H05: Insights into Environmental/Hydrological Models Using Sensitivity and Uncertainty Analysis and Information Theory

Conveners: Amin Haghnegahdar[1], Saman Razavi[2], Steven Weijs[3]

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Session Description

Proper characterization of uncertainty and information remains a major challenge, and is inherent to many aspects of modelling such as structural development, hypothesis testing and parameter estimation, and the adequate characterization of forcing data and initial and boundary conditions. To address this challenge, methods for a) uncertainty analysis (UA) that seek to quantify uncertainty (and how it propagates through a system/model), and b) the closely-related methods for sensitivity analysis (SA) that evaluate the role and significance of uncertain factors (in the functioning of systems/models), have proved to be very helpful.

This session invites contributions on both theory and/or application of SA/UA methods applicable to all Earth and Environmental models (e.g. climatological or hydrological models). Contributions addressing any or all aspects of sensitivity/uncertainty, including those related to structural development, hypothesis testing, parameter estimation and model calibration, forcing data, and initial and boundary conditions are invited. Particular topics of interest include (but are not limited to):

1) Novel methods for effective characterization of sensitivity and uncertainty
2) Implications of SA/UA for model calibration and validation
3) Impact of input data uncertainty on model learning and performance
4) Single- versus Multi-criteria SA/UA
5) Metric specification for model evaluation

6) Improving the computational efficiency of SA/UA (efficient sampling, surrogate modelling, parallel computing, model pre-emption, etc.)
7) Information-theoretical analysis of uncertainty in (the interface between) models and data

Note: The proposed session is mainly intended for Hydrology and Glaciology, but due to its general scope it can be open to submission for both CGU and CSAFM members.

NOTE: THIS DOCUMENT CONTAINS INFORMATION FOR ALL SESSION SUB-SECTIONS. PRESENTER ABSTRACTS ARE FOUND AT THE END OF THE DOCUMENT.

SCHEDULE MAY BE SUBJECT TO CHANGE.

ORAL SESSION H05a

Chairs: A. Haghnegahdar, S. Razavi & S. Weijs **Room: EOSC 135**

Wednesday, May 31st

TIME	AUTHORS	TITLE
9:00	K.C. Kornelsen & P. Coulibaly	Interdependence of hydrological model parameters and precipitation
9:15	B. Nijssen, G.S. Nearing & Martyn P. Clark	Benchmarking of land models to guide model development and improvement **(Invited)**
9:30	T. Smith, C. Perera & C. Corrigan	Understanding the parameter sensitivities of simple snowmelt-runoff models: Strategies for improved performance and robustness?
9:45	C.A. Kellerher & S.B. Shaw	Hydrologic model suitability over decades: Exploring changes in model performance and parameter sensitivity over 50+ year records
10:00	S. Razavi, R. Sheikholeslami & A. Haghnegahdar	A Comprehensive, Efficient, and Robust Approach for Global Sensitivity Analysis
10:15	J.R. Craig, N. Sgro & B.A. Tolson	How to appraise “new and improved” hydrological model algorithms? – An uncertainty-based evaluation approach

ORAL SESSION H05b

Chairs: A. Haghnegahdar, S. Razavi & S. Weijs **Room: EOSC 135**

Wednesday, May 31st

TIME	AUTHORS	TITLE
14:00	A. Haghnegahdar, S. Razavi & R. Sheikholeslami	Dealing with model crashes in global sensitivity analysis
14:15	S. Ul Islam & S. Dery	Evaluating uncertainties in modelling the snow hydrology of the Fraser River Basin, British Columbia, Canada **(Invited)**
14:30	R. Sheikholeslami & S. Razavi	An Efficient and Robust Sampling Strategy for Uncertainty and Sensitivity Analysis of Environmental Systems Models
14:45	S.V. Weijs	You cannot be surprised about the same thing twice, or the art of reducing predictive uncertainty.
15:00	L.C. Galindo* & S.V. Weijs	An evaluation of rating curve uncertainty through information theory
15:15	A. Kumar* & S.V. Weijs	Exploring the Optimal Channels of Information Flow in BC Hydro's Hydro-meteorological Stations

POSTER SESSION H05

Chairs: A. Haghnegahdar, S. Razavi & S. Weijs **Room: ESB Atrium**

Wednesday, May 31st

Poster No.	AUTHORS	TITLE
P01-H05	M. Rohanizadegan, J. Pomeroy & R. Petrone	Improving meteorological forcing of mountain evapotranspiration calculations

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SUBMITTED ABSTRACTS

H05-04 Interdependence of Hydrological Model Parameters and Precipitation

Kurt C. Kornelsen[1] and Paulin Coulibaly[1, 2]

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Abstract

Conceptual hydrological models are the backbone of operational hydrology for applications such as streamflow/flood forecasting and climate change impact studies. In a typical application a model is calibrated using high quality precipitation data and then used in an operational setting with a different precipitation data set, either from numerical weather prediction, radar, or downscaled climate models. We will demonstrate the strong inter-dependence between model parameters and forcing leading to large model uncertainty, particularly for high flows. Three gauge based high quality forcing data sets were used to calibrate the MAC-HBV model in 72 basins across Canada. The results will be presented from an uncertainty analysis and cross validation experiment to demonstrate the importance of the interaction between the particular characteristics of the chosen precipitation product and model parameters to the simulated flow uncertainty. Hydrological model parameters resulted in the largest source of uncertainty for low flows, whereas precipitation uncertainty and model parameter uncertainty were approximately equal contributors to the overall uncertainty of high flows. Interestingly, when considering total model performance, as expressed by the Nash Sutcliffe Efficiency, the largest source of uncertainty in simulated streamflow was the interaction between model parameters and precipitation forcing. The importance of the interaction term will be discussed as well as its implications for hydrological applications such as streamflow forecasting, climate change impact studies and hydrological stationarity.

H05-07: Benchmarking of land models to guide model development and improvement

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Abstract:
Recent benchmarking studies show that some of the most sophisticated operational land models are outperformed by instantaneous out-of-sample linear regressions extrapolated globally. These outcomes suggest that modern land models do not efficiently use the information that is available to them, but we lack a transparent, robust, and agreed-upon process for systematic model improvement. Most land models have a convoluted heritage and model enhancements are typically incorporated in a rather ad-hoc fashion with limited attention given to process coupling, numerical error control, systematic tests, and model extensibility and flexibility. As a result, it can be very difficult to robustly identify and incorporate new modeling approaches and evaluate competing modeling alternatives. This presentation summarizes experiments with the Structure for Unifying Multiple Modeling Alternatives (SUMMA) to evaluate alternative methods for constructing land models and diagnose the changes that result from different model implementations. Of particular interest is the use of benchmarking and information transfer analysis to develop a process for systematic land model development and improvement.

H05-02 Understanding the parameter sensitivities of simple snowmelt-runoff models: Strategies for improved performance and robustness?

Tyler Smith[1], Chamil Perera[1] and Casey Corrigan[1]

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Abstract

Hydrologic models are used extensively in water resources planning and management and, as such, represent a significant tool for understanding, predicting, and responding to the impacts of water on society and society on water resources. Given this central role, the validity of hydrologic models is imperative. While extensive focus has been paid to improving hydrologic models through better process representation, better parameter estimation, and better uncertainty quantification, significant challenges remain. In this study, we explore the sensitivity / variability of parameterizations from simple, coupled snowmelt-runoff models for a number of alternative model calibration scenarios and its impact on model performance, robustness, fidelity, and transferability. Results are considered at the Tenderfoot Creek Experimental Forest (TCEF), located in central Montana, USA, an area that consists of several well-studied and modeled headwater watersheds with a wealth of quantitative and qualitative hydrologic information useful to the analysis of model performance assessments. Our analysis highlights the sensitivity of coupled snowmelt-runoff model parameterizations to alterations in calibration approach, underscores the idea of information content in hydrologic modeling, and provides insight into potential strategies for improving model robustness / fidelity.

H05-08: Hydrologic model suitability over decades: Exploring changes in model performance and parameter sensitivity over 50+ year records

Christa A. Kelleher[1] and Stephen B. Shaw[2]

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Abstract
Hydrological models are useful tools for interrogating systems and predicting future responses to climate change. However, model applications are often problematic for streamflow simulations across long data records, with unclear drivers for declines in model performance through time. Furthermore, model performance, expressed in terms of Nash-Sutcliffe Efficiency or other model-based error functions, may remain high while the water balance is poorly matched. To address these issues, we explored potential sources of error for temporal declines in model performance using parameter uncertainty analysis, model sensitivity analysis, and changes to model structure. These analyses were applied to two conceptual hydrologic models, Hymod and HBV, used to predict streamflow for several watersheds in the Great Lakes region. First, we investigated the impact of potential evapotranspiration method on model performance during a five-year calibration period and 50+ years beyond this period. We found unsurprisingly that model performance, particularly for water balance errors, declines through time when static parameter sets are used to simulate streamflow, but that choice of a PET model is perhaps a more important choice for determining model performance across the entire record. Secondarily, we explored potential changes to model structure and parameter values as explanations for model failure to match the water balance through time. We discovered that changes to soil parameters may adjust water balance errors, but that this approach may have limited physical realism. Alternatively, we introduce a modifier on PET, and evaluate its efficacy to explain external changes to climate and internal changes to watershed characteristics. Ultimately, these types of analyses highlight where models may succeed and fail, and encourage us to link model behavior and performance to physically-based changes. We argue that similar analyses will only be more important as we use conceptual watershed models to understand future scenarios of climate change at similar time scales.

H05-01: A Comprehensive, Efficient, and Robust Approach for Global Sensitivity Analysis

Saman Razavi[1], Razi Sheikholeslami[1], Amin Haghnegahdar[1]

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Abstract

This presentation outlines the features, capabilities, and recent developments of VARS (Variogram Analysis of Response Surfaces), which is a general framework for Global Sensitivity Analysis (GSA). VARS utilizes the variogram/covariogram concept to characterize the full spectrum of sensitivity-related information, thereby providing a comprehensive set of "global" sensitivity metrics with minimal computational cost. VARS is unique in that, with a single sample set (set of simulation model runs), it generates simultaneously three philosophically different families of global sensitivity metrics, including (1) variogram-based metrics called IVARS (Integrated Variogram Across a Range of Scales - VARS approach), (2) variance-based total-order effects (Sobol approach), and (3) derivative-based elementary effects (Morris approach). VARS is also enabled with two novel features; the first one being a sequential sampling algorithm, called Progressive Latin Hypercube Sampling (PLHS), which allows progressively increasing the sample size for GSA while maintaining the required sample distributional properties. The second feature is a "grouping strategy" that adaptively groups the model parameters based on their sensitivity or functioning to maximize the reliability of GSA results. These features in conjunction with bootstrapping enable the user to monitor the stability, robustness, and convergence of GSA with the increase in sample size for any given case study. VARS has been shown to achieve robust and stable results within 1-2 orders of magnitude smaller sample sizes (fewer model runs) than alternative tools.

H05-05 Dealing with Model Crashes in Global Sensitivity Analysis

Amin Haghnegahdar[1], Saman Razavi[1], Razi Sheikholeslami[1]

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Abstract

Global Sensitivity Analysis (GSA) is very important for understanding of the model behavior and subsequently, improving its predictions via, for example, identifying the most influential factors on model predictions. GSA methods often involve running a model thousands of times. One of the main challenges during this process, especially for complex physically-based models with many parameters, is the crash of model simulations. These crashes are mainly caused by "unrealistic" combinations of parameter sets violating the numerical representation of the "physical" processes inside the model. These crashes can be very computationally costly for GSA, because they can waste the rest (e.g., thousands) of model runs and prevent completion of GSA. Modellers, commonly address this issue by reducing (perhaps a few times) the ranges for parameter(s) responsible for the crashes in a hope to prevent them for the next GSA experiment. In this study, we explore alternative innovative strategies to deal with model crashes during GSA that are more efficient as they don't require re-running the entire GSA experiment again. For this purpose, we apply a new variogram-based GSA technique, VARS (Variogram Analysis of Response Surfaces), to a test function and a hydrological model. Furthermore, we provide guidelines on the suitability of each strategy based on the sampling approach used within the GSA method.

H05-06: How to appraise “new and improved” hydrological model algorithms? – An uncertainty-based evaluation approach

James R. Craig[1], Nicholas Sgro[1], and Bryan A. Tolson[1]

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Abstract

New model algorithms are frequently introduced in the hydrologic modelling literature. The foregoing assumption is that each of these new algorithms is somehow an improvement over existing methods for representing the same hydrologic process: the algorithm may be better at capturing the physics, may be better at capturing the impacts of landscape heterogeneity, or somehow better at characterizing the phenomenon seen in the field. However, the means by which we evaluate the skill of these algorithms is typically relatively naïve, particularly since the algorithm is often part of a much more complicated model with a number of parameters adjusted during calibration. Because the output signal of interest (typically the hydrograph) is due to the net contributions of multiple interacting algorithms, purported advances in a single algorithm may lead to little or no model skill improvement, as evaluated in validation. The standard means of evaluating a model improvement – history matching to data with and without the improvement – is easily misinterpreted as it does not address the critical issue of model compensation, i.e., one part of the model may compensate for deficiencies in other parts during the calibration process. Here, a straightforward approach is proposed for comparing two model algorithms in terms of their ability to provide distinguishably different performances in model validation against observed data, given some uncertainty in observation data and forcings. The key output of the approach is a statistical assessment of whether we can differentiate between the performance of two contrasted algorithms. The tests may be used to support model improvement, model selection, or hypothesis testing about system function. The results suggest that simpler models justified by the available data may be more useful than complex physically-based models which fit the data at the cost of decreased performance in validation.

H05-03 Evaluating uncertainties in modelling the snow hydrology of the Fraser River Basin, British Columbia, Canada

Siraj Ul Islam and Stephen J. Déry

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Abstract

This study evaluates predictive uncertainties in the snow hydrology of the Fraser River Basin (FRB) of British Columbia, Canada, using the Variable Infiltration Capacity (VIC) model forced with several high-resolution gridded climate datasets. These datasets include the Canadian Precipitation Analysis and the thin-plate smoothing splines (ANUSPLIN), the North American Regional Reanalysis (NARR), University of Washington (UW) and Pacific Climate Impacts Consortium (PCIC) gridded products. Uncertainties are evaluated in the driving datasets, optimization of model parameters, and model calibration during cool and warm phases of the Pacific Decadal Oscillation (PDO). The inter-comparison of the forcing datasets (precipitation and air temperature) and their VIC simulations (snow water equivalent (SWE) and runoff) reveal widespread differences over the FRB, especially in mountainous regions. The ANUSPLIN precipitation shows a considerable dry bias in the Rocky Mountains whereas the NARR winter air temperature is 2□C warmer than the other datasets over most of the FRB. The USPLINVIC simulation shows considerable underestimation of runoff when compared with the observation for the Fraser River at Hope. The NARR-VIC simulation yields more winter and spring runoff and earlier decline of flows in summer due to a nearly 15-day earlier onset of the FRB springtime snowmelt. The elevation-dependent changes in the maximum SWE (maxSWE) are more prominent at higher elevations of the Rocky Mountains where the PCIC-VIC simulation accumulates too much SWE and ANUSPLIN-VIC yields an underestimation. Additionally, at each elevation range, the day of maxSWE varies 10 to 20 days between the VIC simulations. The VIC calibration process shows that the choice of the initial parameter range plays a crucial role in defining the model hydrological response. Furthermore, the calibration process is biased toward cool and warm phases of the PDO and the choice of proper calibration and validation time periods is important for the experimental setup.

H05-P2: An Efficient and Robust Sampling Strategy for Uncertainty and Sensitivity Analysis of Environmental Systems Models

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Abstract

Advanced complex earth and environmental models are often characterized by a large parameter space and a long run time. These two features prevent adequate implementation of sampling-based analysis such as sensitivity and uncertainty analysis, which require running these computationally expensive models thousands of times to adequately explore the parameter space. Therefore, developing efficient sampling techniques that scale with the size of the problem, computational budget, and users' needs is essential. In this presentation, we propose a new sequential sampling strategy, called Progressive Latin Hypercube Sampling (PLHS), which provides an increasingly improved coverage of the parameter space, while satisfying pre-defined requirements. The original Latin hypercube sampling (LHS) approach generates the entire sample set in one stage; whereas, PLHS generates a series of smaller sub-sets (also called 'slices') while: (1) each sub-set is Latin hypercube and achieves maximum stratification in any one dimensional projection; (2) the progressive addition of sub-sets remains Latin hypercube; and thus (3) the entire sample set is Latin hypercube. Consequently, PLHS preserves the intended sampling properties throughout the sampling procedure. PLHS is better than other methods, particularly because it nearly avoids over- or under-sampling. Through different case studies, we show that PHLS has multiple advantages over the one-stage sampling approaches, including improved convergence and stability of the analysis results with fewer model runs. In addition, PLHS can help to reduce the total run time by allowing termination of simulations when the desired level of quality (e.g., accuracy, and convergence rate) is achieved. [244 words]

H05-10: You cannot be surprised about the same thing twice, or the art of reducing predictive uncertainty.

Steven V. Weijs[1]

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Abstract
From an information-theoretical perspective, predictive uncertainty of a hydrological model is equal to the information content of the observations of the variable we tried to predict, evaluated ex-post for someone who had the forecast available at the moment of observation. For someone with perfect predictions, observing reality does not give any information. Other interpretations of predictive uncertainty are the average surprise caused by the observations (you cannot be surprised about the same thing twice), and the description length needed to describe observations when the forecast is known. These analogies, made possible by the overarching perspective of information theory, throw new light, among others, on the value of probabilistic forecasts over deterministic forecasts, the role of observational uncertainty in model calibration, and calibration as the process of models learning from data. This presentation summarizes some of the insights that are obtained when taking the information-theoretical perspective on modeling.

H05-011: An evaluation of rating curve uncertainty through information theory

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Abstract

Rating curves play a vital part in hydrology for producing streamflow time-series. The derived streamflow is an integral component to any hydrological study and therefore requires proper quantification of not only a point value, but also the best uncertainty band. This research focuses on developing a rating curve model that is more grounded on hydraulic principles and incorporates as much available physical information about the stream characteristics as possible. In doing so, a reduction in modeling error is expected, as well as better estimates in the interpolated and extrapolated regions of the rating curve.

A proper avenue for developing the hydraulic framework of the model could be through the use of the index-velocity method. This approach has proliferated among agencies like USGS and WSC, and could be a useful method for developing our rating curve since the method builds on collection of more hydraulic information than stage and discharge alone. Proper uncertainty quantification and updating is also investigated through various means, including the use of information theory to analyse predictive information. Mutual information between available hydrometric data and the target discharge is evaluated to determine which sources of information most help reduce streamflow uncertainty, and how these sources interact. This could be useful to inform what model complexity is warranted for the rating curve.

H05-12: Exploring the Optimal Channels of Information Flow in BC Hydro's Hydro-meteorological Stations

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Abstract

Hydro-meteorological stations are of prime importance for observing the hydrology of the catchment area and make decisions based on the observed values. For a hydro-electric utility, such as BC Hydro, major decisions on water release from reservoirs depend much on the reliability of the hydro-meteorological data. There has been a growing interest in achieving optimal monitoring network using information theoretic measures. Much of the recent studies have been carried out by taking long-term dataset or temporal subsets to capture seasonal variability. In this research work, we try to explore how does the information flow from different hydro-meteorological stations vary and how different sources interact to inform the variable of interest. Thereby, we try to explore the optimal information flow path in the BC Hydro network. This research study can be used to understand complex temporal dependencies that exist in the hydro-meteorological network and can help the hydro-electric utilities to achieve more reliability on the observed hydro-meteorological data.

H05-P01 Improving meteorological forcing of mountain evapotranspiration calculations

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Abstract
In mountains, the role of diurnal wind due to differential heating and radiation in controlling evaporative fluxes is not well understood. This paper aims to improve upon predictions of diurnal wind flows and evaporative fluxes in a complex topography. The connection between turbulent wind, friction velocity, horizontal advection, and the importance of aerodynamic resistance in evapotranspiration will be explored. Numerical Weather Prediction (NWP) models operational at sub kilometre scale are suggested as a possible method to resolve near surface small scale properties over heterogeneous terrain. Forecasting of wind flows in variable topography of mountainous terrain requires high resolution numerical simulations, and predictions of thermotopographically driven flows in complex terrain are sensitive to initial surface conditions, and spatial resolution. Tests are performed using the Weather Research and Forecasting (WRF) model in Fortress Mountain area in the Kananaskis Valley, Alberta, to investigate model performance in creating driving data for evapotranspiration calculations when compared to sounding measurements and surface station data for fair weather summer days. Simulations were performed for four nested grid spacing (8.1, 2.7, 0.9, 0.3 km), and predictions are evaluated for fine resolution domain (0.3 km) and three consecutive days (9 am - 6 pm; July 18 - 20, 2016). Sensitivity of the results to initial terrestrial data, boundary and surface conditions are examined, with future work aiming at evaluating various turbulent schemes, and including large eddy simulations in WRF runs. Improvements in resolution of topographic data, land cover, and soil moisture improves predictions of surface wind and fluxes in fine resolution domain. High resolution predictions of wind will likely help to investigate the influence of valley and slope winds in an Alpine environment in controlling evapotranspiration by examining correlation between wind components and vertical/horizontal vapor exchange, and the threshold of wind strength at which fluxes become independent of wind.

Presentation type: Poster