Changing Cold Regions Network

Annual Progress Report to the Natural Sciences and Engineering Research Council
Project Year-4
1 December, 2016

Executive Summary

CCRN is now mid-way through its fourth year, with 16 months remaining in the research programme. We have been very active through the work of a large team (42 co-Investigators and government collaborators, 178 students and post-doctoral fellows (PDFs), and 26 technical staff and other professional research support personnel) that is well integrated and productive. It is pleasing to note that important deliverables are emerging from all network Themes. People and plans are in place to successfully complete our remaining objectives by the end of the network in 2018. In particular our modelling strategy has been defined, and includes active collaboration with our sister CCAR project, the Canadian Network for Regional Climate and Weather Processes (CNRCWP). As requested last year by our Board of Directors, we have developed an outreach plan that includes a clear way forward with goals, timelines, deliverables, and now funding thanks to new support through NSERC's CCAR Network Enhancement Initiative (NEI). CCRN has been closely engaged with federal, provincial, and territorial government partners to work collaboratively on common problems and issues. Our 2014 workshop on the 2013 Calgary flood has led to joint research and a set of papers now published. This year we have held several more key workshops to bring the team together and advance our science. We are closely connected with a number of international organizations. CCRN is recognized by the World Climate Research Programme as a Regional Hydroclimate Project and we are leading new international GEWEX initiatives; for example the International Network for Alpine Research Catchment Hydrology (INARCH) is a GEWEX Hydroclimate Panel project that is an international spin-off from CCRN, while we also lead cross-cut topics on inclusion of water management in land surface schemes and on near 0°C precipitation. In addition to our collaboration with Environment and Climate Change Canada (ECCC) to enhance their CLASS/MESH modelling capability, our collaboration with NCAR has led to high resolution (4km) simulations of past and future climate using their WRF modelling system over the entire CCRN domain as a basis for comparative analysis. We have also been actively engaged in outreach with local communities, First Nations, other stakeholders, and the general public though meetings, interactions, the media, and newly developed information brochures.

1. Introduction

CCRN's overall aims are to integrate existing and new experimental data with modelling and remote sensing products to understand, diagnose, and predict changing land, ecosystems, water, and climate, and their interactions and feedbacks over western Canada's cold interior. We use a network of 14 intensely instrumented Water, Ecosystem, Cryosphere, and Climate (WECC) observatories (www.ccrnetwork.ca/science/WECC) to study these detailed processes and connections in the permafrost regions of the Sub-Arctic, the Boreal Forest, the Western Cordillera, and the Prairies, 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: the Saskatchewan and Mackenzie. We are currently North America's only GEWEX Regional Hydroclimate Project. (For a description of the network's science programme and Themes, see www.ccrnetwork.ca/science.)

We have previously submitted annual progress reports to the Board of Directors and to NSERC for Project Years 1–3, and these can all be accessed on our website at www.ccrnetwork.ca/outputs/reports (financial sections are omitted in the versions available here). Other relevant documents can also be found there. Here we focus on activities and progress made during Year-4. In the following sections of the report we include updates on the growth and development of the research team, workshops and meetings held in Year-4, data management activities,

scientific progress and directions, outreach and publicity, HQP training, responses to external reviewer comments, and finally, a summary of our network finances and budget request for next year.

2. Growth and Development of Research Team, and Management Structure

CCRN has developed a large, multi-disciplinary team of researchers, including 41 investigators and 204 current and past students, PDFs, research associates, technicians, and other HQP from eight Canadian universities and four federal government agencies. International collaboration includes 18 scientists from Germany, France, the U.S., U.K., and China, and we have actively engaged most of these people over the past three and a half years.

Our management structure is described on our website at: www.ccrnetwork.ca/organization. There are several changes in leadership to note since our last report. First, due to personal reasons the Chair of the Board, Ming-ko (Hok) Woo, had to step down in September as a member and Chair of the Board. Hok has been instrumental in his time on the Board, especially as Chair, and he will be greatly missed. We thank him for the input and guidance he has contributed over the past few years. In Hok's place, we have invited Michel Jean (Director General, Weather and Environmental, Operations, Meteorological Service of Canada) to serve as Chair, and he has accepted. Given Michel's previous contributions, helpful guidance, and strong knowledge of and experience with the Network, we feel that he makes an ideal candidate to Chair the Board.

In December, 2015, Donna Kirkwood (NRCan) had to resign her position as a Board member, and we thank her for her helpful contributions during her time on the Board. She was subsequently replaced by Linda Richard, who held the same position at GSC/NRCan; Linda has since changed roles and is unable to participate. Dr. Louise Laverdure is currently in the role and acting in place of Linda.

In February Bill Quinton had to step down as Theme E lead due to other commitments he has this year. We thank Bill for taking on the challenges of Theme E and moving it forward to the point where we have a clear strategy and concrete plans. In his place, we have appointed Graham Strickert to serve as Theme E lead—Graham has recently been appointed to a term faculty position at the University of Saskatchewan. We have brought in a new full-time outreach coordinator to replace Graham, Stacey Dumanski, who has a science background and previous experience in stakeholder engagement.

3. Workshops and Meetings

We have held several key workshops this year to advance our science, plan future activities, and promote collaboration among the network. Summary reports and more detailed information are available on our website at www.ccrnetwork.ca/science/workshops. Smaller groups within the network hold regular meetings by phone to work on collaborative activities. The network's scientific steering committee meets monthly by phone, and has held 10 teleconference meetings so far this year.

Theme D Synthesis Workshop (Winnipeg, May 10–11, 2016)

This workshop involved a small group of 17 atmospheric scientists and hydrologists, and their students, to review collective progress and work toward synthesis of activities in Theme D. Insights were shared on some recent extreme events, most notably the Ft. McMurray wildfire and the associated large-scale atmospheric conditions, and plans were developed to move forward collaboratively on several important topics, including an examination of changes in 0°C conditions, which is now well underway.

Cold Regions Hydrological Model (CRHM) Workshop on Diagnosing Change (Saskatoon, June 6–7, 2016)

The workshop involved a group of 26 CCRN investigators and students/PDFs, focused on reviewing CRHM modelling activities at the observatories and developing plans for the application of CRHM towards diagnosing long-term hydrological change. An assessment of the status and developmental needs for CRHM application at each observatory was carried out and plans were developed for two major group synthesis papers as well as other individual papers to follow from this work.

Special Observations and Analysis Period (SOAP) Workshop (Saskatoon, October 3–4, 2016)

This workshop was held to review observations and insights from the CCRN's 2014–15 Special Observation and Analysis Period (SOAP) and to plan common network scientific activities and data management/archiving. It was attended by 32 investigators and students/PDFs (several remotely by WebEx). The workshop led to plans for a synthesis paper on the anomalous hydro-climatic events of the year, and plans for a special issue proposal to the journal *Earth System Sciences Data*, with the intention of submitting at least eight papers on SOAP and CCRN datasets from the observatories.

CCRN 4th Annual General Meeting (Guelph, November 2–4, 2016)

Our AGM was attended by over 90 people, including a large part of our research team, and many students and PDFs. It included a session on the science–policy interface, with prominent invited speakers and a panel discussion. The remainder of the AGM addressed investigator updates (and also over 30 posters by students and PDFs) and Theme discussions, with an emphasis on the topic of scenarios of future change for our modelling efforts in the final year. The AGM was very productive, with fruitful discussions and planning for the final year. The Board of Directors met on the 2nd day, and the Science Committee met after the AGM to discuss follow up activities.

CCRN Modelling Workshop (Saskatoon, November 28–29, 2016)

The modelling workshop was an opportunity to review and synthesize our model advancements, discuss a set of scenarios of change for the future, and crystalize plans for running our final simulations. A report is forthcoming.

4. Management of Data and Research Results

Network data management activities are overseen by our database manager, Branko Zdravkovic, at the Global Institute for Water Security (GIWS), University of Saskatchewan. CCRN uses the Water Information System Kisters (WISKI) platform for data processing and archiving. Information is included on our website to make data management activities transparent (www.ccrnetwork.ca/outputs/data), including guidelines and support, public data access, and contact information.

Imports of WECC observatory time-series data into our central database have been progressing over the past year; we now have imports underway or completed for 12 of 14 WECC observatories with time series observations at over 50 separate monitoring stations. Many of these are providing near real-time data straight into the database, while in other cases, updates are provided periodically. Our automated data collection includes the measurements from 11 new stations that are part of the Canadian Rockies Hydrological Observatory in the Rocky Mountains, all managed by the Centre for Hydrology at the U of S. Our near real-time data now includes close to 1800 variables that are imported into the central repository on a daily basis. Most of our time series records are being processed in a uniform, standardized way ensuring that the same QA/QC procedures are applied at each observatory.

CCRN observational time series and snow survey records are available on-line through the web interface to the central CCRN database. Further, various reports providing the details about the completeness of our import processes for different periods (SOAP: http://giws.usask.ca/meta/reports/soapcompl.html) are also on the web. We continue to add new records to the CCRN database. Our latest additions include 15-minute or hourly flow data from 11 Water Survey of Canada stations across our domain, corresponding to the WECC sites and archived as part of the SOAP initiative (http://giws.usask.ca/ccrn/imports_summary_2016.html), and high resolution outputs from the Weather Research and Forecasting (WRF) Model historical and pseudo-global warming simulations over our domain, to be used as a key driving data source for much of our work in Theme D.

We have been working with ECCC to archive high-resolution GEM (Global Environmental Multiscale) model output over the CCRN domain as a contribution to the 2014–15 SOAP. GEM hourly data for seven forcing variables at 10 km (2013-present) or 15 km resolution (2002-2012) are available per request for the CCRN members. Further details on this are found at www.ccrnetwork.ca/outputs/data/ec-products-for-ccrn.

A final point on data is that we made important progress and plans at our recent SOAP workshop, as noted above, where it was decided that we would submit a proposal to the journal *Earth System Sciences Data* for a special

issue on cold regions observational datasets, focused around our programme and the SOAP. This will be a key deliverable of the network.

5. Scientific Progress and Future Directions

Theme A: Observed Earth System Change in Cold Regions—Inventory and Statistical Evaluation *(Lead: Carey)*
Theme A's objectives, work packages, and milestones are described at www.ccrnetwork.ca/science/themes/A.

Under Theme A, documentation and statistical analyses of Earth system change have been carried out, and a major review paper has been published (DeBeer et al., 2016). We have conducted an extensive dendrochronological examination of local change through collection and analysis of tree core data and local site conditionals across vast latitudinal transects over the domain. We have continued to work on conceptual models of the mechanisms and drivers change and are using this towards the development of scenarios of landscape evolution and change to incorporate in our modelling of future climates.

A large number of publications have resulted from this work (a complete list of CCRN papers is on our webpage at www.ccrnetwork.ca/outputs/publications), while many more are being prepared. Further, we are developing plain language science summaries and information products for public distribution, dealing with observed environmental change and documentation of extreme events—these are both key Theme A deliverables and these products will help a broad audience to better understand the changes taking place. Some of these are already on our website (www.ccrnetwork.ca/outputs/information-products). Key papers and other deliverables contributing to various Theme A objectives are listed below.

- 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), 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), Helbig et al. (2016a, 2016b), Ireson et al. (2015), Johnstone et al. (2016), Lesack et al. (2014), Li (2016), Mamet et al. (2015), Marshall (2014b), Marshall and Baltzer (2015), Masud et al. (2015), Nazemi et al. (2016), Patankar et al. (2015), Paznekas et al. (2015), Quinton and Baltzer (2013b), Shi et al. (2015), Shook and Pomeroy (2015), Spence et al. (2015), Quinton et al. (2016), Whitfield and Pomeroy (2016), Yang et al. (2014b)
- Focal examination of extreme events (floods, fires, droughts) affecting the CCRN region from 2009–16 with several papers published and others forthcoming
    - Relevant publications include: Brimelow et al. (2014, 2015), Fang et al. (2016), Kochtubajda et al. (2016), Liu et al. (2016), Pomeroy et al. (2016a, 2016b), Shook et al. (2015), Szeto et al. (2015), Whitfield and Pomeroy (2016)
- 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 www.ccrnetwork.ca/science/workshops/theme-d-workshop-2016 for a summary of a recent workshop where this work was presented and discussed.

We are now in a position where Theme A is at full maturity and we have largely achieved its objectives. A continuing focus will be on the development of one or more key synthesis papers.

Theme B: Improved Understanding and Diagnosis of Local-Scale Change *(Lead: Pomeroy)*
Theme B's objectives, work packages, and milestones are described at www.ccrnetwork.ca/science/themes/B. A sequence of extreme events has unfolded during this network that provides key focal points for interdisciplinary investigation (spanning Themes B–E), including major floods in Alberta (2013) and Saskatchewan and Manitoba (2014); large wildfires in the Northwest Territories (2014), Saskatchewan (2015), and Alberta (2016); and short-lived, but extreme drought across a large part of the domain (2015). A major effort in Theme B is on developing

and applying models developed using the Cold Regions Hydrological Modelling platform (CRHM) at all WECC observatories.

Under Theme B, we have made major progress in advancing process understanding, based on studies at the WECC sites, and parameterizing these processes in CRHM. A coordinated effort has been initiated to apply CRHM in a systematic manner across most WECC observatories for 1) long-term historical runs to diagnose hydrological functioning and trends and cycling in this functioning over time, and 2) future runs to explore hydrological responses in relation to climate warming, focusing on geographic variability and the sensitivity to change in different environments. Progress on this and a clear path forward were established at a workshop held in Saskatoon, SK, in June 2016, with plans made for two major group synthesis papers (see www.ccrnetwork.ca/science/workshops/crhm-workshop-2016). Our SOAP initiative during the 2014–15 hydrological year has been a major success, with participation from all 14 WECC observatories and a wide range of other supporting observations, modelling activities, and large scale analyses across the domain. Progress was reviewed and plans were made at a recent workshop in Saskatoon in October 2016, where a synthesis paper and a special journal issue on data submissions were planned (see www.ccrnetwork.ca/science/workshops/soap-2016). Other key areas of progress and important deliverables are list below.

- 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 and links to all published papers.)
    - Relevant publications include: Fang et al. (2016), Harder et al. (2015), Kochtubajda et al. (2016), Liu et al. (2016), Pomeroy et al. (2016a, 2016b), Shook et al. (2015), Whitfield and Pomeroy (2016).
- One of our major strengths is in our observatories and the level of process understanding for model development that these provide. A vast number of unique process studies have been carried out, and novel and innovative measurement and observation strategies have been employed at the WECC sites and elsewhere. Significant progress has been made on developing improved algorithms and parameterization schemes for fine scale models, particularly CRHM, and applying the models to better understand process interactions and responses, and to diagnose change.
    - Relevant publications include: Adams et al. (2015), Baltzer et al. (2016), Barr et al. (2013), Bartlett and Verseghy (2015), Brannen et al. (2015), Braverman and Quinton (2015), Burns et al. (2014), Chang et al. (2014), Chen et al. (2016), Connon et al. (2014, 2015, in press), Cosh et al. (2013), Dumanski et al. (2015), Ebrahimi and Marshall (2015), Fang and Pomeroy (2016), Garnaud et al. (2016), Harder and Pomeroy (2014), Harder et al. (2015, 2016), Helbig et al. (2016c), Hood and Hayashi (2015), Hopkinson et al. (2016), Kinar and Pomeroy (2015a, 2015b), Krogh et al. (2015), Kurylyk et al. (2015, 2016), Langston et al. (2013), Lessels et al. (2015), López-Moreno et al. (2013), Mamet et al. (2016), Manns and Berg (2014), Marshall (2014), McClymont et al. (2013), Melaas et al. (2016), Ménard et al. (2014), Mohammed et al. (2013), Mohammed et al. (2014), Musselman et al. (2015a, 2015b), Nagare et al. (2013), Pan et al. (2016), Patankar et al. (2015), Peterson et al. (2016), Pomeroy et al. (2016a, 2016b), Rahimzadeh-Bajgiran et al. (2013), Raleigh et al. (2013), Rasouli et al. (2014, 2015), Razavi and Gupta (2015a, 2015b), Reba et al. (2014), Rowlandson et al. (2015b), Sankaré and Thériault (2016), Shellito et al. (2016), Shook et al. (2013), Spence and Mengistu (2016), Spence et al. (2014), Steeves et al. (2016), Wake and Marshall (2015), Weber et al. (2016), Williams and Quinton (2013), Williams et al. (2015), Zhou et al. (2013, 2014).

We are now in a position in which objectives in B1 (Targeted Process Studies) are complete, objectives in B2 (Development of Improved Local-Scale Models) are more-or-less complete in terms of what we had set out to achieve in this network, and progress is well underway with a solid plan for completion of the objectives in B3 (Diagnosis of Local Past Change) over the coming year. With the development of the improved local-scale models, Theme B is in the process of, and will continue to transition to Theme D in the coming months.

Theme C: Upscaling for Improved Atmospheric Modelling and River Basin-Scale Prediction *(Lead: Wheater)*

Theme C's objectives, work packages, and milestones are described at www.ccrnetwork.ca/science/themes/C. There is a strong collaboration between the network and ECCC, particularly on the development and application of the Canadian LAnd Surface Scheme (CLASS), Modélisation Environmentale Communautaire (MEC) – Surface and Hydrology (MESH), and Canadian Terrestrial Ecosystem Model (CTEM) models.

Work in Theme C has involved a wide range of activities toward these goals. This work has involved collaborative development with ECCC and application of CLASS and MESH at the observatories as well as regionally. We are also using other well-known and widely used models, including the Joint UK Land Environment Simulator (JULES), the Weather Research and Forecasting Model–Hydrologic Processes (WRF-Hydro), the community Noah land surface model with multiparameterization options (Noah-MP), and the Common Land Model (CLM) Parallel Flow (PARFLOW)). 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 expect to have working models in place for both major basins this fall, according to plan. Key areas of progress and important deliverables are listed below.

- 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 workshop last year (see www.ccrnetwork.ca/science/workshops/2015-modelling-workshop).
    - Relevant publications include: Chen et al. (2016a, 2016b), Hassanzadeh et al. (2014, 2015), Li (2016), Mekonnen et al. (2014), Nazemi and Wheater (2014a, 2014b, 2015a, 2015b).
- 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)
- 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)
- Development of a new framework for global sensitivity analysis of large earth, hydrologic, and environmental systems models, called Variogram Analysis of Response Surfaces (VARS). VARS has been applied extensively to the MESH model for different regions, in order to understand the role and functioning of different model parameters on the model response under different climate/environmental conditions. VARS has been packaged in a software toolbox, called VARS-Tool, and been officially released for public use (http://homepage.usask.ca/~ser134/nex_gen_sen_an.php).
    - Relevant publications include: Razavi and Gupta (2015a, 2015b, 2015c).
- 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).
- An important development for the network is that Li, working with NCAR, is producing 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 Sushama's CNRCWP provides access to the regional climate model CanRCM5, based on CLASS, which provides us with a platform for coupled modelling and additional simulations for large scale analysis.

- Driving datasets and the progress of WRF runs were presented and discussed the two most recent CCRN workshops (http://www.ccrnetwork.ca/science/workshops/theme-d-workshop-2016/index.php, and http://www.ccrnetwork.ca/science/workshops/crhm-workshop-2016/index.php)

At present, we have nearly completed our objectives for C1 (Algorithm Development for Weather and Large-Scale Hydrological Models) and progress is well underway in C2 (Large Basin-Scale Application and Testing of Weather, Climate and Large-Scale Hydrological Models, Including Verification and Assimilation of Ground-Based Observations and Remotely Sensed Data). We expect to be able to complete the objectives for Theme C over the coming 6–8 months, as planned, at which point all remaining activities transition into D. Progress and ways forward were reviewed both at our November AGM, and in greater depth, at our recent modelling workshop.

Theme D: Analysis and Prediction of Regional and Large-Scale Variability and Change *(Lead: Stewart)*

Theme D's objectives, work packages, and milestones are described at www.ccrnetwork.ca/science/themes/D. Many of the deliverables in this Theme are slated for late in the project; however, the activities of this Theme are now well underway and substantial progress has been made with key deliverables emerging.

Our Theme D activities have expanded over the past year and we have made much progress through the collective work of a number of individual research scientists on many different aspects of large-scale hydro-climatic variability and change. In particular, a focus of this work has been on linking these conditions with some of the recent extreme events that have been observed in our geographic region (e.g. flooding in AB in 2013, drought in western Canada in 2015, and extreme wildfires across parts of the region in 2014, 2015, and most recently at Fort McMurray, AB, in 2016). This was reviewed in detail at a recent workshop in Winnipeg, MB, in May, where progress was made towards synthesizing the work and planning future activities (see www.ccrnetwork.ca/science/workshops/theme-d-workshop-2016). An important activity has been collaboration with the US National Center for Atmospheric Research (NCAR) to produce 4 km resolution WRF climate simulations for the entire CCRN domain (14-year historical simulations, 2000–14, plus pseudo-warming simulations of future climate), providing comparative data for Theme B, C, and D modelling and large-scale analysis. From here, we will decide on driving products and best approaches moving forward for the large-scale modelling analyses to be done in Theme D. Several focal topics have been added or are being considered as areas of study in Theme D for the coming year, including a synthesis and examination of the three back-to-back extreme wildfire seasons in western Canada (2014–16), an examination of changes in the timing of the 0°C isotherm and associated impacts, a review of future projected changes (following review of past change, and linking with scenarios of change), and an examination of the chain-of-events around recent major disasters in our region. Key areas of progress and important deliverables are listed below.

- A major effort has been on the focal examination of the 2013 Alberta floods and analyses of other recent extreme events (see Themes A and B, above)
- 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. This work was reviewed and discussed at a recent workshop (see www.ccrnetwork.ca/science/workshops/theme-d-workshop-2016 for full details, including a summary report and presentations).
  - Relevant publications include: Asong et al. (2015, 2016), Brimelow et al. (2014, 2015), Dumanski et al. (2015), Khaliq et al. (2015), Kochtubajda et al. (2016), 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).

- 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), Khaliq et al. (2015), Masud et al. (2015)
- Assessment of future sensitivity and response in Earth system behavior at WECC observatories (D4)
  - Relevant publications include: Rasouli et al. (2014, 2015)

Progress in Theme D to this point has been significant and we are well on our way to achieving our objectives and deliverables, as planned. Objectives in D1 (Large/Regional-Scale Land Surface and Climate Controls) are now largely complete, with some diagnostic modelling yet to be done. Objectives in D2 (Changing Climate, Changing Land Surface Systems, and Large-Scale Hydrology) are mostly complete as well, through links to Theme C. Activities in D3 (Atmospheric Circulations, Temperature, and Precipitation) are well underway, with a way forward through the use of WRF pseudo-global warming runs, NARCCAP data, and CMIP5 data, and most deliverables are expected this year. Finally, our objectives in D4 (Water Resources, Cryosphere and Ecosystems) will be met by the end of the programme, and we are actively working toward developing scenarios of future change to be applied in our models in order to achieve these goals.

6. Outreach, Communication, Promotion, and Publication of Research Results

Theme E: User Community Outreach and Engagement *(Lead: Strickert)*

Theme E's goals and strategy are described at www.ccrnetwork.ca/science/themes/E.

Outreach efforts as part of Theme E have expanded this year, in part due to additional funding received through NSERC's CCAR-NEI (Network Enhancement Initiative), which has allowed us to hire a full-time outreach coordinator and support design work for information products we are developing. The funds will also allow us to provide direct support to our members to carry out targeted outreach and engagement activities with various stakeholders and partners. We have put out a call for proposals to our members, asking them to provide plans and budgetary requests for activities that will support Theme E and enhance the delivery of CCRN's results and tools to the user community. We plan to review these at our upcoming AGM. We have continued to be active in outreach and engagement through direct interaction with partners and stakeholders, knowledge mobilization workshops, meeting and interactions with national and international organizations, media engagement and publicity of network activities and results, peer-reviewed literature contributions, and involvement in national and international conferences. Specific activities have included:

- Publication this year of 62 peer-reviewed articles appearing in a wide range of top-tier academic journals, with another 30 papers either in review, accepted, or in press (see www.ccrnetwork.ca/outputs/publications);
- Outreach to community-based stakeholders through involvement with water stewardship groups in SK, AB, and NT, interaction with First Nations communities in SK and NT, and presentations and interactions with secondary schools in NT;
- Delivery of over 40 presentations to stakeholders such as government groups, First Nations and metis, NGOs, the United Nations, business groups, industry, the media, and universities;
- Development of two public outreach products that synthesized two extreme events, the 2013 Alberta Flood and 2014 Assiniboine flood (see www.ccrnetwork.ca/outputs/information-products) to be disseminated widely to various government agencies, watershed associations, and communities;
- Engagement of the media with over 55 interviews and feature articles written this year (see www.ccrnetwork.ca/outputs/media);
- Close linkages with groups such as NCAR, the NASA Arctic–Boreal Vulnerability Experiment (ABoVE), and GEWEX;

- HQP involvement includes over 65 presentations at national and international conferences, over 30 peer reviewed publications with HQP as first author, student profiles on the CCRN website (see www.ccrnetwork.ca/organization/hqp), feature articles on student research, and interactions with CCRN social media sites;
- Dissemination of results and knowledge through major CCRN involvement at national and international conferences, including over 155 presentations (47 invited). CCRN will again have a strong presence at the upcoming 2016 Fall Meeting of the American Geophysical Union;
- Relevant publications on Theme E include: Little et al. (2015), Strickert et al. (2015, 2016).

Theme E activities are progressing well. Last year, we received criticism from the Board that although our outreach programme includes many activities, they are being done in an ad hoc and uncoordinated way, and that the outreach is of limited depth. An action was imposed by the Board to develop an integrated plan for the remainder of the network. We are pleased to report that we have followed through on this and delivered a clear plan that outlines our goals, timeline, and specific deliverables for Theme E. The Board was satisfied with this plan and approved it, and the comment by the Chair (Ming-ko Woo) was, "[The report] gives a comprehensive presentation of the aims, strategy and proposed actions for the coming years. I commend the Theme E team for this effort." We have now been able to fully implement the plan with the support of CCAR-NEI funds.

7. Recruitment and Training of Highly Qualified Personnel

One of the key aspects of the network, and of the NSERC CCAR Program in general, is the training of the next generation of scientists and professionals. The network has strongly supported this, with over 2/3 of our budget allocated to training of HQP training. To this point in our programme, a total of 178 students and post-doctoral fellows have either completed their training or are currently involved with the research, including:

- 27 undergraduate research assistants and summer students, 64 MSc students, 38 PhD students, 49 PDFs;
- We have also employed 26 technicians, research assistants and associates, and other professional staff;

Our network funding from NSERC has provided full or partial support to 98 students and post-doctoral fellows to this point in the network, with the others having been funded entirely through external sources. The level of involvement of these trainees and research assistants has been very high not only in terms of their contribution to the research itself, but also in presenting and discussing outcomes, implications, and future directions at our network workshops and at major national and international conferences. We have been actively encouraging the involvement of our HQP—for example, we had a high turnout of posters describing their work at our recent 4th AGM, we have been posting their profiles on our website (http://ccrnetwork.ca//organization/hqp) and encourage them to contribute detailed research summaries for our newsletters and website, and we have engaged them on social media (Facebook and Twitter), with links via our homepage.

8. Response to Comments by the Board of Directors, International Advisory Panel, and External Reviewers

We are fortunate to have a strong Board and IAP, who have been dedicated and involved, and have offered us solid praise for our accomplishments, fair criticisms for our weaknesses, and useful advice and guidance to take us forward. In the past, the Board has been pleased with the progress, direction, coordination, integration, and management of the network, and together with NSERC, the Board has noted that they are happy to see that the network leadership is responsive to criticism and advice by the Board, the IAP, and the external reviewers of the annual reports. It is also worth noting that we have won many praises from these external reviewers.

This past year we have received criticisms and advice that we have responded to. Firstly, our Board had requested that we produced an integrated and coherent outreach plan. We are happy to report that this had been delivered in April 2016 and the Board accepted this. The plan now has funding to support through the CCAR-NEI, which will allow us to carry out many aspects of our planned outreach.

Our IAP had made some remarks at the last AGM and Board meeting in Saskatoon in November 2015. Their main recommendations were that we should devote effort to synthesis across the different sites (in Theme B

primarily), and that the network should make every effort to document the extreme events in our region and to project likely scenarios for the future. They also underscored the importance of data management. In section 5 above, we have described our progress, and we feel that through our SOAP activities and Theme D work on extremes, we are directly addressing these points.

We received a large amount of feedback from the external reviewers of our last report to NSERC, and we have acted on their suggestions for the most part. Despite being mostly favorable, there were a few minor concerns expressed. Several of the reviewers noted concern about the need for clarity in Theme D and integration towards synergistic science outcomes. This means activating Theme D and broadening it beyond purely atmospheric pursuits. We have made great strides in moving towards this, with a plan in place for our large scale analyses of future change, along with modelling needs, observational and driving data. We are also integrating across research sites and disciplines, with our examination of recent extreme events (floods, fires, droughts) as a focal point for these activities. A point was made that more effort needs to be placed on integrating the ecology with the atmospheric and hydrological work, and that the involvement of the ecosystem scientists needs to be encouraged in the modelling and interpretation (e.g. the influence of fire). We are actively working to strengthen the linkages and making excellent progress in this regard—a workshop to take this forward in the final year has been discussed.