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Determination of structure coefficients from normal mode eigenfrequencies using an autoregressive analysis of stacked signals

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The standard outcome of normal mode studies are splitting function coefficients, also called structure coefficients, which depend on Earth's lateral heterogeneities and consequently put constraints on seismic tomographic models. Most estimates of those structure coefficients are not robust enough and omit realistic standard deviations. We took a different approach than the standard linearized, iterative inversion from partial derivatives of the seismograms for estimating structure coefficients and their standard deviations. They were derived by linear inversion from primarily estimated normal modes eigenfrequencies of some target modes.

Our analysis was performed in three steps: 1) we stacked records of vertical displacement using the least squares method to solve for target modes of harmonic degree l and azimuthal order m and thus taking into account the spatial distribution of recording stations; 2) assuming that after an earthquake our recorded signals consist of sums of normal modes, we represented them as sums of decaying cosinusoids; we also approximated the stacked time series by an autoregressive (AR) time series; a relation between these two approximations is found by the Prony method which allows us to obtain complex frequencies from the poles of the corresponding AR time series; this method enables us to linearize the process of complex frequency estimation; in the same step, we additionally applied an eigenfrequency validity check, using the phasor walkout method, to confirm our estimates; 3) from the obtained eigenfrequencies of our target modes, we performed a linear fit to retrieve structure coefficients. Our motivation for the use of the described methods was their easy and fast implementation and their accurate performances when it comes to eigenfrequency estimates.

The main goal of this study was to test performances of the methods. For this purpose, we first performed the analysis with synthetic seismograms in order to evaluate how the station distribution and noise levels impact the estimates of eigenfrequencies and structure coefficients. Synthetic seismograms were calculated for a 3D realistic Earth model, which includes Earth's rotation as well as ellipticity and other lateral heterogeneities. They were computed by means of normal mode summation and a perturbation theory using self-coupling and cross-coupling of modes up to 1 mHz. To additionally test our methods, we then applied them to long-period seismometer and superconducting gravimeter data recorded after six earthquakes of magnitude greater than 8.3. Finally, we obtained new estimates of the singlet's eigenfrequencies and c_{20} and c_{40} structure coefficients for ${}_0S_2$ that were compared with previously published values.