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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Technical note: Method of Morris effectively reduces the computational demands of global sensitivity analysis for distributed watershed models" *by* J. D. Herman et al.

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General comments

The technical note "Method of Morris effectively reduces the computational demands of global sensitivity analysis for distributed watershed models" presents an application and comparison of the Sobol' sensitivity analysis method and the Morris screening sensitivity analysis method on a fully distributed hydrological model (the Hydrology Laboratory Research Distributed Hydrologic Model). The focus of the comparison is

mainly on the computational demands needed to achieve similar SA results.

In general, the discussion paper addresses an increasingly important issue: research on sensitivity analysis (and indirectly uncertainty analysis) for fully distributed hydrological models. Due to the over-parameterization of the latter type of models, SA and UA remain very often challenging. However, I don't see the need to label this paper as a "Technical note". The power and drawbacks of both the Sobol' method and the Morris method are well known and the results presented in the paper primarily confirm this knowledge.

Overall, the paper is well written and clear. By additionally taking into account the good quality of the presented research, I tend to advise minor revisions for this discussion paper. However, there are a number of specific comments formulated below (sometimes detailed because I have done a big part of my PhD research on this topic), for which I would like to receive an answer (either in the paper or to me) and therefore I advise major revisions.

Specific comments

General: The manuscript does not describe the real purpose of the sensitivity analysis, nor are the obtained results linked with a certain objective. Although the paper tries to provide general insights in the use of the SA techniques for distributed models, formulating a certain objective is of the utmost importance (especially for the comparison of the SA results for the 2 methods). Otherwise, researchers might encounter so called type III errors (Saltelli et al., 2008): "right answers are sought for wrong questions".

p4277, L8-9: It might be useful to add a number of other applications (Factor Fixing, Factor Prioritization,. . .) for sensitivity analysis (in particular in view of my first specific comment). Also a description of the distinction between global and local SA techniques could be useful, since you start talking about global SA on p4277, L14.

p4278, L3: Besides the reference of (Tang et al. 2007b), I would also add the work of

Yang (2011), who presented a detailed comparison of different SA methods.

Yang, J., 2011. Convergence and uncertainty analyses in Monte-Carlo based sensitivity analysis. Environmental Modelling & Software, 26(4): 444-457.

p4279, L7: Although it is mentioned in section 4, I would have expected the total number of studied parameters in section 2.1 or 2.2.

p4280, L9-11: This sentence should be moved, as you start giving general information on the Sobol' SA in this paragraph (or you should not mention any explanation on the first-order index p4280, L12, L15-16).

Add an explanation why you are only using the total sensitivity index. I assume that you are only interested in the parameter rankings (and it is probably also related to the fact that the outcome of the Morris method corresponds with the total sensitivity index). Nevertheless, this should be mentioned, especially in view of my first specific comment. Also with respect to the findings on the computational demand, it is necessary to add this explanation: despite the high computational demand of the Sobol' method, you receive a lot of additional model information "for free" (e.g. based on the first-order index). Hence, for a general view on the use of both methods, the first-order indices should be highlighted.

p4280, L17-18: This requires more explanation or at least a reference, e.g.:

Homma, T. and Saltelli, A., 1996. Importance measures in global sensitivity analysis of nonlinear models. Reliability Engineering & System Safety, 52(1): 1-17.

p4281, L3-4: Using the general formulations for the output mean and the output variance in the computation of the Sobol' sensitivity indices, can have a big influence on the convergence and the accuracy of these indices. Saltelli (2002) introduced an alternative formulation for the mean, which performs well in many cases. Additionally, W. Bauwens and I have studied the convergence of the Sobol' indices by applying different formulas for the square of the expectation value (4 different formulas) and the total

variance (3 different formulas) (conference paper online available and peer reviewed journal paper in preparation):

Nossent, J. and Bauwens, W., 2012, Optimising the convergence of a Sobol' sensitivity analysis for an environmental model: application of an appropriate estimate for the square of the expectation value and the total variance. In: R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp (Eds.) (2012): International Environmental Modelling and Software Society (iEMSs) 2012 International Congress on Environmental Modelling and Software. Managing Resources of a Limited Planet: Pathways and Visions under Uncertainty, Sixth Biennial Meeting, Leipzig, Germany. http://www.iemss.org/society/index.php/iemss-2012-proceedings. ISBN: 978-88-9035-742-8, pp 1080-1087

Nossent, J. and Bauwens, W., 2013, Improving the accuracy and convergence of a Sobol' sensitivity analysis for an environmental model (in preparation for Environmental Modelling & Software)

For the first order index, the equation applied for the square of the expectation value has the highest influence, for the total sensitivity index, the equation applied for the total variance highly determines the convergence.

Finally, also Bessel's correction should be applied for the equation of the total variance (divide by n-1 instead of n).

p4281, L8: The use of N for the number of samples in both matrix A and B is somehow confusing. Mostly, this is denoted as 2N.

p4281, L19: I'm not sure if the formulation N(p+1) is the result of a confusion related to the previous remark or not, but it is wrong. The first-order and total sensitivity indices can be computed based on N/2*(p+2) model evaluations (with your definition of N) (Saltelli, 2002). That is almost half your number.

p4282, L3: The sampling technique that is applied for the Morris method should be

mentioned in the paper (also related to the formulation on p4282, L23-24, since in Campolongo et al., 2007 an alternative sampling technique has been introduced). Additionally, it might be useful to mention the distribution of the parameters from which you are sampling.

p4282, L20-26: This formulation is wrong or at least confusing. I would advise not to use “first-order index” or “total order sensitivity index” when discussing the Morris method. Mu and mu* are both related to the total order sensitivity index (as they are also used to obtain parameter rankings), but they cannot be designated as such. For sure, mu is not a representation of the first-order index. In fact, mu and mu* are equal for monotonic functions. The absolute values in the computation of mu* are added to avoid that the different elementary effects cancel each other out (in case of non-monotonic functions). Interactions between parameters are somehow represented by the sigma value of the elementary effects and can occur for either monotonic or non-monotonic functions. This also shows that mu is not a representation of the first-order index.

p4283, L8: I assume you used a uniform distribution on [0,1] and a linear transformation to get the samples for the Sobol' SA?

p4283, L10: What values did you get for the RMSE? Since you are using random samples of the parameters, the simulated values might deviate from the observed values. If the RMSE value becomes too large (which is possible since the RMSE is not a normalized measure), the variance estimation with the numerical integrals might become inaccurate. This problem was addressed by Sobol' (2001) and studied for environmental models by W. Bauwens and me (conference abstract and the earlier mentioned paper in preparation):

Sobol', I.M., 2001, Global sensitivity indices for nonlinear mathematical models and their Monte Carlo estimates. Mathematics and Computers in Simulation. 55 (1-3), 271-280.

Nossent, J. and Bauwens, W., 2012, Application of a normalized Nash-Sutcliffe efficiency to improve the accuracy of the Sobol' sensitivity analysis of a hydrological model, Geophysical Research Abstracts, 14, EGU General Assembly 2012, Vienna, Austria, April 22-27, 2012.

p4283, L14: The numbers in Table 1 for the Sobol' SA are wrong. This is related with the comment on p4281, L19.

p4283, L19: Did you check the evolution of the sensitivity indices? This can be of great value to assess the convergence.

p4283, L20: Provide the confidence intervals.

p4283, L22: Did you try larger sample sizes for the Morris method?

p4284, L9: It might be useful to additionally emphasize that the sum of the total sensitivity indices is given per cell. One would expect a value higher than 1 for the (total) sum of the total sensitivity indices, but in this case this is still split up over 78 cells. This could be confusing.

p4284, L24-25: I think this is a very strong statement that cannot be justified completely. It is possible, but not sure.

p4285, L21-22: The results on the convergence of the Sobol' SA can be correct in the way you have performed and discussed the analysis here. However, a number of concerns should be taken into account: âĂć The actual sample size is half the one you mention. âĂć The use of other equations for the square of the expectation value and the total variance could reduce the sample size required to achieve convergence. âĂć The slow convergence is related to the very low values of the sensitivity indices (due to the high number of parameters, every parameter only contributes little to the total variance). This is logical, since a higher number of decimal numbers should become stable to achieve convergence and hence the numerical integration requires more samples. In particular, inferring parameter rankings based on these small, very similar values

is very difficult. My colleagues and I also observed this slower convergence for small values of the sensitivity indices:

Nossent, J., P. Elsen and W. Bauwens, 2011, Sobol' sensitivity analysis of a complex environmental model, Environmental Modelling & Software, 26(12), 1515-1525.

p4286, L17-. . .: It is known that in general Morris like screening methods are resilient to type I errors (non-influential factor is erroneously defined as important), but can be prone to type II errors (an important factor is classified as non-influential) (Saltelli et al., 2008). The use of mu* should overcome the latter problem. The bunch of dots in the lower left corner of the figures of the bottom row of figure 5 confirm the strength with respect to type I errors: non-sensitive parameters are identified and Morris method is particularly suitable for Factor Fixing. However, despite the clear trends in both the top and bottom row of figures (Fig. 5), the non-linear trends (discussed on p4287, L2) in the top row and the outliers in the bottom row show that it is much harder to categorize the sensitive parameters. I find it harder to identify the cluster of highly correlated parameter ranks near the most sensitive parameter on these graphs (mentioned on p4287, L11).

I believe that in particular a discussion of the outliers in the upper left corner of the figures of the bottom row is necessary. At this moment, these points are partly hidden behind the box with information. Depending on the purpose of the SA, these outliers might be important.

p4287, L12-14: This statement is correct based on the results shown in the paper. However, the results for a lower sample size for the Sobol' method are not handled. This makes the conclusions somehow biased towards the use of Morris method. I don't doubt the strength of Morris method, in particular for reasonable (high) sample sizes, but we (W. Bauwens and I) found out that the Sobol' method can also yield reasonable SA results and parameter rankings with limited sample sizes (paper under review):

Nossent, J. and Bauwens, W., 2013, Evaluation and comparison of sensitivity analysis techniques for a complex, over-parameterized environmental model (submitted to Environmental Modelling & Software)

Therefore, it might be interesting to put the results into perspective and communicate the findings in this way.

In our paper we also suggest to address future research on the combination of Morris method and Sobol' SA. Morris method could be applied in a first stage to identify non-influential parameters. Due to the resulting reduction of parameters (Factor Fixing), the Sobol' SA would require less model evaluations to obtain the full amount of information on the model and its parameters. The results presented in this paper highly support this suggestion.

p4287, L18-21: It is clear that for the given configurations, Sobol' requires more time. However, as mentioned before, besides the total sensitivity indices, also other information can be retrieved from the same model evaluations (e.g. the first order indices). It is for example also possible to use the random samples and their resulting model evaluation in a sort of GLUE approach to optimize the model and perform an uncertainty analysis. This is not possible with the model evaluations used in the Morris method.

Technical corrections

p4277, L29: In general, it is better to use input factors instead of parameters when discussing the use of SA methods. Although mostly parameters are meant, the definitions for SA are also valid for input variables and the expression "input factor" covers both (Saltelli et al., 2008).

p4278, L4: Replace "significantly" by "quasi linear". This is more precise in this case.

p4279, L24-25: This is a repetition of a part of the introduction. Try to reformulate this.

p4280, L15-16: I suggest to change this sentence to "The first-order index is a measure for the fraction of the total output variance caused by the parameter i, without interac-

tions with other parameters." The last part is essential, since interactions between e.g. parameters i and j can also be interpreted as "caused by the parameter i".

p4281, L15: Reformulate 'the parameter sets are modified'

p4282, L4: Replace "The method of Morris" by "It"

p4283, L14: You have 2 times a Table 1 (the first one is also the Table in the supplement)

p4283, L16: Shouldn't it be "the latter value" instead of "these values"?

p4285, L9: I assume this should be "Fig. 3"

p4285, L25: Figure 4 is very small and difficult to read.

p4290, L33: The reference (Saltelli, 2008) should be (Saltelli et al., 2008), as there are more authors of this book:

Saltelli, A., Ratto, M., Andres, T., Campolongo, F., Cariboni, J., Gatelli, D., Saisana, M. and Tarantola, S., 2008. Global Sensitivity Analysis: The Primer. John Wiley & Sons, Ltd, Chichester, 304 pp.

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