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Analysis of volume attenuation of hydro-acoustic signal propagation in the Romanian Black Sea Coast

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Abstract. The Romanian coastal area of the Black Sea has particularities related to the marine environment, namely a low average salinity and seasonal winter/summer temperature variations that influence the attenuation in volume for the propagation of acoustic signals. In this paper, the influence of the marine environment on the volume attenuation of the acoustic signals was analyzed using different calculation formulas for the attenuation coefficient. For this purpose, the **Hydro-acoustic Forcast Modules** application developed within the Research Center for Navy was used to simulate the acoustic energy losses.

1. Introduction

The Black Sea basin presents some specific characteristics like the interaction between the upper and lower layers causing a non-uniform structure of the marine environment. The temperature and salinity of the seawater layers in the area of the continental platform, corresponding to the Romanian shore, does not remain constant during the entire year. It is worth noting the average low salinity in this area with limit values in the vicinity of the mouth of the Danube river (the phenomenon of dilution). All these factors influence the attenuation of the acoustic signals propagation in the seawater.

The sound propagation in the seawater depends on sound speed profile, sedimentological seafloor structure (seafloor reflections) and marine medium attenuation.

In this paper is analyzed, how the Black Sea specificity of the marine medium influence the volume attenuation of the acoustic signals. When sound propagates in the seawater, part of the acoustic energy is continuously absorbed and transformed into heat. Moreover, sound is scattered by different kinds of unhomogeneities, also resulting in a decay of sound intensity with range. It is not possible in real sea experiments to distinguish between absorption and scattering effects so the both phenomena contribute to sound volume attenuation in seawater. This attenuation varies in a complicated way with frequency, pressure/depth, temperature, salinity and acidity.

To simulate the acoustic energy transmission loss it is used the **Hydro-acoustic Forcast Modules** application developed within the Research Center for Navy. The volume attenuation, of the acoustic signals, in the seawater is theoretical expressed by the attenuation coefficient.

2. Volume attenuation approach

The frequency dependence of volume attenuation can be divided into four regions of different physical origin. Region I is the region of the lowest frequency and is related to low-frequency propagation-duct cutoff. The main mechanisms associated with regions II and III are chemical relaxations of boric acid $B(OH)_3$ and magnesium sulphate $MgSO_4$, respectively. Region IV is dominated by the shear and bulk viscosity associated with salt water (curve AA'), with fresh water (curve BB') respectively.[1]

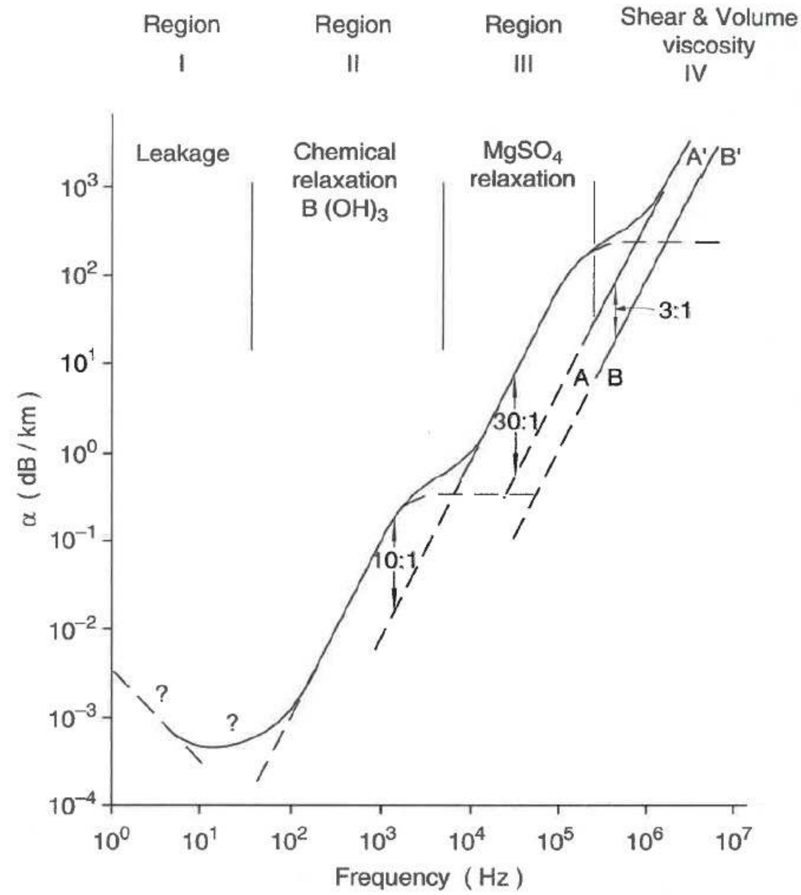


Figure 1. Regions of the different dominant processes of attenuation of sound in seawater

Volume attenuation factor $\emptyset_V$, in the acoustic wave amplitude formula $a = A \times \emptyset_r \times \emptyset_V$, is given by the exponential decaying

$$\emptyset_V = \exp(-\alpha s), \quad (1)$$

where s is the ray arclength and α is the attenuation coefficient.

A simplified expression for the frequency dependence (f in kHz) of the attenuation is Thorp formula

$$\alpha_T = 3{,}3 \times 10^{-3} + \frac{0{,}11 f^2}{1+f^2} + \frac{44 f^2}{4100+f^2} + 3{,}0 \times 10^{-4} f^2, \text{ dB\textbackslash km. [1]} \quad (2)$$

The four terms are associated with regions I-IV from Figure 1. This expression applies for a temperature of 4°C, a salinity of 35 ppt, a pH of 8.0, and a depth of about 1000 m, where most of the measurements on which it is based were made. Thorp formula is considered sufficiently accurate for most problems in ocean acoustics.

However, the specificity of the Black Sea marine medium like an average low salinity (18 ppt) requires to test volume attenuation formulas that take in consideration the dependence on temperature, pressure, salinity and acidity. In this paper the Ainslie&McColm formula was chosen to compare the results of the Thorp formula. This second formula has a larger applicability domain

$$\alpha' = 0{,}106\frac{f_1 f^2}{f_1^2+f^2}e^{\frac{pH-8}{0{,}56}} + 0{,}52\left(1+\frac{T}{43}\right)\left(\frac{S}{35}\right)\frac{f_2 f^2}{f_2^2+f^2}e^{\frac{-D}{6}} + 4{,}9\times10^{-4}f^2 e^{-\left(\frac{T}{27}+\frac{D}{17}\right)} \text{ dB\textbackslash km [2]} \quad (3)$$

where f is signal frequency in kHz, T is temperature in degrees Celsius, D is depth in km, S is salinity in parts per thousand (ppt). f_1 and f_2 are frequencies caused by boric acid and magnesium sulphate in kHz:

$$f_1 = 0{,}78e^{\frac{T}{26}}\sqrt{\frac{S}{35}},\ f_2 = 42e^{\frac{T}{17}}. \quad (4)$$

3. Simulations and analyses

To analyze the propagation of the acoustic signals in the seawater are considered two sound speed profiles (winter/summer) specific in the Romanian coastal area of the Black Sea. The marine medium in the same geographical location presents significant differences in temperature, salinity and sound speed profile between winter and summer that influence the propagation and the attenuation of the acoustic wave.

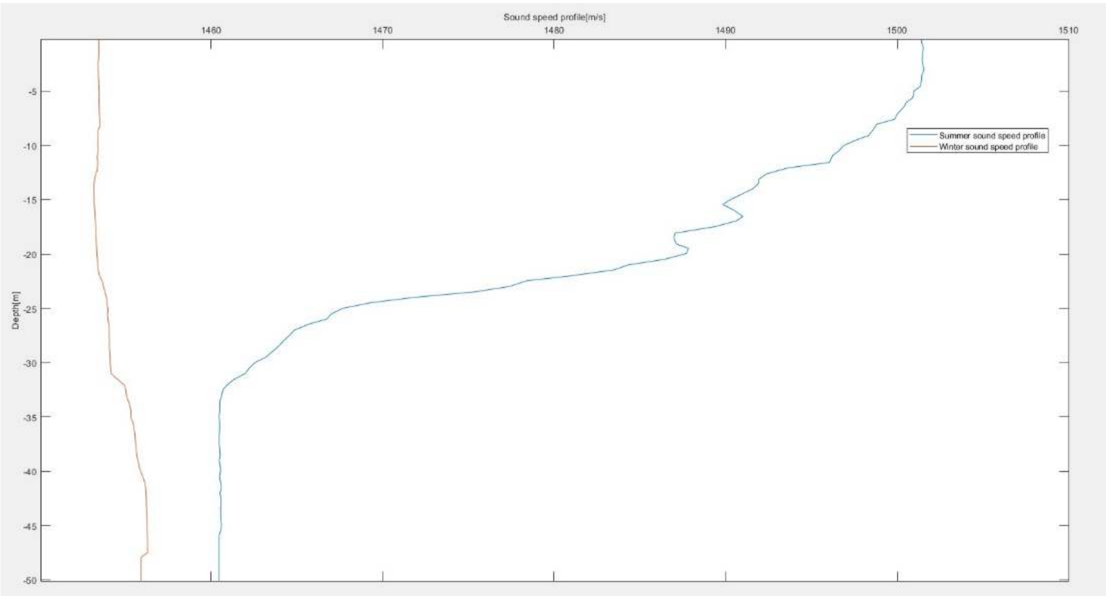


Figure 2. The considered winter sound speed profile/ summer sound speed profile

In the **Figure 3.** are presented the values of the volume attenuation coefficient calculated with the general Thorp formula and with the Ainslie&McColm formula for winter, respectively summer specific marine medium conditions. It can be observed a significant difference between the values calculated with the Ainslie&McColm formula compared with the values calculated with the Thorp formula. The Ainslie&McColm formula, that consider the marine medium particularities, express a lower volume attenuation. For the both formulas, the attenuation increases with the signal frequency. A slight variation occurs with the frequency increase between the attenuation coefficient values obtained for the winter conditions and that obtained for the summer conditions too.

Using the two considered formulas for volume attenuation coefficient, we have simulated the acoustic signals propagation in the marine medium of the Romanian Black Sea coast to evaluate the volume attenuation.

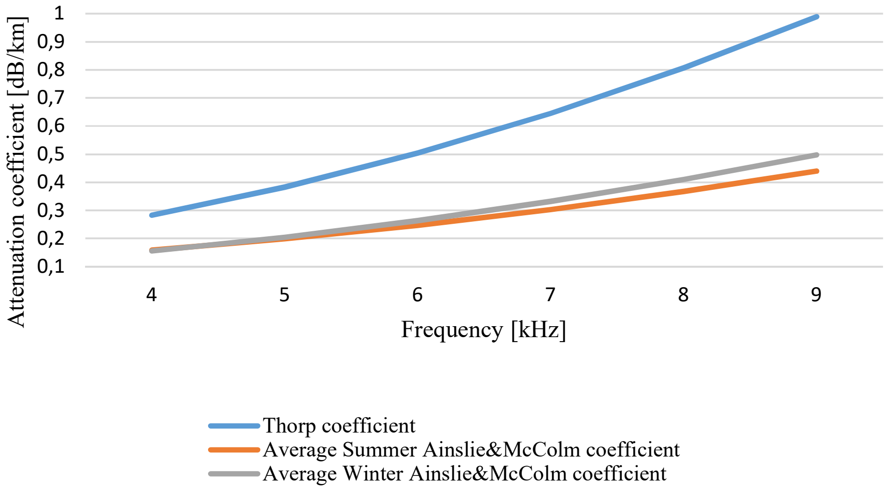


Figure 3. Volume attenuation coefficient calculated with different formulas

The attenuation of acoustic signals in the seawater is expressed in terms of transmission loss defined as

$$TL(s) = -20log\left|\frac{p(s)}{p^0(s=1)}\right| [1] \tag{5}$$

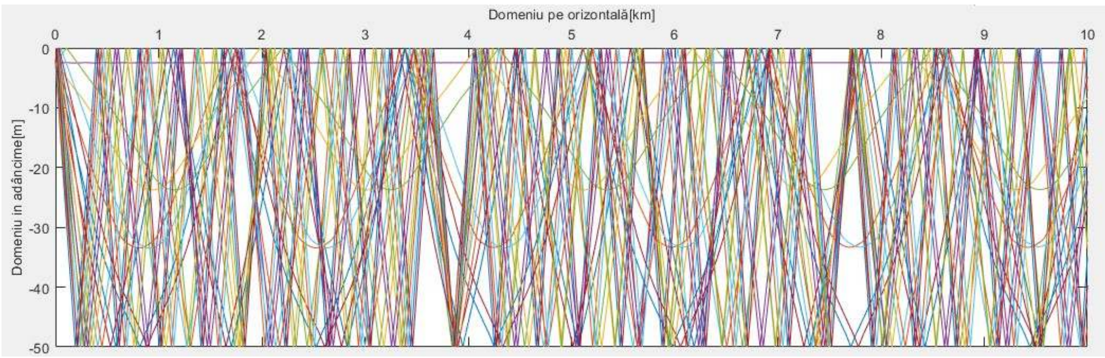
where

$$p(s) = \sum_{j=1}^{N(r,z)} p_j(r,z) \tag{6}$$

is the sum of pressure contributions from acoustic rays which pass through the considered point, $p^0(s=1)$ is the acoustic pressure for a point source in free space evaluated at a distance of 1 m from the source. Thus,

$$p^0(s=1) = \frac{1}{4\pi}. \tag{7}$$

It is considered sound speed profiles a propagating horizontal range of 10 km (in the winter), respectively 5 km (in the summer) and a depth of 50 m, an acoustic source of 8 kHz frequency, 21 rays to trace. To obtain an overview of the attenuation phenomen are chosen three depths to positionate the acoustic source 2,5 m/5 m, 15 m și 35 m. The sedimentological structure of the seafloor is considered of limestone because such a boundary reflect almost entirely the acoustic energy back in the medium.
In the following figures are presented the results of the acoustic signal propagation (acoustic ray trace) and transmission loss simulations obtained with the developed **Hydroacoustic Forcast Modules.**



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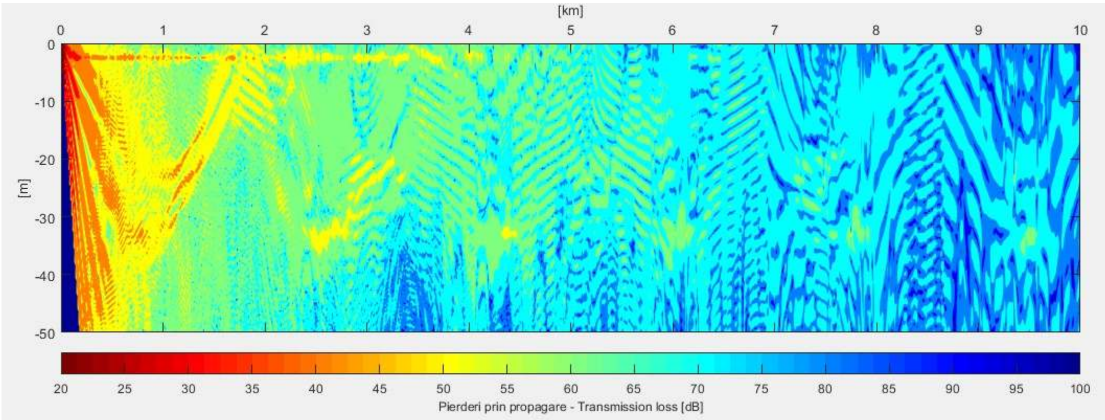

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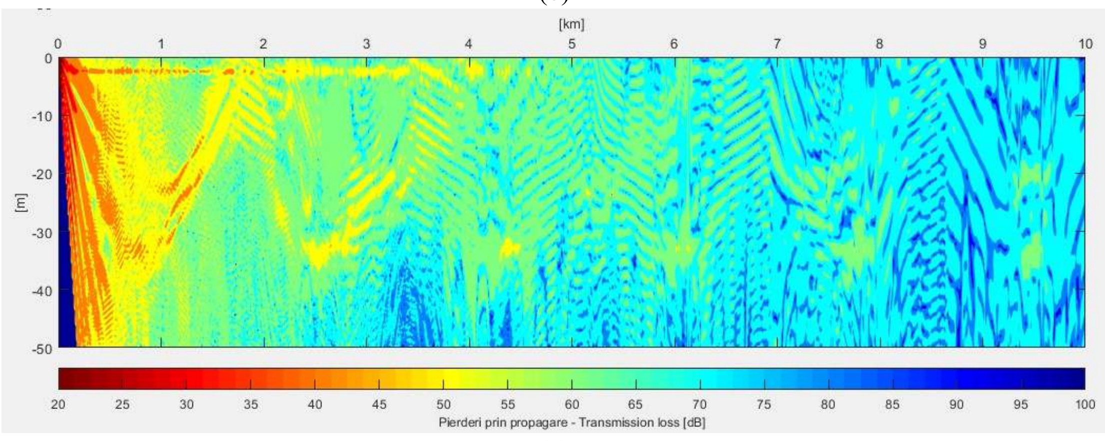
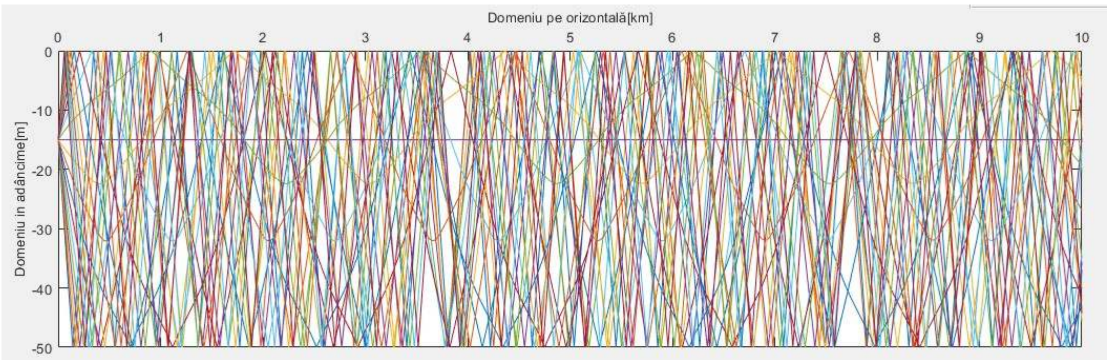


(c)

Figure 4. Winter sound speed profile, acoustic source depth – 2.5 m
(a) acoustic ray trace,
(b) transmission loss (dB) Thorp formula for volume attenuation coefficient,
(c) transmission loss (dB) Ainslie&McColm formula for volume attenuation coefficient.



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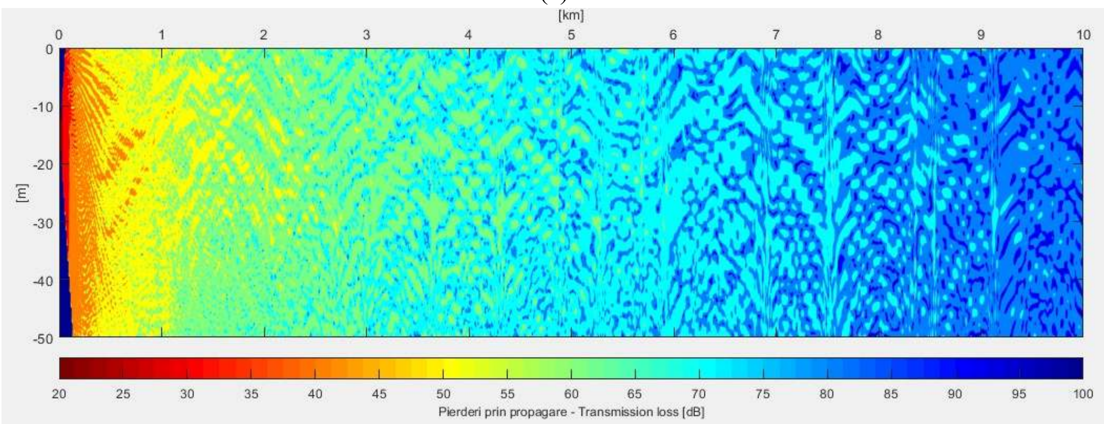

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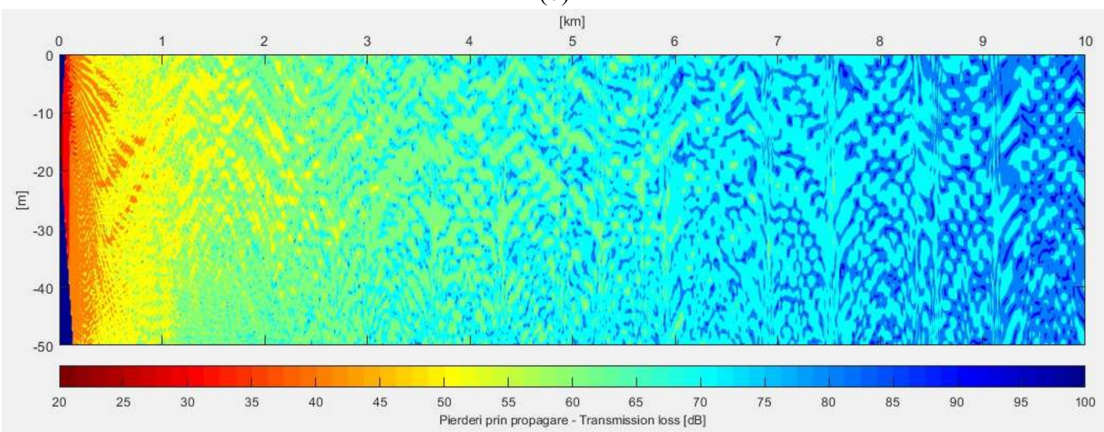


(c)

Figure 5. Winter sound speed profile, acoustic source depth – 15 m
(a) acoustic ray trace,
(b) transmission loss (dB) Thorp formula for volume attenuation coefficient,
(c) transmission loss (dB) Ainslie&McColm formula for volume attenuation coefficient.

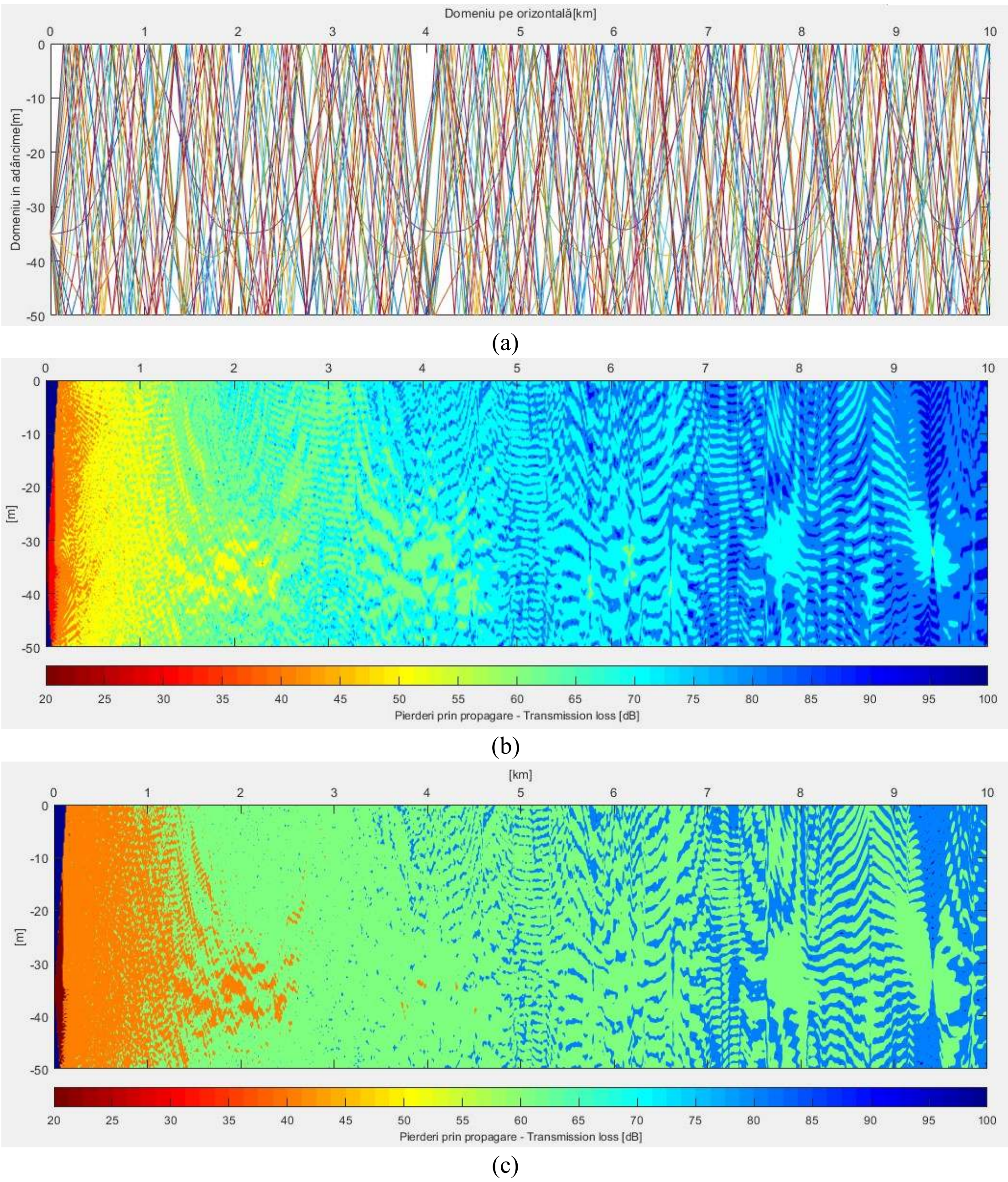
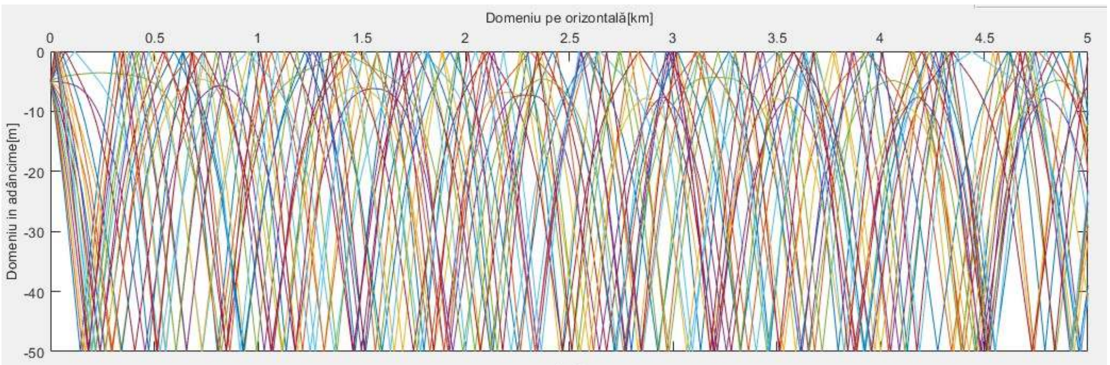


Figure 6. Winter sound speed profile, acoustic source depth – 35 m
(a) acoustic ray trace,
(b) transmission loss (dB) Thorp formula for volume attenuation coefficient,
(c) transmission loss (dB) Ainslie&McColm formula for volume attenuation coefficient.



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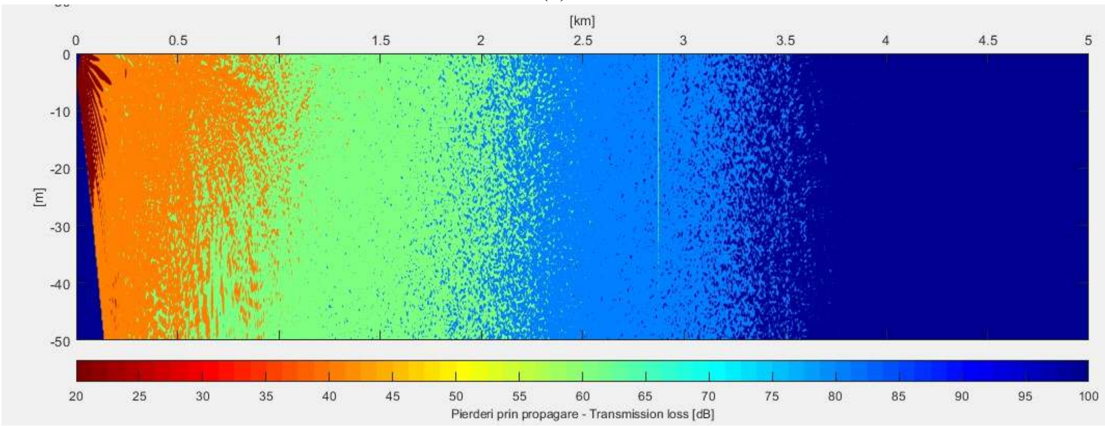

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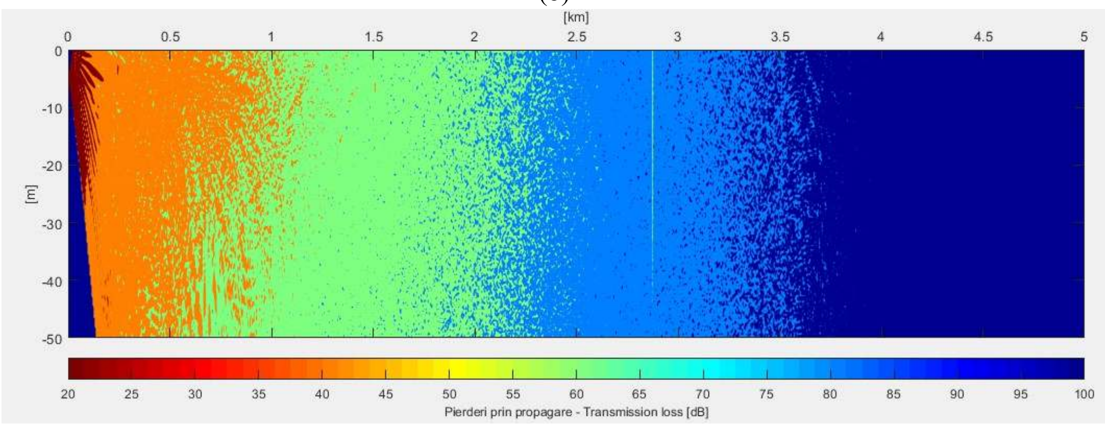
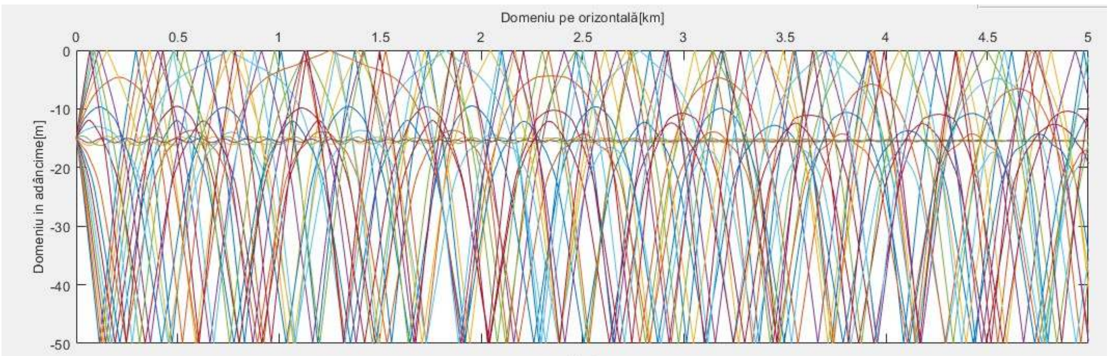


(c)

Figure 7. Summer sound speed profile, acoustic source depth – 5 m
(a) acoustic ray trace,
(b) transmission loss (dB) Thorp formula for volume attenuation coefficient,
(c) transmission loss (dB) Ainslie&McColm formula for volume attenuation coefficient.



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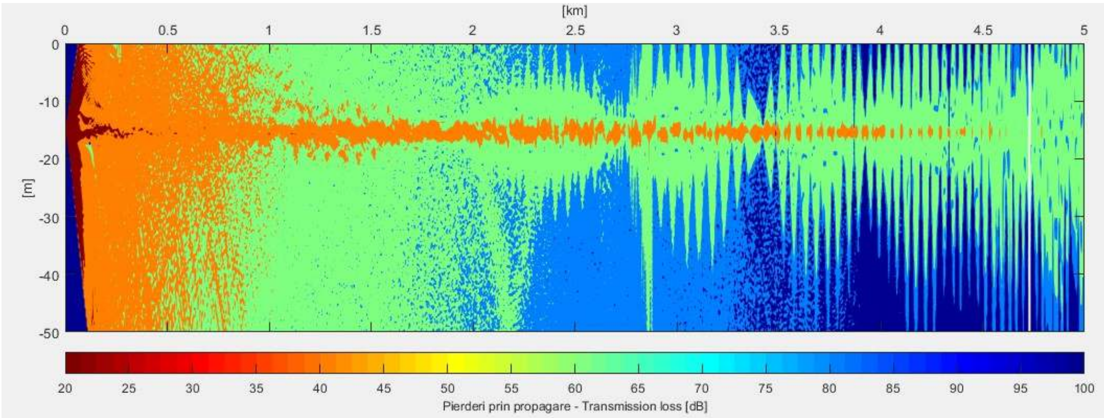

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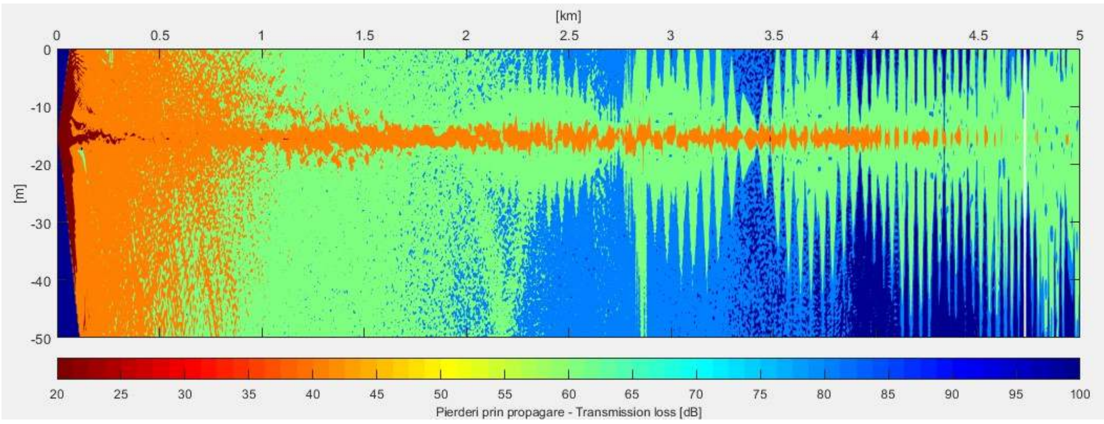
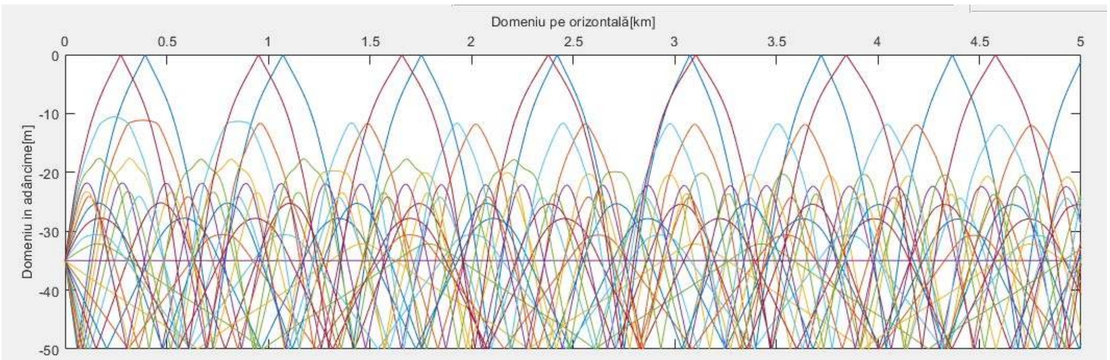


(c)

Figure 8. Summer sound speed profile, acoustic source depth – 15 m
(a) acoustic ray trace,
(b) transmission loss (dB) Thorp formula for volume attenuation coefficient,
(c) transmission loss (dB) Ainslie&McColm formula for volume attenuation coefficient.



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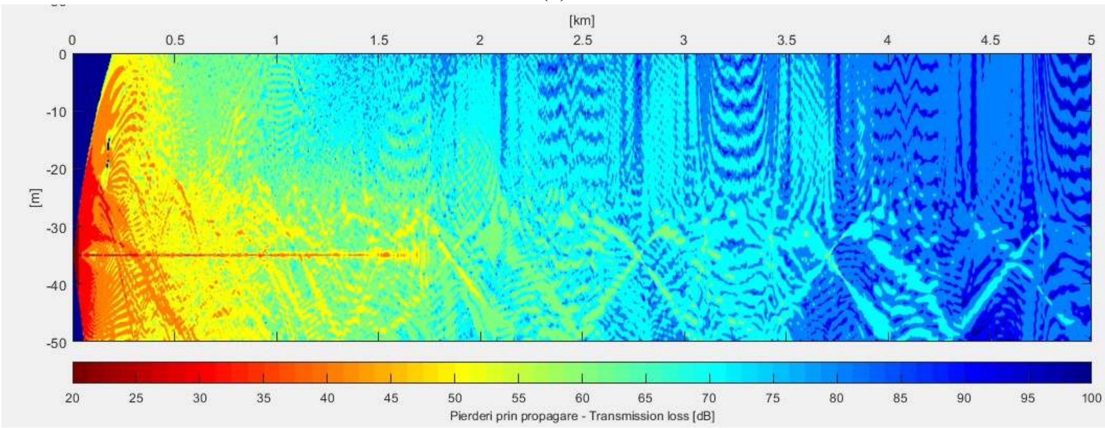

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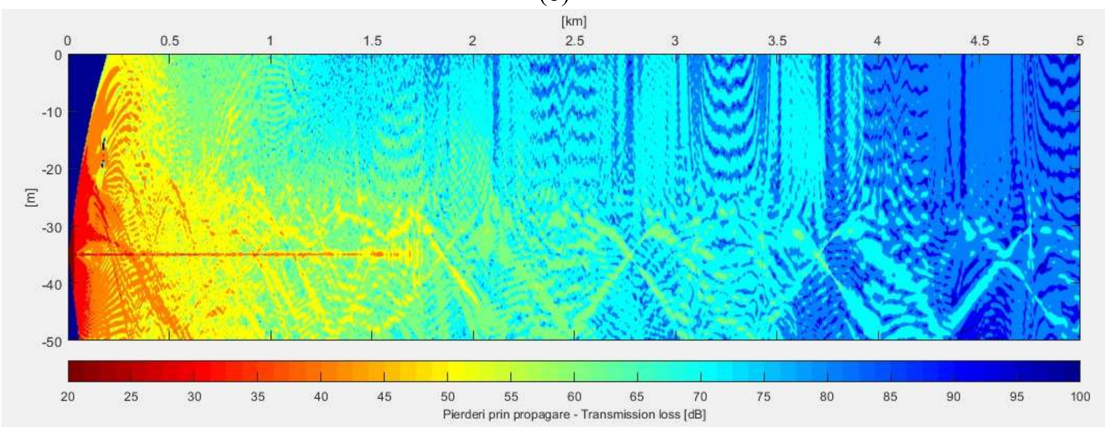

(c)

Figure 9. Summer sound speed profile, acoustic source depth – 35 m
(a) acoustic ray trace,
(b) transmission loss (dB) Thorp formula for volume attenuation coefficient,
(c) transmission loss (dB) Ainslie&McColm formula for volume attenuation coefficient.

4. Conclusions

Can be observed significant differences in the signal propagation mode for the two sound speed profiles that characterize the winter marine medium specificity, respectively summer marine medium specificity. In the both cases, the acoustic rays tend to concentrate in the areas where the sound speed decreases. Thus, in the summer, the acoustic rays focus on deeper areas with the acoustic source immersion.

It was noted that the volume attenuation dependence on the marine medium conditions specificity in the Romanian coastal area of the Black Sea (temperature, pressure, salinity and acidity), determines notable lower values for the attenuation coefficient upon the values obtained considering just the frequency dependence. Thus, in all the simulated situations, it can be observed lower transmission loss when attenuation coefficient is calculated with the Ainslie&McColm formula in comparison with the general Thorp formula. These differences in volume attenuation could become more significant on larger explored areas.

The Black Sea basin particularities influence the attenuation of the acoustic signals in the seawater and it is important to take in consideration the medium parameters when is evaluated the volume attenuation coefficient for accurate results.

5. References

[1] Jensen F B et al 2011 *Computational Ocean Acoustics 2nd ed*. Springer

[2] Kularia Y. et al 2016 Analysis of acoustic channel characteristics for underwater wireless sensor networks *International Journal of Computational Science, Information Technology and Control Engineering* **Vol 3** No. 1/2

[3] van Moll C A M et al 2009 A simple and accurate formula for the absorption of sound in seawater *IEEE Journal of Oceanic Engineering* **Vol. 34** No. 4

[4] Ainslie M A and McColm J G 1998 A simplified formula for viscous and chemical absorption in seawater *Journal of Acoustical Society of America* **Vol. 103** No. 3

[5] Rodriquez O C 2011 *The Traceo ray tracing program* www.siplab.fct.ualg.pt

[6] Mihailov M-E 2019 Sound speed characteristics and impulsive noise hotspots assesment in the north-western Black Sea *Romanian Reports in Physics* **XX** XYZ