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Interactive comment on "Moment-based Metrics for Global Sensitivity Analysis of Hydrological Systems" *by* Aronne Dell'Oca et al.

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This manuscript addresses the improvement of GSA (Global Sensitivity Analysis) by using newly introduced metrics based on the evaluation of the first four statistical moments: expectation value, variance, skewedness, tailedness. These metrics allow to extend the analysis beyond variance-based GSA into the details of the shape of the probability density function (pdf). It allows e.g. to detect when a certain model parameter particularly affects the asymmetry or the tailing of a pdf. The authors motivate and outline their idea in the context of GSA very well and nicely explain the expected benefits of their approach. However, like always, there is no free lunch. The method has the disadvantage that it involves significantly more computational effort, this rendering likely impossible to perform for a complex hydrological scenario of practical relevance. The work-around proposed by Dell'Oca et al is the use of reduced-complexity models

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or surrogate models; in this case, they use the Polynomial Chaos Expansion technique, which can be viewed as an approximation of a target function by polynomials, where the degree of the polynomials determines (at least up to a certain value) the accuracy of the approximation.

Surrogate models like PCE require some smootheness in the targeted model output parameters with respect to the investigated paramters. Otherwise, discontinuities in the model output is difficult to reproduce. Therefore, I suppose, that this might involve the possibility that sophisticated GSA metrics become biased from errors introduced by the surrogate model. Thus, to give added value through several-moment-based GSA, we must first assure that the pdfs from the (surrogate) models are correct, i.e. the model represents the physics in all aspects. The manuscript addresses this issue quite well by some test cases, although I observe that all three test cases are relatively simple and do not provide huge challenges regarding possibly complex hydrological or geological features. The first test case is rather an academic exercise (which has, of course, value in itself), the second is an example where the results are definitely smooth in the parameter space; only the third one involves a heterogeneity, but still not very challenging for a polynomial approximation. I propose, maybe for future work, for example, a scenario where a fluid is injected into a geologic reservoir which has a fault zone in greater distance and where the response in terms of leakage to this fracture is rather a step-function. Would such a scenario be reflected properly by these new metrics? I guess that yes, but would the PCE provide the appropriate model for it? But clearly, the method proposed here is independent of the choice of the surrogate model.

Some further specific comments and questions:

1) What if parameters are not uniformly distributed as assumed e.g. in 221-222? E.g. permeability in a fractured rock. How important is this assumption?

2) A given acceptable level of accuracy for the PCE-based approximation of the new indices requires increasing polynomial order with the order of the statistical moment. I

can comprehend this statement in 3.3 (and in the conclusions with the careful wording "might be") from looking at the corresponding figures. But is there also some comprehensible reasoning or proof why this is the case? The authors are mathematicians and might be able to understand and explain this issue.

3) I understood that the analysis helps better identifying the relative importance of individual parameters. There is enormous practical relevance for this, e.g. it would help to prioritize exploration efforts for a particular parameter when it becomes clear from the sensitivity analysis that knowledge about this parameter reduces uncertainty drastically. The authors might want to emphasize such examples a bit more prominently if they like.

4) In the first conclusion, line 475, I would write: "The CALCULATED sensitivity of a model output ..."

Very few language issues: 201-202: ... are affected by model uncertain parameters collected in x. Here is something wrong with the grammer, or I don't understand the meaning.

326: maybe "characterize" is here not the right wording? What about "control"?

Eventually, I conclude that this is a very well written paper which I recommend to be published after only a few minor revisions.

A second disadvantage is that the new metrics are not so trivial and difficult to understand. But the authors did a good job in explaining their meaning and practical relevance.

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