Monthly and annual maps of soundscape

Final Version of 20/10/2021

Deliverable Number D.5.2.1

European Regional Development Fund

www.italy-croatia.eu/soundscape

Project Acronym	SOUNDSCAPE
Project ID Number	10043643
Project Title	Soundscapes in the north Adriatic Sea and their impact on marine biological resources
Priority Axis	3
Specific Objective	3.2
Work Package Number	5
Work Package Title	Soundscape modelling and planning impact mitigation measures and scenarios
Activity Number	5.2
Activity Title	Soundscape modelling for the Northern Adriatic Sea
Partner in Charge	CNR
Partners Involved	QuietOcean
Authors	Michol Ghezzo (CNR-ISMAR), Antonio Petrizzo (CNR-ISMAR), Marta Picciulin (CNR-ISMAR), Thomas Folegot (QOCean), Roger Gallou (QOcean), Fantina Madricardo (CNR-ISMAR)
Status	Final
Distribution	Public
Citation	Ghezzo M., Petrizzo A., Picciulin M., Folegot T., Gallou R. Madricardo F. Monthly and annual maps of soundscape. SOUNDSCAPE project, WP5, 26 pp, 2021.

Summary

List of figures

Abstract

This report illustrates the monthly and annual maps of SOUNDSCAPE modelling activity, made available through the QUONOPS online platform. The modelling activity calculated the monthly noise distribution on the north Adriatic domain for Four third-octave bands. They correspond to the MSFD control continuous 1/3 octave bands centred at 63 Hz and 125 Hz and two other 1/3 octave band frequencies centred at 250 Hz and 4000 Hz. Two depth levels were calculated the top (0-15m) and the bottom (greater than 30m), otherwise the whole water column was available. For each noise map, seven percentiles were calculated.

1 Introduction

The idea that anthropogenic noise can have detrimental effects on marine life starts since the 1970s but only from the 2000 the studies on this pollutant become cospicous. Nowadays international researches confirmed the detrimental effects of underwater noise on mammals, invertebrate and fishes (Duarte et al 2021). The Directive 2008/56/EC (Marine Strategy Framework Directive, MSFD; EU), which was revised in the Commission Directive 2017/845/EU, 2017, mandates toward a Good Environmental Status (GES) in the European seas by 2020. With regards to underwater sound, Descriptor 11 of the MSFD states that GES is achieved when the introduction of energy, including sound, is at levels that do not adversely affect the marine environment. For implementing this, a monitoring programme has to be established observing the current level and any trend of ambient noise in European seas.

Underwater modelling has long tradition more than 50 years long of scientific and operational development for military purposes. Basic propagation modelling benefits of military research to incorporate the acoustic propagation phenomena into a theoretical and numerical formalism, which gives a quantitative prediction of the sound field for arbitrary ocean environments. There are essentially five types of models (computer solutions to the wave equation) to describe sound propagation in the sea: spectral, normal mode, ray and parabolic equation models, and direct finite-difference, or finite-element solutions of the full wave equation. All these models take into account the variation of the ocean environment characteristics with depth. The most sophisticate and integrated modelling systems allow numerical reconstructing the sound field in a given realistic environmental context; in its turn this permits to map the tri-dimensional noise as a function of time, according to environmental data streams and human activity information and identification streams.

To optimize the value of the data collected during the SOUNDSCAPE project and to better estimate the mitigation actions, the state-of-art modelling was applied to estimate the marine sound in the whole spatial and temporal domain of the project by numerical simulation. For this purpose Quiet-Oceans company and its system Quonops© was selected, which produces an estimate of the spatio-temporal distribution of noise levels generated by human activities at sea, aggregating multiple sources, and assessing short-, mid- and long term source contributions to the global noise field.

2 Quonops© Sound modelling

Acoustic modelling is performed by the Quonops© underwater noise prediction system, which is implemented over the north Adriatic region. Quonops© is built on the same philosophy as oceanographic or meteorological prediction systems (Jensen, Kuperman, Porter, & Schmidt, 2000), (Folegot & Clorennec, 2015) (Figure 1) based on parabolic equation (Collins, 1994),(Collins, Cederberg, & King, 1996) and Gaussian energy distribution ray modelling (Bellhop model; (Porter & Reiss, 1984)), which faithfully reflects the geometric distribution of noise in the water column, while offering computationally interesting performances for a statistical analysis. The speed profiles of sound in water are three-dimensional and derived from water temperature, salinity, and pressure (or depth). The main effect of these non-homogeneities in sound speed distributions is to bend propagation rays and create propagation channels. These complex phenomena are however predictable by numerical simulation. The modelling of sound propagation has been done in this study by a series of cylindrical interpolated vertical planes (Nx2D technique).

Indeed, like oceanographic or meteorological forecasting systems, this powerful and patented platform (European Union Brevet n° EP2488839, 2009) produces an estimate of the spatio-temporal distribution of noise levels generated by all human activities at sea. Covered maritime activities are numerous among which maritime traffic, oil prospecting operations, submarine warfare exercises, construction and offshore operations of hydrocarbon extraction, construction and operation of wind turbines at sea, drilling and underwater blasting, etc. The data produced by Quonops© covers needs as defined in existing and emerging national and international regulations regarding pollution levels and the preservation of habitats, marine ecosystems and the protection of marine species (Folegot & Clorennec, 2015). It offers a new knowledge of sound pollution through distribution mapping and allows to understand both the acoustic components of impact studies and the requirements of the Marine Strategy Framework Directive (MSFD) of the European Union and of other regulations like Taiwanese, Belgian, Dutch, German and other noise thresholds.

The models embedded in the Quonops platform are solving the Helmholtz equation (Figure 2) of wave propagation based on parabolic equation (Collins 1994, Collins et al. 1996) and, for the higher frequency range, Gaussian energy distribution ray modelling (Porter & Reiss 1984), which faithfully reflects the geometric distribution of noise in the water column, while offering computationally interesting performances for a statistical analysis. The real and exact position of all sound sources is used in their marine environmental context. Modelling is done at sub-wavelength scales for each source independently. This means that the modelling of sound is performed down to cm resolutions.

The speed profiles of sound in water are three-dimensional and derived from water temperature, salinity, and pressure (or depth) provided by operational oceanographic services. The main effect of these non-homogeneities in sound speed distributions is to bend propagation rays and create propagation channels. These complex phenomena are, however, predictable by numerical simulation. The modelling of sound propagation is done by a series of cylindrical interpolated vertical planes (N x 2D technique) azimuths around the sound source spaced by 1°.

The sediment properties and the changes of the bathymetry of the marine environment are also taken into consideration in the resolution of the Helmholtz Equation by also calculating the propagation in the marine substrate. These characteristics of the marine environment induce absorption, reflection and diffusion of the sound through the bottom and in the water column. The descriptive data of the bottom and bathymetry are taken from European databases or from available local data.

The results from Quonops' modelling give a description of the distribution of the underwater noise levels as a function of depth and range. The sound distribution is not uniform as depth and range change.

The principle of the modelling is to calculate the acoustic sound field at regular time intervals and to calculate the statistics out of the series of instantaneous maps. At each given time steps, the instantaneous situation that influence the sound propagation is gather from a number of input data. The marine situation is described by:

- The instantaneous positions of every vessel carrying an AIS system on board. The exact position of each vessel at the exact time of the modelling time step is extrapolated from the calculated trajectory of each vessel;
- The temperature and salinity three-dimensional distribution, which is converted into a distribution of sound speed directly used in the acoustic model;
- The two-dimensional wind field that is used to assess the natural component of the noise;
- The bathymetry distribution of the region to model;
- The grain size distribution of the seafloor in the region to model that is converted into compressional speed, compressional attenuation and density of the sediment layer.

The modelling is carried out at the centre frequency $f_m$of each one-third octave in the frequency band of the acoustic sources. To obtain levels in one-third octave bands, we assume that the energy at the centre frequency is constant in the third of an octave. Therefore, the levelis given by:

$$SPL_{1/3} = SPL_{f_m} + 10.\log_{10}(f_2 - f_1)$$

where $SPL_{1/3}$ is the sound pressure level in the one-third octave between f_1 and f_2 as defined by the ISO standard, and SPL_{f_m} is the sound pressure level modelled at the central frequency f_m.

Figure 1 Concept of the modelling platform Quonops© developed and operated by Quiet-Oceans.

$$\Delta p - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = \delta(t-t_0, r-r_0)$$

$$\rho c^2 = p \quad \rho_0 \frac{\partial \vec{v}}{\partial t} + \vec{\nabla} p = 0$$

$$j2\pi f \rho_0 \vec{v} + \vec{\nabla} p = 0$$

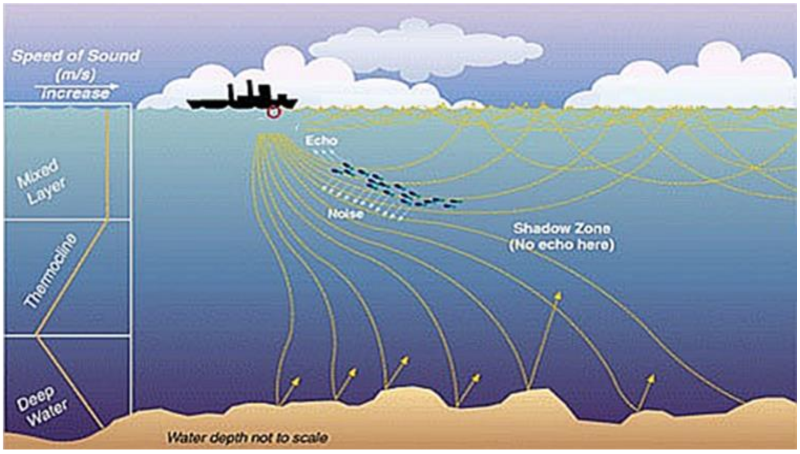

Figure 2Quonops© uses a physics-based model that reflects the propagation of noise in the water column in realistic oceanographic conditions by resolving the Helmholtz Equation (left)

3 Model set-up and calibration

The QUONOPS implementation covers the North Adriatic domain (Lat 42.8, 45.8, Long 12.1, 17.9; Figure 3), performing a more detailed run for the Cres-Losinj archipelago (Croatia; Lat 44.3, 44.9; Long 14,15). The calculation is performed on regular grid with larger resolution in the north Adriatic sea application (181x179 m) than in the Losinj application (40x40 m) .

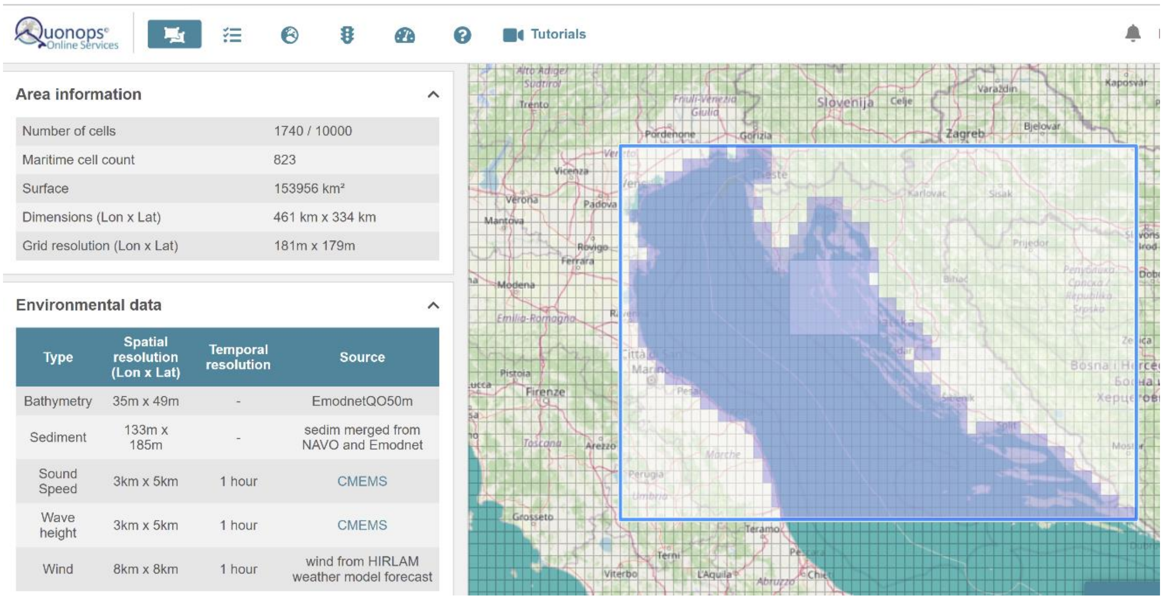

Figure 3 Adriatic domain with grid and input details

Input data for sound mapping

Input data are provided by stakeholders as showed in the Figure 4:

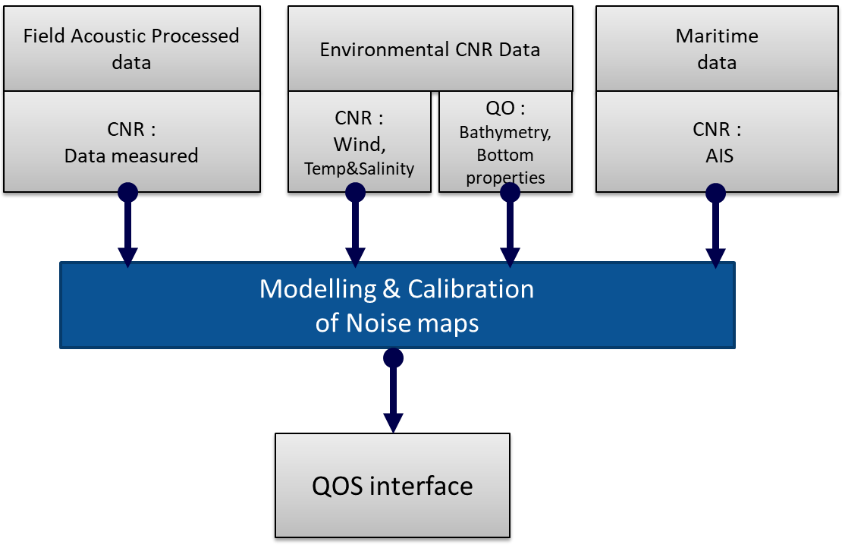

Figure 4Input data identification

Bathymetry

Quonops needs bathymetry layer to describe the channel of propagation of underwater acoustic noise. For this study, bathymetry is based on Emodnet model (https://portal.emodnet-bathymetry.eu/). Quiet-Oceans has reprocessed Emodnet data by extending the resolution to 50 meters and fill the gap until the coastlines.

The following Figures 5 and 6 show the bathymetry used by Quonops for modelling the North Adriatic sea.

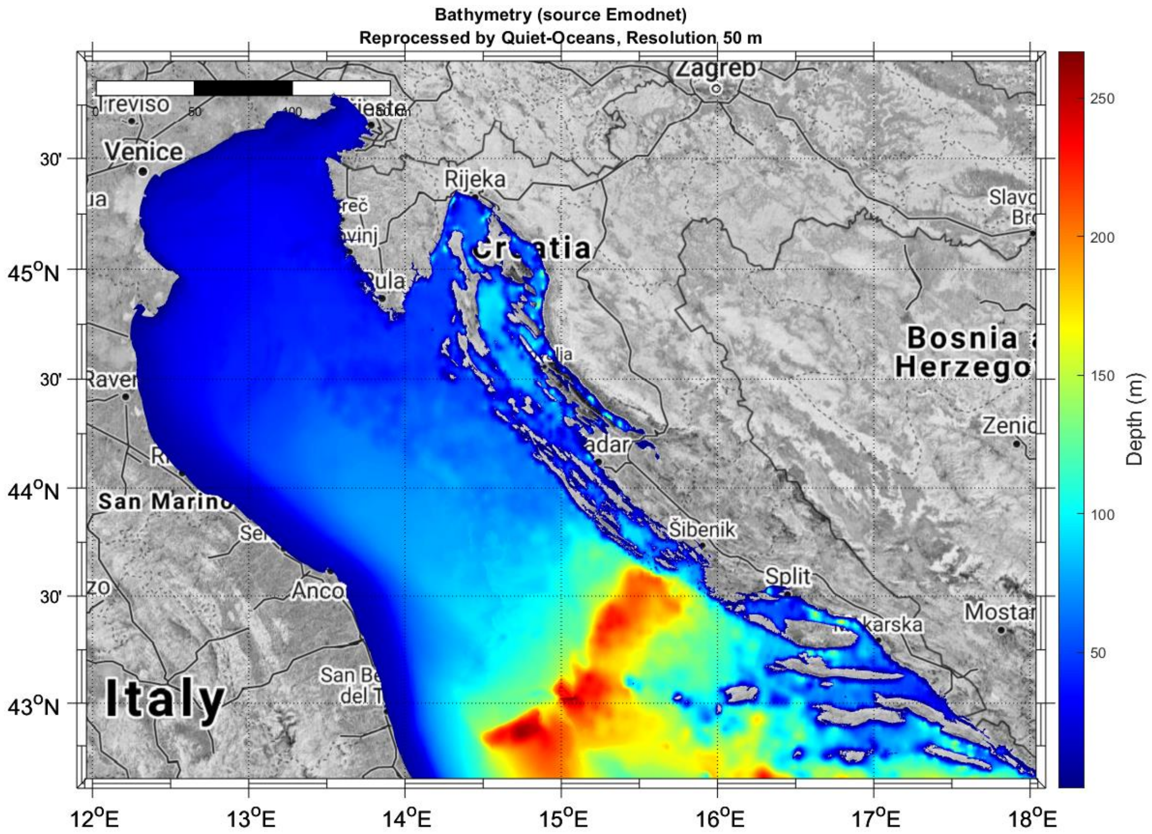

Figure 5 Bathymetry used for modelling - Source Emodnet reprocessed by QO.

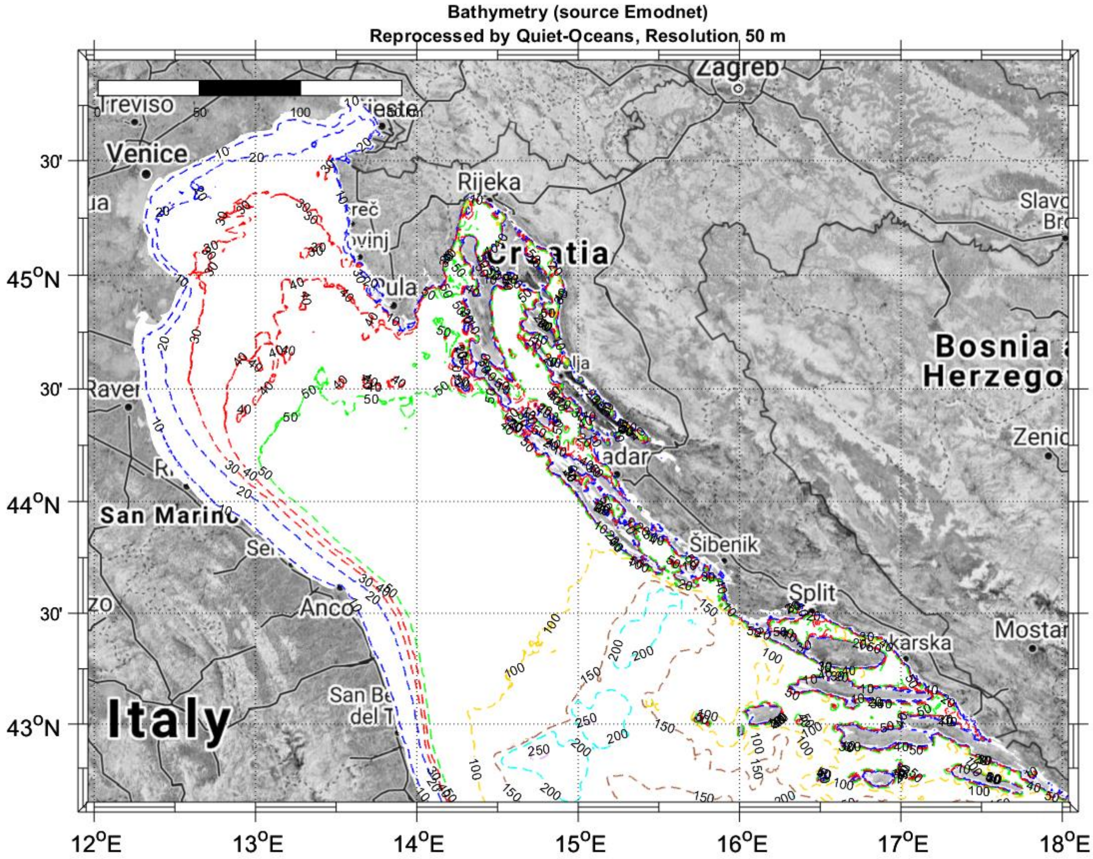

Figure 6. Bathymetry used for modelling - Source Emodnet reprocessed by QO

Bottom characterization

Quiet-Oceans chose the NAVOCEANO bottom type database.

In a first iteration, Quiet-Oceans used the Emodnet seabed substrate database https://www.emodnet-geology.eu/map-viewer/?p=seabed_substrate to assess bottom geoacoustical parameters. But the resolution of the dataset is not sufficient and the calibration results were not as good as expected. Therefore Quiet-Oceans decided to use NAVOCEANO bottom type database which show better resolution and results. Figures 7-9illustrate the seabed substrate for bottom characteristics.

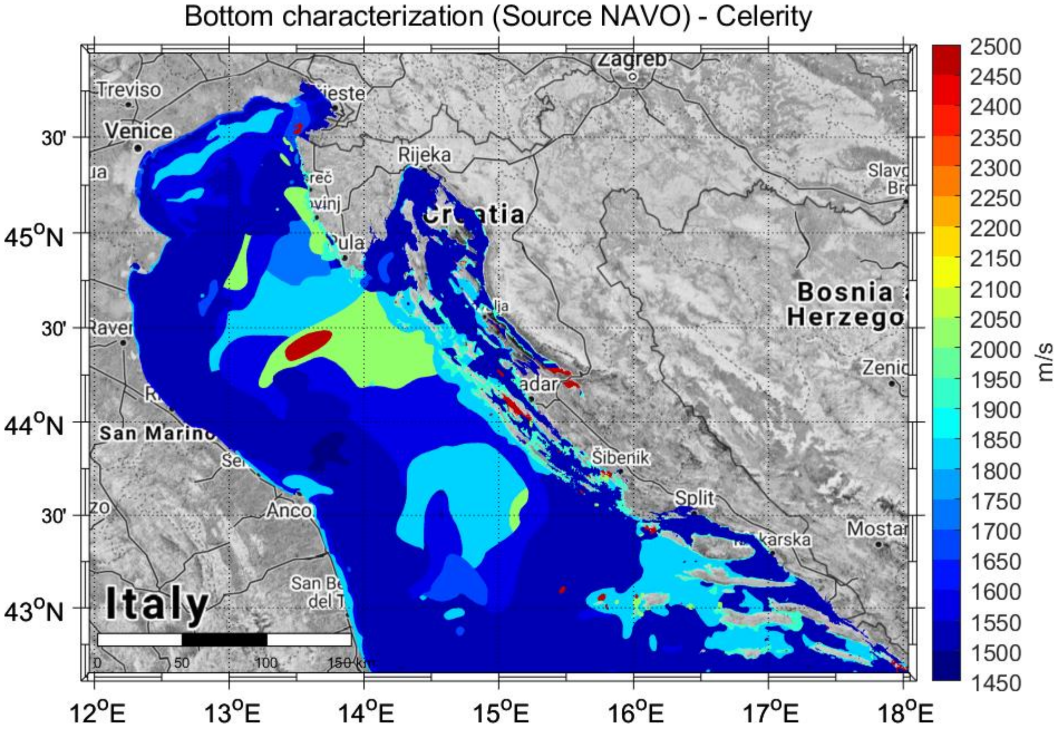

Figure 7 Bottom characterization - Celerity.

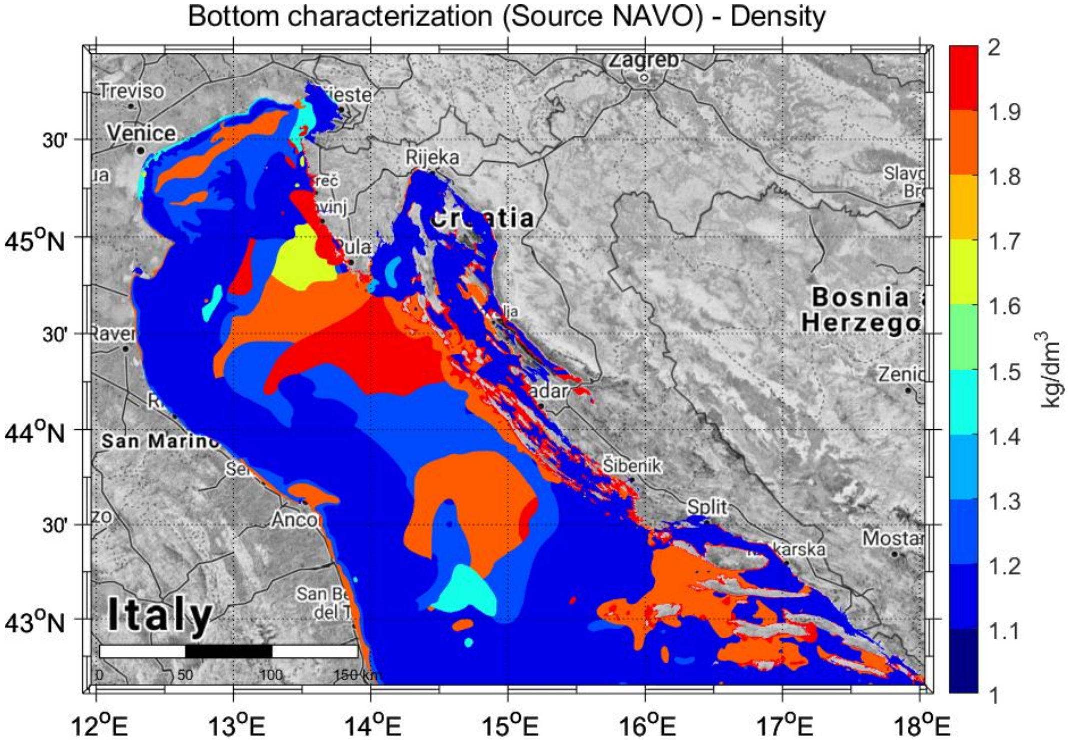

Figure 8. bottom characterization – Density

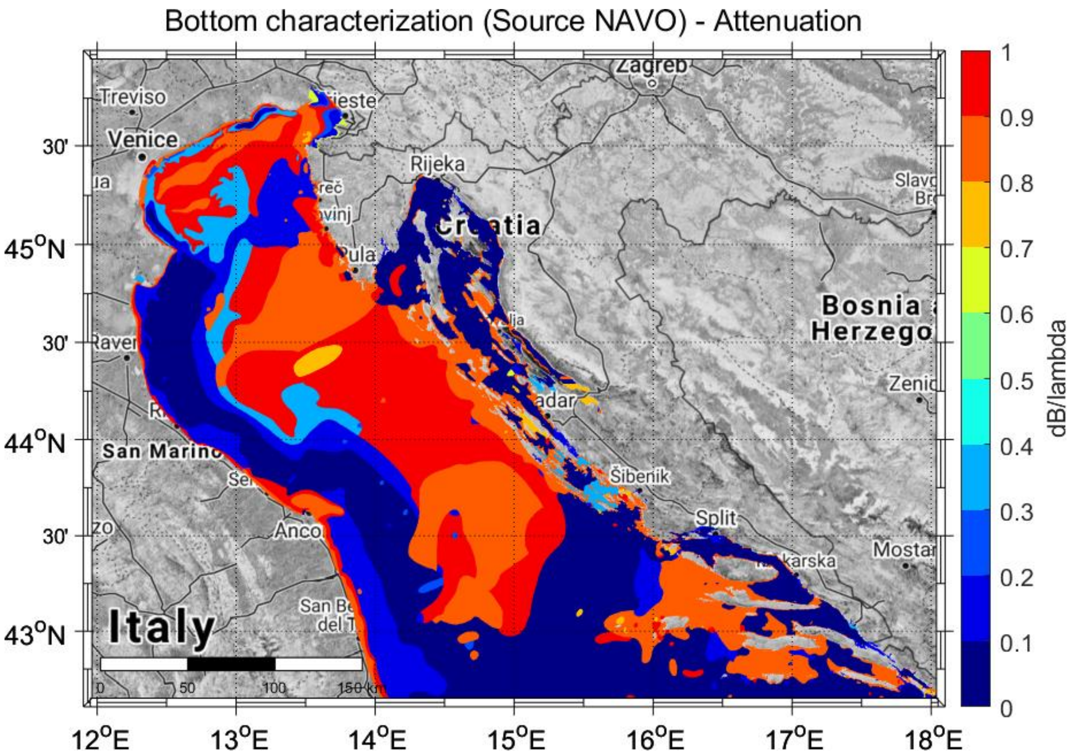

Figure 9 bottom characterization –Attenuation

AIS data

Quiet-Oceans use Authentification and Identification System to describe the maritime traffic. AIS is coming from both providers: AIS Hub (Collaborative AIS Provider) and SPIRE® (https://spire.com/). We carry out fusion data processing by integrating into our QO-AIS database which is connected to modelling service. The maritime traffic contributes as anthropogenic part in baseline noise maps. It highlights spatial and temporal variations, as shown in the Figures 10 to 13 (Unit: density ship/km² in Log Scale).

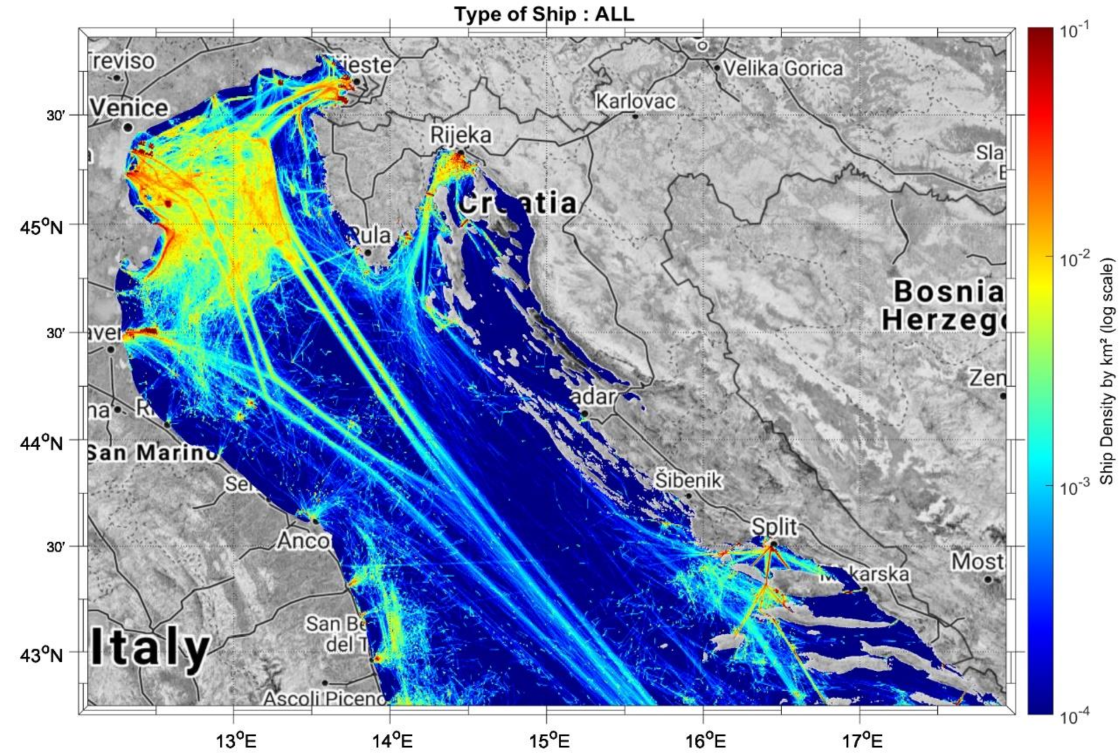

Figure 10. AIS data in Winter 2020

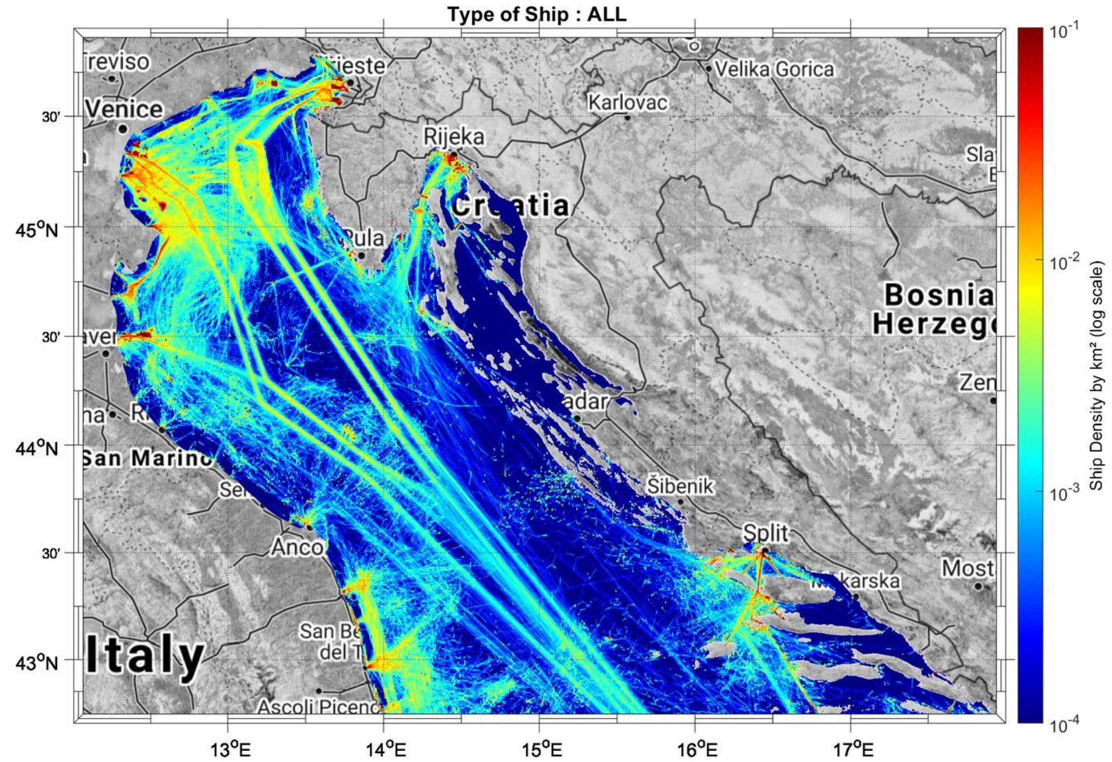

Figure 11. AIS data in Spring 2020

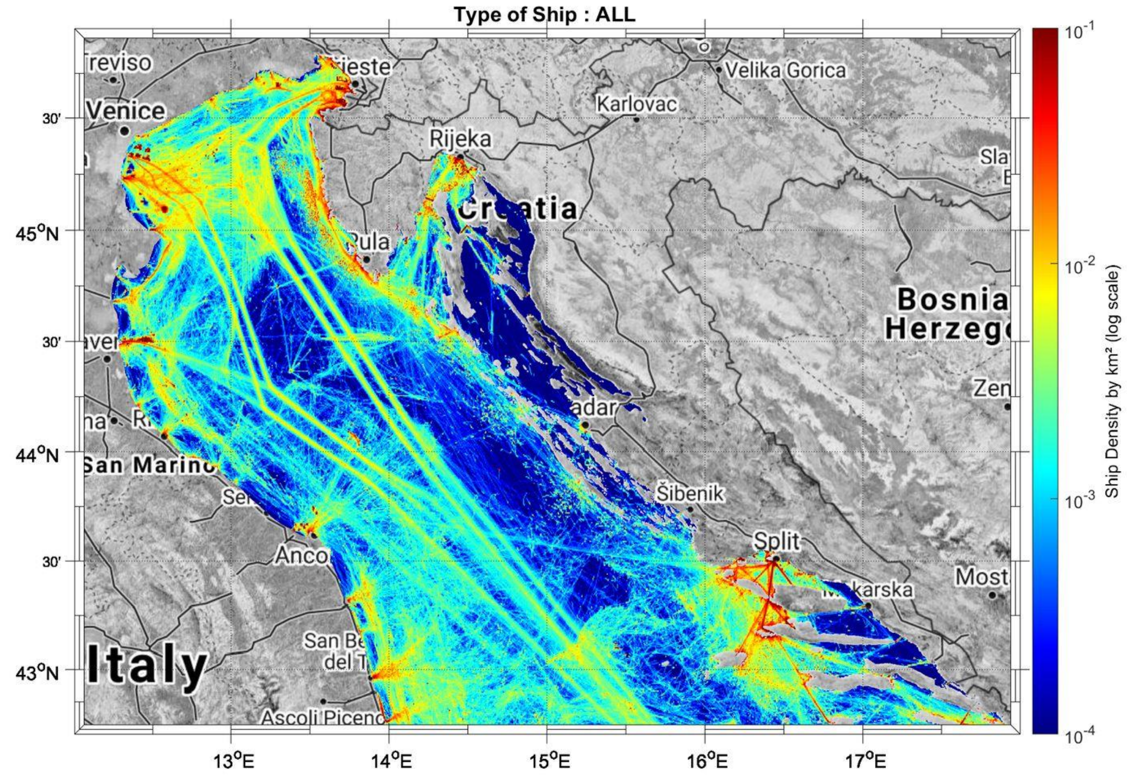

Figure 12. AIS data in Summer 2020

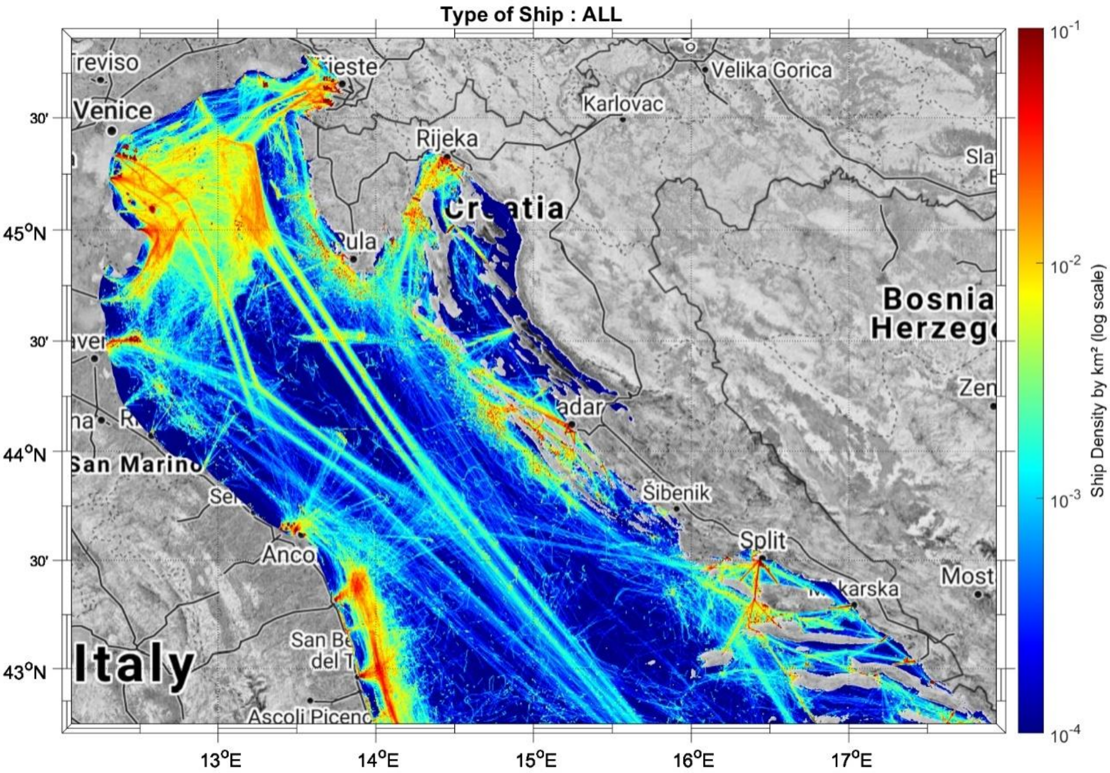

Figure 13. AIS data in Autumn 2020

Operational oceanography

Environmental data have been provided by CNR: Wind, SSP. Quiet-Oceans completed data when needed by Copernicus Marine Environmental Monitoring Service database. Quiet-Oceans uses CMEMS API to download data on area of interest for its modelling services.

Measurement data

Locations

CNR provided measurement data for many stations for which the localisation is detailed in the following map.

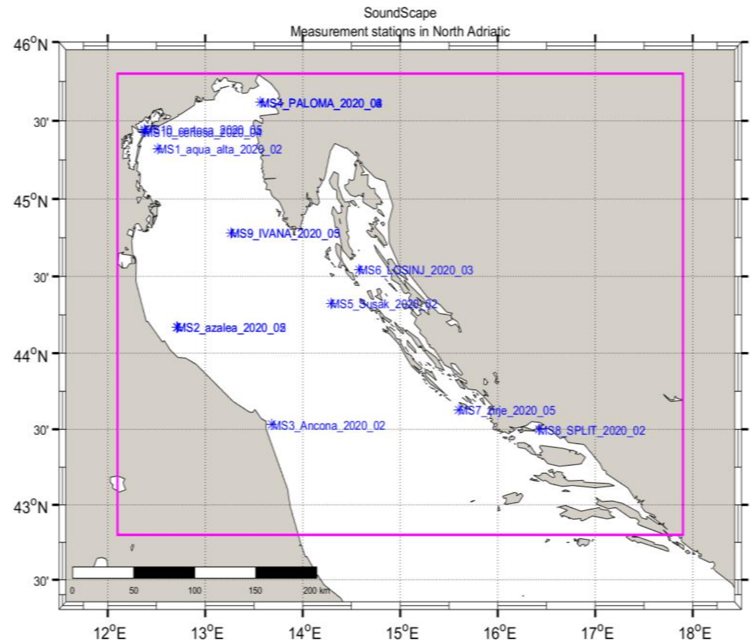

Figure 14 Location of measurement stations

Quality check

CNR has provided data for periods described in following figure, see 15:

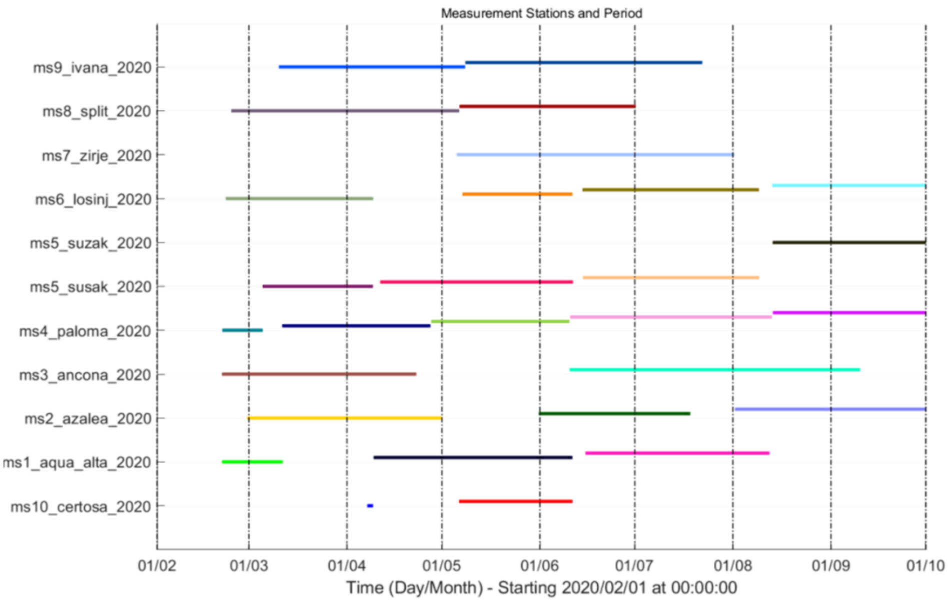

Figure 15 Periods of Measurement data/station

Quiet-Oceans has decided to ignore certain measurement datasets. Some measurement datasets have been left out for:

- differences between the measurement depth available in the measurement file and the depth identified in the bathymetry layer used by QO
- measurement quality problems. Quiet-Oceans highlighted signal instabilities or unwarranted noise variations (Figure 16 and 17)

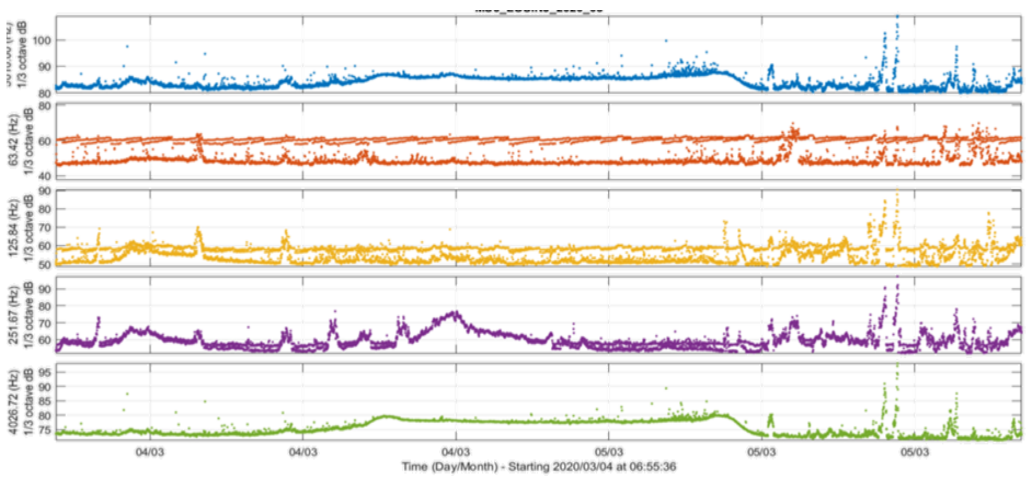

Figure 16 Instabilities in signal for some stations

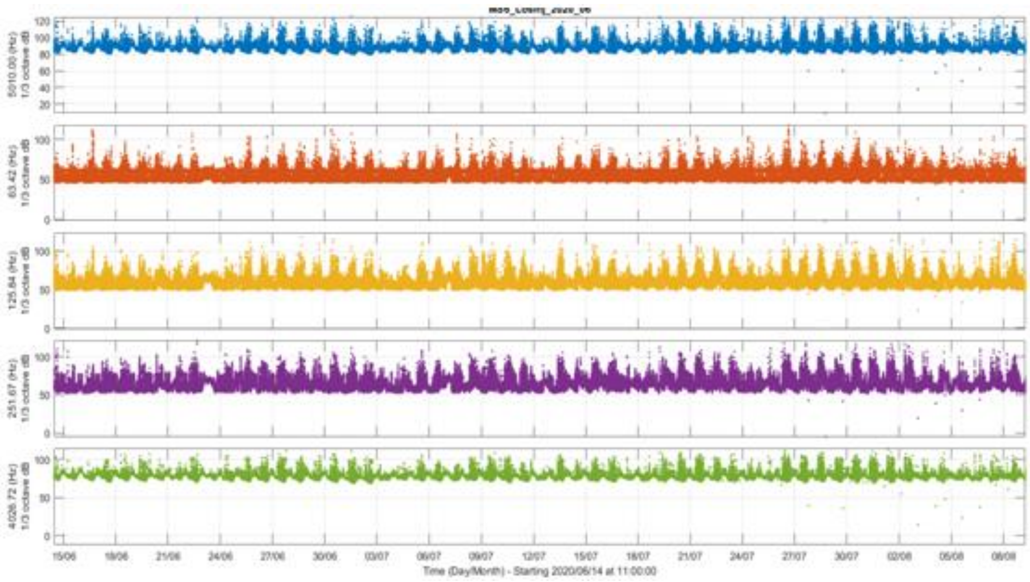

Figure 17 Unjustified noise values

After analysis of values and conditions of measurements, Quiet-Oceans selected following datasets. Table 1 details criteria and verdict for the selection.

Table 1 : Dataset Measurement selection

Station Id	Water depth (m) (Layer Bathy)	Coastal/ Non coastal	Valid frequency	Reason for non-selection	Quality Assessment
MS1 Aqua Alta	19.0	Non coastal	[63Hz, 126Hz, 251Hz]	-	Passed
MS2	18.4	Non coastal	NA	Measurements unusable (weak level, scarce	Failed

Station Id	Water depth (m) (Layer Bathy)	Coastal/ Non coastal	Valid frequency	Reason for non-selection	Quality Assessment
Azalea				anthropic data)	
MS3 Ancona	14.1	Non coastal	[63Hz, 126Hz, 251Hz, 4000Hz]	-	Passed
MS4 Paloma	24.5	Non coastal	[63Hz, 126Hz, 251Hz]	-	Passed
MS5 Susak	60.4	Non coastal	[63Hz, 126Hz, 251Hz]	-	Passed
MS6 Lozinj	5.8	Coastal	NA	Bathymetry data non compliant with hydrophone’s depth given in measurements – Anomalies in the signal	Failed
MS7 Zirje	55.5	Coastal	NA	Measurements unusable (weak level, scarce antropic data)	Failed
MS8 Split	2.2	Coastal	NA	Bathymetry data non compliant with hydrophone’s depth given in	Failed

Station Id	Water depth (m) (Layer Bathy)	Coastal/ Non coastal	Valid frequency	Reason for non-selection	Quality Assessment
				measurements	
MS9 IVANA	42	Non coastal	[63Hz, 126Hz, 251Hz]	-	Passed
MS10 Certosa	NA	NA	NA	No bathymetry data available in Lagoon Venice area	Failed

4 Sound map calibration

Ground truth refers to information collected on site. It allows the acoustic model to be related to real features in the marine environment similarly as what is done in the fields of cartography, meteorology, satellite imagery and oceanography. The calibration of the model is based on the ground truth given by a number of time series of underwater acoustic measurement taken from a diversity of measurement stations. The calibration is a process that aims reducing the uncertainties for a number of model parameters. The remaining difference between the model results at the measurement stations and the measurement gives a quality assessment of the calibration process.

The calibration methodology applied has been developed during the BIAS project (Folegot et al. 2015) and internal research carried on by Quiet-Oceans. The methodology developed overcome the difficulty linked to the fact that the measurement and the modelling are not performed at similar time resolutions by defining a common robust metric. This metric is the Cumulative Density Functions (CDF) that provide a description of the statistical content of the sound for the period considered similarly for both the measurement and the modelling regardless from the technical characteristics of the measurement nor the modelling (Figure 18). The CDF express the relationship between the sound level and the percentile, e.g., the proportion of time a given level occurs.

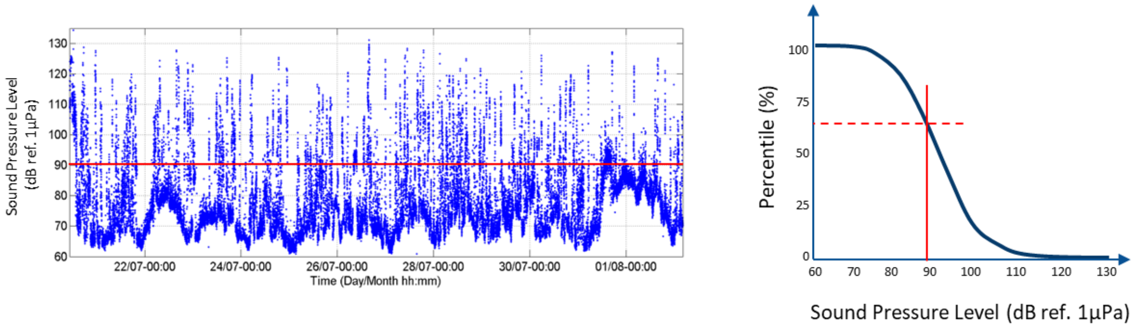

Figure 18 Typical measured processed sound levels time series (left) and associated typical Cumulative Density Function (right).

The calibration process consists in finding the best set of model parameters that minimize the difference between the CDF provided by the measurement and the CDF provided by the model at the position of the measurement and for the same period of time. It is acknowledged that the input data have uncertainties and the calibration process aims at reducing these uncertainties thanks to the ground truth provided by the measured ambient noise. The calibration is performed by minimizing a cost function that takes into account the major uncertainties as detailed hereafter:

- Wind: the wind distribution data is converted into a distribution of natural noise. The ground truth provided by the measured ambient noise enables to take into account the local conditions that influence the natural noise generated by the wind;
- Sediment: the grain size data provides an a priori knowledge of the bottom. The grain size is converted onto the geo-acoustic parameters used in the model. However, a given grain size is equivalent to a range of values for the geo-acoustic parameters, source of uncertainties. During the calibration process, a range of geo-acoustic parameters are modelled and the ground truth data enables to find the best set of geo-acoustic parameters that describes best the influence of the bottom on the sound propagation.
- Vessel source levels: it is acknowledged that the diversity of commercial vessel designs, propellers, sizes and hulls introduce uncertainties in the estimation of the source levels of the vessels. The RANDI 3 source level model used in Quonops gives an a priori assessment. The calibration process accounts for this uncertainty and uses the measured ambient noise levels to adjust the source levels of the vessels.

Model parameters that are calibrated are the bottom properties, the natural sound and the shipping sound. The assessment of the quality of the calibration is quantified by the calculation of the root mean square of the absolute difference between both CDFs between the 5th and 95th percentiles.

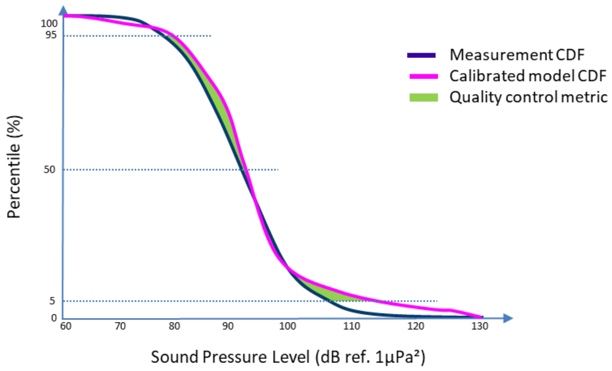

Figure 19 Illustration of the calculation of the quality assessment of the calibration process: the green surface is the difference between the measured and calibrated model CDF at the hydrophone position.

5 Results

The QUONOPS results for the Adriatic and Losinj domain are available in the online platform https://qos.quiet-oceans.com/ usable in the contest of the SOUNDSCAPE project for the next 4 years. The model results were downloaded and stored on the CNR server.

On Quonops Online Service platform, a total of 2016 maps are made available to the Soundscape project:

- 12 months of statistical sound maps from January to December 2020,
- 4 frequencies : 63, 125, 250 and 4000,
- 7 percentiles : 5, 10, 25, 50, 75, 90 and 95 %
- 3 layers of depth (0-15, 15-30, 30-bottom).
- 2 kind of maps : baseline and natural noise level.

Baseline noise maps content traffic and natural noise contributions; natural noise maps contents ambient noise in the absence of any contribution from anthropogenic sources.

North Adriatic

Monthly maps from January 2020 to December 2020 were provided. For each map the noise distribution related to 4 1/3 octave band frequencies centred at 63, 125, 250 and 4000 Hz is displayed, with levels calculated from 5 to 95 percentile. It is possible to visualize (i) the water column top layer from 0 to 15 meters, (ii) the bottom layer from 15 meter to the bottom or (iii) to calculate on the whole water column.

Figure 20 shows an example of a modelled underwater noise map (50th percentile), calculated considering the whole water column for February 2020. The 4 considered 1/3 octave bands are displayed. The corresponding modelled underwater noise maps calculated for August 2020 (50th percentile) on the whole water column is shown in Figure 21.

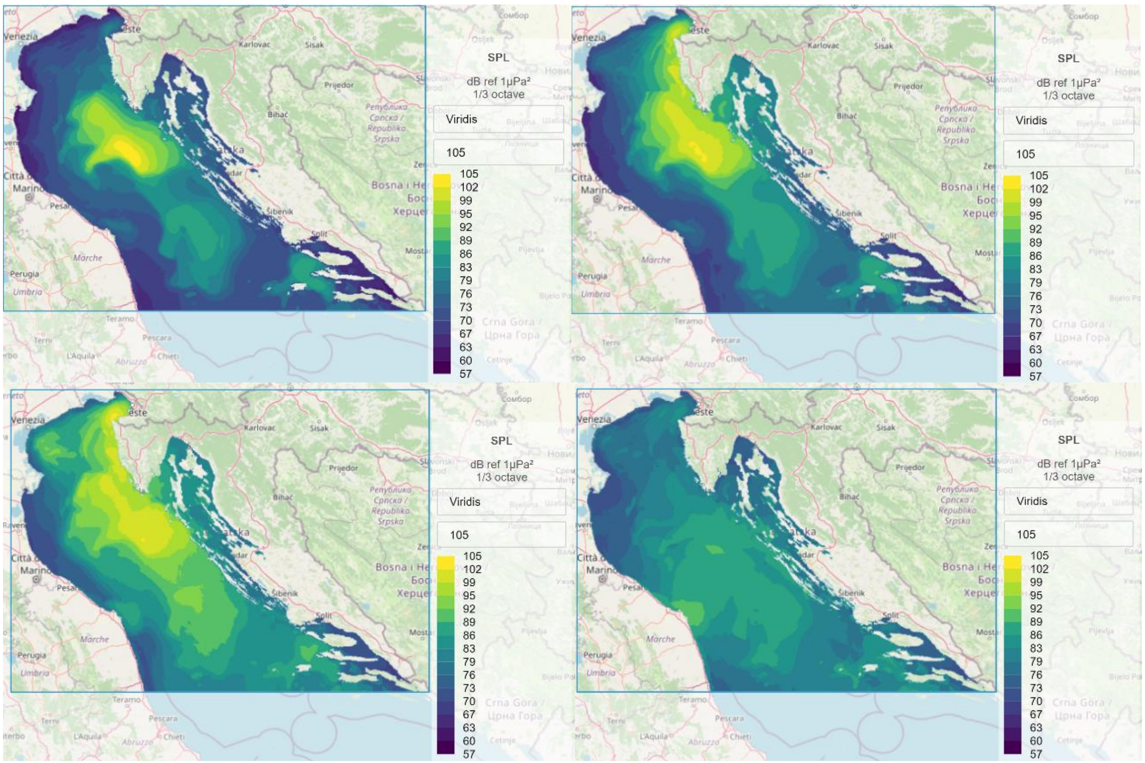

Figure 20 Adriatic baseline noise-level map, generated forFebruary 2020 and calculated on the whole water column. Monthly average for 1/3 octave band frequencies centred at 63, 125 Hz (top panels from left to right) and 250 and 4000 Hz (bottom panels).

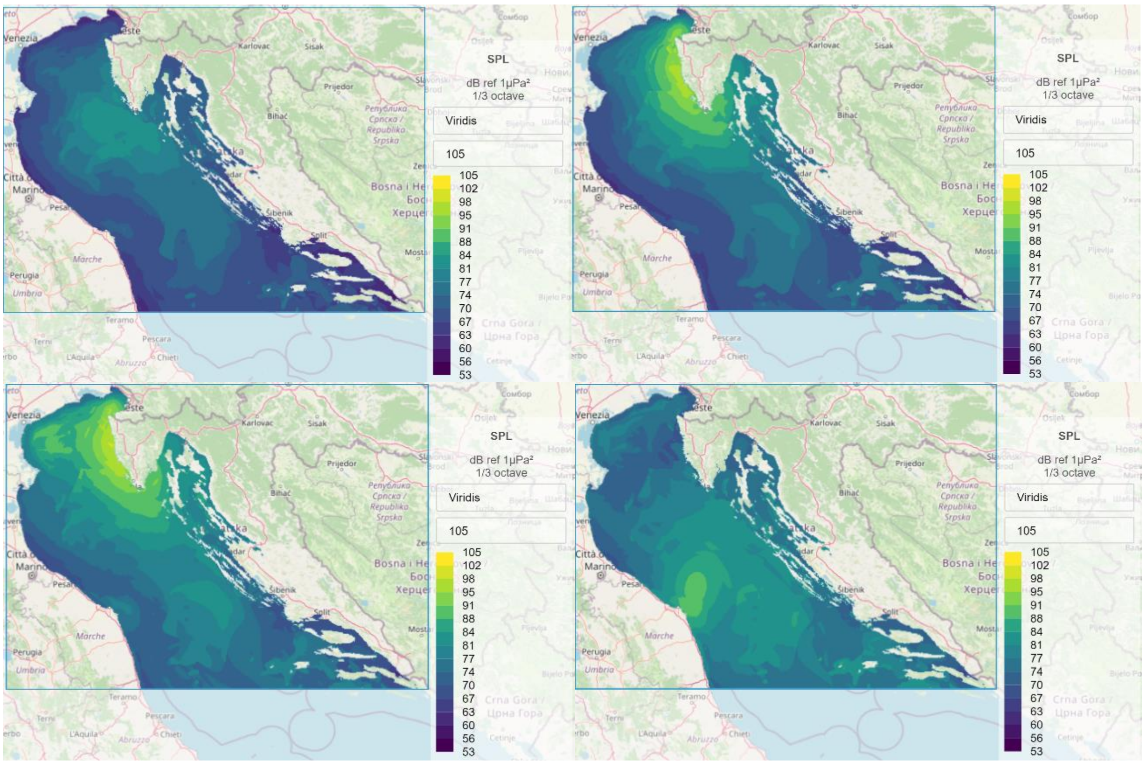

Figure 21 Adriatic baseline noise-level map, generated forAugust 2020 and calculated on the whole water column. Monthly average for 1/3 octave band frequencies centred at 63, 125 Hz (top panels from left to right) and 250 and 4000 Hz (bottom panels).

Losinj

The application of QUONOPS model in the area of Losinj (Figure 22) uses a more refined spatial grid compared to the case of the North Adriatic application. The temporal integration starts from 9th September 2020 at 12:00 AM and it ends24th January 2021 at 12:00 AM. The noise levels are available as instantaneous values calculated on the basis of the AIS data timing. The total number of maps provided by QuietOcean is 42104.

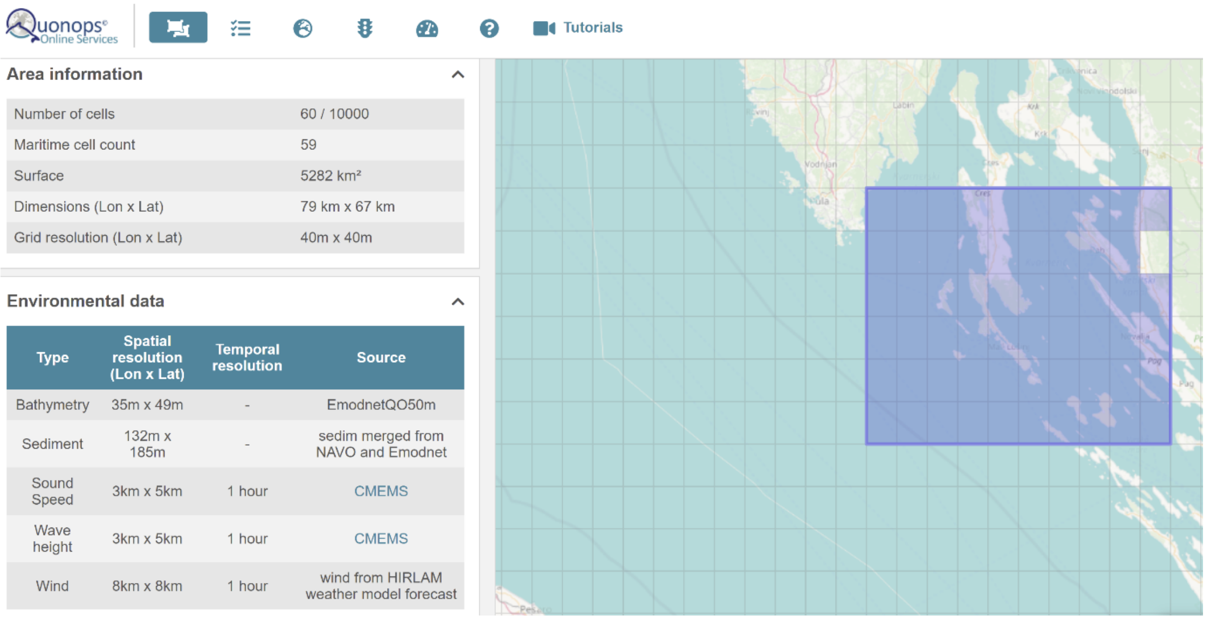

Figure 22 Losinj domain with grid and input details

In this application, the provided maps included not only the 1/3 octave bands frequencies centred at63, 125, 250 and 4000 Hz but also at 16, 31.5, 500, 1000, 2000 Hz; the maps with noise levels calculated for the whole band wide (from 11 to 5.65 kHz) is also available. The water column layers and the percentile calculations are the same as in the Adriatic case study. The temporal statistic includes instantaneous (only 50 percentile), daily, weekly, quarterly and monthly noise levels, described with 5, 10, 25, 50, 75, 90, 95 percentiles. In this case, however, only the baseline noise maps are available.

Examples of monthly average levels (wideband calculated on the whole water column for the 50 percentile) are shown for October, November and December 2020 in Figure 23; here the instantaneous value calculated 9th September at1:34 PM and the colours correspond to variable noise levels with a maximum of 130 dB re 1 µPa.

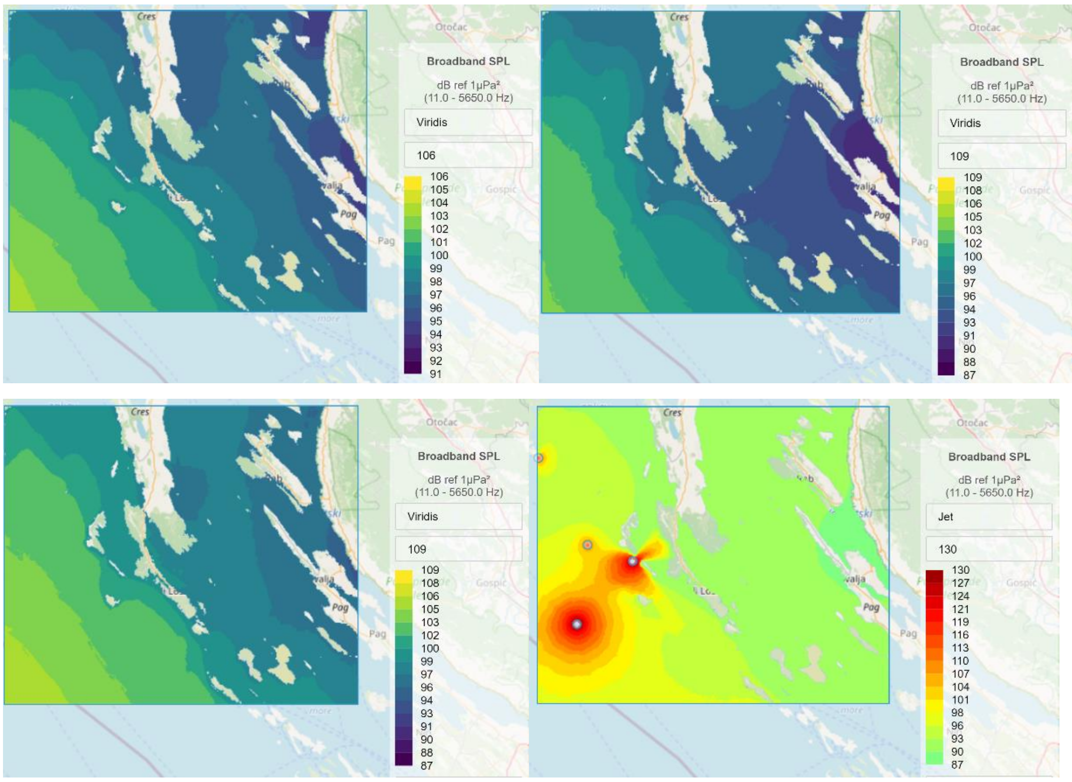

Figure 23 Losinj model, monthly maps for October and November (top panels from left to right), and December plus instantaneous value (bottom panels from left to right).

6 Discussion

The noise maps provide an estimate of the spatio-temporal distribution of noise levels in the Northern Adriatic Sea along one year, with special regards to the inputs generated by human activities at sea. It can be highlighted that the vessel traffic is concentrated along two main lines crossing longitudinally the Adriatic Sea and branching towards the main harbours (Venice, Trieste, Koper) in the northern part of the basin. The noise levels distribution highlighted by the modelling for the study area appears to be clearly affected (i) by locally related variables as the water depth, that is higher in the central part of the basin, the sediment composition, that is mainly sandy along the Italian coast and rocky along the Croatian coast, as well as (ii) by temporal related variables as the stratification of the water column during the summer period. In particular the vertical stratification of water density drives the sound to travel downstairs, whereas the sandy-muddy bottom absorbs the noise more than the rocky bottom, which acts rather as a reflector of the acoustic waves.

Gaps and limits

The implementation of the numerical model suffers of different gaps and limits to be considered when the data are used:

1. The bathymetry: the EMODNET version along the Croatian coast is not very reliable. A better bathymetry is now available but not in time to be used within the model run.
2. The bottom sediment composition: this data is merged form EMODNET and NAVO provider and the spatial resolution sometime could be not very accurate in respect to the real variability of bottom sediment composition.
3. The AIS data coverage: the number of vessels recorded appears scarce in the southern area of the domain
4. Man-made sources of noise as recreational boat, drilling or other industrial activity are not included in the model but they can have locally an important effect; this is particularly true for the recreational boat presence in touristic localities during the summer months
5. The lockdown in 2020 and slow re-opening during the summer: due to the lockdown, the modelled noise values in some periods which could be lower than expected in 'normal' periods
6. Calibration process: since data from some stations were suffering of an instrumental bias (See also Deliverable 3.6.2), the calibration of the model was performed on a limited number of stations mainly distributed along the Italian sandy coasts. This means that values referred to the Croatian coasts, with special regards to the southern part, could suffer of a higher level of uncertain.

7 Conclusion

A first atlas on underwater noise maps in the North Adriatic Sea was achieved. This fills a relevant gap in Mediterranean noise distribution knowledge. The maps are referred to a exceptional period: the year 2020 represents the pandemic lockdown time (from Jan 2020 to May 2020). Limited vessel traffic (Depellegrin et al. 2020) and no other human activity were permitted. This represents a unique chance to model low human impact time.

The model suffers of some input limitations and gaps in calibration data but the comparison with the measured data show that it is reliable to represents an average depicture of the underwater noise levels in the Northern Adriatic Sea.

References

Depellegrin D., Bastianini M., Fadini A., Menegon S., (2020). The effects of COVID-19 induced lockdown measures on maritime settings of a coastal region 2020 Science of The Total Environment , Vol. 740 p. 140-123

Duarte, C.M., Chapuis, L., Collin, S.P., Costa, D.P., Devassy, R.P., Eguiluz, V.M., Erbe, C., Gordon, T.A.C., Halpern, B.S., Harding, H.R., Havlik, M.N., Meekan, M., Merchant, N.D., Miksis-Olds, J.L., Parsons, M., Predragovic, M., Radford, A.N., Radford, C.A., Simpson, S.D., Slabbekoorn, H., Staaterman, E., Van Opzeeland, I.C., Winderen, J., Zhang, X., Juanes, F., 2021. The soundscape of the Anthropocene Ocean. Science 371, eaba4658. doi:10.1126/science.aba4658

Folegot T., Clorennec D., Chavanne R., R. Gallou (2016). Mapping of ambient noise for BIAS. Quiet-Oceans technical report QO.20130203.01.RAP.001.01B, Brest, France, December 2016

T. Folegot , Robert Chavanne and Roger Gallou (2021).