Continuous real-time monitoring with a deep underwater acoustic station. Noise spectra and biological sounds from the NEMO Test Site.

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ABSTRACT
A platform for the study of underwater acoustic noise has been deployed 21 km off the port of Catania, on the East coast of Sicily, at 2050 meters of depth. Connected to the labs in the port by electro-optical cables, it allows continuous monitoring of the underwater acoustic environment with 45 kHz bandwidth. Conceived for astrophysical studies, it is also used to detect the sounds emitted by marine mammals transiting in the area and to track their movements.

INTRODUCTION
Within the INFN (Istituto Nazionale di Fisica Nucleare) NEMO (NEutrino Mediterranean Observatory) Project that addresses the underwater detection of high energy neutrino, an experimental deep station, named ONDE (Ocean Noise Detection Experiment), has been developed for measurement of underwater acoustic noise.
On January 22th, 2005, it has been placed on the sea bottom 21 km East offshore Catania (East coast of Sicily) at 2050 m depth and connected with a ROV to already deployed cables. The station is connected to the shore lab through electro-optical cables to provide real-time continuous data transmission. It was operational till mid December 2005 when the cables were damaged during a storm. In late 2006, the station will be disconnected and replaced by a new one.
The main experiment hosted by the station concerns the study of the underwater acoustic environment to develop the strategies required for the detection of acoustic pulses generated by high energy neutrino interacting with protons or neutrons in seawater. The experiment is highly interdisciplinary and other than providing long term data on the underwater noise, it also provides an unique opportunity to study the acoustic emissions of marine mammals living in the area or passing through it during their seasonal movements within the Mediterranean basin.

METHODS
Four calibrated broad-band hydrophones made by RESON are placed on the outer frame of the platform and connected to a Benthos sphere that contains the AD electronics and the electro-optical interface; hydrophone signals are sampled at 96 kHz with 24 bit resolution and sent to the shore lab 24/24h through two optical fibers (each fiber carries a stereo digital stream). Data recording is made with a 4 channels recording software developed by CIBRA that reads and keeps in synch the two digital stereo streams coming from the underwater station. Data arrives with 24 bit resolution and can be saved to standard Microsoft .wav files either in integer (16 or 32 bit/sample) or 32 bit float format (24+8 bit); float format is useful for importing data in Matlab for accurate noise analysis. Float files can be also converted to 16 bit format to reduce the storage space required.
As the continuous recording was not possible due to storage space constraints (recording float files requires 124GB/day), after an initial period of continuous data storage, most of the time recordings were made for 5 minutes every hour. Nonetheless the amount of data acquired is huge (more than 2TB) and its analysis is still in progress.
Special software was developed to browse and analyze the acoustic data. SeaPro, the sound analysis program developed at CIBRA, has been improved to read 32 bit formats (integer and float) and 4 channels wav files. It is being used to visualize files, to detect sperm whales' clicks and to perform TDA (Time Difference of Arrival) measures to separate different individuals and track their movement.

RESULTS
Data analysis was distributed among INFN, mostly interested in analyzing the background noise, and CIBRA, interested in biological sounds.
A huge collection of biological and non biological sounds (ship noise, sonar, airguns, explosions, and many of unknown origin) was catalogued and stored in the CIBRA Cetacean Sound Library.
To date, systematic analysis and classification has been done on 4 months, as shown figures 3-5, to quantify the occurrence of odontocetes' detections. No investigations were made to possibly reveal fin whale sounds.
Preliminary results provide important data about the anthropogenic contribution to the background noise and about the marine mammals transiting or living in the area, where very few studies are available.
Dolphins (striped dolphins and bottlenose dolphins) have been recorded almost every day whilst sperm whales have been recorded often but with less regularity. Sperm whale clicks are often received loud as the animals may dive at great depth, close to the receiving hydrophones; on the contrary, whistles and clicks from dolphins, to be supposed to stay within few hundred meters from the surface, are recorded with much lower amplitude.

Sperm whale clicks are recorded with good SNR (Signal to Noise Ratio); by using a digital high-pass filter the SNR is further increased to improve click detection. The detection of their characteristic clicks indicate a presence of sperm whales more consistent and frequent than previously believed.
Sperm whales, solitary or in groups of 2 to several individuals, are often detected for few hours only and this may mean they are just in transit. Clicks are the most common vocalizations, chirrups and codas have been recorded frequently, but creaks were seldom heard.
Other than counting and tracking the passing animals, by analyzing click details in the better recordings it is possible to assess the size and, for larger individuals, the sex (work in progress).

Way ahead
The analysis of the acoustic dataset is going on to have a picture of dolphin's and sperm whale's occurrence along the 10 months of recording. On selected time periods, the analysis of the Time Difference of Arrival (TDA) of the clicks on the four hydrophones will allow a more accurate count of whales. By plotting TDAs in a virtual 3D space it is easier to separate different sources and then, by projecting them in the real 3D space, to track the sources' movements within the detection range.
This part of the research will be done in a second phase to associate peaks in the presence of sperm whales with prevalent swimming directions. This may reveal the routes of the animals passing in the area and provide new insights into their seasonal movements within the Mediterranean basin.

CONCLUSIONS
This experiment demonstrates the importance of setting permanent underwater equipment for continuous long-term acoustic monitoring of specific areas, such as critical habitats, migration routes, protected areas, to study the evolution of ocean noise, to monitor marine mammals presence, and consequently to plan, implement and verify long term management and conservation strategies.
Results, still preliminary, are encouraging and, once the analysis will be completed, will provide for the first time the real presence of sperm whales and hopefully reveal their seasonal movements in an area that is an important passage among the western and the eastern basin and also an intense shipping corridor with important infrastructures, including the close to be built bridge on the Messina Strait.

ACKNOWLEDGEMENTS
A special thank to Gabriella La Manna who is browsing and analyzing the huge amount of files collected so far. She also produced the preliminary graphs shown here.

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Table 1 – Recording periods and modes.

Period	Recording mode	Schedule	GB/day
January 22 th - 29th	2 + 2 not synch'ed channels, 16 bit integer	continuous	62
February 1st - 10th	2 + 2 not synch'ed channels, 16 bit integer	continuous	62
February 11th - April 03rd	OFF, due to cable damage		
April 4th – April 16th	2 + 2 not synch'ed channels, 16 bit integer	5min/hour	5.1
April 17th - June 15th	2 + 2 not synch'ed channels, 24 bits, floating	5min/hour	10.2
June 15th - June 24th	OFF, data not recorded		
June 25th - June 28th	2 + 2 not synch'ed channels, 24 bits, floating	5min/hour	10.2
June 28th - December 14th	4 synch'ed channels, 24 bits, floating	5min/hour	10.2
December 15th – now	OFF, due to cable damage		

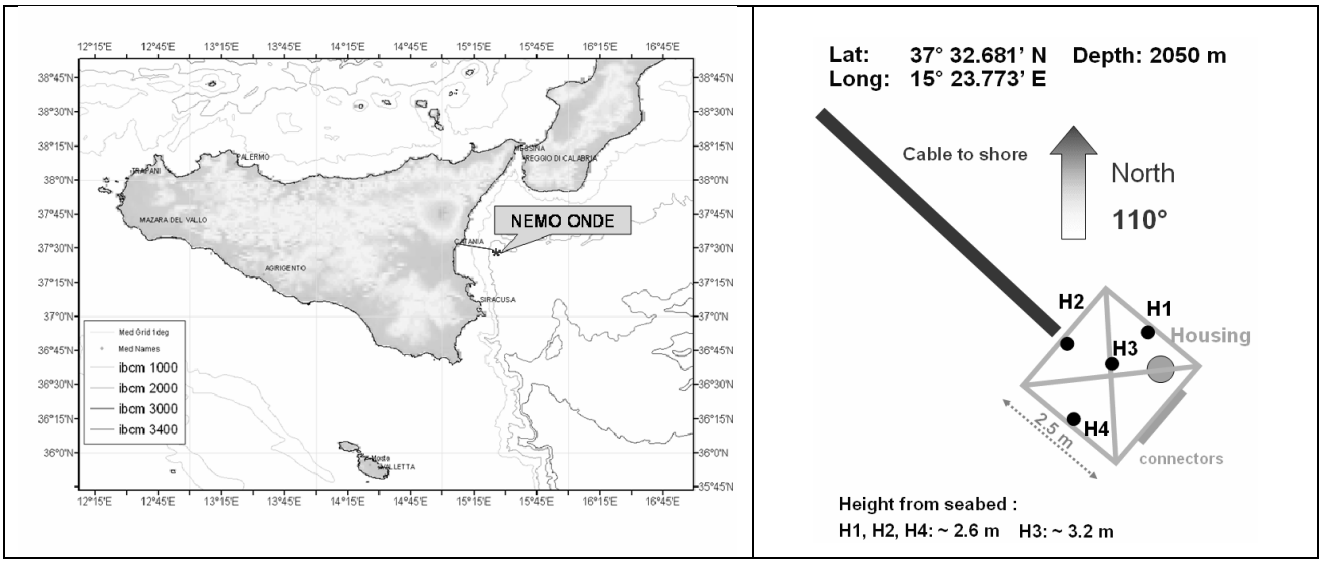

Fig. 1 – Location of the NEMO ONDE station.

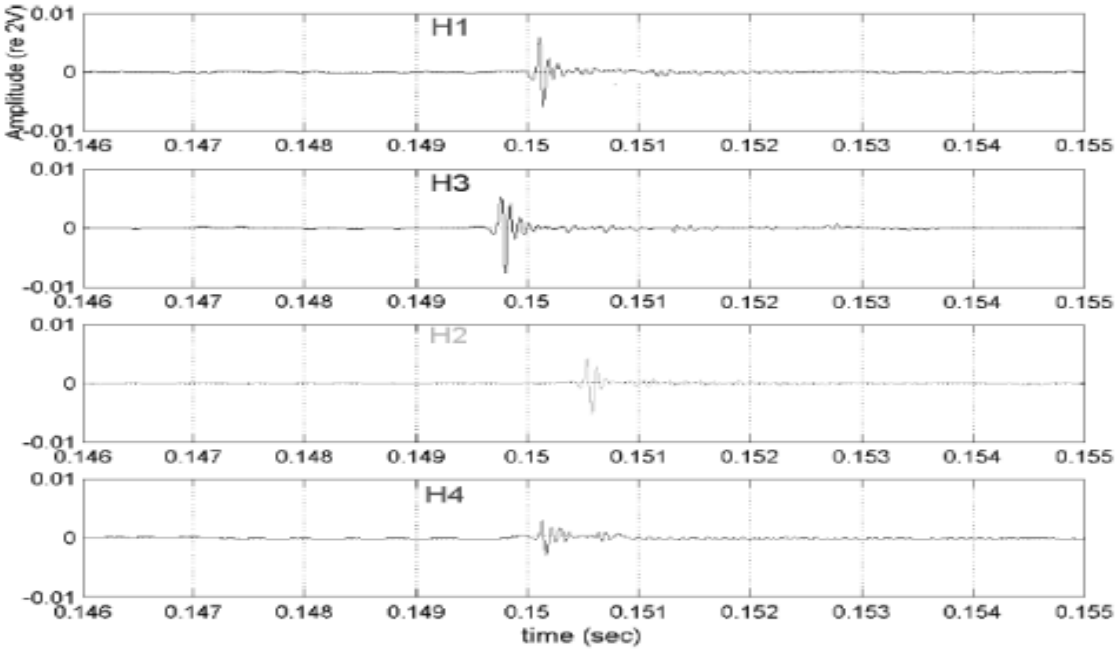

Fig. 2.1 – Plotting of a sperm whale click received on the 4 hydrophones.

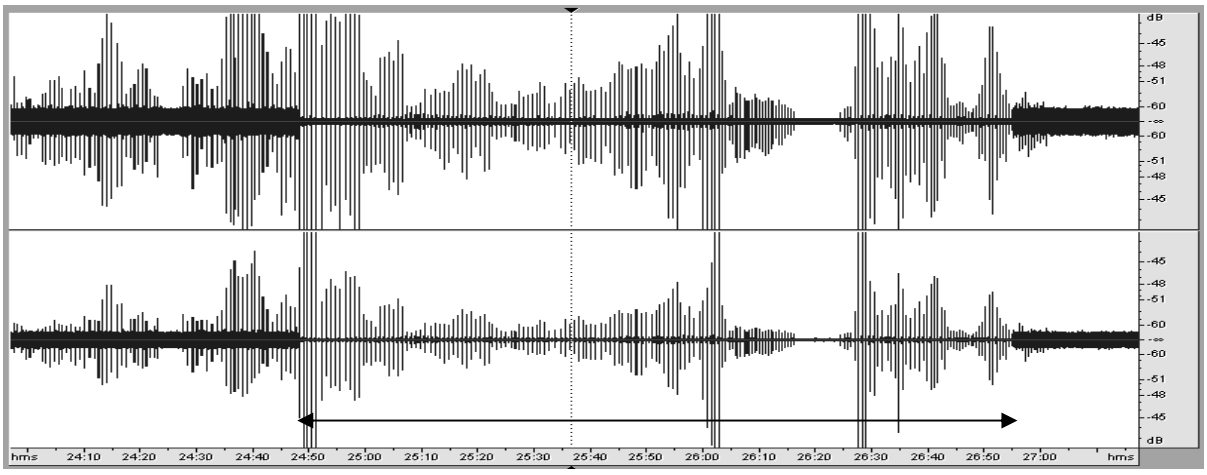

Fig. 2.2 – Sperm whale clicks on two hydrophones. The arrow shows a section where HP filtering is applied.

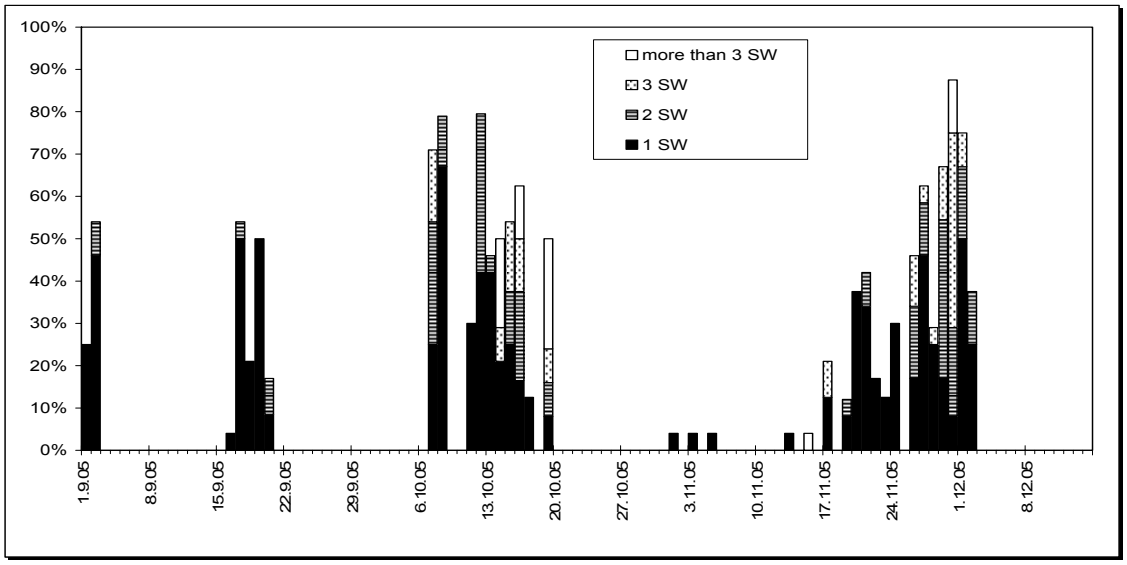

Fig. 3 – Percentage of daily contacts with sperm whales in the period September-December. The height of the bars indicate the % of slots with positive detections each day; internal segments indicate the number of whales detected.

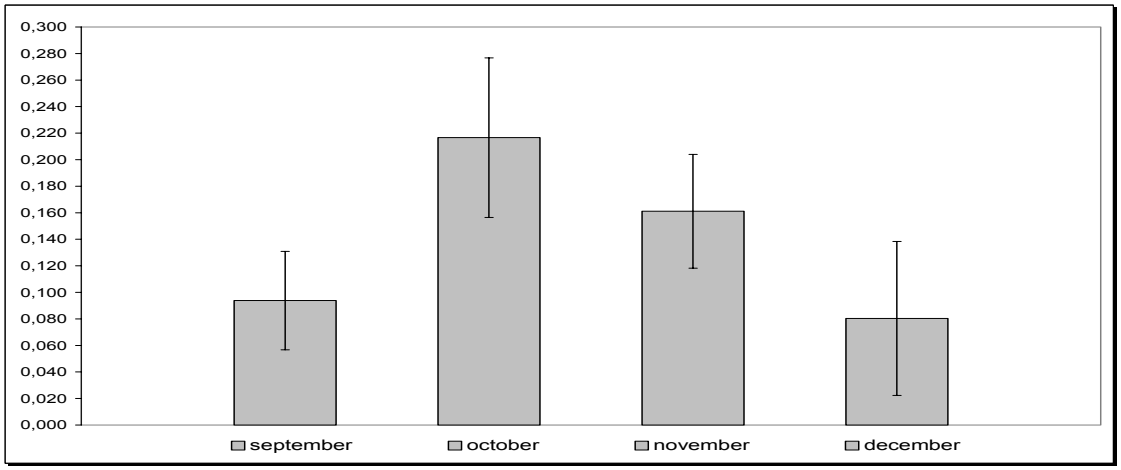

Fig. 4 – Detection frequency of sperm whales by month. Y values must be multiplied by 100; bars indicate the Standard Error (SE).

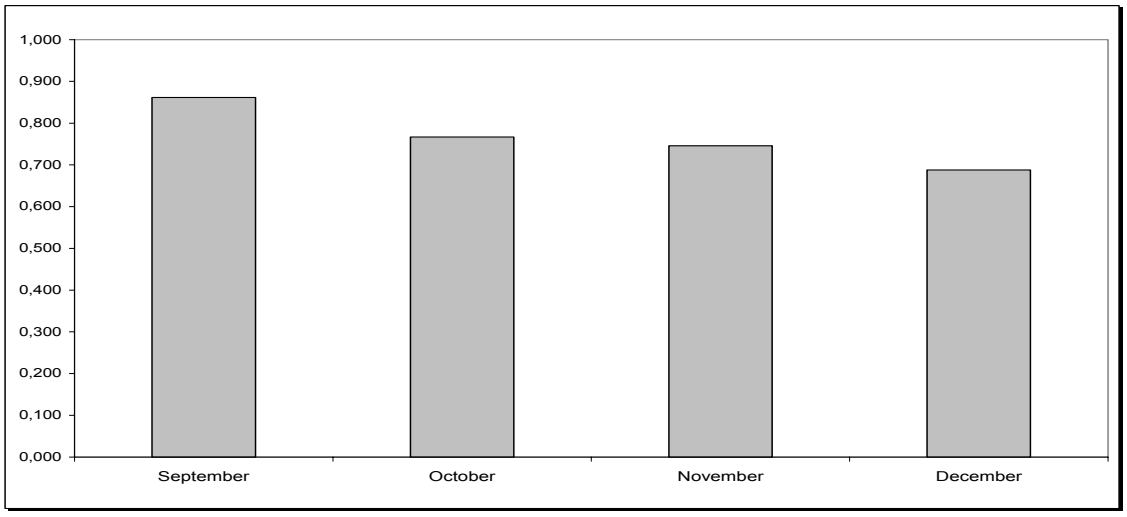

Fig. 5 – Detection frequency of dolphins by month. Y values must be multiplied by 100.