Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
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2007 DRI Progress Report

Project Title: Canadian Hydrological Drought Processes and Modelling

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1.0 Progress (beginning January 2007 to end December 2007)

1.1 **Describe progress towards meeting the project objectives for those theme areas where you have received funding for 2006-2007. How are the original milestones being met (be specific)? List the key objectives and results achieved to date as well as any relevant application(s) of the results.**

1.1.1 Objectives

The overall objective of the Drought Network Initiative (DRI) is *to better understand the physical characteristics of and processes influencing Canadian Prairie droughts, and to contribute to their better prediction, through a focus on the recent severe drought that began in* 1999.

To address this overall objective, the Network is focussed on complementary and cross-cutting research objectives that correspond to the following themes:

1. **Theme 1: Quantify the physical features of this recent drought:**
   a)spatial and temporal features,
   b) flows of atmospheric and terrestrial water and energy into and through the region, and their storage and redistribution within the region.

Quantifications of the physical features of the drought has focussed on two areas, primarily as needed to achieve objectives of Themes 2 and 3:

i) Detailed description of the drought from the St Denis Natl. Wildlife Area, SK
Reliable datasets describing incoming solar radiation, temperature, relative humidity, wind speed, precipitation, soil moisture, snowpack water equivalent and pond level were assembled for St Denis from 1999 to 2006 to show the drought and post-drought recovery period. These data were found in archives of NHRC, Environment Canada and the Meteorological Service of Canada. Supplementary observations were collected of precipitation, wind speed, air temperature, humidity, soil moisture and snow accumulation for 2005-2006, and latent heat flux, soil moisture, air temperature, humidity and all radiation terms for summers 2006 and 2007 in order to characterize the distinctiveness of the previous drought period.

ii) assembly of a proxy dataset suitable for describing the drought using a physically-based prairie hydrological model created using the CRHM platform (or other physically based land surface or hydrology models).

Archival datasets for time periods including the drought were found for air temperature, wind speed, precipitation. However, over the past decade, measurements of solar radiation data and its proxy, daily sunshine hours, have become scarce in Western Canada. As this data is absolutely critical for computing prairie snowmelt, evaporation, and other components of the hydrological cycle, another source is required. Work to date comparing modelled to measured shortwave irradiance at Lethbridge and other sites suggests that the NCEP North American Regional Reanalysis (NARR) data may provide usable estimates of incoming shortwave radiation, particularly on a daily basis.

2. Theme 2: Improve the understanding of the processes and feedbacks governing the formation, evolution, cessation and structure of the drought.

The data assembled for Theme 1 were used to drive a physically based prairie hydrological model created with CHRM to better describe the evolution of the hydrological drought with respect to spring snowmelt runoff at St Denis (Pond 109). Snowmelt provides the major runoff event of the year. Results showed that much lower precipitation, less snow accumulation, shorter snow-covered duration, enhanced winter evaporation, and much lower discharge to the wetland from snowmelt runoff developed in the severe drought period of 1999-2002. As a result, there was only 14.9 mm, 3.7 mm, and 14.4 mm of snowmelt runoff in the basin for the springs of 2000, 2001, and 2002, respectively. Compared to the discharge in the spring of 2006, 68.2 mm, melt water discharge to the Wetland 109 had decreased by 78%, 95%, and 79% for the springs of 2000, 2001, and 2002, respectively. Hydrological memory working to lengthen the hydrological drought was evident at the cessation of the meteorological drought by a return to normal winter snowfall. Normal snowfall did not result in normal runoff the subsequent spring or a return to normal wetland levels in the first year because of
i) "storage memory" of dry fall soil moisture content which strongly affected spring runoff, and
ii) low water storage in ponds resulting in restricted fill and spill from one pond to the next and hence a small contributing area for runoff generation and rapid infiltration into unsaturated pond soils,
both these mechanisms reduced runoff generation dramatically in the subsequent spring.

To understand the dynamics of drought a complete understanding of the evaporation process during drought is necessary. Three physically based actual evaporation models (Penman-Monteith, Granger-Gray, Dalton Bulk Transfer) were examined during a drying summer period in a rolling upland prairie landscape. Each has a unique response to changes in atmospheric and surface conditions and so their sensitivity to drying is instructive as to the appropriate modeling approach for drought conditions. Evaporation was measured directly using a eddy correlation system (full corrections applied). All components of net radiation, soil moisture, surface temperature, plant height, air temperature, humidity and wind speed were measured through the summer period for this study. Penman-Monteith relies on net radiation, aerodynamic transfer with strong controls by soil moisture and plant growth (Jarvis type formulation). Granger-Gray is similar but relies on atmospheric humidity as a feedback rather than soil moisture to index soil moisture and plant growth. Dalton Bulk Transfer relies on measured surface temperature and aerodynamic exchange with adjustments for soil moisture and plant growth (Jarvis type formulation). All three models provided reasonable estimates of evaporation (when compared to observations) from time scales of several days to seasonal periods, but provided poor estimates of daily or sub-daily evaporation. The variance compared to observations increased as the time scale decreased. Based on comparisons with observations for several time periods the Penman-Monteith (P-M) method performed the best overall. However, the Granger-Gray (G-D) method also provided results that were close to the P-M method and did so with far fewer parameters (e.g. did not need soil moisture). Over short periods of 2 – 3 days, the G-D method provided the best results overall of the three methods. The poorest agreement between modeled and measured evaporation was provided by the

Dalton Bulk Transfer (BT) method. One reason for this may be the purely aerodynamic approach of the BT method itself which lacks consideration of the available energy. Given the large observed scatter at higher temporal resolutions it is unlikely that corrections for stability alone will provide a significant increase in agreement between the modeled estimates and observed evaporation. Rather, other factors influencing evaporation such as, heat storage, and the spatial variability of surface parameters need to be considered explicitly in estimating evaporation.

A field study of evaporation from a small pond and adjacent dry prairie soil using eddy correlation was undertaken in summer 2007 to better understand the processes of pond evaporation when surrounded by relatively hot, dry land. This study was supported by the field study supplement provided by DRI. Data are still being analyzed but suggest that evaporation from the pond was enhanced by a drying of the surrounding land, so that interactions between adjacent land surfaces might be necessary to characterize drought evaporation accurately. This means that even evaporation at a point must consider regional evaporation. The CLASS land surface scheme is being evaluated using this dataset.

3. Theme 3: Assess and reduce uncertainties in the prediction of drought and its structure.

Blowing snow redistribution to runoff producing areas and snowmelt are crucial processes in the spring runoff generation during drought on the prairie. CRHM (spatially aggregated into Hydrological Response Units) and a model of similar physics run on 6 m grid cells (spatially distributed) were used to model blowing snow redistribution and melt at St. Denis. Both the spatially distributed and spatially aggregated scales produced similar end of winter Snow Water Equivalent values. The spatially aggregated scale used by CRHM was sufficiently accurate to estimate the end of winter snow accumulation for a small Prairie basin. This suggests that “tiles” as implemented in Canadian land surface schemes (MESH) will have sufficient spatial resolution but will need to consider redistribution of snow amongst tiles in order to characterize the snow available for melt accurately. After this modelling scale test, CRHM was used to set up a complete hydrological model for prairie snowmelt runoff for both Bad Lake and St. Denis research areas. CRHM generally performed well when compared to observed snow accumulation and streamflow and did not require calibration.

CRHM was used to model drought evaporation for Lethbridge (2000) and Kernen Farm, Saskatoon (2001) using various evaporation equations bounded by a soil moisture water balance accounting routines and also run in “unbounded” mode. The water balance bounded the evaporation by limiting evaporation quantities to available surface and soil water, despite atmospheric demands. The bounded conditions are typical of how these equations might be coupled to a water balance model that preserves continuity. Observations of precipitation showed the potential for large variations in available water between years and study sites over the extent of the “drought period” for a particular region. Results showed that the coupled soil moisture balance approach (bounded) was better suited for estimating evaporation under extreme drought conditions rather than simply allowing the evaporation equations to run unbounded by soil moisture limitations. To estimate evaporation accurately during drought required an accurate representative depth of the rooting zone and the soil column in the model, and correct initial conditions for soil moisture at depth. Rooting zones were much deeper than anticipated at Lethbridge under grassland during drought and required modification of the hydrological model parameterization of soil moisture to provide accurate results. Any hydrological or land surface model simulating evaporation during the drought must therefore carefully characterize the rooting zone depth and the initial soil moisture condition.

Although CRHM works well for simulating hydrology at the scale of a small basin, it is desired to extend it to work at larger scales for the prairie region. This is made difficult by the nature of topography in western Canada, where large regions drain internally, and are not connected to the major rivers which flow through the region. Because of the small scale and ephemeral nature of the drainage system, parameters such as contributing areas, water surface area, and drainage connectivity vary over time. Studies of the St. Denis NWA are being undertaken to determine if some of the parameters can be determined statistically for a region, as opposed to a single wetland. If the parameters can be shown to be stable over time, then it may be possible to upscale CRHM statistically.

1.2. **What contributions have you made, if any, to the unfunded themes of DRI through support in kind.**

Theme 4: Compare the similarities and differences of the recent drought to previous droughts over this region and those in other regions, in the context of climate variability and change.

To characterize the extremes of the recent drought in terms of historical variability and to start to answer the question "are the prairies drying out", historical meteorological data were examined to determine any change in the mean conditions and extreme conditions over the time that observations are available for the prairies. Most studies to date have analyzed trends in the mean values of variables, however, analysis of trends in the underlying distributions are required to determine if the frequencies of meteorological events have been changing over time.

Daily values of rainfall, snowfall, precipitation, minimum, maximum and mean air temperatures were analysed for the six prairie stations (Calgary, Medicine Hat, Saskatoon, Regina, Indian Head, and Brandon) which had continuous long term records of high quality. In each case, each of the variables demonstrated that the null hypothesis of stationarity about a single value (rather than about a trend) could not be rejected, even at the 10% level of significance. Therefore, the six analyzed variables must be assumed to be stationary; *their mean and variance do not change significantly* over the period of analysis. Thus, so far, there is no indication of a significant trend in the underlying frequency distributions of the variables, and therefore no indication of any trend in extreme values. This analysis also agrees with the results of Vincent and Mekis, who found few statistically significant trends in the standard deviation of mean air temperature in the prairies. As such there is no evidence whatsoever for an increase in extremes in climate across the prairies during the 20th C. This will be important for characterizing the recent drought in terms of the historical record.

Theme 5: Apply our progress to address critical issues of importance to society.

The CRHM model is being used to describe the hydrology of a small basin in eastern Saskatchewan (Smith Creek) that has been subject to substantive artificial drainage of wetlands. Wetland drainage is a crucial issue in eastern Saskatchewan that has been identified as a cause of recent flooding and of wetland drying in drought periods. By better showing the linkages between wetland water levels, drainage and streamflow, the CRHM model may help in designing sustainable water management strategies that preserve streamflow and wetlands through both wet periods and drought. This study is providing information to PFRA-AAFC, the Prairie Habitat Joint Venture Policy Committee and the Prairie Provinces Water Board.

1.3 **Describe you plans for research during the coming year and the following year and outline how the expected results will support the deliverables and goals of DRI.**

Research over the next period will focus on two main areas
i) characterizing wetland water storage capacity using frequency distributions so that small streams and internally drainaged areas can be modelled with a hydrological model at moderate resolution.
ii) further developing a CRHM hydrological drought model that can accurately represent snow redistribution, melt over frozen soils, wetland filling and spilling, streamflow generation, evaporation and soil moisture evolution on complex prairie land surfaces during drying and wetting.
iii) developing a meteorological and radiation dataset for the drought so that a CRHM hydrological drought model can be run for western Canada to predict snow water equivalent, small scale runoff generation and soil moisture from hydrological principles during drought. Surfaces of these three outputs will be produced to examine the spatial and temporal evolution of hydrological drought and sensitivity to initial water storage conditions will be tested.
iv) examining the hydrological drought development and cessation in the recent drought and other droughts.
v) informing the development of coupled atmospheric-hydrological models such as MESH in the MEC system so that they can more accurately characterize drought.

2.0 Impact

2.1 Describe the significance / impact of the results achieved to date and how this new knowledge has influenced research policy, enhanced research collaboration or competitiveness, or helped attract or train skilled personnel.

Address the following items, as appropriate:

- **The impact of the project on government policy development (federal, provincial or municipal);**
- **How the project has expanded contacts in partner organizations, or increased cross-disciplinary cooperation;**
- **Whether and how it has improved the reliability of predictive methods;**
- **The impact of the project on your own institution;**
- **Whether and how the project has helped increase funding from other agencies, or led to new partnerships;**
- **Any current (or potential) commercial or social applications, which the results may have;**
- **Links with international initiatives and the potential impact of these;**
- **Anticipated benefits of the work for Canadians.**

Demonstration of the importance of blowing snow to drought runoff generation has influenced the development of MESH by Environment Canada so that this process is included. Prairie Province water resource departments are interested in applying the CRHM model in hydrological prediction for prairie small streams. Predictive models such as CRHM and MESH are being applied with reduced or no calibration which will be necessary for drought application as streamflow often becomes negligible during drought and the network of measurement has declined in recent decades.

3.0 Dissemination

3.1 Provide information on dissemination of the research results (publications, including journal names and whether refereed), conference contributions,

seminars, workshops or videos, websites or other methods of transferring the results.

Peer-reviewed Journal Articles

Armstrong, R.N., Pomeroy, J.W., and Martz, L.W. 2007. Evaluation of three evaporation estimation methods in a Canadian prairie landscape. *Hydrological Processes*, Accepted.

Fang, X. and Pomeroy, J.W. 2007. Snowmelt runoff sensitivity analysis to drought on the Canadian prairies. *Hydrological Processes* 21: 2594-2609.

Fang, X. and Pomeroy, J.W. Impacts of 1999-2004/05 drought on Canadian prairie wetland snowmelt hydrology. *Hydrological Processes*: Submitted.

Pomeroy, J.W., Gray, DM, Brown, T., Hedstrom, N.H., Quinton, W.L., Granger, R.J. and S.K. Carey. 2007. The cold regions hydrological model: a platform for basing process representation and model structure on physical evidence. *Hydrological Processes*, 21, 2650-2667.

Pomeroy, J.W., de Boer, D. and L. Martz. 2007. Hydrology and water resources. In, (eds. B. Thraves, M. Lewry, J Dale, H. Schlichtmann) *Saskatchewan: Geographic Perspectives*. Canadian Plains Research Centre, Regina, SK. 63-80.

Thesis

Fang, X. 2007. Snow Hydrology of Canadian Prairie Droughts: Model Development and Application. M.Sc. Thesis, University of Saskatchewan, Saskatoon, Saskatchewan. 172pp.

Presentations

Armstrong, R.N., Pomeroy, J.W., and Martz, L.W. 2007. "Evaluation of evaporation estimation methods during a summer drying period." Canadian Geophysical Union 41st Congress, St. John's, NL, May 29 - June 1, 2007.

Armstrong, R.N. and Pomeroy, J.W.. 2007. Problems in Estimating Evaporation in a Complex Prairie Environment. DRI Evaporation Workshop, Saskatoon, Sask, Canada, May 17, 2007.

Fang, X. and Pomeroy, J.W. 2007. Snow Accumulation, Snowmelt and Snowmelt Runoff to Prairie Ponds. St. Denis NWA Science and Planning Workshop. National Hydrology Research Centre, Saskatoon, SK. April 3, 2007.

Fang, X. and Pomeroy, J.W. 2007. Effects of Drought on Canadian Prairie Wetland Snowmelt Hyrology. CMOS-CGU-AMS Congress 2007: Air Ocean, Earth and Ice on the Rock, Canadian Geophysical Union 33rd Annual Meeting, St. John's, NL, May 28 – June 1, 2007.

Fang, X. and J.W. Pomeroy, 2007. Sublimation of blowing snow in the prairies. Drought Research Initiative Evaporation Workshop, Saskatoon. May 2007.

Fang, X. and Pomeroy, J.W. 2007. Model Scale Comparison for Wind Redistribution of Snow in the Canadian Prairies. Canadian Geophysical Union – Hydrology Section 6th Annual Student Meeting Prairie Regions, Calgary, AB, January 27, 2007.

Helgason, WD, Pomeroy JW. 2006. Observations of turbulent energy fluxes over an open prairie snow field. Drought Research Initiative Evaporation Workshop, Saskatoon, SK. May 9, 2007. *(Oral presentation).*

Helgason, WD, Pomeroy JW. 2007. Energy partitioning over snow surfaces. Canadian Geophysical Union Annual Meeting, St, Johns, NF, May 29 - Jun. 1. *(Oral presentation)*

Pomeroy, J.W. 2007. Improving our Understanding and Prediction of Hydrology and Water Resources in Western Canada. *Plenary* to Canadian Water Resources Association Annual Meeting. Saskatoon, June 2007.

Pomeroy, J.W. 2007. Snow Processes and Modelling. Invited talk to NASA/Environment Canada Snowfall Hydrology Workshop, Montreal. June 2007.

Pomeroy, J.W. 2007. Soil Moisture and Evaporation in DRI. Invited talk to C-GEO Soil Moisture Workshop, Saskatoon, June 2007.

Pomeroy, J.W. 2007. Evaporation in hydrological land surface models. Talk to DRI Evaporation Workshop, Saskatoon, May 2007.

Pomeroy, J.W. 2007. Evaporation from Saline Lakes. Invited talk to International Workshop on Connecting the Gulf of Sirte Depressions with the Mediterranean Sea. Tripoli, Libya, Feb. 2007.

Pomeroy, J.W., Ellis, C.R., Brown, T. Gray, D., Hedstrom, N. The Cold Regions Hydrological Model: a simulation platform for physically based hydrology. *International Union of Geophysics and Geodesy (IUGG).* Perugia, Italy. July 2007.

Pomeroy, J.W. and X. Fang 2007. Spatial scale of blowing snow modeling on the Canadian Prairies *Eos Trans. AGU, 88*(52), Fall Meet. Suppl., Abstract C21B-0468.

Pomeroy, J.W. and Shook, K. 2007. *Prairie and Mountain National Network Research at the Centre for Hydrology, University of Saskatchewan.* CWRA Saskatchewan Branch Board of Directors Meeting. Saskatoon, November 28, 2007

Pomeroy, J.W., Fang, X., Armstrong, R., and Shook, K. 2007. Prairie drought hydrology prediction using the cold regions hydrological model. DRI Prediction Workshop, McGill University, Montreal, Sept 20, 2007

Shook, K and Pomeroy, J.W. 2007. *Prairie Flood and Drought Mitigation*. National Workshop on Watershed Conservation. Winnipeg, November 8-9, 2007

Shook, K. and Pomeroy, J.W. 2007. *Water on the prairies*. 2007 Crop Advisors Workshop. Saskatoon, December 6, 2007

Stewart, R. and J.W. Pomeroy 2006. Drought Research Initiative: A Study of the 1999-2005 Severe Drought over the Canadian Prairies. *Eos Trans. AGU, 87*(52), Fall Meet. Suppl., Abstract GC31A-06.