Surface Characterization Uncertainty Quantification: Monte Carlo with Collocation Method and Bayesian Inference Method

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Handling uncertainties of measurements and inversions always plays a critical role on the subsurface characterization using electromagnetic logging data. With the introduction of newest logging-while-drilling tools using very low frequency (VLF) measurements, a much larger depth-of-detection over 100 feet can be achieved. The deep reading capability involves more details of a formation with multiple structures. Successful interpretation and understanding of the underground formation structure can largely benefit the operators and help them deliver the effective instructions to the subsurface tools, which can maximize the economic production from the explorations. Some questions arise: what structures are measured, and how confident we are to those measurements. To evaluate the sensitivity of the measurements, and to quantify the confidence of the earth model parameters, we expand the idea of sensitivity analysis to a broader application, and propose uncertainty quantification methods via two different perspectives.

Instead of evaluating the sensitivity of all kinds of signals, the uncertainty quantification is concentrated on the earth model parameters. Given the measurements with random noise, the corresponding model parameters are a group of variables with random variations. Monte Carlo method is one approach to understand the uncertainty of the model parameters. By randomly drawing a set of measurements from the relative noise distribution, and apply these drawn samples on the inverse model, a group of inverse parameters are obtained with corresponding distribution and statistical properties. Although straightforward in implementation, Monte Carlo method can be prohibitively expensive as the number of drawn samples increases exponentially with the dimension of model parameter space. The sparse grid collocation is an advanced method dealing with the measurements with Gaussian noise and some other noise models. The implementation of sparse grid collocation greatly reduces the sample numbers of Monte Carlo method while the inverse parameters can accurately describe the statistical properties and reflect the uncertainty of the earth model.

The Bayesian inference gives a comparable approach to handle the uncertainty quantification. Different from the Monte Carlo or allocation methods utilizing the inverse model to project the measurements noise to the model parameter variance, the Bayesian inference directly translates the forward measurements into the knowledge of earth model parameters. By constructing likelihood function, which is usually built upon the forward model and some knowledge about the noise, the Bayesian rule governs the inference to obtain the posterior distribution, from which the solution deduced after combining the likelihood of measurements data and the prior knowledge of earth model parameters. In practice, the Markov Chain Monte Carlo (MCMC) method is a widely used approach to draw the samples from this posterior distribution by keep evaluating the likelihood, and randomly accepting the samples which satisfy the certain criteria. The statistical properties of the earth model parameters are reflected according to the samples. Therefore, the uncertainty can be quantified through statistical properties such as variance.

Both two methods have ability to quantify the uncertainty of earth model parameters through the exploration of parameter distribution, though via different approaches. Our experiments indicate that the quantified uncertainty by two methods have good agreements, and can reflect the uncertainty empirically and theoretically.