Hydrol. Earth Syst. Sci. Discuss.,
https://doi.org/10.5194/hess-2018-118-AC1, 2018

Hydrology and Earth System Sciences Discussions

Interactive comment on "Discharge hydrograph estimation at upstream-ungauged sections by coupling a Bayesian methodology and a 2D GPU Shallow Water model" *by* A. Ferrari et al.

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Received and published: 29 June 2018

The authors gratefully acknowledge the positive and constructive review of Dr. A.D. Koussis. In this document the comments provided by Dr. A.D. Koussis are reported in italic, whereas the authors' response and indications about the original paper modifications are marked in bold fonts.

Estimating an unknown discharge hydrograph at an upstream cross-section is useful in flood hydrology both as a forensic activity (to find the inflow that caused a flood event observed at a certain downstream section) as well as operationally (to determine the

operational mode of a reservoir in order to protect a downstream area). Such (rather special, but not rare) problems are tackled either by reverse routing the observed hydrograph to the upstream cross-section (an inverse problem, the solution of which exists, but is not unique and must be regularised; the authors should note, in their relevant section, that the solution does exist), or via optimisation. Both inversion approaches are subject to instabilities that must be controlled (e.g., smoothing). Past research has been referenced properly.

We thank the Referee for this comment and we agree that the solution of this kind of inverse problems exists. As a consequence, in the revised paper, we will reformulate the sentence about the ill-posedness of the inverse problem clarifying that the challenges we are dealing with are the non-uniqueness and the instabilities of the solution and not its existence.

The submitted research opts for an optimisation approach: the procedure applies a Bayesian geostatistical methodology coupled with forward routing that solves the full 2-D shallow water equations. Using a 2-D flow model in the context of inverse flood routing is an advance beyond the state of the art. But the computational load caused by the necessary multiple 2-D flow runs is heavy. Therefore, the authors have carried out their inversion procedure by parallelising the evaluation of the Jacobian matrix (it assesses the solution sensitivity to each unknown flow value), taking advantage of the floating point calculation capabilities of an array of Graphical Processing Units grouped in a remote High Performance Computing cluster. The testing and validation of the method is sound and thorough; it includes simulations of generic floods with perfect (error-free) and with corrupted data, as well as of real flood events. The achieved accuracy is very good, including the peak region. Large oscillations of the inverted flow (recovered inflow) hydrograph occurring near its end are explained (Figs. 10 and 16); oscillations occurring at the start of the flood (e.g., Fig. 9a) seem to be due to the *somewhat abrupt initiation of the transient from the steady state, while oscillations in the peak region are likely due to the change from a rising to a falling flood flow (Figs. 13a and 14a). The largest oscillations of the stage hydrograph occur at the start of the flood (Figs. 9b and 17) and should be also attributable to the somewhat abrupt initiation of the transient from the steady state (please comment). These oscillations are, of course, stronger in the simulations with corrupted data. Relevant comments by the authors would be appreciated; they would help the reader, too.*

We thank the Referee for his comment since this is an excellent point to discuss. In the Bayesian Geostatistical Approach, the main mechanism by which soft knowledge about the unknown parameter function is imparted is through the prior information. In our approach, this soft knowledge is intentionally limited to the choice of a parameterized covariance model (the structural parameters, which control the balance between smoothness and misfit, are also estimated during the process) such that significant flexibility is available to the algorithm. Nevertheless, the behaviour raised by the Referee in correspondence of abrupt changes of the inflow hydrograph is due to the regularization imposed by the prior-information. We will add the following sentences into the revised manuscript to comment and justify this behaviour: "In addition to this behaviour at the end of the discharge hydrograph (that can be postponed extending the hydrograph total duration), very small differences between the observed and modelled variables appear when abrupt changes in the inflow function are present (e.g. the initial transition from the steady state to the flood wave). This behaviour is due to the regularization introduced into the solution by the prior information that imposes some degree of continuity and/or smoothness to the estimated hydrograph. However, the residuals are practically negligible and abrupt discontinuities in the inflow hydrographs are not common in natural floods."

It is noted, as an aside, that evidence is not conclusive as to which approach, reverse routing or optimisation, is more prone to spurious oscillations; a specific comparative investigation, under identical conditions, is required.

We really thank the Referee for this comment. Due to the fact that the 2D Shallow Water Equations in their complete and conservative formulation, which govern the motion of the fluid, cannot be inverted, for the 2D applications presented in the paper no comparison between the reverse flow routing technique and the Bayesian one can be performed. However, D′Oria et al. (2012a, 2012b) compared the two strategies for the level pool routing algorithm used to compute the inflow hydrograph in a reservoir. They showed that in presence of corrupted observations, the reverse routing procedure amplifies the errors, whereas the regularization provided by the optimization Bayesian procedure avoids spurious oscillations in the solution.

The paper is structured well. The theory is presented succinctly, with adequate mathematics, and contains all relevant information; the same holds for the (important) computational aspects of the modelling approach. Figures and tables add significantly to the understanding of the textual account, and figures are of good quality. The language is generally quite good, yet the paper would benefit from careful editing (e.g., most 'which' should be 'that', 'resulted' should be 'resulting' etc.); some indentations must be corrected. (I will mail my marked up manuscript to the corresponding author for the consideration of the team of authors).

The authors wish to thank the Referee for having provided his marked copy of the manuscript: the suggested corrections will be included in the revised paper.

The Conclusions section could be enhanced. Particularly, given that the computing facilities and arrangements required for the inverse modelling approach reported in the manuscript are currently tailored to research rather than to the work of professional hydrologists, the authors should comment on how they envision their model finding its way to the hydrological practice.

We really appreciate this useful advice since it allows us to better remark the practical aspects of our work. The definition of a discharge hydrograph in an ungauged river section is a relevant issue for professional hydrologists involved for example in the design of hydraulic infrastructures as well as for engineering working on water resource management (i.e. irrigation system, hydroelectric power stations) or forensic activities. With the aim of solving this problem, we propose an application that requires supercomputer and High Performing Computer clusters. These tools are mostly used for University research activities, but they are not only reserved to these environments. In fact, clouds of GPUs or on-line mini cluster are now common and thus everyone can manage to access these facilities. Moreover, the adopted Bayesian software (bgaPEST) is open access and 2D Shallow Water Equations models are nowadays quite common tools for practitioners. The concluding section will be enhanced in the revised paper with the considerations here pointed out.

Assessment: The paper addresses in a novel way an interesting topic (for specialists) that is within the scope of HESS, is scientifically sound and methodologically solid. It is very good and should be published after minor revision.

The authors wish to thank Dr. A.D. Koussis for his suggestions and considerations.

References

D′Oria, M., Mignosa, P., and Tanda, M. G. Reverse level pool routing: Comparison between a deterministic and a stochastic approach. Journal of hydrology, 470, 28-35, 2012a.

D′Oria, M., Mignosa, P., and Tanda, M. G. Response to Comment on "Reverse level pool routing: Comparison between a deterministic and a stochastic approach" by H. Md. Azamathulla, J. Hydrol. (2012),Journal of Hydrology, 475, 499-501, 2012b.

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