SATELLITE DERIVED BATHYMETRY (SDB) AND SAFETY OF NAVIGATION.

By A. K. Mavraeidopoulos [abc] , A. Pallikaris [c] , E. Oikonomou [d]

Abstract

This paper reviews the use of Satellite Derived Bathymetry (SDB) technology to derive depths from remote sensed (RS) data and how this technology can be used to address crucial aspects of safety of navigation. The estimation of bathymetric depth using optical RS techniques has advantages and disadvantages. Using imagery techniques, depths can be determined quickly over large remote coastal areas. These areas can however consist of dangerous hazards, submerged objects and steep seabed morphology. SDB processing techniques introduces new perspectives to potentially improving safety of navigation charting. The feasibility of deriving bathymetry from remote sensed images, requires that the accuracy of such data should be evaluated and an assessed in terms of how this data can be used and depicted in nautical chart production. The parameters associated with SDB capabilities that contribute to cartographic production are further discussed and evaluated against current IHO Standards.

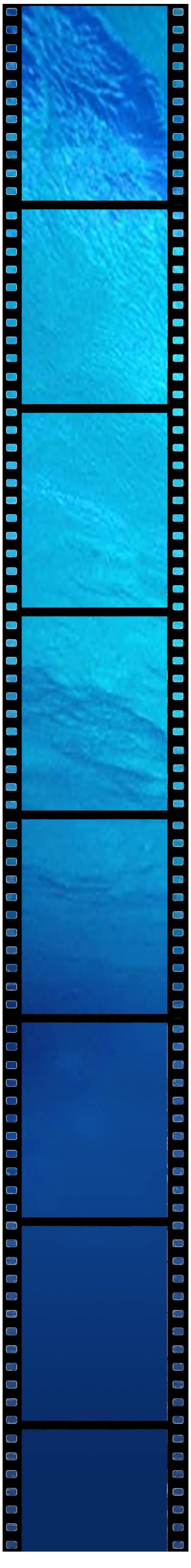
***Keywords* –** Hydrography, Remote Sensing (RS), Satellite Derived Bathymetry (SDB), Cartography, ENCs, Charts, Algorithms for bathymetry extraction, IHO Standards.

Résumé

Cet article étudie l'utilisation de la technologie de la bathymétrie par satellite (SDB) afin de déduire des profondeurs à partir de données de télédétection (RS) ainsi que la manière dont cette technologie peut être utilisée pour traiter des aspects cruciaux de la sécurité de la navigation. L'estimation de la profondeur bathymétrique à l'aide de techniques de télédétection optique présente des avantages et des inconvénients. En utilisant des techniques d'imagerie, les profondeurs peuvent être déterminées rapidement sur de vastes zones côtières lointaines. Ces zones peuvent néanmoins contenir des risques dangereux, des objets immergés et comporter des fonds marins escarpés. Les techniques de traitement de la SDB introduisent de nouvelles perspectives pour une éventuelle amélioration de la cartographie pour les besoins de la sécurité de la navigation. La possibilité de dériver la bathymétrie à partir d'images de télédétection nécessite que la précision de ces données soit évaluée et analysée afin de savoir comment elles peuvent être utilisées et décrites dans la production de cartes marines. Les paramètres associés aux capacités de la SDB qui contribuent à la production cartographique font l'objet de discussions plus poussées et sont évalués par rapport aux normes de l'OHI en vigueur.

***Mots clés* –** Hydrographie, télédétection (RS), bathymétrie par satellite (SDB), cartographie, ENC, cartes, algorithmes pour l'extraction de la bathymétrie, normes de l'OHI.

[a] *National Fleet Fund, Hellenic Navy, (athanasios.mavraeidopoulos@yahoo.com)*
[b] *National and Kapodistrian University of Athens, Remote Sensing Laboratory*
[c] *Hellenic Naval Academy, Navigation and Sea Sciences Laboratory*
[d] *Technological Educational Institute of Athens, Department of Civil Engineering, Surveying and Geoinformatics Engineering*



Resumen

Este artículo revisa el uso de la tecnología de Batimetría Satelital Derivada (SDB) para obtener profundidades a partir de datos obtenidos de sensores remotos (RS) y cómo esta tecnología puede utilizarse para abordar aspectos cruciales de la seguridad de la navegación. La estimación de la profundidad batimétrica utilizando técnicas ópticas RS tiene ventajas y desventajas. Usando técnicas de imágenes, las profundidades pueden determinarse rápidamente en extensas áreas costeras remotas. Sin embargo, estas áreas pueden contener amenazas peligrosas, objetos sumergidos y en una morfología escarpada del fondo marino. Las técnicas de procesado SDB introducen nuevas perspectivas para mejorar potencialmente la representación de la seguridad de la navegación. La viabilidad de la derivación de la batimetría a partir de imágenes obtenidas de sensores remotos requiere que la exactitud de tales datos sea evaluada y valorada en términos de cómo estos datos pueden utilizarse y representarse en la producción de cartas náuticas. Los parámetros asociados a las capacidades SDB que contribuyen a la producción cartográfica se discuten adicionalmente y se evalúan conforme a las normas actuales de la OHI.

Palabras clave - *Hidrografía, Teledetección (RS), Batimetría Satelital Derivada (SDB), Cartografía, ENCs, Cartas, Algoritmos para la extracción de batimetría, Normas de la OHI.*

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1. Introduction

The possibility to use satellite imagery data to generate bathymetric depths has been investigated since the 1970s. A study undertaken by the University of Michigan for the Spacecraft Project of U.S. Naval Oceanographic Office, demonstrated the successful remote determination of shallow water depth by measuring wave refraction changes and using the Fourier transform plane for wavelength measurements with data obtained at a Lake Michigan test site. This study showed that the technique is suitable, provided that water waves of suitable length occur in the region of interest (Polcyn *et al.* 1970).

In 1975, the NASA/Cousteau Ocean Bathymetry Experiment proved the usefulness of satellite bathymetry derived from LandSat MSS imagery. This joint venture proved the feasibility of detecting and mapping dangers to navigation in clear water to depths of 22m (10% rms accuracy). The processed depths were verified by the ground truth team onboard the Calypso Survey ship (Hammack, 1977). Since this study, advances in satellite technology, new techniques, sophisticated algorithms and software have all improved the potential for Hydrographic Offices (HOs) and scientists to improve the knowledge about the seafloor morphology and marine habitat conservation. Whilst SDB techniques can provide adequate data coverage, especially in remote areas and have capable object detection capability with good positional accuracy, it is not always considered that SDB methods have yet been developed sufficiently for safety of navigation purposes.

2. Conventional Hydrographic Surveys versus SDB

The International Hydrographic Organization's (IHO) definition of Hydrography (IHO, 2005) states:

"*That branch of applied sciences which deals with the measurement and description of the features of the seas and coastal are - as for the primary purpose of navigation and all other marine purposes and activities including - inter alia - offshore activities, research, protection of the environment, and prediction services.*"

The above definition does not limit scope of hydrography to the collection of bathymetric data from sea areas. It also covers delivery of reduced depths that are accurate for producing navigational products (charts, warnings, pilots, lights information, etc.) dedicated to the safety of life at sea.

The IHO's S-44 Standard (IHO, 2008) suggests that the "*minimum*" standards for conducting conventional hydrographic surveys are classified in four (4) categories, focusing in their interest to the navigation. These standards should be taken into account by agencies or surveyors when collecting data from sea areas, appropriate for safety of navigation purposes. Specifically, the suggested categories of hydrographic surveying are the *Special Order*, *Order 1a*, *Order 1b* and *Order 2* surveys (***Table 1***).

The agency responsible for acquiring surveys, should choose the most suitable order/category of survey to produce navigational products that will allow the "expected shipping" to navigate safely across the surveyed areas. However, what does the term "*expected shipping*" mean? What are the dimensions and the draft of ships which "expect" to navigate a particular sea area?

The quality measure adopted for assessing the accuracy or even better the uncertainty of the collected data is the *Total Propagated Uncertainty (TPU)*. The *TPU* is a three dimensional quantity consisted of all measurement errors (systematic and random), derived from several sources (i.e. positional errors, settlement, dynamic draft uncertainty, depth errors, latency inaccuracy, etc.) (IHO, 2008). The *TPU* comprises two components. The horizontal component of *TPU* is defined as the *Total Horizontal Uncertainty (THU)*, which

Table 1. *IHO S-44 Classification of Surveys (IHO, 2008)*

Order	**Special**	**1a**	**1b**	**2**
Description of areas.	Areas where under-keel clearance is critical	Areas shallower than 100 metres where under-keel clearance is less critical but *features* of concern to surface shipping may exist.	Areas shallower than 100 metres where under-keel clearance is not considered to be an issue for the type of surface shipping expected to transit the area.	Areas generally deeper than 100 metres where a general description of the sea floor is considered adequate.
Maximum allowable THU 95% *Confidence level*	2 metres	5 metres + 5% of depth	5 metres + 5% of depth	20 metres + 10% of depth
Maximum allowable TVU 95% *Confidence level*	a = 0.25 metre b = 0.0075	a = 0.5 metre b = 0.013	a = 0.5 metre b = 0.013	a = 1.0 metre b = 0.023
Full Sea floor Search	Required	Required	Not required	Not required
Feature Detection	Cubic *features* > 1 metre	Cubic *features* > 2 metres, in depths up to 40 metres; 10% of depth beyond 40 metres	Not Applicable	Not Applicable
Recommended maximum Line Spacing	Not defined as *full sea floor search* is required	Not defined as *full sea floor search* is required	3 x average depth or 25 metres, whichever is greater For bathymetric lidar a spot spacing of 5 x 5 metres	4 x average depth
Positioning of fixed aids to navigation and topography significant to navigation. (95% *Confidence level*)	2 metres	2 metres	2 metres	5 metres
Positioning of the Coastline and topography less significant to navigation (95% *Confidence level*)	10 metres	20 metres	20 metres	20 metres
Mean position of floating aids to navigation (95% *Confidence level*)	10 metres	10 metres	10 metres	20 metres

which concerns the positional accuracy, while the vertical component of *TPU* is called the *Total Vertical Uncertainty (TVU)*, which is calculated in vertical dimension and related to depths accuracy.

From ***Table 1***, the maximum allowable *THU*, at the 95% confidence level, is given in certain values, while the *TVU* is a function of the reduced depth (*d*) and two (2) other parameters (*a*) and (*b*) as follows:

$$TVU = \pm\sqrt{\alpha^2 + (b \times d)^2}$$

Where:

a represents the part of the uncertainty that does not vary with depth, usually related to the system noise,

b is a coefficient which represents the portion of the uncertainty that varies with depth, mostly associated with the physics of interaction of acoustic energy propagating in water,

d is the depth,

b x *d* represents that fraction of the uncertainty that varies with depth.

Translating the S-44 standards, the main concern of a hydrographic surveyor is related to shallow or relatively shallow waters areas to 40m depth. In these depths, there is increased risk in a marine casualty leading to a marine and coastal environment disaster, impacting the marine economy of all affected States. For this reason, the most demanding category of survey is defined as the *Special Order* surveys, and must be undertaken in coastal areas where under-keel clearance is crucial to the safety of navigation (***Table 1).***

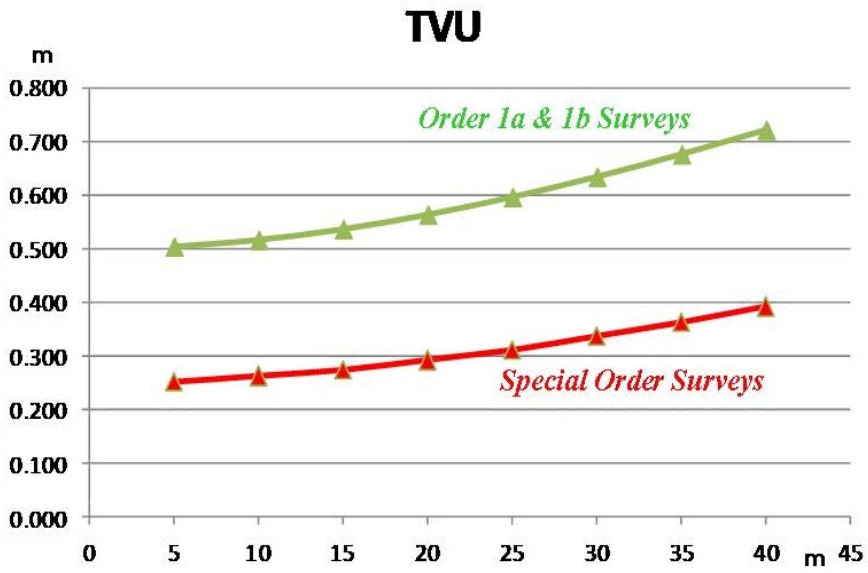


Figure 1. *Total Vertical Uncertainty (TVU) variation for Special Order, Order 1a and 1b surveys.*

Additionally, coastal areas which consist of areas shallower than 100m, often cover the majority of the waters depicted on large to medium scale charts and typically require *Order 1a* surveys. These areas are usually the approaches to ports, channels or adjacent water areas of significant importance to navigation. In these circumstances (*Special Order* and *Order 1a* surveys), total seafloor coverage of data is required.

For reduced depths of 5-40m, the maximum allowable depth uncertainty *(TVU)* should be between 0.253m - 0.391m for *Special Order* and between 0.504m – 0.721m for *Order 1a* and *Order 1b* surveys (***Figure 1***), respectively. Also, it should be noted that the capability of the survey system should be approved for the mentioned *TVU* estimation.

Despite the guidance of the IHO towards the way that hydrographers should collect bathymetric data, paper nautical charts and Electronic Nautical Charts (ENCs), do not (always) depict the depths in line with the aforementioned standards. Both products (paper charts and ENCs), whilst dedicated to the safety of navigation, are compiled from data originating from multiple sources and different systems (sensors) using various procedures, especially in shallow or remote areas. This raises the question about how the HOs prove their capacity in producing marine products with "good coverage" with such limitations. How feasible is it to update their chart portfolios, especially within the current framework of reduced capacity building?

A crucial issue for *Special* and *Order 1a* surveys, is that the survey acquisition system should have the capability to achieve 100% total seafloor bathymetric coverage. Hence, the question - how often do surveys actually satisfy this particular specification in the real world, especially in areas with steep and very irregular topography of the seabed? S-44 requires that the survey system should detect cubic features with dimensions bigger than 1m in coastal areas of category *Special Order*. For *Order 1a* areas, the bathymetric system should detect submerged cubic objects larger than 2m. In reality, how many symmetric "cubic" submerged features exist in a real seabed?

To summarize, how safe are the navigational products since they depict to some extent, "not so safe" data? A nautical chart is not a "static" product and must be updated regularly. Nevertheless, the process of surveying and updating charts quickly and at regular intervals is costly and requires significant human and equipment resources. The fact is that modern acoustic systems can collect bathymetric data with better accuracies than other technologies such as satellite imagery, due to their physics-based techniques related to the propagation and beam-forming of sound in water.

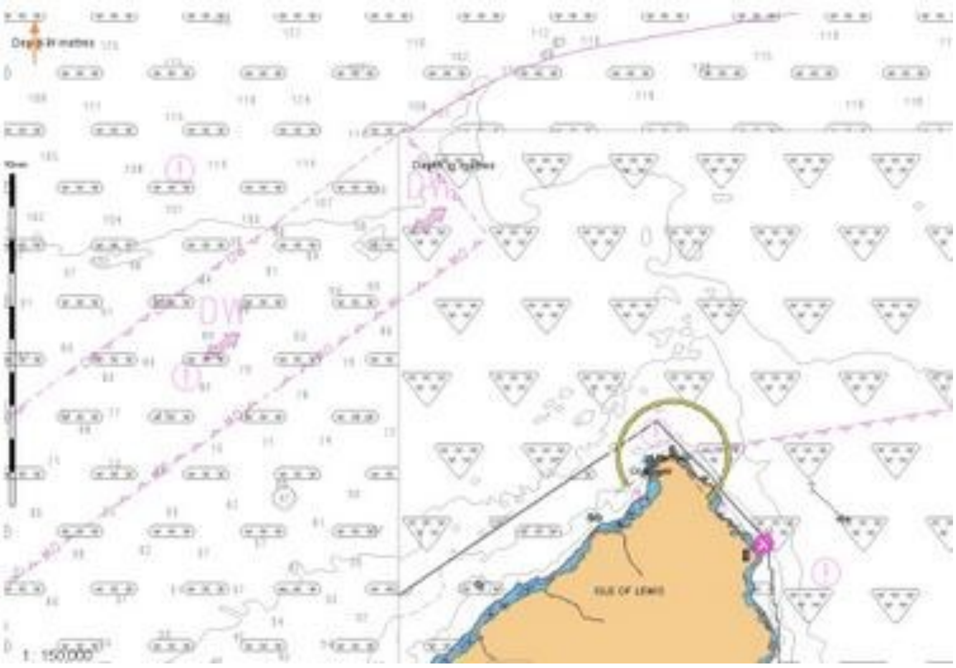


Figure 2. *ENC CATZOC portrayal in the ECDIS as a series of stars.*
(http://www.theartofdredging.com)

Despite the efforts of HOs, paper charts and ENCs do not always depict the reality as it would be desired. When the IHO developed the S-57 Standard (IHO, 2000) for the production of ENCs, a need was identified for ENCs to include quality indicator metadata called "Category of Zone of Confidence" (CATZOC). This indicator takes into consideration the horizontal *(THU)* and vertical uncertainty *(TVU)* of the hydrographic data, along with an estimation of the completeness (seafloor coverage) of the survey and combines these through an algorithm to classify bathymetry in one of five (5) categories (A1, A2, B, C, D), with a sixth category (U) for data which has not been assessed. (Geomares, 2012).

Each CATZOC can be displayed in the Electronic Chart and Display Information System (ECDIS) as a series of stars overlaid on the ENC. The greater the number of stars the better the survey (***Figure 2***). For instance four (4) stars represent a CATZOC B. However, the mariner's impression looking at the ECDIS with "stars" can be at odds when looking at the echosounder which may be indicating a different depth to that of the ENC depths. The CATZOC encoding cannot indicate and/or visualize the temporal degradation of the bathymetry. The problems discussed above will be addressed with new algorithms being implemented in the new S-101 data Model.

An alternative technique of collecting bathymetric data rapidly is by exploiting satellite imagery (Rocchio, 2016). Satellite Derived Bathymetry (SDB) is a technique based on the empirical, semi-analytical or analytical modeling of light transmission through the atmosphere and the water column. SDB offers great advantages to the planning and executing of hydrographic activities as follows (EOMAP, 2014):

- It is a cost-effective methodology, with 5-10 times reduced costs compared to the conventional hydrographic techniques.
- Provides fast bathymetry acquisition and production, in some cases the data collection and processing exceed the 1000 km^2 per month.
- High resolution up-to-date bathymetric data comes from recent imagery, with a spatial resolution of 0.5x0.5m.
- It is no more a problem to gather data from remote areas, or areas which cannot be physically accessible.
- Seabed classification maps can also be produced from coastal areas with optically sensed seafloors.
- SDB is a carbon neutral and non-destructive environmentally technique.

Although the acquisition of imagery data is not a problem today, the processing of imagery data is more complex than data collected from conventional surveys as SDB requires special treatment for processing subsurface irradiance reflectance signal ($R(0^-)$). Imagery data processing consists of atmospheric correction (i.e. 6SV, OPERA, etc.) (Vermote *et al.* 2006 and Sterckx *et al.* 2011); air-water interface corrections (Kay *et al.* 2009) and implementation of inverse optical models (i.e. HYDROLIGHT, SAMBUCA, etc.) (Mobley and Sundman, 2000 and Wettle and Brando, 2006).

The remaining signal contains the bathymetric information propagated from the seabed (***Figure 3***). Empirical or analytical-based inversion models should be applied for estimating corrections that must be used for estimating bathymetry. These models are sophisticated algorithms that retrieve the seafloor signal from the noise induced due to the interaction of radiation with atmosphere, water volume, sky and sea-surface reflected radiance. In general, water bodies reflect (as subsurface irradiance reflectance) in the range of 1% to 15% of downwelling irradiance ($E_d(\lambda)$). The majority of water bodies reflect between 2% and 6% of downwelling irradiance (Brando and Dekker, 2003). In every case, the maximum range of deriving depths depends on water clarity or in other words, the *color of the ocean* (IOPs, turbidity, etc.).

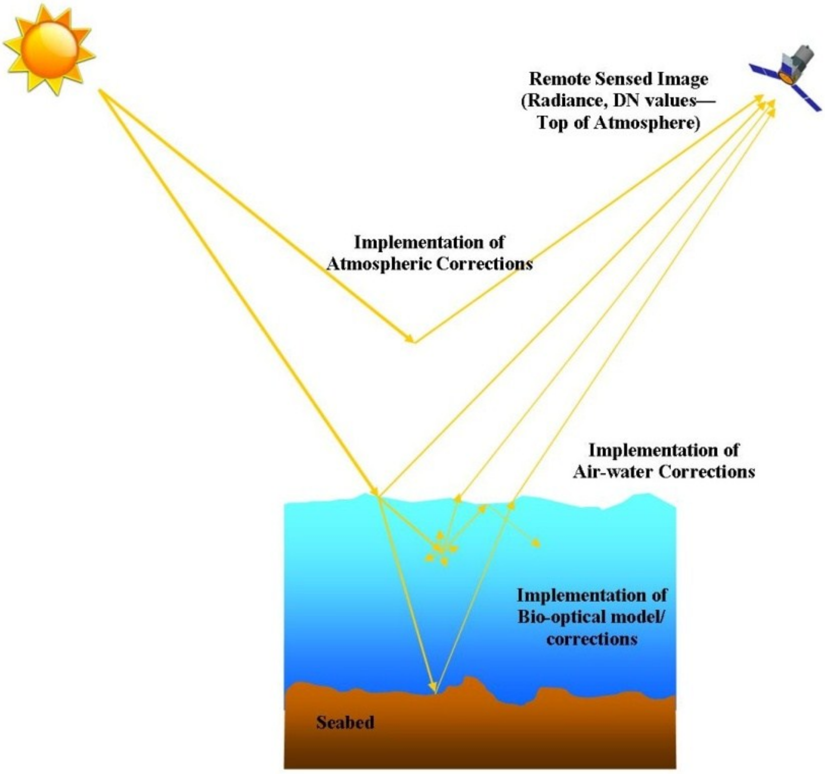


Figure 3. *Radiative Transfer Process*

Typically, depths down to 35m – 40m can be derived in clear waters such as found in the Mediterranean Sea and in particular, Greek coastal waters. Typically, the use of analytical or semi-analytical models results in more accurate depths and deeper penetration ranges. The issue that arises is, how can this data be exploited for safety of navigation products?

As the horizontal accuracy of SDB is a function of the spatial resolution of the satellite sensor used, the uncertainty contained in bathymetric data is usually of the order of 1 pixel size. For instance, if the satellite sensor has a spatial resolution of 5m, then for a 5m resolution product, the horizontal accuracy is ≤ 5m. Recent developments resulted in sub-meter horizontal resolution, specifically in this case 70cm spatial resolution of produced bathymetric data (Muhlbauer, 2014).

The critical issue of SDB is the achieved vertical accuracy. According to EOMAP (2014) the vertical accuracy is a function of an offset parameter equal to 0.5m and a depth-dependent factor of 10%-20%. Hence, for 10m water depths, the accuracy is between ±1.5m and ±2.5m. The depth-dependent factor depends on the Inherent Optical Properties (IOPs) of the water column and seabed texture, which means that areas with turbidity, large chlorophyll-*a* concentrations or dark colored sediments would provide larger uncertainties. Furthermore, some firms producing bathymetric data from imagery, provide pixel-based quality information on the reliability of their deliverables. When using SDB, a full seafloor search is feasible since the final product includes a continuous bathymetric model of the sea area imaged. Tests reported by Dekker et al. (2012) based on ALOS-AVNIR 10m pixel data, confirmed the calculation of a *TVU* value within IHO *1a* and *1b Order surveys* standards.

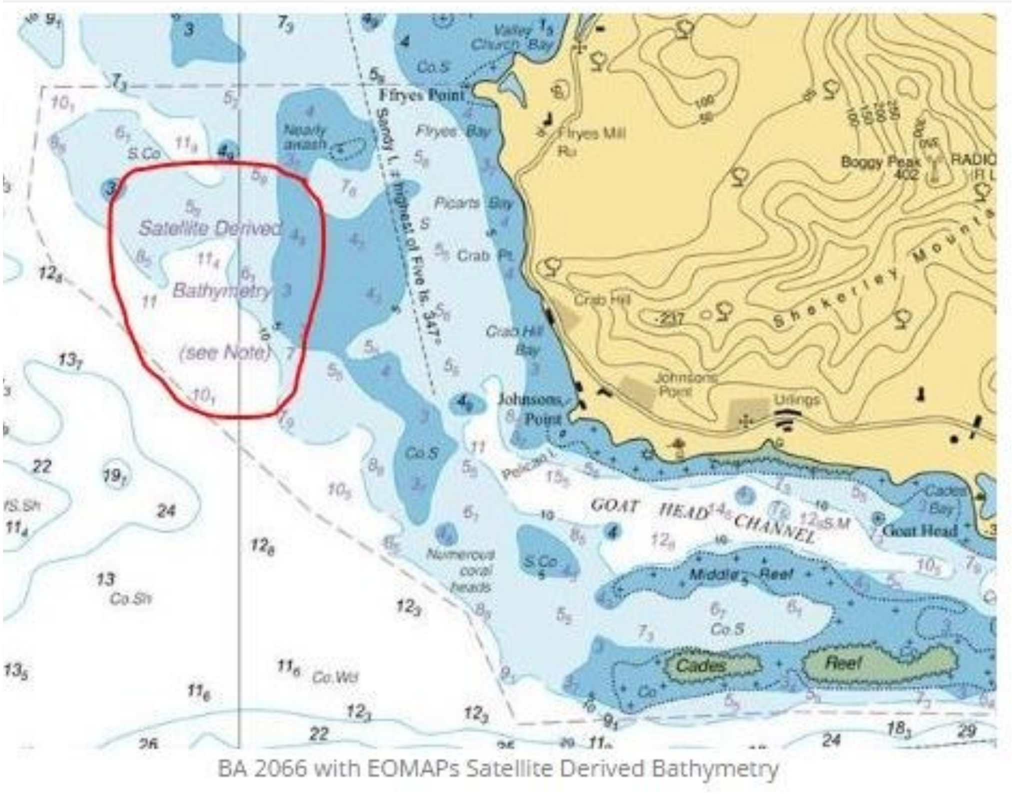
The S-44 standards do not include any particular quality procedure with respect to the bathymetric data derived from satellites. However, recently the IHO and the Intergovernmental Oceanographic Commission (IOC) provided a method (IHO-IOC, 2016) for processing and analyzing bathymetric data using imagery (Landsat) that is free and publicly available.

3. SDB Applications in Marine Cartography

Given the potential advantages of SDB, this technology is of interest to the hydrographic community and several markets including leisure crafts owners, mariners, large infrastructure construction (harbors works), marine science and technology consultancy, seismic surveying companies, and the oil & gas sector (Flemmings and Sartori, 2017). Although, the S-44 standards are intended mainly for safety of navigation purposes, chart products are widely used across a multidisciplinary market.

Several studies have been undertaken in Haiti coastal areas using Landsat and Worldview 2 imagery with encouraging results (Snyder and Maarten, 2013). Trials along the Queensland coast, Australia, using ALOS and Quickbird data, confirmed the adequacy of SDB data for use in cartographic production (Dekker *et al.* 2012). In October 2015, the UKHO published its first nautical chart - BA 2066 (Southern Antigua) (***Figure 4***) incorporating data derived from satellite sensors and in collaboration with the private sector. Likewise, the French HO (SHOM) has used satellite imagery data over the past 20 years for producing and updating their nautical charts (*Satellite Derived Charts-SDCs*). NOAA's Marine Chart Division has made SDB a prominent tool in their charting procedure, especially the Landsat 8 imagery with its new deep blue band, which uses a new and improved signal-to-noise ratio and greater dynamic range (12-bit) (Rocchio, 2016). Recently, SDB was used in the Gulf of Guinea to extract UNCLOS baselines out of the surf bordering two adjacent African states (Geomares, 2015).

In short, SDB is gaining acceptance for daily use, not only as an operational exploration tool, but as a new technique that is capable of providing calibrated and validated depths to the marine cartographer.



BA 2066 with EOMAPs Satellite Derived Bathymetry

Figure 4: *Nautical Chart BA 2066, published with high resolution satellite derived shallow water bathymetry (www.eomap.com).*

4. Some Clues for Further Discussion

The global electronic cartography market can be broken into a number of Application markets (***Figure 5***) such as Marine - Commercial and Defense, Aviation – Commercial and Defence; Components - Systems, Charts; Marine Electronic Navigation Systems (ECDIS, ECS); Aviation Electronic Navigation Systems (Very Large Aircrafts, Wide Body Aircrafts, Narrow Body Aircrafts); Marine Electronic Charts Licensing Mode (PAYS, Direct). These markets operate across all geographic areas (i.e. APAC, Europe, North America, South America, Middle East and Africa). In all, the global market is forecasted to reach $21,267.60 million, growing with a compound annual growth rate (CAGR) of 1.46% from 2014 to 2020 (Electronic Cartography Market, 2014).

As the market demands increase and industry grows to support these markets, this drives an increased requirement for suitable hydrographic data and related nautical information - at a time when current budgets of national HOs are generally reducing. Hence, there is an urgency that is driven by the market, to meet its needs with reliable and up-to-date cartographic products over large sea areas. SDB is a relatively mature technique and due to its advantages, can contribute to safety of navigation issues. Further, imagery can provide surveyors with precise topographic data (i.e. coastlining, positioning of conspicuous points, etc.), bathymetric and benthos information and seabed sediment estimation, all of which are fundamental marine cartography features.

Obviously, the lack of up-to-date hydrographic data over huge regions with dynamic and changing shallow waters can be treated with fast and reliable SDB data, in conjunction with Satellite Positioning Systems (GNSS) and Satellite Communication Services. The aforementioned key elements expect to enhance the cartographic availability and safety of navigation procedures in future. Space-based, value-added technology, can provide the hydrographic community with trustworthy data (Lauzer, 2016). SDB will not substitute conventional hydrographic survey systems and methods, but as it is a “different” technology, it can be used as a complementary product to conventional survey data, satisfying *Order 1a* or *1b* IHO standards. The encoding and visualization of SDB with quality indicators is an important aspect of the use of SDB and the user’s interpretation of bathymetric data quality. In certain circumstances, SDB techniques can also be used to provide reconnaissance information for follow-up survey tasks (Pe'eri *et al.* 2013).

Regardless of the abovementioned comments, it is crucial that further validation and research is undertaken to ensure that the SDB capability satisfies the accuracies specified in S-44.

Figure 5. *Marine Electronic Chart Market covers the needs of different applications, and users such as international shipping, leisure boats etc..*

5. Conclusions and proposals

Coastal environments are the most dynamic and constantly changing areas of the globe. Monitoring and depicting these rapidly changing environments on charts is critical to the safety of navigation where they relate to near-shore constructions, harbors, pipelines and other crucial infrastructures in the coastal zone or shallow off-shore areas. HOs strive to regularly survey and maintain their navigation products in coastal areas that often require *Special Order* and *Order 1a* surveys. As with all survey techniques, it is possible to gather data of varying quality using conventional surveys or SDB techniques. SDB has the potential to provide a key solution to updating charts of coastal waters that experience rapid seabed changes and in areas where little or no existing hydrographic data exists. Publications such as the IHO/IOC GEBCO Cook Book, provides a good introduction to implementing SDB data into a nautical chart production line, but it is only the start. Considering the potential advantages of satellite remote sensing for aiding the marine economy, the IHO is encouraged to continue to develop policy for the technical aspects and quality standards for adopting SDB data in navigational products.

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7. Authors' biographies

Captain Athanasios K. Mavraeidopoulos H.N. joined the Hellenic Navy in 1983. In 1987 he graduated from the Hellenic Navy Academy and served as an officer onboard Navy ships. Consequently, he attended the Civil Engineering Program of National Technical University of Athens (NTUA) and he was awarded the Diploma in Civil/Maritime Engineering in 1996. In 1999, he undertook studies in Hydrography at Plymouth University (School of Marine Science and Engineering) and is accredited by the Royal Institution of Chartered Surveyors (RICS), Chartered Institution of Civil Engineering Surveyors (ICES), Institute of Marine Engineering, Science and Technology (IMarEST) and holds an International Hydrographic Organization (IHO) / Federation Internationale Geometres (FIG) / International Cartographic Association (ICA) Category "A" Hydrographic Surveyor Certificate. Currently, he is a Phd Candidate at Kapodistrian and National University of Athens, in Marine Geology. He has also served in Hellenic Navy Hydrographic Service as Chief Surveyor, and Deputy Director, between 1989-2011 and presently is the Deputy Director of National Fleet Fund of Hellenic Ministry of Defense.
athanasios.mavraeidopoulos@yahoo.com

Athanasios Pallikaris is professor and director of the "Navigation and Sea Sciences Laboratory" at the Hellenic Naval Academy [HNA]. He holds a Diploma in Nautical Science from the HNA (1975) a M.Sc. in Oceanography-Hydrography from the Naval Postgraduate School-USA (1983) and a PHD in GIS applications in Marine Navigation from the National Technical University of Athens (2010). Before joining the faculty of HNA, he has served, as an officer of the Hellenic Navy, initially on board some Hellenic Navy vessels and subsequently in various posts of the Hellenic Navy Hydrographic Service,

including those of the Head of the Department of Cartography, Head of the Department of Hydrographic Surveys and Head of the Department of Digital Cartography. He has served on a number of national and international committees and working groups on Hydrography, Nautical Cartography and Navigation. He is the author/co-author of a number of books and research papers in Navigation, Hydrography and Nautical Cartography. His citation index includes more than 90 references to his work.
palikaris@snd.edu.gr palikari@otenet.gr

Emmanouil K. Oikonomou is currently appointed as Senior Lecturer at the Technological Institute of Athens, Department of Civil Engineering and Surveying Engineering & Geo-informatics. He holds BEng Honours in Rural and Surveying Engineering from Aristotle University of Thessaloniki - Greece (1990), and MSc (1993) and PhD (1997) in Physical Oceanography, both from Southampton University - UK. He has worked in Open University-UK (1999), at the Department of Meteorology in Reading University – UK (2000-2003), as a European Space Agency PostDoc in CNRS Paris – France (2003-2005), at the National Observatory of Athens – Greece (2005-2007), at the Centre for Renewable Energy – Greece (2007-2008), and as a lecturer in Remote Sensing and Satellite Oceanography at the Department of Oceanography, Aegean University - Greece (2009-2010). Since 2011 he is based at the Technological Institute of Athens, where he teaches the undergraduate courses of Remote Sensing, Introduction to Geodesy and Field work Surveying, and the MSc course in Remote Sensing. He has successfully supervised about 20 completed undergraduate projects in the last 5 years and he currently supervises three PhD students. He holds a chartered status in surveying engineering, with a long record of coastal surveying and remote sensing projects in the private sectors. His citation index includes more than 200 references to his work.
eoikonomou@teiath.gr

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