THE NEW GRIDDED KURIL-KAMCHATKA BATHYMETRY FOR TSUNAMI MODELING

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ABSTRACT

In the paper the algorithms and some interface for creating detailed digital regular gridded bathymetry using digital soundings data are described, and examples of obtained data for different regions of the Pacific are shown. For calculations in each grid point where the depth is to be found the algorithm uses up to 9 points from data source. They are chosen using two criteria: the first – they must be situated in various sectors (N, NE, E, SE, S, SW, W, NW) from calculating grid-point, and the second – they must be the nearest to this point in each sector. Then the spline interpolation is used for defining the depth value in the grid-point. Another algorithm uses linear interpolation for obtaining depth value in the grid-point. The new digital bathymetry on the rectangular grid with 1 and 0.5 arc minute resolution has been created for the Kuril-Kamchatka region. These data consist from four rectangular depth arrays, which cover 200 km zone around the Kuril Islands and Kamchatka from 41.00° up to 61.00° N.

INTRODUCTION

Numerical modeling of different oceanological problems and natural hazards in ocean is widely used now. For such a modeling (for example tsunami waves propagation) the detailed digital bathymetry on a regular grid is required. Now no global gridded bathymetry database with resolution better than 5 geographical minutes is available for users. Therefore for modeling local tsunamis (or another hazard) it is necessary to obtain somewhere or create detailed digital bathymetry for the regarded area.

POSSIBLE WAYS FOR CREATING GRIDDED BATHYMETRY

At first we shall consider what kind of information can be used as a source for creating the digital bathymetry over a regular grid. On the bathymetric maps the information about depths is presented as isolines and dot data of depth soundings. A lot of soundings have been collected in a digital form in the databases “Marine Trackline Data” [Marine Geological and Geophysical Data from NGDC] and “Hydrographic Survey Data” [Hydrographic Survey Data, CD-ROM data set]. This base contains the data about measurements of depth during cruises of large number of vessels, and covers practically all regions of the World Ocean with data, but their density vary significantly. Each element of this database represents the trace of a vessel movement (track). Depth values in such elements are the result of measurements made with very small step (about hundred meters). In some coastal regions tracks and the soundings are located so close to each other, that only these data would be sufficient for creating a regular depth array with a rather small step (less than one geographical minute). However, in other regions the distances between tracks are too large, and only this kind of bathymetry information, will be insufficient for creating high quality detailed digital bathymetry on a regular grid. Isolines of depth had been collected in another global bathymetric database

"GEBCO" [GEBCO 97, 1997], where some isolines of depth are stored in a digital vector form. This database covers all regions of World Ocean. The set of isobaths values in this database depends on region, and alongside with water areas, where this set is rather rich (in the Mediterranean sea, for example, it consists of about 40 values), there are also regions, where density of these isolines is insufficient. Also it is possible to find some other data about depth measurements that is now not available for a wide range of the users.

Here we shall describe some ways of creating of the arrays of depths on a regular grid using available bathymetric data. These arrays then can be used for mathematical simulation of processes in ocean.

RECALCULATING RANDOMLY DISTRIBUTED DEPTH SOUNDINGS TO THE REGULAR GRID

Let's describe the technology of creating of the gridded digital bathymetry in case, when the points of depth sounding enough densely cover regarded area. On the first step it is necessary to choose from the whole database "Marine Trackline Data" a subset of points that are located in considered area. That will be the file, each string (line) of which consists of three numbers: longitude, latitude and measured depth. Then we must decide, what there will be a length of a step between grid points, where the depth values will be found. The last stage of the creating process will be execution of the program of recalculation of the randomly distributed depth data (depth soundings) to regular rectangular grid.

Firstly let's describe the recalculation algorithm which uses linear the interpolation. The program considers one by one all our new grid-points. For every grid-point it is necessary to define it's geographical coordinates. Then we look through all points of the depth measurements finding distances from the considered grid-point up to each of them. If among them there is one or several points located closer, than one twentieth part of the new grid step length, then the value of depth in that grid-point is assumed to be equal to the depth value in the nearest point. If the Trackline database does not contain points, located to a new grid-point closer, than established distance, then let's take from it's (grid-point) nearest neighborhood three such points from the database, that considered grid-point is located inside the triangle formed by these three points. Then, using known values of depth in these three points with the help of linear interpolation the value of depth in a considered grid-point can be defined. As the variation of this method it is possible to estimate the depth value in a grid-point using six nearest soundings, which are located in different sectors of Cartesian coordinate system with center in the regarded grid-point. So, considering one by one all points of a new regular grid, we shall find approximate values of depth in each of them. It is obvious, that the better densely coverage of the area by soundings provided the higher quality of the being created gridded digital bathymetry.

Another method is based on the more complicated interpolation method by radial functions. Proposed method uses up to 9 points from data source. One point is the nearest one among all. The other 8 points are chosen using two criterion's: the first – they must be situated in various sectors (between N, NE, E, SE, S, SW, W, NW directions) of Cartesian coordinate system with the center in regarded grid-point, and the second – they must be the nearest ones to this point in each sector. When the algorithm takes into account more that one point in each sector, the quality of gridded data will be better, but computations will take much more time and resources. In this case some procedures for optimizing calculation process are proposed.

The Green's function method, which is the special case of the radial functions method, is used for depth interpolation in grid-points. Let's notice that this method is exact on linear functions. The essence of method is in choosing of one dimensional radial functions ***f(R)***. Then the linear combination

$$S(\vec{P}) = \sum_{i=1}^{k} \alpha(i) \cdot f\left(\left|\vec{P} - \vec{P}(i)\right|\right) + ax + by + c \quad (1)$$

represents two-dimensional function. Here $\vec{P}$ ***=(x,y)*** is an arbitrary point of the area, $\vec{P}(i)$ = ***(x(i),y(i))*** are interpolating points from different sectors. Coefficients ***α(i), a, b***, and ***c*** are to be defined from interpolating conditions (the coincidence of the function $S(\vec{P})$ and sounding values ***d(j)*** in points $\vec{P}(i)$ which are used for interpolation

$$S(\vec{P}(j)) = \sum_{i=1}^{k} \alpha(i) \cdot f\left(\left|\vec{P} - \vec{P}(i)\right|\right) + ax + by + c = d(j), j = 1, k \quad (2)$$

and orthogonality conditions:

$$\sum_{i=1}^{k} \alpha(i) = 0, \quad \sum_{i=1}^{k} \alpha(i)x(i) = 0, \quad \sum_{i=1}^{k} \alpha(i)y(i) = 0. \quad (3)$$

From system of equations (2) and (3) it is possible to find coefficients ***α(i), a, b***, and ***c*** and then to define from the expression (1) the depth value in a new grid-point. Repeating this procedure for all grid-points of the area makes it possible to create the digital gridded bathymetry with arbitrary spatial grid-steps.

EXAMPLE OF APPLICATION

We shall illustrate application of such a technology of the gridded digital bathymetry creating on an example of obtaining the array of depths for small region in a northern part of Pacific around Kodiak Island. In this 5 × 5 degrees area (between 54th to 59th degrees North latitude and from 156th to 151st degrees West longitude) the detailed gridded bathymetry with resolution of 30 arc seconds in both directions was created. Available depth sounding data with the coastline from "Marine Trackline Data" and “Hydrographic Survey Data” sources are presented in the Figure 1. It is seen that in shelf zone the density of sounding measurements is rather higher than in deep ocean. In this area 600 x 600 points array of depth values was created using linear and spline interpolation methods. Both obtained digital arrays are visualized in the Figure 2 as a 3D shaded relief. This style of visualization makes all small-sized details of a bottom relief be very well visible (fig. 2). Here the illumination vector is directed from the upper left corner of the area. In the bottom part of the left picture that is correspond to linear interpolation algorithm, some “star” structures around local depth extremums are visible. In this part of area depth soundings traces are located rather far from each other (fig. 1).

For some areas of interest the information about depths from these global databases is insufficient for obtaining high quality gridded bathymetry. But if there are available the paper bathymetry charts, it is possible to apply technologies for digitizing geographic information developed earlier by the author [Marchuk, 1996] and methods proposed in this paper. For example, the information about depths for Kuril-Kamchatka area in those both global data sets is insufficient for our purposes. So the set of 4 detailed bathymetry charts for this region were prepared in Kamchatka Institute of Volcanology. The Figure 3 shows the coverage of these charts. In the Figures 4 the GEBCO isolines of depth (left) and scanned image of one of this bathymetric chart (right) are shown. Using of this data source (paper charts) make it possible

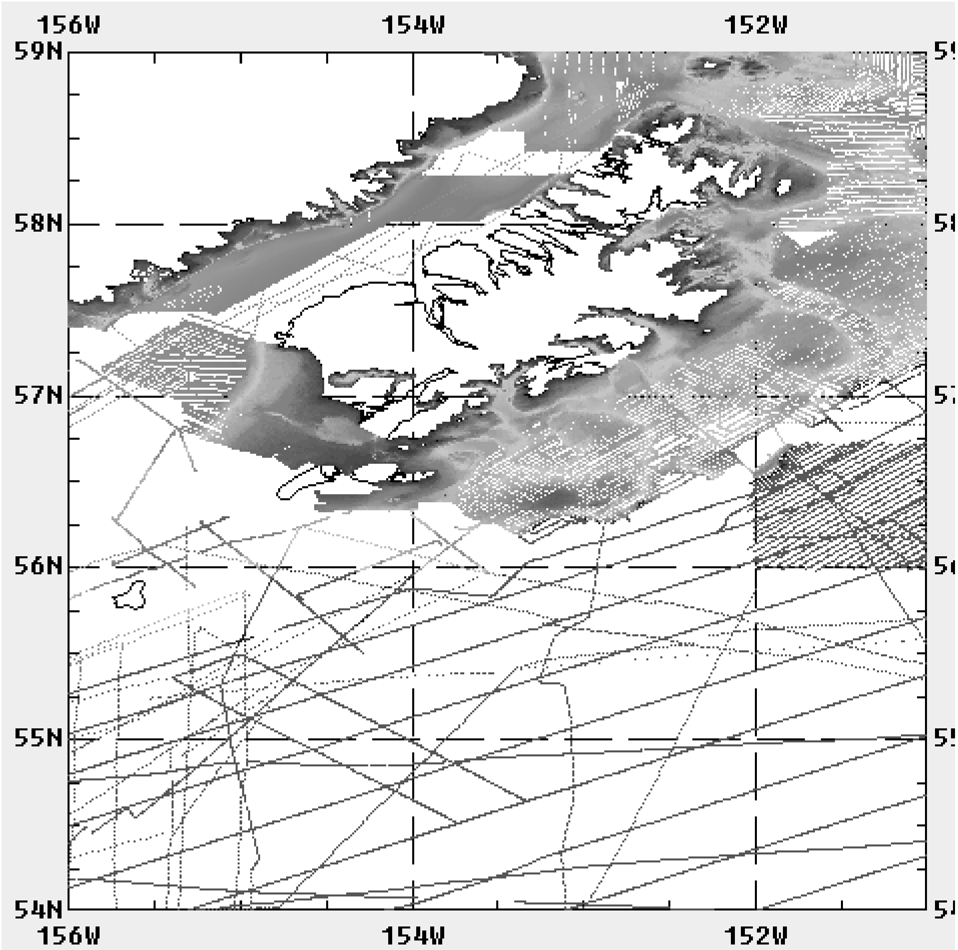

Fig. 1. Data from "Marine Trackline Data" database around Kodiak Island in the northern part of Pacific.

to create the new 1-min gridded digital bathymetry for that region. Comparison of several different gridded bathymetry sets (5-min ETOPO5, 2-min Sandwell's and the one developed by authors) is made on our web site (http://omzg.sscc.ru/tsulab/ the item "Kuril-Kamchatka Bathymetry Project"). Now 1-min gridded bathymetry was produced for areas 1-4 using linear interpolation method and 0.5-min bathymetry arrays, which were produced by spline interpolation, are ready for areas 2 and 3. Bathymetry arrays of this resolution for the last two areas will be completed in near future. As an example the 3-D shaded relief of the area 3 (Middle and Northern Kurils) is shown in the Figure 5.

CONCLUSION

For some regions of World ocean the quality of bathymetric data (on a random grid) that is contained in global databases allows to create rather detailed gridded digital bathymetry using proposed methods. If the number of depth measurements is insufficient, then additional sources of bathymetric information can be used. New digital bathymetry on a regular grid for the Kuril-Kamchatka region was created using the described in this paper technology and some numerical experiments of tsunami propagation was carried out.

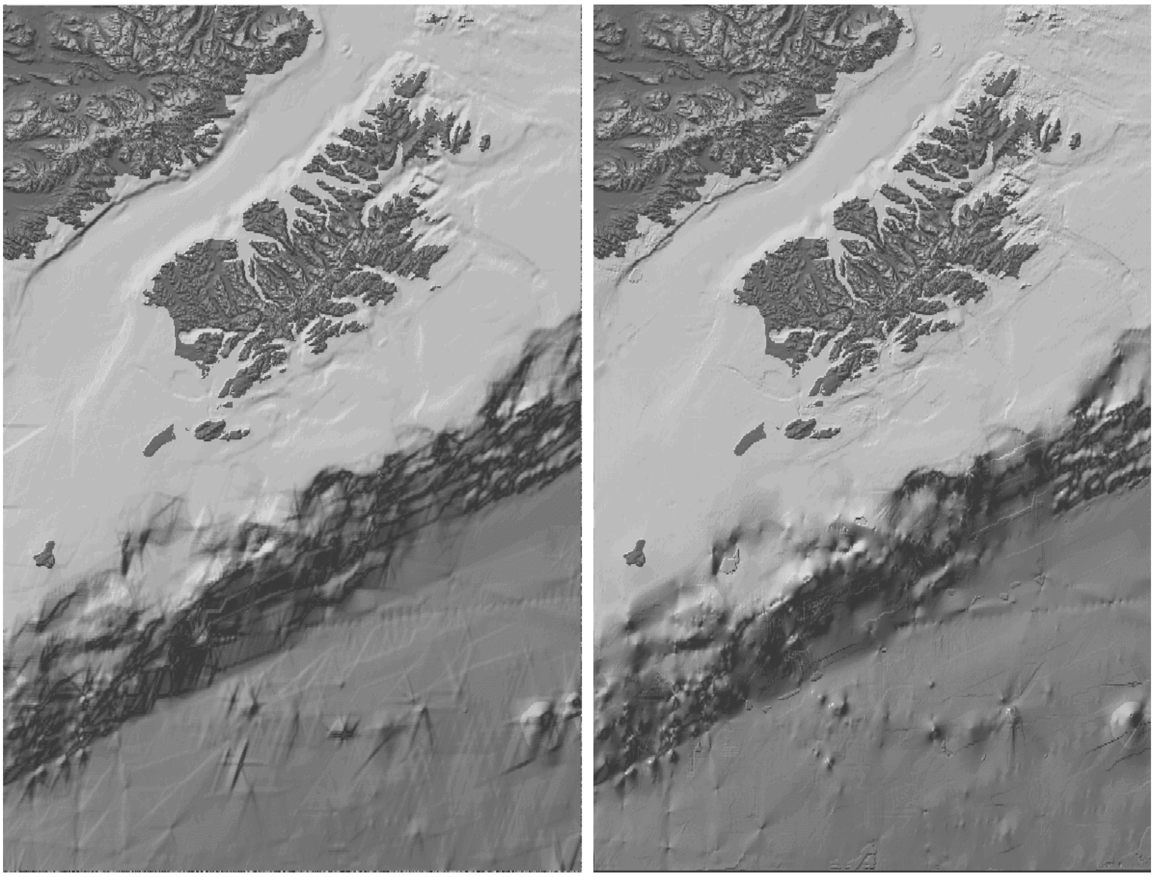

Fig. 2. Pseudo three dimensional pictures of depth data with linear interpolation (left) and spline interpolation (right).

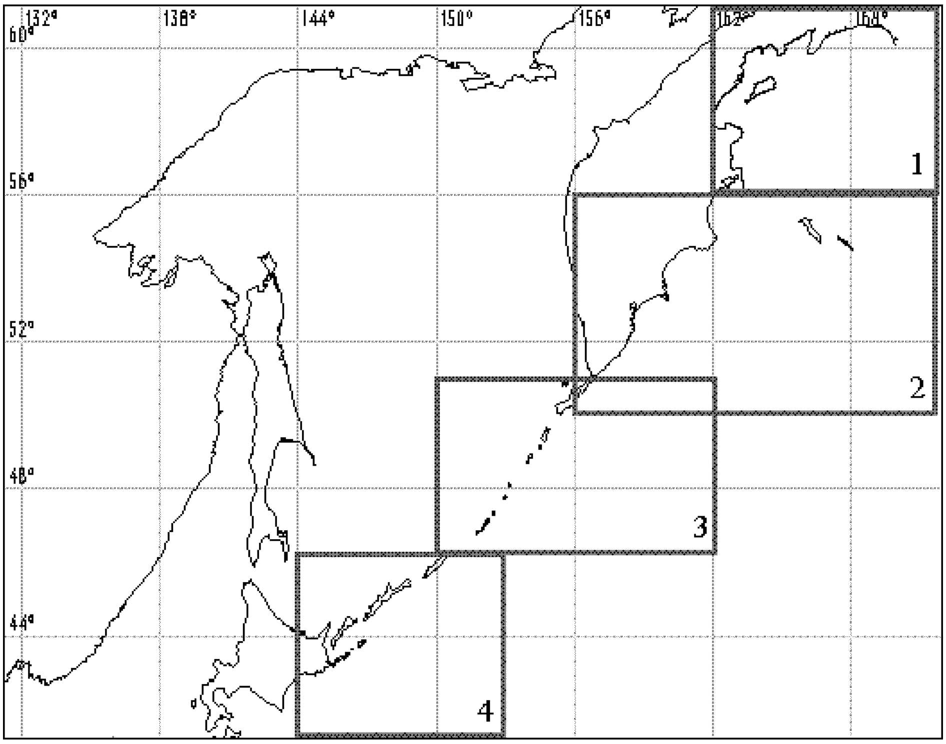

Fig.3. Location of areas with bathymetric maps available.

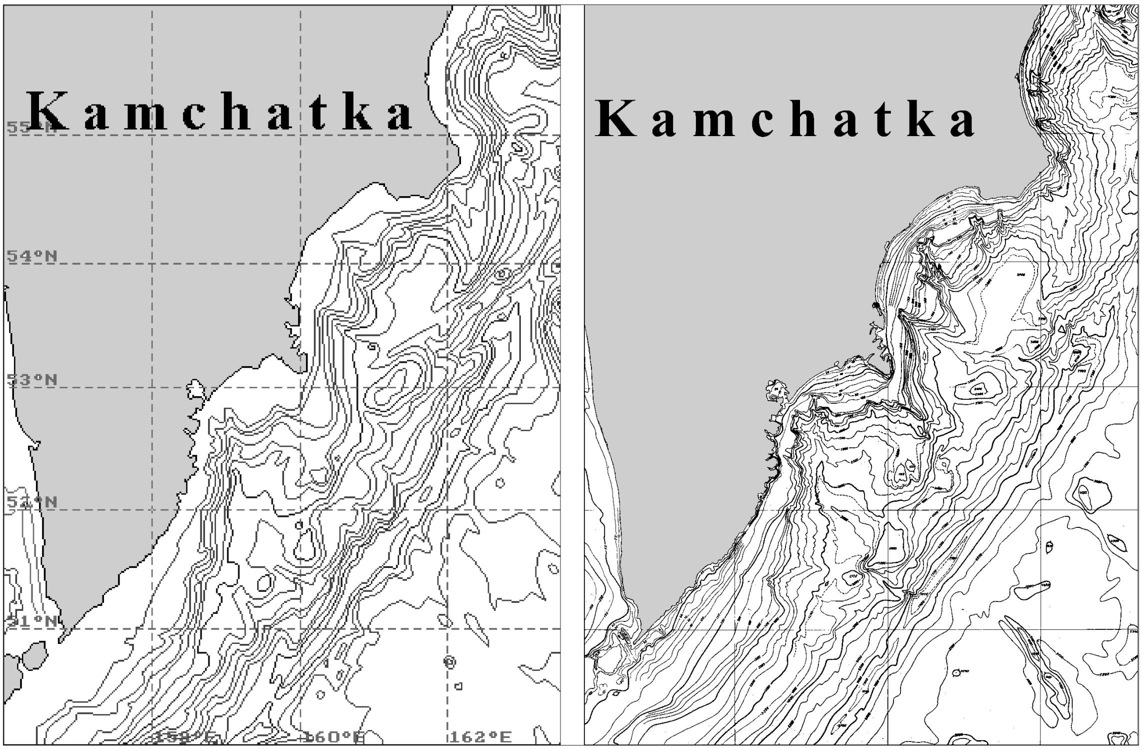

Fig. 4. Comparison of depth isolines from GEBCO database and from new gridded bathymetry data.

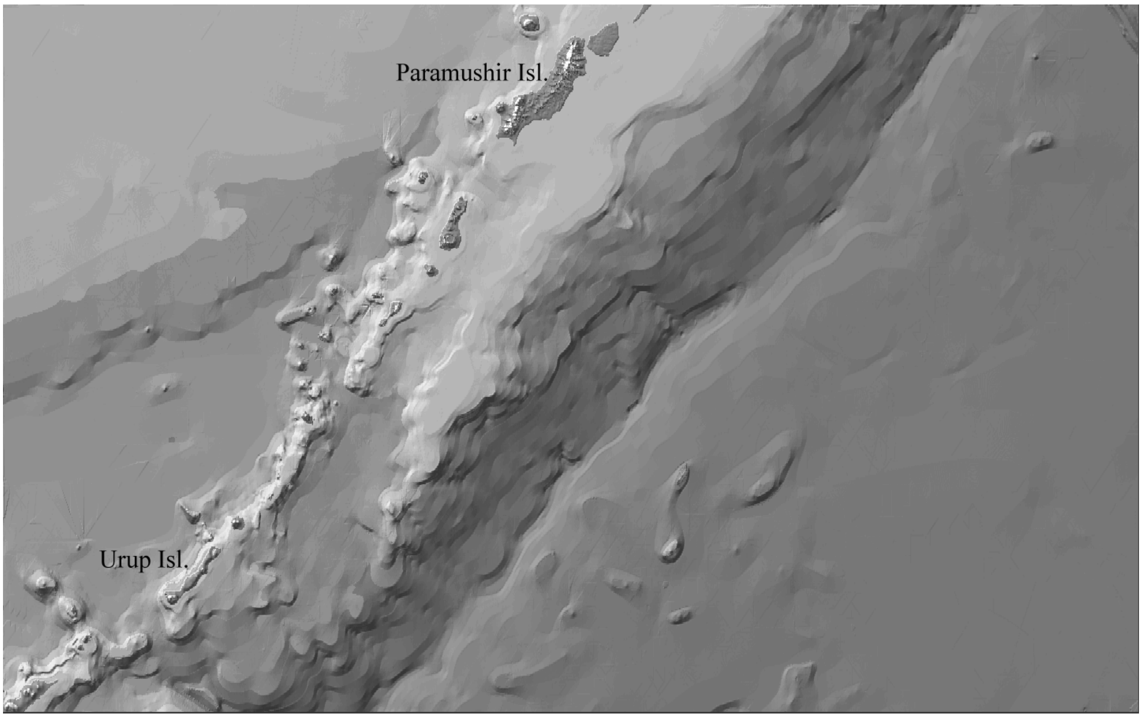

Fig. 5. Side light effected three dimensional picture of oceanic relief of central and northern Kuriles.

ACKNOWLEDGMENTS

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REFERENCES

GEBCO 97, Digital Atlas CD-ROM. 1997. Intergovernmental Oceanographic Commission, International Hydrographic Organization. British Oceanographic Data Centre, Proudman Oceanographic Laboratory. Bidston Observatory, Birkenhead Merseyside L43 7RA, United Kingdom.

Hydrographic Survey Data, CD-ROM data set, Ver. 3.2, National Ocean Service*,* NGDC*,* NOAA, E/GC3, 325 Broadway, Boulder, CO.

Marchuk An. G., 1996: Interactive system for input digital geographic and bathymetric information. *Bulletin of the Novosibirsk Computing center.* Series: Mathematical Modeling in Geophysics, Issue: 2 (1996), NCC Publisher, Novosibirsk: 55-62.

Marine Geological and Geophysical Data from NGDC, Compact disc data set, National Geophysical Data Center, Boulder, Colorado, USA.

Smith W. H. F., and Sandwell D. 1997: Global seafloor topography from satellite altimetry and ship depth soundings. *Science.* 277, 1956-1962.