Estimating excess noise from deep sea mining: a simulated test case

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Abstract—There at least two major potential consequences of deep sea mining: sediment plumes and energy input into the ocean. One of the major forms of energy input is ocean noise generated by the mining process. Project TRIDENT was set up under the Horizon Europe framework of the European Union, with the aim of contributing to a sustainable exploitation of seabed mineral resources, by developing a reliable, transparent and cost-effective system for prediction and continuous environmental impact monitoring of exploration and exploitation activities in the deep sea. Among the parameters monitored under TRIDENT there is ocean sound by means of in-situ, middle field and far-field fixed water column acoustic recorders and moving acoustic gliders. The area chosen for TRIDENT activity and system demonstration is the Tropic seamount, located to the south of Canary Islands. This paper sets up the modelling tools to determine to which extent the noise generated by a continuous mining activity on top of the Tropic seamount couples into the sound channel and propagates to the surrounding area. The difference between the measured (or modelled) ocean sound with and without mining activity is usually called excess noise level and is instrumental for developing indicators of environmental impact to sensitive species within acoustic range of the mining site.

Index Terms—deep sea mining, ocean noise, soundscape, environmental impact.

I. INTRODUCTION

The depletion of terrestrial mineral deposits and growing appetite for rare materials needed for electric cars and renewable energy systems, is leading to the exploitation of the deep ocean seabed. However, deep sea mining (DSM) is a controversial process for its suspected environmental impact on fauna and flora which to date is mostly unknown. There at least two major potential consequences of deep sea mining: sediment plumes and energy input into the ocean. One of the major forms of energy input is ocean noise generated by the mining machinery at the site. Physically speaking energy is power multiplied by duration. Since DSM is a slowly advancing process that may take months or years in vast areas, it may be seen as a continuous/permanent acoustic excitation. The power generated at the DSM site is largely dependent on the ore type being mined (nodules, crusts or sulphides) and on the environmental characteristics of the site, such as water depth and proximity to coasts. It is well known that sound propagates

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to long distances in the ocean, but that is very much dependent on frequency and degree of coupling with the sound channel so, the key question is how does the DSM acoustic energy spreads in the surrounding ocean volume.

There is now an ample scientific consensus that anthropogenic underwater noise is recognized as a major threat to marine life [1], [2]. That is why ocean sound was declared as an Essential Ocean Variable by GOOS¹ and ocean sound impacts were included as a new chapter in the World Ocean Assessment report (WOA II) of the United Nations [3]. Ocean noise is usually classified in two categories: impulsive noise - normally of high or very high intensity and localized in time and space - and continuous noise - ubiquitous and of moderate or high level. Examples of impulsive noise is that generated during pile driving in offshore construction, sonar and seismic surveying for oil and gas. Continuous noise is mainly represented by shipping. According to this description the noise generated by DSM may be classified as a localized continuous noise disturbance. Impulsive noise poses a threat of temporary or permanent physical injury to animals, while continuous noise generates a disturbance that affects animal behaviour in the long term. Both types of noise may lead to animal death. Anthropogenic noise superimposes to naturally present ocean sound such as that produced by waves, wind, earthquakes, ice and by marine animals. In an effort to develop indicators for noise impact, the excess noise level (ENL) is defined as the difference (in dB) between the total sound level and the natural sound level [4], [5].

Project TRIDENT has recently started under the Horizon Europe framework of the European Union, with the aim of contributing to a sustainable exploitation of seabed mineral resources, by developing a reliable, transparent and costeffective system for prediction and continuous environmental impact monitoring of exploration and exploitation activities in the deep sea. A full description of TRIDENT objectives and planned contributions is presented in [6].

The area chosen for the demonstration of TRIDENT is the Tropic seamount, which is the southernmost seamount of the Canary Islands Seamount Province, located near Tropic of Cancer (thus the name). It is well known from general theory that seamounts obstacle coherent sound propagation,

¹https://www.goosocean.org/

creating shadow zones and spurious reflections. How does the sound generated on top of the seamount couples into the sound channel and spread to the surrounding deeper water is virtually unknown. The objective of this work is, through acoustic propagation modeling, to provide credible predictions of sound maps around the Tropic seamount for a variety of changing parameters such as depth, frequency, source level and water column properties. The end objective is to determine the broadband ENL due to DSM in the surrounding area within acoustic reach.

II. BACKGROUND

A common approach in ocean sound analysis and modelling is to consider that the measured (or modelled) sound field may be represented by the summation of two components: the natural background sound and the anthropogenic noise, expressed as

$$L_m(t, f, \mathbf{r}) = 10 \log_{10} \left[10^{L_n(t, f, \mathbf{r})/10} + 10^{L_b(t, f, \mathbf{r})/10} \right]$$
(1)

where L_m is the measured or modelled sound field, L_n is the noise component and L_b is the natural background level, all expressed in dB, and evaluated at time t, frequency f and spatial coordinate **r**, containing latitude, longitude and depth.

A. Ocean noise model

A classical methodology in underwater acoustics is to consider three components: 1) the source(s), 2) the acoustic propagation and 3) the receiver. In our case the receiver is formed by the acoustic sensitive marine life which is a very important and relevant aspect but is clearly out of scope of this study. The sound source encompasses noise generated by machinery operating at the bottom, by riser pumps for slurry transport in the mid-water column (the number and depth of which varies with the water depth at the site), and by the minerals processing ship, transport barges and other supply ships at the surface. So, clearly the important aspect is that of sound propagation that is mainly dependent on the physical properties of the environmental such as bathymetry, water column temperature and salinity variation with time and space. A generic model for noise level calculation may be given by [5] is

$$L_n(t, f, \mathbf{r}) = 10 \log_{10} \left[\sum_{q=1}^Q 10^{L_{H_q}(t, f, \mathbf{r}_q : \mathbf{r})/10} 10^{L_q(t, f, \mathbf{r}_q)/10} \right]$$
(2)

where Q is the number of considered sound sources, L_{Hq} is the transmission loss calculated at any space location **r** from each source location \mathbf{r}_q , and L_q is the q-th source level. Levels are in dB and other quantities have been defined. Equation (2) may include all sources of noise, such as ships, DSM machinery and others. However in this paper shipping noise will not be considered and only DSM exploration noise will be taken into account. This assumption is justified below.

B. Wind sound model

It is commonly accepted that the ocean sound field background is dominated by the noise generated at the sea surface due to the combined action of wind, waves, rain and ice, where wind is the most ubiquitous and wideband [7], [8]. Empirical models aim at drawing dependencies of measured wind sound to wind speed, as for example Wilson [9] that assumes a sheet of virtual wind noise related sources underneath the surface, or Kewley et al. [10] that uses measurements performed in the southern ocean away from shipping to provide better low frequency correlations, or the more recent work of Hildebrand et al. [11] that compiled a large varied data set for better coefficient estimation. The later model has the advantage of providing a depth correction term and a wide bandwidth from 10 Hz up to over 20 kHz. Wind sound spectrum level density will be computed in 1/3-octave bands (base 2) using the Hildebrand model, then summed within each band and represented at the band center frequency, for facility.

C. Broadband indicators and statistics

Excess noise level (ENL) aims at estimating the amount of anthropogenic noise on top of the natural or background sound field [4], [5]. Thus, ENL is the difference between the total level L_T and the background level field L_b , that is $L_E = L_T - L_b$. Using the relation between level and acoustic power, $L(\cdot) = 10 \log_{10} P(\cdot)$, one can write the ENL as

$$L_E(t, f, \mathbf{r}) = 10 \log_{10} \frac{P_T(t, f, \mathbf{r})}{P_b(t, f, \mathbf{r})}, = 10 \log_{10} \left[1 + \frac{P_n(t, f, \mathbf{r})}{P_b(t, f, \mathbf{r})} \right],$$
(3)

where P_n and P_b are the acoustic power fields associated with the DSM generated noise and the background sound, respectively. In our case, it is assumed that the background is formed by surface wind only.

It is often useful to have an ensemble field estimate with all the input energy across the frequency band. Summing power over frequency allows to retrieve total broadband energy and write (3) as [5]

$$L_E(t, \mathbf{r} = 10 \log_{10} \left[1 + \frac{\sum_{k=1}^{K} P_n(t, f_k, \mathbf{r})}{\sum_{k=1}^{K} P_b(t, f_k, \mathbf{r})} \right]$$
(4)

III. Methods

A. Environmental data

The DSM monitoring demonstration foreseen during TRI-DENT project, will take place at the Tropic seamount, a former volcano to the southwest of the Canary Islands at approximately 400 km from the coast of Africa. The bathymetry was obtained from GEBCO database [12] and is shown in Fig. 1. The diamond shaped seamount top has an area of approximately 10×10 km and reaches a minimum depth of approximately 700 m (indicated by the star marker in the figure). Modelled temperature and salinity profiles were



Fig. 1. Tropic seamount bathymetry [from GEBCO database [12]].

retrieved from the Copernicus CMEMS database² for an area of approximately 300×300 km centered at the seamount, with a spatial resolution o 9 km and a time step of 3 hour, for the whole month of January 2023. These profiles are shown in Fig. 2 (in yellow) with mean profiles in red for temperature (left), salinity (centre) and sound speed (right) Modelled wind



Fig. 2. Tropic seamount area: temperature, salinity and sound speed profiles (left to right), over time and space (yellow) and mean profiles (red) for the whole month of January 2023 [CMEMS Copernicus databased].

data was downloaded from the European Center for Medium-Range Weather Forecasts³ (ECMWF) with a 0.125 degree spatial resolution and a time sampling of 3 hours, for the whole month of January 2023. This data was later averaged as one sample per day and the spatial grid linearly interpolated for compatibility with the acoustic modeling.

B. Source level

The noise sources in model (2) include, in principle, all noise sources contributing to the sound field in the considered area, time and frequency. In the considered frequency band the most relevant noise sources are shipping and the DSM activity. However, consulting AIS traffic density in the area shows that the number of ship routes is smaller than 15 for approximately 1 km^2 per year⁴. Dense traffic takes place near the coast, more than 200 km away, well out acoustic range. At this stage shipping noise will be neglected and only DSM noise will be considered in the noise model.

Little information has filtered about levels and frequency bands from recordings made during live deep sea mining tests carried out to date. Figure 3 depicts the various sources of noise possibly involved in DSM activities [13]. It is understood



Fig. 3. Collection of noise sources from DSM activities [with permission from [13]].

that all sources may not be operating simultaneously, which also depends on the specific activity is taking place at any given time. Levels and bands described in [13] are taken from an extensive set of references and, in some cases, approached from similar machines used on land (mine drilling and scratching) and on other activities (*e.g.* dredging). Levels and bands are somehow coincident to those reported in [14]. A list of noise sources is shown in table I and the corresponding source level spectrum shown in Fig. 4 grouped in three categories according to their position in the water column: bottom, midwater and surface.

TABLE IList of DSM noises sources [13].

Position	Source type	Level	Band
		[dB]	[Hz]
surface	converted drill ship	195	100-400
	dredging vessel	188	20-2000
	dynamic positioning	189	30-3000
	transport vessel	192	40-100
	monitoring vehicles	166	1-5000
mid-water	column pumps	183	20-20000
bottom	nodule collector and	181	1-200
	rock fracturing		
	dredgers sucking	192	1 2500

⁴See ship traffic density maps online www.marinetraffic.com

²marine.copernicus.eu

³https://www.ecmwf.int/



Fig. 4. DSM source level spectrum as a acoustic power sum for three depths: bottom, mid-water and surface.

C. Acoustic propagation model

The calculation of transmission loss in Eq(2) was developed using the Bellhop3D Gaussian beam acoustic model [15], which is available online; the sound profile was calculated as the mean average of modelled profiles, predicted by the ocean model of the Corpernicus web service; properties of a sandy bottom were taken from the literature. Broadband calculations at the center frequencies of one third octave frequency intervals were performed for source depths of 10, 500, and 698 m (which were considered representative depths for the surface vessels, a pump of the riser system, and for the mining vehicle operating at the top of the Tropic Seamount), and for three different receiver positions (10, 1000 and 3500 m) on a disk of radius 150 km. Each set of predicted transmission losses from the three sources were combined with Source Level values given in [14] and further wind noise values were added to those predictions. The results are given in the next section.

IV. RESULTS

Deep water propagation is dominated by the structure of the sound speed profile along depth, and how it evolves in time and space. Another important factor is the sound source location relative to the sound speed profile. Most acoustic propagation codes become computationally prohibitive in deep water, at high frequency and for long range. This is why ray tracing is appealing since it captures the essence of the sound field structure at a relative low computational cost, which allows to include 3D features.

An example of the sound field structure propagation is obtained by representing acoustic rays out from the virtual source stretching in a range-depth plane as shown in Fig. 5 along a west-east vertical plane crossing the Tropic seamount peak. The shaded areas from dark blue to yellow represent the bathymetric features. Clearly the alternate shadow areas and convergence zones are compatible with the water depth, and show further decorrelation due to both increasing range and varying bathymetry.



Fig. 5. Range-depth rays propagating from the top of the Tropic seamount to the east.

The ENL results obtained may be summarized in the plots of Fig. 6 that show the noise levels in excess of the background field, as 300 km diameter discs obtained with (4) for a frequency band 12 - 2000 Hz using the DSM source levels detailed in section III-B and the wind baseline and noise models described above. Receiver depths of 10, 1000 and 3500 m are shown in the upper left, upper right and lower left plots, respectively for day January 31st, 2023. The lower right plot shows the three-depth and 31-day time SPL average. The discs are centered on location -20.7729W, 23.9146N, the shallowest point of the seamount, where the virtual multipole DSM source is located. A few comments apply:

- ENL varies widely with receiver depth: lower values near the surface and relatively high sound pressure levels in the deeper portion of the water column both at 1000 m and 3500 m depth. This is due to the fact that the baseline level is several dB higher near the surface then at deeper locations, so the subtracted factor reduces the ENL component at the surface;
- 2) higher sound levels are attained at the deeper receiver location but attenuate out in range faster at 3500 m than at 1000 m due to the tunneling provided by the SOFAR channel, that is located approximately at 1000 m depth.
- for depths larger than, say, 4000 m, below the critical depth, benefit from deep sound propagation, favouring sound emitted near the sea surface;
- as expected convergence zones do provide marked ENL levels which increase with depth;
- as expected ENL is not symmetric around the source point at close range due to bathymetric features, but tends to a circular pattern as range increases;
- 6) time variations of surface wind generated sound of up to 10 dB (not shown) are overcome by the high source emitted noise level and therefore time oscillations become minor, leading to an almost flat mean surface (also due to depth averaging);
- 7) spatial effects of wind generated noise are mild at the scale of 300 km, but can be seen in the border of the second quadrant of the range disc (northwest) with a slight ENL increase, specially when compared to the

12-2000 Hz - 31-Jan-2023



Fig. 6. Predicted excess noise level generated by DSM activity in the band 12-2000 Hz at three depths: 10, 1000 and 3500 m (upper left, right and lower left), on day Janaury 31st, 2023; time and depth averaged levels are shown in the lower right plot.

other borders to the northeast and southeast. The eastern part of the disc points to the African continent with a slight water depth reduction of a few hundreds of meters, increasing loss of rays' coherence and increasing attenuation.

V. CONCLUSION

This paper provides simulated results of the noise field generated by deep sea mining (DSM) activity. Emitted levels and frequency bands are taken from the literature. Environmental data is drawn from databases for the experimental area of project TRIDENT: the Tropic seamount. Particular attention was devoted to the estimation of the noise disturbance generated by DSM, which is evaluated as the excess noise level (ENL), *i.e.*, the noise level distribution above the expected baseline/natural sound level. The results show that ENL exhibits the typical deep water alternate shadow-convergence zones stretching out to at least 150 km at relatively high levels above 10 and up to 50 dB. Therefore near field is defined as below 10 km, mid-field is up to 50 km and far field is well above 100 km. The results also show that the ENL field varies widely with depth: lower results at the surface, long range at SOFAR channel depth, and ray-convergence dominated at the deeper sites.

Care should be taken regarding the limitations of this study: source levels and bands are based on credible assumptions, but actual field measurements are lacking; sound levels of the baseline/natural field are gross estimations based on wind sound models and wind speed from databases. In both cases, the work to be carried out under the TRIDENT project is expected to bring further insight into these missing aspects, of crucial importance for determining DSM activity impact ecosystems.

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