CHANGING COLD REGIONS NETWORK

Saskatchewan and Mackenzie River Basins

A Proposal to the World Climate Research Program's GEWEX Project for an Expanded Regional Hydroclimate Project for Western Canada

SUMMARY PROPOSAL

1. Introduction

In December 2012, GEWEX approved the Saskatchewan River Basin (SaskRB) Project as an initiating Regional Hydroclimate Project (RHP). This major focus for national and international research was designed to support the GEWEX mission, imperatives and science questions, in particular the work of the GEWEX Hydroclimatology Panel. It capitalises on the coincidence of an important and generic set of science and management needs, a set of world-class hydroclimatological observatories, and significant in-kind research funding. Led by the Global Institute for Water Security (GIWS) along with numerous national and international research partners, the SaskRB Project aims to build upon world-class observational facilities to develop new interdisciplinary science and the accompanying modelling tools required to address the challenge of managing environmental change and uncertain water futures.

At the time of submission of the SaskRB proposal, a major bid to the Natural Sciences and Engineering Research Council (NSERC) of Canada for a Changing Cold Regions Network (CCRN), also led by GIWS, was under review, with support from GEWEX and CliC. This $5 million grant proposal (with $24 million in-kind support) was ultimately successful. It expanded the research focus from the SaskRB to the whole of the interior of western Canada, including the Mackenzie River Basin (MackRB), combining expertise of 36 co-Investigators from eight Canadian universities and four Federal Government agencies, and in particular included more strength in atmospheric science than the predominantly hydrological focus of the SaskRB.

Subsequently, at the 7th International Scientific Conference on the Global Water and Energy Cycle held in The Hague in July 2014 it was suggested that there could be significant benefits from a broader RHP in western Canada that mirrored CCRN (SaskRB and MackRB). This draft proposal has been produced to reflect this extension and includes summary descriptions of the expanded context, science needs, facilities and science goals. It focusses on GEWEX Science Question (SQ) on Global Water Resource Systems (SQ2), but also has strong relevance to SQ1 (Observations and Predictions of Precipitation), SQ3 (Changes in Extremes) and SQ4 (Water and Energy Cycles and Processes). We note that given its geographical focus (from the Canadian Rocky Mountains in the West to Lake Winnipeg in the East, and from the Canada – U.S. border in the South to the Arctic Ocean in the North), this project would complement well current proposals for a U.S. RHP focussed on the Colorado Basin.

2. Introduction to the Changing Cold Regions Network RHP

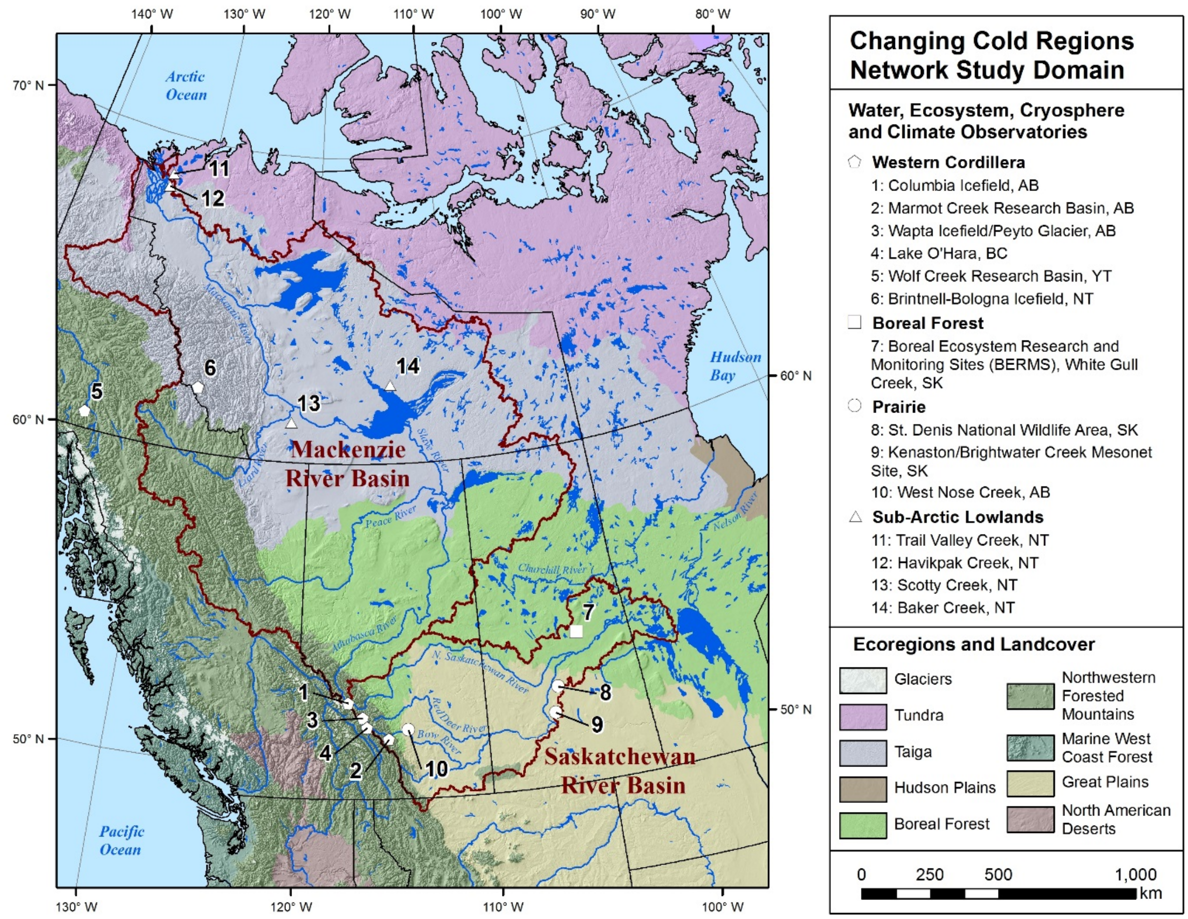

Figure 1. Map of the CCRN geographic study domain in western and northern Canada, showing major river systems, ecoregions, and landcover, as well as the location of Water, Ecosystem, Climate, and Cryosphere (WECC) observatories. Source data is from the North American Environmental Atlas (http://www.cec.org/naatlas/) and the National Hydro Network (http://www.geobase.ca); the projection is UTM Zone 11 on the North American Datum of 1983.

The cold interior region of western Canada east of the Continental Divide, from the U.S. border to the Arctic Ocean and extending across the Prairie Provinces and Northwest Territories (NT), has one of the world's most extreme and variable climates and is experiencing rapid environmental change. Climate warming and precipitation change have resulted in altered patterns of snowfall and snowmelt, conversion of snowfall to rainfall, loss of glaciated area and thawing of permafrost. Effects of these changes on terrestrial ecosystems include changing alpine and arctic treelines, extreme variability in Prairie wetland extent and storage of subsurface water in soil and groundwater, "browning" of the boreal forest and prairie aspen woodlands, forest conversion to wetlands in areas of permafrost loss, increased tundra shrub height and coverage, with associated impacts on snow accumulation and melt and ground thaw regimes. These atmospheric, cryospheric and ecological changes have produced changes to water storage and cycling with lower, earlier and more variable streamflow from the western Cordillera, earlier and more variable Prairie streamflow, more variable agricultural soil moisture, substantially earlier and sometimes higher streamflows with greater winter baseflows in the North, and indications of changes in extreme precipitation events and resulting flooding and drought.

The 336,000 km^2 SaskRB, located in the cold interior of western Canada, is the major water resource for Canada's rapidly developing prairie provinces, Alberta, Saskatchewan and Manitoba, and, with an area half the size of France, is drained by one of the world's larger rivers. The Saskatchewan River drains east from the Rocky Mountains, passing through a major (10,000 km^2) inland delta before entering Lake Winnipeg where it joins the Red River before draining to Hudson Bay. Home to 80% of Canada's agricultural production, and important natural resources, including oil, gas and potash, management concerns include: provision of water resources to more than three million inhabitants, including indigenous communities; balancing competing needs for water between different uses, such as urban growth, industrial development, agriculture and environmental flows; issues of water allocation between upstream and downstream users in the three prairie provinces; managing the risks of flood and droughts; and assessing water quality impacts of discharges from major cities and intensive agricultural production. Superimposed on these issues is the need to understand and manage uncertain water futures, including effects of growth and rapid environmental change, in a highly fragmented water governance environment.

The MackRB covers an area of approximately 1.8 million km^2 (~20% of Canada's landmass) with the majority of the basin's inhabitants living in the southern parts, and flows to the Beaufort Sea of the Arctic Ocean. The MackRB covers nearly 20° of latitude (extending from ~52°N to 70°N) and encompasses highly varied climatic conditions from both south to north and west to east. Northern parts of the basin are affected by permafrost, which significantly influences the hydrology and ecology of the landscape, while agricultural and forestry activities of economic importance occur in the southern parts of the basin. The MackRB extends from the Rocky Mountains and the Mackenzie Mountains in the West, through the Interior Plains to the Canadian Shield in the East. The highly varied landscape across the basin, along with accompanying diverse physiographic and climatic conditions, encompasses eight of Canada's fifteen major ecozones (southern Arctic, Taiga Cordillera, Taiga Plain, Taiga Sheid, Boreal Cordillera, Boreal Plain, Boreal Shield, and Montane Cordillera). The basin is shared by five distinct jurisdictions each with a legal and regulatory framework. Of particular note is the fact that the Northwest Territories (area 1.1 million km^2, population 43,600, mainly First Nations) assumed responsibility for its water management from the Federal government in April 2014. The most important industries are agriculture, fossil energy, forest products, hydroelectricity and mineral extraction. There are eleven Aboriginal languages spoken within the basin. The traditional economy, which depends on healthy ecosystems, remains an important part of these people's lives and livelihoods. Management pressures include tensions between upstream and downstream water users with respect to impacts of dam and other water resource development and management, and water quality, including the downstream impacts of upstream oil sands development. Communities in the North are facing large challenges associated with permafrost thaw, changing patterns of flow, and changing ice conditions in rivers and coastal waters, with serious implications for infrastructure management and for natural resource development.

3. Science Challenges

The CCRN region poses globally-important science challenges due to the importance and diversity in its cold region hydro-climate and ecological zones, the rapid rate of environmental change and the need for improved understanding, diagnosis and modelling of environmental change. The river systems are a major source of freshwater input to the Atlantic and Arctic Oceans, and land–atmosphere feedbacks here have a major influence on global climatic patterns. Major societal concerns include the impacts on water and other natural resources, agriculture, infrastructure, and risk associated with extreme events. Key biomes of regional and global importance include the western Cordillera, western Boreal Forest, Lowland Permafrost and Prairies, as well as the Tundra and Taiga Plains of the sub-Arctic North.

Within the SaskRB, the sensitivities to climate change are most noticeable in the west, where changing temperatures are producing smaller snow packs and earlier melt, decreasing glacier size and shifts in the river's runoff regimes. Glacier mass balance has been predominantly negative and glacier areal coverage has declined considerably in the last quarter century (Demuth and Keller, 2006; Demuth *et al*., 2008; Bolch *et al*., 2010), while the spring snow-covered period has shortened by approximately one month (Brown and Mote, 2009). Associated with these declines is a shift from snow to rain on the eastern slopes and a decrease in streamflow across both glaciated and non-glaciated streams (Demuth and Pietroniro, 2003; Marshall *et al*., 2011; Stahl and Moore, 2006) in the headwaters of the Saskatchewan River.

The western Boreal Forest and Prairies have experienced large swings in climate that have resulted in severe weather, with some of the driest and wettest period in the last 140 years occurring since the turn of the 21st century (Stewart *et al*., 2011). This has resulted in extensive areas experiencing large soil moisture deficits, drought-induced dieback of major tree species (Peng *et al*., 2011), wetland and stream disappearance, and recorded minimum groundwater levels during the drought of 1999-2004, with multi-billion dollar economic losses to agriculture. In contrast, the recent wet periods of 2010 and 2011 produced extensive (>1 in 500 year) flooding in the prairies, inundation of wetland vegetation and record groundwater levels.

Such large swings in climate are occurring at a time of unprecedented resource extraction and agricultural activity, both of which are intricately linked to hydroclimatic conditions (Bonsal *et al*., 2012). Because of the interactions between hydrology and vegetation, the southern Boreal Forests of western Canada are expected to be an area of maximum ecological sensitivity to stressors in the 21st century (Anderegg *et al*., 2012; Bergengren *et al*., 2011; Kurtz *et al*., 2008). Throughout the Prairie Provinces, population growth and the continued demand for more food and biofuels is leading to increased nutrient loadings in runoff, affecting amenity and ecosystem health, and potentially threatening water supplies. Farming practices such as drainage and wetland removal are changing the ecological services that the landscape is able to provide.

Within the MackRB, there have been major cryospheric, hydrological, and ecological changes in association with changing climatic conditions. Changes in permafrost have included widespread patterns of rising ground temperatures, increasing soil active layer thickness, declining area of frozen ground, and degradation of areas of permafrost plateaus (Smith, 2011; Burn, 2012). There have been significant reductions in the spatial extent, duration, and maximum depth of the seasonal snow cover, and melt onset has been occurring earlier in spring (Brown and Robinson, 2011; Kelly, 2012). Glacier coverage has been rapidly diminishing in both the northern Rocky Mountains and the Mackenzie Mountains (Bolch *et al*. 2010; Demuth *et al*. in press), while freshwater ice cover duration has been observed to be decreasing, primarily as a result of earlier breakup in spring (Prowse, 2012). There has been a documented shift towards earlier occurrence of spring runoff and peak flows across most of the basin (Abdul Aziz and Burn, 2006). In the southern part of the basin, including tributaries of the Athabasca River, flows have generally been diminishing, while in the southern Taiga Plains and lower parts of the Liard River Basin, flows have been increasing, especially in winter (Burn *et al*. 2004). These changes reflect both climatic and anthropogenic influences across different parts of the basin, which have not yet been fully resolved. Beyond the Boreal treeline, sub-Arctic and Arctic tundra vegetation has increased in terms of both peak productivity and growing season length (Goetz et al., 2011). There have been changes in the composition and density of herbaceous vegetation, as well as expansion of areas of woody shrub vegetation (Sturm et al., 2001; Tape et al., 2006; Lantz et al., 2013). These changes in terrestrial vegetation communities significantly influence the surface hydrological regime through their influence on and feedbacks with snow cover and permafrost.

The implications of these complex and interconnected changes to the land surface and the resulting feedbacks with the atmosphere remain poorly understood, and the rate of change is so high that there are important concerns that current Earth system models, developed on historical data and an assumption of climate stationarity, have limited predictive capability. Current models have not considered the full range of feedbacks between the atmosphere, hydrosphere, cryosphere and terrestrial ecosystems that occur from small to large scales and are anticipated to be particularly intense in this region. This shortcoming already degrades model predictability and resource management; for instance, North America Regional Climate Change Assessment Program (NARCCAP) simulations of current climate show up to 6^{o}C positive air temperature bias over this region (Mearns *et al*., 2012) and recent years have seen failure of water and land management systems with high economic, environmental and social consequences.

Improved understanding and prediction are urgently needed to provide better planning and management for water supply, transportation, disaster management, energy, food security and ecosystem sustainability. Increasing pressures on the water environment are also leading to the need for new social science research, for example to understand stakeholder concerns for water security, to provide insight into governance structures and policy instruments, and to understand societal resilience to extreme events.

Integrated response at the scales of 1) The Saskatchewan and Mackenzie River Basins and 2) the regional climate system will be explored.

4. What is the CCRN SaskRB/MackRB Project?

The CCRN project is focused on understanding, diagnosing, and predicting interactions amongst the cryospheric, ecological, hydrological, and climatic components of the changing Earth system at multiple scales, with a geographic focus on western Canada's rapidly changing cold interior. This network builds on a legacy of past Canadian and international research in this region that has focused on cold regions hydrology, glaciology, terrestrial ecology, atmospheric science, drought, and modelling, including projects and networks such as the Mackenzie GEWEX Study (MAGS; http://www.usask.ca/geography/MAGS/; Stewart *et al*., 1998; Woo *et al*., 2008), Boreal Ecosystem-Atmosphere Study (BOREAS; http://daac.ornl.gov/BOREAS/bhs/BOREAS_Home.html; Sellers *et al*., 1997; Hall, 1999), Drought Research Initiative (DRI; http://www.drinetwork.ca/; Stewart et al., 2011; Hanesiak et al., 2011), International Polar Year (IPY; http://www.api-ipy.gc.ca/), Western Canadian Cryopsheric Network (WC2N; http://wc2n.unbc.ca/), and Improved Processes and Parameterization for Prediction in Cold Regions Hydrology Network (IP3; http://www.usask.ca/ip3/). CCRN integrates and extends many aspects of these previous research projects, and will improve upon the understanding gained through these initiatives and further advance the state of model development and performance. In particular it includes a set of world-class Water, Ecosystem, Cryosphere and Climate (WECC) observatories (see Figure 1 above) that provide fine-scale data and insights to support development of improved models to understand, diagnose and predict change. In turn these will inform improved large scale modelling, using land surface models and large-scale hydrological models, for improved capability for weather and climate modelling, analysis of large-scale land-atmosphere feedbacks, and the prediction of change to the ecological and hydrological systems.

The CCRN includes over 40 Canadian researchers from eight universities and four federal government agencies, as well as 14 prominent international collaborators from institutions across the world (see Appendix A). As the programme develops, more researchers are continuing to join as collaborators. The network is funded for five years (2013–18) through the Climate Change and Atmospheric Research (CCAR) Initiative of NSERC, and CCRN leverages significant in-kind support through its partner universities and government agencies. Management of the network is by a Scientific Committee, which directs the scientific progress of the network and plans all network activities. A Board of Directors oversees the organizational direction and financial accountability of the network, while an International Advisory Panel (IAP) provides external advice and oversight, and facilitates liaison with the international research community. The IAP includes members of GEWEX GHP and CliC SSG, and the science lead of NASA's ABOVE initiative. Further details on the structure, organization, and management of the CCRN are available in Appendix B and through the network's website at: http://www.ccrnetwork.ca.

The CCRN's research programme brings together existing and new experimental data, utilizing ground-based observations and remotely sensed data products, together with improved modelling tools, to investigate changing Earth system processes and their interactions across a range of spatial scales. The geographic focus is the western and northern interior regions of Canada (including specifically the SaskRB and MackRB; see figure above). CCRN's research is divided into five major thematic components:

- Theme A, Observed Earth System Change in Cold Regions – Inventory and Statistical Evaluation;
- Theme B, Improved Understanding 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, User Community Outreach and Engagement.

Each of these themes is interlinked and the progression from A through to E represents an advancement from characterization of changes from local to regional scales, diagnosis and understanding of the changes, and ultimately prediction of future changes, with each theme's activities and deliverables strongly connected to the user community through E.

Theme A provides a synthesis of observed recent changes of the Earth system within the CCRN study domain and establishes the foundation of the project through the inventory, statistical evaluation, and synthesis of these changes. The key science questions are: 1) How have the hydrological, ecological, cryospheric and atmospheric components of the Earth system changed over the last several decades in response to climate warming?; and 2) What are the collective large-scale trends and variability of the Earth system?

Theme B seeks to address the understanding, modelling, and diagnosis of change, focusing on local-scale interactions and effects. Regional-scale processes and interactions are addressed in Theme D. The work uses a unique legacy of process observations and modelling at long-term WECC observatories to answer the following science questions: 1) How have interacting Earth system processes changed in response to changing climate?; 2) How can fine-scale process models be improved to better diagnose key factors governing change?; and 3) What are the interactions amongst climatic, hydrological, ecological, and cryospheric drivers, processes and feedbacks, and thresholds leading to system changes at local scales?

Theme C builds on the insights from the WECC observations and fine-scale modelling (Themes A and B) to develop and test improved models for large scale application, both as land surface schemes within weather forecasting and climate models, and as large-scale hydrological models that can be used to analyze and predict change at large river basin scale. The application of these models, to address impacts of change on river flows and land-atmosphere feedbacks, is in Theme D. The key science question for this theme is: How can our large-scale predictive models be improved to better account for the changing Earth system and its atmospheric feedbacks?

Theme D uses the comprehensive measures of regional change developed in Theme A and models developed in Theme C to assess how, for example, changing large-scale atmospheric controls interact with regional Earth system processes in governing changes in climate variability and extremes. It addresses the key science questions: 1) What governs the observed trends and variability in large-scale aspects of the Earth system and how well are these factors and effects represented in current models?; and 2) What are the projected regional scale effects of Earth system change on climate, land and water resources?

Theme E has a central goal to build a community of users including policy and decision makers, stakeholders and rights holders, and research scientists and organizations, both nationally and internationally. This aspect of the programme enhances the engagement and knowledge flow between the network and its partners and facilitates the transfer of improved scientific and decision making tools needed for water resource management and climate adaptation and mitigation strategies.

As noted above, the CCRN's research activities are focused geographically on the cold western and northern interior regions of Canada, which includes both the SaskRB and the MackRB.

Some activities and observations span a wider geographic range, however, consistent with a larger continental-scale focus for the climatic domain. The region covers a large diversity of climatic, physiographic, surface landcover, ecological, and hydrological conditions and characteristics, with steep gradients and sharp boundaries dividing many of the major eco-climatic sub-regions within. This vast area can be divided into four such major regions, including: 1) the western Cordillera, 2) the Boreal Forest, 3) the northern Prairies, and 4) the sub-Arctic Lowlands, each with various spatial transitions and variations in their characteristics.

Nested within each of these major eco-climatic regions, CCRN operates a set of 14 unique long-term WECC observatories. All of these observatories have a history of research that pre-dates the CCRN, and most have long-term datasets including hydro-meteorological observations, remotely sensed data products, including Light detection and ranging (Lidar) topographic and vegetation structure mapping, and characterization of soils, geology, vegetation, permafrost, and glacial ice cover. Past and ongoing investigations by CCRN and other researchers at these sites has shed valuable insight on surface hydrology, sub-surface, cryospheric, terrestrial ecology, and atmospheric processes. Although each of these observatories had originally been established with a particular scientific emphasis, many of them are comprehensive and similar in terms of the data being collected and are useful for comparing process dynamics and variability across the spatial and climatic gradients of CCRN's study domain. In addition, these observatories help to supplement the regional federal and provincial government hydrometric and climatological monitoring station networks, which have observations going back as long as 50 to 100 years or more. The WECC sites generally provide a more detailed and comprehensive, albeit shorter, series of observational data that can be used to more closely examine and understand the processes behind patterns of change observed at the regional scale. Detailed information on each of the WECC observatories is available on CCRN's website at: http://www.ccrnetwork.ca/science-programme/research-sites.

Essential Scientific Elements:

This study will integrate the insights and capabilities of a number of disciplines to address the water issues in the SaskRB and the MackRB. To address the needs of users in the basin the research must pursue significant thrusts in the following areas:

- Atmospheric and land-atmosphere studies - to quantify the sources and sinks of moisture for the CCRN region and their seasonal and interannual variability, the land-atmospheric interactions as they are modified by changing land use and climate change, and extremes including heavy rains, droughts, and forest fires.
- Hydrological and land process studies - to examine the unique features of sub-arctic and prairie hydrology such as non-contributing areas; address the role of cold season processes such as snow accumulation, snow and glacier melt and permafrost thaw in the basins; and assess the effects of wetlands, lakes and land use change on heat and moisture fluxes to the atmosphere, runoff, soil moisture and groundwater recharge.
- Socio-hydrology studies - to integrate humans and their activities into water science and ensure that water decision making incorporates a range of perspectives about the meaning, value, and use of water. Social scientists will translate climate and hydrological information into decision tools, orchestrate stakeholder engagement on critical science and policy issues

related to water management in the SRB, and develop scenarios for future development of the region.

- Water Quality studies will focus on the SaskRB - to examine the role of agricultural practices and urban pollution in changing the water quality of streams and rivers and in turn their cumulative effects on eutrophication conditions, including in Lake Diefenbaker.

5. What the Project will deliver:

We will inventory and statistically evaluate observable recent change in the Earth system state, fluxes and variability and explore the complex interrelationships of changing Earth system processes through the development of improved models and their application in diagnosis and prediction at multiple scales, from small headwater basins to large river basins, major western interior biomes and the regional climate system.

The significant value added is the integration of data and analysis across scales, the integration of multi-disciplinary national and international expertise, the strong linkage between university and government scientists, and the development of improved modelling tools to address environmental change and its policy implications. Through this multi-scale analysis and modelling, this project will contribute directly to a set of international initiatives, including the Global Energy and Water Cycle Exchanges (GEWEX), the Climate and Cryosphere Project (CliC), the Group on Earth Observations (GEO) and NASA's Arctic Boreal Vulnerability Experiment (ABoVE).

Equally important, it will provide an improved understanding of critical policy choices in the region's water future. Other priority deliverables will include the training of a new generation of water scientists better prepared to deal with integrated water systems and the human institutions that govern them, and development and implementation of systems that will ensure the advances of research are made available to users in ways that will facilitate planning and decision making.

6. The GEWEX context:

During the period 1992 to 2007, the U.S. and North America benefited from three RHPs, the GEWEX Continental-Scale International Project (GCIP) that covered the Mississippi River Basin, the GEWEX Americas Prediction Project (GAPP), which covered the entire U.S. region and parts of Mexico to account for the complete North American Monsoon System. The third Program, the Mackenzie GEWEX Study (MAGS), was a highly-regarded Canadian-led project to address cold season hydroclimate issues in the Mackenzie River Basin. These projects have now all concluded, which left a void in the global programme for North America in general and Canada in particular. Through the SaskRB study, which was approved as an initiating RHP, a much-needed regional-scale focus for integration of GEWEX science based on detailed ground-based observations and integrated modelling and data assimilation of atmospheric, land surface and hydrological processes has been established. The SaskRB also plays a key-stone role in linking Canadian and U.S. hydroclimate science through integration with a proposed North American Water Project NAWP. Through the securing of $5 million from NSERC in February 2013 for the CCRN, expanded research to address the whole of interior western Canada, (i.e., including the MackRB as well as the SaskRB) has been taken on. The proposed project would, in conjunction with a proposed Colorado Basin RHP, provide an unparalleled scientific focus down the entire western North America mountain ranges, which are continentally-dominant areas for precipitation and runoff generation as well as dominant controls on many aspects of continental climate, and encompass water resources of existential importance for western Canada and the western U.S.

The CCRN SaskRB/MackRB study will address each of the GEWEX 'imperatives':
Datasets: Foster development of climate data records of atmosphere, water, land, and energy-related quantities, including metadata and uncertainty estimates.
Analysis: Describe and analyze observed variations, trends and extremes (such as heat waves, floods and droughts) in water and energy-related quantities.
Processes: Develop approaches to improve process-level understandingof energy and water cycles in support of improved land and atmosphere models.
Modeling: Improve global and regional simulations and predictions of precipitation, clouds, and land hydrology, and thus the entire climate system, through accelerated development of models of the land and atmosphere.
Applications: Attribute causes of variability, trends and extremes, and determine the predictability of energy and water cycles on global and regional bases in collaboration with the wider WCRP community.
Technology transfer: Develop new observations, models, diagnostic tools and methods, data management, and other research products for multiple uses and transition to operational applications in partnership with climate and hydro-meteorological service providers.
Capacity building: Promote and foster capacity building throughtraining of scientists and outreach to the user community.

It will also address directly all of the four GEWEX Grand Challenges: Observations and Predictions of Precipitation, Global Water Resource Systems, Changes in Extremes and Water and Energy Cycles. We note in addition that CCRN investigators are leading several existing or planned GHP cross-cut initiatives. These include Mountain Hydrology (Pomeroy), Water Management in Large Scale Models (Harding/Wheater) and Drought (Stewart), and discussions are underway for CCRN to support an arctic Model Intercomparison Project (Blyth/Wheater).

7. Potential benefits to GEWEX of a Canadian RHP:

Development of an expanded Canadian RHP based on the Saskatchewan and Mackenzie River Basins has several important potential benefits:

- It would be of great scientific value to Canada to develop an RHP as a focus for interdisciplinary integration in addressing the development of improved climate, land surface and hydrological modelling, including the assimilation of remote sensing data products.
- Leading an RHP would reinforce Canada's role as a significant contributor to the WCRP, and in particular in the science and modelling of cold region hydro-climate processes, while also creating a focus for collaboration with some of the world's best scientists.
- Both Basins have important scientific challenges to be addressed. These include:
    - current challenges in climate modelling and weather forecasting performance

    - rapid climate change in the Rocky and Mackenzie Mountains, affecting glaciers, snowfall and snowmelt, liquid precipitation and evaporation, and the magnitude and timing of river flows
    - land management issues in the Rocky mountains, including effects of forest management and bark beetle infestation
    - widespread and rapidly thawing permafrost, with associated issues of landscape and forest cover degradation, and changing hydrological flow pathways
    - altered hydrological regimes, with various changes in the timing, magnitude, and frequency of individual runoff events, as well as monthly, seasonal, and annual flows
    - poorly understood prairie hydrology, with complex issues of connectivity and subject to drainage and agricultural management, an important history of damaging flood and drought extremes, and highly uncertain climate futures
    - ecosystem gradients from prairie to boreal forest, with a need to understand controls on ecosystem transitions and tipping points in the context of climate variability and change
    - complex and uncertain feedback processes among shrub tundra vegetation, snow cover distribution, permafrost, hydrology, and local climate
    - several major delta systems, with a very limited science base
    - in addition to water quantity, there is a range of water quality interests. Probably the most important is nutrient pollution and potential risk of eutrophication in Lake Diefenbaker. The SaskRB is also a major tributary of Lake Winnipeg, with major existing nutrient problems.
- Both Basins face important management challenges. For example:
    - Water management decision making is fragmented among many different jurisdictions with competing interests, and weather and flood forecasting operations are carried out independently by federal and provincial agencies, respectively
    - 75% of SaskRB river water comes from the Rocky Mountains, providing an essential water resource to 3 Provinces; drought forecasting and management is a major issue, and some doubt has been expressed concerning the robustness of inter-provincial agreements under scenarios of multi-year drought
    - More than 80% of consumptive use of water in the South Saskatchewan River Basin (SSRB) is due to irrigated agriculture, primarily in Alberta. The SSRB is at or near its limits for water availability in southern Alberta; a private water market in trading licences is developing and there is scope for increased efficiency through improved forecasting and control
    - There is potential competition for resources across the basins. For example, Saskatchewan currently has interests in expansion of irrigated agriculture, there are major hydropower interests in Saskatchewan and Manitoba, there are significant mining and oil interests in Alberta and Saskatchewan
    - Changing climate and hydrological regimes are creating nonstationary conditions under which models developed from past conditions may no longer apply for future decision making
    - Water quality issues are a constraint on water resource management strategies in Alberta and are also currently of concern to irrigated agricultural producers, in addition to potential lake eutrophication issues

  - The most important industries in the MackRB are fossil energy, forest products, hydroelectricity, mineral extraction, and to a lesser extent, agriculture. This combination of factors creates a complex system of interrelated management systems.
- The Saskatchewan and Mackenzie River Basins have important challenges for governance and policy and associated social science interests. Issues include strong provincial controls on trans-boundary water resources (but different provincial governance structures, priorities and strategies), various Federal responsibilities and powers, First Nations interests, and a wide range of stakeholder interests, including agriculture, industry, hydropower, recreation, traditional livelihoods such as hunting, fishing and trapping, and environmental conservation. The SaskRB in particular is an exemplar of the Water–Agriculture–Energy nexus.

There is therefore a need to deliver improved modelling tools and forecasts of water availability and quality for the region on time scales of weeks, months and years, decadal scenarios of future climate impacts, as well as modelling tools that can represent water resource system controls and future developments on the river basin as a whole.

These prediction capabilities should be built on the latest science, models and data systems for the guidance of Integrated Water Resource Management (IWRM) in the basin, for supporting the transition to stable ecological and food security systems and to minimize the economic losses and social impacts associated with extreme climate events.

<u>The Legacy:</u>

This expanded RHP is not starting without a knowledge base. A number of studies have been carried out either in or adjacent to this region and have addressed science questions similar to those being proposed for this study. These studies have left a legacy of data, models and observational infrastructure that can benefit the expanded RHP. Among these studies are:

- MAGS – a study in the Mackenzie River Basin the examined the regional water balances and land-amtosphere interactions that controlled the flows in the Mackenzie River and the freshwater flux into the Arctic Ocean.
- BOREAS (now BERMS) – a major international experiment running since the 1990s to define carbon, energy and water fluxes, with major experimental infrastructure in the North Saskatchewan River Basin. Now a ground observation site for NASA's AirMOSS experiment.
- The SSRB Study – a modeling study undertaken to assess the impacts of climate change on the South Saskatchewan River basins. The study facilitated the development on models to translate the effects of changes in temperature and precipitation into impacts on streamflow and other hydrological data.
- DRI – a study funded by CFCAS which has recently come to a conclusion. This study which focused on the drought of 1999-2005 produced a large set of data and data infrastructure as well as land-atmosphere models. It also advanced the legacy of MAGS in bringing atmospheric and hydrologic scientists together.
- IP3 – another recently- concluded study funded by CFCAS that has provided new insights and models to address snow and ice issues throughout the SRB.

- WC2N – a third recently- concluded study funded by CFCAS that addressed the character and role of glaciers in the Rocky Mountains and identified the sensitivity to climate change and how declining glacier areas could affect river runoff in the SRB.
- Kenaston/Brightwater Creek –a continuing remote sensing soil moisture experiment, supported by Environment Canada, the Canadian Space Agency and NASA

The expanded RHP provides an opportunity to build upon this legacy, while at the same time resolving science issues that have been elusive for these earlier programmes. We note that CCRN is devoting substantial resources to data management and archiving (see Appendices C, D and E), and that the data from this proposed RHP will be a major legacy product.

Resources and timescales:

The SaskRBstudy has more than $10 million funding from participating Canadian universities and government agencies, providing support for observational infrastructure and research staff. In addition, CCRN has a $5million grant from the Natural Sciences and Engineering Research Council of Canada is focussing on similar questions within the region and includes an additional $24 million in in-kind support. SaskRB funding currently terminates in September 2017 and CCRN currently terminates in April 2018. In both cases, discussions have been initiated concerning longer term support. However contingency plans are in place to continue support for the data resource for a further 7 year period.

8. Conclusions:

The interior of western Canada has one of the most extreme and variable climates in the world, is home to 80% of Canada's agriculture and strategically-important natural resources, and is facing the challenges of major economic development in the face of rapid environmental change. The expanded study will bring together Canadian and international scientists and build on world-class observational facilities to develop the understanding and modelling tools needed to address the challenges of managing water futures. The study has the capability to make a significant contribution to GEWEX as an expanded Regional Hydroclimate Project, addressing each of the Imperatives and Grand Challenges, and has the potential to make a major contribution to international hydroclimate science.

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Appendix A: List of CCRN Co-Investigators and Collaborators

Canadian Co-Investigators and Collaborators

- Arora, Vivek (Environment Canada)
- Baltzer, Jennifer (Wilfrid Laurier University)
- Barr, Alan (Environment Canada)
- Bartlett, Paul (Environment Canada)
- Berg, Aaron (University of Guelph)
- Black, Andy (University of British Columbia)
- Bonsal, Barrie (Environment Canada)
- Carey, Sean (McMaster University)
- Clarke, Garry (University of British Columbia, Emeritus)
- Demuth, Michael (Natural Resources Canada)
- Fortin, Vincent (Environment Canada)
- Hanesiak, John (University of Manitoba)
- Hayashi, Masaki (University of Calgary)
- Helgason, Warren (University of Saskatchewan)
- Howard, Allan (Agriculture and Agri-Food Canada)
- Hudak, David (Environment Canada)
- Ireson, Andrew (University of Saskatchewan)
- Janowicz, Richard (Yukon Environment)
- Johnson, Ed (University of Calgary)
- Johnstone, Jill (University of Saskatchewan)
- Kochtubajda, Bohdan (Environment Canada)
- Li, Yanping (University of Saskatchewan)
- Lindenschmidt, Karl-Erich (University of Saskatchewan)
- MacKay, Murray (Environment Canada)
- Marsh, Phil (Wilfrid Laurier University)
- Marshall, Shawn (University of Calgary)
- McDonnell, Jeff (University of Saskatchewan)
- Pietroniro, Alain (Environment Canada)
- Pomeroy, John (University of Saskatchewan)
- Quinton, William (Wilfrid Laurier University)
- Shook, Kevin (University of Saskatchewan)
- Smith, Craig (Environment Canada)
- Spence, Chris (Environment Canada)
- Stewart, Ronald (University of Manitoba)
- Szeto, Kit (Environment Canada)
- Thériault, Julie (Université du Québec à Montréal)
- Turetsky, Merritt (University of Guelph)
- Van der Kamp, Garth (Environment Canada)
- Wheater, Howard (University of Saskatchewan)
- Whitfield, Paul (Environment Canada, Emeritus)
- Wu, Wanli (Parks Canada Agency)
- Yang, Daqing (Environment Canada)
- Zhang, Xuebin (Environment Canada)

International Collaborators

- Bernhardt, Matthias (Ludwig-Maximilians Universität München)
- Clark, Martyn (National Center for Atmospheric Research)
- Davies, Stuart (Harvard University)
- Essery, Richard (University of Edinburgh)
- Euskirchen, Eugenie (University of Alaska Fairbanks)
- Gupta, Hoshin (University of Arizona)
- Lettenmaier, Dennis (University of Washington)
- Li, Xin (Chinese Academy of Sciences)
- Link, Timothy (University of Idaho)

- Marks, Danny (USDA Agricultural Research Service)
- McIntyre, Neil (Imperial College London)
- Rasmussen, Roy (National Center for Atmospheric Research)
- Sicart, Jean-Emmanuel (L'Institut de recherché pour le développement)
- Wagener, Thorsten (University of Bristol)

Appendix B: Structure, Organization, and Management of CCRN

With such diverse and widely-distributed participation, the network requires a solid managerial framework. The management structure of CCRN will consist of a Scientific Committee (SC), Board of Directors (BoD), International Advisory Panel (IAP), and Secretariat, and will be organized as shown in Figure 2.

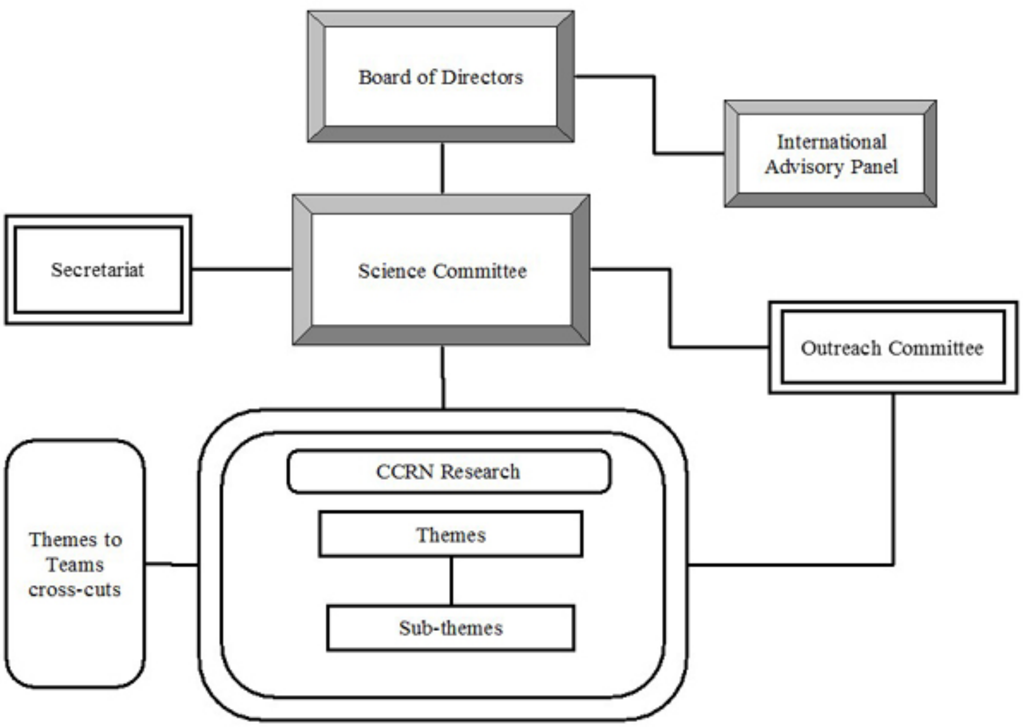

Figure 2. Flow chart showing the network management structure for CCRN.

The CCRN Science Committee will monitor and manage the scientific progress of the network, prepare the annual (and final) reports on CCRN, provide co-investigator funding recommendations to the Board of Directors, develop science plans, organize CCRN meetings and outreach, and oversee the Secretariat. The Science Committee will be chaired by the Principal Investigator, and include leaders of each of the major research themes of the CCRN and other scientists from within the network as members. The Scientific Committee will report to the Board of Directors. Membership of the Science Committee will be as follows:

- Carey, Sean (Theme A lead)

- Howard, Allan
- MacKay, Murray
- Marsh, Phil
- Pietroniro, Alain
- Pomeroy, John (Theme B lead)
- Quinton, William (Theme E lead)
- Stewart, Ronald (Theme D lead)
- Turetsky, Merritt
- Wheater, Howard (CCRN PI and Theme C lead)

The Board of Directors will provide overall organizational direction, guidance, and financial accountability to the CCRN, and conduct annual and final reviews of CCRN performance. It will also facilitate linkages amongst the Network, partner institutions, and international organizations. Membership of the Board of Directors will be as follows:

- Bruce, Jim (Board Chair; Environment Canada (ret.))
- Dybvig, Wayne (Saskatchewan Water Security Agency)
- Greenway, Ken (Alberta Environment and Sustainable Resource Development)
- Jean, Michel (Environment Canada)
- Kirkwood, Donna (Natural Resources Canada)
- Livingstone, David (Wilfrid Laurier – Government of Northwest Territories Partnership)
- Petitclerc, Denis (Agriculture and Agri-Food Canada)
- Woo, Ming-Ko (McMaster university (ret.))

More information on their affiliation and title is available on CCRN's website.

The International Scientific Advisory Panel will engage the Network to offer scientific advice and to guide program developments. The Panel will advise the Network on developments and opportunities in international research, and facilitate liaison with international institutions and research groups. Membership of the International Advisory Panel will be as follows:

- Cline, Don (US National Oceanic and Atmospheric Administration)
- Harding, Richard (UK Centre for Ecology and Hydrology)
- Hinzman, Larry (University of Alaska, Fairbanks)
- Kasischke, Eric (University of Maryland; NASA)

Day-to-day operations will be handled by a Secretariat, based at the University of Saskatchewan's Global Institute for Water Security (GIWS). The Secretariat will report to the Science Committee through the Principal Investigator and ensure i) the ready flow of data and information within the Network and to and from users and collaborators, ii) Network communications including meetings, reports, presentations and workshops, iii) database management, iv) website, v) documented committee meetings, and vi) the smooth operation of the Network and its reporting to NSERC, users and the public. Membership of the secretariat will be as follows:

- DeBeer, Chris (CCRN project manager)
- Hinther, Meagan (Communications specialist)
- Olauson, Sherry (Clerical assistant)
- Schlosser, Tiffany (Finance officer)
- Strickert, Graham (CCRN outreach coordinator)
- Wilson, Kate (Executive assistant to the Canada Excellence Research Chair)
- Zdravkovic, Branko (Database manager)

Appendix C: CCRN Data and Information Management

A major effort will be devoted towards data and information management in CCRN. This will bring together consistent information from in-situ instrumentation as well as a host of model and other observational (including remote sensing) information and it builds on experience gained within previous activities. A data management plan, and quality-assurance and access policies (Appendix D, E) have been developed, making all Network data openly available as was done in the IP3, MAGS and DRI Networks, and the CCRN is committed to document and archive its results in an integrated, long-term repository. The combination of these data sets will be the most comprehensive WECC data collation ever created for western and northern Canada.

The data management plan is based on the values of simplicity, clarity and efficiency, and has been developed to:

- Facilitate the efficient sharing of information and data across the network;
- Define the structure and function of the CCRN Data Information System (DIS), including both the Central Data Repository and distributed elements, with a Data Catalogue to enable efficient navigation and discovery;
- Establish clear and simple protocols for data formatting and metadata submission;
- Support and stimulate network-wide modeling and synthesis activities;
- Ensure the production of a long-term, quality data archive which will serve as a legacy of the network;
- Foster a culture of sharing and trust through a CCRN data access policy (Appendix D), ensuring fair data use and respecting the needs of both data originators and data users.

<u>Data Management Team and Data Manager:</u>
A data management team exists within CCRN, consisting of: Allan Barr, Bohdan Kochtubajda, Phil Marsh, Julie Thériault, Daqing Yang, and Branko Zdravkovic. The CCRN data management team will: report to the CCRN Science Committee and advise them on data management issues; develop the CCRN data management plan and define the data management standards for the WECC observatories; work with CCRN Themes A to E to identify network-

wide needs for archiving and making available non-observatory data sets; and provide direction and support to the CCRN data manager. The CCRN data manager (Branko Zdravkovic, GIWS, U of S) will serve as the primary interface between CCRN scientists and the CCRN DIS. The data manager will: implement and maintain the CCRN-DIS; work with the WECC observatories to support uniform and efficient data processing and archiving; support the archiving and documentation of non-observatory datasets; create and maintain the data catalogue; facilitate the efficient sharing of data and information across the network; and oversee access to the CCRN-DIS by CCRN investigators, collaborators, participants and non-participants.

Data Information System (CCRN-DIS):

The CCRN-DIS will have two key components: a central data repository and a data catalogue, both of which are web accessible. The central data repository will be further divided into two functional units – one dedicated to storage and processing of the standardized time series, and the other for storage of the spatial data, model outputs, vector networks, imagery and other remote sensing data, descriptions, analysis and similar resources. The central data repository will archive: observations from the WECC observatories in uniform, accessible formats; and other data products identified by the CCRN Themes as network-wide data requirements. Datasets that are available externally will not be duplicated in the central data repository, but identified in the data catalogue and made accessible from the CCRN DIS website via links to distributed external databases.

The data catalogue will document the data products that are available through the CCRN-DIS, and enable efficient data discovery and retrieval. The data catalogue will provide access to datasets archived in the central data repository and to datasets available through external databases. We envision a data catalogue that is searchable in a number of ways, including a navigable directory structure, and, if desirable, through queries by observatory, data type, or period of interest.

The CCRN-DIS will be housed at the GIWS, University of Saskatchewan. As far as possible, measurement data will be processed and archived using the Water Information System Kisters (WISKI) software package. The network-wide adoption of WISKI for data management will enable the use of uniform data protocols, including quality assurance, post-processing, naming and organization.

Data will be made available to CCRN participants through the CCRN-DIS website, including FTP access to data products that have been processed within the CCRN-DIS and output in flat ascii (csv) format, and products submitted directly by CCRN participants. If necessary, the CCRN-DIS will include both participant and public portals, with public release after a prescribed holdback period as described in the data access policy (Appendix D).

WECC Observatory Data:

The WECC observatories will contribute four point-measurement data products to the CCRN-DIS: continuous time series of automated meteorological and flux measurements collected at regular intervals; manual measurements that are made less frequently and at particular times; site characterization data; and a metadata document that describes the measurement details. In addition to the point measurement records, observatories can contribute remote sensing and other spatial data types to the CCRN central data repository.

The use of pre-established network-wide procedures within WISKI will simplify and streamline data input/output, quality assurance and post-processing. The WISKI procedures will be developed, implemented and documented by the data manager and the data management team. As far as possible, the primary responsibilities for data preparation and submission will rest with the observatories. Most observatories will have the capacity to input their own data into WISKI using the provided software programs, procedures and templates, with training and support from the CCRN data manager. In some case, additional centralized assistance will be required, particularly for observatories that are not funded through CCRN. Cases may arise where the submission of flat ascii (e.g. csv) files to the CCRN FTP site, in standard formats, is acceptable.

WECC observatory data will be accessible in four ways: by logging onto WISKI Web Portal; by logging onto the central data repository with non-time series data; through web-based queries; and through an ftp site, accessible through the CCRN web site, containing flat ascii (csv) files that the data manager has output from the WISKI database. In all cases, data use will governed by the CCRN data access policy (Appendix D), and access to WECC observatory data will require an account and password from the CCRN data manager.

Appendix D: CCRN Data Access Policy

The CCRN data access policy is based on the policies of the Mackenzie GEWEX Study, and DRI and IP3 research networks, and has been established to promote and govern the access of data collected within the CCRN research area by CCRN Investigators (NIs), CCRN Collaborators (COs), CCRN Partners (PAs), non-participants, and other Canadian and International groups. CCRN will embrace as open an approach as possible to the exchange and access to data for scientific and non-commercial/ non-profit uses. This approach must respect the rights of the data originators who have invested considerable effort in obtaining and/or generating data. For this reason, policies for those participating in CCRN are different from those not participating in or contributing to the project.

The data access policy will be reviewed on at least an annual basis, and may be modified to improve its usefulness.

Data Requests from CCRN Participants:

Data requests from CCRN NIs, COs and PAs will be given priority over requests from non-participants in the project. Access to datasets for CCRN research will be unrestricted to CCRN NIs and COs after the data have been quality-controlled and documented by the originating CCRN NI. CCRN COs will direct their data requests through their associated CCRN NI.

Special CCRN Datasets

Special CCRN-funded datasets (observations and model results) can be obtained by CCRN NIs through the CCRN web site. To ensure that only CCRN NIs and COs have access, this portion of the CCRN web site will be password protected. Passwords will be supplied by the CCRN Data Manager (DM). CCRN datasets can also be obtained directly from the originating CCRN NI. In accordance with the CCRN Network Data Policy, CCRN NIs have a responsibility to make their CCRN-funded datasets openly available to other CCRN NIs and COs after an initial reasonable period for quality control and documentation (following the CCRN Data Documentation Guidelines). This period will nominally be no longer than one year unless there are special circumstances (for example, if early release of data would jeopardize a graduate thesis) and an extension is granted by the Scientific Committee. After this quality-control period, use of the data will be restricted to other CCRN NIs and COs for a period of one year, after which the data must be made publicly available.

CCRN Model Code

Where CCRN funds are used to develop model software code, that code will be made freely available to CCRN NIs, COs and PAs for use in their research during the course of the CCRN. This code will be available in as timely a manner as possible following model tests and validation, unless there are special circumstances (for example, if early release of code would jeopardize a graduate thesis) and an extension is granted by the Scientific Committee. The developer of the model code will be duly acknowledged in all subsequent use of the code.

Requests from Non-Participants:

Data requests from the research community at large are invited, but requests by non-participants will need to be approved on a case-by-case basis. Non-participants may become CCRN COs by teaming with a CCRN NI, who will subsequently apply to the CCRN Scientific Committee for permission to allow the new CCRN CO. Alternatively; non-participants may apply to the CCRN Scientific Committee to become a CCRN PA (following the CCRN Partnership Policy). Where appropriate and possible, some data sources will be made freely available for public viewing and use through a public website

Special CCRN Datasets

Special CCRN datasets (Observational and Modeling results) will only be made available to non-participants after a one year period in which CCRN NIs and COs have exclusive access. This period will begin after the CCRN dataset has been quality controlled by the originator.

CCRN Model Code

Where CCRN funds are used to develop model software code, it will be up to the discretion of the Scientific Committee, together with the NI who developed that code, to release it to non-participants of CCRN. An agreement will be reached between those parties on the terms and conditions of the software release.

Requests from Commercial Entities:

Permission for anyone (CCRN participants (NIs, COs, or PAs) or non-participants) to use CCRN datasets for commercial/profitable purposes must be granted by the CCRN Scientific Committee.

Requests from Other Groups:

National and international commitments for sharing of CCRN datasets before the data becomes public will be considered on a case-by-case basis by the CCRN Scientific Committee.

Acknowledgment:

Any use of special CCRN datasets that results in a publication requires discussion and agreement with the originating CCRN NI, resulting in: appropriate co-authorship in the event of major data usage; or acknowledgement of the originating CCRN NI in the event of minor data usage. For clarification on issues pertaining to publication of special CCRN datasets, contact the CCRN Scientific Committee. At a minimum, any use of a CCRN dataset in a publication requires acknowledgement and citation of the CCRN dataset and, when applicable, citation of earlier studies by the CCRN NI responsible for the data. Appropriate citations are included with many of the CCRN datasets. To cite data for which a citation is not provided, please contact the CCRN DM for help in citing the data.

Any use of CCRN data in publications must be acknowledged using a statement with the following format: *"The [***] data in this paper was provided by the Changing Cold Regions Network (CCRN)."* where *[***]* refers to the actual CCRN data used.

Definitions:

CCRN Dataset: A CCRN dataset can be: observational, either station data or gridded data, resulting from CCRN-funded work; or model derived output, either utilizing CCRN special observations or resulting from CCRN funded work

CCRN Network Investigator (NI): A CCRN NI is defined as one who: contributes scientifically to CCRN, and has been recognized as such by the CCRN Scientific Committee.
CCRN Collaborator (CO): A CCRN CO is defined as one who: is working with a CCRN NI, and has been recognized as such by the CCRN Scientific Committee.
CCRN Partner (PA): A CCRN PA is defined as one who: is not a CCRN NI nor a CO but who contributes scientifically to CCRN, and has been recognized as such by the CCRN Scientific Committee.
CCRN Data Manager (DM): The CCRN DM is the one who manages the CCRN Data Information System.
Non-Participant: Non-participating researchers include any researchers who are not CCRN NIs, CCRN COs or CCRN PAs. Non-Participants include the general public.

Appendix E: CCRN Data Documentation Guidelines

The CCRN data documentation guidelines have been adopted from the IP3 Research Network.

To assist in meeting the objectives of CCRN, and to provide a useful and lasting legacy for further research, it is necessary that all data collected for CCRN, both observational and significant model results, be properly documented. It is the responsibility of the originating CCRN Network Investigator (NI) to ensure that the data collected is properly documented. The CCRN Data Access Policy provides for a time period after data collection for the CCRN NI to quality-control and to document his/her data. With respect to model output, the end of a data collection period is defined as the model run after a significant model revision (e.g. change of physics; improved routing; coupling). Data documentation should be complete enough to allow unfamiliar researchers to replicate and use the data in the future.

<u>CCRN Observational Data Documentation Guidelines:</u>
The observational data documentation should contain the following headings:

1) Title
2) Abstract - *Name the dataset and describe why the measurements were undertaken and how they relate to CCRN.*
3) Contact Information - *Give sufficient detail (name, affiliation, full address, telephone and fax numbers, e-mail, etc.) to contact those most knowledgeable about the dataset.*
4) Site Description - *including the following:*
    a) Data Period(s) and Location(s)
    b) Equipment Used -*including manufacturer and model numbers.*
    c) Methods/Software Used - *in acquiring the data.*
    d) Data Format - *including examples.*
5) Data Processing/Quality Control - *including the following:*
    a) Methods/Software Used - *in acquiring and processing the data*

b) Post-Collection Data Processing -*description of any processing done on the data.*
c) Quality Control Methods - *give an indication as to the degree of quality control.*
d) Datasets Archived -*original "raw" data should be one of the archived datasets in addition to any processed or QCed data.*

6) References

CCRN Model Data Documentation Guidelines:

The model data documentation should contain the following headings:

1) Title - *Model name, version number.*
2) Abstract - *briefly describe the model and its properties; describe why the model run was undertaken and how it relates to CCRN.*
3) Contact Information - *Give sufficient detail (name, affiliation, full address, telephone and fax numbers, e-mail, etc.) to contact those most knowledgeable about the model run.*
4) Run Description - *including the following (valid web links acceptable):*
   a) Period(s) and Location(s)/Resolution/Map Projection
   b) Initialization and Boundary Data used
   c) Model used - *complete description of the model, physics package, any coupling state, etc.*
   d) Data Format - *including examples.*
   e) Archive Location/Media - *online link or offline contact person.*
5) References