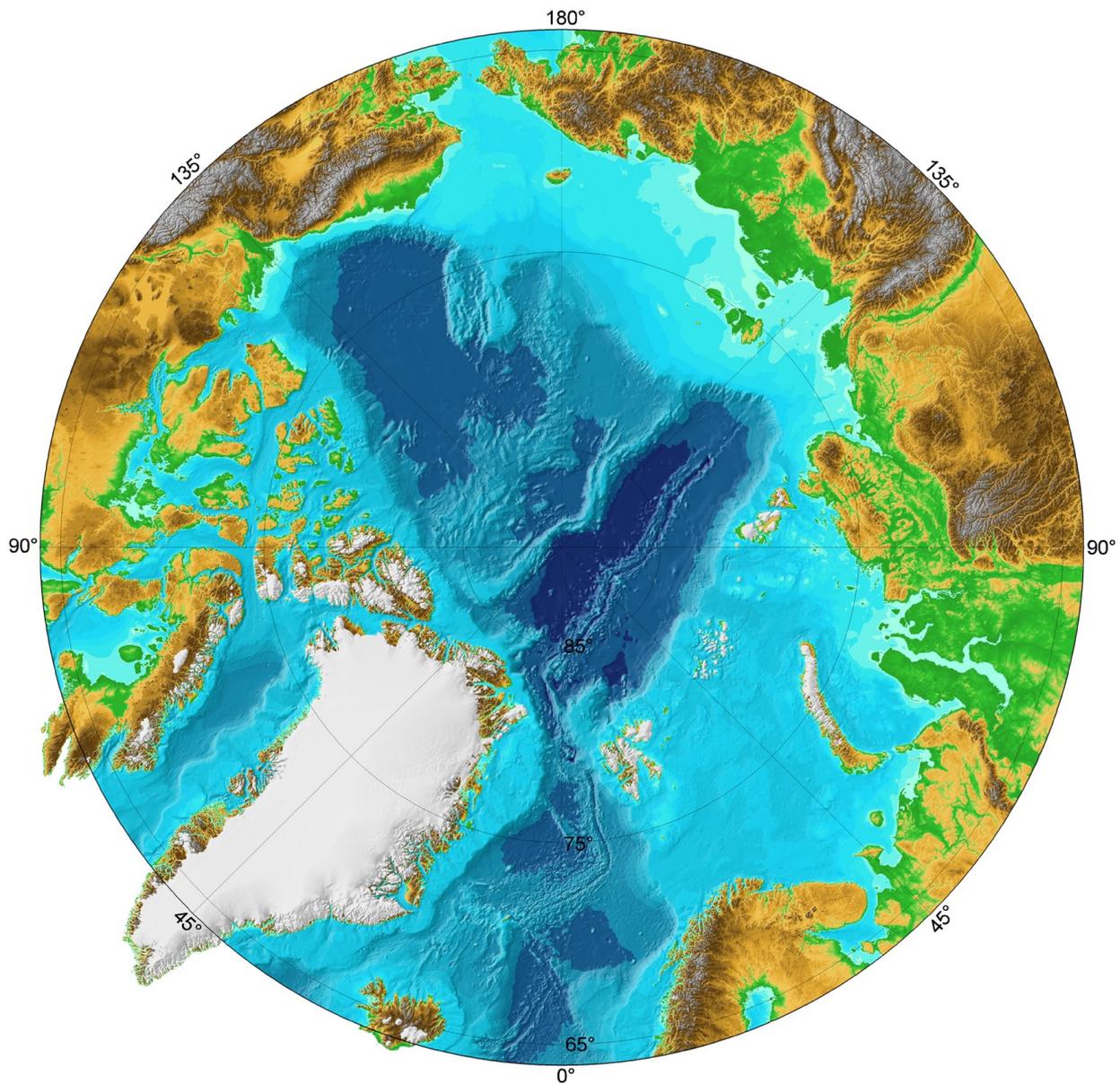# International Bathymetric Chart of the Arctic Ocean (IBCAO)

Beta Version

Technical Reference and User's Guide

Martin Jakobsson, Stockholm University

Ron Macnab, Geological Survey of Canada

Members of the Editorial Board, IBCAO

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Martin Jakobsson, Stockholm University
martin.jakobsson@geo.su.se
Ron Macnab, Geological Survey of Canada
macnab@agc.bio.ns.ca
Members of the Editorial Board, IBCAO
arctic-bathy@ldeo.columbia.edu

1. Compilation of the IBCAO-grid

New approaches to data visualization combined with modern mapping technologies have greatly enhanced our ability to extract information about earth processes. Grids of geophysical data viewed as color-coded shaded relief in 3-D, offer in many aspects a better representation for interpretation purposes than a contour map. A digital grid is also suitable for quantitative analysis and often serves as a base for quantitative modeling.

A gridded data set, or grid, consist of equidistant estimates of a quantity. These estimates are made from irregularly spaced measurements distributed across the gridded area. A grid is constructed by applying a mathematical algorithm in order to fit a continuous and bounded surface. The nature of the applied gridding algorithm will affect the final outcome especially while working with disparate datasets [e.g., *Bernadel,* 1997; *Smith* and *Wessel*, 1990]. Areas with dense data are statistically decimated. Areas that are poorly sampled are filled with interpolated or extrapolated values, depending on the local distribution of observations.

For example, in a Digital Terrain Model (DTM) the surface of the earth may be represented as a digital grid of regularly spaced topographic values. A shaded relief image of a DTM reveals the morphology and, if the resolution of the original data set justifies it, inferences can be made about surface textures, which often are indicative of processes.

The grid resolution is defined as the distance between each regularly spaced grid value. Figure 1, which shows a subset of the IBCAO source data off the coast of Svalbard, illustrates that the values of the grid model in some cases will need a great amount of extrapolation. Like any other DTM covering large geographical areas, the IBCAO model is insufficiently accurate over the full extent to be used for mission-critical applications such
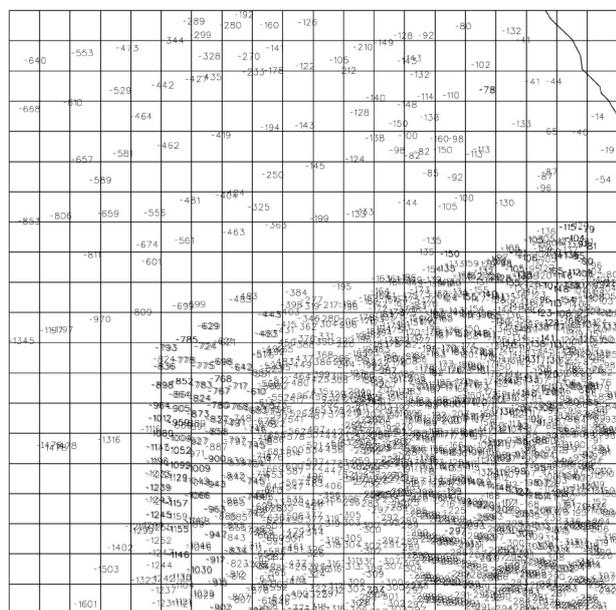

Figure 1. Subset of the IBCAO bathymetry source data off the coast of Prins Karls Forland, Svalbard. The mesh printed on top of the data represents the IBCAO grid (2.5 x 2.5 km cell spacing). Since each grid cell value is determined by the underlying source data the figure illustrates that the gridding algorithm will have to interpolate in areas with little and unevenly distributed data.

as nautical navigation. DTMs must always be interpreted with caution and source distribution maps should be used in order to estimate the accuracy of a specific region.

2. Source Data
2.1. Bathymetry source data
The IBCAO grid has been compiled using information from contour, grid, point, and track data. The data sources are illustrated in figure 2, and listed in table 1.

2.1.1. Ship track data
Ship track data derives both from surface vessels and submarines. The majority of the echo sounding data collected from surface vessels were obtained from the following four archives:
1.   the US National Geophysical Data Center (NGDC)
2.   the US Naval Research Laboratory (NRL)
3.   the Canadian Hydrographic Service (CHS)
4.   the Royal Danish Administration of Navigation and Hydrography (RDANH)

   Data in these archives are somewhat redundant. Therefore, the NGDC database was used as the primary source. Other archives were used as supplements in order to include cruises that the NGDC archive did not contain. In addition to the soundings in the four mentioned archives recent acquisitions were provided from cruises carried out with the Swedish ice-breaker *Oden* (1991, 1996) and the German research vessel *Polarstern* (1990, 1994, 1995, 1997).
   From the newly declassified US Navy and British Royal Navy submarine cruises, approximately 240,000 soundings collected on 26 missions between 1957 and 1982 and about 14,000 of the soundings collected on 22 missions between 1983 and 1988 are included in the IBCAO-grid compilation. In addition to these historic submarine data sets, the SCICEX program has contributed soundings collected along approximately 52,000 nautical miles of track during six under-ice missions between 1993 and 1999. These historic and recent submarine data sets have served as the main resource for IBCAO in the central Arctic Ocean.

2.1.2. Contour maps
Although extensive, the ship track database still features some critical gaps. In the central Arctic Ocean, original soundings were augmented with contour information derived from a newly published Russian map [*Head Department of Navigation and Oceanography et al.*, 1999]. Similarly, contour information extracted from an earlier map published by NRL [*Perry et al.*, 1986] were used in the area of Bering Strait. In the Barents and Kara Seas, information was extracted from maps compiled at NRL (*Cherkis et al*, 1991; *Matishov et al.*, 1995). On the continental shelf adjacent to Siberia, soundings were extracted from a suite of navigational charts published by the Russian Federation's Head Department of Navigation and Oceanography. These soundings were used to manually draw contours which subsequently were digitized. Finally, contours were extracted from the GEBCO Digital Atlas (*Jones et al.*, 1994) and used to supplement our database in the southern Norwegian-Greenland Seas, in Baffin Bay, and in some areas of the Canadian Arctic.

2.1.3. Gridded sources
Bathymetry in the Gulf of Bothnia was derived from a digital grid compiled by Seifert and Kayser [1995] which has a resolution of two minutes in the east-west direction and one minute in the north-south direction.
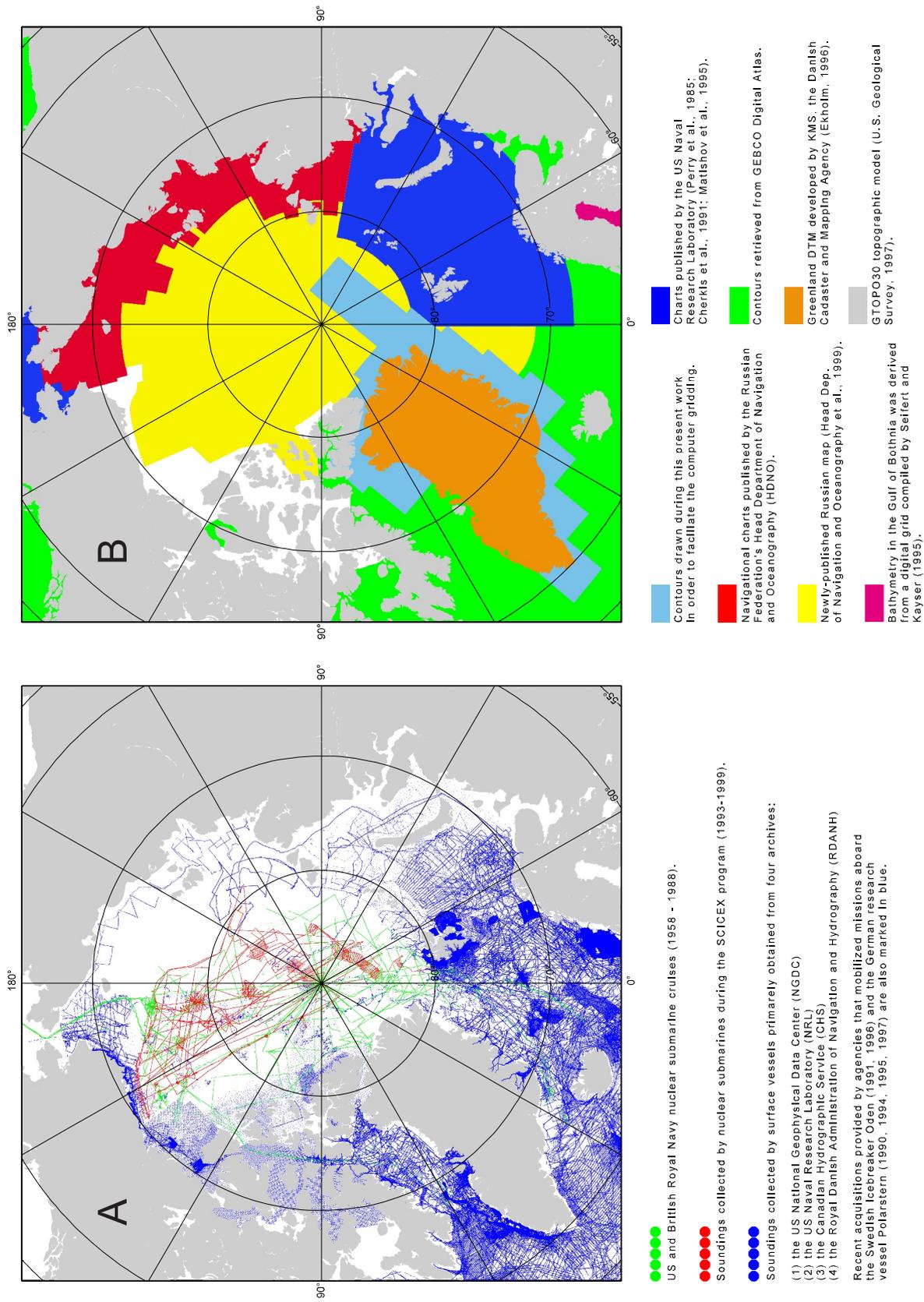
Figure 2. A) Original bathymetric measurements in digital form, used to construct a beta grid for the International Bathymetric Chart of the Arctic Ocean (IBCAO). B) Coverage of navigational charts and compilation maps, from which point measurements and hand-drawn contours were extracted to supplement the original observations shown in a Panel A.

2.2. Land source data
In the future version of the GEBCO Digital Atlas a global grid, comprising both land elevation and bathymetry, is planned to be included. Partly for this reason, it was decided at an early stage to include land elevation data in order to facilitate the incorporation of the IBCAO-grid into the global grid.

2.2.1. Coastline
A coastline definition was achieved by using the World Vector Shoreline (WVS) database in all areas except Greenland and northern Ellesmere Island, where an updated coastline was available from the Danish National Survey and Cadastre (KMS), and Kvitøya were GTOPO 30 (described below) was used to delineate the coast. The World Vector Shoreline (WVS) is a digital data file at a nominal scale of 1:250,000 [*Soluri* and *Woodson*, 1990]. Due to the IBCAO grid resolution (2.5 x 2.5 km) we found it sufficient to include WVS at a reduced nominal scale of 1:1,000,000 which was achieved by retrieving WVS from the GEBCO Digital Atlas. All these data sets have the World Geodetic System (WGS 84) as the horizontal datum. The WVS uses the Mean High Water (MHW) as the vertical datum.

2.2.2. Gridded sources
Land relief was derived largely from the US Geological Survey's topographic model GTOPO 30 [*U.S. Geological Survey*, 1997], with the exception of Greenland where the topographic model developed by KMS was used [*Ekholm*, 1996]. GTOPO 30 is a global digital elevation model (DEM) with a horizontal grid spacing of 30 arc seconds. The DEM over Greenland has a grid cell spacing of (latitudinal x longitudinal): 36 x 90 arc seconds. Both these topographic models refer their heights relative to sea level and uses the World Geodetic System (WGS 84) as the horizontal datum.

Table 1. Data sources included in the gridding of the IBCAO-grid. The reported number of values in track, grid and digitized nodes refers to the remaining amount after cleaning and subsampling to a minimum of 500-1000 m between depths/heights or digitized nodes in contours. *Echo sounding data collected from *Polarstern* 1990, 1994 and 1997 are included in the RDANH data base.

Data Sources	Digitized nodes in contours	Points in track or grid
Bathymetry		
NGDC, NRL, CHS, RDANH		1386455
SCICEX 1993-99		101096
US Navy and British Royal Navy submarine cruises 1957-88		85777
Oden 1991 and 1996		5209
Polarstern 1995*		26676
Ymer 80		3951
IBCAO derived contours over the Gakkel Ridge	76965	
IBCAO derived near coast support contours	229979	
IBCAO derived contours on the continental shelf adjacent to Siberia	547313	
IBCAO derived contours around Greenland	311512	
GEBCO Digital Atlas	223063	
Contours from HDNO map	306569	
Contours from NRL compilation maps	253348	
Grid over the Gulf of Bothnia		34313
Sum	**1948749**	**1643477**
Land elevation and coastline		
WVS	204361	
KMS coastline over Greenland and northern Ellesmere Island	57113	
KMS derived DTM over Greenland		1454075
GTOPO 30		14033391
Sum	**261474**	**15487466**
Total	**2210223**	**17130943**

3. Tools used

An overview of the software tools used to process the source datasets, perform the gridding and view the results is given in this section. More detailed information may be obtained from the software documentation. The non-public domain software is licensed to the Department of Geology and Geochemistry, Stockholm University, except for the *HHViewer/Toolkit* which is licensed to Geological Survey of Canada, Atlantic Division.

3.1. MicroStation SE

This is a CAD program, marketed by Bentley, that contains numerous drawing capabilities both in a 2D and 3D environment. In addition, raster files can be placed as backdrops. Intergraph's GIS applications included in the MGE suite (described below) use *MicroStation SE* as the drawing platform. The CAD files are referred to as *design files* (.dgn).

3.2. Modular GIS Environment (MGE)

GIS applications from Intergraph's MGE family were used for managing and processing of bathymetric and topographic datasets and for the production of bathymetric maps. The GIS maps are stored in the *MicroStation design file* format with attached geographic information. The following MGE applications were used:

Basic Nucleus (core GIS platform: project management, data review and query)
Base Mapper (generating, capturing, validating, and managing GIS data)
Basic Administrator (system and database management tools)
I/RAS B (monochromatic raster manipulation and image processing)
I/RAS C (color/grayscale/monochromatic raster manipulation and image processing)
Projection Manager (coordinate-system conversion and transformation)
Terrain Analyst (digital-terrain-modeling and analysis)
Map Finisher (creation and customization of presentation-quality cartographic outputs)

3.3. MicroStation Descartes

This software adds raster high quality image display, plotting, transformation, editing, mosaicing, and georeferencing (warping) capabilities to *MicroStation*. Since the software is integrated into *MicroStation SE* the tools were used on data in the MGE projects. The main part of the digitizing of scanned bathymetric contour maps were performed using *MicroStation Descartes* heads up vectorizing tools.

3.4. HHViewer/Toolkit

The *HHViewer/Toolkit* is marketed by Helical Systems and designed work on data stored in a standardized Spatial Data Structure (SDS) [*Varma et al.,* 1990]. The software package is suitable for working with bathymetric data and contains tools for gridding, tiling (variable-sized tiles), data visualization and cleaning. The bathymetric data was converted to SDS format and the statistical cleaning capabilities in the *HHViewer/Toolkit* were used.

3.5. Generic Mapping Tools (GMT)

GMT is a collection of data processing and mapping software tools available in public domain [*Wessel*, 1991, see: http://www.soest.hawaii.edu/gmt/]. Filtering and gridding of the bathymetric and topographic data were performed in GMT. In addition we used GMT to create color coded shaded relief and source distribution maps that were imported to *MicroStation SE* as raster backdrops.

3.6. Fledermaus

Fledermaus is software for visualization and interactive exploration of data in a 3D environment (see: http://www.ivs.unb.ca). The ability to "fly around" in a gridded data set, viewed as a color-coded shaded relief in 3D, using an interactive device called a "bat" made it possible to visually explore the grid for artifacts such as outliers, cross over errors and terracing. The powerful 3D visualization tools also helped to reveal the finer details of the grid.

4. Data processing and gridding

All bathymetric soundings were corrected for sound velocity using Carter's table or CTD profiles. An initial cleaning (flagging) of ship track and point data was carried out using statistical routines in Helical-Hyperspatial (HH) *HHViewer/Toolkit* [*Varma*, 1990]. Subsequently, ship track, point and gridded bathymetry and topography data was converted to ASCII files of longitude, latitude and depth/height and imported into MGE map files as text, which was color coded with respect to depth or elevation (MGE map files are *MicroStation design files* with attached geographic information). Digitized contours were imported as vectors using the same color-coding. The projection parameters in the MGE project were set to polar stereographic with the true scale at 75° N and the datum to World Geodetic System 1984 (WGS 84). Ship tracks were subsampled to one value every 500-1000 m along track.

A visual inspection of the statistical cleaning performed with the HH-tools could be carried out in the MGE environment with the benefit of the color-coding. During this process, outliers, cross track errors, and the fit between contours and sounding data were checked. Suspicious soundings were removed and where the contours showed major discrepancies with the bathymetric soundings we adjusted the contours manually to fit the new bathymetric track line data. Subsequently, all data was exported to a XYZ coordinate system by using the capabilities of *MicroStation SE*.

Prior to gridding, the data was pre-processed with a block-median filter in GMT with a block size of 2.5 x 2.5 km. Gridding at a cell size of 2.5 x 2.5 km was carried out with a continuous curvature splines in tension algorithm using the GMT-program *Surface* [*Smith* and *Wessel*, 1990] with the tension parameter set to 0.35.

The netCDF grid produced by *Surface* was converted to ASCII and imported to the MGE module *Terrain Analyst*. This made it possible to create color coded shaded relief images in the MGE environment using artificial sun illumination and at the same time view the original data. Certain discrepancies in the input data set were immediately highlighted and addressed. In several areas near the shorelines the WVS data did not manage to constrain the gridding which resulted in land extending outside the WVS. This was fixed by inserting additional "support" contours (-1 to –10 m depending on the near bathymetry data) very close to the shoreline. The support contours further constrained the gridding, which resulted in a more precise definition of the shoreline.

In order to suppress some of the effects of using randomly oriented ship tracks as input data a final smoothing was applied on the IBCAO-grid. The smoothing was achieved by applying the weighted average convolution filter shown in figure 3.

```
1   1   1
1   8   1
1   1   1
```

Figure 3. Convolution filter used to smooth the IBCAO-grid.

5. Grid format

A Polarstereographic projection with the true scale at 75 °N is "preserved" in the Cartesian grid. The horizontal datum is World Geodetic System (WGS 84). Figure 4 illustrates how the XY system was constructed, the corner coordinates, the grid spacing and the origin which corresponds to the North Pole. The data points are organized in grid registration. Each node is centered on a grid line intersection and the data points represent the average value in a cell of dimensions (2.5 x 2.5 km) centered on the nodes (Fig. 4).
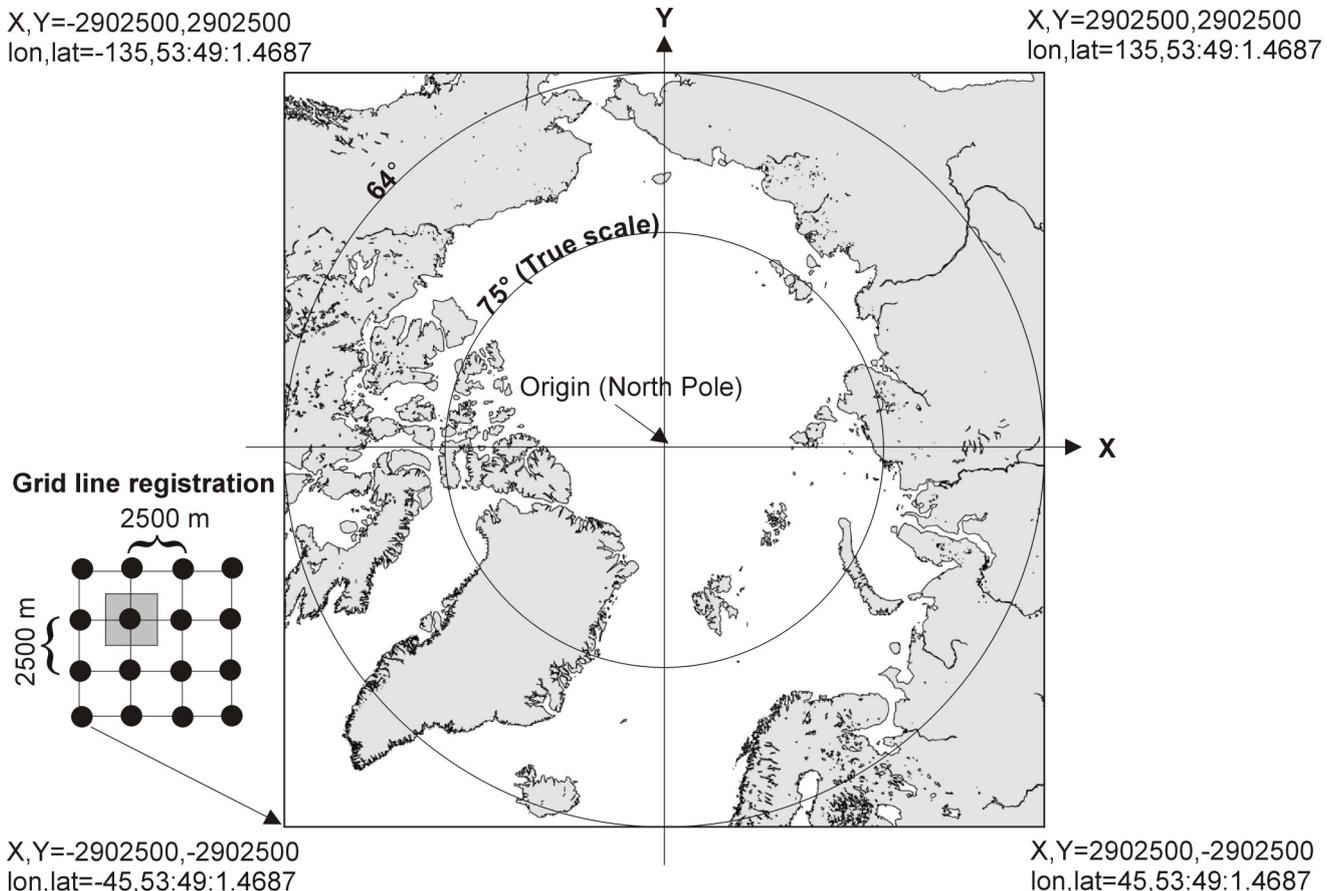
X,Y=-2902500,2902500
lon,lat=-135,53:49:1.4687

X,Y=2902500,2902500
lon,lat=135,53:49:1.4687

Grid line registration
2500 m
2500 m

X,Y=-2902500,-2902500
lon,lat=-45,53:49:1.4687

X,Y=2902500,-2902500
lon,lat=45,53:49:1.4687

64°
75° (True scale)
Origin (North Pole)
Y
X

Figure 4. The figure illustrates the IBCAO Cartesian XY system. The grid data points are organized in grid line registration. Each node is centered on a grid line intersection and the data points represent the average value in a cell of dimensions (2.5 x 2.5 km) centered on the nodes.

6. Grid artifacts

Unwanted features that result from the gridding method can be considered as artifacts. When using 3D visualization with artificial sun illumination in *Fledermaus* many types of gridding artifacts are clearly revealed. The following features are common gridding artifacts, some of which appear in the IBCAO-grid.

1. Terracing is a phenomenon that primarily arises when gridding digitized contours. The problem is due to a bias in the data input to gridding towards the contour values. If artificial illumination is applied to a terraced gridded surface the surface does not slope smoothly between contours. Instead the surface steps between terraces at the contour values. A tendency to terracing is revealed in the IBCAO-grid along the central Arctic Ocean continental slopes where digitized contours have been used.

2. Over- and under-shoot refers to defects in the gridded surface, due to the interpolation algorithm. These errors are often associated with steep slopes in bathymetry. For example, over-shooting can in the worst case lead to "new islands". If such an artifact

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is recognized it may be fixed by applying additional data points in order to constrain the gridding or increasing the tension applied to the grid.

3. Clearly visible ship tracks. This artifact commonly arises when gridding a mixture of bathymetric data which to a large extent contain soundings from randomly oriented ship tracks. The ship track artifact may be suppressed by applying various smoothing filters, but at the expense of losing information. Ship tracks are revealed in the IBCAO-grid especially when applying artificial illumination in *Fledermaus*. In order to avoid over smoothing of the gridded bathymetry, only the convolution filter described above was used.

7. Using the IBCAO-grid in GMT

The following examples refer to the Cartesian version of the IBCAO-grid which is superior for creating shaded relief portrayals in the high Arctic. Users of GMT may directly utilize the IBCAO grid provided in netCDF format independent of computer platform (PC, UNIX or MAC). The following examples are basic GMT scripts to create some simple shaded relief maps which may help to get an idea of the Cartesian grid format. All examples are written for a UNIX c-shell. If GMT is run from a DOS-prompt simply change the >! to > . The examples make use of a color table, which may be downloaded from the IBCAO home page (File: IBCAO_1.cpt). The maps in the examples are written as *PostScript* files. Some basic knowledge of GMT is assumed. For a more detailed description of the parameters used in each script, see GMT manual pages. Only the main script parameters are briefly commented.

7.1. A color shaded relief map of the entire IBCAO-grid

The first step is to use *grdgradient* to compute the directional derivative in order to simulate the shading of a sun from a given direction (-A). The resulting file will later be used to produce all of the shaded relief maps. For the –Nt parameter see GMT manual. Script 1:

```
grdgradient IBCAO_beta.grd -Nt0.6 -A300 -GIBCAO_beta_ill.grd -V
```

The second step is to use *grdimage* in order to create a shaded relief map by reading the IBCAO-grid, the file created by *grdgradient* above and a color table. The resulting postscript file is left open for more plots by the –K parameter. The –JX6/6 parameter means that the grid is treated as a non-map projection and that the resulting image will be 6 x 6 inch (or cm depending on your setting in the *gmtdefault* file). Figure 5 shows the resulting shaded relief map created by script 2:

```
grdimage IBCAO_beta.grd -IIBCAO_beta_ill.grd -R-2902500/2902500/-2902500/2902500 -JX4/4 \
-CIBCAO_1.cpt -P -K >! IBCAO_beta.ps
```

7.2. Plotting shoreline and map border on the IBCAO shaded relief

In the following example the GMT program *pscoast* is used to plot the World Vector Shoreline (WVS) on the shaded relief map produced by script 2. In addition a map frame and grid lines are plotted. This illustrates how the Cartesian coordinates in the grid relate to geographic coordinates. In the example we use the high resolution version of WVS provided by GMT (-Dh). Note that the WVS shows a significant mismatch on the northern coast of Greenland. This is due to the fact that the IBCAO-grid was compiled using the updated coastline provided by KMS. Figure 6 shows the shaded relief with the WVS and map frame plotted by script 3:

```
pscoast -JS0/90/4 -R-45/53:49:1.4687/135/53:49:1.4687r -Ba45g45/20g20 -Dh -W -O >> IBCAO_beta.ps
```
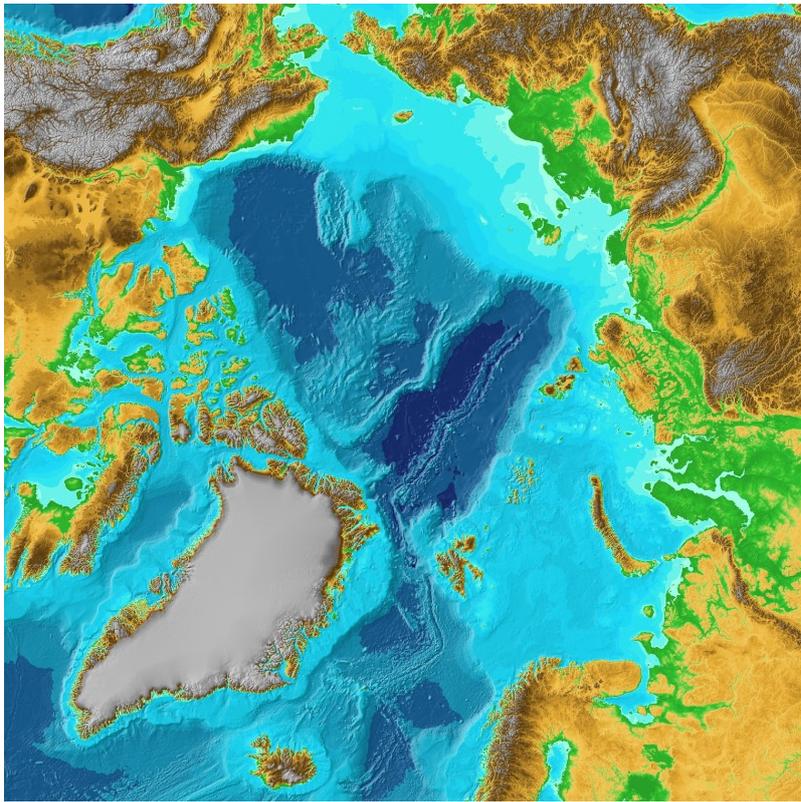
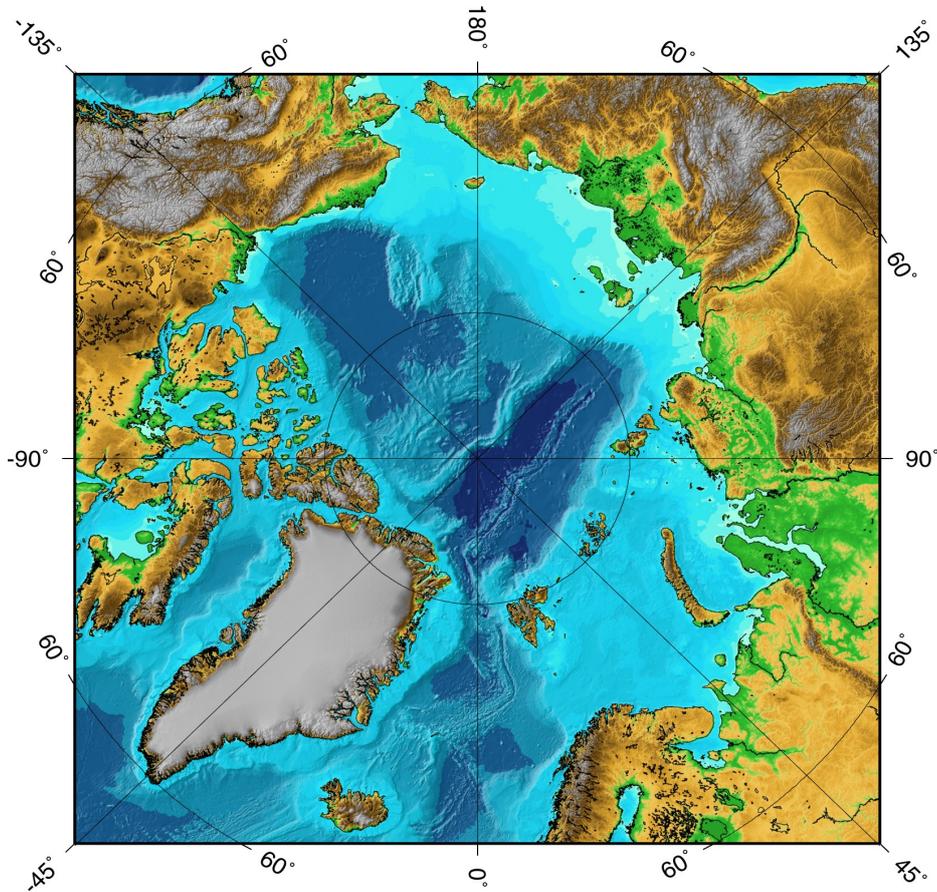**Figure 5**. Shaded relief created using script 2.

Figure 6. Shaded relief of the IBCAO-grid with WVS and map frame plotted using script 3.
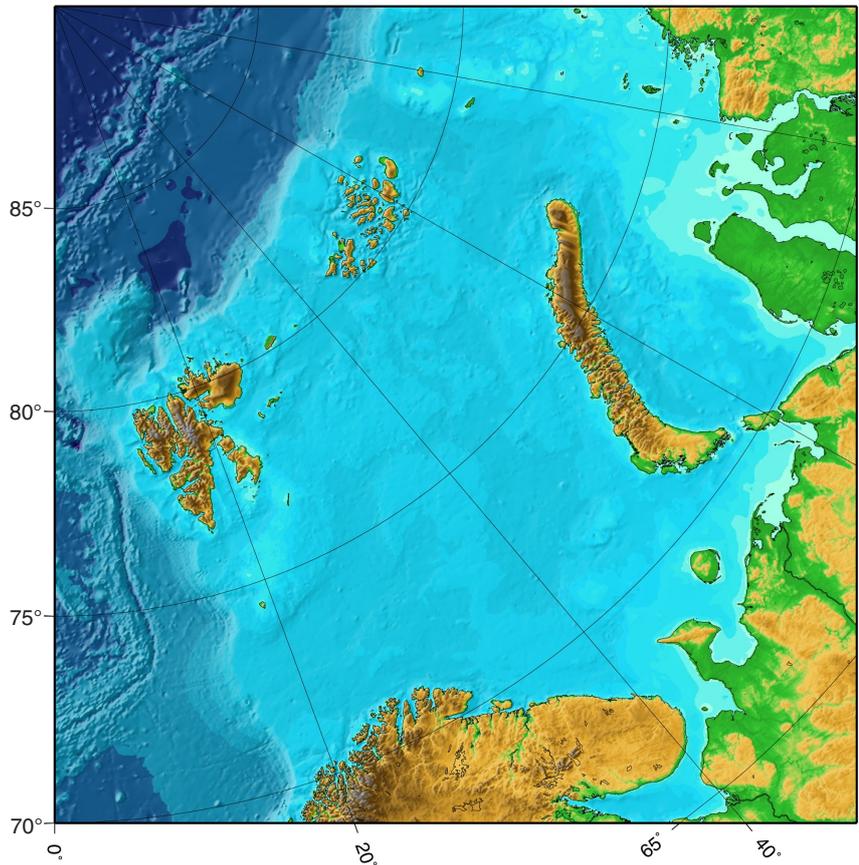
Figure 7. Shaded relief of a subset of the IBCAO-grid with WVS and map frame plotted using script 5 and 6.

7.3. Plotting a subset of the IBCAO-grid

In order to plot a specific area of the Cartesian IBCAO-grid, the geographic coordinates of the area have to be translated into the Cartesian coordinate system. This may be done using the GMT program *mapproject*. The provided script below may be used to convert any pair of geographic coordinates within the extent of the grid assuming that the coordinates refer to WGS 84. An ASCII input file containing the coordinates, which are subjected to the transformation, is needed for the example. We will plot a subset over the Barents Sea. The input file in the example, called geographic.asc, contains the lower left and upper right coordinates of our area organized in the following manner (lon lat):

```
0       70
90      70.5
```

The coordinates are converted by script 4:

```
mapproject geographic.asc -R-45/53:49:1.4687/135/53:49:1.4687r -JS0/90/5805000 -C -V >! cartesian.asc
```

The resulting Cartesian coordinates are:

```
0       -2217500
2161006     0
```

These coordinates are now used to plot the subset of the grid. The size of the shaded relief, which is set by the –JX parameter, needs to be adjusted in order to get the correct ratio of the

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region. If we decide the width to be 4 inches then the height will be (y_distance/x_distance) x 4 inch:

(2217500/2161006) x 4 ~ 4.105 inch

The following script 5 is used to create a shaded relief of the area:

```
grdimage IBCAO_beta.grd -IIBCAO_beta_ill.grd -R0/-2217500/2161006/0r -JX4/4.105 \
-CIBCAO_1.cpt -P -K >! Barents_sea.ps
```

Figure 7 shows the shaded relief produced by script 5 with coastline and a map frame which have been plotted (see GMT manual for information of the parameters) using the following script 6:

```
pscoast -JS0/90/4 -R0/70/90/70:30r -Ba20g20/a5g5WeSn -Dh -W -O -K >> Barents_sea.ps
```

Note:
GMT 3.3.3 was used in all examples except for the creation of figure 7 since we found a bug when using *pscoast* with the -JS option (Polar Stereographic projection). The grid lines created by -Ba20g20/a5g5WeSn do not appear properly. For the creation of figure 7 GMT 3.1 was used and worked properly.

8. Future updates
This beta version of the grid is the first step toward creating a dynamic map. Data from cruises presently planned and as yet unanticipated will be used to improve the grid. For example, the swath bathymetry data collected during the SCICEX program are currently being processed; we plan to include these data in the compilation of grid version 1.0. Similarly, multibeam data collected by the Norwegian Petroleum Directorate is undergoing inspection prior to release for use in the future update of the IBCAO grid. Users of the current beta version of the IBCAO grid are encouraged to evaluate and comment on its utility or inadequacy for their purposes. We particularly encourage individuals holding data sets that have not been made available to IBCAO to contribute those data. Those holding data sets or wishing to comment on particular aspects of the gridded data set should contact one of the authors.

9. Suggested citation
Jakobsson, M., N.Z. Cherkis, J. Woodward, R. Macnab, and B. Coakley. New grid of Arctic bathymetry aids scientists and mapmakers; Eos, Transactions, American Geophysical Union, v. 81, no. 9, p. 89, 93, 96.

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