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A global study of the lowermost mantle using scattered PKKP waves (PK•KP)

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The short-period (1 Hz) seismic wavefield shows strong evidence for scattered energy from the interior of the Earth. This energy mainly arrives in the coda following major seismic phases; however, several ray configurations exist in which seismic energy from the lowermost mantle arrives as precursors to main phases, allowing analysis of energy undisturbed by crustal interference. Here we use the phase PKKP to infer small-scale structure at the Core-Mantle Boundary (CMB) and in the D$''$ layer.

PKKP back-scattered at, or above, the CMB (PK•KP where the • represents the location of scattering) is observed in a time window starting about 1720 s after origin (for a surface focus) and can be observed from 0° to about 60° epicentral distance. PK•KP is not closely related to the parent phase PKKP since it arrives in a time and distance range where only PKKP$_{df}$ could be observed; nonetheless, due to the high attenuation in the inner core PKKP$_{df}$ is rarely detected. The time window used is free from other major and minor arrivals thus allowing the identification of the scattered PKKP energy, despite its relatively low amplitude. The ray path of PK•KP is complicated with scattering occurring off great-circle path, thus avoiding the attenuating inner core. Due to the scattered energy travelling the major arc of the great-circle path (similar to PKKP), PK•KP waves sample regions of the Core-Mantle Boundary inaccessible to most other scattering probes using similar source-receiver combinations. Observations of 1-2 Hz PK•KP energy indicate that the scatterers are discrete heterogeneities with a scale length of ∼10 km.

Here we use the dense, small to medium aperture arrays of the International Monitoring System of the CTBTO to extract the small amplitude PK•KP from seismic noise. Arrays increase signal-to-noise ratio and give directivity information allowing the determination of the scattering location in the lowermost mantle through ray-tracing. We use the frequency-wavenumber (fk) analysis in conjunction with the F-statistic coherency measure, commonly used in forensic seismology, to greatly increase the slowness vector resolution of the small aperture arrays dominating the International Monitoring System. The dataset consists of ∼2800 earthquakes, with magnitudes larger than 6.0, allowing an unprecedented coverage of the Core-Mantle Boundary, especially in the southern hemisphere, greatly increasing our knowledge of small-scale (∼10 km) heterogeneities in the lowermost mantle. These results will be essential for our understanding of mantle processes and dynamics.