# A Hybrid Approach to Under-Ice Sound Propagation

Anatoliy Ivakin

*Applied Physics Laboratory, University of Washington,*

*Seattle, WA 98105, USA*

*E-mail:* aniv@uw.edu

Numerical simulations of under-ice propagation can be made using elastic full-wave codes, see, e.g., [1,2]. Although such calculations are time consuming, they could be worthwhile in the case where a specific sound speed profile (SSP) and source location are known with sufficient accuracy. As it is not the case in many experiments, multiple calculations with varying parameters are needed for better model-data comparisons, which makes such simulations even more time consuming and, in many cases, impractical. Here we show that much faster calculations can be made using a simple correction of a RAM-PE model initially developed for fluid ocean environments with free flat surface [3], which is slightly modified to account for effects of elastic ice cover using some simple ray-based considerations. These corrections can be ray-based combined with using the method of images. This hybrid approach considers an additional acoustic field from an imaginary source assuming that its amplitude is taken such that it will (1) compensate the reflection from the free surface and (2) add the reflection field corresponding to the real surface, the ice cover. It's easy to show that, in case of a homogeneous water layer under the ice, such source amplitude is 1+V, where V is the complex reflection coefficient of the ice layer. In the case of slightly stratified water under ice, it would have a simple additional phase-correction factor for the imaginary source amplitude. In the case of a usually very slight stratification within Arctic surface duct (usually 0-50m depths), this factor is not critical. An example of using this hybrid approach is outlined in a JASA August 2022 paper [4], https://doi.org/10.1121/10.0013503. Here we consider it in more detail, discuss its limitations, and give results of ICEX14 data-model comparisons.

*Keywords:* ICTCA 2023; ICEX14, Arctic surface waveguide; elastic ice cover.

## References

[1] Jensen F.B., W.A. Kuperman, M.B. Porter, and H. Schmidt (2011), *Computational Ocean Acoustics*, Springer, NY, 794p.

[2] Frank S.D. and A.N. Ivakin (2018). Long-range reverberation in an Arctic environment: Effects of ice thickness and elasticity, *J. Acoust. Soc. Amer. Express Letters*, **143**(3), EL167-EL173.

[3] Collins M. (1999). RAM-PE manual, https://oalib-acoustics.org/PE/RAM/ram.pdf

[4] Ivakin, A.N., and Williams, K.L. Midfrequency acoustic propagation and reverberation in a deep ice-covered Arctic ocean. J. Acoust. Soc. Am. 2022; 152: 1035–1044.