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Seismic Coda Envelope as a Distance Proxy for Lunar Impact Localization

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Meteoroid impacts are a prominent class of lunar seismic sources in the Apollo record. Due to the strong scattering and low attenuation in the lunar crust, these hypervelocity near-surface sources generate waveforms dominated by long codas, producing emergent onsets that obscure body wave phases. Consequently, classical source location based on travel times from confident P and S picking is feasible for only tens of large-magnitude events. In contrast, additional information can be extracted from the characteristic coda shape. Oberst (1989) proposed an empirical method to locate impacts using the distance dependence of coda peak amplitude and rise time, successfully locating 73 events. However, it suffers from limitations including algorithm ill-conditioning, simplified modeling assumptions, and weak sensitivity to distance within ~2000 km.
In this study, we optimized and reformulated the two empirical coda–distance relations by incorporating seismic quanta scattering theory for the distance range up to 1200km. This enables the location of local lunar impacts that are commonly recorded by fewer than three stations and therefore cannot be located using classical travel-time methods. We first validated the method using impacts previously located by P- and S-wave travel times, by artificially limiting the number of stations to one or two. In both cases, the estimated locations agreed with reference solutions within ~200 km and exhibited strong robustness against noise. We then applied the approach to previously non-located impacts in the Apollo catalog. A total of 95 high-amplitude local events with identifiable coda envelope signatures were selected and located on an event-by-event basis using available station observations. The inferred locations are independently cross-validated through the distance dependence of coda shape.
This coda-envelope–based approach provides a practical framework for locating lunar impacts under sparse station configurations and enrich the event catalog for future lunar interior and impact seismicity investigations.

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PhD 1st year

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