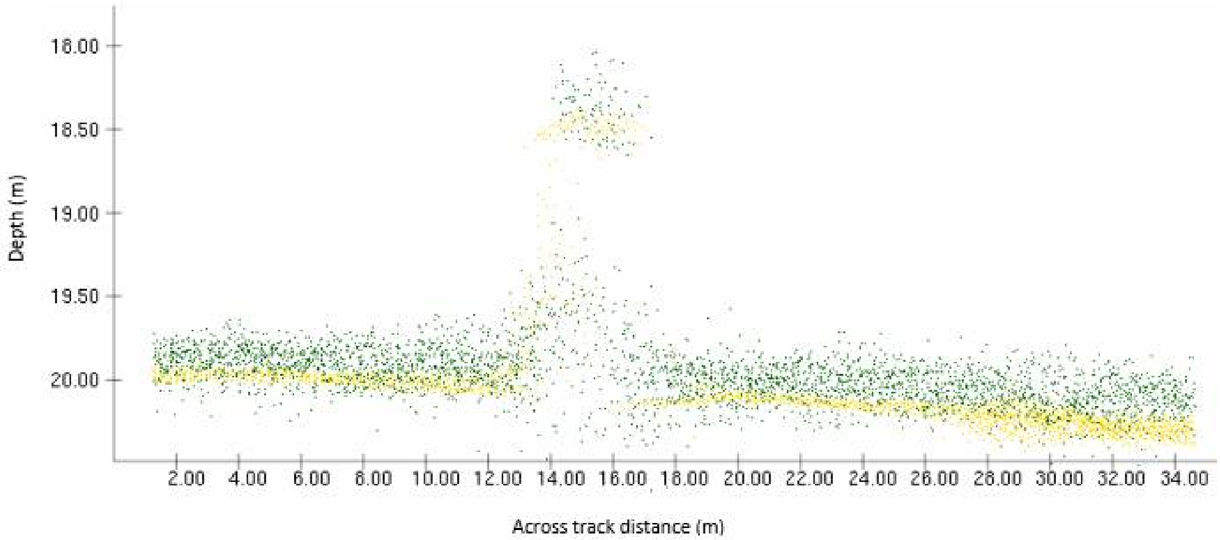


***Figure 12 :** 2m subset slice of MBES (yellow) and ALB data (dark green) over target seabed features*

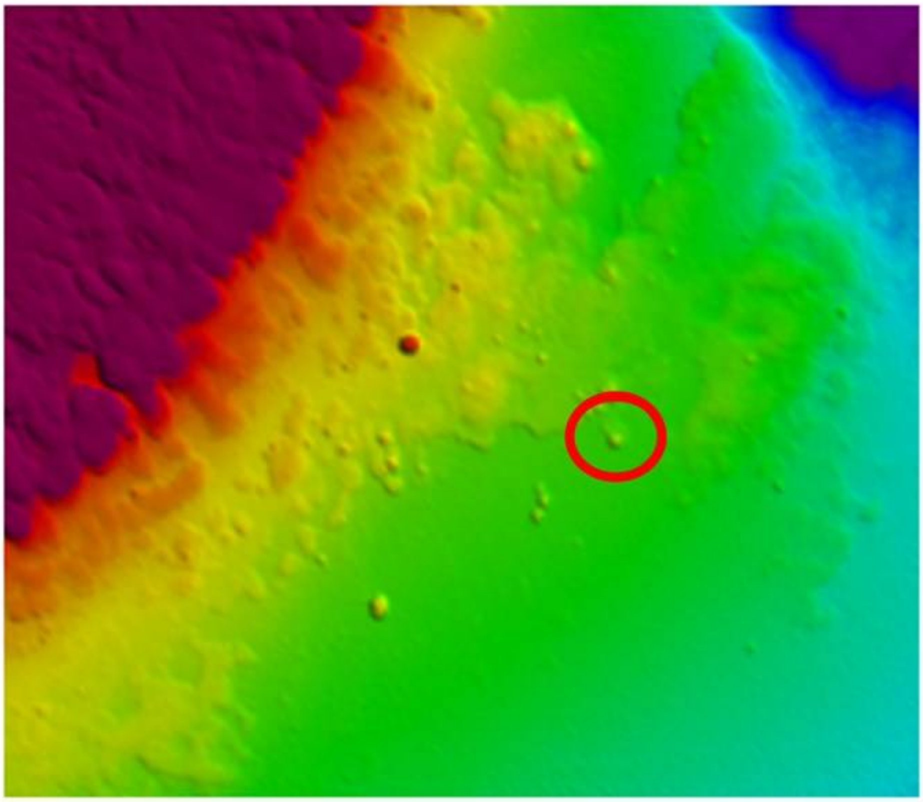


***Figure 13** : Plan view of the feature above in the combined ALB/MBES surface*

Further investigation is required to determine why feature detection is very good in that one area and less so in others. It seems that seabed type has an influence on feature detection capabilities.

One of the limitations in the analysis was that there were not many features in depths <10m to investigate. This is a result of the MBES coverage generally commencing from the 10m water depth and so overlapping data in depths <10m was limited. Further investigation is required to determine if the ALB system accurately delineates targets in depths <10m. Another limitation is that the comparison process across all areas was manual rather than automated, which introduces a bias in the comparison. However, this approach was necessary to understand feature detection at a data centric level but adds a level of subjectivity to the results. The analysis revealed that approximately half the features sampled were not fully detected by the ALB in terms of extent and least depth. As a hydrographic authority the appetite for risk is very low and if there is any doubt in the representation of hazards on the seabed then this needs to be communicated to the mariner.

A more systematic approach could be achieved by comparing sounding selections from the different sensors (SDB, ALB and MBES). This would allow the impact to be assessed for the purpose of charting products. Of course, this approach would mean the data has only been assessed at the one scale which would mean that the assessment would need to be repeated for any larger scale products made from the data in the future. The other limitation is that coverage between the sensors should be similar and cover features across a wide range of depths. In the case of this survey, as full MBES coverage was not required in depths <10m, shoals detected by the ALB in depths <10m were not fully identified by the MBES.

Due to the variable nature of feature detection the decision was made to designate the ALB data to Category of Zones in Confidence (CATZOC)[4] B rating as opposed to an A1 rating which reflects the achieved accuracy. It is possible that feature detection is improved in critical depth areas (depths <10m) or in areas with greater seabed reflectance but it is difficult to prove with certainty. Even if that is the case it would add a level of complexity to the CATZOC information populated in the chart products if the ALB data were split into different Zones of Confidence based on depth. More understanding of the feature detection capabilities of the sensor is required before assigning a higher CATZOC to the ALB data. Ideally this would involve conducting a feature detection test over different areas of surrounding seabed, ideally at different depths. This may also guide innovation in the way the ALB data is processed to improve feature detection across different areas.

ZOC [1]	Position Accuracy [2]	Depth Accuracy [3]	Seafloor Coverage	Typical Survey Characteristics [5]
A1	± 5 m + 5% depth	=0.50 + 1%d Depth (m) / Accuracy (m) 10 / ± 0.6 30 / ± 0.8 100 / ± 1.5 1000 / ± 10.5	Full area search undertaken. Significant seafloor features detected [4] and depths measured.	Controlled, systematic survey [6] high position and depth accuracy achieved using DGPS or a minimum three high quality lines of position (LOP) and a multibeam, channel or mechanical sweep system.
A2	± 20 m	= 1.00 + 2%d Depth (m) / Accuracy (m) 10 / ± 1.2 30 / ± 1.6 100 / ± 3.0 1000 / ± 21.0	Full area search undertaken. Significant seafloor features detected [4] and depths measured.	Controlled, systematic survey [6] achieving position and depth accuracy less than ZOC A1 and using a modern survey echosounder [7] and a sonar or mechanical sweep system.
B	± 50 m	= 1.00 + 2%d Depth (m) / Accuracy (m) 10 / ± 1.2 30 / ± 1.6 100 / ± 3.0 1000 / ± 21.0	Full area search not achieved; uncharted features, hazardous to surface navigation are not expected but may exist.	Controlled, systematic survey achieving similar depth but lesser position accuracies than ZOC A2, using a modern survey echosounder [5], but no sonar or mechanical sweep system.
C	± 500 m	= 2.00 + 5%d Depth (m) / Accuracy (m) 10 / ± 2.5 30 / ± 3.5 100 / ± 7.0 1000 / ± 52.0	Full area search not achieved, depth anomalies may be expected.	Low accuracy survey or data collected on an opportunity basis such as soundings on passage.
D	*Worse than ZOC C*	Worse than ZOC C	Full search not achieved, large depth anomalies expected.	Poor quality data or data that cannot be quality assessed due to lack of information.
U	Unassessed - The quality of the bathymetric data has yet to be assessed			

Figure 14 *: Admiralty CATZOC table, https://www.admiralty.co.uk/news/blogs/category-zones-of-confidence*

4 *IHO S-57 feature object (M_QUAL) attribute, for more on S-57 see https://iho.int/en/standards-and-specifications*

For use on the charting products the ALB CUBE surface was merged with the MBES CUBE surface. Merging with the MBES was done based on a shoal bias approach, acknowledging that both datasets were very close vertically and that the most risk averse surface was used for charting. Merging with a shoal bias was prudent with the uncertainty associated with ALB data in steep areas. In terms of the S-57 M_QUAL object for the merged dataset, the TECSOU attribute was populated with 'found by multi-beam' in the area where the ALB and MBES overlap.

Assessment of SDB

The overlapping MBES and ALB data acquired during the survey provided an excellent opportunity for assessment over a very large area with different characteristics such as water depth/seabed types and water clarity. As the MBES and ALB data was comparable in most areas the two CUBE surface deliverables were combined into one shoal biased grid, at 2m resolution. The SDB grid was produced at the spatial resolution of the Worldview 2/3 sensor, 2m. This meant that the two grids could be easily compared. Only vertical accuracy was assessed as unlike ALB the data density of the SDB product did not fully support feature detection, as defined by LINZ HYSPEC, i.e. a 2m resolution dataset is unable to achieve multiple returns on a 2m target.

It was clear from the outset that SDB vertical accuracy decreases with depth. To understand this better the merged MBES and ALB datasets were split into discrete depth bands (0-5m, 5-10m and 10-15m). This was then compared to the SDB derived surface in two of the regions in Tonga (Nomuka and Lifuka).

Nomuka Results

Table 7 *: Summary table of the differences of SDB to MBES/ALB surface, split by depth range*

Nomuka Area MBES/ALB to SDB Comparisons							
All Data							
Depth band	***Mean Diff (m)***	***St Dev (m)***	***Mean+2SD (m)***	***Min (m)***	***Max (m)***	***Range (m)***	***Count***
<5m	0.178	0.713	1.576	-12.192	4.053	16.245	2039809
5-10m	0.558	1.122	2.757	-5.955	8.031	13.986	700277
10-15m	1.288	1.571	4.368	-5.029	9.06	14.089	673514

As expected the differences in shallow areas are less than in deeper areas. The differences, when binned into a histogram, closely follow the shape of a bell curve indicating a normal distribution. It is also noted that the distribution is skewed to the shoaler side for all depth bands in the Nomuka area.

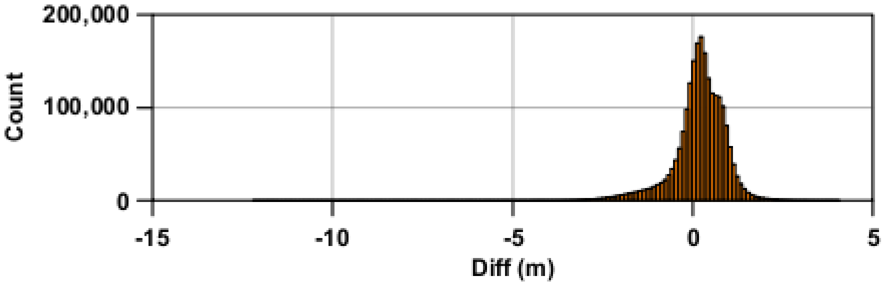


Figure 15 *: Differences in depths <5m, binned to 0.1m. Note bias towards positive (shoaler) difference.*

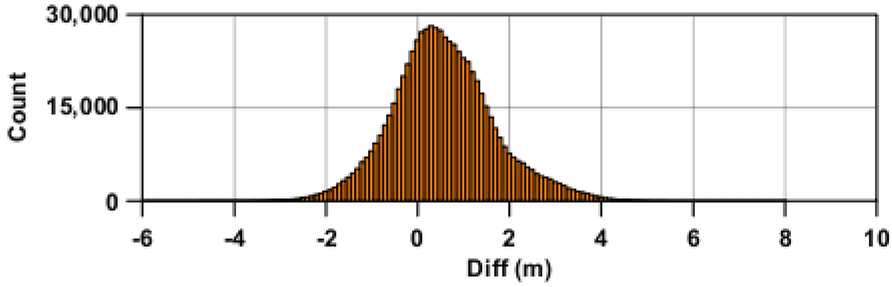


***Figure 16** : Differences in depths 5-10 m, binned to 0.1 m. Widening range of differences as depth increases. Note bias towards positive (shoaler) difference as above.*

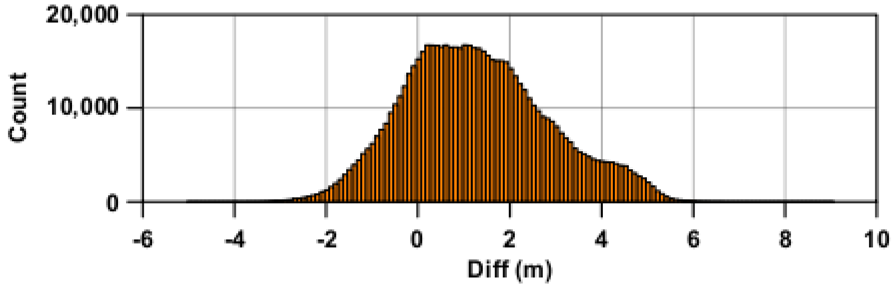


***Figure 17** : Differences in depths 10-15 m. Widening range of differences as depth increases.*

To further understand how accuracy can change with depth, in particular what accuracy can be obtained in depth critical areas (<2 m) the data was analysed at a more granular level. The SDB data was assessed against the MBES/ALB data at increments of 2 m. The results are contained in the ***Table below***.

***Table 8** : Summary table of the differences of SDB to MBES/ALB surface with slopes >15° excluded, split by depth range*

Nomuka Area MBES/ALB to SDB Comparisons - 2m increments							
All Data							
Depth band	***Mean Diff (m)***	***St Dev (m)***	***Mean+2SD (m)***	***Min (m)***	***Max (m)***	***Range (m)***	***Count***
<2 m	0.14	0.61	1.34	-12.19	2.03	14.22	1434656
2-4 m	0.22	0.89	1.96	-6.49	3.40	9.89	517057
4-6 m	0.43	0.91	2.21	-6.13	5.01	11.14	365271
6-8 m	0.50	1.08	2.62	-5.96	6.40	12.36	285653
8-10 m	0.69	1.27	3.18	-5.55	8.03	13.58	247755

The results of the 2 m increment are very similar to the 5m increment data and it can be seen that accuracy quickly degrades with depth. It is worth mentioning that the shape of the distribution is very similar between the 2 m increment bands and the 5m increment bands, both datasets showing an increase of the distribution curve with depth.

Early in the process it was evident that the differences were greater on steep sided features (reefs/steep banks) so it was decided to exclude these areas from the analysis. This was done by calculating the slope for the MBES/ALB surface and excluding areas with a slope greater than 15°. The reason for this is that gridded datasets do not represent steep areas well, particularly at the base of the feature when dealing with a 2 m grid resolution in reef areas where a depth change of 5m across a 2 m horizontal grid cell is possible.

***Table 9** : Summary table of the differences of SDB to MBES/ALB surface with slopes >15° excluded, split by depth range*

Nomuka Area MBES/ALB to SDB Comparisons							
Data with slope <15°							
Depth band	Mean Diff (m)	St Dev (m)	Mean+2SD (m)	Min (m)	Max (m)	Range (m)	Count
<5 m	0.209	0.670	1.523	-12.190	3.874	16.064	2020213
5-10 m	0.581	1.053	2.645	-4.855	6.256	11.111	523724
10-15 m	1.345	1.599	4.478	-4.099	7.139	11.238	512465

Removing the slopes from the assessment has little impact and only slightly reduces the standard deviation of the difference in two of the depth bands. It is interesting that the mean is made slightly worse, perhaps indicating the systematic shoal bias of the SDB data. Removing steep slopes however does reduce the range of differences in the dataset as one would expect.

Some small pockets of difference remain due to other environmental factors. One area of noticeable difference is on the leeward side of a small reef. In this area the SDB is significantly shallower than the MBES/ALB data. Assessing the satellite imagery, a patch of white water on the leeward side of the reef, caused by a breaking wave, is creating this large difference. Spectral properties of water would typically show white water as very shallow. Although this is a large pocket of inaccurate SDB data it looks to be an isolated occurrence in the dataset and had little impact on the depiction of the reef on the chart as it is generalised with the adjacent reef feature at the chart scale.

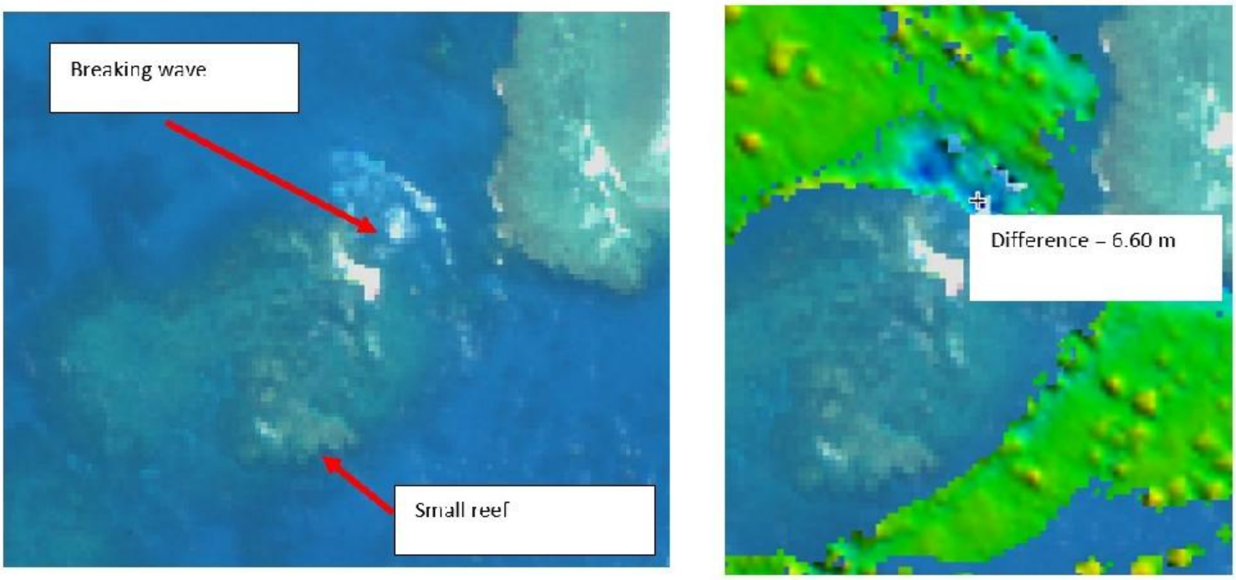


***Figure 18** : Left – Satellite imagery used in the SDB result, note white water on leeward (top of image) side of the reef, Right – Difference surface over same area, differences of up to 6.6m shown*

Some areas were identified where the SDB depths were significantly deeper than the MBES/ALB. These areas were around the edges of very shallow fringing reefs. This could be due to shading or limitations in representing the seabed as a 2m grid. Several other areas were identified where the reef/shoal was darker in colour than other sections of fringing reef. Several of these areas are shown below. The first of the areas is within a reef structure so has no significance on the charting outcome – the surrounding reefs will take precedence in most charting representations. The second area may have an impact on charting products, particularly if the area was to be represented on a larger scale chart as several isolated features were captured approximately 3-4m deeper in the SDB data than the MBES/ALB control data.

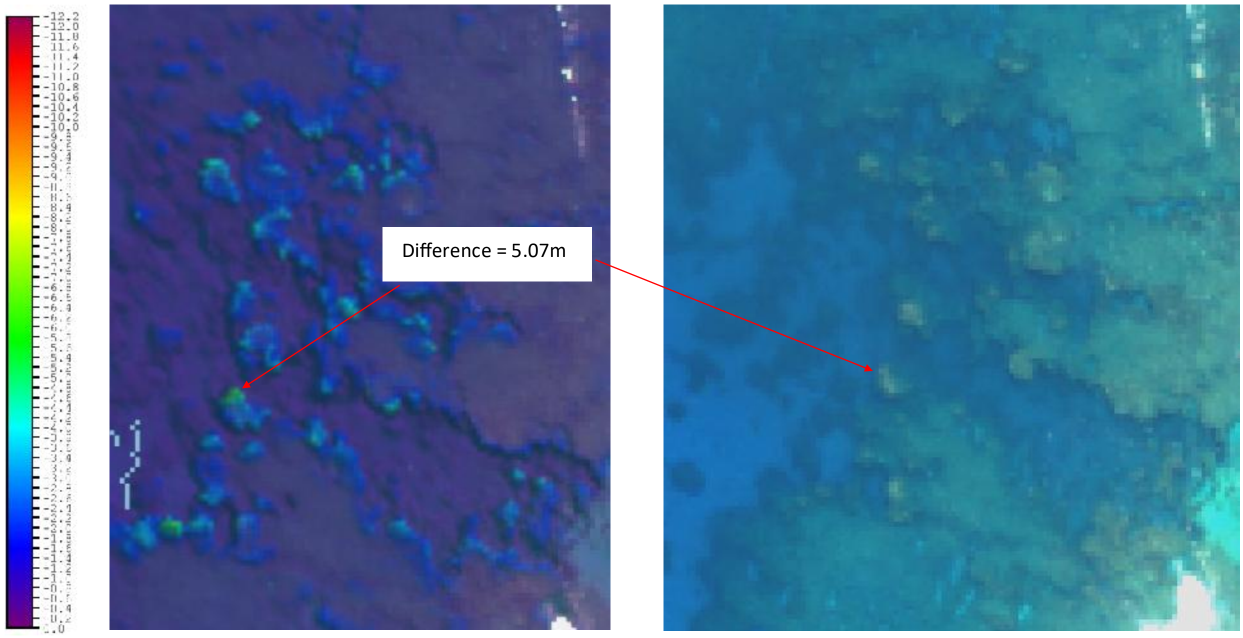


Figure 19 *: Left - difference result showing approx. 5m difference between SDB and combined MBES/ALB surface, Right – true colour satellite imagery of the same area*

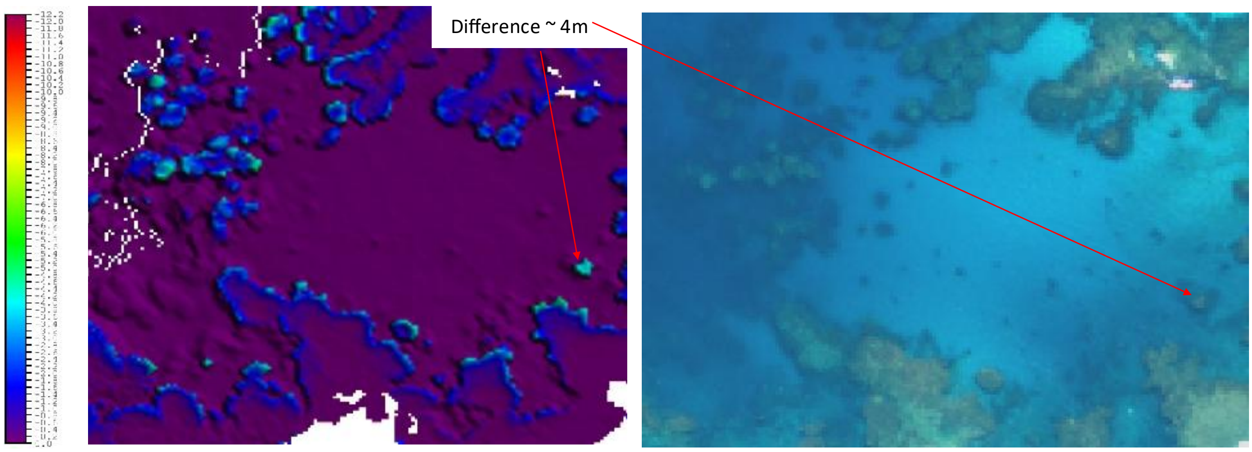


Figure 20 *: Left - difference result showing approx. 4m difference between SDB and combined MBES/ALB surface, Right – true colour satellite imagery of the same area*

Lifuka Results

All differences in the Lifuka area showed a deep bias. The table below presents the statistics of the difference surfaces generated.

***Table 10** : Summary table of the differences of SDB to MBES/ALB surface with slopes >15° excluded, split by depth range*

Lifuka Area MBES/ALB to SDB Comparisons							
All data							
Depth band	Mean Diff (m)	St Dev (m)	Mean+2SD (m)	Min (m)	Max (m)	Range (m)	Count
<5 m	-0.39	0.94	2.27	-12.64	5.32	17.96	3376837
5-10 m	-1.01	1.55	4.11	-10.34	8.86	19.20	1219301
10-15 m	-0.65	1.70	4.05	-7.61	13.19	20.80	863198

The deep bias is best illustrated by viewing a histogram plot of the differences across the surface (see ***Figure below***). There is a significant number of differences which fall on the deep side and a noticeable "bump" in the curve on the deep side. This is quite different to the results from the Nomuka area and is a consequence of the difference between the two areas - Lifuka has a higher proportion of depth areas within the range of 5-15 m. Also noticed is the same characteristic of a widening difference curve with depth, something seen in the difference statistics in the table above.

Having large areas incorrectly portrayed as too deep, even if the relative error is not large, is a concern for a charting authority, it also creates problems when merging the data with overlapping datasets.

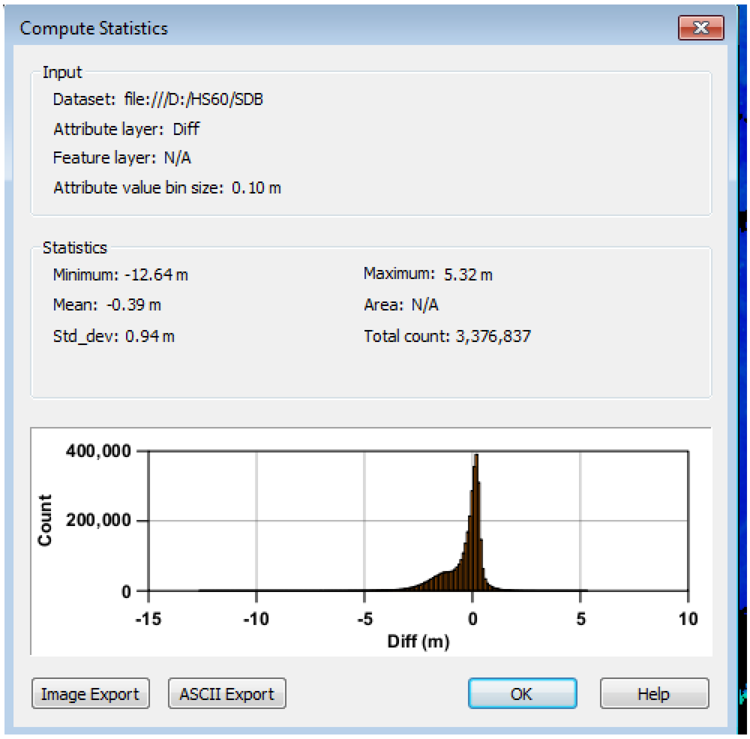


***Figure 21**: Differences in depths <5m in Lifuka, a bump on the deep side can be seen in the histogram indicating a deep bias*

Removing sloping areas, the differences improve slightly but the deep bias still exists. The table below presents the results of comparisons after slopes greater than 15° were removed from the surfaces.

***Table 11** : Summary table of the differences of SDB to MBES/ALB surface, split by depth range*

Lifuka Area MBES/ALB to SDB Comparisons							
Data with slope <15°							
Depth band	Mean Diff (m)	St Dev (m)	Mean+2 SD (m)	Min (m)	Max (m)	Range (m)	Count
<5 m	-0.13	0.58	1.29	-9.24	2.29	11.53	2310070
5-10 m	-0.29	0.79	1.77	-10.44	4.19	14.63	3098956
10-15 m	-1.35	1.60	4.55	-4.01	7.14	11.24	909096

It also seems that the differences and range of differences are similar in depths beyond 5 m and that accuracy does not degrade with depth in the same way. This is different to the Nomuka area and the reason could be a result of the contrasting images of the seabed, one being darker/ rockier, but both in the depth ranges of 5-15 m. The differences between the two areas can be seen in the figure below. Both areas have similar depths.

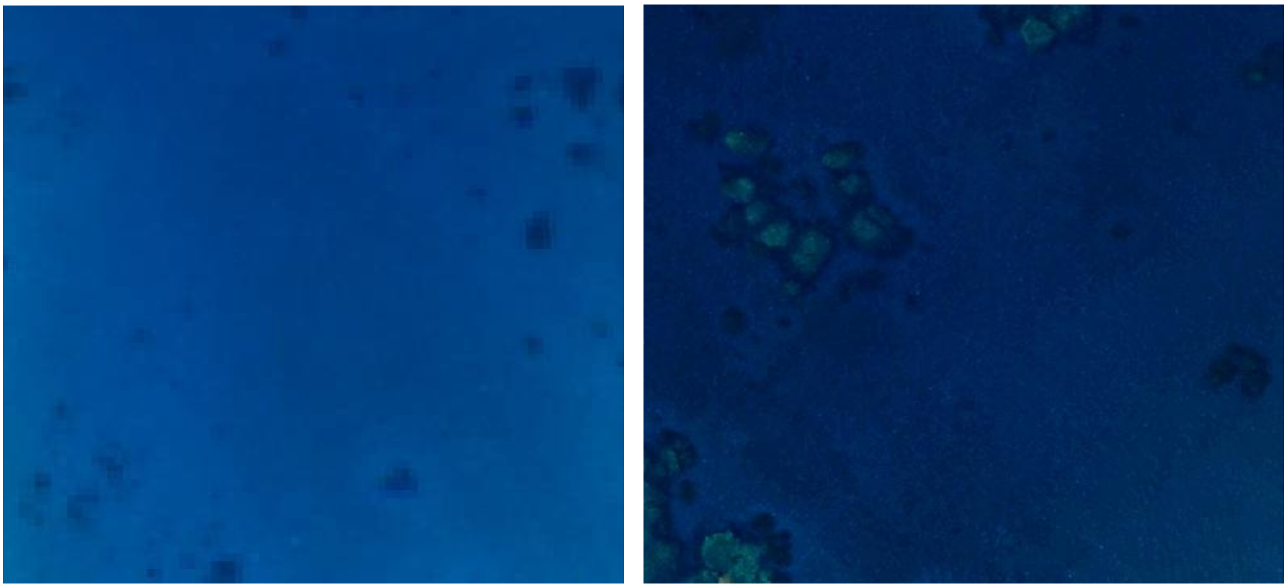


***Figure 22** : left satellite image shows in flat areas of approximately 10m water depth at Nomuka, the right satellite image shows flat areas of approximately 10m water depth in Lifuka*

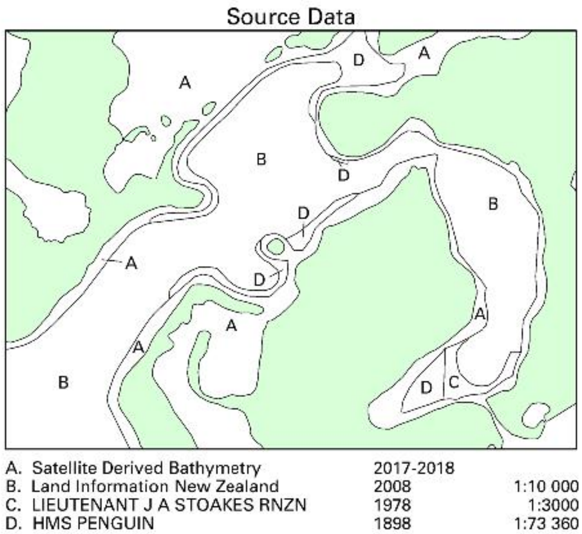
From the assessment it appears the spectral databases used for the physics based SDB approach may not be capturing subtle changes in seabed type from area to area.

It is likely that the SDB will benefit from a 2 stepped approach to processing if a multi-sensor survey is taking place. A first pass is useful for planning other sensors and detecting large shallow features (e.g. larger than 2m, the pixel size of the image data). This first pass may also be the final bathymetry data set for those areas where the other technologies are not able to be deployed, due to remoteness of location. A second step could involve checking and if necessary, re-processing the SDB based on overlapping data from the other sensors. With this second step of reprocessing it is possible that SDB coverage can be extrapolated out to a wider area with increased certainty of its accuracy.

5. DATA PORTRAYAL AND CATZOC

When incorporating the data from multi-sensors on nautical products it was necessary to consider how best to portray the data and capture CATZOC attributes for the M_QUAL object. With multiple data sources (SDB, ALB and MBES) it was important to provide the mariner with a clear picture of the data source and quality, without cluttering the chart - both ENC and paper. Producing CATZOC polygons based on technique of sounding (TECSOU), sounding accuracy (SOUACC) and water depth were not considered appropriate in this situation. A seabed comprising fringing reefs with steep topography and rapidly changing depths over short distances, would result in numerous narrow polygons.

In the case of the Tonga SDB, the decision was made to clip all SDB data to depths ≤8m. This was done primarily to remove vertical misalignment issues when merging with the ALB data. When investigating a suitable way of portraying the SDB data on chart products, LINZ considered the use of magenta polygons to define the areas. However, the Tonga charts already include magenta polygons that depict other features such as Special Management Areas and no-anchorage areas. Including another magenta polygon would increase clutter and possibly cause confusion. Instead, the SDB data is treated as another data source and included in the Source Data Diagram (below left) on the paper chart, and the TECSOU encoded as ‘satellite imagery’ on the ENC. In addition, chart notes (below right) are included with the products indicating that some depths were based on satellite imagery and could have an uncertainty of up to 3m – a figure determined by the comparisons above.



SATELLITE DERIVED BATHYMETRY

Depths within the area indicated on the Source Data Diagram are derived mainly from satellite imagery. Their vertical accuracy is typically ± 3m. Uncharted dangers may exist. For further information see Admiralty publication 'The Mariners Handbook'.

M_NPUB Object

SATELLITE DERIVED BATHYMETRY

Refer to M_QUAL objects for details of depths derived mainly from satellite imagery. Uncharted dangers may exist. For further information see Admiralty publication 'The Mariners Handbook'.

***Figure 23** : SDB Portrayal on paper chart*

In portraying the vertical accuracy of SDB data, another consideration was to display the uncertainty as a percentage of depth. Stating that depths may have a vertical uncertainty of up to 30% of the depth may provide the mariner with more understandable information. It also acknowledges that in shallower locations (depths <5m) depths may be more accurate than the 2-3m vertical uncertainty represented by a CATZOC C rating.

6. CONCLUSIONS

A multi-sensor survey approach has many benefits. It enabled the bathymetric coverage over a very wide area with less effort than vessel-based techniques alone. The sequence of the survey enabled more effective utilisation of resources and increased vessel safety in what was a sparsely charted area. Since no mobilisation or fieldwork is required for the SDB, these data were delivered rapidly as a first phase of the project, contributing to the planning component and further optimising the overall project timelines and resources.

The different sensors performed well in the Tongan survey areas and achieved excellent coverage. The different sensors while providing the bathymetry required also acquired topographic and imagery data to support activities beyond nautical charting.

As a result of the survey 12 ENCs and 7 paper charts were updated with plans to update 4 more of each in the future. A majority of which contain data from all three sensors.

In order for the different datasets to be displayed on charting products a better understanding of the technologies was required. The results of the analysis were not simple; it is difficult to portray "good in some areas, but not so good in others". A degree of simplification was required for placing the information on charting products.

The ALB data was very good and comparable to the MBES datasets in terms of vertical accuracy. Some uncertainty remains as to the feature detection capabilities of the ALB system for safety of navigation purposes. SDB vertical accuracy decreases rapidly with depth and therefore its uncertainty is best captured as a percentage of depth. Furthermore, SDB is at odds with the current CATZOC criteria, one that was developed with older positioning technologies in mind. Taking the new IHO survey standards as guidance, a separate CATZOC category may need to be defined for SDB, which takes into account both the relatively high horizontal accuracy as well as the depth-dependent vertical accuracy term of the SDB data.

The multi-sensor approach would benefit from a few improvements. One improvement would be to revisit and re-process some of the earlier acquired datasets using the later acquired data. For an approach like this to be adopted more overlapping data would be required in shallower areas which would provide the means to do additional processing. The area of overlap should not be a factor but the spatial distribution of overlapping areas should be a key consideration. Ideally several higher confidence MBES sites would be acquired in shallow water. Of course when planning this extra work there will be an additional cost and the benefits of the extra cost need to be taken into consideration.

Furthermore a feature detection trial involving a target of known dimensions should be conducted with the ALB sensor. Ideally this should be done in different areas and different surrounding seabed types. The logistics of this may be difficult as these need to be placed or be found with vessel resources in advance of the plane's mobilisation. The additional trials will give more certainty of how the sensor detects features and may also guide processing efforts later in the project or in future projects.

7. REFERENCES

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8. AUTHOR BIOGRAPHY

Brad Cooper completed a Bachelor of Surveying (BSurv) and IHO Cat A certification in 2011 and spent 7 years working as a hydrographic surveyor based in Perth, Australia. In this time he was involved in a number of survey projects including shallow and deep water multibeam surveys and offshore construction surveys. In 2018 he moved back to New Zealand to join LINZ as a Senior Hydrographic Surveyor. As part of this role Brad helps in the management of the HYPLAN survey programme. His responsibilities include the validation and verification of all hydrographic survey data received by LINZ for use in the production of charting products.
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Articles

AN OVERVIEW OF THE COVERAGE WITH ENC IN THE MESOAMERICAN REGIONAL HYDROGRAPHIC COMMISSION AND THE CARIBBEAN SEA - MACHC

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Abstract

Hydrographic offices worldwide started the production of Electronic Nautical Charts (ENCs) based on paper nautical charts, generating various designs in their schemes.

The design of electronic nautical cartography schemes in the Regional Hydrographic Commissions (RHC) is analyzed, in order to understand the existence of schemes adopted by an entire region, or electronic nautical cartography schemes defined by countries with the capacity to produce them worldwide. The review allows us to know the state of the art in the regional schemes, methodologies and / or parameters used in their definition, and level of compliance with international regulations.

In addition, questionnaires were carried out, which were used to acquire complementary information on hydrographic services, and this combined with the analyzes will determine the strengths and weaknesses in the current ENC coverage. Taking maritime safety into account, the investigations were conducive to presenting a methodological proposal for regional standardized ENC schemes.

This article has been organized into five points, the first one presents the analysis of the coverage of current electronic charts, taking into account the metadata of the coverage used by the different Regional Hydrographic Commissions. In the second, a survey carried out to several Hydrographic Services is presented, including: the review and registration of relevant aspects of the ENC schemes at the RHCs level, as well as the socialization and issuance of the survey to the RENC Member States. IC-ENC; in the third, the results of the analysis of the information collected on the designs of the current ENC schemes in the RHCs that responded to the survey; the fourth presents the strengths and weaknesses found in specific cases of the current ENC schemes; and finally, in the fifth, the work in progress by the subgroup for the ENC Regional Scheme in the MACHC is evidenced.

Key words: Electronic Navigation Charts; ENCs; Schemes; MACHC; Hydrographic Service; Information System and Visualization of Electronic Charts.

Résumé

Les Services hydrographiques du monde entier ont commencé à produire des cartes électroniques de navigation (ENC) à partir des cartes marines papier, générant ainsi divers modèles de schémas.

La conception des schémas de cartes électroniques de navigation dans les Commissions hydrographiques régionales (CHR) est analysée, afin de connaître

Articles

Résumé (suite)

l'existence de schémas adoptés par une région entière, ou de schémas de cartes de navigation électroniques définis par des pays ayant la capacité de les produire dans le monde entier. Cette étude nous permet de connaître les dernières avancées des schémas régionaux, les méthodologies et/ou les paramètres utilisés dans leur définition, et leur niveau de conformité avec les réglementations internationales.

En outre, des questionnaires ont été réalisés et ont permis d'obtenir des informations complémentaires sur les services hydrographiques, ce qui, combiné aux analyses, permettra de déterminer les forces et les faiblesses de la couverture actuelle en ENC. En tenant compte de la sécurité maritime, les investigations ont permis de présenter une proposition méthodologique pour des schémas ENC régionaux normalisés.

Cet article s'articule autour de cinq points : le premier point présente l'analyse de la couverture des cartes électroniques actuelles, en tenant compte des métadonnées de couverture utilisées par les différentes Commissions hydrographiques régionales. Au second point, une enquête réalisée auprès de plusieurs Services hydrographiques est présentée, comprenant : l'examen et l'enregistrement des aspects pertinents des schémas ENC au niveau des CHR, ainsi que la socialisation et la diffusion de l'enquête auprès des Etats membres du RENC IC-ENC ; au troisième point, les résultats de l'analyse des informations recueillies sur la conception des schémas ENC actuels dans les CHR qui ont répondu à l'enquête ; le quatrième point présente les forces et les faiblesses constatées dans des cas spécifiques de schémas ENC actuels ; et enfin le cinquième point met en évidence le travail en cours du sous-groupe pour le schéma régional d'ENC au sein de la CHMAC.

Mots clés : Cartes électroniques de navigation ; ENC ; Schémas ; CHMAC ; Service hydrographique ; Système de visualisation des cartes électroniques et d'information.

Resumen

Los servicios hidrográficos de todo el mundo iniciaron la producción de Cartas Náuticas Electrónicas (ENCs) basadas en las cartas náuticas de papel, generando varios diseños de esquemas.

Se analiza los diseños de esquemas de cartografía náutica electrónica en las Comisiones Hidrográficas Regionales (CHR) para conocer la existencia de esquemas adoptados por una región entera, o esquemas de cartografía náutica electrónica definidos por países con la capacidad para producirlos de manera global. Este estudio permite conocer los últimos avances en los esquemas regionales, las metodologías y/o parámetros utilizados en su definición y su nivel de cumplimiento de la normativa internacional.

Además, se realizaron cuestionarios que se usaron para adquirir información complementaria sobre servicios hidrográficos, y esto combinado con los análisis determinará los puntos fuertes y débiles de la cobertura ENC actual. Teniendo en cuenta la seguridad marítima, las investigaciones fueron favorables a presentar una propuesta metodológica para esquemas ENC regionales normalizados.

El artículo está organizado en cinco puntos, el primero presenta el análisis de la cobertura de las cartas electrónicas actuales, teniendo en cuenta los metadatos de

Resumen (continuación)

la cobertura usada por las diferentes Comisiones Hidrográficas Regionales. En el segundo se presenta una encuesta realizada a varios Servicios Hidrográficos, incluyendo: revisión y registro de aspectos relevantes de los esquemas ENC al nivel de las CHRs, además de la socialización y remisión de la encuesta a los Estados Miembros del RENC IC-ENC; en el tercero, los resultados del análisis de la información recogida sobre los diseños de los esquemas ENC actuales en las CHRs que respondieron a la encuesta; el cuarto presenta los puntos fuertes y débiles encontrados en casos específicos de esquemas ENC actuales; y finalmente en el quinto se evidencia el trabajo en curso por el subgrupo para el Esquema Regional de ENC en la MACHC.

Key words: Electronic Nautical Charts; ENCs; Schemes; MACHC; Hydrographic Service; Information System and Visualization of Electronic Charts.

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1. INTRODUCTION

The International Hydrographic Organization (IHO), with the purpose of unifying the use of digital cartography and the exchange of hydrographic data, published the S-57 Digital Hydrographic Data Transfer standard for the production of electronic nautical cartography (IHO, 2000), which allows paper nautical chart data to be transferred digitally in a standardized form from the elements of an Electronic Navigation Chart (ENC) (Zou, Wang, & Wang, 2012).

The ENC is defined as: A standardized database in terms of content, structure, and format, published by Hydrographic Services under the authority of a government, for use in an electronic chart information display system (ECDIS). ECDIS is adopted by the International Maritime Organization (IMO) as part of the requirement on board ships which must carry the official ENCs for safe navigation (IMO, 2006).

Therefore, the International Hydrographic Organization coordinates world hydrographic activity, with the support of the Regional Hydrographic Commissions (RHC), which are 16 geographical divisions, made up of IHO member states with common interest, urging countries to contribute and unite efforts in planning, execution of hydrographic surveys and production of cartography. However, despite the recommendations of the IHO, it is not guaranteed that countries will fully follow or abide by the regulations.

2. BACKGROUND

As of the fifth meeting of the Hydrographic Commission of the Caribbean Sea and MesoAmerica (MACHC) in 2002, several hydrographers from this region discussed the first guidelines for the creation of electronic navigation charts for the region, using as a basis the existing international paper nautical chart scheme (CHRIS, 2003). It is important to bear in mind that the cartography planes are defined by each State in a sovereign way, in which the charts and scales necessary to cover a territory were obtained. However, there are "International Paper Chart Schemes", which are established for the different Regions. These schemes define the areas covered, the chart scales and the countries responsible for their production. This work is carried out at the regional level but coordinated by the IHO working groups, based on specifications issued by the same Organization, contained in publications such as S-11, for medium and small scales in order to meet the needs of international maritime traffic safety.

In subsequent meetings, member countries that make up the MACHC, such as Brazil, Colombia, Cuba, France, Mexico, Netherlands, Suriname, United Kingdom, United States of America and Venezuela, have reported the progress of their cartographic production within the framework national and international, both paper and electronic. In order to achieve adequate coverage of the ENCs, since the twelfth meeting of the MACHC in 2011, the production of official electronic charts in the region has been encouraged and the availability of the data used in their construction has been promoted through the Committees; Electronic Chart (ECC) and International Chart (ICC), currently known as the MICC, (MACHC Integrated Chart Committee, 2011).

3. PROBLEMS IN ENC COVERAGE

The production of ENCs in the Caribbean has so far been carried out using the schemes that already existed for paper charts, which, although it was the easiest to implement, has generated several problems. The most important is that many cells (ENCs) have a significant overlap area, which although it was advisable for paper charts by facilitating the mariner to move from one chart to another during their route, generates several problems in the ENCs, when cells are presented with areas of irregular overlapping information, poor horizontal consistency and lack of information or gaps in the continuity of the cells, which prevents obtaining a uniform coverage (La Pira, 2010). The foregoing, mainly due to the fact that in the same ENC there are areas overlapped by several nautical paper charts at different scales, which, when used in the creation of a single cell or electronic chart, generate the aforementioned inconsistencies.

Currently, electronic nautical cartography has been replacing paper charts, due to the work advantages offered by the use of ECDIS as a system, by integrating ship sensors and navigation aids, such as: log, gyrocompass, GPS, ENCs , RADAR, buoys, lighthouses, among others (Salgado Don, 2015; Śniegocki & Wieliki, 2010), which allows interrogation, visualization and filtering of the information according to the navigation route or maneuver that the navigator is developing, thereby improving their safety.

According to the Nautical Cartography Working Group of IHO, the use of paper charts has declined from 2008 to 2018 by around fifty percent worldwide, the production of electronic navigation charts has increased (NCWG, 2020). As evidence between 2014 and 2016, based on the production of 40 member countries of the International Center for ENC (IC-ENC) the growth was from 4,916 to 7,330 ENCs. One of the reasons for this increase in ENC production is the IMO regulations that make the use of ECDIS mandatory from 2012 and progressively until 2018 according to the tonnage of the vessels. In the IC-ENC report, for 2016 the increase in the production of electronic charts in the following countries stands out: Ecuador 71.4%, Venezuela 127.8%, Egypt 23.5%, Pakistan 16.7% and Chile 15%. (IC-ENC, 2017).

The reports of the working groups that make up the RHCs are essential for the monitoring of the cartographic production carried out by the working group on the world database of electronic navigation charts. (WENDWG). This group has recommended increasing the execution of the schemes for the nautical purpose or usage bands from 1 to 3, corresponding to the purposes of Oceanic, General and Coastal navigation managed in the scale ranges <1:1.499.999, 1:350.000 – 1:1.499 999 y 1:90.000 – 1:349.999 respectively, (IHO-IRCC9, 2017) This cartographic production should take into account the revisions of the IHO Strategic Plan, the IHO resolution to eliminate overlapping ENCs and the recommendations of the Regional Centers for Electronic Navigation Charts (RENC), on the importance of eliminating the overlap of the data.

Based on the status and progress in the worldwide electronic cartographic production described in the previous paragraphs; not having a regional ENC scheme adopted by the RHC has shown inconsistent coverage due to the various designs, difference between the handling of scales, data, and ENC coverage affecting maritime safety due to the irregularity in the presentation of the data. According to the analysis and results obtained through surveys, the strengths and weaknesses represented in the existing coverage were socialized before the annual meetings of the MACHC and the need to strengthen the RHC was apparent, therefore, through the Assembly it is created the Sub-Working Group for Regional Schemes of standardized ENCs, endorsed at the MACHC 20th meeting.

From the meeting 20th to June 2021 there are investigations involving the producing countries and leaders of the US, UK and CO subgroups who are investigating possibilities and options for the region's scheme, starting with the Oceanic usage band.

There are countries that are re - schematizing their charts to solve problems, as an example the USA (https://nauticalcharts.noaa.gov/publications/docs/ENC-Transformation.pdf), however it is done independently and not as part of a RHC scheme.

4. ENC PRODUCTION BY THE HYDROGRAPHIC SERVICES IN THE MACHC

In the case of the countries that make up the Caribbean Sea, there is a difference, because most do not have a hydrographic office and the nautical publications of these countries have been assumed by other nations, such as the United Kingdom, United States, Holland and France. This is especially true for the United States, who at the beginning of the 20th century made a great effort to carry out surveys and produce nautical charts in the Caribbean Sea and on the coast of America in the Pacific Ocean. Through the National Oceanic and Atmospheric Administration (NOAA) in the 90's, it began the production of its electronic charts from the digitization of paper charts and is currently developing a strategy to transform nautical cartography. in the National Cartography Plan, in order to solve problems in its products, such as: duplication of information, elimination of cells with irregular shape compiled in 130 scales, among others (Office of Coast Survey, 2017).

1. ANALYSIS OF CURRENT ELECTRONIC CHART SCHEMES

To analyze the design of the regional cartographic schemes, information was pulled from the web portals of the Regional Hydrographic Commissions, the Value-Added Resellers (VARs) and the IHO catalog (***Figure 1),*** whose information is provided by RENCs, Member States and distribution agencies.

Figure 1 *: ENC coverage available by RHCs filtered for General navigation purpose, revised December 2019 Source: IHO online catalog*

http://iho.maps.arcgis.com/apps/webappviewer/index.html?id=06d967702c7f4094bbc5b4f8e485b712

For the analysis of the current ENC schemes, a series of activities were carried out, which are listed below. The first two activities involved analysis of the Regional Hydrographic Commissions, based on the information available on the IHO portal:

(i) The ENCs produced by the countries that make up each RHC were reviewed, examining the following aspects:

- The design of the ENC scheme: to identify, first, if there is a scheme approved and adopted by the countries of the region, which allows greater uniformity in the representation and consistency of the data; and second if the ENC design is completely adjacent or, on the contrary, information is lacking in the same navigation purpose (overlap and / or gaps).

- Metadata: allows for identification of the scales used in production and determination if they follow those recommended by the IHO standards, the cartographic production capacity of the

(ii) Information was recorded on the aspects examined by each country of the RHC, taking into account metadata such as the producer country, navigation purpose, scale for each polygon that represents the ENC data coverage, as detailed in the ***Table 1***.

Table 1 *Record of aspects examined in the countries that make up the Regional Hydrographic Commissions, taking into account metadata of the ENC coverage*

CHR[1]	There is a scheme adopted by the region	Adopts the scales recommended by the IHO	Producing agency code[2] on the CHR	Scheme designs [3]
USCHC	No	No	CA, GB, US	E_PC
MACHC	No	Partially	DO, US, GB, CU, BR, MX, VE, NL, PA, CO, SR, FR	E_PC / E_ENC
SWAtH	No	Yes	AR, BR, UY	E_PC
SEPRHC	No	Partially	CL, CO, EC, PE	E_ENC / E_PC
NSHC	No	Partially	GB, IS, NL, DK, NO, BE, FR, DE, NL, IS	Grid / E_PC / E_ENC
NHC	No	Yes	DK, IS, NO	Grid / E_ENC
EAtHC	No	Partially	ES, FR, GB, PT	E_PC
MBSHC	No	Partially	RU, FR, GB, IT, ES	E_PC / Grid, combined system
SWPHC	No	Partially	AU, NZ, GB, FR	Grid/ E_PC / E_ENC, combined system
EAHC	No	Partially	ID, GB, MY, PH, JP, KR, China (CN, C1)	Grid / E_PC
NIOHC	No	Partially	BD, GB, PK, IN, ID, EG	E_PC
SAIHC	No	Partially	GB, FR, IN, ZA, NO	Grid/ E_PC / E_ENC

In the ***Table 1*** the distribution of the designs in each one of the RHCs is appreciated, where the majority use the three designs, finding cases in the countries that use combined designs; For the MACHC Commission, it is the Equivalent to paper charts and Exclusive for ENC, in the purpose of coastal navigation.

The following activities were carried out exclusively for the ENCs that map the Caribbean Sea, considering the complexity in the production.

(iii) The cartographic coverage for each related port or area of interest was reviewed, identifying the products for navigation purposes and scales established by producers.

(iv) The horizontal consistency of the data was examined, filtering the ENCs by navigation purpose from the portal of the MICC committee of the MACHC, which contains the vector product, allowing the analysis of all objects according to the type of geometry, for:

Polygon: Depth Areas, Special Areas, Magnetic Variation, among others.

Line: Series of contours defined for the chart according to the scale or purpose according to the specifications, unify series for purposes taking into account the configuration of the safety contour between the ECDIS parameters; cabling, coastline, among others.

Point: Sounding, hazards, navigational aids, among other point objects that display value is applied to them in the ECDIS through the minimum scale attribute (SCAMIN).

(v) The international paper chart scheme for the region was compared with the coverage of the ENCs published on the MICC committee portal, identifying whether the INT scheme was adopted by the countries for the production of electronic cartography.

(vi) The results of the analysis were shared with the RHCs, RENCs and working groups of the IHO related to the subject, in order to receive suggestions and comments to substantiate the proposal to standardize regional schemes through a re-schematization to unify navigation purposes.

(vii) A questionnaire was formulated and applied to the member countries of the RHCs and the RENCs, to provide feedback and complement the information analyzed, in order to know if the RHC has established standardized schemes in the region that the countries have approved and adopted, or on the contrary if the countries agree to re-schematize for navigation purposes that cover international waters, allowing to have a uniform coverage.

2. SURVEYS TO HYDROGRAPHIC SERVICES

This section develops the analysis of the results of the questionnaire to the member states of the Regional Center for electronic navigation charts.

In general, the analysis indicates that, close to three decades after having published the standard for electronic charts, the producing countries worldwide continue to work in the search for strategies and mechanisms for the continuous improvement of ENCs, in terms of quality, precision and updating.

During the socialization, in technical meetings of the electronic cartography working groups and IHO commissions, criticism and positive comments were received, which show the applicability and the benefit of being able to carry out the objective of Regional Schemes. The president of the International Center for ENCs (IC-ENC), asked if there are similar efforts in his region to that of the present work, giving the result that countries are working independently, due to challenges of sharing data between nations.

Consequently, the idea of presenting an academic questionnaire for IC-ENC members was raised, a commitment that was endorsed by them and supported by IC-ENC in accordance with action 5 of technical report TC03 / 19 (IC-ENC, 2018), in order to obtain more information about the commissions.

The most important aspects of the questionnaire are highlighted below.:

(i) During the third IC-ENC technical conference of 2018, an action was agreed between the participating members, to answer a questionnaire for academic purposes for research.

(ii) IC-ENC sent the survey to 44 member states, of which only 9 responded, in a period of five months. That is, 20.25%, which represents a difficulty in making decisions based on this instrument.

(iii) Five countries do not have regular plans to maintain horizontal consistency between ENCs with border countries.

(iv) The countries agree that the RHCs establish standardized regional schemes for Oceanic, General and Coastal purposes, however, the USA indicates that it would be a difficult task for the hydrographic offices. The difficulty lies in the origin of the data they used to create the ENCs, which leads to handling different levels of compilation scale in current ENCs, fearing that changing the compilation scales could create an ENC with poor data quality.

(v) Regarding re-schematization, a negative response was received by one of the countries stating its commission works in a coordinated manner and, it does not consider it necessary to carry out a complete restructuring in terms of overlaps and gaps. The few remaining cases must be resolved (locally adjusted or modified) among the NCD producers involved; this is encouraged by the NSICWWG.

(vi) Unify the compilation scale by navigation purpose, bearing in mind that the standards do not define scales for each usage band, on the contrary, a wide range of scales is recommended. Set a fixed minimum and maximum, and fixed defined values to use between this minimum and maximum for each band. With respect to this point, the Eastern Atlantic and Mediterranean regions already have these purposes standardized. No argument was received against this procedure.

(vii) Three of the nine countries consider the prior review of ENCs by the RHC to be beneficial, they are countries that are strengthening capacities for the production of their ENCs, one of the countries is replacing the ENCs generated by the UKHO.

3. EVALUATION OF THE DIFFERENT DESIGNS OF CURRENT ENCS SCHEMES

With the result of the questionnaire to the Member States, the information obtained during the analysis of the scheme designs in the RHCs is corroborated. (***Table 1***), of not having standardized regional schemes. In the ***Table 2***, advantages and disadvantages of the diversity of designs of the current schemes are defined. The three evaluated designs are:

Design equivalent to a paper chart. It refers to when the ENC scheme preserves as a pattern the coordinates and scales of a scheme for paper nautical charts, and even the areas of overlap. On paper charts at the same scale, it is necessary that these areas exist to maintain continuity of data during change of charts.

Grid. It is a design using a network of lattices that show parallels of latitude and meridians of longitude, in a uniformly spaced manner.

ENC Exclusive Schematic Design. It corresponds to the electronic chart scheme based on the recommendations of the WEND principles, specifically in not duplicating data and avoiding gaps between cells for the same purpose, optimizing the information compiled from the different cartographic sources and generating a cell that provides the information according to the purpose. navigation.

4. WEAKNESSES AND STRENGTHS

The results corresponding to activities such as a review of designs, metadata, port coverage and consistency of electronic navigation charting schemes, classified into strengths and weaknesses as follows:

WEAKNESSES

(i) Difference in the information published between the portals of the RHCs, IHO and the VARs commercialization catalog.

For the MACHC region, a specific case is presented, where there are differences between the cells reported in the portals of the MICC committee and the MACHC committee with respect to the ENCs that are available in the UKHO VAR catalog.

Table 2 : *Advantages and Disadvantages of severals ENC Scheme Designs*

Design	Advantages	Disadvantages
Equivalent to paper chart	Easy conversion of published paper chart to ENC	Numerous cells with M_COVR CATCOV = 2. Irregular way of presenting data. Cell coverage for the same purpose at different scales. Information display irregularly.
Grid	Provides organized coverage, seamless and without overlapping for purposes Avoid the use of M_COVR atribute CATCOV = 2 Cells standardized in sizes	Increased number of production cells Unnecessary subdivisions. Geographical accidents represented in several cells of the same navigation purpose.
Exclusive ENC	Cells adapted to the geographical feature Avoid overlaps and the use of M_COVR CATCOV = 2 Flexibility of dimensions in cells. Provide information in accordance with recommended purposes	Cells not arranged symmetrically (They do not preserve dimensions)
Combination of designs	Free adaptation to meet a need	Not ideal for the same navigation purpose

Regarding this disparity, the IHO has coordinated with the Hydrographic Service of Korea on the development of a portal where the ENC coverage and complementary information of all the Regional Hydrographic Commissions are centralized and visualized, establishing itself as the only place to obtain the information. The pilot project was presented during 2018 at the meetings of the WEND and NCWG nautical cartography working groups.

(ii) Disparity in the design of the existing schemes in the hydrographic offices, given that there is no standardized pattern for the production of ENCs in the RHCs, which indicates that most of the producing countries are doing it independently, evidenced by a lack of uniform coverage. For each RHC there is a diversity of designs (***Figure 2***), such as the Grid system, the equivalents to paper charts, adjacent rectangular cells, and the combination of systems by the same producer.

(iii) Regarding the analysis of the ENC metadata in the RHCs, the information on the compilation scale is considered a weakness. This is due to the need to know the varied use of scales for navigation purposes in the region, which represents the application of the attribute of minimum visualization difficulty to the objects; does not guarantee a complete visualization of the coverage through ECDIS systems; and shows non-compliance with the series of scales recommended by the IHOI specifications.

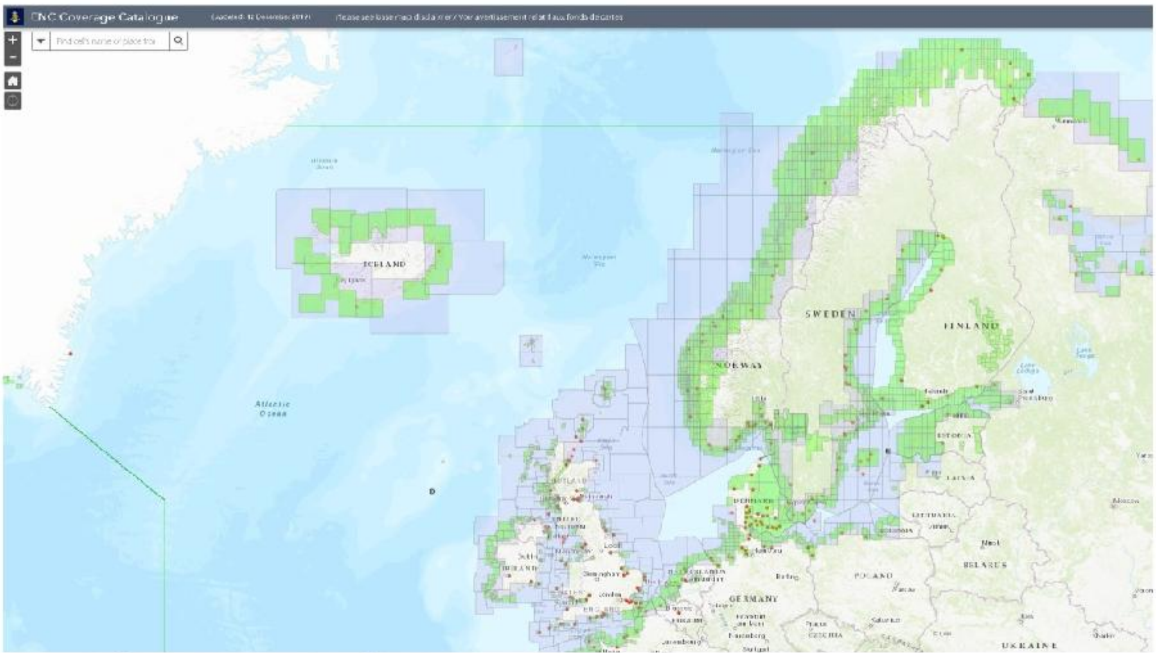

Figure 2** :Shows the diversity of designs in the same region regardless of purpose. The purple cells correspond to the Coastal navigation purpose and the green cells to the Approach purpose, showing irregular shaped designs, Grid, among others. Source: IHO online catalog of ENC coverage and availability, revised July 2021.* ***http://iho.maps.arcgis.com/apps/webappviewer/index.html id=06d967702c7f4094bbc5b4f8e485b712

(iv)In general, in all the RHCs, the dependence on the cartographic production of other countries is evident.

In the framework of uniform coverage available for the region of the MACHC, incomplete coverage is appreciated, due to the inequality in the cartographic capacities of the countries that make up the region, however, some areas are covered by cells produced by other countries. One case is that of the Cayman Islands, (***Figure 3***) ENCs from these islands are produced by NOAA for Oceanic and General purposes and by the UK Hydrographic Office for Approach and Port purposes, on the 1: 2 160 000, 1: 1 200 000, 1: 45 000 and 1: 8 000 scales respectively.

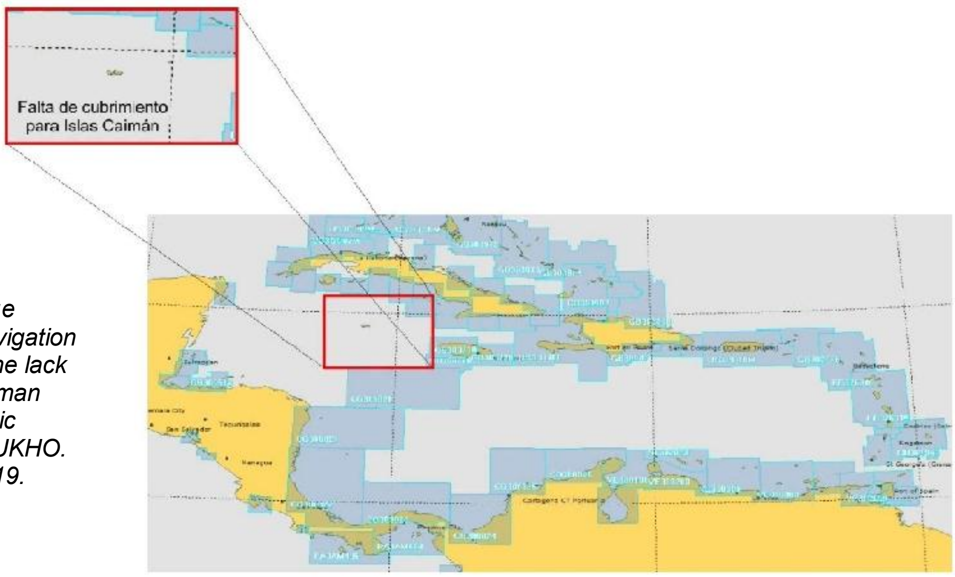

***Figure 3:** ENC coverage available for Coastal navigation purposes, highlighting the lack of coverage for the Cayman Islands. UK Hydrographic Office Digital Catalog - UKHO. Visited in November 2019.*

i

(v) Most of the countries did not adopt the international paper chart scheme for each region during production of ENCs. A specific case, the INT Region B MACHC chart scheme was analyzed, in which Colombia and Venezuela partially used the international chart scheme:

Venezuela and Colombia neighboring countries adopted the INT paper chart scheme, however, the ENC coverage for the General purpose is not continuous; in the area there is a cell captured by the UK Office, it does not use the limits of the INT scheme of the region. As shown in ***Figure 4***.

Figure 4 : *In the General navigation purpose, the irregularity of the coverage of areas in charge of different producing countries is evidenced and the fissure in the cartographic coverage of ENCs is highlighted by the red oval. Source: UK Hydrographic Office digital catalog - UKHO. Consulted November 2019.*

In the coastal scales, the cells present inconsistencies with respect to the adjacent depth area, where the Venezuela cell represents a depth area of 20m to 200m, and the Colombia cell shows the area with a depth range of 50m to 100m. This is the cause of the inconsistent display that is shown in the ECDIS, under certain settings, the two areas in different shades of blue.

Due to the differences between the medium-scale INT chart scheme and the Coastal use band 3 ENC coverage, in this subregion, it is important to assess whether there is adequate ENC coverage for this purpose due to the density of maritime traffic.

In addition, incomplete coverage, whether in a specific region or in bordering situations, is also due to the varied handling of the compilation and display scales for a navigation purpose, (***Figure 5***) generating uncertainty to the end user and unpredictable behavior of ECDIS.

Figure 5 : *Incomplete coverage and visualization of ENCs, in the Caribbean Sea Source: MACHC online catalog, November 2018*

STRENGTHS

Currently, other countries like USA, are implementing strategies for their products such as raster charts, ENCs and paper, re-schematizing their cartographic production plans independently in a Grid system.

The dependence of cartographic production in other countries is shown as a strength, due to the increasing coverage of ports, especially with the purposes of navigation in the Bay and Approach, contributing to the security and economy of the region.

There is a recognized need by the member states of the MACHC region to harmonize ENC coverage for Coastal, General and Oceanic navigation purposes.

Finally, there is strenght in the willingness of the countries to seek strategies to acquire capacities and evaluate their production, in a regional manner, considering the impacts faced by the end user (ECDIS) regarding the management of several scales and designs of ENC schemes for purposes of navigation.

5. WORK IN PROGRESS MRES WORK SUBGROUP (ENC MACHC REGIONAL SCHEME)

Faced with the large task of strengthening the management of the MACHC regarding the coverage of ENCs, evidence of the weaknesses and strengths found on the ENC designs in the regions was presented during the 20th meeting of the MACHC 2019, with special emphasis on the commission. As an initial result of research for academic purposes, the option of Regional ENC Schemes was proposed to be approved by the commission in order to unify scales, scheme origin and cell sizes for Oceanic, General and Coastal navigation purposes. (MACHC, 2019)

Standardization, in this contect, refers to maintaining uniformity and consistency for the purpose of maritime safety. This requires ENC producer countries to take the right course when thinking about providing quality and safety to the end user. As a result, hydrographic offices must address the need to redefine their ENCs to achieve this objective.

The design of the adjustment scheme was socialized, presenting a solution for the study area, proposing a greater coverage with fewer cells based on the ENC coverage and the INT scheme of paper charts; always seeking to maintain contiguous, adjacent cells; and giving coverage to the ports and geographical features. Finally, it was deemed necessary to make adjustments in the Coastal scale before it is discarded because the project line focuses on harmonizing and standardizing, which would leave the solution centrally and temporarily for the MACHC regardless of the current position of the International Hydrographic Organization in achieving consistent integrity with other RHCs.

Therefore, as part of the fruitful discussion on the research, the Assembly approved the creation of the MICC - MRES (MACHC Regional ENC Scheme) working subgroup during the MACHC 20th Regional Hydrographic Conference, led by Mexico and Colombia.

The first action of MICC-MRES was the analysis of the proposal made by Colombia at the MACHC 20th Regional Hydrographic Conference of a Regional Scheme by means of a questionnaire that would capture the point of view and considerations of each country on the convenience, feasibility and the acceptability of having a regional scheme, taking into account the complexity of the needs that are required to change the scheme (technical, professional, financial resources, time, among others).

According to the feedback carried out (MACHC, 2020), opinions were divided between five countries; some supported a new scheme with the Grid system while others supported the need to adjust only the current ENCs, making the size more flexible in sectors where there are gaps under the idea of harmonizing in terms of compilation scale with consistent application rules such as the use of SCAMIN, to ensure visualization for the ECDIS user.

The subgroup decided to start by developing options for the minor bands (Oceanic and General) and assigned actions to develop a common proposal for Grid schemes. The goal is for the producing countries to reach an agreement and start with the implementation and redesign before facing the challenge of the S-101 standard.

The United States supports the proposal to opt for regional schemes, therefore, it has provided the scheme prepared for its country (Nyberg, J. et al, 2020) as a reference for the investigation process (***Figure 6***). However, the United Kingdom continues to explore options in order to adjust the better coverage of your production globally.

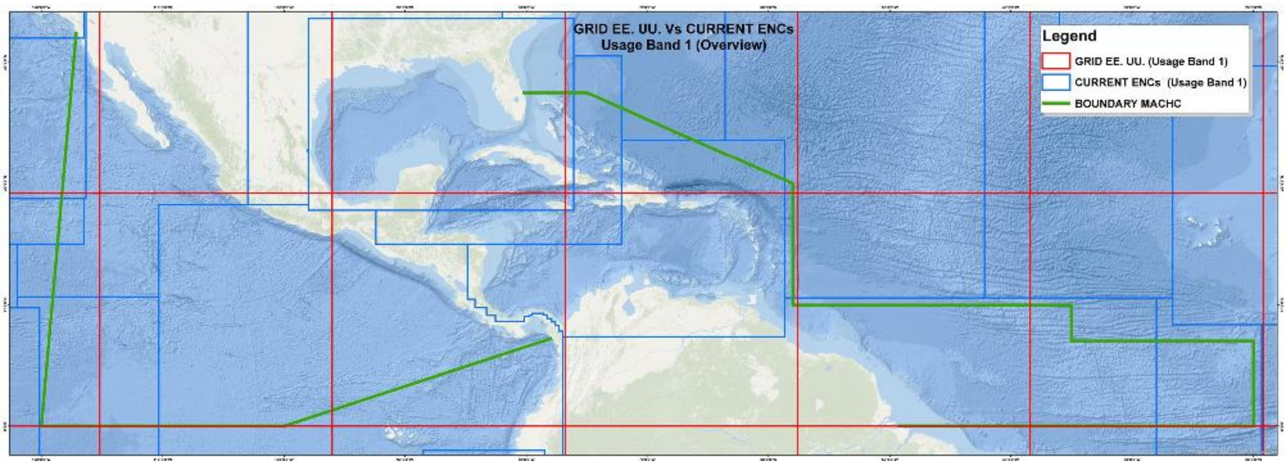

Figure 6 *visualization of scheme Grid EE. UU. Vs Current ENCs in the Usage Band 1.*

Through statistical analysis based on the size of current ENCs in the MACHC, the MRES subgroup has made a proposal for a Grid scheme for the Oceanic usage band (***Figure 7***), in order to jointly discuss with the Member States aspects such as origin of the Grid, cell sizes for navigation purposes and the definition of scales for harmonized production at a regional level with global influence (***Figure 8).***

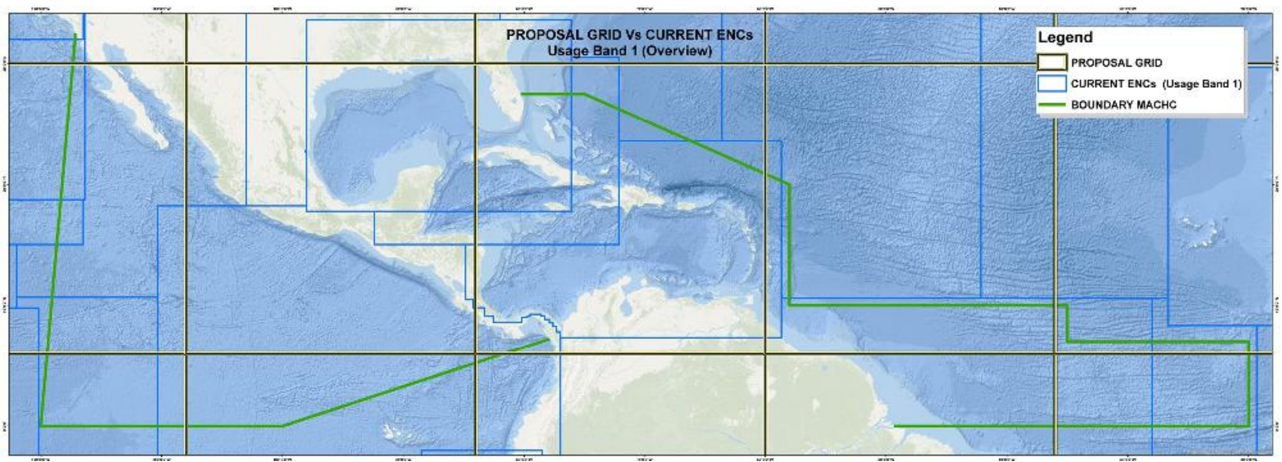

Figure 7 *visualization of proposal scheme Grid. Vs Current ENCs in the Usage Band 1.*

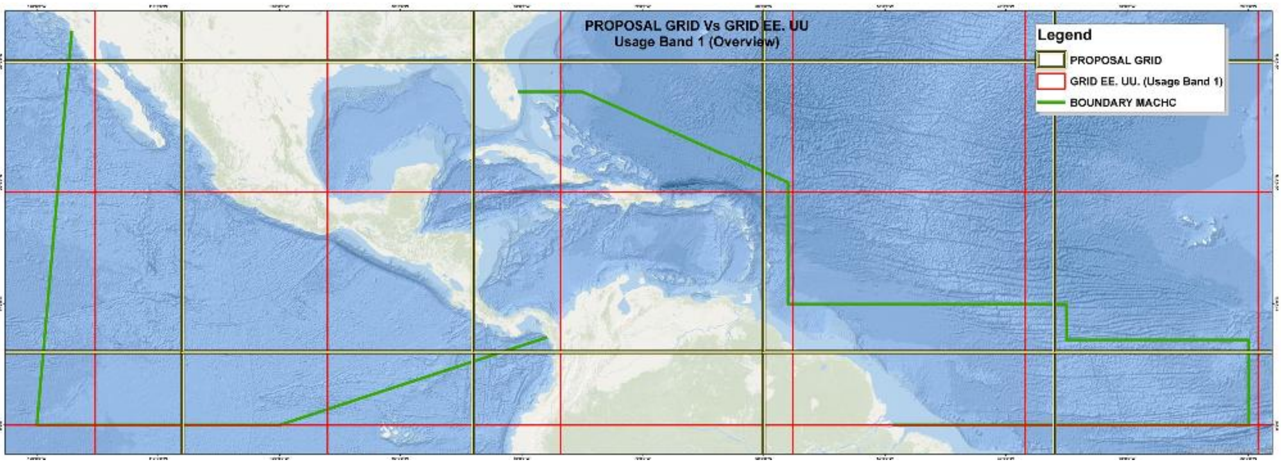

***Figure 8** :Differences about sizes with designs of schemes grid for cover the current ENCs in the MACHC. Origin Grid EE.UU. 0,0; and Proposal Grid MRES -90, -180 for usage band 1.*

5. DISCUSSION

The proposal to adjust the scheme is not a regular Grid system, it is a proposal to unify sizes based on the current coverage and sizes of INT Paper charts, in order to reduce the number of cells to maintain. Considering the differences between the production capacities in the countries of the region, an alternative was proposed to reduce the impact on production.

The design of the proposed regular Grid system would be ideal for a seamless global scheme; therefore, it is necessary for the IHO to approve the scales, the sizes for the cells for navigation purposes and the origin of the grid established by the Subgroup of MRES work in order to avoid transferring the problems of the past. It must be taken into account that some nations have already migrated a gridded ENC scheme, independently presenting a difference between the sizes of the ENCs.

Gridded ENCs can support future solutions for automated paper chart production from ENCs. Some countries like Australia, Germany, Japan, Korea have partially migrated their ENCs to regular grid designs (USCHC, 2021); for the United States, NOAA is currently transforming their ENC scheme.

6. RECOMMENDATIONS

- The working subgroup should conduct further research and discussion on a possible ENC grid for the MACHC. It would be useful to know the opinions of more of the member states, and to get producers to agree on the uniform grid that allows an optimal and comprehensive schema.

- Establish ENC schemes at the level of standardized RHCs for the purposes of Oceanic, General and Coastal navigation that are approved and adopted by the region in order to guarantee the end user a consistent coverage, avoiding continuing the production of ENCs independently.

- When designing the cell scheme, overlaps and gaps should be avoided for coverage in the same navigation purpose, which allows greater consistency between products, increases the confidence of navigators, optimizing the performance and use of ECDIS.

- Every port must be mapped regardless of the size or activity it carries out for the sake of security.

- Unify, among the producing countries of the region, the information corresponding to the range of compilation scales for navigation purposes recommended by IHO Circular 047 of 2004, in order to facilitate the application of the minimum display scale attribute (SCAMIN) in subsequent ENCs and ensure continuous mapping via ECDIS (IHO, 2004).

- In order to provide uniform and quality coverage to the end user, it is recommended that neighboring countries estblish agreements or memoranda of understanding between producing countries in order to authorize shared publication of data.

- Carrying out bathymetric surveys complying with IHO standards is one of the fundamental aspects to have the adequate information that must be represented in the ENCs.

7. CONCLUSIONS

The IHO has long suggested a gridded approach to an ENC scheme, as typified by its many publications on the subject. During an IHO meeting in Singapore, this uniform grid approach was formally proposed to the hydrography community. (HSSC, 2009). However, after a decade there is still a debate on the problem of overlaps and gaps.

This research and analysis concludes that the proposal of a new Grid scheme will avoid overlaps and gaps, which mainly benefits the ECDIS user by having a uniform display increasing maritime safety.

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9. AUTHORS BIOGRAPHIES

Coming soon

Notes

STATE OF HYDROGRAPHY SURVEY IN KENYA TOWARDS HYDROSPATIAL DATA INFRASTRUCTURE

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INTRODUCTION

This article focuses on the current status of hydrographic efforts in Kenya, as well as, the future plans to develop foundational hydrographic elements and layers of data and information towards the implementation of the Kenya hydrospatial data information. “Hydrospatial is all about the Blue of our Blue Planet and its Coastal Zones” (Hains D. & HMCC members 2021). Hydrospatial could be described as that portion of geospatial knowledge infrastructure that addresses the hydrosphere (Smits 2021). Hydrospatial is an expansion of Hydrography and it is a much broader domain. (Hains & al. 2021; 2020; Pang & Oie 2020 + Ponce 2019).

Figure 2: *Kenya location on the World Map. Copyright © Ontheworldmap.com https://ontheworldmap.com/kenya/kenya-location-map.html*

On 26th July 1991 the Cabinet approved the establishment of a National Hydrographic Office under Survey of Kenya (SoK) in the Ministry of Lands and the Kenya National Hydrographic and Oceanographic Committee (KNHOC) currently known as the Kenya National Hydrographic and Oceanographic Committee (KeNHOC) which became operational in January 2006. KeNHOC is mandated to spearhead coordination of hydrographic services in all different government Ministries, Departments and Agencies (MDAs) in the country among other responsibilities and its members are drawn from key government institutions offering maritime and hydrographic services. The members include Survey of Kenya as the secretariat, Kenya Navy (KN), Kenya Ports Authority (KPA), Kenya Maritime Authority (KMA), Kenya Marine and Fisheries Research Institute (KMFRI), University of Nairobi (UON), Regional Center for Mapping and Resource Development (RCMRD), Kenya International Boundary Office (KIBO), NationalOil Corporation Kenya (NOCK), Kenya Coast Guard Service (KCGS), National Environment Management Authority (NEMA) and the Kenya Ferry Service (KFS).

Kenya is endowed with a coastline that stretches approximately 536 km of the Indian Ocean, Lake Victoria; the 2nd largest freshwater lake in the world, eight major lakes along the rift valley and several dams for hydro-electric power production. The Kenyan Exclusive Economic Zone (EEZ) covers approximately 142,000 km^2 with potential extension of its continental shelf beyond the 200nm by approximately 103,302 km^2 from a continental shelf survey that was done in 2007. Kenya made its proclamation of the EEZ in February 1979 through a Presidential Proclamation and was revised in 2005 and published by the United Nations (UN), territorial boundary delimited in 1972 and her continental shelf was delineated and a submission (https://www.un.org/depts/los/clcs_new/submissions_files/ken35_09/ken2009_executivesummary.pdf) on the continental shelf beyond 200 nautical miles was deposited to Commission on the Limits of the Continental Shelf (CLCS) in the year 2009 which is currently undergoing examination by the Commission

Kenya has three major ports: Port of Mombasa, Kisumu Port and the newly launched Lamu Port. Lamu Port is part of Lamu Port Southern Sudan Ethiopia Transport Corridor (LAPSSET), a Vision 2030 mega infrastructure project connecting Eastern Africa countries. Shimoni Port is under construction besides various fishing ports along the Indian Ocean and Lake Victoria. With all these resources, a base map is needed for hydrospatial data infrastructure including physical, biological and chemical data and information in the water domain; marine spatial planning, maritime boundary delineation and resource exploration and exploitation which requires a foundational bathymetric data layer from hydrographic surveys. With the rapid growth in technological advancement, especially in data collection and processing there is need to locally define procedures for data collection, processing, quality control and assurance locally and data archival as per IHO standards, to meet accuracy and interoperability requirements for charting purposes.

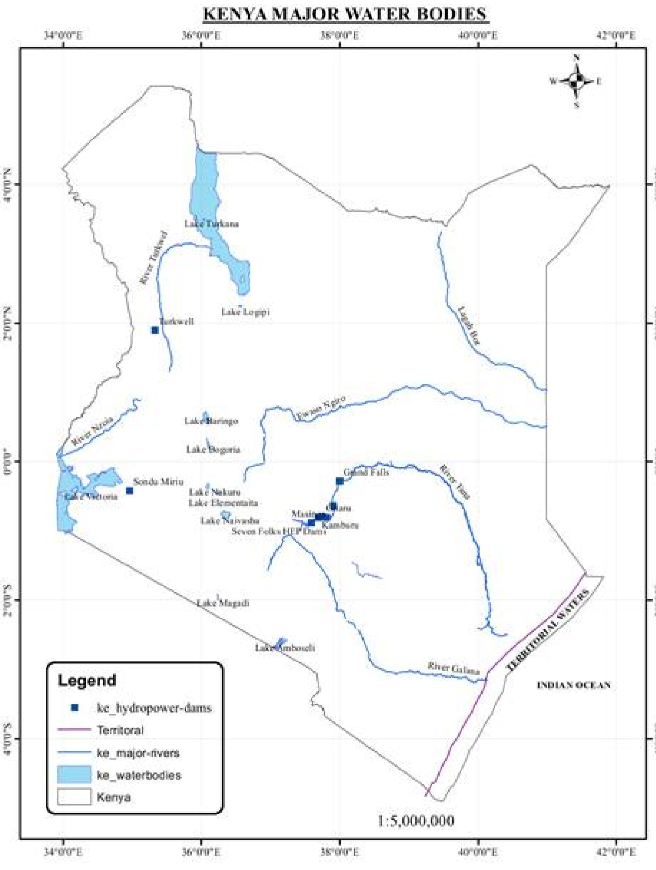

Figure 4: Map showing locations of Kenya's major lakes, rivers and dams

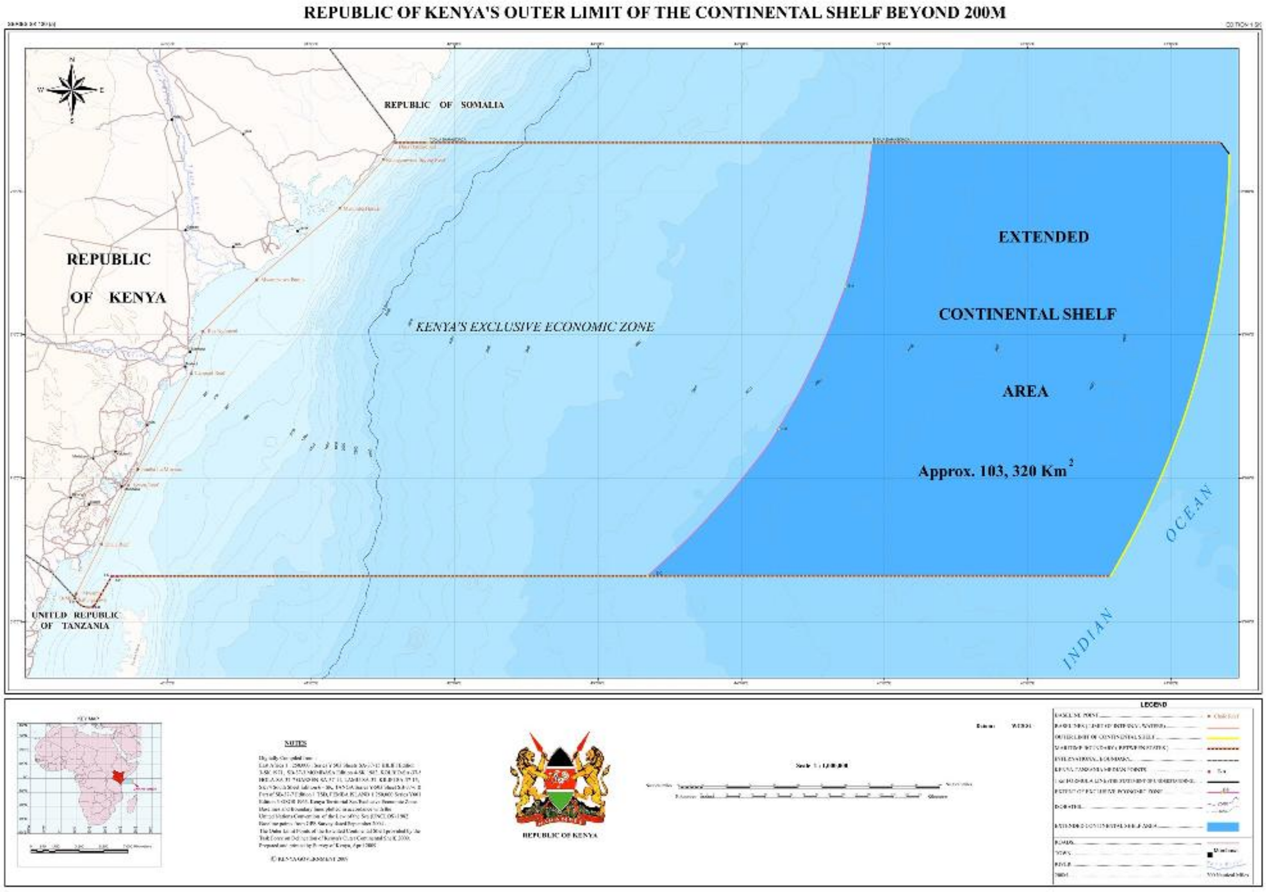

Figure 5: Map Showing the Exclusive Economic Zone and Extended Continental Shelf

South Africa, Nigeria and Mauritius have successfully invested in hydrographic surveying, especially in human resource capacity development, such that they carry out hydrography surveys alongside production of nautical charts with very little help from other organizations. In the Kenyan context, it is a gateway to landlocked east and central African countries and is positioned midway between the Gulf of Aden and South Africa. Therefore, hydrography is very crucial, especially on the issues of safety of navigation and maritime boundary claims, since Kenya is a state party to the Safety of Life at Sea (SOLAS) Convention and is required to ensure that appropriate paper charts and Electronic Navigation Charts (ENCs) are available in accordance with Regulations 9 and 4 of Chapter V of that Convention and United Nations Convention on the Law of the Sea (UNCLOS). Dredging and expansion of ports and harbors, oil and gas offshore production prospects and improvement of lake transport are major projects earmarked for funding towards the realization of the blue economy agenda that includes hydrospatial data and information in a multidimensional context.

THE KENYA NATIONAL HYDROGRAPHIC OFFICE (KNHO)

The United Kingdom Hydrographic Office (UKHO) is the Primary Charting Authority that does publication, maintenance and distribution of all Admiralty nautical charts (paper, raster and electronic charts) and nautical publications (list of light, radio signals, sailing directions, tide tables) on behalf of Kenya. The Kenya National Hydrographic Office currently has one Category (CAT) A hydrographer, seven CAT B hydrographers and one CAT B nautical cartographer. The Kenya Ports Authority and Kenya Marine and Fisheries Research Institute each have one CAT A hydrographer while the Kenya Navy has twelve CAT B hydrographers.

The hydrographic survey section has three offices; Nairobi office is the headquarters; the Mombasa regional office is in charge of the coastal province covering the Indian Ocean, while the Kisumu office is in charge of all activities on and along Lake. Victoria region. The Hydrographic survey section in Survey of Kenya (SoK) is equipped with a Knudsen Single beam Echosounder, RTK GPS Base Station without rover, four portable tide gauges and a recently acquired survey launch that must still be prepared for work.

The Kenya Marine Fisheries and Research Institute (KMFRI) produces tide tables, but due to differences between the data and the predictions in the Admiralty Tide Tables, Kenya Maritime Authority (KMA), the authorized maritime regulatory body, only recognizes the Admiralty Tide Tables as the official product for use in Kenyan waters. Permanent recording tide gauges are installed at: Kenya Port Authority in Mombasa, one each in Lamu and Kilindini Harbour, which were donated in 1986 through Intergovernmental Oceanographic Commission of the United Nations Education, Scientific and Cultural Organization (IOC- UNESCO) and monitored by the University of Hawaii as part of Global Sea Level Observing System network. Kenya Meteorological Department (KMD) has four gauges dispersed as follows: one in Lamu, Mombasa, Shimoni and Malindi which are mainly for tsunami early warning, salinity and conductivity measurement.

KMFRI also has a research vessel, RV-MTAFITI (currently the main research vessel in Kenya), which was donated by the Belgium Government in 2014. Several cruises have been conducted but mainly on biological and physical oceanography expeditions. Members from different government agencies have taken part in various cruises in data collection that fits their specific use.

Figure 6: *The Kenya Marine Fisheries and Research Institute; Research Vessel MTAFITI.*

KNHO Challenges and Opportunities

a. Challenges

i. More coordination is needed between hydrospatial stakeholders, state agencies and other corporations;

ii. The level of hydrography awareness is very low in Kenya;

iii. There are currently no institutions in Africa offering Category A (Professional) or Category B (Technologists) training in hydrography;

iv. Presence of Piracy in the Western Indian Ocean region around the horn of Africa;

v. High cost of equipment (e.g. Research Vessel, Echo sounders, Motion sensors, CTD, ADCP, etc.);

vi. Inadequate scientific and technical capacity in expertise, research and innovation to implement hydrography surveys;

vii. Scarcity in capacity-building and technology transfer;

viii. Little or no data sharing by data producers.

b. Opportunities

i. There are many hydrographic and hydrospatial assets at the disposal of the government that, with national effort and proper coordination, can result to maximum value gain;

ii. Apply for training for the Marine Spatial Infrastructure (MSI) Coordinator under IHO Capacity Building;

iii. As the youngest IHO member, Kenya can apply for the short-term assistance of an established hydrographic office to develop a robust National Hydrographic Structure for Kenya;

iv. Kenya has very strong institutions with resourceful personnel who are recognized on a global scale for the work they are doing for our oceans. Their diversity of different backgrounds should be used as a strength towards integration, which will result in stronger institutional frameworks.

v. Cross-governmental coordination to ensure ‘collect once use many times.’

CURRENT AND UPCOMING PLANS

Kenya is proud to be the 95th member of the International Hydrography Organization. The benefits that come with the status include training opportunities, becoming members of different committees; sub-committees; Regional Hydrographic Commissions; technical working groups that set standards, seeking and providing technical advice and support on hydrographic developments besides establishing collaborative international projects.

Figure 7: *Thumbnail image of the IHO Circular Letter 24/2021 01 July 2021 (https://iho.int/uploads/user/circular_letters/eng_2021/CL24_2021_EN_v1.pdf)*

The Somali maritime boundary claim that is before the International Court of Justice (ICJ) has raised a lot of debate regionally and internationally. Detailed hydrographic survey data on positions and delineation forms part of submission that the courts rely on. The Western Indian Ocean Marine Science Association (WIOMSA) together with the Nairobi convention has been holding meetings and deliberations concerning marine spatial planning which is concerned with much more than Hydrography and corresponds to the strategic intent of creating Hydrospatial Data Infrastructure. This responds to the FAIR principles of being: FINDABLE, ACCESSIBLE, INTEROPERABLE and REUSABLE data and information.

Through the International Oceanographic Commission (IOC)'s Ocean Teacher Global Academy (OTGA), KMFRI has been conducting courses on marine spatial planning among other ocean sciences courses. The introduction of fundamentals of ocean mapping as one of the key courses in the program will help improve the understanding of the relationship between ocean mapping and other marine fields since "Hydrographic data is the foundation layer that all maritime data hangs off".

There are future plans towards development of the seven small ports along the Indian Ocean, which will include modernization and expansion of port facilities, dredging, benchmarking of facilities and services with international best practices and standards. The ports, Funzi, Shimoni and Vanga located in the south coast, Mtwapa, Kilifi, Malindi, and Kiunga located north of Mombasa, were earmarked for development under Kenya's Vision 2030 flagship project that translates to a boost in the blue economy. This therefore, means hydrographic surveys need to be carried out with many more hydrospatial data and information requirements.

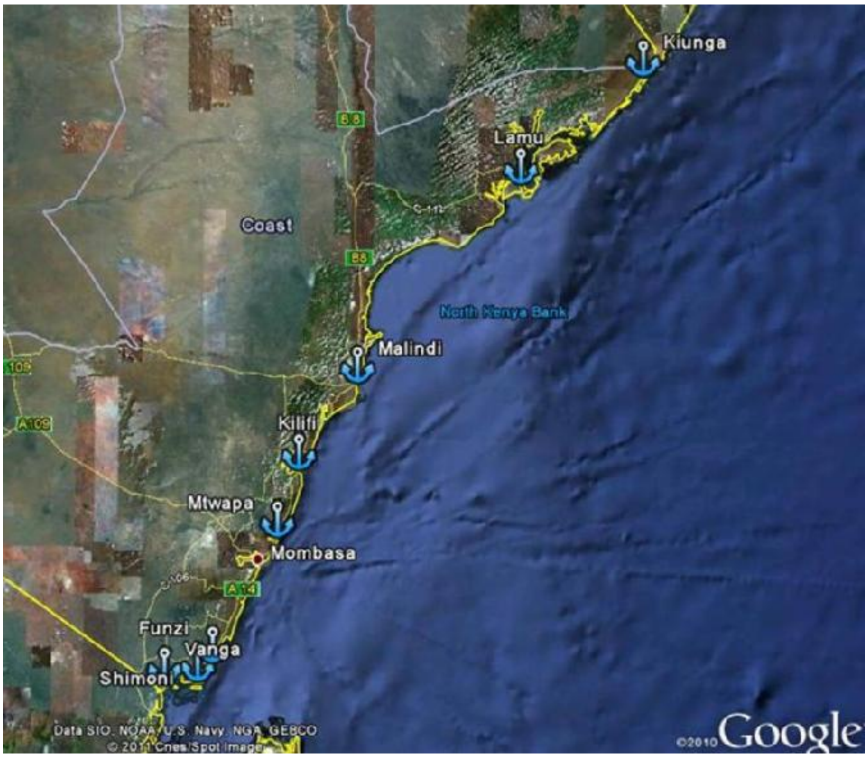

Figure 8: *Kenya Ports including seven small ports earmarked for development*

THE FUTURE

In order for marine and aquatic data and information gathered from around the world to be used by all ocean stakeholders, the digital uniformity of this data is crucial. The S-100 universal data model framework by IHO is set to bridge the gap by offering standards and formats for data gathered from a variety of disciplines operating on the maritime domain. This ensures that data can easily be exchanged among stakeholders operating in the maritime domain. This premise is the basis upon which, going into the future, the country's maritime stakeholders have to cooperate and work together in order to advance the international and national obligation of provision of hydrographic services to mariners.

Due to the development of hydrographic technology, the questions currently have shifted from what the ocean floor looks like to what is in the water leading to an exponential increase of the use of marine and aquatic data and information. Marine Spatial Data is being used to make informed decisions that contribute to sustainable use of the seas.

a. Data and information collected once will respect the FAIR principles to be used many times and the quantity and variety is set to increase significantly with more multi-spectrum data being collected across a broader range of environments from a broader range of sensors employing more autonomous collection methods. Although, as a nation, these systems seem far off, development of capacity, albeit in little steps, is key if we are going to advance in this discipline of hydrography towards hydrospatial for the benefit of the Kenyan people.

b. Change detection and forecasting will improve with increased repeat surveys being an outcome of the use of more autonomous collection methods by satellite, air, land, water and therefore reducing the number of people in the field, at sea and increasing efficiency and effectiveness of data collection. Change detection and forecasting will enable better management of ocean resources for sustainability.

c. The increased volumes of collected data and information will spur innovative methods of data processing. This will result in the increase of the use of the cloud and artificial intelligence in processing of data in near real time. Innovation. in the form of complex algorithms to process the collected data and information, will be a key enabler of hydrographic surveys going forward in Kenya towards hydrospatial.

d. Time spent by the human element to collect and process hydrographic data will tremendously reduce and therefore more time will be spent in analyzing and interpreting data to transform it into actionable information. Therefore, the skills required in the hydrographic and hydrospatial sphere will change creating demand for new training and providing new career opportunities. The opportunities presented in the discipline of hydrography in Kenya are immense considering the current inadequacy of expertise in the field and the need to explore and exploit the oceans and aquatic resources under hydrospatial for the Blue Economy banner.

BLUE ECONOMY

The opportunities presented by the blue economy as sited in the African Union Agenda 2063 https://au.int/sites/default/files/newsevents/conceptnotes/27474-cn-concept_note_eng_0.pdf and Kenya's Vision 2030 http://www.xinhuanet.com/english/2020-12/04/c_139561773.htm are Africa's next frontier. The Kenyan government created the Blue Economy Task Force in 2017 to play an important role in Development of Policy and Strategies to help harness the benefits of the Blue Economy.

So far, Germany, Portugal, France and Italy from the European union have partnered with six coastal counties in Kenya "Jumuiya ya Kaunti za Pwani" namely Mombasa, Kwale, Kilifi, Tana River, Lamu and Taita Taveta under the banner Go Blue Initiative on March 25, 2021. Go Blue Initiative is a four year program that aims to provide technical expertise on economic growth. United Nations Environment Programme (UNEP) and UN-Habitat came on board to ensure environmental conservation of natural resources and biodiversity and urban planning for socio economic balance. The key components of the blue economy are recycling, tourism, small-scale fishing, maritime transport and security, oil and mineral exploitation, spatial land-sea planning and environmental conservation and climate change geared towards a sustainable Blue Economy under Sustainable Development Goal 14 (SDG14).

CONCLUSION

A well-defined hydrospatial infrastructure, defined as "the branch of applied sciences which deals with the analysis, understanding and access to static and dynamic marine geospatial digital and analog data and information, digital signals, measurement and description of the physical, biological and chemical features of oceans, seas, coastal areas, lakes and rivers from all possible available data sources in near-real time, real-time, including history and the prediction of their change over time for the purpose of providing timely access to standard, quality and the most up-to-date marine spatial data infrastructure, including the safety and efficiency of navigation; aquatic and marine activities, for a sustainable Blue environment & economic development, security and defense, and scientific research," supports the three major actions of the United Nations Decade of Ocean Science. A hydrospatial infrastructure will realize: A transparent and accessible ocean whereby all nations, stakeholders and citizens have access to ocean data and information technologies and have the capacities to inform their decisions. A healthy and resilient ocean whereby marine ecosystems are mapped and protected, multiple impacts, including climate change, are measured and reduced, and provision of ocean ecosystem services is maintained. A predicted ocean whereby society has the capacity to understand current and future ocean conditions, and forecast their change and impact on human well-being and livelihoods.

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CANADIAN HYDROGRAPHIC SERVICE'S MODERN APPROACH FOR BATHYMETRY COMPILATION

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1. BUILDING A NATIONAL WORKFLOW ARCHITECTURE

The CHS is seeking optimizations in its ENC production and updating workflows. After conducting an extensive literature review on the bathymetry compilation subject in 2019, it was concluded that no usable solution existed to process automatically the generation of ENC-ready depth contours and soundings respecting the chart specifications described in IHO's S-4 document. The CHS took a collaborative approach with Teledyne CARIS to develop and enhance tools built-in *Process Designer* which would fill its needs. The tools allowed the CHS to develop a mostly automated nationally harmonized workflow to create ENC-ready bathymetric features with minimal human interactions, decision-making and manual work. This workflow takes the shape of Process Models needing simple inputs and executing actions in a precise order using predetermined parameters. These models were proven relevant with multiple seabed types and have significantly cut the level of effort required to create new ENCs. The process models allow the creation of the coastline, the depth contours and the sounding selection. They are described below.

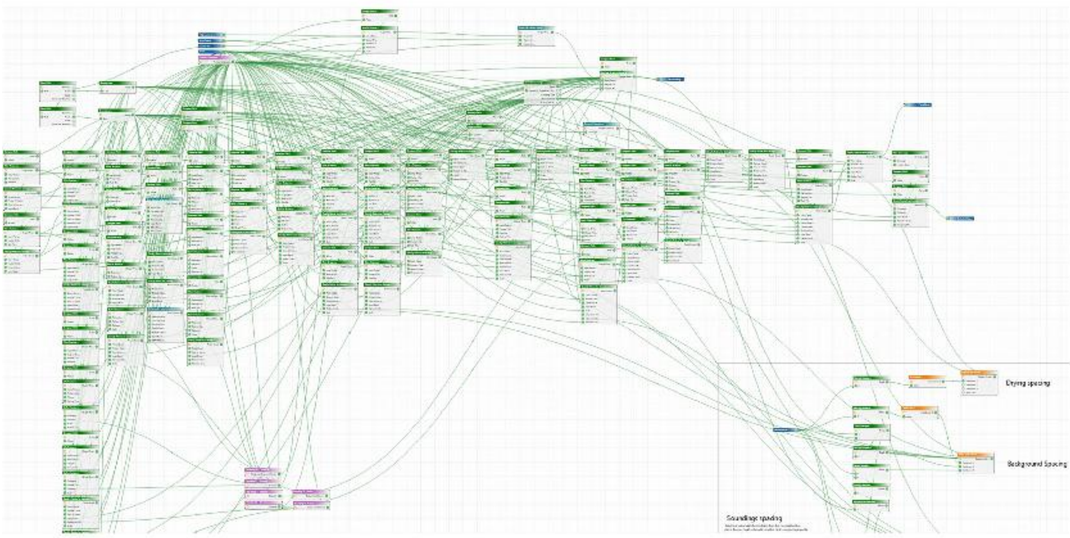

Figure 1. *CHS Process Model Architecture*
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The intent of the above Figure 1 is not to be able to understand simply what it is, but rather to illustrate the complexity of the processes in term of relationships and sequences. It looks more like an unreadable ”spaghetti” lines throughout many processes, than a clear and simple graphic. *Because it is often more complex to get processes simple, while it is simple to make it more complex!*

The following steps represent the sequences of contouring and sounding selection workflow components being developed and being improved through the project. Starting from the perspective that the deconficted combined surface is the surface validated with the best available data at the time of a compilation, considering the variable quality and density of overlapping data coming from different epochs, acquisition methodologies, accuracies, precisions, sources.

Contouring Workflow

A. Point cloud preparation

a. Convert the deconflicted combined surface to a point cloud at a resolution based on the compilation scale for the product focused on (e.g., 1:25,000 = 250 cm).

B. Coastline creation and generalization

The creation and generalization of the coastline are optional. They are relevant when new data are available and there is a need to create a new coastline or update an existing one by change detection in an ENC.

a. Generate a triangulated irregular network (TIN) from the initial deconflicted point cloud surface.
b. Interpolate a seamless surface from the TIN.
c. Smooth the interpolated surface which aggregates nearby islands together or to the continent, exaggerate tiny islands and give a smoother look to the coastline.
d. Extract the coastline (COALNE) using a High-Water Level value or a reference surface.
e. Create the land areas (LNDARE) features inside the COALNE features.
f. Identify inland lakes that are deeper than the coastline and dissolve them into the land areas.
g. Gently smooth the vector coastline to reduce the number of edges and to give it a smoo-ther look.

C. Depth contours creation and generalization

a. Generate a triangulated irregular network (TIN) from the prepared surface.
b. Add the coastline (existing or automatically created) to the TIN.
c. Interpolate a seamless surface from the TIN.
d. Smooth the interpolated surface which aggregates nearby shoals.
e. Identify shoals that do not contain an island.
f. Extract the surface over the identified shoals.
g. Smooth the extracted surface which exaggerates tiny shoals that do not contain an island.

h. Combine both smoothed surfaces using *Least Depth, True Position*.
i. Smooth the resulting surface to give a smoother look to the depth contours.
j. Extract the depth contours using values accounting for rounding (e.g., 0.049 m, 2.049 m, 5.049 m).
k. Gently smooth the vector depth contours to reduce the number of edges and to give them a smoother look.
l. Remove small deeps.
m. Convert the VALDCO value to standard depths values (e.g., 0 m, 2 m, 5 m).
n. Create depth areas (DEPARE) with the appropriate intervals of DRVAL1 and DRVAL2 values.
o. Identify depth areas with incomplete DRVAL1 and DRVAL2 attributes, consult neighbouring depth contours and depth areas and assign the correct values.

Sounding selection workflow

A. Point cloud surface preparation

a. Cut from the deconflicted combined surface the areas without navigable waters and outside of the area of interest.
b. Convert the deconflicted combined surface to a point cloud using an appropriate resolution based on the compilation scale of the product focused on (e.g., 1:25,000 = 250 cm).
c. Convert existing features which bear a sounding value as an attribute (obstructions, wrecks, rocks) to a point cloud and select them. This will ensure the model will not select any sounding in their vicinity.
d. Combine both point clouds.

B. Sounding selection

a. Calculate the density of significant and background soundings needed based on the maximum depth of the dataset and the target spacing input by the cartographer.
b. Densify the numbers of edges of the vector features so that the mathematical interpretation of the existing features matches the one made by the mariner.
c. Suppress soundings deeper than their DEPARE.
d. Suppress soundings inside dredged areas (DRGARE).
e. Suppress soundings too closed from the docks.
f. Select soundings along the docks.
g. Select the shoalest sounding in each isolated shoal.
h. Select the deepest sounding in each isolated deep.
i. Suppress soundings too closed from the coastline.
j. Suppress soundings too closed from the depth contours on the deep side.

k. Select soundings along ranges and routes.

l. Select soundings in anchorage areas and around anchorage points.

m. Suppress sounding deeper than obstructions, rocks, wrecks or marine farms in the area.

n. Select local shoals (soundings shoaler than their neighbours).

o. Select significant soundings in user-designated high-density areas.

p. Select background soundings in user-designated high-density areas.

q. Select significant soundings.

r. Select significant soundings in user-designated low-density areas.

s. Suppress soundings that are too close to the depth contours on both sides.

t. Select background soundings.

u. Select the significant soundings with a second iteration which may catch a few soundings that became unsafely covered by the selection of the background ones.

v. Select the significant soundings in the drying areas.

2. FIRST RESULTS

Automated software functions are proving to be outstanding tools for cartographers in their daily cartographic operations. They provide a safe and useful navigational product to the mariner while requiring much less effort from the CHS staff both in the creation and quality control steps of the workflow. By removing simple and repetitive chores from the cartographers' task list, it frees them up to perform more complex jobs benefiting from their knowledge and expertise such as vetting the automated results, assessing and validating the quality of newly acquired data coming from different sources. Most importantly, the results are reproducible if processed using the same parameters and are optimal given that the computer does not make any misstep. The aspect of the contours and the sounding selection is consistent across the product and across the entire portfolio of products. An unforeseen benefit of using such tools is that it highlights where the codification or the data validation practices have been insufficient. Assessment of abnormal results from the automation often leads to the conclusion that there has been inadequate cartographic work or a deficient data validation decision made in the past.

3. FUTURE DEVELOPMENTS

Pleased with the results of the automation of the bathymetric features creation so far, CHS is currently working with CARIS to develop new tools to automate the creation of the Quality of data features (M_QUAL) based on the attributes of each cell in the deconflicted combined surface. Such an approach will allow their accurate, fast and effortless creation and updating.

The CHS is envisioning a near future where any new product or update to an existing ENC is compiled using automated tools. New models are being currently worked on where the resulting automatically generated bathymetry and quality of data features are replacing the existing features in the relevant product usage band into the hydrographic product database. Such models can fit the new features in place and fix the topology making sure the result is near ENC-ready. The cartographer will then simply verify that the integration of the new features went as expected and proceed with the creation or the update of the ENC. Streamlining the cartographic workflows is essential for the CHS to keep up with the demand and the needs of its clients related to up-to-date data, dynamic hydrographic products and services.

4. CONCLUSION

Capacity building is of actuality in the world of hydrography to ensure an optimal contribution to the safety of life at sea (SOLAS) and to the various aspects of the blue economy. Thus, modernizing and standardizing the way to update hydrographic products for electronic navigation is timely. It will result in increased efficiency for Hydrographic Organisations (HOs) operations' and fluidity of up-to-date data release while preventing or reducing mismatch of consistency between S-57/S-101 and S-102 data products.

Adopting, developing and improving this modern approach to classify bathymetry and automated workflows provides valuable and necessary teaching and support tools for cartographers, enabling them to take part in this complex decision-making process.

Early positive preliminary results of these new tools have earned the confidence of cartographers, hydrographers and encouraged their use. The development of complete and integrated automatic compilation tools and automated workflows meets the needs of modern cartographers and hydrographers.

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Notes

A COMMITMENT TO CROWDSOURCED BATHYMETRY CITIZEN SOURCED DATA - HELP REVEAL THE DEEP AND SHARE YOUR DATA

By J. Jencks[1], M. Pratellesi[2], D. Wyatt[3], and P. Wills[4]

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1. INTRODUCTION

Bathymetry underpins the safe, sustainable, cost effective execution of nearly every human activity at sea. Yet, despite the multitude of data that have been collected over the last two hundred years, roughly twenty percent of the world's ocean depths have been measured with direct observation and shared with the global community (GEBCO_2021). The rest of the data used to compile seafloor maps are estimated depths largely derived from satellite gravity measurements, which can miss significant features and provide only coarse-resolution depictions of the largest seamounts, ridges and canyons. Progress in mapping coastal waters is only marginally better. IHO publication C-55, Status of Surveying and Charting Worldwide, indicates that about fifty percent of the world's coastal waters shallower than 200 meters remain unsurveyed to modern standards.

While the hydrographic and scientific community lament this lack of data, the world's interest in seas, oceans and waterways continues to increase. The concept of a sustainable growing blue economy is firmly established, along with an ever-growing public awareness of mankind's dependence upon, and vulnerability to, the sea. Several high-level global initiatives are now in place that seek to address ocean issues, including the United Nations Decade of Ocean Science 2030 Agenda for Sustainable Development Goals, the Paris Agreement under the United Nations Framework Convention on Climate Change, the Sendai Framework for Disaster Risk Reduction 2015-2030, and The Nippon Foundation-GEBCO Seabed 2030 Project.

The IHO has a history of encouraging innovative and collaborative ways to gather data and data maximizing initiatives so that we can better understand the bathymetry of the seas, oceans, freshwater navigable waterways and coastal waters. In 2014, the IHO, at its Fifth Extraordinary International Hydrographic Conference, recognized that traditional survey vessels alone could not be relied upon to solve data deficiency issues and agreed there was a need to encourage and support all mariners in an effort to "map the gaps." One outcome of the conference was an initiative to support and enable mariners to collect crowdsourced bathymetry (CSB).

The IHO defines CSB as the collection of depth measurements from vessels, using standard navigation instruments, while engaged in routine maritime operations. The information, adequately categorized with respect to quality, would be used to supplement the more rigorous and scientific bathymetric coverage undertaken by hydrographic offices, industry, and researchers around the world.

The key to successful CSB efforts is volunteer observers who operate vessels-of-opportunity in places where surveys are poor, inadequate, non-existent or where the seafloor is changeable and hydrographic assets are not readily available (Figure 1). The International Convention for the Safety of Life at Sea (SOLAS) 1974 carriage requirements oblige all commercial vessels to be equipped with certified systems consisting of at least a single beam echo-sounders and satellite-based navigation systems. As a result, the world's commercial fleet represents a significant untapped source of potential depth measurements. Even most non-commercial ships and boats are equipped to measure and digitally record their depth in coastal waters and an ever-increasing number of vessels can also take measurements in deeper water with more affordable and accurate systems than could previously be achieved. The CSB vision is to tap into volunteer enthusiasm for mapping the ocean floor and coastal zones. Enabling trusted mariners to easily contribute data will augment current bathymetric coverage and enhance surveying and charting capabilities of the bathymetric initiative.

***Figure 1**: Fishing boats such as these can help us map the ocean floor. Image courtesy of NOAA.*

2. VALUE OF CSB

While CSB data may not meet accuracy and precision requirements for charting areas of critical under-keel clearance, it does hold limitless potential for a variety of other uses and to detect hazards to navigation. If vessels collect and donate depth information while on passage, the data can be used to identify uncharted features, assist in verifying charted information with appropriate category zones of confidence, and to help confirm that existing charts are appropriate for the latest traffic patterns (Figure 2). This is especially relevant considering that many soundings on charting products are pre-1950. In some cases, CSB data can fill gaps where bathymetric data are scarce and even non-existent, such as unexplored areas of the polar regions, around developing maritime nations, and the open ocean. CSB also has potential uses along shallow, complex coastlines that are difficult for traditional survey vessels to access. These areas may be more frequently visited by recreational boaters whose data could help illustrate seafloor and shoaling trends from the repeated trips they make along their favorite routes. Finally, crowdsourced bathymetry can provide vital information for reconnaissance and planning purposes to support national and regional development activities and scientific studies in areas where little or no other data exists and accurate hydrographic surveys are not a priority.

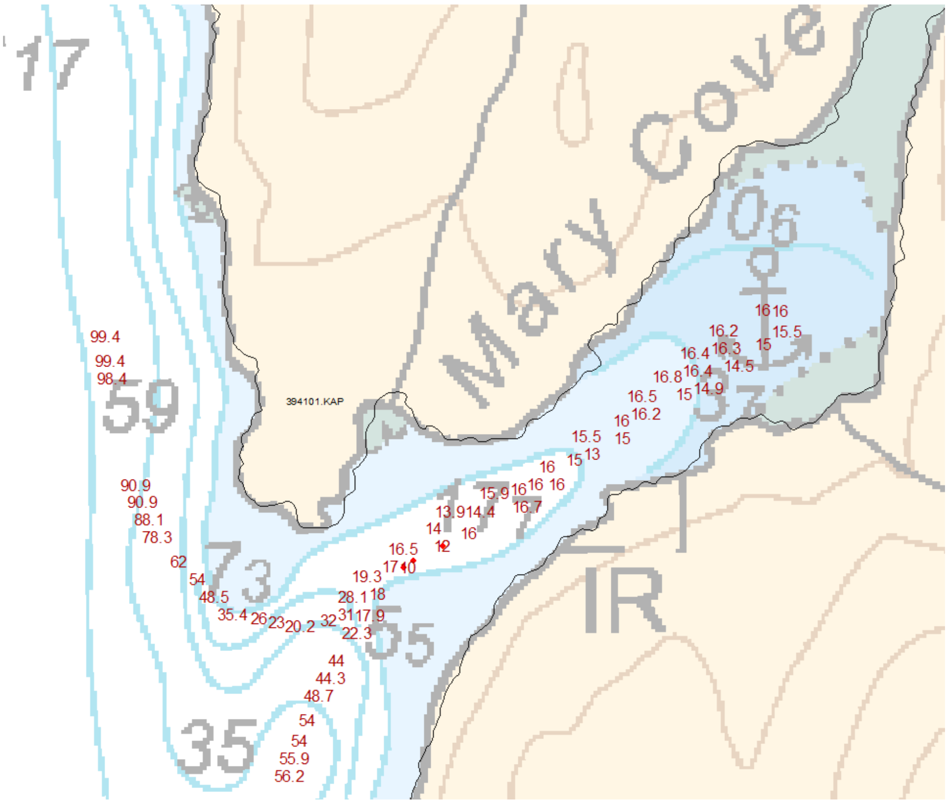

Figure 2*:The Canadian Hydrographic Service (CHS) has used crowdsourced bathymetry to update several Inside Passage charts along the coastal routes stretching from Seattle, Washington, to Juneau, Alaska.*

3. IHO CROWDSOURCED BATHYMETRY WORKING GROUP (IHO-CSBWG)

Another outcome of the Fifth Extraordinary International Hydrographic Conference was to establish an IHO Crowdsourced Bathymetry Working Group (CSBWG) (iho.int/en/csbwg). The IHO CSBWG, composed of international scientific, hydrographic and industry experts, was tasked to draft a guidance document meant to empower mariners to collect and contribute CSB data (Figure 3). This document describes what constitutes CSB, the installation and use of data loggers, preferred data formats, and instructions for submitting data to the IHO Data Centre for Digital Bathymetry (DCDB). The document also provides information about data uncertainty to help data collectors and data users better understand quality and accuracy issues with CSB. Thirty five of the ninety five IHO Member States supported the adoption of Edition 2.0.0 of *B-12 IHO Guidance on Crowdsourced Bathymetry* (IHO Circular Letter 28/2019) and are proactively supporting its maintenance and improvement. It is worth noting that this document provides technical guidelines only that in no way supersede national or international laws and regulations.

B-12 has now been in circulation for over two years and, apart from including feedback from operational use and experience, there is a strong desire to make the document more "equipment agnostic" with the intent of soliciting data from all sources, not just single beam echo sounders. The CSBWG intends to circulate an updated version to MSs for comment in 2022.

In addition to maintaining and updating B-12, the working group is also positioned to investigate and highlight use cases of CSB data, provide guidance on data quality and standards in liaison with the IHO Data Quality Working Group and consider incentives to increase data contributions by mariners. The CSBWG is particularly tasked to work in cooperation and coordination with other IHO bodies and relevant industry stakeholders to ensure a harmonised approach to data gathering and the resultant datasets. Finally, the working group is discussing ways to encourage all vessels engaged at sea that are equipped with appropriate technology, to collect bathymetric data as part of their normal operations – in the same way that mariners currently and routinely observe the weather and make other marine environmental observations.

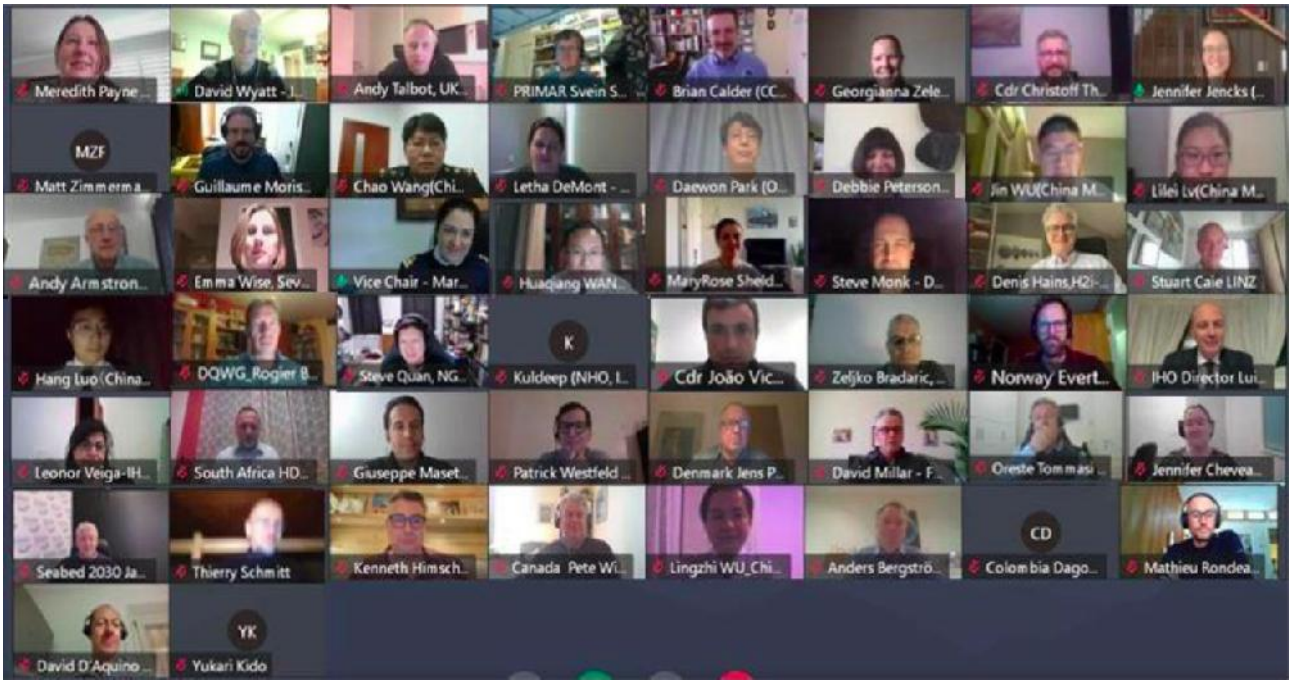

Figure 3*: Screengrab of the CSB Working Group from the 10th meeting held virtually 30 March - 01 April, 2021.*

4. CONTRIBUTING AND ACCESSING CSB DATA

Under the guidance of the IHO Crowdsourced Bathymetry Working Group (CSBWG), the National Oceanic and Atmospheric Administration (NOAA) has volunteered to provide archiving, discovery, display and retrieval of global crowdsourced bathymetry data contributed from mariners around the world. These data reside in the IHO's Data Centre for Digital Bathymetry (DCDB), hosted by NOAA's National Centers for Environmental Information (NCEI), which also offers access to archives of oceanic, atmospheric, geophysical, and coastal data (***Figure 4***).

Crowdsourced bathymetry enters the DCDB through a variety of trusted sources or nodes (e.g. partner organizations, companies, academia and non-profit groups) that enable mariners to voluntarily contribute seafloor depths measured from their vessels. Rose Point Navigation Systems, a provider of marine navigation software, helped establish the stream of data from a crowd of mariners. Specifically, users of their software were given the option to enable logging of their position, time and depth. Users were then given the choice to submit their data anonymously or provide additional information (vessel or instrument configuration) to enrich their dataset.

The intent is that these data, like all bathymetric data submitted to the DCDB, would not necessarily be "harmonised" or reviewed but would reside in the DCDB "as is." It would remain up to the end users to determine their value and utility for their own purpose. In this way, the fundamental data that reside in the DCDB are intended to serve as the world reference raw bathymetric data set which can be used as the basis for refined and processed products.

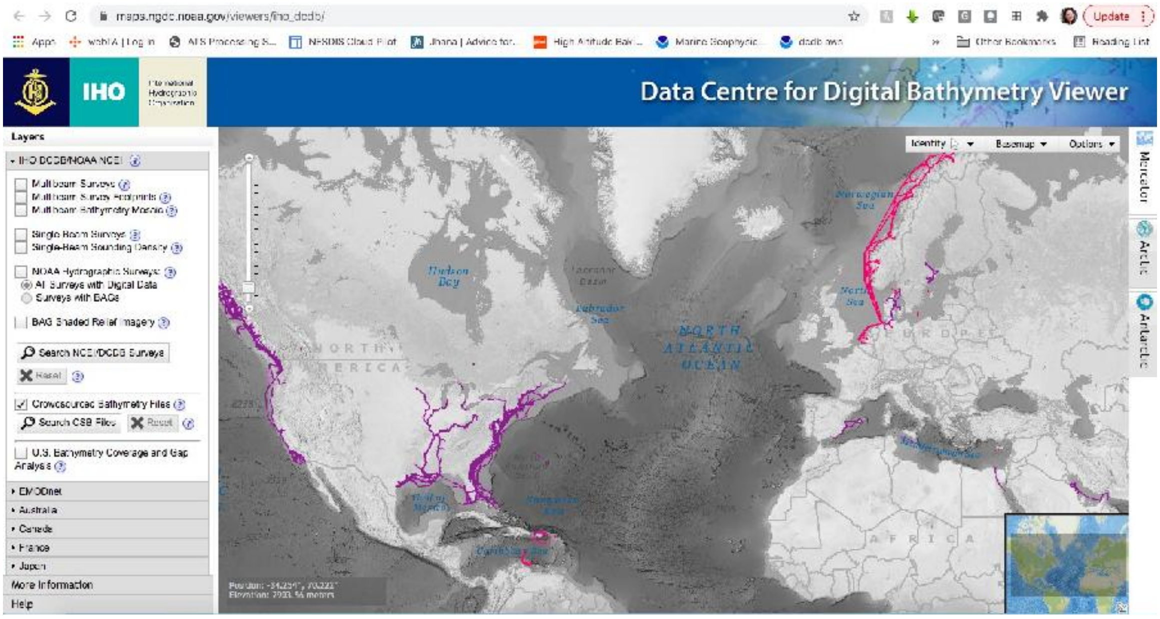

Figure 4: *The IHO DCDB Bathymetry viewer displays various bathymetric data holdings (including crowdsourced bathymetry ship track lines, shown here in purple/red) from data contributors to support international seafloor mapping efforts.*

5. COASTAL STATE SUPPORT OF CSB DATA PROVISION

In 2019, IHO CL 11/2019 was published calling for the approval of IHO Publication B-12. The letter also sought support for the CSB initiative and data gathering activities, not only in deep ocean regions but also within the waters of national jurisdiction of individual coastal states. Only fifteen member states provided positive responses to the request. The DCDB responded by implementing a mechanism that filters out incoming data from coastal countries that responded either negatively or did not reply at all (***Figure 5***). The IHO and the CSBWG believe that the lack of initial responses indicated that the circular letter was not clear and complete.

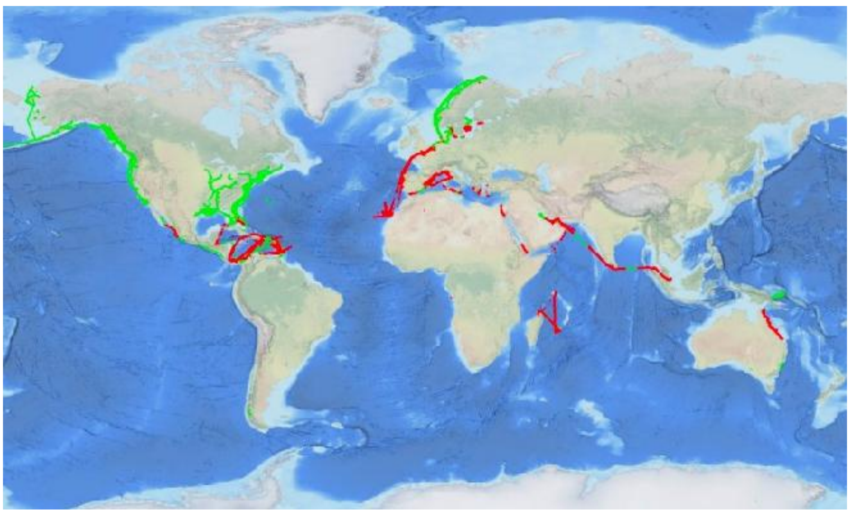

Figure 5*: As a result of IHO CL 21/2019, the IHO DCDB has filtered out over 20 GB of CSB (locations in red). These potentially useful data will not be made available to the public, or to national or international mapping programs until countries provide positive responses to the IHO CL 21/2020 and IRCC CL 1/2020.*

In 2020, a second circular letter, IHO CL 21/2020, was issued. Instead of asking member states if they accepted “CSB activities” in their areas of jurisdiction, the revised questionnaire sought to gain support for the provision of CSB bathymetry data gathered by ships within waters under national jurisdiction, rather than the data being kept on board or deleted. The letter starts from the position that CSB is being and will continue to be gathered, regardless of an individual coastal states position. So the question becomes – can that data be databased and made available for wider uses with necessary metadata as cautionary notes?

Realizing that IHO CL 11/2019 did not provide an opportunity for non-IHO member states to provide their position on the subject, an Inter-Regional Coordination Committee (IRCC) CL 1/2020 was written to the chairs of the regional hydrographic commissions (RHC) requesting they encourage all RHC coastal states to respond with their positions as well. To date, it is encouraging to see that 30 coastal states have replied positively (Figure 6). The DCDB will update the geographic filter this year to reflect updated coastal state positions. It is hoped that all CSBWG members will reply positively and many more MSs will join the CSBWG as active members.

***Figure 6**: To date, 30 Member States (those in green) have replied positively to IHO CL 21/2020 and IRCC 1/2020. The IHO DCDB will update the geographic filter this year to reflect updated IHO Member State positions.*

6. CHALLENGES OF CSB

Since the issuance of IHO CL 11/2019, there has been coastal state opposition to the collection and public availability of CSB data collected in waters under national jurisdiction. While a number of coastal states objected to both CLs without providing any reasons for their objections, several did provide explanations to their negative positions.

The following are the general reasons given for negative responses to CL 11/2019:

I. No Multi Beam Echo Sounder (MBES) data collection in Territorial Waters (TTW) unless a request has been sent and approval received;

II. Not considered and no plans to do so in near future;

III. Bathymetry in territorial waters are in general classified information and therefore crowdsourced bathymetry within territorial waters is prohibited by law;

IV. Majority of the Exclusive Economic Zone (EEZ) already, or will be, surveyed in near future in accordance with the IHO S-44 standard, therefore no need for CSB;

V. National HO is the only authorized organization to collect and store bathymetric data with the aim of chart production and bathymetry modelling within the national waters of jurisdiction;

VI. Bathymetric surveys for knowledge or exploitation of the marine environment are regulated by national legislation in accordance with the United Nations Convention on the Law of the Sea (UNCLOS), these data can only be used by the DCDB and in a digital terrain model after validation by the national HO, the cartographic exploitation of this data is also the responsibility of national HO;

VII. No added value of CSB in national waters, which are already surveyed to the highest standards to assure safe navigation;

VIII. Support for unrestricted CSB only along traditional shipping routes and transit passages;

IX. Data resulting from CSB activities as gridded data sets or as raw data will only be available after analysis and authorization of the national HO;

X. In accordance with national law covering survey activities in waters of national jurisdiction, all activities for the acquisition of any bathymetric data undertaken by all vessels can only be conducted after prior authorization of the relevant government departments;

XI. The national HO must check CSB data acquired in water of national jurisdiction before being forwarded to the DCDB, any data thus forwarded can be disseminated only after approval from the national HO;

XII. Bathymetric measurements for the knowledge or exploitation of the marine environment in waters of national jurisdiction, which includes territorial waters and continental shelf, and is regulated by national laws in accordance with UNCLOS, will be provided exclusively by the national HO; and

XIII. Data under the IHO CSB concept is restricted in accordance with national regulations, it is prescribed by national regulations; lawfully collected bathymetric data can be made available for use only by signing a license agreement.

The following are the general reasons given for negative responses to CL 21/2020:

I. National HO is the sole competent authority for bathymetric data provision within waters of national jurisdiction;

II. MBES is allowed only after prior consent of the national HO, complete datasets should be shared with the national HO in full;

III. No MBES activity without prior permission, copy of dataset must be provided to the national HO;

IV. Support for CSB data provision from the waters of the IHO members states which have not achieved full survey coverage; will not use CSB data because waters fully covered systematic surveys;

V. According to national regulations the performing of scientific research, any study and survey of the sea, seabed or its subsoil or performing other underwater activities in the waters of national jurisdiction is only permissible on the basis of a prior approval to be issued by the relevant government authorities;

VI. Any foreign organization, foreigner or national with an intention of carrying out CSB activities in waters of national jurisdiction must obtain authorization from the relevant government authority. No MBES activity in the waters of national jurisdiction is allowed without prior permission;

VII. According to the national legislation bathymetry is classified in the internal and territorial sea, so CSB is prohibited;

VIII. Opposed to the free use of this data from the waters of national jurisdiction without the express consent of the relevant Coastal State;

IX. Only for areas of 200 m depth or greater; and

X. All EEZ areas have been surveyed to IHO S-44 Edition 5 Order 1a.

It is clear from many of the negative responses received above that there remains confusion between the intent of CSB data gathering, planned scientific data gathering and systematic hydrographic survey operations. It is important to stress further that the focus of the CSB initiative is to collect data in poorly surveyed or unsurveyed areas and to share the data openly for better knowledge and understanding of the seabed. In the case of areas well surveyed, newer data can still add value, whatever the quality, as it can highlight recent changes to the seafloor and around ever-evolving coastlines as well as indicate that the published data is still valid and no re-survey requirement exists. The IHO and CSB Working Group is willing to engage in as many bilateral conversations as necessary with HO MSs to investigate how to increase the level of comfort to join the WG and promote CSB. It is hoped that increased awareness and information as well as continued stakeholder engagement and involvement will help to overcome these reservations, due to both perceived and real issues.

7. CONCLUSION

The success of a global initiative is always dependent on the level of leadership, commitment and activities of the MSs. The IHO invites all HO MSs to consider (1) responding positively to IHO CL 21/2020 and IRCC CL 1/2020, (2) harnessing their own fleets (eg. Coast Guard, academic, Navy) using CSB data collection techniques by default and (3) for the MSs not yet members of the CSBWG to join the group. Crowdsourced efforts and the crowdsourced bathymetry database are poised to become a major source of information for a better knowledge and understanding of our blue planet. They are not only improving nautical chart coverage and accuracy, but contributing to international mapping efforts such as The Nippon Foundation-GEBCO Seabed 2030 Project and thus directly supporting a number of UN initiatives. These data have the potential to become critical resources for coastal zone management and environmental and scientific studies, the marine spatial data infrastructure, the expansion of hydrography towards hydrospatial and particularly in areas of little perceived commercial or strategic value.

This is in line with the IHO strategic plan objectives approved by IHO Assembly (A-2) in December 2020 and in particular with the IHO Strategic Goal 3: *“Participating actively in international initiatives related to the knowledge and the sustainable use of the Ocean”* and the correlated target focused on improving the “*knowledge of the world's seafloors”*. Engaging in CSB does not only mean to provide data or to have access to seabed information but to contribute to spreading the message of global responsibility in order to reveal the deep and fill the existing gaps in mapping the ocean.

All IHO MSs are encouraged to contact the Authors for more information about the CSB initiative and the CSBWG; and for those who are not members of the CSBWG to commit to this important initiative and be part of the leadership to enable and to engage in: “***Citizen Sourced Data - Help Reveal the Deep and Share Your Data!***”

8. REFERENCES

GEBCO_2021 Grid, www.gebco.net, May 2021.

Notes

A CAREER AS A WOMAN WITH THE CANADIAN HYDROGRAPHIC SERVICE

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ABSTRACT

This note was written in the context of the new "Empowering Women in Hydrography" initiative. It is encouraging and remarkable to see the commendable commitment of the International Hydrographic Organization (IHO) to foster and empower women in prominent and increasingly senior positions at the strategic and managerial level in IHO Member State Hydrographic Offices and within the IHO.

1. INTRODUCTION

Approached by a former colleague asking me to share my 33-year “experience as a woman” with the CHS, the following is intended as a review of my career from my personal perspective, having enabled me to reach the position of Director of Hydrography for CHS in a major region of Canada. Many women have encountered and still encounter systemic and cultural obstacles making similar progressions. The situations, environment and experiences encountered in my career were positive and fostered the development and recognition of my leadership skills with the CHS. I appreciate the opportunity to share my professional experience with you, hoping that this can inspire and inform you.

2. YOUTH AND EDUCATION CHOICE

When I was young, I liked to play softball, soccer; I really enjoyed the outdoors. At the end of high school, it seemed normal to me to choose a profession that would allow me to work outside. In high school, the cohort in which I was a student benefited from a pilot project to explore different occupations. I had the chance to do some technical drafting, as well as a few hours of survey levelling. Levelling an instrument on a yellow tripod, learning this new term “surveying,” it occurred to me that I suddenly knew what I wanted to do. At the age of 17, I enrolled in a three-year Geodetic Technical Program (now called Geomatics Technology).

When I look back at those years (1980-1983) it was a really rewarding experience for me. We were five female students in a class of twenty-four. The female students naturally teamed up together for the field projects. After a few projects, the instructors required us to have one female student per team in order to represent the reality of the workplace we were preparing to enter. In the second year of school, a Hydrographer-in-Charge from the Canadian Hydrographic Service came to explain the work of a hydrographer and to recruit students for the summer. It was the first time the class had learned about the need to apply geodesy in the marine environment. I was hired as a student in the summer of 1983.

3. HIRED BY THE CANADIAN HYDROGRAPHIC SERVICE

That first summer I worked at the CHS office, more specifically at the Hydrographic Data Center. I familiarized myself with all types of documents produced by the CHS, such as sounding rolls and other documents created during field data collection.

Following that work term, I went back to school to complete a minor in archaeology at university just in time to join the CHS for another summer season. However, that summer I was assigned to a project on the Îles-de-la-Madeleine, an archipelago in the middle of the Gulf of St. Lawrence in Canada. For duration of four months, a field party composed of about 20 people were on site for the season. With only four women, the Hydrographer-in-Charge did not show discrimination to any of us.

As GPS technology was not yet part of field operations, we were installing microwave positioning system towers in the field as well as using traditional land surveying methods to position lighthouses and conspicuous objects. One of the first days of work after the mobilization, I was assigned to position a launch using a range-bearing technique in the busy Port of Cap-aux-Meules. A hydrographer dropped me at the foot of a 28 metre high hill and said: "*The geodetic point is on the very top of the hill, go up and call me once the instrument is on station and you are ready to start.*" My equipment included: two tripods, two 12-volt car batteries, cables, a microwave transmitter (transponder), a theodolite, a large two-way radio, and my personal backpack. After several trips up and down that steep slope, finally, with the help of the launch coxswain, I began my career as a young apprentice-hydrographer.

Figure 1. *Student, summer 1984. Angle and distance measurements of a hydrographic launch from the bridge at Havre -aux-Maisons, Îles-de-la-Madeleine, Gulf of St. Lawrence, Quebec, Canada.*

That summer, I mainly worked onboard a hydrographic launch running sounding lines and carefully examining identified shoals. We started each day on the wharf in the morning and spent 9-10 hours at sea, six days a week. All data processing was done from a satellite field office organised for the entire duration of the survey. I learned a great deal and I really enjoyed working in the marine environment. Born and raised in an agricultural region of Quebec, Canada, I knew nothing of the sea or even the Saint Lawrence River, the main waterway in Quebec. During that time I could not have predicted that the wind and the sea would become part of me for the rest of my life.

Just a few months later I obtained a permanent position with CHS. The CHS career plan at that time included a continuous training program with on-the-job experience and an in-class curriculum completed over a 5-year period, to become a qualified hydrographer.

Figure 2. *1984 - On board a hydrographic launch in the Îles-de-la-Madeleine, Gulf of St. Lawrence, Quebec, Canada.*

I recall being interviewed back in the 1980s by a Political Science researcher from a Canadian university. She interviewed me and another woman who was also working in hydrography. This researcher was interested in knowing how we were acknowledging our feminism through the work we were doing in a male-dominated environment. We certainly disappointed her with our answers; we were both working in hydrographic surveying because we liked it. I found the expertise required for surveying stimulating and I knew deep within myself that I had my own place in hydrography, equally as did anyone else, man or woman. I was not in hydrography because I was being feminist. Especially at that time, the work brought me to new places far from home and allowed me to work outdoors for several months of the year. I always had the conviction that I had found my place, saying to myself: “I’m able to do it and I like it.” If this was somehow related to being a feminist, then I was there without any specific intentions except doing what I liked to do.

4. BACK TO SCHOOL

Years went by and I worked on different types of hydrographic surveys. Among other things, I was once the only woman onboard a hydrographic ship for a period of several weeks. Despite a few remarks, such as a woman bringing bad luck onboard a ship, I did not face any sexual harassment or challenges. I received good support from the hydrographic team. However, I quickly realized that the minority is more scrutinized; a man with inappropriate behaviour will be forgiven, while how a woman acts in certain situations will be remembered. I quickly realized I needed to behave in a way that kept me away from any controversy. That is the attitude I adopted throughout my career and it has served me well.

Figure 3. *Start of the day aboard a hydrographic launch from the Louis M Lauzier ship, off the Îles-de-la-Madeleine, Gulf of St. Lawrence, Quebec, Canada.*

In 1987, the Government of Canada inaugurated a new marine sciences centre in Canada, which also was the first francophone facility of its kind, the Institute Maurice-Lamontagne, Mont-Joli, Quebec. This required the relocation of employees from Quebec City to Mont-Joli, Quebec, about 300 kilometres east on the southern shore of the St. Lawrence River. Several senior employees chose to move to other government departments rather than leave Quebec City. Those decisions opened opportunities to younger employees who had ambitions within the organization. I was one of them and quickly obtained several acting assignments at higher levels.

Other changes occurred around the same period at the management level. Technologies evolved, and the need for broader knowledge grew. Management positions began to require candidates who graduated from university rather than the traditional advancement of hydrographers who were trained in-house and obtained experience over years of work. Those changes caused me to question and reflect on my interest to access management-level positions. It became clear that I needed to go back to school to get a university degree if I wanted to achieve my goals. I used annual leave (vacations) to complete prerequisite courses such as mathematics and physics in preparation for university admission. Based on excellent performance reviews while working in the CHS, I prepared my case and submitted it to the management team who supported my plan. I applied successfully and began university a few months later.

In the summer of 1989, I was assigned as the first female Hydrographer-in-Charge of the first multibeam hydrographic survey in Canada, onboard the vessel CCGS Louis M. Lauzier. I believe that my assignment was mainly due to my performance at work, my commitment to advance my abilities through university studies and the interest to support my advancement within the CHS Organization. In 1993, I graduated from the University of New Brunswick in Surveying Engineering with Hydrographic Option.

5. MATERNITY

Once I returned to full time work, I learned that CHS had shifted chart production processes to a digital environment. I was assigned to support the geographical information system CARIS used in chart production. My position was reclassified from a technical group to a surveying engineering category, a very well paying job category in the Canadian Public Service. In 2021, the ratio for this category was 25% women and 75% men according to The Professional Institute of the Public Service (PIPS www.pipsc.ca). During these years, I participated in many national committees, where I developed a good network of contacts and I supervised more and more projects for the implementation of new technologies related to hydrography.

I also was working in the office rather than in the field, which was a good change for me. The call of motherhood was felt, and my partner and I welcomed our two children. Thanks to the excellent working conditions at the Government of Canada, it was possible for us to benefit from parental leave and take the time to take care of our young children.

The attraction to management was always there for me. In the early 2000s, I noticed that the women who excelled in management in the Department were often childless, while the men all had families. Was this the price to pay to go into management? For me, as a new mom, it was difficult to reconcile the two. However, I had the opportunity to accept an acting assignment at the management level and understood that if I was well organized, I could do both. In addition, my partner and I equally shared the work to maintain a home and the education of the children. Adaptation and flexibility were also keys to success as we took turns traveling for our respective jobs. The work environment in the Government of Canada increasingly valued work-family balance.

6. THE LEAP TO MANAGEMENT

My partner also encouraged me to apply to different types of work in the CHS, so that I could move to a management position. This is how we came to Dartmouth, Nova Scotia, where I started a position as Manager of Nautical Publications.

A friend of mine, a director in the field of health, mentioned to me that the more you go up in an organization, the more you are isolated. So I realized that going into management separated me from the employee base. When I moved to the Atlantic region of the CHS, this split came more naturally as I did not know many of the people on the team. I was subject to some intimidation in the workplace but I could not say if it was because I was a woman or not. Sometimes I asked myself the question without giving it too much importance. On the other hand, there had always been wonderful people around me with whom it was pleasant to work with and who, without knowing it, supported me a lot. I have always intentionally put some distance between employees and me, and this has made my job easier. I also understand that this way of working was somewhat unique to me - another person would have done otherwise with different or the same results. Gaining access to management opened the door for me to other programs of the Department, and I have learned and enjoyed working together with managers from other groups outside hydrography.

An intrinsic value to me throughout my career had been fairness; I had always felt responsible for the employees under my supervision. In two situations, I had to take action on cases that could have turned into serious situations of bullying or sexual harassment. It was important to me to make sure that I did not put the women on the team in a vulnerable position. In collaboration with the management team, we made sure that there were always at least two women on a field project as well as men in whom we had full confidence. There was no question of depriving women of field experience due to behaviours that only needed to be managed. The human resources advisors provided excellent information to aid in decision-making.

7. FROM SENIOR MANAGEMENT TO EXECUTIVE DIRECTOR

Accessing an Executive Director position was not in my career plan, however I felt I could do as well as my predecessors. I prepared a lot for this interview; never did I consider a position acquired before going through a selection process. Like my colleagues, I was fortunate to have access to the mentoring offered to employees wishing to advance to management and executive positions. This prepared me very well for the interview but also for the day-to-day performance of the job.

Figure 4. *The Canadian Hydrographic Service's National Executive Committee October 2017 - From left to right: Lynn Patterson (Ottawa, ON), Serge Gosselin (Mont-Joli, QC); Stacey Verrin (Sidney, BC); Chris Hemmingway (Ottawa, ON); Denis Hains (Ottawa, ON); Rowena Orok (Ottawa, ON); Dave Prince (Sidney, BC); Jacinthe Cormier (Dartmouth, NS) and Louis Maltais (Burlington, ON) at the Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada.*

Over time when making a management decision, I tried to define what I wanted as the end result and what I needed to do to get there. Sometimes that meant that throughout a process, one step could be against my perspective, but in the long run I felt satisfaction with the end result, and that was important to me. Management work had always stimulated me - little room for routine and each day brought its share of new situations to deal with. Government is made up of great cycles of growth and also reduction of resources. Managing reduction of resources is difficult while managing growth is challenging and demanding where government regulations and process deadlines are numerous and sometimes long. A Regional Director General during a roundtable with new directors told me: "*The key to success is the importance of adapting and always turning a situation to a positive aspect.*" When I faced a difficult situation, I always remembered this discussion.

8. RETIREMENT

I do not know if I have influenced a lot of women around me. I remember a speed mentoring exercise organized in 2018 shortly before my retirement. Each director sat at a table and people with managerial aspirations could come and sit for five minutes. I loved quickly transmitting my ways of doing things and what I thought was essential for gaining access to management: being rigorous, showing interest, being curious, asking to observe during a meeting, learn a second language, etc. Do not hesitate to volunteer for special events: organization of conferences, social activities and union tasks, sitting on committees, accepting acting work. I was surprised and happy to see all the young women who came to my table.

I retired in the spring of 2018 as I planned it. Since then, I allowed myself a lot of rest, I share my time with my partner sailing in the summer, physical training in the winter, spending time with our children, singing in a choir, visiting family and friends.

Figure 5. *Retirement Ceremony April 2018 - Jacinthe with Alain Vézina, Regional Director of Science, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada.*

9. CONCLUSION

In the winter of 2020-2021, I followed the “Vendée-Globe” with passion, an around the world sailing race, solo, non-stop and without assistance. For 4 months, 33 sailors, including 6 women, allowed us to experience emotions of joy, sorrow, determination, concentration and pride. The first woman, Clarisse Cremer, to complete the lap finished in 12th position. All the journalists asked her what it was like to be the first woman and she always answered: “The Vendée-Globe is a mixed race and I finished 12th.” That resonated with me in how I have accomplished my career, Hydrography is a mixed field, I have accomplished the career I have chosen to the best of my ability, and I am proud of what I achieved.

Success in a career depends on self-commitment and also on establishing and maintaining a level of trust with the senior managers you work with. I want to thank everyone who trusted me over the years.

I commend the IHO for the initiative to showcase the involvement of women in hydrography. I am proud to see that several IHO member hydrographic offices support this program including the CHS, the organization where I worked. If my experience shared with you in this note has interested or inspired you, please do not hesitate to contact me by email, it will be my pleasure to share further or communicate with you.

Notes

A COMMITMENT TO ENGAGE AND INVOLVE STAKEHOLDERS: THE EXPERIENCE OF THE UNITED STATES OF AMERICA'S HYDROGRAPHIC SERVICES REVIEW PANEL FEDERAL ADVISORY COMMITTEE

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The United States of America's National Oceanic and Atmospheric Administration (NOAA) uses strategic engagement with key stakeholders such as the members of Federal Advisory Committees to develop, and improve national navigation, positioning and observation services, data, policies, strategies, objectives and action plans. This article highlights the means by which NOAA has been mobilizing stakeholders through the establishment of a NOAA Hydrographic Services Review Panel (HRSP) Federal Advisory Committee (FAC). The article provides information on the structure of the HSRP, its charter, and involvement with NOAA's current and future issues and its recommendations.

1. INTRODUCTION

While public agencies can conduct business as usual on their own, agencies that are interacting with their stakeholders and the public can excel in their services and be more readily accepted by the public. Congress directed NOAA to form an advisory panel to ensure regular communications and enrich the interactions with stakeholders from industry, academia, scientific institutes, organizations as well as the public. The advice from this panel supports NOAA's strategic objective to improve the nation's marine transportation system, marine commerce and the Blue Economy with world-class products and services that will help ensure safe, efficient and environmentally sound marine transportation. Experts in the field serve as members of the Federal Advisory Committee and provide thoughtful comments on the foundational navigation, positioning, and observations data, products, and services needed for climate change and coastal resilience.

2. NOAA'S COMMITMENT TO STAKEHOLDER INVOLVEMENT AND FEEDBACK

NOAA's commitment to its diverse stakeholders which include but are not limited to other federal agencies, defense and national security, local and state government, academia, and the private community is paramount to the successful implementation of its policies. Over the years, issue papers authored by members of HSRP helped the NOAA administration to focus on issues and recommendations that matter the most. The most recent example on HSRP involvement along these issues is the review and the recommendations that HSRP sent to NOAA's Administrator regarding the implementation plan for the National Strategy for Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone (NOMEC) and Alaska Coastal Mapping Strategy (ACMS). In those recommendations, the HSRP recommended an increased emphasis should be placed on public/private partnerships with mechanisms established to allow early, open and full engagement in planning and implementation.

3. HSRP HISTORY

In October 2003, then Secretary of Commerce, Mr. Don Evans established the Hydrographic Services Review Panel as directed by the Hydrographic Services Improvement Act of 2002, Public Law 107-372.

Over time the Panel has provided over 307 recommendations to the NOAA Administrator and served as a reminder and catalyst for change for dozens of issues and topics. The HSRP is closely linked to the goals for the U.S. Marine Transportation System (MTS) in support of commercial and recreational mariners, and also to benefit NOAA's stewardship of the nation's coastal and ocean resources, and includes the data required for coastal resilience goals to respond to climate change. Early on, the HSRP developed two detailed reports documents in 2007 and 2010 "Most Wanted Hydrographic Service Improvements Federal Advisory Committee Update Report," highlighting the key hydrographic services and the panel's best advice to the NOAA, the Administration, and Congress regarding near term priorities and direction. A link to the report is below. The HSRP developed white papers and issue papers with a deeper dive on topics of interest such as the six noted below.

1. OCS's unmanned systems with the "HSRP Comments OCS Autonomous Strategy, Sept 2017".
   https://www.nauticalcharts.noaa.gov/hsrp/recommendations/2016/HSRP-comment-NCMS-final-22Aug2016.docx
2. "HSRP Recommendations to the National Coastal Mapping Strategy".
   https://www.nauticalcharts.noaa.gov/hsrp/recommendations/2016/HSRP-comment-NCMS-final-22Aug2016.docx
3. "A Report from HSRP Emerging Arctic Priorities working group Sept 2015".
   https://www.nauticalcharts.noaa.gov/hsrp/workinggroups/HSRP-ltr-and-Report-Arctic-WG-Group-Sep2015.pdf
4. A series of 14 short issue papers and other NOAA requests.
5. MOST WANTED HYDROGRAPHIC SERVICES IMPROVEMENTS FEDERAL ADVISORY COMMITTEE UPDATE REPORT2010
   https://www.nauticalcharts.noaa.gov/hsrp/2010_Most_Wanted_%20Hydrographic_Services_Improvements.pdf
6. MOST WANTED HYDROGRAPHIC SERVICES IMPROVEMENTS, The Hydrographic Services
   Review Panel Federal Advisory Committee Special Report 2007 https://www.nauticalcharts.noaa.gov/hsrp/archive/general/HSRPspecrpt2007.pdf

Figure 1a + 1b: *"HSRP Most Wanted Hydrographic Services Improvements" 2007. Optional, Figure 1b "HSRP Most Wanted Hydrographic Services Improvements" 2010.*

4. HSRP TERMS OF REFERENCE /ROLES/ OBJECTIVES

The HSRP is a federal advisory committee that provides NOAA with independent advice on improving the quality, efficiency, and usefulness of NOAA's navigation-related products, data, and services. The HSRP advises the NOAA Administrator about its navigation (i.e. nautical charts and ENCs), physical oceanographic (i.e. tides & water levels), geospatial, positioning, and coastal and shoreline programs, products, and services. There are two public meetings each year, often in different port regions at which public comments from stakeholders and partners are sought. Most of the meetings include a webinar capability for those not in the area.

The HSRP public meetings focus on topics related to the navigation, positioning and observations portfolio of the National Ocean Service. The meetings often include the following: updates from the three HSRP working groups (WG); the Planning and Engagement WG, Technology WG, and Arctic Priorities WG; development, discussion and finalization of issue papers and recommendations to NOAA; comments and suggestions regarding white papers, regional, state and national priorities; and review and discussion of proposed priorities for the HSRP. Link to the three working groups: https://www.nauticalcharts.noaa.gov/hsrp/workinggroups.html

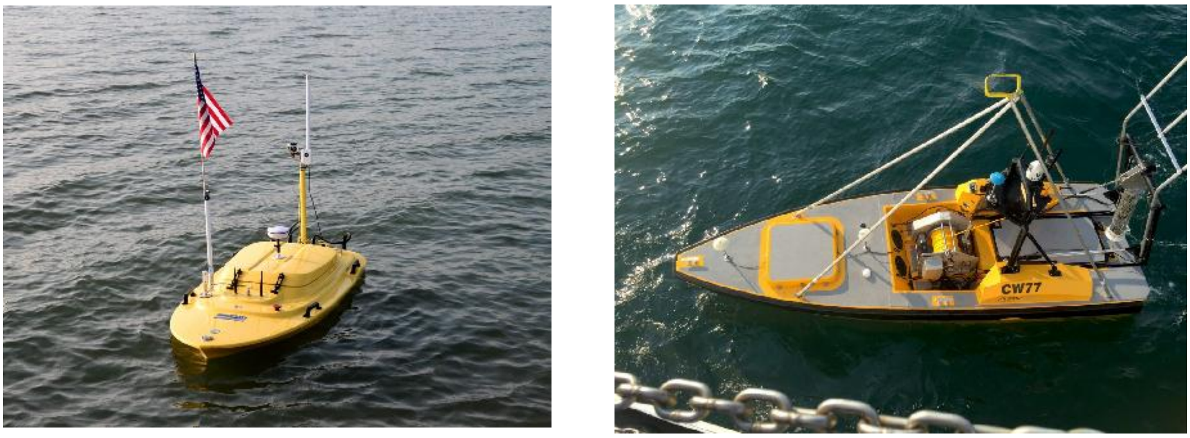

Figure 2a + 2b: *The Technology Working Group learned about the uncrewed Z-boat, with multibeam sonar, as one option to choose from on surveying shallow waters for NOAA's coastal mapping program and to fill voids from topobathy lidar where waters are too turbid for full bottom coverage.*

The HSRP mainly provides recommendations for three National Ocean Service offices and one partner – the National Geodetic Survey (NGS), the Center for Operational Oceanographic Products and Services (CO-OPS), the Office of Coast Survey (OCS), as well as the NOAA-University of New Hampshire's (UNH) Joint Hydrographic Center (JHC). The HSRP occasionally meets or partners with other NOAA Federal Advisory Committees such as the NOAA Science Advisory Board and the Integrated Ocean Observing System (IOOS) Advisory Committee.

Link to the latest version of the HSRP charter, legal statutes, and by-laws:

https://www.nauticalcharts.noaa.gov/hsrp/charter-bylaws-hsia-statute.html

HSRP Charter:

https://www.nauticalcharts.noaa.gov/hsrp/charter/hsrp-charter-signed-8-28-19.pdf

5. MEMBERSHIP

Figure 3: A recent HSRP Virtual Meeting with the members and staff.

There are 15 voting members who serve in their capacity as subject matter experts along with four non-voting members composed of the two Directors from NOAA's CO-OPS and NGS and the two co-directors of the NOAA-UNH JHC. The voting members are considered super stakeholders and serve in their personal capacity and not as a representative of a sector. The Panel is composed of a diverse field of experts in hydrographic surveying, vessel pilotage, port administration, tides and currents, coastal zone management, geodesy, GIS and geospatial, recreational boating, marine transportation, institutes and academia, and related fields.

The role of the members is primarily to advise the NOAA Administrator. They participate, they discuss in public meetings, bring their cumulative experience and knowledge to the discussions and analysis, and ultimately decide/conclude on which topics and initiatives should be forwarded to the NOAA Administrator for consideration and action. The recommendations are forwarded as letters, issue papers, and position papers. This process has proven to be productive and extremely informative. The opinions and advocacy of the members have proven to be both diverse and passionate. The members track ongoing interests and three working groups meet to allow for deeper discussion. A link to the member biographies: https://www.nauticalcharts.noaa.gov/hsrp/panel.html.

6. RECENT AND CURRENT ISSUES

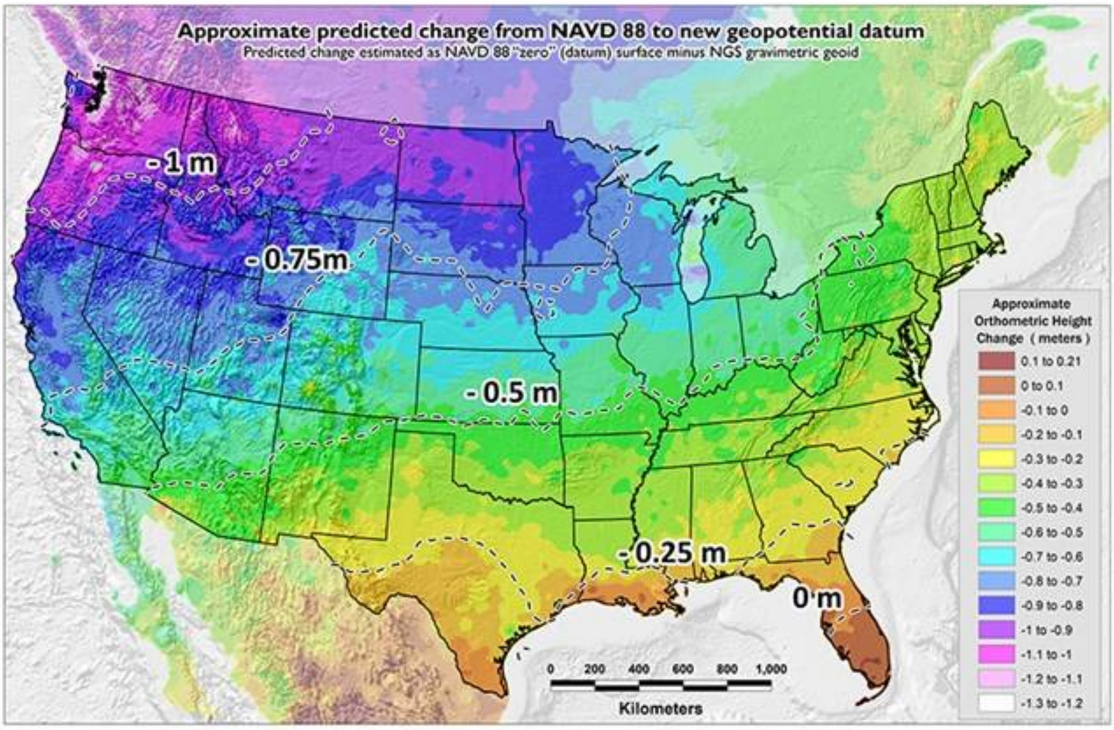

Figure 4: HSRP follows the updates to the NSRS and this figure shows the approximate predicted change from NAVD 88 to new vertical datum.

The HSRP addresses a diverse and broad spectrum of critical and priority issues. The HSRP especially directs its discussion and recommendations to three offices at NOS - the Office of Coast Survey, National Geodetic Survey and the Center for Operational Oceanographic Products and Services. There are a series of short one page issues papers with recommendations as well as longer position papers.

Recent issues papers and recommendations topics: sea level rise; Precision Marine Navigation; charting and maritime Arctic priorities; NOAA hydrographic fleet modernization; and Artificial Intelligence. There are long term and ongoing issues advocated by the HSRP.

Among the recent discussion topics are the following:

- Ocean mapping protocols and standardization. This includes the additional need for high resolution data and focus on the nearshore component in less than 40 meters.
- Continue operations and expansion of water level data, including focus on challenges in remote areas where access is limited.
- Advocate for the continued operations and expansion of the Physical Oceanographic Real-Time System (PORTS®) and full funding from congress for this important program for safe and efficient navigation.
- Support for the modernization of the National Spatial Reference System (NSRS), the framework for the United States geospatial data.
- Discuss adaptive resilience to climate change, including how NOAA can make an impact in this area and the importance of the data backbone that NOS offices provide.

- Data sharing with Integrated Ocean and Coastal Mapping- and most recently with the impact of sustainable renewables with offshore wind energy.
- Defining NOAA's role in charting and operations.
- Explore ways to enable precision marine navigation technology and highlight NOAA's role in providing supporting data.
- Follow technology trends in autonomous systems for mapping the ocean floor.

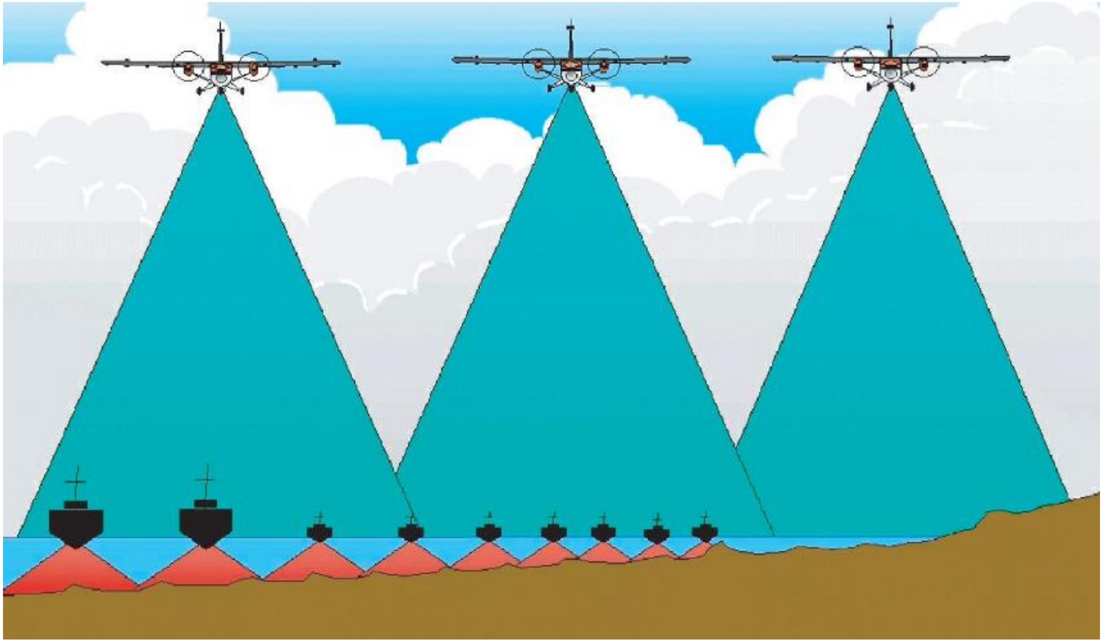

Figure 5: *An HSRP paper addresses this figure which shows why topobathy lidar is efficient in shallow waters, where multi-beam is most efficient in shallow waters, where multibeam sonar is least efficient; topobathy lidar should be collected at low tide. But topobathy lidar may have data voids because of water turbidity; then sonar becomes the most efficient in deeper waters to fill those voids and is most efficient at high tide. This figure also shows why uncrewed surface vessels are better suited for acoustic mapping in shallow waters, compared with larger vessels.*

Below are links and the two of the most recent and important examples of the HSRP position papers. Recommendations are provided to the NOAA Administrator sent after each public meeting. In summer and fall 2020, the HSRP wrote two position papers, one for the ACMS and the second for the NOMEC. Each paper included dozens of recommendations as summarized below. The list of HSRP recommendations and papers is at:

https://nauticalcharts.noaa.gov/hsrp/recommendations.html

1. Hydrographic Survey Review Panel (HSRP) Recommendations to NOAA on the Implementation Plan for the Alaska Coastal Mapping Strategy (ACMS)

https://nauticalcharts.noaa.gov/hsrp/meetings/webinar-september-2020/letter/hsrp-acms-paper-final-with-public-comments.pdf

The HSRP supported all goals and objectives of the Alaska Coastal Mapping Strategy and prepared a detailed whitepaper with recommendations for NOAA's Implementation Plan for mapping the intertidal zone. The paper was authored by HSRP members with expertise in coastal mapping and was discussed and approved at the HSRP public meeting on September 23-24, 2020..

2. Hydrographic Survey Research Panel (HSRP) Recommendations to NOAA on the Implementation Plan for the National Strategy for Ocean Mapping, Exploring, and Characterizing

the U.S. Exclusive Economic Zone
HSRP NOMEC position paper FINAL
https://nauticalcharts.noaa.gov/hsrp/meetings/webinar-september-2020/letter/hsrp-nomec-position-paper-final-with-public-comments.pdf

This position paper provides the HSRP recommendations to the National Oceanic Atmospheric Administration Administrator (NOAA) on the development of the implementation plan for the National Strategy for Ocean Mapping, Exploring and Characterizing the U.S. Exclusive Economic Zone (NOMEC). The HSRP members have considered the whole document and focused recommendations in areas appropriate to their experience and expertise. This is primarily related to Goal 2: Map the United States Exclusive Economic Zone (EEZ), with other comments and recommendations about other goals and objectives that relate to the mapping, including the coordination of efforts of Goal 1, the use of new technologies of Goal 3 and the building of public and private partnerships of Goal 5. This paper was discussed at the HSRP public meeting on September 23-24, 2020, along with public comments received regarding the implementation plans for NOMEC and the Alaska Coastal Mapping Strategy. Appendix A has the public comments and additional oral comments and can be found in the meeting report and transcripts posted at: https://www.nauticalcharts.noaa.gov/hsrp/meeting-webinar-september-2020.html.

7. FUTURE CHALLENGES

How NOAA keeps up with the rapidly changing climate conditions and technologies related to ocean and coastal mapping and weather modeling are among the most pressing challenges to NOAA goals in general and an area in particular where the HSRP can advise. HSRP membership should constantly evolve to include members who are involved in this changing environment and can address novel approaches.

The HSRP is tracking more than a dozen big blue economy, data, climate, resilience and ocean initiatives of NOAA and the U.S. government with a priorities matrix which includes a broad view of hydrographic services (https://www.nauticalcharts.noaa.gov/hsrp/meetings/webinar-march-april-2021/other/HSRP_PRIORITIES_MATRIX%204.10.2021.pdf.) It includes topics relating to all the navigation, observations and positioning services in OCS, CO-OPS and NGS. There are interests and emphasis in the development of the Standard Ocean Mapping Protocol, the implementation of the Alaska Coastal Mapping Strategy, Seabed 2030, updates and changes to the U.S. National Spatial Reference System (NSRS), maritime Arctic priorities, Precision Marine Navigation, replacement of the outdated NOAA hydrographic survey vessel fleet, surveying and charting technology advances, public private partnerships as well as Federal partnerships, Integrated Ocean and Coastal Mapping, coastal resilience and data, recreational boating and changes to tools such as Electronic Navigational Charts (ENC's), Federal partnerships, autonomous navigation in restricted visibility and fog, the chart of the future, relative sea level rise and high tide flooding and full Federal funding for the PORTS® program amongst the list.

Figure 6a: *HSRP advocates for full Federal funding for NOAA PORTS®. PORTS® installations provide multiple real-time data streams that increase safety of navigation and reduce the number of collisions and groundings.*

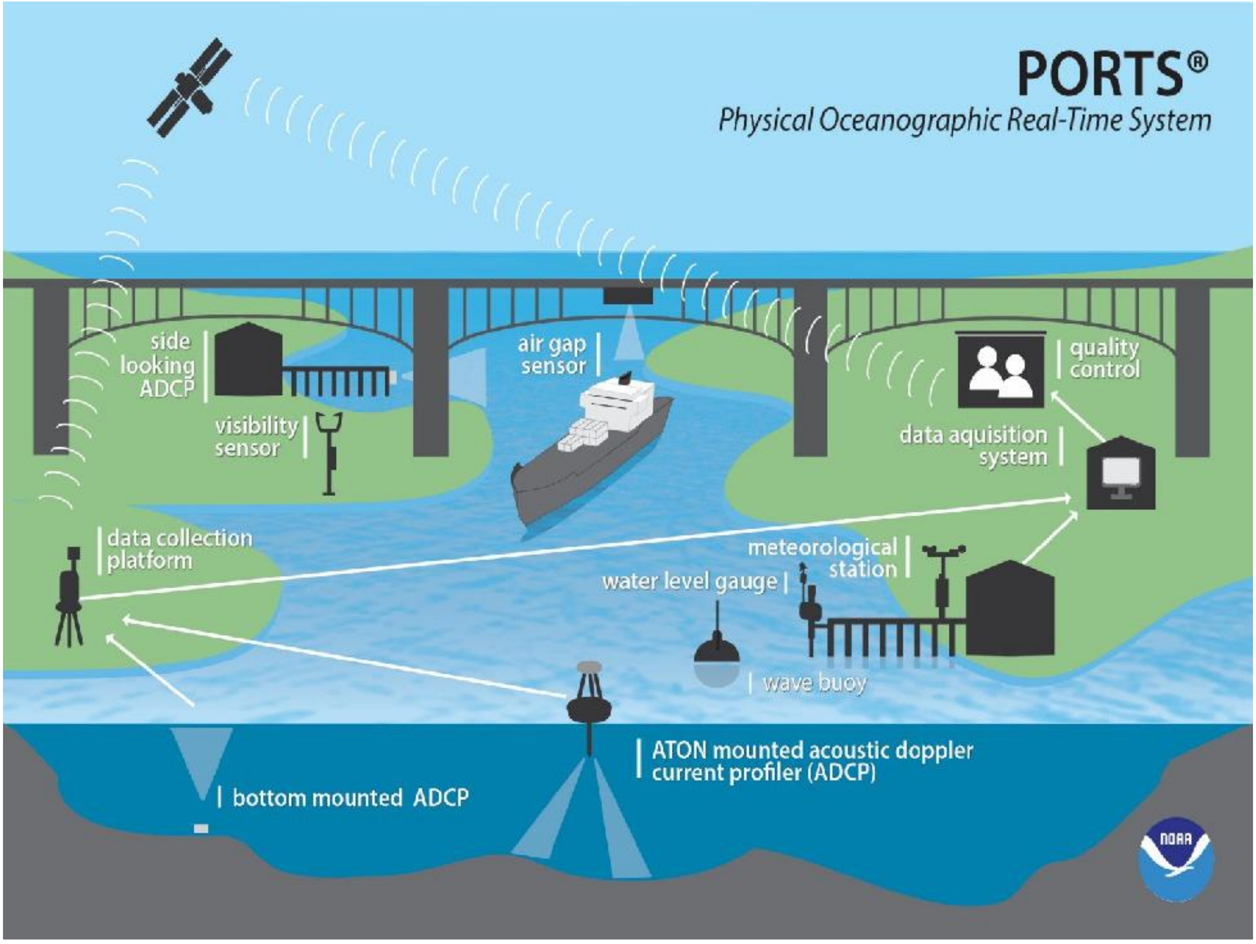

Figure 6b: *With PORTS, current meters and water level sensors are used for safe navigation. An air gap sensor measures the heigh under the bridge precisely to allow for safe passage at the entrance to the New York Harbor under the Verrazano bridge.*

8. CONCLUSION

The HSRP members directly provide their recommendations and prioritization of programs, data, services, projects, and direction to the NOAA Administrator. Indirectly their advice may provide support and advocacy for increased budgets. HSRP provides outreach where members have contacts and connections within the U.S. navigation, observation and positioning community at large. The HRSP has been providing constructive and value-added comments, feedback, observations and suggestions to the strategic directions of NOAA. The HSRP is important to better liaise between the stakeholder needs and requirements and the products, data and services from NOS's navigation, positioning and observations programs.

HSRP welcomes the participation of anyone interested in learning about NOAA's navigation, observations and positioning activities and the HSRP's role and goals, and especially those interested in contributing comments to the public meetings. The easiest way to start such involvement is to attend an HSRP public meeting or to learn about NOS's products through its newsletters and blogs. To be added to the email announcements for HSRP meetings, send an email to the main author, Ms. Lynne Mersfelder-Lewis at lynne.mersfelder@noaa.gov . To be added to NOS blogs, you can sign up by filling in your email in the box at: NOAA Office of Coast Survey's blog: https://nauticalcharts.noaa.gov/updates/. You can find a sample of some of NOS's blogs and sign up: https://oceanservice.noaa.gov/blogs.html.

Figure 7: *A photo of an in person HSRP public meeting with the members and speakers, March 2019, Washington, DC.*

9. REFERENCES & RELEVANT LINKS

HSRP has a series of recommendations and issue papers with a deeper dive on specific topics and additional recommendations to the NOAA Administrator. When requested, the HSRP also reviews NOAA white papers or other priority papers. The HSRP's letters to the Administrator and responses are in the documentation for each meeting: https://www.nauticalcharts.noaa.gov/hsrp/meetings.html

The most recent HSRP recommendations and issue papers from the HSRP to NOAA are listed below: https://nauticalcharts.noaa.gov/hsrp/recommendations.html

HSRP Position Papers - September 2020:

Click below to download the HSRP issue papers with recommendations:

- HSRP ACMS Paper FINAL https://nauticalcharts.noaa.gov/hsrp/meetings/webinar-september-2020/letter/hsrp-acms-paper-final-with-public-comments.pdf
- HSRP NOMEC position paper FINAL https://nauticalcharts.noaa.gov/hsrp/meetings/webinar-september-2020/letter/hsrp-nomec-position-paper-final-with-public-comments.pdf

HSRP Issue Papers - added May 2020:

Click below to download the HSRP issue papers with recommendations:

- Automation and Artificial Intelligence in NOAA's Post-disaster Products and Services May 2020
- https://nauticalcharts.noaa.gov/hsrp/meetings/webinar-2020/emergency-response-ai-hsrp-final-may2020.pdf

HSRP Issue Papers - added Sept 2019:

Click below to download the HSRP issue papers with recommendations:

- HSRP Sea Level Rise Issue Paper 8 October 2019 https://nauticalcharts.noaa.gov/hsrp/meetings/new-orleans-2019/committee-letter/slr-ip-hsrp-sept201-v8oct2019-final.pdf
- HSRP Arctic Issue Paper 8 October 2019 https://nauticalcharts.noaa.gov/hsrp/meetings/new-orleans-2019/committee-letter/arctic-ip-hsrp-sept201-v8oct2019-final.pdf

HSRP Issue Papers - updated for May 2018:

Click below to download the HSRP issue papers with recommendations:

- HSRP MGDI Blue Economy 2 May 2018 https://nauticalcharts.noaa.gov/hsrp/recommendations/2018/HSRP-MGDI-Blue-Economy-2May2018.pdf
- HSRP NOAA fleet 9 May 2018 https://nauticalcharts.noaa.gov/hsrp/recommendations/2018/HSRP-NOAA-fleet-9May2018.pdf
- HSRP Precision Navigation 10 May 2018 https://nauticalcharts.noaa.gov/hsrp/recommendations/2018/HSRP-Precision-Navigation-10May2018%20.pdf

HSRP Issue Papers - updated for Feb 2018:

Click below to download the HSRP issue papers with recommendations:

- HSRP Charting Maritime Arctic 28 February 2018 https://nauticalcharts.noaa.gov/hsrp/recommendations/2018/HSRP-Charting-Maritime-Arctic-28feb2018.pdf
- HSRP Hampton Roads Regional Pilot Project 28 Feb 2018 https://nauticalcharts.noaa.gov/hsrp/recommendations/2018/HSRP-Hampton-Roads-Regional-Pilot-Project-28feb2018.pdf
- HSRP Hydrography A Core NOAA Mandate 28 Feb 2018 https://nauticalcharts.noaa.gov/hsrp/recommendations/2018/HSRP-Hydrography-A-Core-NOAA-Mandate-28feb2018.pdf
- HSRP Improving Access 28 Feb 2018 https://nauticalcharts.noaa.gov/hsrp/recommendations/2018/HSRP-Hydrography-A-Core-NOAA-Mandate-28feb2018.pdf

- HSRP PORTS Critical Data for Critical Decisions 28 Feb 2018
- https://nauticalcharts.noaa.gov/hsrp/recommendations/2018/HSRP-Hydrography-A-Core-NOAA-Mandate-28feb2018.pdf
- HSRP Rec Boating 28 Feb 2018
- https://nauticalcharts.noaa.gov/hsrp/recommendations/2018/HSRP-Rec-Boating-28feb2018.pdf
- HSRP Research Development 28 Feb 2018
- https://nauticalcharts.noaa.gov/hsrp/recommendations/2018/HSRP-Rec-Boating-28feb2018.pdf
- HSRP Surveying Charting 28 Feb 18
- https://nauticalcharts.noaa.gov/hsrp/recommendations/2018/HSRP-Surveying-Charting-28feb18.pdf
- HSRP US Latitudes Longitudes Elevations to Change 28 Feb 2018
  https://nauticalcharts.noaa.gov/hsrp/recommendations/2018/HSRP-Surveying-Charting-28feb18.pdf

Links to the HSRP charter, legal statutes, and by-laws:

https://www.nauticalcharts.noaa.gov/hsrp/charter-bylaws-hsia-statute.html
https://www.nauticalcharts.noaa.gov/hsrp/charter/hsrp-charter-signed-8-28-19.pdf

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Notes

HYDROSPATIAL… A GLOBAL MOVEMENT !

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(*) Member of the **"**Hydrospatial Movement Club & Community**"**

ABSTRACT

In two previous articles published as Notes in the International Hydrographic Review (IHR) No.25 and No.23 the topics of "What's Hydrospatial?" (Hains, 2020) and « So… What is Hydrospatial ? » (Hains & al, 2021), it was suggested to use the new term Hydrospatial as the expansion of hydrography in the context of a sustainable growing Blue Economy. The authors continue to stress and will continue to reaffirm that Hydrospatial is not a replacement for hydrography, it is broader and an expansion of it beyond the realm of sea navigation. The authors have no intention to have hydrography being replaced as a term. The term Hydrospatial is intended to provide a refinement of the concept of Geospatial in the context of the aquatic environment.

"Hydrography" is, and will remain, the foundation of the Hydrospatial and continues to be a very relevant term and field of science. More articles and information have

been published to clarify Hydrospatial and to define it better. In the momentum of exploring the benefits of using the term Hydrospatial to better address geospatial in the water, a global movement of volunteers has been established to generate discussion and advocate the applications of the term Hydrospatial, which could be simply described as the blue geospatial environment.

1. INTRODUCTION

A core team of volunteers suggested the creation of a global Hydrospatial Movement Club and Community (HMCC) to promote the concept of Hydrospatial. Established at the end of 2020, the HMCC was first started by a «club» of professional volunteers globally in the water domain. The HMCC is currently a club of twelve volunteers worldwide interested in promoting and advocating the importantce of marine and aquatic geospatial or blue geospatial data and information, namely the Hydrospatial domain.

Figure 1. *Logo of the HMCC*

«Hydrospatial is all about the Blue of our Blue Planet and its Coastal Zones!»

The working definition of the term Hydrospatial was originally derived from a variation of the existing International Hydrographic Organization (IHO) definition of hydrography. Although this definition still stands as the original definition ; it is encompassing and complex.

In the context of the HMCC, a group of twelve volunteers around the world with an interest on « the Blue of our Blue Planet and its Coastal Zones » agreed to put their heads together to review and exchange knowledge and thoughts on how to simplify the description of the term Hydrospatial. More specifically, the Club aspires to expand its membership to a larger Community of professional volunteers. Together the HMCC aims to clarify and simplify the definition for the term Hydrospatial to something like the title above. Alternatively, we hope to also be inspired by publishing articles and papers using Hydrospatial, which was described by one independent author as: …"*that portion of geospatial knowledge infrastructure that addresses the hydrosphere, and hydrospatial technologies support navigation, economic development, stability, security and defence, resilience and scientific research."* (Smits M., June 2021)

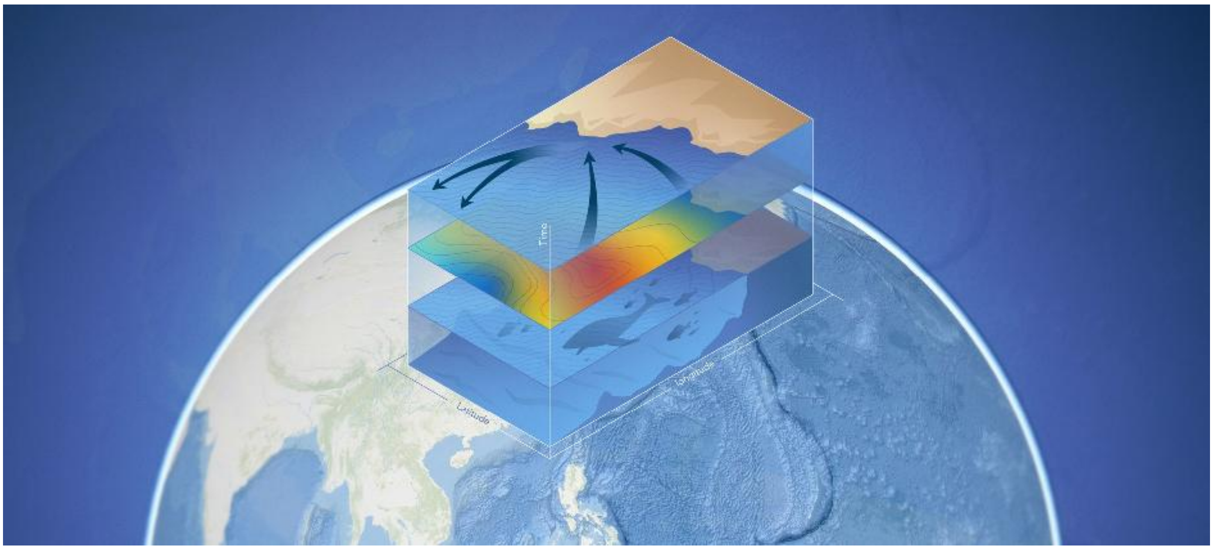

Figure 2. *Hydrospatial is multidimensions and temporal - Courtesy of Esri, Inc©*

2. THE VISION AND MISSION

The HMCC is neither a non-for-profit organization, nor an overly structured group. It is a group of volunteers willing to invest their own time for the importance of bridging interests; creating momentum, synergies and alliances in Hydrospatial of all the existing structured organizations by advocating the importance of knowledge, data and information sharing of the blue of our blue planet and its coastal zones.

The intention is to serve as a voice and advocate of Hydrospatial as the foundation of any activity in the oceans, seas, lakes and rivers, emphasizing the blue economic growth for Sustainable Development and Clean Environment.

The Hydrospatial Movement Club and Community carries out the outreach by publishing, mobilizing, bridging and engaging ocean, inland waters and coastal professionals in understanding and using Hydrospatial to explore and exploit marine and aquatic geospatial data and information to the broadest extent possible.

3. THE VALUES AND OBJECTIVES

Like many other professional groups the HMCC values are based on behaving with trust and respect; demonstrating sustained commitment and proactivity; and interacting in an honest and efficient manner.

All this towards the target to promote, produce, share, and stimulate the production of quality policy and technical papers, articles and presentations on Hydrospatial.

Also by maintaining a strong, credible and active core club of members from every continent of the world. Members have in mind to expand as much as possible the Hydrospatial Movement Club into a large, vibrant Community using the social media as a vehicle.

4. THE TACTICAL ACTIONS

The HMCC has set out some goals and actions to achieve its growth:

Recruit members with a diversified background. In mid-2021, the team comprises volunteers from a mix of senior, mid-career and early career members and from different continents to establish the Club i.e. Americas, Asia, Europe, Africa and Australasia;

Develop a plan to present at events and publish papers yearly on some relevant topics, articles and notes on Hydrospatial in well-known international and domestic events and publications;

Have an integrated publishing plan of Hydrospatial articles and notes in targeted international publications, in areas such as, and not limited to: shipping; ports and harbours management & operations, pilotage, polar and remote marine areas; UN Convention on Law of the Sea; marine cadastre; Marine Spatial Data Infrastructure (MSDI), Marine Spatial Planning (MSP), ocean and coastal management & technologies;

Put in place a flexible and straightforward electronic means to maintain a fluent and frequent communication within the HMCC members;

Establish and implement basic criteria and rules to recruit members beyond the Club to an Hydrospatial Movement "Community".

5. THE CURRENT CLUB MEMBERSHIP

The core Club is currently composed of twelve members including 2 co-leads plus 2 members per continent for the African, American, Asian Australasian and European Nodes as a starting point. Those members drive through leadership in the use of Hydrospatial to create a momentum to get the HMCC taken off as a community, and make a difference and advocate for Hydrospatial..

The individuals authoring this paper are the twelve members of the original Club. The shape, the form and the structure of the HMCC are expected to be flexible and fluid to adapt to the issues and areas of interest for Hydrospatial.

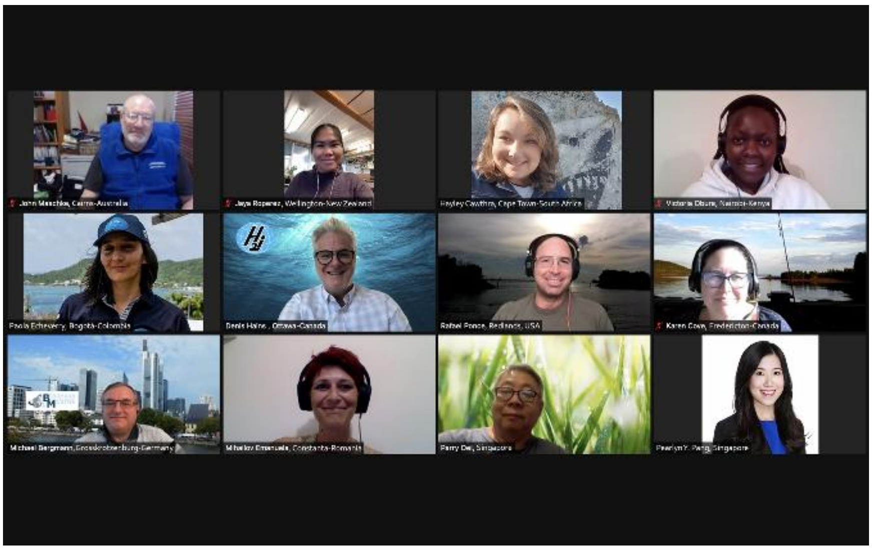

Figure 3. *Authors and members of the Hydrospatial Movement Club of the HMCC photo from ZOOM Screen Shot*

Figure 4. Map of the World showing the locations of the current Club members from the HMCC Story Map.

6. THE EXPANSION TO A GLOBAL COMMUNITY AND HOW TO GET INVOLVED

The HMCC aims to be open and inclusive. More information on Hydrospatial and the HMCC can be found on a Story Map at: https://arcg.is/19fiab .

Everyone interested in joining the volunteer Community can join by becoming a member of the HMCC ***LinkedIn*** Group site at: https://lnkd.in/eBYGfkpq . Activities such as Nodes Virtual Workshops will be scheduled in the last quarter of 2021 and the first half of 2022 on topics of interest starting with the review and feedback on the more straightforward and shorter definition to adopt for Hydrospatial.

7. CONCLUSION, NEXT STEPS AND CALL FOR INTEREST…

Hydrography as we understand it, in the past, in the moment now and for the future, is essential and will continue to be more relevant than ever. We would like to reiterate that it is not the HMCC intention to replace the term Hydrography with the term Hydrospatial. On the contrary, the HMCC is of the view that a term is needed to go beyond the science of hydrography from its traditional meaning into a multi-dimensional and temporal data content that are becoming more relevant and critical in the digital world of Big Data, the Internet of Things and Artificial Intelligence.

Moving towards the use of the term Hydrospatial not only highlights the ongoing benefits and the leadership role of hydrography, but also emphasizes the new roles for hydrographic data and expertise.

All individuals or organizations interested in furthering the thoughts, and the definition and activities of Hydrospatial, are invited to reach out to one of the authors to express their interest.

The Hydrospatial Movement Club & Community (HMCC) is open and inclusive of our blue planet's positive and constructive people.

Feedback, and constructive comments and suggestions are welcome. If you reached to this point, it means you are interetsed and the authors would likw to invite you to register as a volunteer member of the Hydrospatial community by becoming a follower of the HMCC ***LinkedIn*** site. It is free, it is for the blue of our planet and it will be fun !

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