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Imaging the earth's interior with virtual sources and receivers

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Imaging of seismic reflection data is usually based on the assumption that the seismic response consists of primary reflections only. Multiple reflections, i.e. waves that have reflected more than once, are treated as primaries and are imaged at wrong positions. There are two classes of multiple reflections, which we will call surface-related multiples and internal multiples. Surface-related multiples are those multiples that contain at least one reflection at the earth's surface, whereas internal multiples consist of waves that have reflected only at subsurface interfaces. Surface-related multiples are the strongest, but also relatively easy to deal with because the reflecting boundary (the earth's surface) is known. Internal multiples constitute a much more difficult problem for seismic imaging, because the positions and properties of the reflecting interfaces are not known.

Imagine one could place seismic sources and receivers at any desired position inside the earth. Since the receivers would record the full wave field throughout the subsurface, this would give the required information about the structures and properties of the reflecting interfaces. Although in reality one cannot place sources and receivers anywhere inside the earth, it appears to be possible to create virtual sources and virtual receivers at any desired position. For this purpose we derived 3D Marchenko-type equations, which relate reflection data at the surface to Green's functions between virtual sources and virtual receivers anywhere in the subsurface. Based on these equations, we derived an iterative scheme by which these Green's functions can be retrieved from the reflection data at the surface and an estimate of the direct waves between the subsurface positions and the surface.

This methodology involves some major steps beyond standard seismic interferometry. With seismic interferometry, virtual sources can be created at the positions of physical receivers, assuming these receivers are illuminated isotropically. The 3D Marchenko method does not need physical receivers at the positions of the virtual sources. Moreover, it does not require isotropic illumination: to create omni-directional virtual sources and receivers anywhere inside the earth, it suffices to record the reflection response with physical sources and receivers at the earth's surface only.

The retrieved virtual responses form an ideal starting point for accurate seismic imaging and monitoring, without artefacts caused by wrongly imaged multiple reflections. Other potential applications of the 3D Marchenko method are

- the prediction of the propagation of microseismic signals through an unknown complex subsurface,
- improved source imaging in time-reversal acoustics,
- improved 'classical' interferometric Green's function retrieval,
- prediction of primary reflection data from the full reflection response,
- etc.

Current research involves the extension of the 3D Marchenko methodology to vectorial elastodynamic and electromagnetic wavefields.