Third International Symposium on the Effects of Surface Geology on Seismic Motion
Grenoble, France, 30 August - 1 September 2006
Paper Number: 073

APPLICATION OF THE SPAC METHOD TO AMBIENT NOISE RECORDED IN THE VESUVIUS AREA (ITALY)

R. Maresca[1], L. Nardone[1], D. Galluzzo[2], M. La Rocca[2], E. Del Pezzo[2]

1 Università del Sannio, Benevento, Italy
2 Osservatorio Vesuviano – INGV, Naples, Italy

ABSTRACT - Noise measurements were recorded using a dense short-period seismic array in Terzigno (Naples), a town that is located about 6 km from the Vesuvius crater. The aim of this study was to calculate a surface velocity model of the area under investigation through the application of the Spatial Autocorrelation (SPAC) method, with the hypotheses that ambient noise is stationary both in time and space, and that it is composed of surface dispersive waves. The correct knowledge of the surface structure is an important goal in site-effects studies. Correlation coefficients were calculated as functions of the azimuth on noise recorded at pairs of equally spaced stations in the frequency range of 1-8 Hz. Then, the spatial average correlation coefficients were compared to estimates over long-term recordings. The results appear to validate the hypothesis that ambient noise can be considered as a stochastic process. The correlation-frequency curves have been fitted to Bessel functions, from which the Rayleigh wave dispersion curve has been calculated. A velocity model has been derived from the dispersion curve using both trial and error and a standard inversion procedure. The results are consistent with those obtained from array measurements in the area in other studies (Scarpa et al., 2003).

1. Introduction

The site chosen for the present study is located in the town of Terzigno (Na), about 6 km from the Mt. Vesuvius crater (Figure 1). The Somma-Vesuvius Volcano has suffered five plinian eruptions over the last 19,000 years and several subplinian events, which occurred almost continuously from 1631 to 1944. At present, the volcano is in a quiescent stage, which is characterized by moderate seismicity, with low-magnitude events localized in the crater zone down to a depth of 6 km (Bianco et al., 1998).

Multi-dimensional tomographic models that are based on travel-time inversion of shots or local earthquakes have been produced over the last few years, which define the velocity structure under the volcano (De Natale et al., 1998; Capuano et al., 2003). This knowledge is fundamental for studying the details of the seismic sources correlated to the eruptive activity. Experiments with dense seismic arrays have also been carried out to obtain more details of the surface structure of Mt. Vesuvius (De Luca et al., 1997; Saccorotti et al., 2001; Scarpa et al., 2003). The results from a simultaneous inversion of travel times of local earthquakes and shots, and small aperture array data have revealed a strong velocity heterogeneity in the first 5 km of depth (Scarpa et al., 2002).

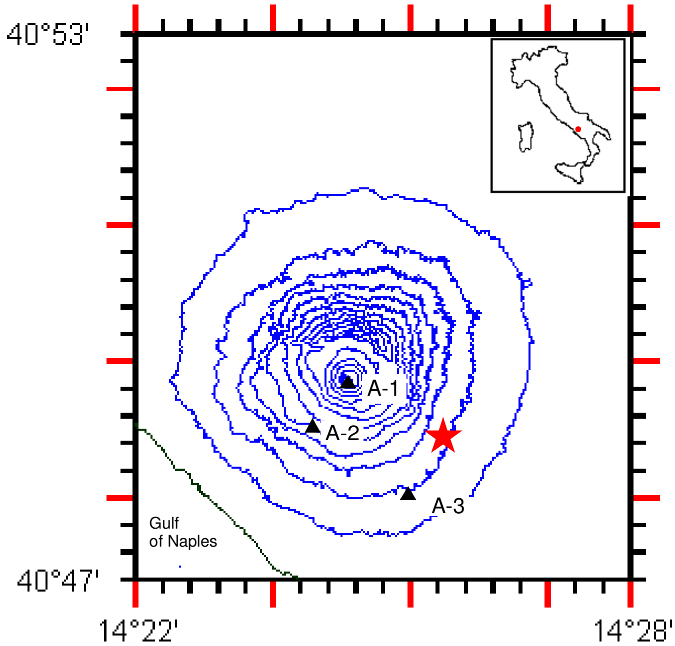

Figure 1. Map showing the array location (red star) on Mt. Vesuvius. Black triangles indicate the locations of the dense seismic arrays installed during previous experiments (A-1, De Luca et al., 1997; A-2, Saccorotti et al., 2001; A-3, Scarpa et al., 2003).

In the present study, we have applied the Spatial Autocorrelation (SPAC) method to array data recorded on the south-eastern flank of Mt. Vesuvius, at an altitude of about 130 m a.s.l., to investigate the dispersive properties of the noise wave field and to derive a surface velocity model. The chosen area is subject to seismic events, as well as being at high volcanic risk, as it is close to the seismogenetic Apenine Chain and it is also densely populated. The knowledge of the surface velocity structure is an important tool in the evaluation of site effects on seismic motion, particularly when local heterogeneities in the surface geology are present, as in volcanic areas.

2. Array site and data acquisition

The array was installed at the site shown in Figure 1 (red star). It consists of 13 stations: a central one, and the others at three circumferences of radii 30, 60 and 90 m. One more station was set up at 123 m from the center (Figure 2).

The stratigraphy is characterized for the first 60 m by a sequence of thin layers of pyroclastic-fall deposits and reworked sediments, from the Avellino (3800 y BP) to the most recent plinian eruption (79 AD). Lavas with scattered pyroclastic interbeds follow to a depth of 252 m, which are related to the Somma-Vesuvius activity prior to 35,000 y BP (Cioni and Vecci, 1988; Principe et al., 1987).

The instruments consist of a multi-channel, 24-bit acquisition system realized by CRdC-AMRA (Del Pezzo and La Rocca, 2004), equipped with 13 Le3D/Lennarz 1-Hz velocimeters. The sample rate is 100 samples/s; instrument response is flat over the 1-50

Hz frequency range. Noise was recorded on 9 and 11 November, 2005, for a total of three hours of selected recordings.

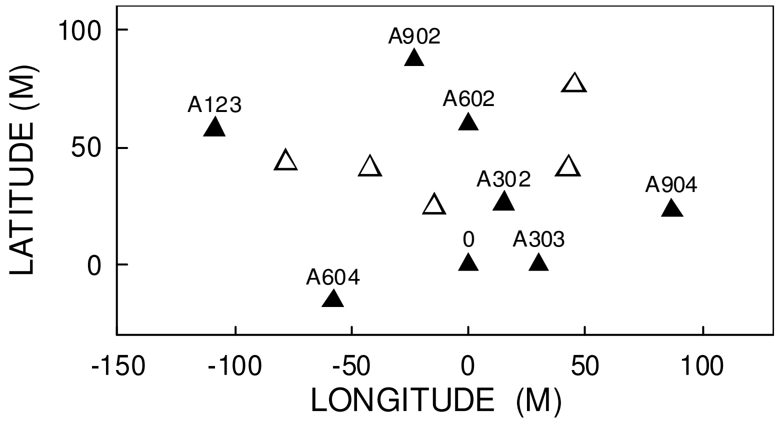

Figure 2. Array configuration. Stations selected for the SPAC analysis are marked by black triangles; the remaining stations by open triangles.

3. Velocity structure beneath the array

The dispersive properties of the noise wave field were analyzed using the SPAC technique (Aki, 1957). The SPAC method assumes that the azimuth average of the correlation coefficients $\rho(r,\omega)$ calculated for pairs of vertical ground velocity records can be expressed as a function of the angular frequency ω and the station spacing r as:

$$\rho(r,\ \omega) = J_0(r\omega\ /\ c(\omega)) \quad (1)$$

in which J_o represents a Bessel function of zero order and $c(\omega)$ is the phase velocity dispersion function. The Rayleigh waves dispersion function $c(\omega)$ can be obtained from records filtered in a series of narrow-frequency bands. An alternative approach to the SPAC technique was proposed by Chavez-Garcia et al. (2005), which is based on the idea of exploiting the recording of microtremors over long times, as a substitute for spatial averaging.

Twelve 163.84-second-long time windows were selected in the signal recorded at eight stations and filtered in narrow-frequency bands, in the range of 1-8 Hz in 0.25 Hz steps; for the middle value of each frequency band, the correlation coefficients were calculated for each peripheral station with respect to the central station. We discarded stations that presented disturbed noise records or stations for which the correlation coefficients with respect to the central station were low (<0.7) at the lowest frequency (1 Hz). This last could be attributed to local heterogeneity in the underlying medium. Then, the azimuth averages of the correlation coefficient were calculated for the three radii, and they are shown by the black circles in Figure 3, as a function of frequency. We compared the azimuth averages with the correlation coefficients calculated for single station pairs over 35 163.84-second-long time windows, depicted by gray lines in Figure 3. We saw that the estimates obtained for single pairs of stations over a higher number of time windows closely followed the azimuth averages for the three radii. Only one station-pair spacing at 123 m is present, so we could not estimate the spatial average for this distance. The correlograms shown in Figure 3 have been approximated with Bessel functions of zero order (pink lines in the figure). The arguments of the J_0 function, corresponding to the zero, minima and maxima identified from the fit with the experimental curves, are related to the Rayleigh waves phase velocity, according to the equation (1). In this way, it is possible to estimate the Rayleigh waves dispersion function shown by the crosses in Figure 4A.

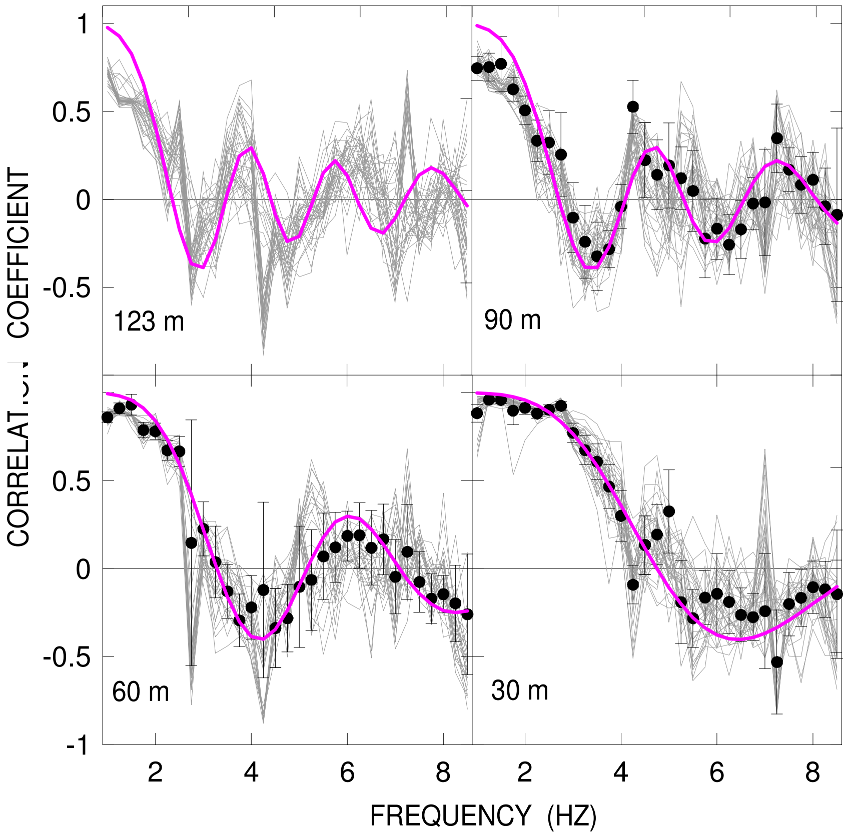

Figure 3. Correlation coefficients (grey lines) as a function of frequency calculated over 35 163.84-second-long time windows for single station pairs with different spacings. Azimuth averages with error bars of one standard deviation are shown by the black circles for the 30, 60 and 90 m spacings. Correlograms are approximated by Bessel functions of zero order (pink lines).

On the assumption that the derived dispersion function represents the first mode of the Rayleigh waves, we derived a velocity model that is consistent with the estimated velocity values. We used both a trial and an inversion technique (Herrmann, 1987) to obtain the best-fit velocity model shown in Figure 4B. The resolution for the last layer is low, but the results are consistent with those obtained from previous array experiments carried out on the volcano at the sites shown by the triangles in Figure 1.

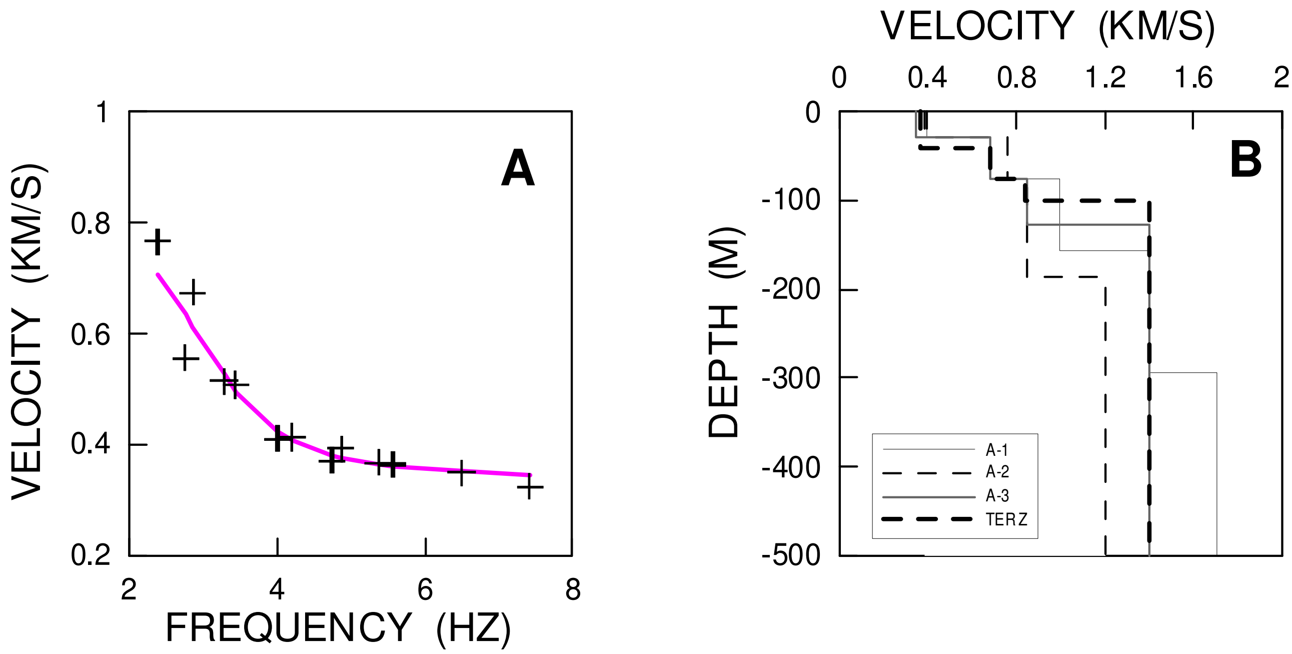

Figure 4. A: Rayleigh waves dispersion function. The crosses indicate the phase velocity values derived from the correlograms of Figure 3. The pink line corresponds to the first mode Rayleigh waves dispersion curve as best fit for the experimental values. B: Comparison of the P-wave velocity model derived in this study (TERZ) with results from other array measurements performed at adjoining sites located in the map shown in Figure 1 (References in Figure 1 legend).

4. Conclusions

In this study, we present the results obtained from an experiment carried out on the south-eastern flank of Mt. Vesuvius, Italy, where we have applied the SPAC method to the ambient noise recorded by a dense short-period seismic array. The aim of this study was to estimate a velocity model under the array, to improve the knowledge of the shallow structure of the volcano.

The SPAC method is based on the hypotheses that the noise is a stochastic process, stationary both in time and space, and that the vertical component of motion is mostly composed of Rayleigh waves. Spatial averages of correlation coefficients calculated between the signals recorded at fixed distances and filtered in narrow-frequency bands were compared to the correlation coefficients evaluated over a long time interval for single station pairs, giving a good correspondence. This result appears to validate the hypothesis of a stochastic noise wave field in the area under investigation. Confirmation of this last hypothesis should come from a spectral analysis in the f-k domain, which we propose for future developments.

The correlation functions estimated for the different distances as functions of frequency have allowed us to compute the Rayleigh waves dispersion function in the frequency band of 2-8 Hz, from which an S-wave velocity model was derived. The model obtained is consistent with previous results obtained at other sites on Mt. Vesuvius, and it improves our knowledge of the details in the shallow structure of the volcano.

5. References

Aki K. (1957). Space and time spectra of stationary stochastic waves, with special reference to microtremors. *Bull. Earthq. Res. Inst.*, **35**, 415-456.

Bianco F., Castellano M., Milano G., Ventura G., Vilardo G. (1998). The Somma-Vesuvius stress field induced by regional tectonics: evidences from seismological and mesostructural data. Journ. Volc. Geothermal Res. 82, 199-218

Capuano, P., Gasparini, P., Zollo, A., Virieux, J., Casale, R., Yeroyanni, M. Eds. (2003). The Internal Structure of Mt. Vesuvius. Liguori Editore.

Chavez-Garcia F.J., Rodriguez M., Stephenson W.R. (2005). An alternative approach to the SPAC analysis of microtremors: exploiting stationarity of noise. *Bull. Seism. Soc. Am.*, **95**, 277-293.

Cioni R., Vecci R. (1988). Stratigrafia delle successioni piroclastiche vesuviane nella zona di Terzigno: la grande cava di Pozzelle. Riv. St. Pompeiani, …..

Del Pezzo E., La Rocca M. (2004). PAS Progetto antenne sismiche. Università di Napoli Federico II - CRdC AMRA – (http://www.amra.unina.it/docs/PUBBLICAZIONI/05.PAS.pdf).

De Luca G., Scarpa R., Del Pezzo E., Simini M. (1997). Shallow structure of Mt. Vesuvius volcano, Italy, from seismic array analysis. Gephys. Res. Lett., 24, No. 4, 481-484.

De Natale G., Capuano P., Troise C. & Zollo A. (1998). Seismicity at Somma-Vesuvius and its implications for the 3D tomography of the volcano. J. Volcanol. Geotherm. Res., Special Issue Vesuvius. Spera F. J., De Vivo B., Ayuso R.A., Belkin H.E. (Eds), 82 (1-4): 175-197.

Herrmann R. B. (1987). Computer programs in Seismology. Univ. of St. Luis, Missouri.

Principe, C., Rosi, M., Santacroce, R., Sbrana, A. (1987). Explanatory note to the geological map. In: Santacroce, R. (Ed.), Somma-Vesuvius, C.N.R.—Quaderni de “La Ricerca Scientifica” 114, pp. 11–52.

Saccorotti, G., Maresca, R.&Del Pezzo, E., 2001. Array analyses of seismic noise at Mt Vesuvius Volcano, Italy, J. Volc. Geotherm. Res., **110,** 79–100.

Scarpa R., Tronca F., Bianco F., Del Pezzo E. (2002). High Resolution Velocity Structure Beneath Mt. Vesuvius From Seismic Array Data. Geophys. Res. Lett., 29, No. 21, 2040, doi:10.1029/2002GL015576.

Scarpa R., Bianco F., Del Pezzo E., Tronca F., La Rocca M. (2003). Shallow velocity structure and heterogeneity of Mt. Vesuvius, Italy, from seismic array analyses. In “The Internal Structure of Mt. Vesuvius- A seismic tomography investigation”, *P. Capuano, P.Gasparini, A. Zollo, J. Virieux, R. Casale, M. Yeroyanni Editors, LIGUORI (Naples),* 612 pp. 423-436.