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Andrea Ficchi

Luciano Raso

Pierre-Olivier Malaterre

David Dorchies

Maxime Jay-Allemand

See next page for additional authors

Authors

Andrea Ficchi, Luciano Raso, Pierre-Olivier Malaterre, David Dorchies, Maxime Jay-Allemand, Francesca Pianosi, Peter-Jules van Overloop, and Guillaume Thirel

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SHORT TERM RESERVOIR OPERATION ON THE SEINE RIVER: PERFORMANCE ANALYSIS OF TREE-BASED MODEL PREDICTIVE CONTROL

A. FICCHÌ (1, 4), L. RASO (1), P.-O. MALATERRE (1), D. DORCHIES (1), M. JAY-ALLEMAND (1), F. PIANOSI (2), P.-J. VAN OVERLOOP (3), G. THIREL (4), M.-H. RAMOS (4), S. MUNIER (1)

(1): UMR G-EAU, Irstea, 361 rue J.F. Breton, B.P. 5095, 34196, Montpellier cedex 5, France

(2): Dept. of Civil Engineering, University of Bristol, University Walk, Bristol, BS81TR, UK

(3): Water management group, TU Delft, Stevinweg 1, 2628 CN Delft, The Netherlands

(4): UR HBAN, Irstea, 1 rue Pierre-Gilles de Gennes, CS 10030, 92761, Antony, France

The Seine River, in France, flows through territories of large economic value, among which the metropolitan area of Paris. A system of four reservoirs operates upstream to regulate the river flows in order to protect the area against extreme events, such as floods and droughts. Current reservoirs management is based on reactive filling curves, designed from an analysis of historical hydrological regimes. The efficiency of this management strategy is jeopardized when inflows are significantly different from their seasonal average. To improve the current management strategy, we investigated the use of Tree-Based Model Predictive Control (TB-MPC). TB-MPC is a proactive and centralized method that uses information available in real-time, as ensemble weather forecasts. Reservoir management is tested under past hydro-climatic conditions using time series of ensemble weather forecasts produced by ECMWF (European Centre for Medium-Range Weather Forecasts) and weather observations. The performance of TB-MPC is compared to that of deterministic Model Predictive Control (MPC), showing the benefits of considering forecasts uncertainty by using ensemble forecasts.

CASE STUDY PRESENTATION AND OBJECTIVES

The reservoir system in the Seine River basin in France includes four reservoirs on the Seine River and its tributaries upstream of Paris, and is operated with the objective of reducing floods and droughts in an area of large economic value, including the Paris metropolitan area.
The four lake-reservoirs, named Aube, Marne, Pannecière, and Seine, have a total capacity of 810 hm^3 and are managed by Seine Grand Lacs (SGL), a public basin authority. The Pannecière Lake was created by damming the Yonne River, a tributary of the Seine, while the other three are bank-side reservoirs, with inlet/outlet channels.

Currently, each reservoir is operated independently from the others following a *filling curve* (FC), which sets the target reservoir volume for each day of the year. The FCs are designed to store water during the high-flow season (from November to June) to reduce the immediate flood risk, while maintaining adequate flood control volumes for later, and to sustain low flows during the dry season (from July to October). These curves are designed from an analysis of historical hydrological regimes. Therefore, current management efficiency decreases when inflows are significantly different from their seasonal averages. *Dorchies et al*. [2] have shown that adaptation strategies are needed to improve the current management efficiency and to cope with the projected increase in frequency and intensity of extreme events. At an operational level, a possible adaptation strategy is the implementation of a centralized and anticipatory Real-Time Control (RTC) system that would overcome the limitations of the current reactive and uncoordinated management. To this end, the present study investigates the use of a centralized RTC system that implements the well-known technique of Model Predictive Control (MPC, *Mayne et al.* [4]) and the more recent Tree-Based Model Predictive Control (TB-MPC, *Raso et al.* [9]), using deterministic and ensemble weather forecasts respectively. TB-MPC is an extension of MPC that can deal with forecasts uncertainty, generating a tree from an ensemble of weather forecasts (see *Raso et al.* [8]) and then calculating different control actions for each branch of the tree. The purpose of using ensemble forecasts in TB-MPC is to reduce the sensitivity to wrong forecasts and enhance the control performance with respect to the deterministic approach of MPC. The goal of this study is to assess the improvement in reservoirs system operation made possible by the use of ensemble forecasts in TB-MPC compared to the deterministic MPC.

MODELS AND METHODS

To compare the different management methods by model simulation, we developed an integrated model of both the physical and decision systems.

A semi-distributed conceptual model (TGR, *Munier* [5, 6]) reproduces the rainfall-runoff process, the reservoirs dynamics and the flow-routing within the river basin. The model reproduces the daily flows at 25 hydrometric stations where observed flows were available at a daily time-step. This model is described in further details in *Dorchies et al*. [2].

A decision model reproduces the reservoirs management, providing the inflow/outflow decisions to be applied at the inlets and outlets of the reservoirs. We implemented different decision-making strategies: the actual current management based on FCs (“no-forecast” operation), and the RTC strategy using deterministic or ensemble weather forecasts, within respectively the MPC or TB-MPC framework.

Reservoir operation performance is evaluated by use of critical low and high flow thresholds, defined at some strategic downstream *control stations* and corresponding respectively to levels of water use restrictions or flood warnings. These thresholds are directly taken into account in the objective function to be optimized in MPC and TB-MPC. In fact, we defined this objective function as the sum of the *step-costs* associated to floods and low flows and a *penalty-cost* based on the final reservoir storages. The step-costs for floods and low-flows are the costs associated to river flows derived from the application of the optimal decisions along the prediction horizon. Since our objective is to prevent crossing the flow thresholds, each step-cost was defined as a linear function of the river flows at the control stations, increasing with the thresholds violation. Nonetheless, short-term forecasts can be exploited to cope with short-term events only. Therefore the long-term objectives are accounted for by using a penalty function over the reservoir storages reached at the end of the prediction horizon. This penalty was defined as a quadratic function of the distance of the final storages from the FCs. An optimizer (*Nelder and Mead*, [7]) seeks the decisions that minimize this objective function respecting the physical and legal constraints of the system (volumes of the reservoirs, capacity of the channels, minimum environmental flows). For details about the cost-function and control problem definition the reader is referred to *Ficchi et al.* [3].

RESULTS

First, we simulated the MPC strategy with perfect forecasts, using meteorological observations in place of forecasts, to evaluate an upper bound of the RTC system improvement with respect to the current management ("no-forecast" operation based on FCs). For further comparison with the use of real forecasts by ECMWF model, we used a prediction horizon of 9 days, as this is actually the lead-time of real forecasts available for this work. We compared the average step-costs for high and low flows over a simulation horizon of fifteen years (1973-1988) using the MPC and current management models. This analysis showed that while MPC does not significantly improve the system operation in low-flow conditions, which should be anticipated over a longer time span than the prediction horizon used here, it provides a significant improvement in high-flows conditions, almost eliminating flood risk. This is made possible by the proactive behavior of MPC management that makes the reservoirs storages diverge from the FCs when a flood is forecasted.

We then compare the use of deterministic and ensemble weather forecasts respectively in MPC and TB-MPC. To simulate these strategies over a historical horizon, hindcast time-series from the ECMWF weather forecasts are used. These are aggregated at daily temporal resolution with a lead-time of 9 days. Since there are no critical flood events over the period of data availability (2005-2008), we lowered the high flows thresholds so as to artificially generate some "critical" flood events. Using lower thresholds, the simulation of the "no-forecast" operation is not sensible, because it implicitly takes into account the actual thresholds in the definition of the FCs. So we simulated the system operation over the (artificial) flood event in 2007 under the management with real deterministic and ensemble forecasts (EF) and compared the performance of these two strategies to the case of perfect forecasts. Results showed that while the use of real deterministic forecasts significantly reduces the system performance, the use of EFs greatly reduces this performance loss due to forecasts uncertainty, providing river flows closer to the "ideal" ones produced by the use of perfect forecasts.

FUTURE RESEARCH

The work here briefly presented is affected by some limitations that will be addressed by future research. First, the model of the system will be improved. Specifically, a fully-distributed model of the hydraulic system (SIC, *Baume et al.* [1]) will replace the hydraulic part of the actual model (TGR) for the closed-loop simulation updating the system states after application of the optimal decisions. In the internal model of (TB-)MPC (that will remain TGR), observations will be assimilated into the model using an Ensemble Kalman Filter to correct the system states from modeling errors.

Finally, the centralized RTC system will be tested under projected climate change scenarios. In fact, our analysis seems to indicate that the efficiency of reservoirs operation in the Seine River basin could be significantly improved to reduce flood risk by using weather forecasts and explicitly considering forecasts uncertainty. So it would be very interesting to also assess the performance of this more efficient operation system in a possible future scenario where the frequency and intensity of extreme events are increased.

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REFERENCES

[1] Baume J. P., Malaterre P.-O., Belaud G., and Le Guennec B., "SIC: a 1D Hydrodynamic Model for River and Irrigation Canal Modeling and Regulation.", *Métodos Numéricos Em Recursos Hidricos*, Vol. 7, (2005), pp 1 – 81.

[2] Dorchies D., Thirel G., Jay-Allemand M., Chauveau M., Dehay F., Bourgin P.-Y., Perrin C., Jost C., Rizzoli J.-L., Demerliac S., Thépot R., "Climate change impacts on multi-objective reservoir management: case study on the Seine River basin, France", *International Journal of River Basin Management*, In press, (2014).

[3] Ficchi A., Raso L., Dorchies D., Malaterre P.-O., Jay-Allemand M., Pianosi F. and Van Overloop P.-J., "Optimal operation of the multireservoir system in the Seine River Basin using deterministic and ensemble forecasts", Manuscript in preparation, (2014).

[4] Mayne D.-Q., Rawlings J.-B., Rao C.-V, and Scokaert P.-O.-M., "Constrained model predictive control: Stability and optimality.", *Automatica*, Vol. 36, No. 6, (2000), pp 789–814.

[5] Munier S., "*Modélisation intégrée des écoulements pour la gestion en temps réel d'un bassin versant anthropisé*.", PhD Thesis, AgroParisTech, (2009).

[6] Munier S., Litrico X., Belaud G., and Perrin C., "Assimilation of discharge data into semi-distributed catchment models for short term flow forecasting: case study of the Seine River Basin", Submitted to *Journal of Hydrologic Engineering*, (2014).

[7] Nelder J., and Mead R., "A simplex method for function minimization.", *The computer journal*, Vol. 7, (1965), pp 308–313.

[8] Raso L., Van De Giesen N., Stive P., Schwanenberg D. and Van Overloop P. J., "Tree structure generation from ensemble forecasts for real time control.", *Hydrological Processes*, Vol. 27, No. 1, (2012), pp 75-82.

[9] Raso L., Schwanenberg D., Van Overloop P.-J. and Van de Giesen N., "Tree-Based Model Predictive Control for Short-Term Management of Reservoir Systems using Ensemble Forecasts.", Submitted to *Advances in Water Resources*, (2013).