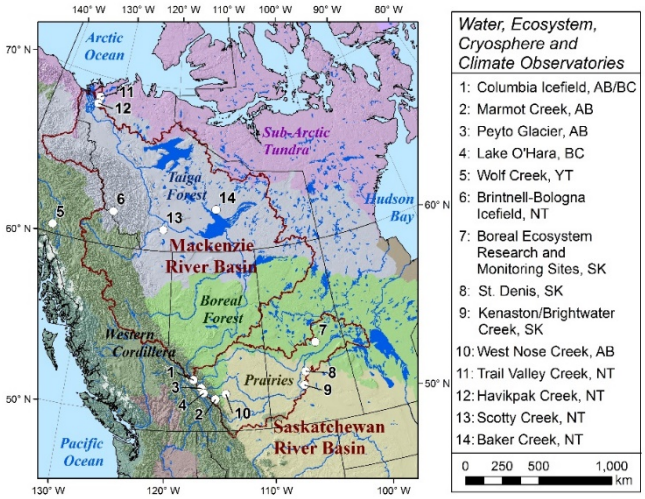
**Changing Cold Regions Network (CCRN) Project Report for the GEWEX GHP Meeting**
**Reporting Period: November 2016 – October 2017**
**Starting Date: February 2013**
**End Date: March 2018**
**URL: www.ccrnetwork.ca**
**Chair(s) and term dates: Professor Howard Wheater (2013–2018)**

## Background

The Canadian RHP known as the Changing Cold Regions Network (CCRN) covers the interior of western Canada, including the Mackenzie and Saskatchewan River Basins. The overall aims of CCRN are to understand, diagnose, and predict changing land, ecosystems, water, and climate, and their interactions and feedbacks over western Canada's cold interior. This includes developing improved land surface and hydrological models for cold regions. We use a network of 14 intensely instrumented Water, Ecosystem, Cryosphere, and Climate (WECC) observatories representing the key biomes to study detailed processes and linkages, and we are working to better understand the changing regional climate and its effects on large-scale Earth system change and the region's major river basins. Our programme is divided into five major thematic components: Theme A, Observed Earth System Change in Cold Regions – Inventory and Statistical Evaluation; Theme B, Improved Under-standing and Diagnosis of Local-Scale Change; Theme C, Upscaling for Improved Atmospheric Modelling and River Basin-Scale Prediction; Theme D, Analysis and Prediction of Regional and Large-Scale Variability and Change; and Theme E, Outreach and Engagement. Further details can be found at www.ccrnetwork.ca/science.




## 1) Regional Hydroclimate Project (RHP) activities over the last year

Key science and outreach highlights from the past year include:

- We have conducted a multi-disciplinary expert synthesis of conceptual understanding and scenarios of future Earth system change across western Canada for the purposes of informing model setup, parameterization, and application under future climates. It is understood that most or all models do not adequately capture the process dynamics and interconnections and the integrated system responses, and thus it is unclear how useful the results are when these are run for future climate conditions. This synthesis is a major first step in overcoming some of these issues and in reducing uncertainty in model outputs. This was a key focus at our scenarios of change workshop in March (http://ccrnetwork.ca/science/workshops/scenarios-of-change) and the work is being written as a two-part manuscript for a special issue of the journal Hydrology and Earth System Sciences (HESS)—see below.
- Fine scale model advancements have included improvement in process representation within the Cold Regions Hydrological Model (CRHM; www.usask.ca/hydrology/CRHM.php), and enhanced computational efficiency and landscape representation within the next generation Canadian Hydrological Model (CHM; http://ccrnetwork.ca/science/workshops/summer-2017-modelling-workshop/files/marsh_ccrn_modelling2017.pdf), both developed at the University of Saskatchewan's Centre for Hydrology. CRHM has been set up and applied at selected WECC observatories for long-term historical runs and diagnosis of hydrological change. Some of this work has been recently published (Cordeiro et al., 2017; Mahmood et al., 2016; Krogh et al., 2017; Rasouli et al., 2014) and further papers are in development.
- We have made major advancements in regional climate, land surface, and hydrological model development and applications. This work has involved close collaboration and a strong partnership with Environment and Climate Change Canada (ECCC) to help them incorporate improvements into their research and operational models. Our main focus is the ECCC Canadian LAnd Surface

Scheme (CLASS), Modélisation Environmentale Communautaire (MEC) – Surface and Hydrology (MESH), and Canadian Terrestrial Ecosystem Model (CTEM) models. The main effort has concentrated on developing and improving large-scale MESH models of the Mackenzie and Saskatchewan River systems, and within this, improving the representation of various processes such as permafrost, wetlands, hydrodynamics and large lakes, and snow processes, and also exploring ways of better handling spatial discretization (especially in mountainous terrain) and in particular, the effects of water management—CCRN is strongly linked to a GEWEX cross-cut project on including water management in large scale models. Various other activities have supported this work, which has progressed well to the point where we have working models in place for both major basins and we are in the midst of running future climate simulations and incorporating scenarios of landscape and ecological change. These activities were reviewed and discussed in detail at a recent modelling workshop (www.ccrnetwork.ca/science/workshops/summer-2017-modelling-workshop).

- In association with the above work, we have set up and run the US National Center for Atmospheric Research Weather Research and Forecasting (WRF) model over our domain and generated high-resolution (4 km), convection-permitting climate simulations for 2001–2015 as well as pseudo-global warming simulations under RCP8.5 for 2086–2100. This provides unprecedented high resolution climate information for running surface hydrological models and gives important insights on precipitation extremes. More information is at www.ccrnetwork.ca/science/PGW.
- We have focused on in-depth analyses of recent extreme events in western Canada. This includes the 2013 Calgary flood (http://ccrnetwork.ca//science/2013-Alberta-flood), summer flooding in the prairies (http://ccrnetwork.ca//outputs/information-products/2014-assiniboine-flood), severe dry conditions in 2015 (Szeto et al., 2016) and 2017, extreme wildfires (Northwest Territories (2014), Saskatchewan (2015), Fort McMurray (2016), British Columbia and southern Alberta (2017), and more). This has included analyses from a variety of perspectives (climate, ecology, hydrology, modelling, etc.) and scales (continental to regional and local).
- CCRN has opened two special issues in the journals Earth System Science Data (ESSD) and Hydrology and Earth System Sciences (HESS). These special issues are important initiatives that aim to pull together our datasets and make them available as a legacy for the network, and to synthesize the recent science advances contributing to CCRN's overall aims and objectives. The special issues are open to all submissions within their scope and welcome related datasets and studies from cold-region environments around the world. More detailed information and links to papers already submitted can be found at www.earth-syst-sci-data.net/special_issue901.html and www.hydrol-earth-syst-sci.net/special_issue919.html.
- Outreach efforts as part of Theme E have continued, ranging from grassroots level engagement among individual researchers and local stakeholders, to collaboration at senior management levels with our federal provincial, and territorial government partners, and linkage to international initiatives such as GEWEX and the World Climate Research Programme. We have been active in developing science outreach communications for public consumption. These products provide plain language and informative summaries of some of the issues CCRN is addressing, and can be found at www.ccrnetwork.ca/outputs/information-products.

**2) Planned panel activities for next year**

CCRN will be coming to an official end in March 2018. As we enter the final six months of the programme we are focused on incorporating scenarios of change into our regional MESH modelling of the Mackenzie and Saskatchewan River systems and examining projected future Earth system change and responses for the 21st century. We will be looking carefully at the results and feeding some of this back to our fine scale models to explore process interactions and feedbacks in more detail and gain further insights into system change. We have a workshop planned for November 2-3 (http://ccrnetwork.ca/science/workshops/index.php) to examine the results, plan final model runs and analyses, and develop output products such as model datasets and papers for publication. Our final network symposium, *The CCRN Finale*, is planned for March 4-7, 2018, where the network will gather for the last time to review our accomplishments, to plan products and publications as a legacy of CCRN, to connect with key stakeholders and partner organizations, and to look to the future in follow-on initiatives (see below). We currently have our two special issues (ESSD and HESS) open for several months beyond the end date of CCRN, and will continue to populate these. We will also be developing a film documentary to showcase the observed Earth system changes, CCRN's science advancements (including projections of future change) and their societal relevance, and the legacy of this important research initiative.

As CCRN is ending, we note a relatively new programme that is ramping up and in many respects following on from, and expanding upon, some of the activities and scientific issues being addressed in CCRN. The *Global Water Futures* (GWF; www.globalwaterfutures.ca) Project is a $143 Million, seven year (2016–2023), University of Saskatchewan-led research initiative that has an overall mission to improve disaster warning, predict water futures, and inform adaptation to change and risk management. GWF is the largest investment of its kind in university-led water research and aims to provide global leadership in water science for cold regions and to address the strategic needs of the Canadian economy in adapting to change and managing the risks of uncertain water futures and extreme events. Its geographic focus will include not only the Mackenzie and Saskatchewan River Basins, but a number of other major watersheds across all of Canada, while its science focus will expand to include water quality, social science, health, and water governance.

We envision our linkage to the GEWEX Hydroclimate Panel continuing through this major new initiative, under the leadership and direction of Distinguished Professor John Pomeroy, who was co-PI for CCRN. The CCRN secretariat staff has been expanded to manage this large and complex programme, and will benefit from including many of the same support and management staff, thus retaining continuity and experience. Most of the CCRN core team and collaborators are also actively involved in GWF and its activities.

### 3) Contributions to the GEWEX Science Questions

GSQ1: Observations and Predictions of Precipitation

- There has been much individual research progress on atmospheric circulation patterns, instabilities for generating convection, large-scale forcing for drought, precipitation phase changes, winter precipitation extremes, surface hydrologic changes, and runoff, with a number of journal submissions and draft manuscripts based on these studies.
    - Publications: Bonsal et al. (2017), Brimelow et al. (2017), Kochtubajda et al. (2017), Zhang et al. (2017)
- Measurements, correction and evaluation of precipitation datasets.
    - Publications: Pan et al. (2016), Scaff et al. (2015), Smith et al. (2017)
- Assessments of various precipitation products and remotely sensed observations, including GPM, and characterization and regionalization of precipitation and drought characteristics over western Canada, with several papers in draft.
    - Relevant publications include: Asong et al. (2015, 2016, 2017), Khaliq et al. (2015), Masud et al. (2015), Wong et al. (2017)
- A major CCRN effort was centered on a comprehensive focal examination of the extreme weather and flooding in southern Alberta in June 2013, focusing on meteorological, hydrological, and water management aspects of the flood. This has led to a collection papers being published in a special issue of *Hydrological Processes*. (See http://ccrnetwork.ca//science/2013-Alberta-flood for further details, information products and links to all published papers.)
- Focal examination of extreme events (floods, fires, droughts) affecting the CCRN region from 2009–2017 with several papers published and others forthcoming
    - Relevant publications include those listed above and: Blouin et al. (2016), Brimelow et al. (2014, 2015), Masud et al. (2016), Szeto et al. (2015)

GSQ2: Global Water Resource Systems

- Completion of inventories and assessments of Earth system change at many WECC observatories and across the CCRN domain.
    - Relevant publications include: Baltzer et al. (2013), Bash and Marshall (2014), Bonsal et al. (2017), Connon et al. (2014), DeBeer et al. (2015, 2016), Demuth et al. (2014), Dumanski et al. (2015), Ehsansadeh et al. (2014), Harder et al. (2015), Hayashi and Farrow (2014), Ireson et al. (2015), Maillet et al. (2017), Mamet et al. (2017), Marshall (2014b), Patankar et al. (2015), Paznekas et al. (2015), Quinton and Baltzer (2013b), Shi et al. (2015), Shook and Pomeroy (2015), Spence et al. (2015), Yang et al. (2014b).
- Analysis of large scale hydrological model performance for the Saskatchewan and Mackenzie basins. Identification of key challenges – input uncertainty, permafrost, cold region lakes and wetlands, mountain hydrology, prairie hydrology, anthropogenic water management. Work initiated

to address these with a number of draft papers underway and some recent publications. Much of this work (at various stages of development) had been reviewed and synthesized at a recent workshop (see http://ccrnetwork.ca//science/workshops/summer-2017-modelling-workshop).
    - Relevant publications include: Hassanzadeh et al. (2014, 2015), Mekonnen et al. (2014), Nazemi and Wheater (2014a, 2014b, 2015a, 2015b), Haghnegahdar and Razavi (2017).
- Progress with assimilation of remotely sensed data to constrain large scale hydrological models, and examination of scaling effects in the models (Yassin et al., 2017).
- Extension of previous work on vulnerability analysis of water resource systems in the SaskRB – now includes risk-based hydro-economic analysis for Saskatchewan.
    - Relevant publications include: Hassanzadeh et al. (2015)

GSQ3: Changes in Extremes

- Regional-scale synthesis of Earth system change through analysis of federal and provincial hydro-climatic datasets, remotely sensed data products, climate model reanalysis, and radar, rawinsonde, and lightning detection observations, as well as an integrated literature review of past change over the CCRN domain.
    - See http://www.ccrnetwork.ca/science/workshops/theme-d-workshop-2016/index.php for a summary of a past workshop where this work was presented and discussed
- Individual research progress on atmospheric circulation patterns, instabilities for generating convection, large-scale forcing for drought, precipitation phase changes, winter precipitation extremes, surface hydrologic changes, and runoff, with a number of journal submissions and draft manuscripts based on these studies. See website link above.
- A major CCRN effort was centered on a comprehensive focal examination of the extreme weather and flooding in southern Alberta in June 2013, focusing on meteorological, hydrological, and water management aspects of the flood. This has led to a collection papers being published in a special issue of *Hydrological Processes*. (See http://ccrnetwork.ca//science/2013-Alberta-flood for further details, information products and links to all published papers.)
- Focal examination of extreme events (floods, fires, droughts) affecting the CCRN region from 2009–16 with several papers published and others forthcoming. Initial work towards an interdisciplinary examination of the 2014 forest fires in the Northwest Territories, involving contributions from university and government organizations.
    - Relevant publications include those listed above and: Brimelow et al. (2014, 2015), Masud et al. (2016), Szeto et al. (2015)
- CCRN will continue to focus on conducting detailed analyses of recent extreme events (floods, droughts, wildfires) in our geographic domain, including the recent short but severe drought in 2015, the sequence of devastating wildfires in parts of the region from 2014–2017, local prairie flooding in several of the past years, hazardous winter precipitation and severe summer weather and hail that has affected several cities in the past year, and examination of the chain-of-events leading up to these events.

GSQ4: Water and Energy Cycles and Processes

- Use of soil moisture monitoring networks for improving observation of soil freeze-thaw processes and evaluation of soil moisture scaling properties at resolutions applicable to the NASA Soil Moisture – Active Passive (SMAP) mission, upscaling of energy and water balance components from point- to field-scales, and evaluation of wetlands and soil moisture using RADARSAT-2 in prairie and taiga–tundra ecoregions
    - Relevant publications: Adams et al. (2015), Burns et al. (2016), Champagne et al. (2016), Djamai et al. (2015), Manns et al. (2015), Rowlandson and Berg (2015), Rowlandson et al. (2015), Roy et al. (2016, 2017), Williamson et al (2017).
- An important development for the network is that Li, working with NCAR, has produced 4km WRF climate simulations for the entire CCRN domain (14 years historical simulations, plus pseudo warming simulations of future climate). This provides comparative data for Theme B, C and D modelling and large scale climate analysis. Similarly, collaboration with ECCC provides access to the regional climate model CRCM4, which provides us with continuous future forcing data to the end of the 21st century.
    - Driving datasets and the progress of WRF runs were presented and discussed the most recent CCRN modelling workshop

(http://ccrnetwork.ca//science/workshops/summer-2017-modelling-workshop )

**4) Activities contributing to the WCRP Grand Challenges as identified by the JSC**

Clouds, Circulation, and Climate Sensitivity

- Theme/ work package D1
    - Specific scientific contributions involve the assessment of large and synoptic scale atmospheric circulation patterns as they relate to observed temporal and spatial trends and variability (including extremes) in hydro-climate over the study region
    - In addition, studies are undertaken to understand the mechanisms which link the regional water and energy response to large-scale forcings. This includes the role of the orographic barrier in amplifying the region's climate sensitivity to upstream large-scale forcings. Statistical techniques and diagnostic studies will be carried out to examine the coupled mode of variability between low-frequency forcings such as sea surface temperature anomalies, large-scale circulation patterns and warm-season synoptic activities
    - Relevant publications include: Armstrong et al. (2015), Asong et al. (2015), Brimelow et al. (2014, 2015), Khaliq et al. (2015), Kochtubajda et al. (2016, 2017), Liu et al. (2016), Masud et al. (2015), Szeto et al. (2015).
- Theme/ work package D3
    - Changes in the large-scale atmospheric circulation are assessed from CMIP5 and other projections. Their subsequent effects on the continental synoptic activities and associated heat and moisture transports which affect critically regional temperature and precipitation responses will be assessed from the downscaled projections.

Melting Ice and Global Consequences

- Theme/ work package D4
    - Projection results are used to address regional scale effects on land and water resources, using the large-scale models developed in Theme C. This includes the change in river flows for the Saskatchewan, Peace-Athabasca and Mackenzie River Basins, and effects of climate change for specific ecosystems.
    - We will determine whether future changes cross 'tipping points' in Earth system behaviour, leading to further extremes and dramatic system changes, such as deglaciation, permafrost disappearance and terrestrial ecosystem transition. Local scale assessments have begun in Theme B with several publications (Pomeroy et al. (2015b), Rasouli et al. (2014, 2015), Krogh et al. (2017), and planned CRHM historical and future diagnostic modelling
      (see http://www.ccrnetwork.ca/science/workshops/crhm-workshop-2016/index.php)
    - Outputs from this analysis will thus be used to identify global climatological controls on broad regional water resource response, and hence to enable specific design, operational or policy development problems under climate change to be addressed in Theme E. To address this issue, specific analyses will be carried out utilizing future conditions along with threshold guidance on conditions needed to trigger a fundamental shift.
- Glaciological studies, including mass and energy balance, glacier hydrology, and development of ice dynamic routines for local to regional-scale models are being conducted, crossing many of our thematic areas. See http://www.ccrnetwork.ca/science/WECC/index.php for information on the glaciological research at several of our WECC observatories.
    - Relevant publications include: Bash and Marshall (2014), DeBeer et al. (2016), Demuth et al. (2014), Ebrahimi and Marshall (2015), Marshall (2014a, 2014b), Samimi and Marshall (2017).

Understanding and Predicting Weather and Climate Extremes

- A large amount of work is being pursued in CCRN that addresses recent extreme events in our geographic domain. See above under GSQ1 and GSQ3.
- Theme/ work package D1

    - Specific scientific contributions involve the assessment of large and synoptic scale atmospheric circulation patterns as they relate to observed temporal and spatial trends and variability (including extremes) in hydro-climate over the study region
    - Another focus is on precipitation. Studies include the occurrence of precipitation extremes from droughts to heavy precipitation including variability and simultaneous occurrence. The regional and larger scale factors leading to such events will be determined. The factors leading to the changing occurrence of winter precipitation will be examined. As well, changes in the occurrence of extreme precipitation rates will be determined over some areas and linked with the large and regional scales forcing factors
    - Relevant publications include: Asong et al. (2015, 2016, 2017), Bonsal et al. (2017), Brimelow et al. (2014, 2015, 2017), Dumanski et al. (2015), Khaliq et al. (2015), Kochtubajda et al. (2016, 2017), Liu et al. (2016), Masud et al. (2015), Pomeroy et al. (2016a, 2016b), Scaff et al. (2015), Schubert et al. (2016), Shook et al. (2015), Stewart et al. (2015), Szeto et al. (2015).
- Theme/ work package D3
    - Key focal points are on regional and local scale temperature changes and variations of prolonged summer hot periods, and extension of above freezing conditions. A focal examination of changes around the zero degree Celsius isotherm is ongoing. In terms of precipitation, the focus is on the development of drought, heavy precipitation, extreme precipitation rates, as well as the changing phase of precipitation
- Theme/ work package D4
    - We are in the process of determining whether future changes cross 'tipping points' in Earth system behaviour, leading to further extremes and dramatic system changes, such as deglaciation, permafrost disappearance and terrestrial ecosystem transition. Local scale assessments have begun in Theme B with several publications (Pomeroy et al. (2015b), Rasouli et al. (2014, 2015)), Krogh et al. (2017), and planned CRHM historical and future diagnostic modelling (see www.ccrnetwork.ca/science/workshops/crhm-workshop-2016/index.php and http://ccrnetwork.ca//science/workshops/summer-2017-modelling-workshop)

Regional Sea-Level Change and Coastal Impacts

- We are not directly addressing global sea level change, but our modelling in Theme D will indirectly provide insights (e.g. through regional projections of ice volume change in western Canada, and through future runoff simulations and projections for the Mackenzie and Saskatchewan Rivers)

Changes in Water Availability

- Use of soil moisture monitoring networks for various objectives (see above under GSQ4)
- Progress has also been made on the quantification of effects of uncertainty in driving variables, and new methods to accommodate this, and in the assimilation of other satellite products in the large scale hydrological models, in particular GRACE (in collaboration with NRCan)
- Various atmospheric research activities contribute to this Grand Challenge, described above under GSQ1 and GSQ2
- Various improvements to CLASS and issues under development, including lakes, wetlands, snow/ mountain hydrology, frozen soils and infiltration, prairie hydrology, water management, coupled land-surface–groundwater, glacier dynamics, and linkage between hydrology, climate, and vegetation
- Setup and evaluation of MESH over both the Mackenzie and Saskatchewan River basins, with several key focal issues identified for ongoing work, including input uncertainty, soil depth and permafrost initialization/representation, wetlands, and water management. Model development is at the stage where it these are ready for future simulations.
- Theme/ work package D1 contributes to the Grand Challenge, as described above under the headings, *Clouds, Circulation, and Climate Sensitivity*, and *Understanding and Predicting Weather and Climate Extremes*
- Theme/ work package D2
    - Research on future conditions over the domain has given some indication of future states and interactions although with a great deal of uncertainty. In general, results

predict continued increase in temperature – more in the cold season and at higher elevations. They also expect an overall increase in precipitation, but with considerable spatial and temporal variability. Northern regions are projected to see more increases in precipitation than southern regions of the study area, which has potentially huge implications for water resources. In parallel, there is a projected increase to in the frequency, intensity and duration of future droughts including more hot droughts. Overall, future water cycle related variability remains a huge knowledge gap.
    - Given the determination and understanding of changing conditions over the region, it is critical to assess how future conditions will evolve, in particular factors affecting water resources and ecosystems. Validated models from Theme C are a critical basis for addressing this issue including our degree of uncertainty. Projections of future conditions over the region are being developed by CCRN (4 km WRF pseudo-warming) and others will be obtained (CRCM4 projections, with improved CLASS algorithms and explicit representation of feedbacks).
    - Some relevant publications include: Asong et al. (2015, 2016, 2017), Khaliq et al. (2015), Masud et al. (2015), Yassin et al. (2017).
- Theme/ work package D3
    - Changes in the large-scale atmospheric circulation are assessed from CMIP5 and other projections. Their subsequent effects on the continental synoptic activities and associated heat and moisture transports which affect critically regional temperature and precipitation responses will be assessed from the downscaled projections. The initial focus will be on projections of temperature, precipitation, and their variation. Key focal points will be on regional and local scale temperature changes and variations of prolonged summer hot periods, and extension of above freezing conditions. In terms of precipitation, the focus will be on the development of drought, heavy precipitation, extreme precipitation rates, as well as the changing phase of precipitation.
    - Relevant publications include: Asong et al. (2015), Bonsal et al. (2017), Khaliq et al. (2015), Masud et al. (2015), Stewart et al. (2015).
- Theme/ work package D4 contributes to the Grand Challenge, as described above under the headings *Melting Ice and Global Consequences*, and *Understanding and Predicting Weather and Climate Extremes*

Near-Term Climate Prediction

- Our work on all future assessments of change is based on various climate model projections and forecasts, such as CMIP5, NARCCAP, CORDEX, but we are directly contributing to the development of climate forecasts. Our WECC observatories provide excellent validation datasets for model downscaling, bias correction, and other activities aimed at improving RCM performance and developing related products.

Carbon Feedbacks in the Climate System

- Activities at some of our WECC observatories, in particular the Boreal Ecosystem Research and Monitoring Sites (BERMS), focus on the spatial and temporal variability in the boreal forest's water and carbon balance, and their sensitivity to climate variability and change. Long-term, high-quality, and intensive observations of water, carbon, and energy fluxes at several towers in different forest stands provide exemplary opportunities to observe and understand the carbon balance and feedbacks with the climate system. Work has examined the net annual ecosystem carbon exchange from $CO_2$ flux measurements and partitioned it between gross ecosystem photosynthesis and ecosystem respiration.
- We have conducted preliminary analyses of the CTEM model, focusing on our BERMS sites, and will utilize the model to simulate different ecosystems, particularly around the boreal–prairie transition zone.

**5) Cooperation with other GHP and WCRP Projects, outside bodies, and links to applications**

- The International Network for Alpine Research Catchment Hydrology (INARCH; http://www.usask.ca/inarch/index.php) is a GEWEX Cross-cut project that is an international spin-off from CCRN, led by Distinguished Professor John Pomeroy. CCRN and INARCH are closely

linked and share many common research priorities and objectives. A workshop will be held February 8-9, 2018, in Zugspitze, Germany, that members of CCRN will attend.

- The Cold/Shoulder Season Precipitation Near 0ºC project is a GHP cross-cut project that addresses multiple aspects of precipitation phase transitions, and is led by CCRN investigators. There are many areas of overlap between these projects; in particular, CCRN is conducting a detailed assessment of changes in the 0°C isotherm, with objectives that are directly linked to this project.
- Another GHP cross-cut project is focused on Including water management in large scale models, and is led by several CCRN investigators, including the Principal Investigator. Considerable progress on this issue has been achieved through CCRN studies, and both initiatives have goals to include newly developed reservoir schemes into models, such as MESH.

**6) List of key publications in the last year**
**(For complete CCRN list see www.ccrnetwork.ca/outputs/publications)**

**2017**


- Asong, Z. E., Razavi, S., Wheater, H. S., & Wong, J. S. (2017). Evaluation of Integrated Multi-satellitE Retrievals for GPM (IMERG) over Southern Canada against Ground Precipitation Observations: A Preliminary Assessment. *Journal of Hydrometeorology*, (2017). doi: 10.1175/JHM-D-16-0187.1
- Berry, P., *Yassin, F.*, Belcher, K., & *Lindenschmidt, K. E.* (2017). An Economic Assessment of Local Farm Multi-Purpose Surface Water Retention Systems under Future Climate Uncertainty. *Sustainability*, *9*(3), 456, doi:10.3390/su9030456
- Bonsal, B. R., Cuell, C., Wheaton, E., Sauchyn, D. J., & Barrow, E. (2017). An assessment of historical and projected future hydro-climatic variability and extremes over southern watersheds in the Canadian Prairies. *International Journal of Climatology*. DOI: 10.1002/joc.4967
- *Brimelow, J.C.*, Burrows, W., *Hanesiak, J.M.* (2017) The changing hail threat over North America in response to anthropogenic climate change, *Nature Climate Change*, doi: 10.1038/NCLIMATE3321
- Chun, K. P.*,* Mamet, S. D.*, Metsaranta, J.,* Barr, A.*,* Johnstone, J.*, &* Wheater, H. (2017). A novel stochastic method for reconstructing daily precipitation times-series using tree-ring data from the western Canadian Boreal Forest. *Dendrochronologia,* doi:10.1016/j.dendro.2017.01.003
- Cordeiro, M. R., Wilson, H. F., Vanrobaeys, J., *Pomeroy, J. W.*, & *Fang, X.* (2017). Simulating cold-region hydrology in an intensively drained agricultural watershed in Manitoba, Canada, using the Cold Regions Hydrological Model. *Hydrology and Earth System Sciences*, *21*(7), 3483, doi:10.5194/hess-21-3483-2017
- *Haghnegahdar, A.*, & *Razavi, S.* (2017). Insights into sensitivity analysis of Earth and environmental systems models: On the impact of parameter perturbation scale. *Environmental Modelling & Software*, *95*, 115-131, doi: 10.1016/j.envsoft.2017.03.031.
- Helbig, M., Chasmer, L. E., Desai, A. R., Kljun, N., Quinton, W. L., & Sonnentag, O. (2017). Direct and indirect climate change effects on carbon dioxide fluxes in a thawing boreal forest–wetland landscape. *Global Change Biology*, doi: 10.1111/gcb.13638
- Kotchtubajda, B., Mooney, C., Stewart, R. (2017) Characteristics, atmospheric drivers and occurrence patterns of freezing precipitation and ice pellets over the Prairie Provinces and Arctic Territories of Canada: 1964-2005. *Atmospheric Research*, 191, 115-127, doi: 10.1016/j.atmosres.2017.03.005
- Krogh, S. A., Pomeroy, J. W., & Marsh, P. (2017). Diagnosis of the Hydrology of a Small Arctic Basin at the Tundra-Taiga Transition using a Physically Based Hydrological Model. *Journal of Hydrology*, doi: 10.1016/j.jhydrol.2017.05.042
- Li, Y., Szeto, K., Stewart, R. E., Thériault, J. M., Chen, L., Kochtubajda, B., ... & Kurkute, S. (2017). A numerical study of the June 2013 flood-producing extreme rainstorm over southern Alberta. *Journal of Hydrometeorology*, doi: 10.1175/JHM-D-15-0176.1
- Maillet, J., Laroque, C., & Bonsal, B. (2017). A dendroclimatological assessment of shelterbelt trees in a moisture limited environment. Agricultural and Forest Meteorology, 237, 30-38, doi: 10.1016/j.agrformet.2017.02.003
- *Mamet, S. D., Chun, K. P.*, Kershaw, G. G., Loranty, M. M., & Peter Kershaw, G. (2017). Recent Increases in Permafrost Thaw Rates and Areal Loss of Palsas in the Western Northwest Territories, Canada. *Permafrost and Periglacial Processes,* doi:10.1002/ppp.1951

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