BATHYMETRIC MAPPING OF THE NORTH POLAR SEAS

Report of a Workshop at the Hawaii Mapping Research Group, University of Hawaii, Honolulu HI, USA, October 30-31, 2002

Ron Macnab
Geological Survey of Canada (Retired)
and
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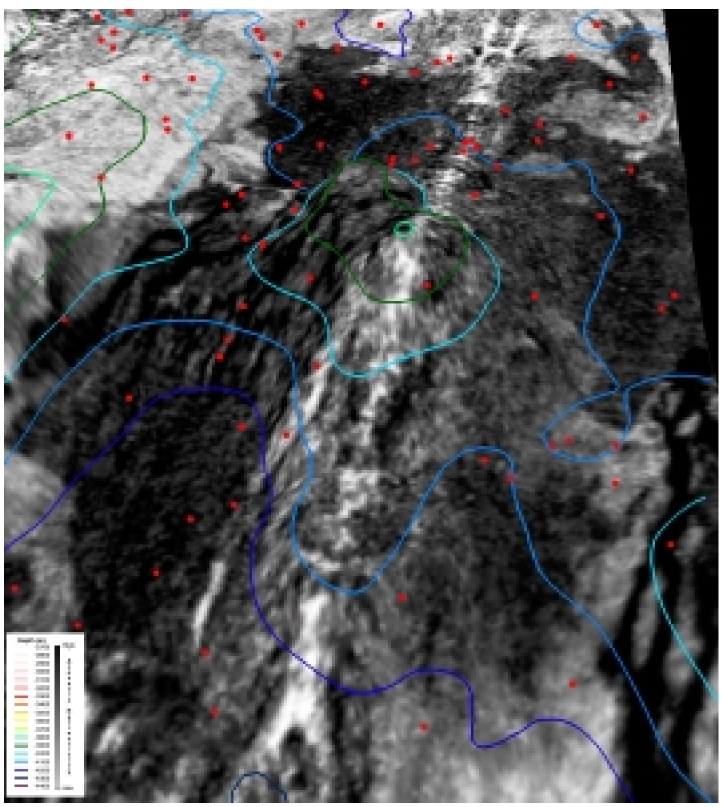

SCHOOL OF OCEAN AND EARTH SCIENCE AND TECHNOLOGY
UNIVERSITY OF HAWAII

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Cover Figure. Oblique view of new eruption site on the Gakkel Ridge, observed with Seafloor Characterization and Mapping Pods (SCAMP) during the 1999 SCICEX mission. Sidescan observations are draped on a SCAMP-derived terrain model, with depths indicated by color-coded contour lines. Red dots are epicenters of earthquakes detected on the Ridge in 1999. (Data processing and visualization performed by Margo Edwards and Paul Johnson of the Hawaii Mapping Research Group.)

This workshop was partially supported through Grant Number N00014-2-02-1-1120, awarded by the United States Office of Naval Research International Field Office. Partial funding was also provided by the International Arctic Science Committee (IASC), the US Polar Research Board, and the University of Hawaii.

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BATHYMETRIC MAPPING OF THE NORTH POLAR SEAS

1. Introduction

Ron Macnab (GSC Retired) and Margo Edwards (HMRG)

Scientific investigations continue to probe at the secrets of the Arctic Ocean, creating demands for better bathymetric maps to assist in the planning and execution of expeditions, and at the same time providing opportunities to collect new data that can be used to build such maps. This situation reflects the reality that in the deep Arctic Ocean, most modern bathymetric mapping is carried out in a somewhat ad-hoc fashion as an adjunct to scientific research, and not in a systematic manner during dedicated surveys. Therefore it behooves the scientific community to coordinate its bathymetric mapping efforts by exchanging information on a regular basis, and by pooling observations in a manner calculated to optimize the overall survey effort while circulating the results as widely as possible.

This meeting was organized in a workshop format to facilitate consideration of current mechanisms for improving our knowledge of Arctic bathymetry, as well as discussion of proposed initiatives for mapping and analyzing seabed features over a range of scales. The following is a list of the broad topics that were initially proposed for discussion, and which provided a framework for more detailed presentations:

1. The status of the International Bathymetric Chart of the Arctic Ocean (IBCAO), and developments that have occurred in northern ocean mapping since the Third Meeting of the IBCAO Editorial Board in May 2001.
2. The status of SCAMP data processing, and the integration of SCAMP results in the IBCAO data base and map.
3. Information concerning (a) the availability of other data sets, and (b) future mapping missions that could enhance the current database.
4. A proposal to produce a 1:6 Million IBCAO map, with consideration of arrangements for producing and circulating the map.
5. Advanced GIS techniques for handling and visualizing bathymetric data, with consideration of a proposal for developing a prototype digital atlas of the Arctic.
6. A suggested intercomparison between IBCAO and the latest (2002) map of Arctic Bathymetry produced by the Head Department of Navigation and Oceanography (HDNO) of the Russian Federation Navy.

The meeting, which was held by invitation at the Hawaii Mapping Research Group of the University of Hawaii, attracted a strong cross-section of specialists in Arctic bathymetry (See Appendix B). Taken together, the presentations summarized in the following sections addressed all of the topics listed above, and they stimulated considerable discussion; the main points of those exchanges are highlighted in the Conclusions of this report.

2. A prototype 1:6 Million map

Martin Jakobsson, CCOM/JHC, University of New Hampshire, Durham NH, USA

Funded by the Office of Naval Research (ONR), 1500 copies of the IBCAO Beta version were printed at a scale of 1:8,795,800 for inclusion in Stockholm University's Geology and Geochemistry thesis series (Jakobsson, 2000). This was a first step towards one of the main goals of the ICBAO project, namely to produce a map that could serve as a replacement for

GEBCO Sheet 5.17 of the Arctic Ocean. However, this first printed map was not perceived to be an adequate replacement for Sheet 5.17, because it was based on an early (Beta) version of the IBCAO grid, and its significantly smaller scale did not completely portray the details of the Arctic Ocean bathymetry that were contained in the IBCAO compilation. Nevertheless, the printed map was well received both within the Arctic scientific community and by the broader public, resulting in the distribution of all printed copies.

During the IBCAO Editorial Board meeting in 2001 at the Center for Coastal and Ocean Mapping/ Joint Hydrographic Center (CCOM/JHC) of the University of New Hampshire, the issue of producing a replacement for Sheet 5.17 was raised. All meeting participants strongly agreed that there is a growing demand for such a printed product. Inspired by this consensus, shortly after the 2001 Editorial Board meeting we began at CCOM/JHC the task of constructing a 1:6,000,000 scale replacement for GEBCO Sheet 5.17. Ron Macnab and I completed a first draft based on the newly released IBCAO Version 1.0 grid. A prototype of this map was printed and brought to Hawaii for review during the 2002 Editorial Board Meeting (Figure 2-1).

Sheet 5.17 is a traditional contour map that employs solid color fill between the GEBCO standard contour intervals. The proposed IBCAO replacement differs in many respects from this traditionally styled map. The most prominent difference is that instead of representing the sea floor bathymetry with color fill between defined isobaths, a shaded relief representing the seafloor is created by applying computer sun illumination to the IBCAO grid model (Figure 2-1). In addition, some selected key isobaths (250, 500, 1000, 1500, 2000, 3000, 4000, 5000) are superimposed on the shaded relief in order to facilitate precise reference to specific depths. The overall cartographic style and the names of seafloor features were taken from Sheet 5.17.

The review of the printed IBCAO draft map during this meeting may be summarized in the following points:

1. A 2500 m isobath should be added due to its importance in the context of Article 76 of the United Nations Convention on the Law of the Sea. This modification will also require an additional color to be added to the current bathymetric color table in order to make it consistent (each of the plotted isobaths is associated with a color change in the shaded relief).
2. As an experiment, it was suggested that a 100 m contour be added to the map.
3. Norman Cherkis will review all the geographic names that have been adopted from Sheet 5.17, and recommend others to be added.
4. Some misspellings were identified in the map legend.
5. Overprinting of hydrology on the shaded land relief has been suggested. This may be achieved by using the Digital Chart of the World (DCW) database. Since DCW is compiled at a scale of about 1:1,000,000 it will have to be reduced to a plotting scale of 1:6,000,000.

NGDC has offered to print the map as part of a formal publication series. An accompanying source distribution map will be prepared for printing at a smaller scale.

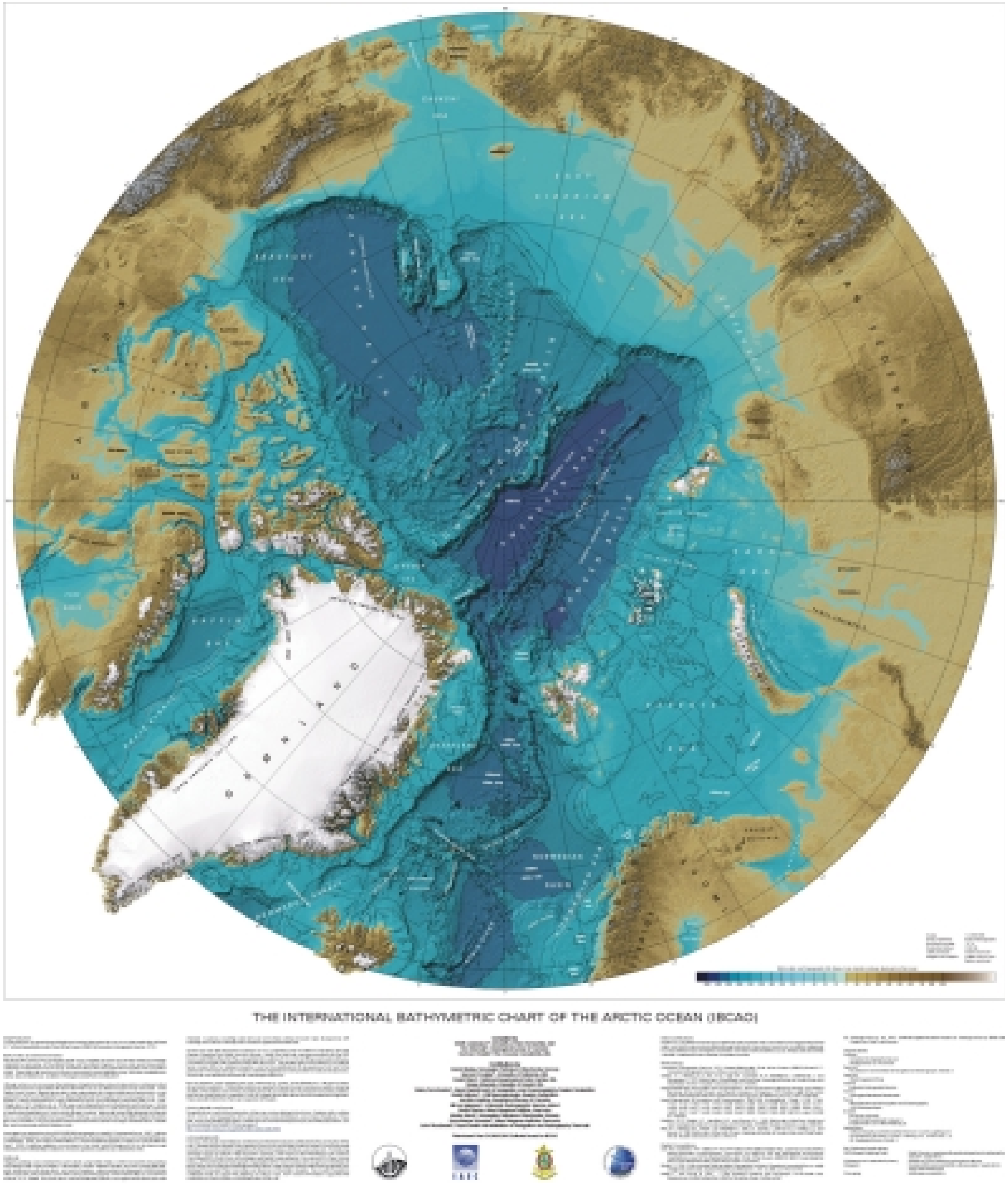


Figure 2-1. Draft of the proposed IBCAO replacement for GEBCO Sheet 5.17, to be printed at a scale of 1:6,000,000.

3. Russian Arctic shelf data

Volodja Glebovsky, VNIIOkeangeologia, St. Petersburg, Russia

A short description of VNIIOkeangeologia bathymetry data was presented at the Third Meeting of the Editorial Board (New Hampshire, May 27-28, 2001).

As explained at that meeting, in 1994 the Ministry of Natural Resources (known then as Roscomnedra), following the public release of some Russian onshore gravity data, declassified the printed offshore 1:1,000,000 gravity sheet series and labeled them as proprietary products that could be used for scientific and/or commercial purposes, subject to approval by the appropriate authorities. This allowed digitizing of depth soundings depicted on the declassified gravity maps, and the development of a 5 X 5 km bathymetry grid for the part of the area that was covered by printed gravity maps (see Figures 3-1 and 3-2). Such a grid was developed in VNIIOkeangeologia, and in 2001 it was submitted to the Ministry of Natural Resources for consideration of the possibility of releasing it in the public domain.

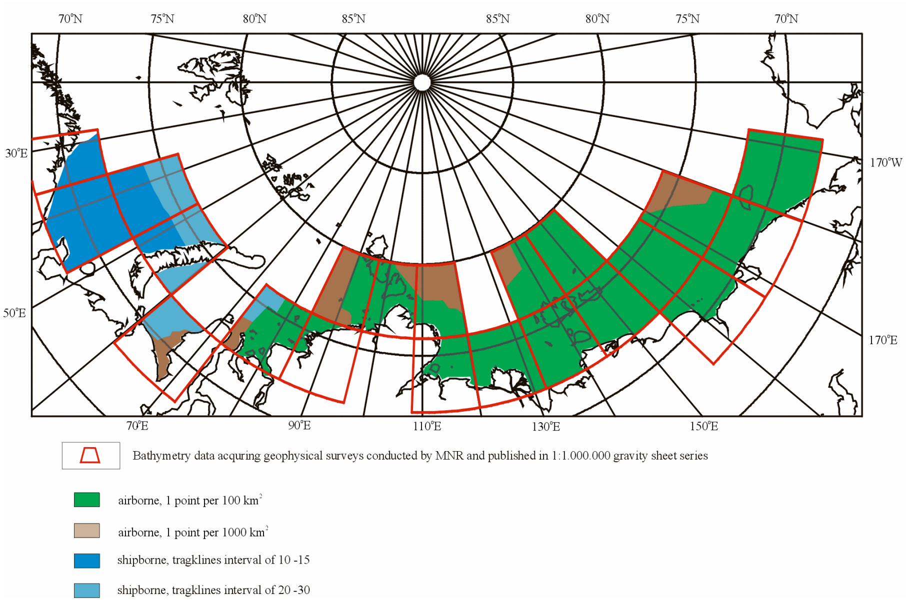


Figure 3-1. Bathymetric coverage of the Russian Arctic shelf.

Due to the reorganization of the Ministry and of the Commission of experts in charge of realization of gravity and bathymetry information, VNIIOkeangeologia still lacks permission to deliver this grid to IBCAO. VNIIOkeangeologia believes that the merging of this grid with the existing IBCAO digital database could significantly improve the dataset for the eastern Russian Arctic marginal seas from where the largest part of observations was derived. Here the IBCAO grid appears most vulnerable because it was developed predominantly by digitizing the contours from navigational charts, and these contours are very widely spaced due to the essentially flat bottom topography. More detailed point data used in the compilation of VNIIOkeangeologia grid could, perhaps, significantly compensate for this deficiency. The main characteristics of bathymetry data presented on sheets of State Gravity Map of the USSR at scale 1:1,000,000 are shown in Table 3-A.

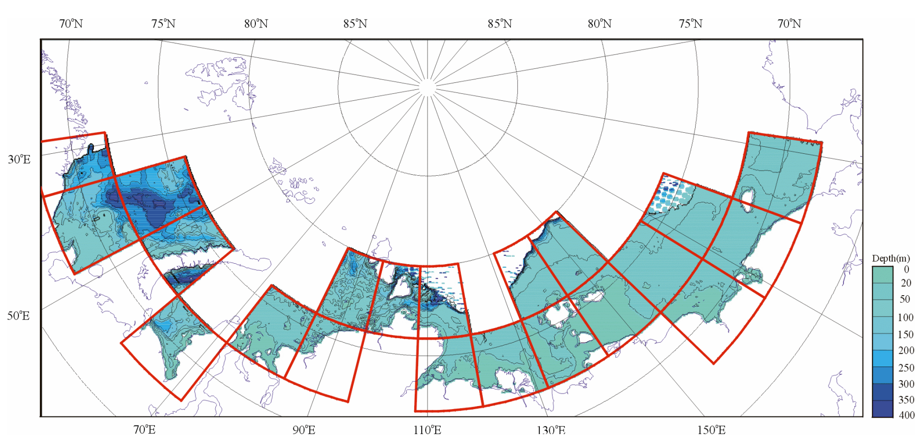


Figure 3-2. Bathymetry of the Russian Arctic shelf.

Type of observations, scale	Area	Navigation		Depth estimations	
		Type	Accuracy (m)	Method	Accuracy (%) of estimated depth (or m)
On ice observations, 1:1,000,000 – 1:3,000,000	Kara Sea, East-Siberian Sea, Laptev Sea, Chukchi Sea, and Deep Arctic Basin	Radio Navigation Integrated Radio Navigation and Astronomy	±200- 600 ±600	Single channel seismic Echosounding Leadline	± 0.1%-1% ± 0.5-1% ±5 m
Shipborne surveys, 1:1,000,000 - 1:3,000,000	Barents and Kara Seas	Satellite Navigation Radio Navigation Astronomy	±300 ±200 ±1000	Echosounding	±1-1%

Table 3-A. Main characteristics of Russian bathymetry data

4. New Russian bathymetry map of the central Arctic basin

Volodja Glebovsky, VNIIOkeangeologia, St. Petersburg, Russia

During the period 1995 to 2002, three maps based on bathymetry information collected by operating departments of the Head Department of Navigation and Oceanography (Russian Federation Ministry of Defense) were published:

1. Orographic Map of the Arctic Basin at scale 1:5,000,000 (1995). The map represents in detail the main geomorphologic structures of the Arctic Ocean.
2. Bottom Relief of the Arctic Ocean at scale 1:5,000,000 (1998). The map portrays isobaths at intervals of 200 meters in deep water, and 50 metres on the shelf.
3. Central Arctic Basin at scale 1:2,500,000 (2002). The map portrays isobaths at the same 200 meter interval in deep water (but in more detail), and 50 metres on the shelf.

All maps were drawn manually, using the photo projector technique to reduce initial large scale maps to the publication scale without generalization.

The bathymetry database used for these compilations included several different data sets:

1. Results of systematic echo-sounding from ice (more than 21,000 point observations)
2. Results of systematic seismic sounding from ice (more than 17,000 point observations)
3. Results of systematic bathymetry surveys from submarines (more than 91,000 linear km of profiles)
4. Results of bathymetry investigations collected by vessels in transit through the Arctic Ocean.

The foregoing data sets cover about 80 percent of the Arctic Ocean.

The best data coverage (about one point for every 5 square km) corresponds to oceanic ridge and rise areas. Flat bathyal (to 3000 m) and abyssal plains (with depth more than 3000-3500 m) are covered with an average distance of 15 km between observations. The accuracy of navigation and depth estimation for systematic investigation is less than or equal to ±600 m and less than or equal to 0.5% of measured depth.

Bathymetry information in the southernmost part of Canada Basin and west of Northwind Ridge is based on profile data collected by different vessels over a period lasting about 60 years. All available raw bathymetry information in the area was first combined, analyzed and adjusted, and next used for manual mapping. It is necessary to point out that in some places the coverage of adjusted facultative profile data is about one point for 3-5 km.

The scales of systematic bathymetry investigations in the Russian Arctic shelf vary from 1:25,000 to 1:2,500,000. In areas with poor systematic data coverage (East Siberian and Chukchi Seas) interpolated profile data was used as additional information to fill the gaps between profiles and points of systematic investigations. The scale of systematic bathymetry investigation in the Russian Arctic shelf was selected in most places to suit the observed characteristics of bottom relief.

In March 2002 Prof. Art Grantz kindly presented to HDNO some public domain bathymetry information that had been collected by Western investigators and which was available via the Internet. At about the same time, the final model of the new Russian bathymetry map was already prepared for publication. A preliminary analysis of the western data sets demonstrated the usefulness of this information in the south Canada Basin where there were no Russian systematic surveys. It is proposed to use these new data sets when developing future versions of the Russian bathymetry map.

It is necessary to point out that that in spite of the fact that all mentioned above maps are mainly based on the same bathymetry database, there are some essential differences between Russian bathymetry maps at scales 1:5,000,000 and 1:2,500.000. These are:

1. Detailed peculiarities of sea bottom relief (especially in the areas featuring steep-sloped rises and troughs) are more visible because of resolution.
2. The dimension and amplitude of an isolated rise in south Canada Basin (west of Northwind Ridge) are significantly reduced to better correspond to western data.
3. The sea bottom relief in the area that is situated between Spitsbergen Archipelago and Greenland (80-83º N) was corrected and is represented in more detail (because results of recent systematic investigations were included in present bathymetry data base).
4. Contours that define a few seamounts at the Gakkel Ridge near the transform zone between the Yermak Plateau and the Morris Jessup Rise have been corrected.
5. The calculated hypsometric scale is more detailed.
6. Additional isobaths of 2500 m are shown due to the statutory requirements of the UN Convention on the Law to the Sea.

Paper copies of the new Russian map of the Central Arctic Basin at scale 1:2,500,000 may be obtained by addressing requests to one of the following persons:

Captain Valeriy Fomchenko
Head Department of Navigation & Oceanography
Russian Federation Navy
8,11 Liniya, B-34
St. Petersburg, 199034 Russia
e-mail: gunio@g-ocean.spb.su

German Narishkin
VNIIOkeangeologia
1, Angliysky Avenue
St.-Petersburg, 190121, Russia
e-mail: vniio@g-ocean.spb.su

5. A new digital bathymetry map of the Laptev Sea

Volodja Glebovsky, VNIIOkeangeologia, St. Petersburg, Russia

This map was constructed in 2001-2002 by a team of six investigators (A.V. Zayonchek, A.A. Chernyh, E.A. Gusev, M.V. Mennies, O.G. Romaschenko, and E.I. Razouvaeva) affiliated with three institutions in St. Petersburg, Russia (St. Petersburg Branch of the Institute of Lithosphere of Marginal and Internal Seas of the Russian Academy of Science, All-Russia Geological Institute for Geology and Mineral Resources of World Ocean, and St. Petersburg State University). The work was funded by the German-Russian Otto Schmidt Laboratory for Polar and Marine Research under the project "Bathymetry of the Laptev Sea Continental Margin and the Main Relief Forms in the Late Cenozoic." These investigators had access to the following data sets that were generally more abundant and more detailed than the information that was used in the development of IBCAO:

1. Bathymetric observations appearing in the appendices of The State Gravity Map, Scale 1:1,000,000;
2. Bathymetric maps appearing in the appendices of State Geological Maps, Scale 1:1,000,000;
3. Bathymetric data from Russian navigational charts;
4. Echosounder and Parasound observations collected during German-Russian expeditions to the Laptev Sea (by AWI and GEOMAR aboard Polarstern).

Analog observations were digitized, analyzed, adjusted, and loaded in a coherent database. A 2.5 x 2.5 km grid was developed for use in constructing the final map in Arc/View. Comparison of the new map and grid with existing regional maps, with the 2001 IBCAO grid, and with observations collected by R/V "Polarstern-95" demonstrated a high correlation with the latter data sets. A new map, *Bathymetry of the Laptev Sea Continental Margin and the Main Relief Forms in the Late Cenozoic*, has been prepared and submitted to the Ministry of Natural Resources for publication approval. It is planned to transfer the results of the project to the Otto Schmidt Laboratory, and upon their approval to the public domain.

6. SCICEX/SCAMP data processing and status

Margo Edwards and associates, HMRG, University of Hawaii, Honolulu HI, USA

1. SCICEX programs and SCAMP

In 1995 the U.S. Navy and National Science Foundation cooperatively developed the SCience ICe EXercises (SCICEX), a five-year project to study the ice canopy, oceanography, biology and geology of the Arctic basin using nuclear-powered submarines. In 1998 and 1999, the U.S. Navy's nuclear submarine Hawkbill was equipped with the Seafloor Characterization and Mapping Pods (SCAMP), which included a 12-kHz Sidescan Swath Bathymetric Sonar (SSBS), a swept frequency High-Resolution Subbottom Profiler (HRSP), a BGM-3 gravimeter and a data acquisition and quality control system. SCAMP produced the first systematic three-dimensional swath-mapping surveys of several features in the Arctic Basin including the Chukchi Borderland, Gakkel and Lomonosov Ridges. Bathymetry swaths collected by the system were typically 2.5 times the water depth, with some 200-500 soundings acquired per sonar ping.

Figure 6-1 portrays the tracks where SCAMP observations were acquired during SCICEX surveys in 1998 and 1999. During SCICEX-99, the *USS Hawkbill* was invited into the EEZ of Norway and collected data outside of the data release box (see red tracks near top of map).

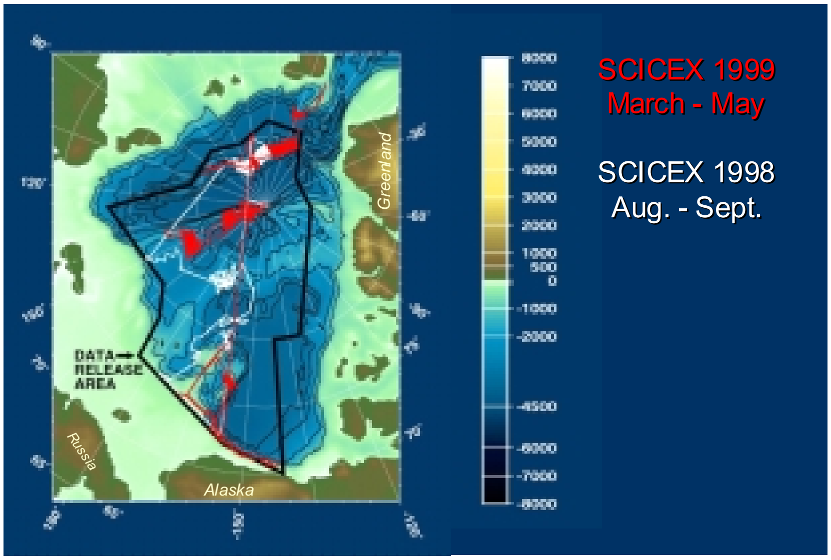


Figure 6-1. Track maps for the 1998 and 1999 SCience ICe EXercises (SCICEX) surveys of the Arctic Basin. The terrain model for this slide was generated from the ETOPO-5 digital elevation dataset. Dark green and brown areas represent continents (Alaska, Russia and Greenland are labeled for reference). Light greens represent regions of shallow water depth; blues correspond to regions with water depths greater than 1000 meters and become darker with increasing depth. Contours are included for water depths of 1000, 2000, 3000, 3500, 4000, 4500, 5000 and 5500 meters. The thick black line around the margins of the Arctic Basin indicates the Data Release Area (labeled) in which the unclassified SCICEX data could be collected.

2. A look at raw SCAMP data

Mounting SCAMP on the hull of a nuclear-powered submarine required that the number of hull penetrations be minimized. For that reason, the SCAMP system was built as an interferometric sonar with just four transducer arrays and one cable penetrator on each side of the system (as opposed to multibeam echosounders with their long along- and across-hull arrays of transducers). Processing data from interferometric systems is distinctly different from processing multibeam data, so discussion of the SCAMP data that will be incorporated into IBCAO begins first with a description of raw SCAMP acoustic data.

In Figure 6-2, blue values show the locations of all magnitude (connected by straight lines in the upper image) and phase (individual crosses in the lower image) values. The red crosses indicate the magnitude and phase values that successfully met the threshold criteria and are therefore considered to be acceptable values for further processing. Note that acceptable phase and magnitude values begin at approximately the same time, which corresponds to the time of first bottom detection for the data stream. Magnitude is measured as R*R+I*I while phase is measured in radians. Time from ping start is measured in seconds along the x-axis of both plots.

3. Processing SCAMP data

Converting raw SCAMP acoustic data into bathymetry requires several steps:

<u>Step 1: Bottom Detection</u>

Why: This step defines the time when useful data begin. Parameters that can be manipulated:
1. Relative magnitude threshold
2. Minimum/maximum depth

Port and starboard sides are treated separately. When necessary, hand-editing or even redrawing the profiles is possible.

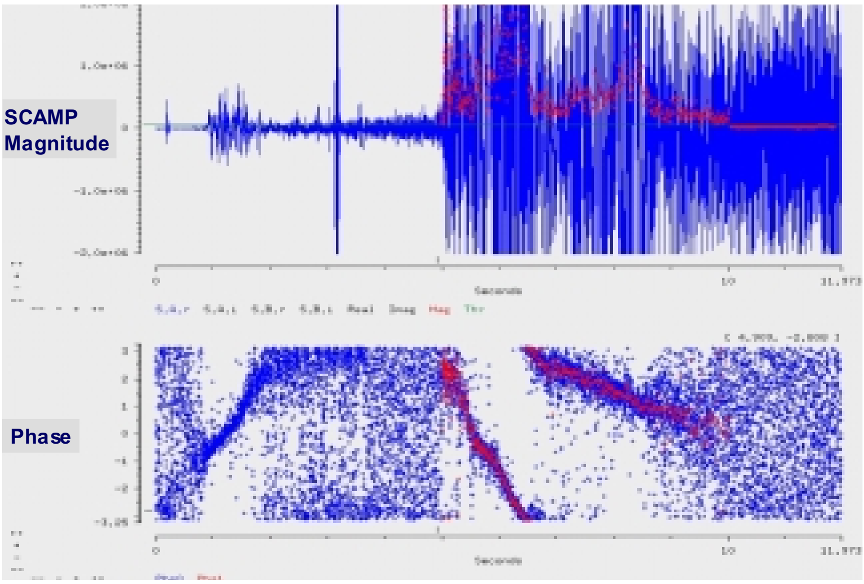


Figure 6-2. Raw SCAMP acoustic data are typically examined as magnitude and phase values (although, as can be seen on the labels near the center line of this figure, it is also possible to examine the real and imaginary components of the synthesized row A and row B data. (The SCAMP SSBS actually has four transducer rows, but these are electronically synthesized to yield two virtual rows of information).

<u>Step 2: Angle-Angle Table Generation</u>

Why: Converts phase difference into geometric angle, thus allowing for the generation of bathymetry data. This task is performed graphically:
1. Locate a region that appears to have a flat bottom.
2. Project the data using an existing flat-bottom table.
3. Force the projected values onto a constant depth equal to the bottom detect value for port or starboard side.
4. Get inverse solution for table that makes flat data.
5. Remove obvious outliers.
6. Filter and subsample to produce new table.
7. Repeat from step 2.

Step 3: Convert "Raw" Data to Bathymetry

Why: Because contour maps are so much easier to read. Parameters that can be manipulated:
1. Relative magnitude threshold
2. Minimum/maximum depth
3. How to look for phase wraps (on the basis of data or geometry of the bottom)
4. Whether/how to filter data across a ping
5. Cell size (typically set to 1-2% of water depth)

Port and starboard sides are treated separately.

Step 4: Edit Noisy Data in Bathymetry

Why: Generic settings for thresholds can only do so much. Parameters that can be manipulated:
1. Minimum/maximum depth

Then perform visual inspection and remove noisy regions:
1. Data within a ping or portion of a ping
2. Data within a rectangular region

Step 5: Changing Tables

Why: Water Column Affects Sound Propagation

Every time the *Hawkbill* moved into a new basin, the angle-angle table needed to be changed. Tables typically changed within a few km of the base of a topographic high.

4. Comparison of multibeam bathymetry with SCAMP data for the Gakkel Ridge

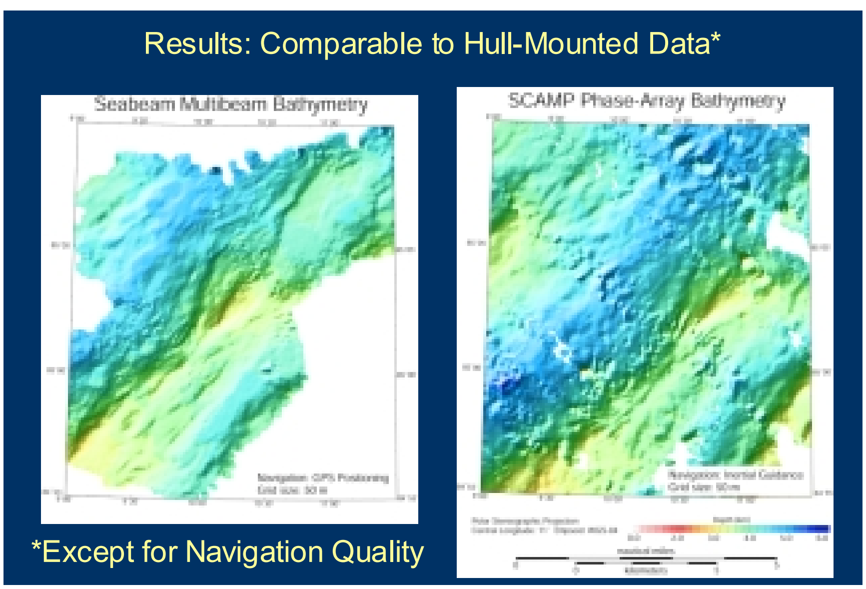


Figure 6-3. Comparison of bathymetry data collected by the USCGC Healy using the hull-mounted Seabeam 2112 system (left) and SCICEX bathymetry for the same region collected by the Seafloor Characterization and Mapping Pods (SCAMP; right). In this figure both datasets are gridded at the same grid cell size (50 m).

To evaluate the performance of the SCAMP processing approach, data collected over the Gakkel Ridge during the 2001 AMORE expedition were compared with SCAMP data for the same region collected in 1999. The AMORE data were collected by the USCGC Healy using a Seabeam 2112 multibeam echosounder.

Identical processing algorithms were used to convert from geographic latitude, longitude and depth to polar stereographic grids using the WGS-84 ellipsoid. The color palettes, sun illumination angles (275 deg) and latitude/longitude boundaries are identical for each chart.

5. Present processing status

Figure 6-4 summarizes the present situation.

6. Questions for the IBCAO Editorial Board (and Others)

1. What data to release? [Is there minimum quality?]
2. What form to provide data?
3. What to do about navigational ambiguities?
4. Can we incorporate other SCICEX observations in the IBCAO database, e.g. sidescan and swept-frequency subbottom data?

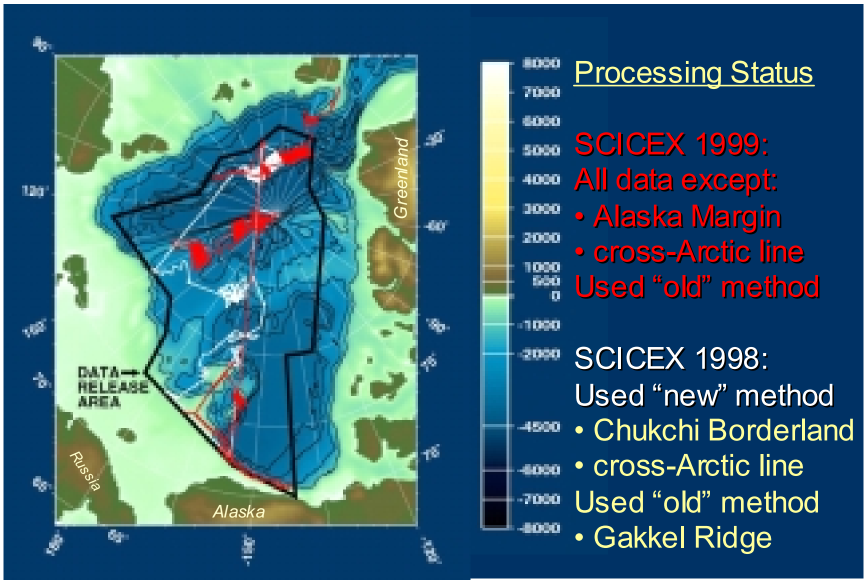


Figure 6-4. Current status of SCICEX processing.

7. Multibeam operations in Arctic waters at the AWI

Hans Werner Schenke, AWI, Bremerhaven, Germany

During the report period 2000-2002, multibeam surveys were conducted during five "Polarstern" Expeditions:

ARK XVI/2 (ARKTIEF)
ARK XVII/1 (ARKTIEF)
ARK XVII/2 (AMORE)
ARK XVIII/1 (ARKTIEF)
ARK XVIII/2 (Fram Strait)

Trackline information for all expeditions is shown in Figure 7-1 (North Atlantic and Fram Strait) and in Figure 7-2 (Gakkel Ridge).

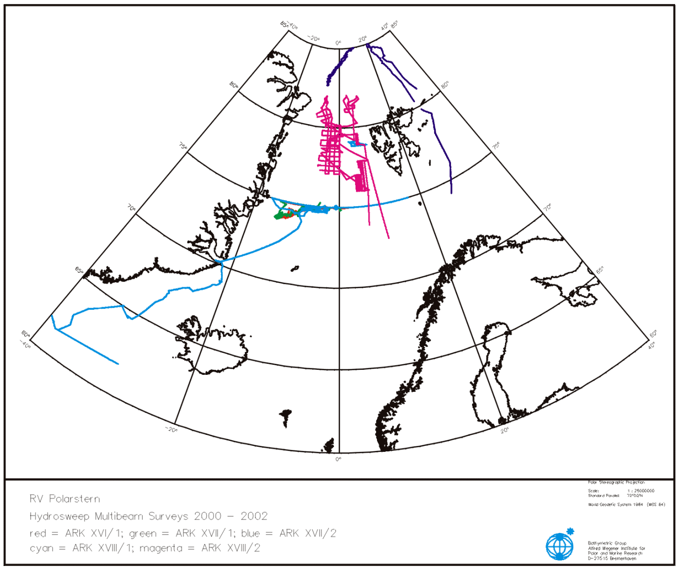


Figure 7-1. AWI 2001-2002 tracklines, Fram Strait

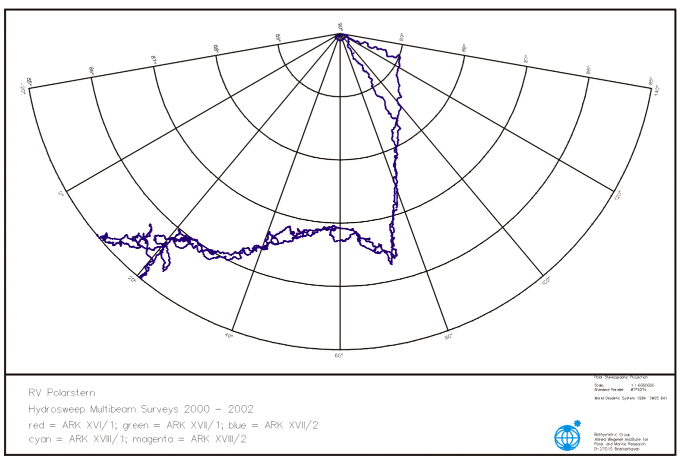


Figure 7-2. AWI 2002-2002 tracklines, Gakkel Ridge

1. The ARKTIEF Project

The ARKTIEF project focuses on the characterization of channel systems on the East Greenland continental slope in terms of geology, oceanography and biology. The transport processes of dense shelf waters and sediments through the channels are of particularly high scientific interest. High-resolution multibeam bathymetry is a crucial prerequisite since it supplies a basic data set for the multifarious scientific work of the ARKTIEF project groups. Thus, multibeam surveys using the Hydrosweep DS-2 system were performed in the investigation area between 74°N, 15°W and 75°N, 2°E in conjunction with marine geological and oceanographic investigations. However, this multidisciplinary work during the various legs caused a rather non-uniform formation of the survey lines (Figure 7-3). From this reason, complete data coverage of the entire region could not be achieved.

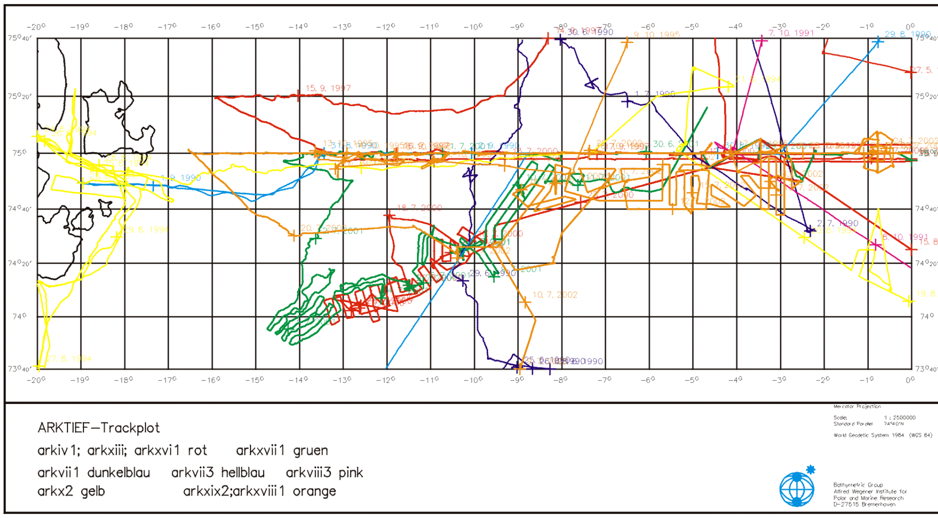


Figure 7-3. AWI tracklines over the continental slope of East Greenland

The multibeam data from all expeditions in this region are at present under post-processing using the CARIS/HIPS software. A first DTM product from all data is shown as a shaded relief in Figure 7-4. The contours as well as the DTM will be made available to IBCAO in the middle of the next year.

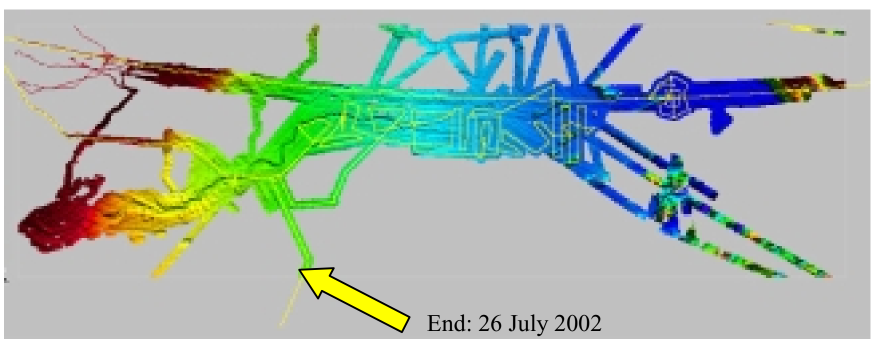


Figure 7-4. Present status of bathymetric mapping in the ARKTIEF-project. Track lines of “Polarstern”-leg ARK XVIII/1 (yellow) from 09 July until 26 July 2002

2. The AMOR Expedition to the Gakkel Ridge

The Gakkel Ridge, located in the central Arctic Ocean, was object of a joint US/German expedition in the boreal summer 2001. This part of the global mid-ocean ridge system is of particular geoscientific interest because of its slow spreading rate and the variety in its morphology. Multibeam measurements are of special importance because they provide basic and indispensable information for mapping and interpreting the geoscientific characteristics of this oceanic ridge. The multibeam data were acquired during the two-ship expedition by RV "Polarstern" (Hydrosweep DS-2) and USCGC "Healy" (Seabeam 2112).

Figure 7-2 illustrates the “Polarstern” track, and Figure 7-5 contains additionally the track from “Healy” during AMORE. Due to the difficult ice situation, the tracks from both vessels are very uneven; sailing along a linear profile was not possible. Furthermore, the quality of the multibeam data is heavily influenced by acoustic noise and ice particles under the ship’s hull due to icebreaking. A first post-processing was performed in the field on both ships in order to create a quick preliminary product. However, given the unfavourable survey conditions, a supervised post-processing was performed at the AWI for both multibeam data sets using CARIS/HIPS (Figure 7-6).

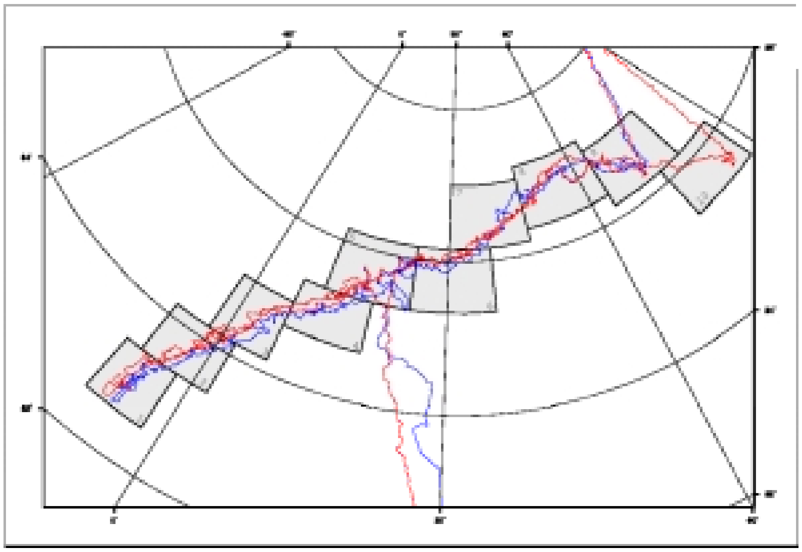


Figure 7-5 Schema of large scale bathymetric charts along the Gakkel Ridge, "Polarstern" tracks in blue, "Healy" tracks in red

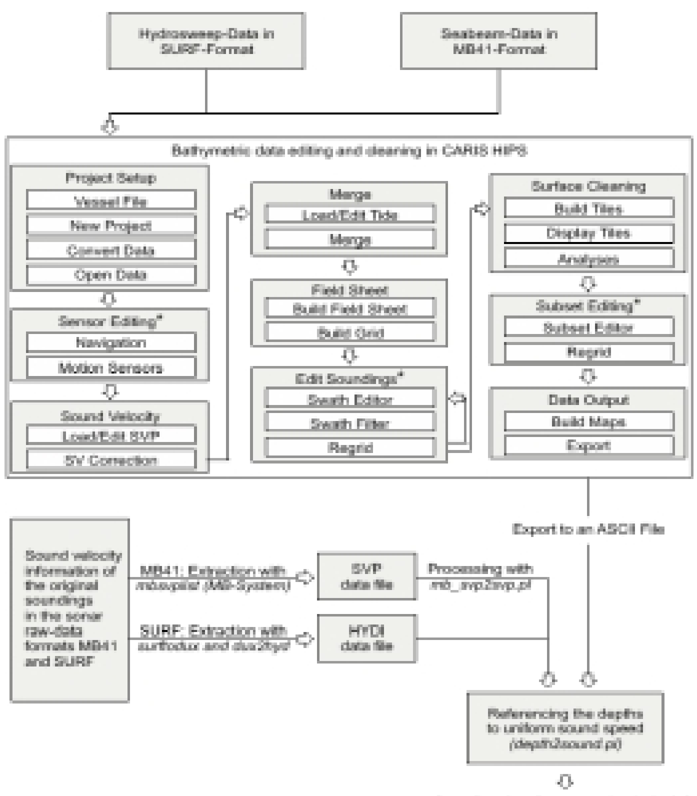


Figure 7-6. Final post-processing at the AWI with CARIS/HIPS

Navigation and positioning

The navigation information in the Seabeam data from “Healy” shows some irregular behaviour and position jumps of up to 60 m (Figure 7-7). In general, GPS provides coordinates with accuracies of approximately 10 m. The navigation data from “Polarstern” are smooth and differentiable throughout (Figure 7-7). The Seabeam positions were manually corrected and fitted in order to get a smooth profile. High-resolution navigation data recorded by a supplementary Ashtech 3D-Receiver on “Healy” may be available in the future in order to further improve the positioning of the Seabeam data.

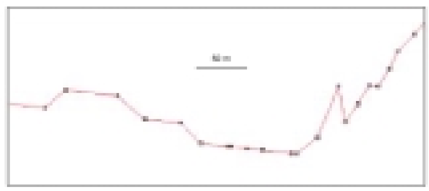


Abb. 3.3: Beispiel der fehlerhaften Positionsdaten des Seabeam 2112

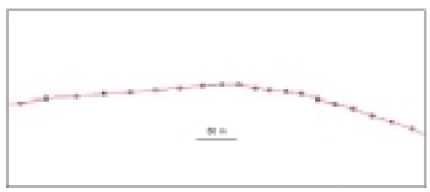


Abb. 3.2: Beispiel der guten Qualität der Hydrosweep DS-2-Positionsdaten

Figure 7-7. Navigation data from “Healy” (top) and “Polarstern” (lower part)

Comparison between on-board and final post-processing

The preliminary on-board and final results were compared at the AWI in order to quantify the differences and the overall accuracy (Figure 7-8). The red coloured regions are deeper than the preliminary product, and the blue areas are shallower. The differences range between +/-2% of water depth, which amounts to 120 m at a depth of 3000 m. Figure 7-8 reveals that the largest differences occur mainly along the slopes. In principle, the differences of 3-4% of water depth exceed by far the specified accuracy for multibeam surveys in the deep sea. The contour lines of the preliminary product are noisy and include artefacts, which may be caused by the relatively quick data editing during the expedition.

However, the preliminary DTM from the on-board processing can be utilized for small-scale mapping (< 1:1 Million). The combination of the preliminary DTM with the IBCAO grid is shown in Figure 7-9. This combination reveals that the multibeam data from the AMOR Expedition can be used to apply a significant improvements to IBCAO, especially when utilized for calibrating the SCAMP bathymetry collected during SCICEX missions.

Figure 7-10 illustrates a comparison between the existing IBCAO bathymetry and the post-processed AMORE data. On the right side of the figure, the final multibeam DTM is inserted into the IBCAO model. In particular, this new data reveals the transition of the MAR along the

Lena Trough into the Gakkel Ridge. Figure 7-11 shows two cross-sections over the Gakkel Ridge that indicate large differences in the depth of the sea floor topography. The position of the Ridge valley differs by nearly 10 km, and the depth differences are sporadically larger than 1000 m.

For large-scale mapping, the multibeam survey region along the western Gakkel Ridge was subdivided into 10 sheets in the scale 1:150 000 (Figure 7-5). Three bathymetric charts in the southwest region of the Gakkel Ridge have been produced at the AWI up to now, and were presented at the IBCAO Meeting. These results demonstrate that the bathymetric information gathered during the AMOR Expedition supplies a new insight into the morphological structures of the Gakkel Ridge. The complete multibeam data from the AMOR Expedition can be released for public use three years after the cruise.

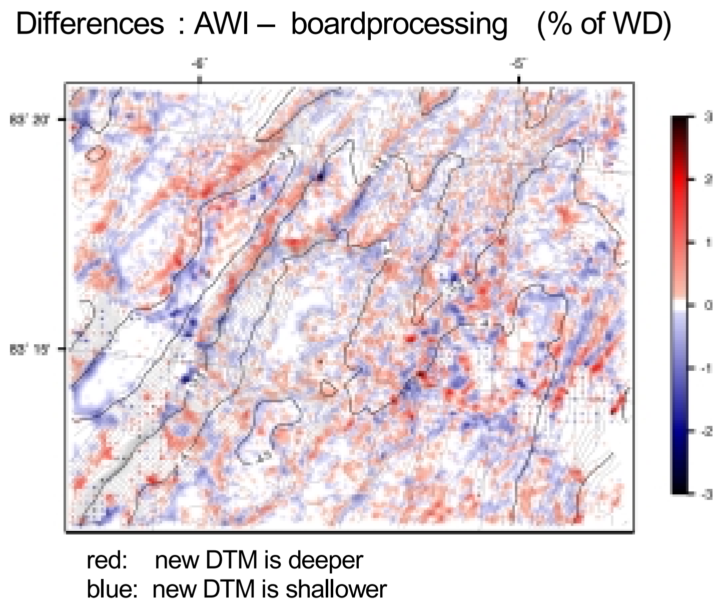


Figure 7-8. Difference between on-board processing and post-processing with HIPS. Contour lines determined after final post-processing

The high-precision bathymetry along the western Gakkel Ridge will be utilized to calibrate the positions of the SCAMP data collected during the SCICEX missions, in order to yield bathymetric information over a much larger region at the Gakkel Ridge. This work will be done in the near future jointly with the Hawaii Mapping and Research Group, SOEST, University of Hawai'i.

3. Fram Strait Expedition 2002

During the "Polarstern" expedition ARK XVIII/2 from August until October 2002, a significant part of the Fram Strait was surveyed with multibeam (Figure 7-12). Along the eastern Greenland continental shelf between 77°N, 6°W and 81°N, 1°W a grid of survey profiles with a spacing of approximately 15 nautical miles was established orthogonal and parallel to the continental shelf, featuring marine seismic, gravity, multibeam, magnetics, and sub-bottom profiling. Additional areal surveys were performed along the mid-Atlantic ridge system, extending the Fram Strait mapping area. (cf. AWI Bathymetric Charts of the Fram Strait, and http://www.awi-bremerhaven.de/GEO/Bathymetry/framstr/framneu.html). The tracklines, including colour-coded swath coverage, are shown as overlay on the IBCAO contour lines in Figure 7-12. Based on this new data along the eastern Greenland shelf, a new bathymetric chart will be compiled during the next 6 months (Figure 7-12, red box). This map will be available for incorporation into IBCAO.

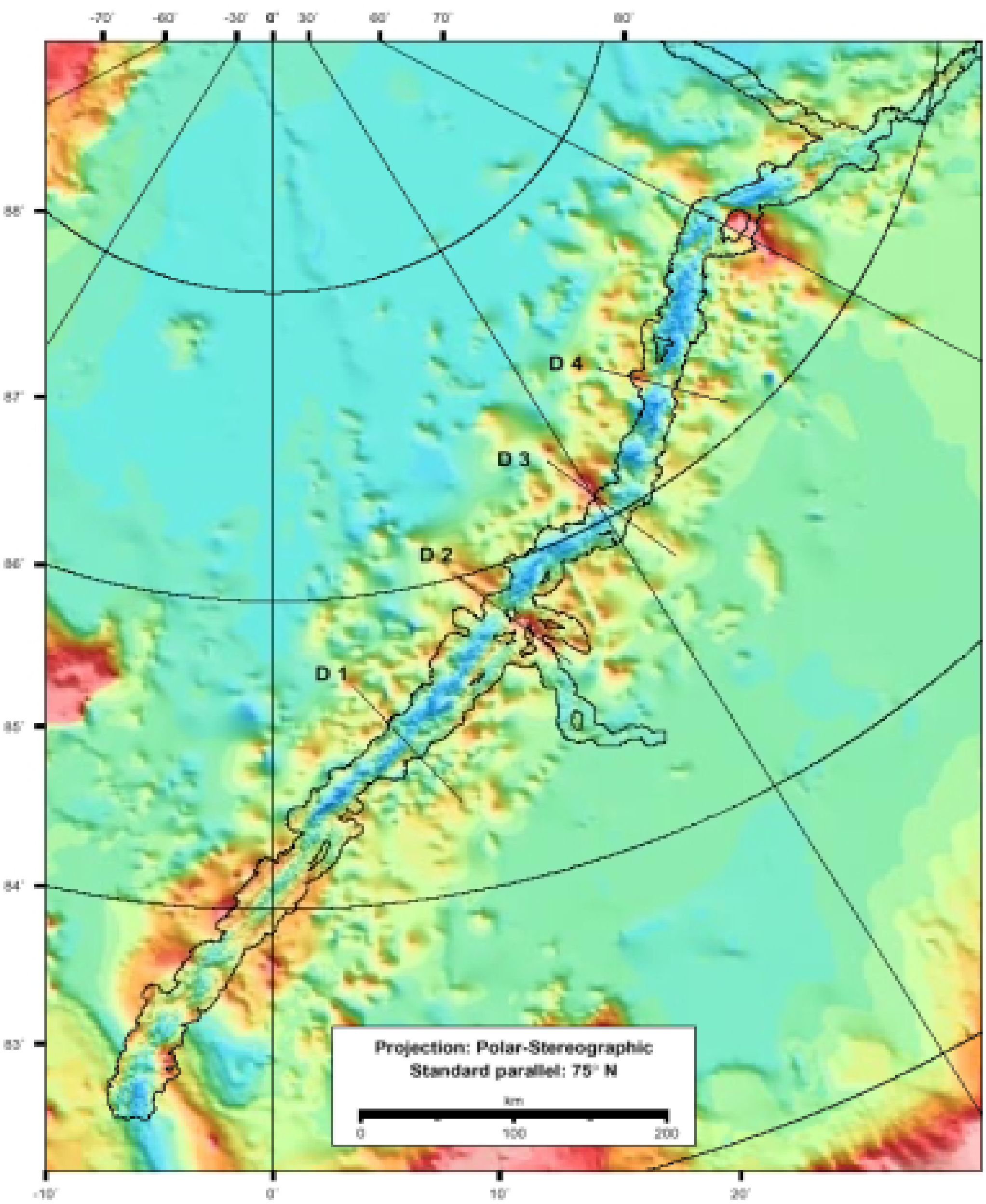


Abb. B.4: Gesamtgebiet der Vermessung des Gakkel-Rückens auf der AMOR-Expedition 2001 *(AMORE Shipboard Scientific Parties* 2001[1]). Die Tiefeninformationen des umgebenden Gebietes beruhen auf der IBCAO Vol. 1.0 *(Jakobsson* 2001[20][22])

Figure 7-9. On-board processed AMORE-bathymetry inserted into IBCCAO

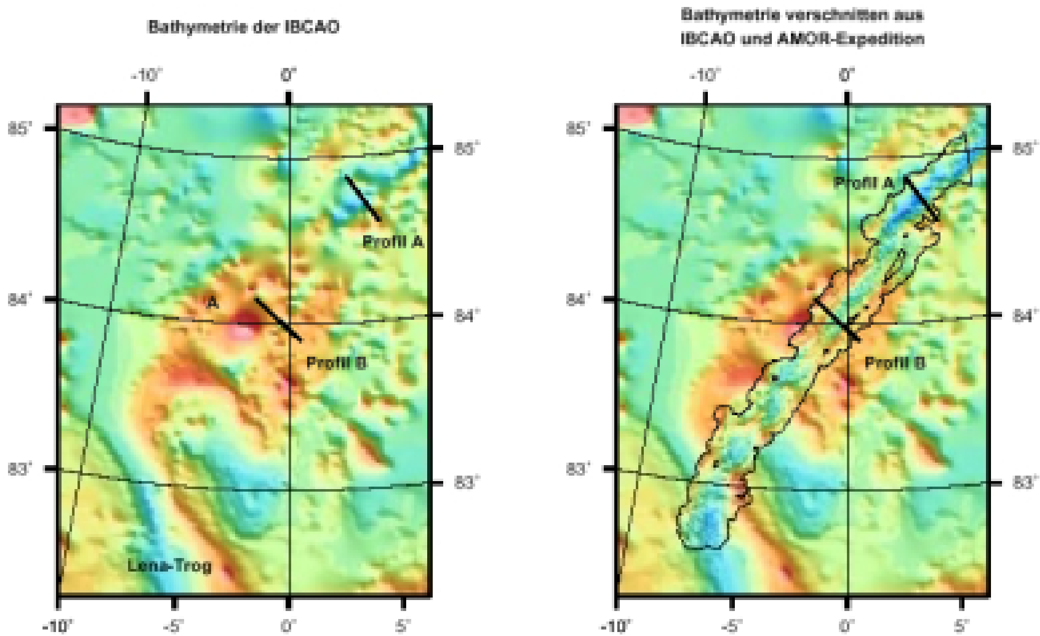


Abb. 6.5: Vergleich des neuen hochauflösenden Geländemodells mit dem Geländemodell der IBCAO *(Jakobsson* 2001[20][22])

Figure 7-10. Comparison between IBCAO (left) and precision bathymetry in the south-west part of the Gakkel Ridge

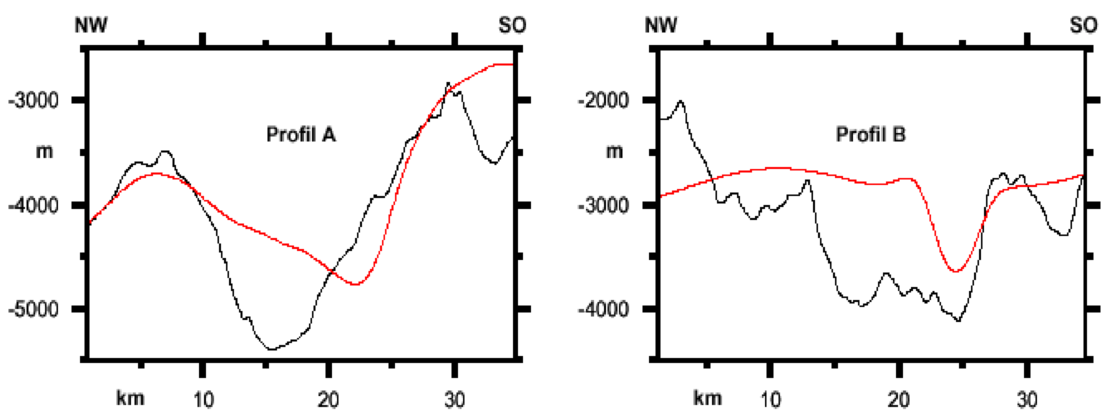


Abb. 6.6: Vergleich der neuen bathymetrischen Daten (schwarze Profillinien) mit der IBCAO (rote Profillinien) durch Profilschnitte über den Rücken (Positionen der Profilschnitte vgl. Abb. 6.2) *(Jakobsson* 2001[20][22])

Figure 7-11. Cross profiles A and B (cf. Fig. 10) over the Gakkel Ridge

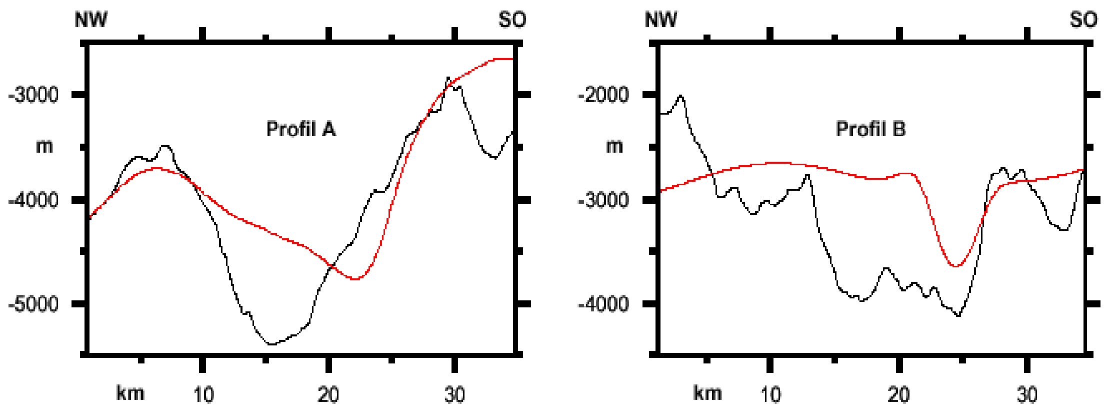


Abb. 6.6: Vergleich der neuen bathymetrischen Daten (schwarze Profillinien) mit der IBCAO (rote Profillinien) durch Profilschnitte über den Rücken (Positionen der Profilschnitte vgl. Abb. 6.2) (*Jakobsson* 2001[20][22])

Figure 7-11. Cross profiles A and B (cf. Fig. 10) over the Gakkel Ridge

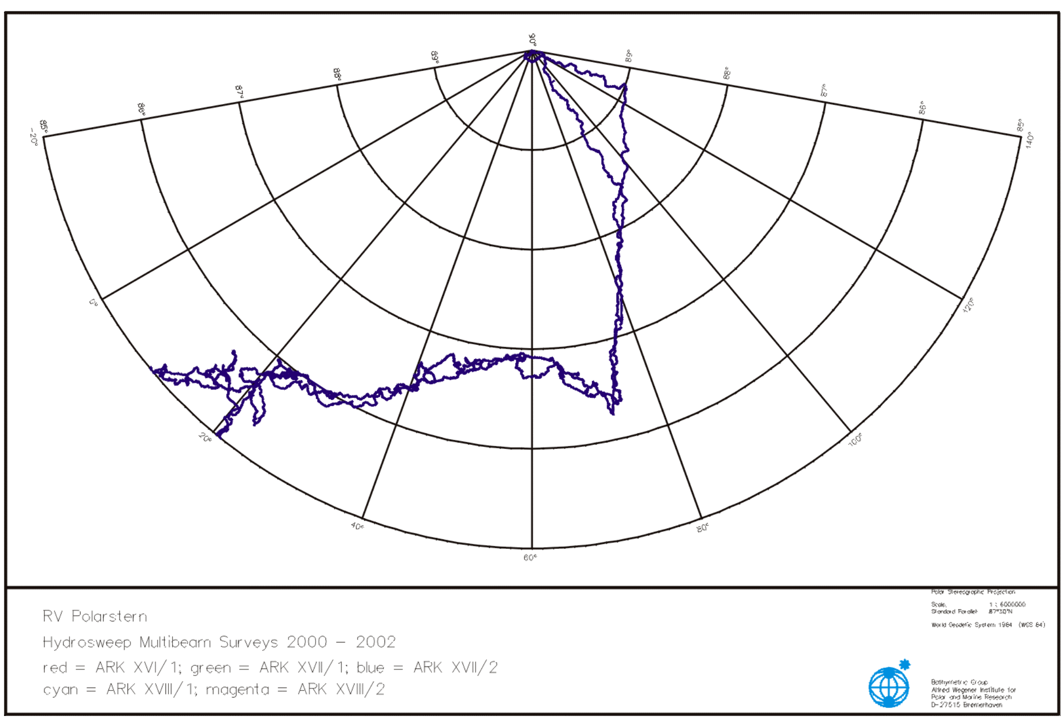


Figure 7-12

8. Mapping of the Norwegian continental shelf

Morten Sand, NPD, Norway

NPD has been given the responsibility for work related to UNCLOS Article 76 – definition of the continental shelf of Norway. Through this work, bathymetric measurements of interest to IBCAO have been acquired.

Most significant is a three-season multibeam echo-sounding (MBES) campaign in the Norwegian-Greenland Sea. Coverage for these campaigns, totalling 271,500 sq km, is shown in Figure 8-1. The Norwegian Hydrographic Office kindly assisted in evaluating the technical and economic aspects of this work. Acquisition and processing were contracted to Gardline Surveys, using 12 khz MBES systems as basic equipment; Simrad EM 12 for the 1999 and 2000 cruises, and Simrad EM 120 for the 2001 cruise. The grid cell size used during processing was 200 X 200 m. A regridded version of 1 X 1 km cell size has been made available to IBCAO. The data acquired in 1999 and 2000 are already incorporated in the IBCAO grid.

Additionally, NPD succeeded in obtaining shiptime during the ODEN cruise in 2001. During our part of the cruise, which took place in September 2001 basically in the western Nansen Basin, some 1900 km of single beam echosounding were acquired. The main intention of the cruise was multi-channel seismic acquisition. 1000 km of such data were successfully retrieved through cooperation with Professor Yngve Kristoffersen of the University of Bergen.

Also worth mentioning is the fact that NPD invited the deployment of a SCICEX submarine into the Norwegian EEZ during the 1999 cruise. This resulted in the acquisition of swath mapping (and other) data along the northeastern slope of the Yermak Plateau, intended for studies of sedimentation processes and detailed definition of morphology. NPD is funding the ongoing processing at HMRG of the 1998 and 1999 SCICEX data to maximize the quality and value of these data sets.

9. Arctic activities of the Royal Danish Administration of Navigation and Hydrography

John Woodward, RDANH, Copenhagen, Denmark

Four new data sets have been obtained in the Norwegian-Greenland Sea, collected by: the Danish Fisheries Research Vessel DANA (1999); the Swedish Icebreaker ODEN (2002); Motor Vessel HAKON MOSBY (2002); and the POLARSTERN (2002).

New projects include: the Greenland Arctic Shelf Project, involving through-ice measurements with a portable echo-sounding transducer; and the Article 76 Continental Shelf Project. The latter is being undertaken as a cooperation venture between five agencies: the Denmark and Greenlands Geological Investigation (GEUS); the Cadaster and Mapping Agency (KMS); the Danish Polar Center (DPC); the ASIAQ Council; and the Royal Danish Administration of Navigation and Hydrography (RDANH). The areas of interest include North Greenland, South Greenland, North East Greenland, the North East Faroe Islands, and the South West Faroe Islands. The activity is scheduled to run from 2003 to 2001, with a $20 Million (US) total projected budget.

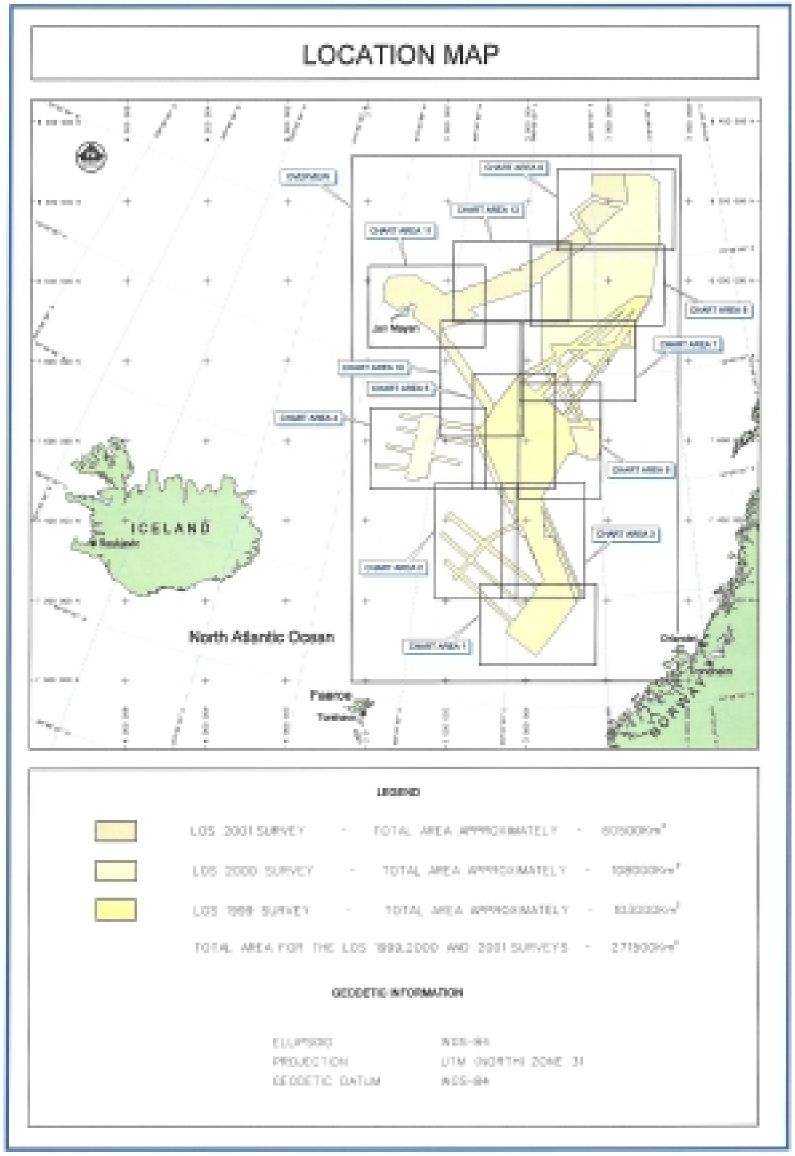


Figure 8-1. Surveys undertaken on behalf of the Norwegian Petroleum Directorate, for determining the outer limit of the juridical continental shelf.

10. Reclaiming data collected in and around the Canadian Arctic Archipelago

Ron Macnab, GSC (Retired), Dartmouth NS, Canada

The IBCAO data base contains a significant number of depth observations that were collected over several decades by hydrographic and geophysical agencies of the Canadian Government (the Canadian Hydrographic Service and the Geological Survey of Canada, respectively), operating independently or cooperatively. One of the more problematic aspects of the cooperative projects was that the agencies would often retain duplicate copies of the collected bathymetric observations once the surveys were completed, in order to apply their own processing procedures and to satisfy their specialized requirements. Thus, hydrographers would apply the corrections necessary to reduce soundings to a chart datum for eventual use by mariners, whereas geophysicists would apply no such correction because they needed to know the depth of water at the time of observation in order to calculate the corrections to their gravity observations.

At some point also, a series of datum transformations was implemented by the hydrographers, which applied an apparent shift to the sounding positions in the hydrographic archives, while those in the geophysical archives remained unchanged. The result, inevitably, was the creation of incompatible data sets – although they were based on the same original observations, their subsequent processing and handling caused them to diverge (Figure 10-1).

These and other problems were noted when the Canadian data points were first assimilated into the IBCAO data base, however the press of other priorities precluded their proper treatment at that time. Instead, the data sets were subjected to rudimentary smoothing and filtering operations that glossed over the errors rather than correct them. To rectify the situation, a project has been initiated with the following objectives:

1. Clean up the CHS/GSC contributions to IBCAO
2. Identify all suitable CHS data sets – many of which are in analog (hand-plotted) form
3. Convert analog data sets to digital form
4. Assemble metadata, particularly reference levels
5. Rationalize all in a coherent data base

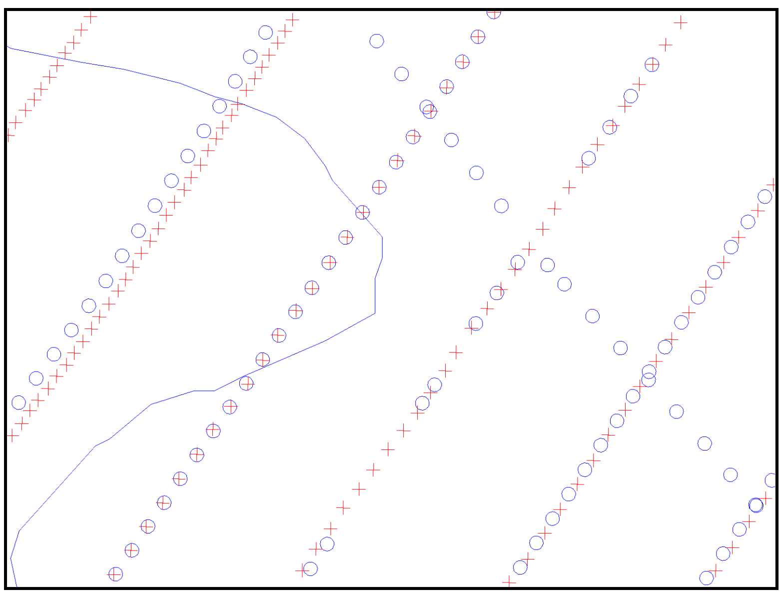


Figure 10-1. Close-up of sounding tracks in the Labrador Sea, showing data points extracted from CHS (red) and GSC (blue) archives. The average separation between points along sounding lines is about 1.5 km. The average separation between parallel ship tracks is about 9 km. In principle, the red crosses should be everywhere coincident with the blue circles, but in practice they are not because the CHS and GSC data points have been subjected to different processing and adjustments.

This operation is concurrent with a wider effort throughout CHS, which seeks to recover all legacy data sets with a view to loading them into a re-organized corporate database.

For the purposes of this project, an individual data set consists of all soundings on a given Field Sheet (analog or digital - see Figure 10-2 or 10-3, respectively), plus the relevant metadata for that Field Sheet. In CHS parlance, the Field Sheet is the final document upon which soundings are recorded once they have been subjected to error checking, tidal corrections, and all the usual procedures (in some other organizations, they are known as Fair Sheets). For the time being, the initiative is concentrating on the recovery and assimilation of CHS survey data as preserved on Field Sheets – other soundings exist from other sources, but they are not believed to be as numerous, as well controlled, nor as well preserved as the CHS information.

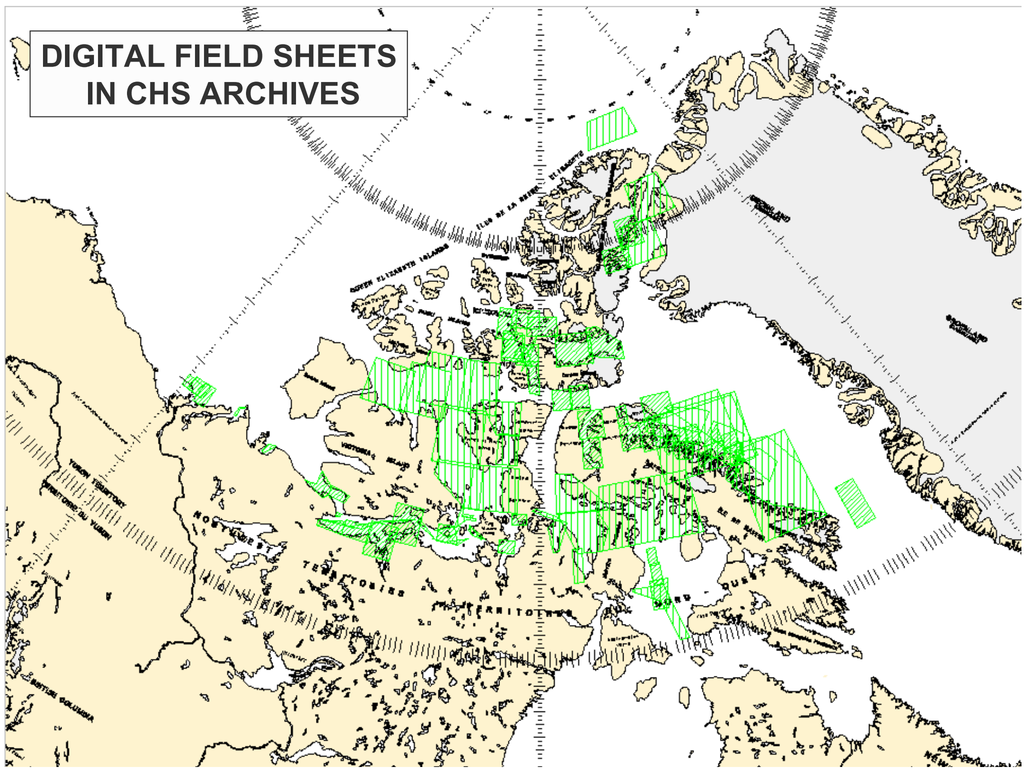


Figure 10-2. Distribution of digital Field Sheets in and around the Canadian Arctic Archipelago, which are held in CHS archives. The data sets represented by these Field Sheets exist in digital form and are ready for assimilation into a corporate database – once all the relevant metadata information is assembled.

With sophisticated optical character recognition, the recovery of sounding values from analog Field Sheets is relatively straightforward, however metadata recovery represents a significant challenge. This latter type of information falls into several categories: administrative details (survey dates, platforms, etc); sounding and navigational instrumentation; sounding datums, field and post processing, etc, etc. Moreover, it is often fragmented among different recording media and formats, e.g. logbooks, header files of digital field sheets, title blocks of analog and digital field sheets, etc. To compound the problem, these records may be widely scattered among multiple archives in different locations, and their formats will most likely be highly inconsistent on account of procedures and standards that evolve over the years. The task requires significant research to recover as much information as possible, complemented by educated guesswork to determine the missing parameters.

In the foregoing context, the determination of sounding datums represents a special problem. Sounding datums serve as local zero reference levels for individual surveys, to guarantee consistency when reducing raw soundings. Usually, there is one sounding datum per field sheet, and it is defined by its vertical distance from a local benchmark, which may or may not be tied to a standard – and regional - vertical reference framework. In principle, the applicable sounding datum should appear in the title block of each field sheet, necessitating a visual check of each document.

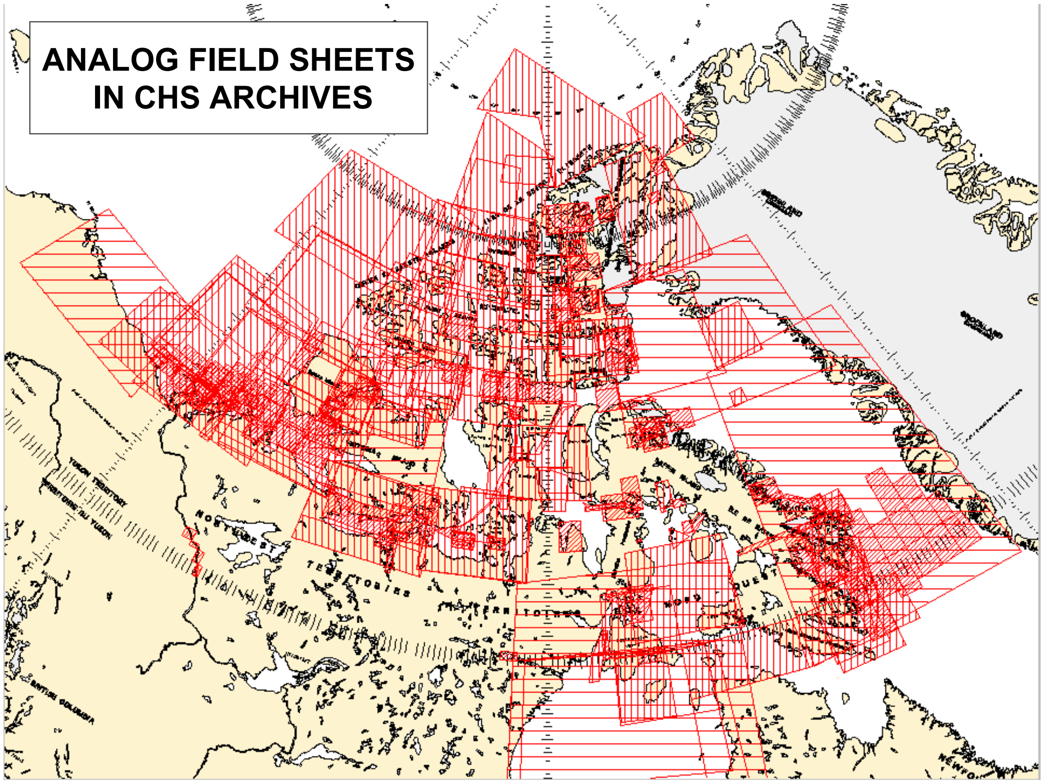


Figure 10-3. Distribution of analog (hand-plotted) Field Sheets that are held in CHS archives. These Sheets need to be individually examined (a) to assess their contents, (b) to extract title block metadata, and (c) to determine their priority order for digitizing.

11. Activity on the IBCAO Website

David Divins, NGDC, Boulder CO, USA

The IBCAO web page (http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/arctic.html) continues to be the most popular of the IOC/IBC web sites hosted by NGDC. Table 11-A itemizes the general statistics for the year and for the week ending at 11:59 PM September 30.

Operation	Year ending Sep 30, 2002	Week ending Sep 30, 2002
Successful requests	103,523	2,261
Average successful requests per day	283	322
Successful requests for pages	80,738	1,968
Average successful requests for pages per day	221	281
Failed requests	6,292	116
Redirected requests	437	6
Distinct files requested	1,585	265
Distinct hosts served	12,905	413
Corrupt logfile lines	8,567	
Unwanted logfile entries	87,273,684	
Data transferred	51.388 Gbytes	967.581 Mbytes
Average data transferred per day	144.181 Mbytes	138.225 Mbytes

Table 11-A. General access statistics for the IBCAO website.

Over the past 12 months, there have been more than 100,000 accesses to the IBCAO web site, originating from a variety of locations (Figure 11-1). The top 15 web pages visited and links downloaded indicate that both the images and the maps available, as well as the gridded and the contoured data, are in demand, and that they are being used for a variety of activities. Table 11-B lists the 15 leading files that were requested during the period October 1, 2001 to September 30, 2002

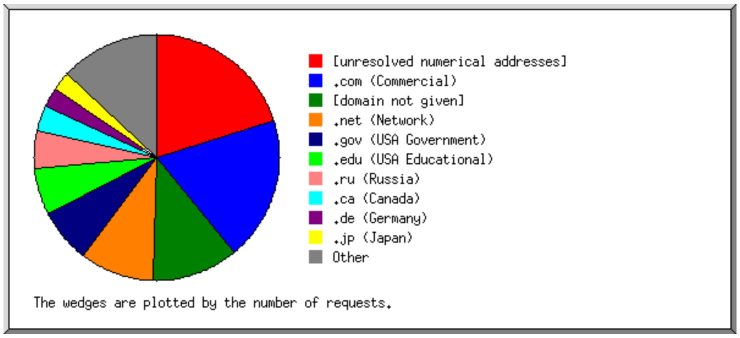


Figure 11-1. Leading domains from which accesses to the IBCAO website were initiated.

Rank	Number of requests	Percentage of requests	File name
1	14760	14.26	/arctic.html (home page)
2	3424	3.31	/ibcaoversion1.html (version 1 main page)
3	3103	3.00	/IBCAO_TechnicalReference.PDF (Technical Reference)
4	2758	2.66	/currentmap.html (Current Map)
5	2578	2.49	/provisionalmap.html (older provisional map)
6	2306	2.23	/ibcao_gebco_comp.html (selective comparisions)
7	2209	2.13	/polardata/plots/ (polarstereographic plots/images)
8	2206	2.13	/polardata/grd/ (polarstereographic grids)
9	2174	2.10	/IBCAO_GEBCO-comp.PDF(selective comparisons)
10	2075	2.00	/geodata/grd/netcdf/ver1_netcdf_geo.grd (geographic grid netcdf)
11	1989	1.92	/polardata/grd/netcdf/ver1_netcdf.grd (polarstereographic grid netcdf)
12	1969	1.90	/geodata/grd/ (geographic grid)
13	1909	1.84	/geodata/contours/ (geographic contours)
14	1883	1.82	/polardata/contours/ (polarstereographic contours)
15	1863	1.80	/geodata/plots/ (geographic plots/images)

Table 11-B. Leading 15 files requested for downloading from the IBCAO website between October 1, 2001 and September 30, 2002

12. Physiography of the Arctic seabed, derived from IBCAO

Ron Macnab, GSC (Retired) and Martin Jakobsson, CCOM/JHC

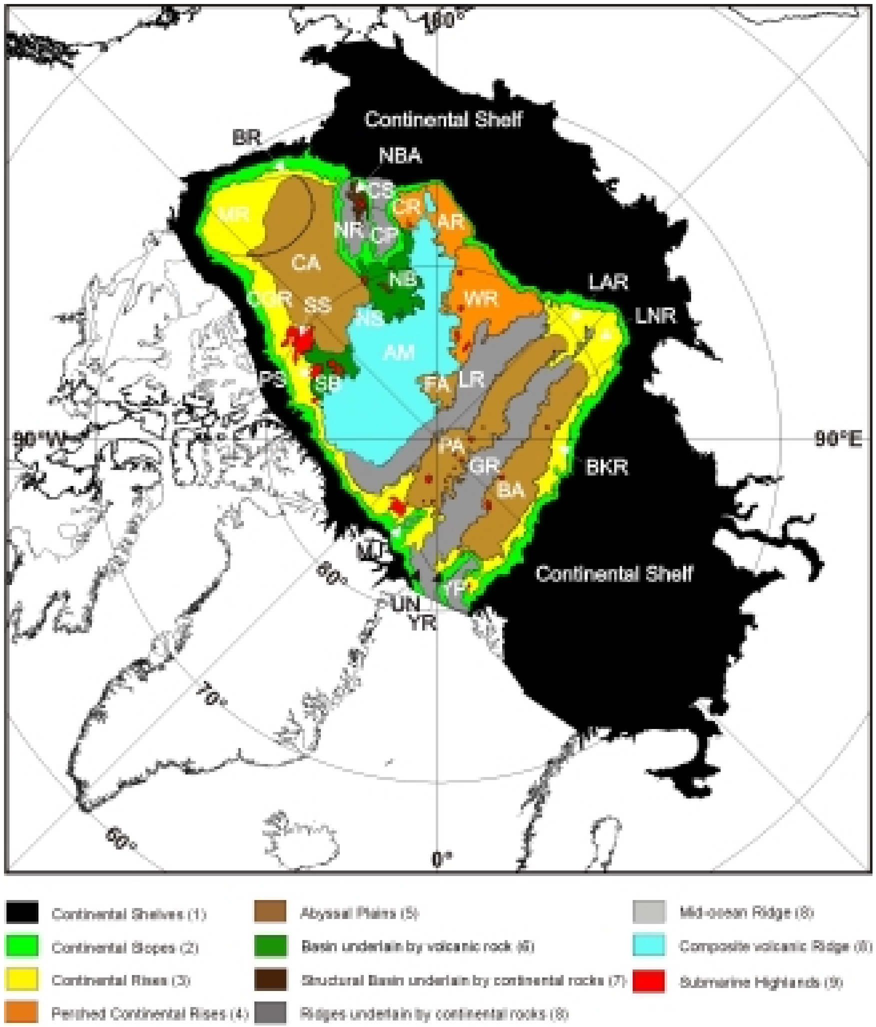
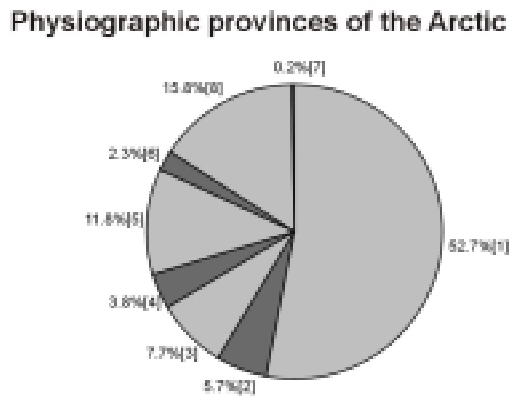


Figure 12-1. Distribution of physiographic provinces in the Arctic Ocean, derived from a numerical analysis of the IBCAO grid. Abbreviations are defined in the caption of Figure 12-3.

An analysis of the IBCAO grid was initiated at CCOM/JHC with a view to developing a semi-quantitative physiographic classification of the floor of the Arctic Ocean. An automated approach was developed that divided the area into different provinces according to the mean slope of the seabed (Figures 12-1 to 12-3). This classification was confirmed by a visual examination of depth profiles and seabed roughness within each province. Art Grantz (USGS, Retired) and Yngve Kristoffersen (University of Bergen) were invited to participate by describing each province in terms of its geological and tectonic significance. The results of this investigation will be presented as a poster at the upcoming Fall Meeting of the American Geophysical Union, plus they have been submitted for formal publication.



1	Continental shelves
2	Continental slopes
3	Continental rises
4	Perched continental rises
5	Abyssal plains
6	Basin underlain by volcanic rock
7	Structural basin underlain by continental rock
8	Ridges of various kinds

Figure 12-2. Relative sizes of physiographic provinces

13. U.S. Arctic Research Commission efforts to renew under-ice mapping by submarine

Lawson Brigham, US Arctic Research Commission, Alexandria VA, USA

Since the 1980's the U.S. Arctic Research Commission (USARC) has been actively supporting the use of nuclear submarines for Arctic Ocean research, including bottom mapping. In addition, the Commission has recommended the earliest ratification of UNCLOS by the United States. Significantly, the highly successful SCICEX expeditions of the 1990's have not been continued due to a reduction in the size of the U.S. submarine fleet after the Cold War, and expanding Navy operational commitments. These key, national assets have not been available recently for dedicated scientific operations in the Arctic Ocean. It is possible this situation may change in the near future with growing U.S. involvement in UNCLOS affairs related specifically to Article 76.

Some believe that the U.S. may soon ratify UNCLOS. Thus, U.S. interests in the possible extension of the EEZ (under Article 76) should gain a higher profile within many U.S. Government agencies. It should not be surprising that USARC has been active in urging expanded surveys of the Arctic Ocean related to Article 76. Recent initiatives include:

1. Briefings regarding Article 76 to the Director of the National Science Foundation and the Science Advisor to the Secretary of State.
2. Article 76 discussions with the Defense Department and U.S. Navy staffs regarding future submarine requirements for surveys in the Arctic Ocean.
3. A presentation to the U.S. Ocean Policy Commission on Arctic Ocean research needs including Article 76 issues and future mapping requirements by submarines and icebreakers

4. Organizing a special meeting of the Arctic Policy Group (chaired by the State Department) on the ramifications of UNCLOS and Article 76 on U.S. requirements in the Arctic Ocean. This meeting is scheduled for 13 November 2002.
5. Development of a plan for submarine and icebreaker surveys off Alaska to establish U.S. Article 76 claims in the Arctic Ocean. This is a joint effort between the Commission and the University of Alaska.
6. Working closely with the Canadian, Danish and Norwegian Governments to establish the potential for submarine surveys in the deep seas and continental shelves off their respective Arctic coasts.

USARC believes that once the U.S. has ratified UNCLOS it will be imperative that extensive submarine and icebreaker surveys be conducted in the Arctic Ocean off Alaska. International cooperation will be necessary between the U.S., Canada, Denmark and Norway to establish possible Article 76 claims off the entire Arctic coastline of North America and Svalbard. The only efficient vehicle to conduct these surveys will be a nuclear submarine.

14. The use of IBCAO in a U.S. desktop study on potential Law of the Sea claim

Andrew Armstrong, NOAA/UNH Joint Hydrographic Center, Durham NH, USA

The Center for Coastal and Ocean Mapping /Joint Hydrographic Center (CCOM/JHC) at the University of New Hampshire was tasked by the U.S. Congress and the National Oceanic and Atmospheric Administration (NOAA) to carry out a study to 1) identify existing publicly available data that could be used in a potential claim under UNCLOS Article 76, 2) to identify where additional data are required for a claim, and 3) to estimate the cost of acquiring those data. The results of this study are presented in a report (Figure 14-1) available on the Center's website: http//www.ccom.unh.edu

With support from NOAA's National Geophysical Data Center, the U.S. Geological Survey, and Norman Cherkis, CCOM/JHC gathered available bathymetric and seismic data and tracklines as well as existing bathymetric and sediment thickness compilations. These data were entered in an Oracle-9i database and evaluated in a Geomedia Professional GIS. CCOM/JHC identified several areas around the U.S as having the potential for extended claims (Figure 14-2). In those areas, available data were examined for suitability.

One identified area of potential extended claim is in the Arctic. Upon examination of the IBCAO bathymetry and the Jackson and Oakey (1990) sediment thickness map, it became apparent that both new bathymetry to locate the foot of the slope and additional seismic profile data for sediment thickness would be required to support a claim under Article 76. As in all potential claim areas, full coverage swath sonar data in carefully selected corridors are recommended for an optimized claim. A U.S. Arctic Research Commission document by Bernard Coakley and Gary Brass (2002), describing an approach to acquiring new bathymetry and sediment data in the Arctic is included as an appendix to the CCOM/JHC report.

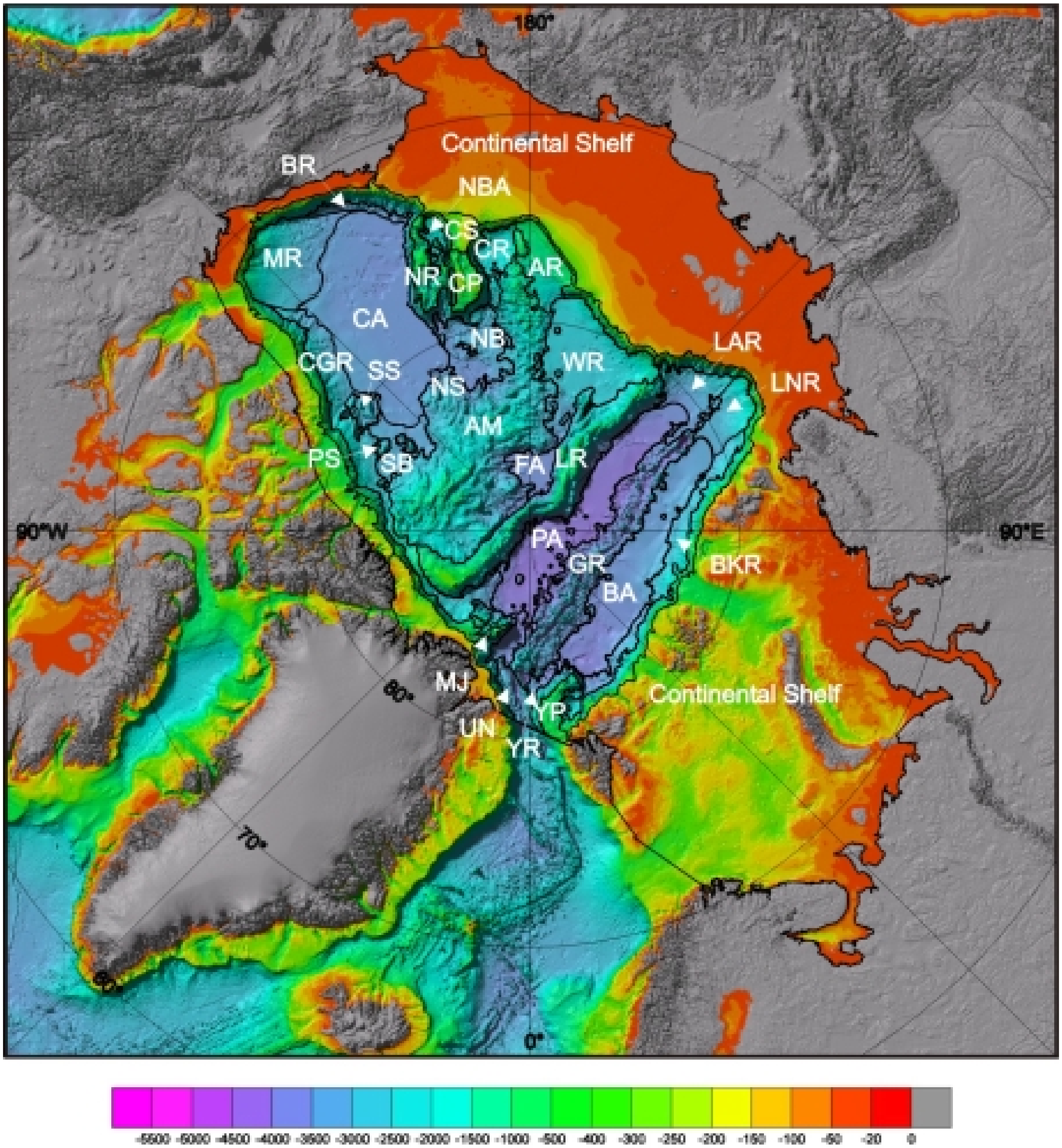


Figure 10-3. Boundaries of physiographic provinces superimposed on IBCAO shaded relief plot. AM: Alpha-Mendeleev Ridge complex; AR: Arlis Perched Rise; BA: Barents Abyssal Plain; BR: Beaufort Rise; BKR: Barents/Kara Rise; CA: Canada Abyssal Plain; CGR: Canada-Greenland Rise; CP: Chukchi Plateau; CR: Chukchi Perched Rise; CS: Chukchi Spur; FA: Fletcher Abyssal Plain; GR: Gakkel Ridge; LAR: Lena/Amundsen Rise; LNR: Lena/Nansen Rise; LR: Lomonosov Ridge; MJ: Morris Jesup Rise; MR: Mackenzie Rise NB: Nautilus Basin; NBA: Northwind Basin; NR: Northwind Ridge; NS: Nautilus Spur; PA: Pole Abyssal Plain; PS: Pearya Spur; SB: Stefansson Basin; SS: Sever Spur; UN: UNamed mid-ocean ridge segment: WR: Wrangel Perched Rise; YP: Yermak Plateau; YR: Yermak Rise.

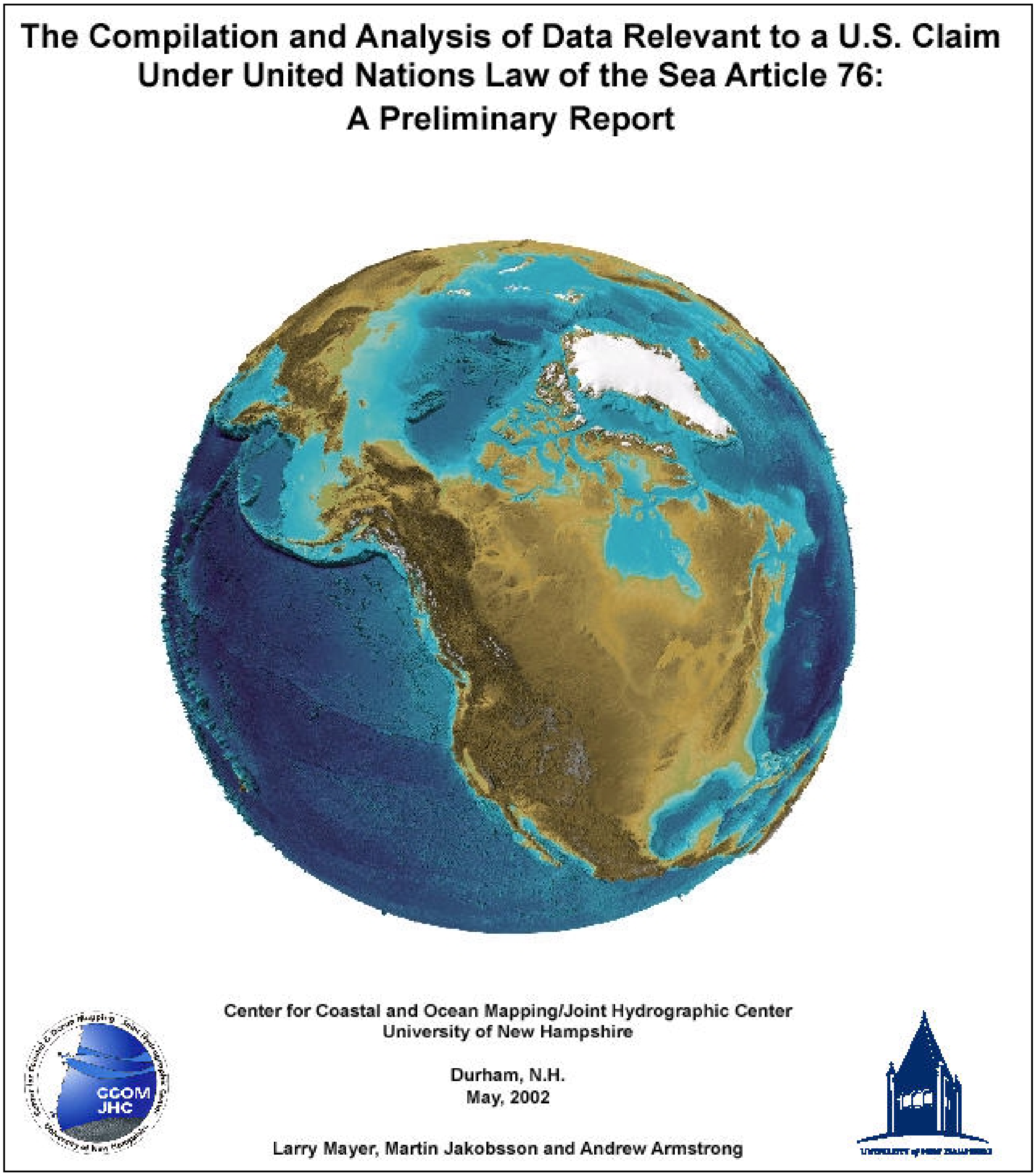


Figure 14-1. CCOM/JHC Report

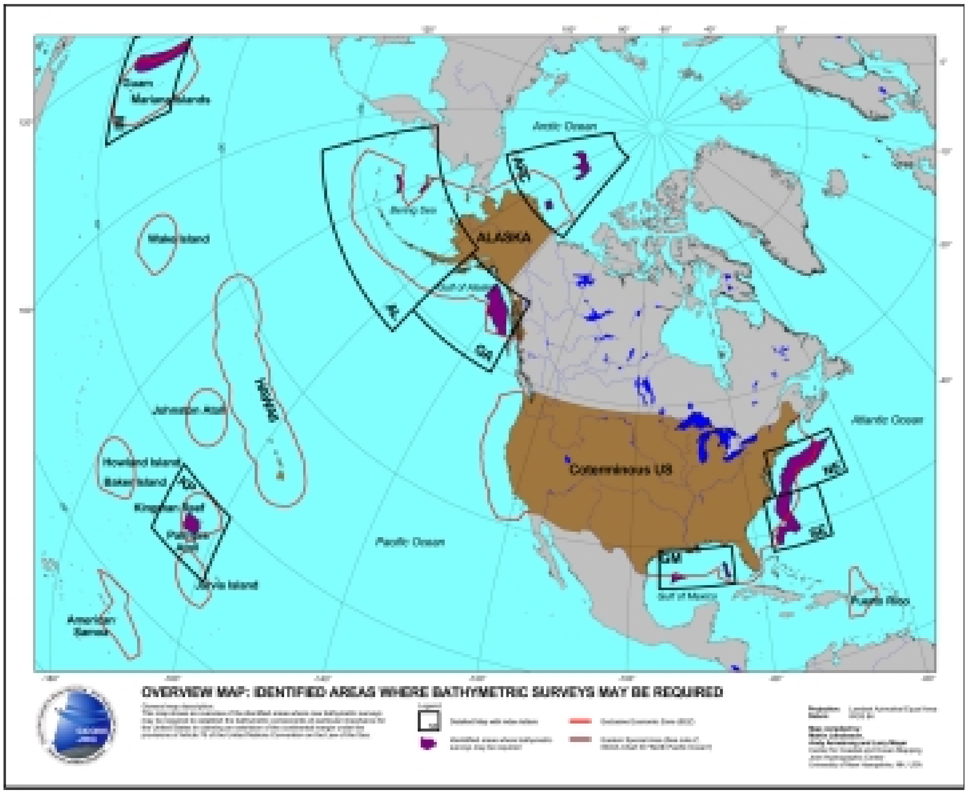


Figure 14-2. Areas of potential U.S. extended claims.

15. Bathymetry and Article 76 in the Arctic

Ron Macnab, GSC (Retired), Dartmouth NS, Canada

The hypothetical outer limits of the juridical continental shelf have been constructed over the entire Arctic Ocean, as though the five surrounding coastal states (Canada, Greenland, Norway, the USA, and the Russian Federation) comprised one single state. This work was undertaken strictly for academic interest and illustrative purposes, and to provoke discussion. The results do <u>not</u> represent the official view of any coastal state.

The investigation was based on information that is presently in the public domain, i.e. the IBCAO (Jakobsson et al, 2000) grid of bathymetry, and the Jackson and Oakey (1986) sediment thickness map. Moreover, it was assumed that the Chukchi Borderlands, the Alpha-Mendeleev Ridge, and the Lomonosov Ridge all fit the criterion of a "natural prolongation of a coastal state's land mass", as stipulated in UNCLOS Article 76. A straightforward analysis of the data sets (Macnab et al, 2001) led to the construction of a juridical continental shelf that underlay the entire high seas area in the Arctic Ocean, except for two "donut holes": one in the Mendeleev Abyssal Plain, combining the outer limits of Canada, Russia, and the USA; the other enclosing the Gakkel Ridge, combining the outer limits of Denmark, Norway, Russia (Figure 15-1).

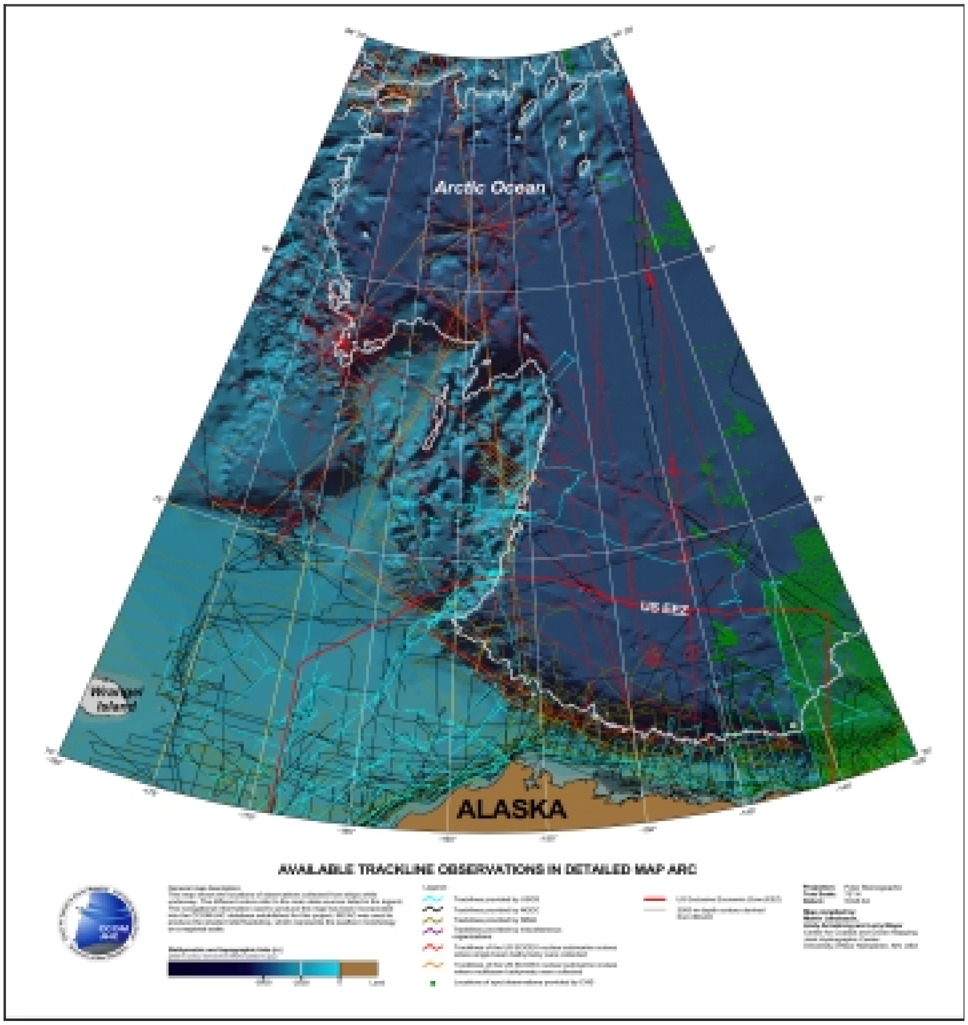


Figure 14-3. Existing trackline data overlaid on IBCAO compilation, from CCOM/JHC Report

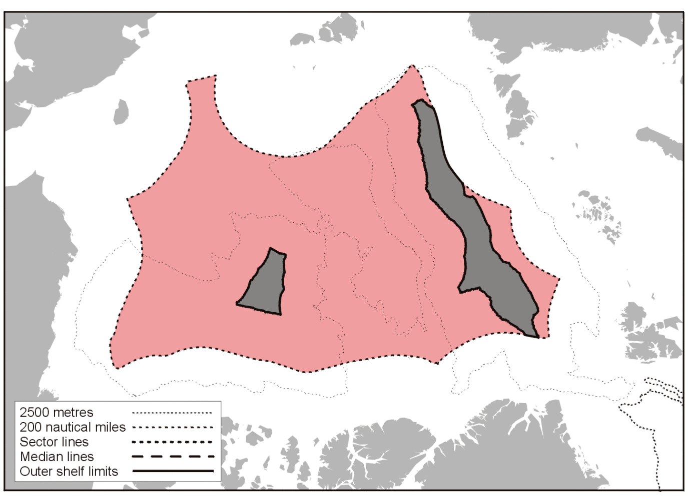


Figure 15-1. The pink zone represents the combined – and hypothetical - juridical continental shelf of the five coastal states that border upon the Arctic Ocean. The two grey zones are high seas enclaves that lie beyond the jurisdiction of any coastal state.

This analysis was complemented by a consideration of how the five Arctic coastal states might partition the combined juridical continental shelf among themselves (Neto and van de Poll, 2001). Two hypothetical geometric approaches were examined: (a) the sector principle, defining meridians that converge at the North Pole; and (b) the median principle, defining successions of points equidistant from the coastlines of adjacent or opposite states (Figures 15-2 and 15-3, respectively).

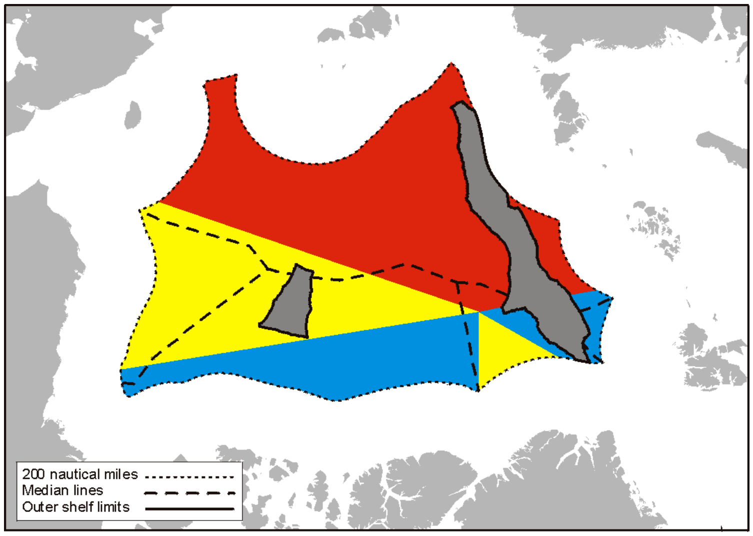


Figure 15-2. The colour portions of the figure above illustrate the continental shelf partitions that could result if all five coastal states agreed to the sector principle. For comparison, the boundaries constructed according to the equidistance principle are shown with dashed lines.

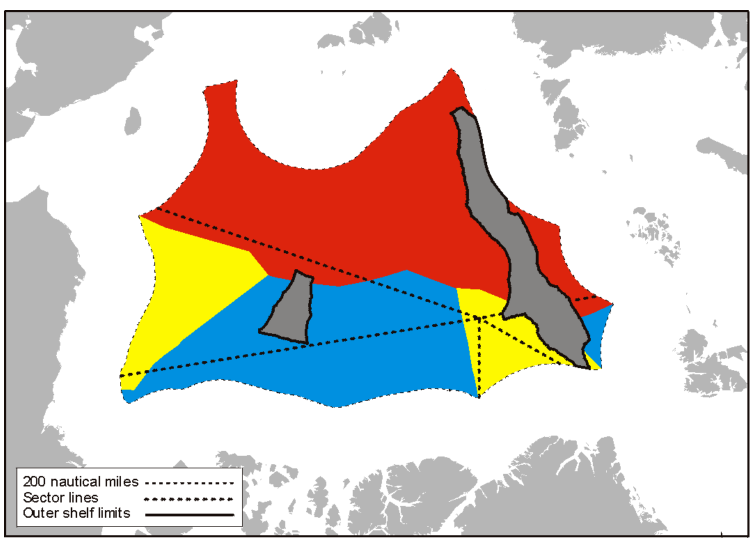


Figure 15-3. The colour portions of the figure above illustrate the continental shelf partitions that could result if all five coastal states agreed to the equidistance principle. For comparison, the boundaries constructed according to the sector principle are shown with dashed lines.

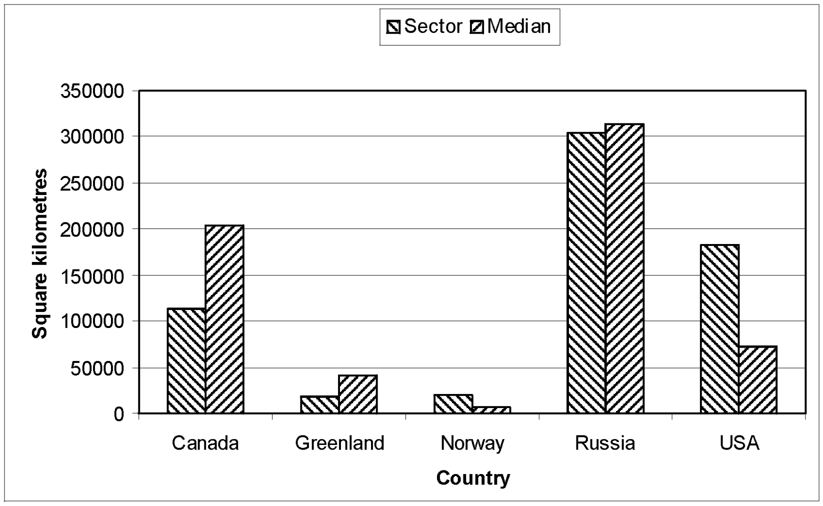


Figure 15-4. A comparison of partition sizes resulting from the sector and median principles.

16. The UN Atlas of the Oceans

Paul Bienhoff, APL, Johns Hopkins University, Baltimore MD, USA

Through a recent exchange of emails (appended below), the editors of the UN Atlas of the Oceans were asked about their potential interest in incorporating polar bathymetric data in the document that is presently under development. The response was positive, offering suggestions on how to proceed. As inclusion in the UN Atlas would raise the IBCAO profile and make its contents more widely available, the situation will be monitored and appropriate action will be taken when circumstances permit.

Letter of inquiry:

```
Subject: UN Atlas of the Oceans
Date: Mon, 14 Oct 2002 14:11:45 -0400
From: Paul.Bienhoff@jhuapl.edu
To: serge.garcia@fao.org, john.everett@fao.org
CC: ron.macnab@ns.sympatico.ca, Doug.Geffert@jhuapl.edu,
margo@soest.hawaii.edu

Mr. Garcia and Mr. Everett,
I'd be interested in discussing ways to incorporate more information
into your atlas, specifically bathymetric data about the Arctic and
Southern Oceans.  I'll be participating in a workshop (the
International Bathymetric Chart of the Arctic Ocean and International
Bathymetric Chart of the Southern Ocean (IBCAO/IBCSO) meeting at the
University of Hawaii) in a couple of weeks (October 30 - November 1),
and would appreciate your insights into how we could collaborate to
ensure the Atlas has access to (or includes) existing Arctic and
Southern Ocean bathymetry.

Here's a website about the workshop:

<http://www.soest.hawaii.edu/HMRG/IBCAO_IBCSO/index.htm>
```

and a site about the IBCAO:

<http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/>

If you could send me additional information about the processes you use to add information to the Atlas, and how other contributors can best assist you, I would be happy to convey that information to the IBCAO Executive Board at the meeting, unless you or one of your representatives would be able to do so. Dr. Margo Edwards is hosting the meeting, and I'm sure she and the rest of the IBCAO Board would welcome your contributions or attendance.

Thank you in advance for your help,

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Response:

Subject: RE: UN Atlas of the Oceans
From: Carocci, Fabio (FIRM)
To: 'Bienhoff, Paul A.'
Cc: Everett, John (FIRM); Garcia, Serge (FIRD)
Sent: 10/17/2002 9:28 AM
Subject: RE: UN Atlas of the Oceans

Dear Mr Bienhoff,
We would welcome your participation in the <http://www.oceansatlas.org/servlet/id/1889> Bathymetry, Topography & Relief Topic.

The Atlas is set up as a hierarchy of editors, with an UN Agency at the top of most topics. Each editor is the authority for his/her topic tree. There are several ways to participate.

We are particularly interested in developing collaborations with government or academic institutions that could contribute materials as well as perhaps take over editing (compilation and maintenance) of sub-topics for which they are highly qualified. To the extent you can cause this to happen, it is a definite plus. I could similarly set you up with an Arctic and Southern Oceans sub-topic, or you could help flesh out the overall topic.

OR

```
If you just wish to review the Atlas areas that interest you and bring
errors or problems (and suggested fixes) and additional materials to
my attention, that is always welcome as well.

Please let me know your preference.

In addition, if you haven't already viewed the Editor roles,
information is available from most pages under the BECOME AN EDITOR
button, or from
http://www.oceansatlas.org/html/docs/adopt_topic.jsp BM__Hlt22525767
and its GET MORE INFO..... link

The first step is to become a member of the Atlas by registering
through the JOIN NOW button.  As a member you can immediately start
contributing by adding RELEVANT KNOWLEDGE such as websites and
documents (for which you have permissions from the copyright holder).

Best wishes!  Fabio Carocci
```

17. The new gravity map of the Arctic

Bernie Coakley, University of Alaska, Fairbanks AK, USA

Begun at ICAM III in 1998, the Arctic Gravity Project has been carried forward to completion by NIMA under the leadership of Steve Kenyon of NIMA and Rene Forsberg of KMS. Data incorporated in this grid were collected from submarines (US SCICEX program), P-3 Orion aircraft (flown by the US Naval Research Laboratory), satellites (data reduction by US NOAA and University College London) and ships operating on behalf of various government agencies, e.g. Germany's Alfred Wegener Institute, the Norwegian Petroleum Directorate, and the Geological Survey of Canada. The observations collected from these moving platforms were combined with point measurements collected on land and ice by Canadian and Russian agencies to create an entirely new map, covering the same area as the IBCAO bathymetry grid.

It is expected that this data and map will soon be made available through the project's website at NIMA; http://www.nima.mil/GandG/agp/index.htm. Members of the IBCAO Editorial Board will be notified when the data set is released.

18. Future Arctic operations by research vessels of the USA

Phil McGillivary, USCG, Alameda CA, USA

Report not available.

19. 3D visualization of IBCAO

Martin Jakobsson (CCOM/JHC) and Ron Macnab (GSC Retired)

The IBCAO model lends itself well to computer 3D visualization since it is a digital grid model containing both bathymetric and topographic information. A 3D shaded relief is capable of visualizing the seafloor morphology in a much more natural appearing form than a traditional contour map. Information between contours is revealed, and the applied shading gives the viewer a "3D impression" which makes the morphology easier to perceive. However, good high quality 3D software packages have not been readily available for the broader public due to high licensing costs and hardware requirements. Recent developments within the software industry, as well as the rapid evolution of hardware, have changed this situation. Today advanced 3D visualization software may be easily operated on a high-end laptop.

In order to promote their software, some companies have released viewers that are free for downloading. One such software package is *Fledermaus*, created by Interactive Visualization Systems (IVS; www.ivs.unb.ca). IVS have recently released *iView3D*, which supports the viewing of 3D objects in the *Fledermaus* format. Accordingly, we have rendered the IBCAO model using *Fledermaus* - the files will be made available through the IBCAO web page, along with information on how to obtain a demo of *iView3D* (Figures 19-1 and 19-2).

Another 3D visualization package is *HHViewer* (Helical Systems, http://www.helical.ns.ca/), which uses the Helical Hyperspatial Code (HHCode) for the efficient compression of multidimensional data sets in a binary interleaved format. A trial version of the viewer may be downloaded from the Company's website, along with an Arctic data set that features the IBCAO grid fused with grids that describe the magnetic and gravity fields, and sediment thickness. Figures 19-3, 19-4, and 19-5 illustrate some of the visualization possibilities that are available with this combination of software and data.

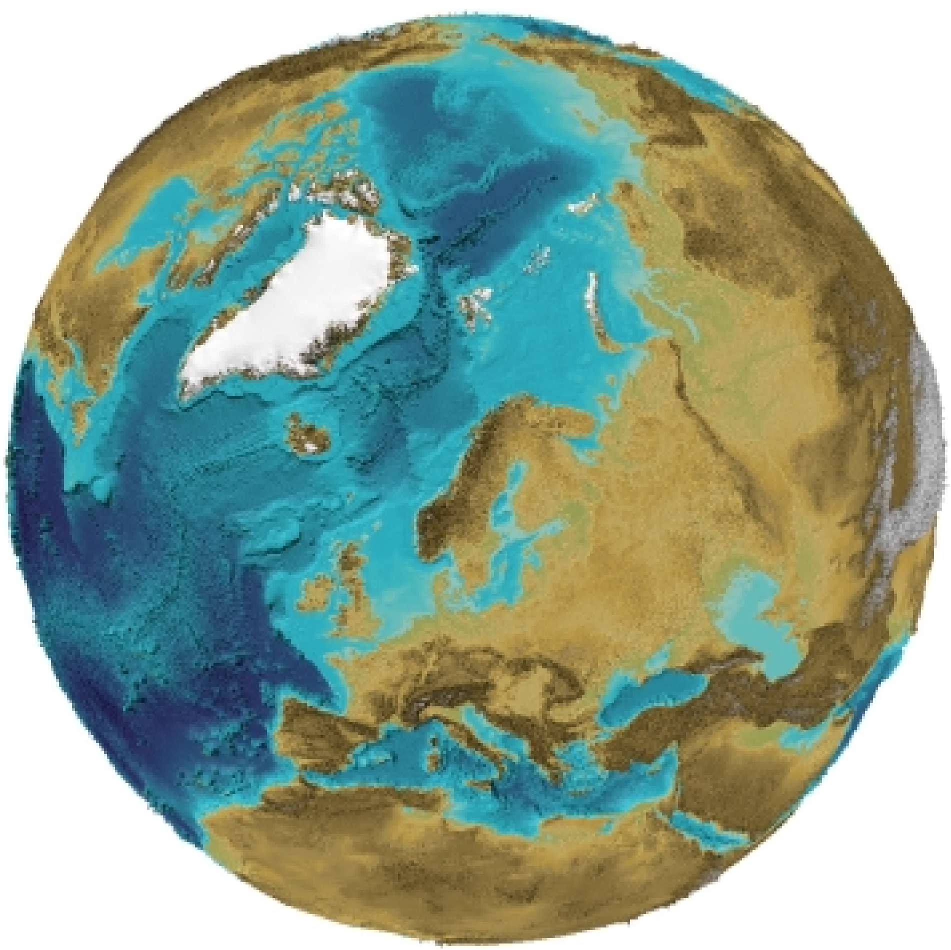


Figure 19-1. Visualization created with the *Fledermaus* software from IVS (www.ivs.unb.ca) of ETOPO2, a data set that is available through the National Geophysical Data Center (NGDC). ETOPO2 consists of IBCAO north of 64°N and the Predicted Topography (Smith and Sandwell, 1997) south of 64°N.

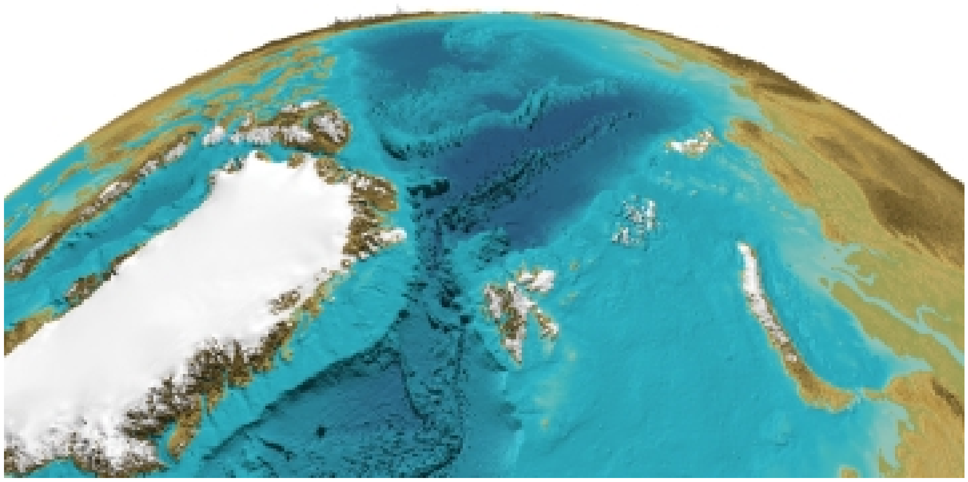


Figure 19-2. Detailed view of Figure 1.

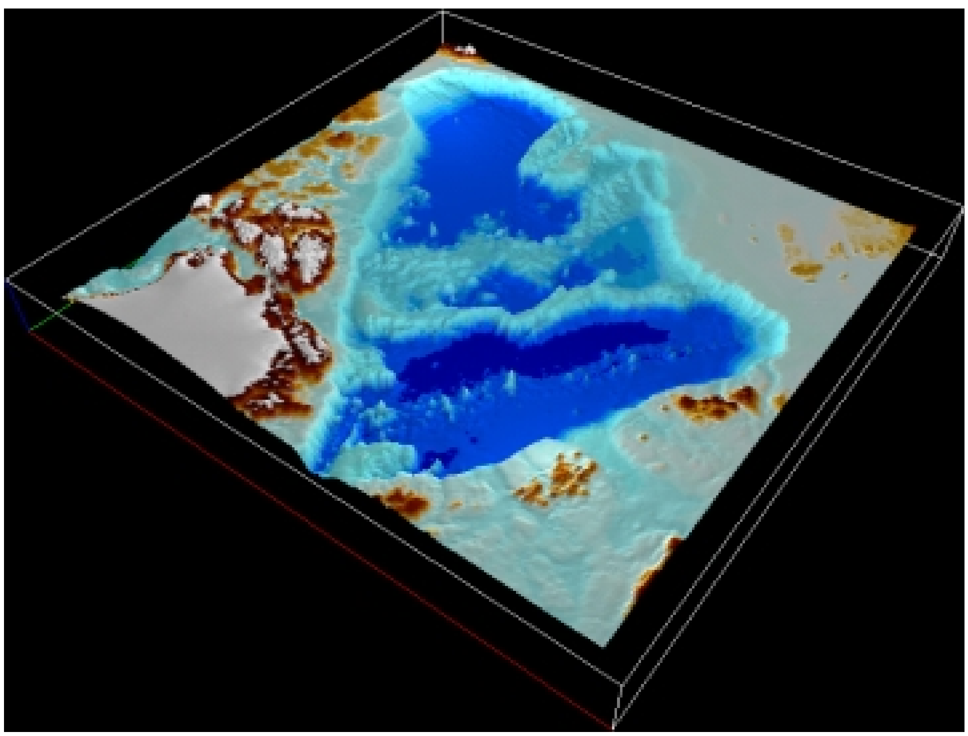


Figure 19-3. *HHViewer* rendition of the IBCAO grid, formatted in HHCode. Light blue: shallow water; dark blue: deep water.

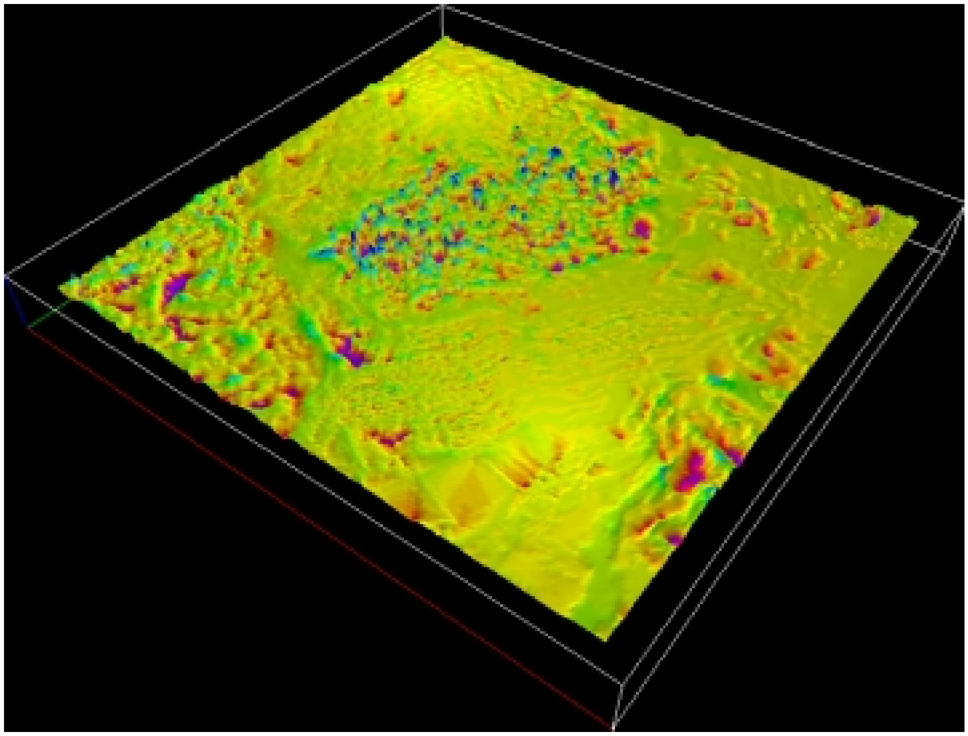


Figure 19-4. *HHViewer* rendition of the magnetic anomaly field of the Arctic Ocean fused with the IBCAO grid in HHCode. Red: positive anomaly; blue: negative anomaly.

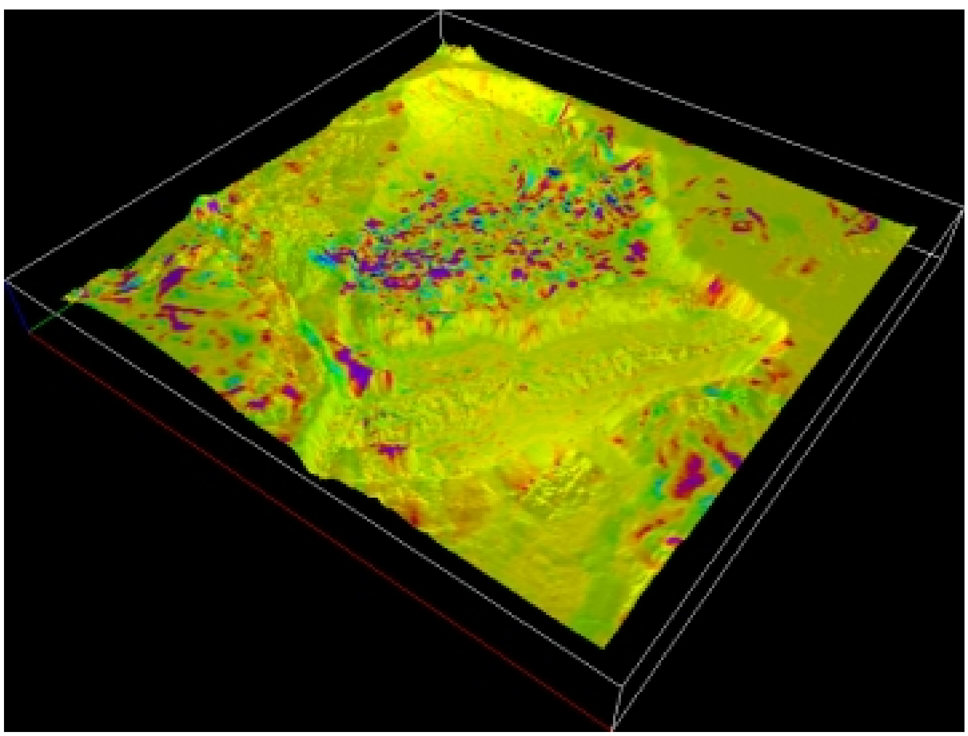


Figure 19-5. *HHViewer* rendition of the magnetic anomaly grid (colour) draped over the IBCAO bathymetric grid (grey tones).

20. Conclusions

Ron Macnab (GSC Retired) and Margo Edwards (HMRG)

The scope and diversity of the presentations in this report, along with feedback from meeting participants, testify to a variety of developments that promise significant improvements in our knowledge of the deep Arctic seabed. These developments may be grouped under the three headings that follow.

Enhancement of the data base through field work and data recovery

The IBCAO data base continues to be upgraded as errors are reported, or as new information is received. Swedish, German, and Norwegian mapping programs have accumulated significant new data sets. Swath mapping information collected with SCAMP instrumentation during the last two SCICEX missions is nearing the end of its processing stage. In the meantime, sizeable data sets that were collected in past years by Russian agencies have been readied for incorporation in IBCAO as soon as official permission is granted for their release. A data reclamation project is also underway in Canada, with a view to converting historic sounding data into digital form.

Future operations by research vessels of the USA are expected to provide opportunities for collecting new bathymetry. There are also initiatives aimed at resuming under-ice mapping operations by nuclear submarines of the US Navy.

Presentations and analyses of the data base

A grid was created from the bathymetric observations in the IBCAO data base, and then complemented with an available model of the surrounding topography for the construction of a map that portrayed land and seabed relief north of 64 degrees, in polar stereographic projection and at a scale of 1:6 million. Cartographically, this map mimics many of the features of Sheet 5.17 of the GEBCO series, and it will be proposed at next year's Centenary Conference as a prototype for a new generation of GEBCO maps. The Internet will serve as the primary medium for distributing the new map in digital form, however it is recognized that there is likely to be a strong demand for a hardcopy version, so it is also proposed to print a quantity.

To facilitate manipulation and examination of the data base, 3D visualization techniques have been applied to produce oblique views and fly-throughs, and to investigate correlations with complementary data sets such as the new Gravity Map of the Arctic. These tools have been used to good effect in various analyses, e.g. the definition of the major physiographic provinces of the Arctic seabed, a review of the availability and status of data sets that could support a claim for extended US jurisdiction beyond 200 nautical miles, and the construction of an extended continental shelf model for the entire Arctic Ocean according to the provisions of UNCLOS Article 76.

Public outreach

The success of an Arctic mapping program is determined to a large extent by how well its outputs are embraced by users who have a broad spectrum of requirements. IBCAO would appear to have met its objectives in this respect, as demonstrated by the ongoing popularity of the project website operated by the US National Geophysical Data Center. Plans are now being considered to use the map and data base as the foundation of a prototype digital atlas that would combine several classes of information, and which would offer users a high level of interactivity. It is expected that such a tool could place the project's outputs into the hands of a great number of users. In the meantime, project outputs are being freely offered for use in a variety of conventional applications that require up-to-date representations of the Arctic seabed. Team members have been invited to disseminate information about the IBCAO project at meetings, within their organizations, and wherever Arctic interests are discussed.

21. Acknowledgements

Thanks are due to associates Bob Anderson, Roger Davis, Jennifer Engels, Leslie Kajiwara, Tomoko Kurokawa, and Doug White of the Hawaii Mapping Research Group, for assistance with the administrative, logistical, and social aspects of the meeting. Lisa O'Neill prepared the final copy of the report. Grants to help defray meeting expenses were awarded by the US Office of Naval Research International Field Office, the International Arctic Science Committee, the US Polar Research Board, and the University of Hawaii.

Bibliography

Coakley, B.J. and G.W. Brass. Mapping the US Arctic Ocean margin: preparation of a US claim under UNCLOS Article 76. Report prepared for the Ad Hoc Working Group, 2002.

Jackson, R. and G. Oakey. Sedimentary thickness map of the Arctic Ocean, Plate 5, The Arctic Ocean Region, Volume L of The Geology of North America (edited by A. Grantz, L. Johnson, and J. Sweeney). Geological Society of America, Boulder CO, 1986.

Jakobsson, M. Mapping the Arctic Ocean: Bathymetry and Pleistocene Paleoceanography, Meddelanden från Stockholms Universitets Institution för Geologi och Geokemi, n 306, p 1-93, 2000.

Jakobsson, M., N. Cherkis, J. Woodward, R. Macnab, and B. Coakley. New grid of Arctic bathymetry aids scientists and mapmakers. EOS Transactions of the American Geophysical Union, v 81, p 89, 93, 96, 2000.

Macnab, R., P. Neto, and R. van de Poll. Cooperative preparations for determining the outer limit of the juridical continental shelf in the Arctic Ocean: a model for regional collaboration in other parts of the world ocean? Proceedings of a Continental Shelf Workshop hosted by the Argentine Council for International Relations (CARI), Buenos Aires, November 13-15, 2000. Reprinted with permission in Boundary and Security Bulletin. International Boundaries Research Unit, University of Durham, England, Spring 2001.

Neto, P. and R. van de Poll. On the relative effects of using sector or median lines for partitioning the juridical continental shelf beyond 200 nautical miles in the Arctic Ocean. International Hydrographic Review, v 2, n 1 (new series), p 37-44, 2001.

Smith, W.H. and Sandwell, D.T., 1997, Global Sea Floor Topography from Satellite Altimetry and Ship Depth Soundings, Science, vol. 277, no. 5334

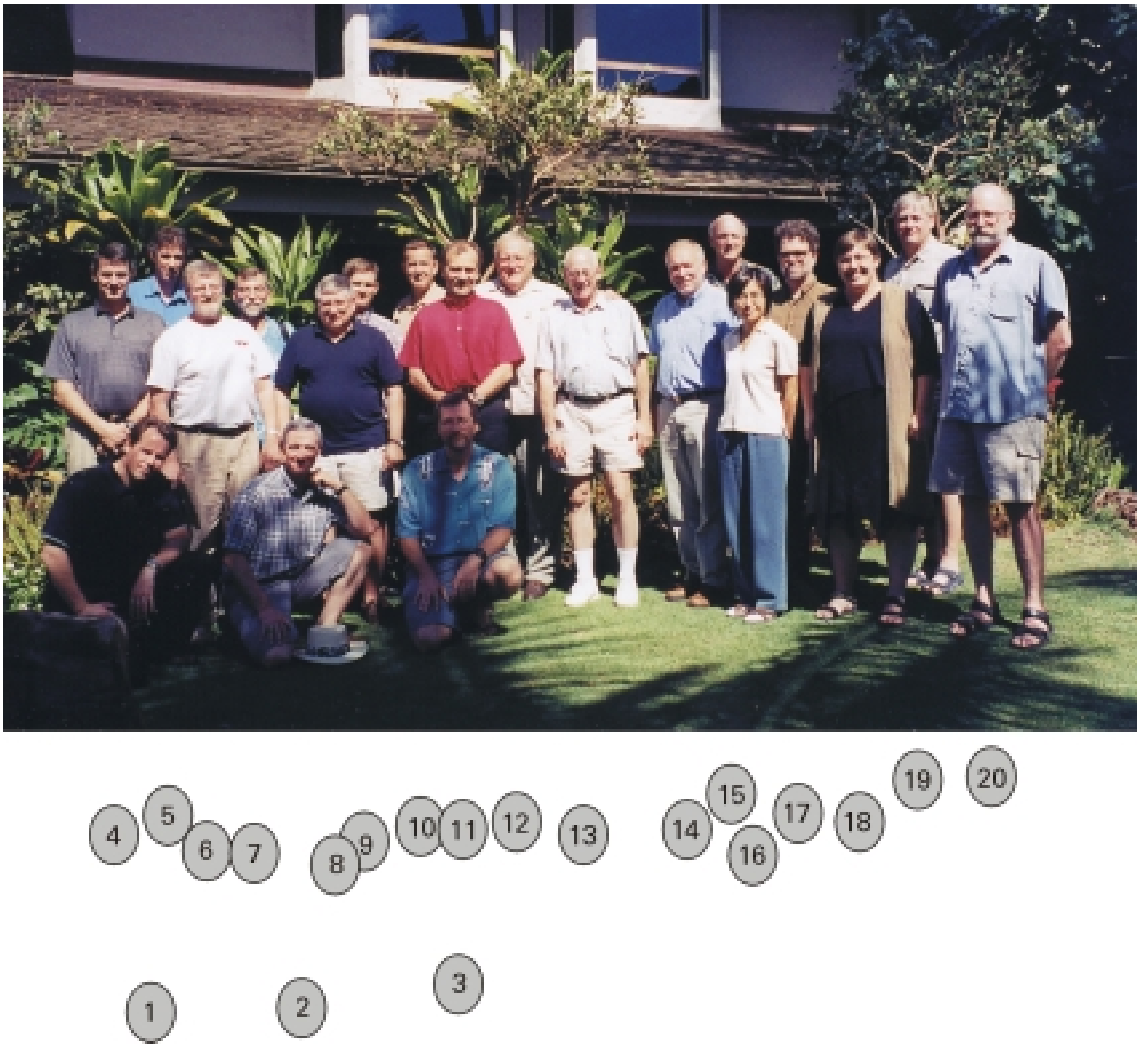
APPENDIX A

Acronyms and abbreviations

AMOR	Arctic Mid-Ocean Ridge
APL	Applied Physics Laboratory
AWI	Alfred Wegener Institute
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe
CCOM	Center for Coastal and Ocean Mapping
CHS	Canadian Hydrographic Service
DCW	Digital Chart of the World
DPC	Danish Polar Centre
DTM	Digital topographic model
EB-IBCAO	Editorial Board for the IBCAO
EEZ	Exclusive economic zone
ETOPO-5	5-minute gridded global elevation data
GEBCO	General Bathymetric Chart of the Oceans
GEOMAR	Research Center for Marine Geosciences
GEUS	Geological Survey of Denmark and Greenland
GIS	Geographic information system
GSC	Geological Survey of Canada
HDNO	Head Department of Navigation and Oceanography
HHcode	Helical hyperspatial code
HMRG	Hawaii Mapping Research Group
IASC	International Arctic Science Committee
IBC	International bathymetric chart
IBCAO	International Bathymetric Chart of the Arctic Ocean
ICAM	International Conference on Arctic Margins
IHB	International Hydrographic Bureau
IOC	Intergovernmental Oceanographic Commission
IVS	Interactive Visualization Systems
JHC	Joint Hydrographic Center
KMS	Cadastre Survey and Mapping Agency
MAR	Mid-Atlantic Ridge
MBES	Multi-beam echo sounder
NGDC	National Geophysical Data Center
NIMA	National Imagery and Mapping Agency
NOAA	National Oceanic and Atmospheric Agency
NPD	Norwegian Petroleum Directorate
ONR	Office of Naval Research
RDANH	Royal Danish Administration of Navigation and Hydrography
R/V	Research Vessel
SCAMP	Seafloor Characterization and Mapping Pods
SCICEX	Science Ice Exercise
SOEST	School of Ocean and Earth Science and Technology
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNH	University of New Hampshire
USARC	United States Arctic Research Commission
USCG	United States Coast Guard
USCGC	United States Coast Guard Cutter
VNIIO	All-Russia Research Institute for Geology and Mineral Resources of the World Ocean (full acronym: VNIIOkeangeologia)

APPENDIX B

Names and addresses of participants



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