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Martian crustal S-wave velocities from apparent incidence angles – A case study for InSight

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The InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) mission will place a lander on the surface of Mars in November 2018 to investigate the planet's internal structure and the differentiation of the terrestrial planets. Crustal thickness and structure of Mars are among the main scientific objectives of InSight, and its major payload is a combined very broad-band and short-period, three-component seismometer. On Earth, receiver functions are a standard, single-station method to study crustal and upper mantle structure using the coda of distant earthquakes. The method has previously also been applied to Apollo lunar seismograms. However, as a travel-time method, receiver functions generally suffer from a trade-off between the depth to a seismic discontinuity and the velocity above, and joint inversion with surface wave dispersion or ellipticity information is a common way to constrain this non-uniqueness. Here, we investigate the alternative option to measure frequency-dependent apparent P-wave incidence angles from receiver functions and derive crustal S-wave velocity structure from them.

We calculate receiver functions and measure frequency-dependent apparent S-wave velocities from synthetic seismograms for a number of Mars models as well as for a complimentary data set of terrestrial data from Central European stations with known differences in crustal structure, including thickness, velocities, and presence of sediments. We investigate the distance range likely usable for the calculation of P-wave receiver functions on Mars and find that models for the spatial distribution of Martian seismicity predict some seismicity within this distance range from the InSight lander during the nominal mission duration of one Martian year. We show that the derived apparent S-velocity curves are distinct for the different Mars models, even taking into account InSight's maximum event localization uncertainty, and provide information on the crustal, and, in cases with a thin (30 km), fast crust, upper mantle velocity structure. The curves for the terrestrial stations all show clear deviations from the one obtained from synthetics for IASP91, and are distinguishable from one another. We compare different forward computation schemes for Mars receiver functions to identify an accurate and fast method and apply a grid-search based inversion approach to both Mars synthetics and measured terrestrial data. Inversion results show a close correspondence to the true models for the synthetic Mars data, but also indicate decreasing resolution with depth and the sensitivity of the data to average velocities over some depth interval rather than fine-scale structure. The latter could be provided by including the receiver function waveforms themselves in the inversion.