MODELLING OF UNDERWATER NOISE DUE TO SHIP TRAFFIC IN THE EASTERN MEDITERRANEAN SEA

E. Skarsoulis[a], G. Piperakis[a], E. Orfanakis[a], P. Papadakis[a], M. Taroudakis[b,a]

[a] Institute of Applied and Computational Mathematics FORTH, Heraklion, Crete, Greece
[b] University of Crete, Department of Mathematics, Heraklion, Crete, Greece

Abstract: *A prediction model for shipping noise in the Eastern Mediterranean Sea is presented combining AIS data for ship locations/characteristics, environmental data and acoustic propagation codes. Taking into account typical acoustic emission characteristics of travelling ships, prevailing temperature and sound-speed distributions subject to seasonal variation, as well as the exact bathymetry in the area, range-dependent propagation calculations are carried out. Results for the geographical distribution of noise levels at various depths are produced and periodically updated on an hourly basis.*

Keywords: *Underwater noise, shipping noise, propagation modelling*

1. INTRODUCTION

Noise due to ship traffic is a substantial component of ambient noise in the sea, and dominates in the low-frequency range, below 500 Hz. Travelling ships 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.

In recent years the European Union introduced the Marine Strategy Framework Directive (MSFD) aiming at the establishment of good environmental status in the sea areas surrounding Europe. The MSFD addresses, among others, underwater noise pollution [1] and requires the monitoring of continuous low-frequency (63 and 125 Hz) noise through measurement by observation stations and/or with the use of models if appropriate.

The Eastern Mediterranean Sea is characterized by heavy ship traffic, with major shipping lanes connecting, among others, the Sicily Strait, the Adriatic Sea, the Black Sea and the Suez Canal. The measurement of ambient noise distribution over time and space in such a large sea area with complicated bathymetry and coastline poses serious challenges. Acoustic propagation modelling in combination with advancements in the availability of ship tracking data can be supportive in this respect.

The propagation of sound in water is influenced by changes in temperature and pressure (also by changes in salinity albeit to a much lesser extent). E.g. the warming of surface layers in summer causes strong sound-speed gradients leading to downward refraction and thus affect noise levels close to the surface [2]. The complicated bathymetry also plays a significant role in acoustic propagation giving rise to bottom losses and acoustic blockage effects.

In earlier times the lack of sufficient information about distant ship traffic was a hampering factor for operational modelling of shipping noise in open sea areas. In this connection early modelling approaches were mainly of statistical nature [3] or relied on certain navigation scenarios [4]. In recent times ship traffic data have become readily available through the Automatic Identification System (AIS) and the corresponding ship tracking services offering world-wide coverage [5].

The present work describes a prediction model for shipping noise in the Eastern Mediterranean Sea combining AIS data for ship locations/characteristics, environmental data and acoustic propagation codes. Typical acoustic emission characteristics of travelling ships are taken from the literature. A wave-theoretic range-dependent acoustic propagation model relying on adiabatic-mode theory is used. Concerning the environmental parameters, the seasonal temperature variation in the water column as well as the bathymetry and bottom composition are accounted for.

The geographical distribution of noise levels at various depths is estimated and periodically updated on an hourly basis. Some of the results can be found on the internet at the address http://www.iacm.forth.gr/shipnoise

2. AIS DATA

The primary purpose of the Automatic Identification System (AIS) is collision avoidance. All ships of 300 gross tonnage and above are equipped with VHF systems broadcasting their characteristics (ship name, type, location, navigation status, speed, etc.) and receiving the corresponding characteristics of nearby ships. In recent years, ship tracking services relying on land and satellite based AIS stations/receivers have been developed. In this way ship traffic data for any sea area are available in near real time. Information about ship type and navigation status contained in the AIS data can be used to infer on sound emission levels of each ship. By combining these data with the bathymetry characteristics and the prevailing propagation conditions in the area of interest and by applying acoustic propagation codes the distribution of noise in the area of interest can be estimated.

In the context of this work, an AIS receiver was installed at FORTH (Heraklion, Crete) and was integrated into the MarineTraffic network, a web-based ship tracking service (www.marinetraffic.com). In response MarineTraffic kindly provides ship traffic data from terrestrial and satellite AIS receivers covering the Eastern Mediterranean Sea on a continuous basis. A typical picture of ship traffic in the area is shown in Fig. 1.

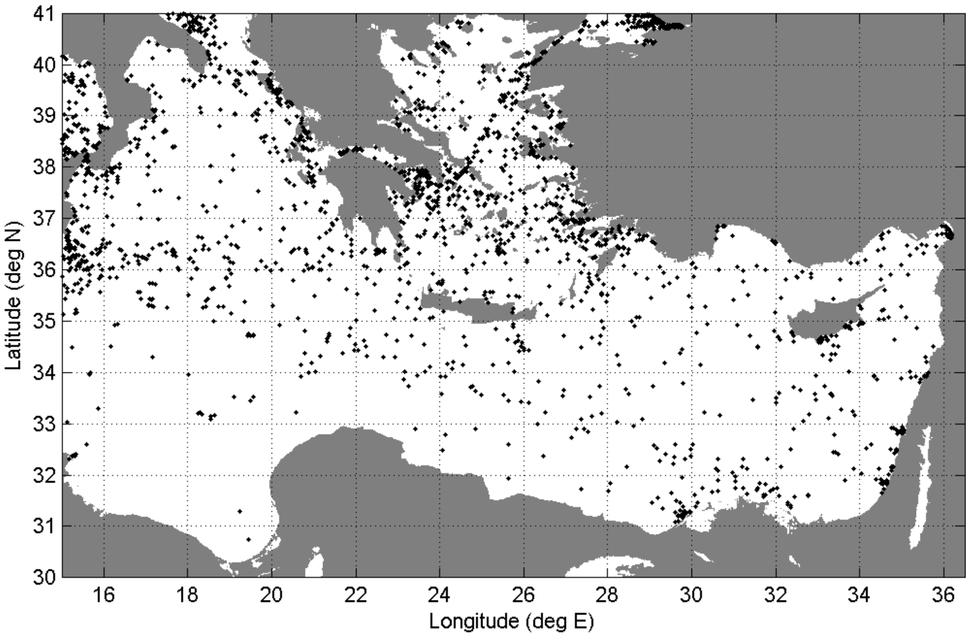

Fig.1: Snapshot of ship traffic on 1 June 2017 in the Eastern Mediterranean Sea, based on AIS data.

3. NOISE MODELING

3.1. Source levels

Travelling ships are sources of underwater noise. The noise is generated by the propellers, the main engines and the auxiliary machinery, as well as by hull vibrations. The characteristics of the produced sound depend on ship type, design and construction, maintenance status, navigation conditions (speed, load, etc.). The emitted sound along a particular direction can be described by the source level spectral density as a function of frequency (acoustic signature) measured in dB re 1 μPa^2 / Hz @ 1m.

Data on typical acoustic signatures for different ship types can be found in the literature. Recent studies [6]-[9] are based on the combination and analysis of underwater acoustic measurements and simultaneous AIS data of large numbers of travelling ships, taking into account propagation characteristics of the measurement sites. Despite the detailed analyses the reported spectral levels are characterized by large variability, reaching 25 dB in some cases. These differences may be due to the different measurement setups and vessels involved.

The spectral source level values given by McKenna et al. [6] and Basset et al. [7] are used in the following as the basis for noise predictions at the frequency of 100 Hz, as they lie close to the middle of the variability intervals. According to those studies, average spectral source levels are about 155 dB re 1 μPa^2/Hz @ 1m for tankers and cargo ships, 150 dB re μPa^2/Hz @ 1m for passenger ships, 145 dB re 1 μPa^2/Hz @ 1m for fishing vessels, 140 dB re 1 μPa^2/Hz @ 1m for auxiliary vessels.

Ideally, each individual ship should have its own set of acoustic signatures corresponding to different navigation / load conditions and different azimuthal directions, which should also be updated from time to time. Such detailed data are collected for some types of naval vessels – and usually remain classified – but are not available for commercial vessels. In any case 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 over a large sea area. Better and more representative acoustic signatures for the involved vessels will lead to more accurate noise estimation results. In the lack of such data the typical sound emission levels mentioned above will be used.

3.2. Acoustic propagation

For long-range propagation calculations each ship is considered as an omnidirectional source (point source) at a depth of 9 m, a representative value taking into account that ship draught values may vary from a few meters up to about 20 m for large vessels under full load [7], [9].

The bathymetry of the Eastern Mediterranean Sea is taken from the ETOPO1 database; this is a 1 arc-minute global relief model of the Earth's surface that integrates land topography and ocean bathymetry. For the acoustic calculations a 2/60 deg grid is adopted (resolution 3.6 km). Ship positions in the horizontal are rounded to the nearest grid point and their acoustic intensities are accumulated assuming incoherence.

A simplified model is used for the temperature distribution assuming seasonal dependence and dependence with depth. Further the bottom is considered to be homogenous and acoustic with sound speed 1800 m/s, density 2 gr/cm^3 and attenuation 1 dB/λ. Thus, range dependence is only due to bathymetry. For the calculation of the acoustic field the KRAKEN normal-mode code [10] is used and the adiabatic approach [11], [12] is applied. The fact that different locations differ only in the water depth allows for categorization of different areas according to the water depth and the use of precalculated eigenvalues and eigenfunctions to accelerate calculations.

The seasonal variation of the temperature (and sound speed) profile is taken into account through a parametric model combining a linear velocity profile, 1510 m/s at the surface and 1570 m/s at 4000 m depth (typical winter profile in the Mediterranean), and a linear heating profile for the upper 150 m layer, starting from zero at 150 m depth and reaching its maximum at the surface. The velocity variation on the surface is taken between 1510 m/s (winter - zero heating) and 1545 m/s (summer - maximum heating).

Thus, on each day of the year a typical temperature (and sound-speed) profile is calculated which determines the acoustic environment. For this environment the eigenvalues and propagating modes are calculated and stored for different water depths to cover all areas of interest, from the shallowest to the deepest. Then for every hour of the day, corresponding to a different source distribution, the acoustic field at any location (receiver location) in the basin is calculated by combining eigenvalues and eigenfunctions at each source and each receiver location, as well as at the locations along the path connecting source and receiver, retaining the minimum number of propagating modes along the path (mode stripping), and incoherently adding the acoustic intensities contributed by the various sources. The number of sources (ship groups) in the Eastern Mediterranean Sea typically ranges between 1500 and 3000, whereas the number of grid points (3.6 km resolution), where the acoustic field is calculated, is about 120000, resulting in a very large number of source-receiver combinations. In this connection the acoustic field calculations are carried out on a cluster using a parallel computation scheme.

4. NUMERICAL RESULTS

Some results are presented in the following for the predicted noise levels due to shipping in the Eastern Mediterranean Sea. The ship distribution of Fig. 1, counting a total of 2130 ship groups, is used as the basis for the calculations. Fig. 2 shows the 5% and 95% percentile values, i.e. the noise levels exceeded 95% and 5% of the time respectively, at a

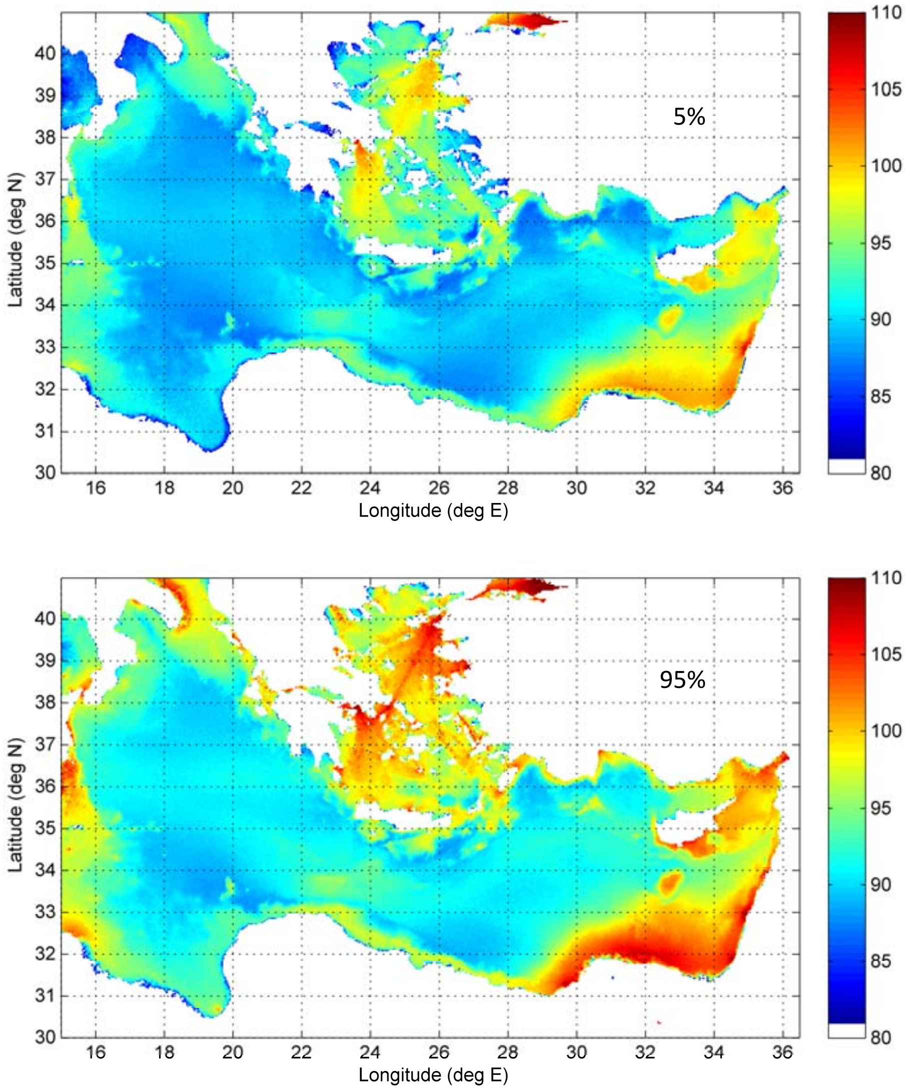

Fig.2: Predicted spectral noise level (dB re 1μPa²/Hz) distribution on 1 June 2017 in the Eastern Mediterranean at the depth of 50 m and frequency of 100 Hz – 5% (top) and 95% (bottom) percentile values over 24 h.

depth of 50 m and frequency of 100 Hz. It is interesting to see that the noise levels are high in shallow water areas, close to major ports and shipping lanes, e.g. in the south-eastern part of the basin near the port of Alexandria and the entry of the Suez canal or in the Aegean Sea, whereas they are lower in the deep-water areas of the Eastern Mediterranean Sea, e.g. in the deep Ionian basin. A physical explanation of this behaviour can be given in terms of the lower amplitudes of the propagating modes in deep water, as contrasted to the higher amplitudes in shallow water. The major shipping routes can be identified in the 95% percentile results.

In order to see the effect of the propagation characteristics on the noise level distribution, Fig. 3 shows the predicted spectral noise levels for the ship distribution of Fig. 1 using two extreme sound-speed profiles, the winter linear profile and the summer profile with maximum heating at the surface. The first sound-speed profile is upward refracting, whereas the second one has a minimum at 150 m depth and a strong temperature (sound-speed) gradient causing downward refraction at shallower depths. It is seen in Fig. 3 that the noise levels at 50 m depth for summer propagation conditions are

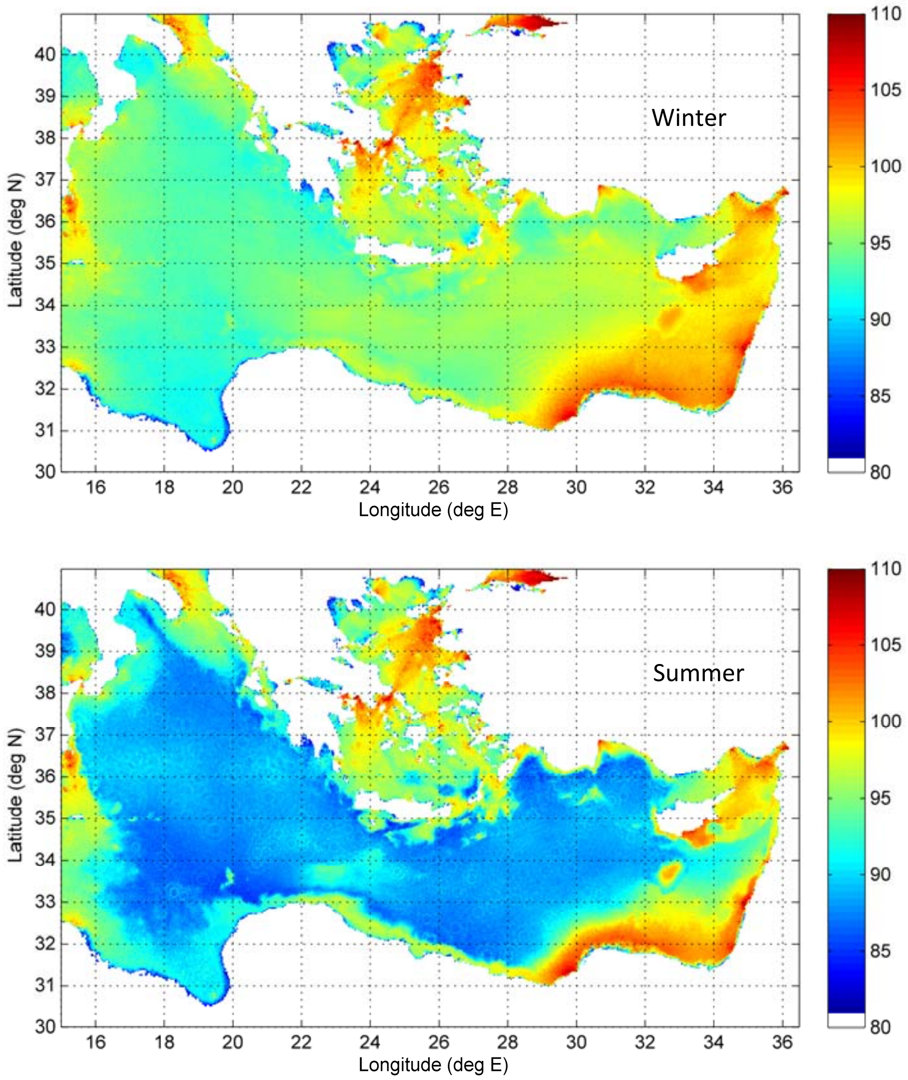

Fig.3: Predicted spectral noise level (dB re 1μPa²/Hz) distribution at the depth of 50 m and frequency of 100 Hz, corresponding to the ship traffic of Fig. 1 assuming winter (top) and summer (bottom) propagation conditions.

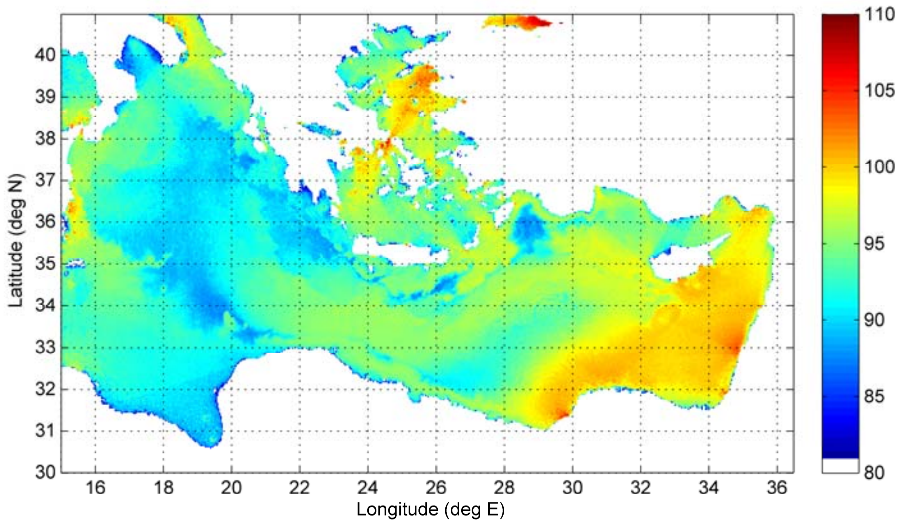

Fig.4: Predicted spectral noise level (dB re 1μPa²/Hz) distribution at the depth of 100 m and frequency of 100 Hz, corresponding to the ship traffic of Fig. 1 assuming summer propagation conditions.

much lower, especially in the deep-water parts of the basin. This is the effect of the strong downward refraction taking place in summer in the upper layers, where the sound sources are located. It is remarkable that this refraction effect is felt so clearly by the low frequency of 100 Hz (wavelength of 15 m). Based on the above argumentation the acoustic energy in summer should be found in deeper layers. Fig. 4 shows the predicted spectral noise level at a depth of 100 m. It is clear from this figure that the acoustic energy is directed to the deep. Results like these are produced on a systematic and continuous basis and are updated hourly and can be accessed at www.iacm.forth.gr/shipnoise.

5. CONCLUSION / SUMMARY

The measurement of ambient noise distribution over large sea areas with complicated bathymetry and coastline such as the Eastern Mediterranean Sea and its variability in time and space poses serious challenges. Acoustic modelling can be supportive in this respect. The combination of propagation models with environmental and AIS data enables the prediction of shipping noise distribution in near-real time and allows for the study of the influence of various factors, e.g. environmental variability or acoustic emission characteristics. A combination of prediction models with actual noise measurements at selected locations is the most appropriate approach for monitoring noise levels over large sea areas with the complex characteristics of the Mediterranean Sea.

In this work a normal-mode approach (adiabatic approximation) is combined with AIS data and typical emission characteristics using a simple environmental model accounting for the bathymetry of the Eastern Mediterranean Sea to produce predictions of the shipping noise distribution at various depths in near-real time. Applications of the results include the environmental characterization of particular marine areas, the performance analysis of sonar systems, etc.

A significant source of uncertainty for the predicted noise level distributions has to do with the acoustic emission characteristics of the contributing ships. Each particular vessel has a different emission level and directivity pattern depending on its design, maintenance status, load, navigation conditions etc. Acoustic models such as the one presented here can account for all these characteristics. Nevertheless, the presently available data on acoustic emissions refer to typical levels depending on ship type and subject to a large amount of uncertainty. The significance of the accurate knowledge of the emission characteristics and its impact on noise estimation accuracy can be assessed with the present modelling approach.

6. ACKNOWLEDGEMENTS

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