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# Combining different types of data for inverse ill-posed problems

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Data assimilation theory for geophysical inverse problems

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The method of generalized cross-validation (GCV) has been widely used to determine the regularization parameter, because the criterion minimizes the average predicted residuals of measured data and depends solely on data. The data-driven advantage is valid only if the variance?covariance matrix of the data can be represented as the product of a given positive definite matrix and a scalar unknown noise variance. In practice, important geophysical inverse ill-posed problems have often been solved by combining different types of data. The stochastic model of measurements in this case contains a number of different unknown variance components. Although the weighting factors, or equivalently the variance components, have been shown to significantly affect joint inversion results of geophysical ill-posed problems, they have been either assumed to be known or empirically chosen. No solid statistical foundation is available yet to correctly determine the weighting factors of different types of data in joint geophysical inversion. We extend the GCV method to accommodate both the regularization parameter and the variance components. The extended version of GCV essentially consists of two steps, one to estimate the variance components by fixing the regularization parameter and the other to determine the regularization parameter by using the GCV method and by fixing the variance components. We simulate two examples: a purely mathematical integral equation of the first kind modified from the first example of Phillips (1962) and a typical geophysical example of downward continuation to recover the gravity anomalies on the surface of the Earth from satellite measurements. Based on the two simulated examples, we extensively compare the iterative GCV method with existing methods, which have shown that the method works well to correctly recover the unknown variance components and determine the regularization parameter. In other words, our method lets data speak for themselves, decide the correct weighting factors of different types of geophysical data, and determine the regularization parameter. In addition, we derive an unbiased estimator of the noise variance by correcting the biases of the regularized residuals. A simplified formula to save the time of computation is also given. The two new estimators of the noise variance are compared with six existing methods through numerical simulations. The simulation results have shown that the two new estimators perform as well as Wahba estimator for highly ill-posed problems and outperform any existing methods for moderately ill-posed problems. More details on this topic can be found in Xu et al. (2006, J Geodesy, 80, 69-81), Xu (2009, Geophys J Int, 179, 182-200) and Shen, Xu and Li (2011, submitted).

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