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ASSESSMENT ON THE POTENTIAL OF DISTRIBUTED ACOUSTIC SENSING IN THE GULF OF CATANIA

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ABSTRACT

Distributed Acoustic Sensing (DAS) technology has emerged as a powerful tool for marine environment monitoring by transforming existing fiber optic cables into dense sensor arrays. In this study, we present the application of DAS to the Istituto Nazionale di Fisica Nucleare–Laboratori Nazionali del Sud's (INFN–LNS) deep–sea optical fiber infrastructure in the seismically active Gulf of Catania, Sicily, Italy. This region is characterized by rich biodiversity, volcanic activity and intense maritime traffic. Using more than 40 km cable interrogated at 2000 Hz with 10.2 m gauge length, we quantified spectral and spatial variations in background noise and transient signals. Analysis revealed distinct noise profiles between shallow and deep–water cable sections, with shipping traffic generating characteristic spectral peaks below 200 Hz and surface gravity waves significantly increasing low-frequency signals (<20 Hz) in shallow regions. The system captured low–frequency signal increases up to 30 dB during a magnitude 5.1 ML earthquake. in addition, vessel–induced noise showed a broadband increase with multiple peaks distributed below 250 Hz including prominent signals within the 63 Hz and 125 Hz third–octave bands monitored under MSFD Descriptor 11. The cable's response varies significantly with both frequency and cable–seafloor coupling conditions.

Keywords: *deep–sea monitoring, distributed acoustic sensing, shipping noise, VONGOLA Project*

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1. INTRODUCTION

The exploration and monitoring of marine environments are important for combating climate change, studying marine biodiversity and detecting natural hazards such as tsunamis and underwater earthquakes. Acoustic sensing has long been a fundamental tool for ocean monitoring as sound propagates efficiently through water over long distances. Despite its importance, traditional monitoring methods such as hydrophone arrays [2], buoys, underwater sensors and Autonomous Underwater Vehicles (AUVs) suffer from high operational costs, maintenance difficulties and limited spatial coverage. To address these

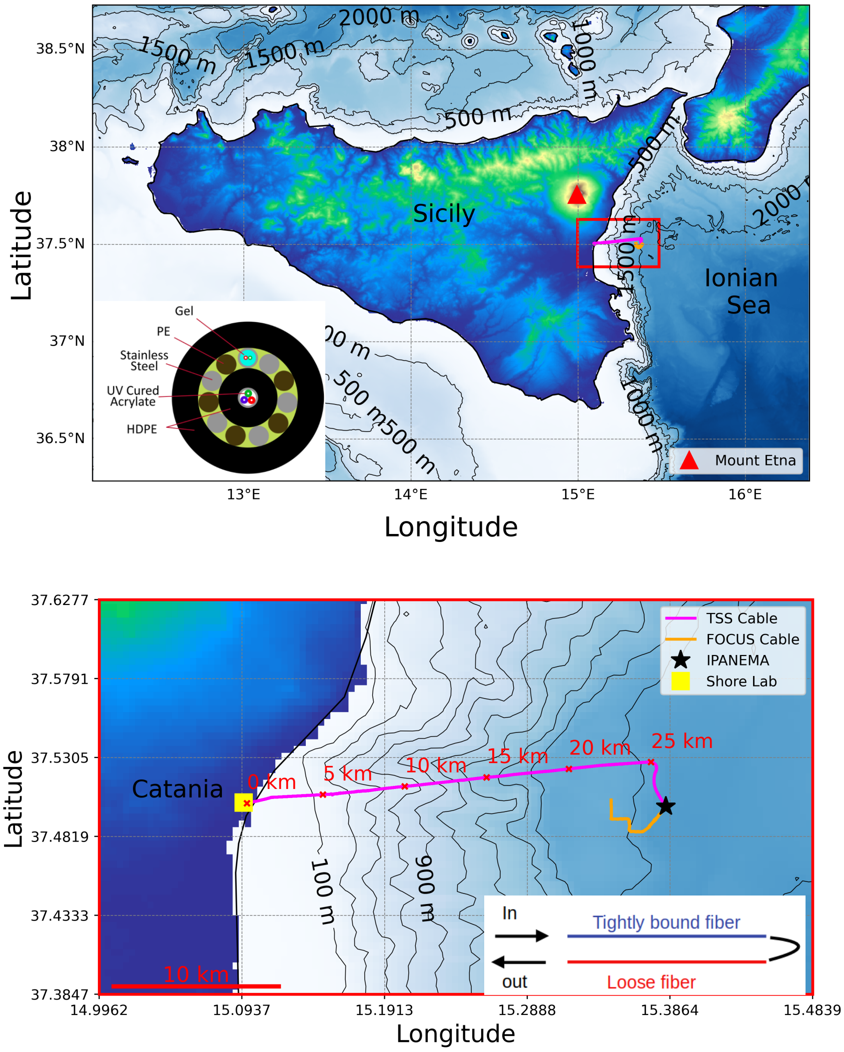

Figure 1: (Top) Map showing the location of the INFN–LNS deep–sea cabled infrastructure off the coast of Eastern Sicily. (Bottom) Map focusing on the electro–optical fiber track, where the black contour lines represent bathymetric depths at 200 m intervals ranging from 100 m to 2100 m. The red distance markers indicate cumulative distances along the cable path at 5 km intervals. Also, a cross–section (adopted from [1]) of the FOCUS cable is depicted in the bottom left of the upper image and its spool path is shown in the bottom right of the bottom map. Bathymetric data from the General Bathymetric Chart of the Oceans (GEBCO) 2024 Grid were used.

challenges, new technologies are being developed to complement traditional sensors and enhance monitoring capabilities. One of the most promising approaches involves utilizing the vast network of submarine optical fiber cables originally deployed for global telecommunications or scientific research. Many of these cables contain unused ”dark” fibers. One promising approach to use this optical fiber infrastructure is Distributed Acoustic Sensing (DAS) which transforms existing fiber optic cables into vast sensor arrays capable of detecting and analyzing acoustic signals over long distances [3].

DAS system operates by transmitting laser pulses through an optical fiber and analyzing the backscattered light to detect minute strain variations along the cable. When the fiber undergoes mechanical disturbances such as acoustic waves, vibrations or seismic activity they cause microscopic changes in the pattern of backscattered light. By continuously measuring phase differences in backscattered light between points along the fiber with meter–scale spatial resolution, DAS effectively transforms the fiber into a dense array of acoustic sensors capable of detecting and localizing mechanical waves and vibrations along the optical fiber in near–real time. This technology has a broad range of applications in marine environments including early warning systems for underwater earthquakes and tsunamis [4], tracking marine mammals [5] and monitoring ocean currents and environmental changes [6].

In this work, we will present the deployment of DAS technology using the Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud (INFN–LNS) deep–sea optical fiber infrastructure in the Gulf of Catania, Sicily, Italy. This fiber was originally deployed for the NEMO–SN1 neutrino observatory [7], part of the Mediterranean neutrino detection network. Using this infrastructure, we will characterize the DAS system's response to background noise, seismic waves and acoustic signature from vessels. The study region in the Western Ionian sea is seismically active, influenced by the complex tectonic interactions between the Eurasian and African plates, making it prone to frequent underwater seismic events. Additionally, its proximity to Mount Etna, one of the world's most active volcanoes, contributes to both volcanic tremors and seafloor deformation, which DAS technology can help monitor in real time. The Gulf of Catania is also known for its rich marine biodiversity such as the presence fin and sperm whales [8, 9]. Furthermore, it is also a hub for intense maritime traffic, with commercial shipping, fishing vessels, and naval operations generating significant anthropogenic noise [10].

2. MATERIALS AND METHODS

LNS–INFN operates an advanced deep–sea electro–optical infrastructure off the coast of Catania in the western Ionian Sea. The infrastructure connects a shore laboratory located in the harbor of Catania to the Test Site South (TSS) via a 28 km long electro–optical cable as shown in Figure 1. Since October 2024, the TSS cable has been connected to a cabled array of four hydrophones for monitoring and tracking acoustic sources, as well as a CTD device for measuring conductivity, temperature, pressure and dissolved oxygen, as part of the IPANEMA project in Catania [11]. This observatory is deployed at a water depth of approximately 2100 meters and remotely controlled with its data streamed in real time to a shore laboratory for continuous monitoring and analysis. Additionally, the TSS is connected to the 6 km–long FOCUS fiber optic cable through a Y–junction box. The FOCUS cable consists of three tightly bound fibers in the core and two loose fibers enclosed in a small steel tube within the armoring layer as represented in Figure 1. It was laid down and buried 20 cm beneath the seafloor where terrain and seabed conditions permitted [1]. Recently, a long–range DAS system prototype provided by Centro Siciliano di Fisica Nucleare e Struttura della Materia (CSFNSM) started interrogating the 28 km TSS cable and the two–fold loop of the FOCUS cable connected at its end via a Y–junction box, where the first 6 km consists of a tightly bound fiber and the second section contains a loose fiber. This experiment is part of the VONGOLA (Visual and nOise–eNhanced AI Analysis for Marine Biodiversity MonitorinG, Observation and LeArning) project, aiming to monitor ocean soundscape in the Gulf of Catania using DAS technology.

During this experiment, the DAS system operated at a sampling rate of 2000 Hz with a gauge length of 10.2 meters and a channel spacing of 1.023 meters. To optimize data handling and processing, a downsampling factor of 5 was applied to the channels resulting in a total of more than 8200 sensing channels with a final channel spacing of about 5.1 meters. The interrogator used a laser source with a wavelength of 1578 nm and a pulse duration of 20 µs. This configuration yielded more than 300 MB of data files every 10 seconds, which were saved in Hierarchical Data Format version 5 (HDF5) format for efficient storage and processing.

3. RESULTS AND DISCUSSION

3.1 Background noise analysis

The data recorded by the DAS system is not calibrated in terms of underwater acoustics, as it measures strain or strain rate rather than acoustic pressure and no direct or well–defined conversion exists between these quantities. However, the sensitivity of the system to the signal depends on several parameters including gauge length, sam-

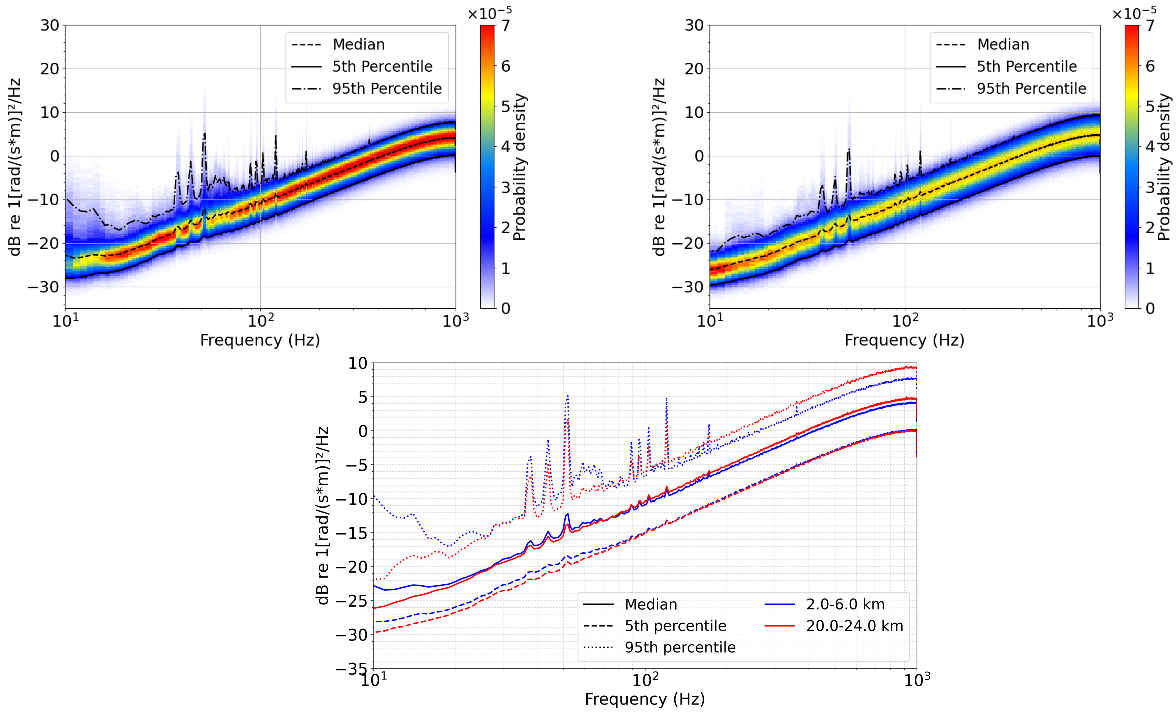

Figure 2: Distribution of PSD values across frequency using one day of data on March, 03, 2025 by taking 10 seconds recording at the beginning of each hour. Results obtained using 1 Hz frequency resolution and averaged in 50% overlapped time windows, (upper left) using shallow water cable section (2–6 km), (upper right) using data from deep water cable section (20–24 km), and (bottom) comparison of the 5th, 50th and 95th percentiles of the PSD data between shallow and deep water cable sections.

pling frequency and the coupling of the cable with the sea bottom [12]. In this section we investigate the variation of background noise along the cable as a function of frequency for constant acquisition parameters.

Figure 2 presents a statistical analysis of the variation of background noise levels as a function of signal's frequency. The results show that the probability density function of PSD values reveal distinct differences in background noise levels between the shallow and deep water. In shallow water, a noticeable increase in noise levels is observed at low frequencies, primarily due to the contribution of surface gravity waves [13]. In contrast, the deep–water section exhibits a lower noise floor at these frequencies, as surface wave effects diminish with depth and distance from the cost. Furthermore, in both cable sections, several peaks at frequencies below 200 Hz were observed. These peaks represents the significant contribution of anthropogenic noise from shipping traffic. Additionally, both sections show a general increase in noise levels with frequency. However, real acoustic measurements from hydrophones in the same region exhibit an opposite trend, mainly at frequencies above 100 Hz as reported in a study by Viola et al. [10]. The difference in noise behavior between DAS and hydrophone data is primarily related the DAS system's configuration and parameters such as gauge length sampling rate. Modification of these parameters can influence the observed noise patterns. While these results are based on analysis of a single day's data, preliminary examination of data from other days shows similar behavioral trends. Comprehensive analysis using extended datasets is currently ongoing to further validate and characterize these patterns.

Figure 3 shows how the signal amplitude changes along the cable length at different frequencies reflecting both environmental factors and the characteristics of cable. At frequencies below 40 Hz, the signal amplitude

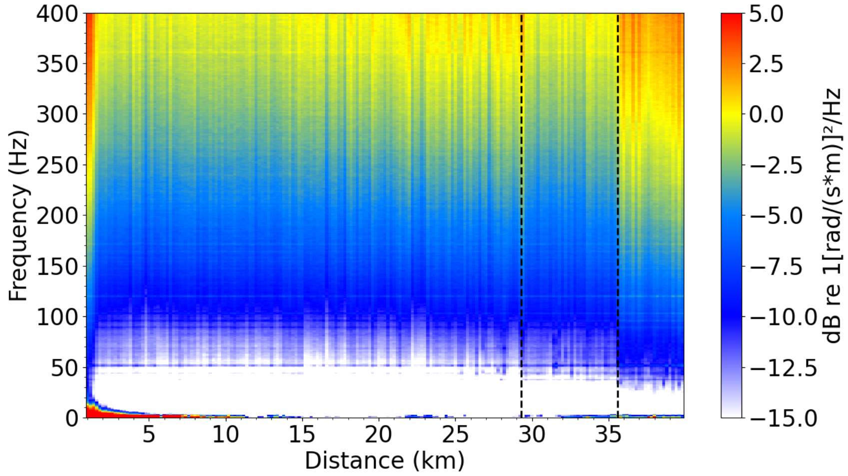

Figure 3: Variation of the median value of PSD as a function of frequency and cable length. Plot obtained using 10 seconds recording of each hour during one day on March, 03, 2025. The vertical dashed black lines represents the start and end of the first 6.2 km of the two–fold FOCUS cable loop.

shows a weak dependence on the distance along the cable, mainly in the TSS cable and the first loop of the FOCUS cable. However, for frequencies <5 Hz, we observe strong signal variations likely attributable to microseismic noise. In the 40–100 Hz frequency range, the signal amplitude is almost constant along the TSS cable and the first section of the FOCUS loop but becomes noticeably higher in the last section of the FOCUS cable. This variation arises from the transition between tightly bound and loosely bound fiber, as well as the coupling of the fiber with the seafloor, since the FOCUS section of the cable is buried 20 cm below the seabed, which can influence signal amplitude. At higher frequencies, the first section of the FOCUS loop shows lower amplitude compared to the TSS cable, whereas the last section has a higher amplitude. These observations show that the response of the DAS system to the signal depends on both cable characteristics and signal frequency. Additionally, in shallow water, especially in the first 5 km, surface gravity waves contribute to increased signal levels at frequencies below 20 Hz.

3.2 Seismic and vessel induced noise

Figure 4 illustrates the variations of PSD values during two distinct signals, a 5.1 ML earthquake on February 18, 2025 [14] and the passage of a cargo ship near the cable compared to background noise levels. The earthquake induced a significant signal increase, particularly at low frequencies, with an overall amplitude rise exceeding 30 dB at around 5 Hz. In contrast, the vessel–induced signal exhibits a different spectral pattern. The most notable increase observed over a broad frequency range, reaches approximately 9 dB at 60 Hz. This rise is attributed to mechanical sources such as the ship's engine and propeller. Additionally, several peaks appear across the spectrum below 250 Hz. These observations align with MSFD's Descriptor 11 monitoring requirements which specifically assess underwater noise in standardized third–octave bands centered at 63 Hz and 125 Hz–key frequency ranges for monitoring anthropogenic impacts on marine mammals [15, 16].

4. CONCLUSIONS AND PERSPECTIVES

This study demonstrates the successful application of Distributed Acoustic Sensing (DAS) technology to monitor marine environmental noise using the existing deep–sea optical fiber infrastructure in the Gulf of Catania, Sicily, Italy. Our analysis of background noise variation along the cable revealed frequency and cable–sea bottom coupling dependent patterns. Moreover, distinct noise characteristics between shallow and deep–water cable sections with peaks in the noise levels at frequencies below 200 Hz

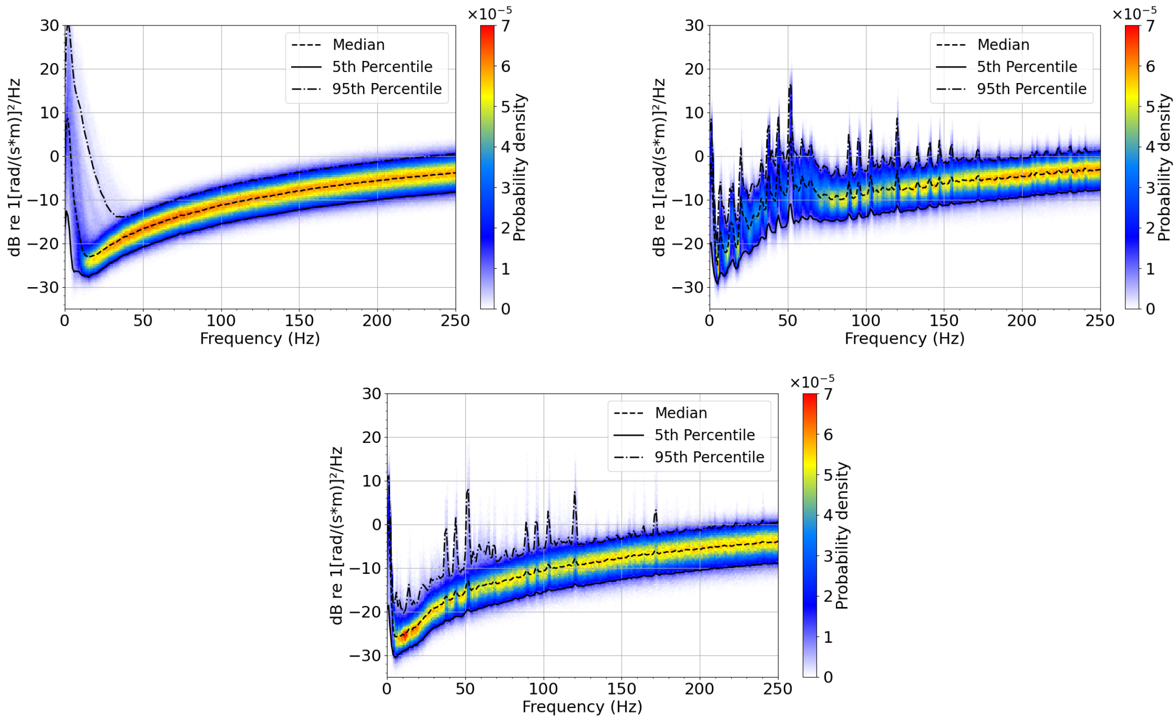

Figure 4: Probability density function of PSD values using 10 minutes of DAS data and cable section between 9–12 km: (top left) during an earthquake event on February 18, 2025, (top right) during the passage of a cargo ship close to the cable on March 5, 2025 and (bottom) background noise levels in the same cable section using the data of Figure 2.

indicating the contribution of anthropogenic noise from shipping traffic in the area. In shallow regions, surface gravity waves produced significant low–frequency (<20 Hz) amplitude increases. The system effectively detected both natural events such as a 5.1 ML earthquake showing about 30 dB increase above the noise levels at 5 Hz, and anthropogenic noise from ship traffic, with a 9 dB increase at 60 Hz and several peaks below 250 Hz that align with MSFD's Descriptor 11 monitoring bands. While the technology shows great promise for marine monitoring, we identified important considerations regarding cable coupling effects and the need for calibration between strain measurements and acoustic pressure levels.

5. ACKNOWLEDGMENTS

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