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Nikolai M. Shapiro, Michel Campillo, Anne Obermann and Andrew Curtis

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Guest editors: Michel Campillo (University Grenoble-Alpes, Institut des Sciences de la Terre, Grenoble, France),
Andrew Curtis (School of GeoSciences, University of Edinburgh, Scotland),
Anne Obermann (Swiss Seismological Service, ETH, Zurich, Switzerland) and Nikolai Shapiro (CNRS, Institut des Sciences de la Terre, Grenoble, France)

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Foreword

New Developments in Passive Seismic Imaging and Monitoring

Foreword to New developments in passive seismic imaging and monitoring

Nikolai M. Shapiro [a], Michel Campillo [a], Anne Obermann [b] and Andrew Curtis [c]

[a] Institut des Sciences de la Terre, University Grenoble Alpes, CNRS, University Savoie Mont Blanc, IRD, University Gustave Eiffel, Grenoble, France

[b] Swiss Seismological Service, ETH Zurich, Switzerland

[c] School of GeoSciences, University of Edinburgh, Edinburgh EH9 3FE, UK

E-mails: nikolai.shapiro@univ-grenoble-alpes.fr (N. M. Shapiro), michel.campillo@univ-grenoble-alpes.fr (M. Campillo), anne.obermann@sed.ethz.ch (A. Obermann), andrew.curtis@ed.ac.uk (A. Curtis)

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During the last two decades, imaging and monitoring methods based on cross-correlations of ambient seismic noise have been extensively developed and have become widely used at different scales and in different natural and human-controlled environments. Application of these methods has been facilitated by improved availability of data from large and dense seismic networks and by several open software packages. At the same time, noise-based imaging and monitoring is far from becoming just a set of "standard" and "routine" methods. As discussed in this special issue, the origin and nature of the seismic noise wavefields, their correlation properties as well as their sensitivity to the medium structure and changes, remain areas of active study. Improving their understanding is necessary in order to refine the existing methods and to develop new approaches for imaging and monitoring. Therefore, noise-based passive seismology remains a dynamic field of research with some first-order problems yet to be solved. In this context, 13 years after the first thematic issue of Comptes Rendus Géoscience on passive seismic noise-based imaging and monitoring [e.g., Campillo et al., 2011] we introduce a new special issue devoted to this topic.

Most passive noise-based seismic imaging and monitoring methods are based on the so-called "noise cross-correlation theorem" [e.g., Lobkis and Weaver, 2001, Wapenaar, 2004, Roux et al., 2005, Campillo, 2006, Gouédard et al., 2008] which states that the time derivative of cross-correlation of an ideal fully diffuse wavefield converge to the Green's function of the medium in which the waves are propagating. The fully diffuse wavefield can be defined either as being composed of all possible medium vibration modes with equally partitioned energy, or locally as composed of isotropic combination of plane waves, or as generated by homogenously distributed random sources. Neither of these definitions applies to the real Earth's seismic noise whose main sources are inhomogeneously distributed over the surface. This makes direct application of the "full" cross-correlation theorem to real seismological data questionable, and requires that we further improve our understanding of seismic noise cross-correlations to develop accurate methods.

So far, the surface wave part of Green's functions has been most reliably reconstructed from the correlations of the ambient seismic noise. Since initial demonstration of this possibility [e.g., Shapiro and Campillo, 2004, Shapiro et al., 2005, Sabra et al., 2005a,b] a family of methods known as Ambient Noise Surface Wave Tomography (ANSWT) has been developed and successfully applied in many studies [e.g., Ritzwoller et al., 2011, Shapiro, 2018]. A systematic application of this approach to image the European Alps is presented by Paul et al. [2024]. The authors show how methodological advances of this approach evolving from simple isotropic group velocity tomography to wave-equation based inversions, and those based on trans-dimensional Bayesian formalism and including anisotropy, significantly improved knowledge of the structure of the crust and shallow mantle beneath the Alps-Apennines system.

Giammarinaro et al. [2024] use two-dimensional simulations of wave propagation to investigate the lateral resolution power of an alternative approach to ANSWT: seismic Rayleigh wave focal spot imaging. They demonstrate that the station configuration can be tuned to improve image quality and properties, and that high-quality data from dense networks can result in super-resolution.

Lavoué et al. [2024] investigate the applicability of the ANSWT at small scales, i.e., those of a single sedimentary basin, to resolve the near-surface structure for estimation of site amplifications required for seismic hazard models. They show that, while ANSWT results reproduce well the main geological structures of the basin, they have limited capability to accurately predict the numerical amplification near the basin edges and other locations with significant 3D wave propagation effects. This allows the authors to suggest perspectives for future improvement of ANSWT, that shows promise for site effect assessment in low- to moderate-seismicity contexts.

Boué and Tomasetto [2024] investigate how the teleseismic body waves are generated by oceanic forcing on the Earth's surface, resulting in a spatially inhomogeneous distribution of microseismic sources. The authors show that, despite the inherent complexity of these noise sources, cross-correlation based methods applied to properly selected pairs of stations result in the isolation of coherent waves for imaging applications and propose a workflow based on ocean sea state models to extract robust interferences.

Influence of the heterogeneous distribution of noise sources on the accuracy of noise-based seismic monitoring is studied by Stehly et al. [2024] who perform a single station analysis at all available European broadband stations. They show that at short periods (<3 s), the noise field in Europe is dominated by surface waves coming from two sources: (1) the north Atlantic Ocean dominating during winters, and (2) the Adriatic and Aegean Seas increasing in summer. The interplay of these two source regions leads to time and space dependent convergence of the coda part of cross-correlations, and thus in across-Europe variations of the accuracy and temporal resolution of detected seismic velocity changes.

Other important aspects of the noise-based seismic monitoring are addressed by Canel et al. [2024] who investigate the physical mechanisms that could explain the seismic velocity changes measured from the noise cross-correlations in the vicinity of active fault zones. The authors perform a set of numerical experiments to test a simple model of a cohesive granular medium and to study the relationship between the damage and velocity of elastic waves. They show that the microscopic deformation of cohesive discrete media quickly becomes very heterogeneous with a small amount of damage inducing a strong decrease in the elastic velocity. As a consequence, they suggest that monitoring the wave velocities in such media could measure subtle transient deformation processes, such as earthquake initiation phases.

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