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METHOD OF THE MATRIX PROPAGATOR FOR SOUND SCATTERING ON STATISTICAL BOTTOM IRREGULARITIES

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The problem of sound propagation in the shallow sea in the presence of random bottom irregularities is considered. In the modal representation, evolution of an acoustic wavefield can be described using a matrix propagator. The paper proposes a method for calculating random propagator matrices based on perturbation theory for matrix operators and adapted for shallow seas. The model of two-dimensional sound propagation described by a wide-angle parabolic equation is taken as a basis. Within the framework of the proposed method, the influence of modes propagating inside the sedimentary layer is taken into account using additives to the mode attenuation coefficients. The inhomogeneity model described by the random Ornstein-Uhlenbeck process is considered, and analytical estimates for the matrix elements of the propagator are obtained. As an example for numerical simulation, a model of a shallow acoustic waveguide with a bottom sound channel is considered. A statistical analysis of the propagation of tonal sound signals with frequencies of 100, 200 and 400 Hz is carried out. Statistical estimates of horizontal variations of the mode spectrum and the scintillation index of individual modes of an acoustic wavefield are obtained. The dependence of sound scattering on the correlation radius of irregularity is studied. It is shown that the scattering–induced inter-mode coupling increases the attenuation of modes at relatively short distances, and at large distances it contributes to slowing down the attenuation and deviation from the exponential law of intensity decay. The scintillation index demonstrates rapid nonlinear growth at short distances, which is further accompanied by the achievement of saturation.

Keywords: random matrix theory, shallow sea acoustics, sound scattering

References

1. Creamer D.B. Scintillating shallow-water waveguides // Journal of Acoustical Society of America. 1996. Vol. 99. № 5, p. 2825-2838. DOI: 10.1121/1.414817

2. Knobles D.P., Sagers J.D. Forward and backward modal statistics for rough seabed surface scattering in shallow water. Journal of Computational Acoustics. 2014. Vol. 22. No. 1, 1440004. DOI: 10.1142/S0218396X14400049

3. Morozov A.K., Colosi J.A. Equations for normal-mode statistics of sound scattering by a rough elastic boundary in an underwater waveguide, including backscattering. JASA Express Letters. 2017. Vol. 142, No. 3. EL292-EL298. DOI: 10.1121/1.5002734

4. Gulin O.E., Yaroshchuk I.O. Peculiarities of attenuation of low-frequency sound in the course of propagation in a 2D arctic-type waveguide with random bathymetry. Underwater Investigations and Robotics. 2023, No. 2(44). C. 67-74. [in Russian]. DOI: 10.37102/1992-4429_2023_44_02_06

5. Evans R.B. A coupled mode solution for acoustic propagation in a waveguide with stepwise depth variations of a penetrable bottom. Journal of Acoustical Society of America. 1983. Vol. 74. No. 1. P. 188-195. DOI: 10.1121/1.389707

6. Makarov D.V., Kon'kov L.E., Uleysky M.Yu. Level spacing statistics in a randomly-inhomogeneous acoustic waveguide. 2010. e-print arXiv 1008.3037 [nlin.CD] (2010).

7. Hegewisch K.C., Tomsovic S. Random matrix theory for underwater sound propagation // Europhysics Letters. 2012. Vol. 97, No 3. P. 34002. DOI: 10.1209/0295-5075/97/34002

8. Virovlyansky A.L., Makarov D.V., Prants S.V. Ray and wave chaos in underwater acoustic waveguides. Physics-Uspekhi. 2012. Vol. 55, No. 1. P. 18-46. DOI: 10.3367/UFNe.0182.201201b.0019

9. Makarov D.V., Kon'kov L.E., Uleysky M.Yu., Petrov P.S. Wave chaos in a randomly inhomogeneous waveguide: spectral analysis of the finite-range evolution operator. Physical Review E. 2013. Vol. 87, No. 1. P. 012911. DOI: 10.1103/PhysRevE.87.012911

10. Hegewisch K.C., Tomsovic S. Constructing acoustic timefronts using random matrix theory. Journal of Acoustical Society of America. 2013. Vol. 134, No 4. P. 3174-3184. DOI:10.1121/1.4818783

11. Makarov D.V. Random matrix theory for low-frequency sound propagation in the ocean: a spectral statistics test. Journal of Theoretical and Computational Acoustics. 2018. Vol. 26. No. 1. P. 1850002. DOI: 10.1142/S2591728518500020

12. Makarov D.V. Random matrix theory for an adiabatically-varying oceanic acoustic waveguide. Wave Motion. 2019. Vol. 90. P. 205–217. DOI: 10.1016/j.wavemoti.2019.05.007

13. Makarov D.V., Komissarov A.A. Modelling of sound propagation in the ocean using the matrix propagator. Proceedings of Meetings on Acoustics. 2020. Vol. 42. P. 055004. DOI: 10.1121/2.0001404

14. Makarov D.V., Komissarov A.A. Chaos and wavefront reversal for long-range sound propagation // Doklady Earth Sciences. 2022. Vol. 507, No. 2. P. 1118-1123. DOI: 10.1134/S1028334X22600931

15. Makarov D.V., Alliluev A.D. On experimental determination of the acoustic waveguide propagator. Underwater Investigations and Robotics. 2021. No. 1(35). P. 80-84. [in Russian]. DOI: 10.37102/1992-4429_2021_35_01_08

16. Makarov D.V., Kholmogorov A.O., Shakirov R.B. Influence of pockmarks on propagation of low-frequency sound in a shallow sea. Underwater Investigations and Robotics. 2021. No. 4(38). P. 60-71. [in Russian]. DOI: 10.37102/1992-4429_2021_38_04_06

17. Louisell W.H. Radiation and Noise In Quantum Electronics. New York.: McGraw-Hill, 1964. P. 336. ISBN: 0070387613

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