Canadian Network for Regional Climate and Weather Processes

Annual report (Feb 2016 - Nov 2016)

Laxmi Sushama
NSERC Grant No: 433915-2012

Contents

1. Research project

The Canadian Network for Regional Climate and Weather Processes (CNRCWP) provides significant advances and innovative research towards the ultimate goal of reducing uncertainty in numerical weather prediction and climate projections for Canada's Northern and Arctic regions (see summary diagram in Appendix A). Progress to date has been excellent with significant accomplishments made in assessing the added value of high-resolution modelling that has helped fill critical knowledge gaps in understanding the dynamics of extreme temperature and precipitation events and the complex land-atmosphere interactions and feedbacks in Canada's northern and Arctic regions. High levels of interaction between co-investigators and highly qualified personnel (HQP) continued through the reporting period, as reflected in the several joint publications, including the one based on the integrative project focussed on the investigation of the Alberta flood event from weather and climate perspectives, which was initiated in Y3. With most of the model developments and analysis planned within the Network nearing completion, the emphasis this year was shifted to technology transfer. An action plan to facilitate technology transfer to partners, i.e., Environment and Climate Change Canada (ECCC), Ouranos Consortium and Pacific Climate Impacts Consortium (PCIC), was put in place during the reporting period (Appendix B). This is partly supported by the Network Enhancement Initiative (NEI) funds of $100K that were awarded to the Network by the NSERC-CCAR program in 2016. This funding is providing the required technical support for delivering additional code/tools and simulations to Network partners. One other area of emphasis during the year had been to further enhance the international linkages and visibility of the Network. To this end, the theme leaders of the Network have decided to host a session at the 2017 EGU meeting in Vienna. In addition, the Network will, in collaboration with other international research groups, synthesize and link existing Arctic System Modelling research, particularly that related to the terrestrial component, in an international workshop that will be held in September 2017 (see Appendix C). The Network has also successfully developed other strategies to disseminate widely the research undertaken, including social media.

1.1 Accomplishments during the reporting period and research directions for the remainder of the award

Progress made in the three theme areas of the Network – (A) Study of specific weather and climate phenomena permitted by high-resolution, (B) Statistical extremes allowed by fine mesh and land-atmosphere feedbacks and (C) integrated land surface types and processes to improve better representation of interactions and feedbacks – are presented below. Overall, all project milestones were achieved, most model developments are near completion, and the Network is in a very strong position to engage in technology transfer with partners, which has already started to occur.

A.1 Large-scale environments favourable to extreme precipitation events (Leader: Gyakum)

Milestones: Complete analysis of cold-season precipitation phases during extreme events and publish results. Complete analyses and simulations of EPI.

Two PhD students Kevin Bowley and Christopher McCray were working on this project during the reporting period. McCray is preparing to take his PhD comprehensive exam during the winter 2017 term. McCray is conducting research on a comprehensive set of cases of extreme ice storms throughout North America. He will in particular look at the unique large-scale environmental conditions that facilitate episodes of long-duration freezing rain events throughout eastern North America. Kevin Bowley is in the process of completing his PhD dissertation concerning the processes associated with extreme increases in northern hemisphere available potential energy (APE), and has found a linkage to North American cyclogenesis and attendant extreme precipitation in the western North Atlantic basin. In particular, Bowley has found that planetary-scale precursors to extreme APE increases include the development of 1) anticyclonic wavebreaking at the dynamic tropopause, 2) high-latitude cold-air generation, and 3) transient waves transitioning to slowly propagating anomalous ridging in regions of climatological cyclogenesis.

Melissa Gervais completed her PhD thesis entitled 'Interpreting air mass and precipitation structures from a weather-climate interface perspective: analyses and projections'. Gervais, currently a postdoctoral fellow at Columbia University, published another paper on arctic air masses in future climate scenarios (Gervais et al. 2016), and continues to work with the network on research relating to linking extreme weather and climate change processes.

Bryn Ronalds also completed her MSc thesis, entitled 'On the relationship between North Atlantic moist baroclinic growth rate regimes and surface cyclogenesis', and is in the process of writing her research for publication.

Shawn Milrad, now an assistant professor at Embry-Riddle Aeronautical University, collaborated with other network members in the integrative Alberta flood project during the reporting period, which got published in June 2016. Additionally, Milrad led the effort to understand the role of orography in the extreme Alberta flood case of 2013, and has submitted a manuscript to the Monthly Weather Review.

A.2 Freezing rain occurrence and severity changes in future climate (Leader: Thériault)

Milestones: Complete the analysis of future climate projections and the timing and location of precipitation types over Eastern Canada.

PhD student Melissa Cholette is finalizing the implementation of freezing rain and ice pellet formation processes in the new microphysics scheme P3 that was developed by Morrison and Milbrandt (2015). A first set of validation was conducted using a one-dimensional cloud model and the results were comparable to observations and other previous studies. The P3 scheme that includes the liquid fraction has been coupled with the Weather Research and Forecasting (WRF) model and it has been initially tested for the 1998 Ice Storm. Results demonstrated clearly the ability of the scheme to predict freezing precipitation. These were conducted at 10 km resolution and the next step is to increase the resolution to 3 or 1 km, to perform a detailed study of the formation mechanisms as well as a Pseudo Global Warming simulation (PGW) of the storm.

In parallel, the climatology of freezing rain over eastern Canada has been investigated. Bresson et al. (2016) showed that the historical climatology of freezing rain can be well reproduced using the CRCM5 at 0.11°. Model ability in reproducing the atmospheric conditions leading to freezing rain is currently being investigated by comparing freezing rain climatology produced at 3 horizontal resolutions (0.44°, 0.22° and 0.11°). Preliminary results suggest that the simulations at 0.11° replicates better the observations compared to the coarser simulations. The next step is to identify in which area the resolution plays a key role on the climatology of freezing rain in terms of, for example, event duration and synoptic patterns.

In addition, to better understand how precipitation types and associated weather conditions of storms would change in a warmer climate, a case study of an ice pellet storm was conducted. The historical and PGW simulations of the 4-km WRF CONUS NCAR dataset was used for this purpose. In general, the preliminary analysis showed that the same storm occurring in a warmer climate (1) could produce 25% more precipitation, (2) would be associated with a narrower rain-snow transition at the surface and moved towards the northwest and, (3) that the amount of ice pellets would have remained the same whereas freezing rain would decrease by 30%.

A.3 Storm track changes in future climate (Leader: Gachon)

Milestones: Finish the study of links between storms and floods/ droughts and wind extremes from available GCM and RCM simulations..

PhD student Sankare Housseyini and PDF Emmanuel Poan worked on this project during the reporting period. Storm tracks as simulated by the CRCM5 model were assessed against reanalyses during the reporting period. Analysis shows that the regional climate model brings added-value with respect to global climate models (GCMs) and global reanalysis products, especially over the eastern coast of North America where the atmospheric low level baroclinicity is crucial for synoptic storm developments. A paper from this study has been submitted to Climate Dynamics (Poan et al., 2016). Furthermore, the relationships between North American storms and daily precipitation indices namely the occurrence of moderate to intense rainfall were also studied. This recent analysis reveals that the CRCM5 storms are able to capture the synoptic scale systems and their signatures on rain-day occurrence over both large spatial scale and specific (smaller) areas, while GCMs tend to overestimate the role of synoptic systems, in particular over the eastern coast of North America. Finally, a composite analysis of the most intense storm life cycle shows that, despite a good representation of circulation and temperature gradients during storm evolution and main tracks, the CRCM5 model fails at representing the associated daily precipitation over key areas (ex. eastern coast). A paper from this recent study is in preparation.

To further develop the storm track algorithm to reconstruct objective extratropical cyclone (ETC) characteristics, an in-depth analysis of the sensitivity to the wind used for the vorticity computation has been realized. Study of the two storm tracking configurations (winds versus wind gradient) has allowed to identify: 1) the highest density of ETCs over the eastern coast-western North Atlantic in both cases, 2) the use of wind gradient is able to detect the regular (well known) occurrence of ETCs over the lee side of the Canadian Rockies, the eastern part of Hudson Bay, the Great Lakes area, Newfoundland and along the east coast, 3) a more robust corresponding and distinctive pattern of ETCs among reanalysis and CRCM5 runs are obtained over the major part of well-known area of storm occurrence with the use of wind gradient than the use of direct model winds, and 4) continental ETC occurrence tends to be systematically weaker when the direct wind is used (in all datasets) but the ocean-continent contrast is higher. From these results, it seems better to use the gradient wind to detect ETCs over the continental area of North America that tend to propagate towards the eastern coast than the use of direct model wind outputs. The next step will be to use/compute all wind gradients from available model variables to reconstruct all storm track characteristics. This work is underway for various regional climate model simulations over North America.

B.1 Distinguishing regional climate changes from natural variability (Leaders: Zwiers, Zhang)

Milestones: Estimate PMP and determine role of circulation change, as well as dependence upon model, resolution, and future time horizon.

PDF Ben Alaya started working on this project in April 2016. Even if the current knowledge of storm mechanisms remains insufficient to properly evaluate the limiting values of extreme precipitation, probable maximum precipitation (PMP) estimation methods view the problem from a deterministic perspective, and thus give only single values without uncertainty estimates.

In the current work, the aim is to provide a probabilistic description of PMP. Such a probabilistic description naturally leads to an assessment of projected PMP changes that includes quantification of their uncertainty. The usual approach that is used to estimate PMP, which is known as moisture maximization, involves a calculation that separately maximizes precipitable water and precipitation efficiency and treats them independently. An approach that exploits extreme value theory and recent developments in copula theory (which is used to represent the dependence between the extremes of two related variables) has been developed and applied to CanRCM4 output. This work has allowed to demonstrate how the uncertainty of PMP estimates can be quantified, and that the traditional engineering approach that does not account for dependence likely overestimates PMP. A paper is in an advanced stage of preparation, but some additional work is still required to evaluate CanRCM4 performance relative to PMP estimates obtained from observationally constrained products. Future work includes intercomparison with CRCM5, assessment of the dependence of PMP estimates on regional climate model resolution, and assessment of projected changes in PMP based on both models. There is also interest in exploring approaches that may be used to reduce uncertainty by borrowing information from nearby grid points (e.g., some type of regionalization) if this can be cast in an appropriate statistical framework.

In parallel, Xuebin Zhang and colleagues continue to finalize an intercomparison of projected changes in PMP based on several RCMs, where PMP is calculated via the traditional moisture maximization approach that has been modified to use information across subsets of gridpoints in an effort to improve estimated changes in precipitation efficiency. Their work suggests that while maximum precipitable water increases at roughly the Clausius-Clapeyron rate, reductions in precipitation efficiency that occur in some regions limit the increase in PMP to about half the Clausius-Clapeyron rate.

In addition, work to finalize papers that were initiated during Kiri Whan's tenure as a CNRCWP supported post-doc continued. In particular, one paper on atmospheric rivers remains in preparation. Calculations for that paper have recently been updated and submission will follow in the coming months.

B.2 Hydrological floods and droughts in future climate (Leader: Sushama)

Milestones: Complete high-resolution CRCM5 simulations for current and future climate and study changes to floods and droughts in a multivariate setting. Complete analysis and publish results.

MSc student Gregory Yang and RAs Dae Il Jeong and Gulilat Diro worked on this project during the reporting period.

Yang completed his MSc focused on intra-annual variability of land-atmosphere coupling over North America in CRCM5 in April 2016. An article based on this work has been accepted for publication in JGR-Atmospheres.

Diro finalized the work on the assessment of the impact of land-atmosphere coupling on current and future climate summer temperature extremes during the reporting period. Results from this study show that for some regions including the Canadian Prairies, changes in land-atmosphere coupling contribute up to 50% of the estimated increase in hot spell days for RCP 4.5 scenario. This work was submitted to Journal of Climate and is currently being revised.

In addition, Diro continued to investigate the role of snow depth and snow cover in modulating current climate using observational analysis and coupled (interactive snow) and uncoupled (prescribed snow) CRCM5 experiments. Interesting results were obtained regarding the impact of snow on temperature extremes over selected regions of north America. For instance, the strong relationship between snow cover frequency and cold spell days that is observed over the northern Great Plains and the Canadian Prairies in the reanalysis dataset is well simulated in coupled CRCM5 simulation, but is significantly weaker in the uncoupled CRCM5 simulation, suggesting that snow variability is important, at least, in the amplification of cold spell days. A related article has been submitted to Climate Dynamics. Additional investigation on the role of snow variation during the snow accumulation period on the large-scale circulation and thickness of the lower troposphere reveals a positive snow-precipitation feedback over selected regions of North America. Currently Diro is writing up a manuscript on this. Projected changes to snow-atmosphere coupling in future climate is also currently under investigation.

We have also dedicated some time during the reporting period to downscale ensembles of ECMWF seasonal forecasts using CRCM5 with the aim of assessing the added value of downscaling over North America, particularly from the extremes point of view. As part of this exercise, each of the nine ensemble members of ECMWF forecasts is downscaled separately to produce a nine-member ensemble regional forecast. Results from deterministic and probabilistic verification suggest that regional climate model shows an improvement over the driving GCM for selected regions and for specific aspects of the forecast. For instance, comparison of the distribution of daily precipitation extremes from the two forecasts over complex topography illustrates that CRCM5 forecasts improve these distributions not only at the spatial scales of CRCM5 but also when up-scaled to the GCM resolution.

Il Jeong studied projected changes to Rain-on-Snow (ROS) characteristics (i.e., frequency, rainfall amount, and runoff) for the future 2041-2070 period with respect to the current 1976-2005 period over North America using six simulations, based on CRCM5 and CanRCM4, driven by two driving GCMs for RCP4.5 and 8.5 emission pathways. Comparison of the ERA-Interim driven RCM simulations with available observations indicate that both models reproduce reasonably well the observed spatial patterns of ROS event frequency and other related features. Analysis of current and future simulations suggest general increases in ROS characteristics during the November to March period for most regions of Canada and for northwestern US for the future period, due to an increase in the rainfall frequency with warmer air temperatures in future. Future ROS runoff is often projected to increase more than future ROS rainfall amounts, particularly for northeastern North America, during snowmelt months, as ROS events usually accelerate snowmelt. Analysis shows that ROS event is the primary flood generating mechanism over most of Canada and north-western and -central US for the January-May period in current climate and the projections suggest that this will continue to be the case in future climate. An article based on this work is currently under review in Climate Dynamics.

C.1 Stochastic representation of intermittent boundary-layer mixing (Leaders: Scinocca, Monahan)

Milestones: Complete CanRCM4 climate simulations and analysis and publish papers.

RA Yanping He has completed implementation of the Turbulent Kinetic Energy (TKE) based boundary-layer scheme in CanAM4. The scheme was compared with the default parameterization in the CanAM4 using three single-column modelling cases (Cabauw, ARM2X, and DYCOMS). In general, the new one performs comparably well for stable, convective, and cloud-topped boundary layer cases. Extensive testing with CanAM4 is being carried out.

Concurrently a new formulation for the moist convection parameterisation developed by McFarlane of CCCma is also being evaluated in the context of CanAM4 tests. This new scheme will be coupled to the TKE scheme in CanAM4 within the next year. To facilitate coupling and evaluation of the combined TKE and moist convection schemes, SCM tests for convectively active conditions for the ARM and TWP-ICE case studies are being prepared and carried out. Documentation papers are in preparation.

He has undertaken all development and testing in a developmental version of the global model CanAM4. Testing of the new TKE scheme in the corresponding version of CanRCM4 is not currently possible as the CanRCM4 infrastructure is currently being transferred from GEM-CLIM support for GEM3-LAM to core climate support for the GEM4-LAM model base version. Additionally, the Climate and Meteorology Research Divisions of ECCC are currently undergoing a supercomputing platform conversion. Even so, due to the fact that CanAM and CanRCM share exactly the same physics package, all of He's work is automatically captured for CanRCM4 and testing and evaluation of the new TKE scheme will be undertaken once the move to GEM4-LAM and the new supercomputer is complete.

C.2 Representation of snow and snow-albedo feedback (Leaders: Déry, Sushama)

Milestones: Compare snow-albedo feedback in high-resolution simulations with and without SSS parameterization and assess the impact of the SSS parameterization on snowpack evolution in western North America.

MSc student Bruno Fang (UQAM) has completed his project focused on snow characteristics and snow-albedo feedback in CRCM5. An article was submitted to Climate Dynamics based on Fang's work and this is currently being revised based on the comments from reviewers. Fang's work will be continued by Sareh Hesaraki, who joined the Network in September 2016. Fang's study had demonstrated an overestimation of snow albedo feedback in CRCM5 simulations and the snow cover feedback was found to be more dominant compared to the metamorphosis feedback, whereas for observations, the two feedback components show more or less similar strength. Hezaraki, in parallel to the course work, has been doing literature review and has performed some sensitivity experiments with CRCM5 to see the impact of a new snow unloading algorithm developed by Paul Bartlett at CPS of ECCC and snow albedo refreshment thresholds. In addition, RA Arman Ganji developed a subgrid snow parameterization, which has been tested over western Canada in offline simulations with CLASS. Ganji is the RA working on C6 and details of this development are discussed under C6. An article based on this work is currently in preparation.

At UNBC, Rachel Hay started her MSc in January 2016 and will be completing her required course work by December 2016. Hay prepared a literature review on subgrid-scale snow parameterizations for improved numerical modelling of snow processes and on the hydrology of the major watersheds of western Canada. She has familiarized herself with the Canadian Land Surface Scheme (CLASS), and has been in contact with CNRCWP and other colleagues in regards to her research, and plans to validate the offline simulations performed by Ganji over selected watersheds of western Canada.

C.3 Glacier and hydrology changes in future climate (Leaders: Marshall, Sushama)

Milestones: CRCM5 simulations of historical glacier change and glacier runoff across Canada.

The new dynamic glacier scheme that was developed for use within the fifth generation Canadian Regional Climate Model (CRCM5), based on volume-area relationship, was applied over western Canada in both offline and coupled simulations by Katja Winger, at UQAM. Both simulations suggested significant decreases in glacier fractions in future climate. During the current reporting period, at UQAM, we have changed our focus to study the evolution of Arctic glaciers. Most of the climate models suggest an increase in winter precipitation for these regions compared to the glaciers of western Canada, where important decrease in precipitation is projected for the future climate. Caio Ruman who joined the network in June of 2016 performed offline simulations with the dynamic glacier scheme and CLASS for the 1980–2100 period over a domain covering the Arctic glaciers, driven by outputs from a CRCM5 transient climate change simulation, driven by the Max Planck Institute Earth System Model (MPI-ESM) for RCP4.5.

CRU data was utilized to assess biases in the driving data, i.e. in temperature and precipitation, which showed a warm bias in CRCM simulated temperatures generally, except during the summer months, and a year round positive bias in CRCM simulated precipitation.

Projected changes to the glacier volume for the future 2071-2100 period with respect to the 1981-2010 period indicate decreases of up to 56%, despite the projected increases in precipitation as the projected increases in temperature is much higher for these regions compared to the western glacier regions.

Ruman will be performing coupled simulations to understand the impacts of changing glacier fractions on the regional climate and hydrology.

At University of Calgary efforts continued to develop and test the relevant 'downscaling' (e.g., radiation, humidity, and temperature lapse rates) at index glacier sites in western Canada, where glacier mass balance records exist. Haig Glacier in the Rockies has been a strong focal point for model development because we also have detailed snowpack, meteorological, and energy balance data from this site. The above work at University of Calgary was done by PDF Marjorie Perroud who completed two years on this project in October, 2016. She has now moved to a full-time position as a Research Scientist at the University of Geneva. Perroud is currently preparing a manuscript that will be submitted to Climate Dynamics by the end of the year.

One of the other objectives had been the century-scale reconstruction of historical glacier variations in western and Arctic Canada (e.g., little ice age to present). We have put together 'paleoclimate indices' to drive these simulations in each region, from tree rings in western Canada and from ice core records in the Arctic. These time series provide annual temperature anomalies from which we can drive the regional glacier reconstructions, but this awaits our fully developed distributed model and final strategy for CRCM5 forcing fields for the glacier precipitation and energy balance fields.

C.4 Vegetation changes in future climate (Leaders: Arora, Sushama)

Milestones: Finalize climate change simulations with and without competition between PFTs. Analyze climate-vegetation feedbacks in current and future climates. Complete analysis and publish results.

PDF Rudra Shreshta implemented CLASS-CTEM over a North American domain at a spatial resolution of 1 degree and evaluated the performance of the competition module of CTEM and its ability to simulate geographical distribution of vegetation. A manuscript documenting this is near finalized and Shrestha is incorporating comments from all co-authors and internal reviewers. Shreshta's 2-year PDF term with the Network ended in October 2016.

Bernardo Teufel, at UQAM, studied the impact of dynamic vegetation (including competition) on projected changes to the pan-Arctic land surface state, including near-surface permafrost (C6), by comparing two simulations of CLASS - one with dynamic vegetation, modelled using CTEM, and the other with prescribed vegetation. These simulations were performed for the 1961-2100 period, using atmospheric forcing from a transient climate change simulation of CRCM5 for RCP8.5. The dynamic vegetation simulation includes (for the first time over the pan-Arctic domain) competition between vegetation types in CTEM, which enables vegetation to expand horizontally. Comparison of this simulation with available observational estimates of vegetation distribution, plant area index, spatial distribution of permafrost and active layer thickness suggests that the model captures reasonably well the general distribution of vegetation and permafrost. In future climate, CTEM projects growth and northward expansion of vegetation in the high-latitudes in response to warming and high CO2 concentrations. Over permafrost regions the effect of the growing and expanding vegetation on spring albedo is strong, leading to faster permafrost degradation in the simulation that includes dynamic vegetation. This permafrost degradation is projected to affect the regional water cycle, decreasing surface runoff, and this effect is amplified when dynamic vegetation is included. An article based on this work will be soon submitted to Climate Dynamics.

Teufel also performed simulations with the LPJ-GUESS vegetation model over the pan-Arctic domain, driven by ERA-Interim reanalysis for the 1979-2014 period and by CRCM5 data for the 1961-2100 period. These simulations with the LPJ-GUESS vegetation model include competition between vegetation types, nitrogen cycling and fire dynamics. During the observational period, both simulations are able to simulate the current distribution of vegetation types and carbon fluxes reasonably well, with errors comparable to those of CLASS coupled to CTEM. For the future climate scenario, LPJ-GUESS projects increases in vegetation productivity and biomass over the pan-Arctic, linked to an advancing treeline and the expansion of broadleaf trees, similar to the results obtained with CLASS coupled to CTEM. Increased fire emissions and widespread decreases in soil carbon also occur in LPJ-GUESS, hinting at the importance of the disturbance processes, which are undergoing testing in CTEM.

C.5 Representation of large lakes in weather and climate models (Leaders: Duguay, Sushama)

Milestones: Compare lake-effect snowfall for the Great Lakes from ground based and satellite-derived SWE and CRCM5 simulations. Perform current and future simulations with the coupled model for the Great Lakes region and study changes to the energy and water budget.

PhD student Baijnath has been assessing historical climatological trends in snowfall and related processes over the Ontario snowbelt region of the Laurentian Great Lakes (LGLs). Work has focused on the analysis of observational data. Spatiotemporal snowfall and precipitation trends using NASA's DAYMET gridded observational datasets have been computed for the 1982-2013 period over the LGLs Basin. Results show significant decreases in snowfall and precipitation along the Ontario snowbelt of Lake Superior, Lake Huron and Georgian Bay at the 90% confidence level during the cold season. Investigation into attribution of these trends using the NARR re-analysis and NOAA Optimum Interpolation Sea Surface Temperature (OISST) datasets show a significant warming in lake surface temperature (LST), significant decrease in ice cover fraction, and an increase in the vertical temperature gradient between the lake surface and the 850 mb level. While the behavioural trends of these variables are believed to enhance lake effect snowfall (LES) by increasing evaporation into the lower

PBL, there are other complex processes involved such as inefficient moisture recycling and increased moisture storage in warmer air masses that inhibits the development of LES.

PhD student Oleksandr Huziy during the reporting period defended his thesis on lake-river-atmosphere interactions over Northeast Canada. The second and third articles based on his PhD got published in Climate Dynamics during the reporting period. His third article focuses on the impact of lake-atmosphere and lake-river connectivity on projected changes to several near surface variables and fluxes using high-resolution transient climate change simulations with and without lakes. Huziy, currently a PDF within the Network, completed the coupling of NEMO with CRCM5 for the Great Lakes during the reporting period. Some preliminary validation of CRCM5 simulations at 10 km resolution, with Hostetler lake model (CRCM5_HL) and NEMO lake model (CRCM5_NEMO), were performed. The results are encouraging for 2-m air temperature and humidity. The warm summer biases in CRCM5_HL are significantly reduced in CRCM5_NEMO. The modelled precipitation is also in good agreement with that observed.

Since it is of interest to assess the differences in simulated heavy lake-effect snow between CRCM5_NEMO and CRCM5_HL, we have developed and refined an algorithm based on suggestions from Notaro et al (2015) to diagnose heavy lake-effect snowfall in CRCM5 simulations and ERA-Interim for the Great Lakes region. Preliminary comparisons suggest more heavy lake-effect snowfall events in the case of CRCM5_NEMO when compared with CRCM5_HL due to higher lake ice cover in the latter.

C.6 Permafrost and high-latitude hydrology changes in future climate (Leader: Sushama)

Milestones: Adapt the lake-river model developed for Quebec watersheds for the other regions of Canada.

Arman Ganji, who is working on this project, improved the representation of surface water-groundwater interactions in CLASS. An article based on this work has been submitted to Advances in Water Resources. He spent part of his time in developing a sub-grid snow parameterization that takes into account topography, aspect and slope. This is related to the objectives of C2 as well, but is important for better representation of high-latitude hydrology in general. In the proposed sub-grid scheme, each grid cell of CLASS is divided into N regularly spaced sub-grid cells of equal area, but different values of elevation, aspect and slope. Since including sub-grid representation in CLASS is computationally demanding, a simple clustering technique is used to classify subgrids based on elevation, aspect and slope values into specified numbers of group. The proposed parameterization was used within the framework of CLASS and its impact on surface hydrological processes assessed. Two offline experiments, CK, and CK-SGS driven by ERA-Interim reanalysis, were performed with CLASS for the 1980-2013 period, over a domain covering Western Canada. Experiment CK is performed with the original version of CLASS in terms of snow representation, while CK-SGS considers sub-grid representation. The proposed parameterization also modifies incoming air temperature and solar radiation for each sub-grid based on its elevation, slope and aspect.

The new parameterization significantly improved simulated SWE compared with observations over the study domain. This led to better simulation of the surface hydrological processes such as runoff and streamflows. An article based on this work is currently in preparation.

C.7 Land-climate interactions (Leader: Sushama)

Milestones: Perform sensitivity tests with combinations of land modules of varying complexity to study impact on surface climate and feedbacks.

This project is an integrative project for Theme C. CRCM5 simulations, with and without the different components included in other projects within Theme C, are performed and analyzed to assess the impact of these modules on associated interactions and feedbacks.

Huziy, Teufel, Duarte, Ganji and Diro worked on integrating all Theme C developments in CLASS and CRCM5 (Appendix B). As components were developed and tested individually, we are now merging all land surface developments into CLASS. Simulations were performed to see the individual and collective impacts of the modifications. This constitutes phase I of the technology transfer plan, which also shows interesting results related to the interplay between various modules/developments. This enhanced version of CLASS is now implemented in CRCM5. Simulations over two domains, pan-Arctic and North America are underway to assess the impact of the developments on the regional climate. This forms phase II of the technology transfer work plan. Several simulations had to be launched for determining the geophysical datasets to be used in these simulations. The chosen datasets for the simulations for vegetation PFT fractions is MODIS, while the soil fractions and organic matter are derived from the harmonized world soil database. This new version of CRCM5 will also be applied to climate change simulations. Selected experiments from Phase III have also been initiated, especially the CRCM5-NEMO coupled simulation over the Great Lakes as discussed under C5.

All tasks above that will lead to the planned technology transfer required high level of interaction between involved HQP. The involved partners will be more involved in analyzing these simulations once they will be completed. At least two articles are expected from this work.

In addition, efforts were undertaken to improve the representation of urban regions in the model. The Town Energy Balance (TEB) model is used for this purpose and is important for better simulation of urban-climate interactions. The impact of urban regions on projected changes to selected surface variables were assessed for a domain covering southeast North America with important urban fractions by comparing offline simulations of CLASS, with and without TEB, driven by CRCM5 data at 0.22° resolution. PhD student Gemechu Fanta worked on this project during the reporting period, while taking required courses for the PhD program at the same time. An article based on this work is currently in preparation. Fanta will be doing CRCM5 simulations with TEB in the coming months. MSc student Francois Roberge on the other hand studied impacts of urban region over Montreal using high-resolution offline simulations with CLASS and TEB as a preliminary step. Coupled simulations with CRCM5 with and without TEB will be performed to assess the impacts of the urban regions on the local circulation and precipitation.

1.2 Delays or departures from the research plan, or the rescheduling of activities, and how they are being addressed.

There were no major deviations from the milestones for the currently active projects. The funds associated with A4, A5 and B3 were diverted to support other projects, particularly C5 and C7 as they involved significant development and were therefore demanding in terms of resources. All other projects have HQP in place and everything is going ahead as planned in terms of research and deliverables.

The model developments are currently near completion and the HQP involved in a number of projects are contributing to the integration of developments in CLASS and CRCM5. Details of this integration work were already discussed under C7.

One difficulty that we had to face during the reporting period was a cut in the computing resources provided by Compute Canada. This had an impact on the number of simulations that we were able to perform. Simulations were prioritized such that student projects and main deliverables were minimally impacted. It is not clear at this point what the allocation for Y5 will be, but we have requested adequate resources to complete all deliverables, backed by a support letter provided by the scientific advisory board. We hope that Compute Canada will consider our request favourably.

1.3 Deviations from the proposed budget

A total amount of $1,100,251 was planned for Y4 expenditures, and based on the projections, there will be no carryover at the end of Y4. Some adjustments had to be made in the distribution of funds among the three categories under salaries and benefits. The amount spent for student scholarships is slightly more than what was planned as a couple of students required an additional session to complete their degrees. As for the PDF category, the amount spent is slightly more than what was proposed, as Oleksandr Huziy continued with the network as a PDF, after defending his PhD thesis in January 2016. He is involved in C5, which incorporates an interactive model of the Great Lakes based on NEMO in CRCM5. Part of his salary came from an NSERC-Engage grant. The actual amount used for RA category is less than what was proposed, as RA Diro continued as a PDF for few months outside of the 2-year term as he was waiting for approval of his RA status. NSERC had agreed to this, given the exceptional nature of the situation. However, none of these changes have impacted the total budget set aside for salaries and benefits. There were no major deviations from the proposed budget for other items as reflected in column 6 of Table 1 of Appendix F).

As for the NEI, the $37,500 that was received in Y4 was used to fund Luis Duarte, who is providing technical assistance to facilitate technology transfer.

In summary, by the end of Y4 (i.e., January 31st 2017), we expect no carryover. It should be noted that the projections for Y5 (presented in Table 2 of Appendix F) are made according to project needs and the total over the 5-year period will be $4,078,255 (excluding NEI) as approved by NSERC.

2. Growth and development of the research team

Significant progress continued to be made during the reporting period as presented under Section 1. Eight HQP completed their training within the Network in Y4 and have either taken up permanent positions or pursuing higher studies. The co-investigators of the Network during the reporting period continued to supervise/co-supervise Network students, PDFs and RAs and were therefore fully integrated into the research aims on a daily basis. The co-investigators from partner organizations, i.e. EC, PCIC and Ouranos, continued to lead many Network research projects. A high level of interaction continued within the Network, with HQP taking a lead this year in organizing regular activities, such as the monthly HQP seminar series. Many joint papers came out in Y4 and a complete list can be found in Appendix D.

The annual science meeting of the Network was held during the May 17–19 period at UQAM (see Appendix H). In addition to the co-investigators and HQP, SAB members and representatives from partner organizations and NSERC also attended the meeting. The SAB met with the HQP and partners of the Network under NSERC observation. The SAB found this meeting very useful as they were able to judge what worked and what could be further improved. A review report was submitted by the SAB following the workshop. SAB was pleased with the positive feedbacks from HQP regarding the interaction between HQP working on various projects. The main recommendations from the SAB this year had been to: 1) submit a proposal for the Network Enhancement Initiative (NEI) funds of $100K to further enhance technology transfer and international linkages and visibility, (2) explore and develop a strategy to exploit social media in communicating results and activities from and within the Network, (3) explore developing a CNRCWP-themed session at international meetings, such as EGU and/or AGU.

Regarding the first SAB recommendation, the Network submitted an NEI application requesting $100K and this was granted by NSERC - $75K will be used to support technology transfer and the remaining $25K will be used to organize an international workshop. Knowledge and technology transfer to partners will continue at an accelerated level during the remaining period of the Network, and an action plan for this to happen has been put in place. Integration of HQP is crucial for this task and will provide them tremendous experience of situations similar to those one will encounter in real work environments.

In addition, a number of national and international level collaborations continued or were established during the reporting period. Some of the most active collaborations during the current reporting period are presented in Appendix D. The two new partners of the Network are the Water Science and Technology Division (WSTD) of ECCC and Manitoba Hydro.

The second recommendation has also been taken care of and the Network posts research highlights regularly on social media. As for the third recommendation, the Network will be hosting a CNRCWP-themed session at the 2017 EGU. Other international activities are also expected to help broadcast Network research to a wider international community.

The Network also reached out to other CCAR Networks such as CCRN and CanSISE. The Network was represented at the modelling and/or regional meetings held by these Networks. In addition, two joint sessions were held at the combined CMOS-CGU congress with CCRN and CanSISE.

Some spinoff projects such as a MITACS accelerate project and an NSERC Engage project, resulted during the reporting period. Discussion is also underway for a potential Collaborative Research and Development project.

3. Extent of highly qualified personnel training

Thirty one HQP were funded during Y4 (please see Appendix E for a complete list) and received training in the area of quantitative climate research (from numerical modelling to process studies and statistical analysis). The total number of HQP who received training within the Network so far is 52. During the reporting period, UQAM continued to host several HQP from outside of Montreal for short periods and helped them with their data and modelling needs. The Network funds continued to be used to support participation of HQP in various international conferences and workshops (please see Appendix D), which provided them the opportunity to interact with international leaders in the domain.

During the reporting period, HQP played an important role in the organization and/or running of various international workshops and projects. For example, PhD student Bernardo Teufel is currently helping with the co-ordination of an international workshop on Arctic Terrestrial Modelling (Appendix C). Teufel in collaboration with PDFs based at other international modelling centres will be contributing to the intercomparison of land surface models over a pan-Arctic domain. Similarly, Gulilat Diro represents the Network in the Belmont forum funded international project entitled 'PAlaeo-Constraints on Monsoon Evolution and Dynamics (PACMEDY)'. In particular, Diro contributes to understanding changes in storminess over the North Atlantic region during the Mid-Holocene.

The monthly HQP meetings, which have been held regularly for the past two years, have been a great success. This has given the HQP the opportunity to acquire knowledge in other related areas and to interact with a wider group of students, PDFs and RAs in a very informal setting. Many ideas, particularly those related to the use of social media in communicating results and activities related to the Network, came out of these meetings. HQP also participated in other outreach activities, such as the seminar series that is given at the partner institution Ouranos, PCIC, ECCC and Manitoba Hydro. HQP also took the initiative to generate a research blog, where results from various projects are posted regularly.

The Network also offered three summer internships to students from high school to MSc levels during the reporting period; two of them worked on Network projects alongside PDFs and RAs and presented preliminary results at the annual science meeting, while the other intern helped with outreach material and co-ordination.

4. Collaboration/interaction with federal government and foreign researchers and other partners

Collaboration with federal government researchers and other partners continued during the reporting period, with many of them supervising or co-supervising Network HQP. For example, the integrative Network project on the Alberta flood event had researchers from partner organizations playing a key role in guiding the HQP to the final paper that got published in June 2016.

Knowledge transfer between the Network and the partners occurred as in previous years and resulted in several joint publications. With many model developments within the Network reaching completion, emphasis has been on technology transfer since the middle of the reporting period.

CLASS, with all developments merged, will be transferred to the Climate Processes Section of ECCC. CLASS is also the land surface scheme in CCCma's global and regional climate models, and the modifications such as the improved representation of surface-groundwater interactions, frozen soil parameterization etc. will be available for use in these models. The glacier model that has been developed will also be transferred to CCCma for possible implementation in CCCma's global and regional climate models. Interactions with the federal labs regarding technology transfer occurred during the reporting period and this is expected to increase further during Y5.

Collaborations with Ouranos continued during the period. The Climate Simulations and Analysis Team of Ouranos employs CRCM5 to generate climate change information required for its client base. The new version of CRCM5, with the developments discussed above, will be transferred to Ouranos over the last year of the Network. These new developments will be crucial for numerous projects in Ouranos' scientific program. For example, realistic simulation of permafrost is of interest for community and industrial infrastructure as covered in projects in the 'Northern environment' program of Ouranos. Dynamic vegetation, including competition, will be useful for projects in the 'Forest resources', 'Agriculture, commercial fisheries and aquaculture', 'Ecosystems and biodiversity', 'Tourism' as well as the 'Built Environment' programs of Ouranos. The integration of the lake and river routing modules, taking into account the feedbacks on climate (e.g. for runoff, evapotranspiration, surface temperature, local precipitation) in CRCM5 will be very relevant for hydrologic studies in all sectors that depend on water resources like public health, ecosystems and industrial development and projects in the 'Energy' and 'Water management' programs. This addition will be useful for end-users from the consortium's membership such as the Québec government's Direction de l'Expertise Hydrique (DEH), Hydro-Québec, Ontario Power Generation and Manitoba Hydro. To ensure smooth technology transfer, the Network is working closely with Michel Giguere and Anne Frigon from Ouranos, who provides technical and scientific support, respectively.

The new developments, particularly those related to glaciers and the representation of sub-grid snow, are important for western Canada with its complex topography. The simulations that will be performed over western Canada, will be assessed by PCIC and the Network in collaboration. In particular, the hydrology in CRCM5 will be compared to that in an ERA-Interim driven VIC (Variable Infiltration Capacity) simulation over selected BC watersheds. These high-resolution CRCM5 climate change simulations from the Network will be an interesting and useful addition for PCIC as they are expected to provide additional insights regarding future changes to the regional climate and hydrology and related extremes for the region, and to provide its stakeholders with climate change information at scales that are relevant for decision-making. In particular, this will contribute to ECCC's objective to develop more robust approaches to estimate engineering design values.

Interactions with international researchers occurred in many projects, in particular in the context of the international workshop that the Network is planning for Y5. The most active collaborations are listed in Appendix D.

5. Data management of research results

❯ The updated list of simulations and data generated within the Network is posted on the Network website (cnrcwp.uqam.ca/documents/simulations). Interested users can obtain access to this data using the form provided on this webpage. The Network supports sharing of this data to the larger scientific community to fully analyze the data and to promote scientific collaboration. The computing support group at UQAM is responsible for data management.

According to the agreement within the Network, the data generated as part of PhD and MSc projects may have access restrictions until the students defend (complete) their PhD (MSc) and publish results based on the simulations. Though the model outputs are generally in RPN standard format, they can also be made available in NetCDF format. The commonly used variables are generally stored on discs, while a more comprehensive collection of variables is stored on tapes and will be available beyond the lifetime of the Network.

The simulations that will be produced as part of the NEI will initially be available to Network partners, and will be made available to researchers outside of the Network at a later date. The simulations that have been contributed to the international project CORDEX by CCCma and Centre ESCER are fully open access, including for commercial use, and can be downloaded from the CORDEX site.

6. Dissemination

❯ The main mode of dissemination continued to be through published articles in peer-reviewed journals and conference papers. Twenty-six articles, based on research undertaken within the Network, got published or submitted to various peer reviewed journals, and 5 articles are currently in preparation; 25 of these had HQP as first authors. The HQP and co-investigators also presented papers and posters at various national and international conferences (80 in total). A complete list for the Feb 2016–Nov 2016 period is given in Appendix D.

Several outreach events were organized during the reporting period, targeting specialists and non-specialists. CNRCWP teamed up with CanSISE and CCRN to host sessions at the CMOS-CGU congress in 2016. The Network also participated in selected workshops organized by other CCAR Networks. The Network will be convening a session entitled 'Representing, understanding and communicating earth system processes in weather and climate' at the 2017 EGU, which will further enhance visibility internationally.

The Network will co-organize an international Arctic System Modelling workshop focused on the terrestrial part, in partnership with NGEE (Next Generation Ecosystem Experiments) Arctic. NGEE Arctic is a 10-year project sponsored by the US Department of Energy, with the goal of reducing uncertainty in ESMs through developing a predictive understanding of carbon-rich Arctic system processes and feedbacks to climate, and thus shares many objectives with CNRCWP. We are leveraging these similarities to jointly organize this workshop focused on Arctic terrestrial modelling, with the ultimate goal of improving global and regional earth system models. The workshop will review current representation of Arctic ecosystem, carbon, water and energy balance processes and properties in the land model component of ESMs, including land-atmosphere interactions, and the next steps to address knowledge gaps. The workshop will also focus on developing a pan-Arctic land model inter-comparison project that includes a broader range of models, and engage the data community to provide benchmarking products for the arctic and sub-arctic. The workshop will be held back to back with the iLEAPS (Integrated Land Ecosystem-Atmosphere Processes Study) meeting that will be held in September of 2017 in Oxford, UK; iLEAPS is co-chaired by Dr. Eleanor Blyth, who is also a CNRCWP scientific advisory board member. This workshop will enable effective interaction and information exchange between the Network and other international research groups. Several planning meetings with international partners occurred during the reporting period, including one at the Arctic Science Summit of 2016, which gave tremendous visibility to the Network.

The co-investigators of the Network gave invited talks at various conferences and workshops during the reporting period. Communicating research results to end-users continued to occur through Network partners – Ouranos, PCIC and CDAS. To further facilitate this communication, the Network is holding a series of seminars at Ouranos, which showcase talks by Network co-investigators and HQP. These seminars/webinars help reach out to a very large community of impact and adaptation researchers and groups across Canada that benefit from the Network. In addition to the above, the Network co-investigators continued with other outreach activities including public lectures, TV/radio interviews and participation in training events.

The Network website is also constantly updated and provides information on projects and publication resulting from the Network research. The research blog and tweets are new additions to reach out to a wider community. The Network pamphlet (Appendix G) downloadable from the Network website gives a condensed view of the Network and recent results. All of the above ensured that the Network research is visible, promotes the science goals and the mission of NSERC-CCAR program.

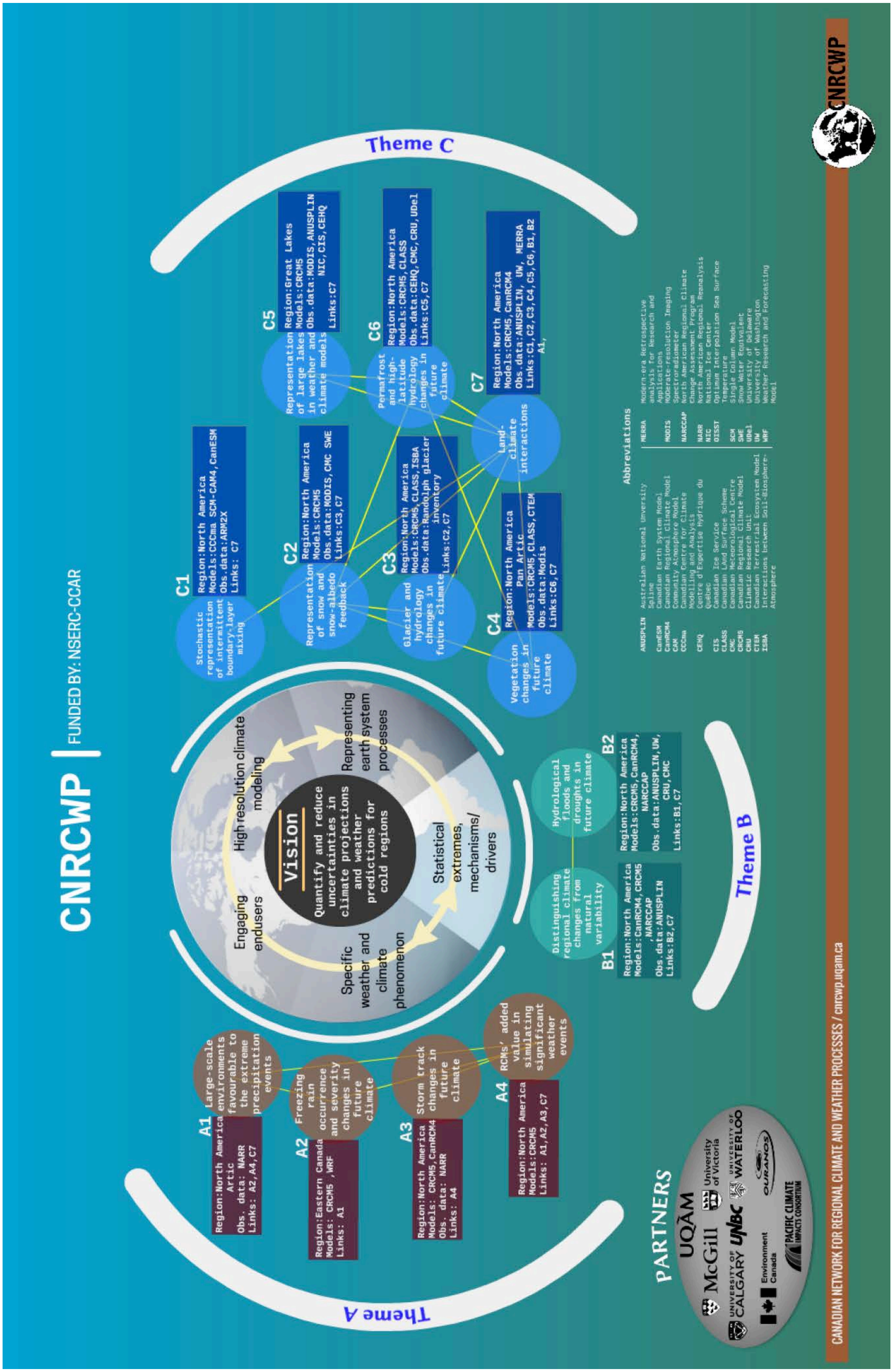
7. Comments from reviewers on the Y3 annual report and how they have been addressed

We received one review for the Y3 annual report. The reviewer applauded the efforts made to improve integration of research results and better coordination among HQP and co-investigators at different institutions. During the reporting period we have tried to keep up this high level of integration and coordination within the Network through integrative projects aimed at technology transfer, which provided even more opportunities for HQP to interact and network with collaborators and partners. As discussed earlier, the SAB had also provided feedbacks and suggested that the Network engage in more activities to increase visibility of the Network research and we have taken actions to promote this via sessions at international conferences and organization of international workshops as already discussed in previous sections. We have also taken into consideration all other comments from the SAB (cf. Section 2), which were very helpful in ensuring that the Network operates at its full potential.

8. Summary

In summary, the Network:

- made innovative research in the three theme areas related to weather and climate
- maintained high level of integration between HQP, co-investigators and partners
- provided excellent training opportunities to HQP
- engaged in outreach, using various media, and planned major international activities for Y5 to further enhance visibility of the Network research.
- NEI activities related to technology transfer are currently in progress. Integration of all land-related developments is expected to be completed during the first half of Y5. This will enable delivery of model/code and simulations, well-tested over domains of interest, to Network partners, for productive use of the research and tools generated within the Network in a timely manner.


CNRCWP
FUNDED BY: NSERC-CCAR
Theme A
Theme B
Theme C
Vision
Quantify and reduce uncertainties in climate projections and weather predictions for cold regions
High resolution climate modeling
Representing earth system processes
Statistical extremes, mechanisms/ drivers
Specific weather and climate phenomenon
Engaging endusers
PARTNERS
CANADIAN NETWORK FOR REGIONAL CLIMATE AND WEATHER PROCESSES / cnrcwp.uqam.ca
Abbreviations

CNRCWP — Work plan for transferring technology to partners

1. Integrating land surface developments into CLASS

CLASS/CTEM enhancements

- +Hydraulic conductivity of frozen soil ✓
- +Surface-groundwater interactions ✓
- +Interflow ✓
- +Subgrid snow ✓

Technology transfer model code

ECCC/CPS | ECCC/CCCma

Geographic datasets selected based on 22 test simulations

Geophysical fields:

- Vegetation: MODIS, GLCC2000
- Soil texture (sand, clay and organic matter contents): Harmonized World Soil Database
- Depth to bedrock: Pelletier et al. 2016

Soil configuration:

- 26 layers down to 60 meters deep

Lake data:

- Lake depth: Kourzeneva et al 2010
- Great Lakes bathymetry: Great Lakes database of National Geographic Data Centre (NGDC)

Glaciers:

- Glacier fractions: Randolph Glacier Inventory (RGI)

Acronyms

CCCma	Canadian Centre for Climate Modelling and Analysis
CLASS	Canadian Land Surface Scheme
CTEM	Canadian Terrestrial Ecosystem Model
CPS	Climate Prediction Section
CRCM	Canadian Regional Climate Model
ECCC	Environment and Climate Change Canada
MH	ManitobaHydro
NEMO	Nucleus for European Modelling of the Ocean
PCIC	Pacific Climate Impacts Consortium
TCC	Transient Climate Change
WSTD	Water Science and Technology Directorate

2. Integration of enhanced CLASS/CTEM and other modules in CRCM5

CRCM5 enhancements

- +Lake-river routing ✓
- +CLASS/CTEM enhancements ✓
- +Glaciers
- +NEMO ✓

Test domains

North America (0.44°)

Pan Arctic (0.5°)

Test configurations

CRCM5-default
+Lakes, +Lake-river routing
NA: PA:

CRCM5-A
+CRCM5-default, +CLASS/CTEM enhancements
NA: PA:

CRCM5-B
+CRCM5-A, +Hydraulic conductivity of frozen soil
NA: PA:

CRCM5-C
+CRCM5-B, +Glaciers
NA: PA:

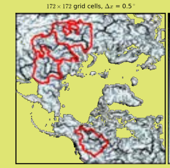
CRCM5-D
+CRCM5-C, +SW-GW interactions
NA: PA:

Technology transfer model code

Ouranos

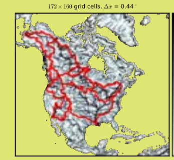
3. Production runs

Pan Arctic, 0.5°



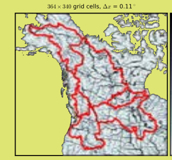
Hist. (1980-2015):
TCC (1950-2100):

North America, 0.44°



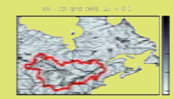
Hist. (1980-2015):
TCC (1950-2100):

West Canada, 0.11°



Hist. (1980-2015):
TCC (1950-2100):

Great Lakes, 0.1°



Hist. (1980-2015):
TCC (1950-2100):

Technology transfer simulations

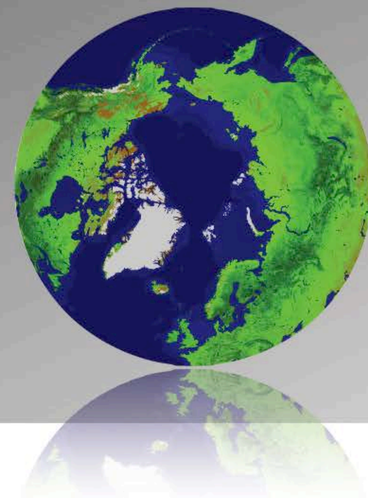
ECCC/WSTD | PCIC | MH

CNRCWP

Canadian Network for Regional Climate and Weather Processes – http://cnrcwp.uqam.ca

Arctic Terrestrial Modelling Workshop

14-15 September 2017



Saïd Business School – University of Oxford

Sponsored by the Canadian Network for Regional Climate and Weather Processes (CNRCWP) – Natural Sciences and Engineering Research Council of Canada (NSERC) and Next-Generation Ecosystem Experiments-Arctic (NGEE-Arctic).

Overview

This workshop will bring together senior and early career scientists to gain insight into the rapidly changing pan-Arctic land surface and boundary layer. The workshop will review current representation of Arctic ecosystem, carbon, water and energy balance processes in the land model component of Earth System Models, including land-atmosphere interactions, and the next steps to address knowledge gaps. The workshop will also focus on developing a pan-Arctic land model inter-comparison project that includes a broader range of models, and engage the data community to provide new validation products for the Arctic and sub-Arctic.

Core focus

- ✓ Representation of Arctic terrestrial ecosystems in Earth System Models
- ✓ Role of observations: calibration, validation, assimilation
- ✓ Water, nitrogen, carbon, and energy dynamics
- ✓ Land-atmosphere interactions and feedbacks across spatial and temporal scales
- ✓ Pan-Arctic Land Model Inter-comparison Project
- ✓ Arctic boundary layer processes
- ✓ Extreme/disturbance events
- ✓ Knowledge gaps

Scientific committee

Laxmi Sushama
University of Quebec at Montreal

Stan Wullschleger
Oak Ridge National Laboratory

Cathy Wilson
Los Alamos National Laboratory

Eleanor Blyth
Natural Environment Research Council

Benjamin Smith
Lund University

David Lawrence
National Center for Atmospheric Research

Gerhard Krinner
Centre National de la Recherche Scientifique

Patrick Samuelsson
Swedish Meteorological and Hydrological Institute

Paul Miller
Lund University

Joe Melton
Environment and Climate Change Canada

Charles Miller
Jet Propulsion Laboratory, NASA

Online registration open until 17 Feb 2017
(limited to 80 participants)
http://www.cnrcwp.uqam.ca/ArcTeMW

Contact
Bernardo Teufel (teufel@sca.uqam.ca)

Sponsors

CNRCWP NSERC CRSNG OAK RIDGE National Laboratory

Joint publications involving researchers from multi-institutions

*** HQP led papers**

Peer reviewed publications

In press/accepted

1. de Elia R., Laprise R., Biner S., Merleau J., Synchrony between reanalysis-driven RCM simulations and observations: variation with time scale, Climate Dynamics
2. *Ebrahimi S., Marshall S., Surface energy balance sensitivity to meteorological variability on Haig Glacier, The Cryosphere, 10.5194/tc-2016-6
3. *Gervais M., Atallah E. H., Gyakum J., Tremblay B., Arctic air masses in a warming world, J. Climate, http://dx.doi.org/10.1175/JCLI-D-15-0499.1
4. Grotjahn R., Black R., Leung R., Weaver M. F., Barlow M., Bosilovich M., Gershunov A., Gutowski B., Gyakum J., Katz R. W., Lee Y. Y., Lim Y. K., Prabhat, North American Extreme Temperature Events and Related Large Scale Meteorological Patterns: A Review of Statistical Methods, Dynamics, Modeling and Trends, Climate Dynamics
5. *Huziy O., Sushama L., Lake–river and lake–atmosphere interactions in a changing climate over Northeast Canada, Climate Dynamics, doi: 10.1007/s00382-016-3260-y
6. *Huziy O., Sushama L., Impact of lake–river connectivity and interflow on the Canadian RCM simulated regional climate and hydrology for Northeast Canada, Climate Dynamics, doi:10.1007/s00382-016-3104-9
7. *Jelassi M., Gachon P., Laprise R., Occurrence, durée et intensité des précipitations simulées par les modèles régionaux du climat sur la région du Maghreb, Atmosphere-Ocean, http://dx.doi.org/10.1080/07055900.2016.1228522
8. *Jeong D. I., Sushama L., Khaliq N., Attribution of spring snow water equivalent (SWE) changes over the Northern Hemisphere to anthropogenic effects, Climate Dynamics, 1007/s00382-016-3291-4
9. *Jeong D. I., Sushama L., Diro G. T., Khaliq N., Projected changes to winter temperature characteristics over Canada based on an RCM ensemble., Climate Dynamics, 10.1007/s00382-015-2906-5
10. *Jeong D. I., Sushama L., Diro G. T., Khaliq N., Beltrami H., Caya D., Projected changes to high temperature events for Canada based on a Regional Climate Model ensemble, Climate Dynamics, 10.1007/s00382-015-2759-y
11. *Lucas-Picher P., Laprise R., Winger K., Evidence of added value in North American regional climate model simulations using ever-increasing horizontal resolutions, Climate Dynamics
12. McTaggart-Cowan R., Gyakum J., Moore W. R., The baroclinic moisture flux, Mon. Wea. Rev.
13. *Milrad S., Lombardo K., Atallah E. H., Gyakum J., Numerical simulations of the 2013 Alberta Flood: Dynamics, thermodynamics, and the role of orography, Mon. Wea. Rev.
14. *Teufel B., Diro G. T., Whan K., Milrad S., Jeong D. I., Ganji A., Huziy O., Winger K., Gyakum J., de Elía R., Zwiers F., Sushama L., Investigation of the 2013 Alberta flood from weather and climate perspectives, Climate Dynamics
15. *Whan K., Zwiers F., The impact of ENSO and the NAO on extreme winter precipitation in North America in observations and regional climate models, Climate Dynamics
16. *Whan K., Zwiers F., Sillmann J., The influence of atmospheric blocking on extreme winter minimum temperatures in North America, J. Climate
17. *Yang K. W. G., Sushama L., Diro G. T., Inter- and Intra-seasonal variability of Land-Atmosphere coupling over North America in the Canadian Regional Climate Model (CRCM5), Journal of Geophysical Research: Atmosphere

Submitted/under review

18. *Bresson E., Laprise R., Paquin D., Thériault J. M., de Elia R., Evaluating CRCM5 ability to simulate mixed precipitation, Atmos.-Ocean
19. *Diro G. T., Sushama L., The role of soil moisture-atmosphere interaction on future hot-spells over North America as simulated by the Canadian Regional Climate Model (CRCM5), J. of Climate
20. *Diro G. T. Sushama L., Huziy O., Snow-atmosphere coupling and its linkage with temperature variability over North America in the Canadian regional climate model (CRCM5), Climate Dynamics
21. *Fang B., Sushama L., Diro G. T., Samuelsson P., Verseghy D., Déry, S., Validation of snow characteristics and snow albedo feedback over North America as simulated by the Canadian Regional Climate Model, submitted, Climate dynamics
22. *Ganji A., Sushama L., Improved representation of surface-groundwater interaction in the Canadian Land Surface Scheme, Advances in Water Resources
23. *Jeong D. I., Sushama L., Rain-on-snow events over North America based on two Canadian regional climate models, Climate Dynamics

24. *Poan D. E., Gachon P., Laprise R., Aider R., Dueymes G., Investigating regional climate modeling added value in simulating North American winter storm tracks, Climate Dynamics

25. Seiler C., Zwiers F. W., Hodges K. I., Scinocca J. F., How does dynamical downscaling affect explosive cyclones along North Americas Atlantic coast?

26. Zhang, X., Zwiers F. W., Li G., Wan H., Cannon A. J., Using temperature change to project extreme short-duration rainfall in a warming world

In preparation

27. *Ben Alaya M. A., Zwiers F., Zhang X., Probabilistic description of probable maximum precipitation

28. *Ganji A., Sushama L., A Novel Parameterization to Improve Snow Subgrid Representation in Land Surface Models, Journal of Hydrology

29. *Shrestha R. K., Arora V. K., Melton J. R., Sushama L., An assessment of geographical distribution of different plant functional types over North America simulated using the Canadian Terrestrial Ecosystem Model (CTEM)

30. *Teufel B., Sushama L., Arora V., Verseghy D., Impact of dynamic vegetation phenology on the simulated pan-Arctic land surface state, Climate Dynamics

31. *Whan K., Zwiers F. W., Merryfield W. J., Influence of ENSO on atmospheric river precipitation and snow

Conferences

13th International Meeting on Statistical Climatology, Canmore

1. Jeong D. I., Sushama L., Projected Changes to rain-on-snow events over North America based on two Canadian Regional Climate Models
2. Teufel B., Diro G. T., Whan K., Milrad S., Jeong D. I., Ganji A., Huziy O., Winger K., Gyakum J., de Elía R., Zwiers F., Sushama L., Investigation of the 2013 Alberta flood from weather and climate perspectives

41st Northeast Storms Conference, Saratoga Springs

3. Gyakum J., The role of air masses in producing extreme precipitation events
4. Mccray C., Influences of the Lake Champlain Valley on freezing rain events at Burlington, Vermont
5. Ronalds B., : On the relationship between North Atlantic baroclinic growth rate regimes and surface cyclogenesis

9th International Cloud Modeling Workshop, Exeter

6. Cholette M., Thériault J., Milbrandt J., Morrison H., Microphysics parameterization of explicit partial melting of snow to study the formation of freezing rain and ice pellets

AGU Fall meeting, San Francisco

7. Garuma F. G., Sushama L., Preliminary results with CLASS and urban canopy model TEB over Eastern North America
8. Roberge F., Sushama L., Simulation of the Montreal urban heat island
9. Ruman C., Sushama L., Winger K., On the State of the Canadian Arctic Glaciers in Future Climate
10. Teufel B., Sushama L., The impact of dynamic vegetation on land-atmosphere interactions over a pan-Arctic domain

Adaptation Canada 2016, National Symposium on Climate Change Adaptation, Ottawa

11. Laprise R., Lucas-Picher P., Added value of very high-resolution regional climate model simulations compared to those of commonly used intermediate resolution
12. Sushama L., Targeted developments in the fifth generation Canadian Regional Climate Model (CRCM5)
13. Zwiers F., Can we provide robust advice to support infrastructure design?

Atmospheric Rivers Conference held at the Scripps Institution of Oceanography, La Jolla

14. Gyakum J., Atmospheric rivers over eastern Canada: their seasonality, impact on air mass dynamics, and links to extreme precipitation

Banff International Research Station (BIRS) workshop, Banff

15. Ben Alaya M. A., Ouarda T. B. M. J., Chebana F., Non-Gaussian multisite simulation of extreme daily precipitation: downscaling application. Uncertainty Modeling in the Analysis of Weather, Climate and Hydrological Extremes

CanSISE meeting, Victoria

16. Sushama L., Canadian Network for Regional Climate and Weather Processes: selected model developments and applications

CMOS, Fredericton

17. Baijnath J., Duguay C., A Climatological Analysis of Lake Effect Snowfall and its Processes over the Ontario Snowbelt Region of the Great Lakes Basin
18. Diro G. T., Sushama L., The role of land-atmosphere interaction on future hot-spells over North America as simulated by the Canadian Regional Climate Model (CRCM5)
19. Diro G. T., Sushama L., Snow-atmosphere coupling in current and future climates over North America in the Canadian Regional Climate Model (CRCM5)
20. Ganji A., Sushama L., On the Frozen Soil Scheme for High Latitude Regions
21. Gyakum J., The role of air masses in producing extreme precipitation events.
22. Huziy O., Sushama L., Lake-river and lake-atmosphere interactions in a changing climate over Northeast Canada
23. Jeong D. I., Sushama L., Projected Changes to rain-on-snow events over North America based on two Canadian Regional Climate Models
24. Poan E., Gachon P., Laprise R., Aider R., Dueymes G., North America Extra-Tropical Cyclones and their relationship with precipitation extremes using Regional Climate Models
25. Ronalds B., On the relationship between North Atlantic baroclinic growth rate regimes and surface cyclogenesis
26. Sankare H., Gachon P., Laprise R., Poan E., Assessment of storm tracks variability in North America using various wind products from Regional Climate Models
27. Sushama L., Winger K., Dynamic glaciers in CRCM5
28. Sushama L., Fang B., Diro G. T., Samuelsson P., Verseghy D., Dery S., Snow characteristics and snow albedo feedback as simulated by CRCM5 over North America
29. Teufel B., Diro G. T., Whan K., Milrad S., Jeong D. I., Ganji A., Huziy O., Winger K., Gyakum J., de Elía R., Zwiers F., Sushama L., Investigation of the 2013 Alberta flood from weather and climate perspectives
30. Teufel B., Sushama L., Impact of dynamic vegetation on the simulated pan-Arctic land surface state
31. Thériault J., McFadden V., Nikiema O., Laprise R., Paquin D., : Evaluation of the atmospheric conditions associated with freezing rain and ice pellets produced by regional climate model simulations
32. Zwiers F., Event attribution: the emerging science of attributing causes to extreme events

CNRCWP Science meeting, Montreal

33. Baijnath J., Duguay C., LeDrew E., A Climatological Analysis of Lake Effect Snowfall and its Processes over the Ontario Snowbelt Region of the Great Lakes Basin
34. Bowley K., Atallah E. H., Gyakum J., Identifying synoptic patterns patterns associated with rapid buildups of zonal available potential energy
35. Bresson É., Biner S., de Elía R., Laprise R., Paquin D., Thériault J., Climatology of freezing rain over eastern Canada
36. Bélair S., Abrahamowicz M., Alavi N., Carrera M., Fortin V., Garnaud C., Husain S., Joshi D., Rochoux M., Vionnet V., Recent Developments at RPN on Land Surface Modeling
37. Cholette M., Thériault J., Simulation of freezing rain and ice pellets
38. Diro G. T., Sushama L., Snow – atmosphere coupling in current and future climates over North America as simulated by CRCM5
39. Diro G. T., Sushama L., Lin H., Dynamical downscaling of seasonal forecasts with CRCM5
40. Ganji A., Sushama L., Winger K., Déry S., Sub-Grid Snow Parameterization in CRCM5/CLASS
41. Gauthier P., Chikhar K., Regional analyses with the CRCM5
42. Golzan S. B., Teufel B., Ganji A., Jeong D. I., Vieira M., Koenig K., Potential climate change impacts on Arctic infrastructure from permafrost degradation related land subsidence
43. He Y., McFarlane N., Monahan A., Scinocca J., New TKE Based Turbulent Transfer Scheme in the CCCma Models
44. Huziy O., Sushama L., Representation of the Great Lakes in CRCM5 using 3D ocean model NEMO: impacts on simulated climate
45. Jeong D. I., Sushama L., Projected changes to rain-on-snow (ROS) events over North America based on two Canadian RCMs
46. Jeong D. I., Sushama L., Rain-on-snow events over North America in CanRCM4 and CRCM5
47. Lin H., GEPS based monthly forecasting at the Canadian Meteorological Centre

48. Milrad S., Gyakum J., Atallah E. H., A Synoptic-Dynamic Analysis of the 2013 Alberta Flood
49. Perroud M., Fasel M., Marshall S., Development and validation of a glacier mass balance algorithm to nest into the Canadian regional climate model
50. Poan E., Gachon P., Laprise R., Aider R., Dueymes G., North America Extra-Tropical Cyclones and their relationship with precipitation extremes using Regional Climate Models
51. Ronalds B., Gyakum J., Atallah E. H., On the relationship between North Atlantic baroclinicgrowth rate regimes and surface cyclogenesis
52. Sankare H., Gachon P., Laprise R., Poan E., Assessment of storm tracks variability over North America using various wind and vorticity fields
53. Scinocca J., RCM Added Value in Climate Projections
54. Shephard M., Li G., Zhang X., Cole J., Yanjun J., Scinocca J., Probable Maximum Precipitation Response to Projected Climate Change over North America
55. Shrestha R., Arora V., Melton J., Sushama L., Simulating fractional coverages of different vegetation types over North America using the Canadian Terrestrial Ecosystem Model (CTEM)
56. Sushama L., Canadian Network for Regional Climate and Weather Processes
57. Teufel B., Diro G. T., Whan K., Milrad S., Jeong D. I., Ganji A., Huziy O., Winger K., Gyakum J., de Elía R., Zwiers F., Sushama L., Investigation of the 2013 Alberta flood from weather and climate perspectives
58. Teufel B., Sushama L., Response of the simulated land surface state in high-latitude regions to competition between vegetation types
59. Thériault J., Cholette M., Bresson É., Freezing rain : Climatology and microphysics
60. Vieira M., Huard D., Regional climate modeling's place in assessing future impacts of climate change: a climate services viewpoint
61. Whan K., Zwiers F., Influence of ENSO and the NAO on extreme winter precipitation in North America
62. Wheater H., The Changing Cold Regions Network: Observation, Diagnosis, and Prediction of Environmental Change in the Saskatchewan and Mackenzie River Basins
63. Winger K., Sushama L., Valin M., Dugas B., Mailhot J., Duarte L., Ganji A., Jeong D. I., Marshall S., Glacier and Hydrology Changes in Future Climate over Western Canada
64. Yang K. W. G., Diro G. T., Joshi D., Sushama L., Scinocca J., Yanjun J., Intra−annual variability of land-atmosphere coupling over North America in CRCM5 and CanRCM4

Community Climate Science Seminar, Victoria

65. Zwiers F., Changing Extremes - is it real, or just imagined?

EGU, Vienna

66. Diro G. T., Sushama L., Snow-atmosphere coupling in current and future climates over North America in the Canadian Regional Climate Model (CRCM5)
67. Ganji A., Sushama L., Improved representation of surface-groundwater interactions in land surface models
68. Huziy O., Sushama L., Lake-river and lake-atmosphere interactions in a changing climate over Northeast Canada
69. Jeong D. I., Sushama L., Projected Changes to rain-on-snow events over North America
70. Teufel B., Sushama L., Impact of dynamic vegetation on the simulated pan-Arctic land surface state

GEWEX Convection-Permitting Climate Modeling Workshop, Boulder

71. Marinier S., Thériault J., On the study of a major ice pellet storm in the Toronto area in a climate change context

Institute for Catastrophic Loss Reduction, Friday Forum, Victoria

72. Zwiers F., Challenges in understanding and projecting changes in extreme precipitation

International Conference on Regional Climate (ICRC)-CORDEX, Stockholm

73. Laprise R., Lucas-Picher P., Evidence of added value in North American regional climate model simulations with increasing horizontal resolutions

Natural Resources and Environmental Studies Institute, UNBC, Prince George

74. Zwiers F., Challenges in understanding and projecting changes in extreme precipitation

S2S workshop at Ouranos, Montreal

75. Diro G. T., Sushama L., Added value of downscaling seasonal forecast over North America

Seminar at University of Oslo, Oslo

76. Marshall S., Meltwater retention and drainage in mountain glaciers

Symposium on Cryosphere-Climate Processes in Mountain Regions, Riederalp

77. Marshall S., Sensitivity of glacier energy balance to meteorological variability

78. Perroud M., Marshall S., Development and validation of a glacier mass balance algorithm to nest into the Canadian regional climate model

The seventh edition of the STAHY International Workshop, Quebec

79. Ben Alaya M. A., Ouarda T. B. M. J., Chebana F., Non-Gaussian multisite simulation of extreme daily precipitation: downscaling application

XVII International Conference on Cloud and Precipitation, Manchester

80. Cholette M., Thériault J., Milbrandt J., Morrison H., Microphysics parameterization of explicit partial melting of snow to study the formation of freezing rain and ice pellets

Collaborations during the reporting period

A1: Collaborations with Ron McTaggart-Cowan (ECCC) continued in the study of baroclinic moisture flux. Collaborations also continued with Shawn Milard (Embry-Riddle Aeronautical University) in the study of the Alberta flood event.
A2: Collaboration continued with Hugh Morrison (NCAR) and Jason Milbrandt (ECCC) in the implementation of a melting snow category in their new microphysics scheme. Collaboration with Dominique Paquin (Ouranos) continued to evaluate freezing rain in CRCM5 simulations. Collaborations with Yanping Li and Ron Stewart from the CCRN Network also continued.
A3: Collaborations ongoing with John Scinocca (ECCC) and the Danish Meteorological Institute with the goal of developing ensemble information of storm track changes over North America.
B1: Collaboration with Xuebin Zhang (ECCC) continued on topics related to extreme precipitation, including temperature scaling of sub-daily precipitation and on robust approaches for accounting for non-stationarity in IDF curve estimation. Francis Zwiers has been collaborating with Christian Seiler (PCIC), Kevin Hodges (Univ. Reading) and John Scinocca (ECCC) on the analysis of explosive extra-tropical cyclones on the Atlantic coast of North America in CanRCM4. These projects are supported from sources other than CNRCWP, and are aligned with CNRCWP objectives.
B2: Collaborated with Hai Lin on assessing the added value of downscaling seasonal forecasts, with a special emphasis on extreme events. Collaborations continued with John Scinocca and Yanjun Jiao (ECCC) in assessing land-atmosphere interactions in CanRCM4 and CRCM5, and with Francesco Paussata (Stockholm University) to study storminess in past climate.
C1: Collaborations continued with Norm McFarlane in developing the TKE-based boundary layer scheme.
C2: Stephen Dery collaborated with Paul Bartlett (ECCC), Matt MacDonald (U of Manitoba), and Waqar Younas (UNBC) related to sub-grid snow parameterization. Laxmi Sushama collaborated with Patrick Samuelsson (SMHI) in studying the snow-albedo feedback.
C3: Shawn Marshall continued collaborations with U of Geneva on regional climate modelling, and with the CCRN Network led by Howard Wheater on glacier-hydrological modelling in western Canada.
C4: Collaborations continued with Joe Melton (ECCC) on dynamic vegetation modelling over North America and pan-Arctic domains. Collaborations with Benjamin Smith and Paul Miller, from Lund University, regarding the LPJ-GUESS vegetation model and the Arctic Terrestrial Modelling workshop was also continued.
C5: Collaborations with Ram Yerubandi and Luis Leon (ECCC) in the Great Lakes study using various lake models, with a view to using regional climate model outputs to perform selected modelling of biochemical processes in the Great Lakes.
C6: Collaborated with Diana Verseghy and Richard Harvey (ECCC), particularly on surface water – groundwater interactions.
C7: Collaborations with PCIC scientists initiated in the assessment of surface and glacier hydrology over western Canada as part of the NEI. Collaborations with several ECCC and Ouranos scientists in the assessment of newly implemented land modules and land-atmosphere interactions. Collaborations established with several international scientists (Appendix C) to organize an international Arctic Terrestrial Modelling workshop, which is heavily based on the success with the land surface related developments and diagnostics within the Network.

	Name	Start date (Month/Year)
Theme A: Specific weather and climate phenomena permitted by high resolution		
A.1	(MSc) Bryn Ronalds (MSc, PhD) Christopher McCray (PhD) Kevin Bowley (PhD) Melissa Gervais	09/2014 - 08/2016 09/2015 09/2015 02/2013 - 02/2016
A.2	(MSc) Médéric St-Pierre (MSc) Sébastien Marinier (PhD) Melissa Cholette	09/2015 09/2015 01/2014
A.3	(PDF) Emanuel Poan (PhD) Housseyni Sankare	02/2014 09/2015
Theme B: Statistical extremes allowed by fine mesh and land-atmosphere feedbacks		
B.1	(PDF) Ben Alaya	04/2016
B.2	(MSc) Gregory Yang (RA) Dae Il Jeong	09/2013 - 04/2016 02/2015
Theme C: Land-surface processes enhanced by improved representation of surface heterogeneity		
C.1	(RA) Yanping He	05/2013
C.2	(MSc) Rachel Hay (MSc) Bruno Fang (PhD) Sareh Hesaraki	01/2016 09/2013 - 04/2016 09/2016
C.3	(PhD) Caio Ruman (PhD) Sameneh Ebrahimi (PDF) Marjorie Perroud (RA) Parisa Rahimian (0.25RA) Katja Winger	05/2016 02/2016 - 02/2016 06/2016 - 12/2016 10/2014 - 10/2016 09/2013
C.4	(PDF) Rudra Shreshta (MSc, PhD) Bernardo Teufel (RA) Luis Duarte	08/2013 - 06/2016 09/2013 02/2015
C.5	(0.25RA) Oleksandr Huziy (PhD) Janine Baijnath	09/2013 02/2013
C.6	(RA) Arman Ganji	12/2014
C.7	(MSc) François Roberge (PhD) Gemechu Fanta (PDF, RA) Gulilat Tefera Diro	05/2016 05/2015 05/2013
CORE		
	(0.5RA) Oumarou Nikiema	09/2013

Table 1: Budget summary for Y4 and proposed expenditures for Y5

	Planned expenditures *(from original proposal plus carryover)*	**Real expenditures** *(from February 1, 2016 to current date)*	**Projected expenditures** *(from current date to January 31, 2017)*	**Year 4 projected expenditures** *(Total for Project Year 4)*	**Difference in funds** *(Planned - Total)*	**Requested carryover to Year 5*** *(indicate the amounts in each category you are requesting to spend any remaining funds)*	**Year 5 Planned Expenditures as of previous progress report**** *(including any carry over from previous years)*	**Year 5 Proposed Expenditures**
Salaries and benefits								
Students	$240,000	$218,056	$80,294	$298,350	-$58,350		$317,157	$300,000
Postdoctoral fellows	$135,000	$133,656	$16,000	$149,656	-$14,656		$284,912	$125,000
Technical/professional assistants	$405,936	$279,524	$51,544	$331,068	$74,869		$168,817	$345,729
Equipment or Facility								
Purchase or rental	$20,791	$18,514		$18,514	$2,277		$20,791	$20,791
Operation and maintenance costs	$28,271	$30,548		$30,548	-$2,277		$28,272	$28,272
User fees	$4,055	$4,555		$4,555	-$500		$4,055	$4,055
Materials and Supplies								
	$3,293	$2,793		$2,793	$500		$3,293	$3,293
Travel								
Conferences	$58,973	$39,973	$19,000	$58,973	$0		$57,936	$57,936
Project-related travel	$16,273	$18,209		$18,209	-$1,936		$16,272	$16,272
Dissemination costs								
Publication costs	$22,159	$22,086		$22,086	$73		$22,158	$22,158
Other activities				$0	$0			
Other (specify)								
Outreach	3000	$2,800		$2,800	$200		$4,000	$4,000
Annual Workshop	$25,000	$25,200		$25,200	-$200		$25,000	$25,000
NEI Initiatives								
RA salary for model integration	$37,500	$30,500	$7,000	$37,500	$0		$37,500	$37,500
Joint workshop with NGEE	$0						$25,000	$25,000
TOTAL	**$1,000,251**			**$1,000,251**	**$0**		**$1,015,162**	**$1,015,005**

Table 2: Budget summary (Y1-Y5)

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Installments 1/2	$307,960	$143,917	$252,600	$481,375	$476,331	**$1,662,183**
Installments 2/2	$503,691	$436,896	$517,778	$518,876	$476,331	**$2,453,572**
NSERC Award	**$811,651**	**$580,813**	**$770,378**	**$1,000,251**	**$952,662**	**$4,115,755**
Total year budget	**$811,651**	**$1,055,238**	**$1,105,485**	**$1,000,251**	**$952,662**	
CNRCWP Spent	$337,226	$720,132	$1,105,484	$1,000,251		**$3,163,093**
Carry Over	$474,425	$335,107	$0	$0		

INTRODUCTION

Canada's territory and the Arctic regions offer distinct challenges to Numerical Weather Prediction (NWP) and climate projection, due to complex processes and feedbacks between various components of the climate system. A better understanding of these regional climate processes and interactions is crucial to improving the quality of both climate projection and NWP for this region, and to better interpret and apply model results for use in weather and climate-change impact and adaptation studies.

OBJECTIVES

The aim of the Network is to augment, evaluate and exploit the added value provided by regional models in climate and weather simulations. This added value is afforded as a result of the expected higher resolution, improved representation of physical processes, feedbacks and interactions through a Regional Earth System Model approach.

CO-INVESTIGATORS

- Sushama Laxmi (PI)
  Université du Québec à Montréal, ESCER
- Arora Vivek
  Canadian Centre for Climate Modelling and Analysis, University of Victoria
- de Elía Ramon
  Ouranos, ESCER
- Déry Stephen
  University of Northern British Columbia
- Duguay Claude
  University of Waterloo
- Gachon Philippe
  Canadian Centre for Climate Modelling and Analysis, ESCER
- Gyakum John
  McGill University
- Laprise René
  Université du Québec à Montréal, ESCER
- Marshall Shawn
  University of Calgary
- Monahan Adam
  University of Victoria
- Scinocca John
  Canadian Centre for Climate Modelling and Analysis, University of Victoria
- Thériault Julie
  Université du Québec à Montréal, ESCER
- Verseghy Diana
  Environment Canada
- Zwiers Francis
  Pacific Climate Impacts Consortium, University of Victoria

CONTACT

Oleksandr Huziy, Network coordinator
University of Quebec at Montreal
201 Avenue President Kennedy
www.cnrcwp.uqam.ca
email: huziy@sca.uqam.ca

CANADIAN NETWORK FOR REGIONAL CLIMATE AND WEATHER PROCESSES

CNRCWP

Based at

Centre ESCER, University of Quebec at Montreal

Funded by

NSERC CRSNG

Participating Universities

UQÀM, McGill, UNBC University of Northern British Columbia, University of Calgary, University of Victoria, University of Waterloo

Government and non-profit organization partners

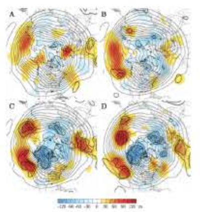
Canada, Ouranos, Pacific Climate Impacts Consortium

Year 4: Network research highlights

THEME A

Specific weather and climate phenomena permitted by high-resolution

This theme focuses on the assessment of added value based on the understanding of physical mechanisms that contribute to temperature and precipitation extremes.



Composite mean 500 hPa heights (thin black contour, m, 60 m contour intervals), 500 hPa height anomaly from weighted DJF climatology (colored, m), and significance criteria from 2-sided students t-test (thick black contour (95th percentile), hatched (99th percentile)) for lag day -9 (A, prior to peak ZAPE buildup day), lag day -6 (B), lag day -3 (C), and lag day 0 (D, peak ZAPE buildup day). Low height anomalies (blue) over Alaska and Northwestern Canada are in response to rapid regional cooling, while high height anomalies (red) over the eastern North Pacific basin are in response to anticyclonic wave break activity and reduced storm activity.

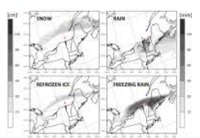
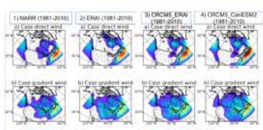


Figure shows the accumulated precipitation at the surface from 4 to 10 January 1998. It is divided into snow, rain, refrozen ice (new category) and freezing rain (new category). In particular, it shows transition from snow, ice pellets, freezing rain and rain over eastern Canada during that storm These new categories are based on the prediction of the liquid fraction within the ice category. Note that the original version of the scheme would give only rain and ice particles. Theses simulations demonstrate clearly the ability of the scheme to predict freezing precipitation. These were conducted at 10 km resolution and the next step is to increase the resolution to 3 or 1 km, to perform a detailed study of the formation mechanisms as well as a Pseudo Global Warming simulation (PGW) of the storm.

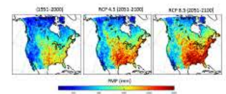


Mean storm occurrence (storm per month) from November to March period (NDJFM) over North America from 1) NARR reanalysis products, 2) ERA-Interim, 3) CRCM5 simulation driven by ERA-Interim, and 4) CRCM5 simulation driven by CanESM2 simulation. In a) The storm track algorithm inputs fields are 1 000 hPa winds (direct model outputs wind) and b) The inputs fields are 1 000 hPa gradient winds compute from geopotential heights and the curvature of parcel trajectory. All mean values are computed over the 1981-2010 period.

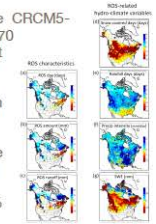
THEME B

Statistical extremes allowed by fine mesh and land-atmosphere feedbacks

This theme documents the ability of high-resolution RCMs to simulate extreme temperature and precipitation events, and their links to circulation variations and land-atmosphere coupling, both in current and future climates. The analysis will make full use of standard extreme indices and statistical extreme value theory.



In the current work, outputs from the CanRCM4 model are used to derive 6-hourly probable maximum precipitation (PMP) estimates at each CanRCM4 grid point over historical (1951-2000) and future (2051-2100) periods. These estimates cover the North American region with 0.44° spatial horizontal resolution and are derived under two representative concentration pathways (RCP) 4.5 (middle panel) and 8.5 (rightmost panel) scenarios. The resulting 6-hourly PMP maps are shown in the figure. Results reveal that PMP will increase by an average of about 24% under the RCP 4.5 emissions scenario and about 41% under RCP 8.5.

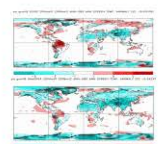


Projected changes to ROS characteristics for the CRCM5-CanRCP4.5 simulations for April for the 2041-2070 period with respect to the 1976-2005 period (left column). Projected changes to the number of snow covered days (i.e., days with SWE larger than 1 mm), rainfall days (i.e., days with rainfall larger than 1 mm), precipitation intensity, and SWE are also presented (right column). The black contour corresponds to the future freezing line (i.e., future Tmean is 0°C). Projected changes are shown only for gird points with statistically significant changes, estimated by the two-sample t-test at the 10% significance level.

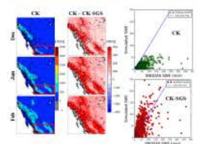
THEME C

Land-surface processes enhanced by improved representation of surface heterogeneity

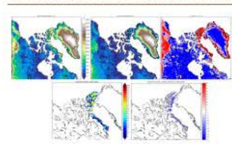
This theme aims to quantify the role and importance of explicitly resolving processes in the land and atmosphere components of the regional earth system and the interactions between them.



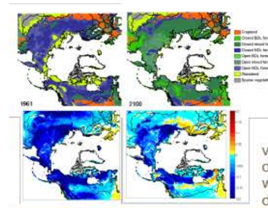
A new semi-empirical diagnostic turbulent kinetic energy (TKE) scheme has been developed to represent downgradient turbulent transfer processes for both clear and cloudy conditions. The figure shows CCCma CanAm4 simulated annual mean surface screen temperature anomaly from observations in the GCM18 operational version (upper panel) and the GCM18 latest TKE version (lower panel) from Jan. 2004 to Dec. 2008.



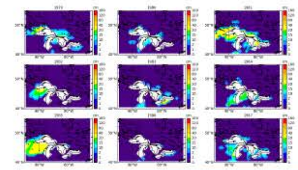
Snow depth (mm) for CRCM5 simulation without subgrid snow representation (left column), and the difference in snow depth between CRCM5 simulations with (CK-SGS) and without (CK) subgrid snow representation (middle column). Values are shown only for grid cells with statistically significant differences, estimated by the t-test at 5% significance level. Scatter plots (right column) of observed and simulated SWE for DJF.



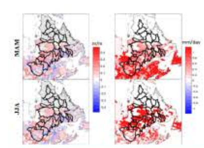
The projected changes in temperature, precipitation and glacier fraction were evaluated for the future period of 2071-2100 with respect to the 1981-2010 period. The preliminary results indicate an increase of the average temperature and precipitation for the summer and winter in the domain area by the end of the century. Although the increase in precipitation means more snow falling on the glaciers, the increase in temperature extends the melting period in summer, meaning that the extra snow won't endure summer to be converted to ice. The projected warming causes the glaciers in the domain area to lose up to 40% of their glacier fraction by 2100, when compared to present day values (figures d and e).



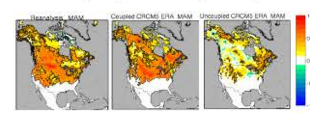
Distribution of biomes as simulated by CLASS+CTEM for 1961 (top left) and 2100 (top right). Orange is used for crops (prescribed), blue for needle-leaved forests, dark green for mixed and broad-leaved forests and light green for grass. Total projected change (2071-2100 minus 1981-2010) in spring albedo (bottom left) and projected change due to dynamic vegetation (bottom right). Atmospheric data to run CLASS and CLASS+CTEM was taken from CRCM5 simulations driven by CanESM2 for RCP8.5.



Annual heavy lake-effect snowfall (cm; events with snowfall greater than 10 cm/day) based on the ERA-Interim (0.75°) data for the 1979-1988 winters. The algorithm used to detect the lake-effect snowfall is based on Notaro et al. 2015.

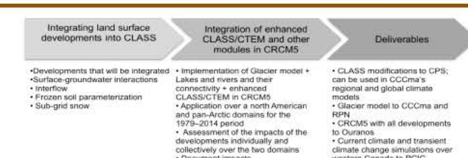


Differences in the (left) soil moisture and (right) runoff fields in two simulations of CLASS, i.e. with improved representation of surface water - groundwater interactions and the original version, for MAM and JJA.



The figure demonstrates that there is a strong relationship between snow cover frequency and cold spell days that is observed over northern Great Plains and Canadian Prairies in reanalysis dataset (left) is well simulated in coupled CRCM5 simulation (middle) but significantly weakened in the uncoupled CRCM5 simulation (right), suggesting that snow variability is important, at least, in the amplification of cold spell days.

WORK PLAN FOR TECHNOLOGY TRANSFER TO CNRCWP PARTNERS



Canadian Network for Regional Climate and Weather Processes
Annual science meeting

May 17—19, 2016
UQÀM, Agora Hydro-Québec (CO-R500)
175 Avenue du Président Kennedy, Montréal, QC, Canada

CNRCWP

Tuesday, May 17

Time	Title	Presenter
13:00 — 15:00	Network HQP meeting, PK-6120	
16:00 — 17:00*	**Public lecture1**: Toward seamless weather-climate and environmental prediction	Gilbert Brunet ECCC-RPN
17:00 — 18:00*	**Public lecture2**: Weather and climate information across time scales for applications	Andrew Robertson IRI, Columbia University
18:00 — 20:00	Icebreaker and dinner	

*** Please note that the public lectures will be at Ouranos (550 Sherbrooke West, 19th floor)**

Wednesday, May 18

08:15 — 09:00	Registration	
09:00 — 09:05	Welcome remarks	Luc-Alain Giraldeau Dean, Faculty of Sciences, UQÀM
09:05 — 09:20	CNRCWP research update	Laxmi Sushama UQÀM
09:20 — 10:00	Integrative project: Investigation of the 2013 Alberta flood from weather and climate perspectives	John Gyakum McGill Bernardo Teufel PhD-UQÀM
	Theme B: Statistical extremes allowed by fine mesh and land-atmosphere feedbacks	
10:00 — 10:30	The influence of variability external to the RCM domain on extremes within the domain	Francis Zwiers Kiri Whan UVic, PCIC
	PMP response to anthropogenic influence	Xuebin Zhang ECCC-CDAS
10:30 — 10:50	Coffee Break	
10:50 — 11:10	**Invited talk:** GEPS based monthly forecasting at the Canadian Meteorological Centre	Hai Lin ECCC-RPN
11:10 — 11:40	The inter- and intra-seasonal variability of land-atmosphere coupling over North America in CRCM5 and CanRCM4	G. Yang Kam Wing MSc-UQÀM
	Dynamical downscaling of seasonal forecasts using CRCM5	Gulilat Tefera Diro RA-UQÀM

	Rain-on-snow events over North America in CanRCM4 and CRCM5	Dae Il Jeong RA-UQÀM
11:40 — 12:00	Open discussion on theme B	
12:00 — 13:30	Lunch & Posters (for all participants)	
	Theme C: Land-surface processes enhanced by improved representation of surface heterogeneity	
13:30 — 13:50	**Invited talk:** Recent developments at RPN on land surface modeling (new SVS scheme, subkm modeling, impact of cities)	Stéphane Bélair ECCC-RPN
13:50 — 14:05	A new TKE turbulence parameterization in the global climate model (CanAM4)	Yanping He RA-UVic
14:05 — 14:35	Snow characteristics and snow albedo feedback, sub-grid snow parameterization, snow-atmosphere coupling over North America as simulated by the Canadian Regional Climate Model	Gulilat Tefera Diro RA-UQÀM Arman Ganji RA-UQÀM Bruno Fang MSc-UQÀM
14:35 — 15:05	Development and validation of a glacier mass balance algorithm to nest into the Canadian regional climate model	Marjorie Perroud PDF-UCalgary
	On glacier-climate/hydrology interactions over NW Canada	Katja Winger RA-UQÀM
15:05 — 15:35	Simulating fractional coverages of different vegetation types over North America using the Canadian Terrestrial Ecosystem Model (CTEM)	Rudra Shrestha PDF-UVic
	Response of the simulated land surface state in high-latitude regions to competition between vegetation types	Bernardo Teufel PhD-UQÀM
15:35 — 15:50	Coffee Break	
15:50 — 16:20	A climatological analysis of lake effect snowfall and its processes over the Ontario Snowbelt Region of the Great Lakes Basin	Janine Baijnath PhD-UWaterloo
	Representation of the Great Lakes in CRCM5 using 3D ocean model NEMO: impacts on simulated climate	Oleksandr Huziy PhD-UQÀM
16:20 — 16:40	Regional climate modeling's place in assessing future impacts of climate change: A climate services viewpoint	David Huard Ouranos Michael Vieira Manitoba Hydro
16:40 — 17:10	**Invited talk:** Canadian Cold Regions Network	Howard Wheater GIWS, U of Saskatchewan
17:10 — 17:30	Open discussion on theme C	
17:30 — 17:45	Regional reanalysis with CRCM5	Pierre Gauthier UQÀM
	Special meetings	
17:45 — 18:40	Scientific Advisory Board (SAB) meeting with users/students, Agora; Scientific Steering Committee (SSC) meeting, PK-1140	

18:30 — 20:30	Dinner (for all participants)

Thursday, May 19

	Theme A: Specific weather and climate phenomena permitted by high-resolution	
09:00 — 09:30	Synoptic-scale increases of Northern Hemisphere zonal available potential energy	Kevin Bowley PhD-McGill
	On the relationship between North Atlantic baroclinic growth rate regimes and surface cyclogenesis	Bryn Ronalds MSc-McGill
09:30 — 10:00	Freezing rain: Climatology and microphysics	Mélissa Cholette PhD-UQÀM Émilie Bresson PDF-UQÀM
10:00 — 10:20	RCM added value in climate projections	John Scinocca ECCC-CCCma
10:20 — 10:40	Coffee break	
10:40 — 10:55	Revisiting North America storm tracks from regional climate models perspective	Emanuel Poan PDF-UQÀM
	Assessment of storm tracks variability over North America using various wind and vorticity fields	Housseyni Sankaré PhD-UQÀM
10:55 — 11:15	Open discussion on theme A	
11:15 — 11:45	**Invited talk:** CanSISE Deliverable 1: Assessment of sea ice, snow, and related climate variability in Canada's Earth System Model and Prediction Systems	Paul Kushner U of Toronto
11:45 — 12:05	Exploring collaboration — Workshop summary	Laxmi Sushama UQÀM
12:05 — 14:00	Lunch & [SAB meeting] (for all participants)	
14:00 — 16:30	**Special meetings:** Joint SAB, SSC meeting, PK-1140	
17:00 — 19:00	5 à 7, Bénélux (245 Sherbrooke West)	

Title	Presenter
Surface-Ground Water Interaction in the Canadian Land Surface Scheme	Arman Ganji RA-UQÀM
Projected changes to rain-on-snow events over North America	Dae Il Jeong RA-UQÀM
Glacier and hydrology changes in future climate over western Canada	Katja Winger RA-UQÀM
Lake-river and lake-atmosphere interactions in a changing climate over Northeast Canada	Oleksandr Huziy PhD-UQÀM
Snow-atmosphere coupling in current and future climates over North America in CRCM5	Gulilat Tefera Diro RA-UQÀM
Soil moisture-precipitation coupling in CanRCM4 and CRCM5	G. Yang Kam Wing MSc-UQÀM
Snow characteristics and snow-albedo feedback in CanRCM4 and CRCM5	Bruno Fang / Sareh Hesaraki MSc-UQÀM
Influence of open water bodies on the modelling of summertime convection over the Canadian Prairies	Deepti Joshi PDF-UQÀM
Spatial spin-up of fine scales in regional climate model simulation driven by low-resolution boundary conditions	Dominic Matte PhD-UQÀM
Assessment of storm tracks variability in North America using various wind products from Regional Climate Models	Housseyni Sankare PhD-UQÀM
The role of acidified aerosols in the evolution of thin ice clouds (TICs) over the Arctic region	Ana Crisan PDF-UQÀM
Precipitation characteristics associated with the large-scale flow field over the eastern side of the Alberta Rockies	Paul Vaquer MSc-UQÀM
Data assimilation of far infrared radiation in polar regions	Laurence Coursol MSc-UQÀM
Far Infrared Radiometer campaign at Eureka.A case study of observed ice clouds	Ludovick Pelletier MSc-UQÀM
CRCM5 dynamical downscaling over the CORDEX Arctic domain	Maryam Takhsha MSc-UQÀM
Design of a new far-infrared radiometer for polar cloud measurement	Yacine Bouzid PhD-UQÀM
Preliminary results with CLASS and urban model TEB over eastern NA.	Gemechu Fanta PhD-UQÀM
Energetic study of a rapid intense storm developing over mid-latitude area	Oumarou Nikiema RA-UQÀM
Potential climate change effects on Arctic infrastructure: permafrost degradation and land subsidence	Behnam Golzan Seyyed UQÀM

Funded by

NSERC CRSNG

Natural Sciences and Engineering Research Council of Canada (NSERC)
www.nserc-crsng.gc.ca

Partners

List of participants

	Name	Last name	Affiliation
1	Aboubacar Keita	Setigui	UQÀM - ESCER
2	Agbazo	Médard	UQÀM - ESCER
3	Alexandru	Adelina	UQÀM - ESCER
4	Anderson	Kevin	ECCC - CDAS
5	Ansley	James	ECCC - CCCma
6	Baijnath	Janine	University of Waterloo
7	Barszcz	Agnès	UQÀM - ESCER
8	Belair	Stephen	ECCC - RPN
9	Biner	Sebastien	Ouranos
10	Blanchet	Jean-Pierre	UQÀM - ESCER
11	Blyth	Eleanor	NERC, UK
12	Bourque	Alain	Ouranos
13	Bowen	Dave	NSERC
14	Bowley	Kevin	McGill
15	Bresson	Émilie	UQÀM - ESCER
16	Brunet	Gilbert	ECCC - RPN
17	Chacón	Arlette	UQÀM - ESCER
18	Chaumont	Diane	Ouranos
19	Cholette	Mélissa	UQÀM - ESCER
20	Christensen	Jens	DMI, Denmark
21	Côté	Hélène	Ouranos
22	Côté	Jean	UQÀM - ESCER
23	Coursol	Laurence	UQÀM - ESCER
24	Crisan	Ana	UQÀM - ESCER
25	de Elía	Ramon	Ouranos
26	Desroches-Lapointe	Aurélie	UQÀM - ESCER
27	Déry	Stephen	UNBC
28	Diro	Gulilat Tefera	UQÀM - ESCER
29	Duarte	Luis	UQÀM - ESCER
30	Dugas	Bernard	UQÀM - ESCER
31	Fanta	Gemechu	UQÀM - ESCER
32	Fournier	Élyse	Ouranos
33	Gachon	Philippe	UQÀM - ESCER
34	Giguère	Michel	Ouranos
35	Ganji	Arman	UQÀM - ESCER
36	Gemechu	Fanta	UQÀM - ESCER
37	Girard	Éric	UQÀM - ESCER
38	Golzan	Seyyed Behnam	UQÀM - ESCER
39	Grenier	Patrick	Ouranos
40	Grotjahn	Richard	UC - Davis
41	Gyakum	John	McGill University
42	Hachelaf	Rabah	UQÀM - ESCER
43	Harvey	Richard	ECCC - CPS
44	Hay	Rachel	UNBC
45	He	Yanping	UVic
46	Hesaraki	Sareh	UQÀM - ESCER
47	Huard	Georges	UQÀM - ESCER
48	Huard	David	Ouranos
49	Huziy	Oleksandr	UQÀM - ESCER
50	Jeong	Dae Il	UQÀM - ESCER
51	Houle	Daniel	Ouranos
52	Keita	Sétigui	UQÀM - ESCER
53	Leduc	Martin	Ouranos

	Name	Last name	Affiliation
54	Leon	Luis	ECCC
55	Lin	Hai	ECCC - RPN
56	Matte	Dominic	UQÀM - ESCER
57	Marinier	Sébastien	UQÀM - ESCER
58	McFadden	Vanessa	UQÀM - ESCER
59	McCray	Cristopher	McGill
60	Melton	Joe	ECCC - CCCma
61	Monteiro	Eva Rosa	UQÀM - ESCER
62	Mohammed-Ali	Ben-Alaya	UVic
63	Music	Biljana	Ouranos
64	Nikiema	Oumarou	UQÀM - ESCER
65	Ngueto	Yves	UQÀM - ESCER
66	Lucas-Picher	Philippe	UQÀM - ESCER
67	Poan	Emmanuel	UQÀM - ESCER
68	Poirier	Emilie	UQÀM - ESCER
69	Pelletier	Ludovick	UQÀM - ESCER
70	Plummer	David	Ouranos
71	Perroud	Marjorie	University of Calgary
72	Qian	Minwei	ECCC - CCCma
73	Robertson	Andrew	IRI - U. Columbia
74	Roberge	François	UQÀM - ESCER
75	Ronalds	Bryan	McGill
76	Rondeau-Genesse	Gabriel	Ouranos
77	Roy	Sylvie	NSERC
78	Sankare	Housseyni	UQÀM - ESCER
79	Scinocca	John	ECCC - CCCma
80	Sghyar	Rajaa	UQÀM - ESCER
81	Sghyar	Rajaa	UQÀM - ESCER
82	Shrestha	Rudra	UVic
83	St-Pierre	Médéric	UQÀM - ESCER
84	Sushama	Laxmi	UQÀM - ESCER
85	Takhsha	Maryam	UQÀM - ESCER
86	Teufel	Bernardo	UQÀM - ESCER
87	Thériault	Julie	UQÀM - ESCER
88	Torlaschi	Enrico	UQÀM - ESCER
89	Verseghy	Diana	ECCC - CPS
90	Vaquer	Paul	UQÀM - ESCER
91	Vieira	Michael	Manitoba Hydro
92	Wehner	Michael	Lawrence Berkeley National Lab, USA
93	Winger	Katja	UQÀM - ESCER
94	Zwiers	Francis	PCIC
95	Walker	Anne	ECCC - CPS
96	Wheater	Howard	University of Saskatchewan
97	Yerubandi	Ram	ECCC