GRADUATE AND POSTDOCTORAL STUDIES

McGILL UNIVERSITY

FINAL ORAL EXAMINATION

FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

OF

JOHN QUILTY
DEPARTMENT OF BIORESOURCE ENGINEERING

AN ENSEMBLE WAVELET-BASED STOCHASTIC DATA-DRIVEN FRAMEWORK FOR ADDRESSING NONLINEARITY, MULTISCALE CHANGE, AND UNCERTAINTY IN WATER RESOURCES FORECASTING

23rd August 2018
13:00

Macdonald-Stewart Building, MS2-022
McGill University, Macdonald Campus

COMMITTEE:
Dr. P. Seguin (Pro-Dean) (Department of Plant Science)
Dr. V. Adamchuk (Deputy Chair) (Department of Bioresource Engineering)
Dr. J. Adamowski (Supervisor) (Department of Bioresource Engineering)
Dr. S.O. Prasher (Internal Examiner) (Department of Bioresource Engineering)
Dr. C.A. Madramootoo (Internal Member) (Department of Bioresource Engineering)
Dr. L. Sushama (External Member) (Department of Civil Engineering)

Dr. Josephine Nalbantoglu, Dean of Graduate and Postdoctoral Studies
Members of the Faculty and Graduate Students
are invited to attend

ABSTRACT

Data-driven forecasting (i.e., regression, machine learning, artificial intelligence, etc.) has become a popular and very useful alternative to physically-based and conceptual forecasting approaches in the water resources domain since such methods solely rely on statistical relationships between explanatory variables and the target process, require no explicit physical knowledge of the processes under study, are rapid to develop, have low-costs, and are easy to implement in real-time. However, similar to physically-based and conceptual forecasting approaches, the nonlinear, multiscale, and uncertain nature of water resources provide challenges in the development of accurate and reliable data-driven forecasts.

To address the nonlinear, multiscale, and uncertain nature of water resources this research develops an ensemble wavelet-based stochastic data-driven forecasting framework (EW-SDDFF) that results in forecasts of a target process in the form of a probability density function. EW-SDDFF is developed, tested, and applied to a real-world daily urban water demand forecasting experiment in Montreal, Quebec where it is shown to produce accurate and reliable forecasts at multiple lead times, outperforming numerous benchmarks, and performing especially well during the July, 2010 heatwave that affected Montreal (and many other parts of Quebec).

EW-SDDFF addresses the nonlinear, multiscale, and uncertain nature of water resources in three main ways: 1) it uses nonlinear information-theoretic input variable selection and nonlinear data-driven forecasting methods; 2) it uses wavelet transforms to address multiscale changes in explanatory variables and the target process; and 3) it adopts stochastics for the uncertainty assessment of input data, input variable selection, parameters, and model output. The end result of EW-SDDFF is a stochastic forecast that holistically addresses nonlinearity, multiscale change, and uncertainty.

EW-SDDFF is developed in four key stages: 1) new computationally efficient, non-parametric, nonlinear information-theoretic input variable selection methods are developed to provide the most important input variables to nonlinear data-driven methods to forecast the target process; 2) a set of best (correct) practices are developed for using wavelet transforms correctly in wavelet-based forecasting models and formed into a new wavelet-based forecasting framework (WDDFF) that can be used with multiple wavelet transforms, different input variable selection methods, and data-driven forecasting models and that may be applied for the correct development of wavelet-based forecasting models for real-world applications; 3) uncertainty assessment is included in WDDFF by adopting a stochastic framework, resulting in a new stochastic wavelet-based forecasting framework (SWDDFF); and 4) to take advantage of the strengths of multiple wavelet transforms, different input variable selection methods and data-driven models, the single-wavelet SWDDFF is transformed into an ensemble multi-wavelet stochastic data-driven forecasting framework (EW-SDDFF) by using multiple WDDFF

forecasts as input data, improving forecast accuracy and reliability when compared to its single-wavelet counterparts (SWDDFF). EW-SDDFF includes both ensemble member selection and weighting uncertainties, using input variable selection and data-driven modeling, respectively, and also accounts for input data and ensemble model output uncertainties. Both SWDDFF and EW-SDDFF represent the most advanced single- and multi-wavelet data-driven forecasting frameworks in the literature.

Since EW-SDDFF quantifies forecast uncertainty (in the form of a probability density function), it may serve as a useful tool for operational, planning, and management tasks faced by water resources managers, especially during decision-making stages.

CURRICULUM VITAE

UNIVERSITY EDUCATION

2013-2018	**Ph.D. Bioresource Engineering** McGill University, Canada
2007-2011	**B.Eng. Civil Engineering with a Concentration in Mgmt.** Carleton University, Canada

EMPLOYMENT

2013 – present	**Automated Metering Infrastructure Network Analyst** City of Ottawa, Canada
2012	**Engineering Technologist** City of Ottawa, Canada

AWARDS

2013-2014	McGill Graduate Excellence Award Bioresource Engineering

PUBLICATIONS

Quilty J. and Adamowski J., 2018. Addressing the incorrect usage of wavelet-based hydrological and water resources forecasting models for real-world applications with best practices and a new forecasting framework. Under review, Journal of Hydrology, 563, pp. 336-353.

Deo, R.C., Downs, N., Parisi, A.V., Adamowski, J.F., **Quilty, J.M**., 2017. Very short-term reactive forecasting of the solar ultraviolet index using an extreme learning machine integrated with the solar zenith angle. *Environmental Research*, 155, pp. 141-166.

Deo, R.C., Tiwari, M.K., Adamowski, J.F., **Quilty, J.M**., 2017. Forecasting effective drought index using a wavelet extreme learning machine (W-ELM) model. *Stochastic Environmental Research and Risk Assessment*, 31, pp. 1211-1240.

Yaseen, Z.M., Deo R.C., Jafar O., Kisi O., Adamowski J., **Quilty J.**, El-shafie A., 2016. Stream-flow forecasting using extreme learning machines: A case study in a semi-arid region in Iraq. *Journal of Hydrology*, 542, pp. 603-614.

Quilty J., Adamowski J., Khalil B., Rathinasamy, M., 2016. Bootstrap rank-ordered conditional mutual information (broCMI): A nonlinear input variable selection method for water resources modeling. *Water Resources Research*, 52, pp. 2299-2326.

Belayneh A., Adamowski J., Khalil B., **Quilty J**., 2016. Coupling machine learning methods with wavelet transforms and the bootstrap and boosting

ensemble approaches for drought prediction. *Atmospheric Research*, 172-173, pp. 37-47.

Ciupak M., Ozga-Zielinski B., Adamowski J., **Quilty J.**, Khalil B., 2015. The application of Dynamic Linear Bayesian Models in hydrological forecasting: Varying Coefficient Regression and Discount Weighted Regression. *Journal of Hydrology*, 530, pp. 762-784.

Goyal M., Bharti B., **Quilty J.**, Adamowski J., Pandey A., 2014. Modeling of daily pan evaporation in sub tropical climates using ANN, LS-SVR, Fuzzy Logic, and ANFIS. *Expert Systems with Applications*, 41, pp. 5267-5276.

Quilty J., Adamowski J., Boucher, M.-A., A stochastic data-driven ensemble forecasting framework for water resources: A case study using ensemble members derived from a database of deterministic wavelet-based models. (Accepted pending moderate revision, *Water Resources Research*, 2018).

Quilty J. and Adamowski J., A stochastic wavelet-based data-driven framework for forecasting uncertain multiscale hydrological and water resources processes. (Under review, *Journal of Hydrology*, 2018).

Ghasri, M., Barzegar, R., Adamowski J., **Quilty J.**, Qi, Z., Using Bootstrap ELM and LSSVM models for river ice thickness estimation in the Athabasca watershed, Canada. (Under review, *Journal of Hydrology*, 2018).