Supplementary Material

Estimation of bottom parameters and sound intensity decay law in the Ural-Caspian channel

Normalization of underwater noise level to a given distance and plotting the safety zone boundaries require the knowledge of sound intensity decay laws typical for the studied region. Whereas a decay law depends on both the geometric parameters of an acoustic waveguide (thickness of a water layer *H*) and the acoustic properties of water column and its boundaries (see the Fig. S1). During the experiments, thickness of a water layer *H* was recorded using an echosounder. Sound speed profile $c(z)$ in the water layer was measured using a CTD profiler. Core data on structure and composition of bottom sediments within the region, as well as a simple matched-field processing (MFP) procedure are used to estimate acoustic parameters of sediments. The latter is to compare the experimental curves of sound intensity decay with the simulated ones, which were calculated for various values of the parameters. The set of parameter values where the best correspondence between the experiment and theory was observed was considered the true one.

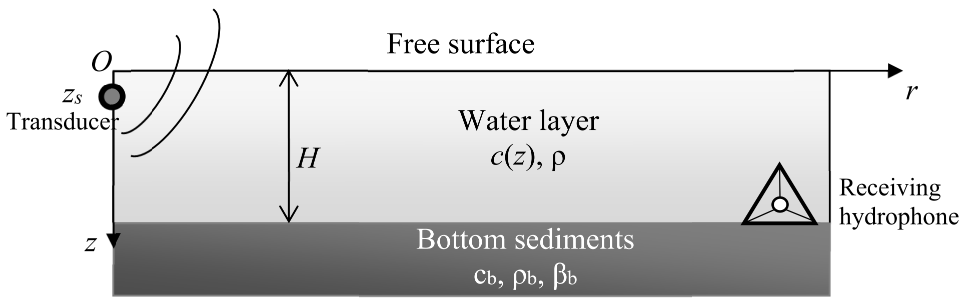

Figure S1. Model of the shallow-water waveguide in the Ural-Caspian channel; z_s is a sound source depth; *H* is the thickness of the water layer; $c(z)$ and $\rho(z)$ are the vertical profiles of sound speed and density in water; c_b, ρ_b and β_b are the sound speed, density and sound attenuation coefficient in the bottom.

Vertical sound speed profiles in the Ural-Caspian channel and in the Caspian Sea are shown in Fig. S2. Note that the change in the sound speed with depth is insignificant (within the value of 1.5 m/s). In simulations, sound speed in the water column is assumed constant.

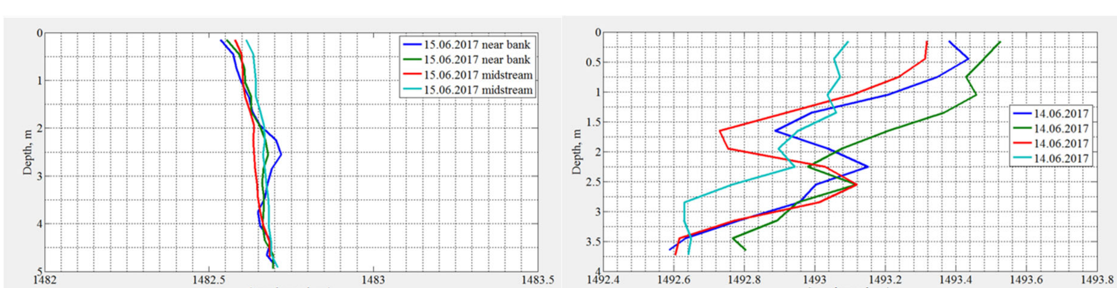

Figure S2. Vertical sound speed profiles in the Ural-Caspian channel (a) and in the Caspian Sea (b).

Parameters of the bottom sediments are chosen based on the analysis of the bottom soil samples in the Caspian Sea near the estuary of the Ural River. Shirshov Institute of Oceanology RAS obtained the data on soil composition during the expedition held in 2017 [31]. Data analysis proved the presence of a significant organic component at all points. Presence of such component is an indirect evidence of the gas saturation of the bottom sediments in freshwater bodies [32]. Soil consistency is soft or semi-liquid. Ultra-low sound speeds (less than the sound speed in water and even in the air) are typical for such soils, due to very high compressibility. This is also relevant to note that when modeling the sound field in a water area with gas-saturated sediments, the sound attenuation coefficient in the bottom can be excluded from consideration β_b, as it weakly affects the sound propagation in a water layer [33]. Parameters of the waveguide model for the Ural-Caspian channel and shelf of the Caspian Sea are presented in Table S1. Bottom in this model is represented as a homogeneous liquid half-space with the sound speed c_b and density ρ_b.

Table S1. Typical parameters of a shallow-water waveguide in the Ural-Caspian channel and on the shelf of the Caspian Sea

Waveguide depth H, m	4-5
Sound speed in water $c(z)$, m/s	1480-1510
Water density, kg/m^3	1000
Sound speed in sediments, c_b, m/s	250-300
Density of sediments ρ_b, kg/m^3	1300

Actual measurements of the sound pressure in a water layer were carried out using a controlled transducer in order to verify the proposed waveguide model. Experimental data on the sound intensity decay were obtained by recording a signal from a piezo ceramic transducer (a sphere of diameter 80 mm) located at various ranges from the receiving hydrophone. Depth of the transducer was 1.3 m; the receiving hydrophone was 0.4 m from the bottom. A signal with the linear frequency modulation (LFM) was radiated in the band of 300-2000 Hz. Duration of one transmission was 1 s. The signal recorded was subject to the correlation processing at the receiving end (correlation of the signal received with the radiated signal) to obtain an impulse response of the underwater channel. The maximum values of impulse responses were averaged over 30 transmission cycles at each point.

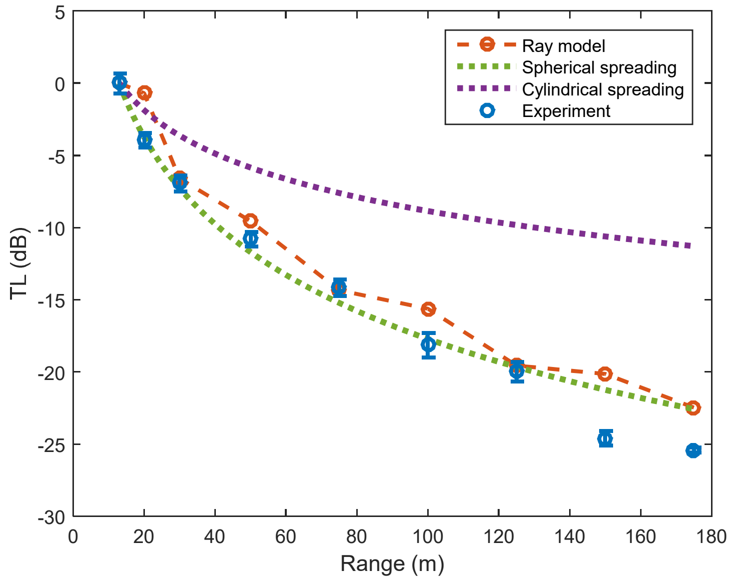

Figure S3. Experimental data and simulated curves of the sound intensity decay.

Consider the measurements of the sound intensity decay in the Ural-Caspian channel at the point N46° 52.619' E51° 36.229'. Depth along the acoustic track was H = 5 m. Average sound speed in the water layer equaled 1482 m/s. Estimated values of the bottom parameters were: the density of ρ_b = 1300 kg/m^3, the sound speed of c_b = 250 m/s. Acoustic signals were recorded at a distance of 13 to 175 m. Result of their processing is shown on the Fig.S3 by blue marks with the 95% confidence intervals. Results of modeling of the sound intensity decay using the ray approach [38], as well as the cylindrical and spherical decay laws are shown in Fig.S3. One can see that the spherical decay law fits well the experimental data. Note that this conclusion turned out to be valid for other measurement sites.

Specifications of Caspian Falcon Hovercraft

Fig. S4. Hovercraft *Caspian Falcon*.

Table S2. The RPM of the hovercraft engines.

	Lift engines	**Propulsion engines**

Slow speed	1300	1200
Half speed	1500	1400
Top speed	1750	1800

Specifications of the water-jet vessels

Figure S5. Water-jet vessels: ultra shallow-draft freight vessel (SD1) on the left, Fast Rescue Craft (FRC) on the right.

Table S2. Specifications of the water-jet vessels

Type	FRC water-jet	SD1 water-jet
Type of vessel	Fast rescue craft	Ultra shallow-draft freight vessel
Engine capacity	276 kW	300*2 kW
Type of fuel	Diesel	Diesel
Manufacturer	India	Estonia
Water draft	0.3 m	0.3 m
Length (m)	8.5	14.4
Width (m)	3.3	4.4