Workshop 8: Complexity and uncertainty and a new role for models

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Introduction

Complexity is one of the main issues of today's environmental problems. We are now faced with the challenge of solving problems where time delays, feedback loops, non-linearities and system interconnectedness make prediction particularly difficult. In this realm small events can have big effects, causes are multiple and separated in time, and problems transcend interdisciplinary arenas. Additionally, we, with our beliefs and perceptions about nature, are part of the problem to be solved influencing the way in which we identify and conceptualize reality, and drive inference from it. These characteristics make environmental problems intrinsically uncertain, difficult to predict and to manage.

When dealing with these types of problems, computer models play a central role. They are crucial to structure our understanding of complex systems. A model constitutes an abstraction of a system existing in reality built for a particular purpose. As such, it can be manipulated, evolved and analyzed in place of the real system. However, developing an abstract description of a complex system is not easy. The uncertainty and indeterminacy present in complex systems, drive modelers to make subjective decision about the behavior of the system and its most relevant features. This implies embedding a series of nested, and sometimes iterative and evolving assumptions in the model. This in turn, incorporates uncertainty into the model at various levels; affecting the model, the way in which it is developed and the value of its inference.

But what does it mean for modelers and the way we do modeling?

First, complexity affects the way in which models are implemented. Traditionally, models are thought to be developed as a sequential of three main activities: *conceptualization*, *implementation* and *evaluation*. However, modeling complex systems requires an iterative process of model formulation, more like a trial and error approach, where modules at different levels of detail are considered in conjunction with different assumptions and hypotheses about how the real system works. As a result, the simple sequence of steps of conceptualization-implementation-evaluation, in reality becomes a series of cycles of conceptualization, implementation, re-conceptualization, code modification, implementation, etc. This iteration typically occurs over the course of time as new knowledge and ideas are generated and subsequently used to modify existing models.

Second, from a conceptual standpoint, the presence of complexity shifts the goals of modeling from the creation of an exact replication of a system in which uncertainties ought to be eliminated, to being a creative process in which the different sources of uncertainties can be embraced. It enlarges the role of models as an "external" representation of reality. Models, and in particular the whole process of model development and application, may be perceived as part of a learning process to make transparent different perspectives and frames. Current model applications expand beyond prediction, to include exploratory analyses, communication and learning. This in turn, changes the type of knowledge needed and how this knowledge is elicited. But most important of all, it changes the inferences making possibilities.

Even though these are not novel ideas, and despite the increasing awareness about these issues, practical applications commonly fail in addressing the complexity and uncertainty of current problems. Generally, complexity gets diluted in simplifications done during model conceptualization and uncertainties are avoided as much as possible as being something undesirable. Commonly, once a model is developed, the assumptions and subjective decisions embedded into model representation are forgotten and only single causes of uncertainties are, sometimes addressed. For many, the presence of uncertainty completely invalidates the use of models to drive inference about a real problem. But, by avoiding complexity when modeling, aren't we throwing the baby out with the bath water?

What we believe is necessary are approaches that bring symmetry to our inference capacity. Complexity has brought a different way of viewing and understanding systems, in parallel, the modeling arena has seen the emergence of several new methods that are able to embrace these new concepts. However, despite these great advances, the goal of looking at a single best, simple and objective explanation still permeates the modeling exercise. We suggest that a more comprehensive way of dealing and handling complexity and uncertainties in modeling is still needed.

Brugnach and Pahl Wostl (in prep) in their paper identified four major modeling purposes that are important for understanding and managing complex human environmental systems: prediction, exploratory analysis, communication and learning. Each of these purposes highlights different system characteristics, role of uncertainty, the properties of the model and its validation. They argue that uncertainty has no meaning in isolation, but only relative to a particular modeling activity and the purpose for which a model is developed (e.g., when a model is developed for predictive purposes uncertainty needs to be eliminated as much as possible, while when a model is developed for exploration uncertainty can be considered a source of creative thoughts). In light of these concepts, the modeling activity is re-contextualized, from being a process that aims at representing objectively an external reality, to one that can only be defined according to the characteristics of the problem at hand: its level of complexity, the knowledge available, the purpose of the model and the modeling tools.

The purpose of this workshop is to bring together these concepts at an operational level and to develop as final product a joint paper. The idea is to illustrate through study cases how the theoretical concepts presented in the paper above mentioned, can be put into practice. We consider this is important to improve our understanding of models and the whole modeling process, allowing us to better design and implement effective modeling strategies. The study cases presented correspond to the contributions made by the workshop participants, showing applications from a range of different fields.

The first case, “*Modelling in transition research: the role of unpredictable innovations”*, discusses the role of models in transition research, focusing on uncertainties that result from the creation, selection and adaptation to innovations. Here models constitute an exploratory device that can be used to better understand when and why regimes break up and a transition sets off. Genetic algorithm is presented as a modelling tool able to capture the evolutionary dynamics of a changing regime. The second case, *Identification of major sources of uncertainty in IWRM and current approaches for including them in IWRM,* discusses the role of models in integrated water resource management where uncertainties are of key importance. In this example, models serve for many different purposes and different modeling strategies appear relevant during the different phases of the managing cycle. The third case, “*Questions and methods to model emergence of land use patterns in coastal zone area”,* discusses the role of models to understand costal land use pattern generation as emerging from individual stakeholder interactions. Here, models constitute mainly an exploratory device that allows considering stakeholder behavior and the associated uncertainties at multiple levels of aggregation. Agent based models is the modeling strategy proposed and the treatment of uncertainty suggests various participatory methods, such as scenario development and role playing games. The forth case, *Issues of uncertainty, complexity, scale and transferability in river water quality modeling with a focus on the Saale River, Germany,* discusses issues of model complexity and uncertainty in river water quality models, focusing in uncertainties associated with parameters, data input and model structure, as well as scaling and transferability problems. The fifth case, *Exploring regionalization of hydrological behavior within a model averaging framework,* discusses the topic of complexity and uncertainty in a case study of Australian catchments where a model averaging framework is utilised for ungauged streamflow prediction.