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TESTING AND CORRECTING GRIDDED BATHYMETRY OF THE ISSYK-KUL

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The available bathymetry data of the Issyk-Kul Lake from different sources are analyzed and corrected for mutual consistency and deviation from the GPS coordinates on the shoreline. As a result, a gridded bathymetry of the Lake with 360×360 m bin size suitable for use in numerical circulation models is compiled and made available on the Internet for free download.

Keywords: Lake Issyk-Kul, gridded bathymetry, GPS coordinates

1. Introduction

Lake Issyk-Kul has estimated volume of 1.730 km^3, which makes it the tenth largest lake on the planet, and the second largest mountain lake. It is also the sixth deepest lake on the Earth. The brackish nature of the Issyk-Kul water makes various aspects of its physical and biological regimes representative of both fresh and salty lakes of the World. The Issyk-Kul is an ultra-oligotrophic lake where the level of primary production and the concentration of phytoplankton biomass is 10–40 times lower than those typical for the ocean – in spite the abundance of river-borne nutrients and solar light. The causes of such a poor productivity are not yet fully understood, but, hypothetically, they may lie in the lake's circulation that tends to remove nutrients from the euphotic zone into deeper layers (Zavialov et al., 2018). This mechanism, as well as other important features of the Issyk-Kul's regime, could be investigated by means of numerical modeling.

To our knowledge, few attempts have been made to develop circulation models for Lake Issyk-Kul (e.g., Arkhipov and Revyakin, 1986; Kochergin et al., 1990; Podsechin, 2013). Keeping in mind our intention to make such an attempt in the nearest feature, we were puzzled by the question of the existence of digital gridded bathymetry of the Lake, which is the basis for creating a circulation model. Somewhat surprisingly, even the available information on the maximum depth of the lake is contradictory and apparently often incorrect. For instance, the bathymetry map published by the USSR General Staff in 1978 indicated 663 m, while Hoffer et al. (2002) suggested 650 m, the value of 668 m was given by Giralt et al. (2004) and a number of other publications, and some authors (e.g., Alamatov and Mikkola, 2011),

as well as various sources on the Internet, including the Russian-language Wikipedia, give value of 702 m.

In view of the motivation, the objective of this study can be formulated as follows:

- to evaluate the available data on the Issyk-Kul bathymetry;
- to test the bathymetry data from different sources for mutual consistency and deviation from GPS coordinates of the Lake shoreline;
- to correct the bathymetry data if needed;
- to compile the corrected and verified gridded bathymetry file and make it available on the Internet for free download.

2. Bathymetry data available

The first source of the bathymetry data is a 1:500 000 topographic map issued in 1978 by the General Staff of Soviet Army which is now free available on the Internet (http://www.svali.ru/show_picture.php?cd=1&cntr=48&id=13&type=1 and http://www.svali.ru/show_picture.php?cd=1&cntr=48&id=16&type=1, last access 05/04/2022). The map contains 0, 10, 20, 50, 100, 150, 200, 300, 400, and 500 m isobaths, as well as a number of reference points of the Lake depth which can be digitized with acceptable accuracy using e.g. Surfer software.

The second source of the bathymetry data is a digital gridded bathymetry of the Issyk-Kul created by international team of researchers from Belgium, France, Russia, and Kyrgyz Republic in the framework of a NATO project (De Batist et al., 2002). The gridded bathymetry of the Lake with 360 × 360 m grid bin was arranged in the form of triplets of numbers *xyz*, where *x*, *y*, and *z* are the coordinates along longitude and latitude and the altitude relative to the ocean level in meters. The *xyz* gridded bathymetry file of 500 × 210 grid points was provided by I. A. Kalugin, a participant of the project and co-author of De Batist et al. (2002).

3. Comparison of bathymetry data from different sources for mutual consistency

The bathymetry contours of 0, 10, 20, 50, 100, 150, 200, 300, 400, 500 m from the General Staff topographic map were carefully digitized using Surfer software; the result is presented in Figure 1a.

The gridded bathymetry file of the *xyz* format was transformed to *xyh* format, where the lake depth *h* was calculated as $h = z_0 - z$, and the altitude of the Issyk-Kul surface, z_0, was conventionally taken at z_0 = 1607.9 m. Further, the *x* and *y* coordinates in meters were re-calculated to degrees of longitude and latitude using GPS coordinates of characteristic points on the lake shoreline assessed from Google Maps.

The bathymetry contours of 0, 10, 20, 50, 100, 150, 200, 300, 400, 500 m from the De Batist et al. (2002) gridded topography re-scaled to the longitude and latitude coordinates are given in Figure 1b.

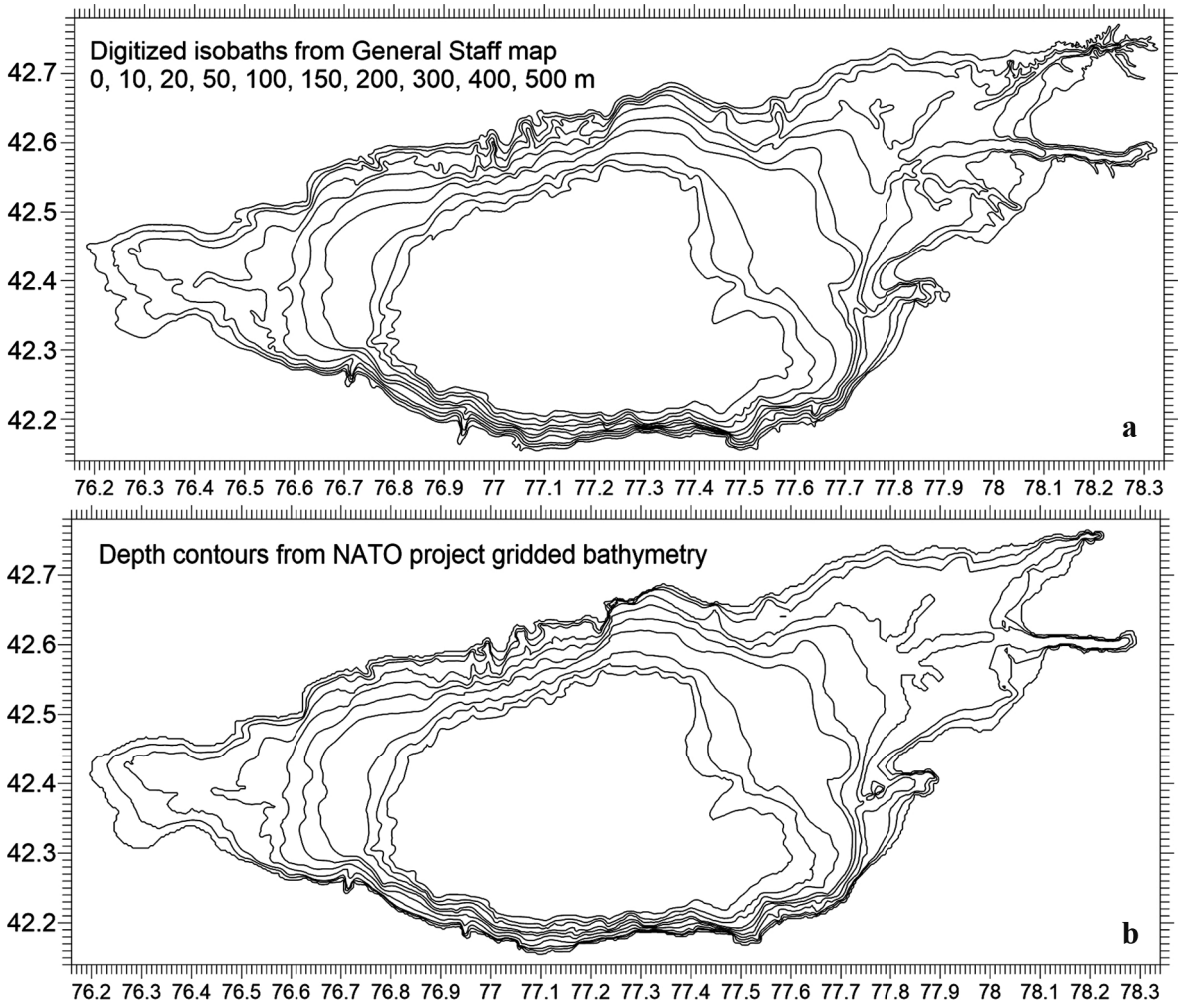

Fig. 1 **a** – Digitized isobaths 0, 10, 20, 50, 100, 150, 200, 300, 400, and 500 m from the General staff map; 1 **b** – the same contours from the gridded bathymetry of De Batist et al. (2002) versus longitude and latitude in degrees

At first glance, the depth contours in Figure 1a seem almost identical to that of Figure 1b, but a closer look at these two plots reveals some differences. To highlight the differences, we have superimposed some of the isobaths of Figure 1a and 1b, namely 0, 50, 200, and 500 m, along with some characteristic GPS points on the Lake's shoreline, on a single panel (Figure 2a).

The first conclusion following from Figure 2a is that all characteristic GPS points on the shoreline of the Lake, as assessed from Google Maps, turned out to lie on the zero isobath of the General Staff map and at some distance from the zero isobath of the De Batist et al. (2002) gridded bathymetry. The second conclusion is that the isobaths from De Batist et al. (2002) gridded bathymetry appear to be turned counterclockwise by some small angle relative to the corresponding isobaths on the General Staff map.

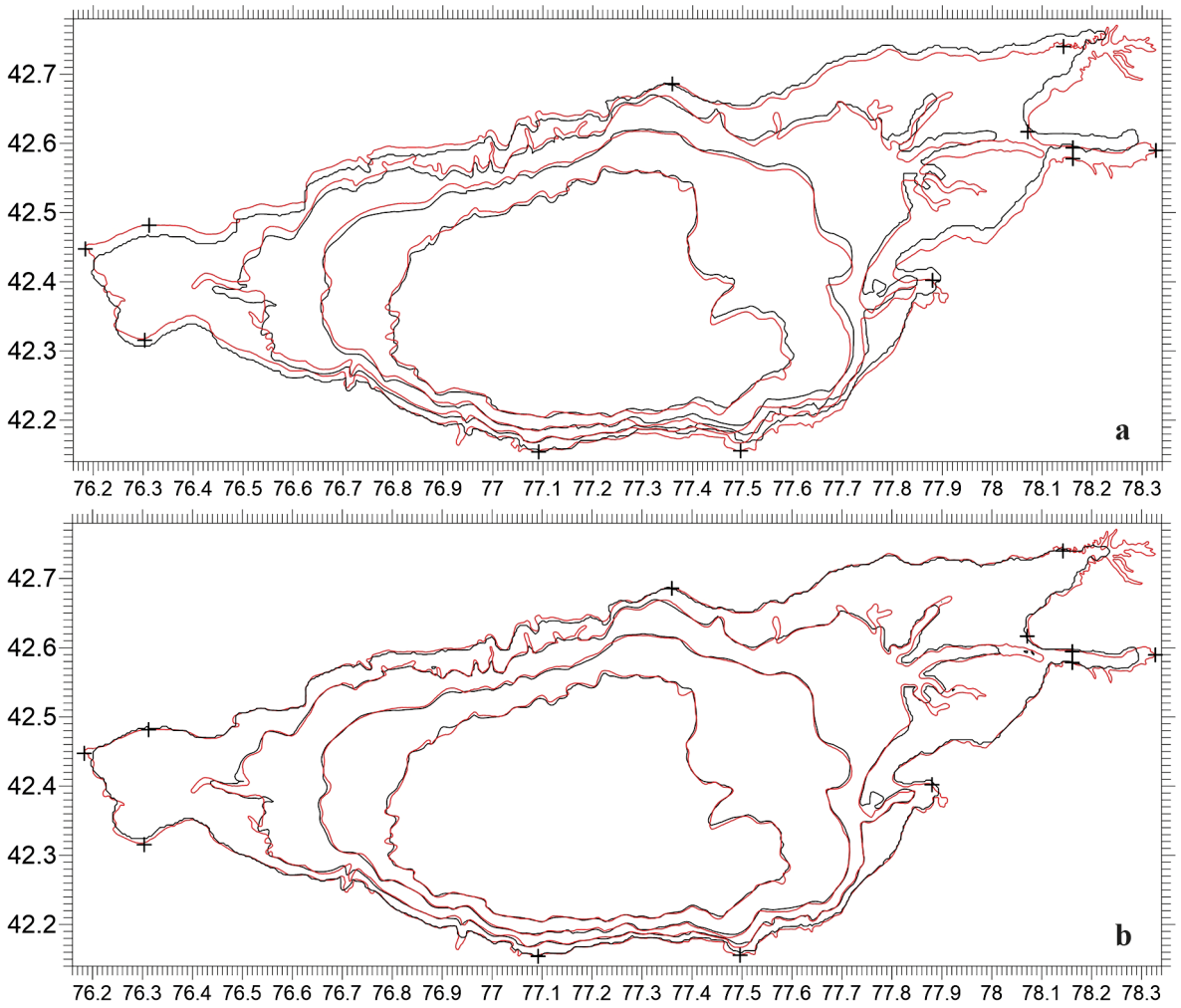

Fig. 2 **a** – The superposition of the 0, 50, 200, and 500 m isobaths from the General Staff map (red curves) and from the De Batist et al. (2002) gridded bathymetry (black curves);
2 **b** – The same as (a) but the De Batist et al. (2002) gridded bathymetry is rotated by –1.5° (clockwise). The black crosses are the characteristic GPS points on the Lake's shoreline assessed from Google Maps

4. Correction of bathymetry data for mutual consistency and deviation from GPS coordinates

To fit the De Batist et al. (2002) gridded bathymetry to the isobaths from the General Staff map, the gridded bathymetry has to be rotated by some small angle clockwise, which can be done as follows.

First, we find the coordinates (x_{mean}, y_{mean}) of the central point of the gridded bathymetry domain, (x_{ij}, y_{ij}), $i = 1, 2, \ldots, 500$, $j = 1, 2, \ldots, 210$,

$$x_{mean} = 0.5(x_{1\,1} + x_{500\,1}),\ y_{mean} = 0.5(y_{1\,1} + y_{1\,210})$$

and transform Cartesian coordinates (x_{ij}, y_{ij}) to polar coordinates (r_{ij}, φ_{ij})

$$r_{ij} = \sqrt{\left(x_{ij} - x_{mean}\right)^2 + \left(y_{ij} - y_{mean}\right)^2}$$

$$\varphi_{ij} = \text{atan}\left(\frac{y_{ij} - y_{mean}}{x_{ij} - x_{mean}}\right), \varphi_{ij} = \varphi_{ij} + \pi \text{ if } x_{ij} - x_{mean} < 0.$$

Then we calculate the coordinates $(\hat{x}_{ij}, \hat{y}_{ij})$ rotated by an angle α relative to (x_{ij}, y_{ij})

$$\hat{x}_{ij} = r_{ij} \cos\left(\varphi_{ij} + \alpha\right)$$

$$\hat{y}_{ij} = r_{ij} \sin\left(\varphi_{ij} + \alpha\right).$$

Finally, we interpolate the depth values h_{ij} defined at points with the rotated coordinates $(\hat{x}_{ij}, \hat{y}_{ij})$ to the "old" grid (x_{ij}, y_{ij}), $i = 1, 2, \ldots, 500$, $j = 1, 2, \ldots, 210$.

The best fit of the rotated isobaths of the De Batist et al. (2002) gridded bathymetry to that of the General Staff map is achieved at the angle of rotation $\alpha = -1.5°$ (see Figure 2b).

The near-margin rows i = 1–3, 483–500 and lines j = 1–12, 200–210 of the (x_{ij}, y_{ij}) matrix do not contain the lake points but the land points only and therefore can be discarded. As a result, the gridded bathymetry matrix of the Lake is reduced to 479 × 187 points instead of 500 × 210 points initially. Such minimization of the grid is desirable in order to speed up the numerical model performance and save RAM.

5. Conclusion

Keeping in mind the goal of receiving a gridded bathymetry of the Lake Issyk-Kul suitable for the circulation model setup, we have compared different sources of the bathymetry data available. A substantial difference was found in the bathymetry data from the General Staff map and the De Batist et al. (2002) gridded bathymetry. Without setting the task to find out the reason for the difference, we focused on testing the data by comparison with the independent and fully reliable GPS coordinates of characteristic points on the Issyk-Kul shoreline and elaborating the way to correct the data. As a result, we compiled the corrected and verified gridded bathymetry of Issyl-Kul Lake consisting of 479 × 187 points at a grid bin of 360 × 360 m, suitable for use in the circulation models and for other purposes, and posted it on the Internet for free download.

6. Supplementary material

The corrected and verified gridded bathymetry of Lake Issyk-Kul is saved as a text format file Issyk_bathy_i479j187_XY_LonLat_H.dat each line of which contains 7 numbers separated by spaces as follows:

1) i is the sequence number of point along the x axis (along longitude); $i = 1, 2, \ldots, 479$;
2) j is the sequence number of point along the y axis (along latitude); $j = 1, 2, \ldots, 187$;
3) x is the x coordinate in kilometers starting from $x = 0$ at $i = 1$;
4) y is the y coordinate in kilometers starting from $y = 0$ at $j = 1$;
5) LON is the longitude in degrees;
6) LAT is the latitude in degrees;
7) h is the lake depth in meters.

Note that the minimum depth in the Lake is settled at 2 m and the depth value of $h = -2$ m is prescribed to all land points.

The file ISSYK_BATHY_i479j187_XY_LonLat_H.dat is posted to Internet at https://doi.ocean.ru/data/zhurbas/jor-50-1/ISSYK_BATHY_i479j187_XY_LonLAT_H.dat.

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ТЕСТИРОВАНИЕ И КОРРЕКТИРОВКА БАТИМЕТРИИ НА КООРДИНАТНОЙ СЕТКЕ ОЗЕРА ИССЫК-КУЛЬ

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Имеющиеся в наличии данные батиметрии озера Иссык-Куль из разных источников анализируются и корректируются на взаимную согласованность и отклонение от GPS-координат на береговой линии. В результате составлена и размещена в Интернете для бесплатного скачивания батиметрия озера на координатной сетке с шагом 360×360 м, подходящая для использования в численных моделях циркуляции.

Ключевые слова: озеро Иссык-Куль, батиметрия на координатной сетке, GPS координаты

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