PROCEEDINGS OF SCIENCE

The Ocean Sound monitoring sub-system for the *Italian Integrated Environmental Research Infrastructures System* (ITINERIS) project

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The aim of the Italian Integrated Environmental Research Infrastructures System (ITINERIS) project, funded under the Italian *Piano Nazionale Resistenza e Resilienza* (PNRR) programme, is to establish the Italian Hub of Research Infrastructures within the environmental scientific domain. ITINERIS will create a flexible system to collect and store, for the first time in a national integrated system, ocean data and metadata and make them available, traceable, accessible, interoperable, and reusable for the entire scientific community (FAIR principles). In this context, the Laboratori Nazionali del Sud (LNS) from the Istituto Nazionale di Fisica Nucleare (INFN) coordinates the design and operation of a new underwater Junction Box (JB) to be installed at the infrastructure of Portopalo di Capo Passero, Sicily - Italy, at a depth of about 3450 m. LNS has already designed and successfully operates a network of 3 prototype JBs at 3450 meters. Each of them is capable of interfacing more than 10 observatories to shore. Each JB also host acoustic sensors so that a phased array like this on the seafloor can be built to efficiently store, collect, and analyse acoustic data almost in real-time. This network of acoustic sensors are mainly used for acoustic monitoring (bioacoustics, geophysics and ship noise monitoring). Data can be also used to complement the positioning system of the KM3NeT Neutrino telescope and to carry-on studies for acoustic neutrino detection. In this contribution, an overview on the JB acoustic section and on the hydrophone data acquisition and analysis chain will be provided, by focusing in particular on the novel acoustic data fairness paradigm. Preliminary results on marine noise analysis will be also presented.

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1. Ocean Acoustics

The sounds produced by humans, like natural ones, propagate effectively underwater, increasing the overall noise level and overlapping with natural sounds. The seas, once relatively quiet environments where numerous species could efficiently use sound as a primary communication channel, have rapidly become extremely noisy. Two categories of anthropogenic sounds can directly or indirectly harm marine fauna: high-intensity impulsive sounds and persistent background noise [1]. While the former is directly linked to specific activities such as the use of sonar or underwater explosions and industrial activities, diffuse noise is due to the presence of hundreds of thousands of ships constantly navigating all the world's seas. Each of these ships produces low-frequency noise that propagates for tens of kilometres, adding to that of others [1]. Consequently, many seas, especially the Mediterranean, have become very noisy due to intense and continuous maritime traffic [2]. Continuous exposure to noise is known to cause increased stress, physiological weakening, difficulties in communication with conspecifics, and the inability to detect prey or predators. It is therefore reasonable to presume that this also applies to all marine organisms that use sound as a primary sense, but this requires further investigations at various levels. Observing the short and long-term effects of noise caused by maritime traffic, at the species, population, and ecosystem levels, requires large-scale long-term monitoring (over decades) to provide time series of data describing how ecosystems respond to this pressure [3].

At the institutional level, underwater anthropogenic noise is now considered as a source of pollution with impacts at both individual and population levels. The Marine Strategy Framework Directive (MSFD) 2008/56/C includes *underwater noise produced by humans* in the definition of *pollution* and includes it in the list of variables (Descriptor 11) to be analysed and monitored for determining the ecological status of marine environments [2].

2. ITINERIS

To design, develop, and implement a national contribution to this need, twenty-two Research Infrastructures (RIs) have jointly agreed to present the ITINERIS project [4] to the relevant ministries. The harmonised activities of the RIs within ITINERIS will create an integrated system of Italian environmental RIs to be proposed as a reference at the European level. To build this system, ITINERIS is constructing a network of RIs, all relevant to environmental studies and operational knowledge, with the main goal of establishing the *Italian Hub of Research Infrastructures* in the environmental science sector for observation and study of processes in all relevant subdomains. ITINERIS will sustainably develop interdisciplinary research through the use and reuse of existing (or pre-operational) data and services, providing access to data and services, supporting Italy (but not only) in addressing the upcoming environmental challenges expected to worsen in the coming years.

2.1 Integrated ITINERIS acoustic system

Building upon the experience acquired on deep sea acoustics systems and data analysis [5–7], the main objective of INFN-LNS, in the contest of the ITINERIS project, is to develop interdisciplinary research in environmental sciences to address scientifically and socially relevant issues such

as sustainable use of natural resources, implementation of nature-based solutions, green and blue economy, pollution reduction, management and restoration of critical zones and ecosystems, carbon cycle, and mitigation of downstream effects of climate and environmental changes. The focal point is, therefore, to create a flexible system to collect and store, for the first time in a national integrated system, ocean acoustic data and metadata and make them available, traceable, accessible, interoperable, and reusable for the entire scientific community (FAIR principles [8]). Furthermore, in order to ensure the data fairness, each dataset from different RI will be coupled with its own metadata set. The inclusion of metadata alongside primary data is of paramount importance. Metadata serve as the foundation upon which the utility, reliability, and longevity of data are built. They provide essential contextual information, detailing the conditions under which the data were collected, such as the time, location, and methodologies used. The reproducibility of scientific findings, a cornerstone of the scientific method, heavily relies on the availability of comprehensive metadata [8]. Without metadata, the reproducibility of research is compromised, making it difficult to validate results or build upon previous work. Metadata also play a crucial role in the integration and comparability of data across different studies. Environmental and oceanographic research often necessitates the combination of datasets from various sources, which may have been collected under differing conditions or with different methods. Metadata provide the necessary information to align these datasets, ensuring that comparisons are valid and that integrated analyses yield meaningful conclusions. Moreover, as scientific data are intended to have lasting value, metadata are indispensable for the long-term preservation and future usability of datasets [8]. They encapsulate the knowledge required to interpret the data, safeguarding it from becoming obsolete as technologies and personnel evolve. This preservation of context ensures that data remain accessible and understandable to future researchers, even those not involved in the original study. In addition, compliance with established scientific standards is facilitated by thorough metadata documentation. Many fields, including oceanography and environmental science, have developed rigorous standards for data collection and reporting. Metadata ensure that datasets adhere to these standards, promoting consistency and enabling effective data sharing within the scientific community.

In this context, LNS coordinates WP 5.7 of the ITINERIS project [4], focused on the integration and testing of a new underwater Junction Box (JB) to be installed at the infrastructure of Portopalo di Capo Passero, Sicily - Italy, at a depth of about 3450 m. The JB will distribute power to various underwater observatories and provide an optical connection for communication and control/data transfer between the observatories and the data acquisition systems hosted on land. Qualified scientific payloads can also be permanently mounted on the JB, thanks to dedicated additional customised ports. LNS has already designed and successfully operates a prototype JB at 3450 meters, capable of interfacing with around 10 observatories [9]. This translates into the ability to efficiently store, collect, and analyse acoustic data from this prototype almost in real-time.

3. DAQ and analysis: preliminary results

The LNS shore laboratory is located in Portopalo di Capo Passero (Sicily - Italy). From the harbour of Portopalo di Capo Passero, two electro-optical cables (MEOC) are laid. The 2 MEOCs, each approximatively 100 km long, are used for power and data transport for the operation of the observatories deployed in deep sea. Each cable is terminated with a Cable termination frame (CTF)

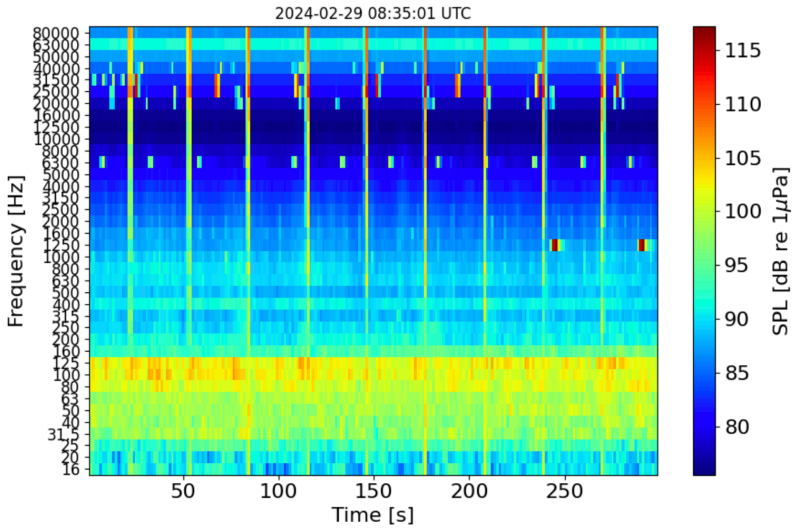

Figure 1: Spectrogram in one-third octave bands obtained from 5 minutes of acoustic recordings from the ITINERIS test site on February 29, 2024 (8:35 a.m. UTC). Details in the text.

that, in turn, is connected with a network of JBs. Three JBs are connected to MEOC-1; six additional JBs will be connected to MEOC-2. Each JB acts as a hub, providing power and data connection for oceanographic probes and for (up to) 14 observatories connected to the JB via electro optical jumper cables. For acoustic monitoring purposes each JB hosts (at least) 1 hydrophone. The latter (DG0330 from co.l.mar.) is omnidirectional, operates from few Hz up to about 90 kHz frequencies range, and has two output channels. The same input signal from the piezoceramic of the hydrophone is addressed to two different amplifiers: the first one has a gain of +26 dB, while the other one has a gain of +46 dB. These gains are used to study distant/weak and close/strong sources, thus avoiding signal saturation. Their Received Voltage Response (RVR) is approximately - 156 dB (re 1 V/μPa at 1 m) in the high-gain channel. The amplified analogue input is the sent to a digital converter that digitises the stereo stream and convert it in a standard consumer AES-3 format and sent to the Junction box. The JB is equipped with a custom electronic board (ICE), designed by INFN that acquires the audio AES stream and route it to shore embedded in the JB optical stream. On land, the data are stored and distributed to analysis stations. In compliance with the MSFD, five minutes of continuous data are acquired every hour and analysed in real-time. The analysis of the Sound Pressure Level (SPL) in one-third octave bands is then performed, with particular attention to the bands related to the central frequencies of 63 Hz and 125 Hz, suggested in the European directive as indicators for acoustic monitoring of marine environments [2].

Figure 1 shows, as an example, a five-minute spectrogram in one-third octave bands recorded on February 29, 2024 (08:35 UTC). Two types of high-frequency signals can be identified: an acoustic emitter at around 6.5 kHz and a time-varying signature from acoustic emitters, positioned on the seabed of the site, captured by the JB hydrophone, at frequencies in the range of 20 kHz - 40 kHz. At lower frequencies, the bands at 63 Hz and 125 Hz show characteristic diffuse noise from maritime traffic.

4. Outlook and future steps

According to the European Marine Strategy Framework Directive, studying the sound pressure level in one-third octave bands is essential for monitoring the ecological status and the impact of anthropogenic noise on marine mammals and animals in oceanic environments. In this context, LNS, within the ITINERIS project, contributes to the establishment of a national database for cataloguing and validating the acoustic data recorded by the various research infrastructures partnering in the project. The quality of data, especially metadata, is of great importance as it will directly influence result management and, particularly, analyses that need to be comparable and repeatable across different RIs. For this reason, a common strategy is being developed among the involved entities to establish, at the national level and for the first time, a common standard for the type and format of result sharing. Since the analysis is primarily conducted at the local level, data management rules will ensure uniformity and universality of processing. Each recording will therefore be accompanied by a set of metadata written in a common format for all RIs, enabling analysis by all partners even years later. Currently, verification tests of analysis algorithms are being conducted using historical data from different databases.

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