Combined hydroacoustic research of Lake Baikal

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Abstract. The article outlines the main approaches to studying the bottom topography of Lake Baikal and interpretation of bathymetric data. Measurement equipment and experimental data processing algorithms are described. A measuring complex is based on using the Kongsberg EM710S multibeam echosounder which allows one to take a detailed digital elevation model of the bottom. The paper demonstrates experimental results obtained during a series of expeditions to the Baikal in 2015 – 2019. Currently an area of about 12117 km² (~38%) of Lake Baikal bottom has been explored. Examples of a digital model of the Baikal bottom are also presented. The paper demonstrates 3D models of detected water columns showing intense of a gas bubbles emanation near the mouth of Selenga river, acoustic images of the Baikal Gigaton Volume Detector (Baikal-GVD), and a bathymetric map of Academician Ridge that was previously examined with the Mir 1 and Mir 2 in July 2009.

1. Introduction

Most part of our planet (79%) is covered with water, 70.8% of which is the World Ocean. According to statistical data published by the Russian Geographical Society only 4% of the World Ocean have been studied so far. The largest natural reservoir of fresh water is Lake Baikal, the deepest lake on the planet. The water surface area of the Baikal is 31722 km² (excluding islands), which is approximately equal to the area of some small countries such as Belgium or the Netherlands. By the area of the water surface Baikal takes the seventh place among the largest lakes in the world and the first place as the largest freshwater lake.

Baikal is located in the southern part of Eastern Siberia on the border between the Irkutsk region and the Republic of Buryatia. The width of the Baikal ranges from 24 to 79 km while the length from southwest to north-east is 636 km and the coastline is 2100 km long. The bottom of Lake Baikal is 1167 meters below the level of the World Ocean, and the water surface level is 456 meters higher.

The lake is in a specific hollow, surrounded on all sides by mountain ranges and hills. At the same time the west coast is rocky and steep when the relief of the east coast is sloping – in some places the mountains recede tens of kilometers from the coast. The maximum depth of the lake is 1642 m at the point with coordinates (53°14′59″ N, 108°05′11″ E). This fact was established in 1983 by L.G. Kolotilo and A.I. Sulimov during hydrographic expedition supported by the the General Directorate of Navigation and Oceanography of the Ministry of Defense (MoD GUNiO) of the USSR [1].

The study of the bottom relief began in the XIX century when B. Dybovsky and B. Godlevsky for the first time carried out surveying work in the Southern Baikal in 1869-1876 [2]. Later from the end of the XIX century and throughout the XX century new repeated attempts have been made in order to create a bathymetric model of the Baikal bottom [3]. One of such studies was the INTAS (International...
Association for the Promotion of Cooperation with Scientists from the New Independent States of the former Soviet Union) project for creating of a “New Bathymetric Map of Lake Baikal” which was completed in 2002 [4].

The main objectives of the project were applying new technologies of acoustic measurements and creating electronic bathymetric maps of Lake Baikal which would be commonly available to scientific, professional and amateur users. For this purpose a recalculation of bathymetric acoustic data on the lake depths obtained by the GUNiO between 1979 and 1985 was carried out. The obtained database formed a new computer-generated version of the bathymetric map of Lake Baikal.

Modern hydroacoustic instruments such as multibeam echosounders (MBES) allows one to fetch huge amounts of experimental data on the bottom relief. Due to its versatility this instrument provides not only depth values but also gives a lot of information about the entire water column and the top layer of the bottom sediments [5].

Since 2015, research workers of Irkutsk National Research Technical University (INRTU) have taken part in various research projects on the study of the Baikal Basin in collaboration with Limnological Institute of the Siberian Branch of the Russian Academy of Sciences (LIN SB RAS) and A.P. Karpinsky Russian Geological Research Institute (VSEGEI).

2. Measuring equipment and experimental data
To study the surface of the Baikal bottom we used a Kongsberg EM710S multi-beam echo sounder installed on the “Titov”, the scientific research vessel of LIN SB RAS. This instrument allows one to obtain bathymetric parameters of several centimeters resolution in vertical direction and several meters in horizontal direction. Currently we have explored 12117 km$^2$ of Lake Baikal bottom after expeditions in 2015 – 2019 (Figure 1).

![Figure 1. Current results of creating a detailed 3D-map of Baikal bottom after annual expeditions in 2015 – 2019.](image)
In order to obtain the most accurate data during multi-beam surveys we make periodically necessary corrections. The corrections depend on hydrological conditions and vertical distribution of the speed of sound propagation in water [6]. Measurements of the hydrophysical parameters of the aquatic environment during the expeditionary work was carried out using an integrated SeaBird SBE 37-smp sensor and a Valeport miniSVS time-of-flight sound velocity meter.

The multi-beam echo sounder “Kongsberg EM710S” allows one to receive a large amount of information immediately over the entire viewing range which can reach 2300 meters. This instrument forms a “fan” of 200 narrow acoustic rays in the plane which is transverse to a vessel’s movement direction. So we can get a topographic view of the seabed and make a digital three-dimensional model of the bottom relief [7].

3. Results and Discussion
A digital elevation model (DEM) is one of the most important components in spatial databases which are used in each geoinformation system. It is impossible to effect bottom topography without it. A highly detailed and correctly implemented DEM integrated with a modern geoinformation system (GIS) allows one to carry out complex morphological and morphometric analysis with high accuracy, simulate various exogenous processes, and serve as the basis for any type of topobatimetric and thematic mapping.

In Figure 2 a highly detailed DEM of Southern Baikal is presented. The bottom relief of this part of Baikal is characterized with river outflows extending deep into the lake and an extensive ridge with a various depth of 600-800 meters.

As an additional research option Kongsberg EM710S has a function of a water column and backscatter imaging along the scanning line (the rays plane). These functions are achieved with the capability of the equipment to detect amplitudes of the echo signals reflected from the bottom and inhomogeneities in the water column.

After corresponding data processing water columns be added to a digital elevation model as independent objects for following analysis. For example, the obtained water column data in Figure- 3b can be used for determining the size of the gas plume and calculating the intensity of the gas bubble outflow emanation.
Another application of a water column DEM is searching, determining the spatial coordinates and sizes of various underwater structures and sunken objects, as well as estimating their technogenic impact on the surrounding underwater environment. Figure 4 shows an image of the first cluster of the Baikal Deep Underwater Neutrino Telescope of a cubic kilometer scale Baikal-GVD (Gigaton Volume Detector) [8], obtained from the data of the MBES. The project aim is detailed studying of the flux of high-energy cosmic neutrinos and searching for their sources. This instrument may promote understanding of the Universe’s evolution, the evolution of stars. Large neutrino telescopes should be placed deep in transparent natural media, thus Lake Baikal is a great natural laboratory for this purpose.
A Fledermaus software package was used for geospatial processing, analysis of data obtained from the multibeam echosounder, and the DEM construction. An integrated set of tools of this software package allows you to display and analyze the data of the reflected signal amplitude and the MBES bathymetry data. For data processing we used the “CUBE” algorithm which works on the principle of calculating the distribution of uncertainties. The result of processing is not only arrays of depth values but also estimated errors of depth determining at each point of the grid. A total propagated uncertainty (TPU) is the measure of accuracy expected for that point in a digital elevation model. After processing with all modules, TPU values can be used for blocking of the sonar data according to the IHO S-44 [9] and IMCA [10] standards.

One of underwater objects investigated during expeditionary work using the MBES is Academician Ridge. It was discovered by Soviet geologist-limnologist G.Yu. Vereshchagin in 1932. Academician Ridge stretches from the island of Olkhon to the Ushkany Islands which are the highest point of the ridge. The length of the ridge is about 100 km, the maximum height reaches about 1848 m above the bottom of Lake Baikal and 1368 m above the modern thickness of bottom sediments.

According to the admitted history of Lake Baikal formation, Academician Ridge was its northern shore about 8-9 million years ago. Then the Baikal began to spread gradually from the northernmost point, where Barguzin River flowed into the lake, to the north. This led to formation of a new area called the North basin. The evidence confirming this part of Lake Baikal history is the fact that the thickness of sediments in the South and Central basins is about 8 thousand meters while in the Northern basin it is only 4-5 thousand meters [11].

From the very beginning of Academician Ridge discovery it has been an object of a great interest among morphologists and geologists studying Lake Baikal. Among all numerous experimental research we can note two major expeditions. In 1995-1996, the ridge was investigated by the Russian-Belgian scientific expedition with the use of a side-scan sonar and a profilograph. In July 2009, as part of the scientific expedition “Mirs on the Baikal” two deep submergence vehicles Mir 1 and Mir 2 accomplished dives to survey Academician Ridge.

An analysis of our DEM of Academic Ridge (Figure 5) revealed on the southern slope two transverse structures consisting of several craters and hills merged into ridges. The ridge in the middle part is named “Akadem-Ridge”, near Olkhon Island – “Khoboy” [12]. The width of each of them is less than 800 m, while length is 6 and 4 km respectively. The “Academ-Ridge” is located at depth of 500-850 m, and "Khoboy" is at 450-600 m. The height of the ridges does not exceed 80 m.

Figure 5. Visualization of a digital elevation model in the area of Academic Ridge with detected gas outlets
4. Conclusion
The experimental results demonstrated in the article are just a part of the long-term and laborious work on creating a detailed 3D-map of Lake Baikal. However, getting a unique digital elevation model of the Baikal is worth it. Building a precise model with the use of modern GIS technologies will make it possible to carry out complex morphostructural analysis in order to study the properties of the modern and ancient terrain of the earth's surface, its origin and development history.

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References
[1] Kolotilo L G, Dotsenko V D and Polevoy B P 2004 Naval sailors of the Baikal (St. Petersburg: Nauka)
[2] Antoshchenko-Olenev I V, Bazarov D B, Galkin V I, Goldyrev G S, Endrikhinsky A S, Zolotarev A G, Logachev N A, Sizikov A I and Ufimtsev G F 1974 Highlands of the Baikal and Transbaikalia regions ed Adamenko O M et al (Moscow: Nauka)
[3] Kuz'min M I, Karabanov E B, Kawai T, Williams D, Bychinskii V A, Kerber E V, Kravchinskii V A, Bezrukova E V, Prokopenko A A, Geletii V F, Kalmychkov G V, Goreglyad A V, Antipin V S, Khomutova M Yu, Soshina N M, Ivanov E V., Khursevich G K, Tkachenko L L, Solotchina E P, Ioshida N and Gvozdkov A N 2001 J. Geol. Geophys. 42 8-34
[4] De Batist M, Canals M, Sherstyankin P and Alekseev S 2006 INTAS Project 99-1669 Team Report A new bathymetric map of Lake Baikal (Potsdam: GFZ)
[5] Khlystov O M, Kononov E E, Kazakov A V, Khabuev A V, Minami H, Gubin N A and Chenskii A G 2018 Geogr. and Nat. Res. 1 59–65
[6] Gubin N A, Chensky D A and Chensky A G 2016 2(109) Proc. Irkutsk State Techn. Univ. 17–22
[7] Churkin O F and Starozhitsky V V 2001 Proc. Int. Conf. on the Present-day State and Problems of Navigation and Oceanography vol 2 (St. Petersburg: GNINGI) pp 95–98
[8] Antipin K V, Ainutdinov V M, Balkanov V A, Borschchev D A, Danil’chenko I A, Domogatskii G V, Doroshenko A A, Dzhilkibaev Zh-A M, Gaponenko O N, Golubkov K V, Zhukov V A, Klabukov A M, Mikheev S P, Panfilov A I, Petukhov D P, Pokhil P G, Poleshchuk V A, Sheifler A A, Budnev N M and D’yachok A P 2007 Bull. Russ. Acad. Sci.: Phys. 71 582-586
[9] International hydrographic organization 2008 IHO Standards for Hydrographic Surveys (S-44) 5th edition vol. 44 (Monaco: International Hydrographic Bureau)
[10] IMCA S-003 2001 Guidelines for the Use of Multibeam Echosounders for Offshore Surveys
[11] Mats V D, Khlystov O M, De Batist M, Ceramicola S, Lomonosova T K, Klimansky A 2000 Int. J. Earth Sci. 89 229–250
[12] Khlystov O M, Mats V D, Vorobyeva S S, Klimanskii A V, De Batist M and Ceramicola S 2000 Geol. and Geophys. 41(6) 819–824