Charting the Secret World of the Ocean Floor. The GEBCO Project 1903-2003

THE INTERNATIONAL BATHYMETRIC CHART OF THE ARCTIC OCEAN (IBCAO) - A NEW DIRECTION FOR OCEAN MAPMAKING

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Abstract

The project to develop the International Bathymetric Chart of the Arctic Ocean (IBCAO) featured innovations that could be usefully applied to the development of future editions of GEBCO and associated digital products. These innovations include: the use of digital data and methodologies in virtually all stages of the operation; the establishment of a single team to work across the entire Arctic region; and liberal policies for the public release of selected data products and images. By emulating some of these practices and through judicious marketing of the resulting outputs, GEBCO may be able to attract a wider range of users while generating revenue that would support future operations.

Introduction

With the General Bathymetric Chart of the Oceans (GEBCO) entering its second century, there is little doubt that the organization can and must continue to develop and maintain reliable descriptions of global bathymetry. In light of the technological advances that characterized ocean mapping in the closing decades of GEBCO=s first century, it is timely and appropriate to review the methodologies employed in the construction and distribution of the organization=s products, as well as the nature of the products themselves. Such a review will help ensure that GEBCO continues to meet the expanding and increasingly sophisticated needs of the ocean community in a manner that is both expeditious and affordable.

This paper begins with a brief overview of a modern multinational project to construct an updated description of the seabed north of 64EN: the International Bathymetric Chart of the Arctic Ocean (IBCAO). It outlines a production and distribution model derived in part from IBCAO that could apply to similar undertakings in other parts of the world ocean, in particular the present initiatives to develop and maintain sheets in the GEBCO and IBC (International Bathymetric Chart) series. It also suggests a few ways of distributing prospective GEBCO outputs in a fashion that could generate revenue to support future operations. Finally, it introduces the concept of the digital bathymetric chart, a set of tools and integrated data sets that feature ease of visualization and high levels of interaction.

IBCAO - a project overview

IBCAO was born of the need to upgrade existing representations of the Arctic seabed that portrayed major features, but with an accuracy that was being called increasingly into question as polar expeditions discovered discrepancies between actual soundings and charted depths. In late 1997, a working group of Arctic bathymetric specialists from eight different countries was appointed to deal with this problem under the sponsorship of three international bodies: the International Arctic Science Committee (IASC), the International Hydrographic Organization (IHO), and the Intergovernmental Oceanographic Commission (IOC).

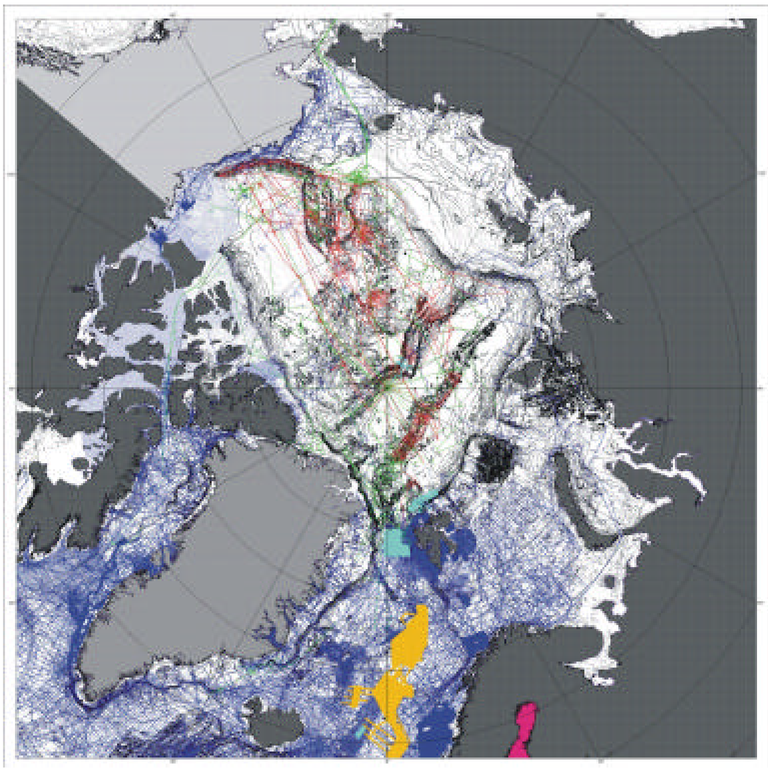


Figure 1. Distribution of original data points and isobath nodes used in the construction of the IBCAO grid.

Macnab and Jakobsson (2000) articulated the primary concepts underlying the structure and organization of the IBCAO project. A guiding principle throughout was the extensive use of digital techniques to facilitate the handling and visualization of large data sets. Altogether, some 1.7 million original data points were assembled in digital form, consisting mostly of historical observations collected with single beam sounders. These were complemented by depth values at about 2 million points on selected isobaths that were digitized from existing contour maps and navigational charts. Figure 1 illustrates the distributions of the data points (including more recent acquisitions of modern - and voluminous - multibeam data sets from the Norwegian Petroleum Directorate), while Figure 2 portrays the coverage of the published maps from which contours were digitized. Jakobsson and Macnab (2000) described the data sets and an overview of the procedures employed in their handling and visualization.

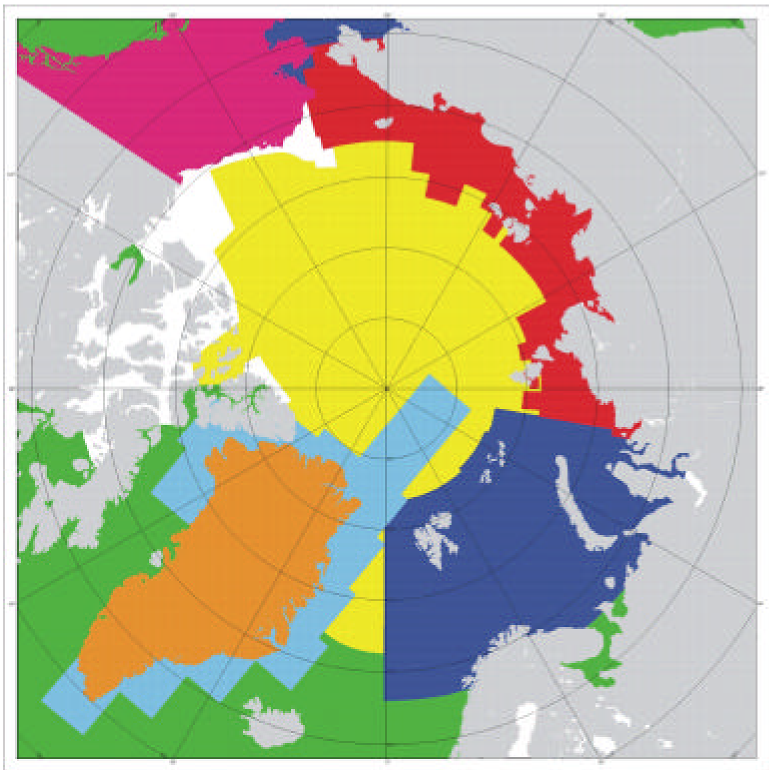


Figure 2. Segments of published maps and charts from which contour lines were digitised for the construction of the IBCAO grid.

By early 2000, a preliminary map and digital grid were ready to be placed in public circulation for review and comment (Jakobsson, 2000; Jakobsson et al, 2000a); this resulted in several corrections to the map, as well as improvements to the data base through the incorporation of new observations in areas where coverage was sparse or of poor quality. Following these refinements, the revised map and grid were posted on the project website from where they could be easily downloaded; both products received widespread acceptance from a broad cross-section of users who applied the information in a variety of mapmaking and research activities.

The history of IBCAO has been documented in a series of meeting reports (Macnab and Grikurov, 1997; Macnab and Nielsen, 1998; Macnab and Jones, 1999; Macnab and Guy, 1999; Macnab and Jakobsson, 2001; Macnab and Edwards, 2002), and in a collection of postings on the project website hosted by the US National Geophysical Data Center in Boulder, CO:

http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/arctic.html

This website has proven to be very popular, attracting 100,000 visitors in 2002 who downloaded nearly 50 gigabytes of information in the form of grids, contours, images, maps, and documents. Of particular interest in the website documentation is a report (Jakobsson et al, 2000b) that compares selected areas of the preliminary version of IBCAO and GEBCO Sheet 5.17 (CHS, 1979), and which illustrates the former=s improved resolution and enhanced information content (Figure 3). This is hardly surprising in view of the paucity of information that was available to the builders of the earlier product.

In 2002, the enhanced IBCAO grid was used to construct a prototype chart (Figure 4) that is proposed as a model for future editions of the GEBCO Series. Featuring the same cartographic parameters as Sheet 5.17, the new map covers the area north of 64EN in a polar stereographic projection at scale 1:6,000,000. The primary and most noticeable difference in the IBCAO map is the shaded relief rendition of the ocean floor and the surrounding land masses, providing a much more descriptive portrayal of the regional morphology than the simple isobaths of Sheet 5.17. To satisfy users who need to determine depths directly from the map, key isobaths have been overprinted on the shaded relief.

The successful outcome of IBCAO, along with the relatively short time frame of its achievement, suggest that a similar approach might facilitate the development of grids and maps that describe regional bathymetry in other parts of the world ocean. The remainder of this paper outlines how the IBCAO project might serve as a model in that respect.

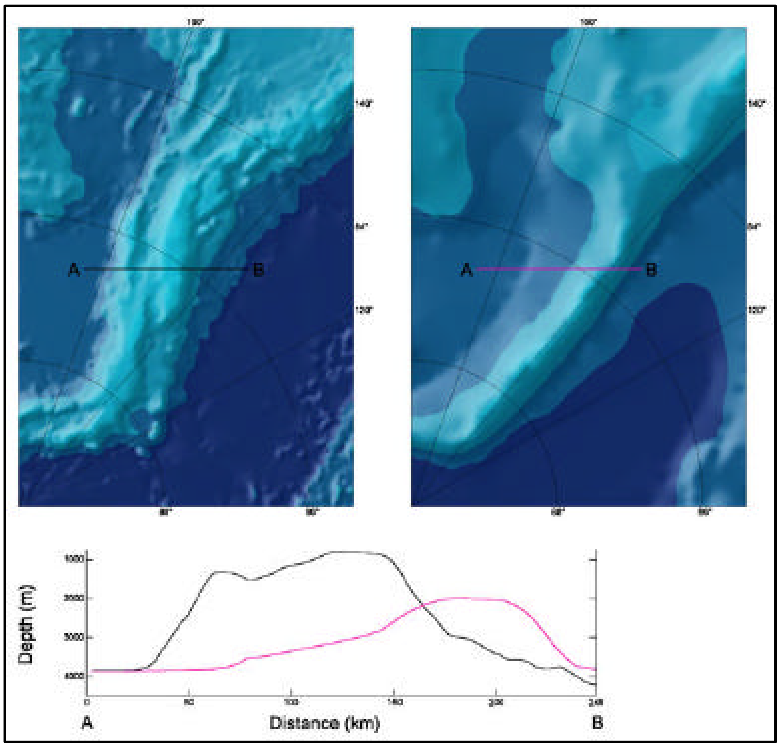


Figure 3. A comparison between the IBCAO (left) and GEBCO (right) portrayals of the central segment of the Lomonosov Ridge

The advantages of operating in the digital domain

Modern bathymetric observations tend more and more to be in digital form, from the moment of their acquisition until their deposition in digital data bases, from which they may be extracted by users for more digital manipulation and visualization. Data sets in digital form lend themselves to a much wider range of processing and interpretive options than does the traditional printed chart, with far less effort and time required to achieve results that would have been unimaginable just a few years ago.
For instance, it is usually easier to maintain the currency of a well populated and properly organized digital database than it is to update a contour chart, particularly if the latter has been drawn by hand. This is not to suggest that hand contouring no longer applies in the construction of modern bathymetric

maps: the technique will likely remain useful as long as there are places where data sets are sparse or unreliable - but it is important to be aware that hand contouring, by and large, consists of intelligent speculation to compensate for the absence of direct measurements that determine the actual shape of the seabed.

The most significant advantage of operating in the digital environment is the total flexibility that it offers for manipulating and visualizing data in a great variety of forms to suit a wide range of applications. Thus it is feasible to convert randomly-spaced soundings into regular grids of depth values, which in turn enables the use of powerful software tools for processing and analysis. Having the data base in grid form also facilitates the implementation of value-added operations such as search and interrogation, or fusion and correlation with other types of observations.

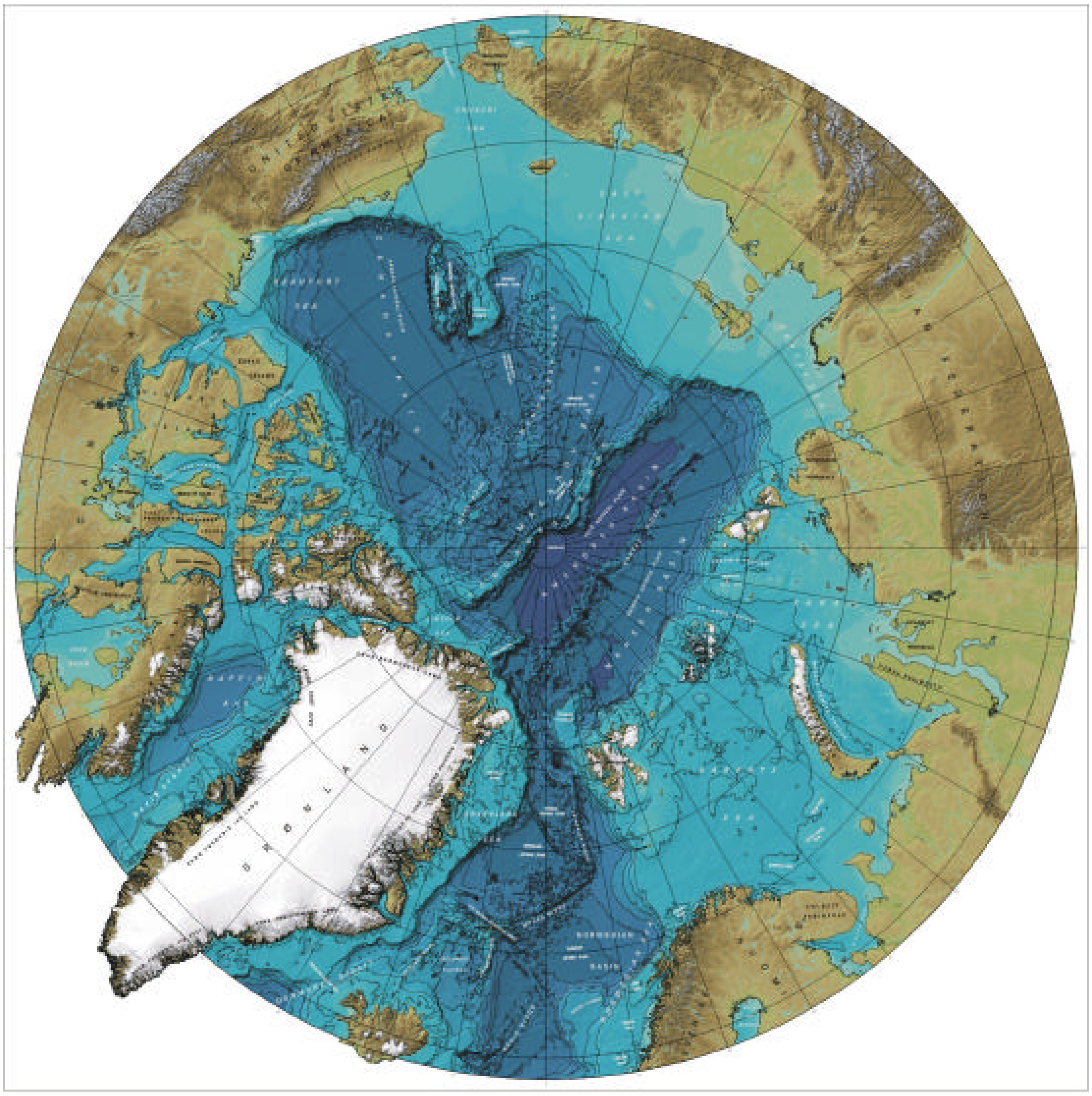


Figure 4. The new IBCAO map, constructed
as a modern version of GEBCO Sheet 5.17.

In this environment, the production of printed charts is almost a secondary process: satisfactory output is a given if the underlying data sets are adequate, and if the appropriate cartographic parameters are selected. Moreover, the production of custom charts is now a routine matter for satisfying specialized requirements - in most instances, these maps appear first on a computer screen, after which they are transferred to paper.

It is worth emphasizing here that none of the above processes suggest an abdication on the part of skilled and experienced bathymetric analysts: modern, well-designed computer systems should and do leave open the option for human intervention wherever and whenever it is needed. The essence of intelligent computer processing, it should be recalled, is to let the machine perform repetitive operations under human control and direction.

GEBCO and the IBC series

For several years now, the Intergovernmental Oceanographic Commission (IOC) has sponsored the development of a series of International Bathymetric Charts (IBCs) that are complementary to GEBCO=s global chart series. These are described in some detail on the IOC website at:

http://ioc.unesco.org/iocweb/activities/ocean_sciences/ocemap.htm

The scope of the IBC series is regional rather than global, with IBCs portraying bathymetry in several series of adjoining sheets that cover particular segments of the world ocean at a smaller scale (i.e. in greater detail) than GEBCO. In an ideal world, the GEBCO and IBC series would be based on the same underlying data sets, however in view of their independent production streams and timetables, it is perhaps inevitable that this may not always be the case.

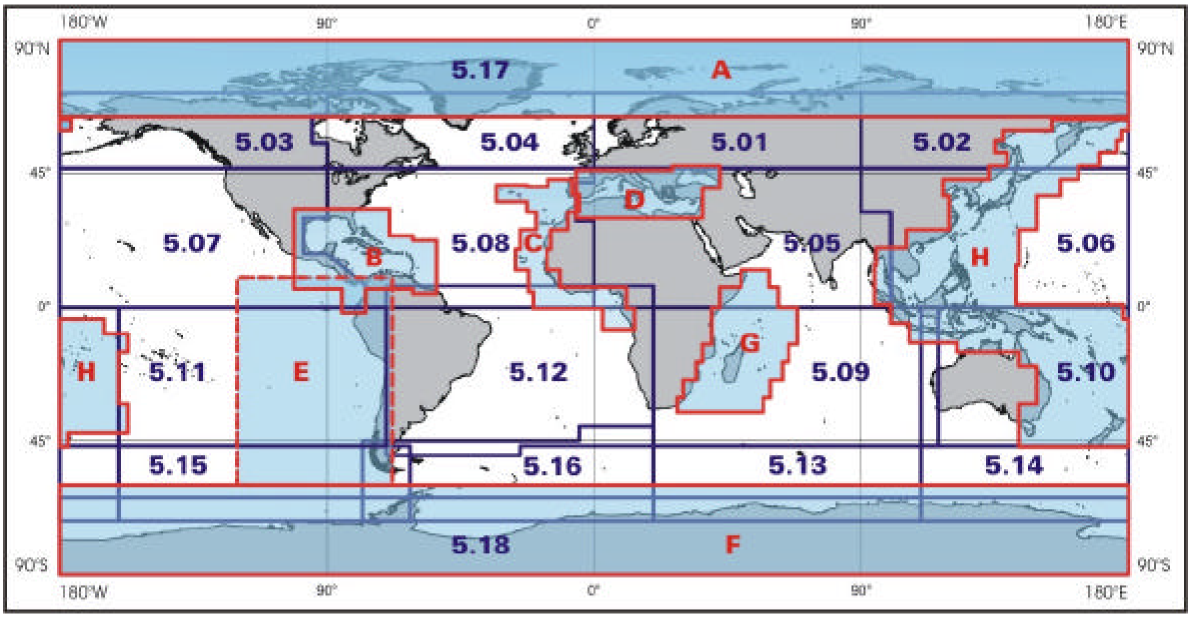


Figure 5. Comparative layouts of sheets in the GEBCO and IBC (International Bathymetric Chart) series. GEBCO sheet numbers are shown in blue. IBC series are labelled in red, with names and regions listed in Table 1.

Figure 5 illustrates the distributions and coverages of the GEBCO and IBC sheets. It will be noted that there is substantial overlap between the eighteen GEBCO sheets and the eight IBC series. Table 1 lists the IBC series and their regions, along with the number of sheets and participating countries in each series. This suggests a need for careful coordination between the GEBCO and IBC undertakings to avoid or at least to minimize several problems: duplication of effort, missed communications, product incompatibility, and data fragmentation.

Figure 5 also suggests that for both GEBCO and IBC, the current process of organizing map production according to cartographic boundaries, and of allocating responsibilities for individual sheet production to different parties, may substantially increase the amount of work, communication, and production time on account of the need (a) to achieve consistency of presentation between large numbers of sheets and (b) to ensure continuity of information across sheet boundaries through careful edge matching, i.e. the largely manual process of comparing and revising contours at the limits of adjoining sheets.

Without delving into the separate histories of GEBCO and IBC, it would seem that the reasons for having two series of bathymetric charts are rooted in a time when cartographic considerations (data availability, geographic coverage, scale of presentation, projection, contour interval, colour scheme, etc.) dominated the time-consuming and labour-intensive production of paper charts, and justified the existence of two distinct product lines. Now that the bathymetric sciences have wholeheartedly adopted digital technology, it seems appropriate to consider whether an evolved approach to the handling and visualization of bathymetric information would make it possible to deal effectively with large, modern data sets in an era of decreasing human and fiscal resources, all the while continuing to serve the interests of investigators and mapmakers.

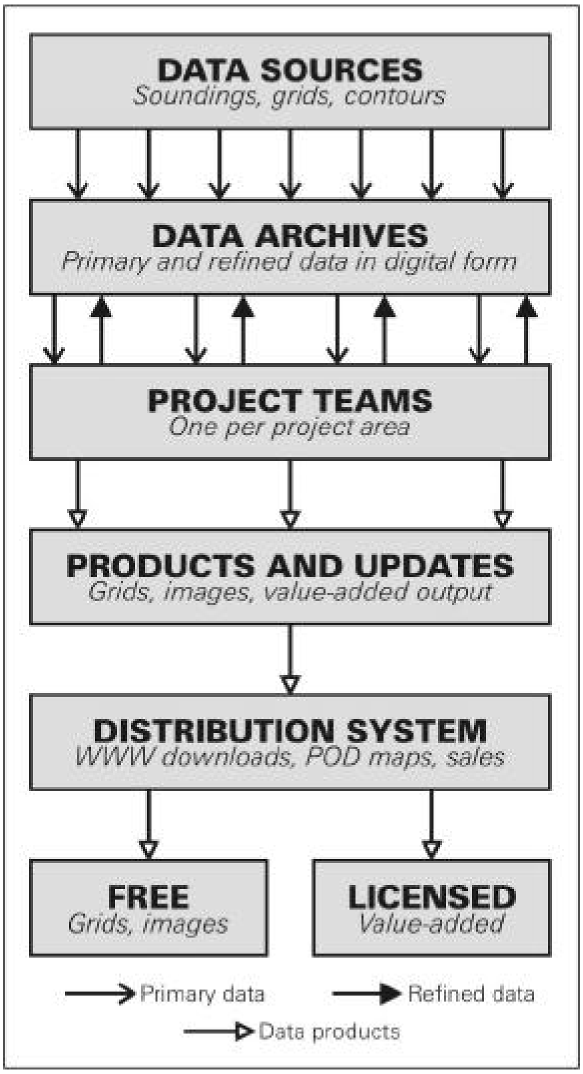
TABLE 1. International Bathymetric Chart Series

Abbreviation	**Region**	**Number of sheets**	**Participating countries**
A. IBCAO	Arctic	1	8
B. IBCCA	Caribbean and Gulf of Mexico	16	7
C. IBCEA	Central Eastern Atlantic	12	2
D. IBCM	Mediterranean	11	7
E. IBCSEP (new)	South Eastern Pacific	?	5?
F. IBCSO (new)	Southern (circum-Antarctic)	1	?
G. IBCWIO	Western Indian Ocean	21	11
H. IBCWP	Western Pacific	55+	6

A proposed change of approach for constructing global bathymetric products

In light of the foregoing considerations, the IBCAO experience suggests a possible model for developing descriptions of global bathymetry over geographic areas of varying extent and at a range of scales. This would require modifications to existing procedures, and the adoption of new arrangements and methodologies that capitalized on the power of digital technology, however the existing organizational infrastructure would be largely preserved. Figure 6 illustrates the flow of information and products in the suggested approach.

Data sources and archives



A fundamental principle would be to use only digital data sets - whether collected in that form, or converted from analog sources. Data providers would be encouraged to consign their data sets to a recognized repository, such as the World Data Center for Marine Geology and Geophysics, or the IOC/IHO DCDB (Data Centre for Digital Bathymetry), which are both hosted by the U.S. National Geophysical Data Center in Boulder, CO. These contributed data sets (hereinafter referred to as *primary data*) would consist of original soundings, grids, or digitized contours, along with their respective metadata. Ideally, the data sets would be cleared for public distribution, although in some cases it might be possible to make provision for protecting the confidentiality of proprietary or classified information.

Figure 6. Flow of data and data products in a suggested reorganization of the GEBCO undertaking

Project teams and areas

Existing project teams would be re-organized into eight units based on geographic regions and assigned the responsibility for performing the data operations necessary to develop the best and most current bathymetric descriptions in each region: compilation and assembly, quality control, correction and adjustment, merging, grid construction, map creation, and database maintenance.

Table 2 lists the eight suggested regions, each one consisting of a major ocean body with its marginal and adjacent seas. Organizing the work on this geographic basis is perceived as more efficient because each oceanic area would be treated as an entity by one group of operators, instead of being cut up along arbitrary sheet divisions and allocated to different implementation teams. It is believed this approach would facilitate data assembly and lead to consistency of operations within each project area, while the smaller number of project teams would simplify management and communication within the overall global operation. Also, the arrangement would eliminate the need to reconcile information at the boundaries of numerous map sheets, as is presently the case. Where one project area abutted another under the suggested scheme, an overlap zone would be defined to foster communication between project teams and to promote the exchange of data between adjacent projects with a view to creating a seamless joint.

Project teams would include strong regional representation in their leadership and makeup, in recognition of the interests of states whose waters fell within project areas, and also to capitalize on the existence and availability of local knowledge and expertise. Involvement by non-regional parties would also be encouraged in situations where the interests of external countries or organizations were pertinent, or where it would be otherwise difficult to obtain the necessary resources, either technical, informational, or financial.

To deal effectively with all aspects of the undertaking, each project team would comprise a mix of specialists in marine surveying, scientific research, and geographical information systems.

TABLE 2. Suggested project areas: main oceans plus marginal seas

1. Arctic Ocean
2. Indian Ocean
3. Mediterranean and Black Seas
4. North Atlantic Ocean
5. North Pacific Ocean
6. South Atlantic Ocean
7. South Pacific Ocean
8. Southern (circum-Antarctic) Ocean

Serious consideration should also be given to providing stability to the overall operation through the designation of an institutional base in each project area, e.g. a survey agency, a research laboratory, or an academic establishment. An institution so designated should be prepared to provide some basic level of support to the operation, but without necessarily committing to underwrite a significant portion of the project costs - which should be covered by funds and in-kind contributions provided by other participating organizations, including the global sponsor. In this context, it is essential to recognize that in each project area, the operation would feature two distinct phases that required different levels of support and which prevailed over different time frames: (1) initial implementation, and (2) ongoing maintenance.

Initial implementation describes the round of startup activities that would inaugurate a given project, i.e. the compilation and treatment of existing data sets to develop outputs such as grids, maps, etc. Ongoing maintenance implies the upkeep of a Alive@ database through the continuing assimilation of new data sets and the updating of outputs to reflect this new information. This maintenance phase would be crucial to avoid repeating the whole exercise a few years after the original project team had dispersed, when major accumulations of new data were ready to be consolidated with historic holdings.

Refined data and data products

Project teams would obtain raw data from the repository and apply appropriate editing and correction procedures to produce error-free and coherent data sets for their respective project areas. These improved data sets (hereinafter referred to as *refined data*) would be used to develop a range of *data products*, such as grids, images, and maps, and would also be incorporated into a variety of value-added packages such as the GEBCO Digital Atlas and the Digital Bathymetric Chart (DBC - described in the section that follows). Upon completion of these products, the refined data would be returned to the repository for safekeeping and for re-use in future updating operations.

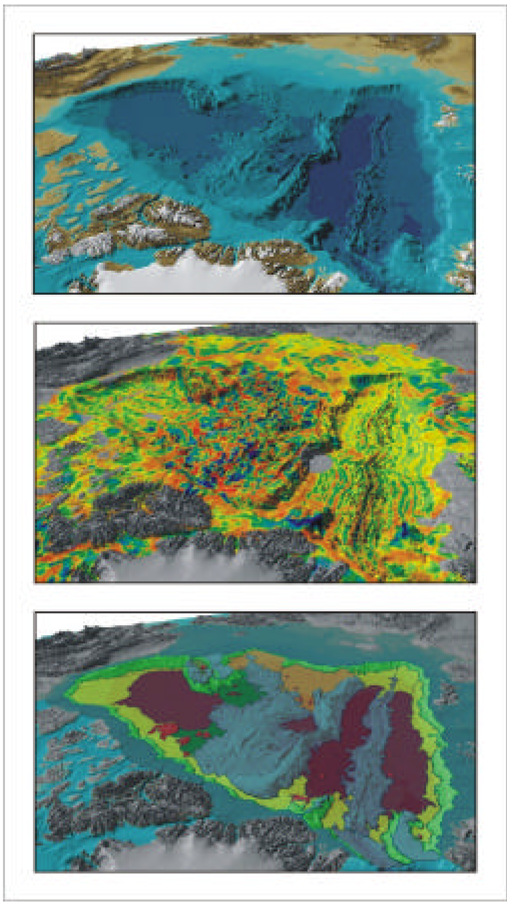
In the interests of promoting uniformity and consistency between data products for the different project areas, existing policies and procedures would be modified and expanded as needed to ensure that standard methods were applied in the management and treatment of digital data, and in the development of products.

Recognizing that global bathymetric mapping is likely to remain a work in progress for the foreseeable future, considerable care and attention, not to mention suitable resources, would be required to ensure that the database was maintained through the constant assimilation of new observations, and though regular updates to basic and value-added products.

Product distribution

The distribution of products would feature a mix of free and licensed delivery. Free delivery would consist of file downloads on the Internet, and would apply to primary data, grids, and selected images. This would enable a wide audience to access basic project outputs in order to evaluate their usefulness in a variety of applications. Licensed delivery would entail a modest fee and would apply to value-added packages, Print On Demand (POD) maps, and updates to these products that resulted from the incorporation of new data sets. The ordering and delivery of certain licensed products and their updates could be accomplished over the Internet, while others (e.g. POD maps) might best be handled through a form of commercial partnership or through a franchise arrangement. Many individuals and organizations have neither the time nor the facilities to produce their own maps and digital products, so it is anticipated that such a service ought to satisfy a popular demand.

Some products would not be released for general circulation. Representing a substantial intellectual and processing investment, refined data would be held by the repository for re-use by project teams whenever new observations were available to update grids, value-added packages, or POD maps. Similarly, the revenue-generating capacity of POD maps would be protected by restricting the circulation of their plot files.



A pricing policy would be adopted that promoted sales while maintaining sufficient profitability to cover the operating expenses of the project teams. In this context, an effective strategy might be to pursue volume sales by developing a range of value-added products and maps that were useful and attractive, and which sold at a cost that was low enough to encourage large numbers of users to buy them instead of attempting to build their own.

Figure 7 illustrates an example of fusing and combining co-registered data sets; this technology lends itself well to investigations that require the correlation and analysis of layered geoscientific information. Figure 8 is an example of a more Aillustrative@ application of the GDC through the presentation of an attractive and instructive graphic that conveys a sense of the shape and texture of the seabed; an image such as this can serve as an effective tool for education and public outreach.

The Digital Bathymetric Chart (DBC)

Digital methodologies offer unprecedented opportunities for the production, distribution, and advanced visualization of bathymetric information in user-friendly form. One way to do this would be to package global bathymetric information and related facts in a series of information layers: locations of data points, bathymetric grids at varying resolutions, depth contours at standard intervals, the IHO Gazeteer, IHO Limits of Seas and Oceans, national maritime boundaries, etc.

To complement these related data sets, the package above would include easy-to-use GIS software that allowed users to combine and visualize selected layers within defined geographic limits, and to manipulate this information to produce special effects e.g. shaded relief maps, custom depth contours, oblique views, fly-throughs, etc. The option for producing printed output would be available, as would be the capacity to export selected data to external GIS environments for specialized manipulation and for combination with other types of information.

In essence, what=s being suggested is an extension of the GEBCO Digital Atlas, one that would feature added information layers and an unprecedented array of functionalities for handling and visualizing that information. Such a package could be sold for a modest price to encourage its widespread acceptance and use, with a subscription fee for regular updates. This could be complemented by a network of franchised, high-quality printing operations, which would produce standard or custom charts on demand for a fee that could be partially remitted to the sponsoring organization for use in defraying at least a portion of the cost of producing and maintaining the DBC.

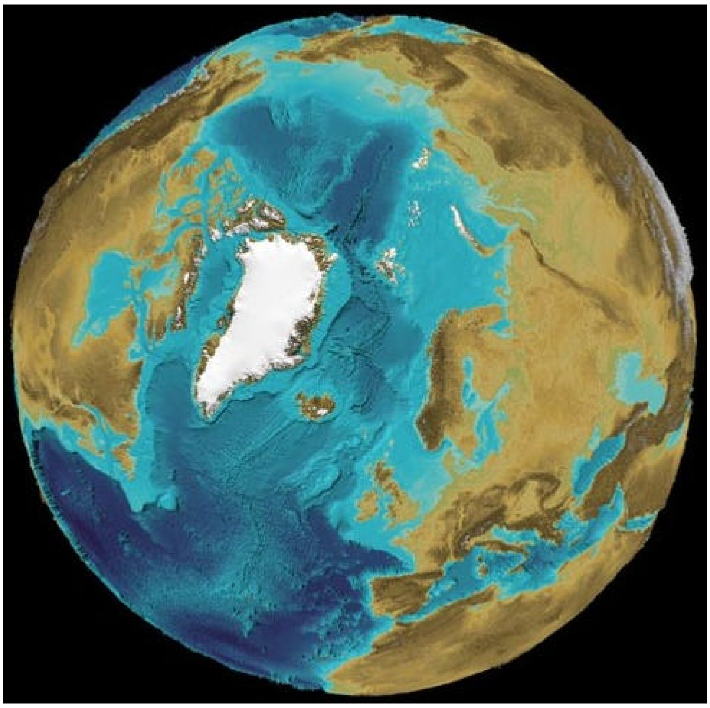


Figure 8. Bathymetry and topography of the Earth as it would appear from a point above the Norwegian-Greenland Sea, with the oceans drained. This representation was constructed with the ETOPO2 data set (NGDC, 2003), in which the sea floor is described by a combination of IBCAO and global satellite-derived bathymetry over a 2 minute by 2 minute grid.

It is beyond the scope of this discussion paper to develop an organizational structure that could handle the administrative and technical tasks involved in the implementation of the DBC. However, should GEBCO and IOC perceive some merit in the idea, it is suggested that a prototype DBC be developed based on the existing IBCAO grid, which is already in a form that would be highly amenable to this kind of packaging.

Conclusions

The success of the IBCAO undertaking and the high acceptance of its outputs are due in large part to project organization, to advanced data handling methodologies, and to a liberal distribution policy. Many of the lessons learned in this initiative, along with the procedures developed, could be used to revitalize GEBCO and to increase the relevance of its outputs to the modern oceanographic community.

Acknowledgements

Since its inception in 1997, the IBCAO activity has benefited significantly from the cooperation of members of the Editorial Board of IBCAO and their parent organizations (all are listed on the project website), from the support of key contact persons in the sponsoring bodies IASC, IHO, IOC, and from the fiscal resources placed at the project's disposal by the US Office of Naval Research and the Swedish Polar Secretariat. The authors are indebted to their many associates with whom they exchanged ideas concerning a new approach for global bathymetric mapping, as well as the concept of the Digital Bathymetric Chart.

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Author biographies

Ron Macnab began his seagoing career aboard vessels of the Royal Canadian Navy, where he developed an interest in marine science. Upon completion of his naval service, he undertook graduate studies in Oceanography and then joined the Geological Survey of Canada as a marine geophysicist. Over the next thirty years, his duties included ocean mapping, data compilation and analysis, and investigations related to the implementation of Article 76 of UNCLOS.

Martin Jakobsson joined the Center for Coastal and Ocean Mapping/Joint Hydrographic Center at the University of New Hampshire in 2000, after completing a PhD at the Department of Geology and Geochemistry, Stockholm University. His thesis was titled "Mapping the Arctic Ocean: Bathymetry and Pleistocene Paleoceanography." Martin=s current research interests are Paleoceanography and seafloor processes of the Arctic Ocean, the development of robust techniques for combining historical and contemporary bathymetric data sets, tracking uncertainty in gridded bathymetric models, and the use of GIS for handling and analyzing marine geological/geophysical data.

Herman Varma joined the Canadian Hydrographic Service in 1972 and served as a marine surveyor for several years before specializing in the management, processing, and visualization of the very large databases that were beginning to proliferate with the routine use of multibeam sounding systems. Among his many contributions are the development of efficient coding systems for complex databases, and participation in international standards work concerning bathymetric data models.