

APPLICATION OF THE DTM-PROGRAM TASH FOR BATHYMETRIC MAPPING

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Abstract

For the new multibeam echosounder 'Atlas Hydrosweep' installed on the German research vessel *Meteor*, an extensive program has been performed in October 1986 in the Bay of Biscay. One part of this test program concerned the generation of contoured bathymetric charts. Data from different positioning systems were available besides the sounding data. After post processing, a three dimensional data set was provided for the computation of a regularly spaced Digital Terrain Model (DTM). As a further step, isolines can be generated from the DTM. Both the computation of the DTM and the plotting of isolines are carried out by the program system TASH of the Institute of Cartography of Hanover University (FRG). Different data sets and different input parameters have been tested aboard *Meteor* in order to get optimal results for the evaluation of data provided from wide angle sounding systems.

INTRODUCTION

As a result of increasing activities in the exploration of the world's oceans, a large demand exists for topographic surveying and mapping of the sea-bottom. New techniques have been developed for efficient surveys of the sea-bed topography.

The objective is to generate depth contours as represented in bathymetric charts from those data. This task is similar to the evaluation of topographic surveys of the land's surface and representation of height contours. Consequently, it has to be tested if the same software can be used in bathymetry. The results may be influenced by the accuracy and density of the sounding data, by the positional accuracy and by the shape of the relief features themselves.

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DATA COLLECTION

All data, on which the following explanations are based, have been collected during the Hydrosweep tests in the Bay of Biscay on the 4th *Meteor* cruise. Especially, a ridge at the continental slope has been considered for the investigations, because most of the interesting features can be found in this area and extended data sets could be provided.

Sounding

The multibeam echosounder 'Atlas Hydrosweep' allows the emission and reception of an acoustic beam fan with an overall angle of 90° . The received 15.5 kilocycle signals are transformed to digital depth values. These are attached to 59 preformed beams. Each beam has an angle of aperture of 2.2° . The wide beam fan requires a method to eliminate refraction effects that would lead to systematic errors, especially for the outer beams. For this purpose, the fan is transmitted in the ship's longitudinal direction at regular intervals (see Fig. 1). The profile that is obtained by this method is compared with the profile measured with the center beam when transiting over the profile. The sound velocity in water is changed iteratively according to a mean square value derived from the differences between both profiles.

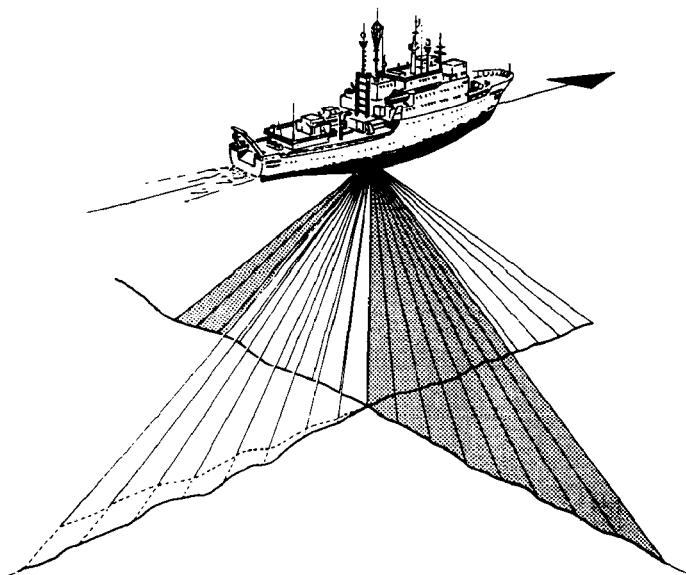


FIG. 1. — Sound velocity calibration (Krupp-Atlas Elektronik).

Regarding the fixed angle of aperture, it becomes obvious that the density of recorded depth values depends on the water depth. In areas with a depth of 5000 m

the distance between recorded points perpendicular to the course is approximately 200 m; in shallow water, with a depth of 100 m, the distance is 4 m. In the direction of the course, the density also depends on the ship's speed. Given a velocity of sound in water of 1500 m/s and a depth of 5000 m, the outer acoustic beams require 10 seconds between emission and reception. The calculation requires an additional 5 seconds. If the speed of the ship is 12 knots, it has covered a distance of 90 m in this time.

Positioning

Two different systems have been used to fix current positions. One of them, the standard system aboard *Meteor*, is the Integrated Navigation System (INS). It is based on Doppler measurements with the aid of Transit satellites. These satellites provide about one position per hour. Between the satellite fixes positions have to be estimated by dead reckoning leading to large positional errors that have to be eliminated by post processing.

More suitable is the NAVSTAR-GPS (Navigation System with Time and Ranging-Global Positioning System) because real time positioning is possible. For this purpose, the transmission time between the satellite and the antenna on board is measured. This gives the distance to the satellites and enables the position of the ship to be calculated if the positions of the satellites are known. At least two satellites have to be visible if height is known and a high precision oscillator is used as a time base. During the Hydrosweep test, two or more satellites could be observed for about 14 hours each day. Two GPS receivers, Texas Instruments 4100 NAVSTAR NAVIGATOR, were used. Positions with an accuracy of 30-60 m and associated time values were given continuously to the Hydrosweep system.

DATA PROCESSING

On-line processing

Hydrosweep offers different facilities to display the recorded data. The bottom map display shows isolines on a graphic screen together with annotation of parameters for navigation, sounding and ship's motions in the form of roll, pitch, and heave. This display scrolls downwards in relation to the progress of the measurements. The screen can be switched over to a display of cross profiles that is overwritten with each receiving cycle. In addition to these non-permanent representations, a so-called isoline strip chart is recorded on a plotter.

All the above mentioned representations are generated in an on-line mode. They are suited to detect missing and overlapping areas and they may help to identify gross errors.

Off-line processing

In order to produce a final representation, post processing has to be performed because the single tracks have to be adjusted, gross errors have to be deleted and, if necessary, positions have to be corrected. For this purpose the following data for each beam fan are recorded and stored on magnetic tape:

- Date of survey,
- Time of survey,
- Position of the centre beam in geographic coordinates ϕ (latitude) and λ (longitude),
- Direction of the ship (heading),
- Number of stored values for port,
- Number of stored values for starboard,
- Distances of the side beams from the centre beam,
- Water depths.

As a first step, all positions are plotted and, if necessary, the course has to be corrected by a smoothing process or, if positions are completely wrong, they must be deleted. Further gross errors among the sounding data have to be detected. Therefore, the environment around each beam has to be regarded and a standard deviation is calculated as a criterion for erasing single measurements. Finally, the data have to be transformed into a form that is usable by TASH. That means that the position for each beam has to be calculated and the data have to be stored in sequential files on magnetic disk, containing a code number, a point number and coordinates x,y,z in each record.

The DTM-program TASH

TASH is a DTM-program for the evaluation of topographic surveys. It was initially developed in 1974 at the Institute of Cartography, University of Hanover (FRG), within the so-called special research area 'surveying and remote sensing on coasts and seas' (KRUSE, 1979). The first version was installed on a Cyber 172/76-14 computer system at the regional computer centre of Lower Saxony, in Hanover. The program has undergone further development and additional versions are available. This development is done on a VAX computer with the virtual operating system VMS. By using this system, many restrictions have been reduced. The program consists of several modules, running in batch mode. Some of the modules have to be executed successively, e.g. starting with the input of data and following through to plotting of the contour lines. Other modules are optional and are only invoked for special applications such as perspective representations or computation of volumes. TASH requires a set of three dimensional coordinates (x,y,z) as input data. Additional input data, some mandatory and some optional, can be provided by directive files.

The following description shows the performance of the TASH-program using the VAX version.

The program TASH-PRE-MAIN reads and checks the input data for the subsequent modules, establishes a control file for further processing, and generates

a log file containing statistical data about the working area such as number of recorded points and dimensions of the area. Also, any consistent errors in the input data are detected and recorded in the log file. Furthermore, the program sorts different line types out of the input data and writes them on files:

- Breaklines
- Lines of ridges and valleys
- No data areas
- Geological faults
- Spot heights
- Grid and plot boundary.

The grid and plot boundary can be found automatically or manually. The program FLE-MAIN calculates a regularly spaced grid in the ground plane (x,y) from the stochastically distributed registration points. To derive the digital terrain model, the depth of each grid point, as represented by the height, has to be calculated. FLE-MAIN uses the method of 'moving surfaces' whereby the terrain around each grid point is approximated by a fitted surface. The equation of the surface is generated by an adjustment. Its parameter gives the height of the grid point itself. The selection of reference points is made by partitioning the area around a grid point into eight octants and choosing a certain number of closest points of each octant. The following four mathematical functions are available to obtain optimal results for different relief features (KRUSE, 1987):

1. Elliptic surface:

$$z_i = a_1 + a_2x_i + a_3y_i + a_4x_iy_i + a_5x_i^2 + a_6y_i^2 \quad (1)$$

2. Hyperbolic surface:

$$z_i = a_1 + a_2x_i + a_3y_i + a_4x_iy_i \quad (2)$$

3. Oblique plane:

$$z_i = a_1 + a_2x_i + a_3y_i \quad (3)$$

4. Horizontal plane:

$$z_i = a_1 \quad (4)$$

A certain function can be chosen either by the user or automatically by the program. In the latter case, the elliptic surface is calculated first. The standard deviation derived from the difference between the height of the reference points and the surface is compared with a given value. If it is not accepted, the next function is used and so on. Sometimes, smoothing of a DTM is desirable for certain applications. This can be done simply by calculating the average of a number of neighbouring grid points. If there are breaklines or geological faults in the area, a module deletes the terrain points which are behind these lines. The program finds these points by calculation of intersections.

The program ISO-MAIN uses the DTM produced by FLE-MAIN to interpolate contour lines. The sections of the contour lines are interpolated in grid cells along the boundaries of grid squares. If there are breaklines, ridges or valleys, geological faults or spot heights, the grid cell is compressed with a triangle net

provided that the lines are parts of the triangle net. Then the interpolation of contour-line sections is done in the triangle (KRUSE, 1979). The points calculated in this manner can be considered as vertices of a polygon. Contour lines are then fitted to these points using a 5th order polynomial. A smoothing process is first applied to avoid loops and critical points in the curved lines. Thus the vertices are displaced depending on the angle γ in the following way (KRUSE, 1987):

$$x_{i'} = x_i + s_{i,i'} \cdot \sin t_i \quad (5)$$

$$y_{i'} = y_i + s_{i,i'} \cdot \cos t_i \quad (6)$$

$$s_{i,i'} = \cos^n\left(\frac{\gamma}{2}\right) \cdot s_{i,HP_i} \quad (7)$$

$$x_{HP_i} = \frac{x_{i-1} + x_{i+1}}{2} \quad (8)$$

$$y_{HP_i} = \frac{y_{i-1} + y_{i+1}}{2} \quad (9)$$

The exponent can be chosen between 1 and 10 by the user. It determines the rate of smoothing (Fig. 2).

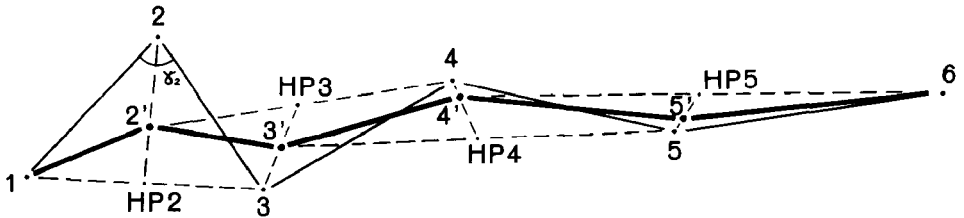


FIG. 2. — Smoothing of contour lines (KRUSE, 1987).

REQUIREMENTS AND RESULTS

In a cartographic sense, the topography of the sea bottom is the same as the topography of the earth's land surface since both are continuous phenomena. Therefore, isolines such as those generated by TASH are an appropriate method of representation. The quality of automatically generated isolines depends on the density and distribution of recorded reference points.

Requirements concerning quality aspects have been formulated for bathymetric charts in the following way (SCHENKE; ULRICH, 1986):

- The bathymetric chart has to be simple, legible, clear and understandable.
- It has to give the user a quick and accurate impression of the relief features on the sea bottom.

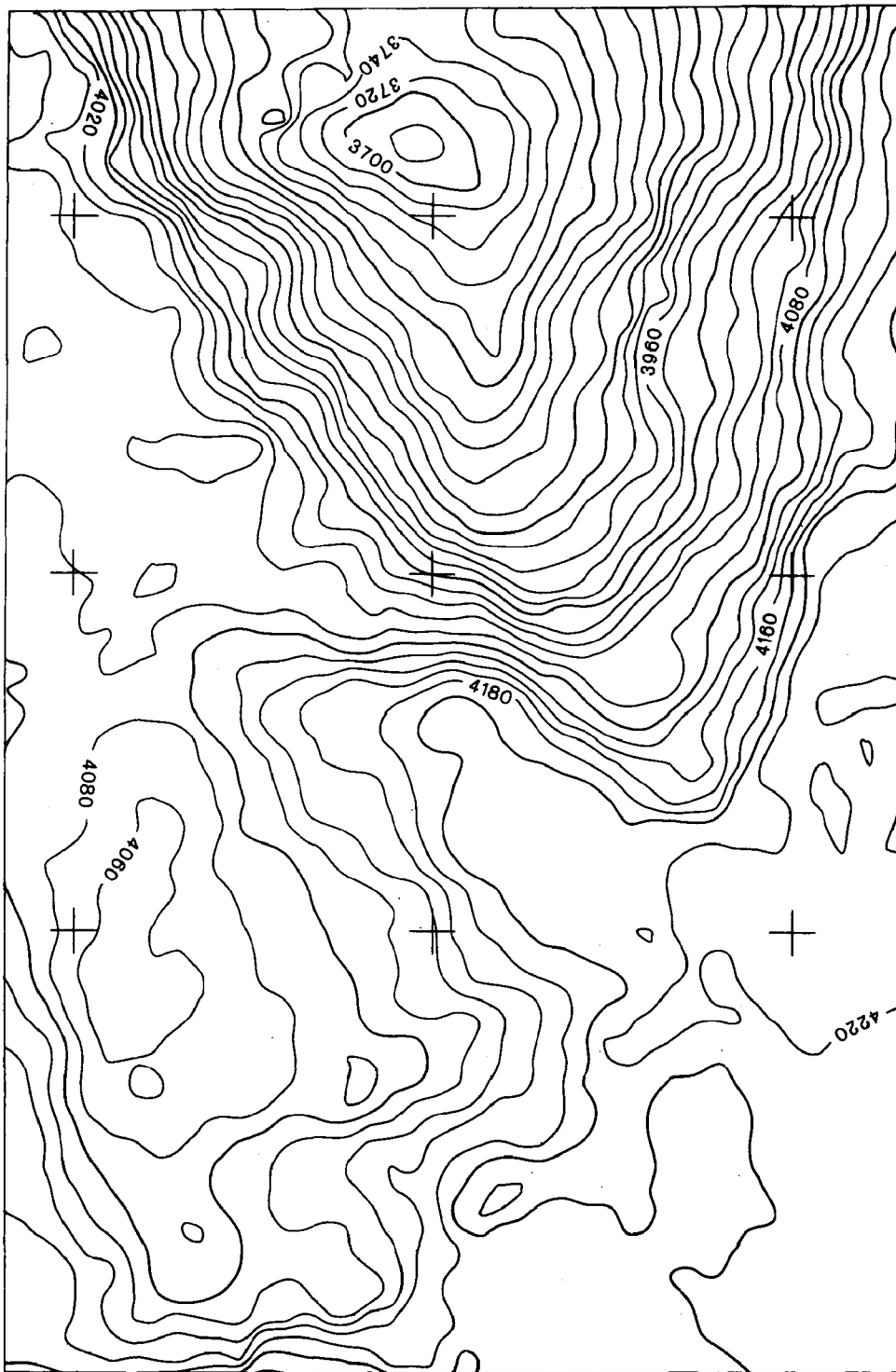


FIG. 3. — Isoline representation 1:50,000.

- Detailed information has to be legible and easily discernible by the user so that it is possible, for example, to read quickly and accurately the correct water depth for any point on the chart.

A pre-condition for meeting these requirements is a correct detection of relief features on the sea bottom. As they are not visible, multibeam echosounders provide a high density of recorded points in order to detect even small features. The accuracy of sounding data is given by the manufacturer as 1% of the water depth. First investigations confirm this value (HÖLTJE, 1987). They come to 5-10 m for the centre beam and 15-20 m for the outer beams in an area with water depths between 3000 m and 4000 m. The DTM-depths are not worse than the input data so that a worst case value of 20 m can be estimated for random errors.

In the example shown in Figures 3 and 4 the maximum slope gradient is 40%. Consequently, the position error of depth contours is 1.5 mm or less in a 1:50,000 scale chart. The above mentioned conditions allow a detailed representation of relief features.

The peaks that can be well identified in Figure 4 are indications of undetected errors in the sounding data set.

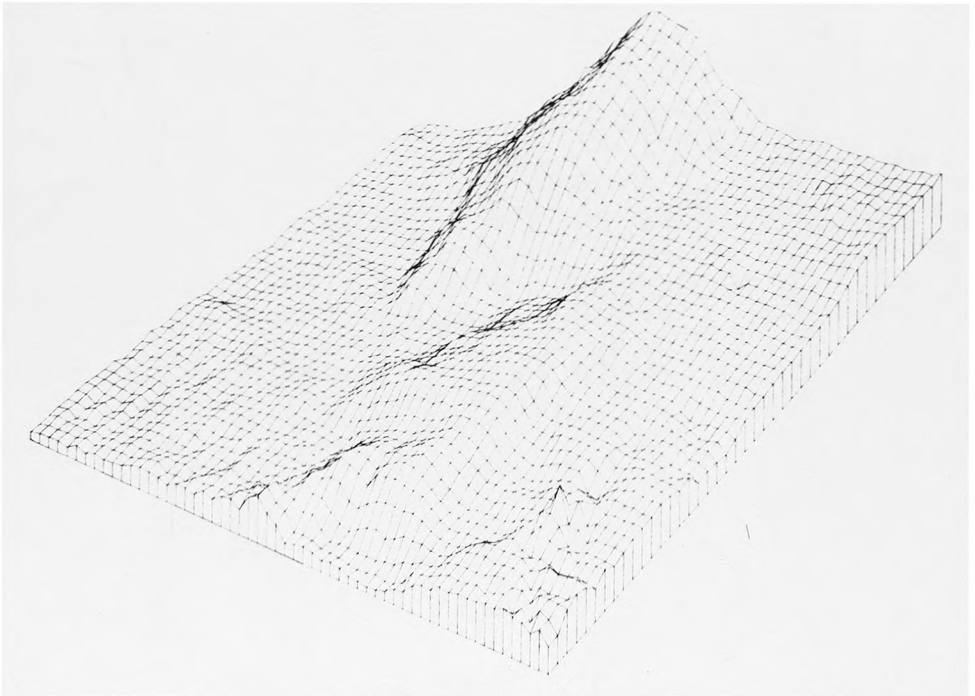


FIG. 4. — Perspective view.

CONCLUSIONS

The DTM-program TASH is practicable for the evaluation of bathymetric surveys. Big areas of the world's oceans can be charted by evaluation of sounding data that have been captured during exploring expeditions of research vessels. In order to utilize the high resolution that can be obtained, the methods for error checking should be optimized. The efficiency of the described method will increase when GPS is completely operational. This will lead to new knowledge in different scientific fields concerning the exploration of the world's oceans.

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