INGV Broad Band Ocean Bottom Seismometers deployed in the Ionian Sea

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Introduction

In **May 2007**, within the monitoring activities carried out in co-operation with the *Italian National Civil Protection Department* (DPC) and within the ***European project NERIES*** (activity NA6), INGV has deployed three Broad Band Ocean Bottom Seismometers in the southern **Ionian Sea** which locations are shown in *Fig. 2*.
OBS's named **A1** (*Lat. 36° 47' 52,1"N Long. 17° 14' 33"E, 3418m of depth*) and **A3** (*Lat. 35° 59' 34"N Long. 16° 30' 25.1"E, 3547m of depth*) were successfully recovered on the **2nd of February 2008**; **A2** (*Lat. 35° 59' 44.7" N Long. 18° 00' 17.2" E, 4018m of depth*) was recovered on the **15th of March 2008**, and another OBS was deployed on the same location to accomplish the continuous long-term seismic monitoring task (*until May 2010*) as predicted within NERIES.
The three OBS's, entirely developed at the **Gibilmanna OBS Lab** of the INGV National Earthquake Center (CNT), are part of a pool of eight ready to deploy instruments and they are the first Italian OBS's taking part in a long term experiment.

Fig. 1: *The three OBS's before the deployment in the Ionian sea*

The instruments are equipped with:
- **Nanometrics Trillium 120p** seismometers (flat response between 120s and 175Hz) installed in a 17 inches pressure glass spheres on a Nautilus gimbals for the levelling;
- **Cox-Webb Differential Pressure Gauge** (bandwidth 150s-2Hz after the preamplifier);
- 21 bits, 4 channels **SEND Geolon-MLS digitizer** setted at 100 sps.

OBS A1 recorded a large volume of seismic data including local, regional and teleseismic events as described in the following paragraphs. OBS A3 had problems on the seismometer levelling system, so from this instrument, the only usable data are the ones recorded by the Differential Pressure Gauge. Finally, data from OBS A2, haven't been analyzed yet.
The area selected for the deployment is a region of high scientific interest for several reasons: *i)* there are no seismological data on the structure of the Ionian lithosphere (except for a few seismic reflection lines, see *Scrocca et al., 2003*); *ii)* the rate and features of the seismicity in the area between the *Hyblean-Malta fault system* and the accretionary prism of the Calabrian Arc are unknown. This experiment allows us to test the pressure waves detection system that will be implemented in the *Tsunami Warning System* that INGV is developing within the IOC-UNESCO "NEAMTWS" (*North-East Atlantic, Mediterranean and connected seas Tsunami Warning System*).

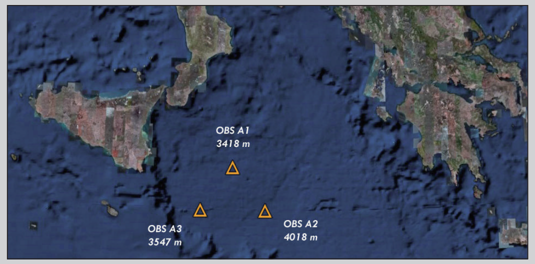

Fig. 2: *INGV OBS's locations and depths in Southern Ionian Sea*

Preliminary data analysis

To better understand and monitor the earthquake processes in the European-Mediterranean region, hundreds of broad band seismic stations were installed in the past ten years, mostly on land. Nevertheless, the seismic monitoring of the European-Mediterranean region is difficult because many seismogenic areas are underwater. The resulting gaps in coverage produce a biased and incomplete image of the Mediterranean seismicity. The extension of the capabilities of the existing land-based infrastructure for a better approach in seismic risk assessment and management is a goal of NERIES project, *activity NA6*. For this reason, three INGV BBOBS were deployed in southern Ionian Sea.

In this first campaign, we recovered more than 250 days of seismic and pressure recordings.

Data from BBOBS are often difficult to analyze for the different seismic noise level and shape, compared to land signals, and for the presence of seismic waves travelling only through the sea.
Generally sea floor and continental noise spectra are different because the ocean surface is an important source of broad band seismic noise. *Fig. 3* shows the *seismic and pressure noise PSD* of 24 hours of signals from OBS A1, without seismic events, compared to the land *High Noise Model* (HNM) and *Low Noise Model* (LNM) of *Peterson (1993)*. Spectra from our OBS

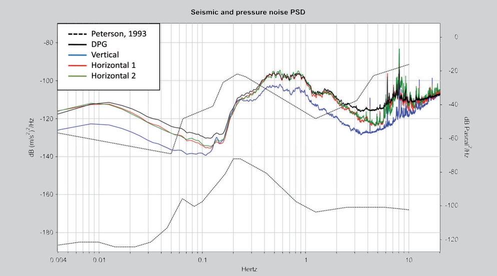

Fig. 3: *OBS A1, PSD of 24 hours of signals without seismic events*

seems to be shifted forward in frequency: seismic and pressure noise PSD have a very similar shape between them, showing a very high level noise below 0.03 Hz and in the band between 0.3 and 3.0 Hz.
This high noise level could involve a poor event detection for local and regional earthquakes. Low noise level in the bands 0.04-0.2 Hz and 3-7 Hz provides windows for the detection of teleseismic events and local earthquakes, respectively.
The magnitude frequency histogram of *Fig. 4* reports the number of events recorded by OBS A1 and by the DPG of the OBS A3, for 0.2 magnitude intervals, and shows a large magnitude gap around 5 due to the seismic sources distribution around the OBS and magnitude recurrence.

During the almost nine months of the experiment, OBS A1 and A3 recorded altogether more than 300 local, regional and teleseismic events.

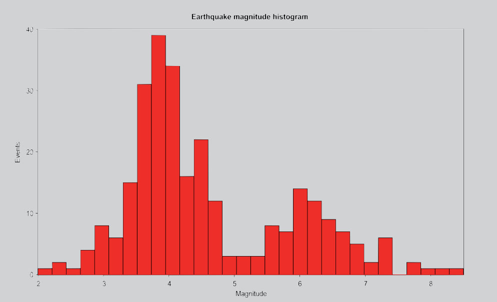

Fig. 4: *Number of seismic events recorded by OBS A1 (DPG and seismometer) and by the DPG of OBS A3, classified by their Magnitude*

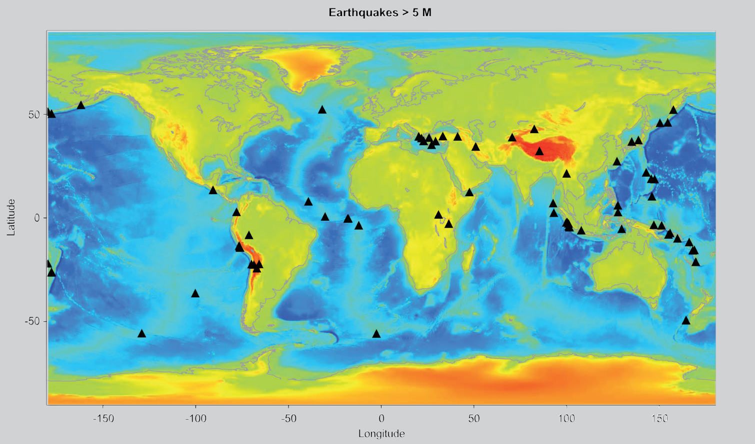

Fig. 5: *Earthquakes with magnitude larger than 5 recorded by DPG and seismometer of OBS A1, and by the DPG of OBS A3*

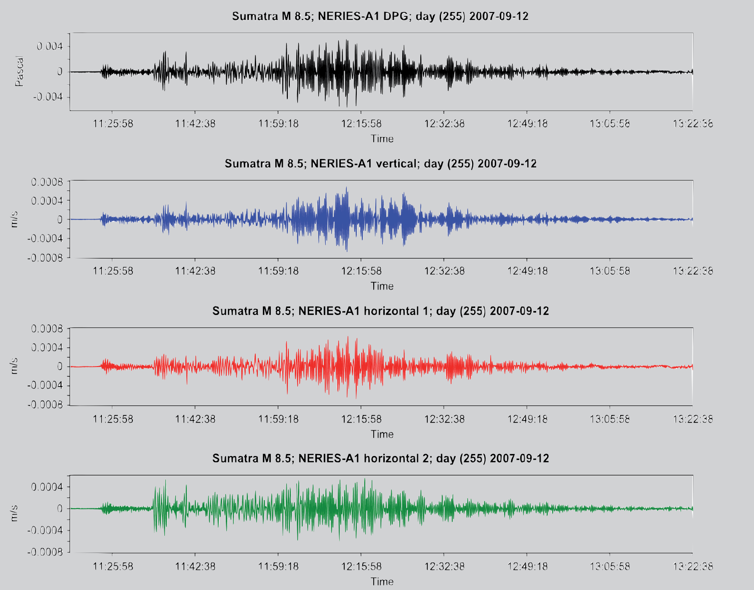

Fig. 6: *8.5 M Sumatra teleseismic event of the 12th of September 2007, recorded by the DPG and the 3C seismometer on the OBS A1*

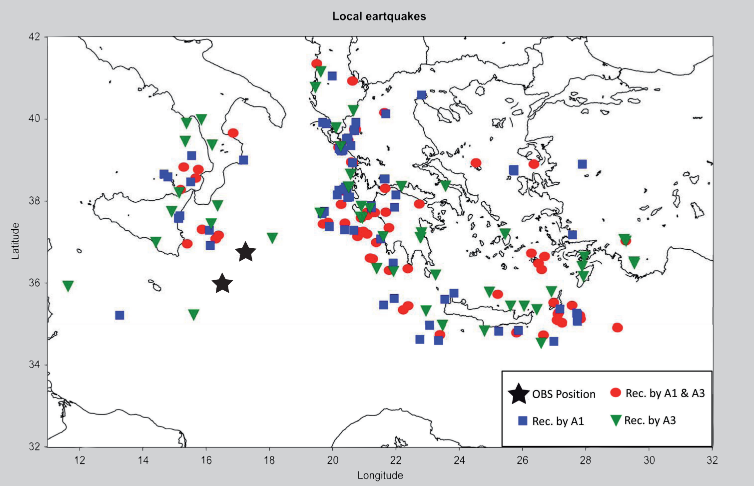

Fig. 7: *Local and regional earthquakes recorded by OBS A1 and A3*

Fig. 5 shows all the earthquakes with magnitude larger than 5 recorded by OBS A1 and A3; the teleseismic events recorded are distributed in all the five continents, with special concentration in eastern Asia. *Fig. 6* shows the *8.5 M Sumatra teleseismic event* of the 12th of September 2007, recorded by the DPG and the 3C seismometer on the OBS A1. The Sumatra earthquake shows several clear arrivals of body and surface waves on all four components. Teleseismic data will be valuable to retrieve the Earth's structure in the Ionian sea.
Fig. 7 shows local and regional earthquakes recorded by OBS A1 and A3, as located by INGV and Greek seismic network: most of the earthquakes are located off-shore Greece and Italy, being related to the Ionian subduction beneath the Aegean and the Calabrian arcs.
Fig. 8 shows a four channel recording (OBS A1) of a Greek earthquake of M 4.8 and its vertical component spectrum compared with the background noise; the use of DPG allow to detect waves that travel only in sea water and are difficult to detect on seismometer.
After P and S phases arrivals, a third phase is evident: this seismic wave, trapped in the channel known as *SOFAR* (*SOund Fixing And Ranging channel*), named **T-wave**, travels at very low phase velocity (about 1.5 km/s) and can be used to constrain the earthquake location, together with P and S waves.
Fig. 9 shows a DPG recording of an earthquake in Greece (M 4.5) with the related logarithmic spectrogram that shows another low energy arrival after the T-wave that is likely related to a reflection on the eastern Sicily coast.

The OBS's also recorded 85 local events not reported by any land seismic network bulletin.

Fig. 10 shows the waveforms of one of these unreported local events recorded on the 23rd July 2007 by OBS A1.

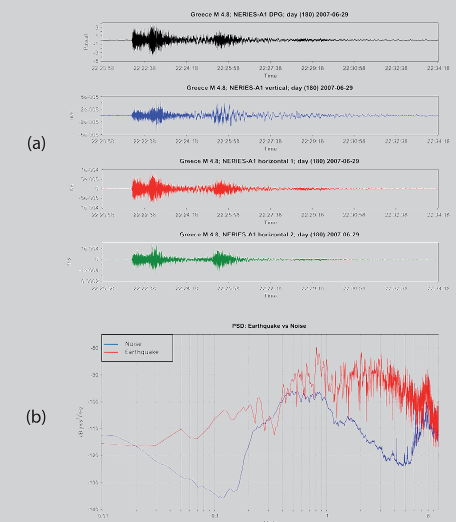

Fig. 8: (**a**) *Four channels recording of an earthquake located in Greece (M 4.8).* (**b**) *The earthquake vertical component spectrum compared with the background noise*

We tried to determine the station-event epicenter distance by P and S arrival times assuming an adequate crustal model. The determination of a suitable crustal model for the Ionian Sea area represents a problem due to the shortage of seismic data recorded by seafloor instruments. Nevertheless, when present, independent and additional information of stations-earthquakes distances, could be estimated from T-waves arrival time. For local seismic event of *Fig. 10* we estimate a station-earthquake distance of about 150 km.
At the moment, we haven't information about the azimuth orientation of the seismic sensor, but we plan on estimating an azimuth correction by polarization analysis of located seismic

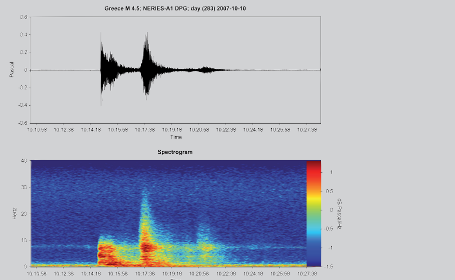

Fig. 9: *DPG recording of a Greek M 4.5 event with a low energy arrival after the T-wave.*

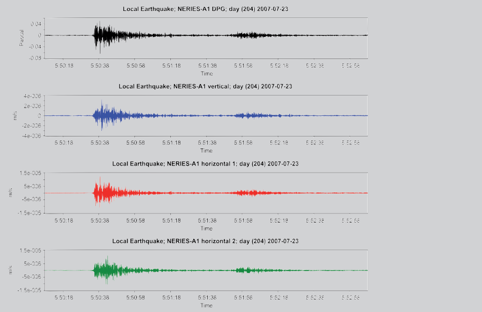

Fig. 10: *Local event not reported by seismic networks bulletins*

earthquakes. In this manner, the sensor orientation will be determined by linear regression between located back azimuth and the computed one.
Very few geophysical informations exist on Ionian lithospheric structure, except for some reflection lines shot in the 90's (*Scrocca et al., 2003; Finetti, 2004*). These OBS data will allow us to extract original informations of the Ionian crust, using *Receiver Function and FTAN* (*Frequency-Time ANalysis*).
Fig. 11 shows the first seconds of a teleseismic event (*Tanzania, 5.9 M, July 17, 2007*) that will be analyzed with the Receiver Function method. *Surface wave* part of the event will be analyzed with the FTAN method.
Time-domain receiver function modeling allow to model the shear-wave converted phases and multiples recorded on the horizontal components of P waveforms. Seismic data from OBS stations show water-layer multiples on DPG and seismometer channels depending on the water depth and the seafloor impedance contrast. Before receiver function modeling, water-layer multiples must be removed by wavefield decomposition or other methods (*Ammon, 1991*).
FTAN (*Frequency Time ANalyses*) method, is a multiple filter analysis, originally developed by *Dziewonski et alii (1969)*. Applied to dispersed Rayleigh wave recorded on vertical component, this method allow to extract the group velocity curves. The inversion of dispersion curve of fundamental mode of Rayleigh wave, could be used to estimate a S wave velocity model and for a surface wave tomography of Ionian region.

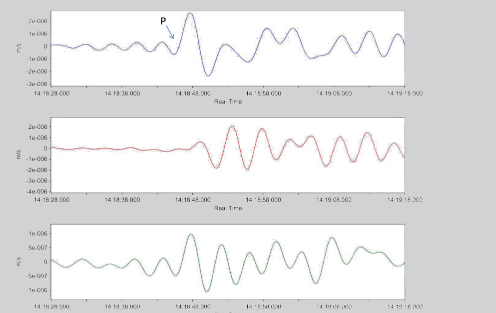

Fig. 11: *First seconds of an earthquake in Tanzania (M 5.9) with highlighted the P wave*

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