**Introduction.** On August 21, 2017, at 18:57 UTC, an earthquake of $M_D$ 4.0 occurred in Casamicciola, district of Ischia island at about 2 Km km depth. In volcanic areas, such as the Ischia Island, the precise localization of the earthquakes requires specific velocity models, both for the wide lithological variability and for the high geothermal gradient. These models are available, for example, for the Vesuvius and for the Campi Flegrei areas, but not for the Island of Ischia because they need to use the local seismicity. Since 1999, at least 78 earthquakes have been recorded on Ischia (updated to 21 February 2018) (D’Auria et al., 2018) and have been localized using the model used for the Campi Flegrei, on the basis of the similar geological and volcanological context of the two volcanoes.

Therefore, the aim of this work is the definition of average 1-D shear-wave velocity model of the shallower crust of Ischia using ambient noise array techniques and spectral ratios evaluated on broad band seismic signals recorded by mobile and permanent networks deployed in the last year.

**Dataset and analysis.** After the $M_D$ 4.0 earthquake, that hit Casamicciola on August 21, the permanent network (CAI, IFOR, IMTC and IOCA) was implemented with other five seismic stations and six seismic stations of the mobile network (T136* in Fig. 1).

All permanent network stations, equipped with broad band, accelerometer and short period sensors, transmit the seismic signals in real-time for seismic surveillance purposes. The stations
of the mobile network, three of which transmit the signal in real-time, acquire locally and are equipped with broad band, short period sensors and accelerometers. The 15 stations currently installed on the island have different technical characteristics and their positions are shown in Fig. 1.

The preliminary dataset consists of ambient noise records of 10 of the 15 broad band stations between the months of June and September 2018.

**Array analysis.** We applied the MSPAC method (Bettig *et al.*, 2001) to the seismic noise recorded by 10 stations (Fig. 2 top left), given that this method allows to compute the spatial autocorrelation even if the array geometry is not semi-circular. We divided the array in semi-circular sub arrays called “Rings”, whose radii are defined by the sensor’s spacing, and we calculated the spatial autocorrelation for all the possible pairs of sensors. Each Ring is the result of an appropriate balance between the number of sensor pairs per Ring (as large as possible) and the thickness of the Ring (as small as possible). Thus our geometry is composed by 6 Rings, ranging from a minimum of about 1000 m to a maximum of about 8400 m spacing of the sensors, for a total of 46 sensor pairs.

Having fixed time windows and frequency band, the MSPAC method calculates the autocorrelation between the station pairs and averages over the azimuthal directions. The time windows are set to a period of $T = 400$ s, with a 20% overlap, for each frequency in the range 0.1-2.0 Hz, using 100 logarithmically spaced frequencies. In order to evaluate the phase velocity, a frequency-phase-velocity histogram has been derived by inverting the azimuthally averaged autocorrelation curves (Fig. 2). To validate the dispersion results of the array obtained with the MSPAC technique, we applied the Frequency-Wavenumber (f-k) technique (Lacoss *et al.*, 1969) to the same data-set in the same frequency range. We found that the f-k results are consistent with the MSPAC results and the additional curve is useful to deduce stable estimations and to improve the interpretation by reducing erroneous, potentially biased data.

**Spectral Analysis.** Taking into consideration the resolution limits of the geometry of the selected stations (Fig. 2 top left), we can see that the available frequency interval for the analysis ranges from 0.1 Hz to almost 1.5 Hz. For this reason we decided to compute the horizontal to
Fig. 2 - Top left: geometry of the array. Top right: frequency-slowness histogram retrieved from the MSPAC analysis. The histogram represents the density of dispersion curve solutions on a grid sampled in velocity. Regions with high solution densities are indicated with green to blue colors. The grey pointed lines are the manually picked minimum and maximum dispersion curves. The black continuous and dotted lines are the lowest ($k_{\text{min}}$) and highest ($k_{\text{max}}$) theoretical frequency limits, respectively. Bottom: Autocorrelation curves of the different ring array diameters. The spatial autocorrelation estimations contributing to the selected dispersion curve are marked as black part of the curve.
vertical spectral ratios (H/V) in the 0.1-1 Hz frequency band. We used the GEOPSY package (Wathelet et al., 2004) selecting at least one hour of noise signals and calculating, on 400 s moving time windows with 20% overlap, the spectral ratios (Fig. 3). The stationary results refer to the stability of the H/V ratios throughout the analysis: which means that the H/V ratios performed on a time-window should be as similar as possible to each other, especially with respect to the amplitude peak frequency. The continuous black curves represent the average H/V ratio, while the dashed black curves are representative of the standard deviation. The grey bands identify the frequency peak, or f₀, with the relative standard deviation bandwidth. We can see that the stations placed near the coast (T1361 and IPSM) exhibit a maximum in the H/V ratios between 0.1 Hz and 0.2 Hz, while the other stations show the maximum at higher frequencies, between 0.4 Hz and 0.8 Hz.

**Inversion procedure and results.** We applied the neighbourhood algorithm employed by Wathelet et al. (2004) (DINVER), which infers the best velocity model thorough a stochastic search in a multi-parameter space. One point of this space corresponds to one velocity model defined by S- and P-wave velocities, thickness, densities and Poisson’s ratios of the soil layers, and a synthetic dispersion curve is calculated by inverting the S-wave equation as function of the surface waves velocity.

We performed a joint inversion of the autocorrelation coefficients (Fig. 2), the dispersion curve obtained from the f-k analysis and the mean H/V ratio obtained from all the station in the 0.2 – 1 Hz frequency band. The resulting models after the preliminary inversion step show a fairly good fit between experimental and theoretical curves using a model parameterization composed of two main layers over half-space with a shear-wave velocity increasing with depth.

**Conclusions.** The results obtained in this preliminary study will be the starting point for a correlation study of all the stations installed on the Ischia island, that will be considered as a large array, to obtain a more accurate S wave velocity model in the first 2-3 km of depth. In fact, the depth resolution depends on the maximum resolvable frequency of the used ring arrays. The lower frequency limit is defined by the largest ring diameter, that was approximately 0.2 Hz. This means that, if we consider the maximum wavelength observable equal to about 8000 m, we can obtain a pseudo-depth of investigation equal to 3200 m (wavelength/2.5). The minimum wavelength, instead, is equal to about 800 m, consequently we can obtain the maximum resolution thickness equal to about 300 m. This value is higher than the local lithological heterogeneity, that are for the most part in the first 200 m (Vassallo et al., 2017), and we can consider the obtained velocity model as representative of the whole Ischia island. Furthermore our result is in agreement with the velocity models achieved by Strollo et al. (2015).

Fig. 3 - Noise H/V ratios as a function of frequency. The colored curves on the H/V vs frequency graphs represent the H/V ratios calculated on each time-window. The grey vertical band indicates the maximum in the H/V, or rather the f₀.
As for the H/V ratios, our data are in agreement with the results obtained by Vassallo et al. (2017), mostly for the peak in the range 0.4-0.8 Hz, which can be related to the presence of the laccolith at a depth of about 800-1000 m (Carlino, 2012).

References


