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On the potential of seismic rotational motion measurements for extraterrestrial seismology

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Classically, seismological recordings consist of measurements of translational ground motion only. However, in addition to three vector components of translation there are three components of rotation to consider, leading to six degrees of freedom. Of particular interest is thereby the fact that measuring rotational motion means isolating shear (S) waves. Recording the rotational motion requires dedicated rotational sensors. Alternatively, since the rotational motion is given by the curl of the vectorial displacements, the rotational motion around the two horizontal axes can be computed from the horizontal spatial gradients of vertical translational recordings if standard translational seismometers are placed in an areal array at the free surface. This follows from the zero stress free surface condition. Combining rotational and translational motion measurements opens up new ways of analyzing seismic data, such as facilitating much improved arrival identification and wavefield separation (e.g., P-/S-wave separation), and local slowness (arrival direction and velocity) determination. Such combined measurements maximize the seismic information content that a single six-component station or a small station array can provide, and are of particular interest for sparse or single-station measurements such as in extraterrestrial seismology.

We demonstrate the value of the analysis of combined translational and rotational recordings by re-evaluating data from the Apollo 17 lunar seismic profiling experiment (LSPE). The LSPE setup consisted of four vertical-component geophones arranged in a star-like geometry. This areal receiver layout enables computing the horizontal spatial gradients by spatial finite differencing of the vertical-component data for two perpendicular directions and, hence, the estimation of rotational motion around two horizontal axes. Specifically, the recorded seismic waveform data originated from eight explosive packages as well as from continuously listening to the natural lunar seismic activity of moonquakes. As an example, the combined analysis of translational and rotational motion from the active-source LSPE data provides, for the first time, the possibility to extract S-wave information from the enigmatic and reverbatory lunar seismic waveform data, which hithertofore had masked later arriving S-waves. The identification of S-waves enables to characterize the shallow lunar crust in a full elastic sense. The resultant Poisson's ratio profile allows discriminating shallow basalt layers of different degree of fracturing. Our successful analysis of the Apollo 17 data highlights the anticipated significant value of rotational measurements for future extraterrestrial seismology missions.