Illuminating the Invisible Deep
- Multibeam Sonar Techniques Serve Marine Sciences -

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Abstract

Global oceans cover more than 70% of the Earth's surface. They are essential to the society as source of food and minerals, an economic means of transporting goods and, moreover, their influence on the global climate and environment is beyond dispute. Despite our reliance on the oceans and its resources, it remains a frontier for scientific exploration and discovery. Until few decades ago, human activities including research and industrial exploitation have focussed mainly on the coastal areas. After the invention of multibeam sonar techniques, mid 70th, marine researches also concentrate on the deep ocean floor. The importance of the submarine relief for the ocean is evident. In general, the sea floor plays an important role to the interaction between geosphere, hydrosphere and atmosphere.

Since 1983, AWI conducts with its research icebreaker RV "Polarstern" interdisciplinary expeditions to the polar oceans. The multibeam sonar system HYDROSWEEP DS-2 serves as a key instrument to map and image the sea floor topography. The 90° fan, oriented perpendicular to the ship's length axes, consists of 59 single sonar beams. HYDROSWEEP supplies depth and backscatter data for each sonar beam and sidescan images. Digital terrain models, derived from the sonar data, are utilized to create bathymetric charts and perform morphogenetic relief studies. Results from investigations in Arctic and Antarctic waters will be presented, using modern techniques, including 3D-visualization and animation.

1. Introduction

Mapping and charting the topography of the seafloor is of great importance to many scientific disciplines as its structures have direct influence on physical, chemical and biological processes in the marine environment, particularly near the seafloor. RV "Polarstern" is equipped with the multibeam system Hydrosweep DS-2 and was nearly two decades worldwide the only icebreaking research vessel capable to survey the unknown seafloor in the ice-covered polar oceans.

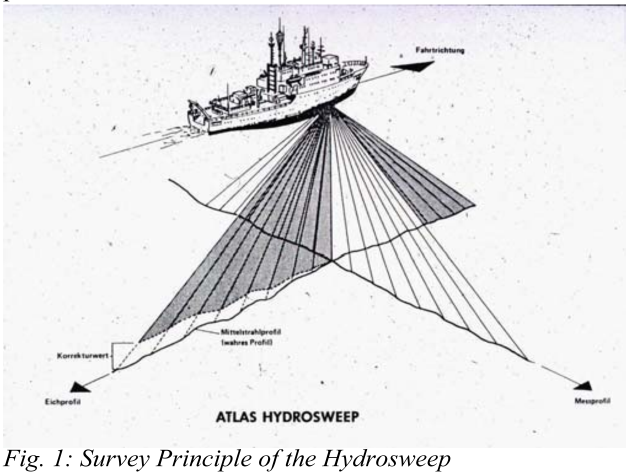

Fig. 1: Survey Principle of the Hydrosweep

The principle of the Hydrosweep survey method is shown in Fig. 1 with the standard survey fan perpendicular to the sailing route, and the so-called calibration fan placed along the track direction

The system operates at a frequency of 15.5 KHz with a bandwidth of 1.5 KHz, which was chosen to achieve two objectives. First, this frequency is low enough to cover the desired depth range, reaching the maximum ocean depths. In the second place this frequency is high enough to secure good vertical resolution, and the signal is reflected from the true bottom, rather than penetrating the sediment layers to the sub-bottom surfaces. The area is covered by a fan of 59 preformed beams (PFB), and has an aperture of 90°. This means that at equal depths the swath coverage is two times the water depth. However the fan aperture can be switched to 120°, having its effect on the swath coverage. The resolution of the system depends on speed and water depth. There are two reasons. The first is that in deeper water the 59 beams cover a wider line because of the swath coverage. The second reason, because the time between sending and arriving of the signal increases. At a depth of about 5000 meters and a speed of 10 knots the interval between two measurements is about 16 seconds. This means that the distance between two lines is about 80 meters. At a depth of about 3000 meters this distance reduces to ~55 meters.

Frequency	15.5 KHz
Bandwidth	1.5 KHz
Number of Beams	59
Fan aperture	90° or 120°
Beam spacing	2.3°
Pulse length	1-20 ms
Pulse repetition	1-22 s
Array dimension	3.0 m × 0.3 m
Stabilization	All axes
Depth range	10 – 11000 m
Swath Width	Min. 2 × water depth
Refraction Correction	Cross fan calibration
Accuracy	~0.5% of water depth
Maximum survey speed	15 Kt (knots)

Tab. 1: Hydrosweep specifications

The ice-protected transducers are installed in specially strengthened frames, in order to avoid damages. However, multibeam data measured during icebreaking are often erroneous and show outliers. Therefore special care is taken to analyse and clean the data.

2. Post processing

The data editing and cleaning forms the first important step in the post-processing of bathymetric data. As mentioned, the quality of the data depends on many factors, such as weather and ice conditions, which have influence on the data. Therefore the task is to remove outliers, and possible systematic errors in the bathymetric data, in order to achieve a homogeneous dataset.

This bathymetric data editing and cleaning is carried out at the AWI with the Hydrographic Information Processing System (HIPS), which is a part of CARIS (Computer Aided Resource Information System). This system is a GIS (Geographic Information System) especially for hydrographic data.

The post processing with CARIS-HIPS covers following major steps:

- Project set-up and vessel configuration
- Editing of navigation data
- Swath editing of depth data
- Editing of ship's attitude data
- Surface filtering and cleaning
- Digital Terrain Modelling

Bathymetric data can be represented in the best way by the use of a Digital Elevation Model (DEM), which can be considered as simplification of the earth's topography. Elevation models are a major constituent in processing geographical information, helping to model, analyse, and display phenomena related to the topography. Geoscientists often use these models as a basis for their research. Further these bathymetric elevation models are used within oceanography and biology. For these purposes many operations are possible on DEM's. Not only the, in bathymetry important, derivation of contour lines, but also complex mathematical operations, for example:

- Volume and visibility analysis
- Slope, aspect or higher derivatives
- Route and cable planning
- Profiling
- 3D-Visualization and animation.

3. Scientific Projects:

"Polarstern" has performed since her commissioning in 1982 nearly fifty expeditions to the Arctic and Antarctic. More than 600 000 nautical miles of multibeam survey data were collected. However, the work focuses mainly on systematic surveys in order to explore scientifically interesting areas.

Arctic Ocean:

Based on data from "Polarstern" multibeam sonar surveys between 1984 and 1997 a high-resolution bathymetry has been generated for the central Fram Strait. The surveyed area covers 36.500 km² between 78°N-80°N and 0°-7.5° W. Basic result of the systematic multibeam survey is a raster Digital Terrain Model with 100 m grid spacing (Fig. 2) which was utilized for contouring and generation of a new series of bathymetric charts (AWI Bathymetric Charts of the Fram Strait, AWI BCFS) at a scale of 1:100,000.

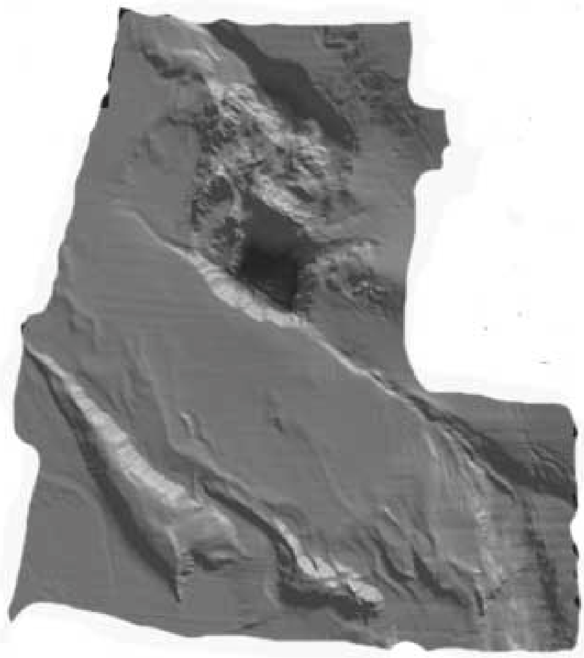

Fig. 2: Shaded high-resolution bathymetry of the Fram Strait

GEOMOUND Project:

GEOMOUND focuses on the geological evolution of giant deep-water carbonate mounds in the Porcupine Basin, off western Ireland. Further studies within this project concentrate on the deep-sea channels, which cut deep into the continental shelf. A multibeam survey with "Polarstern" was carried out in June 2000 to create a large scale and high resolution bathymetric charts to be used for the interpretation of the geological processes, and reflexion seismic data.

The working area has an extension of 70 by 10 nm, and was surveyed in 4 ½ days with 14 parallel profiles and a 10% overlap of adjacent swathes. The depths range from 400 m on the shelf to 2300 m in the Porcupine Basin. For the entire area a DTM was determined using grid interval of 50 m. The DTM-adjustment shows an overall accuracy for the bathymetric data of +/- 3.9 m.

In the mound area, a DTM with 10 m grid cells was determined, and contour lines in 5 m equidistance were derived for the final sheets. The mounds exist only in the depth range between 700 and 1000m. The flanks of the canyons in the southern part are approx. 20° steep and have a width between 2 km and 4 km. They are between 200m and 400m deep (Fig.3). Beside the bathymetric modelling and contouring, external sidescan data was processed, mosaicked and draped over the DTM, to create hybrid images of the seafloor.

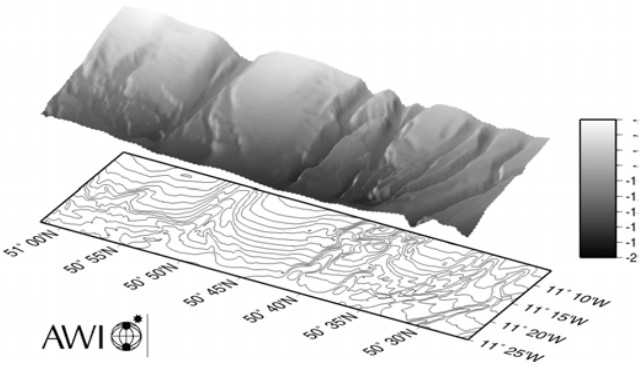

Fig. 3: Gollum Channels in the Porcupine Basin

AWI Bathymetric Chart of the Weddell Sea

From data collected by "Polarstern" and additional echo soundings provided by national Hydrographic Offices, research institutions, and the International Hydrographic Organization (IHO) Digital Bathymetric Data Centre, the 1:1 Mio. Bathymetric Charts of the Weddell Sea (AWI BCWS) series has been developed at the AWI. Nine sheets of the BCWS in the scale of 1:1 Mio. covering the entire Weddell Sea and the southern part of the Scotia Sea between 60° to 78° S, have been compiled until now (Fig. 4). The three northern sheets were developed in collaboration with the Vernadsky Institute in Moscow. From the southern six sheets a generalized bathymetric chart 1:3 Mio. was published.

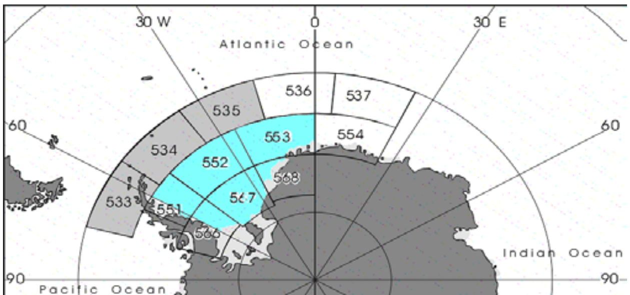

Fig. 4: Chart Scheme of the AWI/BCWS