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Matrix Approach of Seismic Wave Imaging: Application to Erebus Volcano

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This work aims at extending to seismic imaging a matrix approach of wave propagation in heterogeneous media, previously developed in acoustics and optics. More specifically, it will be applied to the imaging of Erebus volcano in Antarctica. Volcanoes are actually among the most challenging media to explore seismically in light of highly localized and abrupt variations in density and wave velocity, extreme topography, extensive fractures, and the presence of magma. In this strongly scattering regime, conventional imaging methods suffer from the multiple scattering of waves. The proposed approach experimentally relies on the measurement of a reflection matrix associated with an array of geophones located at the surface of the volcano. Although these sensors are purely passive, a set of Green's functions can be measured between all pairs of geophones from ice-quake coda cross-correlations and forms the reflection matrix, which gathers all available information on the medium. A series of matrix operations can then be applied for imaging purposes.

First, the reflection matrix is projected, at each time of flight, in the ballistic focal plane by applying adaptive focusing at emission and reception. It yields a response matrix associated with an array of virtual geophones located at the ballistic depth. This basis allows to get rid of most of the multiple scattering contribution by applying a confocal filter to seismic data. Iterative time reversal is then applied to detect and image the strongest scatterers. Mathematically, it consists in performing a singular-value decomposition of the reflection matrix. The presence of a potential target is assessed from a statistical analysis of the singular values, while the corresponding eigenvectors yield the corresponding target images. When stacked, the results obtained at each depth provide a three-dimensional image of the volcano. While a direct imaging method lead to a speckle image with no connection to the actual medium's reflectivity, this matrix approach enables to highlight a chimney-shaped structure inside Erebus volcano with significant statistical accuracy. Although computed independently, the results at each depth are spatially consistent, substantiating their physical reliability. The identified structure is therefore likely to describe accurately the internal structure of Erebus volcano.