Using Optimization for Environmental Simulation Model Calibration Uncertainty Analysis

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EXTENDED ABSTRACT

Environmental simulation models are approximations of reality, and are therefore all subject to varying degrees of uncertainty. In general, uncertainty sources in environmental modeling include parameter, data and model structure. When the uncertainty of these model inputs are quantified in terms of probability distributions, a traditional Monte Carlo propagation of input uncertainty can be performed. However, this traditional approach becomes much more complicated when model calibration data is considered because the random input sets sampled from the joint parameter and input distributions must also be deemed to produce reasonable predictions of the available measured calibration data. Two types of methods that were developed to cope with this complication are the Generalized Likelihood Uncertainty Estimation or GLUE methodology (Beven and Binley, 1992) and Markov Chain Monte Carlo or MCMC methods as demonstrated for a watershed modeling case study by Kuczera and Parent (1998).

A review of the uncertainty literature demonstrating MCMC or GLUE methodologies for model calibration uncertainty analysis shows that the number of model evaluations required (typically more than 10,000 or even 100,000 depending on the number of uncertain model inputs) is extremely prohibitive and perhaps impossible computationally demanding models. The purpose of this research project is to develop an alternative approximate, high-dimensional uncertainty analysis methodology called Dynamically Dimensioned Search – Uncertainty Approximation (DDS-UA). The simple and efficient DDS algorithm developed by Tolson (2005) forms the basis method. We compare DDS-UA to uncertainty analysis results achieved with the GLUE methodology. GLUE was selected for comparison based on its simplicity, prevalence in the literature and because it does not require a statistically based likelihood function. The DDS-UA method is focused primarily on efficiently and effectively identifying multiple high likelihood (i.e. high quality) model parameter sets. We performed comparisons against the Generalized Likelihood Uncertainty Estimation (GLUE) methodology for 14 to 30 uncertain calibration parameters for a watershed modeling calibration case study and showed the DDS-UA approach to be one to three orders of magnitude more computationally efficient. For example, in 20,000 to 150,000 model evaluations, GLUE sampled likelihoods were substantially lower than the known maximum likelihood values generated by DDS-UA. DDS-UA sampling effectiveness and efficiency under both default and reduced parameter ranges was shown to be similar, indicating that DDS-UA can generate high likelihood solutions even when little prior case study knowledge is available.

DDS-UA enables more computationally expensive simulation models and/or a wider range of modeling case studies to realistically undertake a global analysis of uncertainty during model calibration. As with GLUE, the simplicity of the methodology make it an attractive approach that can implemented without excessive programming. Unlike GLUE, which typically relies on uniform random sampling to find high likelihood solutions, DDS-UA utilizes the simple and efficient DDS optimization algorithm to search more efficiently and effectively for these solutions. DDS is specifically used to find multiple high likelihood solutions from independent optimization trials. This approach distinguishes DDS-UA from evolutionary optimization based approaches for approximating uncertainty that identify high likelihood solutions from the search history of a single optimization trial.

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