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Seismic spatial wavefield gradient and rotational rate measurements as new observables in land seismic exploration

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Traditionally, land-seismic data acquisition is conducted using vertical-component sensors. A more complete representation of the seismic wavefield can be obtained by employing multicomponent sensors recording the full vector wavefield. If groups of multicomponent sensors are deployed, then spatial seismic wavefield gradients and rotational rates can be estimated by differencing the outputs of closely spaced sensors. Such data capture all six degrees of freedom of a rigid body (three components of translation and three components of rotation), and hence allow an even more complete representation of the seismic wavefield compared to single station triaxial data. Seismic gradient and rotation data open up new possibilities to process land-seismic data. Potential benefits and applications of wavefield gradient data include local slowness estimation, improved arrival identification, wavefield separation and noise suppression.

Using synthetic and field data, we explored the reliability and sensitivity of various multicomponent sensor layouts to estimate seismic wavefield gradients and rotational rates. Due to the wavelength and incidence-angle dependence of sensor-group reception patterns as a function of the number of sensors, station spacing and layout, one has to counterbalance the impacts of truncation errors, random noise attenuation, and sensitivity to perturbations such as amplitude variations and positioning errors when searching for optimum receiver configurations. Field experiments with special rotational rate sensors were used to verify array-based rotational-rate estimates.

Seismic wavefield gradient estimates and inferred wavefield attributes such as instantaneous slowness enable improved arrival identification, e.g. wave type and path. Under favorable conditions, seismic-wavefield gradient attributes can be extracted from conventional vertical-component data and used to, for example, enhance the identification of shear waves. A further promising application of wavefield gradients is the removal of the free-surface effect on land-seismic recordings to obtain true amplitude and phase information of the desired upcoming wavefield from the recorded superposition of upcoming waves with downgoing reflected and downgoing mode-converted waves.