SEASONAL VARIATIONS OF THE TRANSMISSION LOSS AT THE MOUTH OF THE DANUBE DELTA

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ABSTRACT

Underwater communication devices, such as underwater acoustic modems (UAM) are designed using the passive sonar equation. At the beginning of the design phase we must know very well the parameters that compose this equation, if we want the modem operation to depend as little as possible on the variability of the transmission channel.

The only parameter that is not known a priori is the transmission loss (TL). The measurement of this parameter is fairly expensive because it involves at least one marine research platform, trained personnel and numerous devices. Therefore we need to estimate this parameter and an inexpensive solution is to simulate the underwater acoustic channel (UAC) in the region where we want to deploy the underwater acoustic modem.

Using conductivity, temperature and depth (CTD) information taken from the NOOA's database, information about the wind speed at the surface and information about the geoacustical properties of the sea floor, we modeled the underwater acoustic channel at the mouth of the Danube Delta. With the help of the AcTUP simulation software we were able to estimate the seasonal variations of the transmission loss in the region of interest using a frequency dependent simulation method. These results will be used later to adapt the underwater acoustic modem to the transmission channel.

Keywords: *Transmission loss, passive sonar equation, underwater acoustic channel, underwater acoustic modem, frequency dependent simulation, channel modeling, channel simulation.*

1. INTRODUCTION

An underwater acoustic modem is a comunication device designed to transmit to the surface the data acquired by sensors. Multiple underwater acoustic modems compose an underwater wireless sensor network (UWSN). These communication equipments transmit information wirelessly using acoustic waves with a projector and receive the information with a hydrophone. Usually an UWSN is placed on the seafloor with the purpose of monitoring chemical and biological phenomena of interest [1].

An UAM is designed using the passive sonar equation. At the beginning of the design phase we must know very well all the parameters that compose this equation, if we want the modem to operate correctly in an underwater transmission channel whose parameters vary with temperature, salinity, depth, wind speed at the sea surface and geoacustical properties of the seafloor.

The only parameter that is not known a priori is the transmission loss. The measurement of this parameter is fairly expensive because it involves at least one marine research platform, trained personnel and numerous devices. Therefore we need to estimate this parameter and an inexpensive solution is to simulate the underwater acoustic channel (UAC) in the region where we want to deploy the underwater acoustic modem [2].

Using information obtained from the National Oceanic and Atmospheric Administration's (NOOA) database [3], information about the wind speed at the surface and information about the geoacustical properties of the seafloor we modeled the underwater acoustic channel at the mouth of the Danube Delta. Using Acoustic Toolbox User-interface and Post-processor (AcTUP) simulation software we were able to estimate the seasonal variations of the transmission loss in the region of interest using a frequency dependent simulation method. These results will be used later to adapt the underwater acoustic modem to the transmission channel.

In the next section we will present the proposed underwater acoustic channel model and the method with which the transmission loss was computed. In section 3 we present the seasonal variations of the transmission loss obtained by simulating the propagation of the underwater acoustic waves in the considered transmission channel. In the final section we present the conclusions of this article and future work.

2. UNDERWATER ACOUSTIC CHANNEL MODELLING

The region of interest is shown in Figure 1. It is geographically located on 45.3 N and 29.8 E latitude and longitude respectively. At this location were recorded 465 CTD data between 1986 and 1991. These data have been introduced in equation 1 to compute the sound speed profile (SSP).

$$\begin{aligned} c(T,S,z) = {} & 1449.2 + 4.6\cdot T - 0.055\cdot T^2 \\ & + 0.00029\cdot T^3 \\ & + (1.34 - 0.01\cdot T)\cdot(S-35) \\ & + 0.016\cdot z \end{aligned} \tag{1}$$

where c is the speed of sound in m/s, T is the temperature in degrees Celsius, S is salinity in parts per thousand (ppt or $^{o}/_{oo}$) and z is the depth measured in meters [4]. This equation is valid for

$$0 \le T \le 35^{o}\,C$$
$$0 \le S \le 45\ \text{ppt}$$
$$0 \le z \le 1000\ \text{m}$$

The depth of our location is 20 m. It will be assumed that near this location the depth will be constant.

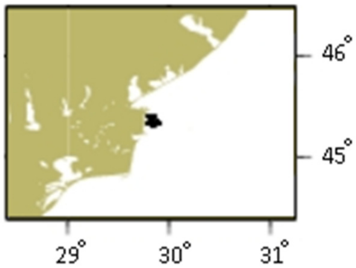
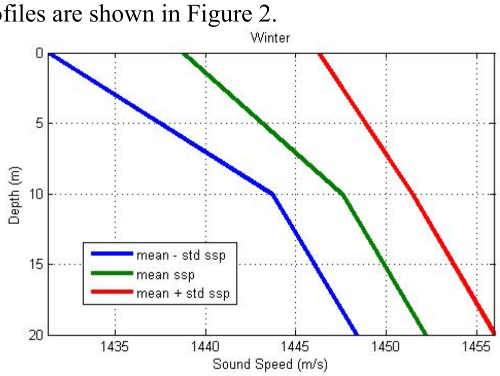


Figure 1 The region of interest at the mouth of the Danube Delta

2.1 Seasonal variations of the sound speed profile

The mean sound speed profile was computed for each season using the data obtained from NOAA. Also we computed the standard deviation (std) of the SSP. These data were used to define two new sound speed profiles. One was obtained by adding the std data to the mean sound speed profile and the other one was obtained by subtracting the std data from the mean SSP. These profiles are shown in Figure 2.



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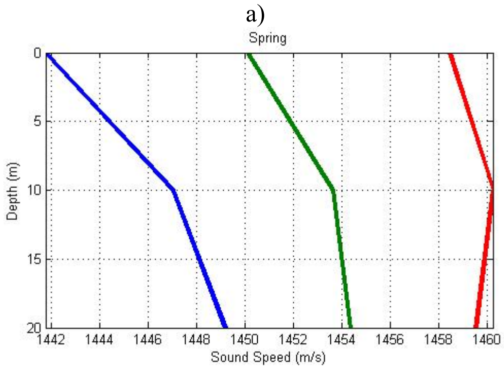

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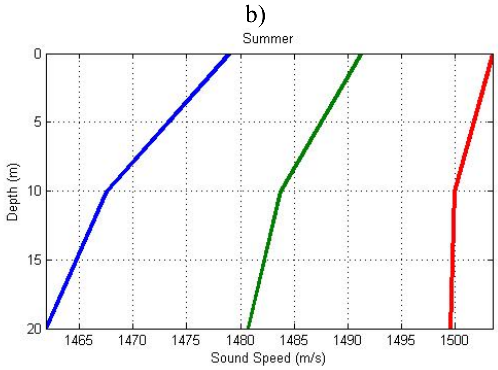

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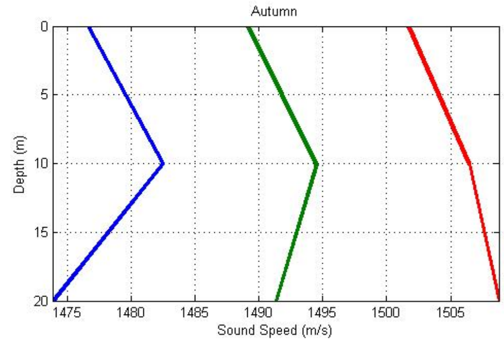


d)

Figure 2 Seasonal variation of the sound speed profile at the mouth of the Danube Delta

In Figure 2 we observe a large variation of the sound speed. This variation is between 1430 and 1510 m/s. In winter and spring we have the smallest sound speeds which are due to low temperatures. The highest sound speeds are observed during summer and autumn. Also we observe that the sound speeds in the mean SSP, the green trace, are less than 1500 m/s (the average value of the underwater sound speed on the globe). This is due to the fact that the average salinity at the mouth of the Danube Delta, 17 ppt, is much smaller than the average salinity, 35 ppt. The low salinity is due to the fresh water brought by the Danube into the Black Sea.

Referring to the mean SSP we observe in Figure 2 a) a positive sound speed gradient. This is called the mixed layer and is due to the harsh conditions in the winter. The bad meteorological conditions determine the mixing of layers with different temperatures resulting in a layer with a constant temperature for the entire water column.

In Figure 2 b) in the mean sound speed profile we observe again the mixed layer. Also in Figure 2 d) between 0 and 10 m the mixed layer is present. Between 10 and 20 m we notice a negative sound speed gradient. This is called the thermocline. Also during summer, Figure 2 c), because of the calm and sunny conditions we notice the thermocline. This is represented by a decrease in temperature with increasing the water column depth.

2.2 Seafloor sound speed profile and geophysical properties

The seafloor consists of three sedimentary layers. The first layer is composed of silty-clay or mud. This is a dynamic layer which consists of river deposits continuously brought by the Danube. The second layer consists of silt and the third layer is made of sand.

The sound speed profile of these layers is shown in figure 3 and in Table 1 we present the geophysical properties for each layer [5], [6].

Table 1. Geophysical properties of the seafloor sediments

Properties	Silty-Clay	Silt	Sand
Depth (m)	0.15	0.05	> 1
Sound speed (m/s)	1491	1575	1650
Density (kg/m3)	1480	1700	1900
Attenuation (dB/λ)	0.15	1	0.8

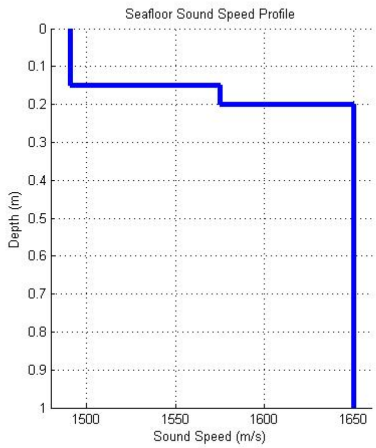


Figure 3 Seafloor sound speed profile. The third sedimentary layer is deeper than 1 m.

2.3 Underwater acoustic channel modeling

We envisioned an underwater wireless sensor network at the mouth of the Danube Delta, consisting of two modems, placed just above the seafloor, which can communicate horizontally. Using the data presented in sub-sections 2.1 and 2.2, we created in AcTUP simulation software [7], which is a MATLAB plug-in, 12 underwater acoustic environments, one for each sound speed profile.

In figure 4 we present the proposed underwater acoustic channel. The sea surface was considered a reflector with 1.75 m rms roughness. The bottom was modeled as a flat reflector and attenuator. The sea depth is considered to be 20 m. The transmitter and receiver were placed at 50 cm above the seafloor in a horizontal configuration. The transmission distance between them is considered to be 500 m.

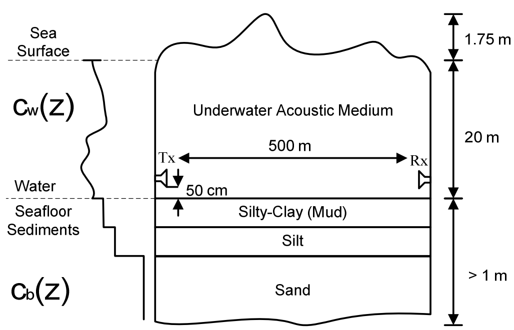


Figure 4 Underwater acoustic channel model at the mouth of the Danube Delta. The sea depth, z, is measured in meters, $\mathbf{c_w(z)}$ represents the water sound speed profile and $\mathbf{c_b(z)}$ the seafloor SSP.

2.4 Transmission loss computation

The method used to compute the transmission loss is described in detail in [8]. We briefly present the most important steps that were performed to compute the transmission loss at the mouth of the Danube Delta.

Using the UAC model presented in figure 4 we performed a frequency dependent simulation in AcTUP.

The simulation results were obtained using the Bounce-Bellhop algorithm [9]-[11]. This is a ray tracing algorithm that simulates the propagation of acoustic waves in the marine medium. The algorithm records his simulation results as channel complex impulse responses.

We simulated our underwater acoustic channel in the frequency range 1-99 kHz with a step of 1 kHz and we obtained 99 simulation files. We used the results from these files and the equation 2 to compute the frequency response of the UAC for the considered transmission distance and for the 12 underwater acoustic environments.

$$\mathrm{H(l,f)} = \sum_{\mathrm{k=1}}^{\mathrm{n}} \mathrm{A_{k,l}} \cdot \mathrm{e}^{\mathrm{j}\theta_{\mathrm{k,l}}} \cdot \mathrm{e}^{-\mathrm{j}2\pi \mathrm{f} \mathrm{t_{k,l}}} \quad (2)$$

In equation 2 $\mathrm{A_{k,l}}$ is the amplitude and $\theta_{\mathrm{k,l}}$ is the phase of the impulse response. The delay of each impulse or the time of arrival relative to the first impulse is represented by $\mathrm{t_{k,l}}$, H is the frequency response, l is the transmission distance and f is the transmission frequency.

The transmission loss was computed using equation 3 and the frequency response from equation 2.

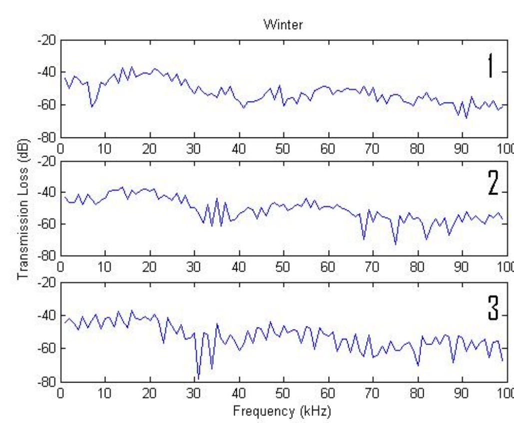
$$\mathrm{TL} = 10\log_{10}|\mathrm{H(f)}|^2 \quad (3)$$

We must emphasize that the presented method has several advantages over the experimental one. A first advantage is that it is less expensive than the experimental one because it requires the simulation of a mathematical model with real input data. The simulation results will be satisfactory if the underwater acoustic channel will be modelled more realistically. Another advantage of this method is that we can simulate the transmission losses for a wide range of frequencies. A third advantage is that we can change at any time the current simulation model.

Next we will present the seasonal variations of the transmission loss obtained using the method described above.

3. SEASONAL VARIATIONS OF THE TRANSMISSION LOSS

The simulation results are shown in Figure 5 for each season and for each sound speed profile. In each sub-figure the upper plot, 1, is characterized by the mean minus one std sound speed profile. The middle plot, 2, is determined by the mean SSP and the lower plot, 3, is characterized by the mean plus one std SSP.



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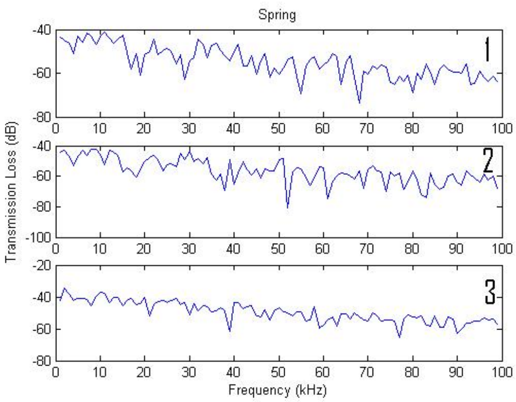

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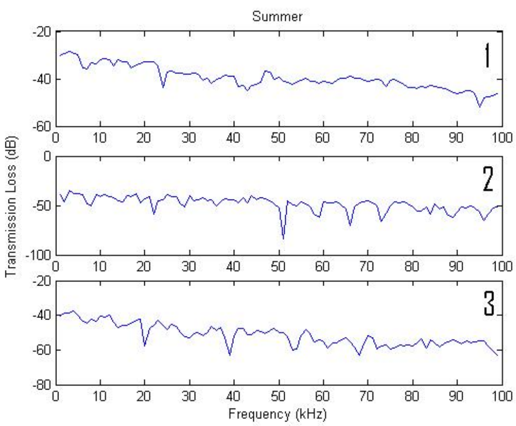

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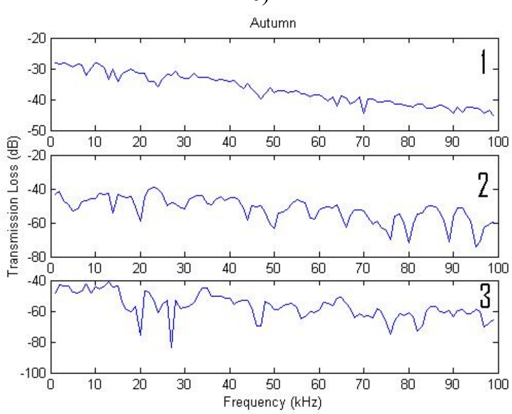

d)

We observe in Figure 5 a.1 three pronounced notches around 8, 40 and 90 kHz. As the sound speed increases we notice in a.2 that these notches are smaller, but others appear around 70 and 80 kHz. In a.3 we see the appearance of a notch around 22 kHz and two pronounced notches around 32 kHz. The one at 8 kHz disappeared and that at 40 kHz is still present. The notches around 70 and 80 kHz have moved 10 kHz away.

We see that the frequency selectivity in figure 5 b.1 and b.2 is much larger than that in Figure 5 a). A quasi-linear decay is observed in b.3 were the notches are very small.

The same linear decay is observed in Figure 5 c.1 but the transmission loss level is 10 dB higher than that in b.3. In c.2 we observe a quasi-constant TL level with a pronounced notch around 50 kHz and three smaller notches around 65, 70 and 75 kHz. In c.3 we observe that the linear decay is somehow restored, with notches around 20, 40, 50 and 70 kHz.

Again the same linear decay is observed in d.1. This pattern is transformed in a random patter in Figure 5 d.2 and d.3 where an increase in frequency selectivity is observed.

As a last observation we can say that if the transmission losses in Figure 5 would have been determined by temporal variations in the SSP we have been noticed a time varying frequency selective fading.

4. CONCLUSIONS

In this article we present the variations of the transmission loss at the mouth of the Danube Delta in response to changes from the mean sound speed profile. We also show these changes for each season. We modeled the underwater acoustic channel using real data and AcTUP simulation software. We used the simulation results to compute the changes in the transmission loss for each season.

These results will be used in designing an underwater acoustic modem. In the near future we want to install in the considered region an underwater wireless sensor network consisting of two modems placed on the bottom in a horizontal link.

5. REFERENCES

[1] Akyildiz, I., Pompili D. and Melodia, T., *Underwater acoustic sensor networks: research challenges*, Ad Hoc Networks 3 (3), pp. 257-279, 2005.

[2] Etter, C. P., *Underwater Acoustic Modeling and simulation*, 3rd ed., Spon Press, 2003.

[3] National Oceanic and Atmospheric Administration, NOOA, http://www.noaa.gov/, 2012.

[4] Brekhovskikh, L. M., *Fundamentals of Ocean Acoustics*, 3rd edition, Springer, 2003.

[5] Oaie, Ghe., Secrieru, D., *Black Sea Basin: Sediment Types and Distribution, Sedimentation processes*, Proceedings of Euro-EcoGeoCentre Romania, 2004.

[6] Jensen, F. B., *Computational Ocean Acoustics*, 2nd edition, Springer, 2011.

[7] Maggi, A. M., *AcTUP v 2.2, Acoustic Toolbox User-interface and Post-processor, Installation and User Guide*, 2010.

[8] Xiao, Y., *Underwater acoustic sensor networks*, CRC Press, Boca Raton, 2010.

[9] Porter, M. B., *The Bellhop Manual and User's Guide*, 2011.

[10] Porter, M. B. and Liu, Y. C., *Finite-Element Ray Tracing*, Theoretical and Computational Acoustics 2, 947-956, 1994.

[11] A. J. Duncan, A. L. Maggi, A Consistent, *User Friendly Interface for Running a Variety of Underwater Acoustic Propagation Codes*, Proceedings of ACOUSTICS 2006, pp. 471-477, 2006.