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Observation and modelling of the seismc high frequency *PKPab* precursor at distances larger than 155°

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Seismic waves traveling through the outer core have been used for a long time to study heterogeneity at the core mantle boundary (*CMB*) and in lower mantle. Earth's velocity structure opens a window for waves that are scattered at 3D structures in the lower mantle to arrive at the Earth's surface prior to the waves that would propagate in a 1D spherically symmetric model. These precursors are particularly well observed as they are not hidden in the coda waves of earlier phases. At epicentral distances below 140° *PKPab* and *PKPbc* waves scattered close to the *CMB* can arrive as precursors to *PKPdf* that travels through the inner core (*IC*). These waves have been studied extensively and provided important information about the structure of the mantle close to the *CMB*. However, theory predicts that *PKP* waves can also be scattered to distances above 155°. These waves have not been well observed before, partly because they arrive at the surface only after the inner core *PKPdf* phase that has far larger amplitudes at lower frequencies. Here we report on the observation of an emergent arrival of seismic energy at distances above 155° that is consistent with the onset times of scattered *PKPbc* energy. The key to observe this scattered phase is the use of signals from large deep earthquakes which are strong high frequency sources. As basis for the observation we used records of the Japanese Hi-Net stations that allowed to observe the scattered waves in the distance range between 135° and 165° when combining records of two events in Peru and Argentina. The Brazilian seismic network provided observations of a deep Bonin Islands event in the distance range from 145° to 175°. Using frequencies around 6Hz we show (A) energy in this frequency band propagates to epicentral distances beyond 170°, (B) attenuation in the *IC* completely removes the energy of the *PKPdf* phase, (C) energy scattered close to the *CMB* arrives prior to *PKPab* wave forming a precursor that we call *PKPab* precursor. This observation extends the frequency range and opens a new time-distance window for investigations of deep Earth heterogeneity.