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Quantitative estimation of source complexity in tsunami-source inversion

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This work analyses tsunami waveforms to infer the spatiotemporal evolution of sea-surface displacement (the tsunami source) caused by earthquakes or other sources. Since the method considers sea-surface displacement directly, no assumptions about the fault or seafloor deformation are required. While this approach has no ability to study seismic aspects of rupture, it greatly simplifies the tsunami source estimation, making it much less dependent on subjective fault and deformation assumptions. This results in a more accurate sea-surface displacement evolution in the source region. The spatial discretization is by wavelet decomposition represented by a trans-D Bayesian tree structure. Wavelet coefficients are sampled by a reversible jump algorithm and additional coefficients are only included when required by the data. Therefore, source complexity is consistent with data information (parsimonious) and the method can adapt locally in both time and space. Since the source complexity is unknown and locally adapts, no regularization is required, resulting in more meaningful displacement magnitudes.

By estimating displacement uncertainties in a Bayesian framework we can study the effect of parametrization choice on the source estimate. Uncertainty arises from observation errors and limitations in the parametrization to fully explain the observations. As a result, parametrization choice is closely related to uncertainty estimation and profoundly affects inversion results. Therefore, parametrization selection should be included in the inference process. Our inversion method is based on Bayesian model selection, a process which includes the choice of parametrization in the inference process and makes it data driven. A trans-dimensional (trans-D) model for the spatio-temporal discretization is applied here to include model selection naturally and efficiently in the inference by sampling probabilistically over parameterizations. The trans-D process results in better uncertainty estimates since the parametrization adapts parsimoniously (in both time and space) according to the local data resolving power and the uncertainty about the parametrization choice is included in the uncertainty estimates.

We apply the method to the tsunami waveforms recorded for the great 2011 Japan tsunami. All data are recorded on high-quality sensors (ocean-bottom pressure sensors, GPS gauges, and DART buoys). The sea-surface Green's functions are computed by JAGURS and include linear dispersion effects. By treating the noise level at each gauge as unknown, individual gauge contributions to the source estimate are appropriately and objectively weighted. The results show previously unreported detail of the source, quantify uncertainty spatially, and produce excellent data fits. The source estimate shows an elongated peak trench-ward from the hypo centre that closely follows the trench, indicating significant sea-floor deformation near the trench. Also notable is a bi-modal (negative to positive) displacement feature in the northern part of the source near the trench. The feature has $\sim$2 m amplitude and is clearly resolved by the data with low uncertainties.