INTO THE DIGITAL AGE – THE GEBCO DIGITAL ATLAS

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Summary

For almost two decades (1984-2003), the technical focus for the development of GEBCO has been provided through its Sub-Committee on Digital Bathymetry (SCDB). During the period 1984-93, the Sub-Committee's activities were centred primarily on the digitization of the GEBCO 5th Edition and the establishment of an international database of digital echo-soundings. Thereafter, the focus switched to considering how digital techniques might be exploited to enhance and develop GEBCO. Particular attention was paid to the updating of the GEBCO contours and the creation of the GEBCO bathymetric grid. The paper reviews GEBCO's activities in the digital field, starting with the introduction of digital techniques in the 1980s and culminating with the release of the Centenary Edition of the GEBCO Digital Atlas in April 2003. An extended version of this paper, complete with figures and bibliography, may be found in the GEBCO Centenary Volume.

Introduction

From the outset, the GEBCO Sub-Committee on Digital Bathymetry (SCDB) rapidly established itself as an international forum for bathymetric mapping experts, from both the hydrographic and geoscience communities, to meet and exchange ideas on an annual basis. It has given GEBCO a mechanism for keeping in touch with ongoing bathymetric mapping activities worldwide and has enabled it to keep abreast of modern developments and technologies. In addition to bathymetrists, the SCDB has over the years attracted a wide range of experts in related fields such as marine geophysics, hydrography, satellite altimetry, geographic information systems, marine data management, and ocean mapping technology. These links have proved invaluable in developing a broad-based vision for GEBCO's activities.

So as to promote the work of GEBCO and engage as wide a community as possible in its activities, the SCDB's annual meetings have been held at a range of institutions worldwide including hydrographic offices, marine laboratories, data centres and university research centres. The list of venues for the annual meetings given below reflects the Sub-Committee's wide-reaching approach:

1984(5): US Naval Oceanographic Office, Bay St Louis, USA
1985(7): *Bureau Gravimétrique International*, Toulouse, France
1986(8): Intergovernmental Oceanographic Commission, Paris, France
1987(12): National Geophysical Data Center, Boulder, Colorado, USA
1988(15): Institute of Oceanographic Sciences, Wormley, UK
1989(19): National Geophysical Data Center, Boulder, Colorado, USA

1990(16): *Alfred-Wegener-Institut für Polar- und Meeresforschung*, Bremerhaven, Germany
1991(25): Head Department of Navigation and Oceanography, St. Petersburg, Russia
1992(17): British Oceanographic Data Centre, Bidston, UK
1993(28): National Geophysical Data Center, Boulder, Colorado, USA
1994(16): University of New Brunswick, Fredericton, Canada
1995(21): SACLANT Undersea Research Centre, La Spezia, Italy
1996(20): East-West Centre, Honolulu, USA
1997(26): UK Hydrographic Office, Taunton, UK
1998(26): Institute of Geological and Nuclear Sciences, Wellington, New Zealand
1999(32): Geological Survey of Canada, Dartmouth, Canada
2000(27): Royal Danish Administration of Navigation & Hydrography, Copenhagen, Denmark
2001(21): Japan Hydrographic Department, Tokyo, Japan
2002(25): University of New Hampshire, Durham, USA

Numbers given in parenthesis above refer to the number of experts attending each meeting. Whereas the SCDB started off as a small group of experts working on a limited number of specific tasks, once progress had been demonstrated on these tasks the SCDB soon attracted a broad forum of experts keen to collaborate in the work of GEBCO.

Digitization of the GEBCO 5th Edition

At the outset, the SCDB was tasked with maintaining a watching brief on those agencies or institutes intending to digitize the GEBCO 5th Edition and with investigating how digital techniques might be used to expedite production of the 6th Edition. In the event, it undertook the lead role in co-ordinating the digitization of the 18 sheets of the 5th Edition and in establishing what is now called the GEBCO Digital Atlas.

Digitization of the 5th Edition proved a major task and took the best part of ten years to complete (1984-1993). As usual, funding was a major problem and the provision of resources for the work was dependent on the foresight and goodwill of national agencies. The successful completion of the task relied heavily on the generous co-operation of two organisations in particular; the French *Institut géographique national* (IGN) through support given to the *Bureau gravimétrique international* (BGI) in Toulouse; and the UK Natural Environment Research Council (NERC) through its support of the British Oceanographic Data Centre (BODC).

The project was initiated by the BGI in 1983 but progress in digitizing was slow in the early years due to difficulties in developing the necessary software to undertake the work. The immensity of the task was well beyond what could be achieved using manual curve-following techniques and the IGN undertook to raster scan the sheets. Although raster scanning technology was readily available in the early 1980s, the associated vectorizing software systems were not capable of dealing with the complexity and richness of information presented on the printed GEBCO sheets. An interactive system for editing and labelling contours was eventually developed at the BGI and work was soon completed in digitizing the contours of the circum-Antarctic sheets (5.13, 5.14, 5.15, 5.16 and 5.18). These data became available through BODC in 1987 and shortly thereafter work was completed on sheet 5.01. However, the sheets of the North Atlantic (5.04 and 5.08) took a further two years to complete due to their complexity and the labour intensive nature of the work. Work was also completed on the Arctic sheet 5.17. Unfortunately, in early 1989, BGI was forced to suspend further work on the digitization project due to lack of resources.

Recognising the importance of a high quality digital data set of global bathymetry for ocean modelling, the UK NERC agreed in 1990 to fund the completion of the digitization project and to provide a facility to support the future updating of the data set. This was achieved by establishing two fulltime posts; the post of GEBCO Digital Atlas Manager at BODC and the post of GEBCO Bathymetric Editor at the Institute of Oceanographic Sciences, which later was moved to Southampton as part of the Southampton Oceanography Centre. Significantly, NERC also provided BODC with specialist technical support from its research unit at the University of Reading, the NERC Unit for Thematic Information Systems (NUTIS). The Unit was instrumental in identifying and installing state of the art technology at BODC to support the project. This included the Laser-Scan VTRAK system which provided BODC with a highly effective facility for vectorizing, editing and labelling raster scanned contours and, for the past decade, this system has underpinned the digitization, manipulation and management of GEBCO data at BODC.

Prior to its installation at BODC, NUTIS staff successfully used the VTRAK system to digitize the contours of the Pacific sheets 5.03, 5.07, 5.10 and 5.11. In parallel with this, the IGN was able to provide BGI with further funding in 1990 which resulted in the digitization of the contours of the Indian Ocean sheets 5.05 and 5.09. The Head Department of Navigation and Oceanography at St Petersburg contributed by supplying digitized contours for sheet 5.02 in the Arctic and north-east Pacific, while BODC successfully compiled the data set for the Pacific sheet 5.06 using digital data provided by the Japan Oceanographic Data Center.

Before the digitization of the 5th Edition was completed, the GEBCO Guiding Committee decided that sheet 5.12 in the South Atlantic should be revised and that digital techniques should be used in the revision. The revised contouring of various sections of the sheet was carried out by scientists in the USA, Russia, New Zealand and the UK. Following review by two nominated GEBCO experts, the hand drawn contours were submitted to BODC for digitizing and compiling into a single seamless sheet. The contents of the digital file were then used by the Canadian Hydrographic Service as a base from which to print a revised version of sheet 5.12 in 1994.

Prior to their release, the digitized contours for each sheet were reviewed in detail at BODC. This review involved plotting out the contour vectors on the same scale and projection as the published sheets, and checking out the registration and labelling of each vector – no mean feat considering that the 18 sheets of the 5th Edition produced some 95,000 contour segments. BODC was also responsible for edge-matching the digitized contours between the various sheets so as to ensure that the resultant data set provided seamless bathymetry across the globe for the basic GEBCO contours i.e. at 0m, 200m, 500m, and at 500m intervals thereafter.

Recognising that the digitized contours would be of limited value without corresponding information on the distribution of soundings used in their original compilation, it was decided that the trackline control information should also be digitized from the 5th Edition sheets. Using almost identical techniques and procedures to those used in digitizing the bathymetric contours and coastlines, the tracklines were digitized on a sheet by sheet basis from 1990 to 1993. Two sheets were digitized by the *Alfred-Wegener-Institut für Polar- und Meeresforschung*, Bremerhaven; three sheets by the Head Department of Navigation and Oceanography, St Petersburg; while the remaining 13 sheets were digitized by BODC. Quality control, final editing and reformatting of these data into a uniform data set were again performed at BODC.

The complete data set of the digital contours, coastlines and tracklines for the GEBCO 5th Edition was finalised in June 1993, thereby providing a high quality digital base from which future editions of GEBCO might evolve. The project was a major undertaking and more than fifteen staff years of effort were involved in bringing it to a successful conclusion.

A digital coastline for GEBCO

Having converted the 5th Edition contours into digital form, the updating of GEBCO was no longer constrained by the 1:10 million scale of the printed chart and it was envisaged that future updates might well be prepared at scales of up to 1:500,000 (or even up to 1:250,000 in isolated cases) in certain regions. However, by its very nature, the digitized 5th Edition coastline, based primarily on the *Carte générale du monde* of the *Institut géographique national*, Paris, was suited only for use at scales of the order of 1:10 million.

In 1989, a search was instigated by SCDB for an alternative coastline satisfying the criteria that it should be: a) digital, b) suitable for scales of up to 1:250,000, c) global in coverage, d) of consistent accuracy across the globe and e) available for use in GEBCO. It was fortunate that, just at that time, the US Defense Mapping Agency (DMA) (subsequently to become the US National Imagery and Mapping Agency (NIMA)) released its World Vector Shoreline (WVS) – the only coastline able to approach the GEBCO criteria. Acting on the advice of SCDB, the GEBCO Guiding Committee agreed in 1991 that WVS should be adopted as the standard coastline for use in the future updating of GEBCO and the DMA generously gave GEBCO permission for such use. The WVS is now also used as the standard coastline in most of the IOC's Regional Ocean Mapping Projects.

The WVS was developed by the DMA as a digital data file, at a nominal scale of 1:250,000. Worldwide coverage of the data set was completed in July 1989, working to a specification that 90% of all identifiable shoreline features should be located within 500 metres (i.e. 2mm at 1:250,000) of their true geographic position with respect to the World Geodetic System (WGS-84) datum.

The SCDB viewed WVS as an impressive product but was concerned that the target accuracy of 500m for WVS applied to only 90% of the world's shoreline and that no indication was given for the accuracy of the remaining 10% or where the areas with lesser accuracy occurred. It was anticipated that the main areas of reduced accuracy would probably occur around Antarctica and parts of the Arctic. Tests conducted on behalf of the SCDB confirmed the inaccuracies in WVS around the Antarctic continent and also identified the problem of defining a shoreline in the presence of ice in the coastal zone.

In non-polar regions of the world, the coastline is simply the boundary between the land and the sea. Being coincident with mean sea level, it also acts as the zero depth contour. However, in the Antarctic, the concept of a coastline is more complex and needs to represent the boundary between three domains *viz.* land, sea and ice shelf. With the publication of the Scientific Committee on Antarctic Research (SCAR) Antarctic Digital Database in 1993, a high quality seamless and coherent coastline of Antarctica became available for the first time. Not only was it in digital vector form but it also clearly codified the different types of coastline and included a far more comprehensive definition of ice shelf limits than had been available previously. Compiled from a combination of existing maps and satellite imagery, this new coastline was suitable for use at scales of up to 1:1 million.

For GEBCO purposes, it was decided in 1996 to standardise the coastline south of 60°S on the SCAR Coastline instead of WVS. As there are no coasts crossing the 60°S latitude boundary between the two data sets, there are no discontinuities of coastline.

Initialising and updating the GEBCO Digital Atlas (GDA)

The digitised contours, coastlines and tracklines of the 5th Edition were used to initialise what is now called the GEBCO Digital Atlas and which is maintained at BODC on behalf of the GEBCO community. The GDA now forms the base for the updating of the GEBCO contours. No longer constrained by the fixed scale and projection of the printed sheet, the GDA enables improved bathymetric compilations to be merged into GEBCO at scales ranging from 1:10 million up to 1:500,000 or better depending on the sounding density. New data can be readily “stitched in” so as to maintain a seamless data set.

Not only does the GDA provide a highly practical method for maintaining and updating GEBCO but it also forms the basis of a product in its own right, providing users with a digital source of data that can be readily manipulated and displayed according to their own particular needs. With this in mind, in 1992, the Guiding Committee invited BODC to prepare a PC-based product for disseminating the GDA data set to users according to specifications prepared by the SCDB.

The First Release of the GDA was published on CD-ROM by BODC in March 1994. It was accompanied by a purpose-built PC software interface, providing the user with a powerful and user-friendly tool kit for selecting, interrogating, visualising, overlaying and exporting data from the GDA. The CD-ROM included a complete set of the digitized bathymetric contours, coastlines and tracklines from the GEBCO 5th Edition. It also included digital bathymetric contours and coastlines from the 1st Edition of the IOC International Bathymetric Chart of the Mediterranean (IBCM) and a set of digital global coastlines based on the World Vector Shoreline.

A Second Release of the GDA was published on CD-ROM by BODC in March 1997 including revised bathymetry for the southern Indian Ocean, Weddell Sea and the north-east Atlantic off the British Isles. In addition, it included the SCAR coastline of Antarctica. The published CD-ROMs are in use in over 1,000 institutions across the globe including research laboratories, hydrographic offices, universities, private companies and government departments. By 2002, BODC had distributed some 1,320 copies to users in 87 countries worldwide.

The updating of GEBCO using digital techniques effectively started with the revision of sheet 5.12 in 1993. Instead of digitizing the printed sheet at a scale of 1:10 million, the digitization was actually carried out prior to the printing process using base material prepared at a scale of 1:5 million. Furthermore, when the GDA was published in 1994 the GEBCO bathymetry for the Mediterranean was replaced by previously digitized contours taken from the 1:1 million scale charts of the IBCM. These serve as the first examples of the GDA being updated at scales of better than 1:10 million.

The GDA is updated and maintained at BODC by the GDA Manager, Pauline Weatherall, using proprietary Laser-Scan mapping and database software. As each new compilation is received, careful checks are made on the quality of digitization including contour labelling, geographic registration, and conformance with any hard copy charts that may have been published from the compilation. Checks are also made against the GEBCO shorelines and any necessary editing is carried out interactively. In merging new sheets into the GDA, careful attention is paid to edge-matching the basic GEBCO contours (i.e. 200m, 500m, and 500m intervals thereafter) across the boundaries of the sheets into the surrounding GDA bathymetry so as to maintain a seamless bathymetry. Intermediate contours are only edge-matched if present on both sides of the boundary.

In recent years, GEBCO has been able to benefit from outputs provided by a number of IOC Regional Ocean Mapping Projects in addition to the IBCM including the International Bathymetric Chart of the Caribbean Sea and Gulf of Mexico (IBCCA), the International Bathymetric Chart of the Central Eastern Atlantic (IBCEA) and the International Bathymetric Chart of the Arctic Ocean (IBCAO).

Since 1994, the bathymetry of about one third of the world's oceans has been revised and submitted to BODC for updating the GEBCO Digital Atlas. This includes nine major contributions of revised bathymetric contours compiled at scales of 1:1 million or better:

a) Arctic Ocean north of 64°N: a completely revised set of contours for the Arctic was prepared for GEBCO by Norman Cherkis (formerly of the Naval Research Laboratory, Washington) and Martin Jakobsson (University of New Hampshire, Durham). It was compiled from the gridded data set of the IBCAO.

b) North-east Atlantic: covering over 50% of the area east of the Mid Atlantic Ridge, this compilation was prepared for GEBCO by Peter Hunter at the Southampton Oceanography Centre. It also includes IBCEA Sheet 1.01 off Iberia prepared by the *Instituto Hydrográfico*, Lisbon; and a bathymetric map of the Bay of Biscay compiled by Jean-Claude Sibuet at the *Institut français de recherche pour l'exploitation de la mer*, Brest.

c) Caribbean Sea and the Gulf of Mexico: covering the Gulf of Mexico and the northern part of the Caribbean, this contribution was submitted to GEBCO by Lisa Taylor of the National Geophysical Data Center, Boulder and by José Frias Salazar of the *Instituto Nacional de Estadística, Geografía e Informática* in Mexico. It comprises IBCCA Sheets 1.01 to 1.09.

d) Central Eastern Atlantic: updated bathymetry for this area comprises the six IBCEA Sheets 1.06 and 1.08 to 1.12 produced by the *Service hydrographique et océanographique de la marine* (SHOM) in Brest, France and delivered to GEBCO in digital form

e) Weddell Sea: covering the area of the Weddell Sea, Bransfield Strait and Drake Passage south of 60°S, this new chart was provided to GEBCO by Hans-Werner Schenke and his co-workers at the *Alfred-Wegener-Institut für Polar- und Meeresforschung* (AWI), Bremerhaven. It also includes a contribution from Gleb B. Udintsev and his colleagues at the Vernadsky Institute of Geochemistry and Analytical Chemistry, Moscow.

f) Greater Indian Ocean – this is by far the largest contribution to the updating of GEBCO, covering almost a quarter of the world's oceans and extending out to 12°W in the Atlantic and to 170°E in the Pacific. It was compiled by Dr Robert L Fisher at the Scripps Institution of Oceanography, La Jolla, and represents a major personal achievement of considerable benefit to GEBCO and its user community. The contours were compiled on some 250 sheets at a scale of four inches per degree longitude (approximately 1:1 million) over a ten year period up to 2002.

g) Waters around New Zealand: the regional bathymetric map of New Zealand was delivered as a contribution to GEBCO by Ian Wright of the National Institute of Water and Atmospheric Research (NIWA) in Wellington.

Work on incorporating these data into the GEBCO Digital Atlas was completed in October 2002. It will be noted that the new material is at a considerably larger scale than the 1:10 million scale of the GEBCO 5th Edition. This reflects the move of GEBCO away from the fixed scale paper chart and the ultimate goal of enhancing GEBCO with the best available bathymetry.

The GEBCO Bathymetric Grid

From the outset, the SCDB clearly recognised the importance of generating a gridded version of GEBCO on a uniform global grid. With modern computing technology, the gridded format offers far more flexibility than traditional contour vectors, particularly in modelling applications and in the visualisation and manipulation of data. The topic first arose in the context of applying Digital Terrain Modelling techniques to bathymetric mapping. Most of these efforts were concentrated on multi-beam survey data where the density of soundings was sufficient for the application of such techniques. For many years, the SCDB was kept abreast of developments in the field through the work of Hans-Werner Schenke and his colleagues at AWI, in the Weddell Sea. In 1988, a small Task Team was established under Dr Schenke to keep the SCDB informed.

In the period up to 1994, considerable discussion took place within the SCDB on possible ways and means of generating a GEBCO grid. The focus of attention at the time was on the generation of a grid based on the actual soundings rather than using the digitized contours. However, these efforts were compromised by the problems inherent in the available coverage of sounding data i.e. the inhomogeneous distribution of data at centres such as the IHO Data Centre for Digital Bathymetry and the fact that the data emanated from a wide diversity of sources with highly variable accuracy. Of particular concern were the navigation errors contained in much of the earlier data, an unknown level of dubious soundings and crossover errors between tracks. These problems were of course well familiar to the traditional bathymetrist forced to apply his own interpretive skills in order to generate a coherent set of contours.

With the publication of the First Release of the GDA, the SCDB reinvigorated its attempts to generate a grid and a small Task Team was established in 1994 to research the issue under the leadership of Walter Smith of the US National Ocean Survey (now at the NOAA Laboratory for Satellite Altimetry). The digital contours from GEBCO sheet 5.12 (revised) were used as a test bed on which to evaluate the various gridding techniques available. Considerable experience was gained in the problems related to generating a GEBCO grid and the focus shifted back to using the GEBCO contours as the source data.

In 1997 a draft paper “On the preparation of a gridded data set from the GEBCO Digital Atlas contours” was prepared by the SCDB Task Team. It provided a comprehensive review of the problem including the needs of potential users, mathematical considerations, and the strengths and weaknesses of the various methods available to compile the grid. Mike Carron of the US Naval Oceanographic Office co-ordinated the next phase of the work which was to discover what was reasonably possible to achieve, given the time and resources available to GEBCO.

In the event, it was decided the GEBCO grid should be based on the most up to date version of the GDA contours and that computation of the grid should be carried out by a network of volunteering centres using common algorithms based on “rubber-sheeting” techniques. Members of the network were well versed in the problems of gridding and made extensive use of the widely-used GMT package of software programs. Initially, the grid was to be produced at 2.5 minute intervals in geographic latitude and longitude but in early 2002 it was decided to create the grid at 1 minute intervals so as to better replicate the contours.

In late 2002, the first version of the global grid was completed and made available for inclusion in the GDA. The work was co-ordinated by Mike Carron with major input provided by the gridding efforts of Bill Rankin and his co-workers at the US Naval Oceanographic Office, Andrew Goodwillie at Scripps Institution of Oceanography and Peter Hunter at Southampton Oceanography Centre. Significant regional contributions were also provided by Martin Jakobsson, Hans-Werner Schenke, John Hall (Geological Survey of Israel) and Ian Wright (NIWA). Technical advice on algorithms was provided by Walter Smith.

IHO Data Centre for Digital Bathymetry

From its first meeting, the SCDB took a keen interest in the establishment of an international computer-based system for the management and dissemination of echo-sounding data. At the time, the international soundings data bank was maintained in hard copy form on 1:1 million scale Ocean Plotting Sheets. These sheets were maintained by a network of volunteering Hydrographic Offices in 18 IHO Member States. Each of the Volunteering Hydrographic Offices (VHOs) accepted responsibility for compiling bathymetric data in specific geographic areas and for periodically updating the Ocean Plotting Sheets in their area of responsibility. Individual Hydrographic Offices were charged with ensuring the regular supply of bathymetric data to the appropriate VHO and the IHB in Monaco maintained a co-ordinating role in this scheme, issuing information on the status of the various sheets from time to time.

The Ocean Plotting Sheets formed the base from which much of the contouring of the GEBCO 5th Edition was compiled. However, during the preparation of the 5th Edition in the early 1980s, it became apparent that a number of the GEBCO scientists responsible for undertaking the contouring had at their disposal considerably more data than appeared on the 1:1 million sheets maintained by the VHOs. The shortfall in data submission to the VHOs appeared closely related to the introduction of computer techniques for the handling of bathymetric data, particularly in the geoscience community. Since the late 1960s, geoscientists had been finding it far more convenient to store and exchange their data in computer files and to plot out data automatically as and when the need arose. Computer techniques also enabled far greater volumes (and densities) of echo-sounding data to be handled than could be readily hand scribed onto plotting sheets.

The SCDB reviewed this situation in 1986, recognising that a major part of the missing data might well be found in the underway marine geophysics database maintained by the US National Geophysical Data Center (NGDC) in Boulder. At that time, the Boulder centre held almost 2,000 cruises of bathymetric, magnetic and gravity data, primarily from US laboratories but also with contributions from Japan, France, Russia, UK, New Zealand, Canada, South Africa and China. The database already included over seven million nautical miles of digital echo-sounding data and had clearly demonstrated the practicality and value of computing techniques for managing such data.

The SCDB advised that, in pursuing its goal of maintaining a global collection of sounding data for the deep ocean, the IHO should seek to collaborate with the US NGDC in creating a digital database for sounding data. At its meeting in Paris in 1986, the SCDB drafted supporting documentation to facilitate such collaboration. In 1987, the US Government submitted a proposal based on the SCDB documentation to the XIIIth International Hydrographic Conference for the establishment of an IHO Data Centre for Digital Bathymetry (DCDB) to be operated by the US NGDC on behalf of the IHO. In 1990, the IHO Member States agreed to this proposal and on 1st June 1990 the IHO DCDB was duly established, co-located with the US NGDC in Boulder.

The IHO database of digital, single beam echo-sounding data is co-held within NGDC's GEODAS (Geophysical Data System) database of worldwide underway geophysics data. When the IHO database was first established in 1990, the GEODAS database held over 18 million echo-soundings collected on more than 2,500 cruises/cruise legs and covering a track distance of 9.3 million nautical miles. By June 2002, the IHO DCDB had assimilated a further 23 million echo-sounding values covering 5.2 million nautical miles of track into the GEODAS database. The total GEODAS database in June 2002 contained some 41 million echo-soundings from 4,425 cruises/cruise legs covering a track distance of 14.5 million nautical miles.

The innovative use of computing techniques at NGDC has revolutionised user access to the worldwide collection of echo-sounding data. A major step forward was taken in March 1993, when NGDC released a two volume CD-ROM version of its complete GEODAS data holding. It contained all data assimilated up to the end of 1992 and was accompanied by a user friendly software interface providing the user with direct access to over 4 gigabytes of marine geophysical trackline data, including the complete holding of single beam echo-sounding data.

Following the success of the CD-ROM publication, NGDC released updated versions of the CD-ROM on an almost annual basis up to the end of 1998, thus ensuring that users were kept up-to-date with the holdings of the GEODAS database. Thereafter, NGDC adopted the methodology of posting updated data on the Internet as soon as they were assimilated into GEODAS, thereby greatly minimising any delay in making newly submitted data (including the echo-sounding data submitted to the IHO DCDB) available to users. In June 2002, a new release of the GEODAS CD-ROM was issued including all updates assimilated up to the end of May 2002. This latest release (Version 4.1) now occupies three CD-ROMs and offers over 7 gigabytes of marine geophysical trackline data. With each succeeding release, the software interface to the data has been enhanced and now provides the user with a powerful set of tools for selecting and plotting the data. It also provides the users with a simple interface for exporting user-selected data into their own applications.

SCOR Working Group 107

In late 1995, the Executive Committee of the Scientific Committee on Oceanic Research (SCOR) decided to establish a new Working Group (WG 107) on the topic of Improved Global Bathymetry with Terms of Reference a) to establish the scientific needs for improved ocean bathymetry; b) to determine the specifications for accuracy and resolution in different areas; and c) to recommend actions and priorities

The Working Group, which included a number of GEBCO experts, met on two occasions; at Southampton Oceanography Centre, UK on 11-13 November 1996 and at Johns Hopkins University, Baltimore, USA on 27-28 October 1997. The Working Group report was finalised in autumn 2001 and published by UNESCO on behalf of IOC in 2002.

WG 107 prepared a strong scientific case for improving global bathymetry, identifying it as a prerequisite for progress in the scientific understanding of the different components of the earth's global systems, and for intelligent management of global resources. It recognised that data on the shape of the seabed are necessary in a great variety of applications e.g. to select sites for communications cables and fisheries; to make inferences about the geological history and energy and mineral resource potential of ocean floor structures; and to guide computer simulations of the behaviour of the oceans. These simulations are important in predictions of the hazards faced by coastal communities (e.g. approaching tsunamis) and in predictions of the future patterns of climate change on time scales of months to decades. Improved knowledge of the shape of the seabed is one of the factors required for success of the planetary scale global observing systems (GOOS, the Global Ocean Observing System, and GCOS, the Global Climate Observing System), the operations of which will help mankind to manage sustainably an increasingly crowded Earth.

The Working Group identified 6 priority actions for the near future and made 34 recommendations as to how these priorities could be met and other issues addressed. Several recommendations relate to changes that are required in the policies of national funding agencies so as to facilitate the acquisition and availability of bathymetric data. Bearing in mind the constraints on funding, WG 107 decided that gathering additional data by ships equipped with swath bathymetry and side-scan sonar systems, though crucially important especially in data gaps, would not be the first priority. It recommended that much could be done by working more effectively and efficiently with what had already been collected, so the initial focus should be on getting more data into the system. Against this background, the Working Group concluded by recommending the following priority actions:

Priority 1: Turn equipment on to generate more data (all too often expensive echo-sounding equipment is not turned on, thus wasting the potential to acquire the data – a penny wise/pound foolish approach to scientific management).

Priority 2: Digitise the data that are presently available, and send new data automatically and in digital form to data centres.

Priority 3: Begin serious investment in data rescue (data archaeology).

Priority 4: Encourage cruises to fill the substantial gaps that exist especially in the South Pacific, South Atlantic, Indian, Southern and Arctic Oceans, in the Arabian Sea, in the back-arc basins between China and Kamchatka, and in places in the North Atlantic and the North Pacific (e.g. between Hawaii and North America).

Priority 5: Use new technology (e.g. drifting floats and autonomous marine vehicles) to gather new data from large data gaps.

Priority 6: Investigate the possibility of acquiring data from commercial ships by voluntary means.

Discussion

SCOR WG 107 has clearly emphasised the need for improving the coverage of bathymetric data whether by improving the management of data already collected or by encouraging the collection of new data, particularly in data gaps. The former is a combination both of developing, resourcing and implementing national policies to ensure the timely delivery of quality data to the IHO DCDB and of rescuing data at risk.

Despite the successes at NGDC in assembling a global database of digital echo-soundings, much work remains to be done to maximise the submission of data and to ensure a routine flow of data from all quarters of the globe. National commitments are required to ensure the searching out and delivery of data. In the pre-digital era, Hydrographic Offices were responsible for ensuring the input of national data to the Ocean Plotting Sheets and the VHOs took responsibility for assembling and searching out data in their respective geographic regions. Analogous but updated networking mechanisms are now required to support the activities of the IHO DCDB. In addition, resources need to be found to rescue and digitise data that currently reside in analogue form.

The defence interests of several countries have led to large areas of high quality bathymetric survey being classified. Some of these areas have since been declassified and made available to GEBCO, but many more remain and could provide extremely valuable additional data for GEBCO. For example, the IBCAO project and GEBCO have benefited greatly from the release of bathymetric data collected by the US Navy and, to a lesser extent, by the British Royal Navy, during patrols beneath the permanent ice cover of the Arctic Ocean between 1957 and 1988.

Unless major new initiatives such as the proposed Global Ocean Mapping Project, GOMaP, come to fruition, it is likely for the foreseeable future that the mapping of the deep ocean will continue to rely to a large extent on the data already collected over the past one hundred years. In this context, the two key problems that confront the bathymetrist in compiling GEBCO scale charts are the quality and coverage of the source data – the former leads to uncertainty as to how to deal with conflicting data, particularly at cross-overs, while the latter means that interpretive skills are required to predict the bathymetry in the vast spaces between tracks.

Two technological advances have greatly eased these problems over the past two decades; the advent of the Global Positioning System (GPS) and a number of highly successful satellite altimetry missions providing sea-surface gravity fields with virtually global coverage. With tracks navigated by GPS (and its forerunner satellite navigation systems), the bathymetrist is delivered sounding depths with virtually no associated positional error and which can be used as control data. The satellite gravity fields on the other hand provide unique insights into the distribution of mass below the sea surface (which is closely associated with bathymetry) – although of limited application in highly sedimented areas, they nevertheless provide key information on trends and structures in sediment free areas. They have also been used to good effect to predict the bathymetry in areas where the sounding coverage is sparse.

The updated sheets of the GEBCO Digital Atlas (including revised sheet 5.12 but with the exception of parts of the Arctic) have all made use of the gravity fields from satellite altimetry and have also benefited from the availability of satellite navigated soundings. However, the sheets in the Pacific and parts of the North Atlantic are in urgent need of updating. They were compiled in the era before satellite altimetry and lack all sounding data collected over the past 20 years and more. This represents a major challenge for GEBCO in the years ahead.

Concluding Remarks

The past two decades have been a challenging period for the SCDB and for GEBCO. The use of digital techniques has played a key role in the updating of the GEBCO contours, the creation of a GEBCO grid and the management of echo-sounding data. More importantly it has revolutionised the use which can be made of GEBCO and the methods by which bathymetry can be compiled and processed. The SCDB has had many stimulating discussions on the relative merits of contouring and gridding data, on the role of automatic techniques in generating GEBCO's products and on the application of satellite altimetry to the prediction of bathymetry.

These discussions will continue well into GEBCO's second century as techniques are sought and developed in support of the goals of GEBCO.

To coincide with the centenary celebrations of the GEBCO project, a Centenary Edition of the GDA is to be released in April 2003. It will contain a full release of the GEBCO contours, including completely new bathymetry for the Arctic and Indian Oceans as well as significant updates for areas of the North Atlantic, the Weddell Sea and the area around New Zealand. Just as importantly, the Centenary Edition will also include the first release of the GEBCO Bathymetric Grid, providing bathymetric data on a one minute global grid.

The Centenary Edition will be delivered as a set of CD-ROMs with a Microsoft *Windows* based software interface developed by BODC's software engineer, Ray Cramer. The interface will enable the GEBCO bathymetry to be viewed in a variety of forms and projections and enable users to select and download contour vectors and gridded data for use in their own applications.

One important aspect of GEBCO, which is continued in the Centenary Edition of the GDA, is the inclusion of trackline information highlighting the coverage of data used in its compilation. This is intended to act as a continual reminder to users that the world's oceans have not been systematically surveyed and that, for virtually all areas of the oceans, the mapping is based on the interpretation of random tracklines of data from a multitude of sources and with highly variable data quality and coverage.

In presenting the 1st Edition of GEBCO to the Paris Academy of Sciences in January 1904, Professor Julien Thoulet remarked "…..Here then is everything that is known today about the relief of the ocean floor. For many years to come, mariners, telegraphists, engineers, oceanographers, and scientists will continue their soundings, for now we must proceed to fill in the details; no point of any sea on the globe will escape our investigations…."

Nearly one hundred years on, Professor Thoulet's remarks appear equally applicable on the release of the Centenary Edition of the GDA. It is salutary to note that, whereas in the meantime high resolution topographic maps have been produced for Mars, Venus and the far side of the Moon, the mapping of the world's oceans will continue well into the foreseeable future. Moreover, it seems likely that it will depend, as in the past, on a small band of enthusiastic scientists across the world who are prepared to volunteer and apply their skills and energies to this challenging endeavour. It is the aim of GEBCO to encourage and facilitate these efforts and to strive continually to ensure that GEBCO can deliver the best available bathymetry of the world's oceans, following in the footsteps of those enlightened individuals who initiated the project a century ago.