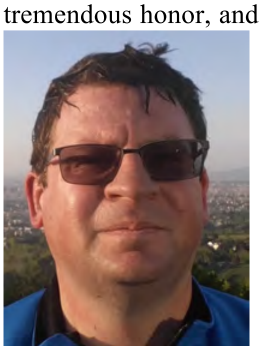
A Fellow Speaks: Advancing large-domain hydrologic simulation and prediction

Martyn Clark, National Center for Atmospheric Research, USA

I am delighted to be elected a Fellow of AGU. It is a tremendous honor, and I sincerely thank my colleagues



for their efforts to nominate and support me. I am also very grateful to my colleagues for sharing in this scientific adventure – it's truly been an exciting ride over the years, where I've had the opportunity to work with influential and provocative colleagues across many different disciplines to advance the science of large-domain hydrologic simulation and prediction.

It all really started for me in my graduate work in snow hydrology in the early 1990s at the University of Canterbury in New Zealand. I had a wonderful opportunity to conduct the research for my Masters thesis at the Broken River ski field in Craigieburn Range. I started my research during winter, learned to ski, and the managers of the ski field gave me the keys to the lodges and rope tows after the field had closed for the season. Now, Broken River was a club field run by volunteers. The four-wheel drive road to the field was only open in the summertime, requiring a 30-minute walk up a steep trail (fun times with car batteries and data loggers in your backpack). And the rope tows were a single rope going from the bottom to the top of the mountain, powered by a tractor in the shed at the bottom. You rode the rope tows by attaching a nutcracker to your climbing harness, flicking the nutcracker over the rope as you careened up the hillside, and hung on for dear life as the nutcracker rattled through the pulleys. The research was also thrilling – I got to study snowpack energetics during large melt events in warm and windy conditions when both the sensible and latent heat fluxes were directed toward the snow surface, and I got to study the heterogeneity of melt water through snow using spatial surveys of volumetric liquid water in snow, dye tracing experiments, and a "thick section cutter" to extract and photograph sections of the snowpack.

My research over the years has focused on advances in large-scale hydrologic simulation and prediction. I've worked on developing models and methods to simulate hydrologic processes, to portray the potential impacts of climate change on water resources, and predict streamflow on time scales ranging from days to seasons. This work has included developments in process-based hydrologic modeling, ensemble data assimilation, probabilistic quantitative precipitation estimation, model evaluation, climate dynamics, and optimization. I've had the benefit of working at the interface between science and applications; for example, developing a streamflow prediction system for New Zealand, and contributing to water security assessments in the USA.

Nowadays there is a problem that gets me especially excited – improving physically motivated hydrologic model simulations over large geographical domains. I'm excited about this problem, in part, due to its difficulty, since developing realistic hydrologic simulations across large domains has arguably been one of the greatest challenges in modern hydrology. The thing that really gets me excited, to be honest, is that the juxtaposition of several synergistic advances in hydrologic science provides us with the necessary tools to substantially accelerate modeling improvements.

The advances that interest me here cut across all areas of hydrologic model development, application, and evaluation. One advance is the development of multiple hypothesis modeling frameworks, now used by numerous modeling groups. These frameworks enable decomposing a model into the individual decisions made as part of model development, evaluating each modeling decision in isolation, and identifying key model weaknesses and model development needs. Another advance is the effort to improve the theoretical underpinnings of hydrologic models by bridging the gap between model algorithms and the process explanations emerging from research watersheds. Important model improvements gained from research watersheds include better representation of small-scale variability and hydrologic connectivity for multiple processes across a range of space and time scales. Still another advance is the development of multi-scale methods to relate geophysical attributes to model parameters, improving estimates of the spatial variability in the storage and transmission properties of the landscape. In addition, we now have better spatial information on climate, topography, vegetation, soils, and the human impacts on the terrestrial water cycle, including probabilistic information necessary to characterize hydrologic model uncertainty. And, perhaps most important, through applications of information theory we have advanced our ability to quantify how effectively models use the available information, providing an estimate of system predictability and identifying opportunities to improve models. Taken together, these advances provide the ingredients to improve model fidelity, to improve the extent to which models faithfully represent dominant processes; and to improve estimates of model uncertainty and information use, in order to better define tractable paths toward model improvement.

I expect that the hydrologic modeling community will undergo a remarkable transformation over the next five years. First, I expect that the current calls for a community hydrologic model will result in concrete efforts to unify hydrologic modeling activities. This will result in greater engagement of field scientists in model development and greater collaboration across diverse modeling groups, resulting in substantial improvements in the physical realism and predictive capabilities of hydrologic models. I expect that the community will be much more effective and efficient in sharing data and model source code, not just by making models and data publicly available, but, critically, integrating models and data in widely-used analysis frameworks and developing model standards to simplify the sharing of source code in models developed by different groups. Second, I expect that many in the hydrologic modeling community will focus attention on advancing process-oriented approaches to estimate spatial fields of model parameters. Such focus will give the parameter estimation problem the scientific attention that it deserves, rather than the far-too-common approach where parameter estimation is simply a "tuning exercise" in model applications. This focus on parameter estimation is necessary to improve the physical realism and applicability of process-based models. Third, I expect that the community will substantially advance capabilities in model analysis, providing important insights on why models behave badly and what can be done to address model inadequacies. Fourth, I expect that hydrologic modeling advances will be used much more rapidly in applications. The modeling advances on the horizon will substantially improve the skill of drought monitoring and prediction, flood and water supply forecasting, coupled environmental prediction, and a broad variety of hydrological and ecological impact assessments. My colleagues often tell me that I have unrealistic expectations – I hope that they are wrong in this case, since I believe that the modeling transformation defined here is critical for the vitality of hydrologic science.

I very much look forward to the future. I believe that the convergence of synergistic research advances places us on the cusp of a new era in hydrologic modeling, and, as a community, we will rapidly transform what hydrologic science can offer to society.

Onward!