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Hydrology and Earth System Sciences Discussions

Interactive comment on "Comment on "How effective and efficient are multiobjective evolutionary algorithms at hydrologic model calibration?" by Y. Tang et al., Hydrol. Earth Syst. Sci., 10, 289–307, 2006" *by* J. A. Vrugt

J. A. Vrugt

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We would like to thank this reviewer for his comments. Our responses are found below the individual comments.

Jan Seibert - first reviewer:

1) What is the MOSCEM-UA algorithm? Or better, is the initial sampling a part of MOSCEM-UA? It is probably not fair to ask Tang et al. to test different ways to improve the various algorithms, but if the initial sampling is part of MOSCEM-UA than of course Tang et al. should have used it. Tang et al. (2006) refer to Vrugt et al. (2003) where the

initial sampling was found to be useful, so one could say that Tang et al. should have used this sampling as it is a part of MOSCEM-UA (although one might argue that the initial sampling was more like an option). On the other hand, as I understand the initial sampling was not part of the implementation of the algorithm as provided by Jasper Vrugt to Tang et al., which would say the initial sampling is not part of MOSCEM_UA. Quite confusing, isn't it. But may be less a scientific issue than a communication problem that easily could be solved over a beer.

Response: We appreciate this question / comment. In the current available MATLAB and C-source code of the MOSCEM-UA algorithm, a Latin Hypercube sampling (LHS) strategy is used to create the initial sample; however, in our original paper we describe a few steps how this approach can be extended to facilitate using prior information on the single criterion ends of the Pareto front in the construction of the initial sample. While this approach is not directly incorporated in the MOSCEM-UA source code, this shouldn't be a reason not to try to use this alternative sampling approach - hence, in our original paper (Vrugt et al. 2003) we demonstrate that this alternative method might be more efficient than classical random sampling of the prior space. To accurately reflect the content of our original work, we believe that this alternative sampling approach should have been used in conjunction with the various algorithms, to appropriate implement and use the ideas presented in Vrugt et al. (2003). Nevertheless, I will modify the existing source code so that one can explicitly use this option in the future.

2) Is MOSCEM-UA with the initial sampling really that much better? HESS-D would be a great platform to put numbers into the discussion, if Jasper Vrugt could provide Tang et al. with a MOSCEM-UA version with initial sampling and they would be willing to re-run part of the analysis or if Tang et al. could provide the necessary input data and model code to Jasper Vrugt. It would be interesting to see these results! Obviously there are not only many different optimization algorithms but each of those has many options for settings (or parameters). In other words, we do not only have an optimization problem in the hydrological model but also in the optimization algorithm.

HESSD

4, S397–S401, 2007

Interactive Comment

Whether the alternative sampling method exhibits greater efficiency than a standard LHS or other random sampling strategy depends on the problem at hand. Our numerical results suggest that with increasing complexity of the optimization problem at hand, it might prove more useful to first locate the single criterion ends of the Pareto front, then followed by approximating the Pareto distribution, and iteratively improving this distribution using any of the algorithms considered in the Tang et al. (2006) paper.

Response: With respect to the second point raised by this reviewer, existing theory and experiments have demonstrated that it is impossible to develop a single evolutionary algorithm that will always be superior to any other algorithm over some set of complex optimization problems. In a recent paper we therefore argue that significant advances to the field of evolutionary computation can be made if we embrace a concept of self-adaptive multimethod optimization in which the goal is to develop a combination of search methods that have all the desirable properties to efficiently handle a wide variety of response surfaces. Particularly, in Vrugt and Robinson (2007) we have presented a new optimization algorithm, called AMALGAM, that implements this new concept of multimethod search, and runs a diverse set of optimization algorithms simultaneously for population evolution and adaptively favors individual algorithms that exhibit the highest reproductive success during the search. By adaptively changing preference to individual search algorithms during the course of the optimization, AMALGAM has the ability to quickly adapt to the specific difficulties and peculiarities of the optimization problem at hand. Synthetic multiobjective benchmark studies covering a diverse set of problem features have demonstrated that AMALGAM significantly improves the efficiency of evolutionary search, approaching a factor of 10 improvement over current available methods. Details can be found in Vrugt and Robinson (2007).

While this discussion certainly is interesting, quite honestly, I must admit that I feel that we have other problems in hydrological modelling. Most models which we can run 5-10 000 times are simple models which we in principle can run as many times as we want to in short times (millions rather than thousand of runs can be done rather quickly). The

HESSD

4, S397–S401, 2007

Interactive Comment

situation is different for more complex models but for those even 5 - 10 000 runs are often not feasible. Even more important, we have all kind of uncertainties and, thus, equifinality issues. In other words, we probably should not aim to find single solutions along the pareto-front by optimization but accept the existence of different solutions.

Response: This is exactly what Pareto optimization does! By posing the optimization problem in a multiobjective context, it is very unlikely that a single solution is found at which all the objectives have their optimum (minimum / maximum as appropriate) value. So, Pareto optimization finds all the behavioral models (parameter combination) that can be considered optimal for conflicting objectives. This range of adaptive solutions typically reflects various sources of uncertainty in the modeling exercise.

With respect to computational efficiency, during the past decade there has been considerable progress in the development of distributed computer systems using the power of multiple processors to efficiently solve complex, high-dimensional computational problems. Parallel computing offers the possibility of solving computationally challenging optimization problems in less time than is possible using ordinary serial computing. Despite these prospects, parallel computing has not entered into widespread use in the field due to difficulties with implementation and barriers posed by technical jargon. This is unfortunate, as many optimization problems in earth science are "embarrassingly parallel" and thus are ideally suited for solution on distributed computer systems. In Vrugt et al. (2006) we describe a user-friendly, computationally efficient parallel implementation of the Shuffled Complex Evolution Metropolis (SCEM-UA) global optimization algorithm for stochastic estimation of parameters in environmental models. Our parallel implementation takes better advantage of the computational power of a distributed computer system. Three case studies of increasing complexity demonstrate that parallel parameter estimation results in a considerable time savings when compared with traditional sequential optimization runs. The proposed method therefore provides an ideal means to solve complex optimization problems

Questions like data uncertainties and which types of data to use in multiobjective model

HESSD

4, S397–S401, 2007

Interactive Comment

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evaluations seem more important to me than the discussion on the optimal optimization algorithms (even here I'd expect some equifinalty).

Response: I respectfully disagree - Given current computational constraints, it is important to have algorithms available that can reliably solve complex optimization problems in a minimum amount of time, and give parameter estimates that are global optimal solutions. If our optimization algorithm can not reliably find the optimum for a given problem, our inferences about the functioning of a certain hydrologic system will at least be partially wrong, because they are based on the wrong optimized parameter estimates (which represent system properties). Having access to the appropriate estimates is therefore important, especially for instance when we are considering the burial of radioactive waste at Yucca Mountain, and need to have accurate estimates (derived from inverse modeling) of transport time to the groundwater, etc..

With respect to data and other uncertainties, this is beyond the scope of the current comment / paper. Nonetheless, in the last few years we have presented a series of papers that deal with these uncertainties within a recursive parameter estimation / combined parameter - state estimation and model averaging framework. For instance consider the work in Vrugt et al. (2002 WRR - PIMLI; 2005 - WRR - SODA; 2006 JHM - SODA; 2007 WRR - BMA).

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HESSD

4, S397–S401, 2007