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Low Frequency Marsquakes and Where to Find Them: Automated Event Back Azimuth Determination Using a Multi-Body Wave Polarisation Analysis Approach

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NASA's InSight mission continues to record seismic data over 3 years after landing using its very broadband seismometer. The situation of working with a single station requires efficient back-azimuth determination based on data of available body wave phases in the seismic record.

This study presents an effective way to estimate back azimuths using a comprehensive polarisation analysis. It uses a continuous wavelet transform to transform the seismic signal into time-frequency domain, and then performs an eigenanalysis of the spectral matrix to obtain information on the polarisation of the signal. Non-polarised signals are masked to enhance the seismic signal. We use the polarisation around both the P- and S-wave arrivals in selected frequency bands to estimate the back azimuth. For stronger signals, the P-wave polarisation provides the main information. For weaker signals, the result can be improved significantly based on the orthogonality of the P- and S-wave polarisation vector, which constrains the result for poorly polarised/contaminated P signals. This method is applied to synthetic marsquakes and to well-located earthquakes recorded in Tennant Creek, Australia. We find that the polarisation method reliably estimates the back azimuth for both sets of events.

The Marsquake Service has provided distance estimates for around 35 marsquakes, but only 10 had been assigned back azimuths. Back azimuth estimation – based on the polarisation at narrow-band of initial P-wave energy - is particularly challenging due to the highly scattered signals and noise in the seismic data. Our method, when applied to martian data, obtains results for 30 events in total, significantly improving our understanding of the spatial distribution of seismic activity on Mars. Most of the located events lie in the general Cerberus Fossae region, a large graben structure towards the east of InSight, though we also find quakes in other directions (e.g. north, towards Elysium Mons) that had previously not been expected to be tectonically active. This extended set of located marsquakes will allow for interpretation of martian tectonics, in particular the Cerberus Fossae region. The method could potentially be applied to sparse terrestrial networks, such as ocean bottom seismometers.