Geophysical Research Abstracts
Vol. 20, EGU2018-4434, 2018
EGU General Assembly 2018

A simple method for earthquake location by surface-wave time-reversal

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The scalar 2-D Helmholtz' equation (i.e. membrane waves) can be used to model surface-wave propagation in a laterally smooth, lossless half space. Building on this known result, we develop an algorithm to localize earthquake sources based on surface-wave data, via numerical time-reversal on a membrane, where monochromatic waves propagate with the phase velocity of Rayleigh or Love waves at the same frequency. Importantly, membrane-wave modeling is computationally much less expensive than three-dimensional surface-wave modeling. We first explain rigorously the relationship between surface waves and membrane waves. Our mathematical treatment is slightly different from those found in the literature, in that it does not invoke variational principles. We next implement our time-reversal algorithm via spectral elements as well as simple ray tracing. Both implementations account for the effects of lateral variations in phase velocity. We validate the two resulting tools by means of several numerical experiments. This includes synthetic tests, as well as the localization of a virtual source based on a data set of real ambient-noise cross correlations, and the localization of the epicenter of a real earthquake from real, raw data. In this study, applications are limited to Northern Italy and the Alpine arc, where we have access to recent, high resolution phase velocity maps, ambient noise cross correlations and data from a recent, relatively large earthquake. The accuracy of epicenter location despite the non-uniform station coverage encourages further applications of our method, in particular to the task of mapping large-earthquake rupture in space and time.