Issues in earthquake-source-inversion analysis, evaluated through singular value decomposition

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Toward solving an inverse problem in Geophysics (e.g., earthquake-source inversion), prior information is used for stabilizing the solution, and an optimal weight between the observed data and prior information is objectively determined by minimizing Akaike's Bayesian Information Criterion (ABIC; Akaike, 1980). However, individual role of observed data and prior information on the resultant solution has not been evaluated in ABIC-based inversion, which makes it difficult to evaluate how much the prior information and its strength are valid in the solution, even though its weight is determined statistically by minimizing ABIC.

Here we resolved each characteristic of the observed data and the prior information that constrains the resultant image by applying singular value decomposition to a kernel of an inverted-source model of the Mw 7.0, 2016 Kumamoto, Japan, earthquake. The source model is represented as five-basis moment tensors (Kikuchi & Kanamori, 1991) distributed at 0.3-sec time and 2-km space intervals in the model space, which can simultaneously model slip evolution and fault geometry (Shimizu et al., 2019, under review). We used models with different weight: one with the weight minimizing ABIC, and the others with the weight artificially weakened and strengthened compared to the ABIC minimum. As prior information, we tested two types of condition: smoothing and L2-norm minimization.

Under the condition of smoothing, the model showed north side uplifting and reverse faulting at the weight stronger and weaker than the one minimizing ABIC, respectively, which is not consistent with the aftershock distribution and field observations (e.g., Yoshida et al., 2016; Shirahama et al., 2016). We found that the specific moment-tensor components, where the amplitudes of Green's function are larger, determining the characteristic of the singular vectors. It is suggested that if the weight of the prior information is stronger and weaker than the one minimizing ABIC, observed-data kernel (corresponding to Green's function) and smoothing-information kernel heavily controls the model characteristics, respectively. Under the condition of the L2 norm, the model showed north side uplifting, which is not evidenced by the aftershock distribution and the field surveys, even though we used ABIC for determining the "optimal" weight of the prior information. We found that the specific moment-tensor components, where the amplitudes of Green's function are larger, determining the characteristic of the singular vectors as is the case under the condition of smoothing. However, regardless of the weight of prior information, Green's function heavily controls the model characteristics.

Our study highlights that, under the condition of smoothing, the ABIC-based inversion works successfully for suppressing bias that violates the final solution generated by kernels of observed data and prior information. We also clarify that the L2-norm-minimization condition does not work properly for constraining source process of the 2016 Kumamoto earthquake.

Keywords: singular value decomposition, prior information, smoothing, L2 norm minimization, Green's function, Akaike's Bayesian Information Criterion

