Geophysical Research Abstracts
Vol. 13, EGU2011-9030, 2011
EGU General Assembly 2011

A data-driven Dynamic Emulation Modelling approach for the management of large, distributed water resources systems

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In hydrological and water resources modeling large, spatially-distributed, process-based models are widely adopted to describe the dynamics of the physical, social and economic processes. Such an accurate modeling comes, however, to a price, since the computational requirements of these models is considerably high, thus preventing them to be utilized in any problem that requires hundreds or thousands of model runs to be satisfactory solved. Typical examples include optimal planning and management, data assimilation, and sensitivity analysis.

An effective approach to overcome this limitation is to perform a top-down reduction of the process-based model by identifying a simplified, computationally efficient emulator, constructed from and then used in place of the original process-based model in highly resource-demanding tasks. The underlying idea is that not all the process details in the original model are equally important and relevant to the dynamic of the outputs of interest.

In this work we propose a new data-driven Dynamic Emulation Modeling (DEMo) approach that combines the many advantages of data-based modeling in representing complex, non-linear relationships, but preserves the state-space representation, which is both particularly effective in some applications (e.g. optimal management and data assimilation) and facilitates the ex-post physical interpretation of the emulator structure, thus enhancing the credibility of the model to stakeholders and decision-makers.

The core mechanism of the proposed approach is a novel variable selection procedure that is recursively applied to a data-set of input, state and output variables generated via simulation of the process-based model. Starting from the subset of input and state variables needed to explain the output, the variable selection procedure is recursively repeated on the state variables that have been selected as significant to the problem to be solved but whose transition functions still need to be explained. The set of selected variables is incrementally built by adding the best variables provided by a ranking algorithm based on a statistical measure of significance that accounts for non-linear dependencies. The approach embodies some very important properties: it is fully automated, independent on domain experts and system knowledge, and suitable for non-linear processes; it has a high potential in terms of complexity reduction; and, finally, it provides an ex-post interpretation of the emulator structure.

The DEMo approach is demonstrated on a real-world case study concerning the optimal operation of a selective withdrawal reservoir (Tono dam, JP) suffering from downstream water quality problems (i.e. strong fluctuations in the values of the released water temperature). The emulator is identified on a data-set generated with the 1D coupled hydrodynamic-ecological model DYRESM-CAEDYM and subsequently used to design the optimal operating policy for the dam. Preliminary results show that the proposed approach significantly simplifies the learning of good operating policies and can highlight interesting properties of the system to be controlled.