Optimal resolution seismic tomography: Lithospheric thinning beneath the British Tertiary Igneous Province and other new observations

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The maximum achievable resolution of a tomographic model varies spatially and depends on the data sampling and errors in the data. Adaptive parameterization schemes match the spatial variations in data sampling but do not address the effects of the errors. The propagation of systematic errors, however, is resistant to data redundancy and results in models dominated by noise if the target resolution is too high. This forces us to look for smoother models and thus limits the imaging resolution.

We develop a surface-wave tomography method that finds optimal lateral resolution at every point by means of error tracking. We first measure inter-station phase-velocities at simultaneously recording station pairs and compute phase-velocity maps at densely, logarithmically spaced periods. Unlike in the classical approach, multiple versions of the maps with varying smoothness constraints are computed, so that the maps range from very rough to very smooth. Phase-velocity curves extracted from the maps at every point can then be inverted for shear-velocity ($V_s$) profiles. As we show, errors in these phase-velocity curves increase nearly monotonically with the map roughness. Very smooth $V_s$ models computed from very smooth phase-velocity maps will be the most robust, but at a cost of a loss of most structural information. At the other extreme, models that are too rough will be dominated by noise. We define the optimal resolution at a point such that the error of the local phase-velocity curve is below an empirical threshold. The error is estimated by isolating the roughness of the phase-velocity curve that cannot be explained by any Earth structure. A 3D $V_s$ model is then computed by the inversion of the phase-velocity maps with the optimal resolution at every point. The estimated optimal resolution shows smooth lateral variations, confirming the robustness of the procedure. Importantly, optimal resolution does not scale with the density of the data coverage: some of the best-sampled locations require relatively low lateral resolution, probably due to systematic data errors. We apply the method to image the
Ireland's and Britain's upper mantle, using our large, new regional dataset. We report a pronounced thinning of the lithosphere beneath the British Tertiary Igneous Province, with important implications for the Paleogene uplift and volcanism in the region.