Short Term and Long Term Bioacoustic Monitoring of the Marine Environment. Results from NEMO ONDE Experiment and Way Ahead

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Abstract. The INFN NEMO-OνDE (Ocean Noise Detection Experiment) station, deployed on the seafloor at 2000 m depth 25 km offshore Catania (Sicily, Italy) in year 2005, was designed to continuously transmit broad-band acoustic data through optical cables to the INFN lab located in the port of Catania. It was operational until November 2006, when it was replaced by other experimental equipment. During the operational period, 5 minutes of recording (4 hydrophones, 45 kHz bandwidth, 96 kHz sampling rate at 24 bits resolution) were taken every hour. The experiment provided long-term data on the underwater noise and an unique opportunity to study the acoustic emissions of marine mammals living in, or transiting through the area east of Sicily. The recordings revealed a more frequent and consistent presence of sperm whales than previously believed.

Acoustic monitoring of the underwater environment is a key component in the study of marine mammals and in the management of the anthropogenic noise issue. Technologies now available allow to extend monitoring capabilities into the deep ocean to monitor the presence and behaviour of marine mammals as well as to long-term monitor both the local and the ambient noise background due to human activities.

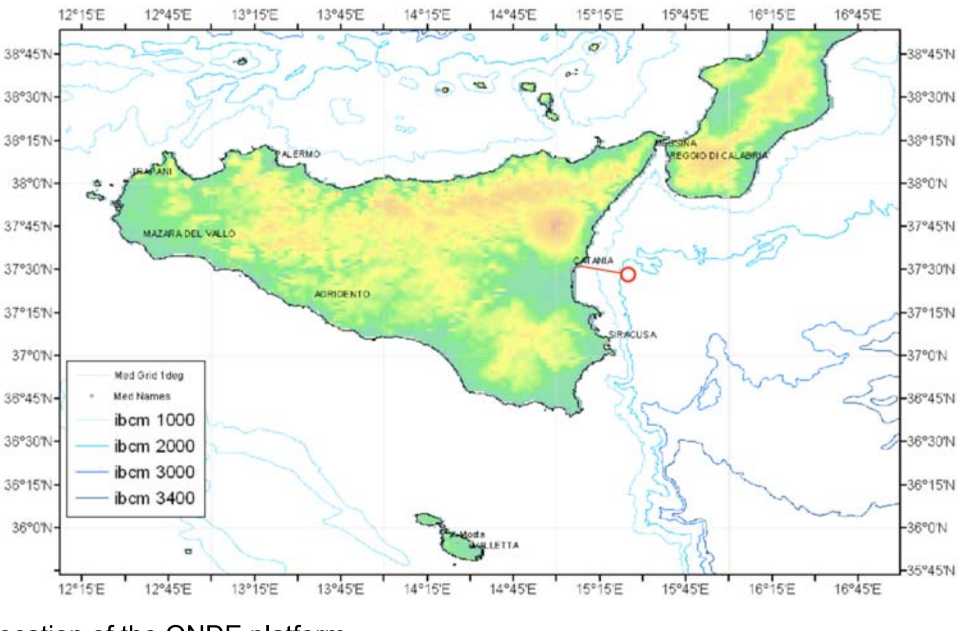

Figure 1: Location of the ONDE platform.

The goal of NEMO is the implementation of an innovative underwater telescope to search for astrophysical neutrinos (MIGNECO et al., 2006). The telescope will be deployed 100 km offshore Capo Passero (Sicily, Italy) at a depth of 3500 m. In this framework a deep sea test site at 2000 m depth has been deployed 21 km offshore Catania, connected to the shore labs through electro-optical cables to provide real-time data transfer.

The test site hosts an experimental deep station, named OνDE (Ocean Noise Detection Experiment) dedicated to the study of the underwater acoustic noise (Fig. 1). OνDE was deployed in January 2005 and was sending data since the end of March 2005 until

November 2006 when the acoustic module was replaced by other instrumentation. The acoustic experiment was concerned with the study of the underwater acoustic environment to develop strategies required for the detection of acoustic pulses that are generated by high energy neutrino interacting with water. The experiment was highly interdisciplinary and in addition to generating long term data on the underwater noise, it also provided a unique opportunity to study the acoustic emissions of marine mammals living in the area or transiting there during their movements within the Mediterranean basin. Bioacoustic research in the Mediterranean Sea dates back to 1958 (PAVAN ET AL., 1997); whereby research was mainly based on sporadic acoustic and visual surveys to monitor the presence of marine mammals in small areas. Bioacoustic research efforts have increased in the last 10 years and this is the first long term monitoring project in the Mediterranean Sea for both noise measures and marine mammals' sounds.

Experimental setup and methods

The hydrophones on the OνDE acoustic module, a special series produced by Reson, are hooked on the upper part of the platform frame, forming a tetrahedral array of about 1 m side (Fig. 2). Hydrophones H1, H2, H4 lie in the same plane at about 2.5 m from the seabed, H3 is placed on the top vertex at about 3.2 m from the seabed. The broad band hydrophones (30Hz-45kHz) have –175 dB peak ref 1V/μPa sensitivity (including a 20 dB gain preamplifier) and are connected to a four channels 24 bit AD board with full scale level of ± 2V; the system allows recording sound pressure levels up to 181 dB peak. The hydrophones were sampled at 96 kHz and send continuously to the shore lab; as the continuous archiving was not possible due to storage space constraints (uncompressed recording would require 124GB/day), continuous recordings were made only for the testing period and then scheduled for periods of 5 minutes every hour. For additional technical details see RICCOBENE ET AL. 2007. Data recording, totalling 2.5TB of scheduled recordings, and 1TB of continuous recordings, was made with SeaRecorder, a 4 channels software recorder developed at CIBRA that reads and synchronizes the two stereo digital streams coming from the underwater station (Fig. 3). Digital data arrives with 24 bit resolution and can be saved as standard Microsoft .wav files either in integer (16 or 32 bit/sample) or 32 bit float format. Data for noise analysis at INFN was saved in 32 bit float format; copies for bioacoustic analysis at CIBRA (PRIANO ET AL. 1997) were reduced to 16 bit to save disk space. Bioacoustic analysis was performed with SeaPro, the sound analysis software developed at CIBRA. The first phase was the classification of recorded sounds into known categories. The results have been arranged in excel tables to show, hour by hour, the occurrence of biological sounds and other relevant acoustic events such as sonar, echo sounders, sparkers or other sound.

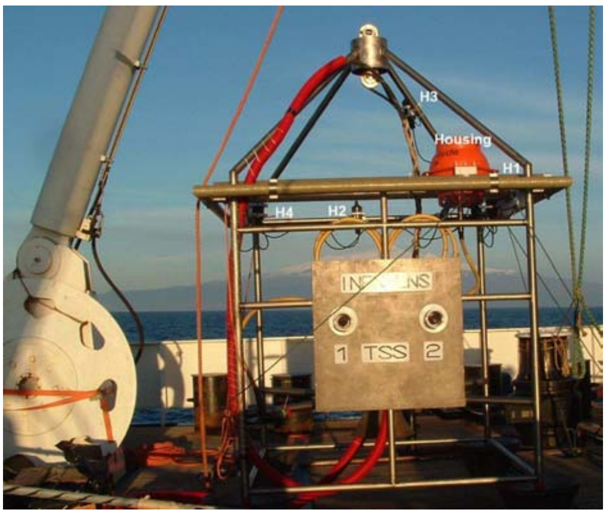

Figure 2: The titanium frame of the OνDE platform. The frontal plate hosts the connectors for the optical cables that connect the platform to the inland lab.

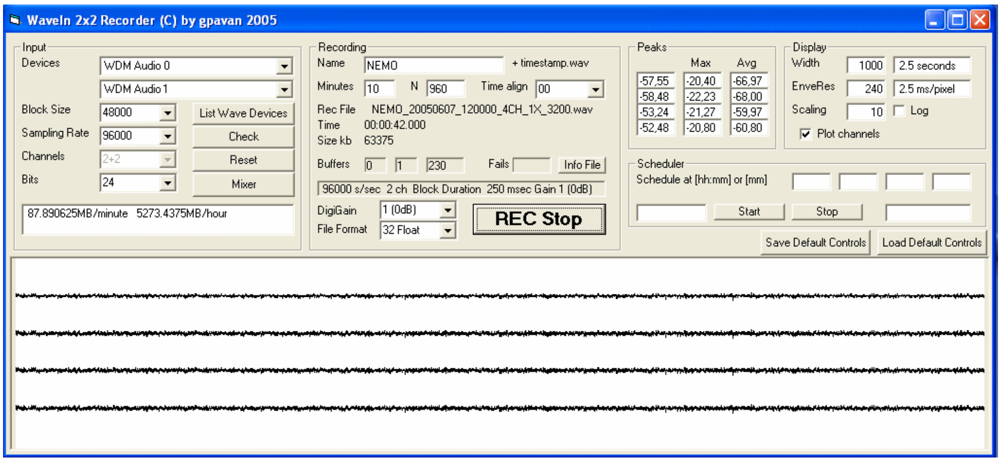

Figure 3: The SeaRecorder main panel.

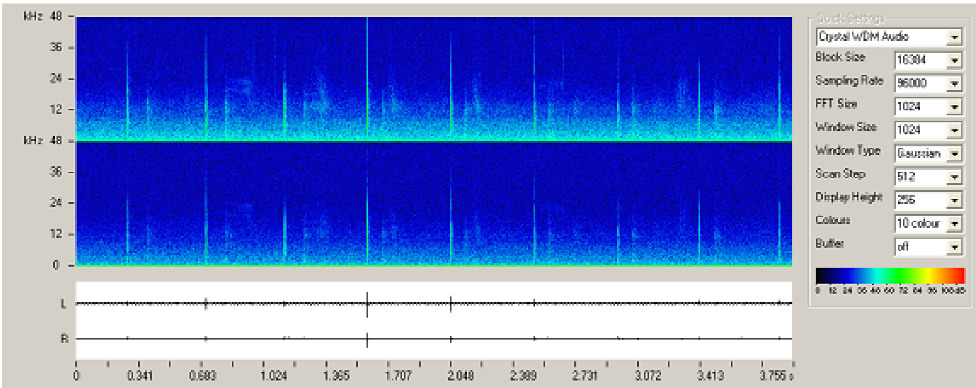

Figure 4: Two channel spectrographic display of a series of sperm whales' clicks.

Sperm whale detections

The most common sounds recorded are those produced by sperm whales (TELONI 2005): impulsive sounds extending in frequency to more than 30 kHz, named click (Fig. 4), arranged in regular sequences (interclick interval in the range 0.5s to 2s), or in special patterned sequences (chirrups, codas, creaks – Fig. 5 & 6). According to studies in the Mediterranean Sea, sperm whales may dive to more than 1000 meters depth, but normally travel and forage at 800-1000 meters depth. Their source level may be greater than 230 dB at 1m and on axis; with OνDE the loudest clicks were received with sound pressure levels up to 170 dB. Clicks were often recorded with high SNR; by using a high-pass filter, the SNR can be further increased to improve the detection, count and analysis of the weakest click series.

Detections indicate a presence of sperm whales more consistent and frequent than previously believed. Although the transiting of sperm whales is known since the end of XIX century (BOLOGNARI 1949), little literature is available for the area. IFAW (2004) reports a low sperm whale density in the Ionian basin with an encounter rate of 5.8 whale groups for 1000 km of transect. Lewis (2006), based on the IFAW surveys, reports a total of 16 whales detected within the truncation distance of 20 km, along 3846 km of survey transects in the Ionian Sea. PANIGADA ET AL. (2007) published a report about marine mammal presence in the area of the Strait of Messina and extending to south to 50km north of the OνDE Station. In the period from June 2005 to May 2006 they conducted 125 days of survey and sighted 80 marine mammals, of which 13.8% sperm whales and 1.2% Cuvier's beaked whales.

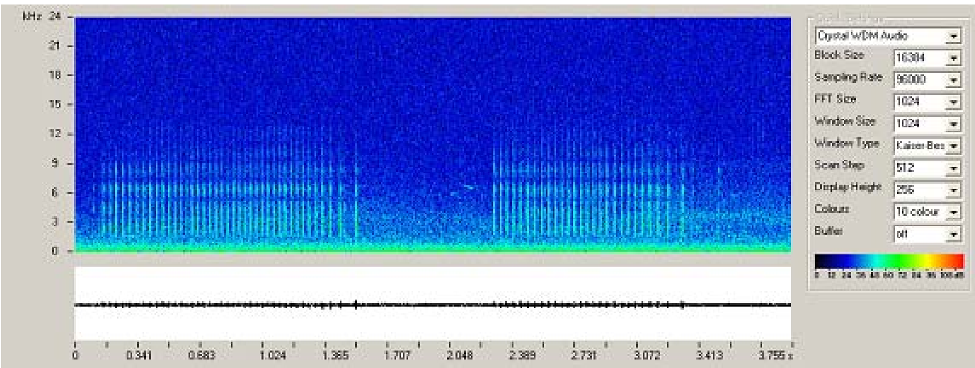

Figure 5: Spectrographic display of chirrup.

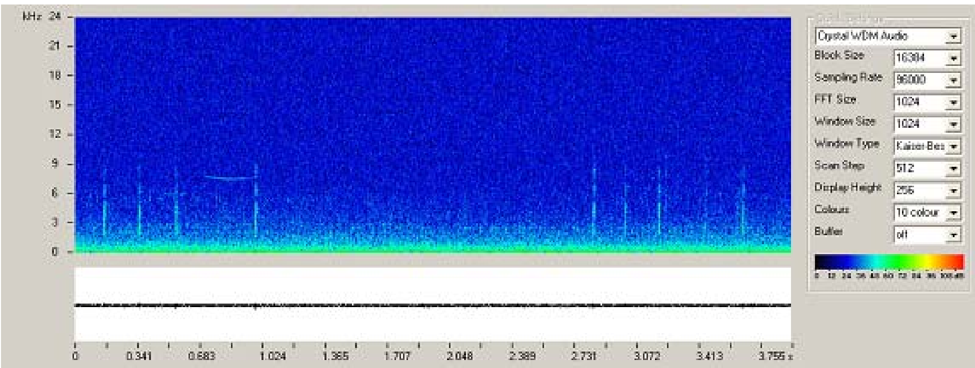

Figure 6: Spectrographic display of two codas with the typical Mediterranean pattern 3+1. A weak dolphin whistle is also shown on the first coda.

With the OνDE station, in year 2005 (Fig. 7), sperm whales have been detected in 117 of the 231 (50.6%) recorded days (1186 out of 5147 recorded hours, 11.5%). In 2006 sperm whales have been recorded in 31 of 83 recorded days (37%). Although several periods of consecutive days were characterized by the presence of sperm whales, solitary whales or groups of several individuals were often detected for few hours only and this may indicate that they were in transit. In few cases whales were present for more than one day and in some occasions, other sounds than clicks and creaks were recorded, in particular chirrups and codas indicating socializing behaviours. The coda pattern that was more frequently recorded followed the 3+1 type (PAVAN ET AL. 2000), however, the number of codas of the 2+1 type was greater than previously reported for this area.

Work in progress

New analysis algorithms are being developed to maximize the SNR ratio and to track the movements of impulsive acoustic sources to reveal the movement of sperm whales whilst in the detection range. Estimating the TDOAs (Time Difference Of Arrivals) between the four hydrophones allows the separation of the sound arrival directions and the tracking of the sources' movements. In some cases, when surface reflections are clearly associated to individual clicks it is possible to exactly locate the animal, i.e. to know range and depth, instead of having only azimuth and elevation information. Such direct ranging will be important to assess the real detection range of the OνDE station and to improve the tracking of the animals. At the same time click details are examined to measure the Inter Pulse Interval, i.e. the intervals among the pulses that constitute the sperm whale click (PAVAN ET AL. 1997; ZIMMER ET AL. 2005). According to the latest models on sound production (ZIMMER ET AL., 2005) reliable IPI measures can be taken if on axis, either frontal or caudal, when a clean (P0)-P1-P2 structure is available (Fig. 8). By measuring the IPI it is possible to assess the whale size and, if the size is greater than 13m, the sex (females' length is up to 13m, males may grow up to 18m). By combining TDOA and IPIs it should be possible to assess the number of transiting animals and the groups' composition allowing a better estimate of population size and structure. The tracking of their movements will possibly reveal if their directions are seasonal and directed to/from the Strait of Messina, as already suggested by BOLOGNARI (1949), or if they follow other rules, if any.

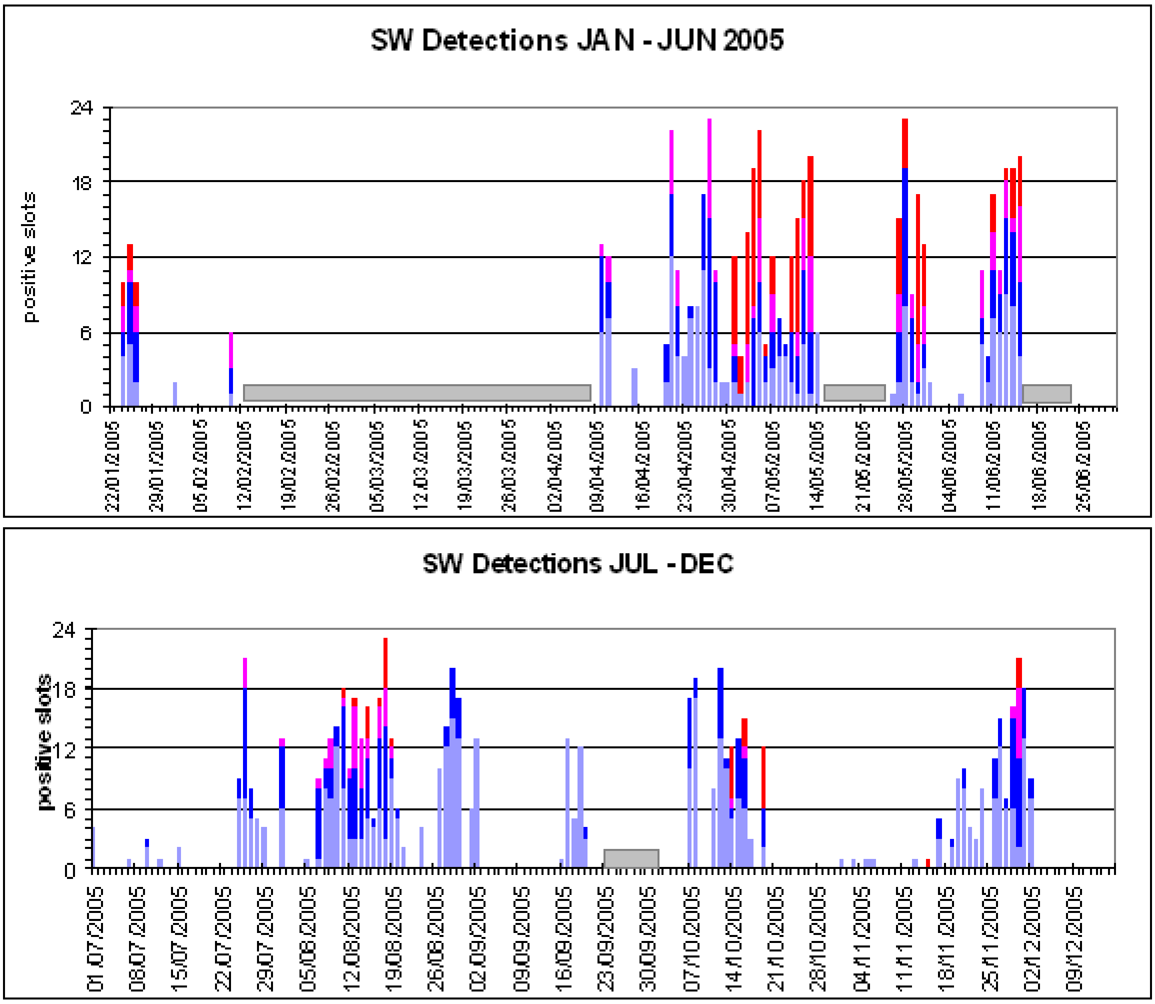

Figure 7: Sperm whales' detections in year 2005. Vertical bars indicate how many hours sperm whales have been detected each day. The stacked bars indicate how many animals were detected each hour: ▇ 1 animal detected; ▇ 2 animals detected; ▇ 3 animals detected; ▇ 3 or more animals detected. Horizontal grey bars indicate periods of recording inactivity. The longest one was due to a cable break.

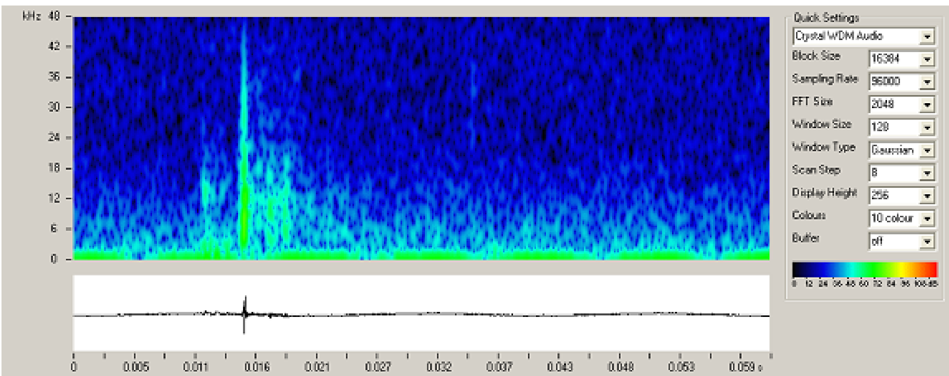

Figure 8: Sperm whale click with visible multi-pulse structure: P0-P1-P2. Based on the IPI, the size has been estimated 9.94-10.27 meters, matching a young male or a female. X-axis shows 64ms.

Cuvier's beaked whales

Sperm whale clicks are often loud as the animals dive at great depth, close to the receiving hydrophones; on the contrary, whistles and clicks from dolphins, which stay within few hundred meters from the surface, are recorded with much lower amplitude. Clicks similar to those emitted by Cuvier's beaked whales (JOHNSON ET AL., 2004; ZIMMER ET AL., 2005) have been detected with amplitude much greater than that of dolphins indicating a deep source that match well with the known dive depths of beaked whales. Cuvier's beaked whales have been recorded to dive to more than 1800m (JOHNSON ET AL., 2004). The habitat of this species appears to be associated to sharp continental slopes, but it was never reported for the OνDE area; few strandings have been recorded on the Calabria coasts and, recently, 10 km South of Messina (PODESTÀ ET AL. 2006, PAVAN ET AL. 2008). PANIGADA ET AL. (2007) reported few encounters in the Messina Strait area in 2005.
Received clicks match well descriptions given by the WHOI team with the D-TAG (ZIMMER ET AL. 2005) but show larger ICI (Inter Click Interval), 460-480 msec rather than 400 msec (Fig. 9 & 10). It may be worth to note that the amplitude of the received clicks is not constant but oscillating, as it can be expected by a directional source swimming and scanning the environment with left-right movements of the head. The hydrophones get the maximum amplitude when it is in the beam axis.
These detections indicate that deep acoustic sensors can be used to reveal and to monitor the presence of this species that seems sensitive to anthropogenic sound and but is difficult to detect.

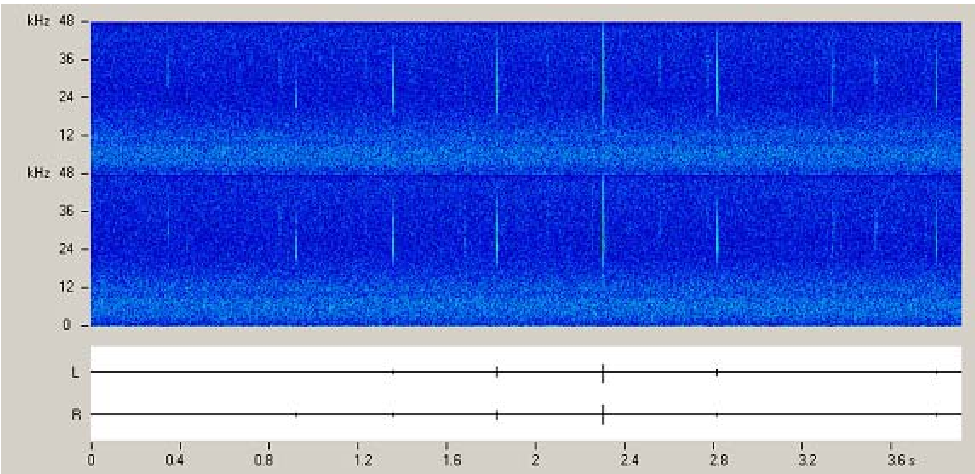

Figure 9: Series of clicks spaced 460-480 ms, much louder than clicks from shallow dolphins, with oscillating amplitude. X-axis shows 4.0 seconds.

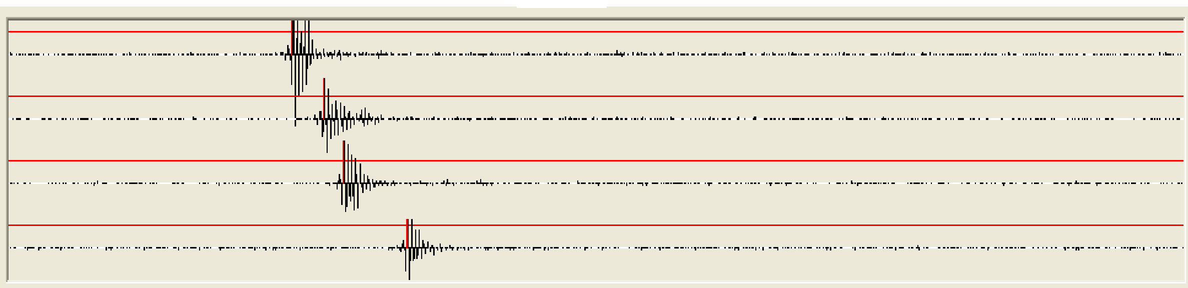

Figure 10: A click received on the 4 hydrophones. Waveform display (x-axis 9.6msec) shows a time length of 300microsec matching well with Cuvier's beaked whales' click sructure.

Other detections

Other than recognizable biological sounds, many man-made sounds have been recorded and identified, including ship noise, sonar, echo sounders, airguns (or maybe sparkers), and explosions. Acoustic events of unknown origin have been also recorded.

Way ahead

Based on the success of OνDE a new EEC funded project named LIDO (Listening Into the Deep Ocean) was set up with the collaboration of INGV (National Institute of Geophysics and Vulcanology) and other international partners to renew the OνDE platform and to create a Mediterranean wide acoustic monitoring network by upgrading existing underwater seismic detectors with broadband acoustic sensors.

The implementation of a number of “whale gates” to monitor the presence and movements of marine mammals in critical areas, will allow to better understand their populations dynamics and the long term changes that are possibly driven by direct or indirect human impact, including climate changes.

Following the increasing interest in autonomous underwater acoustic monitoring, a new low cost bottom recorder was developed in cooperation with Nauta-rcs, a company specializing in underwater equipment. Based on a modified commercial M-Audio Microtrack 24/96 digital audio Compact Flash recorder, custom electronics that add scheduled recording features, additional power supply with NiMH rechargeable batteries, and a customized Sensor Technology hydrophone, this system is installed into a 50cm x 9cm aluminium canister designed to operate down to -500m. In the present configuration, it allows an operating life of up to a week (depending on the recording schedule and available storage capacity); the unit can be pre-programmed from a PC to follow an extremely flexible recording scheme. Within the LIDO project, it will be used to monitor and select locations suited for a permanent monitoring platform.

Long-term acoustic monitoring programs that are made possible by present technologies generate huge amounts of recorded data, the analysis of which is a serious issue that presses for the development of reliable automatic sound recognition software. LIDO includes a project to develop and test semi-automatic and automatic classification software able to make browsing of huge amount of acoustic data easier and also to perform in real-time providing immediate feedback.

Technologies developed for the underwater environment could be easily adapted to monitor both the acoustic biodiversity and the anthropogenic noise contamination of terrestrial habitats.

Acknowledgements

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