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Prediction of shipping noise in the Eastern Mediterranean Sea

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ABSTRACT

Shipping noise is one of the most common underwater sounds and a substantial component of ambient noise in the sea. Traveling vessels are sources of low-frequency acoustic waves which propagate efficiently through the water mass and thus affect underwater noise levels at large distances from the major shipping lanes. A prediction model for shipping noise in the Eastern Mediterranean Sea is currently being developed combining real-time ship data (AIS data) provided by the MarineTraffic ship tracking service, typical acoustic emission characteristics, environmental data and acoustic propagation codes. Taking into account prevailing temperature and sound-speed distributions, as well as the exact bathymetry in the area, range-dependent propagation calculations are carried out using a simple ray-theoretic approach combined with sound-speed smoothing to account for low-frequency effects, and the three dimensional distribution of sound intensity is estimated. Results for the distribution of noise level at various depths are presented on a geographical background (map) and periodically updated.

Keywords: Underwater Noise, Shipping Noise, Prediction I-INCE Classification Number: 54.3

1. INTRODUCTION

Shipping constitutes a major source of noise in the sea. Ships that are underway using their engines generate low-frequency noise in the water. It is known that low-frequency acoustic waves are subject to extremely low absorption and thus propagate efficiently through the ocean sound channel. This causes shipping noise to be present nearly everywhere, even at distant locations from the major shipping lanes.

Further, the influence of pressure, temperature and salinity on the sound velocity profile, and the existence of a sound-speed minimum at a certain depth (channel axis) in temperate oceans cause the acoustic energy to be trapped in the so-called SOFAR channel due to refraction, which in turn supports efficient propagation over long ranges. On the other hand, the presence of warm surface layers may cause downward refraction which prevents from hearing the noise of nearby passing ships. Depending on location, season and environmental conditions the propagation of sound/noise can be very different (1). In the Eastern Mediterranean Sea typical winter sound-speed profiles are close to linear with a minimum at the surface whereas in summer seasonal warming gives rise to a channel axis at a relatively shallow depth of a few 100 m. The complicated bathymetry in the Eastern Mediterranean Sea also plays a significant role in acoustic propagation giving rise to bottom losses and acoustic blockage effects.

In earlier times the operational prediction of shipping noise in open seas was a difficult task due to lack of sufficient information about distant shipping contributing to ambient noise. In this connection early modelling approaches for shipping noise estimation were mainly of statistical nature (2). In the last decade ship location data have become available through the Automatic Identification System (AIS). The AIS is an automatic tracking system used by ships and vessel traffic services for identifying and locating vessels by electronically exchanging data with other nearby ships, AIS base stations, and satellites. The primary reason for the introduction of the AIS was collision avoidance. According to Regulation 19 of the International Maritime Organization's International Convention for the Safety of Life at Sea (SOLAS) Chapter V (Carriage requirements for shipborne navigational systems and

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equipment) all ships with gross tonnage of 300 or more, and all passenger ships regardless of size, are required to have an AIS unit installed and operational (3). This requirement became effective in 31 December 2004.

In recent years, ship tracking services were developed offering world-wide coverage by combining data from AIS land-based receiving stations and satellites. In this way the positions of ships travelling in any area can be obtained in near-real time. Further, AIS data include descriptions about sailing characteristics (vessel speed, navigation status, ship type, etc.) which can be used to estimate sound-emission levels. By combining these data with the knowledge about the bathymetry and the prevailing propagation conditions in the area of interest and using acoustic propagation codes the spatial distribution of sound intensity (noise level) can be estimated (4).

The present work reports on preliminary results for noise prediction using AIS data in the Eastern Mediterranean Sea. AIS ship data are received from MarineTraffic (www.marinetraffic.com) ship tracking service on a continuous basis, averaging at about 1500-2000 travelling ships. The ships are considered as acoustic point sources at the given locations and propagation calculations are carried out to estimate the cumulative acoustic field in the Eastern Mediterranean basin. The results for the distribution of noise level at various depths are presented on a geographical background (map) and periodically updated.

The contents of this work are as follows: Section 2 describes the AIS data and their processing for the preparation of the inputs for the acoustic propagation calculations. Section 3 describes the acoustic modeling approach. In Section 4 some typical results are shown. Finally, Section 5 includes some conclusions from this work and a brief discussion.

2. AIS DATA

The primary use of AIS is as a support aid for collision avoidance. A VHF AIS transceiver is installed on each ship which emits information about the ship itself to other AIS receivers and receives information from other neighboring ships which enables monitoring of local traffic. An AIS transceiver emits ship data every 2-10 s depending on the vessel's speed while underway, and every 3 minutes while a vessel is at anchor. The AIS uses the globally allocated Marine Band Channels 87 and 88 in the frequencies 161.975 MHz (Channel A) and 162.025 MHz (Channel B). Port authorities also operate AIS receivers for monitoring and control purposes. AIS receivers are commercially available and anyone can acquire and install such a unit to receive AIS data of nearby ships within a range of 20-30 km – the range can vary depending on receiver location and weather conditions.

Received AIS data are formatted using the AIVDM protocol of the NMEA standard. Each message from a ship usually occupies one line (sometimes 2 lines) of the form presented in Table 1.

Table 1 – Example of an AIS message and brief explanation

!AIVDM,1,1,,A,14eG;o@034o8sd<L9i:a;WF>062D,0*7D	
!AIVDM:	The NMEA message type
1	Number of Sentences/Lines (some messages need more than one)
1	Sentence Number (1 unless it´s a multi-line message)
	The blank is the Sequential Message ID (for multi-sentence messages)
A	The AIS Channel (A or B)
14eG;o ..	The Encoded AIS Data
0*	End of Data
7D	NMEA Checksum

The encoded AIS data is an ASCII-encoded bit vector, with each character representing six bits of data. The first field of the AIS data in each message is the message type followed by other information fields. There are 27 different message types, nevertheless of interest for travelling ships are message types 1, 2, 3 and 5. The first 3 report on dynamic data (data changing with time, such as location, speed, direction), and their difference is just in the triggering mechanism (1: position report, 2: position report according to assigned schedule, 3: position report caused by interrogation), whereas a message of type 5 reports on so-called static data (data that is trip-specific, such as vessel name, ship type, dimensions, draught). Each ship usually emits dynamic data on a frequent basis, whereas static data are emitted separately and less often. The dynamic and static data have to be correlated using the Maritime Mobile Service Identity (MMSI), the unique nine-digit identification number of each ship in the AIS, which is included in all messages.

In the framework of this work an AIS receiver was acquired and installed at FORTH in Heraklion. The data received by such a unit can be shared via a local or wide area network via TCP or UDP protocols, nevertheless this data is limited by the collective range of the VHF antenna, which is usually a few tens of km. Thus, it is not possible to cover a broader area with a single receiver. The solution to this problem came in recent years with the development of ship tracking services which combine data from a large number of land- as well as satellite-based AIS receivers offering world-wide coverage. For applications such as the modelling and prediction of shipping noise this broad coverage is a necessary condition for realistic results since low-frequency noise efficiently propagates over long distances of hundreds of kilometers, far longer than the range of any single land-based AIS receiver. The usual requirement for access to such data is the installation of an AIS receiver and contribution of its data to the ship tracking service, as a way to expand and increase the redundancy of the corresponding receiving network.

The AIS data for the present work is provided by MarineTraffic (www.marinetraffic.com), a leading ship track service provider (5), in whose network the FORTH receiver has been integrated. AIS data from land stations and satellites are provided as a continuous data feed via the UDP protocol for the entire Eastern Mediterranean Sea. On the reception side the data are processed to extract ship positions and ship characteristics to be used as input for the acoustic propagation calculations. The data are also archived in 5-minute files. A problem that often arises is that a ship present in a particular 5-min window can be absent from the next 5-min window. This might be due to failure of reception of the AIS signal by the corresponding land station or the satellite. To cope with such cases the ships are followed one by one over the subsequent time windows. If a ship travelling in the interior of the basin does not appear in a particular time window its location is taken from the previous time window and so on up to a limit of two hours. A snapshot of ship locations is shown in Figure 1.

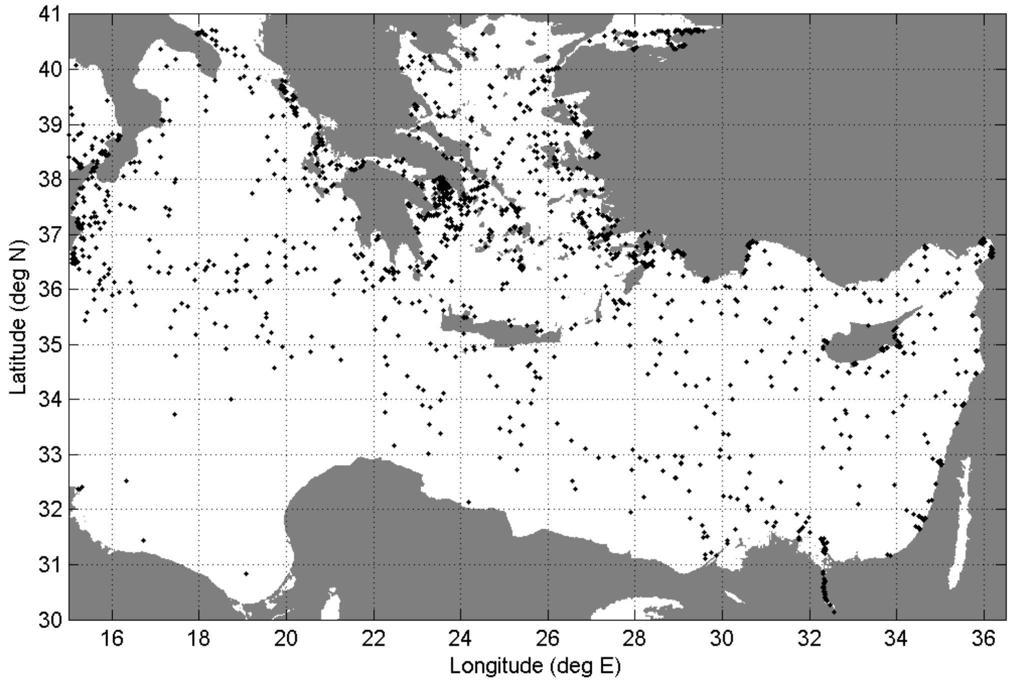

Figure 1. Snapshot of ship locations in the Eastern Mediterranean.

It is seen from this figure that ships are concentrated along major shipping lanes, such as the route connecting the Straits of Sicily with the entrance of the Suez Canal, the route connecting the Ionian and the Adriatic Sea off the west coast of Peloponnese, the route through the Aegean Sea to the Dardanelles and the Black Sea, etc.

3. NOISE MODELLING

3.1 Noise characteristics

Travelling ships are sources of underwater noise due to their running engines, auxiliary machinery, rotating propellers and vibrating hulls. The characteristics of the generated sound depend on the ship type, ship design and construction, state of maintenance and navigation status (speed, load condition, etc.) and are described by the source spectral density as a function of frequency measured in dB re 1 μPa/Hz @ 1m, known as acoustic signature. While the acoustic signatures of different ships are different and even that of a specific ship changes with time, typical values are given in the literature for various ship types. Table 2 shows typical spectral levels of five ship types used for the estimation of shipping noise in the RANDI ambient noise model (6, 7)

Table 2 – Typical spectral source levels (monopole source) for five ship types (6) in dB re 1 μPa/Hz @ 1m.

Ship type	10 Hz	25 Hz	50 Hz	100 Hz	300 Hz
Supertanker	185	189	185	175	157
Large tanker	175	179	176	166	149
Tanker	167	171	169	159	143
Merchant	161	165	163	154	137
Fishing vessel	139	143	141	132	117

There are several works focusing on the measurement of the acoustic signatures of various types of commercial vessels (8, 9). Attention is necessary when comparing source levels; some authors describe spectral densities in octave or 1/3 octave bands, others describe band levels (integrated source levels over frequency). Further, some of the given levels refer to a monopole source, others to a dipole source, the latter also including the mirror image of the primary source (monopole source) with respect to the sea surface. Table 2 refers to monopole source levels.

Based on the analysis of measured data empirical formulas have been developed describing the spectral source density depending on ship characteristics such as ship length, speed etc. (10, 11). These empirical formulas refer to particular sets of measured data and ship types, and it often occurs that new data sets, possibly associated with new ship designs, ask for new analyses. Ideally, each individual ship should have its own set of acoustic signatures corresponding to different navigation / load conditions, which should also be updated from time to time. This procedure is followed in the case of naval ships for operational reasons but not in the case of commercial vessels.

The focus of the present work is not on the acoustic signatures but rather the pilot application of AIS data for real-time estimation of ambient noise levels in the Eastern Mediterranean. Better and more representative acoustic signatures for the involved vessels will lead to more accurate noise estimation results. In the lack of such data typical sound emission levels will be used.

3.2 Propagation modelling

For long-range propagation calculations each ship is considered as a point source at a depth equal to the ship draught, which can range from a few meters up to about 20 m for large ships under full load. The bathymetry of the Eastern Mediterranean Sea is taken from the ETOPO1 database; this is a 1 arc-minute global relief model of Earth's surface that integrates land topography and ocean bathymetry. One arc-minute equals 1/60 of a degree which results in a grid cell resolution of about 1.8 km. Ship positions in the horizontal are rounded to the nearest grid point. Further, at each grid point vessels of similar draught are grouped and their source levels are accumulated. For the calculation of the accumulated source level the individual source levels are converted from logarithmic to physical units – acoustic intensities – which are then summed and the result is converted back to logarithmic units.

A ray-theoretic code is used for the calculation of the acoustic field around each source taking into account acoustic refraction caused by the spatial variation of the sound-speed (temperature) in the vertical and also the bathymetric change in range and azimuth giving rise to bottom losses and blockage effects. In order to account for finite-frequency effects on the propagation the sound-velocity profile is smoothed with a moving window inversely proportional to the propagation frequency (12). For the calculation of bottom losses the sea bed is considered as an acoustic medium consisting of a sediment layer followed by a sub-bottom.

3D coverage is obtained by solving the propagation problem along a number of vertical range-dependent sections extending radially around the source location in fixed angle steps and by interpolating the propagation results in the azimuthal direction providing acoustic level values on the points of the regular grid. This procedure is repeated for all sources on the grid. The acoustic levels on each grid point are then accumulated. As in the case of the source level accumulations the individual acoustic levels are converted from logarithmic to physical units – acoustic intensities – which are then summed and the result is converted back to logarithmic units.

4. NUMERICAL RESULTS

In this section some preliminary results are presented for the predicted noise level distributions in the Eastern Mediterranean due to shipping. The acoustic sources correspond to the ship locations shown in Figure 1 – including a total of 1790 travelling ships. For the preliminary calculations all ships are assumed to have the same spectral level equal to 160 dB re 1 μPa/Hz @ 1m and the corresponding source depths are set to 15 m. For the water column a linear sound-velocity profile is considered, 1510 m/s at the surface and 1585 m/s at 5 km depth, being an approximation to typical late-winter conditions (uniform temperature distribution). The sea bed is modelled as a 3-m thick sandy sediment layer (sound-speed 1650 m/s, density 1.9 gr/cm^3 and attenuation 0.8 dB/wavelength) on top of a rocky substrate (sound-speed 1800 m/s, density 2 gr/cm^3 and attenuation 0.6 dB/wavelength) – parameters taken from reference (1). The propagation calculations from each source are carried out along 15 azimuthal directions (angle step of 24 degrees) and up to a range of 500 km. The range-dependent section extracted along each azimuthal direction is discretized with a range step of 5 km by considering a piecewise linear variation of the bathymetry. In this connection the water-sediment and sediment-sub-bottom interfaces are not assumed to be horizontal but they are allowed to be tilted and follow the bathymetry.

Figure 2 shows the predicted spectral noise level at a depth of 40 m. The ship locations correspond to the distribution peaks and can be easily identified. Clearly the areas around routes with heavy traffic are characterized by increased noise levels. The area in the southwest of the basin, off the central Libyan coast, is characterized by very low shipping density and accordingly by low noise levels. On the other hand the highest noise levels are observed in the Saronic Gulf, off the busy port of Piraeus and the east coast of Peloponnese.

Figures 3 and 4 show results for depths of 100 m and 200 m, respectively. Moving from 40 to 100 m the noise levels undergo a significant reduction. This is due to the fact that the linear sound-velocity profile used for the propagation calculation is upward refracting and in combination with the shallow depth of the sources causes acoustic energy to be trapped in the upper layers close to the surface (surface duct propagation conditions). A significant degree of homogenization has taken place at the depth of 100 m such that the source location can no longer be identified, especially in areas of high ship concentration. Lower noise levels are observed at the depth of 200 m.

The effects of the bathymetry can also be seen in these figures. The most pronounced effect is that of acoustic blockage by the land and island masses. In this connection the noise distribution in the North Aegean sea is mostly affected by the ships travelling in that area and not by ships travelling further south, e.g. by the noisy area around the Piraeus port.

On the basis of these preliminary results the western Mediterranean Basin appears to be a noisy environment, with the exception of its southwestern part, characterized by low shipping density. A systematic long-term statistical analysis would be required to draw more definitive conclusions regarding the noise characterization of the various areas.

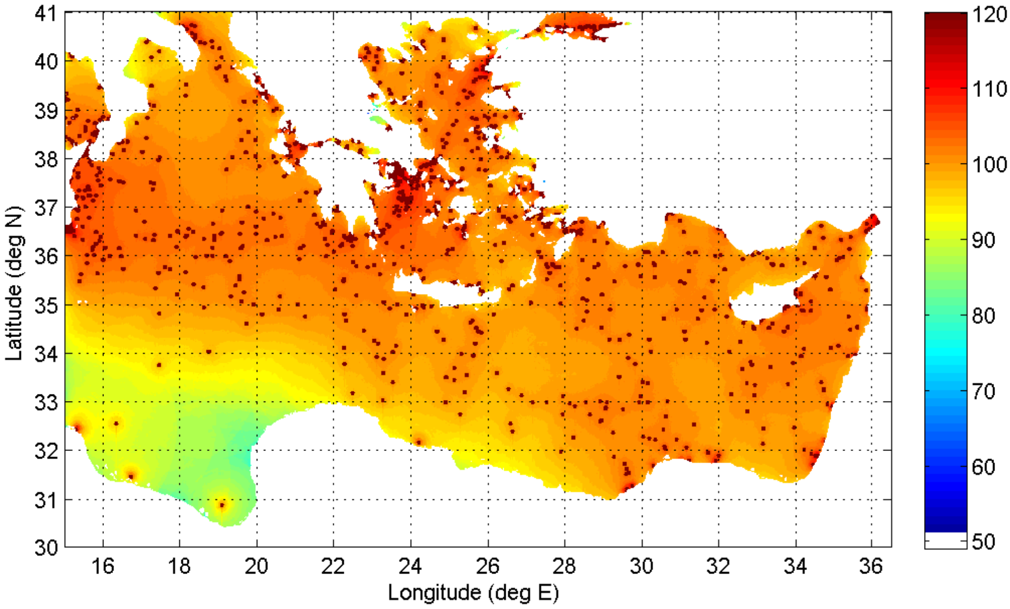

Figure 2. Predicted noise levels in dB re 1 μPa/Hz at a depth of 40 m.

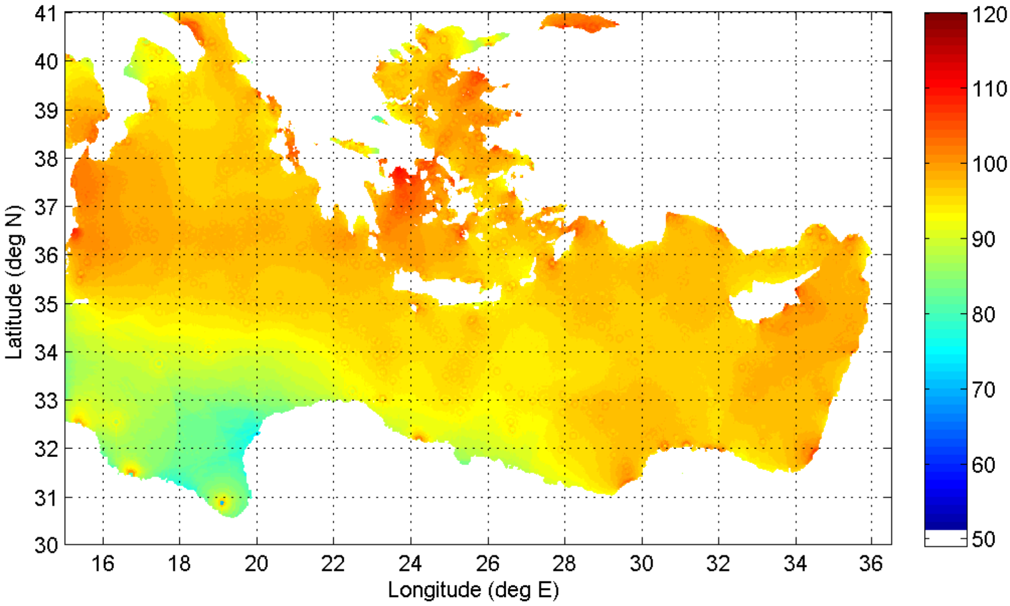

Figure 3. Predicted noise levels in dB re 1 μPa/Hz at a depth of 100 m.

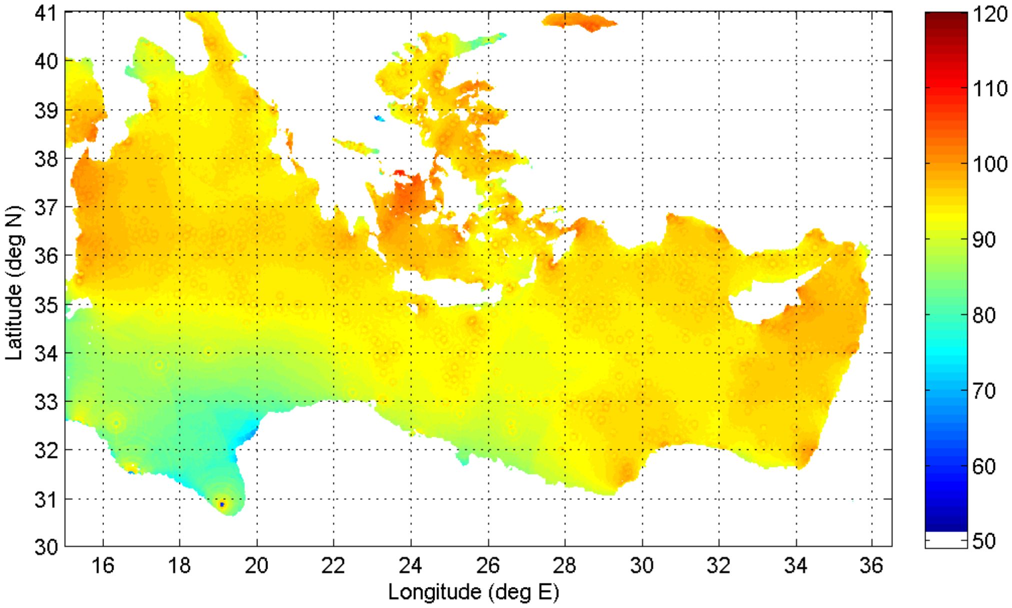

Figure 4. Predicted noise levels in dB re 1 μPa/Hz at a depth of 200 m.

5. DISCUSSION - CONCLUSIONS

The measurement of ambient noise distribution over large areas with complicated bathymetry and coastline such as the Eastern Mediterranean and its variability in time and space poses serious challenges. Acoustic propagation modelling in combination with advancements in the availability of ship tracking data offers a solution to this problem.

In this work a ray-theoretic modelling approach is used for propagation calculations combined with sound-speed smoothing to account for low frequency effects. This approach is computationally efficient and accounts for range dependence. Future plans include the application of wave-theoretic propagation modelling and comparisons with the present geometric approach in terms of efficiency and accuracy. Future plans also include parallelization of the propagation calculations as a means to accelerate the calculation and increase the update frequency as well as publication of the predicted noise levels on the Internet.

A source of uncertainty for the obtained noise level results has to do with the acoustic emission characteristics (acoustic signatures) of the contributing ships. The available data are limited and refer in general terms to certain ship types. On the other hand, each particular vessel has a different acoustic signature and thus a different emission level depending on its design, maintenance status, load and navigation conditions. The significance of the accurate knowledge of ship acoustic emission characteristics and its impact on noise estimation accuracy can be assessed using the present modeling approach.

Last but not least, the validation of the predicted noise levels by in situ measurements is of great importance for the assessment of the prediction model and the whole processing chain involving ship data, acoustic emission characteristics, environmental data and propagation model. Maps of predicted noise distribution can help in selecting critical locations for installation of noise recorders for model validation.

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