GIS based data compilation of the new International Bathymetric Chart of the Southern Ocean (IBCSO)

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Summary The SCAR expert group for the compilation of the International Bathymetric Chart of the Southern Ocean (IBCSO) focuses on the buildup of a revised and updated bathymetric database for the entire Southern Ocean with additional seamless data derived from radar satellite images, satellite altimetry, and gravity. Bathymetric and additional data are provided by a great number of hydrographic offices, research institutes, and geoscientific data centers. The work plan in terms of data processing can be summarized by following steps: (i) data transfer to the IBCSO database management system, (ii) compilation of the heterogeneous data sets, (iii) data merge of georeferenced data sets, (iv) data analyses and optimization and, (v) iterative quality control. Data management and processing is conducted by use of geographic information systems. This approach allows production of traditional cartographic paper products and digital web maps. Hence the up-to-date bathymetric chart is generated time and cost efficiently.

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Introduction

The seafloor topography of the Southern Ocean with morphological features such as mid-ocean spreading ridges, trenches, seamounts, depressions, canyons, and abyssal plains reflects tectonic processes and provides information about the geologic evolution of the Antarctic and neighboring oceanic plates (Lonsdale, 1994; McAdoo and Laxon, 1997; Cande et al., 2000). Moreover the knowledge of submarine gateways and barriers is important for understanding ocean circulation systems (Gille et al., 2004) and its impact on global climate systems (Jayne et al., 2004). It is also important in defining and understanding the sensitive ecosystems around Antarctica.

Unfortunately, the depth and the shape of the seafloor topography measured by acoustic echo sounding systems are largely unknown. Large gaps of bathymetric information occur especially in the polar areas with limited access. Additionally the existing echo sounding data sets for the Southern Ocean are archived in widely scattered locations throughout the world. One of the main objectives of the IBCSO expert group is to collect and compile these heterogeneous bathymetric data sets that presently reside in numerous national and international databases and repositories. These will include single- and multibeam observations acquired during upcoming IPY 2007/2008 projects.

Geographic Information Systems (GIS) are computer-based systems that are used for data input, data storage, data manipulation, and data output. GIS software provides users with functions which allow maintenance and integrated analyses of spatial and non-spatial attribute data. The GIS implementation requires phases in evaluation, development and operation of all system components: hardware, software, data, and applications. Due to the rapid development in digital processing techniques GIS based concepts have become an indispensable strategy in many fields of applications (Tomlinson, 2004). Therefore the IBCSO data compilation, which maps an area sized four times the European continent, is realized in a GIS environment with additional software modules for networking and supply of digital web maps.

International Bathymetric Chart of the Southern Ocean (IBCSO)

Figure 1. The IBCSO emblem.

The implementation of a southern equivalent to the International Bathymetric Chart of the Arctic Ocean (IBCAO) was proposed and accepted by an ad-hoc working group meeting during a General Bathymetric Chart of the Oceans (GEBCO) meeting in 2002. The resulting ocean mapping program for the compilation of the International Bathymetric Chart of the Southern Ocean (IBCSO) was adopted as an International Bathymetric Chart mapping project by the 37th Executive Council of the Intergovernmental Oceanographic Commission in 2004. The SCAR Expert Group IBCSO (see Figure 1) is well established within international and intergovernmental organizations, e.g. the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the International Hydrographic Organization (IHO), and the Scientific Committee on Antarctic Research (SCAR). The following groups and subcommittees set up IBCSO in an official frame: the Consultative Group on Ocean Mapping, the Hydrographic Committee on Antarctica, and the SCAR Geosciences Standing Scientific Group. IBCSO has liaisons with the SCAR/SCOR Expert Group on Oceanography and with the SCAR Standing Com-

mittee on Antarctic Geographic Information. After an interruption in 2004, the IBCSO project has been restarted at the end of 2006 and is now coordinated at the Alfred Wegener Institute for Polar and Marine Research, Germany.

Consistent Database of the Southern Ocean and Antarctica

An initial goal of IBCSO is to transfer echo sounding data that is now distributed world-wide into the project database management system. These data sets are maintained by a great number of research institutes, universities, agencies and related data centers from many countries. Echo sounding data is very heterogeneous in terms of age, acquisition systems, accuracy, preprocessing, and documentation. Other data sets that are imported to the IBCSO database, e.g. satellite data, are homogeneous and manageable compared to the echo sounding data sets. The variety of data types and data formats necessitates the use of GIS for data collection, storage, manipulation, and visualization (Aronoff, 1989). Echo sounding data is commonly stored as ASCII point data representing x- and y-coordinates with depth information. In contrast to that, satellite images are usually stored in raster data formats while DEMs are stored as cell-based grid data. Coastlines and other borders are stored as line features in vector format. Consistent integration of the diverse IBCSO data sets is assured in a GIS environment with extensive data import and export capabilities (Hohl, 1998).

Acoustic echo sounding data

Search and acquisition of existing echo sounding data is one of the crucial factors in digital ocean mapping. Existing narrow single-beam and multibeam data of the Southern Ocean is scattered throughout the world and documentation is often poor. These factors might hamper the integration of data to the IBCSO database management system. The IOC Consultative Group on Ocean Mapping recommends close collaboration with IOC, IHO and SCAR, especially in the acquisition of new data and the retrieval of existing data from a great number of data centers and repositories.

The bathymetry group at AWI hosts one of the largest databases mainly of multibeam data for polar areas in the world. As a result, the Bathymetric Chart of the Weddell Sea (BCWS) was published in cooperation by AWI and Vernadsky Institute (Udintsev and Schenke, 2004). This map series consists of one Master Sheet Scale 1:3,000,000 and nine Sheets Scale 1:1,000,000. It covers the area between 66°W-2°E and 66°S-78.5°S. Compilation and contouring are in accordance with the IHO standards (Schenke et al., 1998). New data was collected by AWI in the area of the Bellinghausen, Amundsen Sea, Scotia Sea, and Northern Weddell Sea. A new bathymetric chart of the Ross Sea has been prepared by New Zealand. This data covers parts of the South Pacific and will be integrated with the IBCSO database. Russian data covers large areas of the southern Indian Ocean including Prydz Bay, Cooperation Sea, Cosmonaut Sea, and Riser-Larsen Sea. Australian data covers also parts of the southern Indian Ocean. Bathymetric data is integrated from the Geophysical Data Center (GEODAS), the IHO Data Center for Digital Bathymetry (DCDB) and the SCAR Antarctic Digital Database (ADD). There are many more patches spread world-wide. Nevertheless, large gaps occur especially in the South Pacific. To fill these gaps, global data from GEBCO, ETOPO2 and other data will be merged with the high resolution single- and multibeam data.

Integration of additional data

The land mass of Antarctic has remained a poorly mapped area for many reason as, e.g., extreme weather conditions, darkness, and cloud coverage. To map the entire land mass of Antarctica which is surrounded by the Southern Ocean, high resolution remote sensing data from Radarsat-1 will be added to the IBCSO database. Radarsat SAR images were collected during the Radarsat-1 Antarctic Mapping Project in 1997 (Jezek et al., 2000; Jezek et al., 2002). A high resolution digital elevation model of Antarctica has been calculated from satellite altimetry of Radarsat SAR images acquired during the RAMP and is available from the Digital Elevation Model Version 2 (Liu et al., 1999; Liu et al., 2001).

The boundary between the ice-covered ocean and the continental ice or rock exposures describes the geometric shape of the Antarctic coastline. Other boundaries define the minimum and maximum extent of shelf ice and the ice rim. The data sets are stored in various data centers (BAS, BPRC, and USGS) and are being integrated into the IBCSO database. The length of the 1:1,000,000-scale Antarctic Digital Database coastline for the Antarctic continent is calculated to be 36.780 km (Fox and Cooper, 1994). The length of the coastline generated automatically from SAR imagery varies from 39.900 to 43.450 km, depending on the spatial resolution of the SAR data. The absolute accuracy of the high resolution coastline position extracted from orthorectified Radarsat SAR images is better than 130 meters and is adequate for large scale cartographic maps (Liu and Jezek, 2004). Coastlines, grounding lines, ice shelves and ice rims represent important borders between land, water, and ice. These features are sensitive indicators for global change and sea level rise.

The shape of the ocean surface is partly determined by the Earth's gravitational field. Variations in the gravity field cause perturbations in the shape of the ocean surface, and can be detected by satellite radar altimeters. Global data sets from satellite altimetry (Sandwell and Smith, 1997) and predicted seafloor topography (Smith and Sandwell, 1997) provide morphological information in areas where bathymetric data is only sparse or not available. Advantages of satellite data are the uniform and global coverage at high speed and low costs. A significant disadvantage is that the tech-

nique provides only indirect measurements of the gravity anomalies, and not direct observations of water depth. Additionally there is only limited correlation with depth at wavelengths greater than 160 km, so actual soundings are required to calibrate the output (Smith and Sandwell, 2004). The Smith and Sandwell grid is the basis for other global grids, e.g. the 2-minute Earth Topography (ETOPO2v2). An evaluation of available global grids was performed by Marks and Smith (2005), concluding that the Smith and Sandwell grid may be the best choice, given that other grids degrade the solution by interpolating or cause problems by dislocation of features. Subsets of the global Smith and Sandwell data and ETOPO2v2 data are integrated into the IBCSO database to fill data gaps within the collected bathymetric data sets. Global bathymetric data provided by the GEBCO Digital Atlas Centenary Edition is used as additional reference data to fill abundant data gaps and proof reliability of bathymetric data. GEBCO represents a seamless digital bathymetric chart. The latest edition of the GDA-CE contains the GEBCO 1-minute global bathymetric grid, digitized GEBCO contours, and coastline databases (IOC, IHO, and BODC, 2003).

Metadata

Metadata, data about data, provide detailed information of data and respond to many questions concerning data sets. Background information from cruises very long ago is often fragmentary or incomplete. To prevent the loss of data or its consignment to data cemeteries from which it cannot be retrieved, the structure and content of metadata is standardized. Objectives of standardization are to provide common sets of terminology and definitions for the documentation of digital geospatial data. Standardization is based (i) on the Content Standard for Digital Geospatial Metadata (FGDC-STD-001-1998). This defines the US metadata standard of the Federal Geographic Data Committee (FGDC, 1998). Another standard is defined by (ii) the international metadata standard ISO 19115 of the International Organization of Standards (ISO, 2003). Both standards provide core elements which are mandatory: identification, data quality, data organization, spatial reference, and distribution. Bathymetric data at AWI Bremerhaven are stored in ASCII files with FGDC standard. Therefore the FGDC standard is realized within the IBCSO project in the Extensible Markup Language (XML) for two reasons. Most of the required metadata is consistently provided by information of the processed GIS data, and XML metafiles are easily implemented using web maps.

Concepts behind Contours and Grids

Since the early developments in computer graphics, sophisticated algorithm and procedures have been implemented in the form of software tools for the mathematical description of planar and perspective surfaces. The representation of a continuous surface in digital form requires the position of finite points in x- and y-direction and the depth-value. The surface generation is based on sampling of bathymetric data which shows normally a non-statistical spatial distribution of depth measurements. In some areas data density is very high while in other areas no or only sparse data is available. This random distribution strongly influences the quality and reliability of the generated surface.

The methods used to capture and store digital elevation data can be grouped into several approaches. These are contour lines, triangulated irregular networks (TIN), lattices, and most commonly grids. Choice of the surface representation technique must be made on the basis of purpose and type of terrain. Subsurface depth estimation from limited information by sparse data can be done best by grids (Laurini and Thompson, 1992). Another advantage of grid data is the possibility of merging bathymetry of the Southern Ocean with topography of Antarctica for a seamless digital elevation model without any gaps between land and water.

In addition to the density and distribution of depth measurements, the quality of calculated digital elevation models depends on the choice of interpolation techniques applied to the data. The choice of a suitable interpolation algorithm for data merging, filtering, convolution, and finite element modeling is crucial for optimized surface modeling and visualization. But data quality tends to decrease with increased manipulation, and this will be evaluated in defined test areas through a comparison of reference data with grids derived from various interpolation techniques.

Discussion

At present, two international initiatives are compiling bathymetric data for use in construction of seafloor topography in polar areas. These are the ocean mapping groups on the International Bathymetric Chart of the Artic Ocean (IBCAO) and the IBCSO. The IBCSO mapping project is the southern equivalent of the IBCAO (Macnab and Jakobsson, 2000). The voluminous bathymetric database for the Southern Ocean maintained by AWI needs to be supplemented by echo sounding data from other facilities and data centers. Additional global data sets from other sources are essential for the IBCSO data compilation to fill large gaps of sparse single-beam and multibeam data.

From the restarting point of IBCSO in November 2006, some important topics have been revised or updated: (i) collection of new bathymetric data by various cruises with R/V Polarstern, (ii) planning of new expeditions, (iii) restoration of the communication network (www.ibcso.org), (iv) revitalization of the IBCSO expert group, and (v) conceptual design and implementation of the IBCSO GIS and metadata structure. Future work comprises (i) continuous data transfer to the data management system, (ii) updating the heterogeneous data sets, (iii) evaluation of digital data processing techniques for optimized data merge, (iv) improved visualization of the International Bathymetric Chart of the

Southern Ocean, and (v) promotion of the IBCSO to the Antarctic Earth Sciences community, the ocean mapping community and the data infrastructure community.

Summary

The SCAR expert group for the compilation of the new International Bathymetric Chart of the Southern Ocean (IBCSO) proposes to build a consistent bathymetric database for digital ocean mapping of the entire Southern Ocean together with additional data that covers the land mass of Antarctica, e.g. satellite data, digital elevation models, and data derived from the DEM. Data acquisition, data transfer, data compilation, and data modeling of the heterogeneous data sets will be realized in a GIS environment. Digital data processing throughout the work will facilitate the production of cartographic printed maps (print on demand) and digital web maps. The continuous data transfer from collaborative data centers is one of the crucial points for the success of the IBCSO, as recognized recently by the SCOR and SCAR Oceanography Expert Group in the context of the International Polar Year 2007/2008.

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