PROJECT:

EastMed Pipeline Project

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Abbreviations

Abbreviation	Description
Decibels (dB)	Unit to measure the intensity of a sound by comparison of a given level on a logarithmic scale.
Dynamic Positioning (DP)	System of maintaining a position of a vessel using thruster units.
GDEM	Generalized Digital Environment Model.
Mean Square Sound Pressure	The mean square pressure level measured over a given time and represents a measure of the average sound pressure over that time.
MMNET	Marine Mammal Noise Exposure Tool.
Permanent Threshold Shift (PTS)	A permanent change in the auditory threshold which results in permanent hearing loss.
Received Level (RL)	The strength of the acoustic field at a given depth and range or distance away from the source. Since the sound varies with range and depth, it is important to state the range and depth at which the measurement has been taken or the estimate has been made.
Root Mean Square Pressure (RMS)	The square root of the mean square pressure over a given time.
SELcum	Cumulative Sound Exposure Level (cum). The logarithmic sum of received sounds from events over a time period of 24 hours.
Sound Exposure Level (SEL)	The time integral of the square pressure over a time window long enough to include 90% of the energy of a sound pulse expressed as a decibel relative to a standard reference.
Sound Pressure Level (SPL)	The pressure values above expressed as decibel (dB) values relative to stated reference pressure values.
Source Level (SL)	The apparent strength of a sound source at a reference distance, usually 1 m, from the source. It is usually defined as an RMS noise level but it is calculated using the peak pressure, in which case it is known as the peak pressure source level.
Spectral Density Levels	Noise data are usually represented in the frequency domain, although occasionally a time-domain waveform of a transient event will be displayed. It is most common for noise signals to be represented in the frequency domain as noise spectral levels plotted as a function of frequency. The data for ambient noise is usually expressed as spectral density levels, where the data in each frequency band had been normalised by dividing by the bandwidth of the frequency band. The units of the levels in bands that are 1 Hz wide band are then dB re 1 µPa2/Hz.
Temporary Threshold Shift (TTS)	A temporary change in the auditory threshold resulting in temporary hearing impairment.

Third Octave Frequency Band	A specific set of frequency bands used in acoustics which have set centre frequencies and band widths, and which are often used to describe the spectral content of underwater noise sources. The bandwidth is one third of an octave, where an octave represents a doubling in frequency. One third of an octave is a frequency ratio corresponding to a ratio of 21/3.
TL	Transmission Loss

External cooperation

This document was drafted with the cooperation of:

- PhD candidate Jannis Karagiannis, Prof. Alex Sotiropoulou

ANNEX 9 H UNDERWATER NOISE PROPAGATION MODEL DURING CONSTRUCTION PHASE

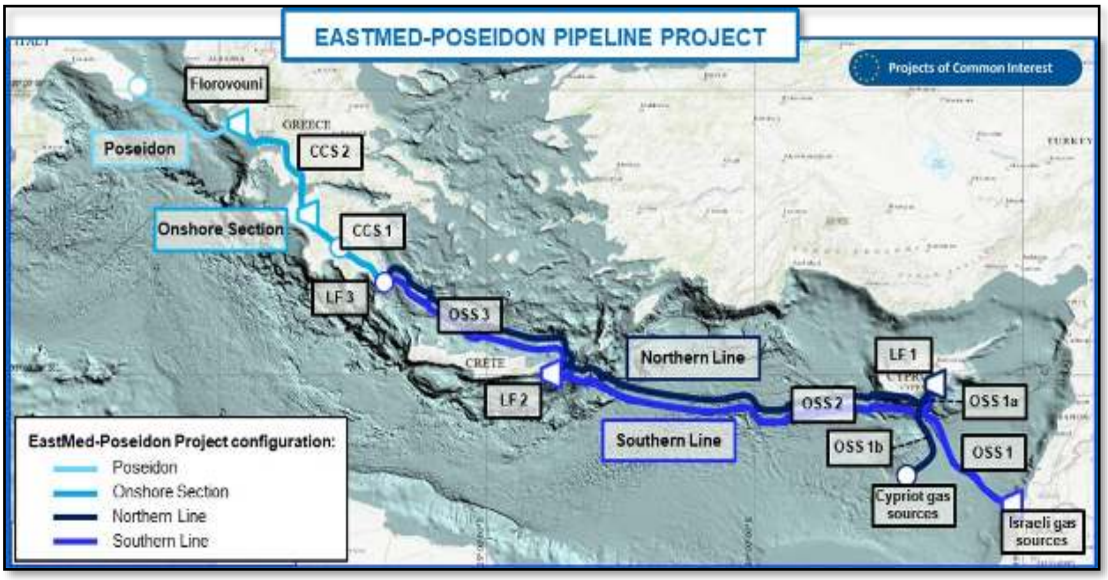
9 H.1. INTRODUCTION

The construction and operation of the EastMed Pipeline Project (the Project) will generate underwater sound that can potentially be an environmental impact on marine life. Levels of sound generated by the Project are expected to be generally low, increasing during the use of thrusters during pipelaying and dredging.

This annex describes the underwater sound modelling which has been carried out to inform the assessment of the underwater sound effects on marine fauna in terms of disturbance and significant effects on behaviour for the Greek offshore sections of the pipeline.

9 H.1.1. Scope of the Study

Acoustic propagation modelling was performed to estimate the extent of potential noise effects on marine mammals and fish during construction of EastMed at the bottom of the sea alongside the route (see Figure H-1).



Source: IGI Poseidon, 2022

Figure H-1 EastMed Route

The pipeline system comprises the following sections (Combined Line, Southern and Northern Lines):

Table H-1 Combined Line Components

Component	Description	Location	Design Capacity [BSCM/yr]
CCS1a	Onshore trunk line from LF3 Stations in Laconia to Megalopoli including landfall stations and scraper stations at LF3 and multiple block valve stations at regular intervals along the pipeline	Peloponnese	21/20
	Heating Station in Megalopolis	Peloponnese	20
CCS1b	Onshore trunk line from Megalopoli to LF4 including landfall station and scraper station at LF4 and multiple block valve stations at regular intervals along the pipeline	Peloponnese	20
CS3	Compressor station in Peloponnese with functionality to recompress gas for onward transport toward the Poseidon compressor station at Florovouni in north-west Greece	Peloponnese	20
OSS4	Subsea trunk line (diameter 46’’) crossing the Gulf of Patras between LF4 and LF5 including short onshore pipeline sections at LF4 and LF5	Gulf of Patras	20
CCS2	Onshore trunk line from LF5 Station in Akarnania to Florovouni in Thesprotia including landfall station and scraper station near LF5 and multiple blockvalve stations at regular intervals along the pipeline	West Greece	20
	Florovouni Metering Station in Thesprotia	Thesprotia Region	20
O&M Base	Dispatching and Operations and Maintenance (O&M) Base in Achaia Regional Unit	Peloponnese	

Source: P616-000-DB=BDS-01_3_Design Basis Memorandum – Pipeline and Facilities

Table H-2 Southern Line Main Components

Component	Description	Location
ECP	EastMed Compression Platform in Israeli waters	Israel
OSS1 – OSS2	Subsea trunk line from the ECP to Crete (dual diameter 30”+26”), including short onshore pipeline section and landfall station at LF2 in Crete	Israel -> Crete
OSS1a	Subsea 12.75” diameter branch pipeline from the subsea Tie-in point in Cypriot waters to LF1 in Cyprus including subsea tie-in arrangement and short onshore pipeline section and landfall station at LF1 in Cyprus	Subsea tie-in point -> Cyprus

Component	Description	Location
MS1a/PRS	Metering and Pressure Reduction Station with functionality to receive high pressure gas from the OSS1a branch pipeline and to deliver at conditions suitable for Cypriot domestic use	Cyprus
CS2/MS2	Compressor and Metering station in Crete with functionality to receive gas from the OSS1-OSS2 trunk line and to recompress this gas for onward transport toward the Greek mainland	Greece (Crete)
OSS3	Subsea trunk line from Crete to LF3 landfall in Peloponnese (diameter 28'') including short onshore pipeline section and landfall station at LF2 in Crete and short onshore pipeline section at LF3 in Peloponnese	Crete -> Peloponnese
MS4/ PRS4	Megalopoli Metering Station / Pressure Reduction Station with functionality to measure and regulate the flow before the tie-in to the national gas grid including a branch Line from Megalopoli MS4/PRS4 to the tie-in to the national gas grid, the Megalopoli branch downstream of MS4/PRS4 is a component of the project.	Peloponnese

Data from: P616-000-DB=BDS-01_3_Design Basis Memorandum – Pipeline and Facilities

Table H-3 Northern Line Main Components

Component	Description	Location
FPSO	Floating production storage and offloading unit (FPSO) located at the Cypriot gas field	Offshore Cyprus
OSS1b	Subsea trunk line from Cypriot offshore gas field to Cyprus, diameter 24'', including short onshore pipeline section and landfall station at LF1 in Cyprus	Cyprus
CS1/MS1	Compressor and Metering Station in Cyprus with functionality to receive gas from the OSS1b trunk line and to recompress this gas for onward transport toward the compressor and metering station in Crete (CS2/MS2 N)	Cyprus
OSS2N	Subsea 26" diameter trunk line from Cyprus to Crete including short onshore pipeline section and landfall station at LF1 in Cyprus and short onshore pipeline section and landfall station at LF2 in Crete	Cyprus -> Greece (Crete)
CS2/MS2 N	Compressor and Metering station with functionality to receive gas from the OSS2N trunk line and to recompress this gas for onward transport toward the Greek mainland	Greece (Crete)
OSS3N	Subsea trunk line from Crete to landfall LF3 in Peloponnese (diameter 28'') including short onshore pipeline section and landfall station at LF2 in Crete and short onshore pipeline section at LF3 in Peloponnese	Crete -> Peloponnese

Data from: P616-000-DB=BDS-01_3_Design Basis Memorandum – Pipeline and Facilities

This report concerns only the offshore parts of the Greek section of the Project.

9 H.1.2. Background Underwater Acoustics

This section describes some basic principles and terms used in underwater acoustics, which will be relevant to understanding the model based estimation of sound exposure.

9 H.1.2.1 Types of Sound Sources

Underwater sounds can be classified in two major categories: continuous or impulsive. Continuous sounds, which include sound from stationary sources such as dredging operations at a marine terminal or moving sources such as transiting ships, gradually vary in intensity with time. Impulsive sounds, such as sounds from survey equipment or pile driving, are characterised by brief, intermittent acoustic events with rapid (usually less than a second) onset and decay back to ambient levels. All sources considered in this study except side-scan sonar produce continuous sounds.

9 H.1.2.2 Sound Level Metrics

Underwater sound amplitude is measured in decibels (dB) relative to a fixed reference pressure of p_0 = 1 μPa.

The zero-to-peak sound pressure level, SPL, or peak SPL (L_{pk}, dB re 1 μPa), is the maximum instantaneous sound pressure level in a stated frequency band attained by an acoustic event, p(t)

$$L_{pk} = 10log_{10}\left[\frac{max\left(p^2(t)\right)}{p_0^2}\right]$$

The peak SPL metric is commonly quoted for impulsive sounds, but it does not account for the duration or bandwidth of the noise. At high intensities, the peak SPL can be a valid criterion for assessing whether a sound is potentially injurious; however, because the peak SPL does not account for the duration, it is a poor indicator of perceived loudness.

The root-mean square (rms) SPL (L_p, dB re 1 μPa) is the rms pressure level in a stated frequency band over a time window (T, s) containing the acoustic event

$$L_p = 10log_{10}\left(\frac{1}{T}\int_0^T \frac{p^2(t)dt}{p_0^2}\right)$$

It is a measure of the average pressure or as the effective pressure over the duration of an acoustic event, such as the emission of one acoustic pulse or sweep. Because the window length, T, is the divisor, events more spread out in time have a lower rms SPL for the same total acoustic energy.

The sound exposure level (SEL, L_E, dB re 1 µPa^2 ·s) is a measure of the total acoustic energy contained in one or more acoustic events. The SEL[1] for a single event is computed from the time-integral of the squared pressure over the full event duration (T_{100})

$$L_E = 10log_{10}\left(\frac{\int_0^{T_{100}} p^2(t)dt}{T_0 p_0^2}\right)$$

where T_0 is a reference time interval of 1 s. The SEL represents the total acoustic energy received at some location during an acoustic event; it measures the sound energy to which an organism at that location would be exposed.

SEL can be a cumulative metric if calculated over periods containing multiple acoustic events. The cumulative SEL (L_{EC}) can be computed by summing (in linear units) the SELs of the N individual events (L_{Ei}).

$$L_{EC} = 10log_{10}\left(\sum_{i=1}^{N} 10^{\frac{L_{E_i}}{10}}\right)$$

Transmission Loss (TL) is a measure of how sound levels change between a source and receiver over some distance. TL depends on the frequency and acoustic environment, including water sound speed profile, bathymetry, and sub-bottom geoacoustic properties. TL is calculated from source and received levels according to the equation

TL=SL–RL

Where:

SL is the source level (dB re 1 µPa at 1 m)

RL is the received sound pressure level (dB re 1 µPa), and

TL is the transmission loss (dB re 1 m).

[1] Because the rms SPL and SEL are both computed from the integral of square pressure, these metrics are related by a simple expression, which depends only on the duration of the energy time window T:

$L_p = L_E - 10\log_{10}(T)$, $L_{p90} = L_E - 10\log_{10}(T_{90}) - 0.458$

where the 0.458 dB factor accounts for the rms SPL containing 90% of the total energy from the per-pulse SEL

9 H.1.2.3 Frequency Band Analysis

Sounds that are composed of single frequencies are called "tones"; however, most sounds are generally composed of a broad range of frequencies ("broadband" sound) rather than pure tones. The distribution of sound power over frequency is described by the spectrum (or power spectral density, S(f)). The spectrum describes the fine scale features of the frequency distribution of a sound source. A coarser representation of the sound power distribution is often better suited to quantitative analysis. Frequency-band analysis divides the power spectrum into discrete passbands. An octave band usually spans the frequencies from the lower limit frequency[2] of the band i.e. f_{min}, up to the upper limit f_{max} (factor of two e.g. 125 to 250 Hz).

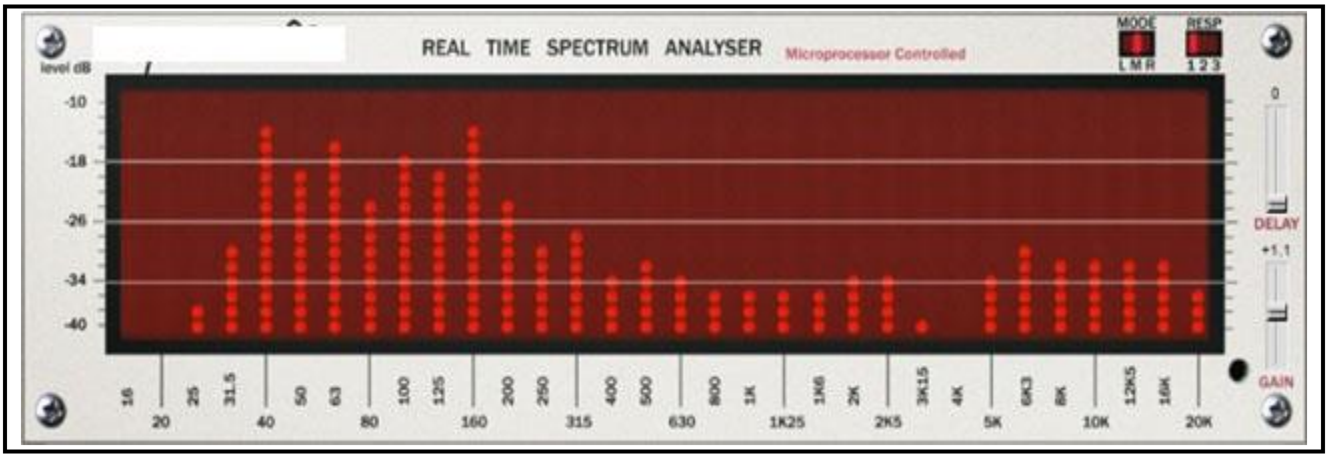


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Figure H-1 Real Time Spectrum Analyser in Octave or 1/3 Octave Bands

9 H.1.3. Frequency Weighting

The potential for anthropogenic noise to affect marine animals depends on how well the animal can hear the noise. Noises are less likely to disturb or injure animals if they are at frequencies that the animal cannot hear well except when the sound pressure is so high that it can cause physical injury. For sound levels that are too low to cause physical injury, frequency weighting based on audiograms may be applied to weight the importance of sound levels at particular frequencies in a manner

[2] if f_c is the centre frequency of an octave band, one can compute the octave band boundaries as $f_c=f_{min}*2^{1/2}=f_{max}*2^{-1/2}$ where f_{min} is the lower frequency and f_{max} the upper one, in the case of a 1/3 octave band $f_c=f_{min}*2^{1/3}=f_{max}*2^{-1/3}$

reflective of an animal's sensitivity to those frequencies (Nedwell and Turnpenny[3] 1998, Nedwell *et al*. 2007).

The dB_{ht}(Species) provides a measurement of sound that allows comparison of the effects of noise on a wide range of species. The loudness of a sound to a given species may be assessed by passing the sound through a filter that mimics the hearing ability of that species. The behaviour that is required of the filter is defined in terms of the measured hearing threshold of the animal. The metric therefore resembles the dB(A) scale that is used for the behavioural effects of noise on humans, and may be regarded as a generalisation of the approach to other species. It is a dB scale where the simple fixed reference pressure (typically 1 μPa for underwater sound) is replaced by the threshold of hearing of an animal, so the level is in "dBs referenced to hearing threshold", hence the "ht" suffix. It should be noted, however, that since the hearing threshold will vary with frequency, the weighting will also be frequency dependent and the dB_{ht} must be calculated as an integral over frequency. The dB_{ht}(Species) level therefore corresponds to the likely loudness of the sound perceived by that species. Since different species have different hearing abilities, a given sound will have a different level on this scale for each species. Therefore, the animal for which the level is calculated (for a given noise source) must be specified as well as the corresponding level. This is achieved by appending the specific name to the level. For instance, a sound having a level 90 dB above a cod‟s threshold may be specified as 90 dB_{ht}(Gadus *morhua*).

A benefit of the metric is that it yields realistic values for the level of the noise. While the unweighted levels of man-made noise are often apparently very high, the perceived levels are much lower because the sound will contain frequency components that the species cannot detect, and also because most marine species have high thresholds of perception of (are relatively insensitive to) sound.

Marine mammals were divided into six groups for analysis. For each group, a frequency dependent weighting function and numeric thresholds for the onset of TTS (temporal threshold shift) and PTS (permanent threshold shift) were derived from available data describing hearing abilities and effects of noise on marine mammals. Measured or predicted auditory threshold data, as well as measured equal latency contours, were used to influence the weighting function shape for each group. For species groups for which TTS data are available, the weighting function parameters were adjusted to

[3] Nedwell, J.R. and A.W. Turnpenny. 1998. The use of a generic frequency weighting scale in estimating environmental effect. Workshop on Seismics and Marine Mammals. 23– 25th June, London, U.K.
Nedwell, J.R., A.W.H. Turnpenny, J. Lovell, S.J. Parvin, R. Workman, and J.A.L. Spinks. 2007. A validation of the dBht as a measure of the behavioural and auditory effects of underwater noise. Report No. 534R1231 Prepared by: Subacoustech Ltd. for the UK Department of Business, Enterprise and Regulatory Reform under Project No. RDCZ/011/0004. www.subacoustech.com/information/downloads/reports/534R1231.pdf

provide the best fit to the experimental data. The same methods were then applied to other groups for which TTS data did not exist.

The shapes of the Phase 3 auditory weighting functions are based on a generic band-pass filter described by:

$$W(f) = C + 10log_{10}\left(\frac{\left(\frac{f}{f_{low}}\right)^{2a}}{\left[1+\left(\frac{f}{f_{low}}\right)^{2}\right]^{a}\left[1+\left(\frac{f}{f_{high}}\right)^{2}\right]^{b}}\right)$$

C weighting function gain (dB). The value of C defines the vertical position of the curve. Changing the value of C shifts the function up/down. The value of C is often chosen to set the maximum amplitude of W to 0 dB (i.e., the value of C does not necessarily equal the peak amplitude of the curve).

f_{low} low frequency cut-off (kHz). The value of f_{low} defines the lower limit of the filter band-pass i.e., the lower frequency at which the weighting function amplitude begins to decline or “roll-off” from the flat, central portion of the curve. The specific amplitude at f_{low} depends on the value of a. Decreasing f_{low} will enlarge the pass-band of the function (the flat, central portion of the curve).

f_{high} high frequency cut-off (kHz). The value of f_{high} defines the upper limit of the filter pass-band; i.e., the upper frequency at which the weighting function amplitude begins to roll-off from the flat, central portion of the curve. The amplitude at f_{high} depends on the value of b. Increasing f_{high} will enlarge the band-pass of the function.

a low frequency exponent (dimensionless). The value of a defines the rate at which the weighting function amplitude declines with frequency at the lower frequencies. As frequency decreases, the change in weighting function amplitude becomes linear with the logarithm of frequency, with a slope of 20a dB/decade, larger values of a result in lower amplitudes at f_{low} and steeper roll-offs at frequencies below f_{low}.

b high frequency exponent (dimensionless). The value of b defines the rate at which the weighting function amplitude declines with frequency at the upper frequencies. As frequency increases, the change in weighting function amplitude becomes linear with the logarithm of frequency, with a slope of - 20b dB/decade. Larger values of b result in lower amplitudes at f_{high} and steeper roll-offs at frequencies above f_{high}.

Table H-4 Coefficients of Type 3 Weighting Functions

			KHz		dB	Non-Impulsive		Impulsive	
Group	a	b	f_{low}	f_{high}	C	TTS -K	PTS	TTS	PTS

			KHz		dB	Non-Impulsive		Impulsive	
Low freq	1	2	0.2	19	0.13	179	199	168	183
Medium freq *Updated to High freq.*	1.6	2	8.8	110	1.20	178	198	170	185
High freq *Updated to Very High freq.*	1.8	2	12	140	1.36	153	173	140	155
Otariids in water	2	2	0.94	25	0.64	199	219	188	203
Phocids in water	1	2	1.9	30	0.75	181	201	170	185

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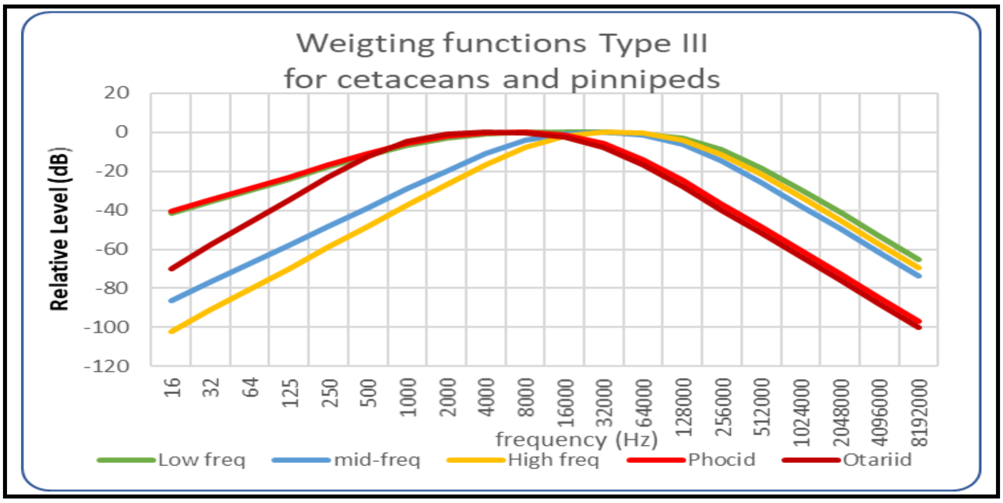

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Figure H-2 Weighting Functions for Cetaceans, Phocids, Otariids

- Exposure function

$$E(f) = K - 10log_{10}\left(\frac{\left(\frac{f}{f_{low}}\right)^{2a}}{\left[1+\left(\frac{f}{f_{low}}\right)^{2}\right]^{a}\left[1+\left(\frac{f}{f_{high}}\right)^{2}\right]^{b}}\right)$$

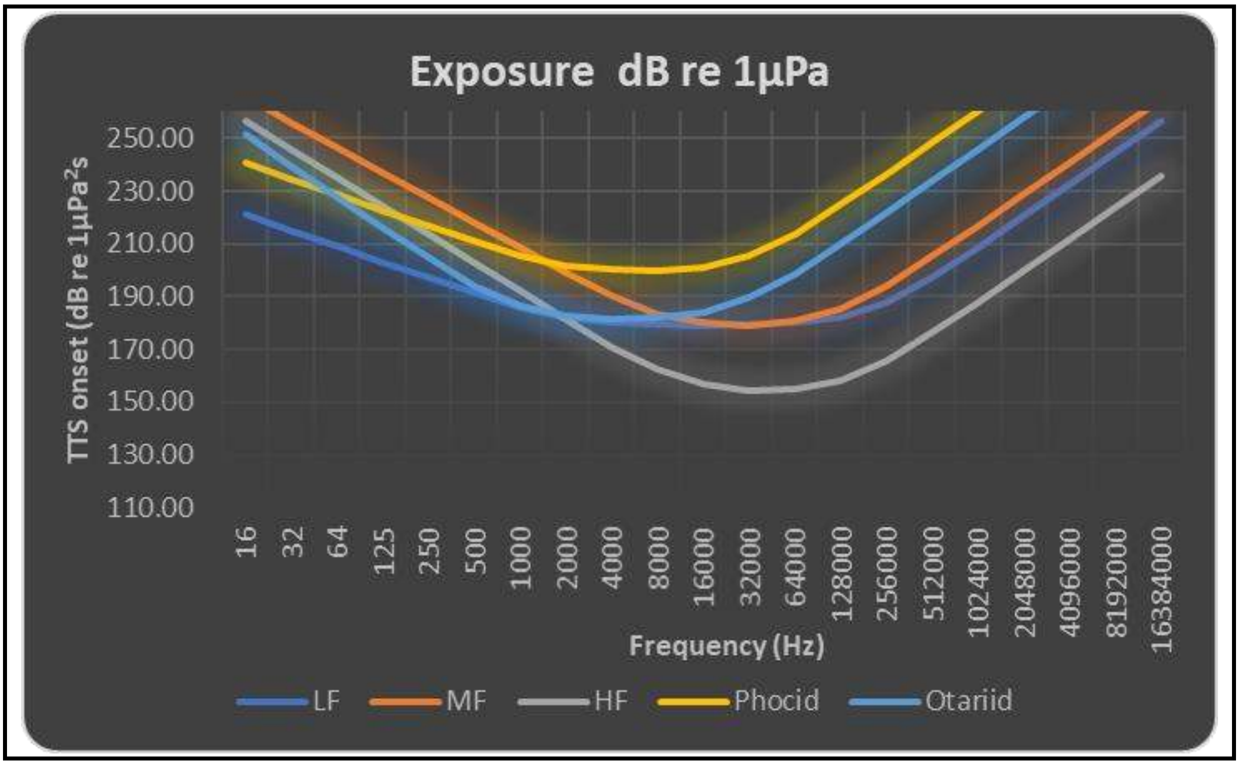

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Figure H-3 TTS Exposure Levels

9 H.1.3.1 Audiogram Weighting

An audiogram is a standard way of presenting an animal's hearing sensitivity in functional form as a variable threshold over a frequency range. Audiograms represent the hearing threshold for pure tones as a function of frequency. These species-specific sensitivity curves are generally U-shaped, with higher hearing thresholds at opposite ends of the audible frequency range. Noise levels above hearing threshold are calculated by subtracting species-specific audiograms from the received 1/3-octave-band sound levels. The audiogram-weighted 1/3-octave-band levels are summed to yield broadband sound levels relative to each species' hearing threshold. Audiogram-weighted levels are expressed in units of dB above hearing threshold (dB re HT). Sound levels less than 0 dB re HT are below the typical hearing threshold for a species and therefore it is likely the animal does not hear them. Weighting functions have more recently gained momentum in the marine mammal scientific community due to a desire to better predict the auditory effects of anthropogenic sound on marine mammals.

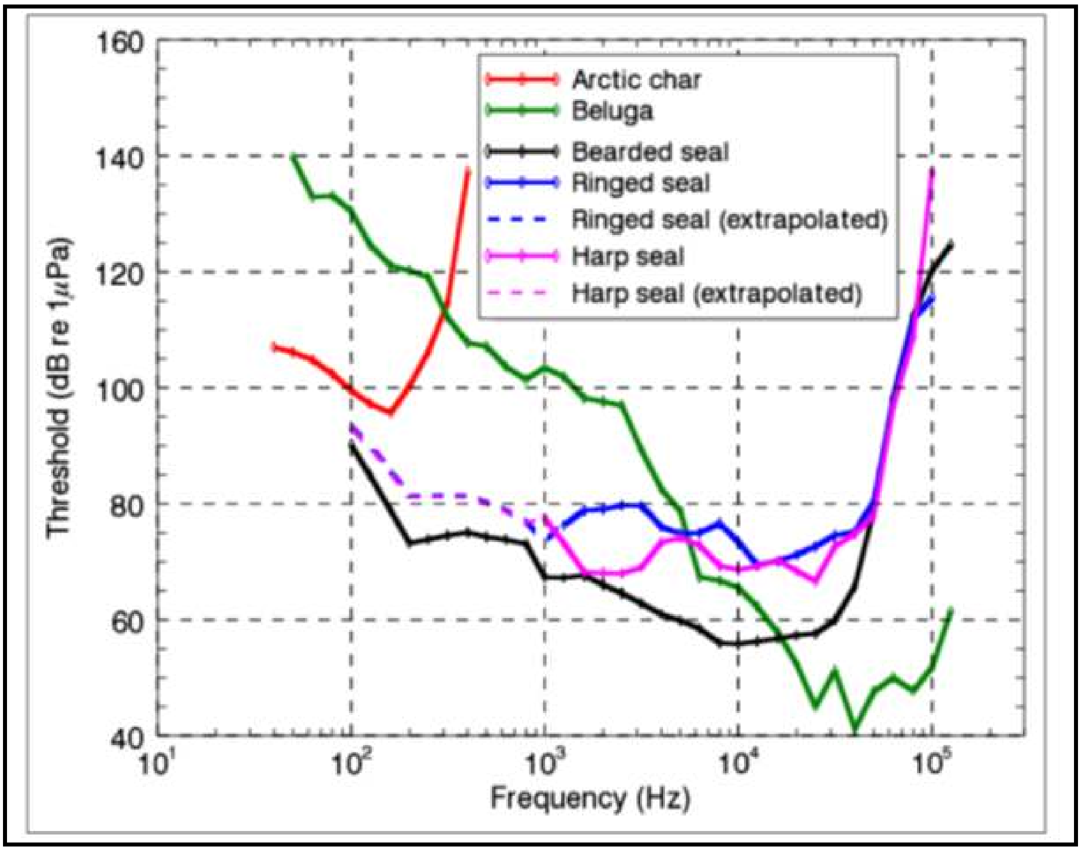

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Figure H-4 Audiograms of Five Different Marine Mammal Species

9 H.1.3.1.1 Marine Mammals Species[4,5] Groups

March 2019 saw the publication of new marine mammal exposure criteria from Southall *et al*. The paper utilises research from the NMFS[6] (2018) study that introduced the weightings and criteria that we and the underwater noise industry currently use. ***A through analysis of the new report found that***

[4] Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene Jr., D. Kastak, D.R. Ketten, J.H. Miller, *et al*. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals 33(4): 411-521.

[5] Southall B L, Finneran J J, Reichmuth C, Nachtigall P E, Ketten D R, Bowles A E, Ellison W T, Nowacek D P, Tyack P L (2019). Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. Aquatic Mammals 2019, 45(2), 125-232, DOI 10.1578/AM.45.2.2019.125.

[6] National Marine Fisheries Service. 2018. 2018 Revisions to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OPR-59, 167 p

the weightings and criteria presented in Southall's paper are actually identical to those from NMFS, with one minor difference; the naming of the marine mammal groupings.

The four main groups that were used from the NMFS paper were low-frequency cetaceans (LF), mid-frequency cetaceans (MF), high-frequency cetaceans (HF), and phocid pinnipeds in water (PW). Southall keeps the same frequency responses but renames these same four groups, respectively, to be low-frequency cetaceans (LF), high-frequency cetaceans (HF), very high-frequency cetaceans (VHF) and phocid carnivores in water (PCW).

Furthermore Jakob Tougaard[7] (2021) on page 18 mentions: ***"For all practical purposes the differences between the groups is terminology".***

LOW FREQUENCY (LF) CETACEANS

The LF cetacean group contains all of the mysticetes (baleen whales). Although there have been no direct measurements of hearing sensitivity in any mysticete, an audible frequency range of approximately 10 Hz to 30 kHz has been estimated from observed vocalisation frequencies, observed reactions to playback of sounds, and anatomical analyses of the auditory system. A natural division may exist within the mysticetes, with some species (e.g., blue, fin) having better low-frequency sensitivity and others (e.g., humpback, minke) having greater sensitivity to higher frequencies; however, at present there is insufficient knowledge to justify separating species into multiple groups. Therefore, a single species group is used for all mysticetes.

MID FREQUENCY (MF→HF) CETACEANS

The MF cetacean group contains most delphinid species (e.g., bottlenose dolphin, common dolphin, killer whale, pilot whale), beaked whales, and sperm whales (but not pygmy and dwarf sperm whales of the genus Kogia, which are treated as high-frequency species). Hearing sensitivity has been directly measured for a number of species within this group using psychophysical (behavioural) or auditory evoked potential (AEP) measurements. This group is the High Frequency (HF) group in Southall *et al*. 2019.

HIGH FREQUENCY (HF →VHF) CETACEANS

The HF cetacean group contains the porpoises, river dolphins, pygmy/dwarf sperm whales, *Cephalorhynchus* species, and some *Lagenorhynchus* species. Hearing sensitivity has been measured for several species within this group using behavioural or AEP measurements. High-frequency cetaceans generally possess a higher upper frequency limit and better sensitivity at high frequencies

[7]Jakob Tougaard. 2021. Thresholds for noise induced hearing loss in marine mammals. Background note to revision of guidelines from the Danish Energy Agency. Aarhus University, DCE - Danish Centre for Environment and Energy, 34 s. – Scientific note no. 2021|28 https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notater_2021/N2021|28.pdf

compared to the mid frequency cetacean species. This group is the Very High Frequency group in Southall *et al*. 2019.

PHOCIDS →PCW

This group contains all earless seals or "true seals," including all Arctic and Antarctic ice seals, harbour or common seals, gray seals and inland seals, elephant seals, and monk seals. Underwater hearing thresholds exist for some Northern Hemisphere species in this group. This group is renamed as PCW (Phocid and Carnivores in Water) in Southall *et al*. 2019.

OTARIIDS AND OTHER NON PHOCID CARNIVORES --OCW

This group contains all eared seals (fur seals and sea lions), walruses, sea otters, and polar bears. The division of marine carnivores by placing phocids in one group and all others into a second group was made after considering auditory anatomy and measured audiograms for the various species and noting the similarities between the non-phocid audiograms. Underwater hearing thresholds exist for some Northern Hemisphere species in this group. This group is referred to as OCW (Otariids and Carnivores in Water) in Southall *et al*. 2019.

Other marine organisms that are sensitive to underwater sounds include:

- Marine reptiles;
- Fish;
- Marine invertebrates; and
- Sirenians (SI) are a group found in Southall *et al*. 2019.

Among the species we find the most in the east Mediterranean Sea, we can see:

- Sperm whales (*Physeter macrocephalus*);
- Dolphins;
- Basking Sharks;
- Mediterranean Sea monk seals (*Monachus monachus*);
- Common porpoises (*Phocaena phocaena*); and
- Whales.

In what follows, the Southall *et al*. (2007) grouping LF, MF, HF is meant also as LF, HF, VHF according to Southall *et al*. 2019.

Table H-5 Cetacean and Pinniped Genera and Auditory Bandwidth

Functional Hearing Group	Estimated Auditory Bandwidth	Genera Represented	Example Species
Low frequency cetaceans LF	7 Hz to 22 kHz	*Balaena*, *Caperea*, *Eschrichtius*, *Megaptera*, *Balaenoptera* (13 species/subspecies)	Grey whale, right whale, humpback whale, minke whale
Mid frequency cetaceans (updated as HF High Frequency)	150 Hz to 160 kHz	*Steno*, *Sousa*, *Sotalia*, *Tursiops*, *Stenella*, *Delphinus*, *Lagenodelphis*, *Lagenorhynchus*, *Lissodelphis*, *Grampus*, *Peponocephala*, *Feresa*, *Pseudorca*, *Orcinus*, *Globicephala*, *Orcaella*, *Physeter*, *Delphinapterus*, *Monodon*, *Ziphius*, *Berardius*, *Tasmacetus*, *Hyperoodon*, *Mesoplodon* (57 species/subspecies)	Bottlenose dolphin, striped dolphin, killer whale, sperm whale
High frequency cetaceans (updated as VHF Very High Frequency)	200 Hz to 180 kHz	*Phocoena, Neophocaena, Phocoenoides, Platanista, Inia, Kogia, Lipotes, Pontoporia, Cephalorhynchus* (20 species/subspecies)	Harbour porpoise, river dolphins, Hector's dolphin
Pinnipeds (in water) PCW	75 Hz to 75 kHz	*Arctocephalus, Callorhinus, Zalophus, Eumetopias, Neophoca, Phocarctos, Otaria, Erignathus, Phoca, Pusa, Halichoerus, Histriophoca, Pagophilus, Cystophora, Monachus, Mirounga, Leptonychotes, Ommatophoca, Lobodon, Hydrurga* and *Odobenus* (41 species/subspecies)	Fur seal, harbour (common) seal, grey seal

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9 H.1.4. Sound Level Threshold Criteria

9 H.1.4.1 Injury Assessment

In keeping with the latest scientific approaches, injury effects assessment has been based on the cumulative sound exposure level (SEL) over a period of 24 hours. The pipelaying operation (loudest among any possible activities at the three representative sites) has been modelled including realistic motion of pipelay vessels and support vessels such as pipe carrier ships shuttling to resupply (see sample maps listed in spreadsheet).

Two sets of criteria are available and currently considered valid for the assessment of ranges to injury (onset of PTS) from continuous noise: the Southall[8] *et al*. (2007) criteria and the Finneran and Jenkins (2012) criteria also referenced as the US Navy criteria. The former uses a single threshold of 215 dB re µPa^2-s SEL weighted according to the hearing class of the subjects using Type I weighting curves (M-weighting). The latter uses variable thresholds and newer Type III weighting functions that take into account subjective loudness and some additional data collected since the Southall *et al*. study. For Mid Frequency cetaceans (MFC in the Project area, primarily dolphins) the threshold is 198 dB re µPa^2-s SEL with Type 3 MFC weighting. For High Frequency cetaceans (HFC in the Project area, primarily harbour porpoises) the threshold is 187 dB re µPa^2-s SEL with Type 3 HFC weighting. According to Southall *et al*. (2019) MFC is renamed to High Frequency and HFC to Very High Frequency.

Adult fish not in the immediate vicinity of the noise generating activity are generally able to vacate the area and avoid physical injury. However, larvae and spawn are not highly mobile and are therefore more likely to incur injuries from the sound energy, including damage to their hearing, kidneys, hearts and swim bladders. Such effects are unlikely to happen outside of the immediate vicinity of even the highest energy sound sources.

For fish, the most relevant criteria for injury are considered to be those contained in ASA S3/SC1.4 TR-2014, Sound Exposure Guidelines for Fishes and Sea Turtles (Popper *et al*., 2014). The guidelines set out criteria for injury due to different sources of noise. Those relevant to the Project are considered to be those for injury due to impulsive piling noise (although it seems that no impulsive piling is required for the Project, these criteria have been used to inform the assessment of snapping) and those for injury due to continuous noise (which are applicable for shipping and drilled piles). However, because the qualitative risks are generally qualified as "low", with the exception of a moderate risk at "near" range (i.e. within tens of metres) for some types of animal and impairment effects, this is not considered to be a significant issue with respect to determining the potential effect of noise on fish due to continuous sound, although some caution is necessary in applying the guidelines if sounds of particularly high intensity are to be introduced.

[8] Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene Jr., D. Kastak, D.R. Ketten, J.H. Miller, *et al*. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals 33(4): 411-521.

The assessment of fish injury range is by far the most uncertain scientifically.

Fish are typically sensitive only to low frequency sounds, with the best hearing range of most fish from about 100 Hz to 400 Hz. A low-pass filter with a corner frequency of 2 kHz is a conservative weighting function that rejects sounds at frequencies that fish do not hear. There are no data to indicate that shipping and shipping-like sounds can damage the hearing of fish with swim bladders but lacking specialisations for enhanced acoustic pressure reception.

Table H-6 Suggested Criteria for Onset of Injury to Fish Due to Continuous Sound

Type of Animal	Parameter	Mortality and Potential Mortal Injury	Impairments	
			Recoverable Injury	TTS
Fish: no swim bladder (particle motion detection)	SEL, dB re 1 μPa²s Peak, dB re 1 μPa	(Near)Low (Intermediate) Low (Far) Low	(Near)Low (Intermediate) Low (Far) Low	(Near)Moderate (Intermediate) Low (Far) Low
Fish: where swim bladder is not involved in hearing (particle motion detection)	SEL, dB re 1 μPa²s Peak, dB re 1 μPa	(Near)Low (Intermediate) Low (Far) Low	(Near)Low (Intermediate) Low (Far) Low	(Near)Moderate (Intermediate) Low (Far) Low
Fish: where swim bladder is involved in hearing (primarily pressure detection)	SEL, dB re 1 μPa²s Peak, dB re 1 μPa	(Near)Low (Intermediate) Low (Far) Low	170 dB re 1 μPa (rms) for 48 hours	158 dB re 1 μPa (rms) for 12 hour
Eggs and larvae	SEL, dB re 1 μPa²s Peak, dB re 1 μPa	(Near)Low (Intermediate) Low (Far) Low	(Near)Low (Intermediate) Low (Far) Low	(Near)Low (Intermediate) Low (Far) Low

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9 H.1.4.2 Behavioural Assessment

Behavioural criteria based on weighted metrics, such as those proposed by Finneran[9] and Jenkins (2012) for marine mammal species other than harbour porpoises, are questionable in the case of continuous sounds such as those from vessels. The relatively high reaction thresholds that arise from their use would be difficult to defend by comparison with empirical evidence.

Audiogram-based behavioural effect criteria seem to be the most justified for this assessment, given the well-defined identity of the relevant species in the region and the availability of reliable audiograms for those very species or reasonable surrogates. The most uncertain element in the use of audiogram-referenced levels (dB relative to hearing threshold or dB_{ht}) is the threshold to adopt for onset of behavioural disturbance. Nedwell[10] *et al* (2005) proposed fixed thresholds of 75 and 90 dB_{ht} for all species as onset of mild and pronounced behavioural reactions, respectively.

The "traditional" unweighted rms SPL criterion for behavioural effects onset at 120 dB re μPa cannot be dismissed outright despite its inability to account for species-specific hearing differences, and it is included at least for completeness and reference to common practice, given that it is on the current interim US National Oceanic and Atmospheric Administration (NOAA) (2019). It is also a criterion still invoked as the only acceptable approach for the harbour porpoise by studies as Finneran and Jenkins (2012), who explicitly exclude that species from weighted metrics criteria because of its unique susceptibility and reaction to sound stimuli.

Table H-7 Criteria for Effects of Continuous Noise Exposure, Including Vessel Noise for Marine Mammals to Cause PTS or TTS (Southall *et al*., 2019,NOAA (2019), NMFS (2018))

Marine Mammals		Behaviour	TTS Onset Threshold (Received Levels)	PTS Onset Thresholds (Received Levels)
Hearing Group		SPL (L_p; dB re 1 μPa	SEL_{24h} (weighted) $L_{E,24h}$; dB ref 1μPa^2 s	SEL_{24h} (weighted) $L_{E,24h}$; dB ref 1μPa^2 s
Low Frequency (LF)	cetaceans	120	179	199
High Frequency (HF)			178	198
Very High Frequency (VHF)			153	173

[9] Finneran, J. and A.K. Jenkins. 2012. Criteria and Thresholds for Navy Acoustic Effects Analysis Technical Report. SPAWAR Marine Mammal Program.

[10] Nedwell, J.R., J. Lovell, and A.W.H. Turnpenny. 2005. Experimental validation of a species-specific behavioural impact metric for underwater noise. Journal of the Acoustical Society of America 118(3): 2019-2019.

Marine Mammals		Behaviour	TTS Onset Threshold (Received Levels)	PTS Onset Thresholds (Received Levels)
Sirenians (Si)			186	206
Phocid Seals in water (PCW)			181	201
Otariid Seals (OCW)			199	219

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9 H.2. METHODS

9 H.2.1. Source Levels

Source level is a measure of the intensity of sound that a source emits, measured at a reference distance of 1 m. For point sources, such as a small transducer, source levels can be measured directly with a hydrophone at 1 m distance. For larger sources, source levels must be determined indirectly by measuring received levels at larger distances and back propagating the levels to a reference distance of 1 m. For example, because ships radiate sound from their hull and propeller, their source levels must be measured at a distance such that the TL from the different points on the ship emitting sound is roughly the same. Source levels are calculated by:

$$SL=RL+TL$$

In order to predict the impact of underwater sound, transmission loss modelling has been carried out. This type of modelling takes into account the specific acoustic properties of the Study Area which determines how far sound will spread from a source of underwater noise. This section describes in more detail the methodology which has been used to carry out these predictions.

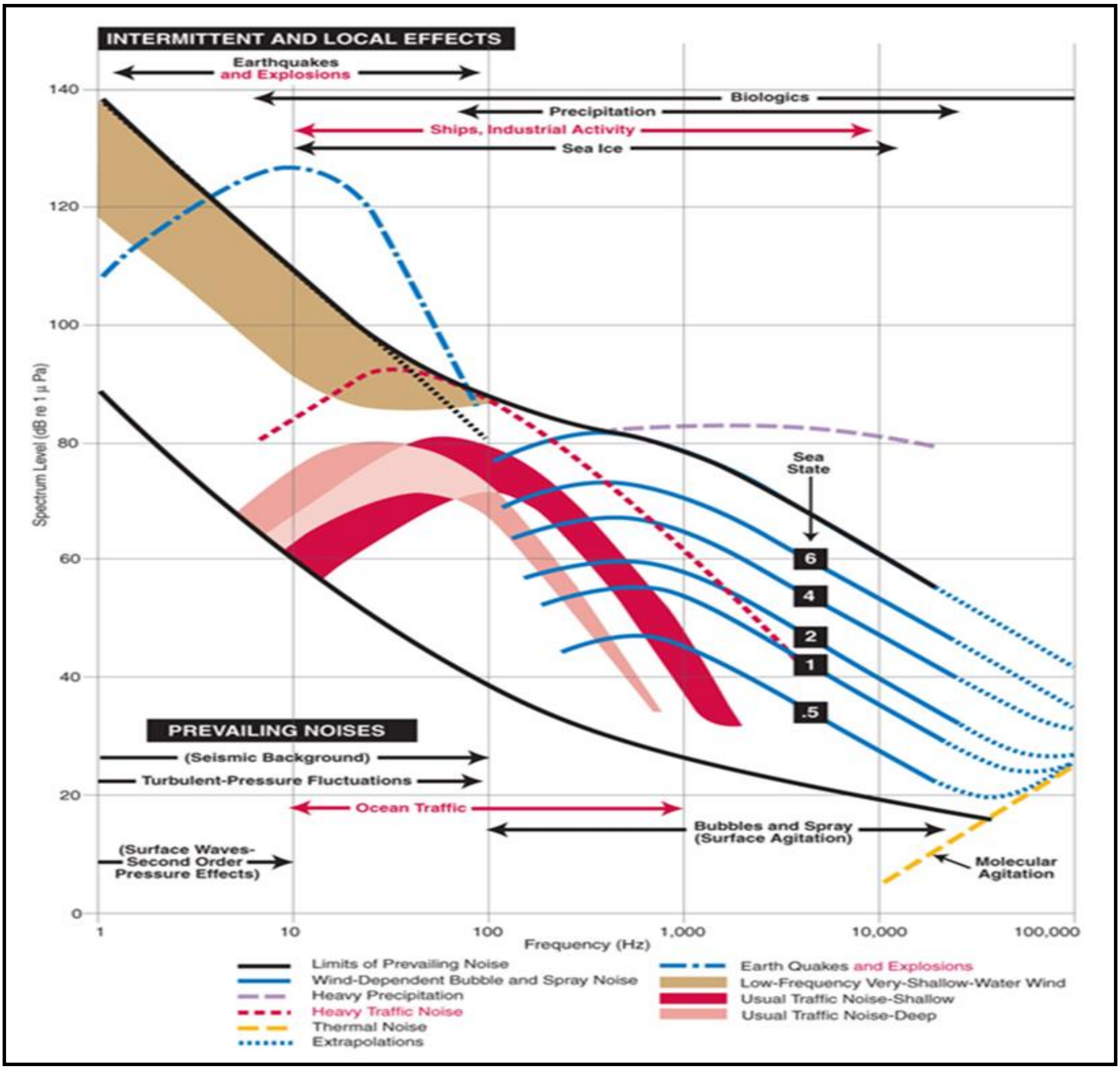
The background sounds in the sea can be summarised in

Figure H-5 showing typical sound levels at different frequencies, as proposed by Wenz (1962)[11] based on available data. This graph is therefore also referred to as the Wenz curves. The sound levels are given in spectral density levels over 1 Hz frequency bands, with the units dB re 1 μPa^2/Hz. It is noted that the overall baseline noise levels from human activity such as shipping have tended to increase over time; however, the frequency ranges indicated later on are still representative of the underwater sound environment.

[11] Wenz, G. M. (1962). Acoustic ambient noise in the ocean: Spectra and sources. J. Acoust. Soc. Am., 34(12):1936–1956. 40, 41

The most significant widespread effects from the Project are likely to be behavioural disturbance, and absolute noise criteria have been selected to identify the noise levels at which these effects will occur. Since the background noise levels have been assumed to be low, it is likely that the absolute noise criteria are likely to be met before the sound has reached the background noise levels. Therefore, this assessment does not rely on background noise levels, but instead it is based on absolute noise level criteria. Whilst noise may be audible over wider ranges, the effects on fauna are more subtle and are likely to be limited given the duration of the Project.

Thrusters on vessels that are manoeuvring during dredging and pipelaying will generate high levels of thrust, resulting in significant propeller cavitation and consequent high underwater sound levels. The predicted underwater sound levels peak in the frequency range of 25 to 50 Hz for the noise from thrusters.



Source: Miksis-Olds *et al.*, 2013 (reproduction from Wenz (1962))[12].

Figure H-5 Wenz Curves[13]: Spectra and Frequency Distribution of Underwater Sound Sources

[12]Miksis-Olds, J. L., Bradley, D. L., and Maggie Niu, X. (2013). Decadal trends in Indian Ocean ambient sound. J. Acoust. Soc. Am., 134(5):3464–3475. 41, 42, 56

[13]Source Miksis-Olds *et al.*, 2013 (reproduction from Wenz (1962)). Wenz, G.M. 1962. Acoustic ambient noise in the ocean: Spectra and sources. Journal of the Acoustical Society of America, 34: 1936 – 1956.

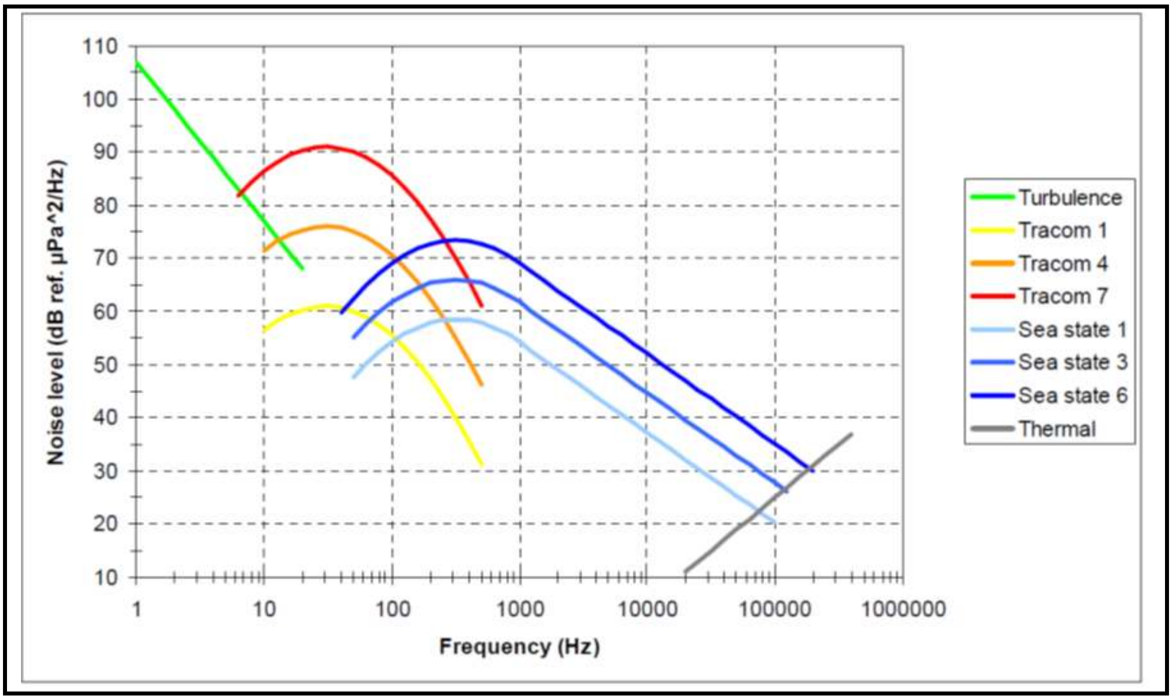


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Figure H-6 Wenz Curves: Underwater Sources Simplified

Whilst some approximations need to be made where specific data are not available, the modelling is expected to represent a reasonable indication of the likely noise emissions from the Project.

It has been assumed that they will operate full time 24 hours per day to estimate the worst-case propagation scenario; however, this is unlikely to happen.

The combination of vessels which will operate during dredging and pipelaying and their sound level characteristics are shown in Table H-8.

Vessels associated with the dredging were assumed to generate sound levels of a total of 192 dB re 1 µPa at 1 m (RMS) whereas vessels associated with the pipelaying were assumed to generate sound levels of 196 dB re 1 µPa at 1 m (RMS).[14] The depth of the noise source has been assumed to be 7 m below the water surface (see Figure H-7).

Since the source level of pipelaying activities is greater than the source level of dredging activities, only pipelaying activities have been modelled which represents a worst-case scenario.

[14]Wyatt R. Joint Industry Programme on Sound and Marine Life Review of Existing Data on Underwater Sounds Produced by the Oil and Gas Industry, Issue 1, 2008.

Table H-8 Combinations of Operating Vessels during Dredging or Pipelaying

Phase	Ship/ Equipment	Number	Source Level (dB re 1 µPa at 1 m RMS)
Dredging	Backhoe dredger	1	186
	Trailer Suction Hopper Dredger	1	188
	Tug and barge	1	171
	Support vessel	1	188
Pipelaying	Tug	3	189
	Pipelay vessel	1	183
	Pipe carrier	1	188
	Support vessel	1	188

Prepared by:: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS, 2022. Source: IGI Poseidon, 2021.

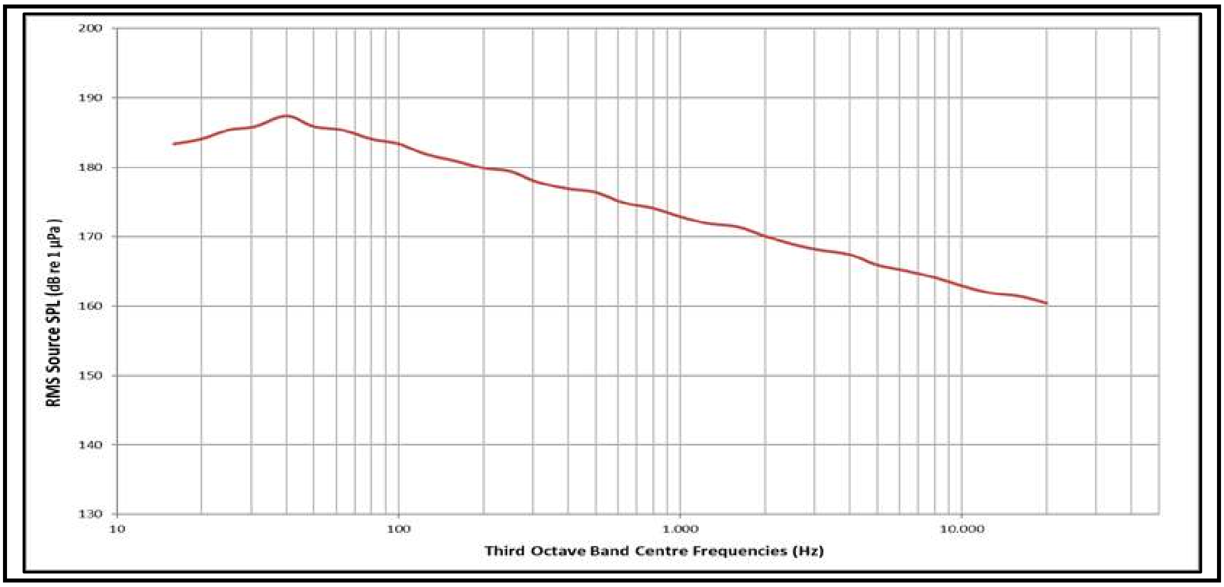

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Figure H-7 Pipelaying Vessels Frequency Spectrum, 7 m below Water Surface

9 H.2.2. Prediction Model

The noise propagation component calculates how the sound level varies in the marine environment according to source and receiver environment characteristics. The exposure level calculation is based on the accumulation of sound exposure over time for a marine organism moving relative to the sound source and experiencing variations in noise levels in the water column.

- Choice of propagation loss model:[15]
  - Our purpose is to identify a source level threshold that is both realistic and conservative. This implies calculation of a reasonable lower limit on propagation loss (PL). Absorption is not relevant at the frequencies of this indicator (low and medium frequency i.e. below 10 kHz) and ranges (~ 1 km) considered here and therefore not used in the PL model. [At 1 kHz, absorption is less than 0.1 dB/km, see Calculation of absorption of sound in seawater (npl.co.uk)]
- Shallow Water:
  - At ranges of interest, we expect mode stripping to give a conservative (lower limit) PL value (spherical and cylindrical spreading regions are restricted to distances up to a few water depths). For the sediment we choose medium sand because this results in good low frequency waveguide (by comparison, clay, silt and gravel are poor reflectors of sound [Ainslie 2010]). Long range shallow water propagation at distances R of interest can be described by mode stripping, i.e. (see Ainslie 2010 chapter 9, pp 452-458)

$$PL(R) = 15 \log 10 (R / r_{ref}) + 5 \log 10 (\eta H / \pi r_{ref}) \qquad [1]$$

with:

η = reflection loss gradient = ¼ (representative of sand)

H = water depth = 20 m

r_{ref} = 1 m

This equation, of the form PL = constant + 15 log R, is more realistic than (say) cylindrical spreading, and by taking lowest reasonable values of η and H is a reasonable value for the shallow waters that are of interest; low frequency sound does not propagate well in water depth less than 20 m. We therefore adopt the criterion with PL given by eq (1). The equivalent inequality relating SL to SPL is

$$SL > SPL_0 + PL.$$

[15] From Monitoring Guidance for Underwater Noise in European Seas - 2nd Report of the Technical Subgroup on Underwater noise (TSG Noise). Part III Background Information and Annexes. Interim Guidance Report. May, 2013.

- Deep Water:
  - In deep water, we assume spherical spreading at short range, followed by cylindrical spreading (CS). For CS in a surface duct (surface sound speed c, sound speed gradient g and duct thickness D) we use (see Ainslie, 2010 chapter 9):

    $$PL = 10 \log 10 (R/ r_{ref}) + 5 \log 10 [c D/(8g\ r_{ref}\ 2)], [R > (c D/8g) 1/2] \quad [2]$$

    Sample calculations with c = 1490 m/s, D = 100 m, g = 0.016 /s show that deep water propagation loss is higher than the shallow water loss in the range 0-5 km. While a higher threshold could be considered for deep waters, for simplicity we advise use of a single threshold for data registration, irrespective of water depth. In subsequent analysis of register data, it will be possible to distinguish between the very loud sources and the sources of less relevance.

There are a large number of options for relative movement between the hypothetical animal and the sound source, but some of them are more likely than others. What is usually accepted in this regard is that marine mammals will move away from the source.

The calculation assumes that the mammals will remain at the end of the transect (60 km from the source) for the remaining time until the 24-hour period is completed. The speed of the hypothetical animals in this study has been assumed to be 1.5 m/s. Since the animal would swim 60 km in less than 12 hours (i.e. less than the 24 hours period being considered), the assumption that the mammals remain at the end of the transect without swimming further away is conservative.

It is more difficult to apply SELcum criteria for fish due to the uncertainties about their behaviour and therefore location, and this may make criteria relating to maximum noise levels more appropriate as guidelines are developed. As a compromise, in this case, a swim away model has been adopted in this assessment when estimating the cumulative SEL using the same swim speed as above. The most stringent criteria have been adopted so that the assessment is robust for all fish in the Study Area.

These calculations are necessarily approximate, as mentioned previously, as the potential hypotheses and input variables are numerous. However, the hypotheses and variables that have been adopted fall generally on the safe and protective side, for instance the animal swimming speed, is at the low end of the range.

For a project of this extent, prediction codes such as RAMGEO or RAMSGEO at low frequencies, and BELLHOP or Bounce at high frequencies are only of theoretical interest as most of the main input parameters like sound speed profile in a water column, bathymetry and seabed characteristics but also even water density, salinity and temperature can differ alongside the pipeline.

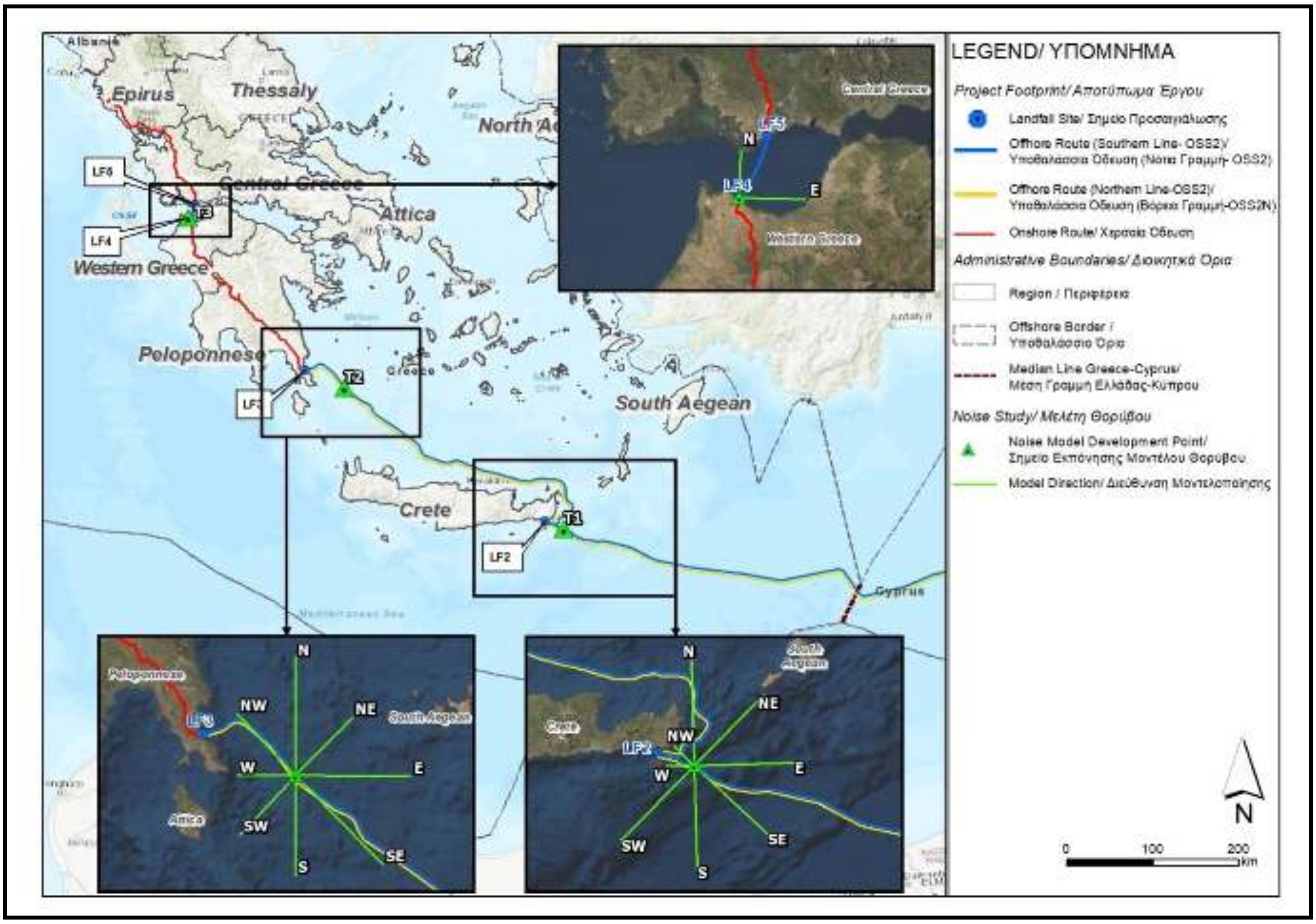

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Figure H-8 Points Analysed with RAMGEO and BELLHOP

In order to fulfil the specifications indenture, Transmission Loss calculations were performed in three spots on the pipeline path:

- T1: At Crete SE area, **at a distance 24,516 m from LF2** (latitude 34.917° and longitude 26.376°);
- T2: At Peloponnese **at a distance 59,485 m from LF3** (latitude 36.422° and longitude 23.567°); and
- T3: At Peloponnese Patraikos Gulf, **at a distance 490 m from LF4 (**latitude 38.185° longitude 21.485°).

These points were analysed with RAMGEO and BELLHOP codes using MATLAB. The inputs and parameters for each model are included in the volume of calculations**. A sample of the calculations, presented as figures, can be seen in appendix II**. Transmission loss calculated with RAMGEO and BELLHOP are in very good agreement with the above chosen model.

Since the noise sources (vessels) and the level produced by their combination depend on availability of the ships, the "predicted" disturbance cannot be well defined. The Transmission Loss is independent on the specific source and the prediction of the disturbance can be easily calculated by subtracting the Propagation Loss (PL see equations above) from the level of the disturbing noise source.

9 H.2.3. Mitigation Measures

The potential opportunities for mitigation of noise from vessels are considered by ACCOBAMs[16] and several mitigation measures are presented. ACCOBAMS states that:

'It is thought to outline practices and technologies that should be used during or instead conventional maritime activities producing underwater noise. References are also included for those technologies which are very likely to become increasingly used (and market available) in the next future. Further, this guide reviews information on areas where spatial mitigation measures should be applied in the Mediterranean Sea, i.e., areas where activities having an acoustic impact on cetaceans should be avoided.'

The measures can range from ship design, technologies for existing ships and operational and maintenance considerations. The details of the vessels that will be used, and what mitigation measures could be applied to reduce noise, are not available at this stage of the Project, and we have used a noise source term which does not assume modifications to the vessels that might reduce noise. The noise source terms that have been used were derived over ten years before the ACCOBAMS methodological guidance on mitigation was produced and are likely to represent a worst case if vessels which are fitted with a higher level of mitigation become available for the Project to use. However, mitigation in the form of good practice minimisation of speeds and cleaning propellers and hulls will be implemented before the execution of the Project.

9 H.3. RESULTS

A. Alongside the pipeline route.

[16] Methodological Guide Guidance on Underwater Noise Mitigation Measures V.3.0, ACCOBAMS-MOP7/2019/31Rev1, 2019

As can be seen in Figure H-9 and Table H-9, the anticipated sound exposure levels (SEL) for the standard cetacean species are less than the thresholds mentioned in Table H-7 but the SELcum which is calculated and tabulated at the rightmost column of Table H-9 is at most 10 dB over the criteria.

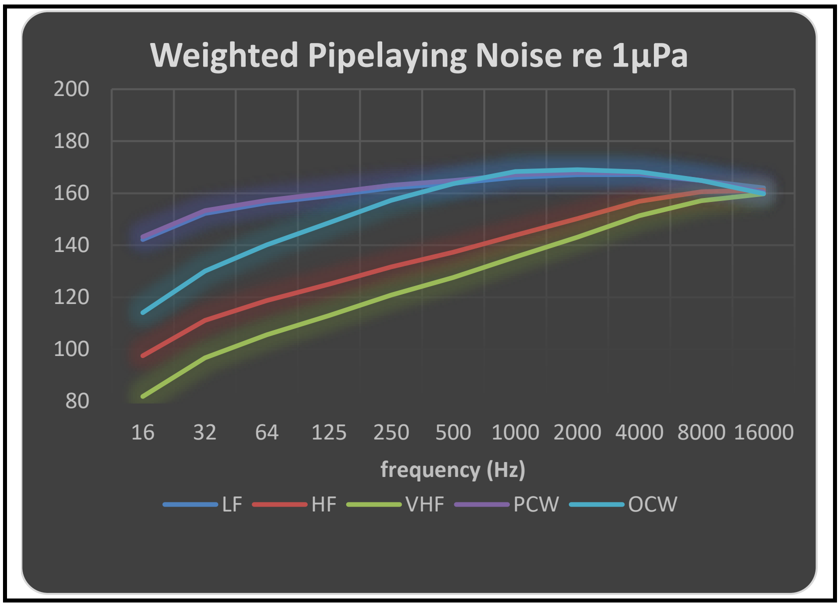

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Figure H-9 Weighted Pipelaying Noise from Group of Vessels for Cetaceans, Phocids and Otariids

Table H-9 Calculated Exposure from Pipelaying Group Vessels for Cetaceans, Phocids, Otariids

Standard Mammal species	SEL dB ref 1μPa^2 s	SELcum 24h dB ref 1 μPa^2 s
Cetaceans Low Frequency (LF)	173.89	183.63
Cetaceans High Frequency (HF)	164.92	174.66
Cetaceans Very High Frequency (VHF)	162.10	171.84
Phocid in water (PCW)	174.52	184.26
Otariid in water (OCW)	174.53	184.27

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Given the calculated SELcum (weighted) noise levels, the appropriate distances from the centre line of the pipeline route are presented in Table H-10

Table H-10 Calculated Distances in m alongside the Path using TTS and PTS Criteria for Marine Mammals

Marine Mammal Hearing Group	Calculated Distance for Adopted SELcum TTS Criteria,(m)	Calculated Distance for Adopted SELcum PTS Criteria,(m)
Low Frequency cetaceans (LF)	<20	<20
High frequency cetaceans (HF)	<20	<20
Very High frequency cetaceans (VHF)	<40	<40
Phocid & Carnivores in Water (PCW)	<20	<20
Otariid & non Carn. Phocids (OCW)	<20	<20

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These conditions hold alongside the path of the Project and for the chosen spots of Figure H-8. Calculation of transmission loss at the chosen spots using RAMGEO, BELLHOP and BOUNCE codes were performed and are presented in Appendix 2 - Samples of Transmission Loss Calculations with RAMGEO and BELLHOP models

Sound exposure levels in Table H-9 were calculated after weighting the proposed noise source in Figure H-7 according to the type 3 filter for each species.

For fish where swim bladder is involved in hearing (primarily pressure detection) the safe distance from sources for the worst case scenario level is 100 m considering recoverable injuries and 400 m for TTS.

Based on the advice in Popper *et al*. (2014), fish are only likely to exhibit high behavioural reactions near the source (within tens of metres from the source), and then only for the most sensitive types of fish (i.e., those with swim bladders involved in hearing). Other species would be expected to exhibit moderate reactions at most. All fish species are expected to demonstrate moderate behavioural reactions at intermediate distances (within hundreds of metres from the source), and low reactions further away.

Sea turtles are expected to react in a similar way to the most sensitive fish species, with high behavioural reactions close within tens of metres of the pipelaying activities, but moderate and low reactions further from the source.

As described in the scope of the study, the goal is the investigation of disturbances and undesirable damages due to the construction phases alongside the Project. Because of the very long path and big differences concerning sound speed, sound speed gradient and channel thickness, change in sound speed and speed gradient give differences less than 1% in PL (Propagation Loss). Channel thickness is a major contributor in PL (2 to 5% per 100 m). Variability of Propagation Loss (or Transmission Loss) can be studied from equations [1] and [2] as seen in 9 H.2.2 (Prediction Model). These equations give the results above applicable to the entire Project as the statistics of the worst case scenario.

B. AT POINT T1

Point T1 lies near the south-east edge of the island of Crete and specifically at 34.917 Lat 26.376 Lon. Calculations were performed for a bundle of 8 transects centred at the mentioned T1 point spanning an entire circle with 45° increments.

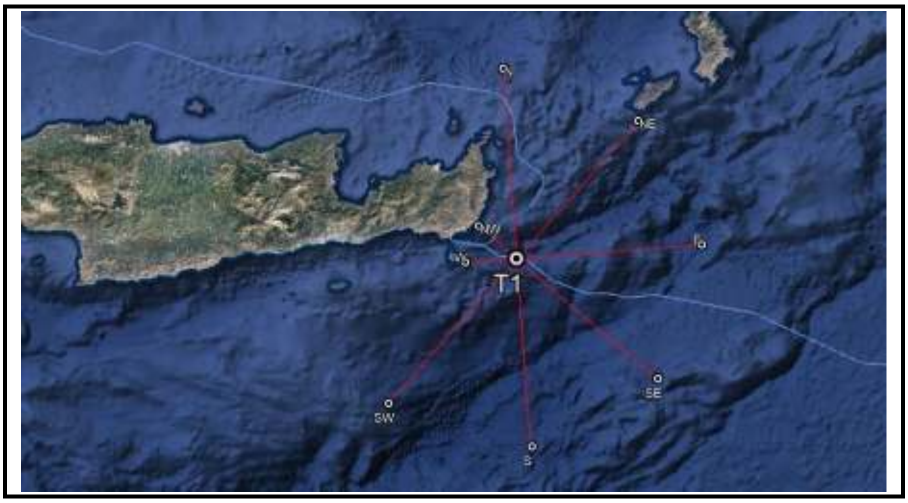

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Figure H-10 Point T1 and the 8 Transects around It (34.917 Lat 26.376 Lon)

In Appendix 2 - Samples of Transmission Loss Calculations with RAMGEO and BELLHOP models, a sample of the computed output is presented. Transmission Loss was calculated vs a) Range and b) Depth. Code RAMGEO was used for low frequencies and BELLHOP+BOUND at higher frequencies. As can be seen in Figure H-7, at T1 the unweighted anticipated RMS noise level is 184 dB at 16 Hz, 188 at 40 Hz, and 177 at 500 Hz, probably with a small deviation due to measurement discrepancies. The noise level at a distance from the source is obtained by subtracting the propagation loss from these values.

After weighting the source noise with the appropriate filter (see Figure H-2) the anticipated disturbance fulfils the criteria of Table H-7. The statistics for the RAMGEO and BELLHOP + BOUNCE codes verify the expected results from the previous calculations, following the good practices code (EU TSG Noise[17] 2014).

[17]EU TSG Noise (2014). Monitoring Guidance of Underwater Noise in European Seas, Part 3: Background Information

Table H-11 Estimated Distances in m at T1 Spot Using TTS and PTS Criteria for Marine Mammals

Marine Mammal Hearing Group	Estimated Distance for Adopted SELcum TTS Criteria,(m)	Estimated Distance for Adopted SELcum PTS Criteria,(m)
Low Frequency cetaceans (LF)	<50	<50
High frequency cetaceans (HF)	<50	<50
Very High frequency cetaceans (VHF)	<50	<50
Phocid & Carnivores in Water (PCW)	<50	<50
Otariid & non Carn. Phocids (OCW)	<50	<50

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For fish where swim bladder is involved in hearing (primarily pressure detection), the safe distance from sources for the worst case scenario level is 100 m considering recoverable injuries and 400 m for TTS.

Sea turtles are expected to react in a similar way to the most sensitive fish species, with high behavioural reactions close within tens of metres of the pipelaying activities, but moderate and low reactions further from the source.

C. AT POINT T2

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Figure H-11 Point T2 and the 8 Transects around It (lat 36.422 °, lon 23.567 °)

Point T2 lies near the south-east edge of Peloponnese and specifically at 36.422 Lat 23. 567 Lon. Calculations were performed for a bundle of 8 transectscentred at the mentioned T2 point spanning an entire circle with 45° increments.

The results reported for point T1 above, apply for this point (T2), too.

D. AT POINT T3

Point T3 lies near the north-west edge of Peloponnese at Patraikos Gulf, specifically at Lat 38.185 Lon 21.485. Calculations were performed for a bundle of 2 transects across and along the straits.

Figure H-12 shows the relationship of Point T3 to LF4 and LF5 which are across the straits at the entrance of Patraikos Gulf.

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Figure H-12 Point T3 at Patraikos Gulf (lat 38.185 °, lon 21.485 °)

Appendix 2 - Samples of Transmission Loss Calculations with RAMGEO and BELLHOP models a sample of the computed output. Transmission Loss was calculated vs a) Range and b) depth. Code RAMGEO was used for low frequencies and BELLHOP+BOUND at higher frequencies. As can be seen in Figure H-7 at the unweighted RMS, anticipated noise level is 184 dB at 16 Hz, 188 at 40 Hz, and 177 at 500 Hz, probably with a small deviation due to measurement discrepancies. The noise level at a distance from the source is obtained by subtracting the calculated propagation loss from these values.

Table H-12 Estimated Distances in m at T3 Spot using TTS and PTS Criteria for Marine Mammals

Marine Mammal Hearing Group		Estimated Distance for Adopted SELcum TTS Criteria,(m)	Estimated Distance for Adopted SELcum PTS Criteria,(m)
Low Frequency cetaceans (LF)		<50	<50
High frequency cetaceans (HF)		<50	<50
Very High frequency cetaceans (VHF)		<55	<55
Phocid & Carnivores in Water (PCW)		<50	<50
Otariid & non Carn. Phocids (OCW)		<50	<50

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For fish where swim bladder is involved in hearing (primarily pressure detection) the safe distance from sources for the worst case scenario level is 130 m considering recoverable injuries and 420 m for TTS.

Sea turtles are expected to react in a similar way to the most sensitive fish species, with high behavioural reactions close within tens of metres of the pipelaying activities, but moderate and low reactions further from the source.

9 H.4. CONCLUSION

For many marine organisms, including most mammals, many fish, and perhaps even some invertebrates, sound is important to communicate, to locate mates, to search for prey, to avoid predators and hazards, and for short- and long-range navigation. Anthropogenic sound emitted to the marine environment can potentially affect marine organisms in various ways. It can mask biologically relevant signals; it can lead to a variety of behavioural reactions; hearing organs can be affected in form of hearing loss, and at very high received levels, sound can injure or even kill marine life. Manmade sound sources of primary concern with regard to disturbance of marine life are explosions, shipping, seismic surveys, offshore construction (for example offshore wind farms or hydrocarbon production and transport facilities), and offshore industrial activities (dredging, drilling etc.), sonar of various types, and acoustic deterrent devices. Documented effects on marine life vary greatly from very subtle behavioural changes, avoidance reaction, hearing loss, injury and death in extreme cases.

During the planned activities, no emissions of impulsive, high energy type sounds are envisaged, that are recognised worldwide as being potentially harmful to the health of marine mammals and reptiles.

The results of the modelling study presented in this annex show that the anticipated risk from the construction activities of the Project concerning underwater fauna are minimal.

BIBLIOGRAPHY

1. Nedwell, J.R. and A.W. Turnpenny. 1998. The use of a generic frequency weighting scale in estimating environmental effect. Workshop on Seismics and Marine Mammals. 23– 25th June, London, U.K.
2. Nedwell, J.R., A.W.H. Turnpenny, J. Lovell, S.J. Parvin, R. Workman, and J.A.L. Spinks. 2007. A validation of the dBht as a measure of the behavioural and auditory effects of underwater noise. Report No. 534R1231 Prepared by: Subacoustech Ltd. for the UK Department of Business, Enterprise and Regulatory Reform under Project No. RDCZ/011/0004. www.subacoustech.com/information/downloads/reports/534R1231.pdf
3. Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene Jr., D. Kastak, D.R. Ketten, J.H. Miller, *et al*. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals 33(4): 411-521.
4. Southall B L, Finneran J J, Reichmuth C, Nachtigall P E, Ketten D R, Bowles A E, Ellison W T, Nowacek D P, Tyack P L (2019). Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. Aquatic Mammals 2019, 45(2), 125-232, DOI 10.1578/AM.45.2.2019.125.
5. National Marine Fisheries Service. 2018. 2018 Revisions to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OPR-59, 167 p
6. Jakob Tougaard. 2021. Thresholds for noise induced hearing loss in marine mammals. Background note to revision of guidelines from the Danish Energy Agency. Aarhus University, DCE - Danish

Centre for Environment and Energy, 34 s. – Scientific note no. 2021|28 https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notater_2021/N2021|28.pdf

7. Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene Jr., D. Kastak, D.R. Ketten, J.H. Miller, *et al*. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals 33(4): 411-521.
8. Finneran, J. and A.K. Jenkins. 2012. Criteria and Thresholds for Navy Acoustic Effects Analysis Technical Report. SPAWAR Marine Mammal Program.
9. Nedwell, J.R., J. Lovell, and A.W.H. Turnpenny. 2005. Experimental validation of a species- specific behavioral impact metric for underwater noise. Journal of the Acoustical Society of America 118(3): 2019-2019.
10. Wenz, G. M. (1962). Acoustic ambient noise in the ocean: Spectra and sources. J. Acoust. Soc. Am., 34(12):1936–1956. 40, 41
11. Miksis-Olds, J. L., Bradley, D. L., and Maggie Niu, X. (2013). Decadal trends in Indian Ocean ambient sound. J. Acoust. Soc. Am., 134(5):3464–3475. 41, 42, 56
12. 1 Source Miksis-Olds *et al*., 2013 (reproduction from Wenz (1962)). Wenz, G.M. 1962. Acoustic ambient noise in the ocean: Spectra and sources. Journal of the Acoustical Society of America, 34: 1936 – 1956.
13. Wyatt R. Joint Industry Programme on Sound and Marine Life Review of Existing Data on Underwater Sounds Produced by the Oil and Gas Industry, Issue 1, 2008.
14. From Monitoring Guidance for Underwater Noise in European Seas - 2nd Report of the Technical Subgroup on Underwater noise (TSG Noise). Part III Background Information and Annexes. Interim Guidance Report. May, 2013.
15. Methodological Guide Guidance on Underwater Noise Mitigation Measures V.3.0, ACCOBAMS-MOP7/2019/31Rev1,2019
16. EU TSG Noise (2014). Monitoring Guidance of Underwater Noise in European Seas, Part 3: Background Information

Appendix 1 Red Flags Assessment for Foloi Area.

A non-comprehensive list of national legislation possibly applicable to the Project is hereafter given in chronological order.

- Law No. 4141 of 1913 concerning the Contiguous Zone for security purposes;
  - Date of text: 26 March 1913
  - ID: LEX-FAOC021174
  - Link to full text: gre21174.pdf
- Law No. 230/1936 concerning the extension of the territorial waters of the Kingdom of Greece;
  - Date of text: 17 September 1936
  - ID: LEX-FAOC021140
  - Link to full text: gre21140.pdf gre21140E.pdf
- Law No. 1650 on the protection for the environment;
  - ID: LEX-FAOC051736
  - Link to full text: gre51736.pdf
- Presidential Order No. 67 on the protection of the flora and fauna;
  - Date of text: 29 November 1980
  - ID: LEX-FAOC023470
  - Link to full text: gre23470.pdf
- Errata Corrige on Presidential Order No. 67 regarding the protection of the flora and fauna;
  - ID: LEX-FAOC023478
  - Link to full text: gre23478.pdf
- Law No. 1740 on the development and protection of coral formations and fish breeding areas;
  - Date of text: 04 December 1987
  - ID: LEX-FAOC023637
  - Link to full text: gre23637.pdf
- Ministerial Joint Decree establishing conservation measures for natural habitats and of wild fauna and flora; and
  - Date of text: 11 December 1998
  - ID: LEX-FAOC081745

  - Link to full text: gre81745.pdf

- Law No. 177 amending and complementing provisions of Decree Law No. 86.
  - ID: LEX-FAOC051875
  - Link to full text: gre51875.pdf

Table 1 National/International Standards - Rules of Classification Societies

National/International Standards
ANSI/ASA, 2009, Quantities and procedures for description and measurement of underwater sound from ships, Part 1: General requirements, ANSI/ASA S12.64-2009/Part 1
ISO 17208-1:2016 Underwater acoustics – Quantities and procedures for description and measurement of underwater sound from ships – Part 1: Requirements for precision measurements in deep water used for comparison purposes
ISO/CD 17208-2:2016. Underwater acoustics – Quantities and procedures for description and measurement of underwater sound from ships – Part 2: Determination of source level from deep water measurements (under preparation in ISO/TC43/SC3)
ISO/NP 17208-3:2016 (Proposal Stage– New Project on 2016-06-27) Underwater acoustics – Quantities and procedures for description and measurement of underwater sound from ships – Part 3: Requirements for measurements in shallow water
ISO/DIS 18405.2:2016 Underwater acoustics – Terminology. (under development in ISO/TC43/SC3)
<u>Rules of Classification Societies</u>
DNV, 2010, Silent Class Notation, Det Norske Veritas (DNV), Rules for Ships, January 2010, Pt 6, Ch. 2
BV, 2014, Underwater Radiated Noise (URN), Bureau Veritas Rule Note NR614

Table 2 Guidelines in the Form of Good Practices

Guidelines in the form of Good Practices
AQUO D3.1, 2014, Task T3.1, WP 3: Measurements, European URN Standard Measurement Method
National Physical Laboratory, 2014. NPL Good Practice Guide No. 133, Underwater Noise Measurement
AQUO and SONIC, 2015, Guidelines for Regulation on UW Noise from Commercial Shipping, Prepared by:: Bureau Veritas, DNVL GL
EU TSG Noise (2014). Monitoring Guidance of Underwater Noise in European Seas, Part 3: Background Information

Appendix 2 Samples of Transmission Loss Calculations with RAMGEO and BELLHOP models

Codes

Sound propagation modelling was carried out using two codes. Frequencies lower than 500 Hz was modelled with RAMGeo, a modified version of the Range-dependent Acoustic Model (RAM), and Bellhop & Bounce model was used for higher frequencies.

Both algorithms were carried out using MATLAB Software.

Noise Source locations

Transmission Loss calculations were performed considering the point of noise source at the next three points on the pipeline path.

T1: lat 34.917°, lon 26.376°, Crete (near LF2)

T2: lat 36.422°, lon 23.567°, Peloponnese (near LF3)

T3: lat 38.185°, lon 21.485°, Patraikos (near LF4)

The noise source depth was considered 7 m.

Selection of the specific points was made so that they are located on the axis of the pipeline, and have a relatively short distance from the Landfalls (maximum 60 km i.e. the distance for which Transmission Loss calculations were performed). So both Nearshore and Offshore cases are covered.

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Figure 1 Chosen Points on the Path Where Models were Calculated

Sections

Eight sections were modelled for points T1 and T2 covering both nearshore and offshore cases in a range of about 60 km. For point T3 where the sea area is much smaller, two sections were modelled. The sections are presented in the figures below.

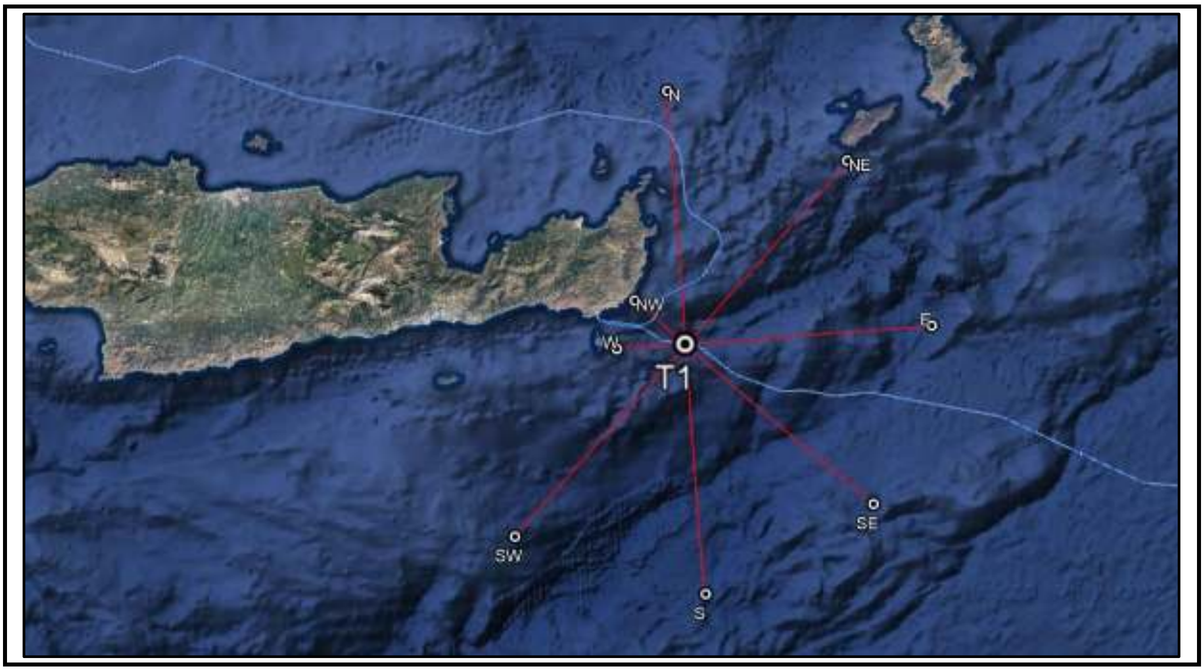

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Figure 2 Transects Bundle near Crete Landfall

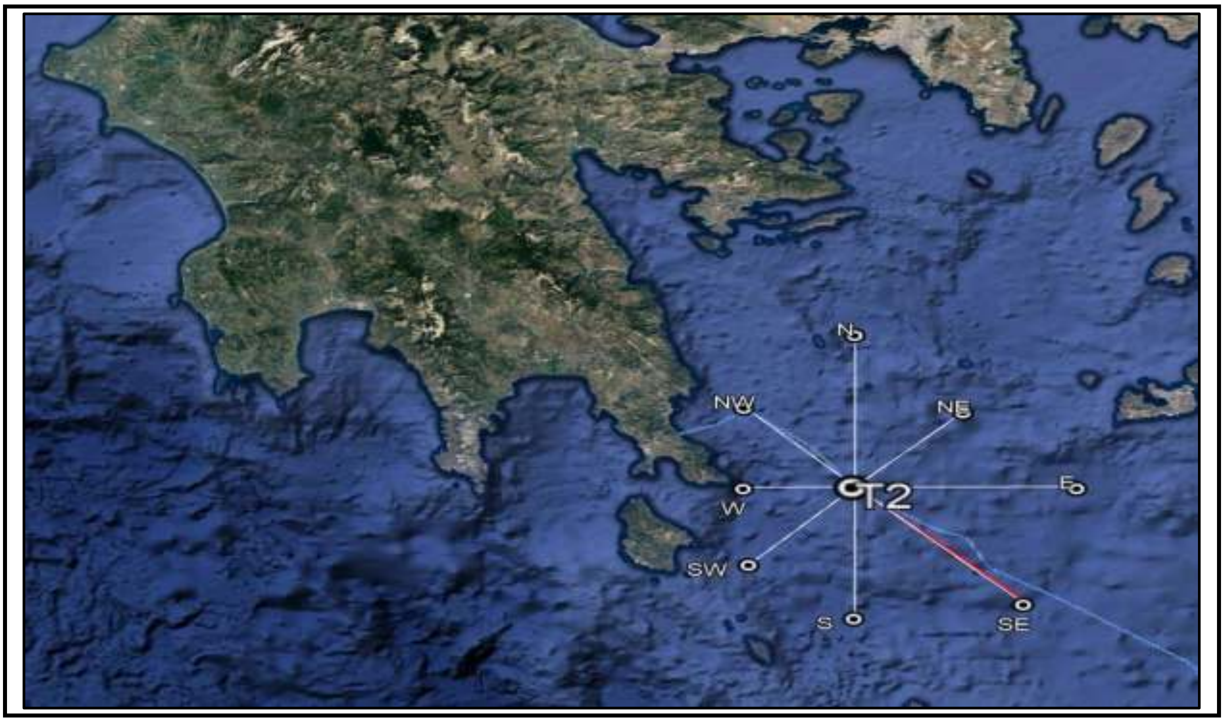

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Figure 3 Transects Bundle near Landfall in Peloponnese

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Figure 4 Transects near Patraikos Landfalls

Sound speed

The sound speed profiles used as modelling inputs were the data from the in-situ measurements at the respective Landfalls provided by Asprofos.

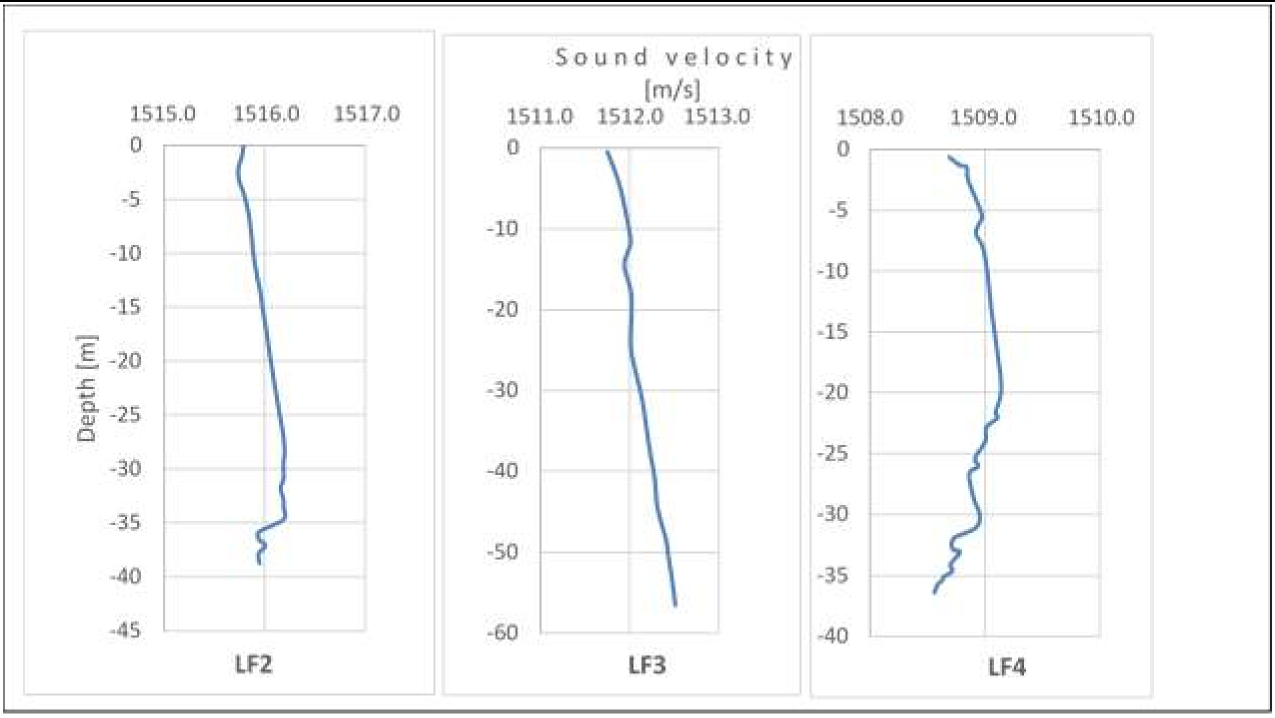

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Figure 5 Sound Speed Profiles for Shallow Waters at the Chosen Points T1, T2, T3

At depths greater than those given by the above data, for Peloponnese and Patraikos it was considered that the sound velocity is constant and equal to 1,512.5 m/s and 1,509.7 m/s, respectively. In the region of Crete, where the depth is significantly greater, additional data for the sound speed in the eastern Mediterranean from research was used [Ref. "Sound speed in the Mediterranean Sea: an analysis from a climatological data set", S. Salon *et al*., Annales Geophysicae (2003) 21: 833–846, European Geosciences Union 2003]

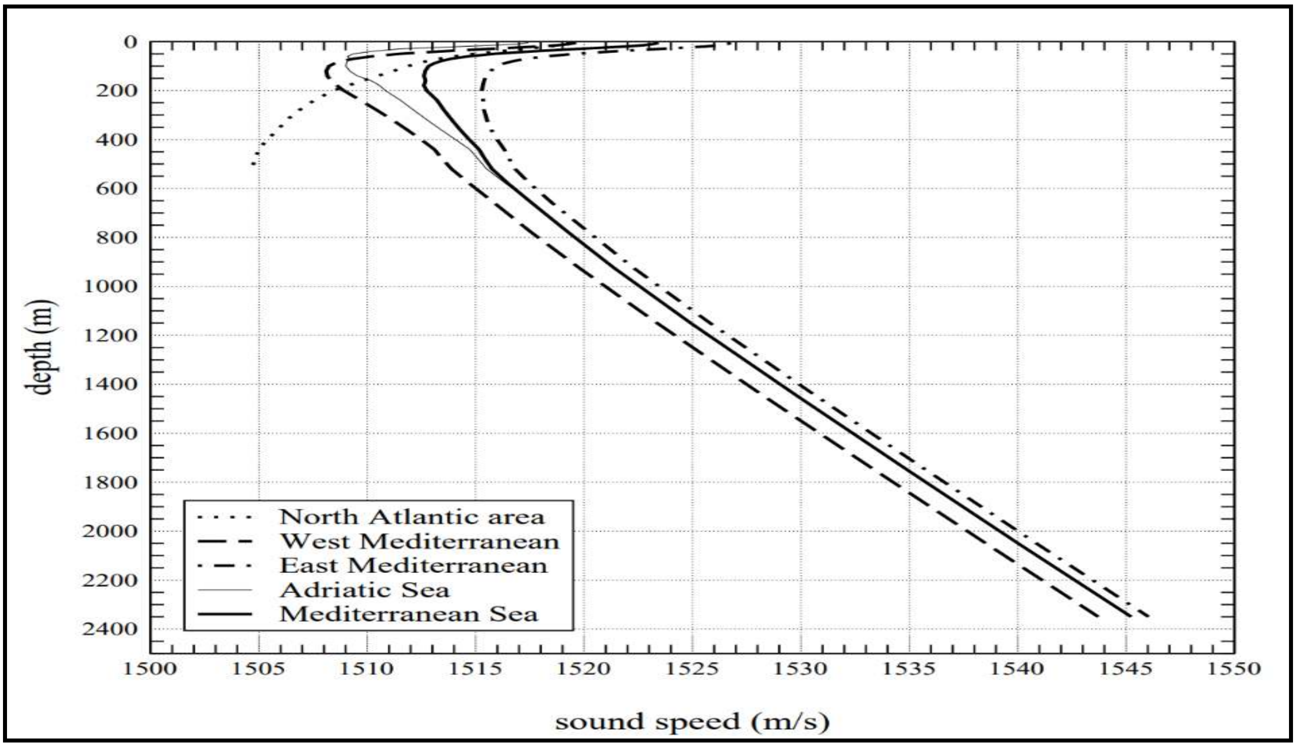

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Figure 6 Sound Speed Profile Used as Input at Depths > 40 m

Water density

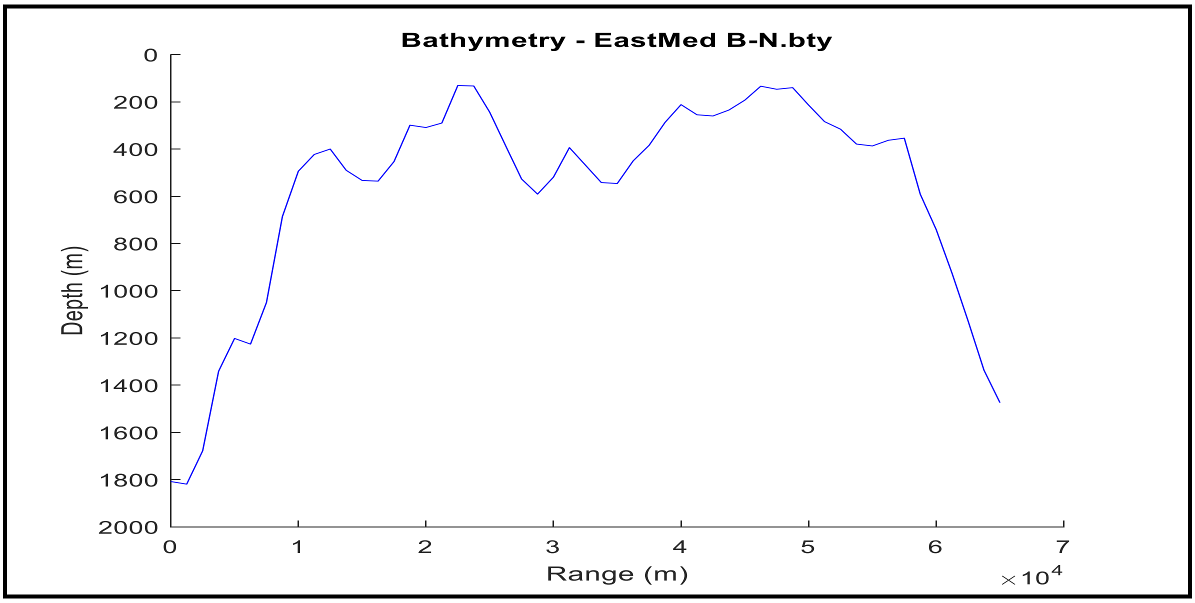
Regarding the density of water, the variation is such that it does not significantly affect the results of the calculations. Nevertheless, in order to cover the worst-case scenario, for each of the modelled regions water density was considered constant and equal with the maximum of the "All year Summary" value, according to the data provided by Asprofos. These values are 1,042 Kg/m^3 in Crete, 1,036 Kg/m^3 in Peloponnese and 1,030 Kg/m^3 in Patraikos.

Bottom half space

The seabed density was considered constant and equal to 1.940 Kg/m^3 in all regions

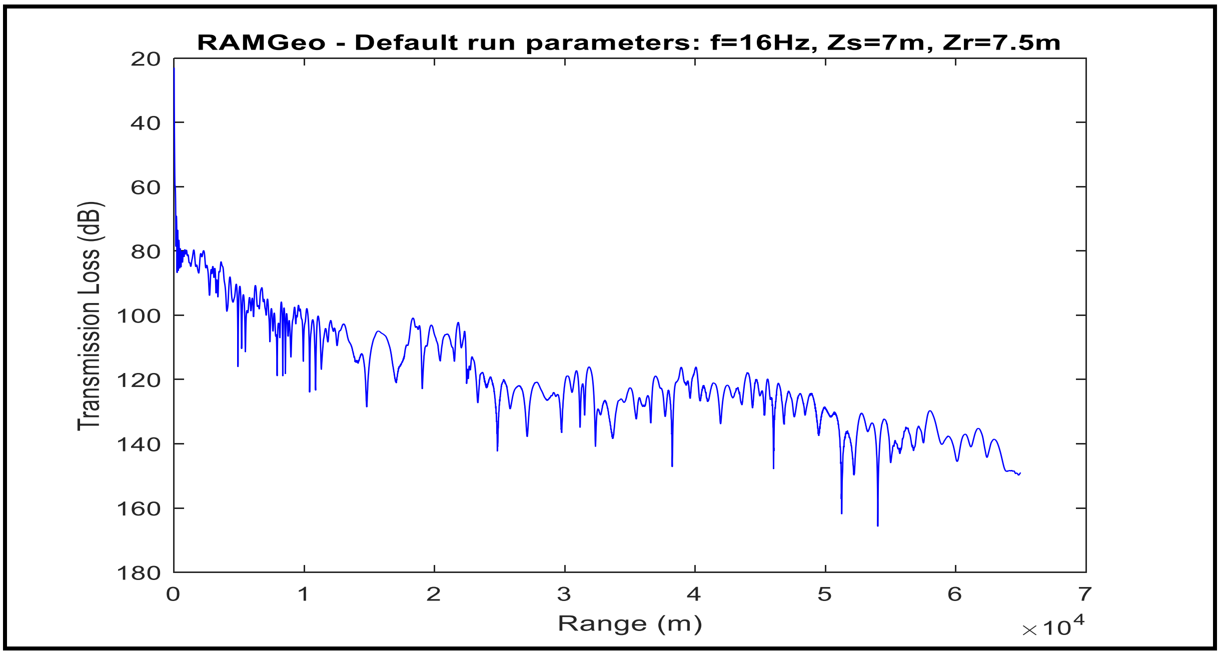
Bathymetry

All bathymetry data used in the models as well as part of the model results are presented in the figures below.



Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 7 Due North Bathymetry at Point T1 Crete 34.917 Lat 26.376 Lon.



Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 8 Transmission Loss vs Range. Due North Transect at point T1 Crete (34.917 Lat 26.376 Lon). RAMGeo. Frequency 16 Hz, Source Depth 7 m, Receiver Depth 7.5 m.

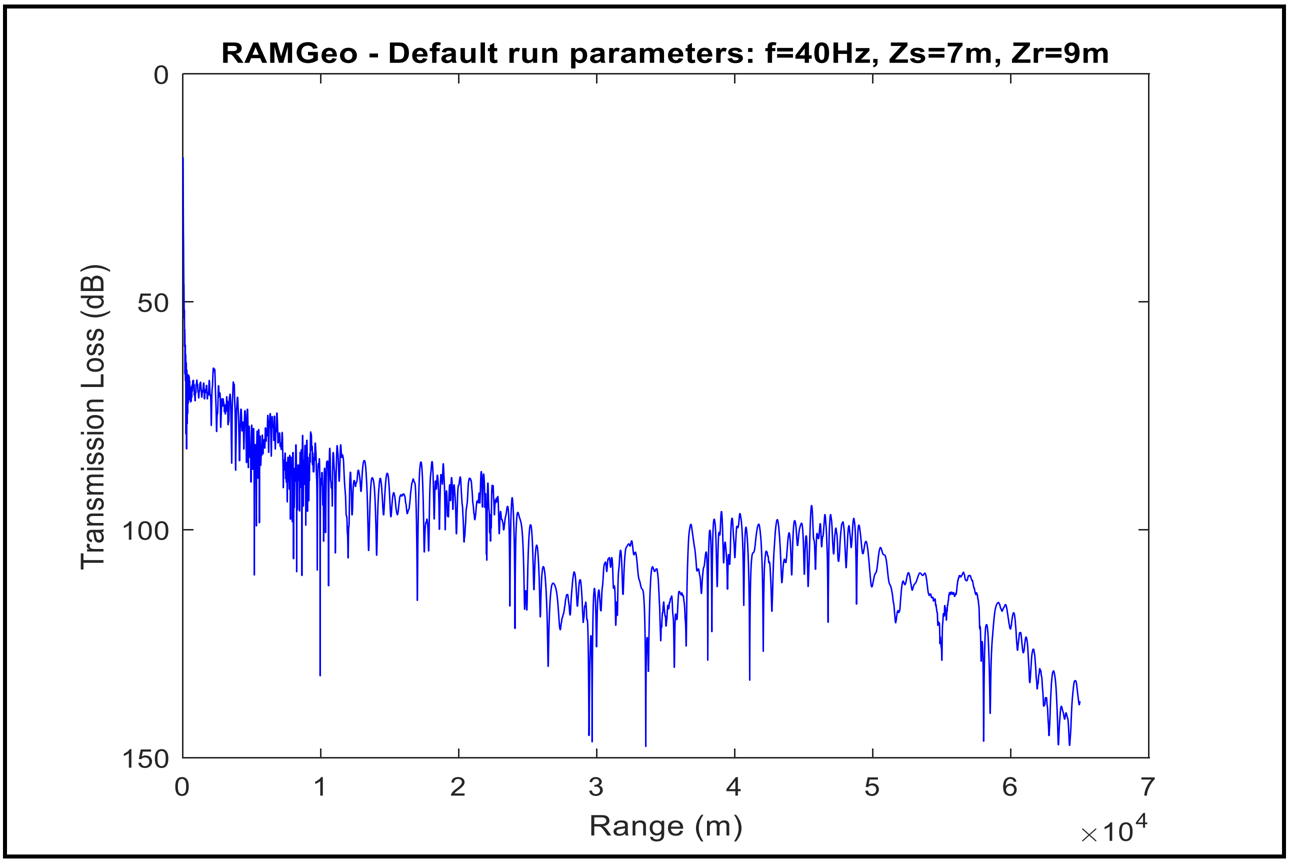


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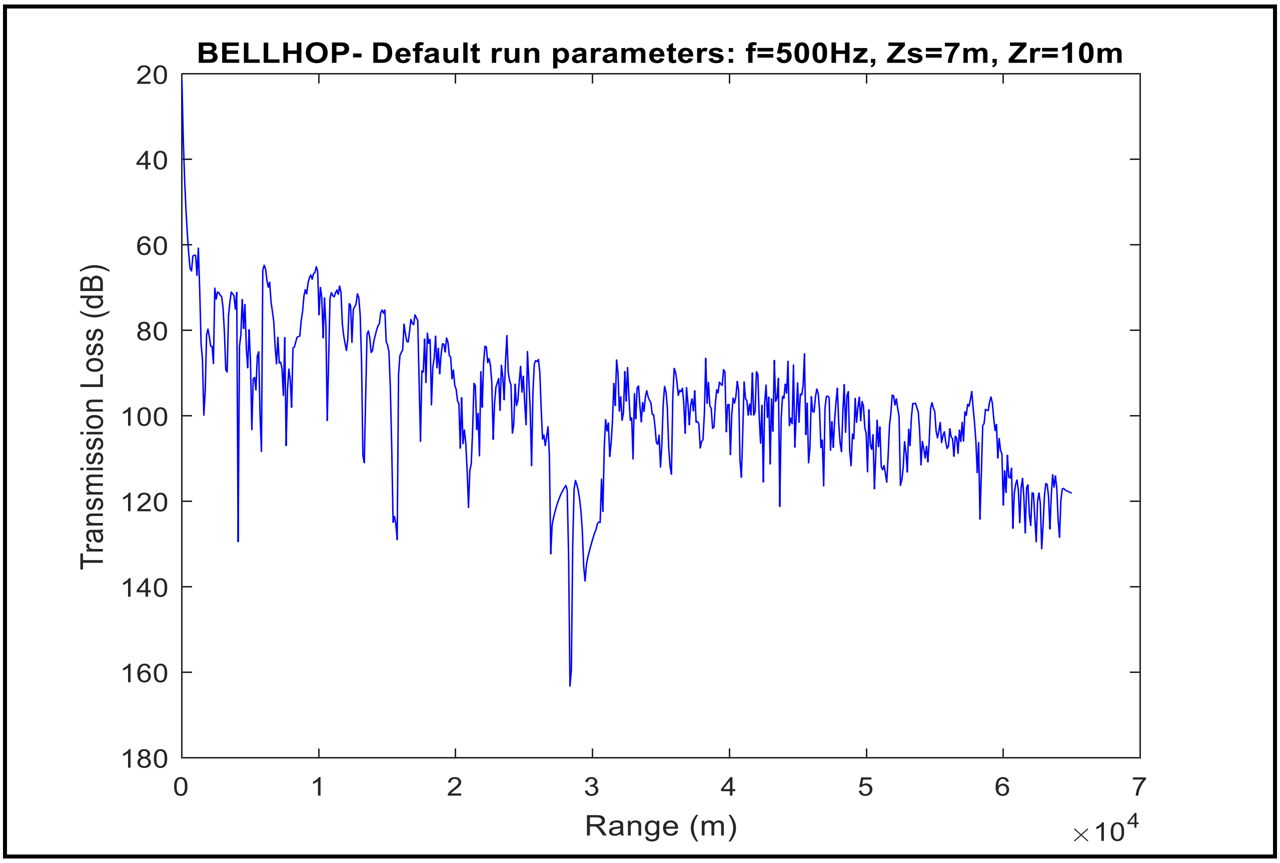
Figure 9 Transmission Loss vs Range. Due North Transect at point T1 Crete (34.917 Lat 26.376 Lon). RAMGeo. Frequency 40 Hz, Source Depth 7 m, Receiver Depth 9 m.



Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 10 Transmission Loss vs Range. Due North Transect at point T1 Crete (34.917 Lat 26.376 Lon). BELLHOP +BOUNCE. Frequency 500 Hz, Source Depth 7 m, Receiver Depth 10 m.

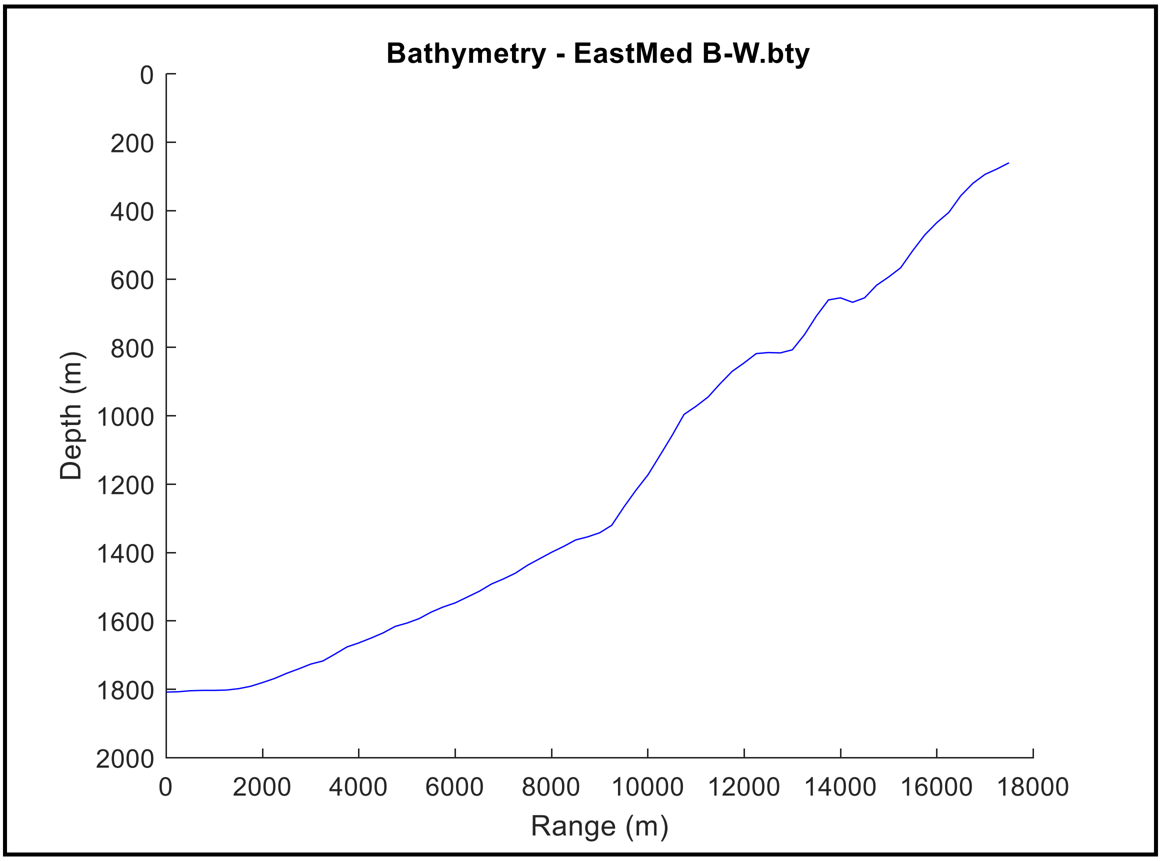


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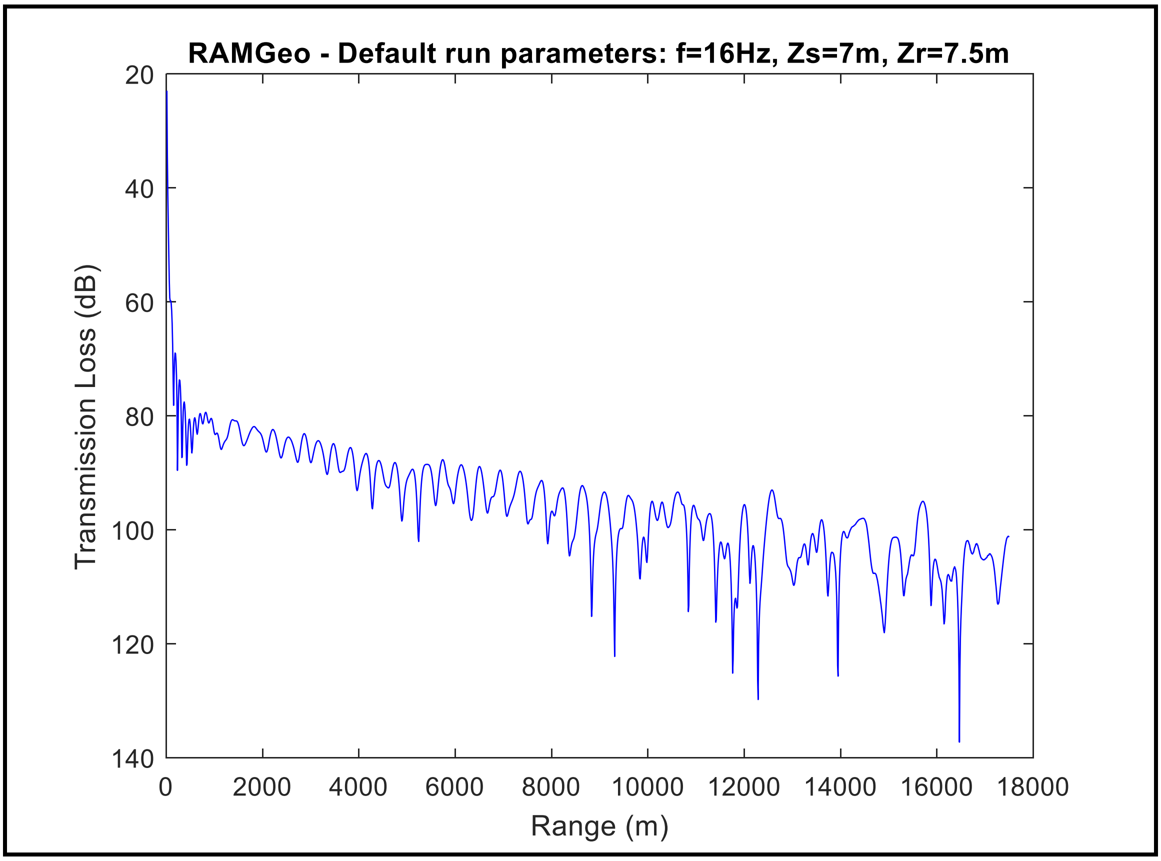
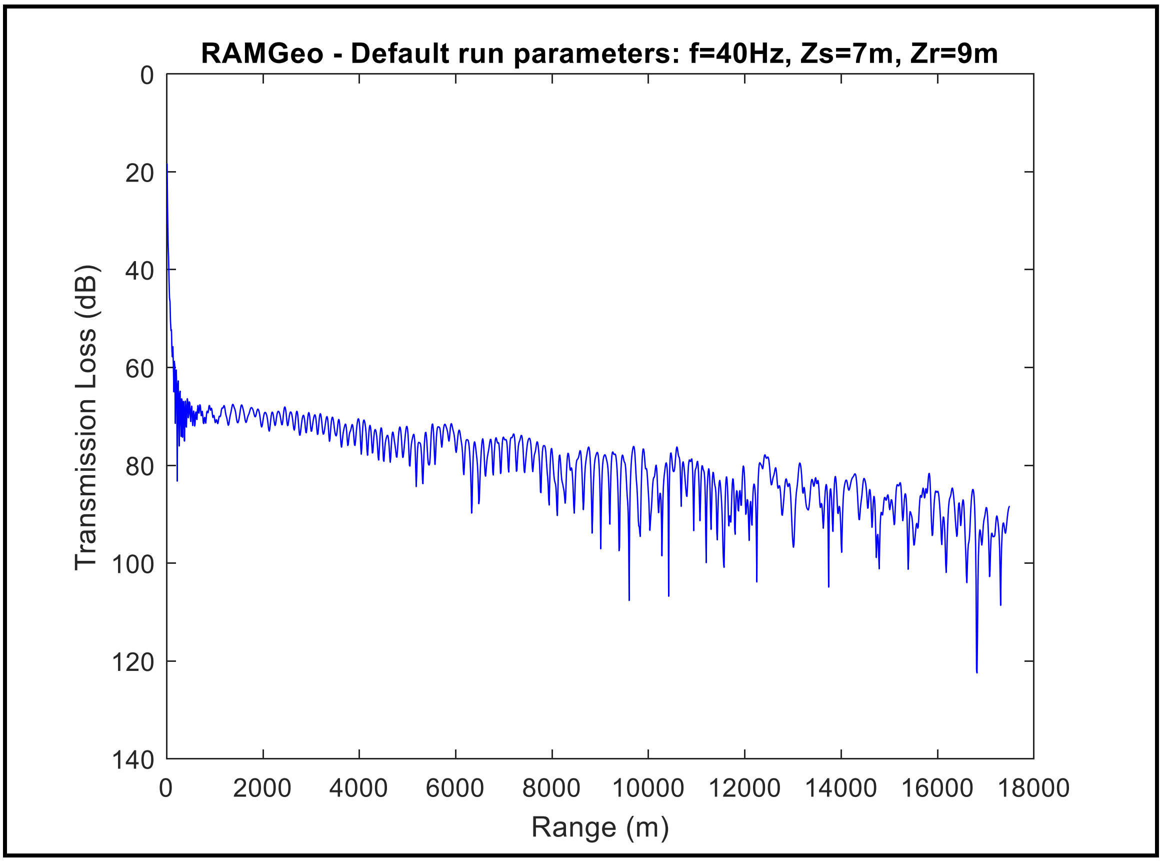
Figure 11 Due West Bathymetry at Point T1 Crete (34.917 Lat 26.376 Lon)



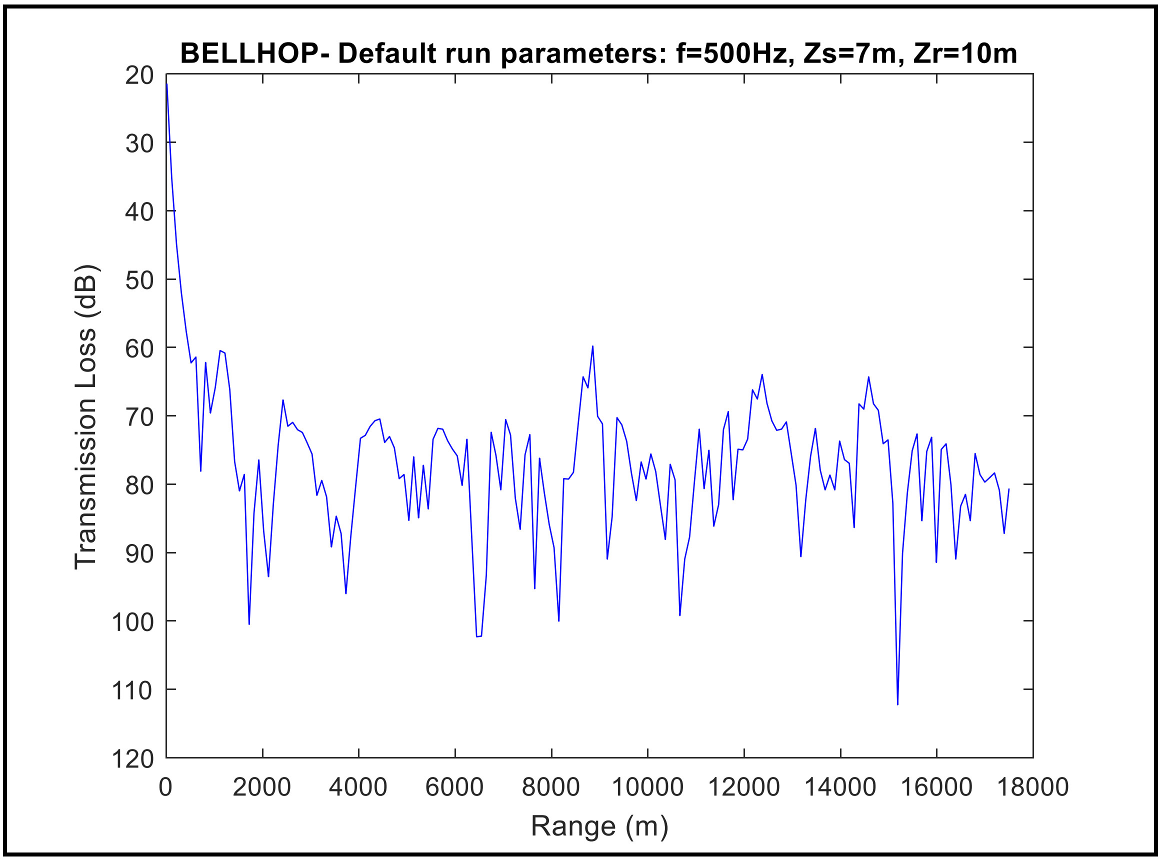
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 12 Transmission Loss vs Range. Due West Transect at Point T1 Crete (34.917 Lat 26.376 Lon). RAMGeo. Frequency 16 Hz, Source Depth 7 m, Receiver Depth 7.5 m.



Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 13 Transmission Loss vs Range. Due West Transect at Point T1 Crete (34.917 Lat 26.376 Lon). RAMGeo. Frequency 40 Hz , Source Depth 7m, Receiver Depth 9 m.



Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 14 Transmission Loss vs Range. Due West Transect at Point T1 Crete (34.917 Lat 26.376 Lon). BELLHOP+BOUNCE. Frequency 500 Hz, Source Depth 7 m, Receiver Depth 10 m.

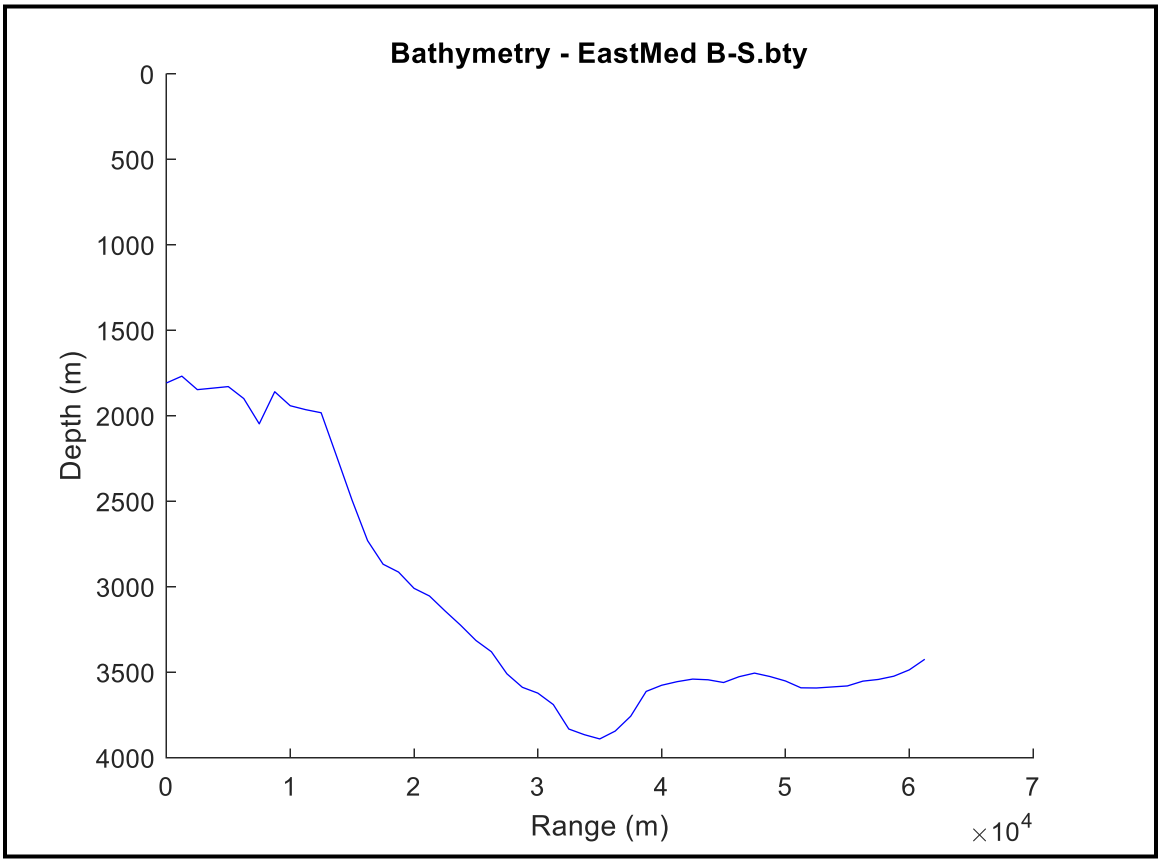


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Figure 15 Due South Bathymetry at Point T1 Crete (34.917 Lat 26.376 Lon)

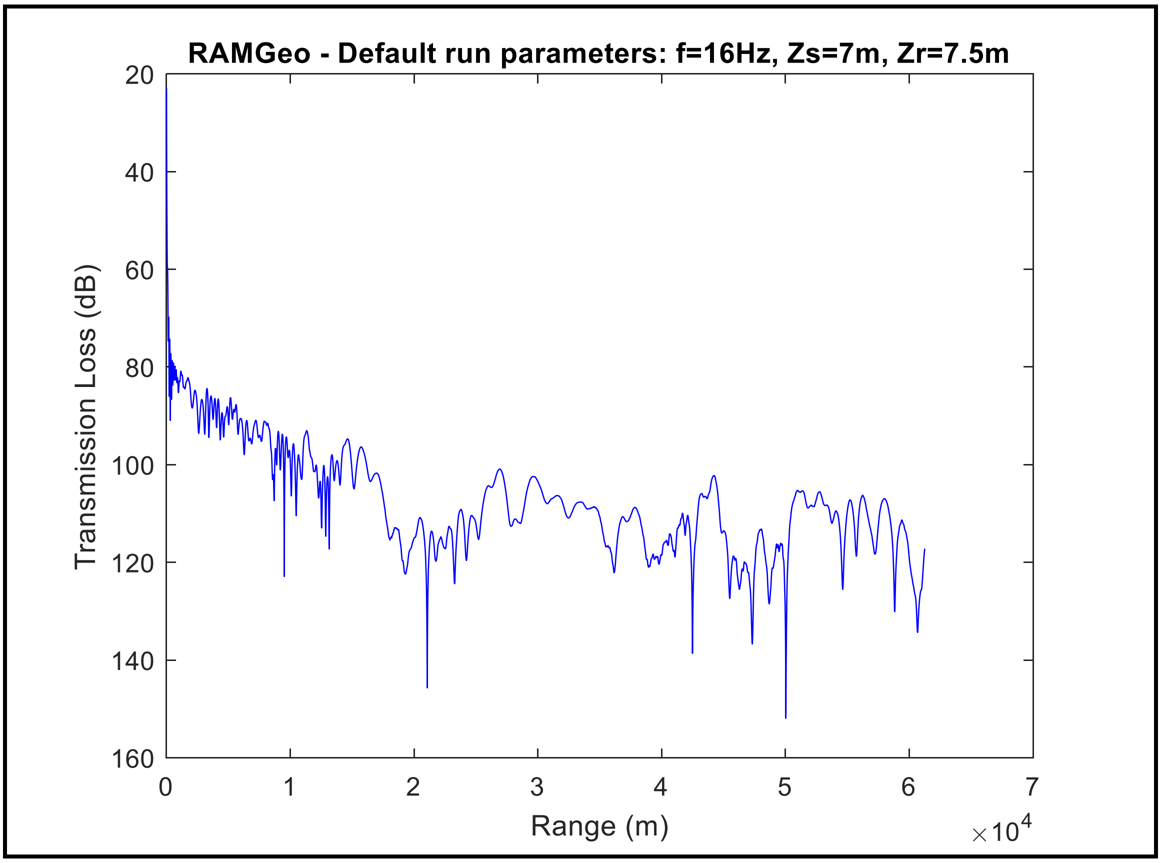

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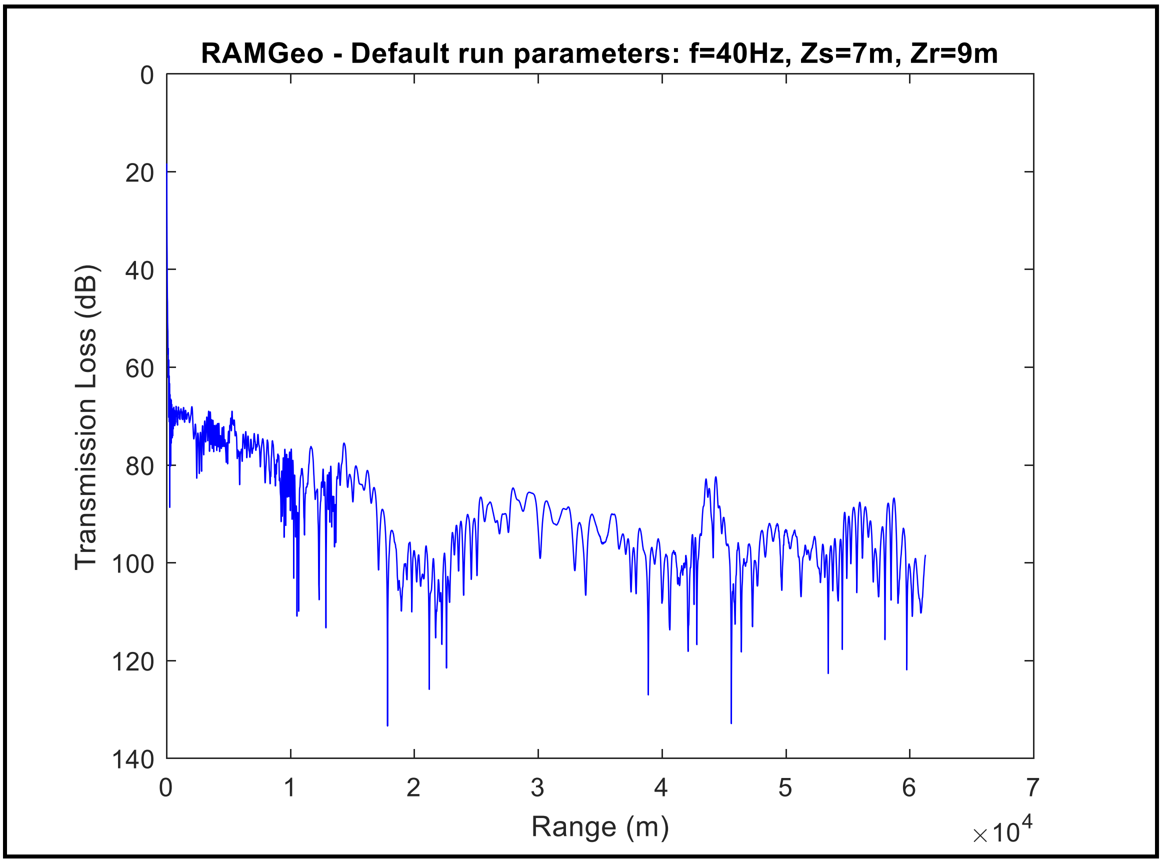
Figure 16 Transmission Loss vs Range. Due South Transect at Point T1 Crete (34.917 Lat 26.376 Lon). RAMGEO. Frequency 16 Hz, Source Depth 7 m, Receiver Depth 7.5 m.



Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 17 Transmission Loss vs Range. Due South Transect at Point T1 Crete (34.917 Lat 26.376 Lon). RAMGEO. Frequency 40 Hz, Source Depth 7 m, Receiver Depth 9 m.

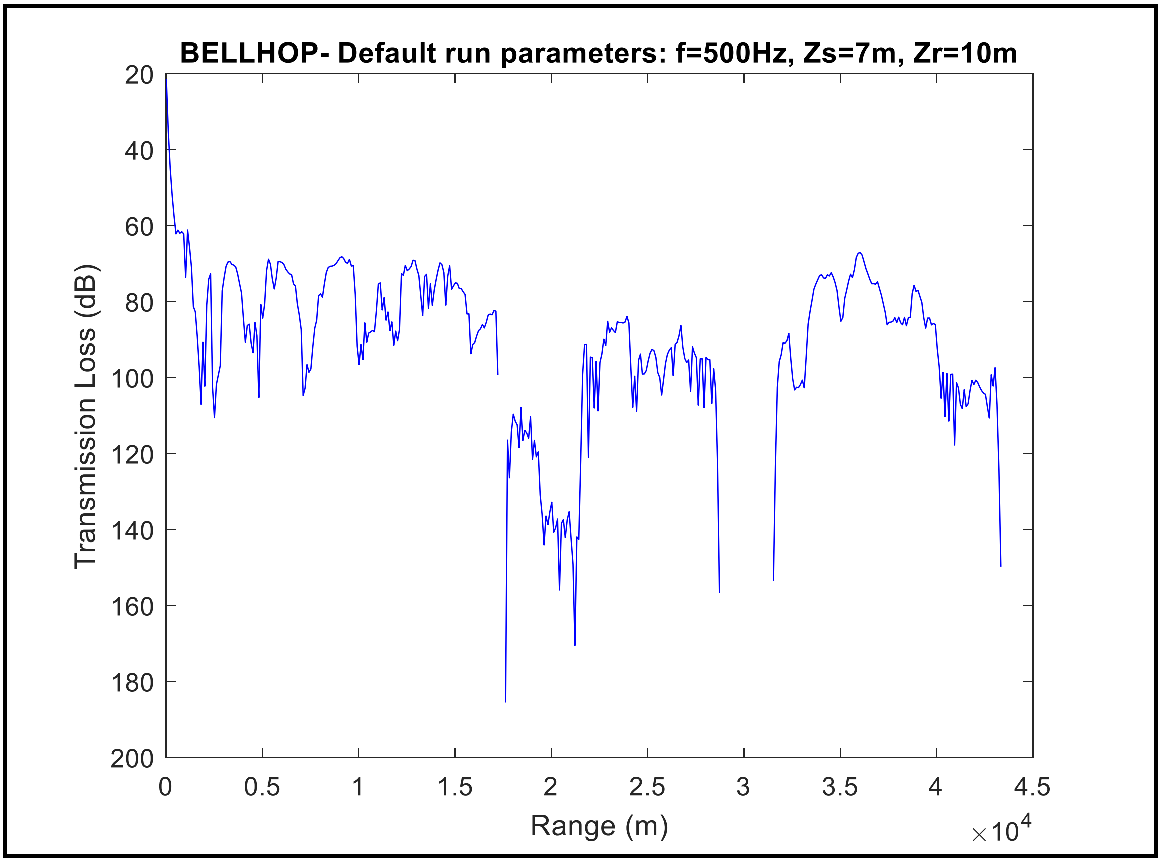


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Figure 18 Transmission Loss vs Range. Due South Transect at Point T1 Crete (34.917 Lat 26.376 Lon). BELLHOP+BOUNCE. Frequency 500 Hz, Source Depth 7 m, Receiver Depth 10 m.

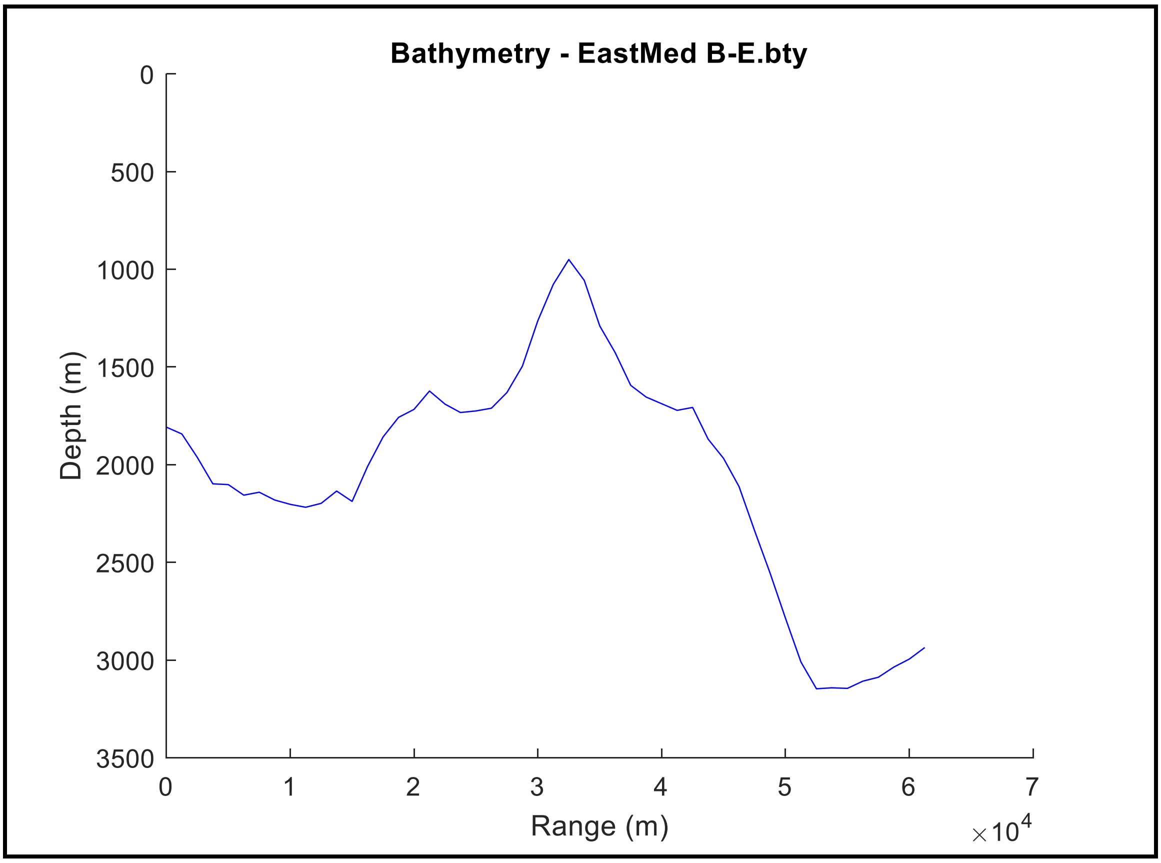

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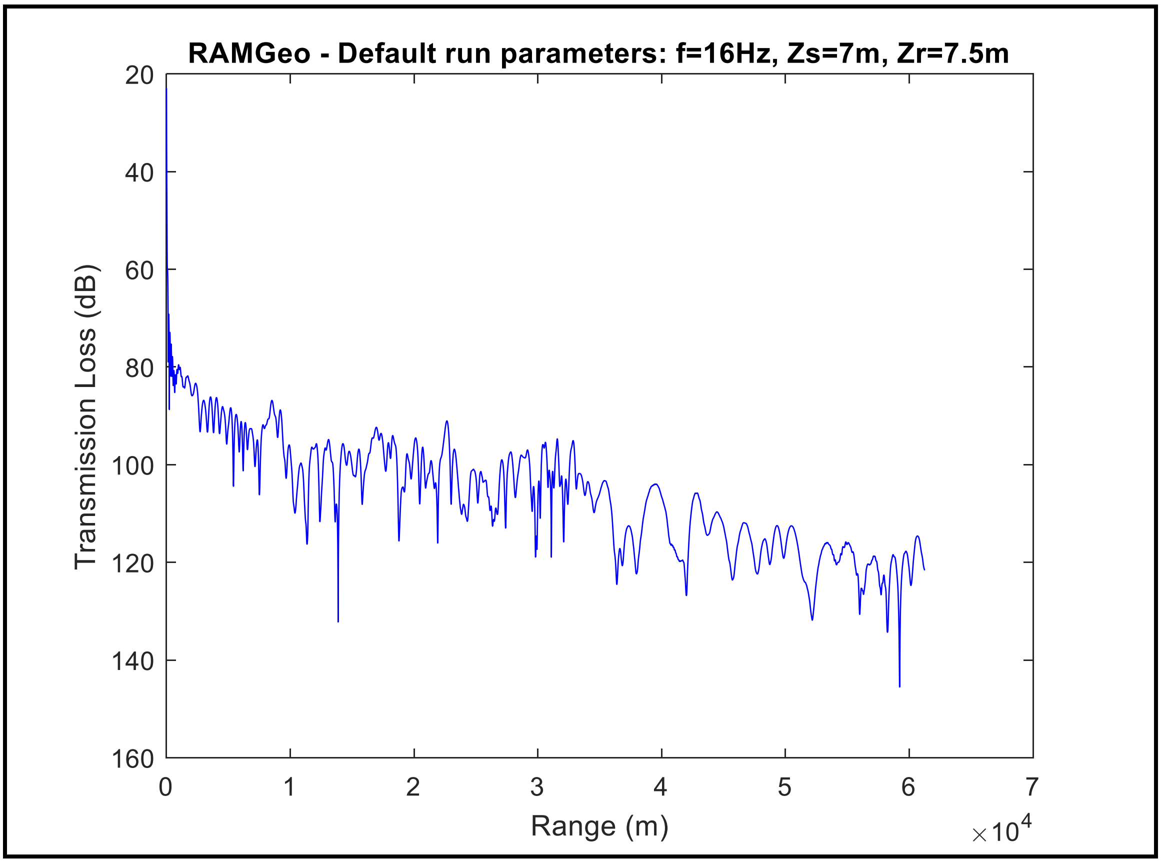
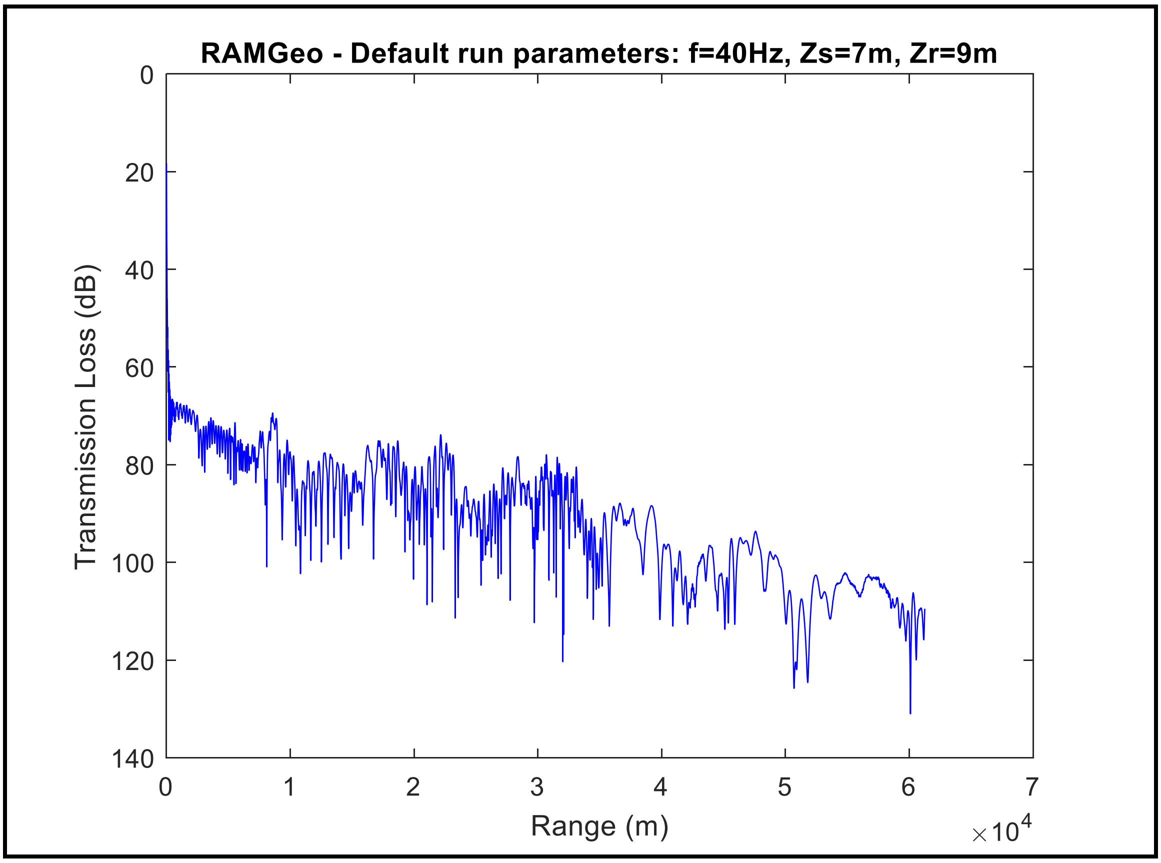
Figure 19 Due East Bathymetry at Point T1 Crete (34.917 Lat 26.376 Lon)



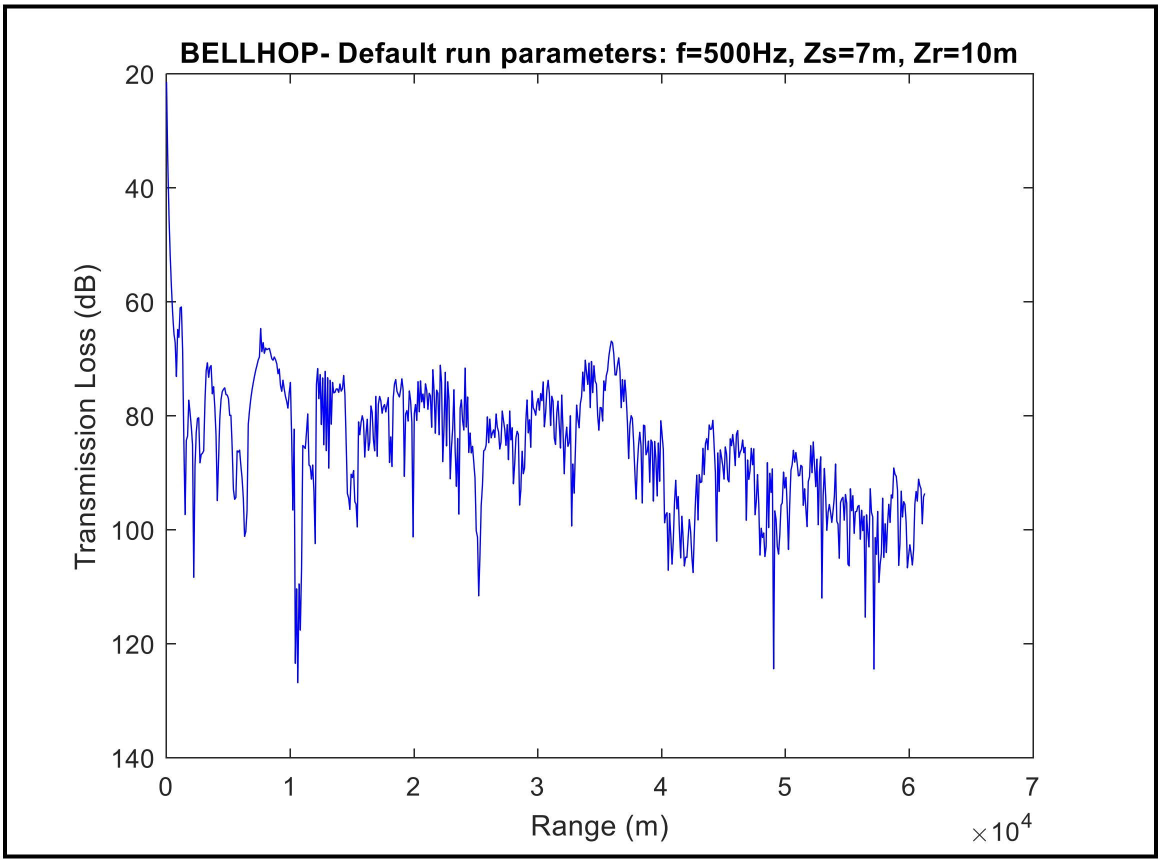
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 20 Transmission Loss vs Range. Due East Transect at Point T1 Crete (34.917 Lat 26.376 Lon). RAMGEO. Frequency 16 Hz, Source Depth 7 m, Receiver Depth 7.5 m.



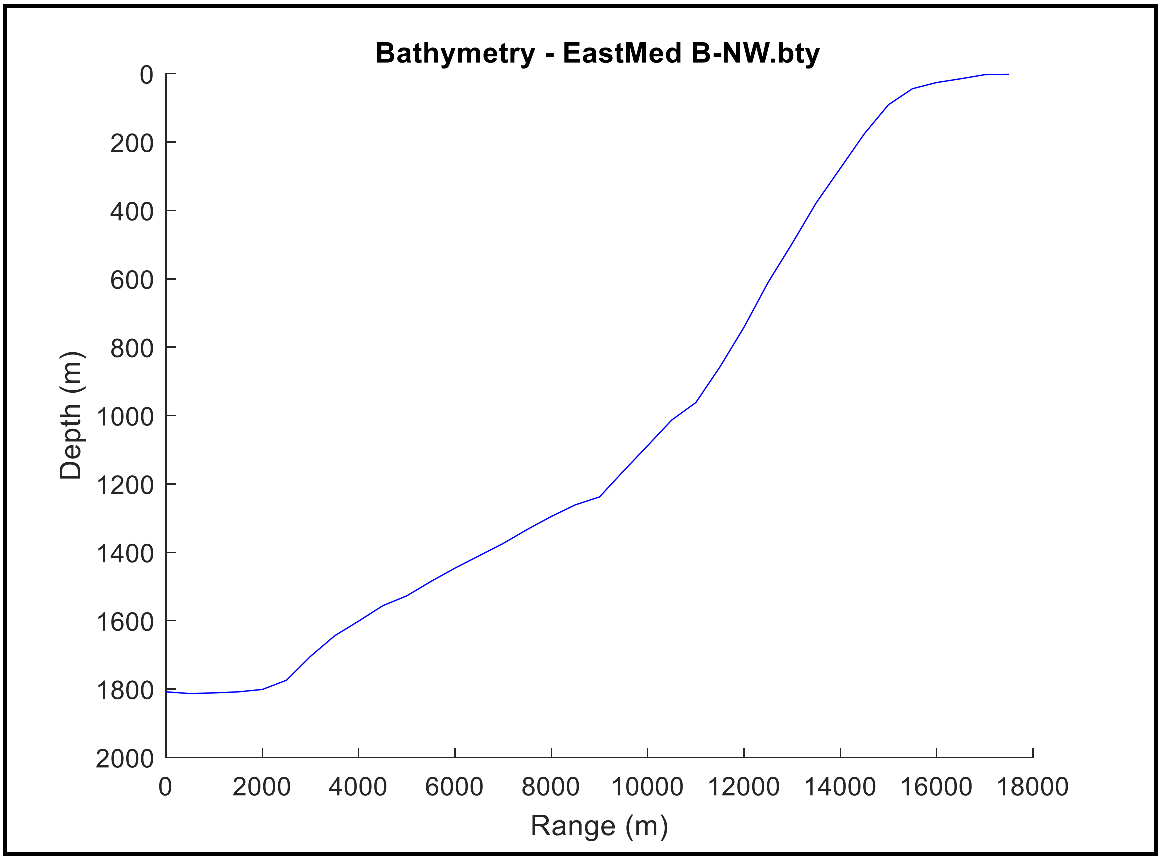
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 21 Transmission Loss vs Range. Due East Transect at Point T1 Crete (34.917 Lat 26.376 Lon). RAMGEO. Frequency 40 Hz, Source Depth 7 m, Receiver Depth 9 m.



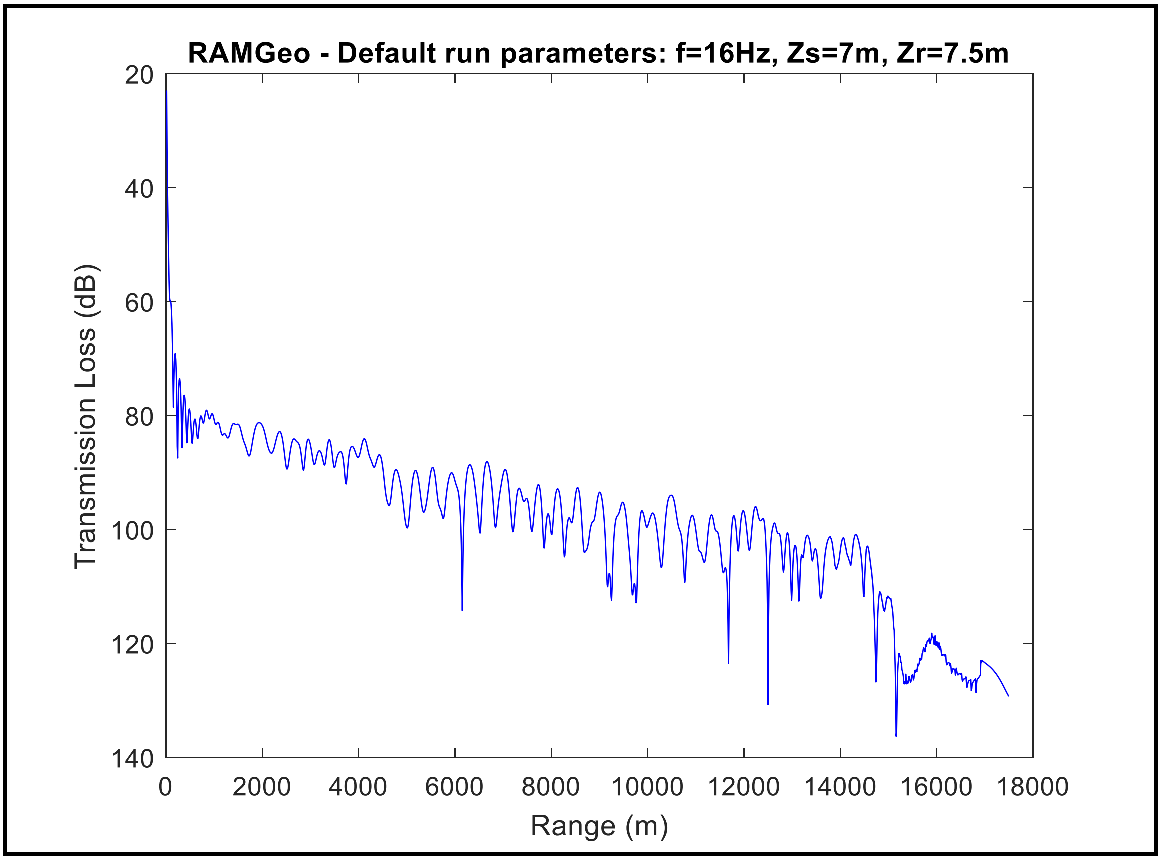
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 22 Transmission Loss vs Range. Due East Transect at Point T1 Crete (34.917 Lat 26.376 Lon). BELLHOP+BOUNCE. Frequency 500 Hz, Source Depth 7 m, Receiver Depth 10 m.



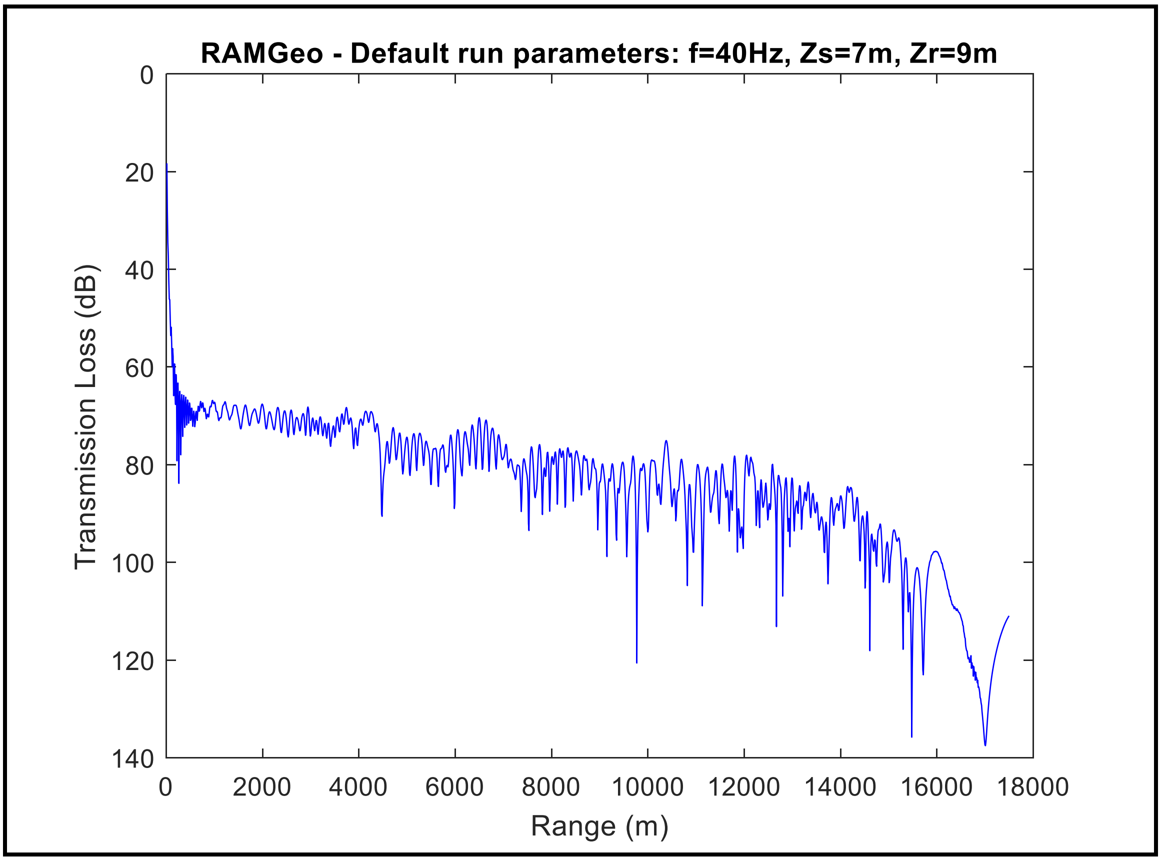
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 23 North-West Bathymetry at Point T1 Crete (34.917 Lat 26.376 Lon)



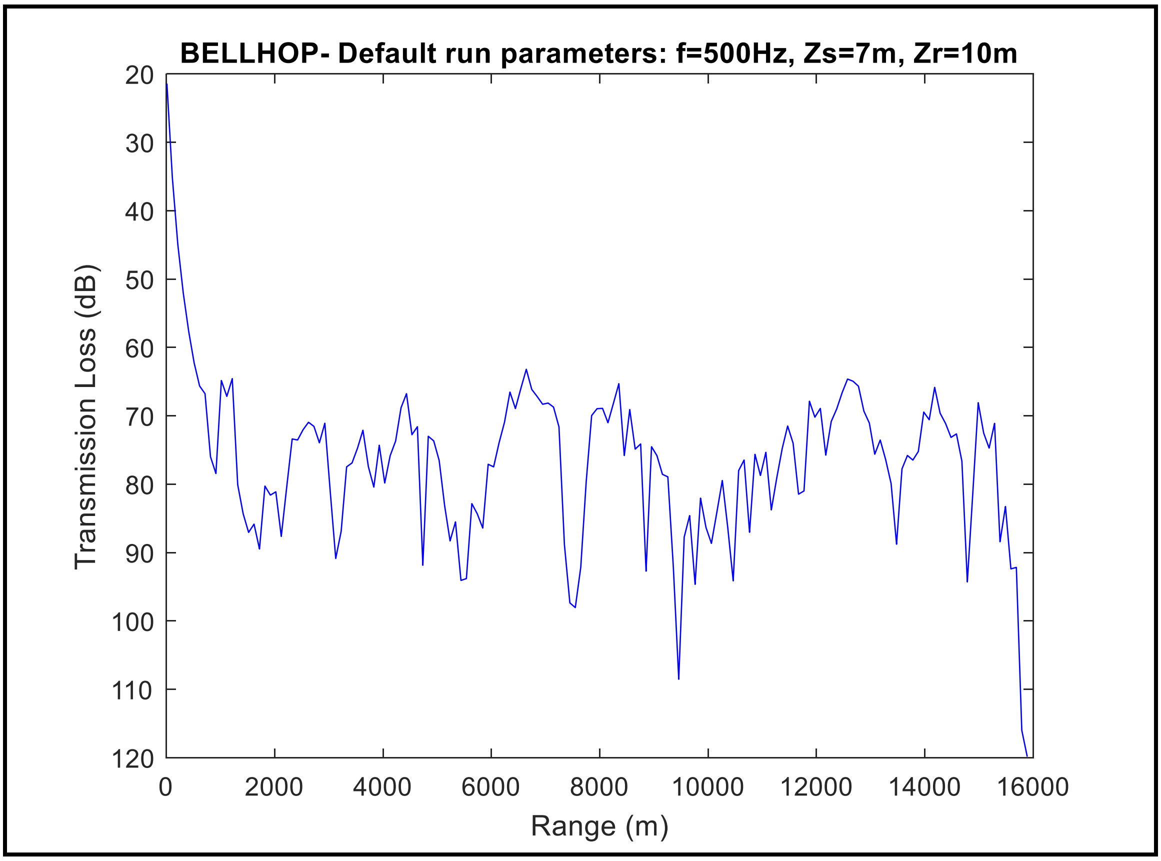
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 24 Transmission Loss vs Range. North-West Transect at Point T1 Crete (34.917 Lat 26.376 Lon). RAMGEO. Frequency 16 Hz, Source Depth 7 m, Receiver Depth 7.5 m.



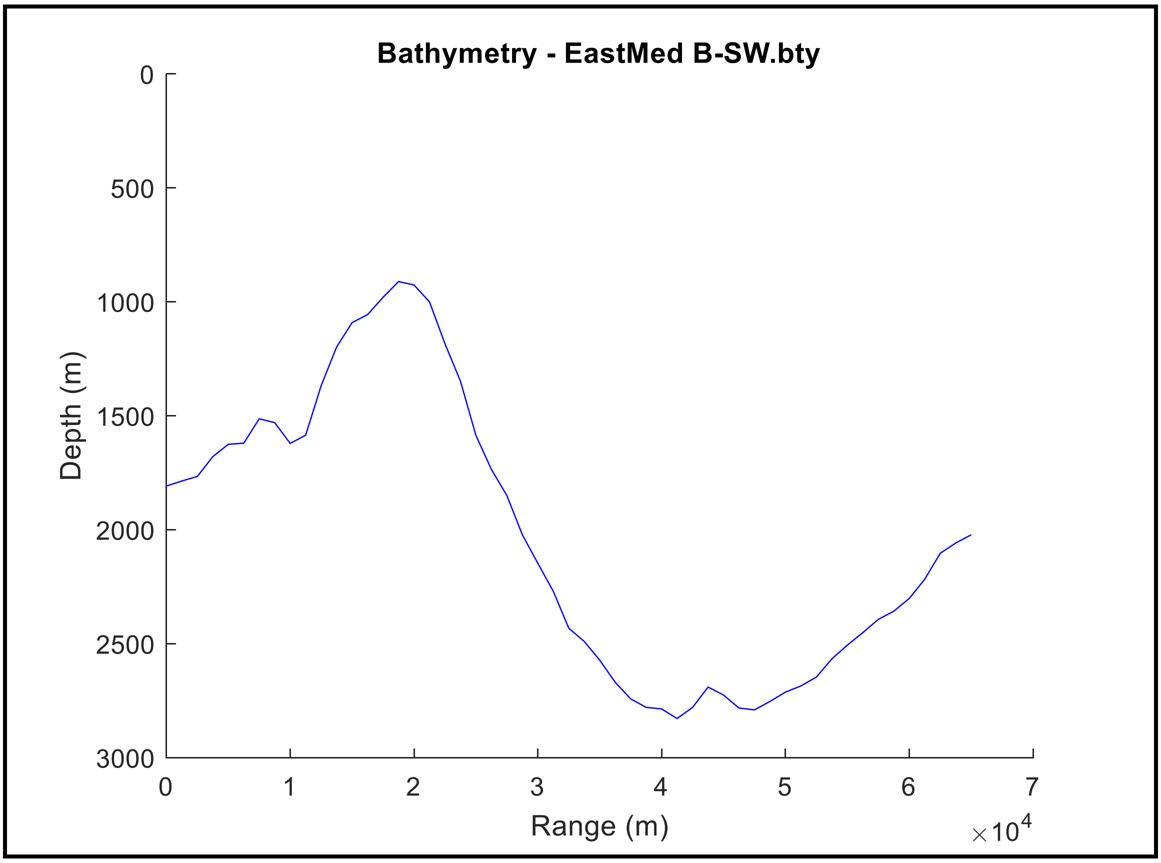
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 25 Transmission Loss vs Range. North-West Transect at Point T1 Crete (34.917 Lat 26.376 Lon). RAMGEO. Frequency 40 Hz, Source Depth 7 m, Receiver Depth 9 m.



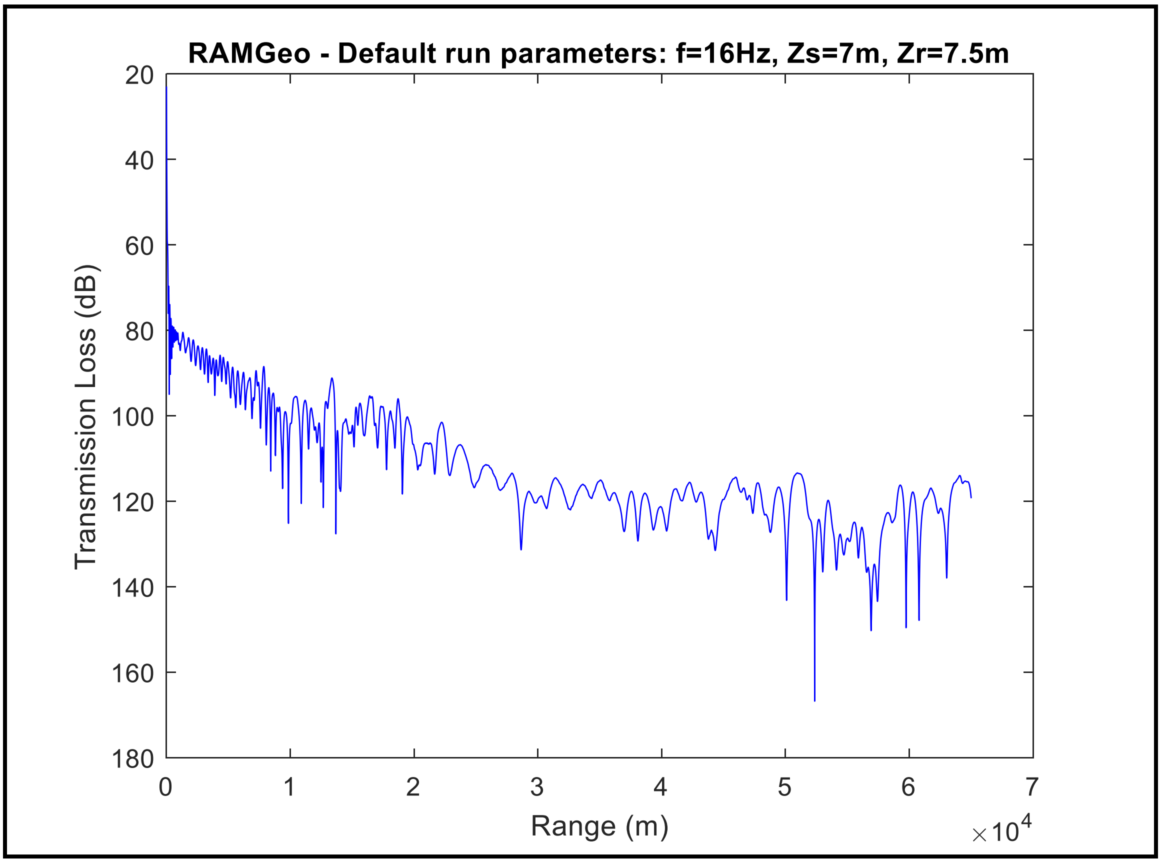
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 26 Transmission Loss vs Range. North-West Transect at Point T1 Crete (34.917 Lat 26.376 Lon). BELLHOP+BOUNCE. Frequency 500 Hz, Source Depth 7 m, Receiver depth 10 m.



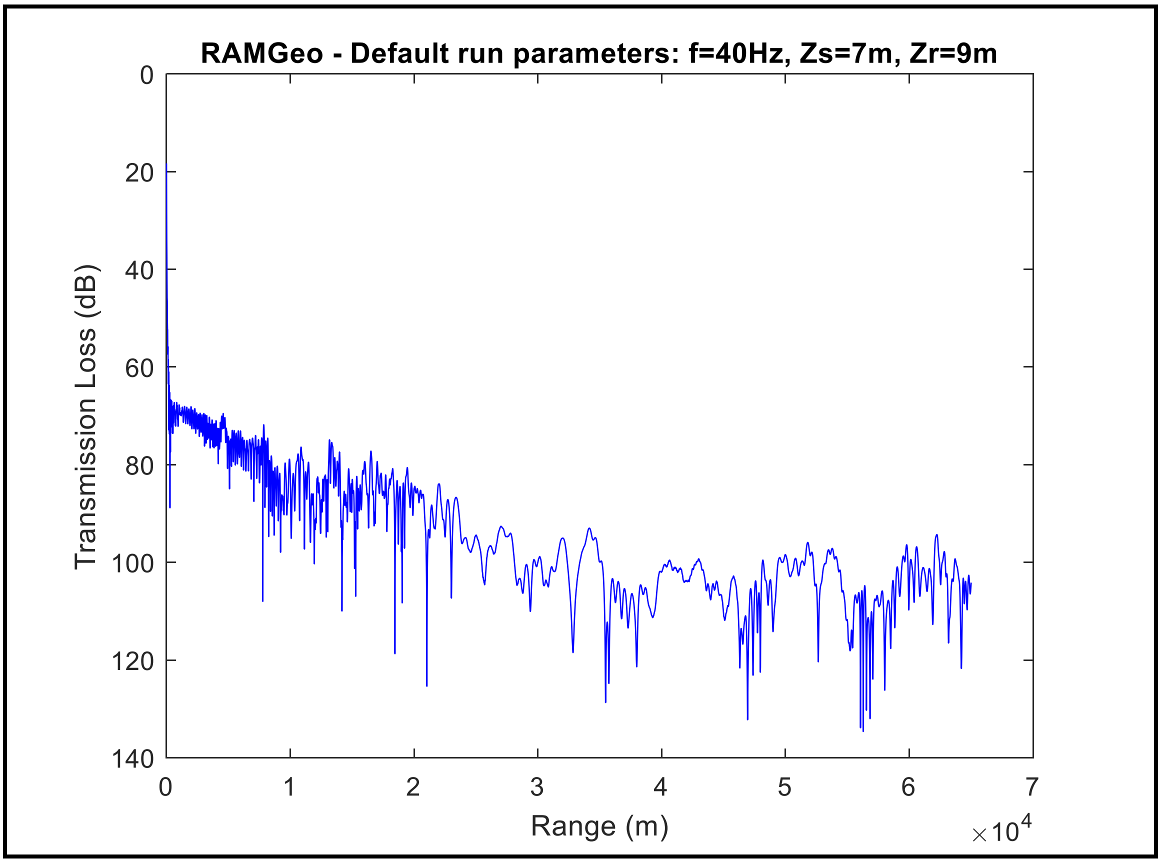
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 27 South-West Bathymetry at Point T1 Crete (34.917 Lat 26.376 Lon)



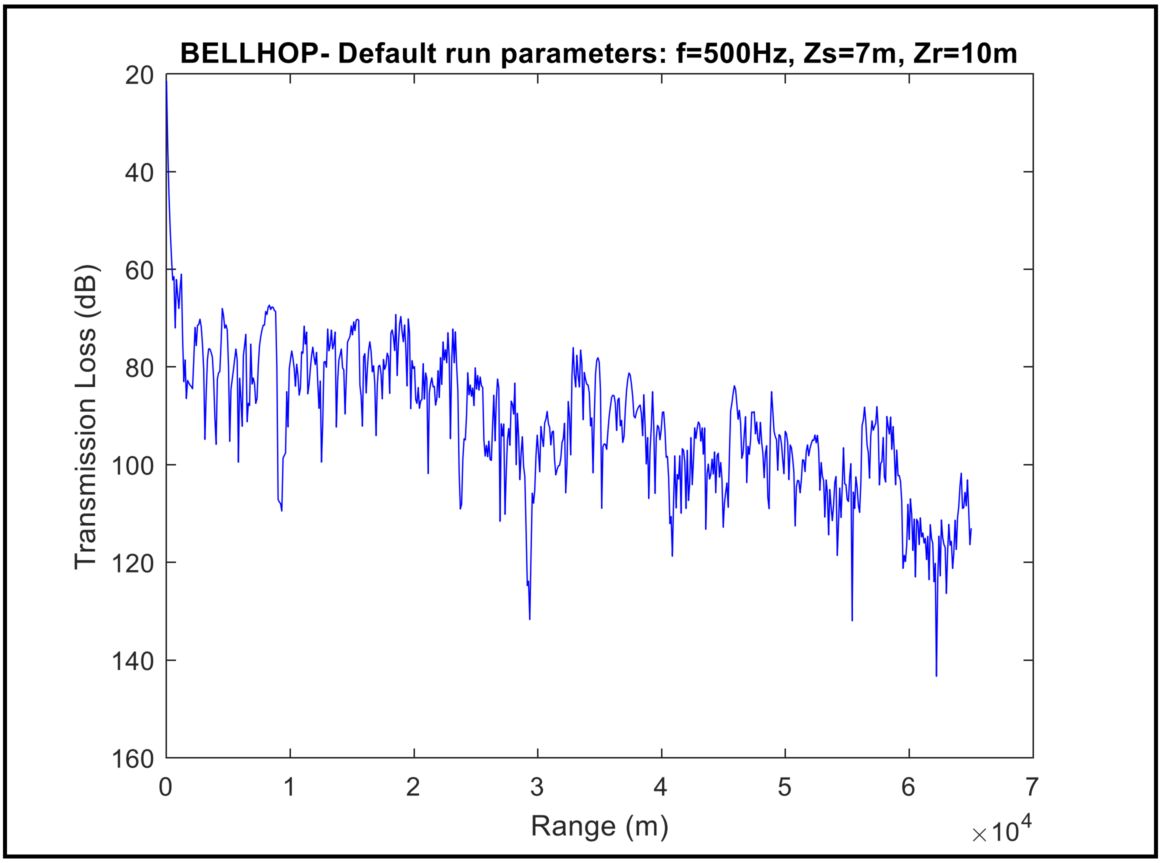
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 28 Transmission Loss vs Range. South-West Transect at Point T1 Crete (34.917 Lat 26. 376 Lon). RAMGEO. Frequency 16 Hz, Source Depth 7 m, Receiver Depth 7.5 m.



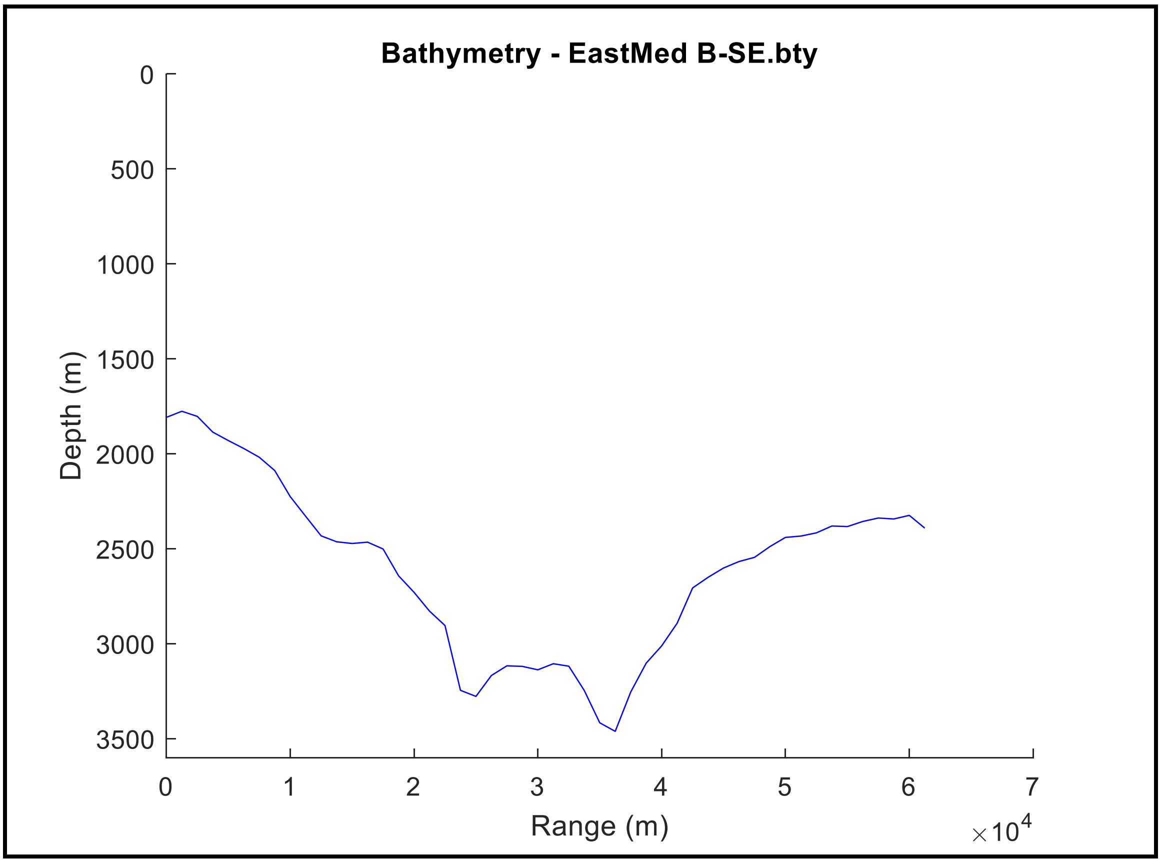
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 29 Transmission Loss vs Range. South-West Transect at Point T1 Crete (34.917 Lat 26.376 Lon). RAMGEO. Frequency 40 Hz, Source Depth 7 m, Receiver Depth 9 m.



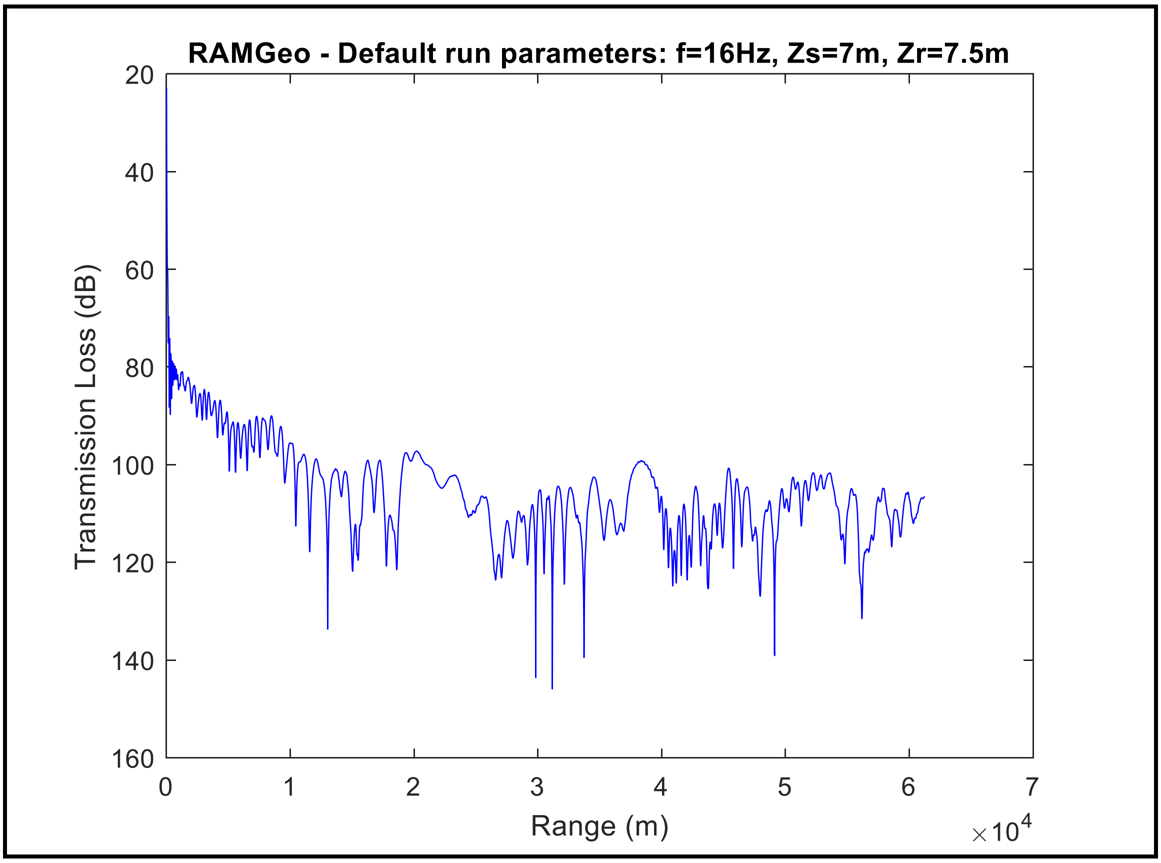
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 30 Transmission Loss vs Range. South-West Transect at Point T1 Crete (34.917 Lat 26.376 Lon). BOUNCE+BELLHOP. Frequency 500 Hz, Source depth 7m, receiver Depth 10 m.



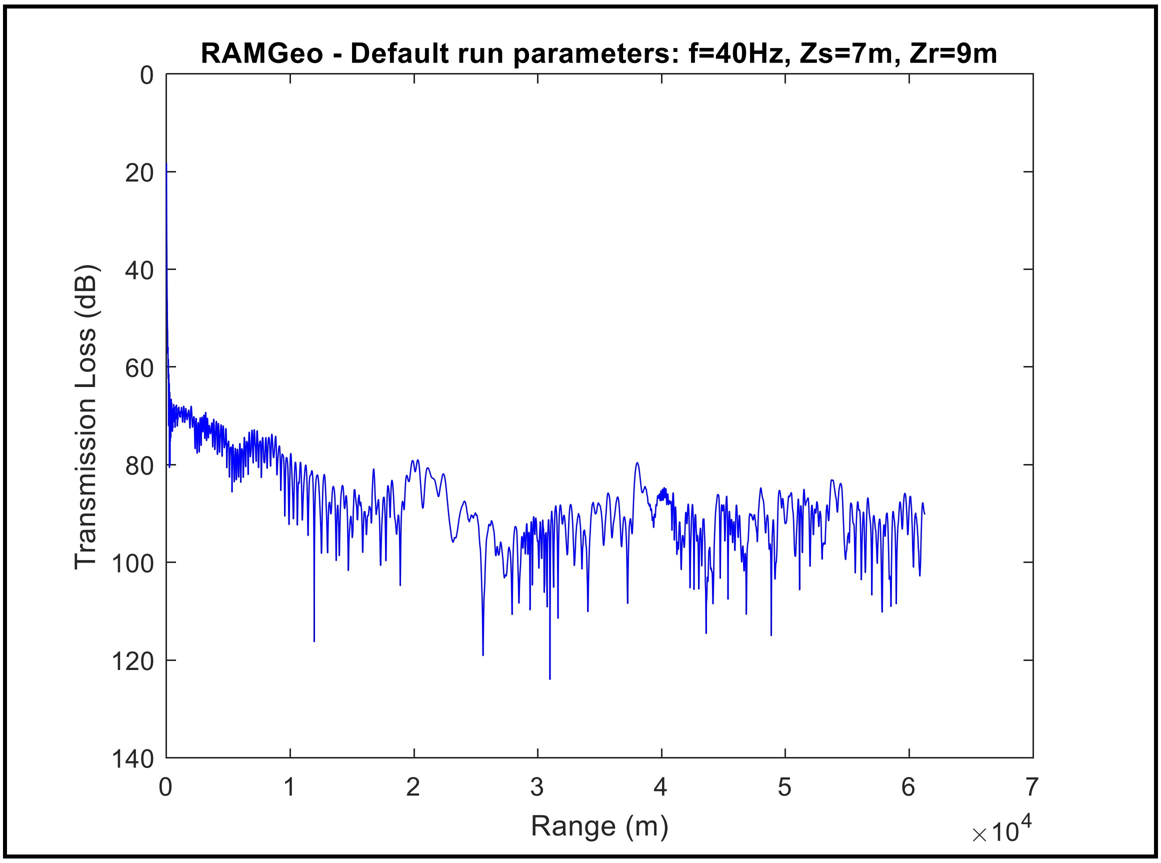
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 31 South-East Bathymetry at Point T1 Crete (34.917 Lat 26.376 Lon)



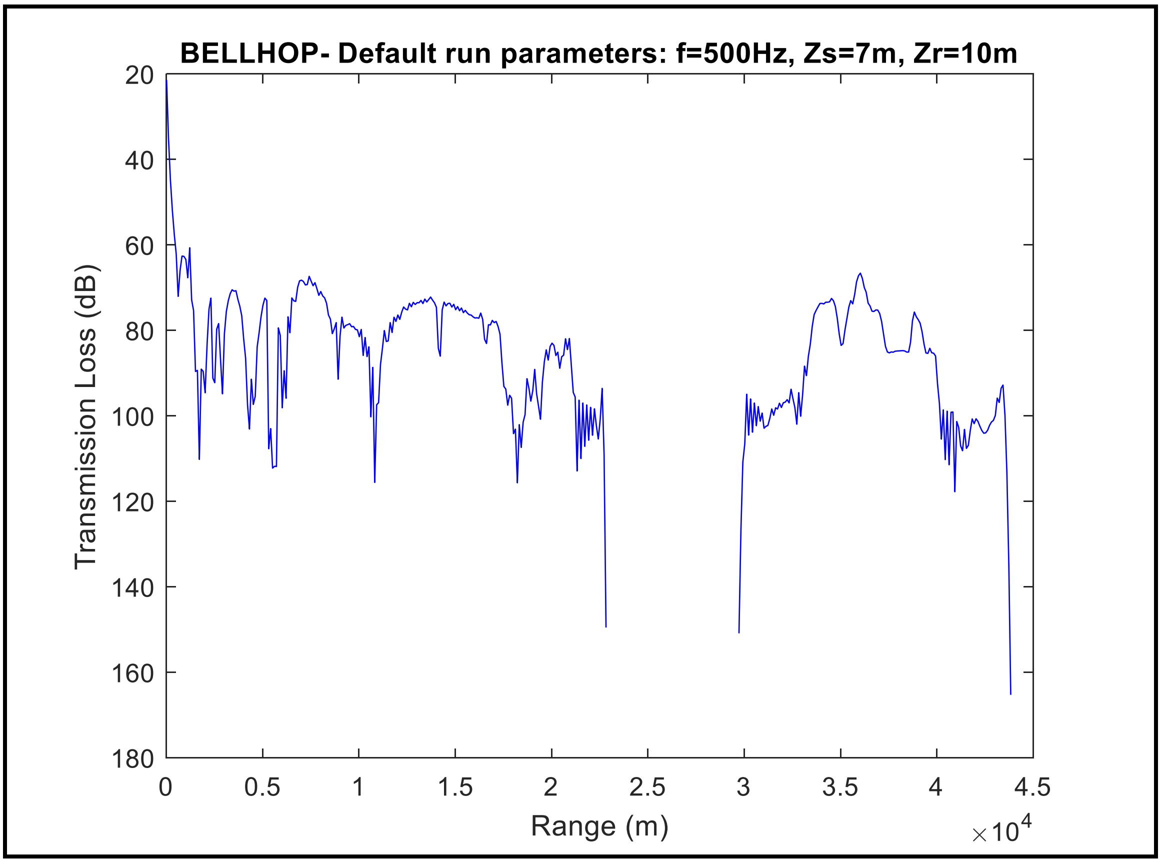
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 32 Transmission Loss vs Range. South-East Transect at Point T1 Crete (34.917 Lat 26.376 Lon). RAMGEO. Frequency 16 Hz, Source Depth 7 m, Receiver Depth 7.5 m.



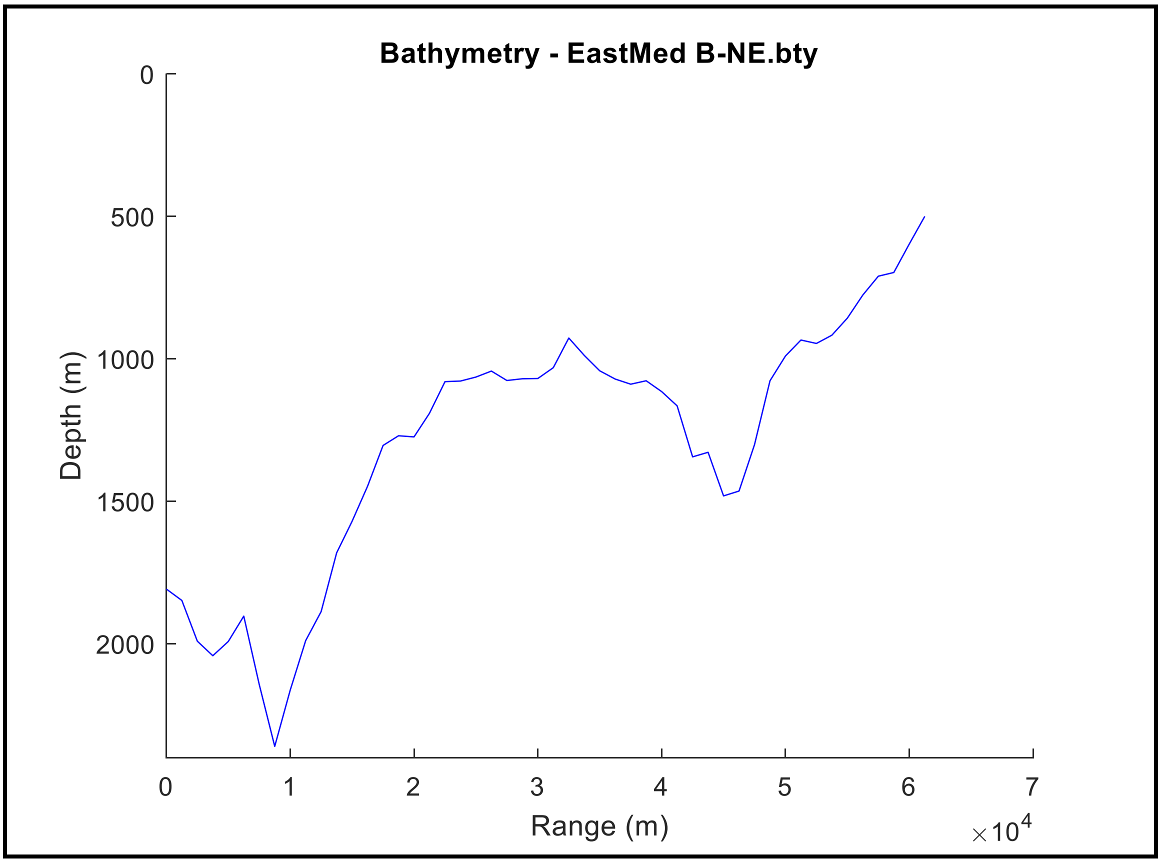
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 33 Transmission Loss vs Range. South-East Transect at Point T1 Crete (34.917 Lat 26.376 Lon). RAMGEO. Frequency 40 Hz, Source Depth 7 m, Receiver Depth 9 m.



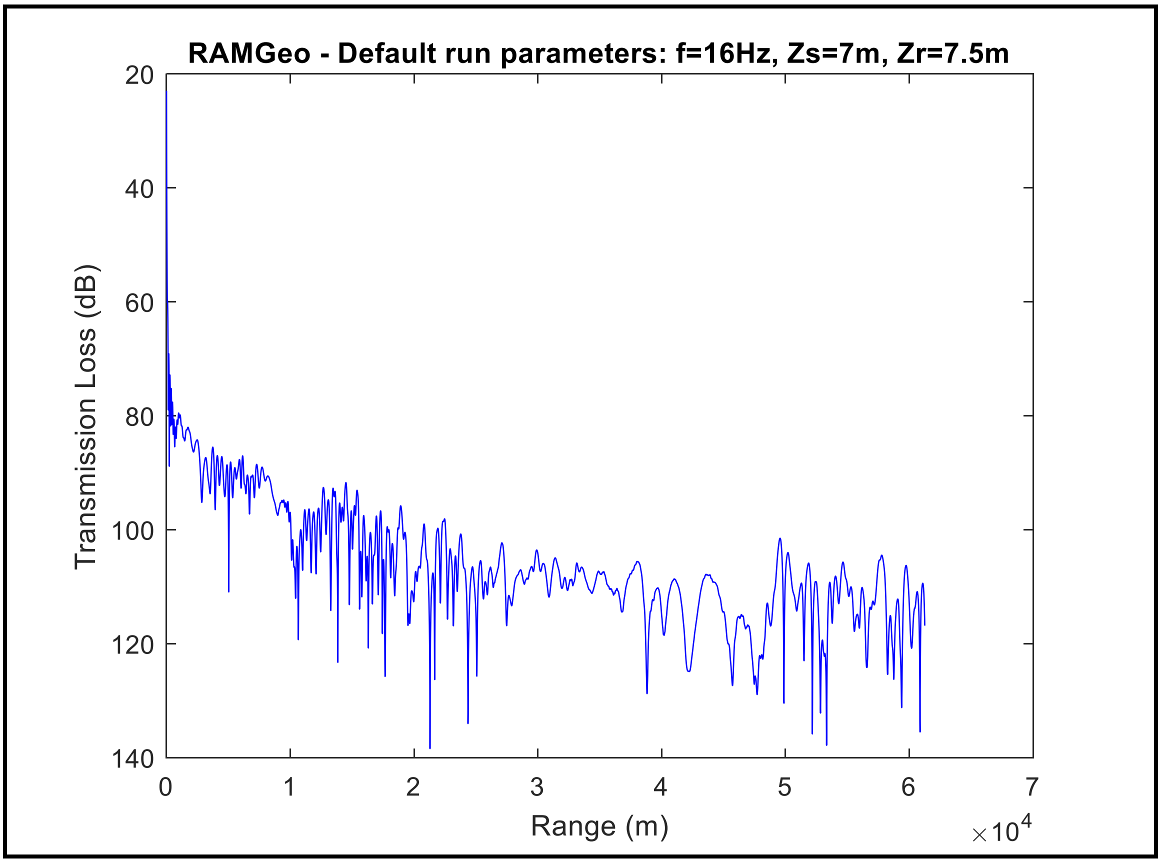
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 34 Transmission Loss vs Range. South-East Transect at Point T1 Crete (34.917 Lat 26.376 Lon). BOUNCE+BELLHOP. Frequency 500 Hz, Source Depth 7 m, Receiver Depth 10 m.



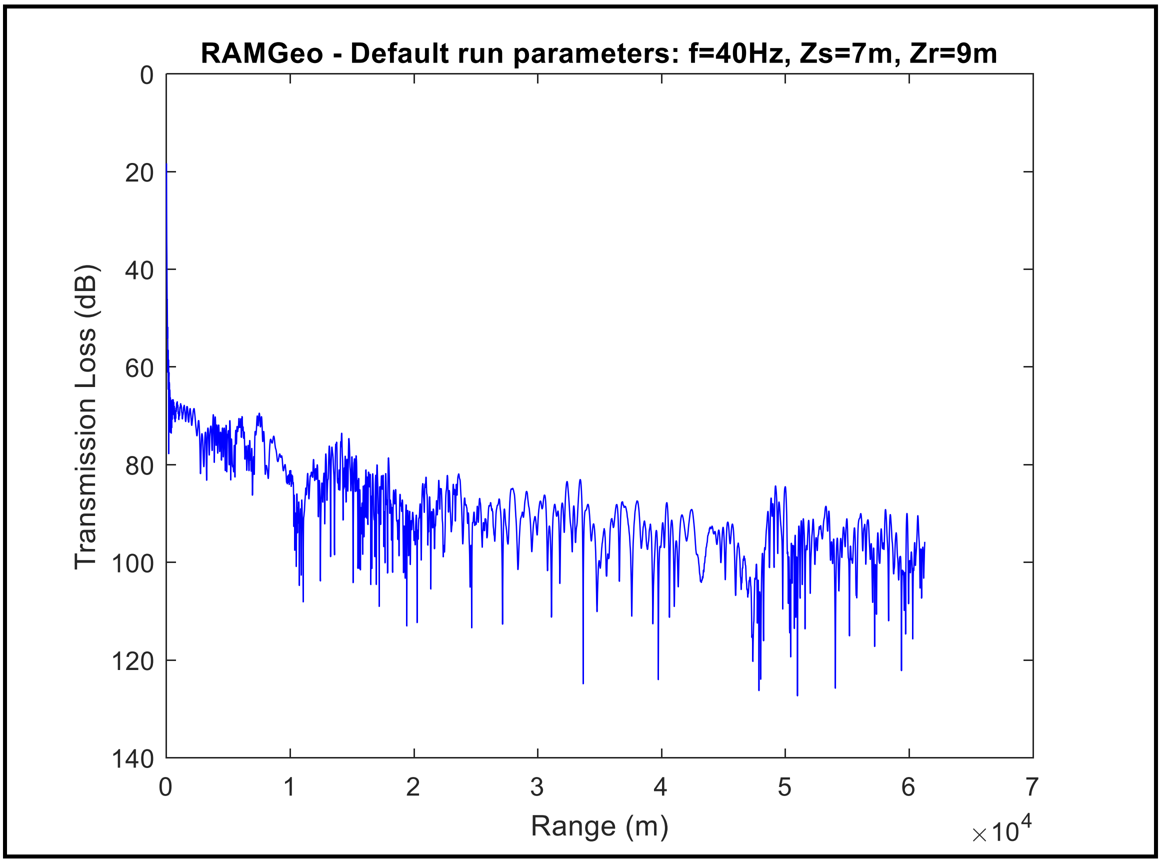
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 35 North-East Bathymetry at Point T1 Crete (34.917 Lat 26.376 Lon)



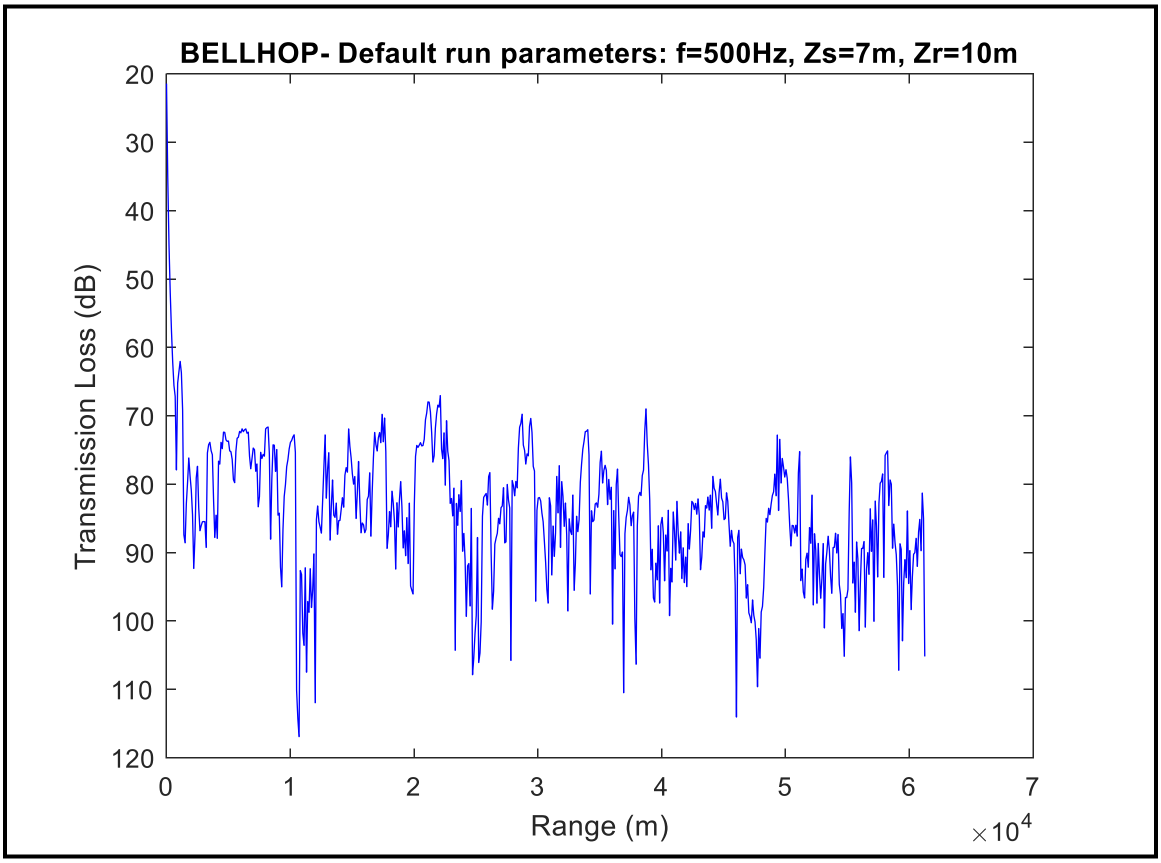
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 36 Transmission Loss vs Range. North-East Transect at Point T1 Crete (34.917 Lat 26.376 Lon). RAMGEO. Frequency 16 Hz, Source Depth 7 m, Receiver Depth 7.5 m.



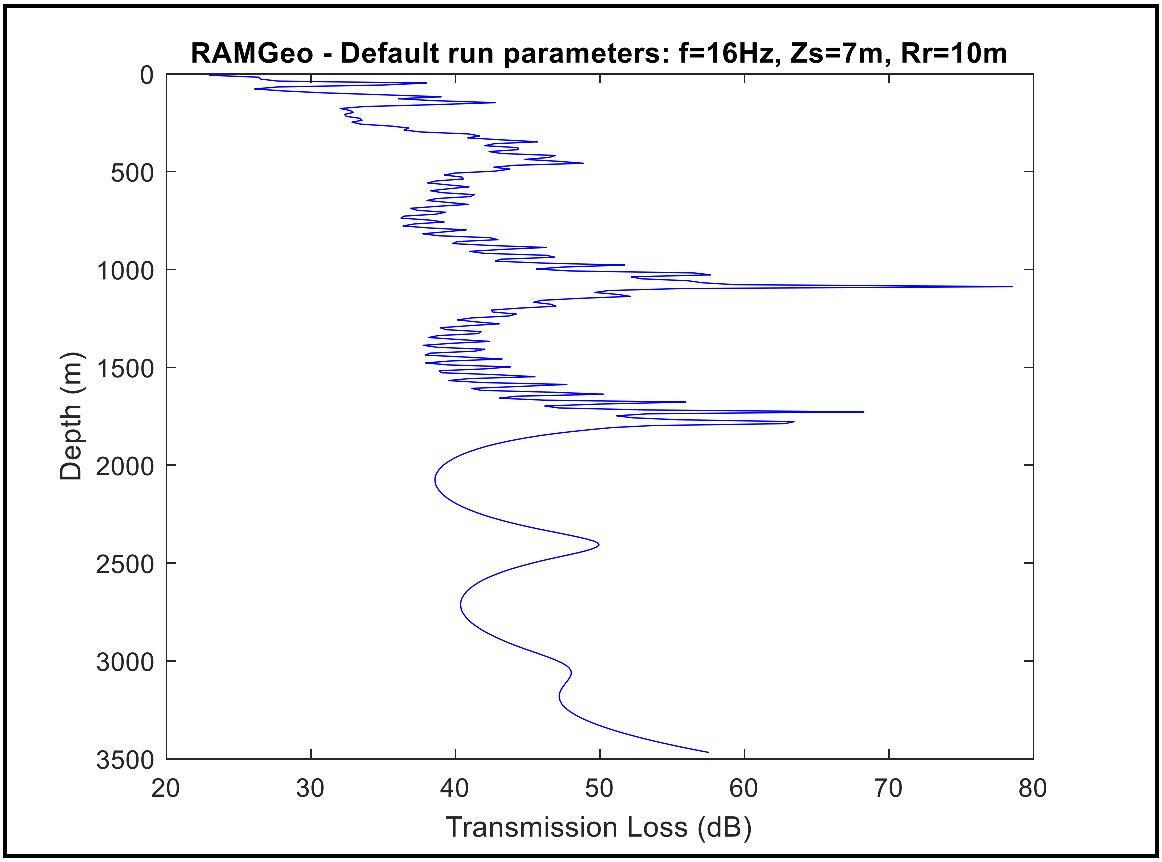
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 37 Transmission Loss vs Range. North-East Transect at Point T1 Crete (34.917 Lat 26.376 Lon). RAMGEO. Frequency 40 Hz, Source Depth 7 m, Receiver Depth 9 m.



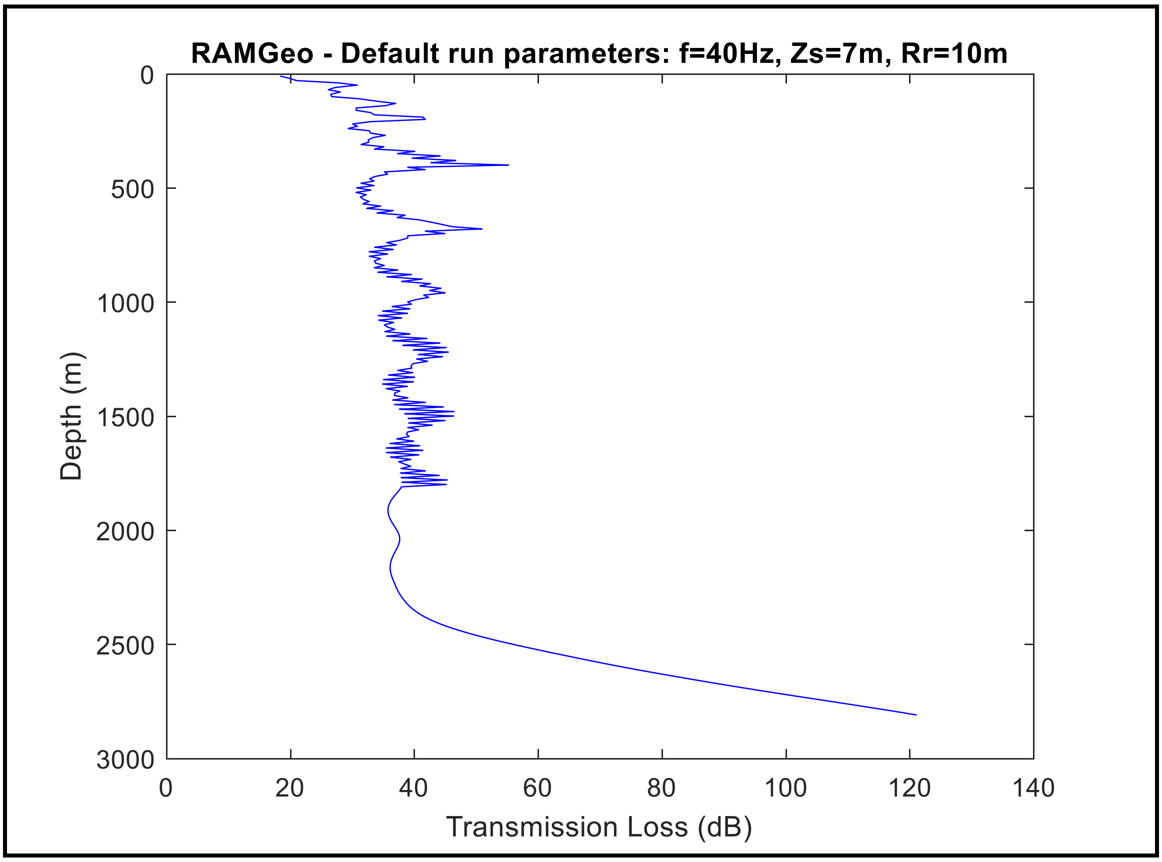
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 38 Transmission Loss vs Range. North-East Transect at Point T1 Crete (34.917 Lat 26.376 Lon). BOUNCE+BELLHOP. Frequency 500 Hz, Source Depth 7 m, Receiver Depth 10 m.



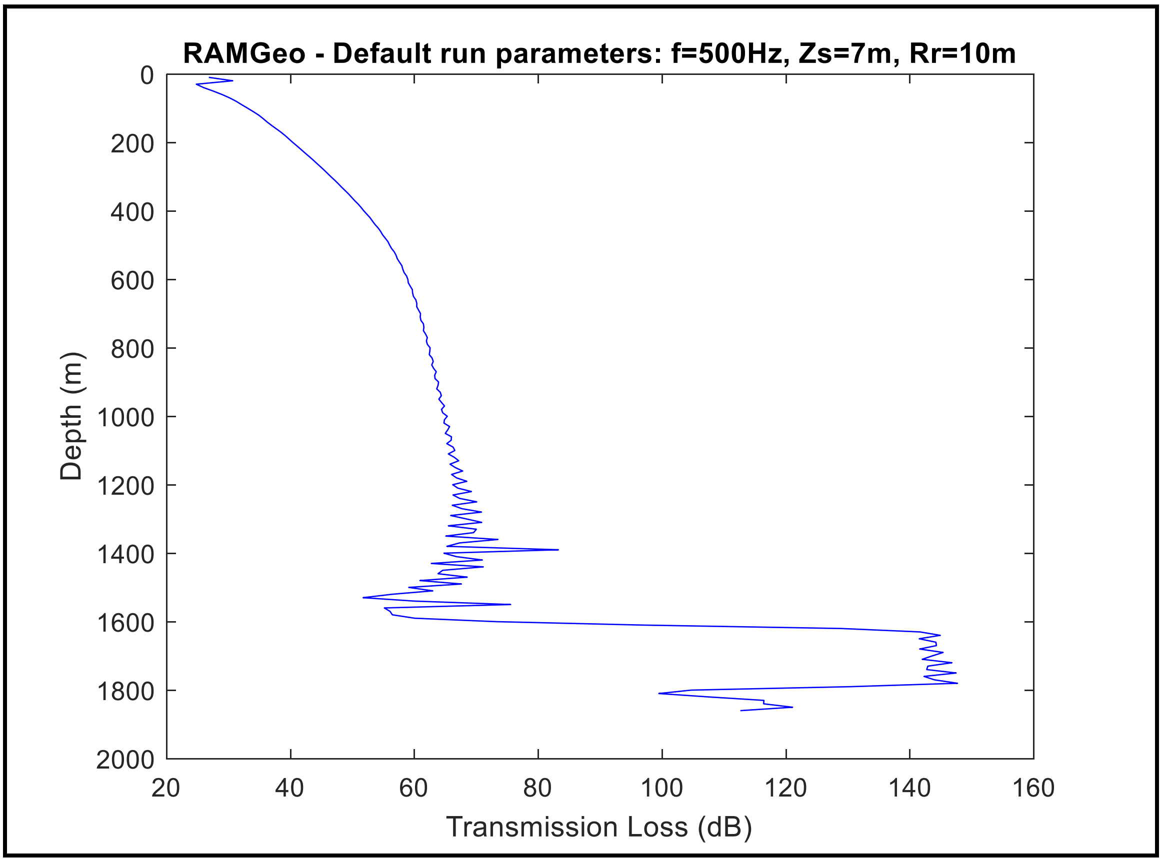
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 39 Transmission Loss vs Depth. At Point T1 Crete (34.917 Lat 26.376 Lon). RAMGEO. Frequency 16 Hz, Source Depth 7 m, Receiver Depth 10 m.



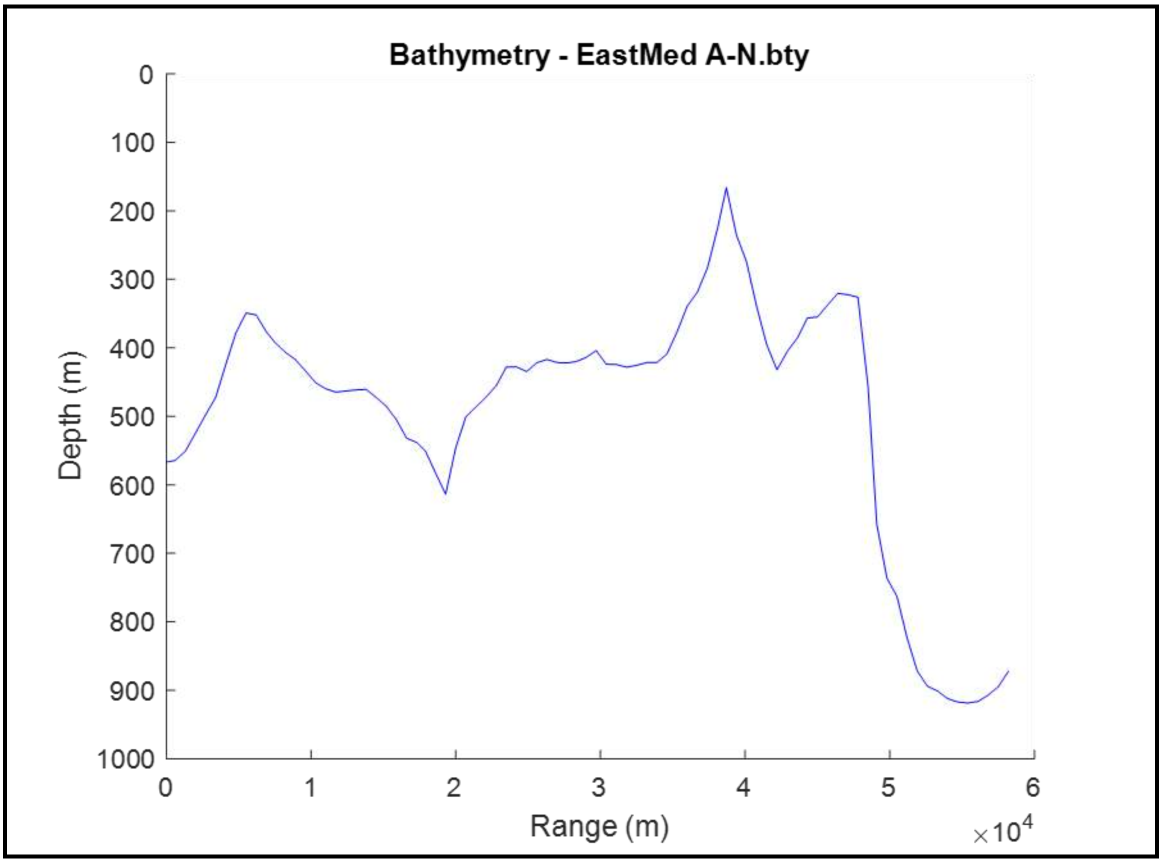
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 40 Transmission Loss vs Depth. At point T1 Crete (34.917 Lat 26.376 Lon). RAMGEO. Frequency 40 Hz, Source Depth 7 m, Receiver Depth 10 m.



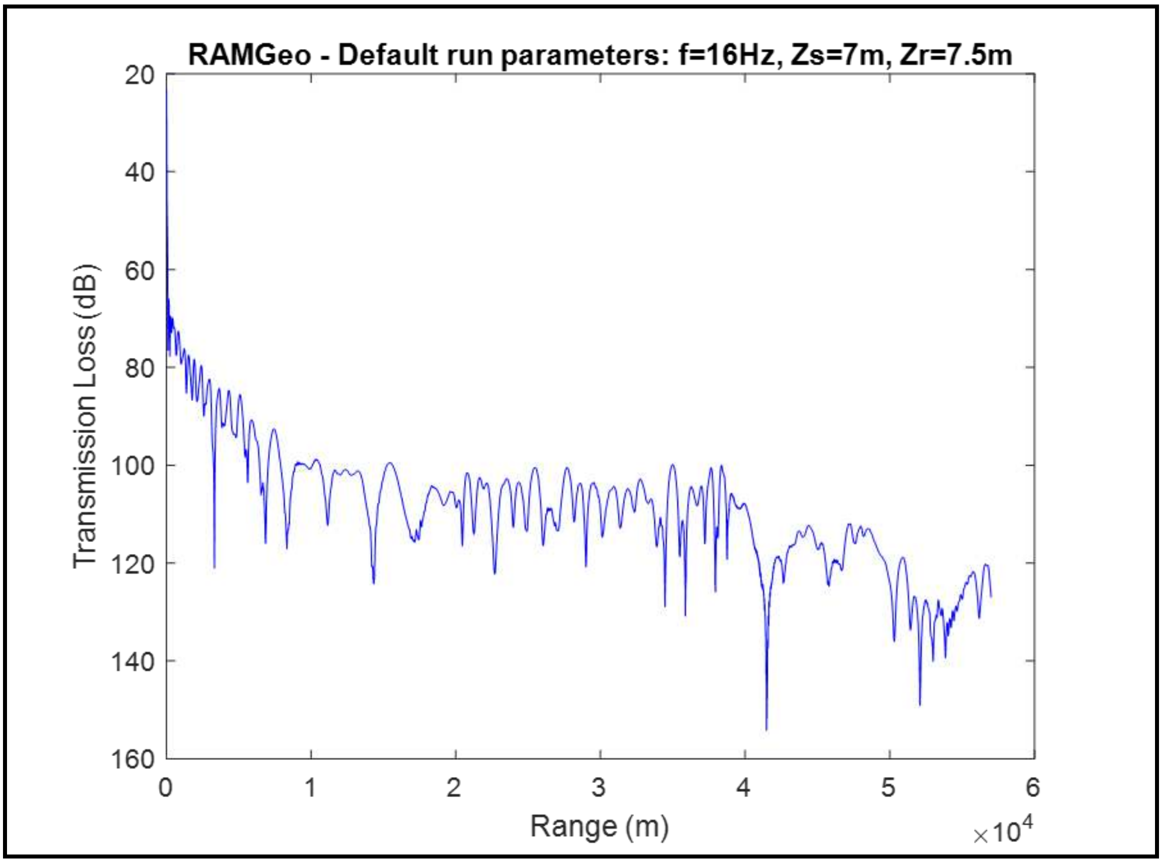
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 41 Transmission Loss vs Depth. At Point T1 Crete (34.917 Lat 26.376 Lon). BELLHOP+BOUNCE. Frequency 500 Hz, Source Depth 7 m, Receiver Depth 10 m.



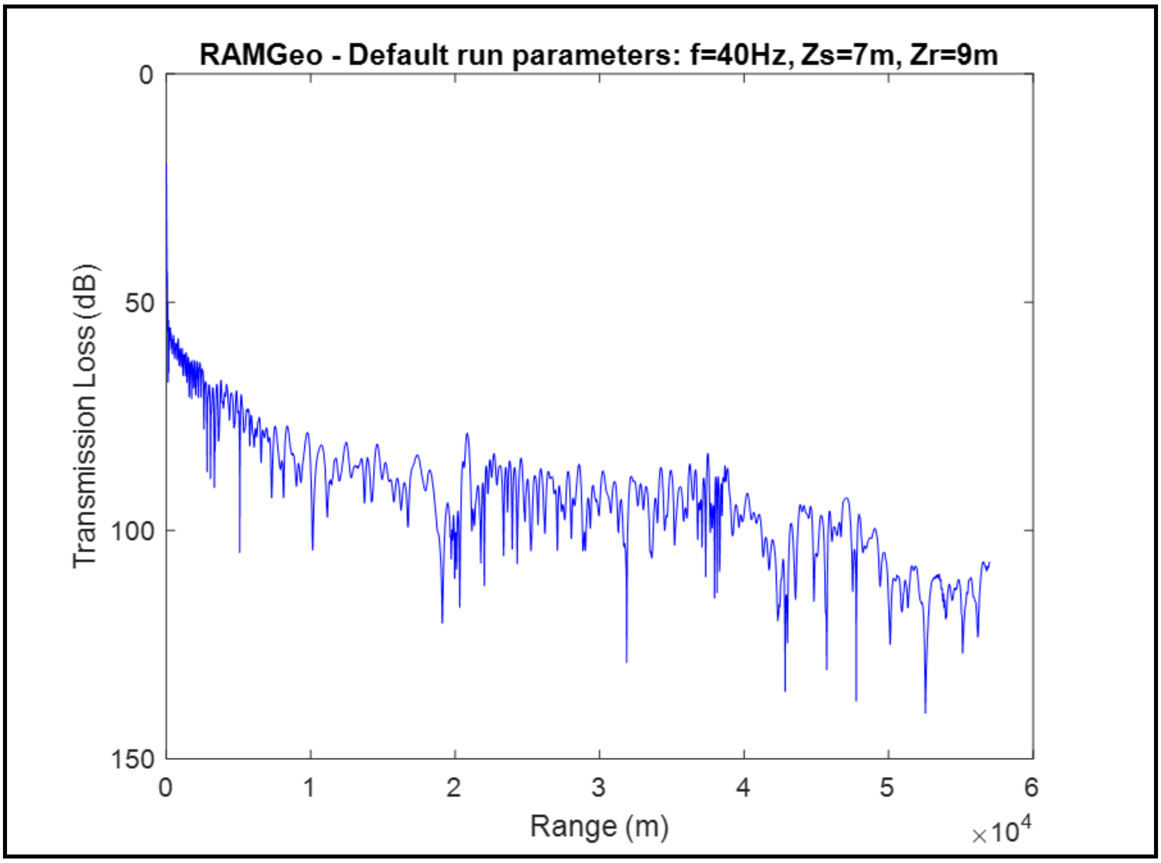
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 42 Peloponnese Noise Source at lat 36.422^0, lon 23.567^0. Bathymetry in the North Direction



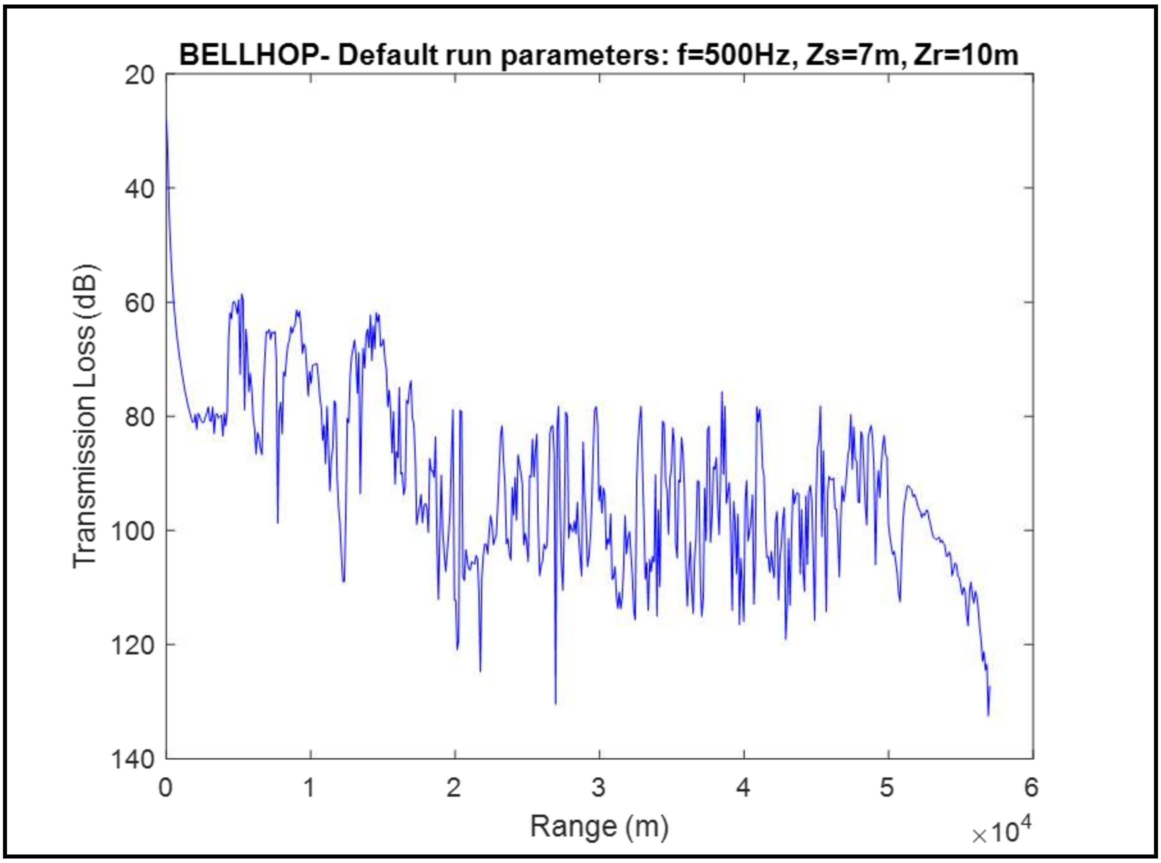
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 43 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Range at 16Hz in the North Direction. Propagation Prediction Code: RAMGEO



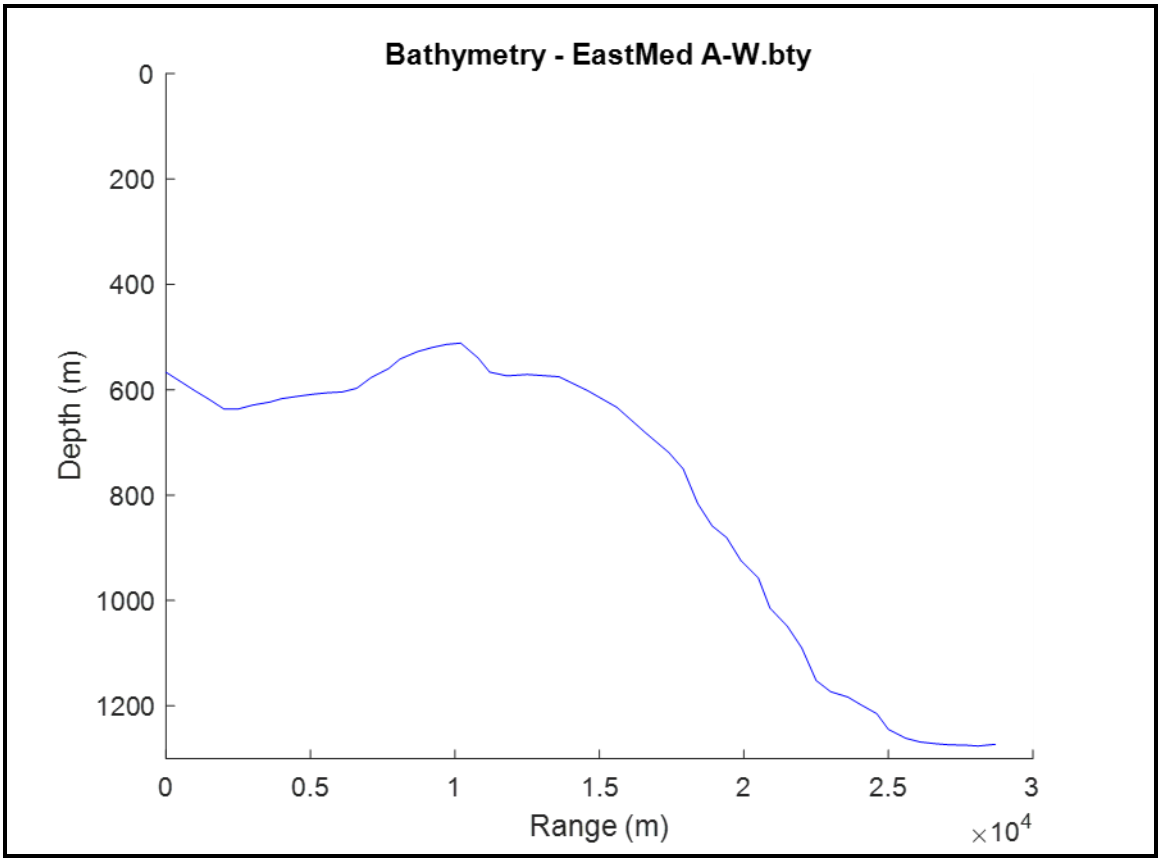
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 44 Peloponnese. Noise Source at lat 36.422°, lon 23.567°. Transmission Loss vs Range at 40Hz in the North Direction. Propagation Prediction Code: RAMGEO



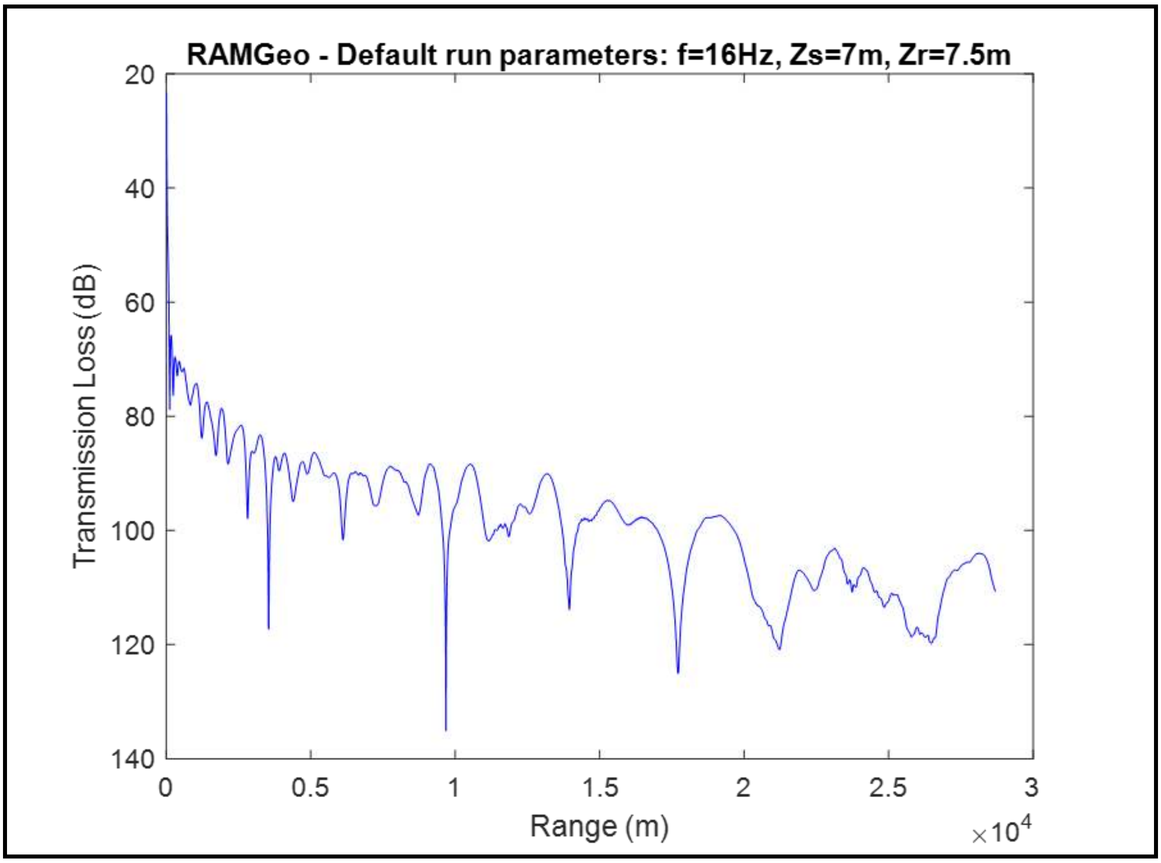
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 45 Peloponnese. Noise Source at lat 36.422°, lon 23.567°. Transmission Loss vs Range at 500Hz in the North Direction. Propagation Prediction Code: BOUNCE + BELLHOP



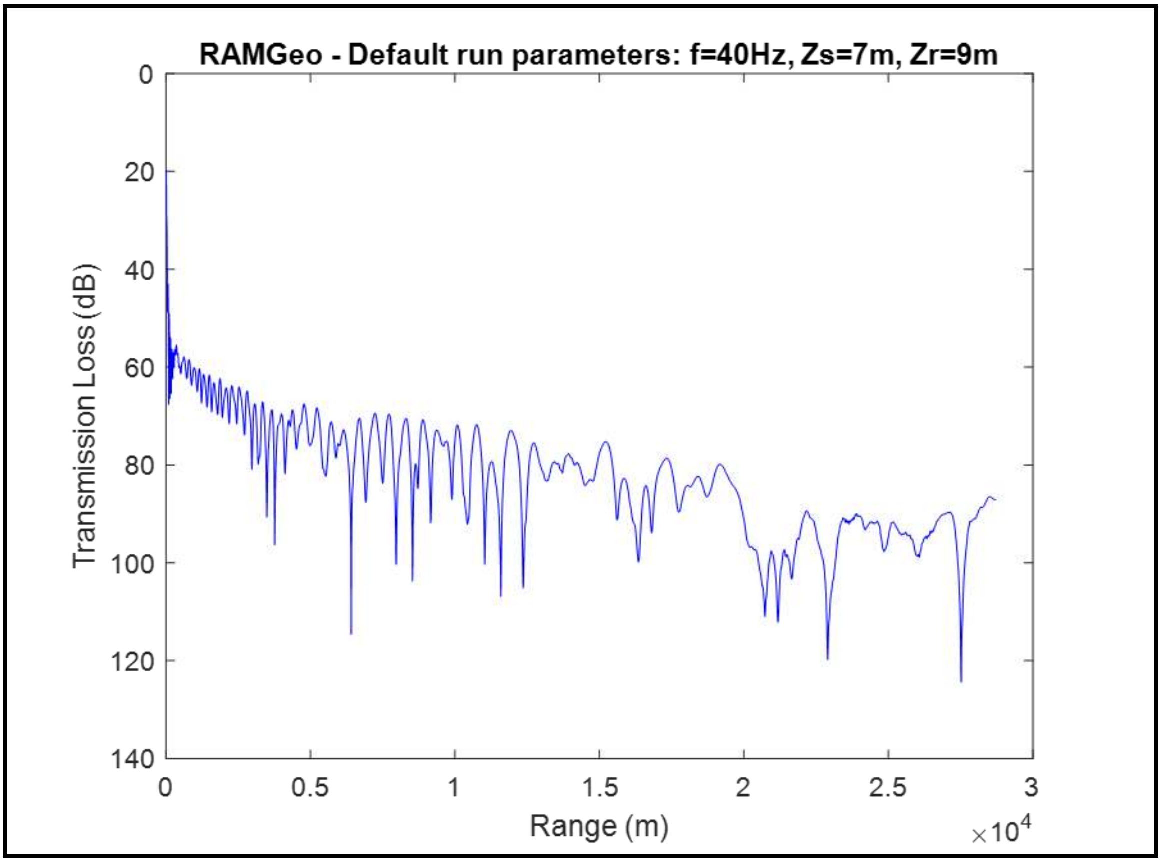
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 46 Peloponnese. Noise Source at lat 36.422^{0}, lon 23.567^{0}. Bathymetry in the West Direction



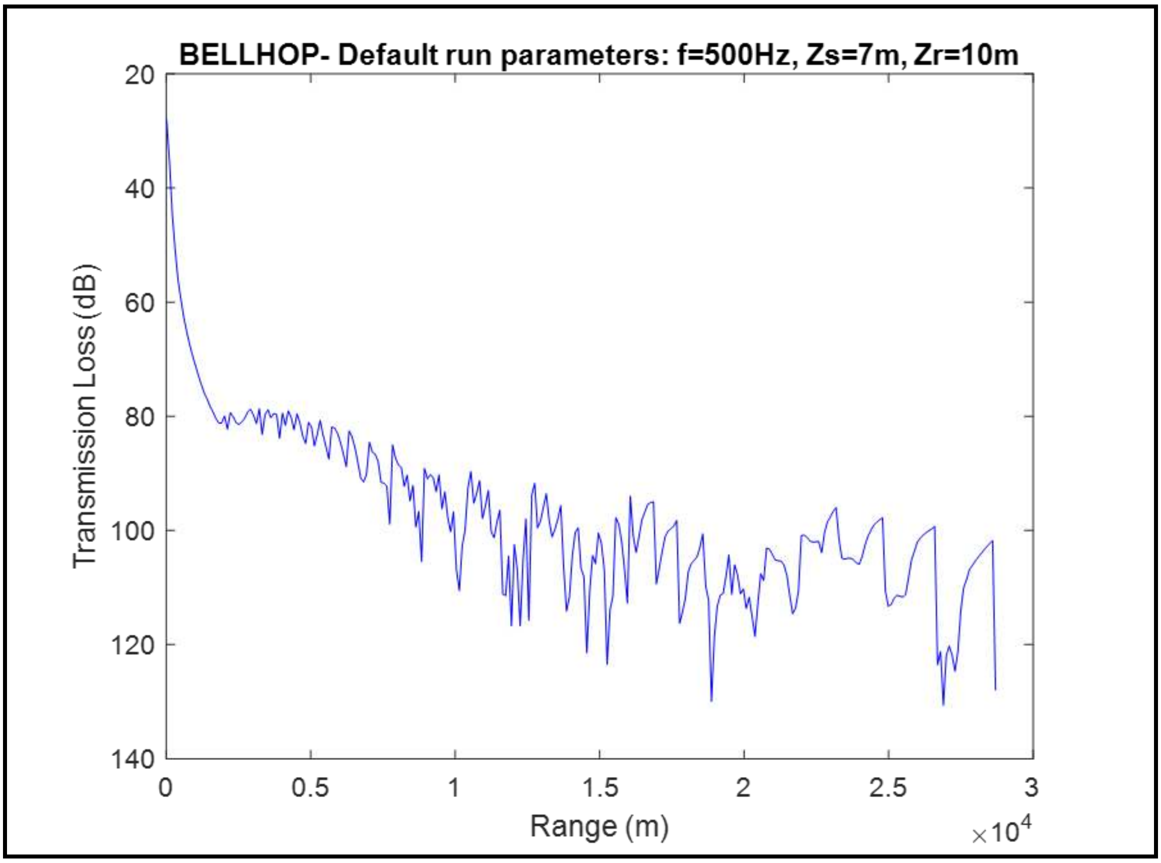
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 47 Peloponnese. Noise Source at lat 36.422^{0}, lon 23.567^{0}. Transmission Loss vs Range at 16Hz in the West Direction. Propagation Prediction Code: RAMGEO



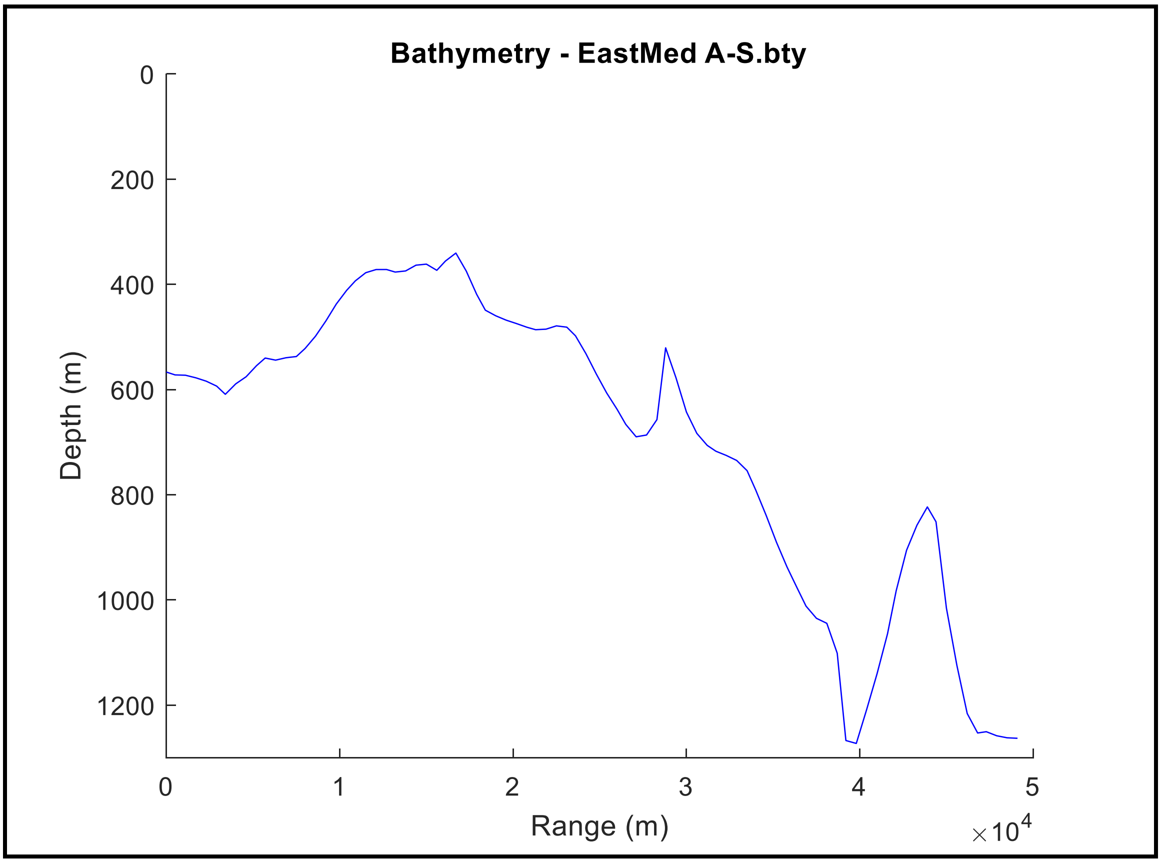
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 48 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Range at 40Hz in the West Direction. Propagation Prediction Code: RAMGEO



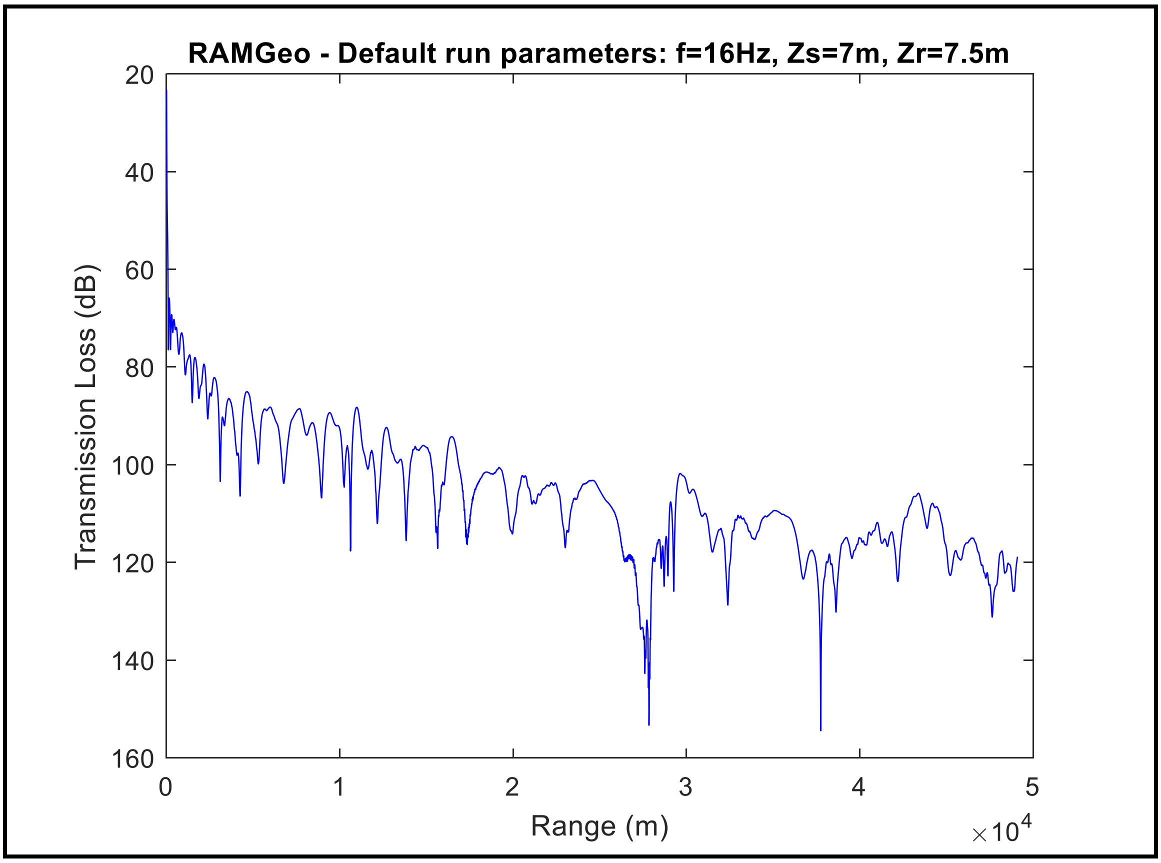
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 49 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Range at 500Hz in the West Direction. Propagation Prediction Code: BOUNCE + BELLHOP



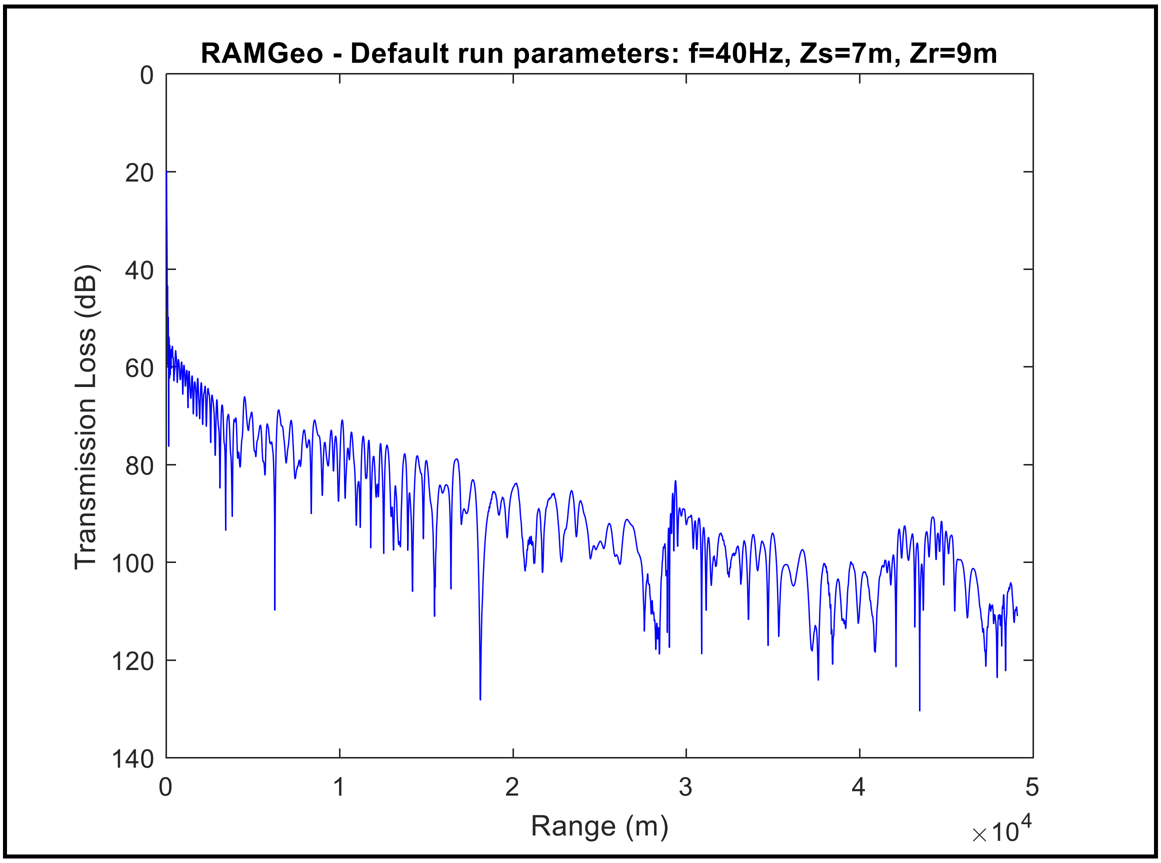
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 50 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Bathymetry in the South Direction



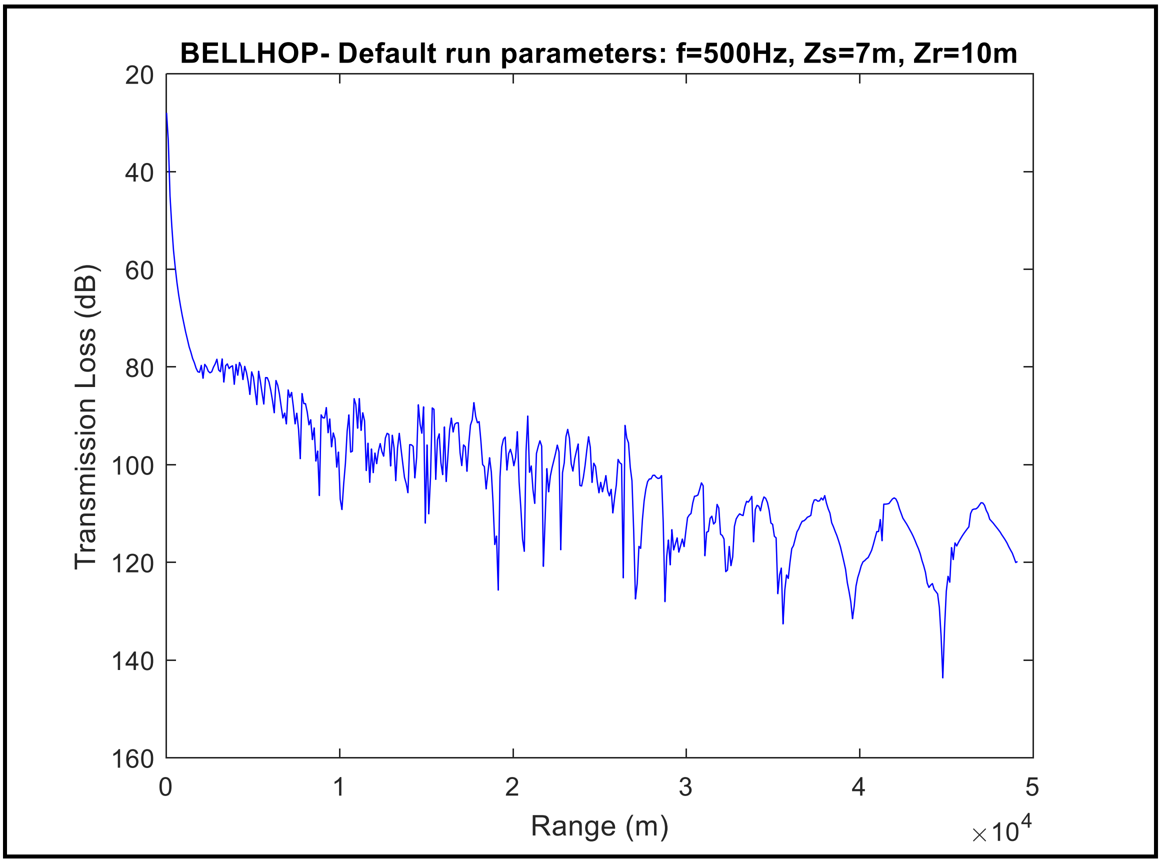
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 51 Peloponnese. Noise source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Range at 16Hz in the South Direction. Propagation Prediction Code: RAMGEO



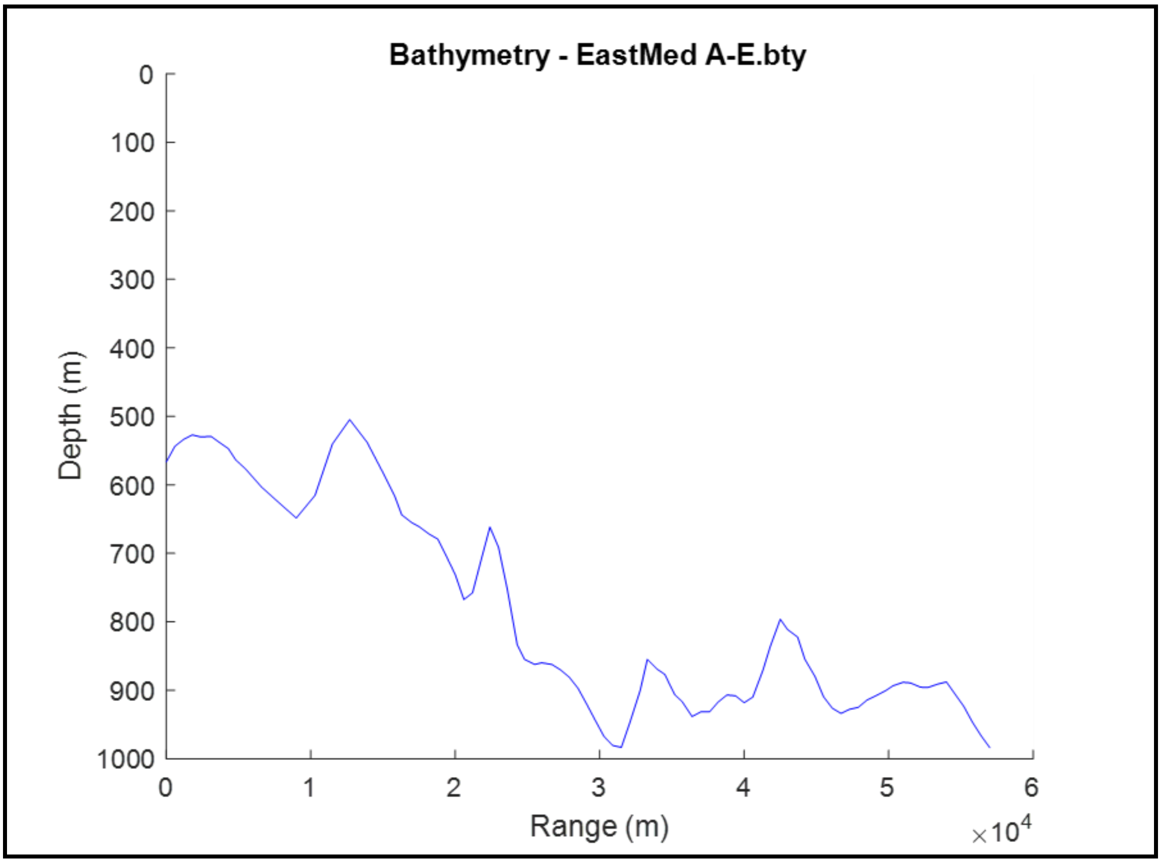
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 52 Peloponnese. Noise Source at lat 36.422⁰, lon 23.567⁰. Transmission Loss vs Range at 40Hz in the South Direction. Propagation Prediction Code: RAMGEO



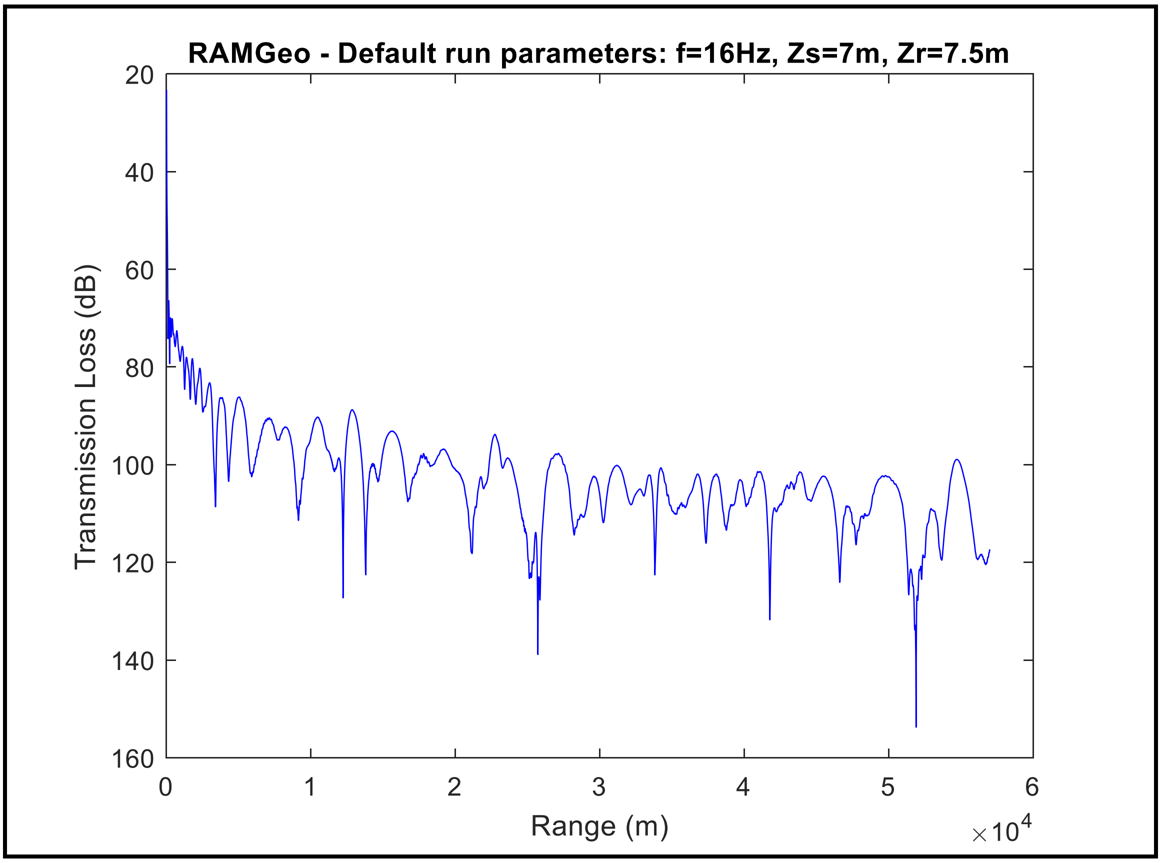
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 53 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Range at 500Hz in the South Direction. Propagation Prediction Code: BOUNCE + BELLHOP



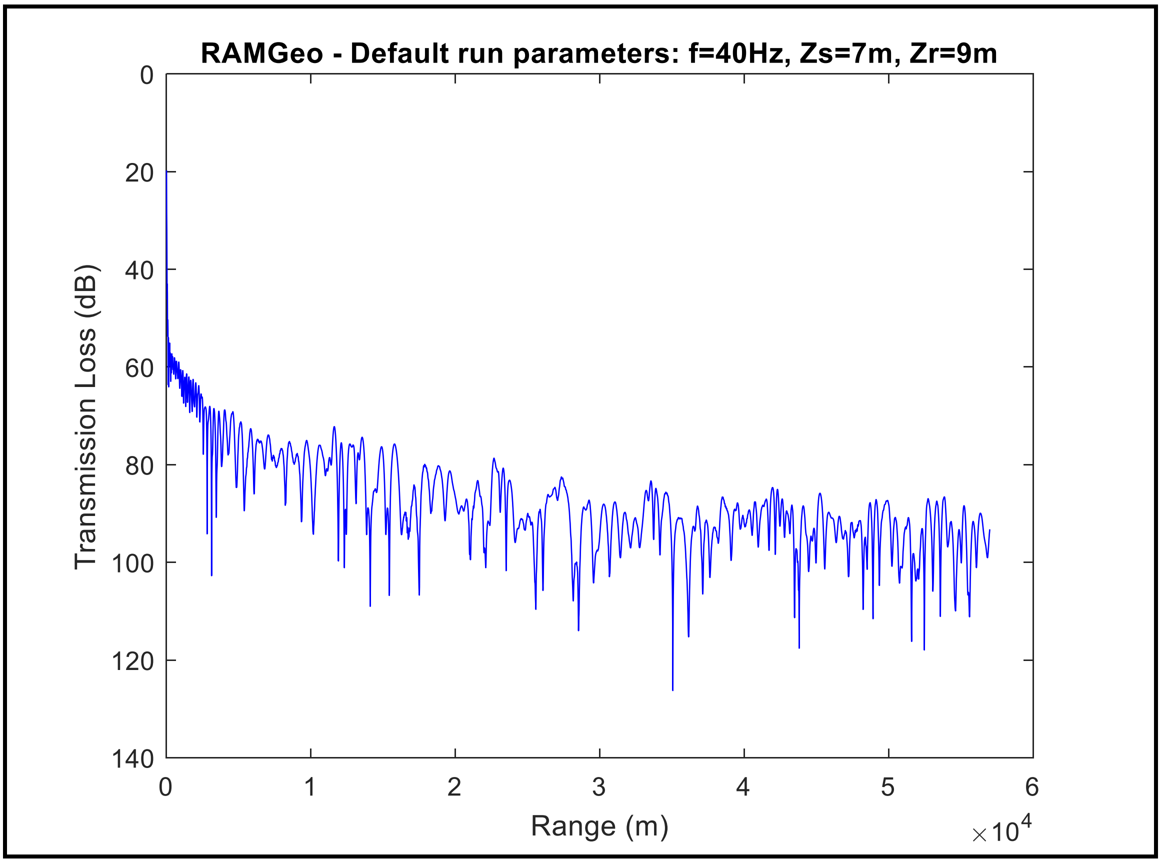
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 54 Peloponnese. Noise Source at lat 36.422^{0}, lon 23.567^{0}. Bathymetry in the East Direction



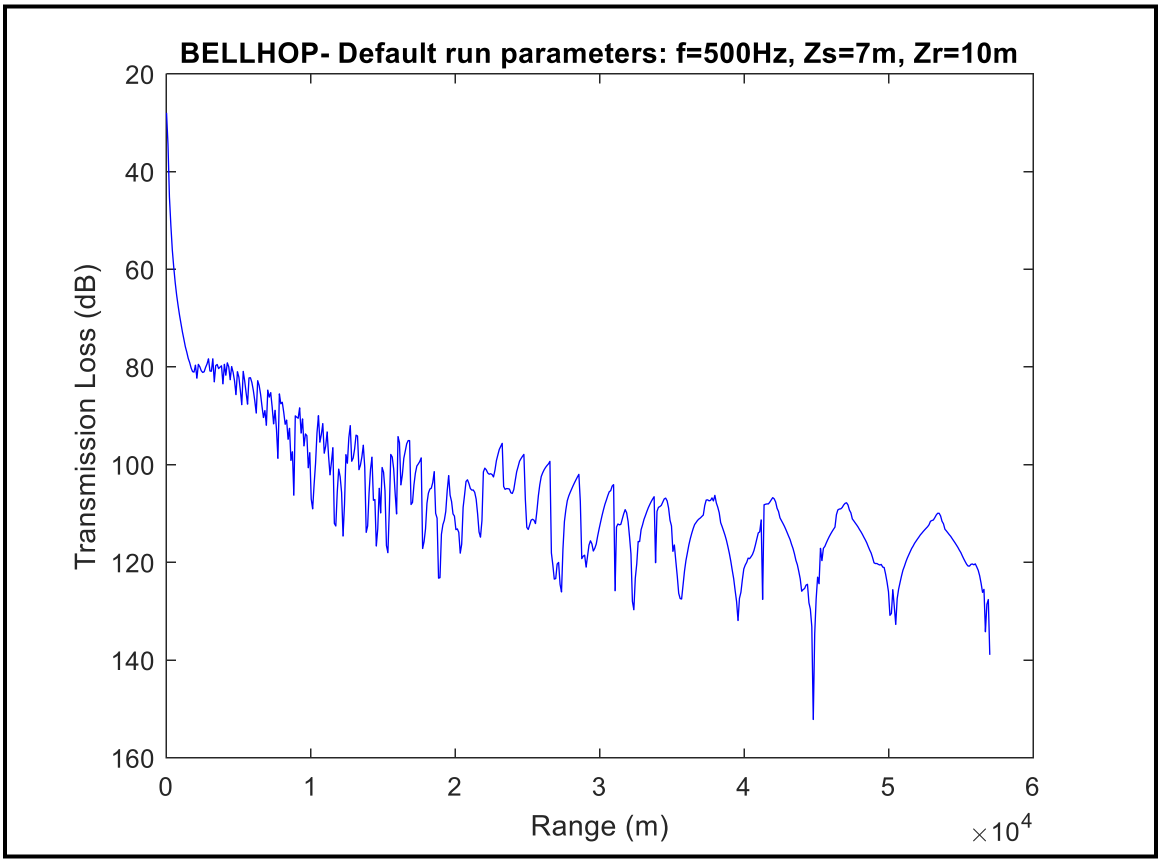
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 55 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Range at 16Hz in the East Direction. Propagation Prediction Code: RAMGEO



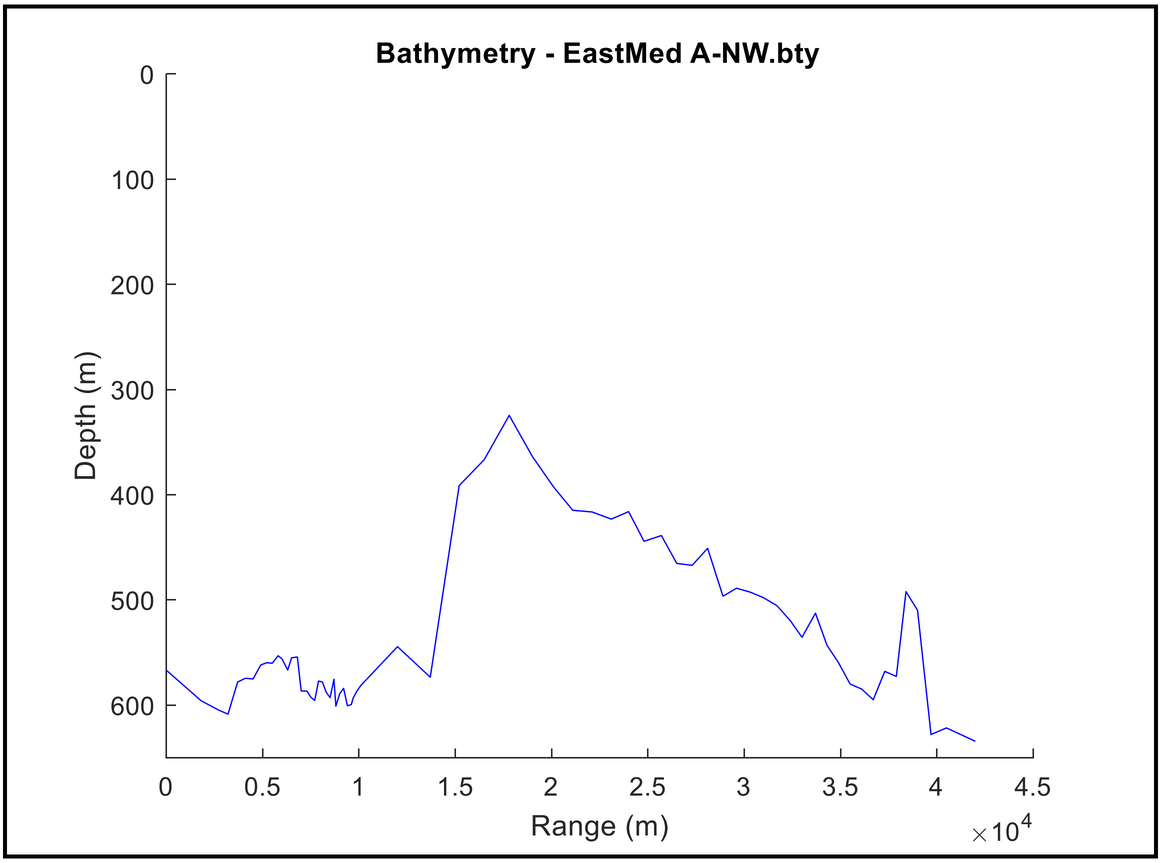
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 56 Peloponnese. Noise Source at lat 36.422°, lon 23.567°. Transmission Loss vs Range at 40Hz in the East Direction. Propagation Prediction Code: RAMGEO



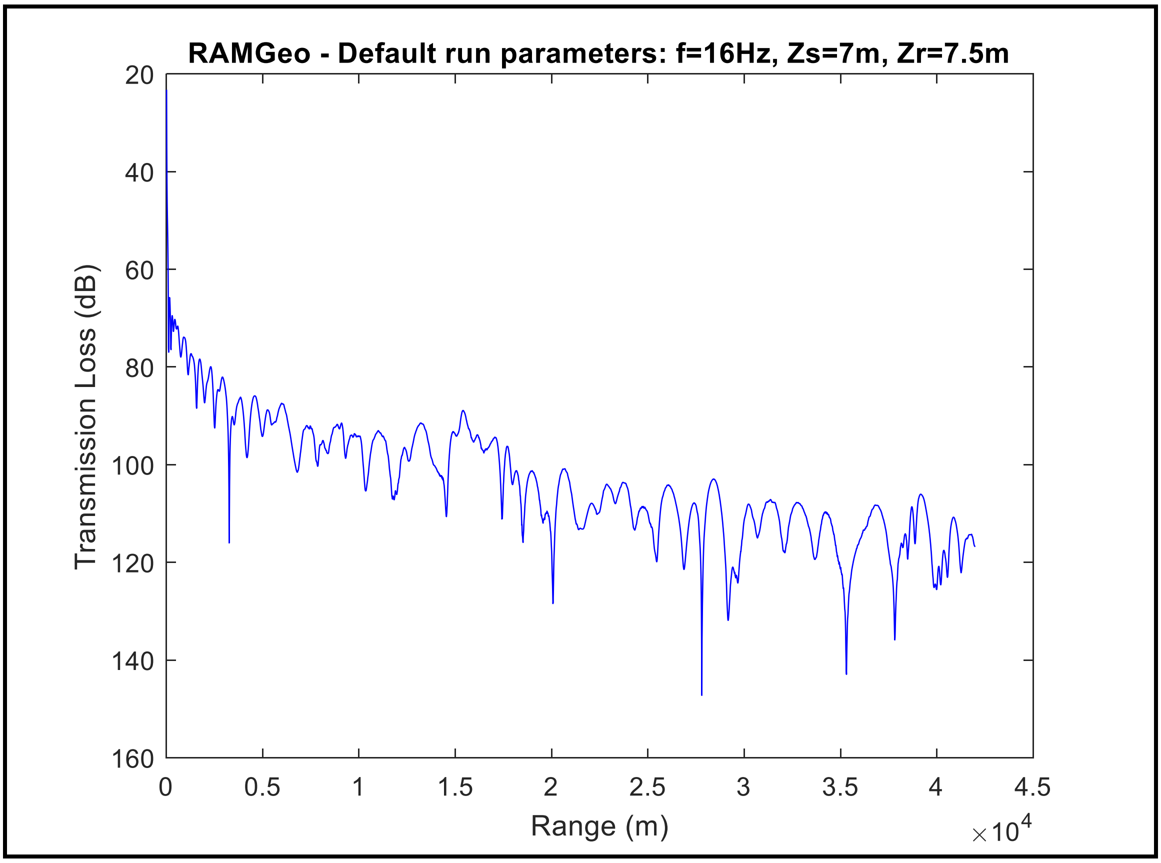
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 57 Peloponnese. Noise Source at lat 36.422°, lon 23.567°. Transmission Loss vs Range at 500Hz in the East Direction. Propagation Prediction Code: BOUNCE + BELLHOP



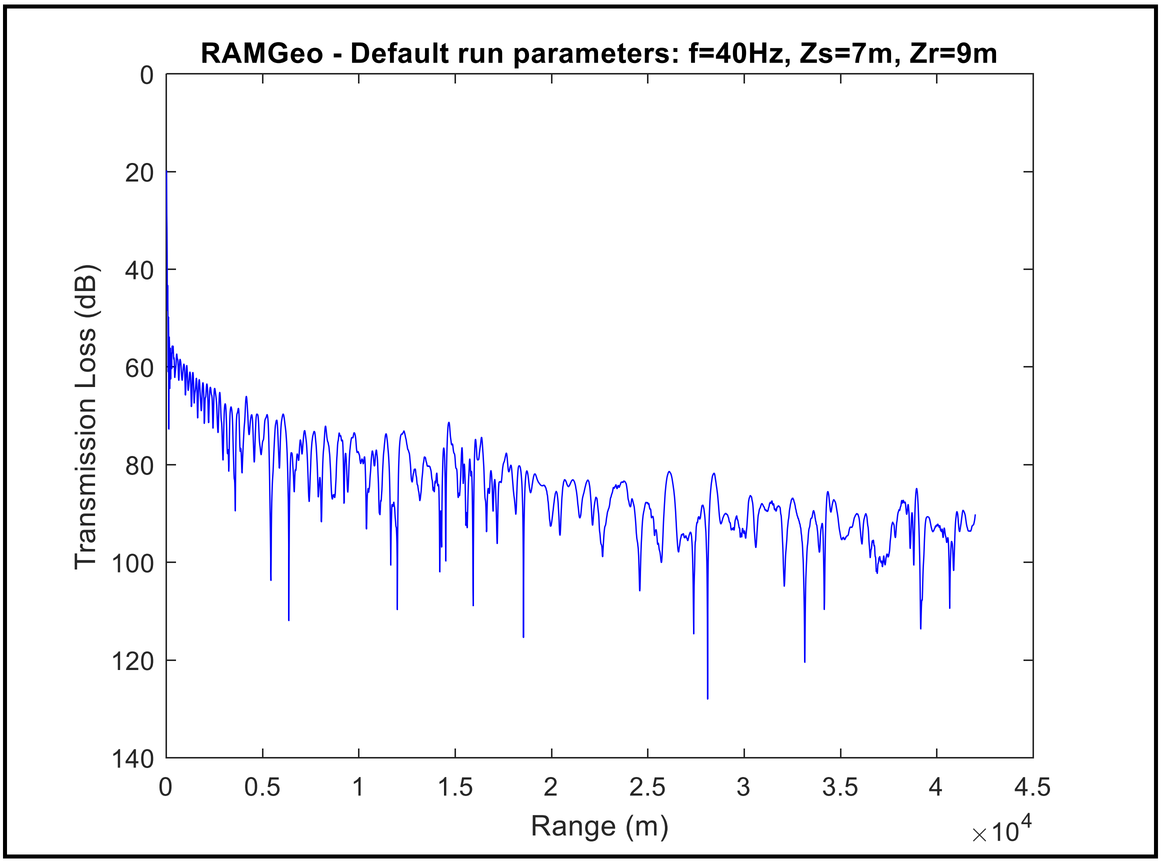
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 58 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Bathymetry in the North-West Direction



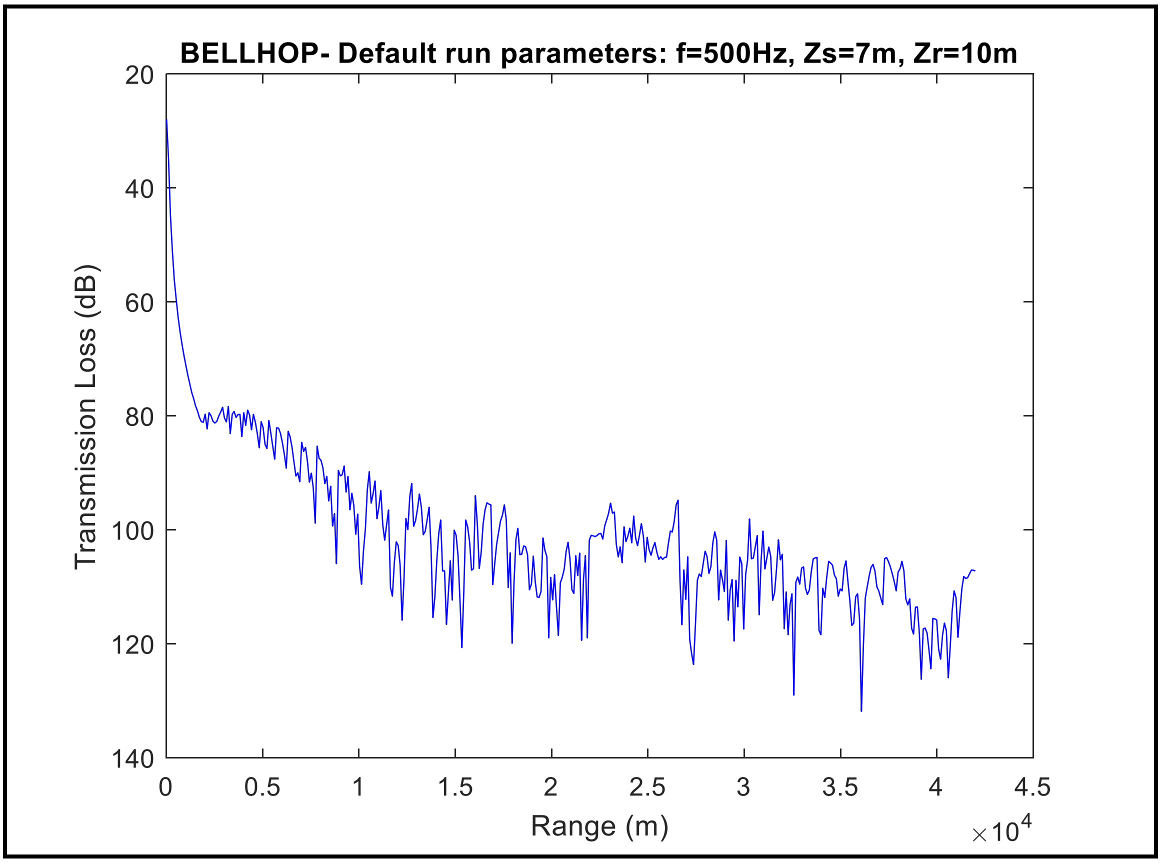
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 59 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Range at 16Hz in the North-West Direction. Propagation Prediction Code: RAMGEO



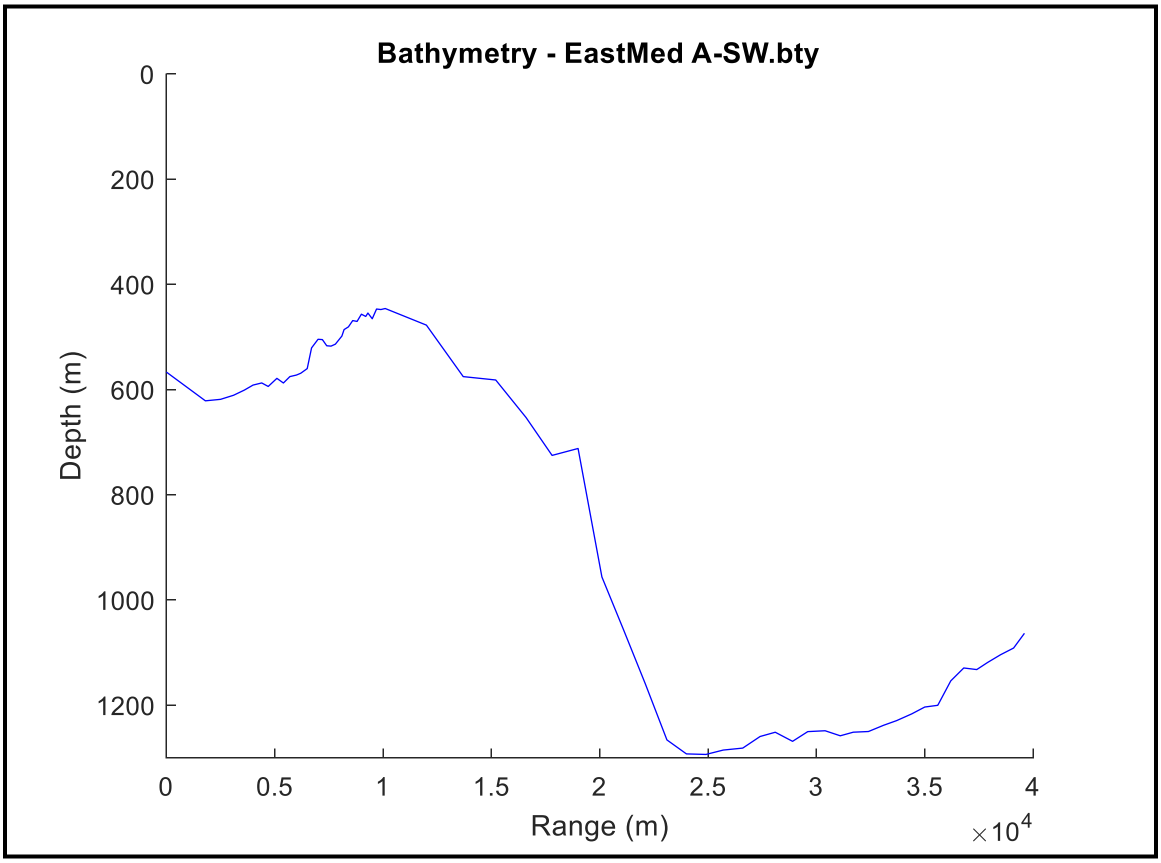
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 60 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Range at 40Hz in the North-West Direction. Propagation Prediction Code: RAMGEO



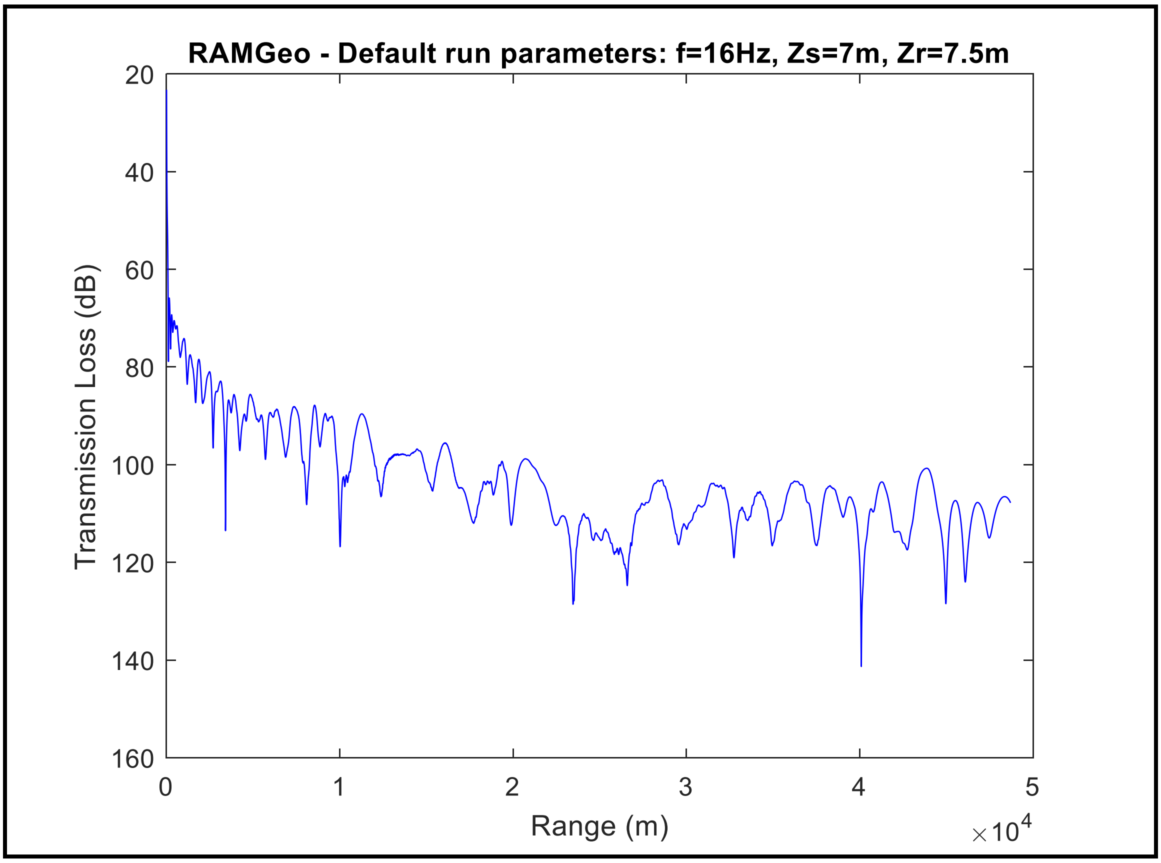
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 61 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Range at 500Hz in the North-West Direction. Propagation Prediction Code: BOUNCE + BELLHOP



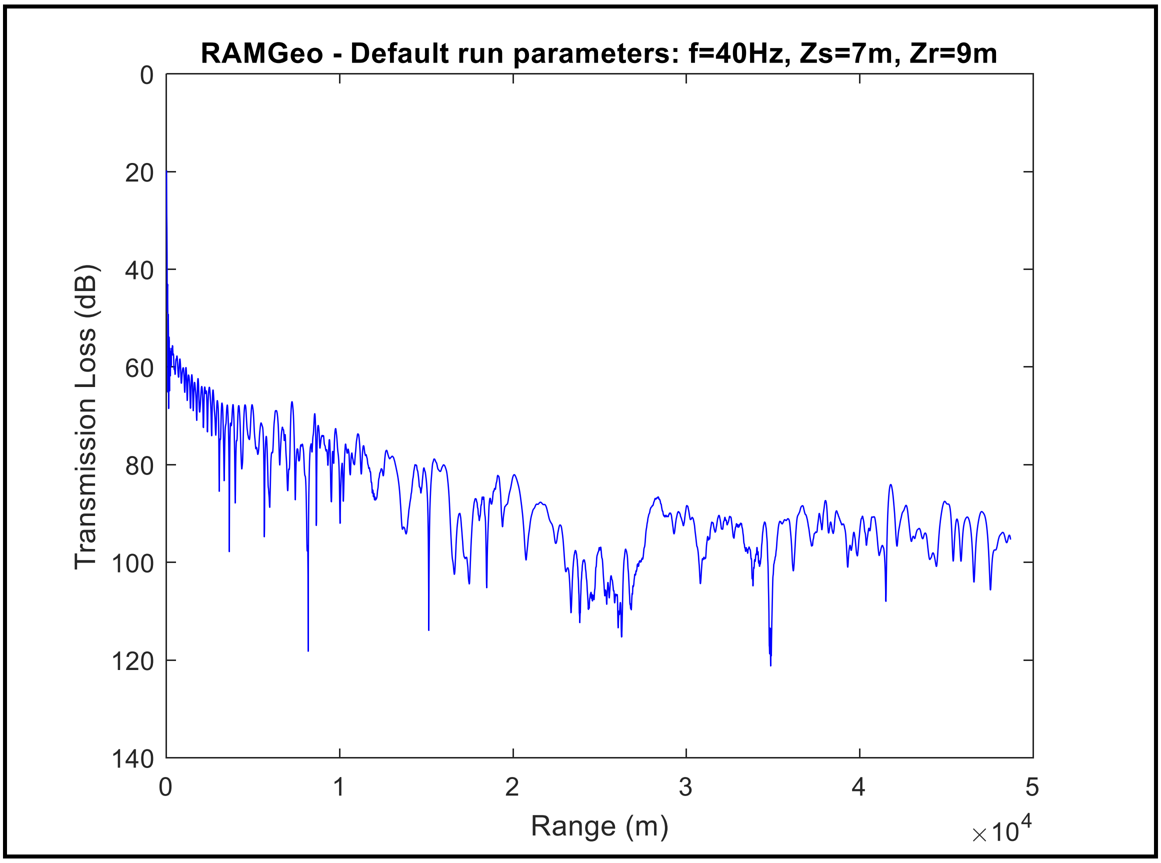
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 62 Peloponnese. Noise Source at lat 36.422^{0}, lon 23.567^{0}. Bathymetry in the South-West Direction



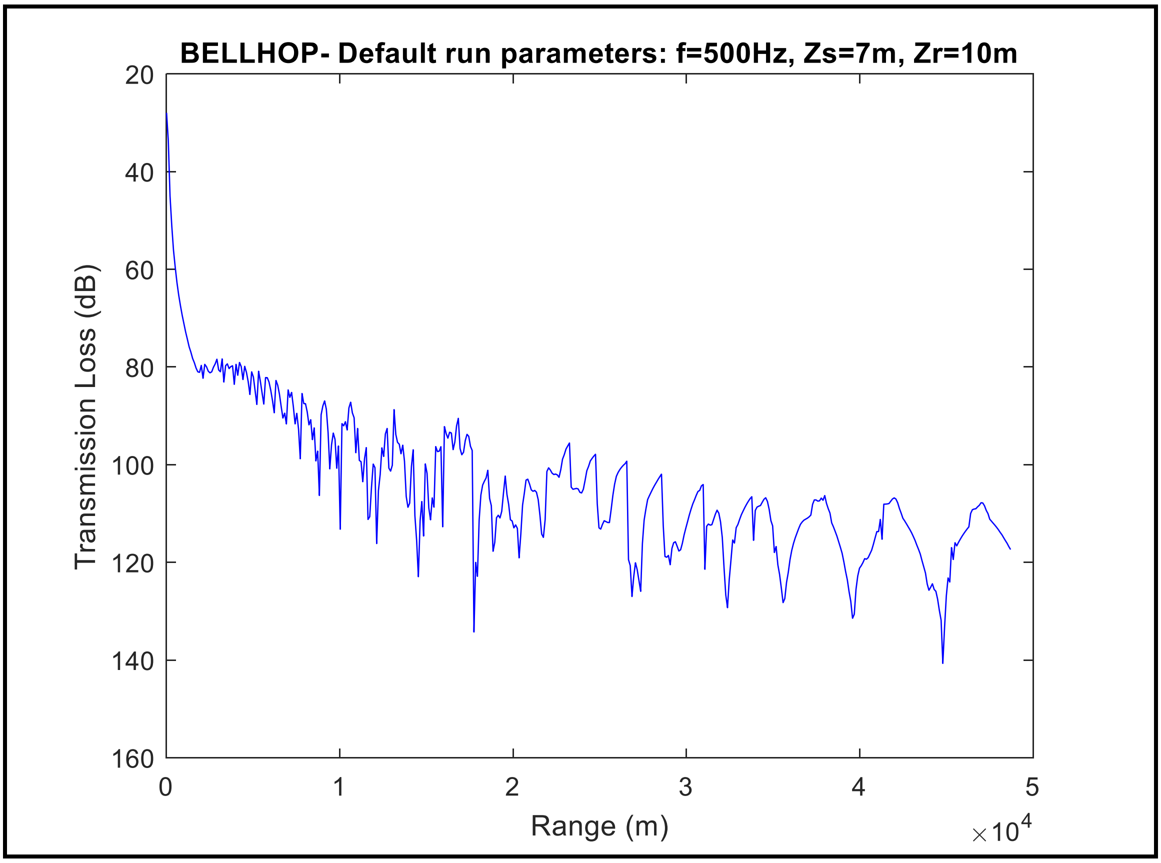
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 63 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Range at 16Hz in the South-West Direction. Propagation Prediction Code: RAMGEO



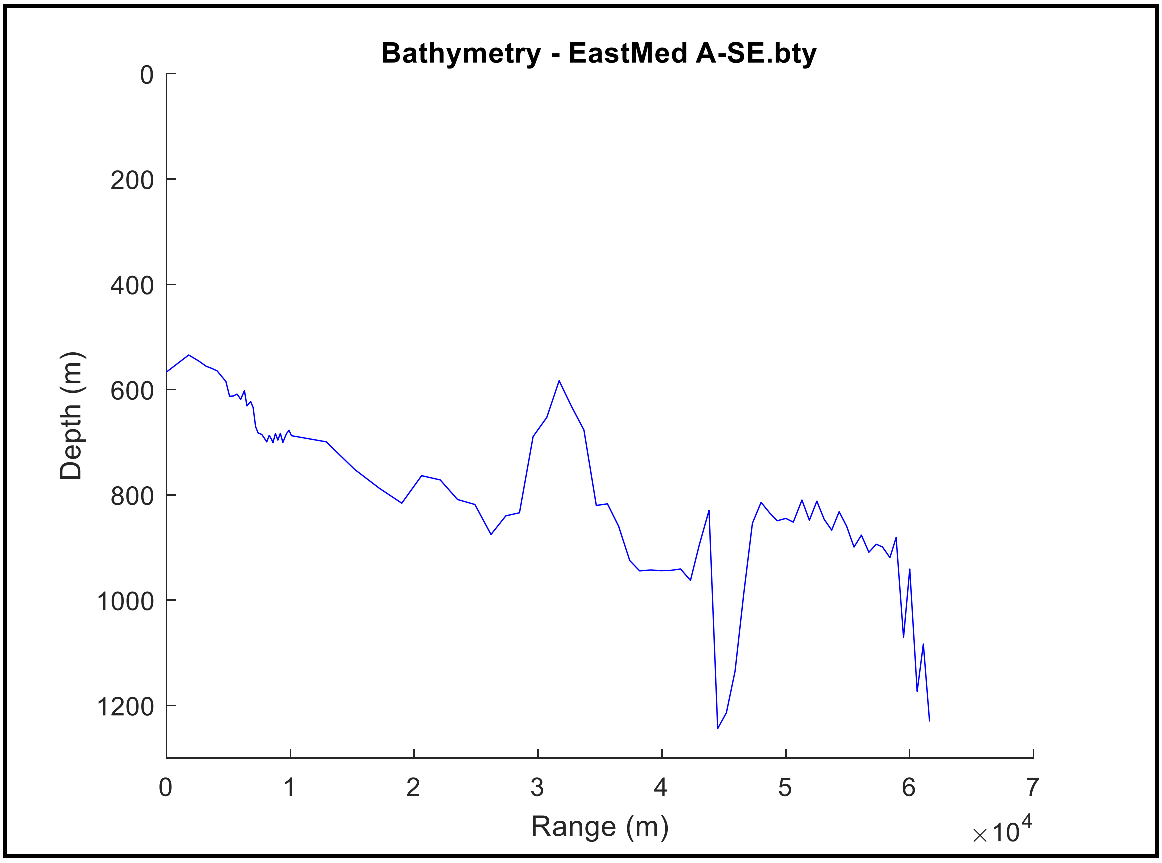
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 64 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Range at 40Hz in the South-West Direction. Propagation Prediction Code: RAMGEO



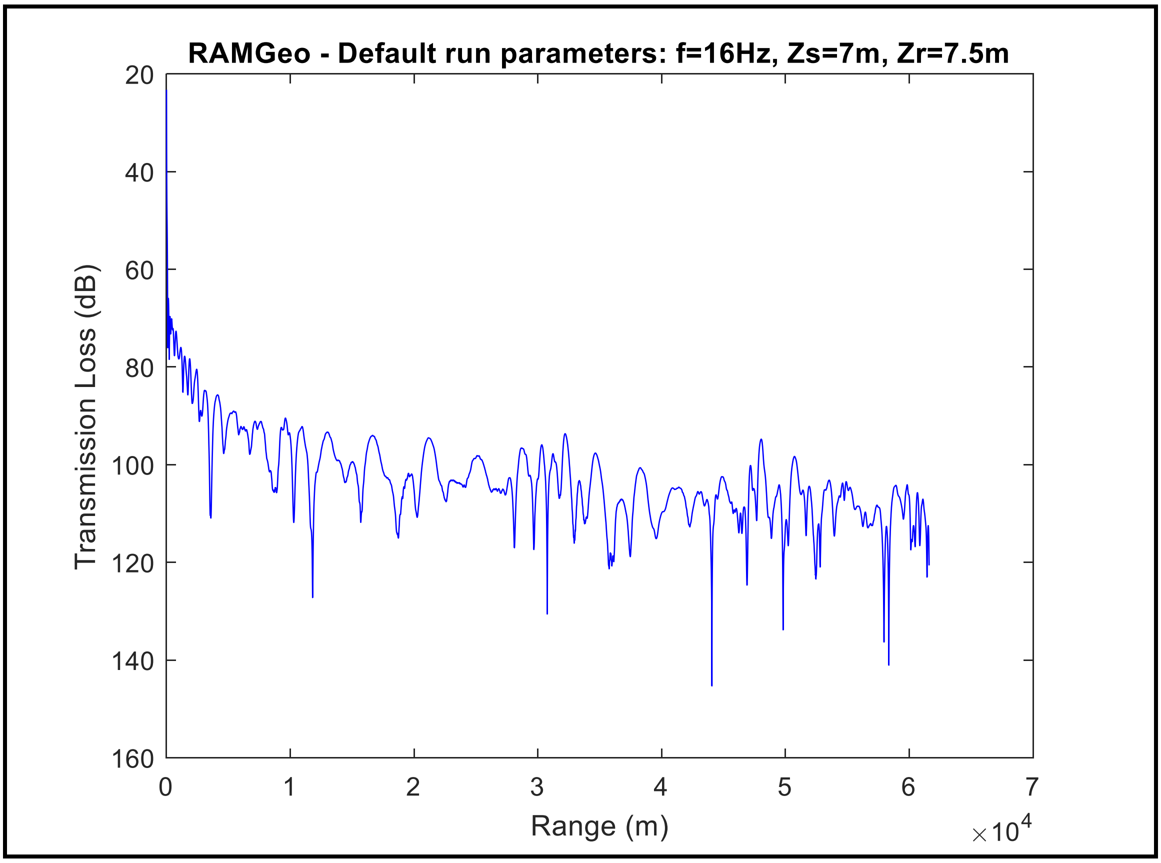
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 65 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Range at 500Hz in the South-West Direction. Propagation Prediction Code: BOUNCE + BELLHOP



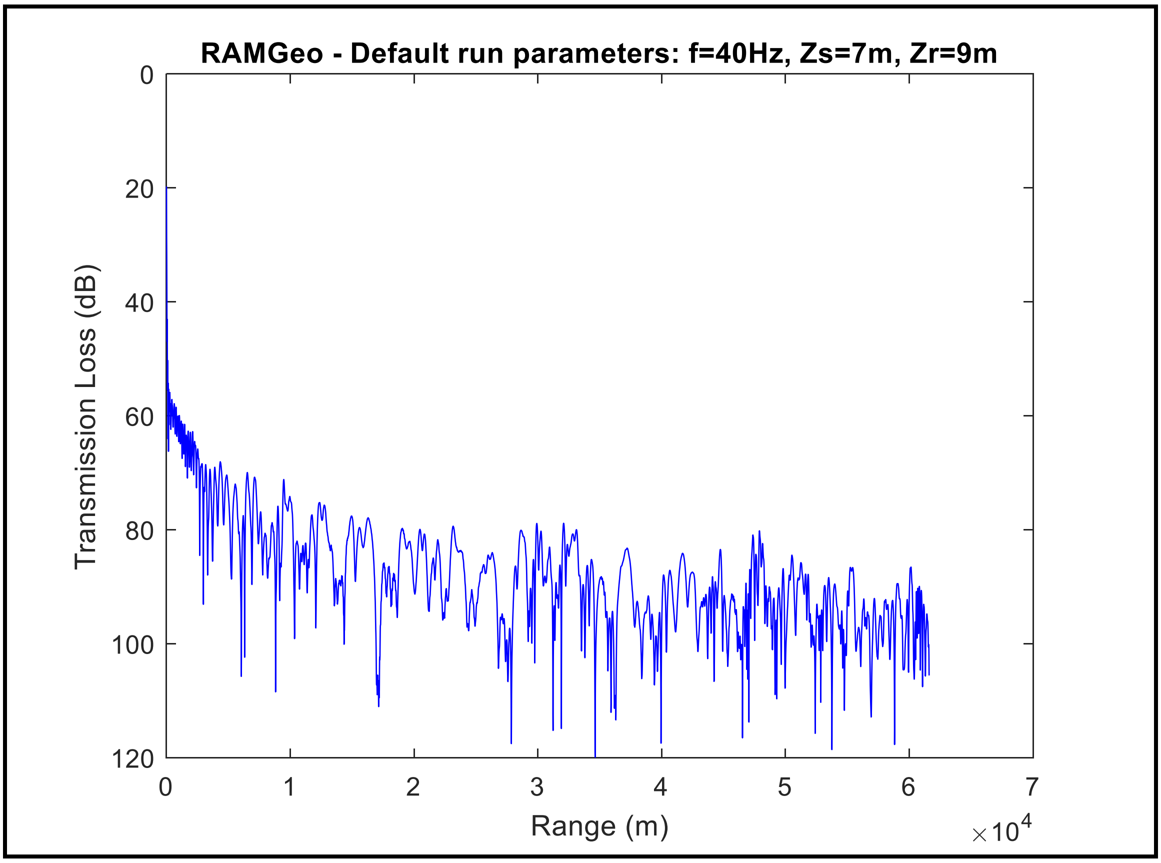
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 66 Peloponnese. Noise Source at lat 36.422^{0}, lon 23.567^{0}. Bathymetry in the South-East Direction



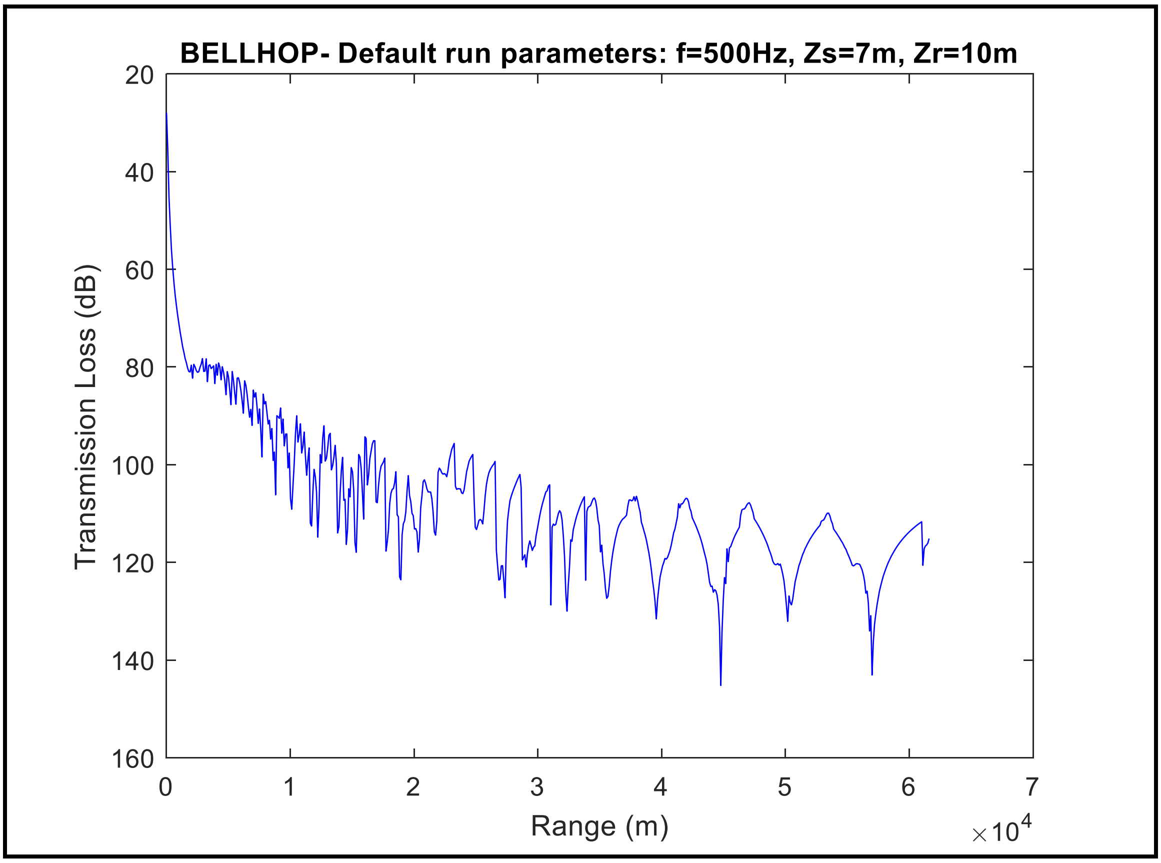
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 67 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Range at 16Hz in the South-East Direction. Propagation Prediction Code: RAMGEO



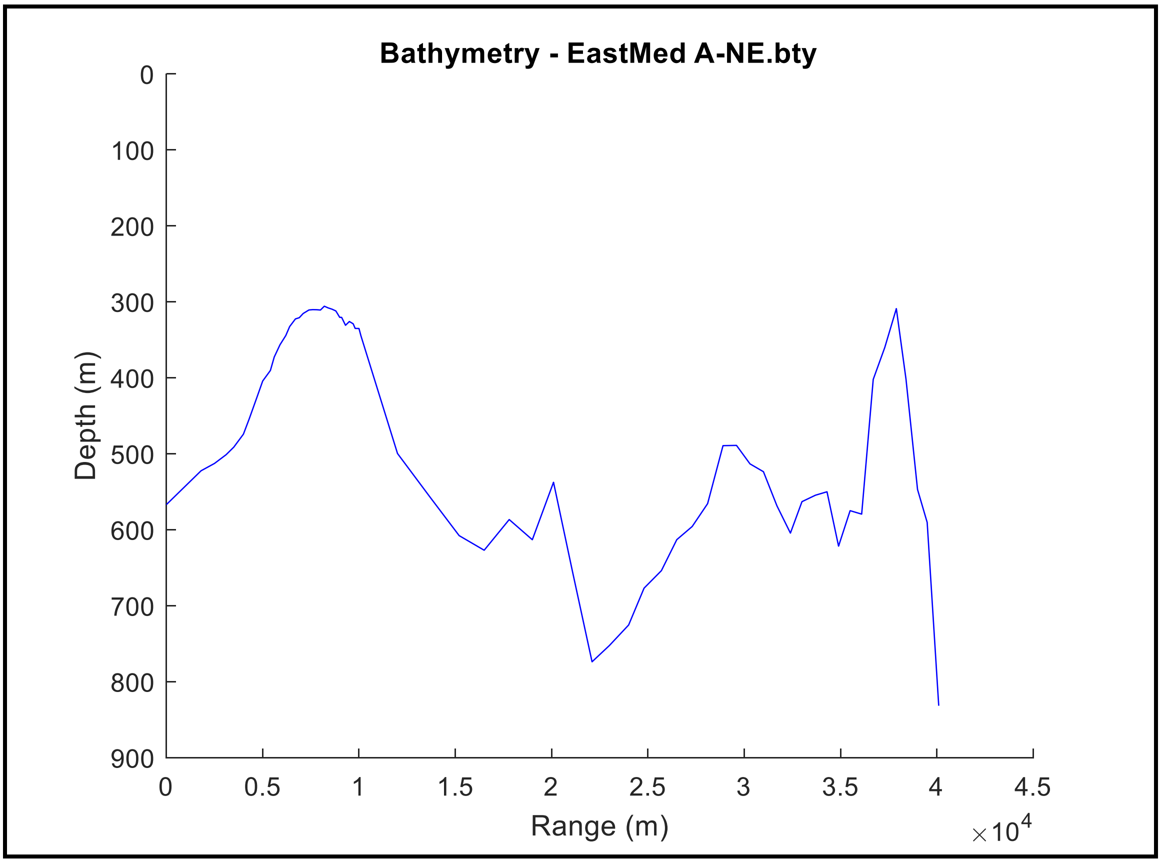
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 68 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Range at 40Hz in the South-East Direction. Propagation Prediction Code: RAMGEO



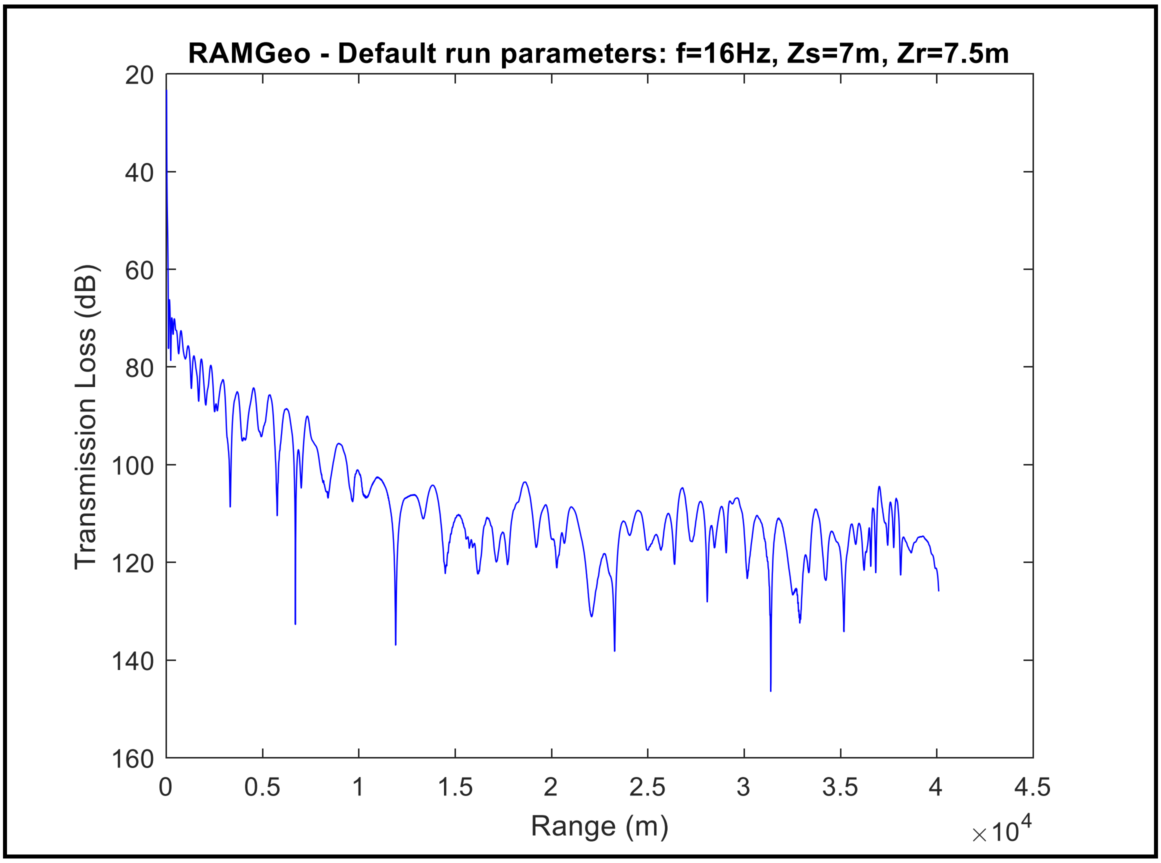
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 69 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Range at 500Hz in the South-East Direction. Propagation Prediction Code: BOUNCE + BELLHOP



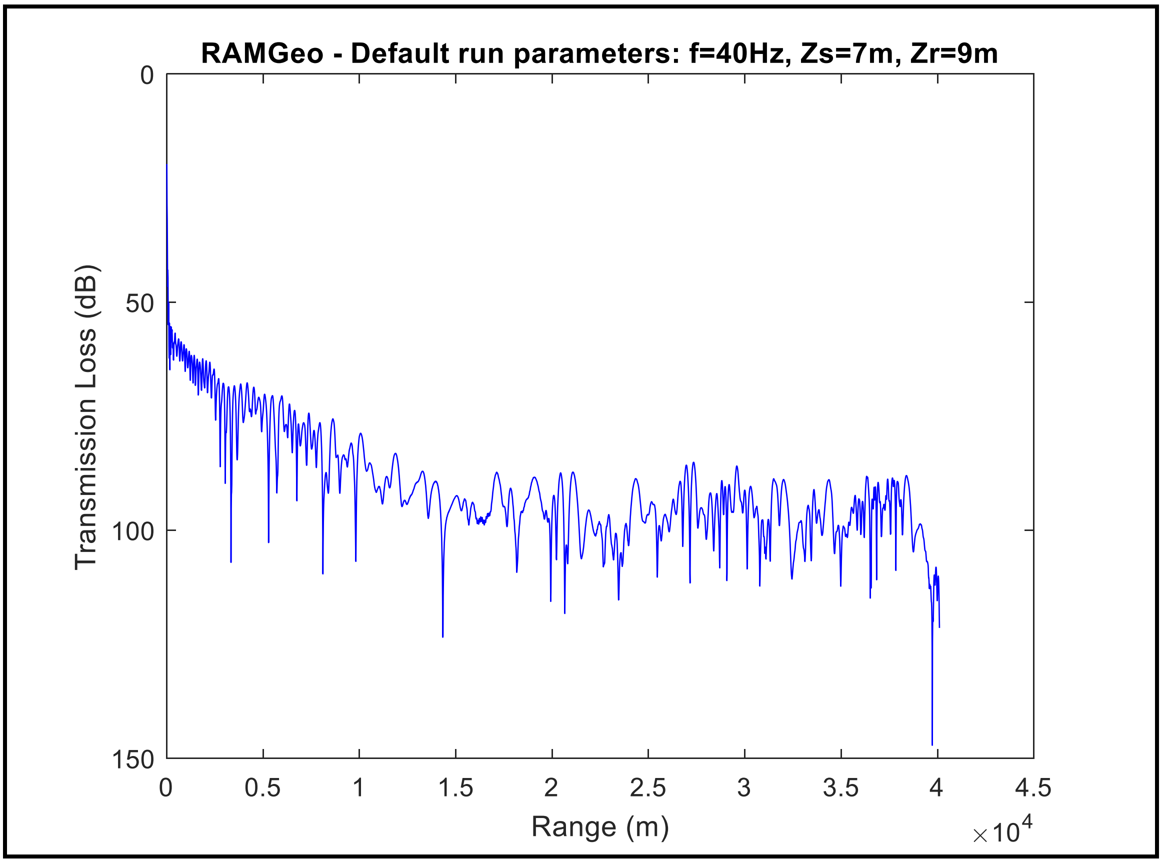
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 70 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Bathymetry in the North-East Direction



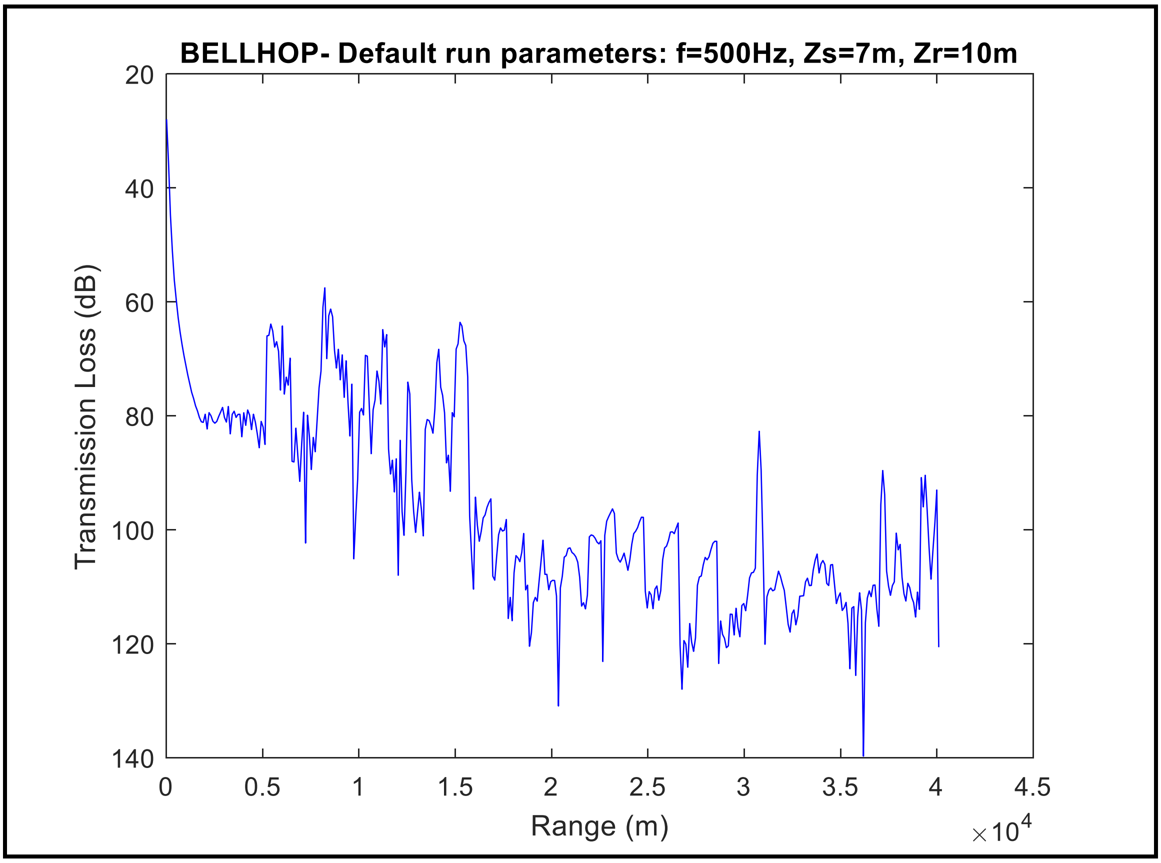
Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 71 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Range at 16Hz in the North-East Direction. Propagation Prediction Code: RAMGEO



Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 72 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Range at 40Hz in the North-East Direction. Propagation Prediction Code: RAMGEO



Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 73 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Range at 500Hz in the North-East Direction. Propagation Prediction Code: BOUNCE + BELLHOP

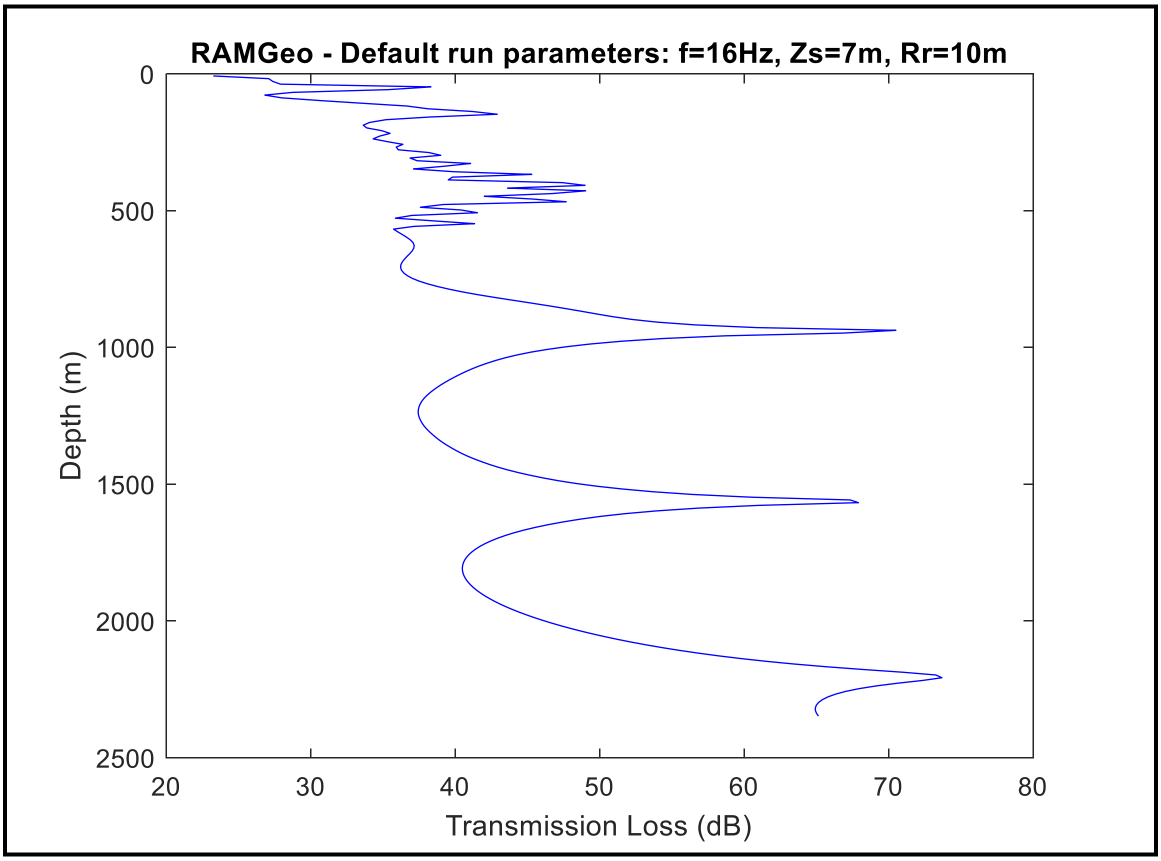


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Figure 74 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Depth at 16Hz. Propagation Prediction Code: RAMGEO

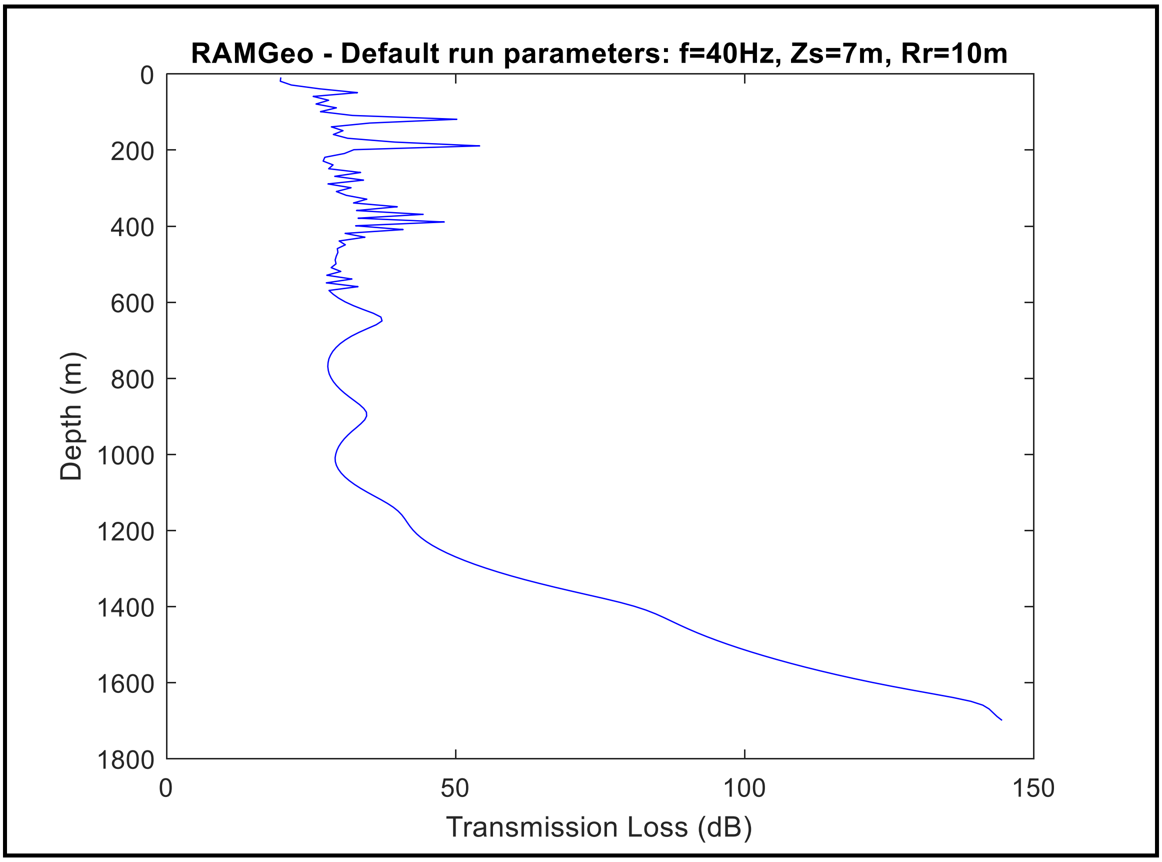

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Figure 75 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Depth at 40Hz. Propagation Prediction Code: RAMGEO

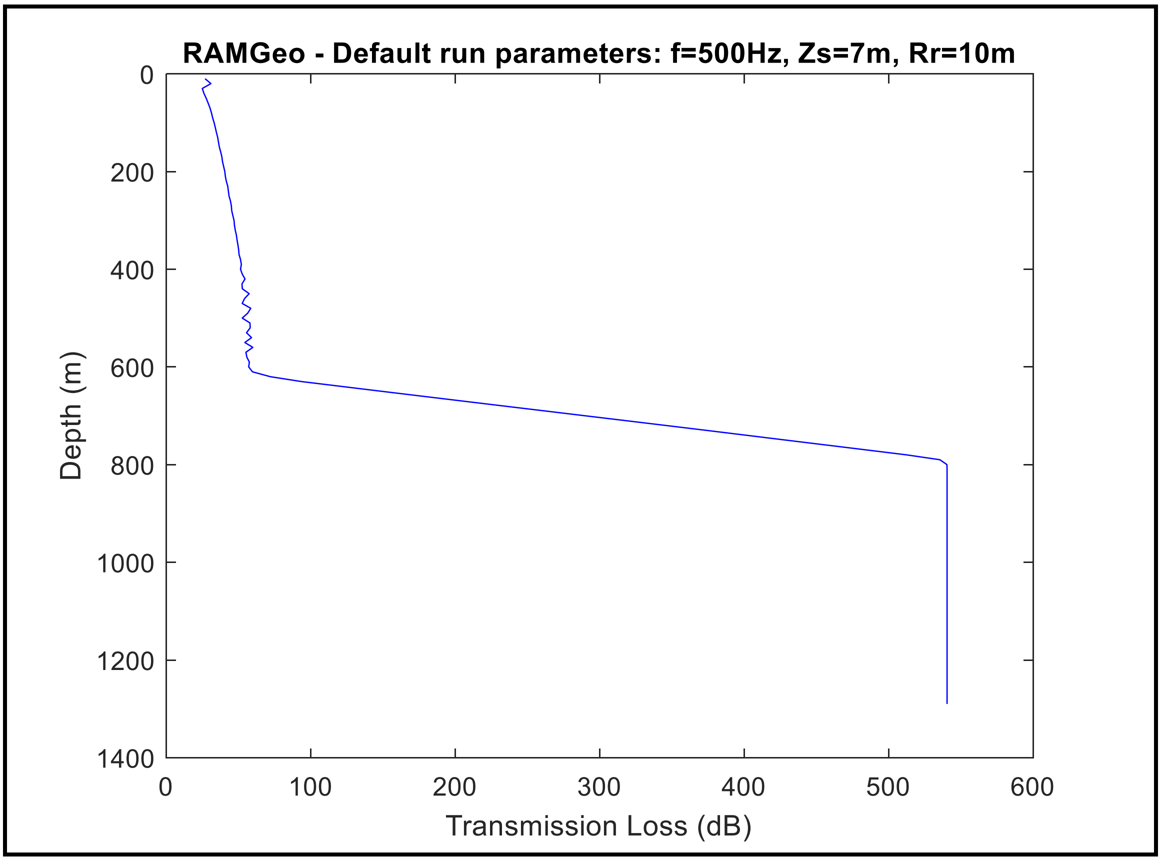

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Figure 76 Peloponnese. Noise Source at lat 36.422^0, lon 23.567^0. Transmission Loss vs Depth at 500Hz.Propagation Prediction Code: RAMGEO

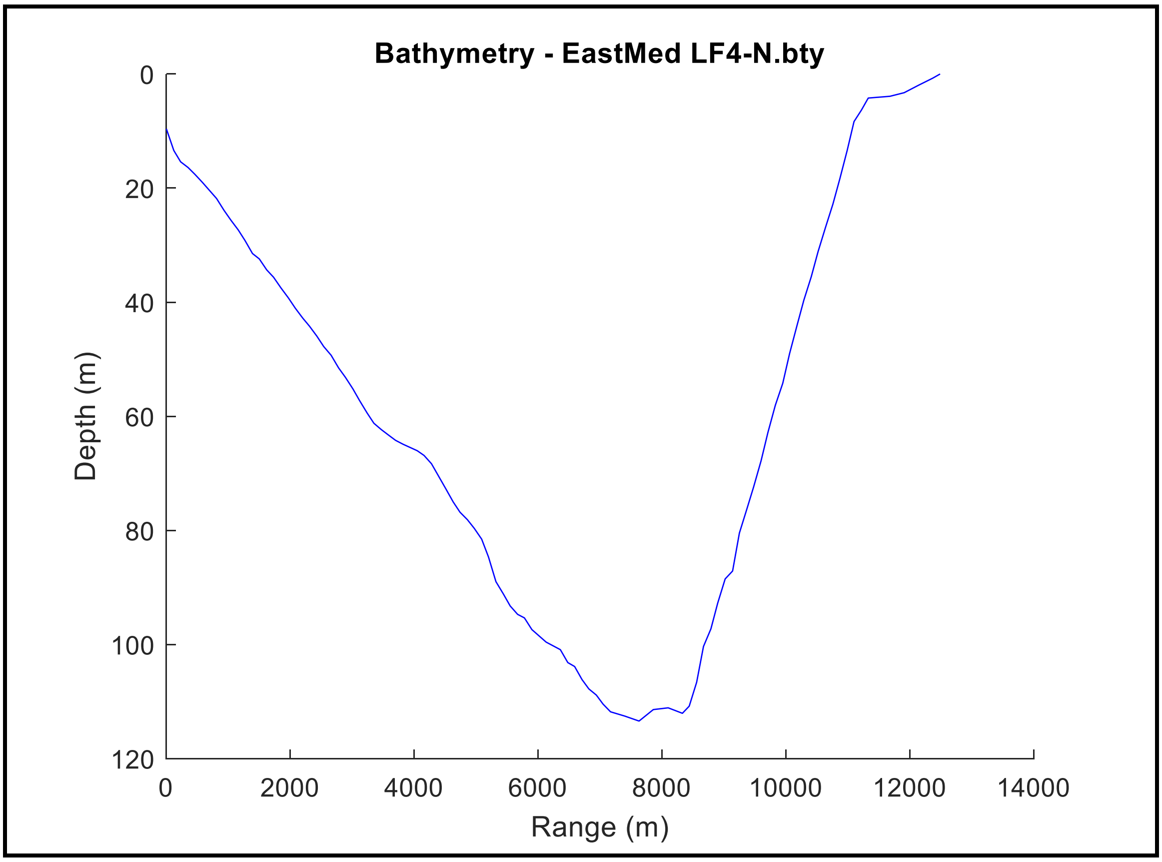

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Figure 77 Patraikos. Noise Source at lat 38.185^0, lon 21.485^0 (LF4). Bathymetry in the North Direction

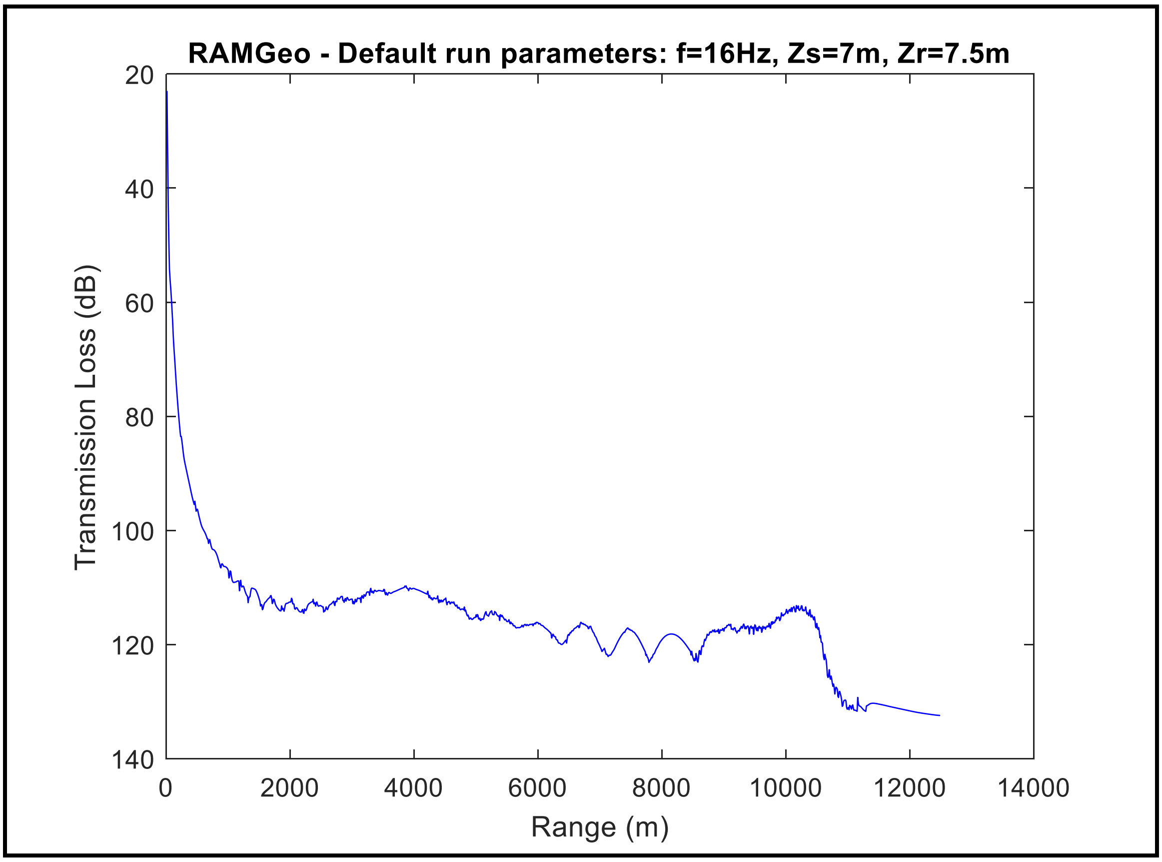

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Figure 78 Patraikos. Noise Source at lat 38.185^0, lon 21.485^0 (LF4). Transmission Loss vs Range at 16Hz in the North Direction. Propagation Prediction Code: RAMGEO

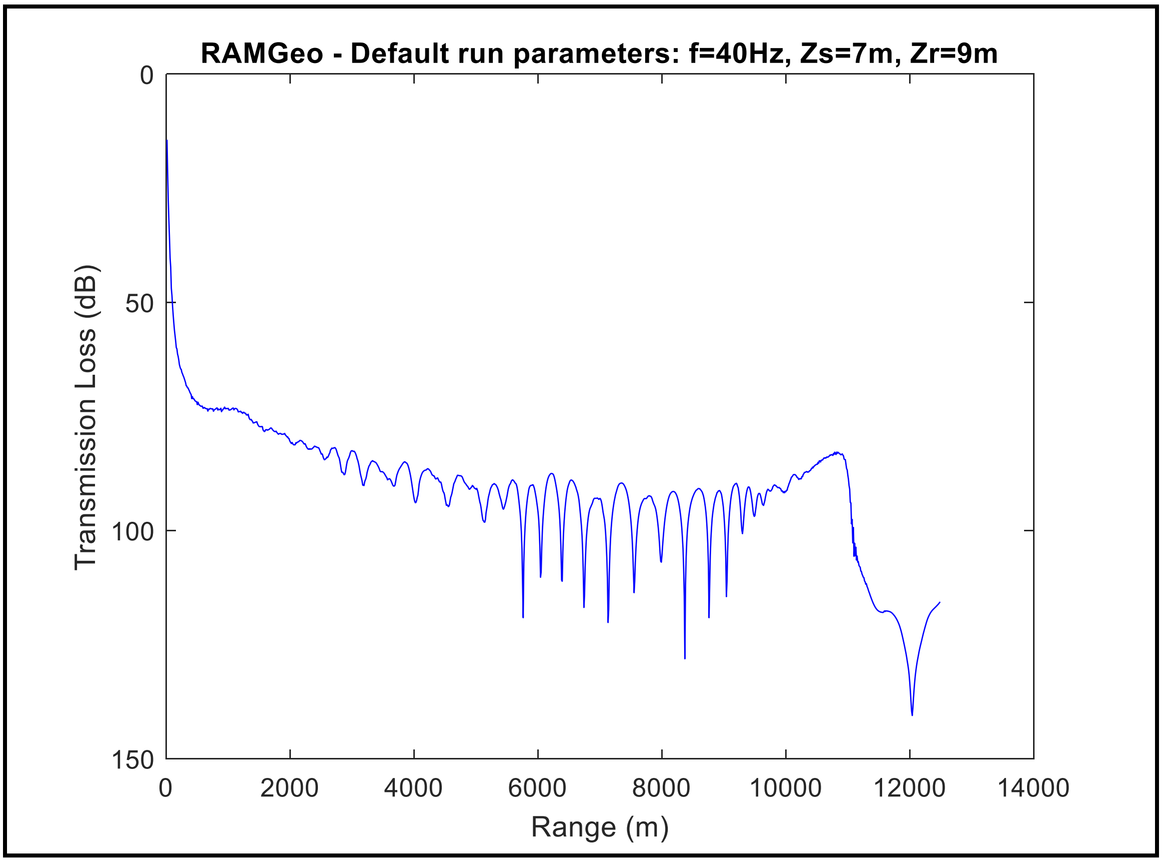

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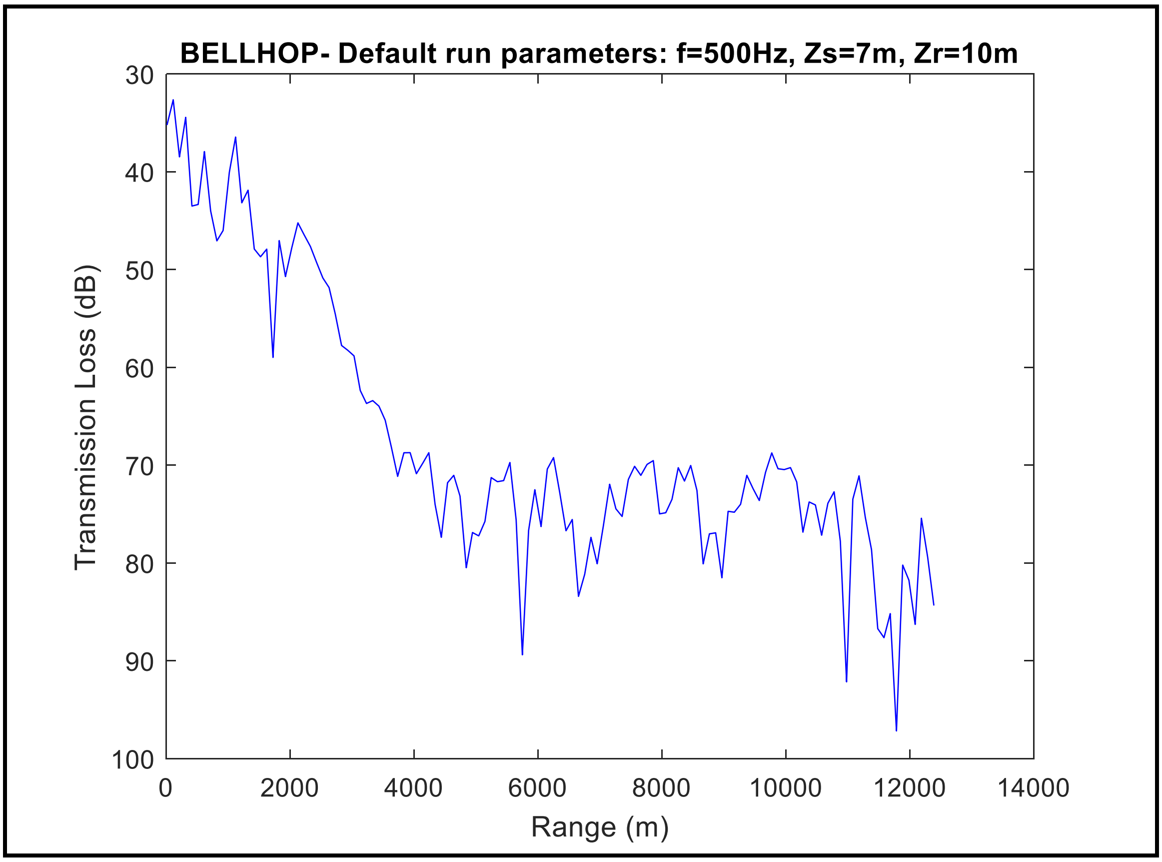
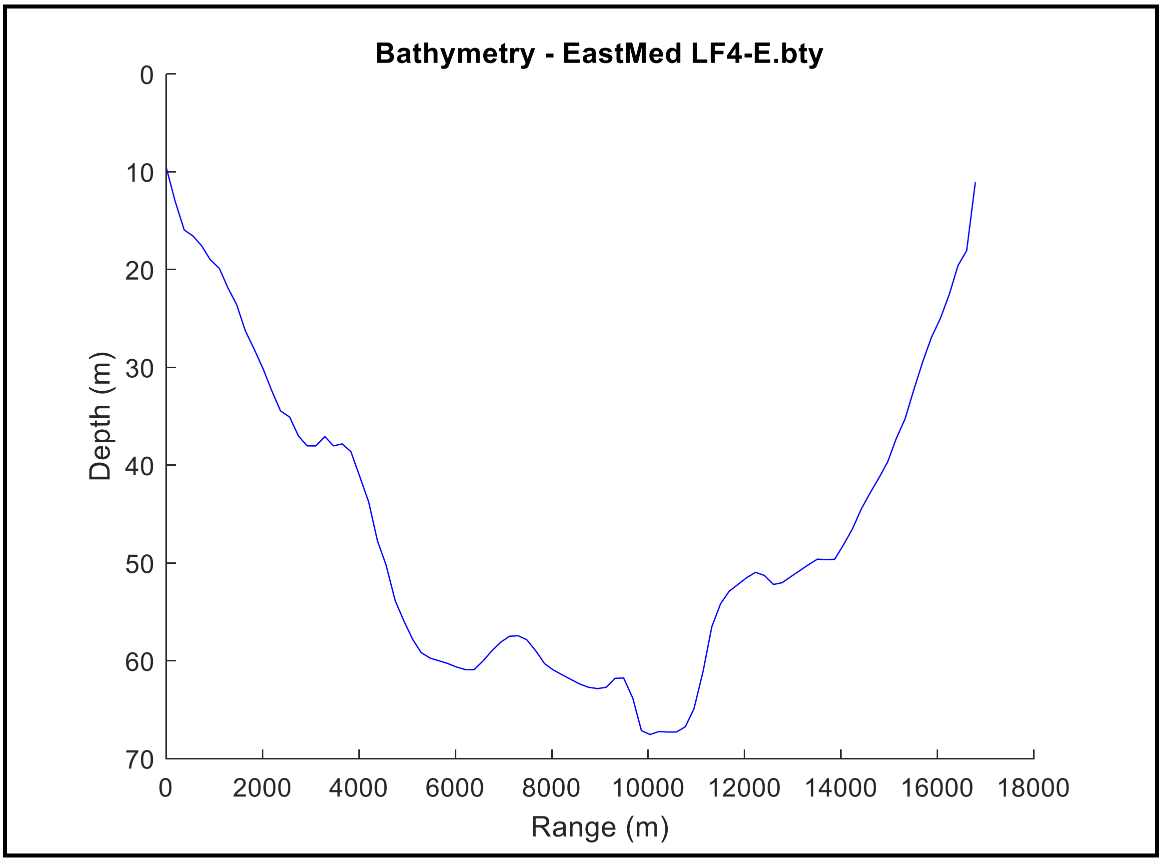
Figure 79 Patraikos. Noise Source at lat 38.185^0, lon 21.485^0 (LF4). Transmission Loss vs Range at 40Hz in the North Direction. Propagation Prediction Code: RAMGEO



Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 80 Patraikos. Noise Source at lat 38.185^0, lon 21.485^0 (LF4). Transmission Loss vs Range at 500Hz in the North Direction. Propagation Prediction Code: BOUNCE+BELLHOP



Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 81 Patraikos. Noise Source at lat 38.185^0, lon 21.485^0 (LF4). Bathymetry in the East Direction

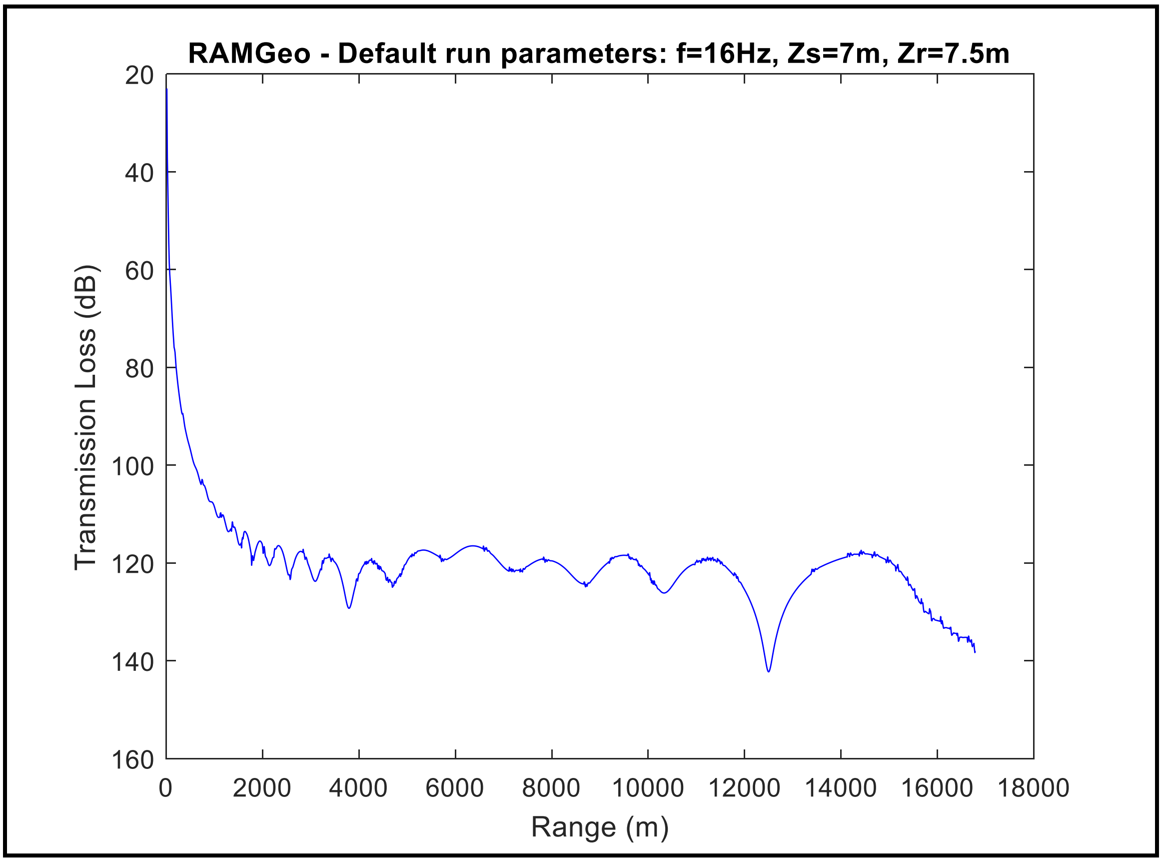


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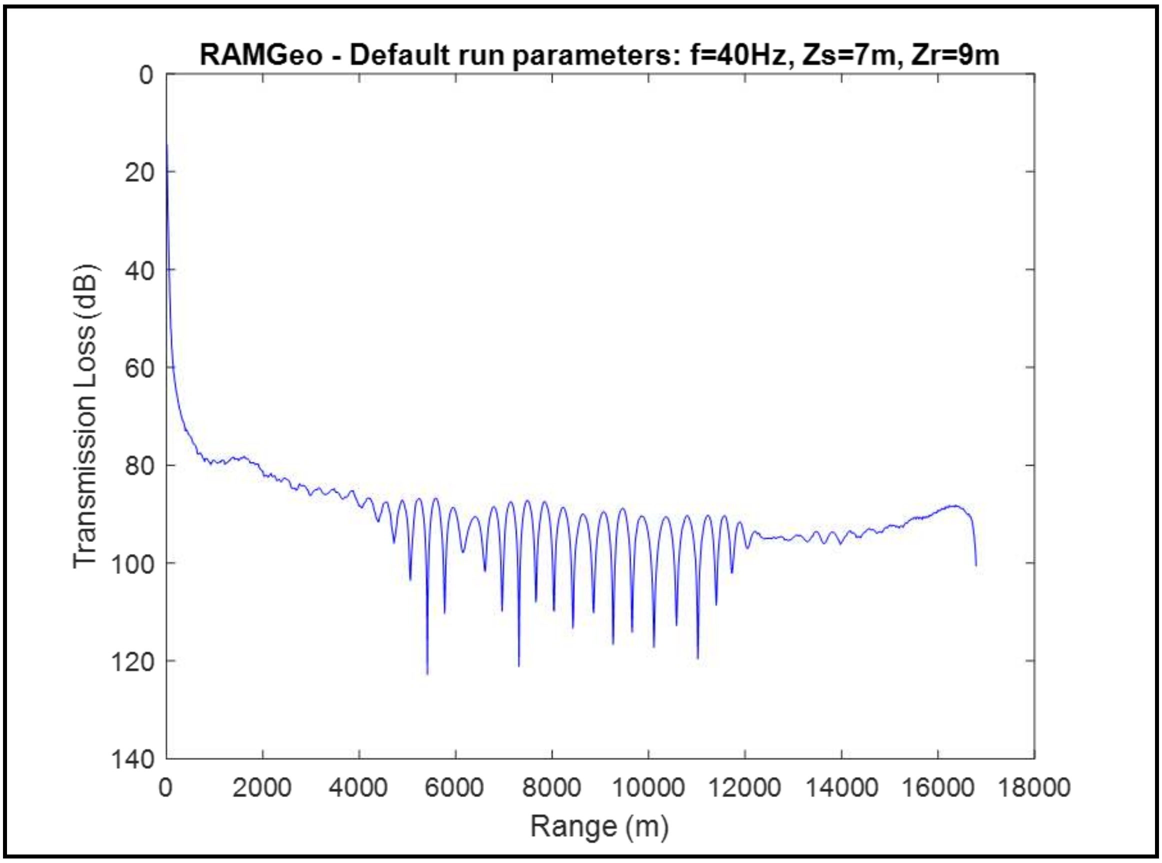
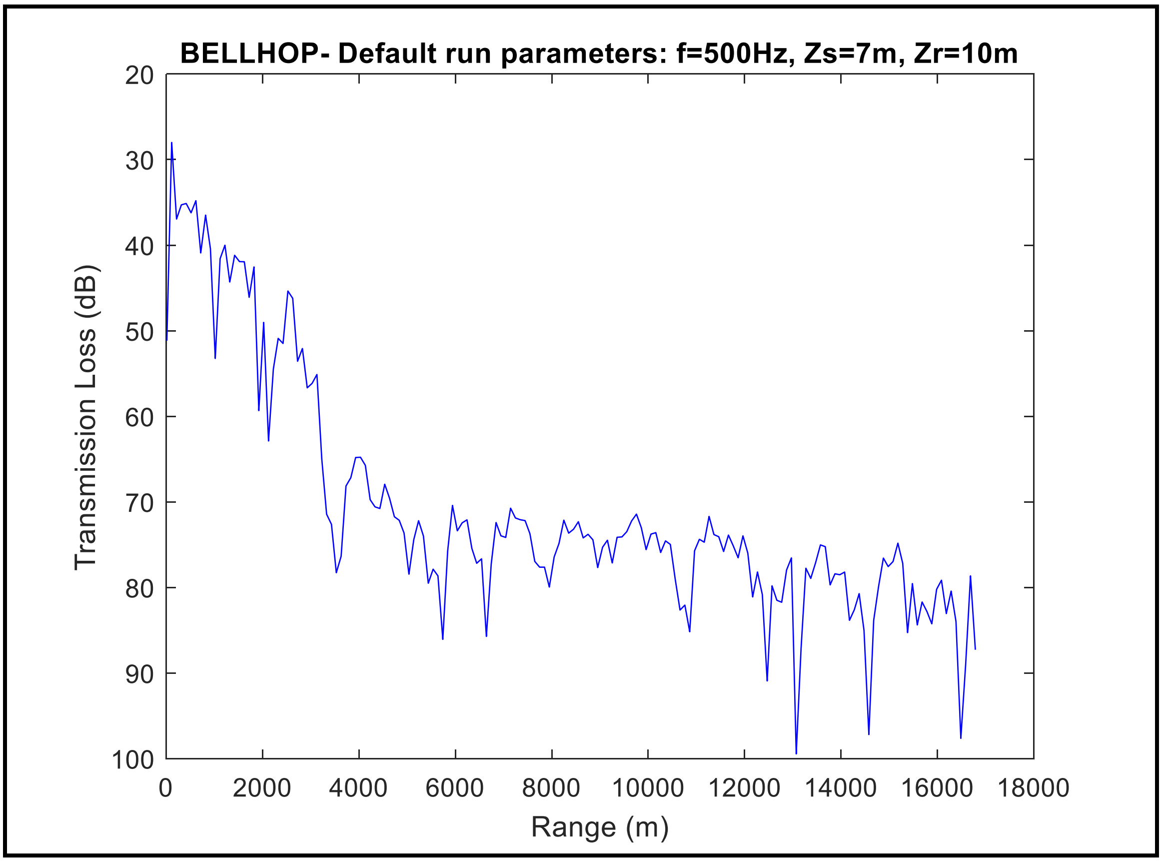
Figure 82 Patraikos. Noise Source at lat 38.185^0, lon 21.485^0 (LF4). Transmission Loss vs Range at 16Hz in the East Direction. Propagation Prediction Code: RAMGEO



Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 83 Patraikos. Noise Source lat 38.185^0, lon 21.485^0 (LF4). Transmission Loss vs Range at 40Hz in the East Direction. Propagation Prediction Code: RAMGEO



Prepared by: National Technical University of Athens School of Electrical and Computer Engineering on behalf of ASPROFOS,2022

Figure 84 Patraikos. Noise Source at lat 38.185^{0}, lon 21.485^{0} (LF4). Transmission Loss vs Range at 500Hz in the East Direction. Propagation Prediction Code: BOUNCE+BELLHOP

- Sediment type average reflection coefficient
- Coarse sand 0.4098 (-- 7.8 dB)
- Fine sand 0.3749 (-- 8.5 dB)
- Very fine sand 0.3517 (-- 9.1 dB)
- Silty sand 0.3228 (-- 9.8 dB)
- Sandy silt 0.2136 (- 13.4 dB)
- Sand-silt-clay 0.2504 (-- 12 dB)
- Clayey silt 0.1767 (-- 15 dB)
- Silty clay 0.1586 (--16 dB)

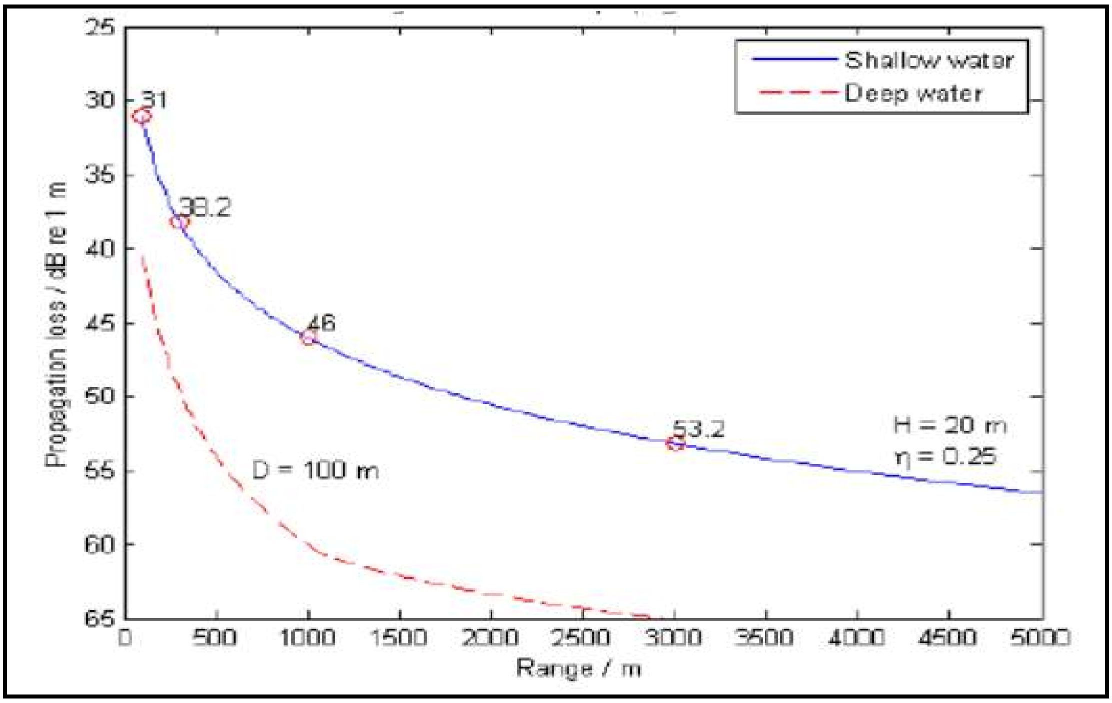


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Figure 85 Propagation Loss [dB re 1 m] vs Range [m].

The solid blue line in the above figure shows the expected lower limit for propagation loss in shallow water. [According to Monitoring Guidance for Underwater Noise in European Seas – Part III §2.3.1]