HypoSVI: Hypocenter inversion with Stein Variational Inference and Physics Informed Neural Networks

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High resolution earthquake hypocentral locations are of critical importance for understanding the regional context driving seismicity. We introduce a scheme to reliably approximate a hypocenter posterior in a continuous domain that relies on recent advances in deep learning.

Our method relies on a differentiable forward model in the form of a deep neural network, which is trained to solve the Eikonal equation (EikoNet). EikoNet can rapidly determine the travel-time between any source-receiver pair for a non-gridded solution. We demonstrate the robustness of these travel-time solutions are for a series of complex velocity models.

For the inverse problem, we utilize Stein Variational Inference, which is a recent approximate inference procedure that iteratively updates a configuration of particles to approximate a target posterior by minimizing the so-called Stein discrepancy. The gradients of this objective function can be rapidly calculated due to the differentiability of the EikoNet. The particle locations are updated until convergence, after which we utilize clustering techniques and kernel density methods to determine the optimal hypocenter and its uncertainty.

The inversion procedure outlined in this work is validated using a series of synthetic tests to determine the parameter optimisation and the validity for large observational datasets, which can locate earthquakes in 439s per event for 2039 observations. In addition, we apply this technique to a case study of seismicity in the Southern California region for earthquakes from 2019.