Near-surface ambient-noise seismic tomography of Bucharest, Romania

Alina Coman[1, 2], Laura Petrescu[1]

1. National Institute for Earth Physics, Măgurele, Ilfov, Romania

2. University of Bucharest, Faculty of Physics, Măgurele, Ilfov, Romania

contact: *laura.petrescu90@gmail.com*

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Introduction

Bucharest is a densely populated urban region situated in the southern part of Romania. In the past, it was affected by strong earthquakes generated in the Vrancea seismogenic area. Studying and understanding its underground structure can help constrain seismic risk and improve estimates of seismic hazard and resilience.

We cross-correlate vertical-component seismograms (24h) to obtain virtual Rayleigh waveforms and extract the phase velocity dispersion curves between pairs of stations using an automated Bessel function analogue algorithm for periods between 2s and 10s (*Fig. 2*). The dispersion curves are then combined in a fast marching seismic tomography (FMST) to estimate the lateral distribution of phase velocities at discrete periods.

Our results reveal complex, heterogeneous and layered structures beneath the Bucharest metropolitan area and offer fundamental constraints on the anomalous ground motion amplification and its relationship with the geological structures from the uppermost crust.

Data and methods

To illustrate a high resolution 3D image of the near - surface structure underneath Bucharest, we used continuous ambient vibration records from 29 seismic stations (*Fig. 1*) deployed between 2003 - 2004 during the URS project (Ritter et al., 2005).

We used the Continuous Wavelet Transform filter (CWT, Yang et al., 2020) for an efficient de-signaling process, in order to retain both realistic amplitude and phase information.

The cross-correlation C(t, ω) as a function of time (t) and frequency (ω) can be performed over a time window (T) and expressed as follow (Boschi et al., 2013):

$$C_{xy}(t, \omega) = \frac{1}{2T}\int_{-T}^{T} u(x,\tau,\omega)u(y,t+\tau,\omega)d\tau,$$

x, *y* - the location of the seismic stations; *u* - the signal taken into consideration for the analysis.

For the extraction of Rayleigh wave phase velocity dispersion curves, we used an automated Bessel-function analogue algorithm (Kästle et al., 2016; Magrini et al., 2022).

In order to map lateral variations in seismic velocities across the study area, we used the FMST technique in the interest of outlining the travel times tomography at near - surface layers (Rawlinson and Sambridge, 2005).

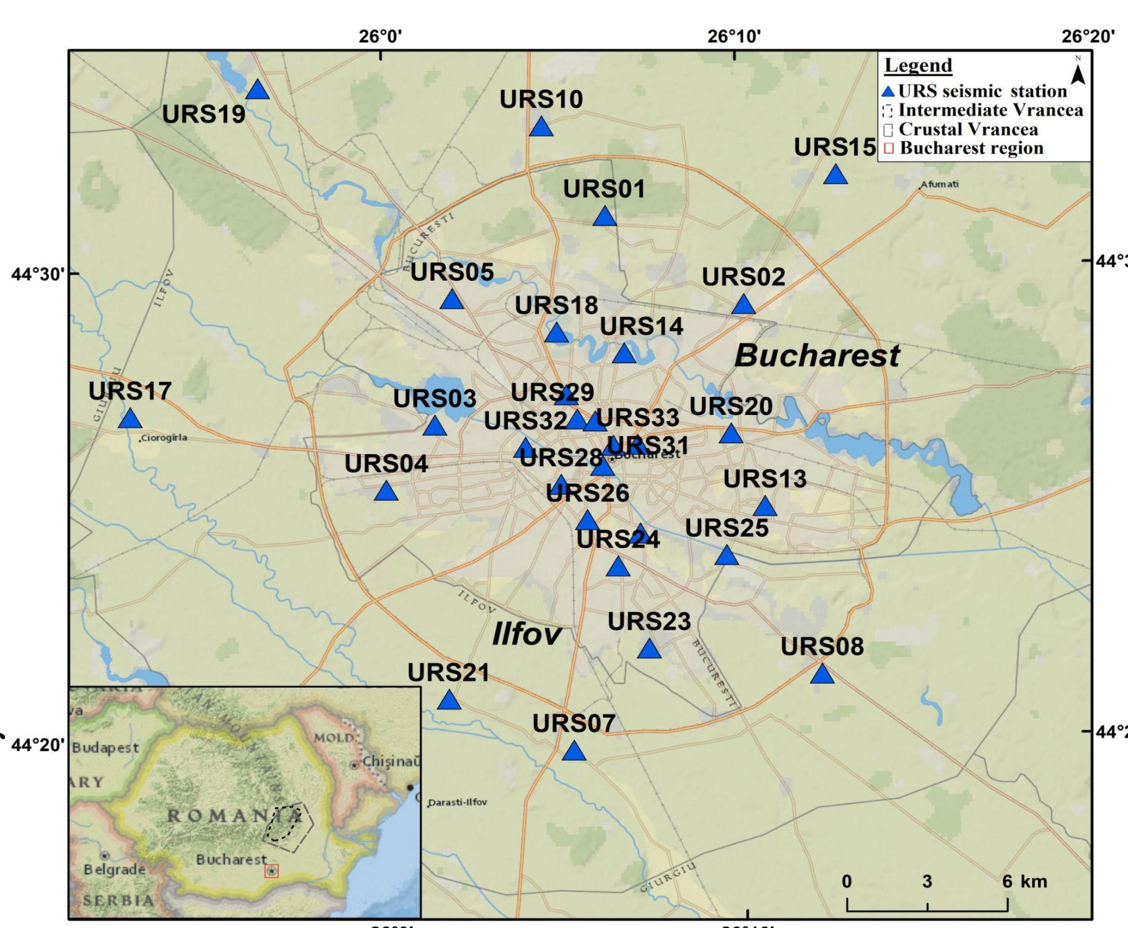

Fig. 1. Distribution of the URS seismic network used in this study.

Results

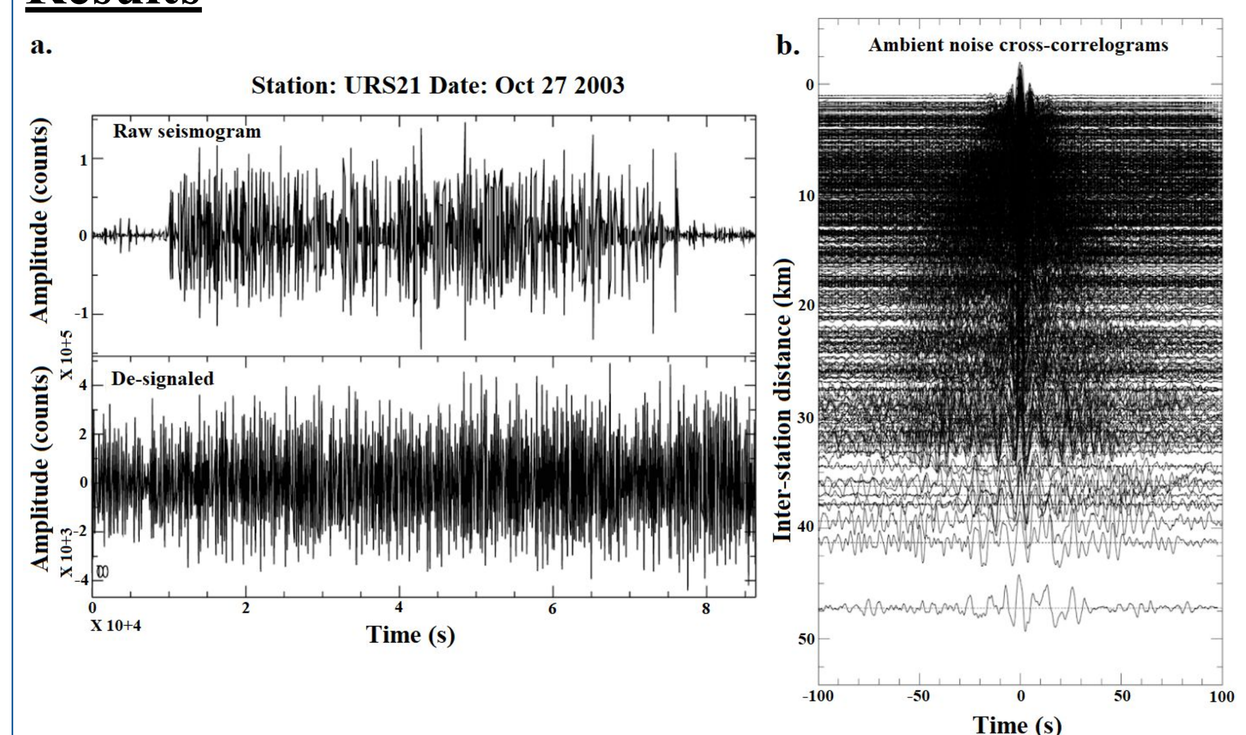

Fig. 2. a) Raw 24-hour long seismogram from station URS21 and the de-signaled seismogram using the CWT algorithm. b) All cross-correlograms between URS stations showing high amplitude Rayleigh waves with increasing arrival times as a function of inter-station distance.

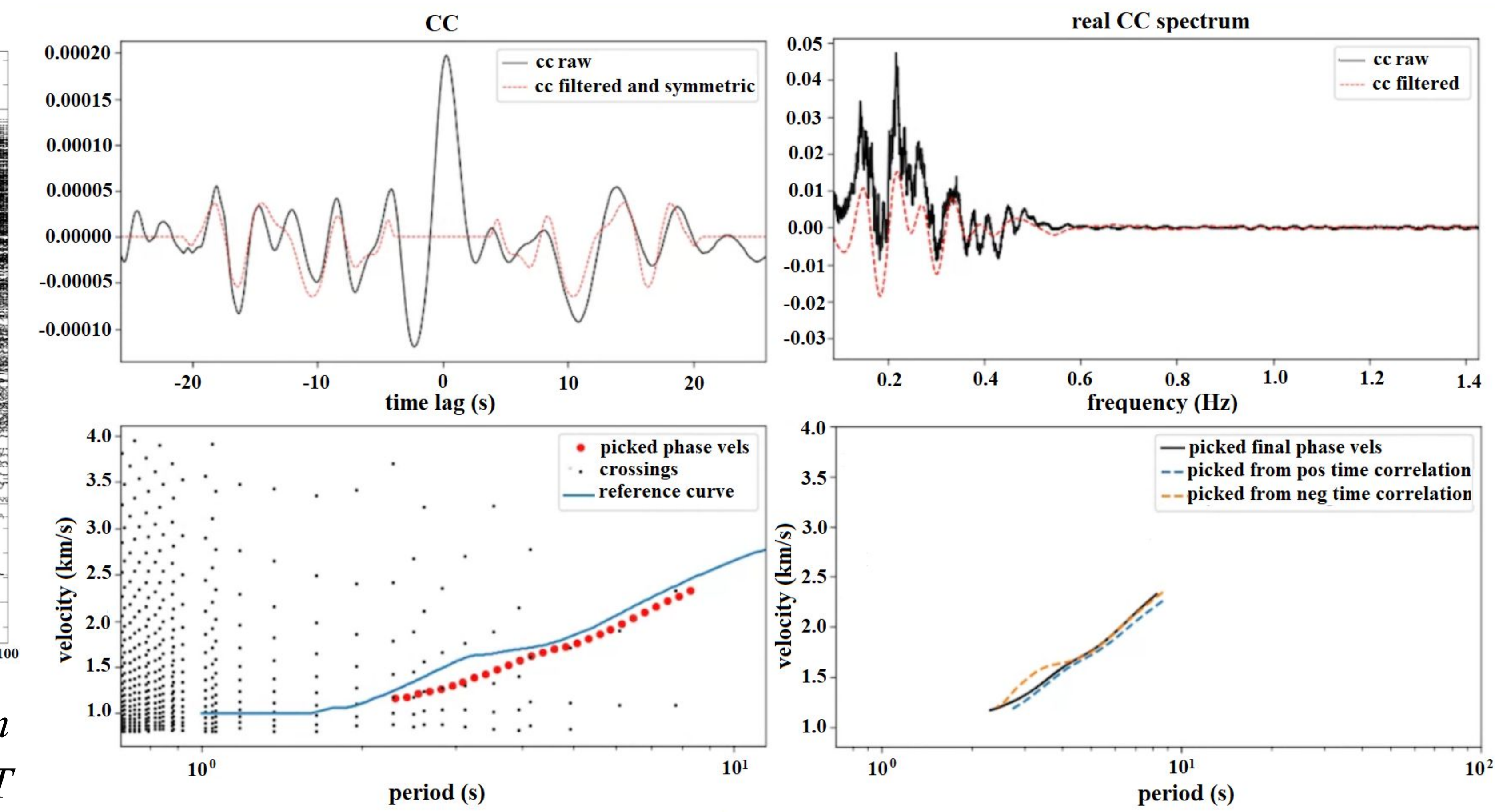

Fig. 3. Rayleigh wave phase velocity dispersion analysis based on the vertical component cross-correlation function between stations URS03 and URS25 (periods interval 2 - 9 s). a) The raw and filtered cross-correlation (cc) spectrum; b) The real cross-correlation spectrum; c) The phase velocity dispersion picks (red circles) based on zero crossings of the cc spectrum (black dots) and the similarity with a reference dispersion curve (blue line); d) The final phase velocity curve (black) based on the picks from the causal (dashed blue) and the acausal (dashed orange) cross-correlation.

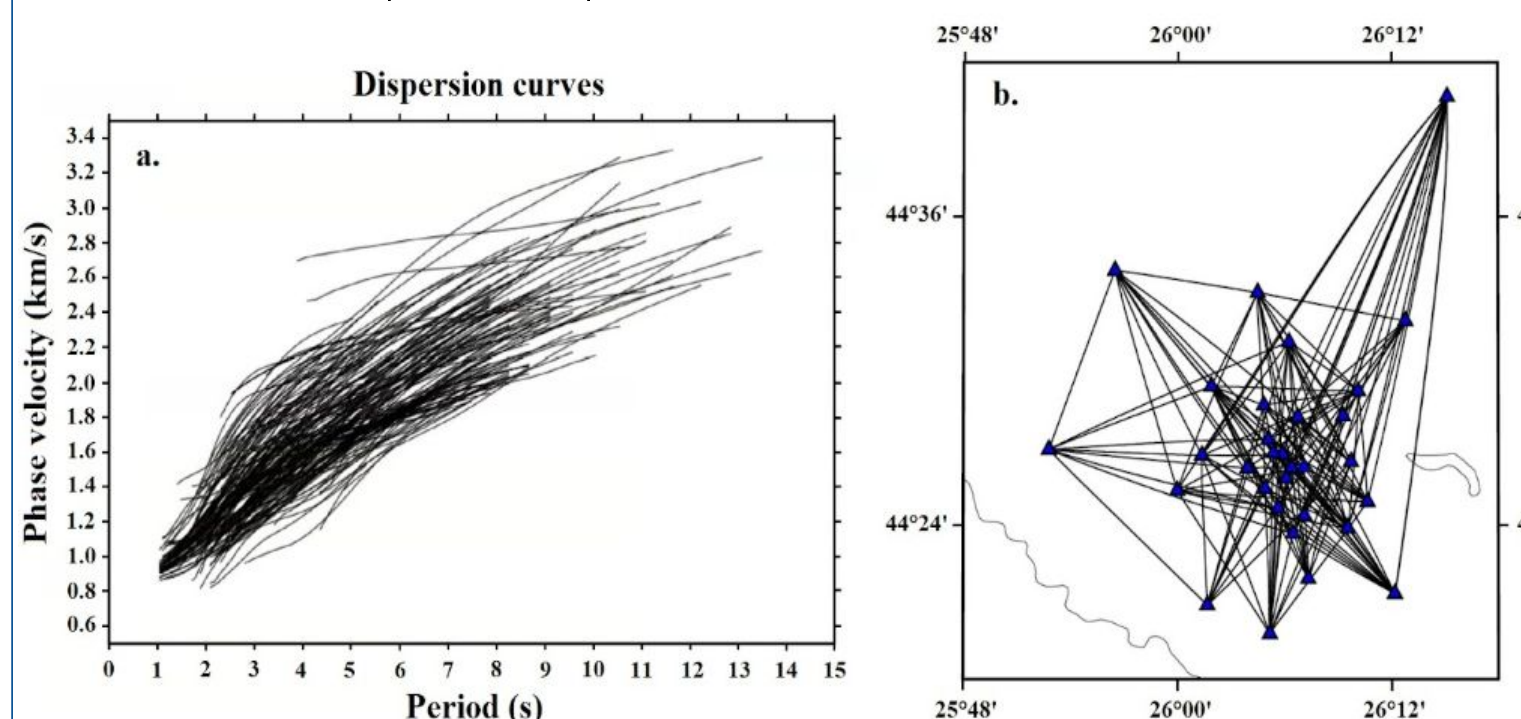

Fig. 4. a) The dispersion curves obtained between pairs of URS seismic stations. b) Corresponding inter-station ray coverage from the ambient noise cross-correlations between the URS stations in the Bucharest metropolitan area.

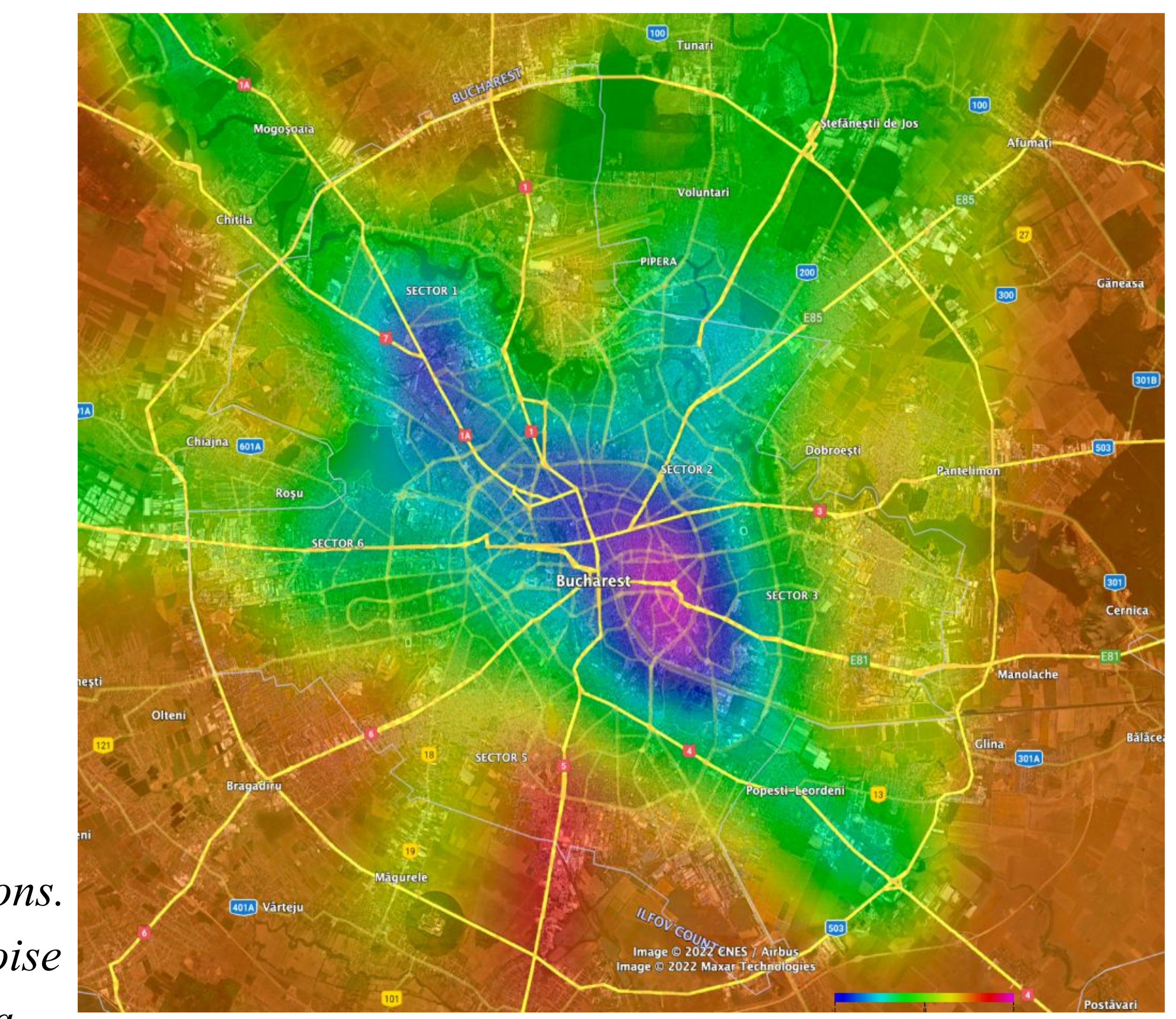

Fig.5. Map of Rayleigh wave phase velocity distribution for 5s period for the Bucharest metropolitan area.

We obtained 462 cross-correlograms (*Fig. 2*) and 222 Rayleigh wave phase velocity dispersion curves (*Fig. 4*) corresponding to inter-station ray paths sampling the Bucharest metropolitan area between pairs of URS seismic stations.

We inverted those for phase velocity variations on a regular grid with 50X50 sized cells at discrete frequencies between 2-10s.

Conclusion

- We used ambient vibrations recorded at 29 broadband seismic stations operating in Bucharest in 2003 - 2004 to construct Rayleigh wave phase velocity images of the near-surface structure in the period band 2-10s.
- We used the most recent noise processing techniques to estimate empirical Green's functions based on noise cross-correlations and a Bessel-analogue automatic algorithm to extract the phase velocity dispersion functions.
- We invert inter-station dispersion curves for 2D phase velocity maps at discrete periods for the Bucharest metropolitan area, using the fast marching method for solving eikonal equations in complex layered media.
- Our results provide the highest resolution seismic tomography of Bucharest to date, offering a unique glimpse into the underground structure of this highly seismically vulnerable city, often devastated by large magnitude earthquakes generated in the SE Carpathians.
- The new images shed light on the complex subsurface heterogeneous structures and are of fundamental importance for future assessments of seismic hazard and civil engineering design.

Acknowledgments

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