Report on the “Modelling Change in Cold Regions” Workshop
Held on September 28–30, 2015
National Hydrology Research Centre, Saskatoon SK

Workshop Summary

The Changing Cold Regions Network (CCRN) held a three-day modelling workshop in September 2015, hosted by Environment Canada at the National Hydrology Research Centre in Saskatoon. The workshop was aimed at reviewing and evaluating progress across our Themes, including fine-scale and large-scale hydrological, hydro-ecological, and atmospheric modelling, and in particular addressing issues involving the diagnosis and prediction of change. This brought together a large group of researchers from within the network, other Canadian university and government collaborators, and several of our international collaborators who provided important keynote talks. A total of 41 oral presentations were given, which are available for viewing on our webpage (www.ccrnetwork.ca). There were many fruitful discussions that allowed participants to share insights and advance the research agenda on a number of important issues such as understanding the sources and effects of uncertainties in our models, challenges and priorities in scaling up from fine- to large-scale model application, the need for better constraint of model parameters and physical realism in models, and our ability to distinguish change from model uncertainty in historical sequences and future projections. Progress was made in solidifying aspects of CCRN’s modelling strategy, including definition of some driving datasets and approaches for simulation of land–atmosphere feedbacks and future climate, which will be supported through both network activities and a collaborative partnership with the Canadian Network for Regional Climate and Weather Processes (CNRCWP), led by Laxmi Sushama. Other important collaborative linkages were also made during the workshop, and will continue to be fostered.

We wish to express our thanks to all those who contributed and made this workshop a big success, especially those who travelled far to join us. We are also grateful to Environment Canada and the National Hydrology Research Centre for hosting us.

Chris M. DeBeer
CCRN Project Manager

Participants

Melkamu Ali (U of S)  Julian Brimelow (EC)  Bruce Davison (EC)
Emily Anderson (U of S)  Tom Brown (U of S)  Chris DeBeer (U of S)
Rehan Anis (U of S)  Martyn Clark (NCAR)  Samaneh Ebrahimi (U of C)
Holly Annand (U of S)  Jono Conway (U of S)  Vincent Fortin (EC)
Amin Haghnegahdar (U of S)  Jeffrey McKenzie (McGill U.)  Kevin Shook (U of S)
Manuel Helbig (U de M)  Samson Mengistu (U of S)  Craig Smith (EC)
Warren Helgason (U of S)  Joe Melton (EC)  Chris Spence (EC)
Andrew Ireson (U of S)  Ali Nazemi (Concordia U.)  Jilmarie Stephens (UBC)
Hammad Javid (U of S)  Saskia Noorduijn (U of C)  Maciej Stetkiewicz (U of S)
Michel Jean (EC)  Xicai Pan (U of S)  Laxmi Sushama (UQAM)
Sebastian Krogh (U of S)  Vanessa Pedinotti (U of S)  Julie Thériault (UQAM)
Sopan Kurkute (U of S)  Patricia Pernica (U of S)  Garth van der Kamp (EC)
Barret Kurylyk (U of C)  AL Pietroniro (EC)  Thorsten Wagener (U. Bristol)
Dennis Lettenmaier (UCLA)  Dhiraj Pradhananga (U of S)  Howard Wheater (U of S)
Yanping Li (U of S)  Dan Princz (U of S)  Daqing Yang (EC)
Jinfeng Liu (Chinese Academy of Sciences)  Kabir Rasouli (U of S)  Fuad Yassin (U of S)
Zhibang Lv (U of S)  Saman Razavi (U of S)  Omer Yetemen (U of S)
Chris Marsh (U of S)  Gonzalo Sapriza-Azuri (U of S)  Wei Yu (EC Dorval)
Jeff McDonnell (U of S)  Lucia Scaff (U of S)

Workshop Sessions and Presentations

Introduction (Monday, September 28)
- Workshop introduction: The Changing Cold Regions Network (Howard Wheater)
- CCRN’s modelling strategy (John Pomeroy)
- Overview of Environment Canada science and research in hydrometeorology and water cycle prediction – adventures in uncertainty (Al Pietroniro)

Part I – Developments in Process-Based Modelling (Monday, September 28)
- Keynote: Advances in land surface and hydrologic modelling (Martyn Clark)
- Precipitation type formation and evolution in complex terrain (Julie Thériault)
- Atmospheric boundary layer dynamics; drivers and implications for surface lapse rates over the Athabasca Glacier, Columbia Icefield (Jono Conway)
- Accounting for the hysteretic affect in canopy conductance modelling (Jilmarie Stephens)
- Advances in distributed modelling of mountain snow processes in forested and alpine terrain (John Pomeroy)
- Sensitivity and compensation in the spring surface energy balance in a mountain basin (Chris Marsh)
- A dual pathway heterogeneous flow snow model (Nicholas Leroux)
- Evaluation of SNODAS SWE data in western Canadian environments and its correction by assimilating into a cold regions hydrological model (Zhibang Lv)
- A glacier snow and ice hydrological model for CCRN (Dhiraj Pradhananga)
- Static energy and mass balance sensitivity of glaciers in the Canadian Rockies: a case study of Haig Glacier (Samaneh Ebrahimi)
- Simulation of lake heat fluxes by the Canadian Small Lake Model: offline performance assessment (Patricia Pernica)
• Towards a large scale modelling of wetlands water dynamics in northern basins (Vannessa Pedinotti)
• Investigating contributing area dynamics and its recurrence (Samson Mengistu)
• Recent advances in modelling the thermal regime of frozen ground (Barret Kurylyk)
• Cold-regions groundwater modelling status and challenges (Jeff McKenzie)
• Variable contributing area, storage dynamics and synthesis of flow frequency (Kevin Shook)
• Catchment scale estimation of depression-focused recharge (Saskia Noorduijn)

**Part II – Developments in Land Surface Schemes (Tuesday, September 29)**

• The Canadian Network for Regional Climate and Weather Processes (CNRCWP) (Laxmi Sushama)
• Simulating carbon and water balances in the southern Boreal Forest (Omer Yetemen)
• CCRN: Land surface schemes intercomparison project (Andrew Ireson)
• The evaluation of coupled WRF +Noah-MP and 1-D offline Noah-MP at the FLUXNET sites over Canada (Yanping Li)
• Recent advances in Environment Canada's CLASS-CTEM modelling framework and opportunities for future collaboration (Joe Melton)

**Part III – Developments in Large-Scale Modelling (Tuesday, September 29)**

• **Keynote:** Representing cold climate processes in macroscale land surface models (Dennis Lettenmaier)
• Modelling studies of regional climate of western Canada using 4-km WRF (Sopan Kurkute)
• Recent progress in hydrological modelling at CMC (Vincent Fortin)
• MESH developments in the Bow River basin and elsewhere (Bruce Davison)
• Modelling reservoirs in the Saskatchewan River basin (Ali Nazemi)
• SaskRB modelling: A multi-objective calibration approach for identification of hydrological models using streamflow and satellite water storage data (Fuad Yassin)
• Model structure and initial conditions in hydrological land surface models for cold regions (Gonzalo Sapriza-Azuri)
• Sensitivity analysis: insights for model parametrization (Saman Razavi)

**Part IV – Modelling for the Diagnosis of Change (Wednesday, September 30)**

• **Keynote:** Understanding the time-varying importance of different uncertainty sources in hydrological modelling using sensitivity analysis (Thorsten Wagener)
• Sensitivity of snow and streamflow regimes to climate and vegetation changes in mountain basins (Kabir Rasouli)
• Effects of climate variability on hydrological processes in Marmot Creek: approach and results (Evan Siemens)
• Future hail characteristics using HAILCAST and well-behaved dynamically downscaled regional climate models (Julian Brimelow)
• Diagnosing the hydrological impacts of climate change in an Arctic basin (Sebastián Krögh)
• Diagnosing Land Use Change Impacts in a Canadian Prairie Catchment (Xing Fang)
• Diagnosing controls on basin-wide snowmelt during rain-on-snow floods (Nic Wayand)
• Wildfire, post-fire regrowth, and permafrost thawing: Diverging boreal forest tree cover trends across the Taiga Plains (Manuel Helbig)
• Watershed discretization and parameter sensitivity (Amin Haghnegahdar)

Synthesis of Workshop Discussions and Outcomes

Part I of this workshop was on fine-scale, process-based modelling developments, and began with a keynote from Martyn Clark on advances in land surface hydrological modelling. Following this talk, discussion began with a key challenge: where are we going in terms of model resolution, and with the increasing focus on hyper-resolution atmospheric modelling capability, where does this leave the hydrological community? Martyn responded by noting there is often a hope in hydrology that as we increase the horizontal resolution things will just get better, but we need to recognize the limiting uncertainties. We need to be in the middle between two extremes—on the one hand assuming we know too much (e.g. process-based modelling using hard-coded parameters and treatment of very uncertain parameters as physical constants), and on the other assuming we know too little (e.g. omission of physical treatment of key processes and inferring knowledge through the calibration process). This led to a productive discussion dealing with issues of model uncertainty, parameter estimation and constraints, future scenarios and methodology (e.g. we cannot rely on the past as a guide to the future, and projections are uncertain), and how far we can get with increasing model complexity. It was expressed that better realism of the models doesn’t necessarily require more complexity.

Further discussions following the presentations in Part I also dealt with these general issues and addressed matters arising from the various fine-scale process modelling initiatives described. A challenge is how to scale this work up in terms of application, with increasing uncertainty coming into play at larger scales and under a future changing environment. It was noted there is danger in complacency in thinking that current generation models can handle the effects of non-stationarity. The discussions centered on questions/topics such as how much detail is needed for large-scale simulation and what are the benefits, how can effective spatial representations be employed, and to what degree and where do we need to focus on improving model sub-grid parameterizations vs. explicit representation of variability? A point was made that performance depends on how the models are used—in a predictive sense, uncertainties can be a major limiting factor, but for examination of sensitivity, we can at least get a sense of direction of change if there is robustness under certain variability, which can be useful in decision making. In the discussions there was also focus on large-scale driving data sets and their uncertainties, downscaling methodologies for climate model outputs, and the assimilation of large-scale remotely sensed and other data products in the models.

On the second day, Laxmi Sushama provided an overview of the CNRCWP (a parallel network under the NSERC Climate Change and Atmospheric Research program), and her participation in the workshop was helpful for exploring synergies and opportunities to bring the two networks together. Discussions during Part II of the workshop dealt with several collaborative issues, including the community involvement on development of the CLASS and CTEM models and the possibility for future coordinated efforts between CCRN and CNRCWP on a multi-layer snow model and on glacier dynamic modelling. CLASS has a long standing history of community development, carried on in CCRN, and there is viability
moving forward with these models. Some caution was noted, including the need to ensure proper structure and that the approach is done properly from the beginning.

Part III of the workshop was focused on large-scale modelling, beginning with a keynote from Dennis Lettenmaier on the representation of cold regions processes at large scales, and including presentations on various large-scale modelling activities as part of Themes C and D in CCRN. Following Dennis’ keynote, there was a point expressed that the time is ripe for convergence of the fine-scale atmospheric modelling and fine-scale mountain hydrology to pull processes together, and then there is the challenge of upscaling. Discussion dealt with some of the issues related to upscaling and uncertainty raised on the first day, and the need to consider the potential for large-scale forcing and validation datasets (e.g. gridded, remotely sensed, reanalysis products, etc.) was emphasized. Some technical matters relating to individual work projects were discussed; an interesting observation is that model initialization is very important in terms of performance, yet difficult, and that using current climate does not yield current permafrost or glaciers.

A large part of the afternoon on day two was devoted to an in-depth review and discussion on CCRN’s modelling plans and strategy, with the goal of resolving some outstanding issues relating to how we will handle land–atmosphere feedbacks and simulation of future climate. Beginning with Theme B and progressing through Theme D, individual activities and work packages were reviewed and gaps to be filled were addressed. The discussions helped to solidify plans and a way forward in terms of the models to be used, how they will be run, and driving datasets to be collected in parallel with modelling needs, and will be used to finalize the CCRN’s modelling strategy document in advance of the network’s upcoming annual general meeting.

Part IV of the workshop was on modelling for the diagnosis of change and opened with a keynote from Thorsten Wagener on the importance of understanding model uncertainty. Some key questions were posed, such as where are we in terms of our ability to distinguish change in the historical sequence and how do we constrain the community to focus on standardized approaches to diagnosing change? The responses and follow-up discussions highlighted the need to understand where change in the models is really coming from (i.e. to understand model and parameter choices and their implications), and to decide what among these are the most critical aspects to focus on. The talks in this session clearly illustrated the subtleties, complexities, and distributed nature of sub-basin processes and the difficulty in unscrambling the patterns of change. A point was made that to understand and diagnose, we really must represent all of these very complex effects, and although here we have seen some powerful exploratory analyses, we really need more in terms of discriminating change against a background of uncertainty analysis. Discussion followed on some of the challenges and limitations, which include issues such as how much of the system can be represented, tradeoffs between ability to perform detailed modelling and carrying out robust uncertainty analyses, moving up to larger scales while retaining physical realism, the fact that models are not conditioned to explore systematic changes under non-stationarity, and the presence of major external drivers of change (e.g. insect infestations, wildfire, etc.). There was agreement that the best way forward is to continue to evaluate process uncertainty, to use fine-scale modelling to determine what processes are important to represent at larger scales, and to place emphasis on historical change and evaluate how much of that the models can capture.
The final afternoon of the workshop involved a discussion period on the topics of snow and frozen ground modelling, with the aim of setting a research agenda on both of these issues. In terms of snow processes, the workshop included presentations that spanned a wide range of approaches and levels of complexity for model representation, and a discussion, led by John Pomeroy, focused on what are the essential features to consider. First, slope and aspect effects are critical. Albedo decay was also noted as being important, yet there are large uncertainties regarding dust, multiple reflections, and, under forest canopies, spectral shifts. At small scales, the models should include full complexity while at larger scales, much of the detailed treatment of phenomenon (e.g. ray tracing through forest canopies, heat flow around tree trunks, etc.) will be omitted. We need to explore the understanding gained from fine-scale modelling, put this in a simple framework for the large scale, and evaluate in a multi-objective sense the performance for land–atmosphere exchanges, including tradeoffs. There are also issues involving wind speed, particularly for rain-on-snow events, and parameterization of katabatic winds in large-scale models. Here there are some opportunities to engage with the work being pursued by the atmospheric scientists in the network using fine-scale atmospheric models, and develop insights. Patchy forest cover and forest disturbance is another issue that needs to be examined, and this links with the frozen ground modelling as this has major implications for permafrost thaw. Some discussion here also focused on how to handle glaciers and glacier dynamics in models, how we can account for other dynamic landscape features, and the difficulties in doing this. Lastly on snow, it was noted that drip out of forest canopies is poorly handled and we can expect more of this in a warmer future climate.

On the topic of frozen ground modelling, Jeff McKenzie led a review and discussion to summarize the issues. First, the intersection between frozen ground and groundwater was noted; there are many implementations, scales and depth of investigation, questions (i.e. permafrost, seasonal active zone), and complexities of models (ranging from simple 1D analytical to complex 3D with varying dynamics and flexibility). Depending on where we are looking, different questions and complexity issues come into play: 1) arctic permafrost, 2) prairie (where seasonal freezing is important), 3) mountain environment (with very different dynamics). Discussion then focused on how we deal with frozen soils and infiltration to frozen soils in our models, some technical aspects of the parameterization in CLASS, groundwater aspects being pursued in CCRN at various WECC sites, and the level of complexity needed for various modelling purposes. To summarize, there is a lot of interesting work in CCRN and the SUTRA capability and application at some northern sites is opening up new avenues; an issue to focus on includes interaction with the surface boundary layer (connections with John Pomeroy can take those discussion forward); alternative ideas and application of other models at some sites where we have detailed near surface data to evaluate are being pursued by Andrew Ireson; with regards to LSS, the work of Gonzalo Sapriza will resolve what we need to do in terms of permafrost representation in the next few months; Laxmi Sushama has put in an 80 m soil profile in CanRCM5 to represent the permafrost layer; we have ideas of trying to simplify the thermal model to reproduce the lower boundary condition without having to go to the full level of complexity. There are various strands and we should keep on top of this and revisit in a year’s time to see where we’re going to go in terms of project deliverables.

In some concluding remarks by Howard Wheater and John Pomeroy, it was noted that the workshop was very productive in demonstrating where we are in the programme, with many deliverables coming through and people in place to continue this work. The linkage with the CNRCWP and Laxmi Sushama is helpful for being able to run CLASS in a coupled mode using CanRCM5 and look at feedbacks, while
another stream is high-resolution WRF modelling and pseudo-warming simulations being led by Yanping Li. With this we now have a clear way forward on land–atmosphere feedbacks and future climate simulation. Going forward, we need to focus more on parameter uncertainty and thereby allow us to better look at sensitivity. It was noted that although projections of temperature are robust, a major issue is whether we will see more or less precipitation, what its form will be, and how the nature of precipitation may change, and so we need to better understand the sensitivities. Despite the analyses, we are getting more surprises of extreme hydro-climatic events, which are occurring close together and switching from flooding to drought. We need to understand how our models perform under these conditions, whether we think this is realistic, and if so, determine how basins and systems respond.