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Editorial

This edition provides a collection of interesting articles that hopefully will challenge our concepts of data management and the potential use of S-100 to provide useful data modelling and applications to improve ECDIS.

The first article addresses the fundamental issues of map projections used in ECDIS and e-nav applications. This paper identifies some interesting and surprising technical issues with the projection of ENC data in ECDIS. What follows is a comprehensive study of projections and their characteristics to determine optimal portrayal depending upon key parameters such as scale, coverage, location and usage.

The second paper describes the new S-102 Bathymetric Product Specification. In the early days of S-57 development (when it was considered a data exchange format), the data structure for handling large volumes of soundings was identified as not being suitable. At that time, large volumes of soundings from the early multibeam systems were predominantly in the realm of the oceanographers and had not yet become mainstream technology for hydrographic surveys. With the widespread adoption of multibeam technology for hydrographic surveys, the development and adoption of S-102 is crucial to the delivery, management and dissemination of this data for many applications. This includes the provision of high density bathymetry data in port areas and critical navigation scenarios. Combined with tidal, meteorological and oceanographic data, high quality, dense bathymetric data can provide enhanced navigation and under-keel clearance capabilities.

I am excited by the work undertaken by the Canadian team. This development continues a long history of cooperative relationships that the HO’s have with private industry to provide true innovation.

Our third paper explores the opportunities that S-100 provides to enable the development of marine sites for pollution monitoring. The identification and management of Potentially Polluting Marine Sites (PPMS) are important for monitoring and maintenance of our fragile marine environment. This paper provides excellent insights into how S-100 can be used to develop the necessary data models and tools to build complex geospatial hydrographic management systems – a very important paper for users who need to become more familiar with the capabilities of S-100.

The final paper is a discussion on Marine Research activities such as military surveys, operational oceanography, marine archaeology, remote sensing, etc. in respect to the complex Law of the Sea Conventions. The authors identify several issues relating to legislation, technology, financing, that should be considered to develop a consistent and enforceable ocean policies to support these activities.

On behalf of the Editorial Board, I hope that this edition is of interest to you. Thank you to the authors for their contributions and to my colleagues who provided peer reviews for the Articles in this edition.

Ian W. Halls
Editor
MAP PROJECTIONS FOR ELECTRONIC NAVIGATION AND OTHER MARINE GIS APPLICATIONS
By Athanasios Pallikaris
(Hellenic Naval Academy, Sea Sciences and Navigation Laboratory)

Abstract
The results of a research on the identification of suitable map projections for Electronic Chart Display and Information System (ECDIS) are presented. Eighteen map projections have been selected and evaluated according to criteria based on the calculation and analysis of distortion as well as on specific requirements for marine navigation. Six map projections are proposed for use in Electronic Navigation (e-Nav) systems together with specific selection rules based on the location and the extent of the area displayed on the screen. Additional map projections for potential use in other marine GIS applications are also identified and proposed.

Résumé
Les résultats d’une recherche sur l’identification de projections cartographiques adaptées au système de visualisation de cartes électroniques et d’information (ECDIS) sont présentés dans cet article. Dix-huit projections cartographiques ont été sélectionnées et évaluées selon des critères établis à partir de calculs et d’analyses de distorsion ainsi que des demandes spécifiques à la navigation maritime. Six projections cartographiques destinées à être utilisées dans le cadre de systèmes de navigation électronique (e-Nav) sont proposées en même temps que des règles de sélection spécifiques établies selon le lieu et l’étendue de la zone affichée à l’écran. Des projections cartographiques supplémentaires destinées à être éventuellement utilisées dans d’autres applications SIG maritimes sont également identifiées et proposées.

Resumen
Se presentan los resultados de una investigación sobre la identificación de proyecciones de mapas adecuadas para el Sistema de Información y Visualización de las Cartas Electrónicas (SIVCE). Se han seleccionado dieciocho proyecciones de mapas, que se han evaluado según los criterios basados en el cálculo y el análisis de distorsión, así como en los requisitos específicos para la navegación marina. Se proponen seis proyecciones de mapas, para su uso en los sistemas de Navegación Electrónica (e-Nav), junto con unas reglas de selección específicas basadas en la localización y en la extensión de la zona visualizada en pantalla. Se han identificado y propuesto también proyecciones de mapas adicionales para su uso potencial en otras aplicaciones del SIG marino.
1. Introduction.

This article presents the results of research on the feasibility of acquiring improved visual perception in ECDIS through the proper choice of map projections. Section 2 of the paper presents a brief overview on the status and the trends in the employment of map projections in marine Electronic Navigation (e-Nav). Section 3 presents the criteria and methodology used in the conducted study for the selection and evaluation of map projections. Section 4 presents the results of the selection and preliminary evaluation of an initial set of map projections for potential use in ECDIS and in other e-Nav applications. Eighteen map projections are initially selected and evaluated. As a result thirteen map projections are proposed for further analytical evaluation. Section 5 presents the results of the calculation and analysis of the distribution of distortion of the thirteen map projections selected in section 4. As a result nine map projections with reduced visual distortion over extended geographical areas are proposed for further evaluation. Section 6 presents the results of the final stage of evaluation of the nine map projections selected in the section 5 according to specific requirements and criteria for marine navigation. As a result six of the evaluated nine map projections are proposed for use in e-Nav systems (ECDIS and ECS). Section 7 presents consolidated rules for the choice of map projections for improved visual perception in e-Nav and other applications. Section 8 presents a brief overview of the results and proposals.

2. Trends in the use of map projections in marine navigation

2.1. Map projections in Traditional Navigation

In traditional marine navigation the employment of map projections is practically restricted to the “Mercator” and the “Gnomonic” projection. The Mercator projection depicts directions correctly, rhumblines (loxodromes) as straight lines and meridians and parallels as orthogonal straight lines. These properties have been exploited for the development of simple graphical solutions for the fundamental navigational problems, such as that of “Rhumbline Sailing” (Loxodromic Navigation) on the mercator chart. The Gnomonic projection depicts great circles (shortest navigational paths) as straight lines. This property is used in conjunction to the properties of the mercator projection in simple graphical solutions of “Great Circle Sailing” (orthodrome).

2.2. Map projections in Electronic Navigation

The official adoption of ECDIS for marine navigation in the mid 90s marked a revolutionary milestone in the evolution of marine Electronic Navigation (e-Nav) methods (IMO 1996). Despite the significant developments in many technical, operational and scientific aspects of ECDIS and Electronic Navigational Charts (ENCs) [IHO 2010], it is surprising that the international standards on ECDIS and on ENCs do not provide for specific requirements or recommendations on the employment of map projections. The lack of standardization on the use of map projections does not cause any real problem, since in ECDIS the solution of navigational problems and the measurements of distances and directions on the electronic chart can be conducted analytically on the surface of the reference ellipsoid without any graphical work on the nautical chart, as it is done in traditional navigation. Therefore, in electronic navigation the use of the mercator and the gnomonic projections is not indispensable and consequently it is possible to identify alternative map projections providing better visualization (Pallikaris and Tsoulos 2010).

Figure 1. Poor visual perception in Electronic Chart Display and Information System due to the automatic selection of map projections

The possibility to adopt alternative map projections has been utilized from the evolution of the first commercial ECDIS systems in the 90’s and is continuing up to nowadays. In the span of the seventeen years from the 1st edition of the IMO performance standards for ECDIS (IMO 1996) and despite the fact that these standards as well as the revised ones (IMO 2006) do not provide for specific requirements or recommendations on the use of map projections, many commercial ECDIS products have employed map projections, other than the mercator and gnomonic.
Most of the early ECDIS and ECS systems in the 90’s used one map projection only “the plate carré”. Subsequent systems (mainly in the period 2000 – 2005) provided the opportunity to manually select the desired projection between a limited number of cylindrical and azimuthal map projections such as: plate carré, mercator, gnomonic, orthographic, stereographic. In some new systems the selection of the proper projection is conducted automatically between only two map projections: the mercator and the azimuthal stereographic. Nevertheless the automatic selection of map projections in these systems may in some cases cause poor visual perception and misinterpretations, as those shown in figure 1. Some ECDIS systems employ map projections that cannot depict polar areas. This deficiency can be overcome by the selection of a suitable map projection for very high latitudes (the Arctic).

3. Criteria and methodology for the selection of map projections in the conducted study

3.1. Generic criteria and methodology for the selection of map projections

In conventional cartography the selection of the proper map projection is accomplished according to various criteria that can be classified into the following three categories:

- **Quantitative criteria for the assessment of the linear, angular and area distortions.** These distortions can be initially evaluated through distortion ellipses and analyzed by the calculation of distortion and the plotting of relevant distortion isolines. Other specialized quantitative criteria and tools can be also used, such as: the Airy least square criterion and its variations and the Chebychev theorem and its variation (Bugayevskiy and Snyder 1995, Maling 1973, Snyder 1984) etc.

- **Qualitative criteria such as perception of the shape of the earth, representation of the pole as a point or a line, shape of parallels and meridians, continuity, symmetry, eumormism,** etc. (Bugayevskiy and Snyder 1995, Pearson 1990, Delmelle 2001).

- **Combined quantitative and qualitative criteria.** Quantitative criteria have been extensively used in conventional cartography for the minimization and optimization of distortion to values that provide optimum results for cartometry (direct measurement of distances, angles and areas on the map or chart). Depending on the requirements of the application, the use of the proper quantitative criteria lead to the identification of existing map projections, or to the development of new map projections, with the desired characteristics such as “conformality”, “equivalency”, or “equidistance”. Conformality is the property of map projections to depict directions correctly (projections with zero angle distortion). Equivalency is the property of map projections to depict areas correctly (projections with zero area distortion). Equidistance is the property of map projections to depict distances correctly (projections with zero linear distortion). “Conformality” and “Equivalency” are two essential but mutually inconsistent properties. There is no projection that is both conformal and equivalent. There is no real equidistant map projection preserving distances in all directions. Equidistance is possible only in certain directions, normally along the meridian(s) or parallel(s). A lot of quantitative criteria have been developed for the evaluation of conformality, equivalency and equidistance. Grafarend and Krumm (2006) present more than twenty such criteria.

In traditional cartography, qualitative criteria are mainly used for the selection of map projections for world maps and atlases in order to provide better representation of the reality, or in order to retain some special properties, such as: orthogonality of graticule lines, graticule equidistance, the manner of representing the poles (as points or as lines), the relative length of the equator, central meridian and poles (if the poles are represented as lines); visual perception of the projection in terms of how spherical it appears etc. (Bugayevskiy and Snyder 1995 p 235-237).

In GIS applications the selection of map projections has the advantage that there are not strict requirements for conformality, equivalency or equidistance, as in many applications of traditional cartography where the map or chart is used for direct measurements of angles, distances, or areas. In GIS applications these measurements can be conducted through direct access to and processing of the geospatial database of the system and not necessarily by graphical measurements on the map. It is therefore possible to select map projections in a more flexible way seeking best visualization results. Nevertheless, it appears that in GIS environments including ECDIS map projections are often used without rigorous selection criteria, and not as a result of relevant research for each application. (Pallikaris 2010, IHO/AHC 2011).

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1. The name eumorphism connotes approximate true shapes of continents (Delmelle 2001). Although it is possible to obtain true shapes at a local scale through conformal projections, it is impossible to obtain true shape representation of landmasses in world maps.
The quantitative criteria of analytical cartography, depending on the requirements of a particular application, provide solutions for conformality, equivalency, or equidistance along a particular direction. The qualitative criteria provide best solutions for other desired properties such as the shape of orthodromes (Great Circles-GCs) and loxodromes (Rhumb lines RLs) on the projection.

The criteria used in the conducted research for the restriction of visual distortion to no noticeable limits over extended geographical and the fulfillment of other specific requirements for marine navigation are a combination of quantitative and qualitative criteria.

3.2. Basic principles for the selection of map projections in ECDIS and other e-Nav systems

In the conducted research the determination of specific selection criteria of map projections for e-Nav applications has been based on the following principles and requirements:

i. In ECDIS it is not imperative to use specific map projections for direct measurements of distances, directions and areas on the displayed chart or map.

ii. The set of map projections that will be finally proposed should not consist of a big number of map projections (less than 10) in order to avoid complicated and impractical selection/implementation rules.

iii. Due to the dynamic feature of e-Nav applications the employed map projections must have direct and inverse map transformation formulas allowing the convenient dynamic parameterization of the map projection.

iv. In ECDIS, map projections can be dynamically parameterized and calculated so that the central point or central line of the projection coincides or approximates the center of the area displayed on the screen in order to control the amount and the distribution of angular and area distortion to limits ensuring that no noticeable visual deformation is generated (§ 3.3.a).

v. The shape of Great Circles (GCs) and Rhumb Lines (RLs) should depict their basic true characteristics on the spherical/ellipsoidal surface of the earth (§3.3.b).

vi. The shape and pattern of the meridians and parallels should facilitate the importance for marine navigation “visual perception of the relative geographical location between any two points” (§ 3.3.e).

The conducted study focused on small scale applications, corresponding to “display ranges” larger than 200 nm, which for a typical 21 inch ECDIS screen corresponds to natural scales smaller than 1:2,350,000. For medium and large scales, according to numerical tests and evaluations conducted by Pallikaris (2010), Pearson (1992) and Maling (1973), different map projections provide practically the same visual results on the screen.

3.3. Specific criteria and parameters for the selection and evaluation of map projections in ECDIS

The selection and evaluation of map projections for e-Nav systems (ECDIS, ECS) has been conducted in accordance to the criteria of Table 1.

a. Criteria for the control of angle distortion and area distortion within limits ensuring minimum visual distortion

In the conducted study the calculation and the analysis of angle distortion and area distortion aimed at the control of visual distortion to non noticeable limits over extended geographical regions. Visual distortion depends on area and angle distortion. The tolerances for not noticeable visual distortion depend on the experience and the visual ability of the user. Average values are listed in Table 2.

Table 1. Basic criteria for the selection of map projections in ECDIS

<table>
<thead>
<tr>
<th>Criteria for the control of angle distortion and area distortion within limits ensuring minimum visual distortion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Criteria and parameters for the assessment of the shape of Great Circles (GCs) and Rhumb Lines (RLs)</td>
</tr>
<tr>
<td>2. Criteria for the desired shape and pattern of the graticule lines (meridians and parallels).</td>
</tr>
</tbody>
</table>

Table 2. Distortion values for reduced visual deformation [Bugayevskiy and Snyder 1995, Pallikaris 2010]

<table>
<thead>
<tr>
<th>kind of distortion</th>
<th>no visual distortion is noted</th>
<th>some visual distortion may be noted</th>
<th>some visual distortion is noted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area Distortion</td>
<td>up to ±(6-8)%</td>
<td>between ±(8 -10)%</td>
<td>between ±(10-12)%</td>
</tr>
<tr>
<td>Angle Distortion</td>
<td>up to 6°-8°</td>
<td>between 8°-10°</td>
<td>between 10°-12°</td>
</tr>
</tbody>
</table>

For the restriction of visual distortion over extended geographic areas, the tolerances of angle and area distortion have been initially set to 8° for angle distortion and 12% for area distortion. These tolerances have been intentionally set stricter for angle distortion than those for area distortion, since for marine navigation it is reasonable that conformality takes precedence over equivalency.

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2 According to the IMO standardization (IMO 2006) the scale of an electronic chart can be described by “natural scale” given as a ratio (e.g. 1:100,000) like in traditional paper charts, or by “display range” given in nautical miles like in radar (e.g. 3, 6, 12 or 24 nm). The display range (e.g. 6 nm) corresponds to the distance from the centre of the chart to the top and bottom edge of the screen.
b. The criteria of the shape of Great Circles (GCs) and Rhumb Lines (RLs)

For better portrayal of the reality in e-Nav systems the lines showing Orthodromes (Great Circles - GCs) have to be shorter than corresponding Loxodromes (Rhumb Lines - RLs). In addition GCs should preferably bend towards the equator and RLs towards the poles, as on the surface of the spherical or ellipsoidal earth.

In the conducted study the assessment of the proper shape of Orthodromes (GCs) and Loxodromes (RLs) has been based primarily on the calculation of the loxodromicity factor $\xi_L$ and the orthodromicity factor $\xi_\Omega$ (Fig.2), given by [1] and [2] (§ 6).

$$\xi_L = \frac{h_0}{L}$$  \hspace{1cm} [1]

$$\xi_\Omega = \frac{h_r}{L}$$  \hspace{1cm} [2]

Where:
- $L$ is the length of the straight line segment connecting the points of departure and destination on the projection.
- $h_0$ and $h_r$ are the maximum distances of the GC or the RL from the straight line segment connecting the points of departure and destination on the projection.

![Figure 2. Loxodromicity and Orthodromicity factors](image)

In e-Nav systems it is very useful to portray meridians and parallels as straight lines, intersected orthogonally. This property offers direct perception of the relative geographic location of any points appearing in the electronic chart.

Direct perception of the relative geographic location of any points is the ability to conclude for any point appearing on the screen if this point is located “to the north or to the south”, “to the east or to the west” of any other point on the screen. These conclusions should not depend on the portrayal of the parallels and meridians, since this portrayal is not always available in ECDIS. The implementation of map projections that do not satisfy the requirement for the shape and pattern of the meridians and parallels contains the risk of creating false impressions, as those in figure 1.

4. Determination of the initial set of map projections for potential use in e-nav applications.

According to the criteria and methodology outlined in Section 3 and the results of the comparative study of the basic characteristics of all kinds of map projections, as they are presented in the relevant bibliography [Snyder and Voxland 1989], [Delmelle 2001], [Capek 2001], [Pearson 1990], the eighteen map projections listed in Table 3 have been selected for further evaluation.

The initial assessment of the map projections of Table 3 has been based on the construction of special maps for each projection showing distortion ellipses, orthodromes (Great Circles - GCs) and Loxodromes (Rhumb Lines - RLs), such as those shown in figure 3. The eighteen map projections of Table 3 have been also evaluated against the simplicity of map projection equations in order to provide convenience in the incorporation into any GIS application. As a result of this initial assessment the thirteen map projections of Table 4 have been selected for further analytical evaluation.

<table>
<thead>
<tr>
<th>Cylindric</th>
<th>Conical</th>
<th>Azimuthal</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercator</td>
<td>Conformal</td>
<td>Gnomonic Orthographic</td>
<td>Robinson</td>
</tr>
<tr>
<td>Plate Carré</td>
<td>Equivalent (equal area)</td>
<td>Conformal</td>
<td>Loximuthal</td>
</tr>
<tr>
<td>Cylindrical equidistant</td>
<td>Equivalent (equal area)</td>
<td>Conformal</td>
<td></td>
</tr>
<tr>
<td>Miller</td>
<td>Equivalent (equal area)</td>
<td>Conformal</td>
<td></td>
</tr>
<tr>
<td>Miller modified</td>
<td>Equivalent (equal area)</td>
<td>Conformal</td>
<td></td>
</tr>
<tr>
<td>Cylindrical Sterographic/Braun</td>
<td>Equivalent (equal area)</td>
<td>Conformal</td>
<td></td>
</tr>
<tr>
<td>Cylindrical Sterographic/Gall</td>
<td>Equivalent (equal area)</td>
<td>Conformal</td>
<td></td>
</tr>
</tbody>
</table>

* BASM: Bol’soy Sovetskiy Atlas Mira cylindric projection (Cylindrical stereographic at 30°)

<table>
<thead>
<tr>
<th>Cylindric</th>
<th>Conical</th>
<th>Azimuthal</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercator,</td>
<td>Conformal</td>
<td>Conformal</td>
<td>Loximuthal</td>
</tr>
<tr>
<td>Plate Carre,</td>
<td>Equivalent</td>
<td>Conformal</td>
<td></td>
</tr>
<tr>
<td>Equidistant,</td>
<td>Equivalent</td>
<td>Conformal</td>
<td></td>
</tr>
<tr>
<td>Miller</td>
<td>Equivalent</td>
<td>Conformal</td>
<td></td>
</tr>
<tr>
<td>Miller modified</td>
<td>Equivalent</td>
<td>Conformal</td>
<td></td>
</tr>
<tr>
<td>Cylindrical Sterographic/ Gall</td>
<td>Equivalent</td>
<td>Conformal</td>
<td></td>
</tr>
<tr>
<td>Cylindrical Sterographic /BASM</td>
<td>Equivalent</td>
<td>Conformal</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Map projections selected for further analytical evaluation
5. Distortion analysis.

The distortion analysis of the map projections of Table 4 has been conducted by:
- The calculation of “angle distortions” and “area distortions” for each projection and the construction of relevant plots, such as those shown in figure 4.
- The construction of special maps showing isolines of area and angular distortions for each projection, such as those shown in figures 5 and 6.

The analysis of distortion distribution according to the tolerances of 8° for angle distortion and 12% for area distortion that have been set in section 3 (§ 3.3.a), showed that:
- For the restriction of visual distortion over extended geographical regions, the evaluated map projections have different visual distortion characteristics in the geographic areas of the latitude zones of Table 5 instead of the areas of low, medium and high latitudes \([\phi \leq 30^\circ], (30^\circ < \phi \leq 60^\circ), (60^\circ \leq \phi \leq 90^\circ)\] that are normally suggested for the initial evaluation of map projections in the standard bibliography (Iliffe 2000, Pearson 1990, Snyder 1987, Maling 1973).
- Nine of the thirteen projections of Table 4 have values of angular and area distortion within the accepted levels over extended geographical areas. These nine map projections are listed in Table 6.
- The determination of the geographic areas over which the map projections of Table 6 have distortion values within the accepted tolerances, depends on the location of the central line, or the central point of each projection.

The basic features of the distortion distribution of the nine map projections of Table 6 are presented below.

The Mercator modified projection at latitude 15° has zero angle distortions and retains area distortions within limits ensuring reduced visual distortion over extended geographic areas of latitudes on the zone \([-24^\circ 24^\circ]\).

The Miller cylindrical modified projection at latitude 30° restricts considerably the great area distortions of the Mercator projection and concurrently retains the angle distortions to less than 8° in order to avoid visually detectable angular distortions over extended geographic coverage of latitudes on the zone \([-59^\circ 59^\circ]\). The Miller cylindrical projection is normally used in the equatorial form. Nevertheless for the requirements of the conducted research, some modified versions of this projection have been also evaluated. These modified versions of the Miller cylindrical projection have been derived according to the methodology for the derivation of formulas of projections on the ellipsoid suggested by Snyder (1978).

The Cylindrical Stereographic projection with standard parallels at [30° (BASM\(^3\) projection), retains reduced visual distortion over geographical areas of latitudes on the zone \([24^\circ 37^\circ]\).

The Cylindrical Stereographic projection with standard parallels at 45° (Gall cylindrical projection) retains reduced visual distortion over geographical areas of latitudes on the zone \([37^\circ 49^\circ]\).

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[^3]: BASM: Bol’soy Sovetskiy Atlas Mira cylindric projection
The Conical conformal with standard parallels at $\phi_1=40^\circ$ and $\phi_2=80^\circ$ has zero angle distortions and retains area distortions within no visually detectable values ($\leq 8\%$) over extended geographic areas of latitudes on the zone $[28^\circ, 83^\circ]$.

The azimuthal equidistant projection provides the best results in terms of the control of the distribution of distortion to no visually detectable values, over extended ocean regions. This projection retains area distortions within no visually detectable values ($\leq 8\%$) over extended geographic areas of angular distances of $36^\circ$ from the central point. Angle distortions are retained within no visually detectable values ($\leq 8^\circ$) over extended geographic areas of angular distances of $52^\circ$ from the central point.

The loximuthal projection, compared to other pseudo-cylindrical projections, provides the best compromise between restriction of visual distortion, desired shape and pattern of graticule lines, and simple map projection equations providing convenience in the incorporation into any GIS application.

The nine map projections of Table 6 that have been selected as the result of the conducted distortion analysis, have been further evaluated for potential use in e-Nav systems against the specific requirements for marine navigation as they are set in section 3 (§3.3.b, § 3.3.c). The results of this evaluation are presented in the following section 6.

Table 5: Geographical areas for the evaluation of Map projections

<table>
<thead>
<tr>
<th></th>
<th>Geographical areas for the evaluation of Map projections</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Geographical areas of latitude on the zone [-24°, 24°]</td>
</tr>
<tr>
<td>2</td>
<td>Geographical areas of latitude on the zone (24°, 37°]</td>
</tr>
<tr>
<td></td>
<td>north or south</td>
</tr>
<tr>
<td>3</td>
<td>Geographical areas of latitude on the zone (37°, 49°]</td>
</tr>
<tr>
<td></td>
<td>north or south</td>
</tr>
<tr>
<td>4</td>
<td>Geographical areas of latitude other than above and</td>
</tr>
<tr>
<td></td>
<td>coverage less than a hemishere</td>
</tr>
<tr>
<td>5</td>
<td>Hemishere coverage</td>
</tr>
<tr>
<td>6</td>
<td>Worldwide coverage</td>
</tr>
</tbody>
</table>
Figure 5. Area distortion isolines in selected map projections


The evaluation of the nine map projections of Table 6 for potential use in e-Nav systems (ECDIS, ECS) has been conducted by:

- The assessment of the shape of Great Circles (GCs) and Rhumb Lines (RLs) by the calculation of the orthodromicity and loxodromicity factors for selected long navigational paths. The criterion was that preferred projections are those in which the orthodromicity factor is smaller than the loxodromicity factor (§ 3.3.b).

- The final assessment of the criteria of Table 1 as a whole set, taking into consideration that some of the criteria cannot be met simultaneously, as in the case of the desired shape of “meridians and parallels” and the shape of “Great Circles (GCs) and Rhumb Lines (RLs)”.

Table 6: Map projections providing reduced visual distortion over extended geographical areas

<table>
<thead>
<tr>
<th>Cylindric</th>
<th>Conical</th>
<th>Azimuthal</th>
<th>Pseudocylindric</th>
</tr>
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<tbody>
<tr>
<td>Mercator modified</td>
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<td>Equidistant</td>
<td>Loximuthal</td>
</tr>
<tr>
<td>Miller modified</td>
<td>Equivalent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cylindric Sterographic/Gall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cylindric Sterographic / BASM</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6. Angle distortion isolines in selected map projections
The calculations of the loxodromicity and orthodromicity factors have been conducted on the eight standard routes (baselines) that have been repeatedly used for the comparison of calculations of shortest navigational paths in various studies, as they are summarized by Pallikaris and Latsas (2009). The initial and final points of these eight baselines lie on the successive parallels 10°, 20°, 80° and all of them have the same difference of longitude equal to 100°. For better visual perception, these eight routes have been mapped over the geographical area of the Pacific Ocean (Fig. 7). The results of the calculations of the loxodromicity and orthodromicity factors of these trial routes are shown in figure 8.

**Figure 7. Baselines for the assessment of the shape of GCs and RLs**

The results of the final evaluation of the nine map projections of Table 6 for potential use in e-Nav systems has been conducted in accordance to the criteria of Table 3 and showed that:

- The map projections that satisfy the whole set of the selection criteria of section 3 in the best possible degree and consequently can be used in ECDIS and in other e-Nav systems are listed in Table 7.
- The map projections that satisfy the requirements for reduced visual distortion over extended geographical areas and consequently are proposed for other GIS applications are those listed in Table 7.
- The proper choice between the map projections of Table 7 must be done according to specific selection rules based on the location and the extend of the area portrayed on the screen. These rules are presented in section 7.

### Table 7. Map projections proposed for use in e-Nav and other GIS applications

[The selection of the proper projection depends on the location and the extend of the area portrayed on the screen]

<table>
<thead>
<tr>
<th>Map projections</th>
<th>Proposed for</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercator modified at latitude 15°</td>
<td>√</td>
</tr>
<tr>
<td>Miller modified cylindrical at latitude 30°</td>
<td>√</td>
</tr>
<tr>
<td>Cylindrical Stereographic with standard parallels at 30° (BASM projection)</td>
<td>√</td>
</tr>
<tr>
<td>Cylindrical Stereographic with standard parallels at 45° (Gall projection)</td>
<td>√</td>
</tr>
<tr>
<td>Conical Conformal with standard parallels at φ₁=36° and φ₂=54°</td>
<td>√</td>
</tr>
<tr>
<td>Conical Equivalent with standard parallels at φ₁=40° and φ₂=80°</td>
<td>√</td>
</tr>
<tr>
<td>Conical Equidistant with standard parallels at φ₁=40° and φ₂=80°</td>
<td>√</td>
</tr>
<tr>
<td>Azimuthal Equidistant</td>
<td>√</td>
</tr>
<tr>
<td>Loximuthal</td>
<td>√</td>
</tr>
</tbody>
</table>

### 7. Rules for the selection of map projections in ECDIS and other GIS applications

The analysis of the results of the evaluation of the nine map projections of Table 7 showed that the choice of map projections in ECDIS and other MGIS applications over extended geographical areas, according to the tolerances for reduced visual distortion set in §3.3.a (8° for angle and 12% for area distortion) must be done according to the following rules.

#### 7.1. Map projections for Regional/Oceanic Coverage

i. When the location of the depicted on the screen geographic area corresponds to geographic areas of latitudes on the zone [-24° 24°], then the Mercator modified projection with standard parallel at φ₀=15° should be used.

ii. When the location of the geographic area depicted on the screen corresponds to geographic areas of latitudes on the zone [24° 37°], in north or south hemisphere, then the Cylindrical Stereographic projection with standard parallel at φ₀=30° (BASM projection) should be used.

iii. When the location of the geographic area depicted on the screen corresponds to geographic areas of latitudes on the zone [37° 49°], in north or south hemisphere, then the Cylindrical Stereographic projection with standard parallel at φ₀=45° (Gall cylindrical projection) should be used.
Figure 8. Assessment of the shape of GCs (Orthodromes) and RLs (Loxodromes)

- i. Geodesic (dashed lines) and RLs (solid lines)
- ii. Conical Equidistant Projection with standard parallels at $\phi = 40^\circ$ and $\phi = 80^\circ$
- iii. Plots of Loxodromicity and Orthodromicity factors

<table>
<thead>
<tr>
<th>$\phi$</th>
<th>Loxodromicity and Orthodromicity factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>10°</td>
<td>0.099, 0.191</td>
</tr>
<tr>
<td>20°</td>
<td>-0.006, 0.189</td>
</tr>
<tr>
<td>30°</td>
<td>-0.0048, 0.184</td>
</tr>
<tr>
<td>40°</td>
<td>-0.0012, 0.190</td>
</tr>
<tr>
<td>50°</td>
<td>0.0015, 0.192</td>
</tr>
<tr>
<td>60°</td>
<td>0.0057, 0.193</td>
</tr>
<tr>
<td>70°</td>
<td>0.034, 0.172</td>
</tr>
</tbody>
</table>

Note: The table values indicate the orthodromicity and loxodromicity factors at various latitudes.
iv. For coverage less than a hemisphere and for geographical areas within latitude limits other than those mentioned in the above cases i, ii and iii, the azimuthal equidistant projection with central point selected on the basis of the limits (outline) of the area should be used. Nevertheless in most cases, zero or little visual distortion over extended geographical areas can be achieved if the central point of the azimuthal equidistant projection is selected as follows:

- For the depiction of geographical areas with approximately the same extend of latitude in either hemisphere the azimuthal equidistant equatorial (central point at 0°) can be used.
- For the depiction of large ocean areas exceeding the parallel of 45°, the selection of the central point at latitude 15° provides very satisfactory results, as in the example of figure 5b for the depiction of the area of the North Atlantic Ocean.

7.2. Map projections for Coverage approximating a hemisphere

For e-Nav systems and coverage approximating a hemisphere, normally it is not possible to fulfill concurrently the requirements for the shape of GCs and RLs and the requirements for the desired shape and pattern of the graticule lines. If priority is given to the shape and pattern of the graticule, then the Miller Cylindrical modified projection at latitude 30° can be used. Otherwise if priority is given to the shape of Orhodromes (CLs) and Loxodromes (RLs), the azimuthal equidistant projection can be used.

7.3. Map projections for the Arctic

The expectation of increasing shipping in the Arctic in both easterly and westerly directions evolved the requirement for the identification of suitable map projections for navigation with ECDIS in very high latitudes [ARHC 2011]. Navigation with ECDIS in the Arctic needs some special consideration due to the following reasons.

- For some projections it is impossible to depict Polar Regions. Consequently some ECDIS systems that employ these projections cannot depict ENCs for the Arctic. This inefficiency has nothing to do with the structure and content of the ENCs, but is due only on the map projections employed by ECDIS.
- In the Arctic there is a very significant difference between Great Circle and Rhumb line sailing even for small sailing distances.
- In the Arctic the dynamic parameterization of map projection employed in many ECDIS systems and the subsequent orientation of the ENC may cause inconvenient changes in the geographical directional perspective (Fig 9).

Taking into consideration the abovementioned special conditions, the results of the conducted analysis showed that for navigation with ECDIS in the Arctic the projections that provide minimal visual distortion are the azimuthal equidistant and the azimuthal stereographic projections. The polar azimuthal equidistant projection provides zero or little visual distortion for areas extending from the pole down to the 75° parallel. The polar azimuthal stereographic projection provides zero or little visual distortion for areas extending from the pole down to the 82° parallel.

In order to avoid inconvenient changes of the directional perspective of the ENC, the central meridian of the polar azimuthal projection should be preferably set at longitudes 000° or 180° only [Fig 9a and 9c] instead of the longitude of the vessel’s current position, as in the normal practice for oceanic ship routing used in most ECDIS systems.

7.4. Map projections for Worldwide Coverage

For worldwide coverage and concurrent restriction of distortion in an extended geographical area the loximuthal projection should be used. The proper selection of the central point, as in the case of figure 6B for the restriction of angle distortion in the coasts of Africa, is vital.

7.5. Map projections for other than e-Nav applications

For other than Electronic navigation GIS applications, where only criteria for reduced visual distortion are applied, conical projections can be also used. In these cases depending on the requirements of each application (e.g. percentage of equivalency over conformality) the tolerances for reduced visual distortion set in §3.3.a may be modified accordingly. For the tolerances set in section 3 (8° for angle and 12% for area distortion), best results, in terms of the extent of the geographic region with reduced visual distortion, can be obtained in the following three cases.

- Conical Conformal with standard parallels at $\phi_1=36^\circ$ and $\phi_2=54^\circ$. This projection provides zero or minimum visual distortion between latitudes of 18° and 66°.
- Conical Equivalent with standard parallels at $\phi_1=40^\circ$ and $\phi_2=80^\circ$. This projection provides zero or minimum visual distortion between latitudes of 25° and 82°.
- Conical Equidistant with standard parallels at $\phi_1=40^\circ$ and $\phi_2=80^\circ$. This projection provides zero or minimum visual distortion between latitudes of 28° and 83°.

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8. Conclusions overview

Eighteen map projections have been initially selected for evaluation in order to identify those that provide reduced visual distortion for potential use in Electronic Navigation systems (ECDIS, ECS). The comparative study of the features and the calculation and analysis of the magnitude and the distribution of angle and area distortions of these projections showed that in e-Nav systems, as well as in other GIS applications, the use of map projections other than those commonly used can provide better visualization results. In addition the employment of proper map projections can overcome the inadequacy of some ECDIS systems to depict ENCs in very high latitudes.

The study focused on small scale applications (≤1:2,350,000). Map projections for medium and large scale applications are not proposed, since at these scales different map projections practically provide the same visual results.

Six map projections are proposed for optimum distribution of angle and area distortion ensuring reduced visual distortion in the ECDIS screen: Mercator modified at latitude 15°, Miller cylindrical modified at latitude 30°, Cylindrical Stereographic with standard parallels at latitude 30° (BASM projection), Cylindrical Stereographic with standard parallels at latitude 45° (Gall projection), Azimuthal Equidistant and the Loximuthal pseudo-cylindric projection.

If it is desirable to restrict the number of map projections that are used in ECDIS, only two projections can be used: i) The Miller cylindrical modified at latitude 30° and ii) The Azimuthal equidistant. These two projections provide better visualization results than the Mercator and the Azimuthal Stereographic that are used in many commercial systems.

In any case the choice of the proper map projection must be done according to specific selection rules based on the location and the extent of the area depicted on the screen.

For “hemisphere depiction” the azimuthal equidistant projection provides the best results in terms of the control of the distribution of angle distortion and area distortion to limits ensuring reduced visual distortion over extended ocean regions.

For “worldwide depiction” the loximuthal projection, compared to other pseudocylindrical projections, provides the best compromise between restriction of visual distortion, desired shape and pattern of graticule lines, and simple map projection equations providing convenience in the incorporation into any GIS application.

For navigation with ECDIS in the Arctic, the azimuthal equidistant projection and the azimuthal stereographic projection provide the best results for reduced visual distortion.

The proposed six map projections for use in ECDIS and e-Nav systems have been determined not only for the satisfaction of the requirement for the control of angle distortion and area distortion to values ensuring reduced visual distortion over extended geographical areas but also
for the satisfaction of additional requirements for the shape and the pattern of the graticule lines, and the shape of othodromes (CLS) and loxodromes (RLs).

Conical map projections have not been proposed because for small scale applications they do not fulfill satisfactory the requirements for the shape of GCs and RLs.

Despite the fact that the scope of the conducted study was the identification of suitable map projection for ECDIS, the basic results can be also applied to other than e-Nav GIS applications. Thus the following nine map projections can be used in other than marine navigation small scale GIS applications ($\leq 1:12,350,000$): Mercator modified at latitude 15°, Miller cylindrical modified at latitude 30°, Cylindrical Stereographic with standard parallel at 30° (BASM projection), Cylindrical Stereographic with standard parallels at 45° (Gall projection), Azimuthal Equidistant, Conical Conformal with standard parallels at $\pm 36^\circ$ and $\pm 54^\circ$, Conical Equivalent with standard parallels at $\pm 40^\circ$ and $\pm 80^\circ$, Conical Equidistant with standard parallels at $\pm 40^\circ$ and $\pm 80^\circ$ and the Loximuthal pseudocylindrical projection.

The selection of suitable map projections for marine GIS applications is not usually unique. Normally more than one map projections fulfill the requirements for a particular application. Depending on the main scope of the application, different or additional requirements may be determined which in turn result to more specialized selection rules, so that the set of the proposed map projections can be further reduced. In any case the choice of map projections for a particular application must be based not only on criteria for the restriction of visual distortion, but also on additional criteria based on the requirements for the particular application, as it has been done in the conducted research for the case of e-Nav systems (ECDIS, ECS).

References


Acknowledgements

The author would like to express his thanks to Dr. Mathias Jonas, Head of the Department of Nautical Hydrography of the Federal Maritime and Hydrographic Agency of Germany for his constructive comments on the initial version of the paper.

Dr. Jonas comments triggered the expansion of the article with the addition of a short presentation on the principles and suggestions for the selection of suitable map projections for navigation with ECDIS in the Arctic.

Biography of the author

Athanasios Pallikaris is associate professor at the Hellenic Naval Academy [HNA]. He holds a Phd from the National Technical University of Athens, a M.Sc. in Oceanography (Hydrography) from the Naval Postgraduate School/USA and a B.Sc. in Nautical Science from HNA. From 1979 to 2002, as an officer of the Hellenic Navy, he served 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. In 2002 he retired as Commodore and in 2003 has been elected member of the faculty of the HNA. He has served on a number of national and international committees and working groups on Hydrography, Cartography and Navigation. He is the author/co-author of a number of books and articles in Navigation and Hydrography. [e-mail: palikari@snd.edu.gr].
THE NEW IHO S-102 STANDARD
CHARTING A NEW FRONTIER FOR BATHYMETRY
By Ed Kuwalek (IIC Technologies), Louis Maltais (Canadian Hydrographic Service)*
& Marc Journault (CHS)*

Soundings and contours are the only official way data producers can push bathymetric information to the wide hydrographic community. The introduction of the S-102 standard for bathymetry will enable many possibilities within the community of bathymetry users. Liaising with the International Hydrographic Organization’s (IHO) Transfer Standard Maintenance and Application Development (TSMAD) Working Group, the Canadian Hydrographic Service (CHS) and the US Naval Oceanographic Office (NAVO) has led the development and practical testing of this revolutionary standard, officially called the Bathymetric Surface Product Specification S-102. In partnership with IIC Technologies, GeoNet Technologies, and CARIS, CHS created one of the first prototypes of S-102 datasets, using the CARIS Bathy DataBASE software suite. A portfolio of 86 high definition bathymetric charts was subsequently produced within a few weeks, successfully validating a specification that will potentially change the manipulation of bathymetric data we’ve known for years.

Les sondes et les isobathes constituent la seule manière officielle qu’ont les producteurs de données pour diffuser les informations bathymétriques à l’ensemble de la communauté hydrographique. L’introduction de la norme S-102 pour la bathymétrie offrira de nombreuses possibilités à la communauté des utilisateurs bathymétriques. Les liaisons avec le groupe de travail de l’Organisation hydrographique internationale (OHI) sur la maintenance et le développement d’applications de la norme de transfert (TSMAD), avec le Service hydrographique canadien (SHC) et avec le Service océanographique naval des USA ont conduit au développement et à la mise à l’essai de cette norme révolutionnaire, officiellement appelée Spécification de produit pour la bathymétrie surfacique, S-102. En partenariat avec IIC Technologies, GeoNet Technologies et CARIS, le SHC a créé l’un des premiers prototypes des ensembles de données de la S-102, à l’aide du logiciel Bathy DataBASE de CARIS. Un portefeuille contenant 86 cartes bathymétriques en haute définition a ensuite été produit dans les semaines qui ont suivi, validant avec succès une spécification qui modifiera potentiellement la manipulation des données bathymétriques connues depuis des années.

Los sondeos y las curvas de nivel son las únicas fuentes productoras de datos de forma oficial que pueden hacer llegar la información bathimétrica a la vasta comunidad hidrográfica. La introducción de la Norma S-102 para batimetría permitirá varias posibilidades en el seno de la comunidad de los usuarios de batimetría. La coordinación con el Grupo de Trabajo de la Organización Hidrográfica Internacional (OHI) sobre el Mantenimiento de la Norma de Transferencia y el Desarrollo de Aplicaciones (TSMAD), con el Servicio Hidrográfico Canadiense (SHC) y con el Servicio Oceanográfico de la Marina de EE.UU. (NAVO), ha guiado el desarrollo y las pruebas prácticas de esta norma revolucionaria, oficialmente denominada Especificación de Producto para la Batimetría de Superficie S-102. En asociación con IIC Technologies, GeoNet Technologies y con CARIS, el SHC creó uno de los primeros prototipos de las colecciones de datos de la S-102, utilizando la serie de programas informáticos “Bathy DataBASE” de CARIS. Un catálogo de 86 cartas bathimétricas de alta definición fue producido posteriormente en pocas semanas, validando con éxito una especificación que cambiará potencialmente la manipulación de los datos bathimétricos que hemos conocido durante años.
High Definition Grid Bathymetry (HDGB)

In shallow water, ship navigation and manoeuvring demands cautious decisions made with the best information available. In these circumstances, the most recent details of the seafloor are usually considered essential. A three dimensional "picture" of the bottom would provide this capability; this representation is referred to as High Definition Gridded Bathymetry (HDGB).

The grid bathymetry can be described as a Navigation Surface (Smith 2003) or a Digital Terrain Model (DTM) of the seafloor in the form of regular rectangular meshes. By its nature, the resolution or the density of bathymetric data collected usually varies according to the depth range and it would be contentious to assign a quantitative value to the term “high definition” for bathymetry. The context of HDGB used in this article is simply defined as a much higher resolution than what is available on the navigation charts. For the source bathymetry of a multibeam system, the resolution can be similar to the insonified footprint. For digitized legacy data, the resolution could be equivalent to field sheet density.

The existing tools used to process and manage bathymetric data can generate and combine grid datasets for chart compilation and contour generation. A bathymetric gridded dataset can also be a product by itself, created for different usages such as hydrodynamic modelling, spatial data analysis with GIS, coastal management with land DTM, or marine navigation.

To develop a HDGB product for navigation, CHS adopted a collaborative approach where navigators and software manufacturers were informed of the intentions and consulted for specifications of a future product. For the consultation, prototype datasets were produced and made available in a simple format for experimentation and trials. The work of the IHO TSMAD WG on the new Geospatial Standard for Hydrographic Data (S-100) (IHO 2010) was promising and CHS decided to use it. S-100 is a framework standard for the registration, maintenance and capture of hydrographic geospatial data and product specifications. It is a flexible standard, based on the international ISO 19000 series of geographic standards. CHS and NAVO worked together to draft and propose a product specification for grid bathymetry based on previous work done by the Open Hydrodynamic Surface group. The standard is named the Bathymetric Surface Product Specification and identified as S-102.

At the 3rd IHO Hydrographic Services and Standards Committee (HSSC) meeting in November 2011, the TSMAD WG invited the HSSC to approve the final draft of S-102 and instruct the IHB to submit it to IHO Member States for their endorsement. Subsequently, the IHO Circular Letter 10/2012, requested the Member States to review and consider the draft edition of S-102 which is available IHO website (www.iho.int). In April 2012, the S-102 product specification was adopted.

To partition HDGB coverage, allow unambiguous dataset exchange and to facilitate the updates, CHS intends to implement a systematic tiling scheme with three levels of resolution. Each tile is comprised of 1000 by 1000 grid cells. The level 1 (harbour) is 0.02º x 0.02º, level 2 (coastal) is 0.1º x 0.1º, and level 3 (overview) is 1º x 1º. For the low and mid latitudes, the orientation of the tiles fit the meridians and parallels with an origin based on a round number in latitude and longitude. Figure 1 shows an example of the tiling scheme.

Figure 1: Example of a level 2 (coastal) tiling scheme for the St. Lawrence River

Production of datasets for trials

In January 2011, CHS contracted IIC Technologies and GeoNet Technologies to produce a portfolio of 86 HDGB datasets based on the draft version of the IHO S-102 product specification. Developing a uniform, high definition bathymetric surface for the St. Lawrence River between the ports of Quebec and Montreal was the key goal for the project. As this was the first attempt to produce a large number of datasets based on this new product specification, the project provided an ideal opportunity to validate the feasibility of S-102 production in practice.

The main requirements for the portfolio included creating seamless data coverage with a final surface grid resolution of 0.0001º (approximately 8 metres) divided into 0.1º x 0.1º tiled datasets. The final bathymetric surface needed to be created by integrating a variety of source datasets available for the area. These ranged from sparse sounding sets to much higher resolution grid data for channels. ENC-derived high-water lines were included along with the corresponding drying spot values. The intention behind using all available source data was to integrate all information in a complete dataset, capable of significantly enhancing the information already available on the ENC cells. The project required the deliverables to be provided in multiple formats including CARIS Spatial Archive (CSAR), Bathymetric Attributed Grid (BAG) and 32-bit GeoTiff files to cater to a variety of potential end users.
The production processes consisted of four main stages:

i. source data assessment and preparation,
ii. point data processing,
iii. surface data integration and conflict resolution, and
iv. final product surface extraction and export.

For the first stage, all source data was assessed and prepared for production. CARIS S-57 Composer and BASE Editor were used to create all auxiliary components, such as the tiling scheme, coverage, and breakline vector layers. The same tools were also used to cut all data sources into individual data tiles to facilitate their efficient processing.

During stage two, the XYZ point data was loaded into BASE Editor and used to build a TIN model. This model was enhanced by the addition of the high-water-based breakline vector layer. Subsequently, a high resolution bathymetric surface was interpolated from the TIN models for each dataset.

In stage three, the additional high definition surface data available for channels was merged with the product surface data created in stage two. This was achieved by using rule-based conflict resolution tool available in BASE Editor.

For the final stage, the coverage polygon was used to extract the final product surface, effectively facilitating a complete river bank to river bank data coverage. CARIS BASE Editor was used to export CSAR and BAG deliverables and CARIS Easy View was used to export 32-bit GeoTiff rasters. Figure 2 illustrates the key stages of the data production process used during the project.

All project goals were successfully achieved and the required portfolio of 86 HDGB datasets was efficiently produced, confirming the feasibility of HDGB data production using the currently available CARIS production tools.

**Generation of S-102 Bathymetry Grids**

As described above, the interpolated grids from the point data are combined with the high definition grids from the ship channel to produce the final grids for each cell, in the CSAR format, which are then exported to the desired carrier format of the grid. The draft S-102 standard follows the principle of separating the “carrier” from the “content” which means that the encoding of the grids will be flexible. Following that principle, the CARIS software tools provide choices for export formats. At the time of this S-102 prototype work, the choices were:

- **32bit Floating Point GeoTIFF format.** This option for a carrier format is available from the GDAL open source library (www.gdal.org). The 32bit floating point option is used so that the depth values can be encoded without loss of precision.
- **BAG format.** At the time, the CARIS Bathy DataBase (BDB) v3.1 was supporting BAG v1.3. The support for BAG format is possible through the API provided by the Open Navigation Surface Working Group (www.opennavsurf.org) of which CARIS is a participant. Since then, BDB has been updated to support BAG v1.4. CARIS is currently working with the ONSWG on BAG v1.5, which will be supported when finalized and released.

![Figure 2: S-102 Production Process – Stages (i) to (iv)](image-url)
Metadata
Adjusting this production line to match the coming S-102 standard is going to require the creation of metadata that is compliant with the S-102 profile. The details of the S-102 metadata profile are still being developed but many aspects of the content are already known. Fortunately, this area has received significant attention over the past two years at CARIS with the creation of the metadata profile for the CSAR format that is compliant with the ISO 19115 / 19115-2 standards and using XML encoding from ISO 19139. Drafts of the S-102 standard indicate that its metadata profile will share many of the same elements that are already being populated in exported CSAR metadata XML files.

The draft of the S-102 metadata profile indicate that most of the core metadata elements in the profile, each of which will be identified as mandatory, conditional or optional, will be selected from these ISO 19115 metadata packages.

Evolution of CARIS BDB and S-102 Software Tools
Bathymetry management has improved lately. New tools will enable the use of scripts to automate some functions. S-102 when pushed to the maximum could be the source bathymetry layer that the hydrographer uses for chart compilation. Once new source data is validated and incorporated in the database, users will be able to automatically generate S-102 datasets. Having the S-102 dataset updated continuously opens new possibilities. Instead of manually combining different bathymetry sources, choosing resolution and defining other parameters, the S-102 dataset could be used to compile chart products, post on the web, and do considerably more than is possible now. With predefined grid resolution and extents, these new functions will be able to automatically update the S-102 datasets. This is a key element, especially for achieving a fast turnaround time from survey to bridge. The only manual intervention is to assess if the new information is valid. Once that is done, one can launch the scripts and moments later you are in a position where the S-102 dataset are fully updated and ready to be used in many ways.

S-102 Gridded Bathymetry on the Web
The CARIS web mapping solution, Spatial Fusion Enterprise (SFE), supports the discovery and dissemination of high definition bathymetry through the Internet using Open Geospatial Consortium (OGC) (www.opengeospatial.org) standard formats. S-102 bathymetric datasets residing in the CARIS BDB database as CSAR grids are requested by SFE through a specialized bathymetry web service. The CSAR format was designed with the optimization required for web distribution of this type of data in mind. OGC requests are made from any OGC-capable client. The SFE Server handles the OGC request and returns the relevant information residing in the bathymetry database. SFE currently supports the OGC Web Map Service (WMS), Web Map Tile Service (WMTS) or Web Coverage Service (WCS) for bathymetry data: it is the WCS that provides download capabilities for the grids including options for the format to be received from the download. Efficient browsing and simple query capabilities are increasingly being provided through the use of WMTS which is a variant on the traditional WMS protocol which chunks data into image tiles. These tiles are cached on initial draw so that the next time an image request is made, the tile is drawn from cache rather than going back to the database – a much faster method to display the results.

Use of S-102 for navigation
With S-102 it will be easy for hydrographers to quickly provide navigators with HDGB data sets to enrich and update the information of their ENC’s. Partitioned into standardised geographic cells, the provision of updates also becomes easier: an entire new cell with the new bathymetry can be supplied which supersedes the previous tile.

One possible way to implement HDGB for navigation use is to add the S-102 data in the background, overlapping the S-101 data but without the display of S-101 soundings, depth areas and contours. Figure 3 shows such usage.

Figure 3: Filtered ENC and S-102 in background.
However, electronic chart systems can do more than just display the data. The HDGB can be used to:

- generate safety contour on the fly;
- compute the available water column by the addition of water level (tidal data) on top of the bathymetry; and calculate a dynamic under keel clearance, etc.

The exploitation of HDGB in an innovative way is left to the users and the software industry. CHS and its partners wish to involve them at an early stage of design to consider feedback from the user communities.

Getting ECS and ECDIS manufacturers on board

The upstream work is done. The method to generate S-102 data efficiently is known and at a speed that is impossible to achieve using traditional methods. S-102 will be the fastest way to provide new bathymetric information to the mariner - not just the notices to shipping, but the complete survey coverage that was done by the survey vessel. Before S-102 adoption by the IHO, manufacturers were shy to jump into development. The product specification has been adopted recently and it is time for the manufacturers to get on-board with S-102. Many of the functions that hydrographers use in their professional acquisition survey software will end up in ECS and ECDIS. Displaying grids and applying water levels in real-time are critical functions that have been used in survey software for years and should now be available with the software used by mariners. Navigation is so tight these days with ever increasing vessel size that mariners need those functions to make well informed navigation decisions.

Ship bridge simulators

When the prototype dataset was ready, data was offered to a navigation simulator center. No clear direction was given on how to use the data. As a first step, the simulation center decided to replace the bathymetry model of the simulator with the S-102 dataset. The previous model was based on traditional contours so they realized that using S-102 would be beneficial to their simulator, improving the quality of the overall simulation. Simulation centers are the ideal way to test how S-102 can be integrated on the ship’s bridge. ECS and ECDIS manufacturers could propose displays and functions that would be tested in these simulation centers to evaluate how this information could be portrayed to improve safety of navigation. Simulator work is a new tool available to speed up development on the manufacturer side.

Conclusion

The IHO S-100 framework standard represents a step foreword for electronic navigation products and services. This flexible standard is a building block to rethink the way hydrographic offices (HO) can deliver their official data and services. This ongoing S-102 experiment clearly shows how modern tools and standards enable quick delivery of rich bathymetric information. Work on the manufacturer side needs to start and some early discussions are progressing.

When mariners start working with S-102, they will experience a level of detail for bathymetry never seen before. We need to work with that community of users because they have a need for better information and will put pressure on manufacturers for development. Using the latest technologies available from CARIS (BDB and SFE) we will work at implementing the efficient updating and distribution of S-102. Easy access and updating is critical if we want users to work with the latest and best available information.

Biography of the Authors

**Louis Maltais** has been for the Canadian Hydrographic Service (CHS) for 13 years. He is involved in numerous R&D projects, implementing solutions to improve productivity, efficiencies and better meet the clients’ needs. [Louis.Maltais@dfo-mpo.gc.ca](mailto:Louis.Maltais@dfo-mpo.gc.ca)

**Marc Journault** has been for the Canadian Hydrographic Service for 28 years. He is manager of the Quebec region’s Marine Geomatics Division, responsible for technological support and development in the fields of hydrographic surveys, nautical publications and marine services. [Marc.Journault@dfo-mpo.gc.ca](mailto:Marc.Journault@dfo-mpo.gc.ca)

**Ed Kuwalek** is the Director of R&D at IIC Technologies in North Vancouver, Canada. Mr. Kuwalek has 18 years of experience in the field of nautical charting, electronic-chart production systems, and spatial data conversions. He has been involved in the technical leadership of many industry-leading projects and is an active participant in the IHO Transfer Standard Maintenance and Application Development (TSMAD) Working Group. [edward.kuwalek@iictechnologies.com](mailto:edward.kuwalek@iictechnologies.com)

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POTENTIALLY POLLUTING MARINE SITES GEODB:
AN S-100 GEOSPATIAL DATABASE AS AN EFFECTIVE CONTRIBUTION TO THE PROTECTION OF THE MARINE ENVIRONMENT

By Giuseppe Masetti, Brian Calder and Lee Alexander
(Center for Coastal and Ocean Mapping & Joint Hydrographic Center)
University of New Hampshire

Abstract

Potentially Polluting Marine Sites (PPMS) are objects on, or areas of, the seabed that may release pollution in the future. A rationale for, and design of, a geospatial database to inventory and manipulate PPMS is presented. Built as an S-100 Product Specification, it is specified through human-readable UML diagrams and implemented through machine-readable GML files, and includes auxiliary information such as pollution-control resources and potentially vulnerable sites in order to support analyses of the core data. The design and some aspects of implementation are presented, along with metadata requirements and structure, and a perspective on potential uses of the database.

Résumé

Les sites marins potentiellement polluants (PPMS) sont des objets situés sur le fond marin, ou des zones du fond marin, qui sont susceptibles dans le futur de relâcher de la pollution. La raison d’être et la conception d’une base de données géospatiales visant à inventorier et à manipuler les PPMS sont présentés. Conçue en tant que spécification de produit de la S-100, elle est définie via des diagrammes UML lisibles par l’homme et mise en œuvre via des fichiers GML lisibles en machine, et elle inclut des renseignements auxiliaires, tels que les ressources anti-pollution et les sites potentiellement vulnérables, aux fins d’appuyer les analyses des données de base. La conception et certains aspects de la mise en œuvre sont présentés, en même temps que les exigences et la structure des métadonnées, et une perspective sur les utilisations potentielles de la base de données.

Resumen

Los sitios marinos potencialmente contaminantes (PPMS) son objetos o zonas de fondos marinos que pueden producir contaminación en el futuro. Se presenta un fundamento para y un diseño de una base de datos geoespacial para hacer un inventario y manipular los PPMS. Creada como una Especificación de Producto de la S-100, se especifica mediante un diagrama UML de fácil lectura y se implementa mediante ficheros GML (de maraje geográfico) legibles por máquinas, e incluye información auxiliar como recursos para controlar la contaminación y sitios potencialmente vulnerables, para apoyar los análisis de los datos fundamentales. Se presentan el diseño y algunos aspectos de la implementación, junto con los requisitos y la estructura de los metadatos, y una perspectiva sobre los posibles usos de la base de datos.
Introduction

The presence of marine sites that are potentially polluting represents an increasing threat to the marine environment together with ocean acidification, ballast water and introduced marine species.

These marine sites may contain various types of hazards, including fuel oil, hazardous cargo, military weapons or munitions carried by warships or delivered to dumping areas, abandoned wellheads, etc. Even if petroleum-based pollutants represent the main threats to the global marine environment, mercury and other toxic substances also represent hazards since, for instance, they can cause contamination of the food chain. Collectively, these sites can be referred to as Potentially Polluting Marine Sites (PPMS).

Independent of the specific type, each of these PPMS represents a potential source of pollution for the marine environment. Each site may release toxic components in amounts variable with the state of preservation. This state is a function of many factors: the period of submergence, building materials, exposure to wave motion, presence of marine organisms, damage at the time of sinking and any attempt at salvage or demolition, etc. (Macleod, 2002). All of these factors influence the marine corrosion that inexorably corrodes the iron and carbon steel of anthropogenic structures.

A mean value of the general corrosion rate varies from 0.05 to 0.1 mm per year (Macleod, 2010, Schumacher, 1979, Southwell et al., 1976). As a consequence, many shipwrecks from the Second World War (WWII) may start to spill their polluting content during the next two decades (Figure 1). Internal structures of ships are often considerably thinner than the external parts, however, and their collapse can lead to premature release of pollutants even if the main hull remains intact. Localized corrosion can cause perforation of tank walls and damage to internal pipes and valves so that recent shipwrecks may also start to leak their polluting content. Similarly, historic shipwrecks may spill pollutants much earlier than might otherwise be predicted.

Recent pollutant releases from PPMSs have resulted in significant impacts, including loss of marine life, economic impacts to coastal areas, and high costs to mitigate the effects. Events occurring throughout the world have led to an increased focus on the need to look proactively at the risks of oil and other pollutants being released from such submerged sources as shipwrecks, pipelines and dumping areas (Gertler et al., 2009, Michel et al., 2005). Furthermore, these events are related to the density of PPMSs in a particular area. For instance, the Mediterranean contains a high percentage of the world’s sunken vessels – about 5% – when compared with its dimension and the intrinsic environmental fragility of a closed basin. Often driven by the occurrence of an environmental disaster, there are around the world many national and regional databases with different structures that are variously related to PPMS. The idea here is to delineate common requirements for a global database that, standardizing the collection of information about these sites, may better monitor and also contribute to reducing these events.

Although International treaties forbid the dumping of toxic wastes and national administrations strictly control their transportation and disposal, the illegal sinking of ships carrying toxic and nuclear wastes is an increasing concern. For instance, there are reports that this is a lucrative activity for various organized crime groups (PAM, 2010).

The cooperation among countries for identifying all the existing PPMSs represents means for better monitoring the presence of new ones. In a resolution adopted in March 2011, the Parliamentary Assembly of the Council of Europe underlined that “without maps charting these risks, no accurate assessment of the threat can be made”. The final recommendations of the cited resolution for the member States are, among others, to “carry out systematic assessments of wrecks to identify any that pose a threat to the environment and keep them updated”, and to support research in this field (CoE, 2012).

The increasing availability of geospatial marine data provides both an opportunity and a challenge for hydrographic offices and environmental centers to contribute to...
the identification and risk assessment of various PPMS.

To adequately assess the environmental risk of these sites, relevant information must be efficiently collected and stored in a modern geo-database suitable for site inventory and geo-spatial analysis. Improved methods for the analysis and interchange of information on PPMS and threatened marine resources are also needed. Successfully managing information about such sites, and making it available for use and exchange in a uniform manner, is critical to effectively supporting a proactive approach to monitoring and remediation.

In particular, if a solution is to be effective, it must address three fundamental requirements:

- It must be generic enough to handle different types of potential polluters and auxiliary information;
- It must enable easy exchange and re-use of information; and,
- It must be standards-based to allow for ready adoption into available tools.

Shipwrecks are the most obvious, but by no means the only, source of pollution. For example, pipelines or abandoned wellheads can release pollutants, and old munitions or chemical weapons dumping sites are obvious risks to fishermen, divers and the local community. A successful database solution must be generic enough to represent various types of potential polluters, but do so in such a manner to allow specific analyses to be conducted that enable the site to be properly classified.

At the same time, the solution must support integrated thinking about how to plan for and respond to potential polluters. This was recognized by the International Maritime Organization recommendation “to develop regional co-operation on aerial and satellite surveillance” for problems (IMO, 2004). Gathering all relevant data in a sufficiently flexible database is one way of supporting this process.

Determining who is responsible for both the activities and cost of remediation after a polluting event if often complex, and may be exacerbated by national and international law. For example, it is generally held that shipwrecks continue to belong to their nation after they are sunk (Aznar-Gomez, 2010, Johnson, 2008), but it is unclear whether the owner is responsible for damages caused by pollution related to these wrecks. The U.S. Navy removed oil from the USS Mississinewa after a storm caused leakage of fuel (U.S. Navy, 2004) but asserted that this did not constitute a precedent (Guerin et al., 2010). It is likely that many events or potential events will include more than one actor, therefore, and exchange of information in a uniform manner is essential in timely appraisal and response (Woodward, 2008). Definition and adoption of a state-neutral database is therefore important in supporting the planning and response goals.

As a consequence of the requirement for interchange of information, it is inevitable that data related to PPMS are going to be used by different agencies across multiple software and hardware platforms. Although often dismissed as an implementation problem, it is important to consider requirements for compatibility and standardization when defining the structure of any putative database. In addition, while working within the constraint of a given standard often implies extra effort, this is rewarded by re-use of already available resources (e.g., feature catalogues) and can significantly improve rate of adoption in standard data manipulation packages such as desktop GIS systems. A practical (rather than merely efficient) solution for PPMS must therefore consider the requirement for a standards-based definition.

We propose in this article a model for the implementation of a PPMS geo-spatial database that attempts to satisfy all of these requirements. Drawing on previous example databases that were built parochially for specific purposes, core and extension requirements were extracted for a variety of potential polluters. This is further augmented by auxiliary information such as relevant resources (e.g., availability and location of pollution response equipment) and complementary information (e.g., sensitivities of coastlines to particular pollutants).

To ensure standards compatibility, the database was developed based on the International Hydrographic Organization’s S-100 approach (IHO, 2010), while providing generic descriptions of various potential polluters. It is defined through a UML description (to assist in clear documentation) and uses an XML-based schema to provide a GML-structured computer-translatable description of the model. This paper describes the basic structure of the model and its XML implementation, and concludes with the proposal of a possible efficient implementation for the data storage of a PPMS GeoDB.

Adoption of the S-100 Workflow

If a new data structure for managing PPMSs at a global level has to be created, the new IHO S-100 Universal Hydrographic Data Model represents its natural framework (Figure 2).
A principal reason for this is the potential to adopt into the developing data structure some of the geographic features already present in the existing S-100 Feature Concept Dictionaries. These features have been created for some of the incoming Product Specifications of the S-100 series, and it is part of S-100 to share structures among different products to promote application interoperability and data reusability. The PPMS GeoDB project integrates the existing IHO data elements with new features and new attributes, derived from different solutions already implemented in existing databases. These new elements will be collected into a dedicated domain of the Supplementary Feature Concept Dictionary, and they will become themselves available for future use by other S-100 Products.

As defined in IHO S-100, a Product Specification (PS) is “a description of all the features, attributes and relationships of a given application and their mapping to a dataset” (IHO 2010). A PS is different but related to metadata: while metadata describes how a dataset actually is, a data PS describes how it should be, focusing on the requirements. The proposed PPMS GeoDB PS conforms to the S-100 requirement to be a precise and human readable technical document that describes a particular geospatial data product for hydrographic requirements (IHO 2010). This includes machine readable files that define the structure (XML Application Schemas), and can be converted to a XML Product Specification.

An S-100 based workflow was used to create the PPMS GeoDB PS. Outputs included:

- Definition of a vector-only product.
- Selection of required features, feature attributes, and enumerates in existing IHO Data Dictionaries.
- Identification of some new features that will be submitted for inclusion in an IHO Supplemental Dictionary.

The defined features and attributes were then described in a Feature Catalogue, and geometry types required in the product were determined. New geometry types will not need to be added to the S-100 framework for the proposed PS.

At this point, it was possible to construct an Application Schema. The creation was conducted in two different but related ways: a Logical model, using a conceptual schema language, and a Physical model using an encoding specific language (XML Schema).

Data Structure

Evaluating the entities required in a PPMS database is complicated by the diversity of objects to be represented. However, some important work was previously conducted with the aim of cataloging shipwrecks by ocean/basin location. This includes the South Pacific Regional Environment Program (SPREP) (Talouli et al., 2009, SPREP, 2002, Monfils et al., 2006) and Barrett Project (Barrett, 2011), the Atlantic, Mediterranean and Indian Ocean (AMIO) database (Monfils, 2005), a Mediterranean area in the Development of European guidelines for Potentially Polluting shipwrecks (DEEPP) project in 2005 (Alcaro et al., 2007), a global International Oil Spill Conference (IOSC) study in 2005 (Michel et al., 2005), among others. Collectively, these have been analyzed in regard to the types of information that are fundamental for a PPMS GeoDB to inform the design outlines here. A similar approach for non-shipwreck PPMSs was more difficult to conduct since there is less in the literature about this type of information in an integrated environmental-risk framework (Overfield, 2005, Aichele, 2010).

The successful collection and integration of PPMS information requires some effort to ‘normalize’ and standardize the data based on recognized international standards. As recommended in S-100, the Unified Modeling Language (UML) was used to create conceptual models that are implementation-independent. Each UML model class (or attribute) equates to a data dictionary, or an entity (or element). The resulting UML model indicates how the data are logically organized. Some selected UML views, that are portions of the total abstract model, will be discussed in the remaining part of this section.

In the proposed PPMS GeoDB PS, any product has a root element instance of the Root class. This root element may be related by composition with three types of composite Feature Collections (Figure 3). Thus, each PPMS product may have 3 main types of feature collection:

![Figure 3 - Relationships of Root class. The GeoDB consists of zero or more collections of PPMS, resources and complementary information, as required by the applications for which it will be used. Note that each collection includes an unlimited number of features of common abstract type so that common methods can be applied that are usable on all features within the collection.](image-url)
The Potentially Polluting Marine Sites;

- The Marine Resources threatened by the PPMS; and

- Different types of Complementary Info that represent auxiliary information that may be useful to the different phases of the disaster management cycle (Figure 4).

Each of these main feature collections can have infinite instances of different basic feature collections. Further, each collection inherits from an abstract class in which are defined all the shared characteristics between the different features. This allows the definition of shared methods that can be applied to any derived feature type. Finally, each of these composite Feature Collections can have an unbounded number of basic Feature Collections.

This data structure presents a certain level of complexity. For instance, the entities to model the possible types of PPMS are heterogeneous: from submarines sunk during WWII to oil rigs (Figure 5). Since some of these entities are already present in a basic “safety-of-navigation” form in the IHO Registry, they are enriched with a series of new attributes and enumerations, mainly on the basis of the content of the existing databases previously reported and the classification proposed by a Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC, 2004). Similar to the feature collection level, the characteristics common to all the feature types have been efficiently grouped in a feature.

Figure 4 - The disaster management cycle. Used correctly, the PPMS GeoDB could provide key information at all stages of the cycle.

Figure 5 - Sub types and relative relationships of the AbstractPPMS class. All of the specializations of a PPMS derive from the Abstract class to allow common methods to be defined, but each specialized PPMS augments the resources maintained to provide information specific to the object being represented.
As an example, Figure 6 outlines attributes and relationships proposed for one of the PPMS types: the Potentially Polluting Shipwreck (PPSW) class. This class may have different optional attributes. Most are derived from the “hydro” domain - already present in the IHO Registry. The limited number of additional attributes will become part of a specific domain of the IHO Supplementary Dictionary.

![Diagram showing attributes of the PPSW class](image)

**Figure 6** - Attributes of the PPSW Class derived from the AbstractPPMSFeature Class. Note particularly the many-to-many relation between the SunkVessel and PPSW, expressing the possibility that any one SunkVessel might be attributed to a number of PPSWs (e.g., the same wreck reported in different locations), and that any one PPSW might be associated with any number of SunkVessel objects (e.g., a wreck of unknown or dubious provenance). This is typical of the complexity of a general representation of uncertain features such as that expressed in the PPMS GeoDB.

During the modeling process, many problems have been focused and solutions have been provided. For instance, a common problem with a shipwreck database is related to occasionally uncertain identification of the vessel sunk at a wreck site. For example, a wreck site can be associated with more than one vessel sunk in the area (Figure 7, top), or a sunken vessel can be associated to many possible wreck sites (Figure 7, middle). In some cases, a site inspection (e.g., by diver or ROV) is required to resolve uncertain associations (Figure 7, bottom). The many-to-many relationship between Sunk Vessels and PPSW classes is the solution adopted for this particular problem (Figure 6), since it allows for expression of the uncertain association of ships and sites.
Figure 7 - Examples of different possibilities of the many-to-many relationship between PPSW and SunkVessel classes. Many shipwrecks may be associated with one PPSW (top) if the provenance of the wreck is not known, while one shipwreck may be associated with many PPSWs (middle) if its location is uncertain. Typically, a one-to-one relationship (bottom) can only be determined if auxiliary resources are used to investigate the wreck and establish a positive identification. Since this last case is rare, the PPMS GeoDB must support the uncertainty represented by the many-to-many relationship.
Dumping areas are another selected entity due to the large quantities of live ammunition, mines, chemical warfare agents (CWA), and other explosives present in a large number of marine sites (Plunkett, 2003, Sato, 2010, Beddington and Kinloch, 2005). This situation is the result of the past conviction that the dumping of CWA at sea was the best disposal method rather than to store them or incinerate them (Overfield, 2005). Currently, an increasing number of injuries and problems related to these dangerous objects are being reported (Laurin, 1991, Simons, 2003). Although the position of a large proportion of these dumping sites is known, many problems come from the buoyancy of containers used to store the waste materials, and the difficulties for the local authorities to supervise the correct position during dumping operations.

Abandoned and exploratory wells also represent a threat for structural failure over time, and the Deepwater Horizon disaster recently highlighted the dangers related to oil rigs and offshore extraction of hydrocarbons (Orth, 2011). Even if this last event remains in the memory of public opinion, large platform accidents represent only a limited part of marine oil pollution (Fingas and Charles, 2001) when compared to periodic releases of water containing small amounts of oil from offshore oil installations (Espedal and Johannessen, 2000, Farmen et al., 2010). Having these represented in the proposed GeoDB allows for spatial analysis to correlate objects with satellite Synthetic Aperture Radar (SAR) or other remote sensing sensors to distinguish between slicks due to hydrocarbon release and natural phenomena (Brekke and Solberg, 2005).

Some additional data resources are required to enable useful products to be generated from the GeoDB. These include shoreline, archaeological sites, fishing areas/farms, marine sanctuaries, tourist installations, but are not necessarily ‘objects’ in the PPMS sense. As such, they are organized in two related groups: ResourcesCollection for marine resources directly or indirectly related to PPMSs, and ComplementaryInfoCollection for information auxiliary to the previous two entity clusters. Which of these entities have to be implemented is usually correlated to the applications that the database is called to answer. In fact, while for a simple inventorial aim the implementation of these entities may be simply ignored, a specialized application – as, for instance, oriented to risk assessment – will typically require them to be fully populated.

Metadata and Metadata Collections

A key element of the PPMS GeoDB is represented by the wide use of ISO 19100 Series Metadata, and the related S-100 profile currently in development (Figure 8).

In fact, the application schema alone is not always sufficient to grasp the meaning of the underlying data model: for instance, the labels identifying different entities may be ambiguous, and application-specific knowledge and semantic heterogeneities are common sources of misinterpretation (Maue and Schade, 2009). Misunderstanding and incorrectly using geographic data can be usually traced back to missing or unclear descriptions of their intended interpretation (Guarino, 1998).

Figure 8 - Sources for the metadata implementation of the PPMS GeoDB. Metadata that supports multiple levels of search and description (e.g., from presence of data to a specific detail of geospatial projection information) must be allowed to make best (and correct) use of the available data.
A typical activity for a PPMS GeoDB includes the discovery of relevant geospatial data, their pre-processing, the application of appropriate analysis methods, and finally rendering the results on a map. Most potential semantic conflicts during this workflow may appear if source data has not been sufficiently specified at the beginning.

A PPMS GeoDB, as with any geographic data set, is a description of the real world at some level of approximation and simplification. The metadata developed for a PPMS GeoDB fully documents this process, explaining the data limitations and the adopted assumptions. At the same time, metadata permits any potential user to better understand the data, evaluate the applicability for an intended aim and, thereafter, use the data correctly. Furthermore, metadata could be used by the same PPMS GeoDB producer for data management (storage, updating, etc.) and by any user for facilitating data discovery.

The PPMS GeoDB adopts the ISO 19115:2003 core metadata that represent a minimum number of metadata elements required to identify a dataset for catalogue purposes. Their duty is to answer the following four primary questions:

- **What**: Does a dataset on a specific topic exist?
- **Where**: For a specific place?
- **When**: For a specific period?
- **Who**: Who is a point of contact to learn about/order a dataset?

In addition to this core metadata, the following ISO 19115:2003 optional entity sets are implemented:

- **Discovery Metadata**, based on actual web metadata catalogues.
- **Quality Metadata**, extended for describing the risk assessment process adopted.

Along with these, the ISO 19115:2003 concepts of metadata hierarchy (three different levels of metadata), multilingual support (required for the international profile of the S-100 framework), and support files (to preserve usability) were also adopted. Furthermore, some complementary information collections are represented as collection of metadata (Figure 9). This unusual approach should permit an easier integration with other databases (providing a connection gate), and it should also limit wasteful and potentially dangerous data duplication.

### Physical implementation by Geography Markup Language

One important new feature provided by S-100 is the possibility for Product Specifications to adopt encodings different than the “ENC-traditional” format for information interchange (ISO 8211). In fact, the peculiarities of this latter format (e.g. the updating functionality and the minimal data volume) do not represent the best fit for many products other than ENC. Different encodings are available, and for several reasons the PPMS GeoDB has been defined using the Geography Markup Language (GML).

GML is an XML-encoding tag language defined by the Open Geospatial Consortium (OGC) to describe geographic objects (Lake, 2004).

Being built on the Extensible Mark-up Language (XML), it has some advantages of binary file formats (i.e., easy to understand by a computer, compact, the ability to add metadata), as well as some advantages of text files (i.e., universally interchangeable).

Since it is accepted by most industrial companies and research institutions, GML has become a de facto standard in spatial data processing and exchange. In 2007, version 3.2.1 became an ISO standard (ISO 19136). This ISO GML provides “[…] an open, vendor-neutral framework for the description of geographical application schemas for the transport and storage of geographic information in XML” (ISO, 2007). GML is one of the S-100 cited encodings, and the creation of a hydrographic community profile for GML has been recently proposed (TSMAD, 2012).
Other reasons for using GML include:
- It is an emerging standard;
- It is not a proprietary format;
- It offers wide interoperability with GIS and web applications; and
- Usability of the developed GML products by existing XML technologies.

A number of steps were followed to create several GML Application Schemas for a Potential Polluting Marine Sites GeoDB:
- Provide the declaration of a target namespace.
- Import the appropriate GML Core Schemas.
- Derive directly or indirectly all objects and object collections from the corresponding GML abstract types.
- Define properties (as global or local elements) for each object’s content model.
- Define attributes for all of these objects and properties.
- Define Metadata Schemas as a function of the schema -defined objects.

Since GML is a markup data format (i.e., data without instructions) and not a programming language, the application of any operation to the information stored has to be implemented in an application written in a suitable programming language. Thus, in order to apply some data validation and manipulation on GML document based on the PPMS GeoDB PS, a basic C++ application is being developed.

Commonly, a program working with data stored in an XML format adopts either the Document Object Model (DOM) or Simple API for XML (SAX) method. Both DOM and SAX work on a raw representation of the XML structure (elements, attributes, and text). Thus, the developer needs to write a substantial amount of bridging code to transform information encoded in XML to a representation more suitable for the application. For the PPMS GeoDB application, an alternative approach called XML Data Binding was used. This approach skips the raw representation of XML, and delivers the data in an object-oriented representation generated by a compiler from an XML schema (Surhone et al., 2010, Kolpackov, 2007). XML Data Binding is a more efficient way to handle the GML documents, given the complexity of the PPMS GeoDB Application Schemas.

A possible efficient implementation for data storage and query application

Even if the PPMS GeoDB PS does not mandate any particular data storage, we consider a possible implementation for storing and querying GML since it represents a key element in obtaining the full efficiency from this technology.

A pure XML database does not represent, at the moment, the best choice for the necessary expensive process in its adoption (Ahmad, 2011). It has also been debated whether XML can be effectively used as a database language, since it is best supporting other applications (Schewe, 2005). Thus, a database language for XML is needed, and relational database languages such as SQL represent one possible mature, widely used and scalable solution for storing and querying XML data, if not necessarily the best language.

As a consequence, mapping XML data into relational data represents a crucial step. This operation – called ‘shredding’ – maps XML data into rows and columns of a relational table. After that, the original queries translated into SQL queries can be applied, and their results are internally translated back to XML. Currently, there is no easy, automated, or free solution for this task. In fact, database vendors are currently building tools to assist in mapping XML documents into relational tables. But, since they are still competing with one another, a standard for the mapping method does not yet exist (Atay et al., 2007).

The mapping process is not an easy operation due to the intrinsic differences between an XML document and a relational database. A relational database stores the data into “flat” tables; while, in a XML document, the information has a hierarchical structure, with elements that may be nested and repeated. Thus, as a first approximation, an XML document can be represented as a tree, where data are the nodes and their relationships are represented by the edges. It is also evident that the structural constraint information represented by the XML Schema may represent a useful element in the creation of the mapping design.

Based on the above considerations, three possible approaches to the mapping were developed. A possible evaluation criterion for these approaches is the number of relation redundancies produced in the relational schema (since they could create anomaly problems).

1. One approach is model-based, and basically traverses the tree, storing the path for every node visited into a table (Bohannon et al., 2002, Qin et al., 2005, Yoshikawa et al., 2001). The main problem is that this splits the data into small pieces that must be joined, increasing the storage size and potentially creating a lot of duplications.

2. In the structural-based approach, the constraint information represented by the XML Schema (or XML DTD) is used as a key element in the creation of the mapping design (Florescu and Kossman, 1999, Lee and Chu, 2001, Shanmugasundaram et al., 1999). In this approach, system generated IDs (that is, “parentID” and “parentCODE”) are widely adopted, creating additional data and relation redundancy.
3. Another approach is semantic-based, and potentially without relation redundancies. However, some effort is required to capture the semantics of XML for mapping by keys, foreign keys, and functional dependencies (Liu et al., 2006, Atay et al., 2007, Lv and Yan, 2006).

The proposed PPMS GeoDB storage implementation is based on the third approach, mainly because its correct implementation permits the absence of relation redundancies that are wasteful in large databases. The implementation takes the advantages of the XML Data Bindings to store the PPMS GeoDB information into a dedicated relational database (Figure 10). The implementation of this approach is basically transparent for the user, since all the operation of validation, import, query and export are internally managed by the application interface.

Since the GML is not stored internally as XML, this structure is commonly called an XML-enabled database. The main reasons for the adoption of relational databases are:

- They are well known.
- They are widely used in the database industry.
- Users are largely familiar with them and with their performances.
- They are largely considered a safe choice by corporations.
- A producer could hesitate to switch suddenly to a new technology.

The above reasons reflect the current situation. But, with the likely development of XML native databases in the future, they could become the best fit for GML and thus also for the PPMS GeoDB.

Current/Future Applications

The PPMS GeoDB, developed in the S-100 framework, is a practical means of providing a geo-referenced picture of hazardous sites and related marine resources. Although the main target of the PPMS GeoDB Application is a PPMS inventory, its implementation can be a tool for each phase of the disaster management cycle: emergency response, recovery, development, mitigation, and preparedness (Figure 4). In addition, a risk index – representing an assessment of the magnitude of risk associated with any site – can be derived to determine the potential impacts of these PPMS using a GeoDB of this type (Masetti et al., 2012).

The impacts of natural or technological disasters can be prevented, or at least bounded, through an integrated approach to environmental risk assessment and safety management to identify the elements of risk and to prioritize actions (Fedra, 1998, Goodchild, 2010). While many studies are present in fields like floods, earthquakes and forest fires, a limited number are centered on the detection, study and analysis of risk from oil spill and other marine pollutants incidents (Castanedo et al., 2009, Kassomenos, 2004, Pincinato et al., 2009, Sofotassios et al., 1997). The information collected by the proposed PPMS GeoDB represents a contribution to this issue at global and sub-national scale; nevertheless the development of some tools and indicators structured on this product is desirable to better manage and monitor the risk of a large number of PPMSs.

The possibility to identify potential risks before the release of pollutants is a key element for a proactive approach. This approach could permit evaluation of each shipwreck site in order to decide on a direct intervention (i.e. the removal of the threat sources), the isolation of the threat, the preparation of a release management plan before the event, or the definition of a monitoring protocol, etc.

At the same time, a PPMS GeoDB permits inventory of possible assets and responders present in the area in case of a release notice. In the case of an unidentified source of oil (or any other pollutant) the PPMS GeoDB could return a list of suspected sites, possibly on the basis of the results from an analysis of oil samples recovered that permits determination of the type and age of the oil.

Because of different types of marine sites potentially dangerous to the marine environment, a PPMS GeoDB represents a better global solution to efficiently manage many PPMS-associated types of information. At the same time, the decision to develop an S-100 compliant Product Specification has the advantage of enabling a wide exchange of PPMS information. Furthermore, the proposed data structure – with the connection gates represented by the collections of metadata combined with the large adoption of existing IHO features and attributes – permits an easy integration with other existing HO’s databases.

The adoption of an S-100-compliant GeoDB standard can thus become an important global contribution from the hydrographic community to reduce or at least better manage environmental and economic risks related to Potentially Polluting Marine Sites.
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**Biography of the authors**

Giuseppe Masetti has served with Italian Navy since 1999 and, in 2008, received a Master in Marine Geomatics (University of Genoa, Italy).

After a period onboard the hydrographic vessel ITN Aretusa as Operation Officer, he achieved the FIG/IHO Category A certification.

In addition, he graduated (with honors) in Political Sciences in 2003 from the University of Pisa (Italy), and in Diplomatic and International Sciences in 2004 from the University of Trieste (Italy).

In 2010 he started a Ph.D. program in System Monitoring and Environmental Risk Management at University of Genoa.

At the Center for Coastal and Ocean Mapping he is studying Ocean Engineering mainly focusing on various issues related to the implementation of the new S-100 data model and the management of potentially polluting marine sites.

Brian Calder is an Associate Research Professor and Associate Director at the Center for Coastal and Ocean Mapping at the University of New Hampshire.

He has a Ph.D in Electrical and Electronic Engineering, completing his thesis on Bayesian methods in Sidescan Sonar processing in 1997. Since then he has worked on a number of signal processing problems, including real-time grain size analysis, seismic processing, and wave-field modeling for shallow seismic applications.

His research interests include methods for error modeling, propagation and visualization, and adaptive sonar backscatter modeling.

Dr. Calder is currently focusing on statistically robust automated data processing approaches and tracing uncertainty in hydrographic data.

Lee Alexander is a Research Associate Professor at the Center for Coastal and Ocean Mapping and Joint Hydrographic Center at the University of New Hampshire, and an Adjunct Professor at the University of New Brunswick (Canada).

Previously a Research Scientist with the U.S. Coast Guard, he was also a Visiting Scientist with the Canadian Hydrographic Service.

His area of expertise is applied RDT&E on electronic charting, international standards development, and the use of electronic charts for safety-of-navigation and marine environmental protection. He serves on several international committees and working groups dealing with electronic charting, including the International Hydrographic Organization, the International Electrotechnical Commission, and the International Association of Lighthouse Authorities.

In addition, he chairs the Harmonization Group on Marine Information Overlays (MIOs).

Dr. Alexander received his M.S. from the University of New Hampshire, and Ph.D. from Yale University in Natural Resource Management and is also a captain (now retired) in the U.S. Navy Reserve.
MARINE RESEARCH IN MODERN LAW OF THE SEA
LOSC and Reality

By Tilemachos Bourtzis and Gerasimos Rudotheatos
(European Centre for Environmental Research and Training, Department of International
and European Studies, Panteion University of Social and Political Sciences)

Abstract

Marine Research has proved to be one of the most controversial legal topics in terms of practice. While Law of the Sea Convention (LOSC) contains a special Part (XIII) on Marine Scientific Research, it fails to regulate topics of dual, ambiguous and/or evolving content. The current paper makes an inquiry into those topics (e.g. Military Surveys, Marine Archaeology, Remote Sensing) and tries to identify problems or gaps. These activities can have an extremely large footprint as they are connected with State and financial interests. The consequences of allowing marine research activities to proceed without solid rules could be grave. It is of extreme importance that each of the activities mentioned in this paper should have a clear set of rules of conduct.

Résumé

La recherche marine s’est révélée comme l’une des questions juridiques les plus controversées dans la pratique. Tandis que la Convention sur le droit de la mer contient une partie spéciale (XIII) sur la recherche scientifique marine, elle ne parvient pas à réglementer des questions dont le contenu est double, ambigu et/ou en évolution. Le présent article expose une investigation de ces sujets (par exemple les levés militaires, l’archéologie marine, la télédétection) et essaie d’identifier les problèmes ou les lacunes. Ces activités peuvent avoir des répercussions très importantes étant donné qu’elles sont liées à des intérêts nationaux et financiers. Le fait de permettre la poursuite des activités de recherche marine sans règles solides pourrait entraîner des conséquences graves. Il est extrêmement important que chacune des activités mentionnées dans le présent article devrait posséder un ensemble de règles de conduite claires.

Resumen

La Investigación Marina ha demostrado ser uno de los tópicos legales más polémicos en la práctica. Aunque la Convención de las Naciones Unidas sobre el Derecho del Mar (LOSC) contiene una Parte especial (la XIIIª) sobre Investigación Científica Marina, deja de regular tópicos relativos a un contenido doble, ambiguo y/o que evoluciona. El presente documento hace averiguaciones sobre estos temas (pe. Sondeos Militares, Arqueología Marina, Teledetección) e intenta identificar problemas o carencias. Estas actividades pueden tener un impacto extremadamente grande ya que están vinculadas a intereses estatales y financieros. Las consecuencias de permitir que las actividades de investigación marina avancen sin reglas sólidas podrían ser graves. Sería sumamente importante que cada una de las actividades mencionadas en este documento tuviese un conjunto de reglas de conducta.
A. Introductory Remarks

In the mid 19th century, mankind turned its scientific view on the marine environment. The first research activities were ocean observations, depth measurements, surveys for navigational purposes and placing submarine telegraphic cables and finally marine resources exploitation research (Wegelein, 2005). These main activities of marine research, despite technological advancements, largely remain unchanged even today.

As a result of State practice, by the period up to World War II, hydrographic surveying was considered as part of the freedom of navigation in the high seas, due to its importance for navigational safety. In this same period and due to the lack of State sovereignty beyond the territorial sea, scientists enjoyed the freedom to conduct marine research almost everywhere. Non living marine resources exploitation activities were, due to technical limitations, usually conducted in coastal areas inside the States’ territorial seas, which despite the lack of a common rule on their breadth, usually did not exceed a 3 nautical mile zone (Tsaltas & Kladi Efstathopoulou, 2003). Technological advancement and the mounting wartime needs for hydrocarbon fuel, eventually led to the creation of the concept of the continental shelf. This legitimized access to areas beyond the territorial sea (Roukounas, 2005).

The customary regime for marine research was depicted in the four Geneva Conventions on the Law of the Sea, most importantly on the Continental Shelf Convention and the Territorial Sea Convention. One major characteristic of the marine research regime codified in the 1958 Geneva Conventions, was (and still is) the distinction between basic and applied marine research (“pure marine research” and “natural resources exploitation regime”). Based on this distinction, coastal State’s consent for scientific purposes research would be granted easier than in the case of research for economic purposes (Tsaltas, 2003). As mentioned earlier, hydrographic surveys by that time were regarded as a part of the freedom of navigation and this was confirmed in the High Seas Convention. The same Convention affirmed the right of scientific research for all States in the high seas (United Nations Convention on the Continental Shelf, 1958, Art. 5.1 and 5.8 for the non interference with fundamental research activities).

However, the aforementioned right was misused and over exploited during the following years (the two most famous cases being the Pueblo and the Glomar Explorer incidents). The aforementioned conditions placed all types of marine research in focus, initially of the Sea Bed Committee (1970-1972) and later of the 3rd Conference on Law of the Sea (1973-1982, from now on UNCLOS). The Sea Bed Committee recognized the need to provide a distinction between basic and applied marine research but also noted the difficulty to do so (Soons, 1982; Wegelein, 2005). It was only after a very long and tenuous negotiation, that an agreement was finally met on the various marine research regimes. The final Law of the Sea Convention text provides 3 distinct regimes on marine research (Soons, 1982):

1. Marine Scientific Research Regime (MSR). LOSC Part XIII. Research regarding marine environment or other non commercial purposes.
2. Prospecting, Exploration and Exploitation Regime. LOSC Part XI and Agreement relating to Part XI of the Convention. Research regarding the exploitation of non living marine resources.

B. Marine Research in LOSC

The main characteristic of LOSC regulated marine research is the variation of status depending on the scope of the activity and the maritime zone. The consent regime for research has crept in ocean areas previously open to unconditional research, mainly through the adoption of Exclusive Economic Zones (EEZ). The following table

<table>
<thead>
<tr>
<th>Research Activity</th>
<th>Content and Specifications</th>
<th>Regime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine Scientific Research</td>
<td>Research regarding marine environment or other non commercial purposes / Consent Regime</td>
<td>Part XIII and specific articles dealing with maritime zones regulation</td>
</tr>
<tr>
<td>Exploration and Exploitation</td>
<td>Research regarding the exploitation of non living marine resources / Consent Regime</td>
<td>Part XI and implementation of Agreement relating to Part XI of the Convention and specific articles dealing with maritime zones regulation</td>
</tr>
<tr>
<td>Hydrographic Surveys</td>
<td>Surveys and mapping of sea and ocean floor for safety of navigation purposes</td>
<td>Articles 19(2)(j), 21(3)(g), 40 and 54</td>
</tr>
</tbody>
</table>

Table 1 – Marine Research Regimes according to LOSC

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1. See the Caracas Treaty between UK and Venezuela of 1942 for the Delimitation of the Continental Shelf in the Gulf of Paria and the Truman Declaration of September 28 1945 on the continental shelf, regarding the exclusive jurisdiction of the USA as to fishing and research exploitation activities up to the depth of 100 fathoms.
2. See the Caracas Treaty between UK and Venezuela of 1942 for the Delimitation of the Continental Shelf in the Gulf of Paria and the Truman Declaration of September 28 1945 on the continental shelf, regarding the exclusive jurisdiction of the USA as to fishing and research exploitation activities up to the depth of 100 fathoms.
3. As “pure marine research” was understood the study of the marine environment for non commercial scientific purposes, whereas commercially targeted research would come under the GCCS regulation as “natural resources exploitation regime”.
4. In the first case (which took place in 1968), USS Pueblo was boarded and captured by North Korean authorities under the accusation of spying while on North Korean territorial sea, whereas the crew claimed that the ship conducted routine research activities outside the North Korean territorial sea. In the second case (which took place in 1974), USNS Glomar Explorer while claiming to conduct research for mineral deposits, was actually proved to be searching for the Soviet submarine K-129 (sunk in 1968).
As a general rule, conduct of Marine Scientific Research (MSR) activities is subject to less strict regulation than the more economically crucial Exploration and Exploitation research. Hydrographic Surveys have contextually been dealt, as in previous codifications, as a non separate part, of the navigational freedom (Churchill & Lowe, 1999; Guilfoyle, 2009; Rothwell & Stephens, 2010), though it is true that State practice can often contest this approach, especially in the case of EEZ where LOSC is silent. The following table shows the regulatory jurisdiction of the three marine research regimes in each maritime zone.

<table>
<thead>
<tr>
<th>Maritime Zone</th>
<th>Marine Scientific Research</th>
<th>Exploration and Exploitation</th>
<th>Hydrographic Surveys</th>
</tr>
</thead>
<tbody>
<tr>
<td>Territorial Sea</td>
<td>Coastal State</td>
<td>Coastal State</td>
<td>Coastal State</td>
</tr>
<tr>
<td>Continental Shelf / Exclusive Economic Zone</td>
<td>Coastal State</td>
<td>Coastal State</td>
<td>LOSC: no reference / Varying State / Practice</td>
</tr>
<tr>
<td>High Seas</td>
<td>Flag State</td>
<td>Flag State</td>
<td>Flag State</td>
</tr>
<tr>
<td>International Seabed</td>
<td>Flag State / International Seabed Authority (responsibility to promote and encourage marine scientific research)</td>
<td>International Seabed Authority</td>
<td>Flag State</td>
</tr>
<tr>
<td>Archipelagic Waters / International Straits</td>
<td>Archipelagic / Ulltoral State</td>
<td>Archipelagic / Ulltoral State</td>
<td>Archipelagic / Ulltoral State</td>
</tr>
</tbody>
</table>

Table 2 – Marine Research Jurisdiction in Different Maritime Zones according to LOSC

It should be clear that in comparison to the 1958 Geneva Conventions, LOSC applies much stricter rules for marine research. Coastal States control research activities in very large areas created by EEZs and Extended Continental Shelves (which under conditions can stretch up to 350 nautical miles from baselines). In the beginning, these limitations caused much concern to scientists as to the disappearing right of research, but the up to date practice showed no serious hindrance. Generally, LOSC provisions are regarded as a genuine codification of customary rules, regarding the various research regimes and limitations within national jurisdiction maritime areas.

Certain disputes can be identified as to the exact nature of State rights in the EEZ regarding research. This is mainly due to the fact that the EEZ has not been a traditional maritime zone, leading to different interpretation theories as will be examined below. Especially difficult has been the adoption and implementation of LOSC articles on the International Seabed (or the Area). Developed States would not readily accept the sole right of International Seabed Authority to regulate the exploration and exploitation of non living resources of the Area. An objection strong enough to halt the entry into force of LOSC, until the signing of the 1994 Implementation Agreement.

Another serious issue that rose up during the UNCLOS negotiation was the difficulty to agree on definitions for the various research activities described. In the end a decision was made; the context of research activities would derive from the various regulatory articles (Soons, 1982). While this proved a useful decision at the time, it has started to cause problems as advancements on marine technology and contemporary international relations lead to possible abuse of the Convention regulations through ambiguous interpretations.

C. The Practical Application of LOSC on Marine Research Issues

It is quite clear that on the issue of marine research activities, LOSC tried to compromise two different trends. Traditional maritime powers, opting for the maximum possible freedom in world oceans, found themselves against the developing countries’ hopes for ocean resource fueled development. Not surprisingly, the majority of developing coastal, island and archipelagic States immediately declared their will to establish Exclusive Economic Zones, soon after the Convention’s adoption (Koh, 1987; Pardo, 1987). It’s also hardly surprising that the EEZ, as a newly inducted institution of the Law of the Sea and covering large parts of the ocean, causes the most problems relating to marine research.

Undeniably, the reality of marine research can be quite different from legal provisions. Two issues act as the major differing factors between the LOSC and State practice: the different approach and interpretation of LOSC regulation and the ambiguous regime of certain research activities, especially since these activities are a result of recent technological advancement.

a) Different Interpretation of Rules. The Liberal and Restrictive Approach.

Due to the ambiguous regulation on some fields of research activities, it is quite common to face contradicting interpretations. It must be noted here, that the LOSC regulation is generally accepted, even in cases of States that originally voted against it, such as the USA (Kotsina, 2008; Scott, 2004). The problem usually lies in the interpretation of articles. These are usually viewed through the national interest lens, differing from the actual content of regulation and aiming at greater coastal State control or in other cases greater freedom of action.
The most usual problem is found in the sphere of national legislation, particularly in the distinction between various research regimes. For example, in many countries the legislation regarding marine research, does not distinguish between MSR, Exploration for Ocean Resources and Hydrographic Surveys and in addition is older than the Convention (Churchill & Lowe, 1988; Gorina-Ysern, 2003). This can create dubious situations on the application of rules, especially in the EEZ's and in changing international and regional conditions.

Closely connected to the above, one can identify the issue of interpretation of LOSC by the various States. The two major tendencies can be identified as the restrictive and the liberal approach of LOSC. These tendencies are not very different from the stance that various States had during the UNCLOS negotiations, maritime powers being in support of the liberal stance and the developing countries supporting the restrictive one.

At this point, it is quite interesting to note that the liberal stance supporters, regard any activity not namely mentioned in LOSC as “free for all”, whereas the restrictive stance supporters regard it forbidden. This ambiguity will become clear in the cases that follow.

b) Contentious Research Regimes and Marine Research

Military Surveys

Military Surveys (or Military Data Gathering) are rightfully regarded as one of the most contentious issues in marine research and lately a source of tension, particularly between USA and China (Bateman, 2005). The major problem lies with the Convention’s total silence on warship activities and, in our case, with their conduct of marine research. This research can take the form of oceanographic research (focusing on the marine environment, similar in content to MSR) or hydrographic surveys (focusing on water properties and depth measurements similar to the LOSC hydrography).

The main areas of concern, regarding military research, are the Continental Shelf and EEZ, where the coastal State exercises jurisdictional rights but has no sovereignty. The liberal / restrictive debate has strong impact on military surveys and the concern these activities cause. USA and UK, as major maritime powers with strong blue water military fleets, champion the liberal approach on the subject, insisting that the lack of mentioning in LOSC places military surveying out of regulation. This viewpoint is strongly opposed in practice by China, Canada and Australia (Bateman, 2005).

The main argument in favour of free military surveying is, according to its supporters, the clear distinction between MSR and Hydrographic Surveys in LOSC articles 19, 21, 40, 54. By using these arguments, liberal supporters place military surveys under the freedom of navigation, on the same terms as hydrography, based on flag State sovereignty and warship immunities in areas beyond the Coastal State’s Territorial Sea. Based on this and on the fact that LOSC Part XIII doesn’t mention the term “survey”, their claim is that Marine Scientific Research consent regime cannot be applied in such cases.

The US Naval Commander’s Handbook defines military surveys as “…the collecting of marine data for military purposes and, whether classified or not, is generally not made publicly available. A military survey may include collection of oceanographic, hydrographic, marine geological, geophysical, chemical, biological, acoustic, and related data” (Department of the Navy, 2007). The UK Navy terminology is similar to the above, with the exception of using the term “military data gathering” instead of “military survey” (Bateman, 2005). It is thus clear that military surveys can have any content, normally regulated under different regimes (Bateman, 2005; Valencia, 2004).

An important aspect of differentiation between MSR and Military Surveys, accepted in academic literature, is that of research outcomes dissemination. Whereas dissemination of research results is a clear obligation of scientists conducting Marine Scientific Research under Part XIII, it clearly contradicts the classified nature of military surveys despite the obvious relation of results. This final argument seems to provide a basis for the non inclusion of military surveys in MSR and the coastal State consent regime.

Operational Oceanography

Operational Oceanography is another case of marine research with dubious status. LOSC doesn’t include a solid remark of research conducted via floaters or other similar automated instruments.

7 A clear example can be found in the increasingly restrictive stance of China in research related issues in its zones of jurisdiction and the problems created especially with the USA, strong supporter of the LOSC liberal approach. See bellow.
8 See the State Department’s opinion on the absence of control over research issues in USA EEZ at http://www.state.gov/g/oes/ocns/opa/rvc/ (last accessed November 16 2010), while regarding China’s strict control stance see Zou Keyuan, China’s Marine Legal System and the Law of the Sea, Martinus Nijhoff Publishers, Leiden/Boston, 2005.
10 Operational Oceanography is defined as the activity of longtime systematic data recording regarding seas and oceans and their rapid interpretation and dissemination. See http://www.eurogoos.org (last accessed November 16 2010).
11 Part XIII, Section 4, articles 258 – 262 refer to Marine Scientific Research conducted via installations or similar equipment, not to the real time data transmission provided by floaters.
The negotiation procedures in UNCLOS III, provide for clues that show States had accepted and supported the need for unhampered data flow\(^\text{12}\) (Bork, Karstensen, Visbeck, & Zimmermann, 2008; Roach, 2007). It is true that at the time of UNCLOS negotiation and the Convention’s signature, data from similar instruments (fixed or free floating) were mostly of meteorological use, which was connected with the safety of navigation (Roach, 2007).

The number of internationally sponsored research programs that use a wide variety of equipment for measurements (including the “ships of opportunity” Program) (Bork et al., 2008; Roach, 2007; Soons, 2007) grows daily and so does the amount and quality of data provided. In addition the data provided are far more inclusive and contain many results usually provided by Marine Scientific Research and are not anymore of purely meteorological use.

In 2003, IOC ordered the IOC/ABELOS committee to examine the issue of oceanographic data collection on the high seas (which for the purposes of the activity include EEZ waters). The result was the adoption of the 2008 Resolution EC.XLI.4 (Guidelines for the Implementation of Resolution XX-6 of the IOC Assembly Regarding the Deployment of Profiling Floats in the High Seas within the Framework of the Argo Programme) concerning the ARGO data collection Programme\(^\text{13}\). The guidelines suggested prior information of coastal States for the placement of floaters, which could eventually drift into their EEZs. This resolution wasn’t easily accepted and many found its legal basis controversial. Concluding, both liberal and restrictive viewpoints provide arguments for the defense of their position, and based on today’s evidence, the precise regime seems unclear.

“Modern” Hydrography\(^\text{14}\)

The LOSC text, as in the case of Marine Scientific Research, doesn’t include a definition on what constitutes Hydrographic Survey and its precise content. As a result, many countries (most notably the USA) and competent organizations such as the International Hydrographic Organization, have developed their own definitions in order to clarify the issue (Bateman, 2005; Wegelein, 2005).

Marine Scientific Research and Hydrographic Surveys regime differences have been mentioned in previous parts of this paper. These differences depicted the needs at the time of UNCLOS negotiations. An example on that, is that since hydrographic surveys tended to be conducted by government vessels enjoying sovereign immunity (and even more often by military vessels), it wouldn’t make much sense to try to strictly regulate them.

However, one cannot fail to notice today’s elements that create new conditions. Firstly and most importantly, in practice States don’t seem to differentiate between MSR and Hydrographic Surveys in their legal provisions (Bateman, 2005). The applicable legislation for MSR (most importantly the application of the consent regime) is usually applied to Hydrographic Surveys too. On an academic level, discussion as to the validity of variation between the two research types has taken place and objections have been expressed, most notably in the 2003 Tokyo Meeting on the Regime of the EEZ\(^\text{15}\). In that meeting, it was noted that the Hydrographic Surveys regime, as mentioned and codified in LOSC, referred to its use in straits and the territorial sea for navigational safety reasons. Contemporary technological conditions and means for conducting surveys differ greatly and can provide data comparable to those provided by MSR (Bateman, 2005; Valencia, 2004, 2005; Valencia & Akimoto, 2005).

It’s true that the freedom to conduct hydrographic surveys in parts of the high seas under coastal State jurisdiction is currently, according to State practice, debatable. Once again, one can clearly see the two aforementioned stances (liberal and restrictive) being present in this debate. Concluding, “Modern” Hydrography is often viewed suspiciously in the prospect of the dual application of results and is thus many times treated similarly to MSR as to the obligation for previous notification and consent (Bateman, 2005; Xiaofeng & Colonel Cheng Xizhong, 2005).

Maritime (or Marine) Archaeology

Another marine research regime, which remains doubtful, mainly due to the vague reference in LOSC, is the Maritime Archaeology regime. The main references can be found in Art. 149 (“Antiquities in the Area”) and 303

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\(^{12}\) The statement of UNCLOS Third Committee President Dr. Yankov for the necessity not to hamper operational oceanography, is one of these clues thought it is not generally accepted as recognition of the Convention’s drafters purpose to exempt it from MSR provisions.


\(^{14}\) According to IHO “Hydrography is the branch of applied sciences which deals with the measurement and description of the physical features of oceans, seas, coastal areas, lakes and rivers, as well as with the prediction of their evolution, for the primary purpose of safety of navigation and all other marine purposes and activities, including economic development, security and defence, scientific research, and environmental protection.” at [http://www.iho.int/srv1/index.php?option=com_content&view=article&id=290&Itemid=282](http://www.iho.int/srv1/index.php?option=com_content&view=article&id=290&Itemid=282) (last accessed November 16 2010).

\(^{15}\) Organized in 2003 by the East West Center and the Ship and Ocean Foundation (SOF) - Institute for Ocean Policy, with the participation of many distinguished scholars on the subject.

\(^{16}\) Hydrographic Surveys do not have a special “regime” or Part devoted as MSR, but references as in the articles shown on Table 1.
(“Antiquities in Contiguous Zone”). This was a result of the open disagreement in UNCLOS for the creation of a regime. What remains certain is the rejection of the proposal to extend coastal States’ rights beyond the territorial sea. Based on the Convention’s provisions, in areas beyond the contiguous zone applies the freedom to conduct research for antiquities, while in the Area (international seabed) research is also free, but must be conducted for the benefit of mankind, while recognizing preferential rights to the State of origin (Hayashi, 1996; Strati, 2006).

Hardly surprising, State practice is quite different. Deviant practices include both coastal State efforts to claim exclusive jurisdiction on antiquities found in their EEZ (e.g. Malaysia) (Nayati, 1998) and researchers’ efforts to grant their activities MSR status, in order to gain faster and easier consent. Such practices are regarded commonplace behavior for modern treasure hunters. The 2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage, tried to answer to the exploited LOSC gaps, by enforcing the role of coastal States in the EEZ and the Continental Shelf. The UNESCO Convention has only recently (January 2009) entered into force and its efficiency remains to be seen\(^\text{17}\), but the fact that it was required to create a new legal instrument to enforce underwater antiquities protection shows the inadequacy of LOS Convention to regulate maritime archaeology research.

<table>
<thead>
<tr>
<th>Regime Uncertainties</th>
<th>UNCLOS Negotiations</th>
<th>Contemporary Practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Military Surveys</td>
<td>LOSC lack of mention of warships and their research activities</td>
<td>Maritime Powers effort to prevent regulation of activity</td>
</tr>
<tr>
<td>&quot;Modern Hydrography&quot;</td>
<td>Change of technological capabilities and use</td>
<td>-</td>
</tr>
<tr>
<td>Operational Oceanography</td>
<td>No mentioning in LOSC</td>
<td>Under discussion. Recognition of need for non impairment of activity</td>
</tr>
</tbody>
</table>

ii. Marine Research Technological Developments

In addition to research activities with contentious regime connected with LOSC, there are a number of research activities completely out of the Convention’s context, these being results of technological advancements of post-UNCLOS era. These research activities are usually conducted under various regimes, connected with LOSC, such as the 1992 United Nations Convention for Biological Diversity (CBD 1992) and others.

Bioprospecting

Technological advancement in recent years, have created the capability to conduct marine research in the ocean abyss and especially on the ocean floor areas, where lithospheric plates meet. The discovery of unique life forms proved to be financial beneficial in many fields and the consequent result was a rise in research activity connected with the deep ocean floor biodiversity.

What makes this type of research special is that it is conducted almost exclusively on the international ocean floor and LOSC doesn’t include any provisions for it. In 2003, the Subsidiary Body on Scientific, Technical and Technological Advice of CBD defined bioprospecting as “…the exploration of biodiversity for commercially valuable genetic and biochemical resources” or “…the process of gathering information from the biosphere on the molecular composition of genetic resources for the development of new commercial products”. These definitions include scientific and economic aspects of bioprospecting (Leary, Vierros, Hamon, Arico, & Monagle, 2009; Scovazzi, 2004)18.

Bioprospecting has created disputes both on academic and State levels. The discussions for a possible regime take place simultaneously in the United Nations (through the United Nations Informal Consultative Process on Oceans and the Law of the Sea – ICP), the International Seabed Authority (through the Legal and Technical Commission) and the Convention on the Biological Diversity (through the Subsidiary Body on Scientific, Technical and Technological Advice) (Scovazzi, 2004; UNU-IAS, 2005). Indicative of the variety of views on the subject is, that in the 2004 ICP discussions, when the subject of bioprospecting was set on the table, the participating States’ opinions varied between those that regarded that living resources of the international seabed are part of the Common Heritage of Mankind regime, those who regarded bioprospecting as a form of MSR and those who regarded it, as a new research activity without present legal regulation (UNGA, 2004; UNU-IAS, 2005)19.

Remote Sensing20

The last form of marine research examined in this paper is the method of remote sensing. Remote Sensing is a very special method of research in marine environment, because it doesn’t include any physical contact with water mass. The importance of Remote Sensing is very high, especially in the cases of electronic charting of large marine areas. This is proved by the number of national, regional and international programs on the subject (Wegelein, 2005). If one would try to identify similarities of Remote Sensing with other research activities, the closer match is Operational Oceanography, as to the ability to collect and transmit data in real or near real time (Ryder, 2003).

Depending on the altitude, research can be conducted from air space or outer space. Air space research is usually conducted by airplanes and other flying platforms, which are subject to established rules while flying over maritime zones21. The important and problematic legal

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20 As “remote sensing” is defined “…the sensing of the Earth's surface from space by making use of the properties of electromagnetic waves emitted, reflected or diffracted by the sensed objects, for the purpose of improving natural resources management, land use and the protection of the environment…” See principle 1, UNGA/41/65 “Principles Relating to Remote Sensing of the Earth from Outer Space” of 3/12/1986.

21 Law of the Sea as well as Air Law make no reference to Marine Research conducted through aerial means. The rights, mainly, of third states are implied by various clauses of the Law of the Sea Convention and the Chicago Convention on International Civil Aviation, 1944 (which applies to all but the-military aircrafts, those conducting research included. See art. 3). Furthermore, there exist no relevant international regulations on law enforcement in case a violation occurs. Verification of research activity conduct, along with law enforcement are practically impossible when we are referring to aerial means of Marine Research; thus overflight ban seems to be the most effective measure.

In the airspace over Territory, Internal Waters and Territorial Sea (National Airspace) the coastal state has the right to ban overflight and/ or regulate third states’ activities. Contrarily, the Freedom of Overflight and Marine Research applies in the airspace superjacent to the High Seas (see LOSC art 87)[1]. Things get more complicated in the EEZ, where conduct of MSR and Exploration – Exploitation requires prior consent by the coastal state, no matter what technique or method is applied. Despite the fact that this Zone is a part of the High Seas (esp. under an Air Law viewpoint) a research activity without the coastal state’s consent would, actually, be a violation of its sovereign rights (LOS art. 56). Of course this assumption remains on a theoretical level, since no such jurisdiction over the EEZ has been explicitly attached.

To conclude, two clauses included in the Chicago Convention are of relevant interest to our issue, since they could also apply to marine research activity: a) article 36 states that “Each contracting State may prohibit or regulate the use of photographic apparatus in aircraft over its territory.” and b) article 8 “No aircraft capable of being flown without a pilot shall be flown without a pilot over the territory of a contracting State without special authorization by that State and in accordance with the terms of such authorization.”
vacuum lies with the use of satellites for observation, which by being outside the atmosphere are not subject to similar restrictions.22

Technological advancements in satellite observations mean that a large spectrum of information can be collected and by all probability more will be collectable in the years to come. Bearing in mind today’s legal ambiguity in LOS terms, it is essential to find a form of effective consensus on coordination, for the type of data transmitted.

D. Conclusions

Research activities and their respective regimes in LOSC seem at first notice clearly distinguished, on the rule of different scopes. 30 years after UNCLOS and the Convention’s signing this image seems to be fading. Marine Scientific Research, Exploration and Exploitation and Hydrographic Surveys regimes seem to overlap, allowing the use of the various research regimes for ambiguous activities. Whereas other research activities, such as those presented in part C.b, are often conducted under ambiguous regimes, and are open to interpretation and exploitation. These vacuums and unregulated research activities can have an extremely large footprint as they are connected directly or indirectly not only with State interests but also with major financial interests. The consequences of allowing marine research activities to proceed without a solid rule set, whether this was provided by LOSC or not, could be grave. This does not imply that Coastal States regulation authority should go beyond the LOSC scope, especially in cases of common benefit (most obvious examples would be environmental monitoring and common resources management).

In modern maritime environment, where the State’s role as sole actor is retreating constantly and new or renewed issues such as maritime security, marine environment and intellectual rights of research products play an important role in ocean governance, it is more than certain that research activities will increase, especially on the high seas. It is of extreme importance that each of the research activities mentioned in this paper should have a clear set of rules of conduct, in order not become a sort of Trojan horse for destabilizing the world’s oceans. Any rules should have at their heart the relative LOSC provisions, with a view on the needs for update of a major but, aging text.

As part for the need for modernization or updating of the Law of the Sea and considering the difficulties of doing so via the official amendment procedures of LOSC, it is very important to strengthen the role of competent international organizations in keeping Law of the Sea up to date with contemporary demands. The competent international organizations can provide a much more flexible platform for modernization and rules of conduct on the various aspects of ocean policies in the new century.

References


22 If we oversee the issue of vertical airspace delimitation, state practice has shown its tolerance concerning space objects’ overflight through consecutive National Airspaces (during their launch) as well as to the conduct of various activities over them (always in accordance with International Law and the United Nations Charter). Additionally, Hard Law regulations not only permit, but also encourage scientific research of Outer Space and the Earth. There are no specific rules dealing with Marine Research, thus the most relevant clauses are met in UNGA/41/65 “Principles Relating to Remote Sensing of the Earth from Outer Space” (12/3/1986). Shortly, Remote Sensing, that can be used in MSR, is permitted over all maritime zones, under the following terms: a) It should be conducted for the benefit of the Mankind (Principle II), b) state sovereignty should be well respected (Principle IV), c) access to data should be guaranteed for States whose territory in sensed (Principle XII). For the Intellectual Property Rights stemming from Remote Sensing see Doldirina, C. A rightly balanced intellectual property rights regime as a mechanism to enhance commercial earth observation activities, Acta Astronautica, Vol. 67, 2010, pp. 639-647.


**Official Documents**


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UNGA/41/65. “Principles Relating to Remote Sensing of the Earth from Outer Space”


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Webpages


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Biographies of the Authors

Tilemachos Bourtzis is PhD candidate on the Law of the Sea, focusing on Marine Scientific Research, in the Department of International and European Studies of Panteion University of Athens. He holds a MSc on Environmental Policy and Management from the University of Aegean and has Graduated the Rhodes Academy of Oceans Law and Policy (2012). Mr. Bourtzis is a researcher with the European Centre of Environmental Research and Training for the last 10 years. tbourtzis@gmail.com

Gerasimos Rodotheatos is PhD candidate on the Law of the Sea, focusing on Artificial Islands and Structures, in the Department of International and European Studies of Panteion University of Athens and Irakleitos II Scholar. He holds a MA on Environmental Governance and Sustainable Development from Panteion University of Athens and has Graduated the Rhodes Academy on Oceans Law and Policy (2011). Mr. Rodotheatos is a researcher with the European Centre of Environmental Research and Training for the last 10 years and Member of its Steering Committee (2012-2014). yrodo@panteion.gr

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OBITUARY

REAR-ADMIRAL
G. STEVE RITCHIE, CB, DSC

On 8 May 2012, the international hydrographic community lost one of its most celebrated practitioners. Steve Ritchie was a most wonderful man both professionally and socially. He will long be remembered by those who worked with him or associated with him for his many interests and originality. He was born in Burnley, Lancashire, in 1914 of Scottish parents, Sir Douglas Ritchie and Lady Margaret Ritchie. His father had been the secretary of the Port of London Authority, although it seems to have been persuasion within the Navy that set him on his hydrographic career. He was educated at the Royal Naval College, Dartmouth, which he joined at the age of 13. He went to sea at age 17 and joined the Survey Service of the Navy in 1936.

His career in the Surveying Service extended over thirty years during which he surveyed in many different parts of the world and rose in rank from Lieutenant to Rear Admiral. His service covered the years of the Second World War during which he was active surveying the beaches behind the lines in North Africa, for which he was awarded the Distinguished Service Cross (DSC) for bravery. It has been reported that during his war service he had a lucky escape when his commanding officer, Captain Hennessey, ordered him out of a boat just before it was blown up with the loss of all hands. During the invasion of northern Europe he was in command of HMS Scott being involved in the setting up of navigational systems for the invasion fleet. Altogether he was in command of four survey ships and his time aboard HMS Challenger clearly had a strong influence on his attitude to giving hydrography a broader oceanographic mission. The ship was tasked to take a very multidisciplinary role and as well as conventional hydrographic surveying she was employed on oceanographic and research activities across the world from the Labrador to the Pacific islands. During the time that Steve Ritchie was aboard, a small contingent of scientists from the Department of Geodesy and Geophysics, Cambridge, which included the eminent oceanographers Tom Gaskell and John Swallow, was assigned to the ship. There is no doubt that the experiences on the Challenger had a very strong bearing on Steve Ritchie’s wider interests in the oceans. A particularly interesting part of the ship’s programme was to survey and locate the deepest depth in the oceans. This being in the Marianas Trench, where a depth of 10,863 metres was reported. Subsequently other researchers from the USA, USSR and Japan have slightly refined this measurement. At a later stage he was employed on more mundane aspects of hydrography, such as surveys in the Persian Gulf and the north coast of Borneo aboard HMS Dalrymple but during that time new technology was appearing on the scene, first in the form of Two Range Decca. This gave him a lifelong interest in new technical developments and a constant desire to keep up to date. In 1963, he commissioned HMS Vidal, a thoroughly modern survey vessel in which he visited the Soviet Union and carried out surveys in the North Atlantic. Once again he found himself in the more scientific aspects of hydrography in the international NAVADO programme in which a fleet of international survey ships measured geophysical profiles from side to side of the Atlantic. It also carried him to Trinidad and a glance of his very active social life!

As was expected of senior surveyors he spent time on assignments to the Hydrographic Office, no doubt learning much about the details of cartography and chart production. His first such assignment was as Superintendent of the Oceanographic Branch (SOB) and his last was as the assistant Hydrographer. Another aspect of his career was to assist New Zealand establish a Hydrographic Office. HMS Lachlan had been transferred to the New Zealand Government and provided the nucleus for that operation. Before leaving his final sea going billet he became ADC to the Queen in 1965.
In January 1966, Steve was promoted to Rear Admiral and became the nineteenth Hydrographer of the Navy, a post that he was to hold for five years. In 1967, he was made a Companion of the Bath (CB). During that relatively short period his actions were to have a major and long-term effect on British Hydrography, the production of nautical charts and the wider development of navigation. The first of these was the completion of the move and consolidation of the Hydrographic Office at Taunton. Part of this move was to acquire and install three new colour presses that permitted the printing of charts in colour rather than the previous tones of black and grey. This fortunately coincided with another move and that was the adoption of the metric system, in particular the move from depth units in fathoms to metres. Although the International Hydrographic Bureau had been encouraging the use of metric units, the UKHO had until that time resisted this change. Although there was considerable contention in marine circles on the way it should go he strongly supported the development of traffic separation schemes in the Dover Straits and later in the English Channel as a whole. It led to the first mandatory schemes being adopted by the International Maritime Consultative Organization (IMCO). Finally, during his time in office he did much to encourage the construction of new survey ships.

After leaving his post as Hydrographer, in addition to taking a course on bricklaying that was available to all retiring naval personnel, he was invited to join Southampton University as a research fellow. Although he failed to complete his planned hydrographic history he did hold discussions with Alan Ingham which were to lead to a much wider communication between hydrographic personnel. This was the development of The Hydrographic Society of which he became the first President. Hydrography, which at one time had been mostly confined to the navy and government personnel, had taken on, with the development of North Sea oil, a much broader mission that was employing civilian practitioners and commercial companies. The Hydrographic Society initially established itself nationally but later became international, holding annual conferences, workshops and publishing the Hydrographic Journal. In 1972, Steve was elected President of the International Hydrographic Bureau in Monaco, which is the Secretariat of the International Hydrographic Organization (IHO). He was re-elected for a second five-year period in 1977. The prime objects of the IHO are to encourage the uniformity of hydrographic charts and publications and to assist in the development of global expertise on the subject. One of the major tasks that he carried out to assist in these aims was to draft an international Convention which formed the administrative background for the detailed technical work. He took a particular interest in the work of the GEBCO (General Bathymetric Chart of the Oceans). This programme brought together hydrographers and oceanographers in the production of a global set of charts describing the bathymetry of all the oceans. He retired from the IHB to live in Scotland in 1982.

Nothing has been mentioned so far about his ‘other life’! In his work he was full of originality and hard work, socially he was a ‘bon vivant’ and in that capacity he will be remembered internationally by many people. He was flamboyant in his dress and many will remember his red socks and striped blazer. His ruddy face and a mass of curly white hair topped this image. Some of us will remember seeing him at a Hydrographic Society Christmas party dressed as Father Christmas and dancing with a beautiful American girl! Taking advantage of his ship visiting Trinidad he became part of a ‘band’ during Mardi Gras celebrations. Dressed as a butterfly he joined the dancing, something he was to repeat in other years. In the Pacific Islands we find him dressed in a grass skirt and drinking Kava with the local Fijians. From this we go to the formality of a visit by Princess Anne to the Hydrographic Office where we see him dressed in his uniform as a Rear Admiral – whether he was wearing red socks on that occasion is not known! His time in Monaco had its own special social occasions as a member of the Monte Carlo Club, including social exchanges with Prince Rainier and as a member of the local boules team. He met his wife Disa in 1942 on board the SS Ceramic on a voyage from Canada to South Africa. They had three sons and a daughter; a grandson has followed in his grandfather’s footsteps and is a hydrographic surveyor.

Yet another life was his life as an author and scholar. He wrote four books about hydrography and numerous articles in scientific literature. These can be found in publications such as the Journal of Navigation and the International Hydrographic Review and he also published in Hydro International a series of highlights of hydrographic history in the Old Hydrographer’s Column. These were subsequently published together in book form. During his time as Hydrographer of the Navy he was responsible for the production of numerous charts which bear his name and especially noteworthy are the annual reports of the UKHO during that time.

Adam J. Kerr

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Vice Admiral Civetta passed away in Bogliasco (near Genoa) in Italy at the age of 81. He was born in Kos, Greece, on 26 October 1930, and joined the Naval Academy in 1950.

In the course of his outstanding career in the Italian Navy, he was the Commanding Officer of one of the four classes in the Naval Academy.

Following that he was the Commanding Officer of the frigate “Canopo”, and, with the rank of Captain, was Commanding Officer of the destroyer “Audace”. From 1979 to 1982, Captain Civetta was a Naval Attaché based in London.

From 1983 to 1987 Alfredo Civetta was the Director of the Italian Hydrographic Institute, where his work in the development of hydrography was internationally recognized, to the extent that he was elected Director of the International Hydrographic Bureau (IHB) in Monaco for the period 1987 to 1992, where he served alongside Sir David Haslam (President) and Adam Kerr (Director). As an IHB Director and with his excellent diplomatic skills, he proved to be a valuable liaison with the authorities in the Principality of Monaco. After leaving the IHB he regularly attended the five-yearly International Hydrographic Conferences, and was also a discerning member of the jury to select the best display at the IHO Cartographic Exhibition, held alongside the I.H. Conferences.

In 1993, he became a member of the Civic Protection Service of the Province of Genoa.

A Member of the National Committee of the Italian Sail Training Association, Vice Admiral Civetta published a number of articles in the magazine “Rivista Marittima”, the last one of which was about Italian research in Antarctica.

He will be remembered as a passionate and hard-working gentleman, who devoted his life to many activities with a high level of competence and professionalism.

Vice Admiral Civetta was married to Lucia and had a daughter, Paola, and a son, Francesco.

Based on information provided by Paulo LUSIANI and HYDRO International.
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