

7th Eawag Summer School in Environmental Systems Analysis 2015

- Recommended Literature

05.02.2015/PR/CA/AS/DK

The course will provide an introduction to and practice in model-based data analysis. Major topics will be sensitivity analysis, identifiability analysis, and frequentist and Bayesian inference. Emphasis will be on Bayesian techniques. The exercises will be done using the freely available software environment for statistical computing and graphics R (<http://www.r-project.org>).

As the course will be very intensive, we strongly recommend some preparatory reading in sensitivity analysis, identifiability analysis, frequentist and Bayesian statistics, and some familiarization with R. In the following we provide some links to short introductory material on the web that would be suitable for this purpose and a list of papers and books that go into more depth.

Sensitivity Analysis

Links to introductory texts:

Overview of sensitivity analysis: http://en.wikipedia.org/wiki/Sensitivity_analysis

Books:

Saltelli, A., Chan, K., and Scott, E. M., eds (2000) *Sensitivity Analysis*. John Wiley & Sons, Chichester, England.

Saltelli, A., Tarantola, S., Campolongo, F., and Ratto, M., eds (2004) *Sensitivity Analysis in Practice - A Guide to Assessing Scientific Models*. John Wiley & Sons, Chichester, England.

Saltelli, A., Ratto, M., Andres, T., Campolongo, F., Cariboni, J., Gatelli, D., Saisana, M., and Tarantola, S., eds (2008) *Global Sensitivity Analysis - The Primer*. John Wiley & Sons, Chichester, England.

Identifiability Analysis

Links to introductory texts:

Definition of identifiability: <http://en.wikipedia.org/wiki/Identifiability>

Papers:

Brun, R., Reichert, P. and Künsch, H.R. (2001) Practical identifiability analysis of large environmental simulation models, *Water Resources Research* 37(4), 1015-1030.

Renard, B., D. Kavetski, G. Kuczera, M. A. Thyer, and S. W. Franks (2010) Understanding predictive uncertainty in hydrologic modeling: The challenge of identifying input and structural errors, *Water Resources Research*, 46, W05521, doi:10.1029/2009WR008328.

Frequentist Statistics

Links to introductory texts:

Frequentist interpretation of probabilities: http://en.wikipedia.org/wiki/Frequency_probability

Frequentist inference: http://en.wikipedia.org/wiki/Statistical_hypothesis_testing

Frequentist confidence intervals: http://en.wikipedia.org/wiki/Confidence_interval

Books:

Regression analysis:

Seber, G. A. F. and Wild, C. J. (1989) *Nonlinear Regression*. Wiley, New York.

Bates, D. M. and Watts, D. G. (1988) *Nonlinear Regression Analysis and its Applications*. Wiley & Sons, NY.

Rawlings, J.O., Pantula, S.G. and Dickey, D.A. (1998) *Applied Regression Analysis – A Research Tool*. Springer

Hill, M.C. and Tiedeman, C.R. (2007) *Effective Groundwater Model Calibration: With Analysis of Data, Sensitivities, Predictions, and Uncertainty*, Wiley.

Numerics:

Nocedal, J. and Wright, S. J. (2006) *Numerical Optimization*. Springer, 2nd edition.

Bayesian Statistics

Links to introductory texts:

Bayesian interpretation of probabilities: http://en.wikipedia.org/wiki/Bayesian_probability

Bayesian inference: http://en.wikipedia.org/wiki/Bayesian_inference

Markov chain Monte Carlo techniques: http://en.wikipedia.org/wiki/Markov_chain_Monte_Carlo

Books:

Concept-oriented texts:

Gelman, A., Carlin, J.B., Stern, H.S. and Rubin, D.B. (1995) *Bayesian Data Analysis*, Chapman & Hall.

- Box, G.E.P. and Tiao, G.C. (1973) *Bayesian Inference in Statistical Analysis*, Wiley.
- Congdon, P. (2001) *Bayesian Statistical Modelling*, John Wiley & Sons.
- Lee, P.M. (1997) *Bayesian Statistics: An Introduction*, Arnold, 2nd edition.
- Bernardo, J.M. and Smith, A.F.M. (1994) *Bayesian Theory*, John Wiley & Sons.
- O'Hagan, A. and Forster, J. (2009) Kendall's Advanced Theory of Statistics, Volume 2B: Bayesian Inference, Wiley.

Numerical techniques (MCMC):

- Gelman, A., Carlin, J.B., Stern, H.S. and Rubin, D.B. (1995) *Bayesian Data Analysis*, Chapman & Hall.
- Gamerman, D. (1997) *Markov Chain Monte Carlo – Stochastic Simulation for Bayesian Inference*, Chapman & Hall.
- Robert, C.P. and Casella, G. (2004) *Monte Carlo Statistical Analysis*. Springer.

Papers:

Interpretation and controversial discussions of the use of Bayesian statistics:

- Gillies, D. (1991) Intersubjective probability and confirmation theory, *Brit. J. Phil. Sci.* 42, 513-533.
- Ellison, A.M. (1996) An introduction to Bayesian inference for ecological research and environmental decision-making, *Ecological Applications* 6(4), 1036-1046.
- Dennis, B. (1996) Discussion: Should ecologists become Bayesians?, *Ecological Applications* 6(4), 1036-1046.
- Reckhow, K.H. (1990), Bayesian inference in non-replicated ecological studies, *Ecology* 71(6), 2053-2059.
- Berger, J.O. and Berry, D.A. (1988), Statistical analysis and the illusion of objectivity, *American Scientist* 76(2), 159-165.
- Efron, B. (1986) Why isn't everyone a Bayesian? *The American Statistician* 40(1).

Model formulation and implementation:

- Kavetski, D. and M. P. Clark (2011) Numerical troubles in conceptual hydrology: Approximations, absurdities and impact on hypothesis testing, *Hydrological Processes*, 25, 661–670, DOI: 10.1002/hyp.7899.

MCMC:

- Kuczera, G. and Parent, E. (1998) Monte Carlo assessment of parameter uncertainty in conceptual catchment models: the Metropolis algorithm. *Journal of Hydrology* 211, 69-85.

Input uncertainty:

- Kavetski, D., Kuczera, G., and Franks, S. W. (2006) Bayesian analysis of input uncertainty in hydrological modelling: 1. Theory. *Water Resources Research*, 42:W03407, doi:10.1029/2005WR004368.
- Kavetski, D., Kuczera, G., and Franks, S. W. (2006) Bayesian analysis of input uncertainty in hydrological modelling: 2. Application. *Water Resources Research*, 42:W03408, doi:10.1029/2005WR004376.
- Vrugt, J.A., ter Braak, C.J.F., Clark, M.P., Hyman, J.M. and Robinson, B.A. (2008), Treatment of input uncertainty in hydrologic modeling: Doing hydrology backward with Markov chain Monte Carlo simulation, *Water Resources Research*, 44, W00B09, doi:10.1029/2007WR006720.
- Renard, B., Kavetski, D., Leblois, E., Thyer, M., Kuczera, G. and Franks, S.W. (2011) Toward a reliable decomposition of predictive uncertainty in hydrological modeling: Characterizing rainfall errors using conditional simulation. *Water Resources Research* 47, W11516, doi:10.1029/2011WR010643.

Model structure uncertainty/bias:

- Kennedy, M. C. and A. O'Hagan (2001) Bayesian calibration of computer models. *J. R. Statist. Soc. B: Statistical Methodology* 63 (3), 425-464.
- Bayarri, M. J., J. O. Berger, R. Paulo, J. Sacks, J. A. Cafeo, J. Cavendish, C.-H. Lin, and J. Tu (2007) A framework for validation of computer models. *Technometrics* 49 (2), 138-154, 2007.
- Vrugt, J.A., Diks, C.G.H., Gupta, H.V., Bouten, W. and Verstraten, J.M. (2005) Improved treatment of uncertainty in hydrologic modeling: Combining the strength of global optimization and data assimilation, *Water Resources Research*, 41, W01017, doi:10.1029/2004WR003059.
- Kuczera, G., Kavetski, D., Franks, S. W., and Thyer, M. (2006) Towards a Bayesian total error analysis of conceptual rainfall-runoff models: Characterising model error using storm-dependent parameters. *Journal of Hydrology*, 331(1-2): 161–177.
- Yang, J., Reichert, P., Abbaspour, K. C., and Yang, H. (2007) Hydrological modelling of the Chaohe Basin in China: Statistical model formulation and Bayesian inference. *Journal of Hydrology* 340, 167– 182, 2007.
- Reichert, P., and Mieleitner, J. (2009) Analyzing input and structural uncertainty of nonlinear dynamic models with stochastic, time-dependent parameters, *Water Resources Research*, 45, W10402, doi:10.1029/2009WR007814.
- Reichert, P. and Schuwirth, N. Linking statistical description of bias to multi-objective model calibration. *Water Resources Research*, 48, W09543, doi:10.1029/2011WR011391, 2012.

R

- Main page: <http://www.r-project.org>
- R Editor: <http://www.rstudio.com/ide>
- Introduction to R: <http://cran.r-project.org/doc/manuals/R-intro.pdf>
- Reference card to the most important commands: <http://cran.r-project.org/doc/contrib/Short-refcard.pdf>
- An easy accessible introduction to R: <http://cran.r-project.org/doc/contrib/usingR.pdf>