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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Hybridizing Bayesian and variational data assimilation for robust high-resolution hydrologic forecasting" *by* Felipe Hernández and Xu Liang

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We would first like to express our appreciation to both Referee 1 and Referee 2 for their careful and thorough review of our manuscript. Their comments will certainly help us improve the quality and clarity of our manuscript. Below we offer our response to Referee 1.

Anonymous Referee 1 on 13 October 2017: *"I really enjoyed reading the paper, which deals with the important issue of improving model updating techniques for better flood predictions. This manuscript proposes a new data assimilation procedure which combines Bayesian and variational approaches. I believe this is an important contribute*

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Discussion paper

to DA research field and of notable interest and modernity, especially for the HESS readership. However, I still have some comments regarding method, structure, and readability of the paper. Below you can find some major comments:"

We are very glad that you enjoyed the manuscript and found it of value. We appreciate your generous compliments and hope that our work will be a worthy contribution to the community. We thank you for your careful analysis and suggestions. Below we respond to your comments.

"Results of this research are not well described in the abstract and it is somehow difficult to grasp the main advantage of this approach."

We will modify the last sentences of the abstract to better convey the findings of our experiments: that OPTIMISTS allowed to produce more robust forecasts when compared to a more traditional method, and that its application on a high-dimensional model was successful in that it maintained the levels of performance observed in the case of lower dimensionality without sacrificing computational efficiency.

"From the introduction, it is not really clear the difference between OPTIMIST and other hybrid 4D approaches. Novelty has to be better explained in order to further appreciate the added value of such method."

We will extend the introduction to better convey the differences and our proposed innovations in the revised manuscript. For your information, the main differences were summarized in the conclusions (p16-l28) in the original submission: that OPTIMISTS is inspired in part by the particle filter (instead of being inspired by the EnKF), that it allows for multi-criteria evaluations of candidate particles, and that it utilizes global (evolutionary) optimization methods (instead of using convex ones). Further differences can be extracted from table 1: e.g., that OPTIMISTS allows for non-Gaussian state estimates through kernel density estimation.

"Nowadays, there are many DA methods with varying complexities and accuracies.

However, few of these methods are used in early warning system to improve flood predictions. Did the authors investigate the way to easily implement OPTIMISTS by water authorities for flood forecasting in any existing early warning system? Is there any advantage in terms of computational time if compared to PF and 4D-Var?"

It is our vision that, once OPTIMISTS' advantages prove greater than its disadvantages (e.g., its relatively higher complexity) in a significant set of test cases, the method will be considered for integration in operational prediction systems for multiple applications. Applicability in high-dimensional cases has been one of our guiding design principles, as we believe this is key for adequate performance in these large-scale/complex systems. While the method currently can be executed in parallel environments and it offers configurations that work well with very large state variable vectors, we are already working in developing enhancements to take the next step in scalability and efficiency, and we will be happy to continue working alongside government agencies or private partners to carry out our vision.

Regarding the comparisons with the PF and 4D-Var, we believe our experiments indicate that OPTIMISTS can provide gains in computational time given that the main strategy for increased performance in most DA methods is through the use of additional model runs: e.g., enlarging the ensemble size in EnKF and PF or the number of candidate solutions explored in the optimization problem in Var. Therefore, showing a more robust performance indicates not only that OPTIMISTS can produce better forecasts with the same resources, but that the same level of performance can be obtained with fewer resources (in this case particles/ simulations).

"Page 1, lines 14-16: Is this sentence related to the watershed's location or to the use of different models for different case studies? Authors should clarify this point."

Both: two different locations are used and, because the watersheds are of significantly different scale, we used a different modelling engine for each. We made this decision to diversify the test conditions of our experiments. We will change the wording in this

sentence to convey the correct meaning more clearly.

"Page 3, lines 8-9: The authors mentioned that "a hybrid data assimilation algorithm that incorporates the most valuable features from both Bayesian and variational methods ". Which ones are these valuable features? Description of Table 1 should be better included within the paper. Right now it looks quite disconnected from the other part of the introduction."

Our intention was to let Table 1 convey the contrast in features between OPTIMISTS and traditional methods. We will add discussions in the main text so that there is a stronger connection with the table and that these claimed advantages are more easily understood.

"I found very difficult to follow the flow of thoughts of the authors in describing the DA method. I think it will be beneficial for the readability of the paper to include in section 2 a figure representing the structure of OPTIMISTS. In addition, authors tend to use complex terms for non-DA expert. I suggest revising the description of the paper in order to make it "accessible" to everyone and increase its impact on the scientific community."

Thank you for your good suggestions. We will use more common terminology in the revised manuscript to accompany technical/domain-specific terms to improve the accessibility of the section. We will also add a figure that will help in understanding how the algorithm works.

"At this point, results are valid only for the 5 considered flood events and 2 basins obtained. As expected, results largely depend on the features of the flood events and quality of rainfall data. I am afraid that the samll number of events makes results rather random. I suggest to increase the number of flood events to make more general conclusions for this study."

Thanks for the good suggestions. We will change the comparative test design so that

we can analyze multiple months' worth of forecasts using OPTIMISTS and the particle filter. We already developed some scripts that allow performing assimilation and forecast continuously for this purpose. This will allow for a more thorough and realistic comparison between the two methods. However, we decided to drop the comparison with Evo4DVar as this is not a standard method found in the literature, and its deterministic nature makes a direct comparison complicated.

"A crucial component in each DA application is the proper definition of model and observational error. While model error is accurately described, I could not see a clear definition of the observations error (standard deviation in Eq.10). The authors have to include more information and references about it."

We will incorporate the effect of uncertainties in the observations within the description of the algorithm to better convey the multiple ways in which it can be addressed through OPTIMISTS and the contrasts with traditional methods.

"Are you using actual meteorological forecasts or are you using the observations as perfect forecasts? Please specify"

In this study, "perfect" meteorological forecasts are used to force the model in all cases (see in page 12, lines 8-13). We also argue that this advantage is applied uniformly to both OPTIMISTS and the other algorithms so that it does not represent an unfair advantage to any. In the revised manuscript, we will make this clearer.

"I suggest the authors to split results and discussions in two different sections, this would make reading the text so much easier."

We understand that having separate results and discussion sections allows having the "cold facts" separated from the "subjective" interpretations and opinions of the authors. However, as many authors do, we prefer having these two sections combined because otherwise the discussion section will often have to reference results and figures from the previous section and have the reader jumping back and forth between sections.

This both helps the readability of the article and its compactness. Having both styles be accepted in many communities, we hope this reviewer would agree with us on this point to maintain the two sections combined. We will, however, scan the entire section in search for instances where the distinction between objective results and subjective opinion is not clearly established and revised them accordingly based on this reviewer's good comments.

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