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A Bayesian approach to analysing structural uncertainties in flood risk analysis

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Analysis of uncertainties in hydraulic models of flooding processes is a perennial area of investigation. Here our concern is with analysis of uncertainties in flood risk calculations. In common with other approaches, a distinction is made between different sources of error, that is, between input, model structural error or inadequacy, and output measurement error. The objective is to be able to formulate the uncertainty estimates in such a way that they can be used within risk analysis, where the risk is formed from an integral over all forcing scenarios and the entire range of modelling errors, of the product of the probability of flooding and the damage caused.

The Bayesian approach to model calibration and uncertainty analysis provides the capacity to (i) combine prior knowledge with information from calibration exercises to generate well justified posterior distributions on model parameters, whilst (ii) at the same time also using observations to understand the structural uncertainties that separate model predictions from hydraulic processes in reality. The calibration formulation used is derived from that of Kennedy and O'Hagan (2001). Distinction is made between the contributions of model inadequacy (structural uncertainty) and measurement error to observed data by considering the covariance associated with the values of the model inadequacy, describing it as a Gaussian process. The values at the locations (in time or space) where data are measured are considered to jointly vary as a stochastic process with a multivariate Normal distribution. Further, in a hierarchical description, the mean of this Gaussian Process is itself a regression on some suitable basis.

The approach has been successfully applied to steady state models in several fields, including the calibration of a flood extent model (Hall et al., 2011). To extend the approach to hydrodynamic flood inundation models we construct of a dynamic emulator of a Hec-Ras model of a 22 km reach of the river Severn, UK, immediately upstream of Shrewsbury. A simple but effective form for the emulator is a transfer function model with a non-linear state-dependent transformation of the inputs. Following work by Romanowicz et al. (2008) an autoregressive moving average (ARMA) transfer function is applied to the output of a nonlinear transformation of the upstream stage measurement. A similar approach is adopted for the observed data, so that the structural uncertainty is reflected in the discrepancy between the non-linear state-dependent functions. The approach is shown to enhance the accuracy of models with known deficiencies at the same time as providing well justified uncertainty estimates.

References

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