Observations of the Earth's major mantle discontinuities using ScS reverberations

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Questions? Ask Annemijn

Introduction

The Earth's mantle is characterized by a few large global seismic velocity discontinuities, as well as several regional smaller ones. These velocity discontinuities are generally caused by mineral phase changes and they are influenced by anomalies in temperature, composition and water content. A range of seismic techniques has been used to successfully to observe the global transition zone discontinuities at 410, 520 and 660km depth (Figure 1). The combined results of different data types can connect these seismic observations with mineral physical phase changes. The main observation from Figure 1 is that the 410 is visible in all data types, the 660 shows more complexity. The goal of this study is to add ScS reverberation data, and compare the findings of these different data types, in order to better understand phase transitions in the Earth's mantle.

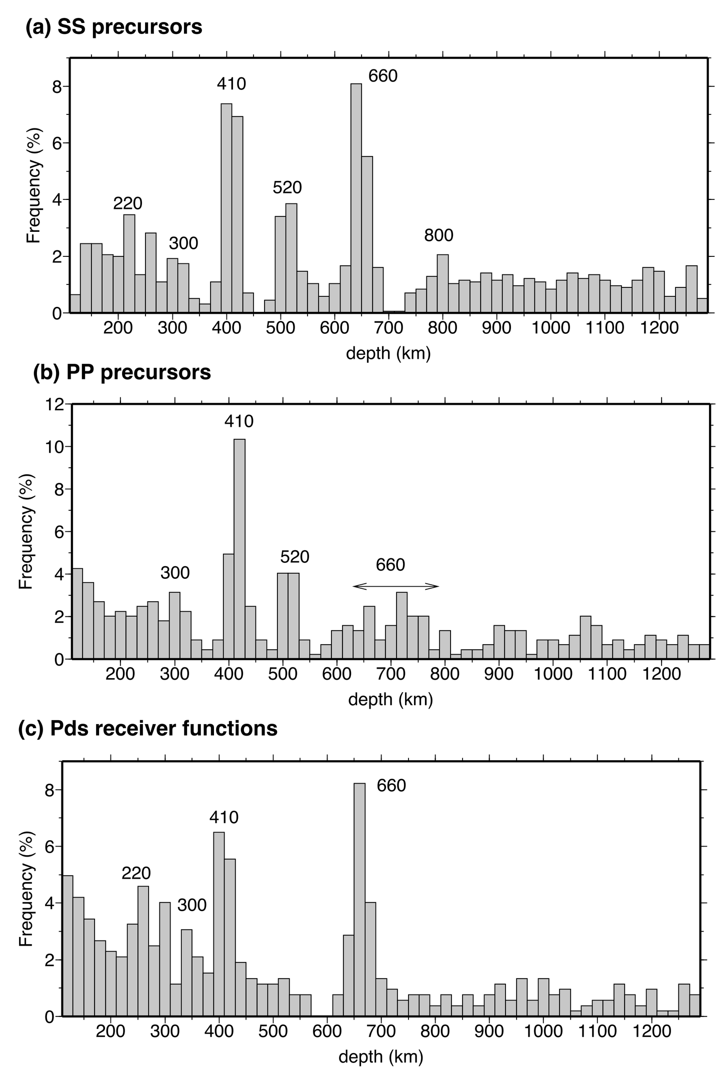

Figure 1: Histogram of depth at which robust reflectors are found in (a) SS precursor data (b) PP precursor data and (c) Pds receiver function data. PP and SS precursor data are taken from Deuss et al. (2006) and receiver function data are from Andrews and Deuss (2008). Figure from Deuss et al. (2013).

Preliminary Results I: Synthetics

- The deconvolved traces are converted from time to depth.
- Figure 4a shows the five deconvolved traces for the synthetic event of 10-12-2009 calculated with PREM.
- The locations of the 220, 400 and 670 in PREM are well resolved.
- 51 synthetic events are depth stacked and shown in Figure 4b.

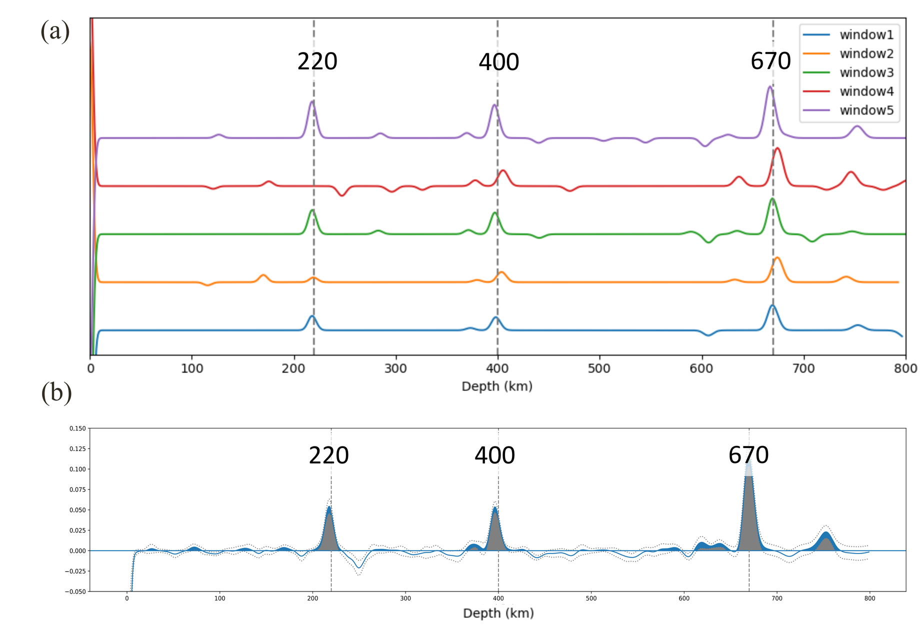

Figure 4: (a) Time to depth converted deconvolved traces for five windows in a synthetic trace. (b) Depth stack for 51 synthetic traces recorded by IC.MDJ. The major discontinuities in PREM can be seen in the depth stack.

Preliminary Results II: Data

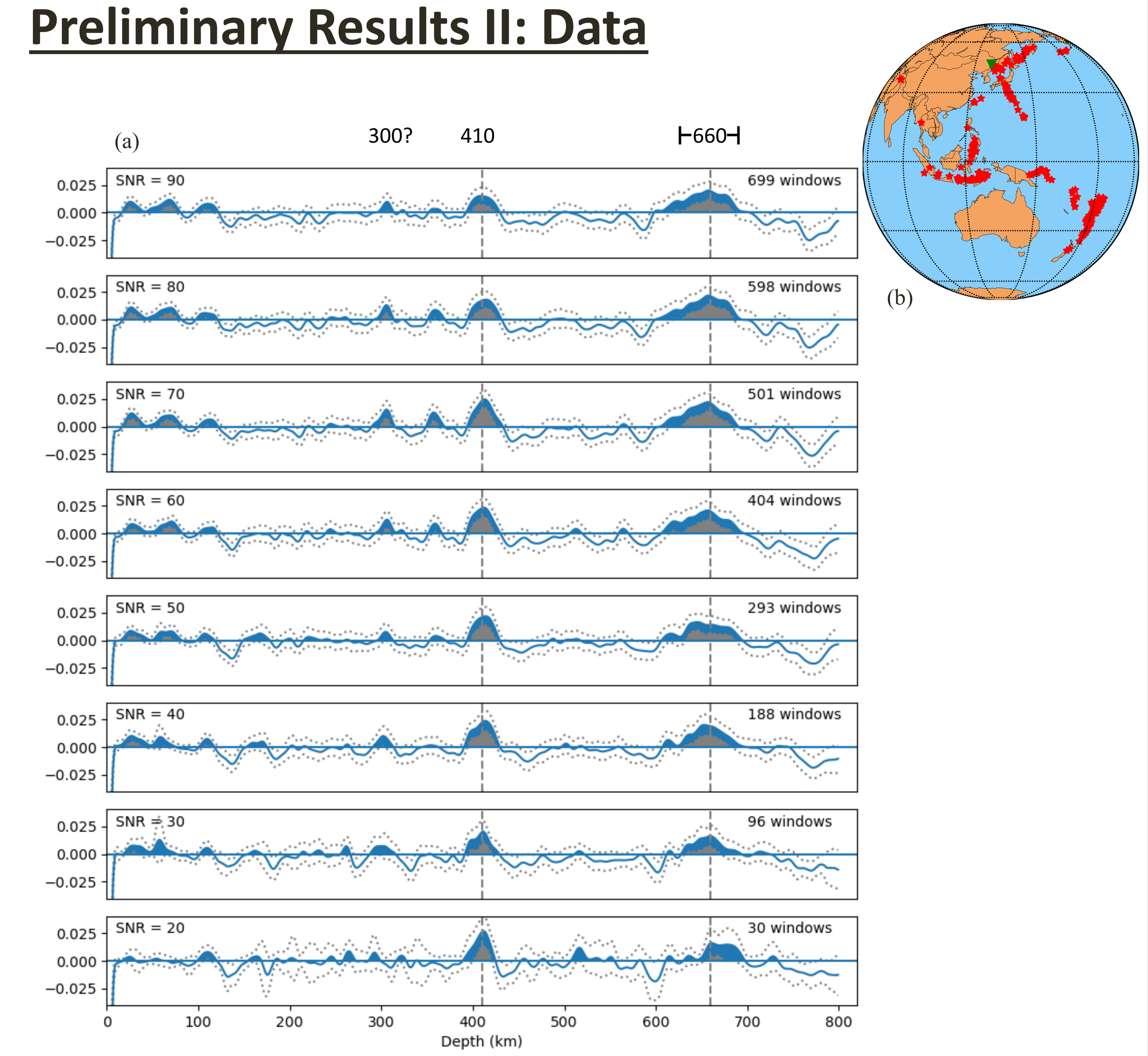

Figure 5: (a) Depth stacks with different SNR, shown in left upper corner. Right upper corner indicates the windows used in every depth stack. (b) Distribution of events recorded between 2003 and 2019 with Mw between 5.6 and 8.5 and minimal depth 220 km, shown with red stars. The green triangle indicates the location of station IC.MDJ.

- Depth stacks are calculated for 423 events recorded by station IC.MDJ.
- Every depth stack shown has a different signal to noise ratio (SNR) in the quality control requirements.
- The 410 is visible as a simple peak while the 660 looks more complicated.
- A 300 seems to be visible as well.
- These observations are independent of noise level.

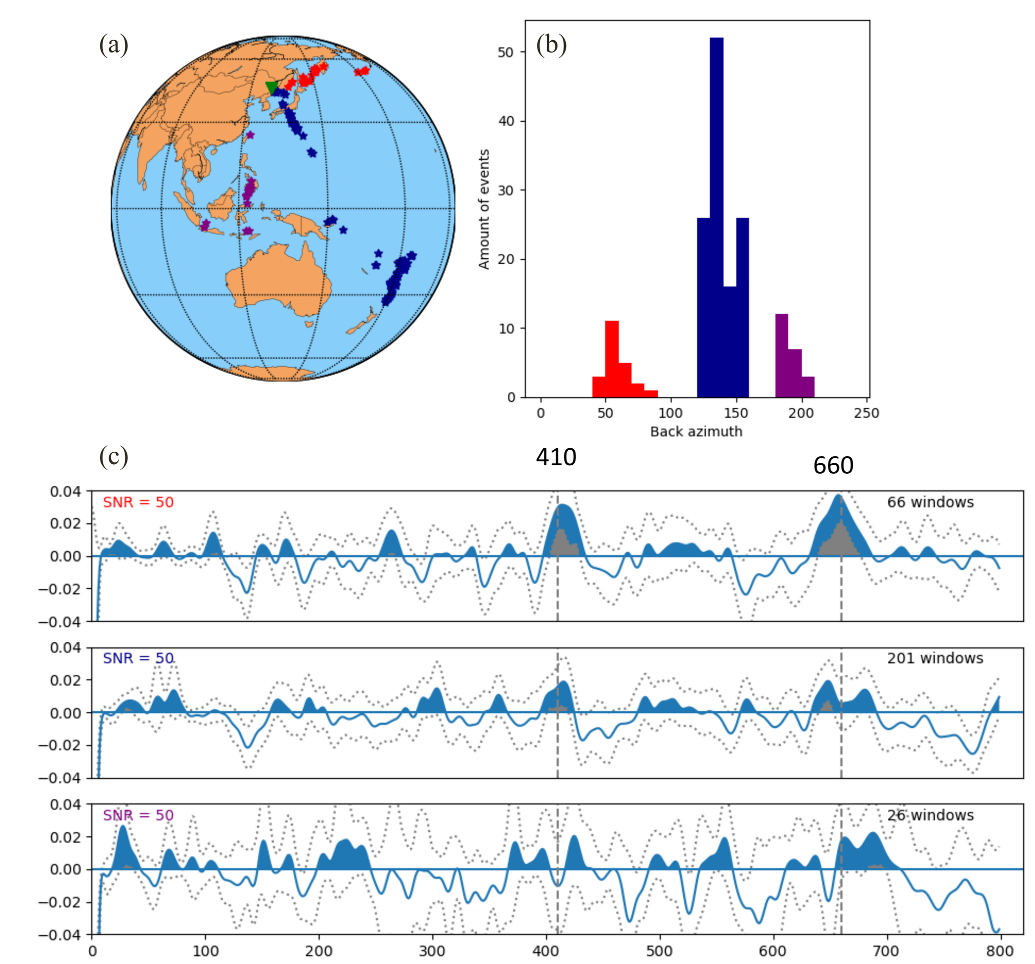

Figure 6: (a) The data from Figure 5(b) is divided into three clusters. (b) histogram showing the amount of events for each cluster. (c) Depth stacks for the same data as Figure 5, but now divided into three back azimuth ranges.

- Three stacks with SNR = 50 are calculated with different back azimuths (Figure 6).
- The depth of the 660 is different in the first two stacks.
- The first stack shows one distinct peak for the 660, the second stack samples a larger area and does not show one distinct peak.
- The third stack does not have enough data to image robust discontinuities.

Method

ScS phases are horizontally polarized shear waves, and the multiple ScS phases reflected between the surface and the core mantle boundary are denoted as ScSn or sScSn, where n denotes the number of core mantle boundary reflections. These phases are called zero-order reverberations or parent phases in this study. ScS phases that reflect one or more times from a discontinuity are called first and higher order reverberations or daughter phases. Figure 2 shows parent phase sScS with its two first order daughter phases reflected from the 660.

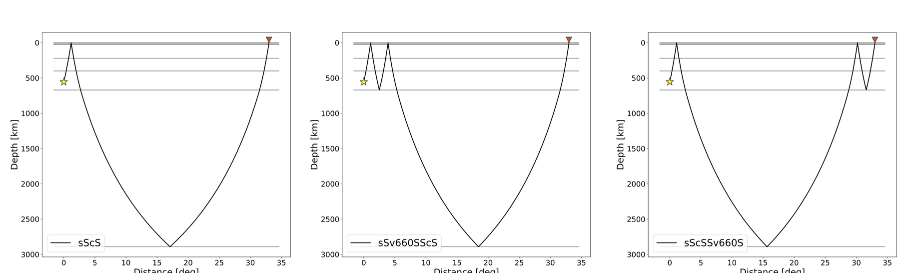

Figure 2: Ray paths for parent phase sScS and its two daughter phases for a discontinuity at 660 km depth. The daughter phases will arrive as postcursors with a smaller amplitude and similar waveform.

A reflection from a discontinuity does decrease the amplitude, but leaves the waveform of the daughter phases unchanged. Therefore, the waveforms of and around the parent phase can be used to look for arrivals of reflections. This is done by deconvolving the parent phases from the seismograms to look for their post and precursors, similar to Wang et al. (2017). We use the iterative time domain deconvolution method described by Ligorria & Ammon (1999).

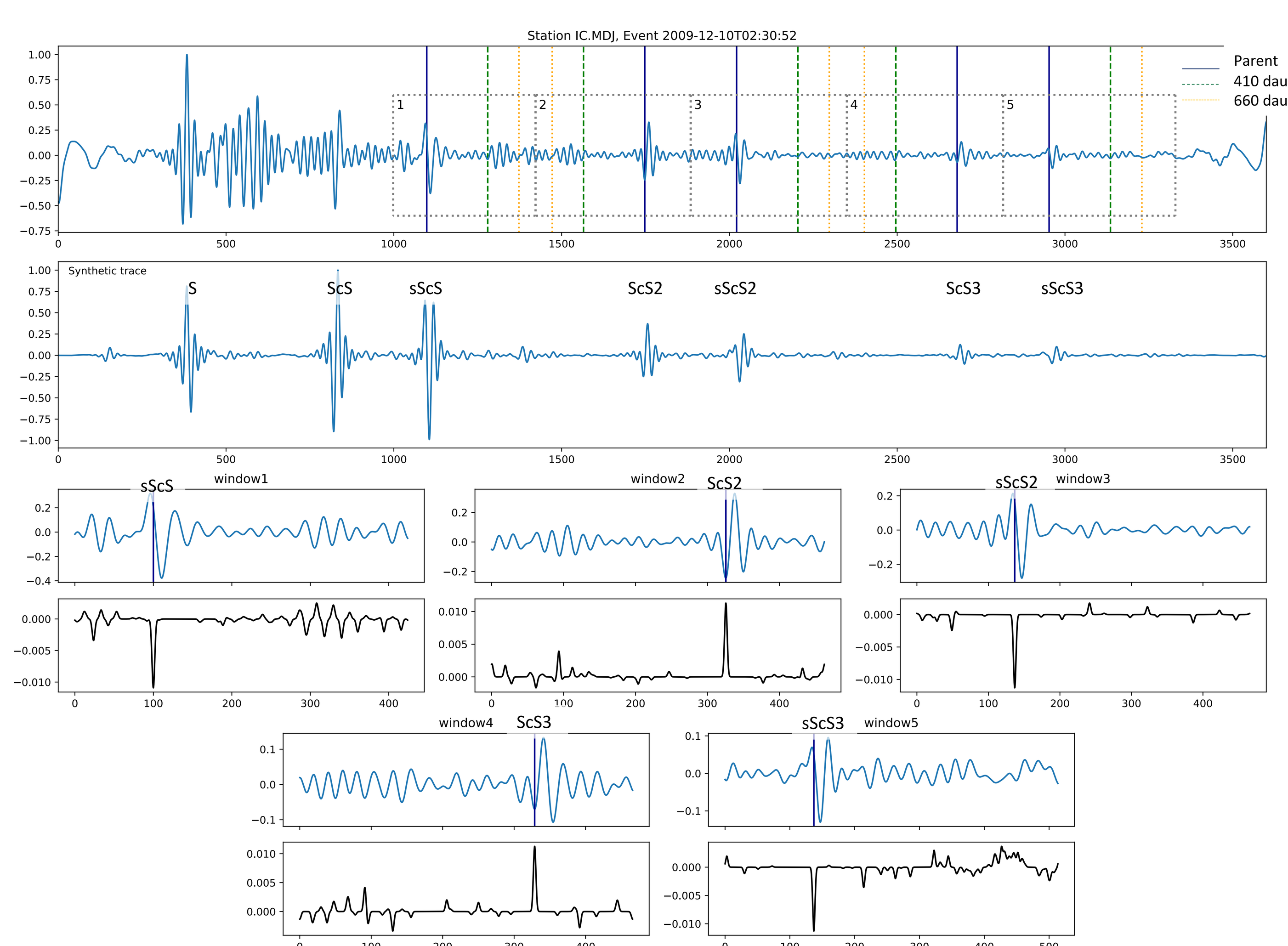

Figure 3: Transverse component seismogram (a) and corresponding synthetic (b) trace for the 10-12-2009 event, recorded by station IC.MDJ. (c) - (g): For every time window (blue) the parent phase is deconvolved from the rest of the window. Corresponding deconvolved traces are shown in black.

Next steps

- Decide on the best quality control mechanism.
- Map regional differences in discontinuity depths and transition zone thickness, e.g. by stacking windows with reflection points in the same area. Figure 7 shows two example events and their reflection points on the 660.

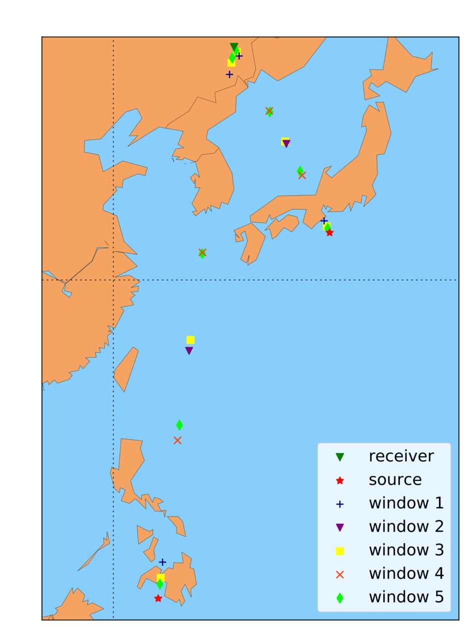

Figure 7: Location of the reflection on the 660 for the 5 different windows for two example events travelling to a station.

Take home message

- ScS reverberations can be used to constrain the depth of mantle discontinuities.
- The first results show a simple 410 and a more complex 660 signal, in accordance with what is seen with other data types.
- regional variations in discontinuity depth can be mapped by stacking data with common reflection points.

Deuss et al. Seismic observations of mantle discontinuities and their mineralogical and dynamical interpretation. Physics and chemistry of the deep Earth (2013) vol. Edited by S. Karato (ISBN: 978-0-470-65914-4) pp. 297—323

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Ligorría, J. P. and Ammon, C. J. (1999). Iterative deconvolution and receiver-function estimation. Bulletin of the seismological Society of America, 89(5):1395–1400

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