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Does gravity help to improve seismic inversion for density?

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Density is one of the most important material properties that influence the dynamics of our planet's interior, and knowledge of it alongside with knowledge of seismic velocities will help constrain composition more directly. However, the variation of density inside the Earth is poorly known. The travel times of seismic waves, the classical tool to probe the Earth's interior, are barely sensitive to density (with large tradeoffs) and gravity is so extremely non-unique that very little information can be extracted from it without placing very strong prior constraints. As a result, density has, up until now, usually only been regarded as a derived quantity, which may lead to erroneous interpretations.

Here, we aim to determine to what extent it is possible to image density as an independent parameter using modern geophysical techniques. The main technique is seismic (full) waveform inversion, which is more sensitive to density than travel-times alone, for the simple reason that more information of the seismogram is being used: basically the amplitude and phase of every wiggle. We construct synthetic tests in 2-D where density is a completely independent parameter from S-wave velocity and P-wave velocity – this setup (albeit physically unrealistic) has the advantage that our ability to image density independently is assessed in an unbiased way.

We find that it is indeed possible to image density using waveform inversion. If prior information, such as constraints on S- and P-velocity structure, is included in the inversion, the results for density are markedly improved. The use of gravity data as an additional observable, however, deteriorates the inversion results. This is because of the significant non-uniqueness of potential field measurements, so that an unconstrained update based on gravity will only almost definitely work to push the inversion in the wrong direction.